ACCIDENT REPORT

Report on the investigation of

the fire and subsequent loss of power on board the Finland registered roll-on/roll-off cargo ship

Finnmaster

at King George Dock, Hull, England

on 19 September 2021

SERIOUS MARINE CASUALTY REPORT NO 13/2025 SEPTEMBER 2025

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

°	-	angular degrees
°C	-	degrees Celsius
1/E	-	first engineer
2/E	-	second engineer
2/O	-	second officer
AE1	-	auxiliary engine 1
AE2	-	auxiliary engine 2
AER	-	auxiliary engine room
BDC	-	bottom dead centre
C/E	-	chief engineer
CABA	-	compressed air breathing apparatus
cm	-	centimetre
CMS	-	Continuous Machinery Survey
CO_2	-	carbon dioxide
CO_2 system	-	fixed carbon dioxide fire-extinguishing system
DNV	-	Det Norske Veritas Group AS
ECDIS	-	Electronic Chart Display and Information System
ECR	-	engine control room
EDG	-	emergency diesel generator
Geeve	-	Geeve Hydraulics B.V.
GMDSS	-	Global Maritime Distress and Safety System
HSR	-	HSR Hydraulics BV
IACS	-	International Association of Classification Societies
IMO	-	International Maritime Organization
Inter Marine	-	Inter Marine Oy
ISM Code	-	International Safety Management Code for the Safe Operation of Ships and for Pollution Prevention
ISO	-	International Organization for Standardization
kg	-	kilogram
kW	-	kilowatt
m	-	metre
m^3	-	cubic metre

MCA	-	Maritime and Coastguard Agency
MGN	-	Marine Guidance Note
MGO	-	marine gas oil
MHI	-	Mitsubishi Heavy Industries
mm	-	millimetre
MoU	-	memorandum of understanding
MPMS	-	machinery planned maintenance system
MSA	-	Marine Safety Agency
MTEE	-	Mitsubishi Turbocharger and Engine Europe B.V.
OEM	-	original equipment manufacturer
Parker	-	Parker Hannifin Manufacturing S.r.l
PMS	-	planned maintenance system
RINA	-	RINA S.p.A
RO	-	Recognised Organisation
ro-ro	-	roll on/roll off
SD	-	circuit breaker trip contact
SEC	-	safety equipment certificate
SIAF	-	Safety Investigation Authority, Finland
SMS	-	safety management system
SOLAS	-	The International Convention for the Safety of Life at Sea, 1974, as amended
STCW	-	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978, as amended
TDC	-	top dead centre
TRAFICOM	-	Finnish Transport and Communications Agency
UHF	-	ultrahigh frequency
UMS	-	unattended machinery space
UPS	-	uninterruptible power supply
UR-Z17	-	Unified Requirement Z17: Procedural requirements for service suppliers
USCG	-	United States Coast Guard
UTC	-	universal time coordinated
UVT	-	undervoltage time delay unit

VAC	-	volt alternating current
VDC	-	volt direct current
VHF	-	very high frequency
Viking	-	Viking Life-Saving Equipment Oy Finland
Viking LSE	-	Viking Life-Saving Equipment B.V., Netherlands

TIMES: all times used in this report are UTC +1 unless otherwise stated.

Finnmaster

SYNOPSIS

At 2013 on 19 September 2021, a fire broke out in the auxiliary engine room on the Finland registered roll-on/roll-off cargo ship *Finnmaster* during departure from Hull, England. *Finnmaster* lost power, but the fire was later extinguished and the vessel safely re-berthed with the assistance of tugs. The auxiliary engine room was significantly damaged but there were no injuries.

The investigation found that:

- The fire started after mechanical failures on one of the auxiliary engines caused hot exhaust gases to impinge on a flexible hose that failed, leaking fuel under pressure onto a hot component in the exhaust system where it ignited.

- The flexible hose installed in the fuel system during a modification did not meet the required standard, was fitted in an inappropriate position, and had not been subject to approval or oversight by the responsible classification society.

- A fault in *Finnmaster*'s emergency generator circuit breaker prevented the generator from supplying power to the emergency systems on board.

- The fixed carbon dioxide fire-extinguishing system was activated by the crew, but failed to fully operate due to a defective flexible hose assembly and leaks in the pilot system.

- The crew's response to the fire did not follow accepted procedures for the release of carbon dioxide into the engine room.

Recommendations have been made to:

- The Finnish Transport and Communications Agency to update its guidance to industry on machinery space fire prevention and propose that the International Maritime Organization develop functional requirements for communication systems as well as guidance on the testing of fixed fire-extinguishing systems and emergency power supplies.

- Finnlines Plc to provide guidance on the identification and reporting of machinery failure trends, and to update the onboard response and training procedures.

- RINA S.p.A to propose guidance to the International Association of Classification Societies to improve the surveys conducted by chief engineers, and a revision of Unified Requirement Z17 on the approval of service providers.

SECTION 1 – FACTUAL INFORMATION

1.1 PARTICULARS OF *FINNMASTER* AND ACCIDENT

SHIP PARTICULARS	
Vessel's name	*Finnmaster*
Flag	Finland
Classification society	RINA S.p.A
IMO number/fishing numbers	9132014
Type	Roll-on/roll-off cargo ship
Registered owner	Finnlines Plc
Manager(s)	Finnlines Plc
Construction	Steel
Year of build	1998
Length overall	154.50m
Registered length	145.87m
Gross tonnage	12,433
Minimum safe manning	11
Authorised cargo	Freight vehicles, containers
VOYAGE PARTICULARS	
Port of departure	Hull, England
Port of arrival	Helsinki, Finland (Intended)
Type of voyage	International trade
Cargo information	Freight vehicles, containers
Manning	16
MARINE CASUALTY INFORMATION	
Date and time	19 September 2021 at 2013
Type of marine casualty or incident	Serious Marine Casualty
Location of incident	Hull, England
Place on board	Auxiliary engine room
Injuries/fatalities	None
Damage/environmental impact	Significant fire damage to a compartment
Ship operation	Manoeuvring
Voyage segment	Departure
External & internal environment	Still water; light easterly breeze; darkness; good visibility; air temperature 16°C
Persons on board	16 crew, 1 passenger

1.2 BACKGROUND

Finnmaster was owned and operated by Finnlines Plc (Finnlines) and carried both roll-on/roll-off (ro-ro) cargo and containerised freight between Hull, England and Helsinki, Finland. The ship departed Hull each Sunday evening for an afternoon arrival in Helsinki on the following Wednesday. *Finnmaster* sailed from Helsinki each Thursday afternoon to arrive back in Hull early on Sunday morning.

1.3 NARRATIVE

On the evening of 19 September 2021, *Finnmaster*'s crew completed loading cargo and prepared to leave 9 Quay in Queen Elizabeth Dock, Hull bound for Helsinki. The departure was originally scheduled for 1930[1] but was delayed by 30 minutes due to the scheduling of ship movements in the port.

At 1920, the first engineer (1/E) started auxiliary engine (AE) number one (AE1) and paralleled[2] it with the running auxiliary engine number two (AE2), which had been supplying the full ship's load since 0755 that morning. Once AE1 was connected to the switchboard, the 1/E performed a routine visual check of the two running engines in the auxiliary engine room (AER). At 1930, the 1/E was joined in the engine control room (ECR) by the chief engineer (C/E).

At 2005, *Finnmaster* departed the berth using both the main engine and bow thruster. There was a pilot on board. The ship manoeuvred stern-first into the basin of King George Dock in preparation to transit the King George Lock into the Humber Estuary **(Figure 1)**.

At 2013, the fire detection system alarmed, indicating that smoke had been detected in the AER **(Figure 2)**. The fire alarm automatically sounded throughout the ship. The 1/E went to the AER and saw smoke coming from the aft end of AE2. Approaching the instrument panel in between the two alternators, the 1/E saw that the two exhaust gas temperature gauges for AE2 each read more than 650°C, which was the highest recordable temperature on the scale. A fire ignited below AE2's outboard turbocharger shortly afterwards, next to where the 1/E was standing.

The 1/E immediately returned to the ECR and reported the fire to the C/E. The 1/E then collected a 6kg carbon dioxide (CO_2) fire extinguisher and returned to fight the developing fire on AE2. The C/E called the bridge by telephone to brief the master about the fire and then stopped the bow thruster.

When the fire alarm sounded some of the crew remained at their operational stations on the forward and aft mooring decks. The other crew members went to their emergency muster stations. The second engineer (2/E) was woken in their cabin by the fire alarm and dressed and went to the ECR, where the C/E briefed them about the fire. Leaving the 2/E in the ECR, the C/E went to retrieve a 50kg dry powder[3] fire extinguisher from the boiler room.

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[1] All times in this report are local time – British Summer Time (UTC+1). *Finnmaster* operated on Eastern European Time (UTC+3).

[2] The process of connecting the alternators to operate as one unit that requires the waveforms of the electricity generated to be aligned before the circuit breaker is closed.

[3] Dry powder extinguishers use a fine monoammonium phosphate powder to chemically interrupt the reaction of fire and are suitable for use on solid, liquid and gaseous fires. They do not have a cooling effect.

Having unsuccessfully attempted to fight the fire, the 1/E returned to the ECR and instructed the 2/E to stop AE2. The 1/E then went to help the C/E carry the dry powder fire extinguisher up the single flight of stairs to the AER. The 2/E switched AE2 into manual control on the alternator engine control panel in the ECR and stopped the engine. The circuit breaker connecting AE2 to the main switchboard opened automatically, immediately transferring all electrical load to AE1.

The C/E and 1/E entered the AER with the dry powder fire extinguisher, but the intensity of the heat from the fire forced them to withdraw from the compartment before they could use it. The two engineers closed the door to the AER and returned to the ECR.

As the emergency in the engine room was developing, *Finnmaster* continued moving slowly astern. The master moved the propeller pitch control on the bridge slightly ahead to arrest the ship's astern movement. The master, pilot, and shore-based dock control officer discussed options for berthing the ship within King George Dock and started to mobilise tug assistance from the port.

At 2017, AE1 stopped and *Finnmaster* lost all main electrical power and propulsion. The ship then drifted in the basin of King George Dock with its momentum swinging its bow slowly to starboard. The emergency diesel generator (EDG) started automatically on the loss of power but did not connect to supply power to the emergency switchboard. The C/E instructed the 2/E to go to the emergency generator room on the weather deck **(Figure 2)** to investigate.

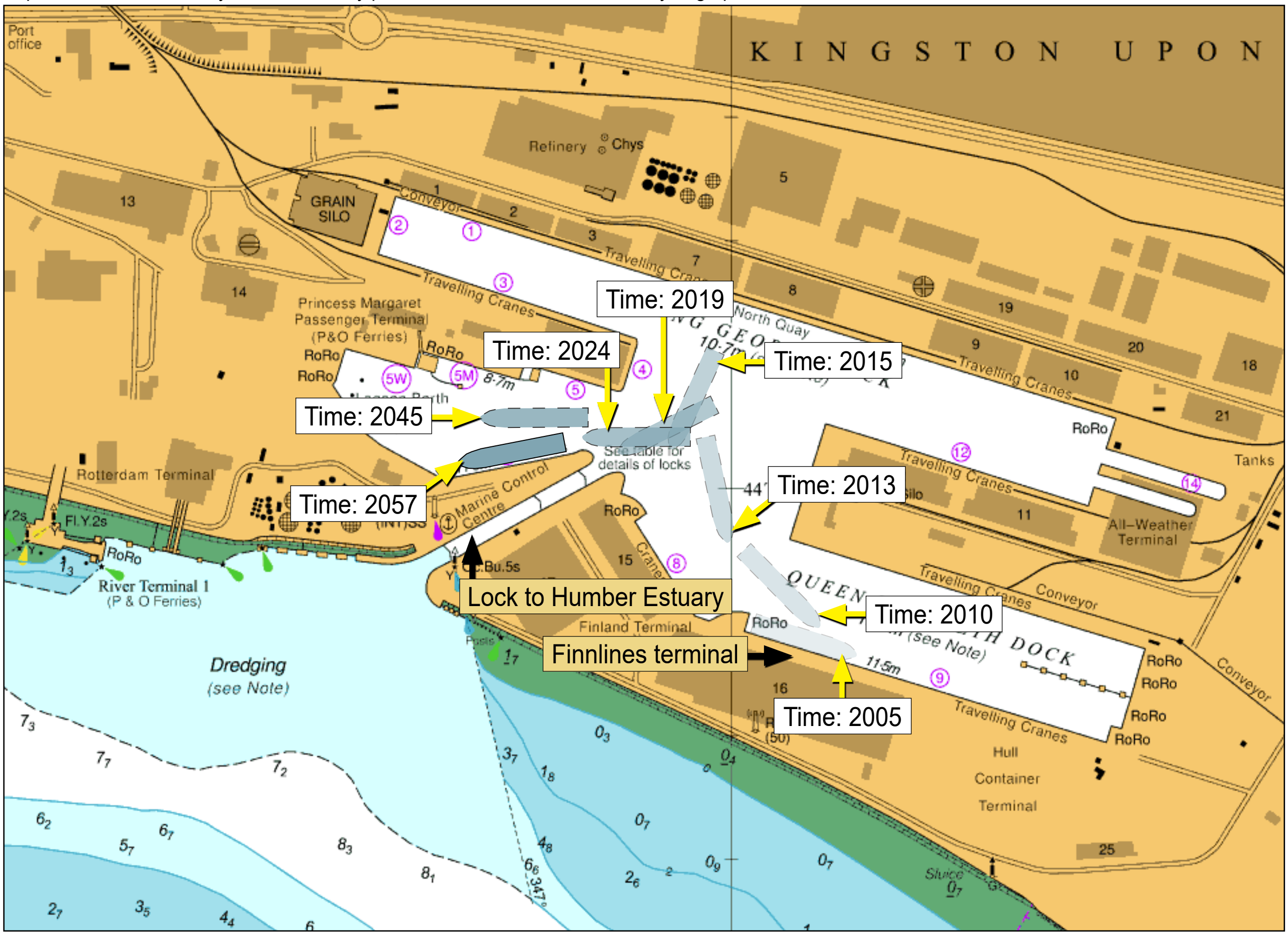

Figure 1: Movements of *Finnmaster* within King George Dock

Base images courtesy of Birka Cargo

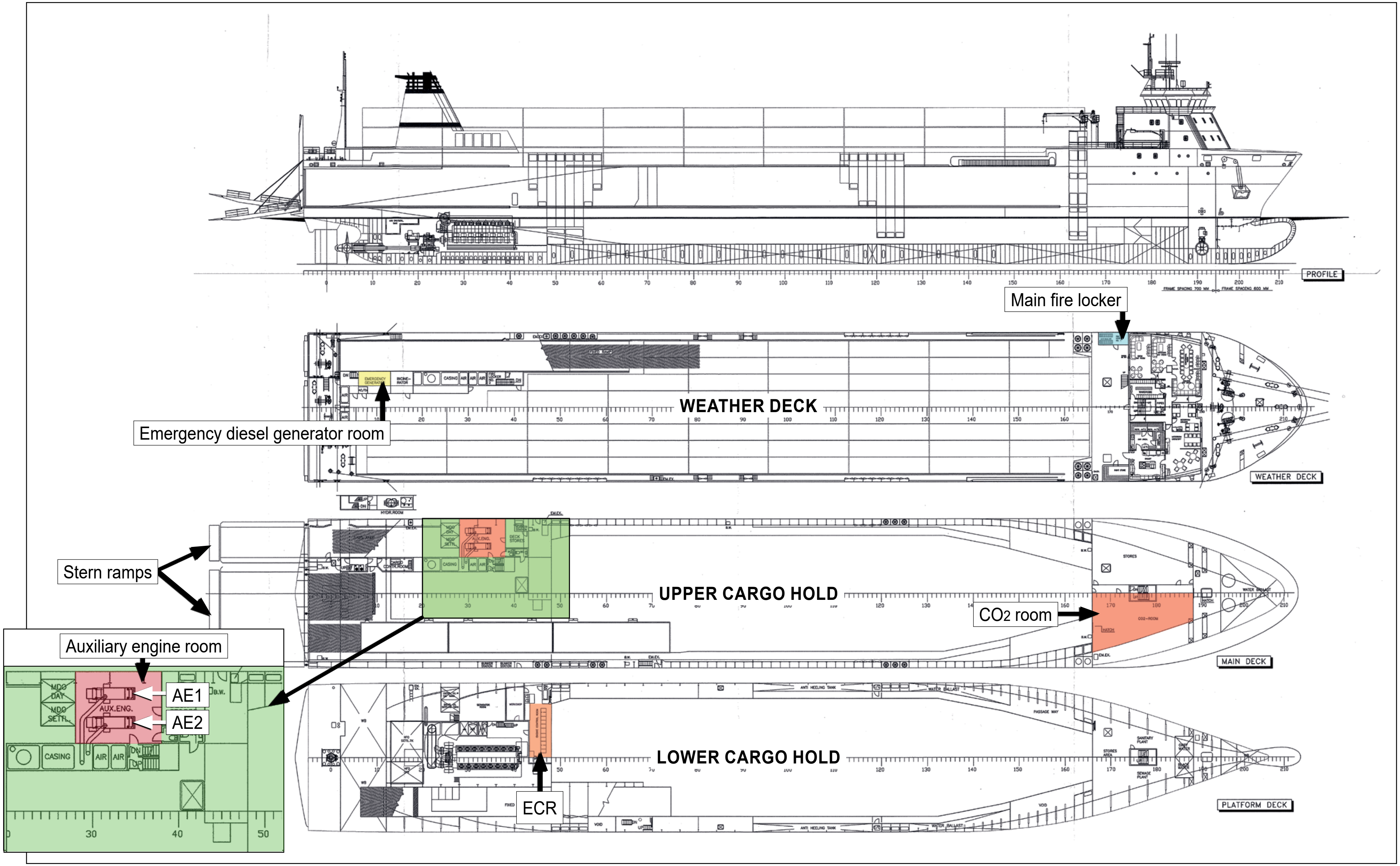

Figure 2: *Finnmaster* general arrangement

The C/E and 1/E collaboratively decided that the fixed CO_2 fire-extinguishing system (the CO_2 system) needed to be used to extinguish the fire. The C/E and 1/E initially intended to activate the system from the CO_2 room at the forward end of the main deck. Having started to make their way there by torchlight, they decided instead to go to the main fire locker at the forward end of the weather deck, where the remote control station for the CO_2 system was located. The C/E sent the 1/E to request permission from the master to activate the CO_2 system.

The ultrahigh frequency (UHF) handheld radio system having failed, the master attempted to use the sound-powered telephone to the ECR but received no response. The master instructed the second officer (2/O) to take a handheld very high frequency (VHF) radio to the ECR to attempt to establish communication with the C/E. This coincided with the 1/E's arrival on the bridge. The master gave permission for the release of CO_2 into the engine room and recalled the departing 2/O.

On arrival at the emergency generator room the 2/E found that the EDG was running but its circuit breaker had not closed to connect the generator to the emergency switchboard. The 2/E tried to close the circuit breaker manually by using the push button on its front panel, but it did not operate. The EDG cooling water temperature was high and the cooling fan was not operating so the 2/E stopped the engine manually and left to inform the C/E of the problem with the circuit breaker.

The 1/E met the C/E at the main fire locker and reported that the master had authorised the activation of the CO_2 system. At 2021, the C/E activated the system to release CO_2 into the engine room. Under instruction from the 1/E the available fire team members started to prepare their equipment.

The C/E instructed the newly arrived 2/E to go to the CO_2 room to check the fixed fire-extinguishing system. The 2/E entered the compartment and identified by torchlight that not all of the CO_2 gas cylinders allocated to the engine room had operated. The 2/E returned to the main fire locker and informed the C/E, then returned to the emergency generator room with the electrician to try to restore power to the emergency switchboard.

Finnmaster continued to drift slowly past the west knuckle at the entrance to King George Lock. At 2026, the tug *Serviceman* arrived and was made fast by *Finnmaster*'s crew who passed the lines manually as the ship's winches had no power. At 2037, the arrival of the second tug, *Nobleman*, enabled *Finnmaster* to be brought fully under control.

The 1/E led *Finnmaster*'s fire team to the main cargo hold via the aft crew stairway. At 2040, two fire team members entered the AER wearing compressed air breathing apparatus (CABA). The fire team withdrew from the space and reported the remnants of a small fire on AE2. They re-entered the space and extinguished the fire with a dry powder extinguisher.

At 2057, *Serviceman* and *Nobleman* manoeuvred *Finnmaster* alongside the quay to the west of King George Lock. By 2117, the ship was secured alongside. Humberside Fire and Rescue Service firefighters boarded *Finnmaster* and confirmed that the fire had been extinguished.

Finnmaster's crew installed a temporary arrangement to bypass the faulty EDG circuit breaker and restored power to the emergency switchboard at 0233 on 20 September 2021.

1.4 DAMAGE SUSTAINED

Finnmaster sustained fire damage to the equipment in the AER **(Figure 3)**. The heat generated during the fire was sufficient for plastic components to melt, causing damage to electrical wiring and other susceptible equipment. Smoke damage was largely limited to the interior of the compartment.

The fire significantly affected the area of the AE instrument panels. The pressure gauge indicating the fuel supply pressure to the outboard fuel injection pump on AE2 had seized, showing 3.8 bar after the fire. The inboard fuel injection pump coupling bolts on AE2 had failed and jammed in the coupling. The fuel injection timing on the cylinders that side of the engine had changed.

The terminal box containing the wiring for the instrumentation on both AE1 and AE2 was positioned on the frame of the instrument panel for AE1. The door of the terminal box had failed, causing the internal wiring to melt due to its exposure to the heat of the fire.

The external alternator output, exciter and monitoring cables serving both AEs were heat-damaged. Both AE1 and AE2 sustained significant damage, necessitating their later removal from the ship for repair.

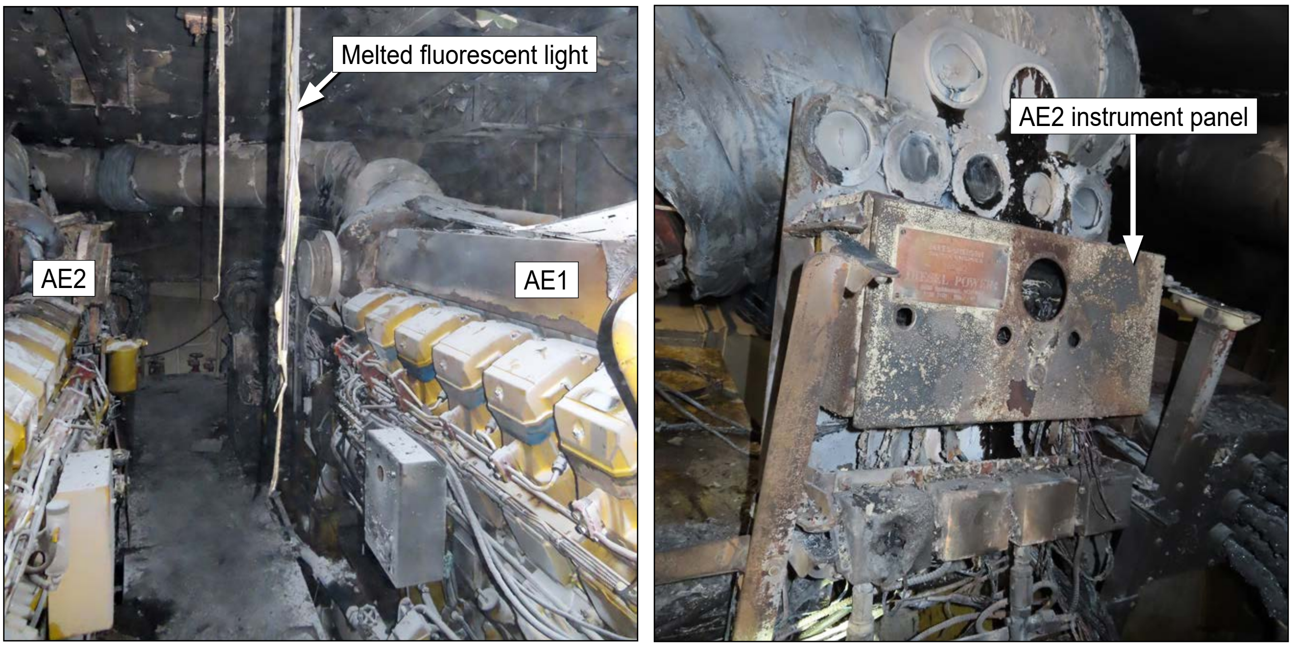

Figure 3: Damage to the auxiliary engine room

1.5 ENVIRONMENTAL CONDITIONS

At the time of the accident, the air temperature was 16°C with light airs from the east. Sunset had occurred at 1907 and it was dark, though the dock was well-illuminated by lights on the surrounding berths. The King George Lock outer gates, which provided access to the Humber Estuary, were closed and there were no currents or tidal flows within the basin.

1.6 *FINNMASTER*

1.6.1 Overview

Finnmaster was a Finland registered combination container and ro-ro cargo ship built in Norway in 1998. *Finnmaster*'s upper cargo hold on the main deck and lower cargo hold on the platform deck were used to carry vehicles. The ship's open weather deck was used for both vehicles and containerised cargo and was accessed via a fixed ramp on the port side **(**see **Figure 2)**.

Finnmaster had been classified by the Det Norske Veritas Group AS (DNV) from its construction until 1 January 2016, when the ship's management changed to Finnlines Plc (Finnlines) and classification transferred to RINA S.p.A (RINA) at the request of the owners.

1.6.2 Finnlines Plc

Finnlines was a Finnish public limited company and one of seven independent shipping companies wholly owned by the Grimaldi Group headquartered in Italy. Finnlines operated a fleet of 21 ships, including cargo and passenger ro-ro ships. The company had three ro-ro cargo and two ro-ro passenger ships under construction as part of a newbuilding programme. The fleet's operational and technical management was based in Helsinki.

Finnlines held a Document of Compliance[4] issued by the Finnish Transport and Communications Agency (TRAFICOM), certifying the company for the operation of both cargo ships and ro-ro passenger ships. Finnlines' operations centred on trading routes in north-west Europe and Scandinavia.

1.6.3 Crew

TRAFICOM issued a minimum safe manning document[5] to *Finnmaster* requiring a minimum of 11 crew to operate the ship. At this level of manning, *Finnmaster* was certified to operate with an unattended machinery space (UMS)[6]. On 19 September 2021, there were 16 crew on board *Finnmaster* and all were qualified in line with the requirements of the minimum safe manning document.

The crew comprised Finnish, Estonian, Latvian and Filipino nationals. The working language on board *Finnmaster* was English.

Finnmaster's deck department operated a three-watch system while at sea, but all deck crew were needed for mooring operations. The engine room operated in UMS mode but was manned by the C/E and a duty engineer officer for port arrivals and departures. On the day of the fire the 1/E was the duty engineer officer.

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[4] A safety certificate issued to shipping companies in line with the requirements of SOLAS Chapter IX to certify compliance with the ISM Code.

[5] A certificate detailing the number of qualified and experienced seafarers necessary to operate the ship safely.

[6] Essential requirements included the provision of an approved alarm and monitoring system that maintained the ship's safety to a standard equivalent to that of an operator being present.

1.6.4 Cargo

On 19 September 2021, *Finnmaster* loaded 102 wheeled freight units into its lower and upper cargo holds. A further three wheeled freight units and 51 containers were loaded onto the weather deck.

The loaded cargo included various dangerous goods that had been stowed in line with the requirements of the International Maritime Dangerous Goods Code.

1.6.5 Propulsion overview

Finnmaster's single main engine provided 15.6 megawatts of propulsion power through a reduction gearbox to a constant speed single shaft driving a controllable pitch propeller. The ship had a single rudder and was equipped with an 800 kilowatt (kW) bow thruster used for manoeuvring at low speed.

1.6.6 Machinery space arrangement

The engine room was located in the aft section of *Finnmaster*'s platform deck, below the main deck. The ECR was located across the port side of the engine room's forward bulkhead, which separated the space from the lower cargo hold. Immediately aft of the ECR on the port side was a staircase leading up to two doors on the main deck: an inboard door led to a stairwell giving access up to the weather deck and, through a further door, into the main cargo hold; the outboard door at the top of the stairs led into the AER containing the two AEs and their ancillary equipment **(**see **Figure 2)**.

1.6.7 Electrical systems

Main power supply

Electrical power at 380 volt alternating current (VAC) and 50 hertz was provided by three alternators connected to the main switchboard **(Figure 4)**. Alternators AE1 and AE2 were each rated at 850kW. The third (shaft) alternator was driven by a power take-off from the propulsion engine gearbox and was rated 1,000kW. This alternator could be connected either to the main switchboard or directly to the bow thruster.

The main switchboard in the ECR contained individual starter boxes for the ship's equipment and also supplied power to distribution switchboards elsewhere on board. A bus-tie breaker[7] electrically divided the main switchboard into two, enabling each side to be operated independently. *Finnmaster* normally operated with the bus-tie breaker closed.

The circuit breakers connecting the alternators to the main switchboard were designed to open automatically should electrical parameters vary from safe limits[8].

Finnmaster was provided with a power management system that regulated the sharing of electrical load between the alternators. Either AE1 or AE2 would be designated the 'lead alternator' and the other the 'follower'. The power management system would automatically start and stop the follower unit and share the load between the alternators as necessary dependent on the electrical demand on board.

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[7] A circuit breaker connecting two parts of the switchboard.

[8] Low frequency, low voltage, short circuit current, overcurrent, reverse power or current differential.

Each of the three alternators on *Finnmaster* had sufficient electrical capacity to power the ship in normal operation. More than one alternator would be used when higher load necessitated, for example during the carriage of refrigerated cargo units. When entering or leaving port, *Finnmaster* would operate with two alternators connected to provide security of supply. If the bow thruster was required during periods of high electrical load it would be connected directly to the shaft alternator, with the two main alternators connected in parallel supplying power to the main switchboard consumers.

Lower voltage main power at 220VAC was provided by step-down transformers connected to the main switchboard.

On the day of the fire *Finnmaster*'s electrical system was configured with AE1 and AE2 supplying the full ship's load for departure from Hull. AE2 was set as the lead alternator. The shaft alternator was not connected.

For illustrative purposes only: not to scale

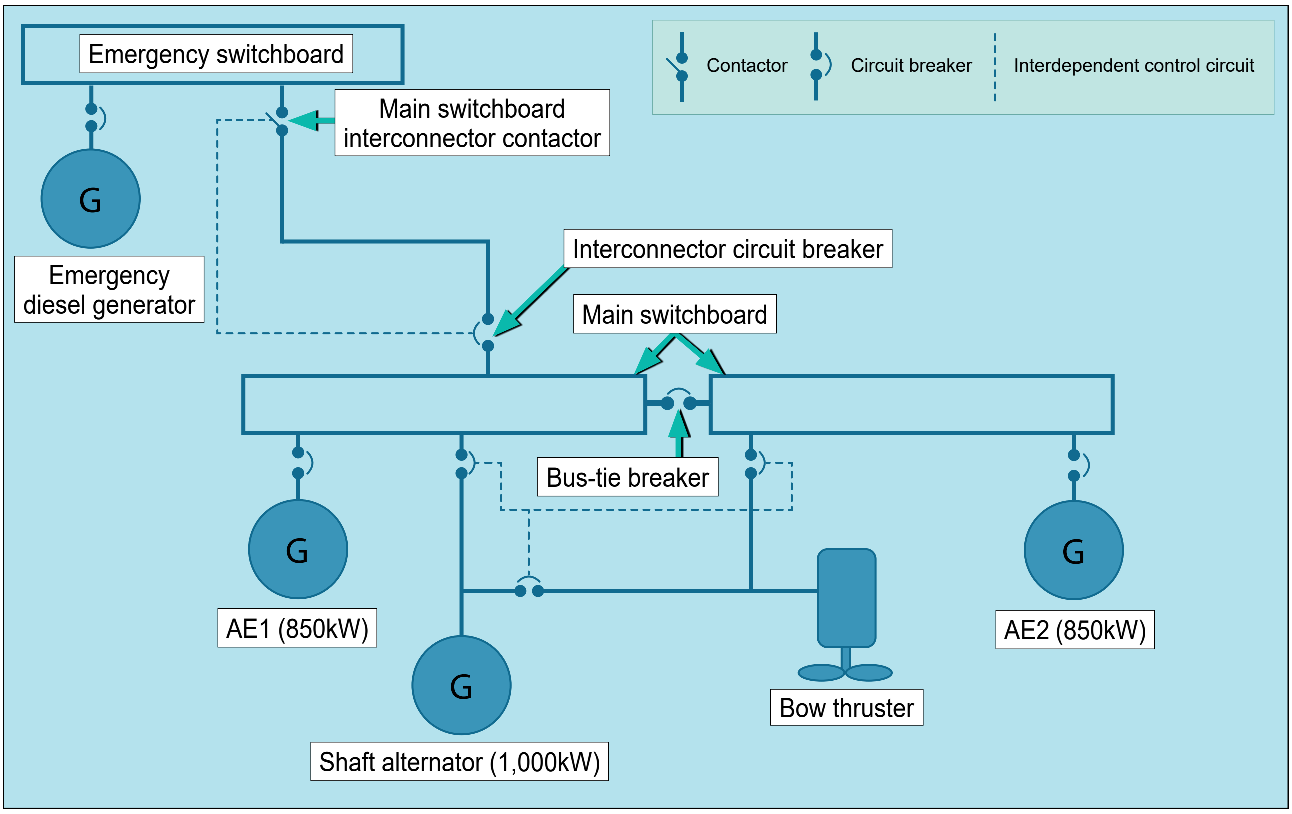

Figure 4: Schematic of *Finnmaster* electrical distribution system

Emergency power supply

The equipment requiring an emergency power supply on *Finnmaster* was connected to an emergency switchboard. In normal operation, the emergency switchboard was supplied through an interconnector circuit breaker on the main switchboard and an interconnector contactor on the emergency switchboard **(Figure 4)**. A step-down transformer supplied from the emergency switchboard provided 220VAC power to lower voltage critical equipment such as emergency lighting.

The EDG supplied *Finnmaster*'s emergency power. The EDG was a diesel engine-driven generator located with the emergency switchboard in the emergency generator room **(see Figure 2)**. The EDG was required to automatically start and connect to the emergency switchboard within 45 seconds following a loss of power.

The EDG supplied power to the emergency switchboard through a circuit breaker and was rated at 156kW. It was not possible to operate the EDG in parallel with the main switchboard.

The diesel engine powering the EDG was water cooled. The water circulated through a radiator provided with a fan powered from the emergency switchboard. When the EDG started, and power was available on the emergency switchboard, the fan would start automatically and ventilation dampers on the radiator outlet would open automatically to provide a cooling airflow through the radiator.

An uninterruptible power supply (UPS), provided by 24 volt direct current (VDC) batteries, supplied power to instrumentation and some of the ship's communication systems.

Emergency diesel generator circuit breaker

The circuit breaker between the EDG and the emergency switchboard[9] comprised two main components: the circuit breaker switch, a mechanical device that physically connected the two sides of the circuit together when made; and the motor mechanism module (motor module), which allowed the switch to be operated electrically. The motor module contained a small electric motor that moved a mechanism to operate the mechanical switch. The serial numbers indicated that both the switch and motor module were produced in the late 1990s, coincident with the construction of *Finnmaster*.

The circuit breaker motor module allowed either automatic or manual operation of the EDG circuit breaker using a circuit breaker mode selector on the front of the motor module cover. In manual mode it was possible to compress a charging spring in the motor module using a ratchet lever and then open or close the circuit breaker using push buttons on the front of the unit. During the emergency on *Finnmaster* the mode selector switch was set to automatic. In later attempts to close the circuit breaker, the crew set the mode selector switch to manual **(Figure 5)**. In automatic mode, the motor module charging spring was compressed by the action of a 220VAC motor acting through a gear mechanism in the unit. The design criteria for the charging motor limited its operation to a maximum of four operations per minute.

The EDG circuit breaker motor module control circuit diagram is shown in **Figure 6**. An undervoltage time delay unit (UVT) was installed to delay the opening of the circuit breaker[10] and prevent nuisance tripping in the event of a transient voltage drop. A loss of power to the undervoltage trip contacts on the motor module would cause the circuit breaker to open.

An auxiliary relay (16K5) was connected in parallel with the UVT's input terminals[11]. When this relay was energised, and if the motor module was set to automatic operation, the motor rearming connection started the control unit motor and compressed the motor module charging spring.

9 An MT400 motor mechanism module attached to a ComPacT NS400NA 3-pole switch, both manufactured by Schneider Electric.

10 The time delay was set to 500 milliseconds.

11 Time delay terminals 1 and 2 in **Figure 6**.

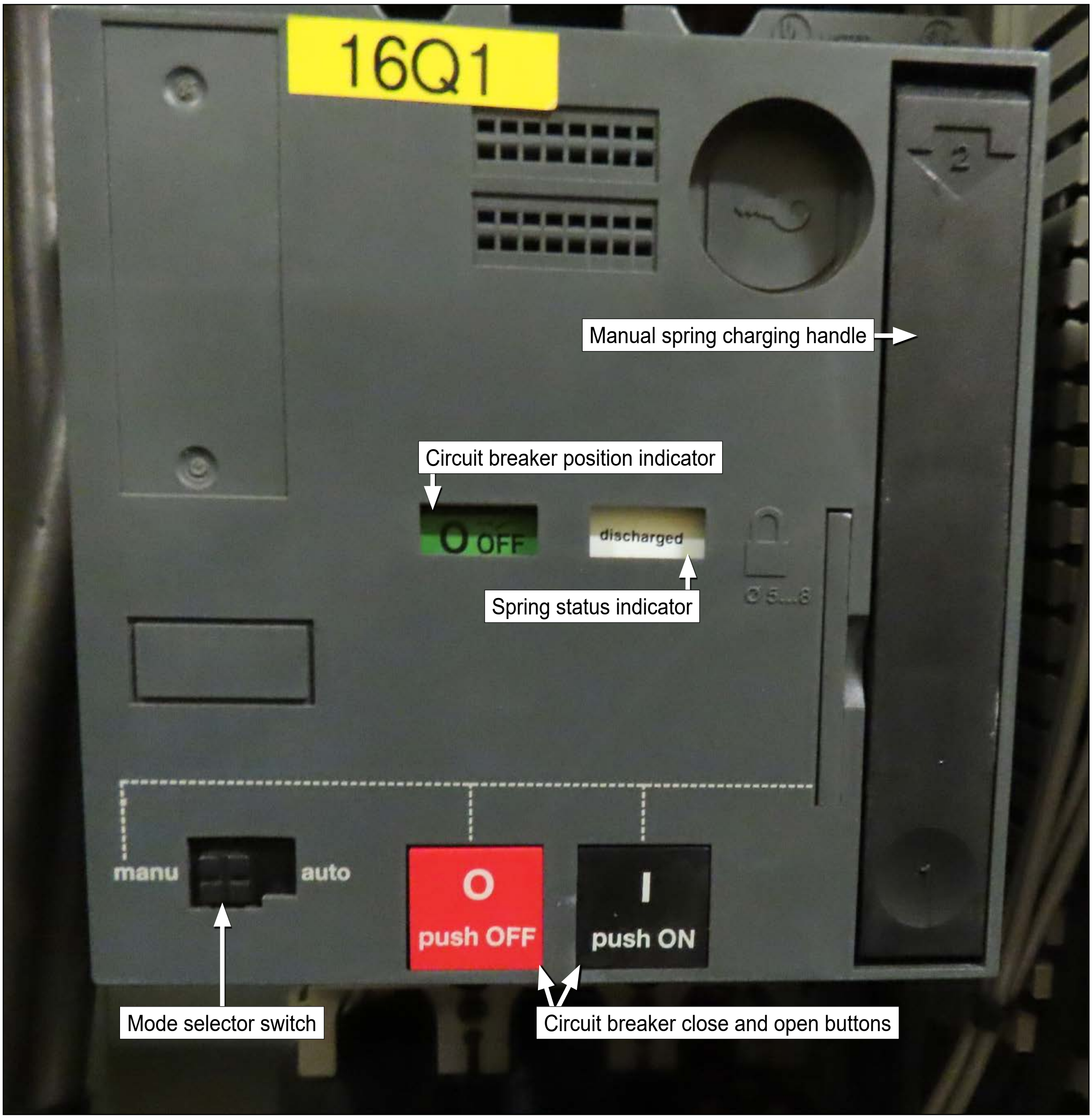

Figure 5: Emergency diesel generator circuit breaker motor mechanism front panel

For illustrative purposes only: not to scale

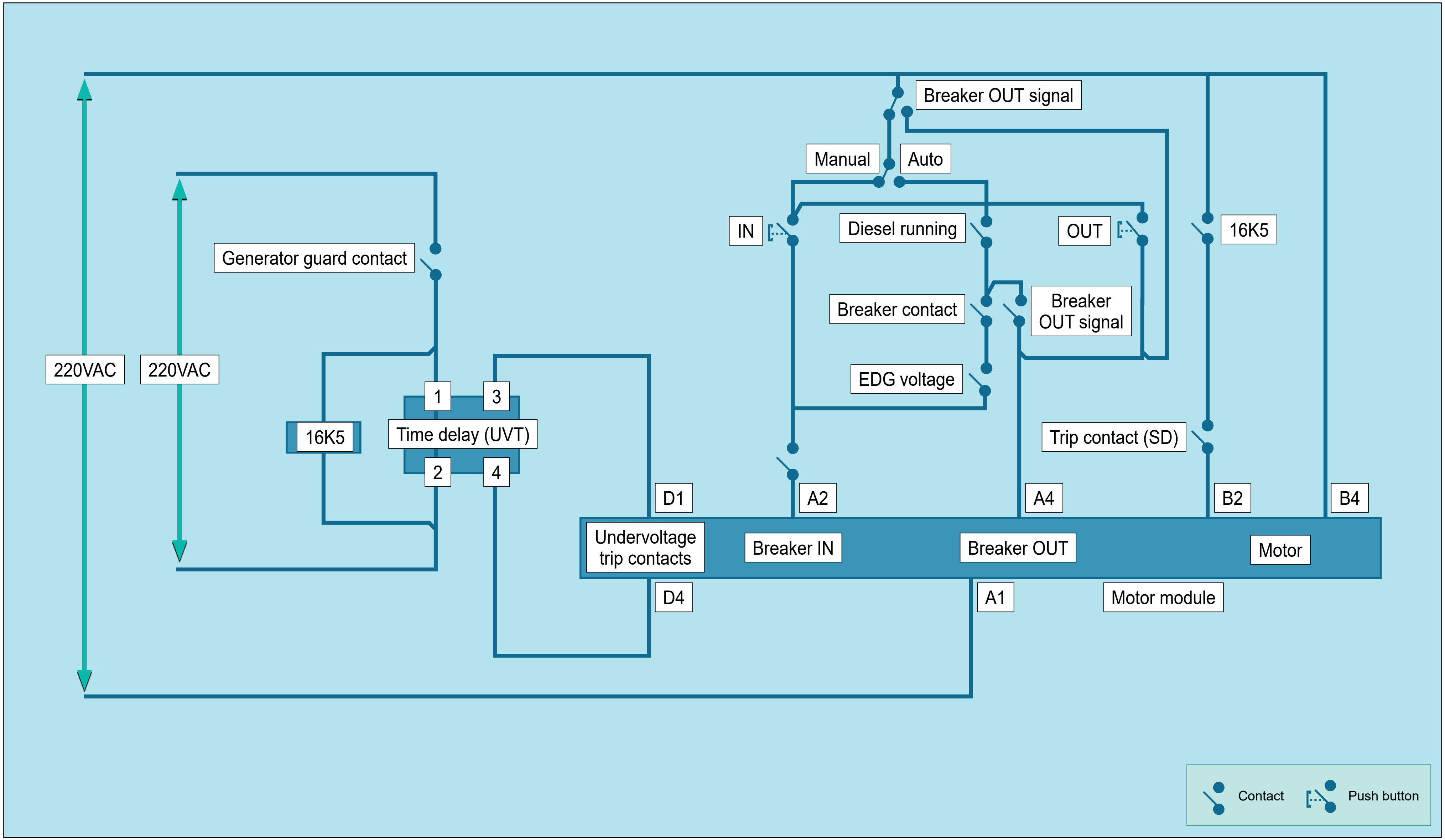

Figure 6: Emergency diesel generator circuit breaker motor mechanism control circuit

1.6.8 Communication systems

General

Finnmaster had an independent sound-powered telephone system with handsets on the bridge and in the ECR, CO_2 room and emergency generator room, among other main control stations. There was no handset in the main fire station from where the CO_2 system was activated.

The communication systems on board *Finnmaster* had been subject to inspection during the periodic survey for the safety equipment certificate (SEC), carried out in July 2021.

Very high frequency communication system

The main VHF radio installation on *Finnmaster* formed part of the Global Maritime Distress and Safety System (GMDSS)[12]. The system was powered from the emergency switchboard, backed up by 24VDC batteries provided expressly for a situation where both main and emergency sources of power to the radios were unavailable. The GMDSS system remained operational throughout the incident. *Finnmaster* was also equipped with three handheld VHF battery-powered radios intended for use in survival craft.

Ultrahigh frequency communication system

A UHF radio system provided the means for *Finnmaster*'s crew to communicate with each other. The system comprised individual handheld transceivers and an analogue repeater unit, which boosted the signal to overcome communication issues in areas where the ship's structure interfered with the radio signals.

The carriage of a UHF repeater system was not a mandatory requirement. The system was powered from the bridge 220VAC distribution board supplied from the emergency switchboard. It was not connected to a UPS.

1.6.9 Planned maintenance system

Finnmaster's machinery maintenance was managed using a planned maintenance system (PMS) and scheduled in line with manufacturer recommendations based on machinery running hours or calendar frequency.

The PMS was approved by DNV, the ship's original classification society. In 2004, DNV conducted a survey of *Finnmaster*'s PMS to confirm that the system met the requirement for safe and reliable operations. The surveyor recorded that:

> *some changes had been made based on the owner's and/or ship's experiense due to traffic pattern. All changes had been agreed with the owner's superintendent.* [sic]

The same PMS continued to be used on board *Finnmaster* after the ship's classification transferred to RINA in January 2016. Finnlines maintained a list of *critical equipment* in the PMS that included the EDG and emergency switchboard but none of the radio installations nor the UHF analogue repeater unit.

[12] A worldwide integrated communication system used to transmit emergency and distress messages.

The responsibility for maintenance of machinery was delegated to individual engineering officers. The assigned engineer monitored the condition of the equipment they were responsible for and completed maintenance in line with the instructions contained in the PMS. The 2/E was assigned the majority of the AE maintenance tasks; electrical tasks were carried out by the electrician. The C/E carried out surveys of machinery and maintained oversight of the records that the engineering officers entered into the PMS.

When personnel changed, an overview of the maintenance carried out during the duty period was passed to the joining engineer in a set of handover notes. The C/E was provided with a copy of these notes.

1.6.10 Fire protection arrangements

Firefighting equipment

Finnmaster had portable foam, dry powder and CO_2 fire extinguishers located around the ship for the extinguishing of small fires.

A distributed network of fire hydrants connected to a fire main provided access to seawater for fighting fires using fire hoses. The fire main was supplied by three fire pumps driven by electric motors, one of which was situated in the forward pump room and supplied with power from the emergency switchboard. The other two pumps were supplied with power from the main switchboard and were situated in the main engine room.

Finnmaster had a CO_2 system capable of being activated from the main fire locker on the weather deck. The system could inject a set quantity of CO_2 into the engine room or either cargo hold to extinguish a fire.

Engine room ventilation

Ventilation for the AER was provided from the main engine room supply fans positioned forward of the funnel on the first bridge deck. Air from the main engine room supply fans entered the AER through a set of fixed louvres on the inboard side of the compartment. Air flowed out of the AER through permanent openings into the main engine room from where it passed up the engine casing, exhausting through louvres on the rear of the funnel. There were no exhaust fans.

The inlets to the engine room supply fans were fitted with automatic fire dampers that would close if the fans were stopped or there was a loss of power to the fire damper actuators.

The engine room supply fans could be stopped locally at the fan or from control panels in the ECR and on the bridge. The fans would also stop automatically, and the automatic fire dampers would close, if the control cabinet for the engine room CO_2 system was opened. The supply dampers had automatically closed when power was lost during the fire.

The fire dampers on the exhaust from the engine room were manually operated shutters on the inside of the funnel louvres. These shutters were actuated using handles at deck level on the aft bulkhead of the funnel. The exhaust fire dampers were in working order, though the labels for the exhaust damper actuator handles were obscured by paint.

The exhaust dampers were open when inspected as part of the investigation. Crew members were unaware of the operation of the exhaust fire dampers, believing that they were not present at all, or that all fire dampers were automatic and closed on a loss of power.

Fuel system emergency shutdowns

The fuel valves from the service tank supplying marine gas oil (MGO) to *Finnmaster*'s main engine and AEs, as well as those supplying the boiler, separators and fuel transfer pumps, could all be remotely closed from the emergency generator room.

The outlet valve from the service tank to the AE fuel system was not closed during the response to the fire. The ship's engineers closed the outlet valve the following morning to halt leakage from the fuel system identified during their post-fire inspection of the AER.

Remote stop activation panels on the bridge and in the ECR enabled the fuel pumps, including the fuel feed pump to the AEs, to be stopped remotely in the event of an emergency. The remote stops for the fuel pumps were not activated during the response to the fire before the loss of electrical power on board.

Fire detection system

Finnmaster was fitted with an automatic fire detection system. In the event of a low level of smoke being detected in a space, a pre-warning would sound an alarm on the bridge and at the remote stations in the ECR and in the cargo control room. This alarm required acknowledgement within 2 minutes to prevent the fire alarm sounding throughout the ship. The detection of a significant amount of smoke would initiate an immediate fire alarm. The location of any detected smoke would be displayed on the fire alarm panels.

The AER had a single smoke detector fitted at deckhead level between the two AEs. The smoke generated when the flexible hose on AE2 failed, releasing fuel onto a hot surface, was sufficient to trigger an immediate fire alarm that sounded throughout *Finnmaster*.

1.7 AUXILIARY ENGINES

1.7.1 General

Finnmaster's marine variant Mitsubishi Heavy Industries (MHI) S12R series AEs were 12-cylinder, V-configuration, direct fuel injection engines with a maximum continuous rating of 1,088kW at a speed of 1,500 revolutions per minute.

Each bank of six cylinders on the engine had a separate high-pressure fuel injection pump driven by the main gear wheel through an accessory drive at the rear, or flywheel, end of the engine[13]. The exhaust outlet from each bank of cylinders led to a separate turbocharger at the aft end of the engine.

[13] On *Finnmaster* the auxiliary engines were installed with the front of the engine at the forward end of the compartment and the rear of the engine at the aft.

The wiring for both engine alarm and shutdown functions led to a frame-mounted terminal box positioned next to AE1 between the two alternators. This terminal box also contained the cabling for the engine stop solenoids, which needed to be energised for the engines to operate.

1.7.2 Operating parameters

The engine that was to become AE2 was tested in the Netherlands at Mitsubishi Heavy Industries Equipment Europe B.V.[14] before being delivered to the shipyard for installation on *Finnmaster*. Under test, AE2 delivered 871kW with exhaust gas temperatures of 561°C from the left six-cylinder bank and 564°C from the right six-cylinder bank. A common exhaust gas temperature of 453°C after the turbocharger was recorded.

Exhaust gas temperatures of approximately 400°C after the turbocharger at loads of 450kW were recorded in *Finnmaster*'s engine room logbook during normal operation.

At the time of the fire AE1 and AE2 were connected in parallel. Each alternator was supplying 200kW to 250kW, rising to around 600kW when the bow thruster was in use.

1.7.3 Fuel system

Finnmaster's two AEs ran on MGO supplied from a service tank sited immediately aft of the AER. The MGO had a flash point of 60°C and an autoignition temperature of approximately 240°C. At the time of the fire the service tank contained 8.5m^3 of MGO, equating to a level of 1.58m measured from the bottom of the tank.

A remotely operated outlet valve from the service tank led to a fuel feed pump that pressurised the fuel supply to the engines. A duplex filter installed after the feed pump provided the initial filtration of the fuel before the system divided to supply the AEs. A manual valve in the system allowed each AE to be isolated individually. The fuel system divided after the engine's fuel isolation valve to feed the two high-pressure fuel injection pumps via two sets of fuel cartridge filters **(Figure 7)**.

The two AEs operated on a four-stroke cycle. Fuel injection happened on every second rotation of the crankshaft. To achieve this, the gear arrangement for the high-pressure fuel injection pumps rotated at half the speed of the engine.

Each cylinder on the AE was fitted with a single fuel injector. The fuel injection pumps supplied a metered volume of fuel to each fuel injector at a specific point in the rotation of the engine. The static timing of the injection was 23° before top dead centre (TDC)[15] towards the end of the compression stroke.

A single-speed governor controlled both fuel injection pumps on each engine, adjusting the position of the fuel injection pump control rack, and hence the amount of fuel injected, to maintain the engine at a constant speed as the load on the engine varied.

[14] The company name subsequently changed to Mitsubishi Turbocharger and Engine Europe B.V.

[15] The angular position of the crankshaft when the piston is in its uppermost position.

For illustrative purposes only: not to scale

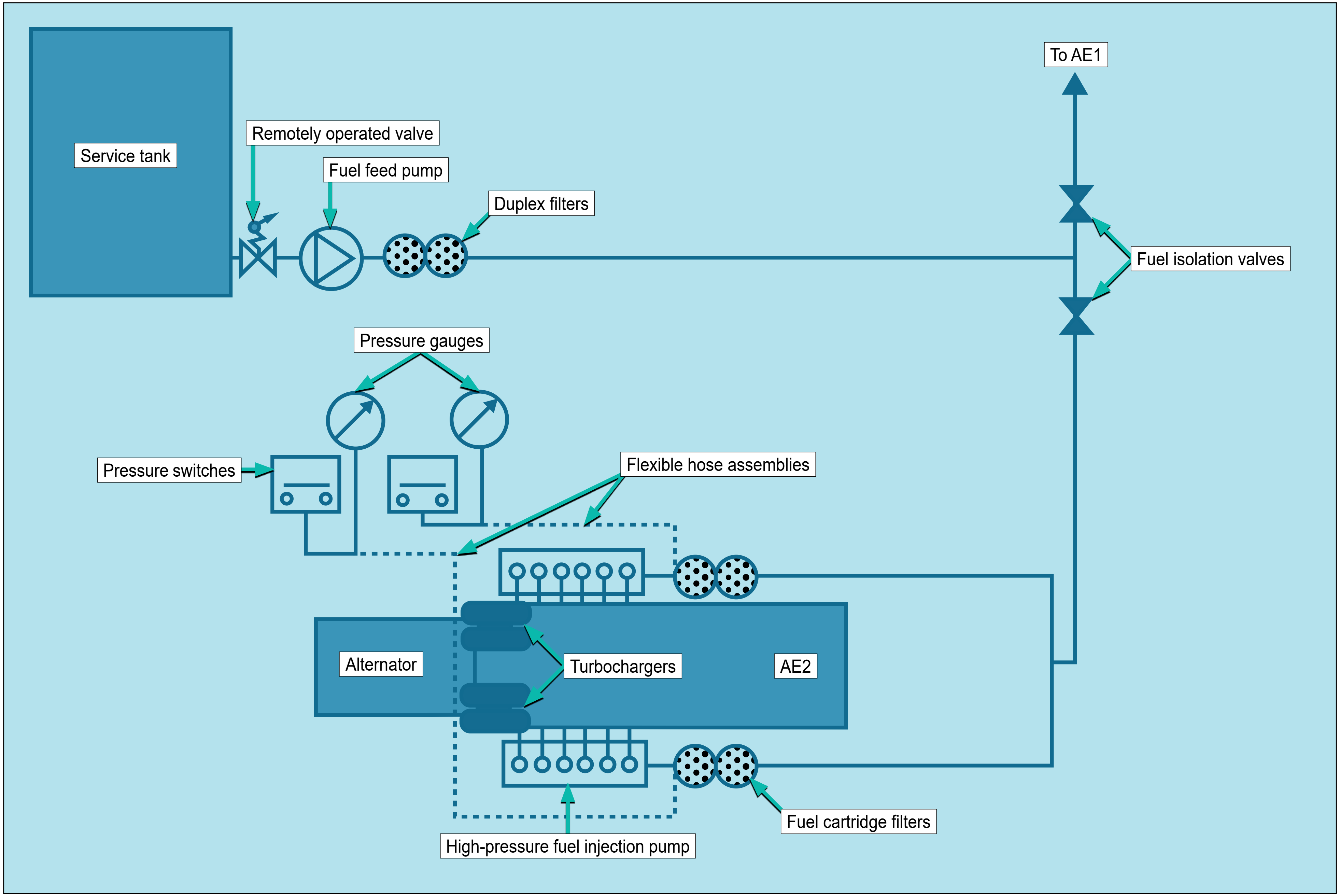

Figure 7: Auxiliary engine fuel system

Fuel injection pump coupling

Each fuel injection pump drive had a coupling between the accessory drive on the engine gear case and the fuel injection pump drive shaft. The couplings comprised two coupling flanges separated by two laminated plate stacks with a cross-coupling in between. The laminated plate stacks were secured on each side by an M12[16] bolt passed through a bushing set into the holes in the laminated plates **(Figure 8)**. The service instructions identified that the rounded washers' orientation against the laminated plate stacks was key to prevent damage to the plates. A solid steel cover extended over the coupling assembly to protect crew from the rotating parts.

The fuel injection timing could be adjusted by loosening the two bolts in the slots of the drive end coupling flange, turning the fuel injection pump coupling flange relative to the position of the engine to the desired position, then retightening the bolts. The timing adjustment slots extended over an arc of 22° on the coupling.

The difference in rotational speed of the fuel injection pump drive compared to the crankshaft meant that an alteration of 1° in the timing adjustment slot would have the effect of changing the fuel injection timing by 2° against the position of the crankshaft.

Over time, MHI had modified the fuel injection pump coupling design. The details of these modifications were published in MHI service bulletins and included design changes, compatibility with existing parts, part number references and amendments to the servicing instructions.

Service bulletins did not require an immediate change to the parts or maintenance procedure referred to. A field campaign would be completed if the engine manufacturer decided an immediate change was needed. No field campaign was initiated for any of the design changes to the fuel injection pump couplings installed on *Finnmaster*'s AEs. Renewal coupling components for the AEs were sourced from MHI as the original equipment manufacturer (OEM).

AE2 fuel injection pump coupling damage

The inboard fuel injection pump coupling on AE2 had partially failed. Both bolts connecting the drive end coupling flange to the first set of laminated plates in the coupling assembly had failed. The bolts remained lodged in their respective timing adjustment slots and laminated plate stacks. One bolt was intact, and the other had sheared part way along the length of the shank **(Figure 9)**.

The intact bolt was wedged in position between the cross coupling and drive end coupling flange **(Figure 10)**. The bolt shank was heavily worn and the bolt head was worn on its upper surface. The nut from this bolt was retrieved from the tank top below the engine following the fire. The sheared bolt was heavily worn across the fracture of the shank and its head was worn where it had been in contact with the cross coupling. The end of the bolt and nut were retrieved from the tank top below the engine following the fire.

After the failure the rounded washers remained in place where the bolts passed through the laminated plates. The washers were oriented in line with the servicing instructions.

[16] Metric thread (M) + the outer diameter of the thread in mm.

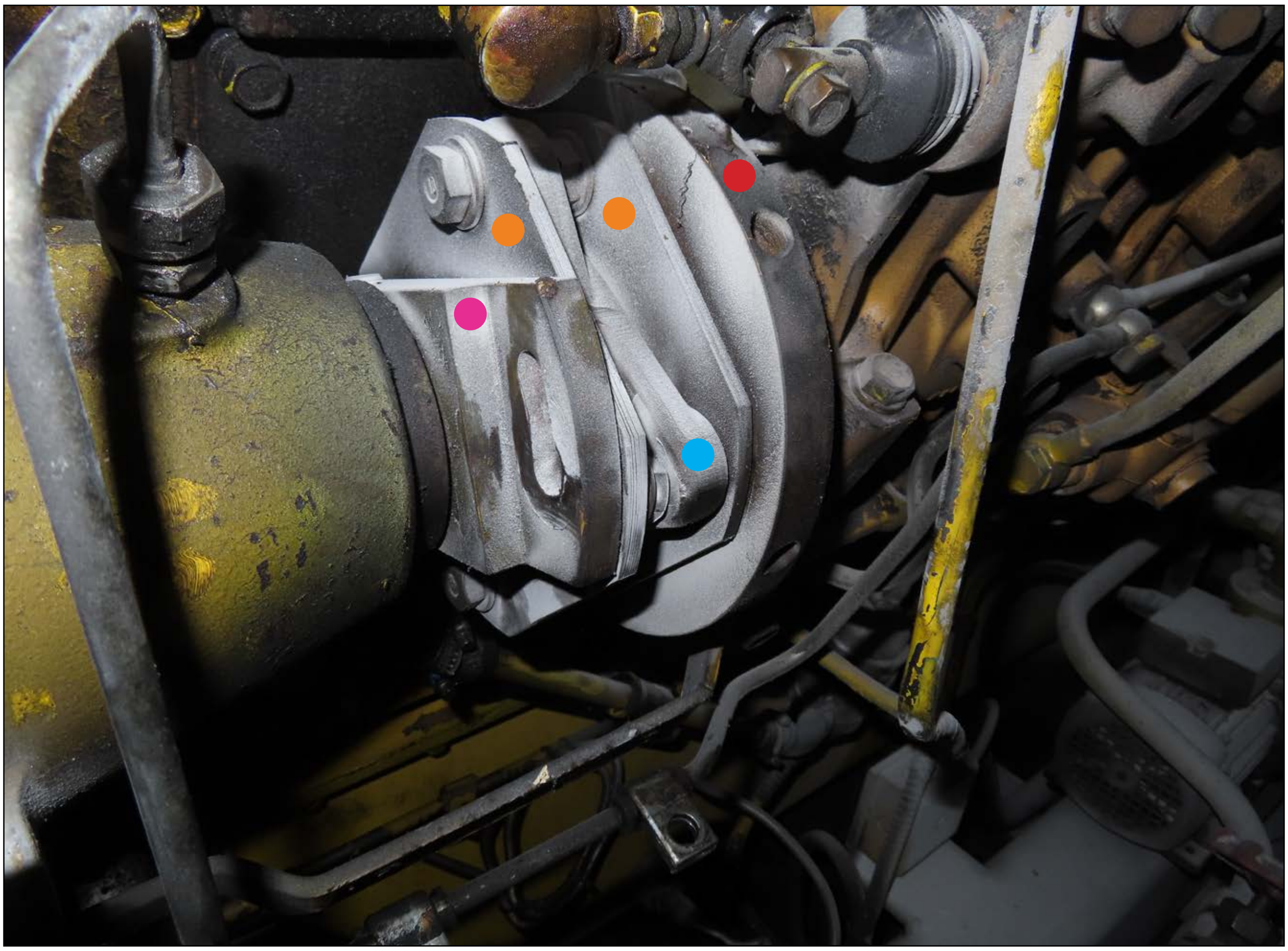

Image courtesy of Mitsubishi Heavy Industries Engine & Turbocharger Ltd. (Service Bulletin 16-411-E)

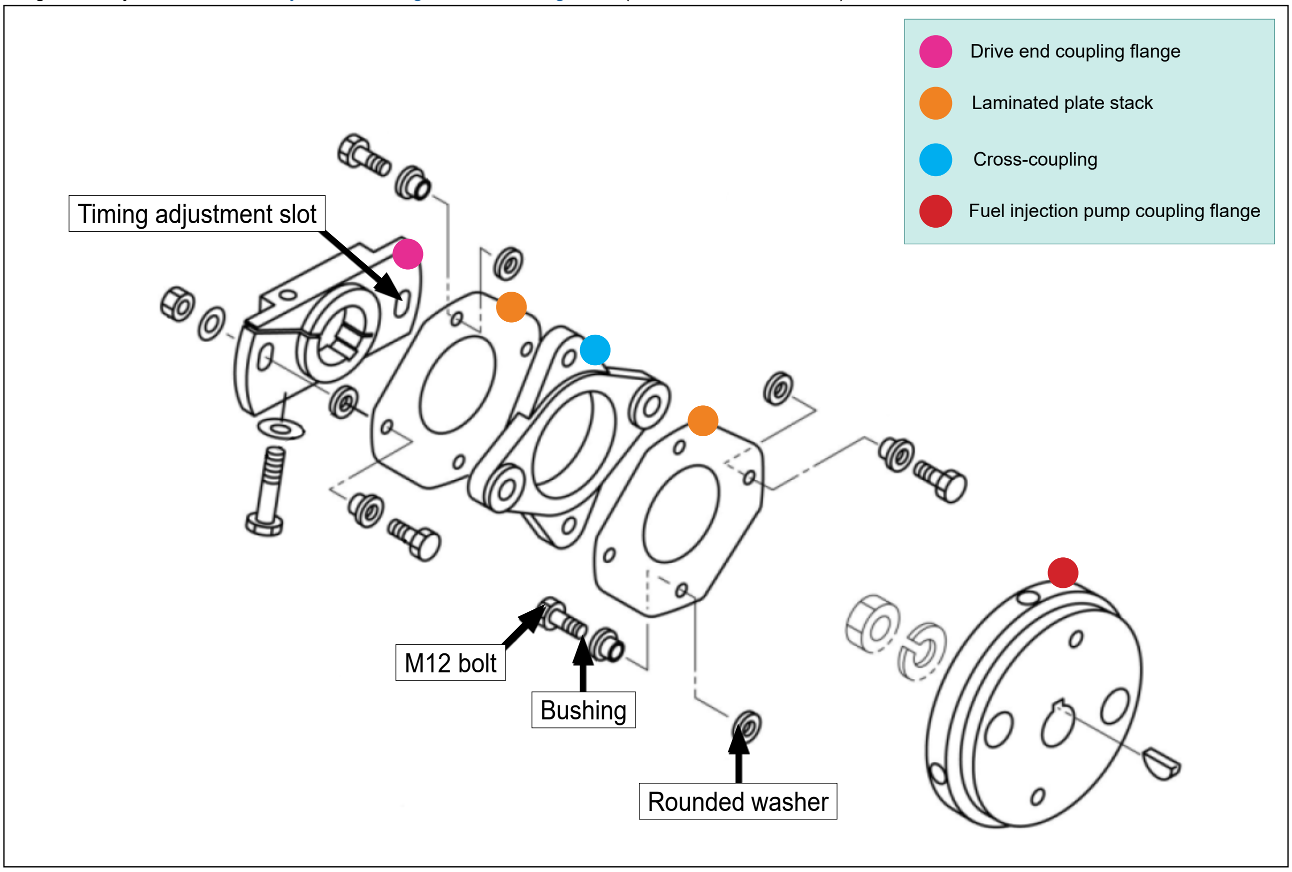

Figure 8: Fuel injection pump coupling

Figure 9: Damaged coupling drive bolts

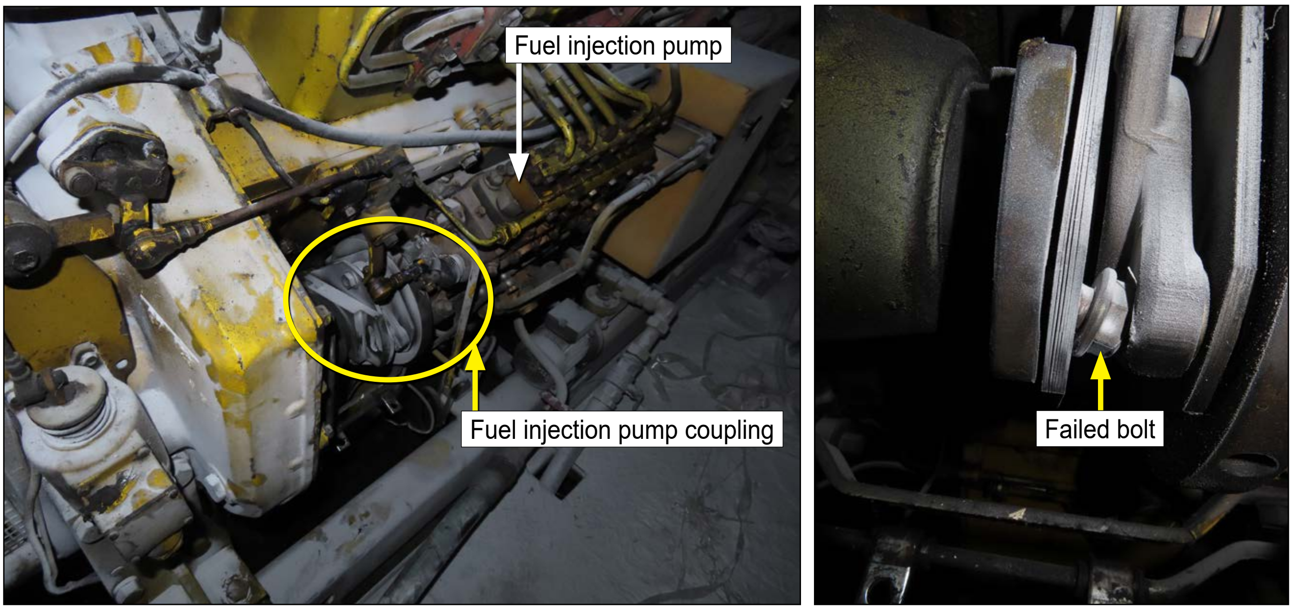

Figure 10: Fuel injection pump coupling with failed bolt in situ

The laminated plates on the drive end of the inboard fuel injection pump coupling were damaged and cracks ran from the coupling bolt holes **(Figure 11)**. This damage extended through the full thickness of the laminated plate stack with substantially more damage on one side than the other. The face of the drive end plates adjacent to the drive bolt holes showed evidence of fretting damage.

Witness marks were visible on the surface of the drive end coupling flange where the flat washer had previously been seated **(Figure 12)**. An examination of the accessory drive assembly in the gear drive for AE2's inboard fuel injection pump did not indicate any defects.

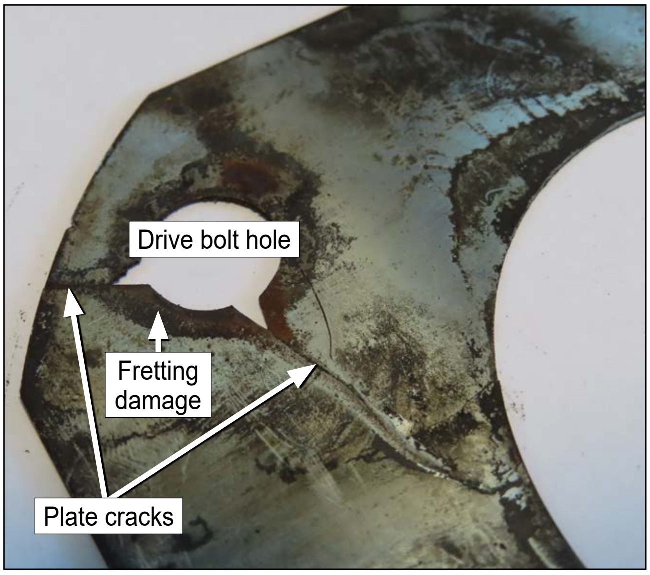

Figure 11: Drive end laminated plate damage

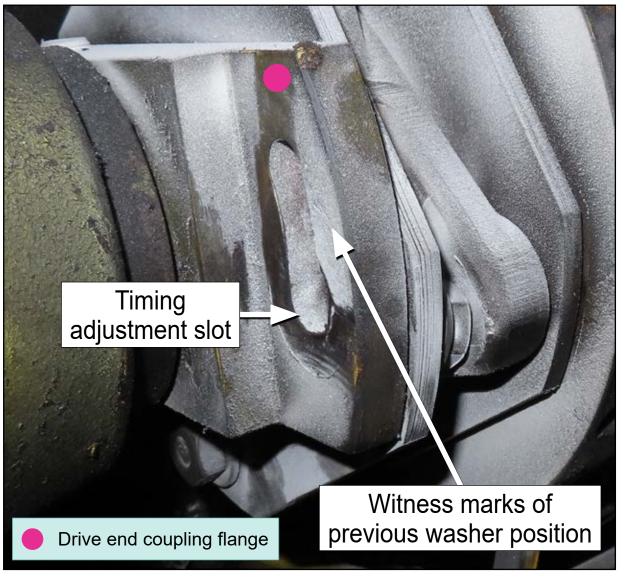

Figure 12: Witness marks on drive end coupling flange

1.7.4 Exhaust system

General

Each AE cylinder emitted exhaust gases into one of two manifolds. The manifolds were constructed of cast steel sections joined by stainless steel expansion bellows secured at each end by a gas-tight clamping arrangement.

The two exhaust manifolds each led to a turbocharger at the rear of the engine. From the outlet of the turbochargers, the exhaust was joined to a common exhaust pipe that was bolted to the exhaust uptake leading to the funnel. Between the outlet from each turbocharger and the exhaust pipe was a cast steel transition ring, which was clamped to the turbocharger outlet casing. The other end of this ring was fitted with a sealing arrangement that allowed a degree of axial movement between the engine and the exhaust pipe. The seal took the form of two spiral wound seal rings set into radial grooves in the transition ring **(Figure 13)**.

Exhaust insulation

The exhaust system on each of the auxiliary engines was installed within an insulated box structure to prevent contact of the flammable liquids with the very high temperature surfaces of the turbocharger turbine casings and central exhaust pipe **(Figure 14)**. A transverse oil supply pipe for the turbocharger bearings ran along the lowest point of the insulated box structure. Behind this pipe there was a gap of approximately 25mm between the lowermost panel of the box structure and the engine frame.

Image courtesy of Mitsubishi Heavy Industries Engine & Turbocharger Ltd.

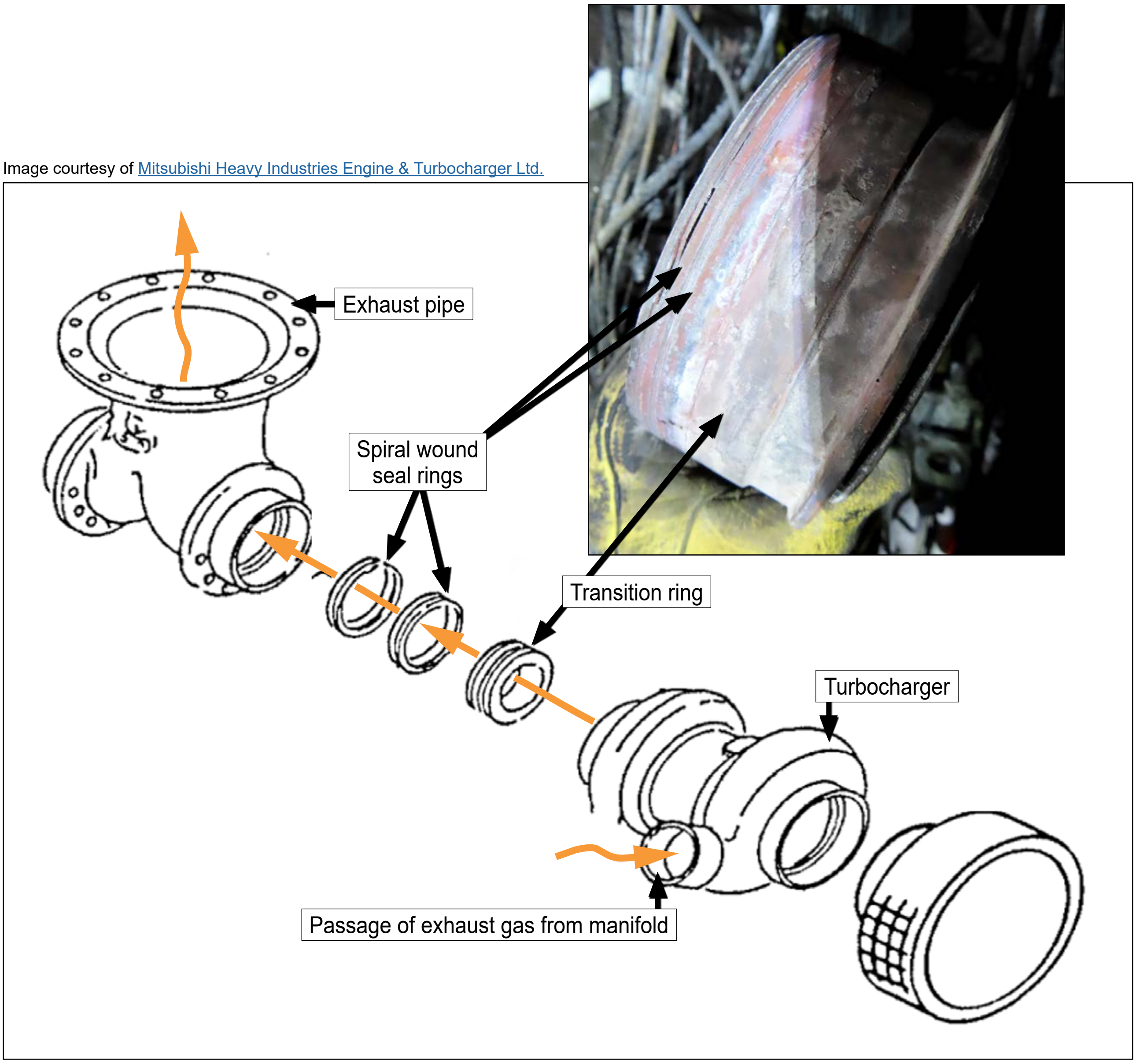

Figure 13: AE2 exhaust system

Image courtesy of Det Norske Veritas AS

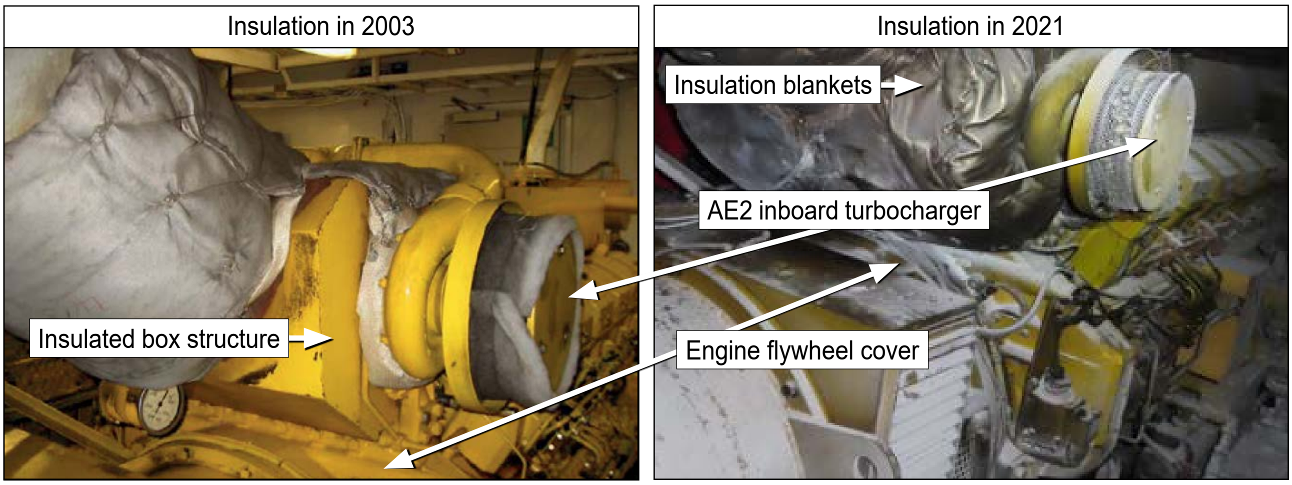

Figure 14: AE2 exhaust insulation

In April 2003, a survey by a DNV surveyor verified that the installation on AE2 met the requirements for the protection of the high temperature surfaces.

Insulation blankets were installed over the original insulated box structure, covering the two turbocharger turbine casings and the central exhaust pipe. The insulation blankets were in place at the time of the fire and extended down to the top of the flywheel cover between the engine and alternator.

AE2 engine exhaust system damage

The surfaces of the insulation blankets over the turbochargers of AE2 were found to be heat damaged following the fire. Beneath the insulated box structure, witness marks on the support frames for the outboard turbocharger showed evidence of gas emitting from the junction of the turbocharger outlet transition ring. The marks extended over an arc of approximately 120°, angled down towards the top of the engine block **(Figure 15)**.

Disassembly of the outboard turbocharger allowed the removal of the exhaust transition ring. A layer of hardened insulation cement compound was partially in place at the junction of the transition ring and the exhaust pipe. When the transition ring was removed, the cement compound was found to extend the length of the ring past the seal arrangement. The spiral wound seal rings were seized in their grooves, and there was evident clearance between the transition ring and the exhaust pipe **(Figure 16)**.

No evidence of leakage from the exhaust system of AE2's inboard turbocharger was visible, though the rings were similarly contaminated by insulation cement compound.

1.7.5 Alarm and monitoring system

Finnmaster was constructed in line with DNV classification society rules. The DNV rules set the requirements for alarm, monitoring and automatic shutdown systems and accounted for the operation of the ship in UMS mode.

The alarms for each AE were connected to a bespoke panel in the ECR that provided engine control and alarm monitoring functions. This panel allowed the engineers to monitor the alarm status of each AE and manually start and stop it as necessary.

A separate machinery alarm and monitoring system was provided to manage the UMS operation of *Finnmaster*, allowing the engineers to monitor the machinery and be alerted to any abnormality. An alarm registered on the AE control and monitoring panel would also trigger an alarm in the machinery alarm and monitoring system.

Local thermometers provided the means to monitor the exhaust gas temperature after the turbocharger on the AEs on *Finnmaster*. The thermometer sensors were located in pockets in the exhaust pipe on the turbocharger outlet, close to the junction of the gas flows from the inboard and outboard turbochargers. *Finnmaster* did not have any means of remote oversight of the AEs' exhaust temperatures.

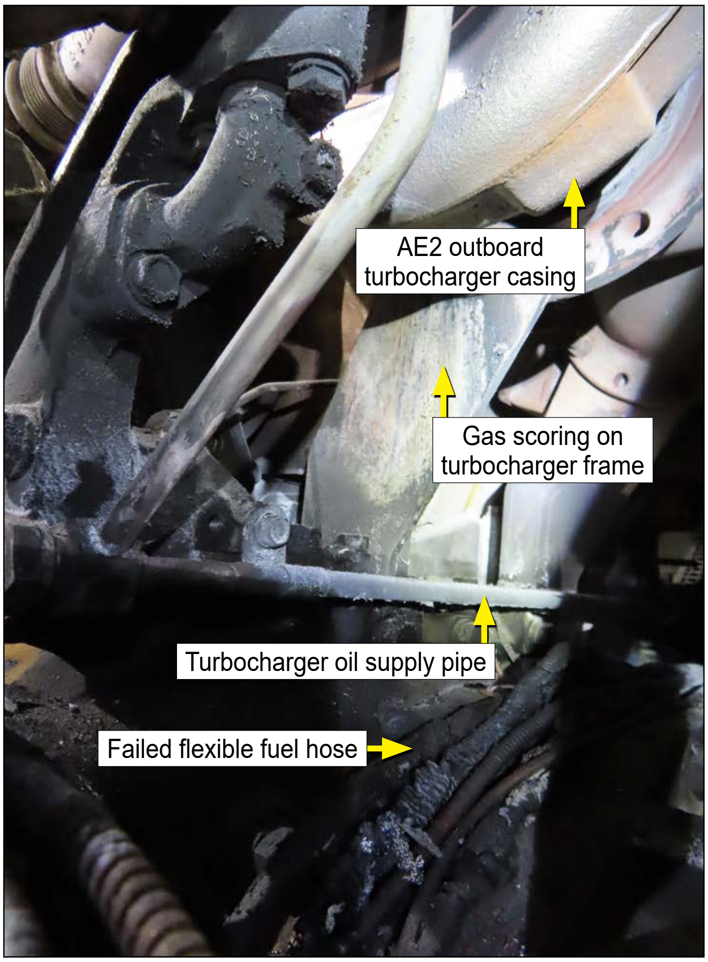

Figure 15: Gas scoring marks on turbocharger frame surface

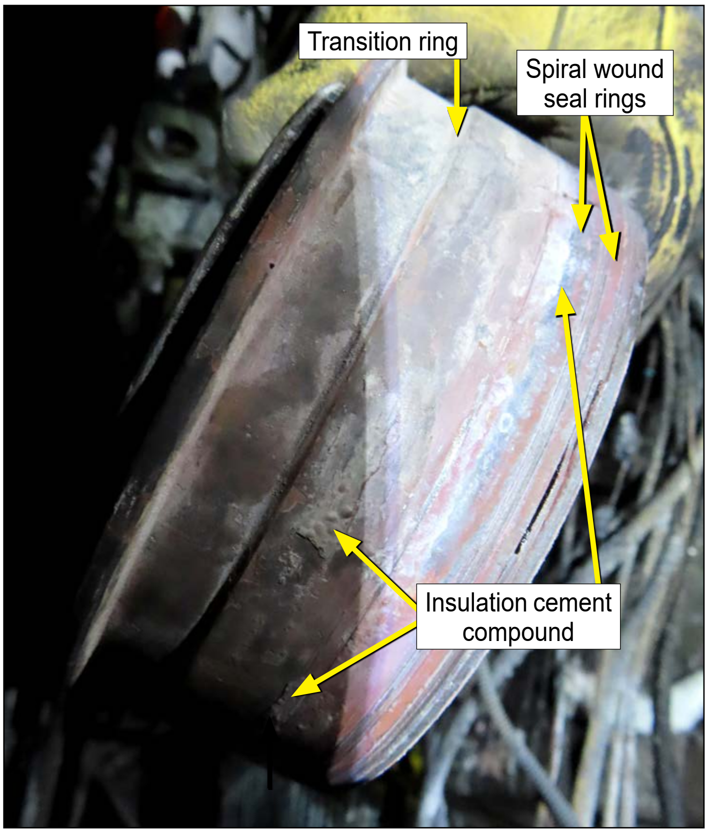

Figure 16: Turbocharger exhaust gas outlet transition ring

Modification to alarm and monitoring system

At some point between 2003 and 2006, *Finnmaster*'s alarm and monitoring system was modified to alert the ship's engineers if the fuel pressure supplied to the AE's fuel injection pumps fell below 0.5 bar, and to enable local monitoring of the fuel supply pressure.

The modification involved the installation of two pressure gauges and two pressure switches on the local instrument panel of each AE. The two pressure switches serving each AE were electrically connected to the associated AE alarm and monitoring panel in the ECR. If the fuel pressure fell below the set pressure an alarm would sound on the alarm and monitoring panel as well as on the local machinery alarm and monitoring system.

A flexible fuel hose led to the local instrument panel from a banjo connection[17] on the fuel cartridge filter outlet on each side of the engines. The flexible hose assemblies each consisted of a single length of hose with steel fittings crimped at either end.

The 3.6m flexible fuel hose installed on AE2 from the inboard fuel cartridge filters was routed aft, over the top of the fuel injection pump and across the flywheel cover of the engine to the local instrument panel. The flexible hose passed below the exhaust insulation blankets fixed over the insulated box structure that covered the exhaust system at the aft end of the engine **(Figure 17)**. The flexible hose was looped across the back of the frame around the local instrument panel and connected to a steel tee piece at the bottom of the frame. Steel pipes led from the tee piece connection and on through separate isolation valves to the pressure switch and pressure gauge. Plastic cable ties secured the length of the flexible fuel hose. The flexible hose passed over the flywheel cover at 1.08m above the level of the bottom of the daily service tank.

The 1.7m flexible fuel hose routed aft from the outboard cartridge filters on AE2 passed above the outboard fuel injection pump and across the junction of the engine and alternator to the frame of the local instrument panel. The flexible hose was then also looped across the back of the frame before connecting to the pressure gauge and pressure switch through steel pipes in a similar configuration to the inboard pipework.

To retain classification, the DNV rules required changes to a hull, machinery, equipment or systems covered by classification to be documented and approved in advance. A proposal for the modification to *Finnmaster*'s alarm and monitoring system had not been submitted to DNV for assessment and no approval was granted.

The DNV rules permitted the use of flexible hoses in fuel systems *limited to a length necessary to provide for relative movement between fixed and flexibly mounted items of machinery/equipment or systems*.

The rules also required means to be provided to *isolate flexible hoses used in systems for fuel oil*. The only valve in the instrumentation line was at the local instrument panel and served only to isolate the pressure gauge and pressure switch.

[17] A hydraulic fitting comprising a perforated hollow bolt and a spherical union. The bolt is assembled through the centre of the union to create a fluid path between the external ports on the union and bolt.

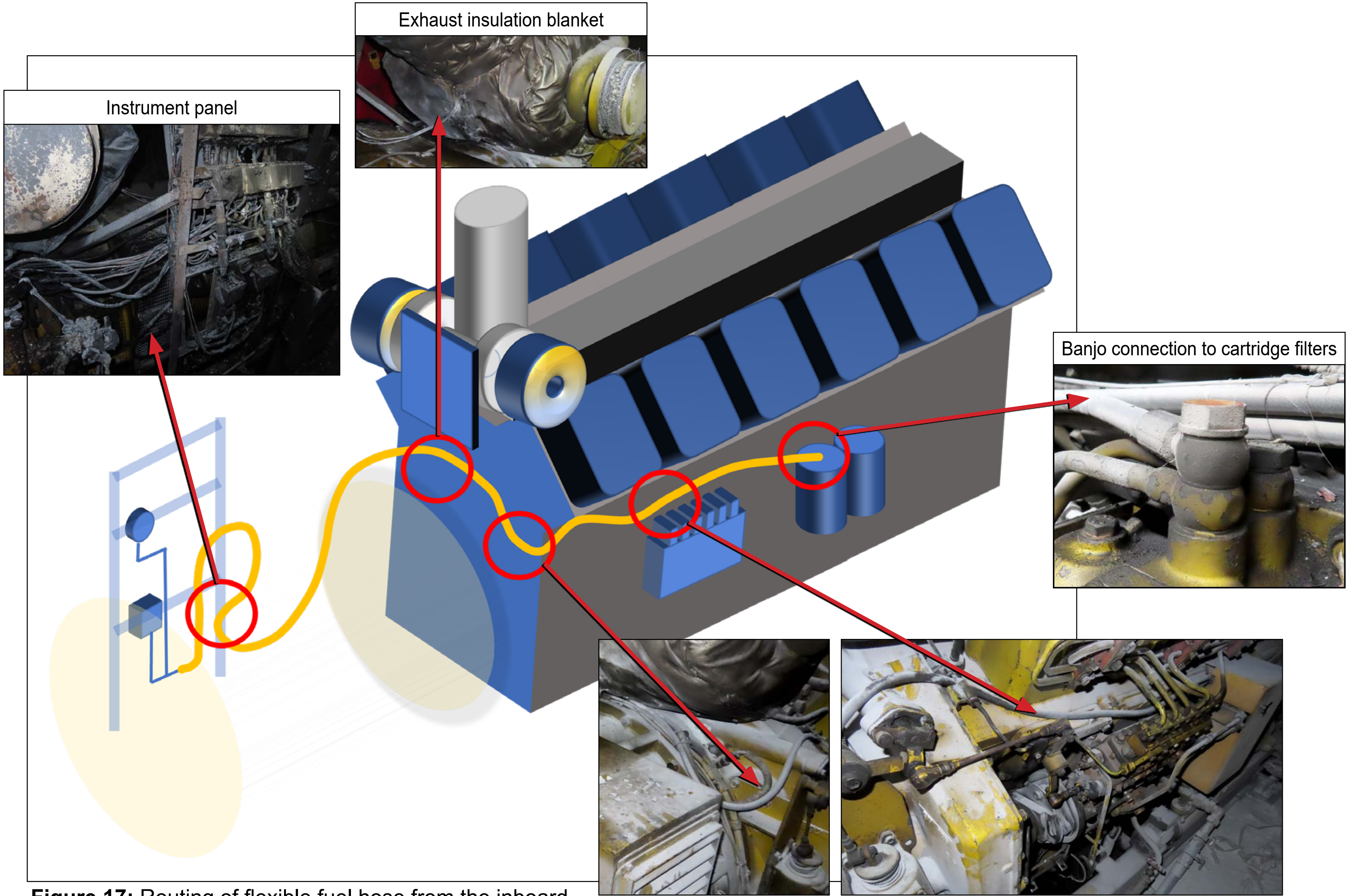

Figure 17: Routing of flexible fuel hose from the inboard cartridge filters to the AE2 local instrument panel

The banjo connection at the fuel cartridge filter outlet was an open connection without any means of closure. The flexible fuel hose remained under pressure at all times unless the engine in question was isolated as a whole from the main fuel supply.

In June 2006, a DNV surveyor issued a Condition of Class[18] to *Finnmaster* for the condition of the exhaust insulation on the main and auxiliary engines and included a photograph of the insulation in the survey record. Visible in this photograph was the flexible fuel hose from the inboard fuel cartridge filters where it passed over AE2's flywheel casing. The flexible hose was not visible in a photograph taken during the survey for the protection of high temperature surfaces in April 2003.

1.7.6 AE2 major overhaul

From 4 October to 10 October 2017, three Inter Marine Oy (Inter Marine) technicians carried out a scheduled overhaul of AE2 under the supervision of a maintenance manager. The engine had completed 48,750 running hours.

The engine was disassembled during the overhaul and components were serviced or renewed as necessary based on their condition. Any replacement parts were sourced from the OEM by Inter Marine.

Reconditioned fuel injection pumps were installed in line with the OEM procedure, which used a go/no-go gauge[19] to measure the distance between the face of the fuel injection pump drive coupling half and that of the fuel injection pump flywheel to confirm the coupling was correctly aligned.

Reconditioned turbochargers were installed on the engine using the existing transition rings fitted to the exhaust outlet. There were no records that the seal rings[20] on the transition rings were replaced during the service as required by the service instructions. On assembly, a sealing compound was used to fill the annular gap between the transition ring and the exhaust pipe **(Figure 18)**. This was contrary to the servicing instructions, which required that new seal rings were fitted and that no sealing compound was used.

Finnmaster's crew did not actively monitor the engine overhaul. The PMS records stated that the C/E surveyed the engine on completion of the service. The post-maintenance trials and alarm tests were witnessed by the chief engineer and a surveyor employed by RINA. The records indicated that the trials and tests were satisfactory but did not include the low fuel pressure alarms in the list of alarms tested.

[18] Specific remedial measures issued by a surveyor on identification of a defective or damaged survey item affecting the ship's classification.

[19] A tool used to test a dimension against a specific tolerance. One end of the tool will fit the assembly dimension being measured (go) but the other end will not (no-go).

[20] MHI part number 37432-14700.

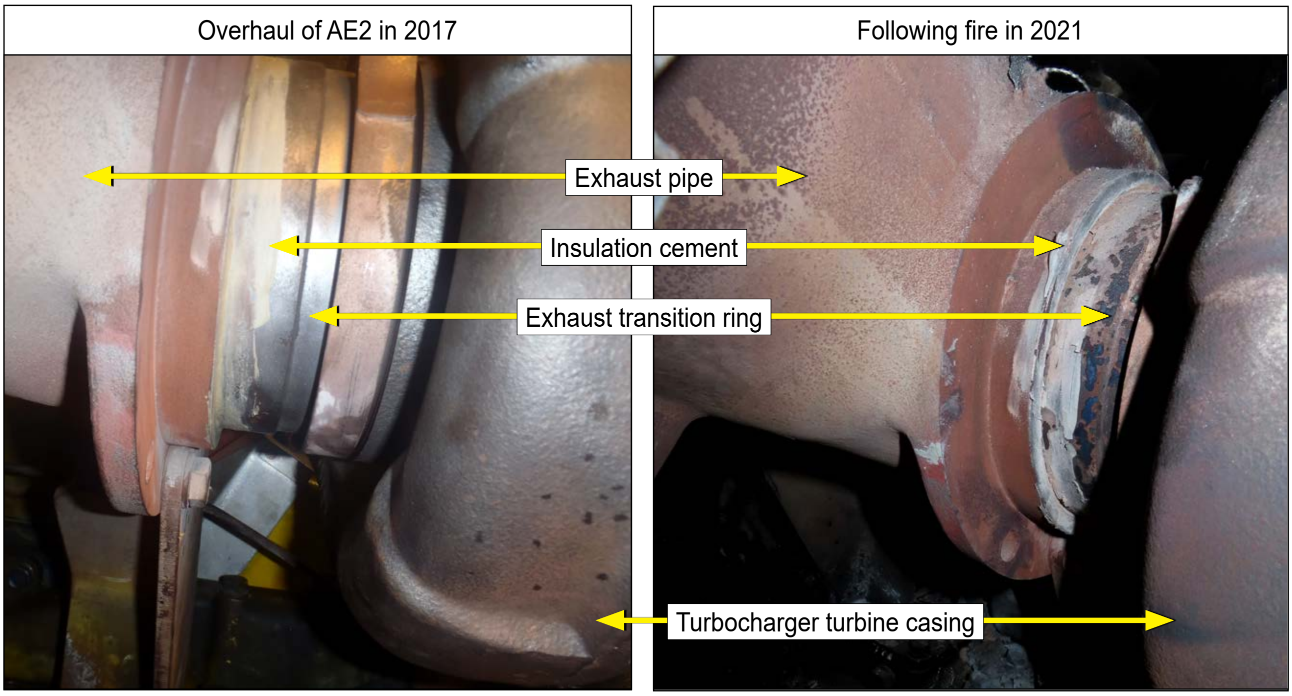

Figure 18: Use of insulation cement on the inboard turbocharger transition ring seal

1.7.7 Maintenance of AE2 fuel injection pump couplings

Operation and maintenance manual

The maintenance requirements for the AEs were set out in the *operation and maintenance manual* supplied by MHI when *Finnmaster* was built. A statement in the manual enabled operators to shorten the scheduled intervals between maintenance if it was considered necessary.

The original manual contained a task to retighten all bolts and nuts on the engine at 1,000-hour intervals. A further 1,000-hour task required a visual check of the fuel injection timing. This latter requirement was later revised to a 2,000-hour frequency, and this change was reflected in the manual carried on board *Finnmaster*.

In July 2016, Mitsubishi[21] revised the manual for the AEs to include a 2,000-hour requirement to check the fuel injection pump laminated plates. The manual also included a requirement for a major engine overhaul between 8,000 and 12,000 hours.

Alternative maintenance instructions

The fuel injection pump coupling maintenance regime had undergone numerous updates since the AEs' installation on *Finnmaster*. The changes were set out in MHI service bulletins, which had been filed with the on board copy of the operation and maintenance manual.

A separate *service manual* provided instructions for the method of overhauling the engine and specified the torque settings to be used for tightening the fixings. From April 1997, the fuel injection pump coupling incorporated the use of high-tensile steel bolts, identifiable by a number 10 stamped on the head of the bolt, with a higher tightening torque setting than had previously been applied.

[21] The company was renamed Mitsubishi Heavy Industries Engine & Turbocharger, Ltd on 1 July 2016.

The AE fuel injection pump couplings on *Finnmaster* were fitted with M12 x 1.25 bolts that were marked with the number 10. The service manual on board reflected the torque setting for this type of bolt.

Planned maintenance system requirements

The PMS on *Finnmaster* contained two jobs specific to the fuel injection pump couplings on the auxiliary engines: At a frequency of 2,000 hours, a check of the fuel injection pump drives including the coupling bolts; and, at a frequency of 5,000 hours, a check of the fuel injection timing of the engine. There was no requirement in the PMS to check the security of any bolts on the engines at 1,000-hour intervals.

Finnmaster AE maintenance records

The maintenance of the AE2 inboard fuel injection pump coupling was recorded in the PMS. The maintenance records for the period between October 2017 and the fire on 19 September 2021 is summarised in **Table 1**.

Date	Engine hours	Notes as written
11 October 2017	48,750	AE2 service completed
18 June 2018	49,981	*Injection pump coupling problem* *One nut had loosened and dropped from the right-side pump coupling and the injection timing had changed.* *There was one washer missing from another bolt (between laminate plate and coupling) which caused the nut to loosen from another side bolt.* *Bolts, bushings, washers, nuts and laminate plates were changed to new ones on right side and of course Injections timings were re-adjusted.* *Also checked LH injection pump coupling but everything was ok there.* [sic]
20 January 2019	52,081	*Checked tightening of the injection pump coupling bolts.* *No loosen bolts founded.* *Also checked injection timing.* [sic]
4 February 2020	54,119	*Checked tightening of the injection pump coupling bolts.* *No loosen bolts founded.* *Also checked injection timing.* [sic]
9 September 2020	55,034	No remarks
19 September 2021	56,365	Engine fire

Table 1: PMS records of AE2 fuel injection pump couplings

On 29 April 2021, the 2/E left *Finnmaster*. Before departing on leave, the 2/E completed a set of handover notes containing details of the work completed during their time on board. The handover notes stated that *AE1/AE2 bolts on coplings is tighted and fixed by locktide 270*[22] [sic]. There was no corresponding entry in the PMS to reflect this work, though the spare gear transactions recorded in the PMS showed the withdrawal of coupling components from stock on 7 April 2021. The engine manufacturer did not recommend the use of a thread-locking compound on the coupling bolts.

Anecdotal evidence from the engine manufacturer, the service technicians, and ship's engineers working for Finnlines and on other ships operating Mitsubishi S12R engines indicated that bolt failure and slippage of the fuel injection pump coupling resulting in a loss of the fuel injection timing was a known weakness.

1.7.8 Flexible fuel hose routine inspection and replacement

No inspection or maintenance records for the flexible fuel hoses before Finnlines took *Finnmaster* into management were available. Finnlines did not have a system for recording the identity and maintenance history of individual flexible hoses on board.

In October 2018, Finnlines engaged a hydraulic hose company to assess the condition of the flexible hoses and expansion joints on the auxiliary engines on board *Finnmaster*. The report produced by the company noted various defects in the flexible hose installation but did not comment on the length or routing of the flexible hose assemblies. In December 2018, the hydraulic hose company replaced AE2's flexible hoses like-for-like, including those between the fuel cartridge filters and the local instrument panel. The replacement flexible hoses had an oil-resistant synthetic nitrile rubber inner tube with two braids of high-tensile steel wire sheathed in a synthetic rubber exterior cover.

Flexible hose assemblies used on board *Finnmaster* were required to be approved for use by RINA. The flexible hose used held a valid RINA type approval certificate[23] that set out the criteria for its use. This certificate did not state that the flexible hose met a fire resistance standard nor include fuel systems in its range of application. A later RINA type approval certificate[24] for the same flexible hose did include this information.

The replacement of the flexible hoses on the auxiliary engines was overseen by *Finnmaster*'s engineers. The PMS entry for the work indicated that the C/E had undertaken a survey of the completed work. No type approval certificate was provided to the ship on completion of the maintenance.

1.7.9 Maintenance service providers

Inter Marine was based in the port of Kotka, Finland, and provided a wide range of engineering support services focused mainly on the maritime sector. The company was experienced in maintaining Mitsubishi engines and employed ex-ships' engineers as technicians to undertake the work.

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[22] Loctite 270 is a high-strength thread locking compound for securing bolts, nuts and studs to prevent loosening due to vibration.

[23] RINA Approval MAC215618CS/02.

[24] RINA Approval MAC3247221CS/003.

Inter Marine was accredited to provide service and sales of Mitsubishi engines by Mitsubishi Turbocharger and Engine Europe B.V. (MTEE), the Netherlands-based European subsidiary of the MHI group of companies. The contract between Inter Marine and MTEE gave Inter Marine access to the service and training literature for Mitsubishi engines. MTEE provided individual training to service personnel, both at their Netherlands site and via online tutorials.

MTEE held an International Organization for Standardization (ISO) 9001:2015 quality management certificate issued by Lloyd's Register Quality Assurance. Clause 8 of the ISO9001:2015 standard set out the requirements for monitoring, inspection or testing activities undertaken by the company to ensure the quality of services provided. MTEE did not undertake audits of the accredited service providers but had recognised a need to do so before the COVID-19 pandemic of 2020. The pause in operations during the pandemic had delayed any development of a programme to verify the conduct of accredited service providers. Inter Marine was not certified to a quality standard.

Inter Marine did not have a rolling agreement for work undertaken on the Finnlines fleet, though the work they did formed a significant proportion of its overall business. Each job was quoted individually for service and spare parts.

Finnlines had identified Inter Marine as a key supplier of services and completed an audit of the company in May 2017. The report produced following the audit recognised the ability of Inter Marine to provide the technical services required. It indicated that the primary focus of the audit was *supply chain risk elimination*. Secondary to this was the *assessment of the quality, environmental, ethical and regulatory aspects* of the company's performance.

1.7.10 Machinery survey and inspection

General

The machinery on *Finnmaster* was required to be maintained to the technical aspects of the relevant International Maritime Organization (IMO) conventions on machinery installations, and the rules of a classification society recognised by the TRAFICOM as the ship's administration.

From *Finnmaster*'s delivery the ship's classification societies, DNV until 1 January 2016 and thereafter RINA, had conducted statutory surveys on behalf of TRAFICOM in addition to the surveys they completed to maintain the certificates of classification.

The statutory surveys required by SOLAS Chapter I, Regulation 10[25] included inspection of the machinery and equipment, control systems and electrical installations to ensure that they remained satisfactory for the ship's intended service. Both DNV and RINA were members of the International Association of Classification Societies (IACS). The IACS was an organisation of classification societies that established common minimum technical standards and procedural requirements among its members.

[25] Surveys of Structure, Machinery and Equipment of Cargo Ships.

DNV surveys of AE2

The DNV rules required that surveyors undertaking the annual survey for crediting the certificate of classification complete a *general survey of the hull, machinery, equipment and systems to confirm that the ship remained in satisfactory condition and in compliance with approval or accepted standards*.

Additionally, the specific survey requirements for machinery and systems during each annual survey included *a verification of the integrity/function of the shielding of flammable oil piping systems and insulation of hot surfaces exceeding 220°C*.

Until the DNV rules were amended in July 2013, the annual survey also included a survey of alarm functions, control panels and *local indicating instruments*. After this date, the rules were amended to require an examination of the electrical and mechanical condition of the control and monitoring system and a test of alarm function. The amended rules did not explicitly require examination of the local indicating instruments.

During surveys for the renewal of the certificate of classification, the survey of auxiliary systems included a test of alarm and safety functions. The examination of the fuel oil system pipes, valves and filters at the renewal survey was permitted to be undertaken through a visual examination and performance test.

No specific reference was made in the DNV rules to the IMO guidance contained in the IMO publications MSC/Circ.647[26] or, latterly, MSC.1/Circ.1321[27]. The DNV rules provided technical requirements aligned with the contents of the circulars but did not outline the installation, inspection and maintenance guidance detailed within them.

The initial machinery surveys carried out after *Finnmaster* entered service were completed by DNV surveyors under a Continuous Machinery Survey (CMS) framework. The CMS framework allowed for the systematic survey of machinery such that all equipment would be surveyed once within a 5-year period. These surveys would be undertaken by an attending classification society surveyor; however, the classification society's rules allowed some to be carried out by the ship's C/E, including surveys of the AEs.

The DNV survey rules required partial or full disassembly of the AEs and, when considered appropriate by the surveyor, an engine function test. Alarms and safety systems were to be subject to a performance test.

In May 2004, the company operating *Finnmaster* requested that the system used for the survey of machinery on board be changed. The new system of survey, called *machinery planned maintenance system* (MPMS) enabled the classification society's surveys to be credited based on the maintenance activities recorded in a ship's approved PMS, supported by additional checks carried out by a DNV surveyor if deemed necessary. The system had a degree of flexibility, enabling variations to be made to the maintenance schedules based on the experience of the operator.

[26] Maritime Safety Committee/Circular.647 – Guidelines to Minimize Leakages from Flammable Liquid Systems.

[27] Maritime Safety Committee.1/Circular.1321 – Guidelines for Measures to Prevent Fires in Engine-Rooms and Cargo Pump-Rooms.

From the implementation of MPMS on board *Finnmaster* to the transfer of classification to RINA in January 2016, an annual assessment was conducted by a DNV surveyor to verify compliance with the MPMS requirements. The assessment included an audit of the PMS and a general inspection of the machinery on board.

Besides the annual general inspections completed as part of the classification survey, DNV had completed specific surveys of AE2 in 2006 for the issue and subsequent deletion of a condition of classification when the flexible hose assemblies were in place.

RINA surveys of AE2

On 1 January 2016, *Finnmaster* changed classification societies from DNV to RINA at the request of the ship's owner. The change followed an IACS procedure for transfer of classification between member classification societies[28]. The ship's machinery survey system reverted to a CSM framework under RINA's oversight.

The checklist used by RINA surveyors during the conduct of annual classification surveys required a *general examination of the machinery and boiler spaces with particular attention to fire and explosion hazards*[29].

The 2017, AE2 survey records on board *Finnmaster* indicated that the *fuel injection devices*; *turbo blowers*; and *tripping/alarm/safety device* [sic] had been surveyed. The PMS record stated that the survey of AE2 at that time was completed by the C/E and that a test of the alarm and trip functions was undertaken. The list of alarm tests in the PMS did not include the fuel low pressure alarms for the AEs.

The post-service survey of AE2 was recorded by RINA in its central recording system. The RINA record indicated that a satisfactory test of AE2 and survey of the engine components was carried out, appending the report provided by Inter Marine. The record did not indicate that the survey was conducted by the C/E, which implied that it had been completed by the attending RINA surveyor. The RINA rules did not explicitly require the survey to be completed by a surveyor, stating only that:

> *Generally, within a 10-year cycle comprising two consecutive classification cycles, all the items surveyed under CMS are to be inspected once by the Society's Surveyors.* [sic]

In June 2018, RINA surveyors completed statutory surveys for the renewal of the safety construction and safety equipment certificates held by *Finnmaster*. The surveys included:

> *A general examination of machinery and boiler spaces with particular attention to the fire and explosion hazard.*
>
> *A general examination of the machinery, steam, hydraulic, pneumatic and other systems and their associated fittings, for confirmation of their proper maintenance.*

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28 IACS procedure PR1A – Procedure for Transfer of Class (Revision 3).

29 RINA report of machinery annual form: Item MA.2.01.

Between 4 May 2021 and 17 May 2021, a survey for the intermediate safety construction certificate was carried out. This survey included:

> *A confirmation that the machinery, boilers and other pressure vessels, associated piping systems and fittings are installed and protected so as to reduce to a minimum any danger to persons on board, due regard being given to moving parts, hot surfaces and other hazards.*

The survey checklist for the safety construction survey[30] referred to SOLAS Chapter II-2, Regulation 4.2, relating to restrictions on the use of flexible pipework in oil fuel piping systems. The checklist entry completed during the survey indicated this check had been completed.

Delegation of machinery surveys

The rules of the classification societies required chief engineers undertaking surveys on their behalf to meet specific qualification, experience and employment criteria.

The DNV requirements at the implementation of MPMS on board *Finnmaster* required a ship to be manned by chief engineers who were familiar with the PMS and a chief engineer approved by DNV to be on board at least 50% of the time. The requirements for approval of a chief engineer were that the company *confirmed the required qualifications of the chief engineer and that they had sailed a minimum of 3 years as chief engineer or were serving as chief engineer and had been employed with the company for at least 3 years*. The DNV rules stated that the company was responsible for ensuring that a *chief engineer* was *qualified to register and carry out maintenance on all classification related machinery items*, referring to the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), 1978, as amended, section III/1[31].

The RINA survey requirements stated that the company was responsible for ensuring the *chief engineer was qualified to register and carry out maintenance on all classification-related items*. RINA also required a C/E to hold the STCW certificate of competency appropriate to the power of the main propulsive installation of the ship, and have at least 3 years of seagoing experience as a senior engineer officer on ships of the relevant type.

The RINA rules required the company to provide the C/E with a copy of the appendix to the RINA classification rules on surveys by C/Es[32]. This appendix provided general guidance on the conduct of surveys, stating that:

> *As regards the procedure for carrying out surveys, the Owner is to inform the chief engineer that surveys are to be conducted in accordance with the rules of the society and, specifically, the requirements for classification renewal surveys related to machinery and systems contained in Ch 3, Sec 5[3]*[33] [sic]

[30] RINA report of SAFCON H INTERMEDIATE: Item CA.2.09.

[31] Mandatory minimum requirements for certification of officers in charge of an engineering watch.

[32] RINA Rules: Annex 1 to Part A, Chapter 2, Appendix 1 – CMS and PMS: Surveys carried out by the chief engineer.

[33] RINA Rules: Part A, Chapter 3, Section 5 – Class renewal surveys.

Finnlines produced a booklet defining the PMS roles and responsibilities of people working on board its ships and ashore. Section 2.1 of the booklet stated that the person responsible for the PMS was the *chief engineer which is duly recognized by the Classification Society to plan, carry out and record Survey jobs at the scheduled due dates according the Planned Maintenance System Database* [sic].

Finnmaster surveys conducted by a C/E were subject to a confirmatory survey by a RINA surveyor that included an external examination of the equipment surveyed.

1.7.11 Further regulation and guidance

The ISM Code

Chapter IX of SOLAS applied the requirements of the International Management Code for the Safe Operation of Ships and for Pollution Prevention (ISM code).

The ISM code required the company to establish procedures *to ensure that the ship was maintained in conformity with the provisions of the relevant rules and regulations and with any additional requirements which may have been established by the Company* [sic].

Section 10.3 of the ISM code stated that:

> *The Company should identify equipment and technical systems the sudden operational failure of which may result in hazardous situations. The safety management system should provide for specific measures aimed at promoting the reliability of such equipment or systems. These measures should include the regular testing of stand-by arrangements and equipment or technical systems that are not in continuous use.* [sic]

The ISM code also required that the *measures aimed at promoting the reliability* of equipment identified under the provisions of section 10.3 of the Code be integrated into the ship's operational maintenance routine.

In 2001, the IACS produced Recommendation 74 – A Guide to Managing Maintenance in Accordance with the Requirements of the ISM Code[34] (Recommendation 74) to help ship operators meet the maintenance requirements of the ISM Code. The recommendation provided ship operators with guidance on a systematic approach to maintaining their ships, specifically that:

> *The Company's responses should be aimed not only at the rectification of the immediate technical deficiency, but also at addressing the underlying maintenance management system failures (non-conformities) that led to the problem in the first place.* ***Any lessons learned from the investigation of these failures should be examined for their applicability to other ships in the fleet, and the resulting trends and patterns should be used to identify opportunities for continual improvement.*** [sic]

[34] Revised in May 2008 and August 2018.

SOLAS requirements governing the use of flexible hose assemblies

When the alarm system on *Finnmaster* was initially modified, SOLAS II-2 allowed the restricted use of flexible hoses on board ships *where the administration was satisfied that they were necessary*. SOLAS required that flexible hose assemblies used in fuel systems be of an approved fire-resistant type and, at that time, referenced MSC/Circ.647, as supplemented by MSC/Circ.851 – Guidelines on Engine-Room Oil Fuel Systems.

IMO guidance on flexible hose assemblies

The guidelines in MSC/Circ.647 were developed to, *assist designers, shipyard personnel, engine-room personnel, owners, operators and maintenance personnel to be aware of measures that should be taken to reduce fires originating from machinery space flammable oil systems*.

In June 2009, the IMO published MSC.1/Circ.1321 consolidating existing IMO guidance on the prevention of fires in machinery spaces, including MSC/Circ.647.

Both MSC/Circ.647 and MSC.1/Circ.1321 contained guidance on the use of flexible hose assemblies stating that:

> *Flexible pipes, hoses and hose assemblies – which are flexible hoses with end fittings attached – should be in as short lengths as practicable, but should not, in general, exceed 1.5m in length, and only be used where necessary to accommodate relative movement between fixed piping and machinery parts.*

The guidance further recommended that flexible hoses be constructed to a recognised standard, approved for their intended use, inspected frequently, and replaced should there be signs of distress likely to lead to failure. It also raised the expectation that flexible hose assemblies would require replacement *a number of times in the life of the ship*.

MSC.1/Circ.1321 also provided recommendations on the installation of pressure, temperature and oil level gauges, stating that:

> *All pressure gauges and other similar instruments in oil systems should, wherever possible, be fitted with an isolating valve or cock at the connection to the pressure take off point. The number of pressure take off points should be kept to a minimum and gauge piping runs should be as short as practicable.* [sic]

TRAFICOM had not actively promulgated the guidance as invited to by the IMO in both MSC/Circ.647 and MSC.1/Circ.1321.

Classification society rules and guidance on flexible hose installations

TRAFICOM had delegated the responsibility for statutory certification services for ships registered in Finland to six classification societies, each acting as a Recognised Organisation (RO)[35]. The delegations were set out in formal agreements with each individual RO. The level of delegation in these agreements included the survey of ships for compliance with the main conventions, including SOLAS.

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35 Classification societies working under delegated authority from a flag state administration to survey ships and certify that they comply with the relevant international conventions.

From its construction until 1 January 2016 *Finnmaster* was classed by DNV, which also undertook the statutory survey and certification of the ship as an RO acting for Finland. When Finnlines took *Finnmaster* into management on January 2016, it transferred the classification and statutory certification of the ship to RINA.

The RINA rules set out the general requirements for the installation of flexible hose assemblies on ships classed by RINA[36] and included, inter alia:

- *Flexible hoses are to be so arranged as to be clearly visible and readily accessible at all times.*

- *In general, flexible hoses and expansion joints are to be limited to a length necessary to provide for relative movement between fixed and flexibly mounted items of machinery/equipment or systems.*

- *The number of flexible hoses and expansion joints is to be kept to a minimum.*

- *Where flexible hoses and expansion joints are intended to be used in piping systems conveying flammable fluids that are in close proximity to heated surfaces, the risk of ignition due to failure of the hose assembly and subsequent release of fluids is to be mitigated as far as practicable by the use of screens or other similar protection to the satisfaction of the Society.*

- *The installation of flexible hose assemblies and expansion joints is to be in accordance with the Manufacturer's instructions and use limitations…*

Other guidance on the use of flexible hose assemblies

The manufacturer of the flexible hose used in the fuel flexible hose assemblies installed on board *Finnmaster* did not set out specific requirements for the replacement interval for its flexible hoses but did provide generic guidance[37] that:

> *Specific replacement intervals must be considered based on previous service life, government or industry recommendations, or when failures could result in unacceptable downtime, damage, or injury risk;*

and that:

> *even with proper selection and installation, hose life may be significantly reduced without a continuing maintenance program.* [sic]

The safety guide further required that a maintenance programme must be established and followed, to include, as a minimum, visual inspections, a function test and replacement schedule consideration.

Aside from the guidance available from the hose manufacturer, general guidance on the installation and care of flexible hose installations was available from a wide range of sources[38]. The guidance supplemented that contained in IMO MSC/Circ.647 and the later MSC.1/Circ.1321.

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[36] RINA rules Part C, Chapter 1, Section 10, Paragraph 5.9.3

[37] Alfagomma safety guide: Basic Factors for the Selection, Installation and Maintenance of Hose and Hose Assemblies.

[38] DNV-GL Technical and Regulatory News No. 08/2016 – Enhancing Fire Safety Awareness; UK Offshore Operators Association – Flexible Hose Management Guidelines, 2003.

In 2017, the United States Coast Guard (USCG) issued a safety alert[39] **(Annex A)**, highlighting the risks associated with the degradation and failure of flexible hose assemblies carrying flammable liquids.

Protection of hot surfaces

In July 1994, the IMO adopted amendments to SOLAS Chapter II-2. The amended regulations required all surfaces above 220°C that may be impinged as a result of a fuel system failure to be insulated. Following the adoption by IMO of retrospective application of these requirements in 2000, *Finnmaster* was required to install such protection from 1 July 2003.

1.7.12 Similar accidents involving machinery maintenance

Stena Europe – engine room fire

On 11 February 2023, a fire broke out on the UK registered ro-ro passenger ferry *Stena Europe*, resulting in significant damage to the engine room (MAIB report 20/2024[40]). The fire was caused by fuel leaking under pressure from the fuel system of a main engine and igniting on a hot exhaust.

The Maritime and Coastguard Agency (MCA) was recommended to submit a paper to the IMO proposing an amendment to MSC.1/Circ.1321 to introduce a requirement for the use of thermographic equipment to identify hot surfaces exceeding 220°C that could be impinged by pressurised oil.

The ferry's operator, Stena Line Ltd, was recommended to:

2024/171 *Review the use of the existing defect reporting functions within the PMS on vessels within its fleet to ensure that defect reports and remedial actions can be tracked readily; and*

2024/172 *Review and provide training to improve how its chief engineers conduct class-related equipment inspections that are credited to class surveys to ensure that inspections are conducted thoroughly and reported accurately.*

Finlandia Seaways – engine failure and fire

On 16 April 2018, the Lithuania registered ro-ro cargo ship *Finlandia Seaways* suffered a catastrophic main engine failure that caused serious structural damage to the engine and a fire in the engine room (MAIB report 2/2021[41]). The factors contributing to the engine failure included the standard of maintenance management; a lack of appreciation of the importance of following the engine manufacturer's instructions; and external oversight of the engine maintenance process.

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[39] USCG Marine Safety Alert 06-17, dated 6 June 2017.

[40] https://www.gov.uk/maib-reports/engine-room-fire-on-board-ro-ro-passenger-ferry-stena-europe

[41] https://www.gov.uk/maib-reports/engine-failure-and-subsequent-fire-on-ro-ro-cargo-vessel-finlandia-seaways-with-1-person-injured

The investigation report also highlighted oversight of surveys conducted by chief engineers as an issue. This resulted in *Finlandia Seaways*' classification society updating its guidance on the examination by chief engineers of surveyable machinery items, and a recommendation to the ship's operator to:

2021/102 *review and improve how its chief engineers conduct classification-related equipment examinations as part of the Continuous Survey Machinery cycle to ensure that examinations are conducted thoroughly and reported accurately.*

The report also recommended the engine servicing company to:

2021/103 *Fully apply equipment manufacturers' maintenance and repair guidance and procedures*; and

2021/105 *Review and update staff training to ensure familiarity with engineering methods appropriate for the various repair and overhaul tasks, backed up with a suitable quality assurance process to ensure standards are maintained.*

Wight Sky **– two catastrophic engine failures**

The MAIB investigation into multiple engine failures on the ro-ro passenger ferry *Wight Sky* in 2018 (MAIB report 4/2022[42]) identified the management of maintenance, oversight of service technicians and effective communication with the engine manufacturer as safety issues directly contributing to the engine failures.

The report stated that the classification society's delivery of robust classification and statutory services, as well as its ability to offer sound technical advice to the operator, was impacted by *weak levels of communication between the engine manufacturer, its authorised service centre, and the ferry operator*. It also noted that *If the engine manufacturer had been consulted about the engine block repairs, it would have had a greater understanding of the ongoing issues, and this would almost certainly have prompted higher level technical investigations*.

Pride of Canterbury **– engine room fire**

On 29 September 2014, a fire broke out in the engine room of the ro-ro passenger ferry *Pride of Canterbury* (MAIB report 22/2015[43]). The investigation highlighted the importance of applying the contents of MSC.1/Circ.1321 to prevent engine room fires, specifically the shielding of high temperature surfaces from flammable oils.

[42] https://www.gov.uk/maib-reports/two-catastrophic-engine-failures-one-resulting-in-a-fire-on-board-ro-ro-passenger-ferry-wight-sky

[43] https://www.gov.uk/maib-reports/fire-in-engine-room-on-ro-ro-passenger-ferry-pride-of-canterbury

1.8 FIXED CARBON DIOXIDE FIRE-EXTINGUISHING SYSTEM

1.8.1 Description

At the time of *Finnmaster*'s build, SOLAS required the installation of a fixed firefighting system in category A[44] machinery spaces. The SOLAS requirements for a CO_2 system stated that the quantity of CO_2 was to be sufficient to give a minimum volume of free gas[45] equal to the larger of either:

40% of the gross volume of the largest machinery space so protected[46]*; or*

35% percent of the gross volume of the largest machinery space protected, including the casing.

The volume of CO_2 required for cargo holds was 45% of the gross volume of the individual spaces.

A high-pressure CO_2 system was installed to extinguish fires in *Finnmaster*'s engine room and the two internal cargo spaces. Activation of the system would release a set quantity of CO_2 through nozzles in a network of distribution pipes installed throughout the protected space. The injected CO_2 would displace the air in the compartment and the consequential reduction in oxygen in the atmosphere would extinguish the fire. A single nozzle was positioned in the AER at deckhead level between the two auxiliary engines. The CO_2 system on Finnmaster had been approved by the Finnish Maritime Administration[47] in October 1997.

The machinery spaces on *Finnmaster* had a calculated volume of 3,010m³ including the AER, which was common with the engine room, and the casing. The design quantity of CO_2 to be injected into the engine room was 1,890kg, equating to a free volume of 1,058m³ at the design concentration of 0.56m³/kg.

The CO_2 system **(Figure 19)** comprised 268 steel cylinders, each holding 45kg of CO_2. This volume of gas was sufficient to extinguish a fire in the upper cargo hold, the largest protected space on *Finnmaster*. The cylinders were stowed in a CO_2 room at the forward end of the main deck, accessed from a central alleyway leading from the main cargo deck to the forward crew stairway **(**see **Figure 2)**. The CO_2 room was ventilated by two dedicated fans; a supply fan and an exhaust fan. These fans provided a flow of air through the space to minimise the risk to people from any accumulation of leaked CO_2. An instruction at the entrance to the compartment required the fans to be running when the space was occupied.

The CO_2 system was activated by pressurising a pilot system consisting of a series of small-bore flexible pilot hoses connected to the discharge valves on the top of each cylinder. The pressure to activate the system was provided from one of two pilot CO_2 cylinders at the release station. Pressure in the pilot system would act on

[44] Defined as spaces and trunks that contain internal combustion machinery used for main propulsion; or other internal combustion machinery with an aggregate power of more than 375kW; or any oil-fired boiler or oil fuel unit.

[45] For the purpose of the calculation, the volume of CO2 was calculated at 0.56 m³/kg.

[46] Excluding *that part of the casing above the level at which the horizontal area of the casing is 40% or less of the horizontal area of the space concerned taken midway between the tank top and the lowest part of the casing.*

[47] A forerunner of TRAFICOM.

For illustrative purposes only: not to scale

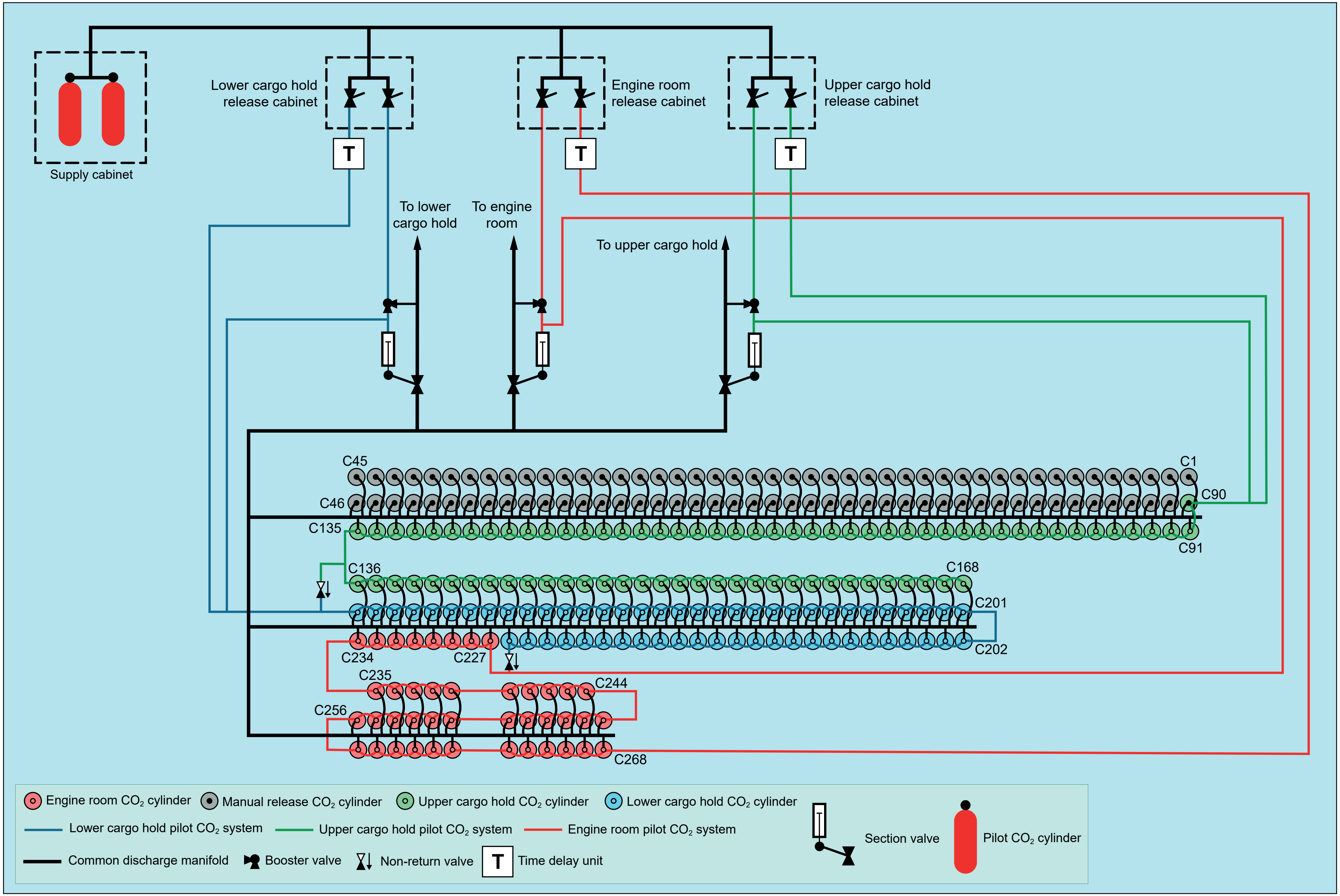


Figure 19: *Finnmaster* CO2 system schematic drawing

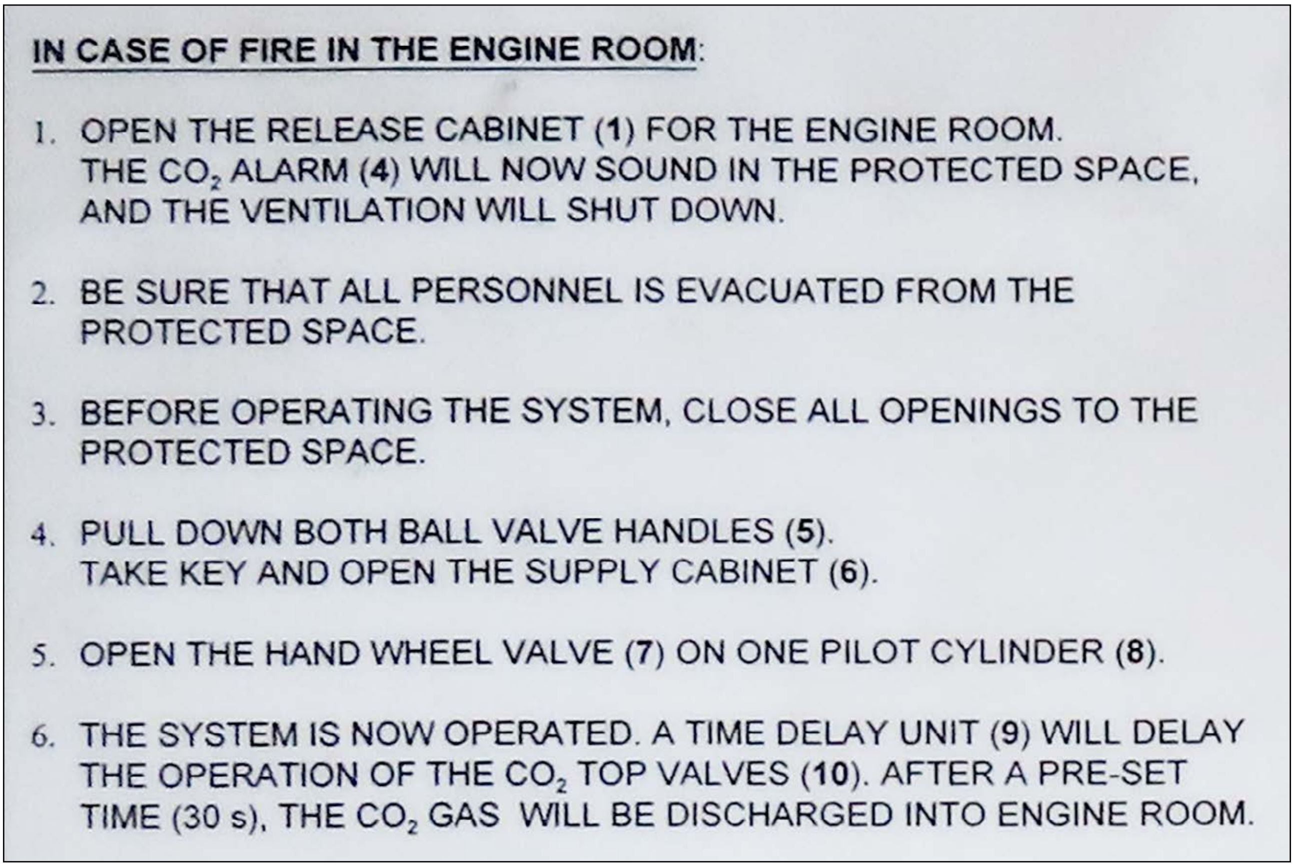
a piston in the cylinder discharge valve and open it to allow the cylinder contents to pass into a common discharge manifold, from where it would flow into the assigned distribution network through one of three section valves.

The number of cylinder valves opened by the pressure in the pilot system depended on which of three control cabinet valves for the protected spaces were opened when the system was activated. For a fire in the upper cargo hold, the system was configured for the automatic release of 179 cylinders[48] For a fire in the lower cargo hold, the system would release 100[49] cylinders, and for an engine room fire the system would release 42 cylinders[50]. The cylinders assigned for the lower cargo hold and engine room were subsets of those allocated to the upper cargo hold.

The amount of CO_2 discharged could be supplemented by the manual release of CO_2 from a reserve of 89 cylinders connected to the common discharge manifold. The release instructions reflected this provision, and manual release handles were placed in a rack on the bulkhead of the CO_2 room for this purpose.

1.8.2 System operation

The system operating instructions for both local and remote activation of the CO_2 system on *Finnmaster* required a check that all personnel were confirmed as being evacuated from the protected space and the closure of all openings to the protected space before the system was activated **(Figure 20)**.


IN CASE OF FIRE IN THE ENGINE ROOM:

1. OPEN THE RELEASE CABINET (**1**) FOR THE ENGINE ROOM.
THE CO_2 ALARM (**4**) WILL NOW SOUND IN THE PROTECTED SPACE, AND THE VENTILATION WILL SHUT DOWN.
2. BE SURE THAT ALL PERSONNEL IS EVACUATED FROM THE PROTECTED SPACE.
3. BEFORE OPERATING THE SYSTEM, CLOSE ALL OPENINGS TO THE PROTECTED SPACE.
4. PULL DOWN BOTH BALL VALVE HANDLES (**5**).
TAKE KEY AND OPEN THE SUPPLY CABINET (**6**).
5. OPEN THE HAND WHEEL VALVE (**7**) ON ONE PILOT CYLINDER (**8**).
6. THE SYSTEM IS NOW OPERATED. A TIME DELAY UNIT (**9**) WILL DELAY THE OPERATION OF THE CO_2 TOP VALVES (**10**). AFTER A PRE-SET TIME (30 s), THE CO_2 GAS WILL BE DISCHARGED INTO ENGINE ROOM.

Figure 20: Extract from CO_2 system operating instructions posted in CO_2 room

[48] CO2 cylinder references shown in the figures in this report reflect the cylinder numbers on the original Unitor drawing: 8164/5/6-02 – *CO2 Room Arrangement*.

[49] Numbered C169 to C268.

[50] Numbered C227 to C268.

The CO_2 system was operated from a remote station in the main fire locker **(Figure 21)** on the weather deck. A supply cabinet contained the two pilot cylinders, each holding 1.8kg of CO_2. Three release cabinets were installed adjacent to the supply cabinet, one for each protected space. When the relevant release cabinet door was opened, the ventilation fans for that space automatically stopped, the automatic ventilation dampers closed, and alarms sounded to warn personnel that CO_2 was about to be released.

Figure 21: Main fire locker CO_2 release cabinets

The system was activated by opening both valves in the release cabinet for the affected space and one pilot cylinder in the supply cabinet. One of the two release cabinet valves led to a booster valve on the main outlet discharge manifold. The second valve led to one of three time delay units set below the release cabinet. A 6mm pipe from the time delay unit led to the CO_2 room, where it connected to the series of flexible pilot hoses linking the individual cylinder valves together. Non-return valves fitted in specific positions in the pilot system controlled the number of cylinders activated when pressure was applied from the release cabinets.

The operation of the booster valve allowed CO_2 from the common discharge manifold, once pressurised by the discharging cylinders, to open the section valve leading to the protected space. It also directed additional CO_2 from the common discharge manifold into the pilot system to boost the pressure and assist in the rapid activation of the cylinder valves. The booster connections for the cargo hold pilot systems were connected at the entry point for the timed pilot signals from the release cabinets. The booster connection for the engine room was connected at the opposite end of the pilot system pipework.

The control system could be activated manually from the CO_2 compartment if necessary. To extinguish the fire in the AER, the C/E followed the instructions provided at the release station on the weather deck to activate the high-pressure CO_2 system, opening both valves in the release cabinet for the engine room and the valve on the forward pilot cylinder in the supply cabinet. After an automatic delay of 30 seconds, controlled by the time delay unit incorporated into the pilot system, the main system activated and injected CO_2 into the engine room. The system was designed to empty the contents of 42 cylinders into the engine room.

1.8.3 Post-fire inspections

On board inspection

Finnmaster's high-pressure CO_2 system was examined during the investigation, supported by a technician from a specialist servicing company.

In the CO_2 room, the section valve to the engine room was found closed, having been shut by *Finnmaster*'s crew following the fire. The associated booster valve was in the open position. The booster valves for the cargo holds were closed and had their safety pins installed, preventing their inadvertent operation.

Of the 42 main cylinders intended to discharge their contents into the engine room when activated, the inspection found 21 with their discharge valves in the open position[51].

The pilot system pipe leading from the time delay unit below the engine room release cabinet in the main fire locker was found to be connected to the pilot pipework at cylinder C268. The pilot system pipe leading from the engine room booster valve was found to be connected to the pilot pipework at cylinder C227. This was the reverse of that contained in the original plan of the system.

A test of the pilot system was carried out with the main cylinder discharge hoses disconnected and their cylinder discharge connections capped[52]. Significant gas leakage was observed from 12 of the pilot hose connections[53] when the system was pressurised with CO_2. This leakage was sufficient to prevent the operation of all of the cylinder valves. Additionally, the test revealed a lack of flow through the system in three positions[54]. Removal of the flexible hose assemblies in these positions showed them to be blocked. The system defects were found in both the engine room and cargo hold systems **(Figure 22** and **Figure 23)**.

The activation and booster pipework from the release stations through to the point the pipes connected to the pilot system in the CO_2 room were proved free from blockage.

The discharged CO_2 cylinders were refilled following the initial tests of the engine room CO_2 system. The identified gas leakages in the pilot system were repaired and the blocked flexible pilot hose assemblies were replaced. A full test of the system was carried out on completion of the remedial work, during which all the cylinder valves operated satisfactorily when the pilot system was pressurised from the remote release station in the main fire locker.

Flexible pilot hose assembly examinations

The three blocked flexible pilot hose assemblies were removed from *Finnmaster* and subjected to radiographic examination, which indicated blockage at the end couplings **(Figure 24)**.

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[51] Cylinders C227 to C241, C262, C263, and C268 to C265.

[52] This was done as a precaution against accidental release of CO_2.

[53] At cylinders C131, C152, C165, C175, C177, C181, C197, C207, C209, C224, C227 and C268.

[54] Between cylinders C215 and C216; C207 and C208; C241 and C242,

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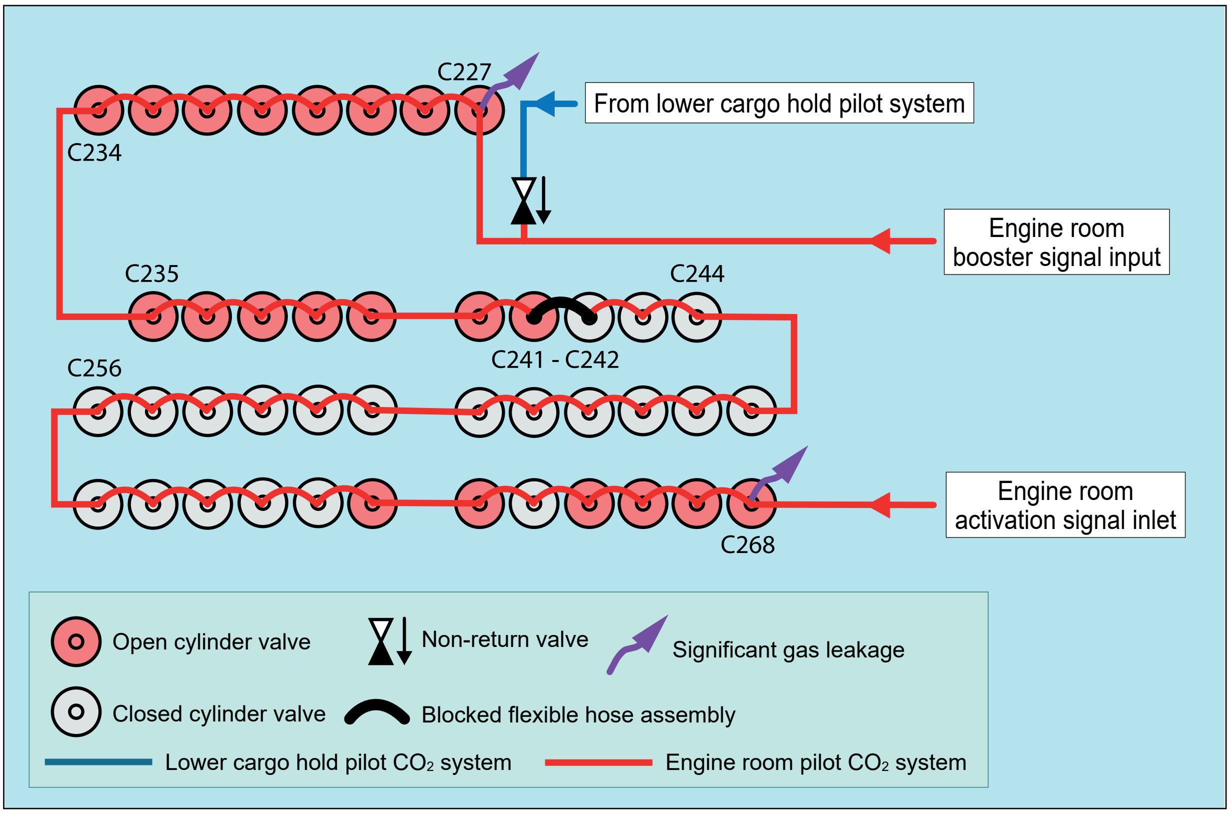

Figure 22: Identified faults in CO_2 pilot system serving *Finnmaster*'s engine room

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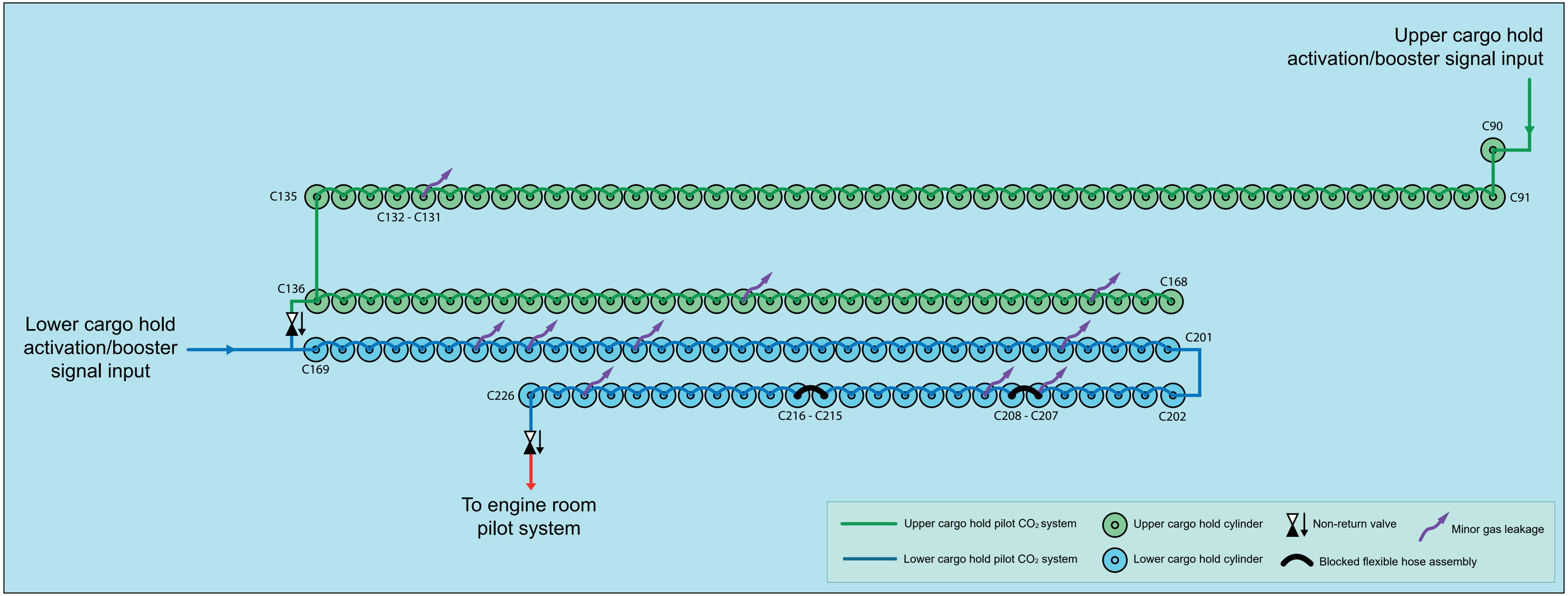

Figure 23: Identified faults in CO_2 pilot system serving *Finnmaster*'s cargo holds

Images courtesy of [Inidam Ltd]

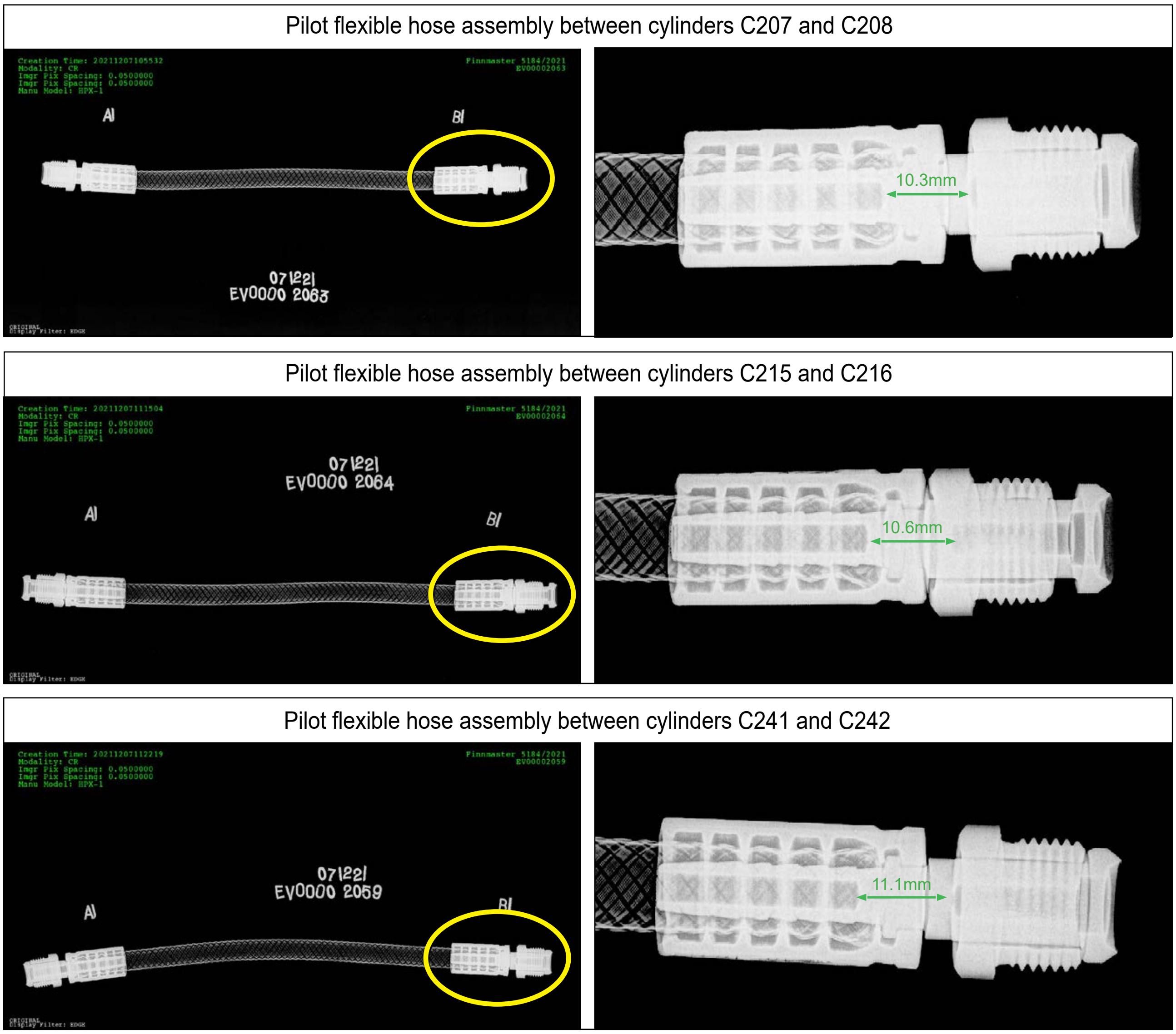

Figure 24: Pilot flexible hose assembly radiographic images

The flexible hose assembly from between cylinders C241 and C242 in the AER's pilot hose system was subsequently sectioned to fully investigate the blockage identified in the radiographs. The section revealed that the 4mm bore through the pilot hose coupling had not been fully drilled during manufacture, preventing the passage of gas through the flexible hose assembly **(Figure 25)**.

Figure 25: Section through flexible hose assembly coupling between cylinders C241 and C242

1.8.4 Onboard maintenance information

The PMS set out the routine maintenance of the CO_2 system, including tasks to be undertaken at 4-monthly intervals; after dry-docking of the ship; and annually to check the cylinder contents.

The 4-monthly checks included an inspection of the CO_2 release station; a test of the alarm and ventilation fan shutdown functions; an inspection of the seals and fastening assemblies for the CO_2 cylinders; and a manual check of the section control valves.

While it did not set a frequency for when tests were to be completed, the instruction manual initially supplied to *Finnmaster* provided an outline procedure[55] for testing the CO_2 system to enable verification of the pilot system's integrity and completeness. The test entailed locking the individual discharge valves on the main cylinders in the closed position, except for the valve that was furthest from the pilot system activation signal inlet from the release cabinet. The discharge hose from the last CO_2 cylinder would be disconnected, and a cap fitted to prevent accidental CO_2 release. The activation of the release mechanism would then pressurise the pilot system throughout its length and the cylinder discharge valve at the furthest point would operate. The entire pilot system would be under pressure during the test and the system could be inspected for leakage.

1.8.5 Service history

Maintenance of all the high-pressure CO_2 systems on *Finnmaster* was carried out by the marine fire service division of Viking Life-Saving Equipment Oy Finland (Viking), latterly under a service agreement with Finnlines made in October 2018. The service agreement set out the commercial arrangement for the services provided by Viking to the Finnlines fleet. It incorporated annual or biannual services on each ship and included the main and local fixed high-pressure CO_2 systems; portable fire extinguishers; CABA, and other firefighting equipment.

The service procedures used by Viking service technicians to service the CO_2 system on *Finnmaster* were aligned with the framework contained in MSC.1/Circ.1318 – *Guidelines for the Maintenance and Inspections of Fixed Carbon Dioxide Fire-extinguishing Systems* **(Annex B)**.

The service manual available to the Viking service technicians was produced for a later CO_2 system than that installed on *Finnmaster*, though the system was of the same type. This later version of the document[56] detailed a different system test procedure to that contained in the earlier manual on board *Finnmaster*. It included a full test of all the cylinder valves with their outlets fitted with a blanking cap to prevent the release of any gas during the test. This test dispensed with the need to fit safety pins to the release valves attached to the CO_2 cylinders as set out in the manual held on board *Finnmaster* and ensured that all cylinder valves operated when the pilot system was pressurised.

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[55] Unitor Document 50-00-999-4-E (September 1990) – *Description of inspection chart Unitor high pressure CO2 system*, page 7.

[56] WuChang Shipyard, Hull A169M: Document 50-00-999-4-E (Revision 3, dated May 2002).

The Viking records for each service completed on *Finnmaster*'s CO_2 system stated that the *cylinder fixtures and HP hose connections had been checked and re-tightened* [sic]. An entry also stated that the *servo tubing/pilot lines were pressure tested and checked for leakage and blockage*.

The service completed at the renewal survey in June 2018 was recorded as having met the standard contained in section 6.1 of MSC.1/Circ.1318, indicating also that the cylinder valves had been inspected but not tested. The records for the service completed in March 2021 stated that the cylinder valves had undergone a *release test*, which would be included in a service completed to the standard of a renewal survey.

It was unclear how *Finnmaster*'s CO_2 system test was completed during the last service. The test was reported both as a full test of the cylinder valve activation with the discharge hoses disconnected and caps installed to the cylinder discharge outlets, and as having been carried out with the cylinder valve safety pins installed and no activation of the cylinder valves.

None of the inspected service reports indicated any defects in the CO_2 system on *Finnmaster*. The report of the service carried out in March 2021 did not identify any blockage or leakage of the pilot system, either at the time of installation of the flexible pilot hoses or during the tests conducted as part of the service procedure.

On completion of the service in March 2021, Viking issued a certificate of inspection to *Finnmaster* stating that, along with other firefighting systems, the main CO_2 system had *been inspected/checked in accordance to the design specification and performed service* [sic] and noted that where repair and/or replacements had been completed as recommended the details would be recorded in the report.

There was little crew oversight of the activities of the technicians from Viking, who were viewed as being the competent authority for the work. RINA surveyors did not perform any CO_2 system surveys during the service activities carried out in March 2021.

1.8.6 Flexible hose replacement

The checklists completed by the Viking technicians in 2018, 2019 and 2020 all noted that the high-pressure flexible hose assemblies had last been replaced in 2010. In July 2020, both the discharge and flexible pilot hose assemblies on the CO_2 system were renewed. The flexible pilot hose assemblies were drawn from a stock of 220 purchased in the Netherlands by Viking Life-Saving Equipment B.V. (Viking LSE) from Geeve Hydraulics B.V. (Geeve), a wholesaler of hydraulic hoses and components located in Rotterdam. The flexible pilot hoses were accompanied by a test certificate issued by Geeve that provided technical details of the flexible hose assemblies supplied and the approvals held.

Finnmaster's crew noted cracking on the exterior of some of the flexible hose assemblies during later routine inspections of the CO_2 system. It was agreed that Viking technicians would replace these assemblies under guarantee at their next attendance. In February 2021, Viking LSE purchased a further 60 flexible hose assemblies from Geeve. These were delivered to Finland accompanied once again by a Geeve test certificate.

On 4 March 2021, the defective flexible hose assemblies were replaced in conjunction with the 5-yearly service of *Finnmaster*'s CO_2 system. The replacement flexible hose assemblies had identical markings to those previously installed, indicating a production date of July 2020. It has not been possible to determine whether the defective flexible hose assemblies identified following the fire were installed at the July 2020 renewal of the flexible hose assemblies or during the later change.

1.8.7 Flexible hose procurement and production

The flexible hose assemblies supplied to Viking and subsequently installed on *Finnmaster* were produced to order by Geeve and comprised a 300mm section of flexible hose with a carbon steel fitting at each end. The couplings were installed by means of a hydraulic crimp that compressed a ferrule onto the flexible hose against a central stem through which a 4mm bore had been drilled during manufacture.

The flexible hose component of the flexible hose assemblies was produced by Parker Hannifin Manufacturing S.r.l. (Parker). The type 421SN flexible hose was made of synthetic rubber with one braid of wire reinforcement and had a nominal diameter of 6mm. It was designed in line with the EN 853 1SN standard[57], manufactured to the type approvals held by Parker and marked with the hose trade name, *Parker*; the type designation; maximum working pressure; temperature range; and size. Parker held type approvals issued by both DNV and RINA for the manufacture of *flexible hoses of non-metallic material with permanently fitted couplings* of type 421SN. The couplings fitted at either end of *Finnmaster*'s flexible hose assemblies were neither supplied by Parker nor contained in the Parker 48 series range of couplings, which was contrary to a requirement stated in the type approvals.

Geeve placed orders for the couplings through HSR Hydraulics BV (HSR), a local hydraulics procurement provider that sourced its stock of the couplings from a manufacturer in China based on a specification provided to them by Geeve. Neither HSR nor its supplier were informed that the flexible hose assemblies the couplings were to be fitted to needed to be type approved.

1.8.8 Flexible hose assembly delivery certification

A sample of the flexible hose assemblies were subject to a hydraulic pressure test when Geeve had completed their manufacture. The practice in the Geeve workshop was to test up to 20% of the hose assemblies by applying 1.5 times the working pressure[58], either individually or by connecting a number of hose assemblies together in a series with the end assembly blanked. No test for blockage was carried out.

The initial supply of 220 flexible hose assemblies to Viking LSE on 2 July 2020 was supplemented by a Geeve test certificate **(Annex C)**. The certificate stated that the flexible hose assemblies complied with DNV type approval certificate number TAP000013G **(Annex D)**.

[57] European Standard EN 853:2015 Rubber hoses and hose assemblies – Wire braid reinforced hydraulic type – Specification.

[58] The flexible hose assemblies used were rated to a working pressure of 225 bar.

The later supply of 60 flexible hose assemblies was also supplemented by a Geeve test certificate **(Annex E)**. The certificate indicated that the flexible hose standard was the same as that previously supplied but referenced DNV type approval certificate number TAP00001JV **(Annex F)**.

The Geeve hose test certificates supplied with the flexible hose assemblies indicated that the batch supplied in July 2020 were tested to 450 bar (twice the working pressure) and those supplied in February 2021 were tested to 340 bar (1.5 times the working pressure).

1.8.9 Flexible hose assembly approvals

The DNV type approval class programme for *Flexible hoses – Non-metallic materials* (DNV-CP-0183) set out specific requirements for the type approval of CO_2 flexible hose assemblies made of synthetic rubber. This class programme provided a description of the procedures and requirements related to the documentation, design and testing applicable for the type approval of flexible non-metallic flexible hoses with permanently fitted couplings and rubber compensators.

DNV type approval certificate TAP000013G

The DNV type approval certificate TAP000013G was issued on 28 December 2017 and was valid until 27 December 2022. The applications detailed in the certificate indicated that the flexible hose assemblies were suitable for use with *Petroleum base hydraulic fluids, water glycol and water oil emulsion hydraulic fluids, compressed air & fresh water*. The application to CO_2 systems was not included. The type approvals required Parker 48 series couplings to be fitted at either end of the flexible hose assemblies.

The type approval certificate required each flexible hose assembly to be hydraulic pressure tested to 1.5 times the maximum working pressure, and to be delivered with a pressure test certificate referencing this type approval certificate number.

Each flexible hose assembly was required to be marked with the manufacturer's name or trademark, the type designation, maximum working pressure and size.

DNV type approval certificate TAP00001JV

The DNV type approval certificate TAP00001JV revision 1 was issued on 9 September 2020 and was valid to 21 April 2025. This certificate covered the same approval requirements as the TAP000013G type approval, but specifically approved the flexible hose assemblies for use in CO_2 fire-extinguishing systems.

RINA flexible hose approvals

A RINA type approval for the type 421SN flexible hose produced by Parker was available for the flexible hose assemblies installed on *Finnmaster*. The RINA type approval certificate **(Annex G)**[59] for the production of the initial 220 flexible hose assemblies supplied by Geeve in July 2020 was renewed in November 2020 **(Annex H)**[60]. The new certificate was valid until November 2025.

59 RINA Type approval certificate MAC176015CS/004, valid from 24 July 2015 to 23 July 2020.

60 RINA Type approval certificate MAC241320CS/002, valid until 22 November 2025.

The field of application detailed in the RINA certificates indicated the flexible hose assemblies were suitable for *Hydraulic systems with a hydraulic oil having a flash point not less than 150°C*. Neither certificate referred to the use of the flexible hose assemblies for pressurised gases nor their suitability for use in CO_2 systems. The type approvals required Parker 48 series couplings to be fitted at either end of the flexible hose assemblies.

The acceptance of the flexible hose assemblies for installation on RINA classed ships was *subject to the satisfactory outcome of testing as per RINA Rules*. The RINA rule requirement for testing stated that:

> *Each flexible hose or expansion joint, together with its connections, is to undergo a hydrostatic test under a pressure at least equal to 1,5 times the maximum service pressure.* [sic]
>
> *During the test, the flexible hose or expansion joint is to be repeatedly deformed from its geometrical axis.*

1.8.10 Flexible hose assembly production oversight

RINA had no oversight of the production process of the flexible hose assemblies produced by Geeve and installed on *Finnmaster* by Viking. Geeve did not hold a certificate indicating that it was approved by RINA for the manufacture of flexible hose assemblies.

Both of the flexible hose test certificates issued by Geeve contained an entry that the flexible hose assemblies had been tested *in accordance with* the DNV rules and met the specified requirements of the approval of manufacturer certificate **(Annex I)**[61]. The approval of manufacturer certificate issued to Geeve by DNV certified that the company was approved for the assembling of type approved flexible hoses and couplings for delivery to DNV ships. The certificate set out the type and size of individual flexible hose assemblies and the associated DNV conditions of approval.

The DNV type approval procedure contained in the DNV-CP-0183 class programme specifically allowed for an approved flexible hose assembly to be manufactured by a company other than the component manufacturer using appropriate components. As Geeve was not the holder of the relevant type approval certificates the class programme required it to be approved by DNV as a manufacturer of the flexible hose assemblies.

DNV maintained a separate class programme to cater for the approval of manufacturers of flexible hose assemblies that were not the component manufacturers[62]. To be issued with a DNV approval of manufacturer certificate a document review and site survey, including review of the production and testing facilities, was required. The class programme stated that, during the survey, *Focus will normally* be given to *quality control of critical production steps, and that manufacturing, testing and inspection facilities are available and supervised/ operated by qualified personnel*.

[61] DNV-GL certificate AMT0000051.

[62] DNV class programme CP-0346 – Approval of manufacturer scheme.

The initial survey of Geeve was conducted by DNV in May 2017 and the checklist completed at the time indicated that the company met all the requirements for the issue of the approval of manufacturer certificate without remark. A renewal survey was carried out in June 2020, again without comment, and the certificate was reissued.

The approval of manufacturer certificate class programme contained a requirement that *Any significant alteration to the approved condition during the period of validity… shall be reported to the Society*. No report was made by Geeve to DNV reflecting the change of supplier of the flexible hose assembly couplings.

On 26 April 2022, following the highlighting of issues with the manufacture of flexible hose assemblies by Geeve[63], DNV completed an additional survey of the company. This activity was carried out to the standard of an initial approval. The checklist used for the onsite inspection contained 18 items to be verified as part of an initial survey. Of the 11 items marked as having been completed on the checklist, seven indicated noncompliance with the requirements. The remarks section of the report recorded shortcomings in quality management, testing procedures, and control of subcontractors and suppliers. The inspection was suspended before the remaining items were assessed. A remark on the checklist indicated that the outstanding items would be included in the scope of the next audit. DNV required corrective action by Geeve on the noted items before recertification for the production of flexible hose assemblies under the relevant class programme.

Following corrective action by the company, the recertification process was completed by DNV in August 2023 and a new approval of manufacturer certificate issued to Geeve, valid until 7 August 2026.

1.8.11 Service supplier approval

It was a requirement of MSC.1/Circ.1318 that technicians completing services of CO_2 systems were trained to standards accepted by the administration, which in this case was TRAFICOM. *Finnmaster* was classed by RINA from 1 January 2016, which from this date carried out both the classification and statutory functions on behalf of TRAFICOM.

The activities of RINA were governed by an *agreement governing the delegation of statutory certification services for ships registered in Finland between the Finnish Transport and Communications Agency and RO*, which was renewed on an annual basis.

The appendix to the agreement set out the degree of authorisation held by RINA. It did not delegate the responsibility for the acceptance of training of technicians servicing CO_2 systems.

[63] MAIB Safety Bulletin 1/2022 https://www.gov.uk/maib-reports/safety-warning-issued-after-discovery-of-blocked-fixed-co2-fire-extinguishing-system-pilot-hoses

International Association of Classification Societies

The IACS produced unified requirements for the rules and practices of its members, of which RINA was one. The IACS maintained a unified requirement on *Procedural requirements for service suppliers*[64] (UR-Z17) for firms providing services, including the maintenance of safety systems and equipment. Section 3 of UR-Z17 defined a service supplier as:

> *A person or company, not employed by an IACS Member, who at the request of an equipment manufacturer, shipyard, vessel's owner or other client, acts in connection with inspection work and provides services for a ship or a mobile offshore unit such as measurements, tests or maintenance of safety systems and equipment, the results of which are used by surveyors in making decisions affecting classification or statutory certification and services.*

The unified requirement incorporated a wide range of services for statutory and non-statutory work. It included the approval of *firms engaged in inspections and maintenance of fire extinguishing equipment and systems* [sic] and set out the requirements for approval and certification. UR-Z17 required service suppliers to have professional knowledge of fire theory, firefighting and fire-extinguishing appliances sufficient to carry out maintenance and inspections, and documented procedures on how to carry out the servicing of the systems. These were to contain or refer to the manufacturer's servicing manuals, servicing bulletins, instructions and training manuals as appropriate, and to international requirements.

The unified requirement also required the service supplier to have access to type approval certificates, *showing any conditions that may be appropriate during the servicing and/or maintenance of fire-extinguishing equipment and systems*.

RINA S.p.A

RINA provided a framework for the approval of service suppliers covering the requirements set out in UR-Z17. The scope of the RINA rules for the certification of service suppliers included the approval of suppliers performing inspection and maintenance of fire-extinguishing equipment and systems contributing to statutory certification. The RINA rules stated that:

> *Where such services are used by RINA Surveyors in making decisions affecting statutory certification and service, the firms are subject to approval and verification by RINA where RINA is so authorised by the relevant flag Administration (i.e. the flag of the ship on which the servicing is to be done or the service equipment is to be used). For such services RINA may accept approvals done by:*
>
> *a) the flag Administration itself;*
>
> *b) duly authorized organizations acting on behalf of the flag Administration; or*
>
> *c) other organizations acceptable to the flag Administration (e.g. other governments, etc.).*

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[64] Revision 14 of UR-Z17, dated March 2020 and required to be implemented by member classification societies by 1 January 2020, was extant during the timeframe of the activities discussed in this report.

The rules further noted that:

> *Firms providing services on behalf of the Interested Party, such as measurements, tests and servicing of safety systems and equipment, the results of which may form the basis for the surveyor's decisions, are subject to the acceptance of the society, as deemed necessary.*[65]

On spare parts used in the maintenance of the ship, the rules placed the responsibility for compliance on the shipping company, in that:

> *…in the case of repairs or replacement, spare parts used are to meet the requirements of the Rules as far as practicable.*[66]

RINA surveyors conducted statutory surveys on behalf of TRAFICOM under the agreement governing the delegation of statutory certification services.

1.8.12 Viking Life-Saving Equipment Oy Finland

In March 2018, RINA approved Viking under the requirements of its *rules for the certification of service suppliers* for services being provided to ships classed by RINA. The services itemised on the certificate included firms engaged in *inspections and maintenance of fire extinguishing equipment and systems* [sic]. The certificate of approval expired on 7 March 2021. The subsequent certificate of approval issued by RINA was valid until 19 January 2025.

Viking also held approvals issued under the IACS UR-Z17 procedures from Lloyd's Register, DNV and the American Bureau of Shipping. Contributing to the approval under UR-Z17, the Viking group of companies maintained an internal audit programme within the group and provided a centralised training framework for staff undertaking servicing of firefighting equipment under a quality management system[67] certified by DNV. The training provided by the Viking group at its facility in the Netherlands included that required for the servicing of high-pressure CO_2 systems. The Viking quality management system procedures were all assessed as meeting the functional requirements for the approval.

Though the quality management system of Viking formed part of the wider group system, the RINA approval of Viking for certification as a service supplier was based on audits conducted on Viking's specific operation in Finland. The RINA approval was valid at the time of the service completed on board *Finnmaster* in March 2021.

1.8.13 Finnlines service supplier audit programme

The Finnlines internal procedures required an audit of Viking's operation as a supplier of services to the company. The last audit carried out by Finnlines in 2018 showed a focus on the commercial aspects of the relationship between the two

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65 RINA Rules: Part A, Chapter 1 Section 1 - General principles of classification. Section 3.5 Use of measuring equipment and of service suppliers.

66 RINA Rules: Part A, Chapter 1 Section 1 - General principles of classification. Section 3.6 Use of measuring equipment and of service suppliers.

67 The Viking group held ISO 9001:2015 – International Organization for Standardization certification covering the design, development, manufacture, sale and service/maintenance of maritime liferafts, slides, evacuations systems, glass fibre reinforced polyester man overboard/rescue boats, personal protective and safety equipment. The system also covered the service of marine firefighting equipment, lifeboats, davits, release hook systems and personal protective equipment.

companies and recorded a need to *take a proactive approach, arrange training for crew etc.* [sic], but it was unclear to which organisation this was addressed. There was no evidence that specific training was requested from, or provided by, the Viking technicians.

1.8.14 Installation survey and oversight

Survey requirements

Chapter I of SOLAS[68] required that *Finnmaster* was routinely surveyed for the issue, endorsement and renewal of the statutory certificates held. From 2016, the surveys were completed by RINA surveyors in line with RINA procedures. These procedures reflected the guidelines contained in IMO Resolution A.1140(31)[69] – Survey Guidelines under the Harmonized System of Survey and Certification.

Finnmaster held an SEC that was issued on 26 September 2018 and valid until 31 May 2023. SOLAS required a periodic survey to be completed instead of either the second or third annual survey for the endorsement of the SEC.

The RINA rules required any repair resulting from maintenance and overhauls that affected or may affect the classification to be recorded and submitted to the attending surveyor for use in determining further survey requirements.

Finnmaster surveys

The SEC renewal survey for *Finnmaster* was conducted in June 2018 by a RINA surveyor. The fire safety systems and appliances were included in the survey, as well as other equipment set out in the IMO survey guidelines.

Subsequent annual surveys conducted in May 2019 and June 2020 included a general inspection to ensure relevant equipment had been maintained in line with the provisions of the applicable regulations, and that the ship remained fit to proceed to sea.

Although the SEC carried on board *Finnmaster* did not indicate which of the two surveys carried out in June 2020 and July 2021 met the standard of a periodic survey, the RINA survey records showed that it was completed in July 2021.

Coincident with the surveys for statutory certificates, RINA also surveyed *Finnmaster* for the renewal, or endorsement as appropriate, of the certificate of classification in line with the RINA rules.

Service records for the CO_2 system, the test certificates for the flexible hose assemblies used in the system, and the certificate of approval for Viking as a service provider were all available on board *Finnmaster* at the periodic survey conducted in July 2021 for the endorsement of the SEC. It was reportedly uncommon for classification society surveyors to be present during the service of a CO_2 system.

[68] General Provisions – Part B – Surveys and Certificates – Regulation 8 – Surveys of life-saving appliances and other equipment of cargo ships.

[69] Resolution A.1140(31) was adopted on 4 December 2019, replacing Resolution A.1120(30), and revoked itself in December 2021, when revised guidelines were adopted by Resolution A.1156(32).

1.8.15 Further regulation and guidance

Maintenance of firefighting systems

It was a requirement of SOLAS that *firefighting systems and appliances be kept in good working order and readily available for immediate use*. To achieve this, the convention expected that:

> *maintenance, testing and inspections shall be carried out based on the guidelines developed by the organization and in a manner having due regard to ensuring the reliability of fire-fighting systems and appliances.*

SOLAS referenced IMO Circular MSC.1/Circ.1432 - *Revised Guidelines for the Maintenance and Inspection of Fire Protection Systems and Appliances* (MSC.1/Circ.1432). These guidelines provided the minimum recommended level of maintenance and inspection for fire protection systems and appliances. On the maintenance and inspection specific to CO_2 systems, MSC.1/Circ.1432 referenced IMO Circular MSC.1/Circ.1318[70].

Maintenance and inspection of fixed carbon dioxide fire-extinguishing systems

The maintenance scheme provided in MSC.1/Circ.1318 included monthly and annual inspection tasks that could be conducted by the ship's crew. Section 6.1 of MSC.1/Circ.1318 covered the servicing to be carried out by service technicians at intermediate, periodic, or renewal surveys. The work included a test of the discharge piping to the protected spaces. Section 6.2 covered the additional servicing necessary at renewal surveys and included, among others:

1. *where possible, all activating heads should be removed from the cylinder valves and tested for correct functioning by applying full working pressure through the pilot lines.*

   In cases where this is not possible, pilot lines should be disconnected from the cylinder valves and blanked off or connected together and tested with full working pressure from the release station and checked for leakage.

   In both cases this should be carried out from one or more release stations when installed. If manual pull cables operate the remote release controls, they should be checked to verify the cables and corner pulleys are in good condition and freely move and do not require an excessive amount of travel to activate the system;

2. *all cable components should be cleaned and adjusted as necessary, and the cable connectors should be properly tightened. If the remote release controls are operated by pneumatic pressure, the tubing should be checked for leakage, and the proper charge of the remote releasing station pilot gas cylinders should be verified. All controls and warning devices should function normally, and the time delay, if fitted should prevent the discharge of gas for the required time period; and*

3. *after the completion of work, the system should be returned to service.* [sic]

[70] MSC.1/Circ.1318 Revision 1 was issued on 25 May 2021 to address the need to clarify the hydrostatic testing regime for high-pressure CO_2 cylinders and align the relevant requirements with the revised guidelines contained in IMO Circular MSC.1/Circ.1432.

The appendix to the guidance provided a proforma example service chart to assist with monitoring the inspection and maintenance activities carried out on CO_2 systems. Neither MSC.1/Circ.1318 nor the RINA classification rules contained any requirement for a CO_2 system to be surveyed on completion of a service.

The servicing records on board *Finnmaster* showed the servicing requirements at renewal and periodic surveys had been transposed. It could not be determined why.

1.8.16 Similar accidents involving fixed carbon dioxide fire-extinguishing systems

Eddystone/Red Eagle – unintentional release

In September 2018 the MAIB published its findings (MAIB report 16/2018[71]) on investigations into the unintentional release of CO_2 from fixed firefighting systems on board two ships: *Eddystone* on 8 June 2016; and *Red Eagle* on 17 July 2017.

The report noted that:

> *Flag administrations, classification societies, ship's owners, operators and crew all rely on approved service suppliers to ensure that CO_2 fixed fire-extinguishing systems are in a continuous state of readiness, by means of regular maintenance and testing.*

The report's findings included that:

> *The level of service given by approved service suppliers regularly fails to maintain the safety of CO_2 based fixed fire-extinguishing systems on board ships.*

The report recommended to DNV and Lloyd's Register that they:

> *Propose to the International Association of Classification Societies that an investigation be carried out into the application of Procedural Requirements for Service Suppliers, UR-Z17. This should take into consideration the finding of this report, that the level of service provided by approved service suppliers regularly fails to maintain the safety of CO_2 based fixed fire-extinguishing systems on ships.*

Lloyd's Register submitted this recommendation to the IACS survey panel in September 2018.

DNV recommended to IACS member classification societies that letters be sent by each classification society to its approved service suppliers, taking into consideration the conclusions from the report. DNV further requested that the system manufacturers *issue an attention letter providing specific guidance for the specific manufactures/parts and include them to the notifications by each classification society to the service providers* [sic]. DNV noted that discussions at IACS were ongoing in December 2019.

[71] https://www.gov.uk/maib-reports/unintentional-release-of-carbon-dioxide-from-fixed-fire-extinguishing-systems-on-ro-ro-vessels-eddystone-and-red-eagle

The IACS unified requirement UR-Z17 was revised twice in the period between publication of the MAIB report in September 2018 and Viking's service of *Finnmaster* in March 2021, with the second revision published but not coming into force until 1 July 2021.

The two revisions did not update any general requirements for the assessment, approval or certification of service suppliers, or any specific requirements for the assessment of firms engaged in inspections and maintenance of fire-extinguishing equipment and systems.

1.9 ELECTRICAL SYSTEM FAILURE

1.9.1 Emergency power system failure

On loss of power, the interconnector circuit breaker at the main switchboard opened, as did the contactor for the main switchboard supply at the emergency switchboard. The EDG started automatically as intended but its breaker did not close to allow the EDG to supply power to the emergency switchboard.

1.9.2 System loss due to power failure

The lack of power to the emergency switchboard rendered the EDG radiator fan, emergency fire pump, CO_2 room ventilation fans, and the supply to the 380/220VAC transformer inoperable.

The loss of power to the 220VAC emergency distribution panels supplied from the emergency transformer meant that *Finnmaster* was in darkness with both main and emergency lighting supplies inoperative. The loss of the 220VAC to the bridge distribution panel meant that much of the bridge equipment was inoperative including:

- radars
- echo sounder
- navigation lights
- gyro compass.

The Electronic Chart Display and Information System (ECDIS) and global positioning system were fitted with UPS so remained operational when the emergency power to the bridge was lost. *Finnmaster*'s voyage data recorder lost main power but remained operational during the accident as it was supplied by its own battery backup system. The UHF radio system repeater lost power, limiting the ability of the handheld UHF radios to receive or transmit messages. The UHF radios were inoperable in the machinery spaces.

1.9.3 EDG circuit breaker

An initial examination of the EDG circuit breaker following the accident identified several areas of damage **(Figure 26)**, including:

- signs of external heat damage to the left-hand side of the casing

- resistance-free movement of the motor module manual charging handle, which could not compress the charging spring

- burnt motor windings and signs of heat exposure to the adjacent gearing

- the plastic switch handle had snapped into four pieces.

- the pawl from the manual charging lever mechanism, along with a number of mechanical components, had fallen from the motor unit.

The circuit breaker, motor module and damaged components were removed from *Finnmaster*.

The circuit breaker manufacturer, Schneider Electric, was commissioned to carry out a detailed examination to determine the cause of the unit's failure. The report **(Annex J)** indicated that the circuit breaker switch lever and the manual ratchet on the motor module had broken, and that the ratchet pawl had fallen into the mechanism of the circuit breaker switch. The plastic circuit breaker trip contact[72] lever arm had also failed. The return spring from the ratchet pawl was not located during the investigation.

The undervoltage relay operated correctly when tested in isolation, but operated intermittently when tested in conjunction with the UVT unit relay. Detailed examination of the of UVT unit showed that three soldered connections on the circuit board inside the unit were cracked. There was a lack of fusion in the soldered connection between the circuit board and the pins from the connector block where the input and output wires were connected.

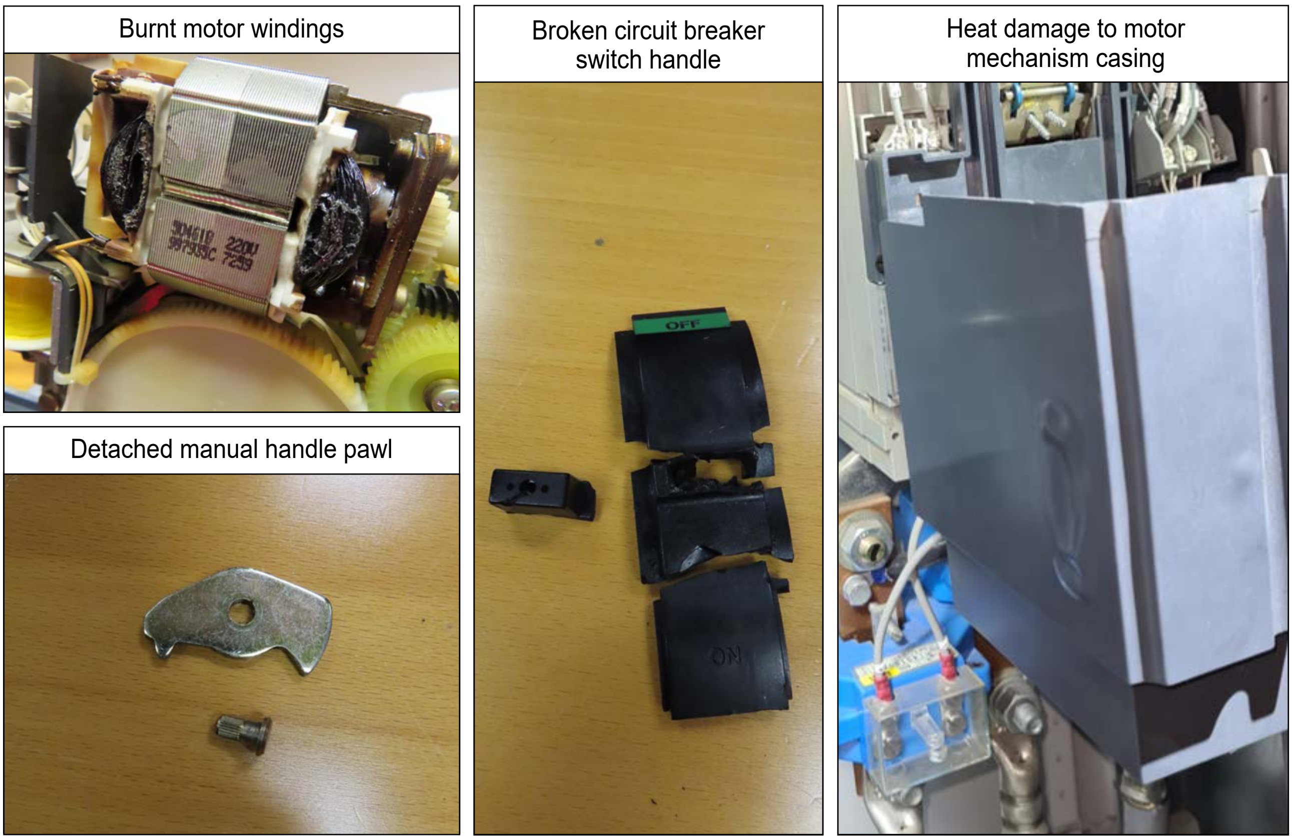

Figure 26: Damage to the EDG circuit breaker

[72] Labelled as *Trip contact (SD)* in the **Figure 6** circuit diagram.

1.9.4 EDG on board testing

The EDG on board *Finnmaster* was subject to a routine test programme as part of the PMS that included:

- a monthly off-load test, i.e. without delivering power to the emergency switchboard;
- a 6-monthly load test with the EDG connected to the emergency switchboard;
- a yearly survey of the EDG's operation carried out in the presence of a classification society surveyor at the ship's annual survey.

To test the EDG off-load, the engine would be started manually. The EDG circuit breaker would not close. In this mode the emergency switchboard would continue to be supplied from the main switchboard.

A test switch was provided on *Finnmaster* to prove the operation of the EDG on load. When this switch was operated, the interconnector contactor would open so that the emergency switchboard lost power. The EDG would then start automatically, the EDG circuit breaker would close, and the EDG would provide power to the emergency switchboard.

The procedures to be used for both the on-load and off-load tests were posted in the EDG room. The emergency switchboard was subject to a routine inspection by the on board electrician and a 5-yearly survey by a classification society surveyor.

The last 6-monthly load test of the EDG had been completed on 24 April 2021. The record of this test indicated that the EDG was *in good condition*. Off-load tests of the EDG were recorded in the PMS at roughly monthly intervals in the 6 months before the fire. All of the PMS entries indicated that the test run of the EDG had been completed without any abnormalities being identified.

The practice on board *Finnmaster* was to complete a weekly off-load test of the EDG, though this was not recorded in the PMS. A test had been competed about 6 hours before the fire.

No records were identified that showed the EDG test schedule for *Finnmaster* before the ship was taken into management by Finnlines in January 2016.

In May 2021, a RINA surveyor completed and examination of the EDG's operation as part of the intermediate survey to credit *Finnmaster*'s safety construction certificate. The checklist for this survey contained an entry for *confirmation, as far as practicable, of the operation of the emergency sources of power, including their starting arrangements, the systems supplied and, when appropriate, their automatic operation*. The survey checklist indicated this had been carried out, though there was no record of the activity in *Finnmaster*'s PMS.

1.9.5 Regulation and guidance

Testing emergency sources of power

The SOLAS Convention Chapter II-1, Part D, Regulation 43 required that:

> *Provision shall be made for the periodic testing of the complete emergency system and shall include the testing of automatic starting arrangements.*

The Convention did not specify the frequency of the periodic testing. On safety of navigation, SOLAS Chapter V, Regulation 26 required ships' crews to test the emergency steering system every 3 months to include, *where applicable, the operation of alternative power supplies*.

Internal communication equipment

From 1 July 2018, amendments to SOLAS[73] Chapter II-2 applicable to *Finnmaster* required the provision of *a minimum of two two-way portable radiotelephone apparatus for each fire party for fire-fighter's communication*. This requirement was met by the UHF portable radios carried on board *Finnmaster*.

The two-way portable radiotelephone apparatus was required to be explosion-proof or intrinsically safe but the IMO did not define performance standards or functional requirements for the equipment.

SOLAS chapter III required the provision of an emergency means for two-way communications between emergency control stations, muster and embarkation stations and strategic positions on board.

Reference information

In 1998, the Marine Safety Agency (MSA)[74] produced Marine Guidance Note (MGN) 52 (M+F) – Testing of Emergency Sources of Electrical Power. MGN 52 (M+F) applied to UK registered ships and stated that:

> *Investigation into marine casualties has indicated that a number of incidents have occurred in which the emergency source of electrical power has not operated correctly following the loss of main power.*

The guidance served to remind those responsible for the operation of ships that:

> *the Regulations required periodic testing of the complete emergency electrical system including any automatic starting arrangements.* [sic]

MGN 52 (M+F) recommended that tests of the emergency source of power be conducted with a load as near to the capacity of the generator as practicable and that these tests be incorporated into the ship's weekly safety checks.

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[73] IMO Resolution MSC.338(91) – Adoption of Amendments to the International Convention for the Safety of Life at Sea, adopted 30 November 2012.

[74] The MSA was responsible for implementing the UK government strategy for marine safety and prevention of pollution from ships. The MSA was amalgamated with Her Majesty's Coastguard in 1998 to become the Maritime and Coastguard Agency (MCA). The MSA issued MGN 52 (M+F) shortly before this merger.

Port State Control inspections

The Paris Memorandum of Understanding on Port State Control (Paris MoU) comprised 28 maritime administrations participating in a harmonised system of inspection[75] for ships visiting ports in the region.

In the 12 months before the fire on board *Finnmaster*, the emergency source of power was inoperable in 281 instances when tested as part of an inspection[76]. An inoperable emergency source of power contributed to the detention of 41 ships, which equated to 9.4% of the detentions recorded[77].

Finland safety study of power failures on ships

In December 2017, the Safety Investigation Authority, Finland (SIAF) published *Power Failures on Ships*[78]. The safety study was conducted over a period of 12 months, starting in February 2016, during which ship accidents and incidents involving failures in the distribution of electricity were examined. Twelve cases were included in the investigation. The safety study noted anecdotal evidence of additional power failures on ships that were not reported to the authority. Of the 12 cases investigated as part of the safety study, the emergency source of power, where recorded, operated as intended in four cases and failed to operate as required in one case.

The SIAF safety study reported that:

> *Tests are done to detect deficiencies. It is of outmost importance to carefully test automation systems and all their functions, already when taking them into use. According to chapter 10.3 in the ISM Code, also systems that are not in continuous use must be tested in accordance with system-instructions and on a regular basis. Automation systems' fast ageing is a problem.* [sic]

and;

> *Deficiencies in the backup and emergency systems were found in all investigated cases. Failure situations, like serious power failures, are not always tested due to the risk of damaging the systems. According to chapter 10.3 of the ISM Code, a shipping company must design measures to ensure the reliability of systems whose failure may cause hazardous situations. According to the ISM Code, the measures must include testing of backup and emergency systems as well as of systems in non-continuous use. The testing must be done in accordance with the instructions for the test.* [sic]

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75 Port State Control inspections were a mechanism to verify compliance with statutory requirements through structured inspections of ships.

76 Inspectors had a degree of discretion over what areas were subject to detailed examination. The number of inspections where the emergency source of power was operationally tested was not available.

77 Data retrieved from the Paris MOU data sharing service https://parismou.org/

78 Investigation number: M2016-S1 – Power Failures on Ships, ISBN: 978-951-836-507-8 (PDF). https://turvallisuustutkinta.fi/material/attachments/otkes/tutkintaselostukset/en/vesiliikenneonnettomuuksientutkinta/2016/LgMHaYu9f/M2016-S1_Power_Failures_Safety_Study.pdf

1.10 EMERGENCY PROCEDURES

1.10.1 General

The safety management system (SMS) used on *Finnmaster* provided procedures and training to enable the crew to respond to emergencies on board.

1.10.2 Muster list

The muster list posted on *Finnmaster* set out the duties and actions to be taken by each crew member in the event of an emergency. At the time of the fire *Finnmaster* had a crew of 16, which exceeded the requirement of the minimum safe manning document. The muster list identified 14 emergency positions. There were two trainees on board who were not included on the muster list.

1.10.3 Emergency response procedures

The *training and fire training manual* (training manual) on *Finnmaster* provided general guidance on fire safety practices and firefighting procedures, including the *operation and use of firefighting systems and appliances* and the *operation and use of fire and smoke dampers*.

The training manual provided a general overview of fixed fire-extinguishing systems, with one section specific to the activation of *Finnmaster*'s high-pressure CO_2 system that stated:

> *It is usually only the ship's chief engineer or his deputy who is permitted to discharge the CO_2 system, at the Master's order. The discharge process starts with the lid of the box containing the release being opened to activate the alarm.*
>
> *Personnel then wait until the areas have cooled down and the seat of the fire has been properly extinguished before any doors to the area are opened.*
>
> *When a fixed extinguishing system of the CO_2 type is to be discharged, it is very important to check the following:*
>
> - *That all personnel have left the area*
> - *That all doors and fire dampers are closed*

Further, it stated that:

> *in case of fire, all fire dampers must be closed. They prevent air (oxygen) from reaching the fire through ventilation channels.*

Finnmaster's SMS contained two emergency procedures relevant to fires on board: one covering the actions to be taken in the event of a fire in port, and one for a fire at sea. There was no procedure covering a fire during pilotage as a separate activity.

The procedure to respond to a fire at sea detailed actions to be taken by the watchman and bridge watchkeeper once a fire had been confirmed, including instructions for the bridge watchkeeper to:

> *sound the alarm and inform the fire groups. Let the signal sound for 2-3 min;*

ensure that fire doors and WT-doors[79] *are closed;*

stop the fans and ventilation at the scene of fire; and

ensure that the fire dampers are closed at the scene of fire.

The procedure then directed the crew to act in line with the muster list instructions, which placed responsibility on the C/E to decide what fire-extinguishing method to use.

The procedure required one fire group to:

go to the scene of the fire and start to extinguish it or prepare extinguishing equipment, evacuating and sealing off the area.

The other fire group was directed to:

meet at the fire station and put on the fireman's outfits to prepare to fight and restrict the fire. [sic]

The procedure further instructed the crew to consider evacuating passengers to the muster stations by making an announcement and sounding the general emergency alarm. It also provided advice on other response elements to consider, among others, the need to:

pay attention to communication between the bridge and fire groups; the consideration of the use of the fixed firefighting installation; the closing of fuel quick closing valves[80]*; energy supplies; and the analysis of risk.* [sic]

The procedure for a fire in port set out tasks to manage the crew and cargo operations and raise the alarm ashore, though this latter process involved the on-duty deck officer phoning the *local fire brigade* by calling 112; this was the emergency telephone number in Finland but not the UK. This procedure called for the preparation of the fire groups, the stopping of ventilation and the closure of the fire dampers.

1.10.4 On board emergency training

Finnmaster's SMS contained a programme of emergency preparedness exercises in compliance with SOLAS. The programme required a monthly full crew fire drill. The training manual suggested including elements such as *knowledge of fire dampers, fire doors and watertight doors*; *function of means of communication*; and *knowledge of the CO_2 system*.

Following each fire drill *Finnmaster*'s C/E completed a fire drill checklist that recorded the date, who had participated, and a description of the drill scenario or activity undertaken. Remarks were also made on the conduct of the drill.

Finnmaster's senior officers held a monthly *shipboard management meeting*. These meetings had a standard agenda item of *safety and security* in which notes on the conduct of the drills were recorded. In the 6 months before the fire the minutes from these meetings stated that *all drills were OK*.

[79] Watertight doors.

[80] Remotely operated valves – refer to section 1.6.10: Fuel system emergency shutdowns.

An internal ISM audit completed over two port calls in Finland in late 2020 and early 2021 did not include an operational drill due to the additional risks associated with the COVID-19 pandemic. The report completed in respect of the internal audit stated that drills had been completed in line with the SMS and were well recorded.

A summary of the monthly fire drills conducted in the year before the fire, including which senior officers participated, is set out in **Table 2**.

Date	Location of simulated fire	Details	Master	Chief officer	C/E	1/E
13/10/2020	Paint store	Use of local CO_2 system/closure of fire dampers/use of boundary cooling			X	
23/11/2020	Sauna	Electrical fire		X	X	
30/12/2020	Galley	CABA drill/use of local CO_2 system			X	X
23/01/2021	Accommodation	Fire in passenger cabin		X		
16/02/2021	Not applicable	CABA instruction			X	X
17/03/2021	Accommodation	Fire in passenger cabin		X		
13/04/2021	Incinerator room	CABA drill/local CO_2 system/ boundary cooling		X	X	X
26/05/2021	Not applicable	Fire station equipment and fire monitor instruction	X	X	X	X
29/06/2021	Not applicable	Video – *Engine Room Fires*[81]				X
31/07/2021	Weather deck	Container fire	X	X	X	X
14/08/2021	Not applicable	Fire station equipment check			X	

Table 2: *Finnmaster* crew fire drills completed between October 2020 and August 2021

Details of the drills that might have been undertaken by senior officers on other ships in the fleet during this timeframe were not examined.

The *Engine Room Fires* video shown to the crew in June 2021 provided advice on the methods used to prevent fires in machinery spaces and guidance on the use of fixed installations for extinguishing fires in engine rooms. It highlighted the need to act quickly when faced with a small fire, noting that:

> *because of the heat and smoke generated by an oil fire in the machinery space, fighting a fire with portable equipment would only be an option for a smaller fire, and only when the fuel had been successfully shut off.*

The video also included guidance on the operation of a CO_2 system. It included: the closure of all openings to the machinery spaces; the closure of remotely operated fuel valves; and the need for a full muster of crew prior to the activation of the system. It also advised to *allow time for structural cooling before considering opening up the engine room.*

[81] Videotel training module 2687: Machinery space fires.

1.10.5 Regulation and guidance

The ISM Code

Section 8 of the ISM Code required that the company identify potential emergency shipboard situations, establish emergency drill programmes and provide measures to respond to accidents and emergencies. It also required the company to ensure that ships were crewed with *qualified, certificated and medically fit seafarers in accordance with national and international requirements*.

STCW training requirements

STCW set out standards for the training and certification of seafarers. Chapter VI of the Convention provided the required standards for emergency, occupational safety, security, medical care and survival functions. The requirements for firefighting training were separated into three levels:

Safety familiarisation[82] – familiarisation training required for all seafarers on joining a ship before being assigned to shipboard duties.

Fire prevention and firefighting[83] – required for seafarers with designated safety or pollution prevention duties in the operation of the ship. This training included:

Shipboard fire-fighting organization

Fire-fighting equipment and its location on board

Instruction in:

.1 fixed installations

.2 fire-fighter's outfits

.3 personal equipment

.4 fire-fighting appliances and equipment

.5 fire-fighting methods

.6 fire-fighting agents

.7 fire-fighting procedures

.8 use of breathing apparatus for fighting fires and effecting rescues [sic]

Training in advanced firefighting[84] – required for seafarers designated to control firefighting operations. The minimum expected standard of competence for the advanced firefighting certificate of proficiency included knowledge of:

Fire-fighting procedures at sea and in port, with particular emphasis on organization, tactics and command;

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[82] STCW A-VI/1-1.

[83] STCW A-VI/1-2.

[84] STCW A-VI/3.

Communication and coordination during fire-fighting operations;

Ventilation control, including smoke extraction;

Control of fuel and electrical systems;

Strategies and tactics for control of fires in various parts of the ship;

Fire-detection systems; fixed fire-extinguishing systems; portable and mobile fire-extinguishing equipment, including appliances, pumps and rescue, salvage, life-support, personal protective and communication equipment. [sic]

The IMO produced a model course[85] to support training establishments to meet the functional requirements of the STCW Code for advanced firefighting. The model course material identified the entry requirements and trainee target group in universally applicable terms and defined the skills necessary to meet the technical intent of the STCW Convention.

To be issued with a certificate of proficiency, course participants had to be able to state that:

communication and co-ordination during firefighting operations is two-fold, I.e. internal communication and co-ordination in the ship and external with the management representatives of owner, classification society and coastal states for external assistance.

shore fire fighters must be informed in case of fire in port. Master and ship staff must take immediate action to control fire as per contingency plan till the shore fire fighters arrive.

walkie-talkie and ship's internal telephone systems are vital in developing internal communication in addition to direct communication by messengers.

engine room ventilation flaps must be closed in case of engine room fire.

And,

state why shutting off fuel supply from settling tanks is essential in engine-room fires. [sic]

The senior officers who managed the response to the fire on board *Finnmaster* on 19 September 2021 had all undertaken firefighting training to the advanced level.

The SOLAS Convention

SOLAS contained provisions intended to ensure that the crew were able to respond to emergencies on board. To restrict the potential for fires to grow once ignited, SOLAS Chapter II-2 included a requirement for the provision of means to:

- remotely stop fuel oil pumps
- remotely close the outlets from fuel tanks

[85] IMO Model Course 2.03 – Advanced Training in Fire Fighting.

- control ventilation fans and openings in the boundaries of machinery spaces.

Chapter II-2 also required all ships to be provided with a fire training manual covering fire safety aspects and use of the onboard fire safety systems.

SOLAS required fire drills to be planned with the purpose of practising the various emergencies that could occur on board, and that these exercises, *as far as practicable, be conducted as if there were an actual emergency*.

Carbon dioxide release management

The available guidance[86] and the training provided to the crew detailed consistent principles and procedures to be undertaken for the safe and effective release of CO_2 to tackle fires in machinery spaces.

1.10.6 Similar accidents involving emergency response

The Calypso – engine room fire

On 6 May 2006, an intense fire broke out in the engine room of the Cyprus registered cruise ship *The Calypso* while on passage from Tilbury, England to St. Peter Port, Guernsey with 708 passengers and crew on board (MAIB report 8/2007[87]).

The subsequent firefighting response highlighted flaws in the knowledge, experience and training of some of the ship's senior officers, who did not follow recognised good practice. On several occasions soon after they thought CO_2 had been released, senior officers re-entered the engine room without the proper equipment or backup and with the consequent risk of allowing air to feed the fire.

The investigation report recommended to the Cyprus Maritime Administration to, in cooperation with the MCA, propose to the IMO that a circular be produced to include:

> *The required crew actions following the use of fixed installation CO_2 systems, aimed at improving the general knowledge of these systems, including inspections and checks of the system status after use.*

The recommendation did not result in the IMO issuing a circular.

Oscar Wilde – auxiliary engine room fire

On 2 February 2010, a fire broke out in the auxiliary engine room on the Bahamas registered ro-ro passenger ferry *Oscar Wilde* following its departure from Falmouth, England (MAIB report 3/2011[88]). The fire was eventually extinguished by the ship's crew.

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86 Guidance on the procedure for the release of CO_2 was available from a wide range of sources, including IMO Model Course 2.03 – Advanced Training in Fire Fighting; Standard Club: A Master's Guide to Fire Safety on Ferries; and Videotel training module 2687: machinery space fires.

87 https://www.gov.uk/maib-reports/fire-in-engine-room-on-passenger-cruise-ship-the-calypso-off-beachy-head-england

88 https://www.gov.uk/maib-reports/fire-in-machinery-space-on-ro-ro-passenger-ferry-oscar-wilde-in-falmouth-bay-england

The actions taken by the crew to combat the fire were swift and positive following the initial alarm. The commander of the firefighting effort had recently completed a command and control training course, and this was reflected in their performance during the fire.

While noting issues with re-entry procedures and UHF radio communication, the report highlighted the effectiveness of the shore-based training arranged by the company; realistic emergency drills; and the determination and efforts of the ship's crew in dealing with the emergency.

Pride of Canterbury – engine room fire

The investigation into a major fire in the engine room of the ro-ro passenger ferry *Pride of Canterbury* on 29 September 2014 (MAIB report 22/2015[89]) noted that:

> *The swift and timely response of the crew can be credited to their training and to the regular emergency drills held on board Pride of Canterbury. While the emergency did not follow any one set procedure, the drills enabled good team working and ultimately led to a successful outcome with no injuries to passengers or crew.*

Arco Avon – engine room fire

On 18 August 2015, a fire broke out in the engine room of the dredger *Arco Avon* off Great Yarmouth, England. The fire was extinguished following activation of the CO_2 smothering system; however, 50% of the CO_2 cylinders had failed to operate and required manual activation to inject the correct amount of gas into the engine room.

The investigation (MAIB report 17/2016[90]) noted a concern 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.* [sic]

and that:

> *There was a significant risk that CO_2 would have escaped into the cylinder room and thus depleted the oxygen content of the atmosphere.*

89 https://www.gov.uk/maib-reports/fire-in-engine-room-on-ro-ro-passenger-ferry-pride-of-canterbury

90 https://www.gov.uk/maib-reports/fire-in-the-engine-room-on-the-suction-dredger-arco-avon-with-loss-of-1-life

SECTION 2 – ANALYSIS

2.1 AIM

The purpose of the analysis is to provide an overview of the individual technical and operational factors that contributed to the accident as the basis for making recommendations to prevent similar accidents occurring in the future.

2.2 OVERVIEW

The fire on board *Finnmaster* occurred after the inboard fuel injection pump coupling on AE2 partially failed. The resulting effect on AE2's fuel timing caused excessive exhaust temperatures and rough engine running; an incorrectly sealed joint leaked exhaust gas, which impinged on an adjacent low pressure flexible fuel hose; the flexible hose failed and fuel sprayed under pressure onto hot exhaust components and immediately ignited, causing a fire in the AER.

The fire disrupted the running of the AEs and *Finnmaster* lost main electrical power; the EDG started but was unable to supply emergency power due to a fault in the circuit breaker. *Finnmaster*'s crew operated the CO_2 system, but it did not operate as designed due to leaks and blockages in the pilot activation system.

The analysis will determine the contributory causes and circumstances of the initial failure of AE2 leading to the fire. These include: the partial failure of the inboard fuel injection pump drive coupling; the use of flexible fuel hoses in the alarm and monitoring system; and the conduct of maintenance activities on board. The analysis will also discuss the framework and oversight of machinery installations and maintenance.

The analysis will examine the circumstances leading to the partial failure of *Finnmaster*'s CO_2 system and its impact on the system's ability to extinguish the fire. The analysis examines the maintenance of the CO_2 system, including the sourcing of components, and the systems of oversight and approval in place.

The analysis will also examine the technical factors leading to the failure of the electrical supplies on *Finnmaster*, the consequences of the power failure, and the effectiveness of the measures used to promote the reliability of safety critical equipment on board.

The conduct and effectiveness of the response of the crew to the emergency will also be analysed.

2.3 AUXILIARY ENGINE 2

2.3.1 Partial failure of AE2 fuel injection pump drive coupling

Mechanism of failure

It is likely that the initial failure of the inboard fuel injection pump coupling was due to fatigue of one of the drive end coupling bolts. The threaded portion of the bolt failed, detached from the coupling and fell into the bilge. The shank of the bolt remained in the coupling slot where it was subject to significant wear due to movement in the slot, also causing damage to the laminated plates in the coupling.

The failure of the bolt released the tension on one side of the laminated plate stack. The increased loading of the opposing bolt resulted in damage to the laminated plates in that area, incrementally releasing the tension in that bolt. The nut on the opposing bolt eventually loosened and also fell into the bilge. The bolt remained in the coupling slot and tilted, jamming it against the cross coupling where it continued to drive the fuel injection pump. However, the relative position of the input and output shafts of the coupling was changed, resulting in the retardation of the fuel injection timing on the inboard bank of cylinders.

It is possible that a significant period of time passed after the initial failure of the drive end coupling bolt. The protection cover over the coupling probably prevented a passing inspection of the engine identifying the missing bolt, and the engine parameters would not have indicated a problem until the fuel injection timing changed. It is therefore unlikely that the crew would have been able to identify the failure of a single bolt unless specifically tasked to inspect the coupling.

Effect of the coupling partial failure on fuel injection timing

The failure of the bolts in the inboard fuel injection pump coupling did not result in the complete failure of drive to the fuel injection pump. The pump continued to rotate and inject fuel into the cylinders.

It was not possible to accurately determine the fuel injection timing on the inboard bank of cylinders before the failure of the coupling. From the last recorded inspection of the coupling on 9 September 2020[91], AE2 operated for a cumulative total of 1,331 hours before the fire occurred **(**see **Table 1)**. As no abnormal exhaust gas temperatures were recorded in the engine logbook, and due to the lack of comment following the 1/E's inspection of AE2 immediately before the fire, it is almost certain that the fuel injection timing was correct up to the completion of this last inspection of the running engine.

While it is possible that the witness marks noted on the surface of the coupling flange reflected a previous securing position, the marks suggest that, before the accident, the bolts were likely positioned approximately 9° along the slot when measured from the extreme clockwise position, viewed from the drive end. Following the failure of the bolts, the position of the coupling had rotated approximately 17° from the position as indicated by the witness marks. The angled position of the bolt shank retained in the slot allowed movement beyond the end of the adjustment slot **(Figure 27)**.

Due to the difference in speed of rotation between the fuel injection pump and engine crankshaft, the failure of the fuel injection pump coupling bolts caused the injection timing on the inboard bank of cylinders on AE2 to retard by approximately 34°. This equated to a static injection timing of 12° after TDC.

91 Analysis of the records showed a further inspection was probably carried out in April 2021, but not recorded in the PMS.

Image courtesy of Mitsubishi Heavy Industries Ltd

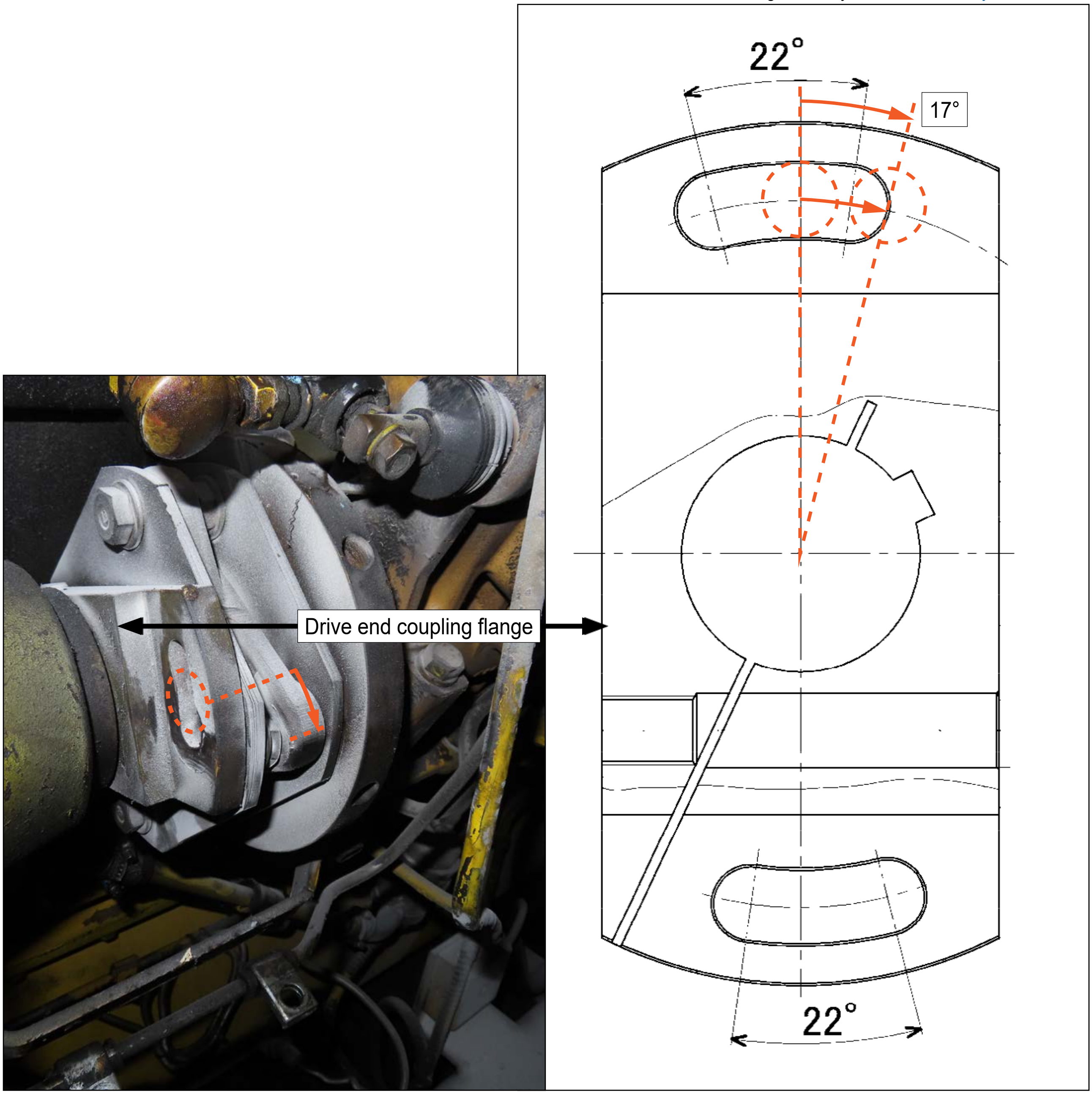

Figure 27: Displacement of fuel injection pump coupling due to partial failure

Effect of fuel injection timing retardation on AE2

In normal operation, fuel injection would commence before the piston reached TDC on the compression stroke. The fuel, ignited by the heat of compression, would build pressure in the cylinder. The combustion gases would expand and increase pressure in the cylinder to a peak pressure at approximately 10° after TDC, pushing the piston down the cylinder until the exhaust valve opened at 57°[92] before the piston reached bottom dead centre (BDC)[93].

[92] 57° before BDC is the design value with no clearance at the tappet. The actual value on each cylinder would be dependent on the actual tappet clearance and temperature of the engine components.

[93] The angular position of the crankshaft with the piston in its lowermost position in the cylinder.

With the fuel injection timing retarded, fuel on the inboard bank of cylinders was injected when the pistons were already descending on the expansion stroke. Combustion continued during the exhaust stroke and into the exhaust system. The temperature of the exhaust gases in the manifold rose significantly, leading to a very high temperature at the inlet to the turbocharger.

The late injection of fuel significantly reduced the power being produced by the inboard bank of cylinders. The power reduction caused AE2's governor to react and increase the fuel setting to inject more fuel into the cylinders to maintain the speed of the engine. The increase in fuel rack setting affected both banks of cylinders and the exhaust temperature of the outboard bank increased proportionally, though the fuel injection timing, and hence the quality of combustion, was unaffected on this side of the engine. The electrical loading on AE2 increased during departure from Hull with the use of the bow thruster, further raising the exhaust temperatures in the engine.

Immediately before the fire, the 1/E noted that the temperatures on the outlet from both turbochargers were at least 650°C; the maximum reading on the gauges. The temperature of the exhaust gas before its entry to the turbochargers is unknown but would have been significantly higher than that observed at the outlets.

Despite the effect of the partial failure of the fuel injection pump coupling on combustion in the engine, AE2 remained capable of producing the required power and it remained connected to the main electrical switchboard in parallel with AE1. None of the measured parameters on AE2 were sufficiently affected to activate any alarm or trip function to either alert the engineers of a problem or shutdown the engine.

AE2 was last inspected shortly after 1920 on 19 September 2021, while running during preparations for departure from Hull. With no indication of a problem at that time, the engineers remained unaware of the partial coupling failure until the fire alarm sounded at 2013 to signal smoke in the AER.

Maintenance of the fuel injection pump coupling

Finnmaster's PMS records showed that the fuel injection pump couplings on AE2 had a history of failure. The recorded failure of the coupling in June 2018 and the use of thread locking compound in April 2021 evidenced the weakness in this assembly, and its recognition as such on board. The correct orientation of the remaining rounded washers noted in the coupling following the fire suggested that the coupling was assembled with the correct components at that time. Though the PMS records did not indicate what torque that had been used to secure the coupling bolts, all the instructions on board were consistent with the correct value and no evidence suggested that the incorrect torque had been applied when the bolts were installed.

The use of thread locking compound by the ship's engineers was probably intended to mitigate the known risk of a coupling failure. It cannot be determined whether the use of the compound contributed to the failure; however, its use was contrary to the maintenance instructions of the engine manufacturer. One nut had detached from its bolt thread, indicating that the compound had not prevented the nut loosening.

As maintenance on *Finnmaster* was managed through the PMS and not with reference to the service manual, it is unlikely that the differing fuel injection pump coupling inspection frequency between the PMS the operation and maintenance manual would have been identified.

With no formal mechanism to report failures outside the AEs' warranty period, it is possible the OEM was unaware of the ongoing tendency for these couplings to fail in the manner that *Finnmaster*'s AE2 inboard coupling did, though MTEE personnel understood the risk of slippage. Operational failures of the couplings that did not result in such catastrophic outcomes as on *Finnmaster* would likely only result in remedial maintenance, and not necessarily be highlighted as a significant issue.

The OEM had modified the design of the coupling arrangement over time to improve its reliability, but it was evident from *Finnmaster*'s PMS records and the anecdotal evidence from other users of the engine series that the design modifications had been unsuccessful in delivering a comprehensive solution. The repeated failures of the couplings on *Finnmaster* were not escalated to the company as recommended in the IACS guidance on the management of maintenance. The lack of reporting prevented concerns being raised with the OEM to enable it to consider further design amendments to reduce the risk of failure.

As with the multiple engine failures identified in the *Wight Sky* investigation, greater consultation on known and repetitive failures might have provided the opportunity for higher level technical investigations, including by the engine manufacturer if appropriate.

2.3.2 Exhaust gas leakage

The exhaust temperatures on the outlet from both turbochargers were noted as being *at least* 650°C immediately before the fire. The timing of fuel injection into the cylinders on the outboard side of the engine was unaffected and, although significantly overloaded, the combustion in these cylinders would have been complete.

The seizure of the spiral wound seal rings in the grooves of the exhaust transition ring on the outlet from the outboard turbocharger was caused by the presence of the exhaust sealing compound, which had been applied to the joint during the October 2017 service of AE2 by Inter Marine.

Though the sealing compound provided a seal for the transition ring joint when initially applied, this was broken by relative movement between the engine and the exhaust system once the compound hardened. The seizure of the sealing rings in their grooves prevented them working as intended and provided a route for the passage of exhaust gas to atmosphere.

Exhaust gas leaked past the spiral wound seal rings on the outlet from the outboard turbocharger. While the exhaust gas leakage was inside the insulated box structure covering the exhaust pipe between the two turbochargers, the leaking gas was able to emerge from the gap between the box structure and the flywheel casing.

The flexible fuel hose leading from the inboard fuel cartridge filters to the instrument panel passed across the engine flywheel casing adjacent to the gap and beneath the insulation blankets covering the box structure.

The volume and temperature of the exhaust gas produced by the engine rose significantly when the inboard fuel injection pump coupling partially failed. The incorrect maintenance procedure on AE2's exhaust allowed high temperature exhaust gas to leak into the insulated box structure, below which the flexible hose containing fuel under pressure was positioned **(Figure 28)**.

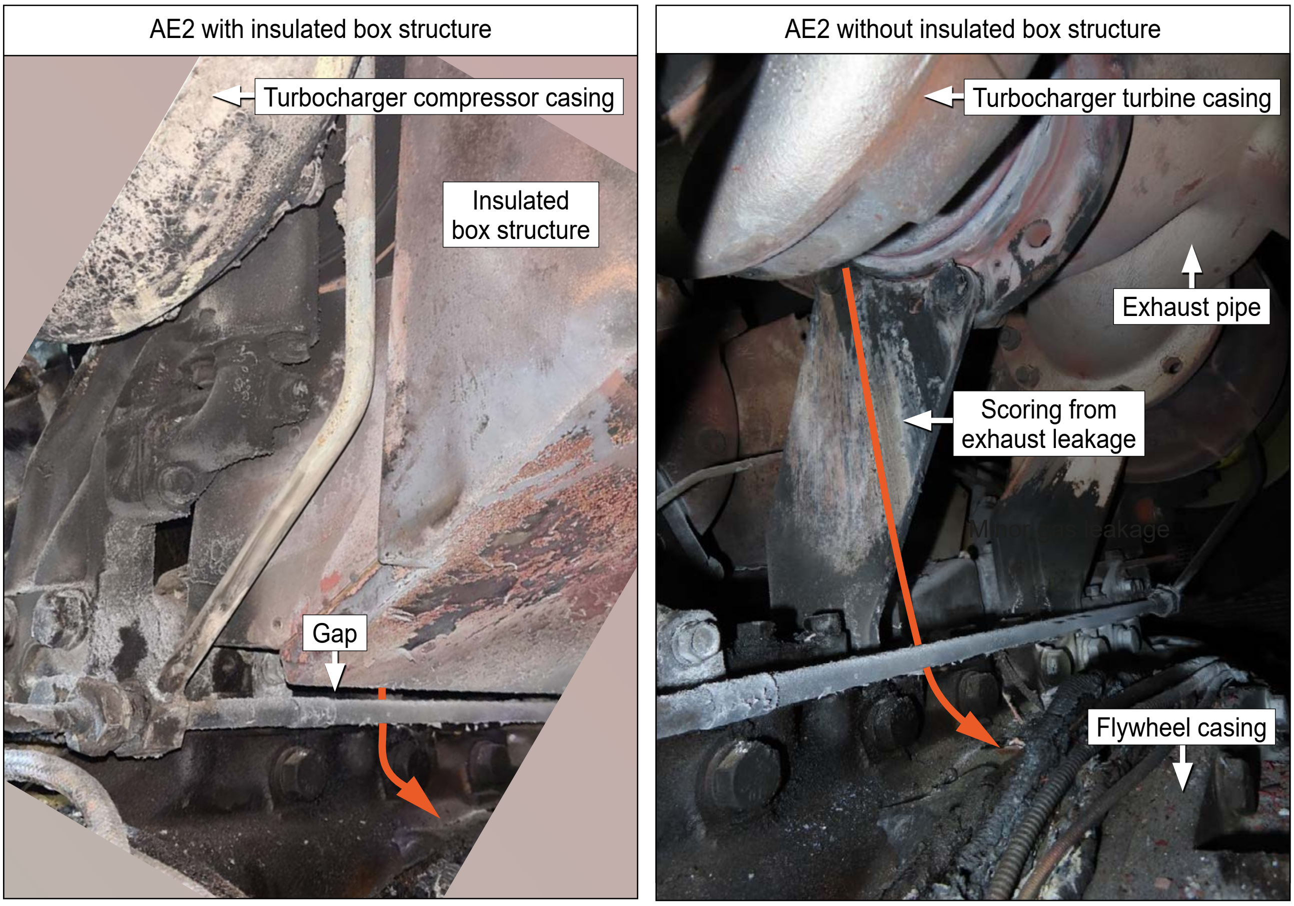

Figure 28: AE2 exhaust gas leakage path

2.3.3 Use of service technicians

Finnlines provided support to the ship's crew by engaging Inter Marine to complete AE2's major overhaul in October 2017. The technicians employed by Inter Marine were experienced marine engineers. MTEE provided a passive training framework for use by its approved service and spare parts suppliers. The system relied on the service provider, Inter Marine, to maintain the competence of the service technicians.

The investigation identified that the overhaul of AE2 had not fully been completed in line with OEM instructions, specifically: the lack of washers identified by the crew in the coupling assembly at the time of the June 2018 failure; and, the use of sealing compound in the assembly of the exhaust transition ring on the outlet from the turbochargers. The latter was a contributory factor to the cause of the AER fire.

There was little oversight of Inter Marine by *Finnmaster*'s engineers, and none by the classification society other than a test on completion of the work. The crediting of the survey for the classification certificate was primarily based on the report produced by Inter Marine and the running tests on its completion.

Inter Marine and MTEE measured the performance of the service technicians through feedback from customers. With no negative feedback, the service was accepted as completed to a satisfactory standard. The lack of a formal process of audit or verification by MTEE of the services provided by Inter Marine did not provide a mechanism for continual improvement or the identification of shortcomings in the conduct of the work undertaken.

The audit by Finnlines of Inter Marine as a service provider was focused on business risk rather than technical performance.

The monitoring, approval and assurance of work carried out during the major overhaul of AE2 was ineffective and put the safe operation of *Finnmaster* at risk.

2.3.4 Oversight of the alarm and monitoring system modification

The original alarm and monitoring system modification to the AEs was installed no later than July 2006, but the then operator of *Finnmaster* did not submit the design for classification society approval.

It is possible that the flexible hoses originally installed were replaced between their original installation and their assessment in October 2018, but no records were identified to verify this.

The hydraulic hose company engaged to check the flexible hoses on the AEs in 2018 replaced them on a like-for-like basis. Neither that company nor *Finnmaster*'s crew referenced the appropriate type approval certificate or classification rules to ensure the relevant criteria were met.

The original modification to the alarm system on *Finnmaster*'s AEs included flexible hoses that were longer than 1.5m, installed in a position that exposed them to elevated temperatures, and had no means of isolation. The modification did not meet the requirements of SOLAS Chapter II-2 or classification society rules.

It is almost certain that the modified system would not have been approved had it been presented to DNV for approval. The lack of submission for approval meant that the opportunity to critically assess the system to ensure compliance with the requirements, and to identify the risk it presented, was missed.

2.3.5 Failure of flexible fuel hose and ignition of fuel leakage

It is very likely the flexible hose leading from the fuel cartridge filters to the instrument panel on AE2 had been subject to elevated temperatures above its design criteria in the 4,687 running hours since installation. The fuel in the flexible hose was static and was unable to provide a cooling effect. Flexible hoses are known to degrade, become brittle and crack as the temperature increases. The USCG safety alert issued in 2017 **(**see **Annex A)** provided a very similar example of the deterioration of a flexible hose installation that led to an outcome comparable to that on *Finnmaster*.

It is apparent that the leaking exhaust gas impinged the degraded flexible fuel hose, which allowed fuel at a pressure of about 3.8 bar to spray onto AE2's hot exhaust components and spontaneously ignite.

The heat from the fire initiated at the aft end of AE2 further damaged the flexible fuel hose, leading to a progressive increase in the amount of fuel being released under pressure. When *Finnmaster* lost power the auxiliary engine fuel feed pump stopped. The fire was already well established by this point and fuel continued to flow from the damaged flexible hose, though at a much-reduced rate.

The insulated box structure, covering the exhaust manifolds and turbocharger turbine casing and supplemented by the insulation blankets, was intended to prevent any external oil spray impinging on a high temperature surface within it.

The routing of the flexible hose as part of the modification to the AE2 alarm and monitoring system exposed it to elevated temperatures that degraded the hose and increased the risk of failure. The routing of the flexible hose meant that any fuel leakage was likely to come into contact with high temperature surfaces. Both of these elements increased the potential for a fire.

2.3.6 Surveys by classification societies

The annual endorsement of *Finnmaster*'s classification and statutory certificates was completed by DNV surveyors from June 2006, when the flexible hoses for the modified alarm system were known to have been in place, until the transfer of classification to RINA in January 2016. The risks posed by the flexible hose installation were not identified during inspections carried out on board as part of the classification society oversight of the vessel.

From 2013, when the DNV rules were amended, there was no requirement for a specific examination by a surveyor of the AEs' local instrumentation. Consequently, the instruments on the local panels on *Finnmaster*'s AEs would not have been scrutinised during the ship's annual survey for the certificate of classification.

The survey of the protection of high temperature surfaces, instrumentation and fuel piping systems, as well as a critical examination for fire safety during the general examination of the machinery spaces, was included in the scope set out in the rules of both DNV and RINA for annual surveys.

The only fire safety deficiencies recorded were those identified in 2006 for the condition of the exhaust insulation, which led to the issue of a condition of classification. The failure to identify a noncompliance with the classification rules when specifically examining for fire safety, and photographing, a noncompliant installation indicated a possible lack of awareness on the part of the attending surveyor.

Despite requirements in both DNV and RINA rules for the annual fire safety examination of machinery and equipment, the expectation for the conduct of a general examination was a brief inspection of the machinery spaces to identify obvious shortcomings. Without significant focus in the instructions to surveyors on the guidance available to prevent fires in engine rooms, it is very unlikely that a surveyor would identify the flexible hoses installed on the AEs as noncompliant during an inspection covering the entire machinery space. This would be further compounded as time passed and the visible condition of the flexible hose blended into the appearance of the other system components so it would not stand out as a modification to the original system.

Throughout the extended period of time that the flexible fuel hoses were in place on the auxiliary engines on *Finnmaster*, none of the inspections or surveys carried out by either classification society identified the noncompliance or the potential risk arising from their installation.

2.3.7 Surveys and inspections by *Finnmaster's* crew

The responsibility for ensuring that *Finnmaster* was maintained in compliance with the regulatory requirements and classification society rules lay with the companies operating *Finnmaster*. The C/E had technical responsibility for all maintenance on board Finnlines ships.

Both DNV and RINA permitted the survey of machinery items by a C/E under the CMS survey framework and relied on the C/Es for the examination of class items during maintenance when under the MPMS framework. The rules placed responsibility on the company to ensure that C/Es met the required levels of qualification and experience to carry out surveys.

Neither the classification societies nor Finnlines provided C/Es with effective guidance or support on the rule requirements to assist them to identify noncompliances. Consequently, *Finnmaster*'s C/Es did not identify the inappropriate flexible hose installations on the AEs or the variations to OEM maintenance routines during AE2's major overhaul.

The investigation showed that the lessons identified in the *Finlandia Seaways* report about the support provided to C/Es in the conduct of surveys of machinery items had extended no further than the organisations directly involved in that case. The subsequent *Stena Europe* recommendation to provide training to improve how C/Es conduct class-related equipment inspections indicated that this continues to be a problem.

The passive nature of Finnlines' management of its C/Es' authorisations to conduct surveys did not ensure that they were fully familiar with the expectations for the survey of equipment. Consequently, the conduct of surveys relied on a C/E's knowledge and experience.

The surveys and inspections conducted by C/Es were ineffectively managed under delegation from the classification societies. They were neither supported nor controlled by the operating companies. This resulted in a risk that nonconformities would not be identified.

2.3.8 Guidance on measures to prevent fires in machinery spaces

The IMO Circular MSC/Circ.647 and the later MSC.1/Circ.1321 provided information on the prevention of fires in machinery spaces and advised flag states to promulgate the guidance to the shipping industry. The importance of disseminating guidance on measures to prevent fires in machinery spaces was highlighted in the *Pride of Canterbury* accident report (see section 1.10.6).

Finnmaster's flag state did not circulate these IMO publications to Finnlines, resulting in a lack of readily available guidance to C/Es during their examinations of the flexible hose installations on *Finnmaster*'s AE.

The lack of effective dissemination of safety information potentially caused a lack of awareness of the risks associated with flexible hose installations, reducing the effectiveness of the inspections and surveys conducted on board *Finnmaster* and increasing the risk of a machinery space fire.

2.4 FIXED CARBON DIOXIDE FIRE-EXTINGUISHING SYSTEM

2.4.1 System operation

The sequence that the C/E followed to activate the CO_2 system matched the operating instructions for system. After the time delay unit in the system activated, CO_2 was admitted to the pilot system connected to the series of flexible hose assemblies at cylinder C268 in the CO_2 room **(**see **Figure 19)**. The system operated as intended up until this point in the activation sequence.

The discharge valves on six[94] main cylinders operated and released CO_2 into the common discharge manifold. The engine room booster valve, already opened by the activation signal from the release station, directed CO_2 from the common discharge manifold to open the engine room section valve and admitted CO_2 into the pilot system at cylinder C227.

The blocked flexible pilot hose assembly installed in the pilot system between cylinders C241 and C242 prevented the flow of CO_2 through the system and effectively divided the engine room system in two. CO_2 from the booster valve was unable to pass beyond the blocked flexible hose.

The leakage of CO_2 from the pilot system was significant. The pressure generated in the section of the pilot system from the activation time delay unit did not rise sufficiently to open all the connected cylinder valves before the pilot cylinder's contents were exhausted.

The section of the pilot system pressurised from the booster valve contained leaks. However, the pressure achieved in this section was supplemented from the common discharge manifold and so was sufficient to operate the cylinder valves on a further 15 cylinders[95]. The post-fire system activation tests showed that all of the cylinder valves would have operated as designed had they received pilot CO_2 of sufficient pressure.

The reversal of the inlet pipework to the pilot system from the time delay unit and booster valve did not affect the operation of the system. However, due to the position and magnitude of the leaks in the pilot system, the reversal might have influenced the number of cylinders released.

The blockages and leaks identified in the system would not have prevented manual operation of the valves individually to inject the appropriate quantity of CO_2 to the engine room.

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[94] Cylinders C262, C263, C265, C266, C267 and C268.

[95] Cylinders C227 to C241.

Finnmaster's CO_2 system was activated correctly by the C/E but failed to operate as designed due to a combination of leaks and the blockage in the pilot system. Leakage from the pilot system allowed a proportion of the CO_2 discharged by the system to enter the CO_2 room. With no active ventilation in the space the gas would accumulate, placing any crew entering the space in danger.

CO_2 concentration achieved in the engine room

Normal atmospheric air has an oxygen content of approximately 21%. A full discharge of the CO_2 system would release 1,890kg of CO_2 with a free volume of 1,058m³ into the engine room. This would reduce the oxygen content to approximately 14%, a level that could not sustain combustion.

The partial failure of the system reduced the quantity of CO_2 injected to 945kg with a free volume of 529m³, which was 50% of that intended. At this concentration the proportion of oxygen in the atmosphere in the engine room was reduced to approximately 17%, allowing combustion to continue.

Ventilation openings to the engine room remained open throughout the fire, which might have allowed fresh air to be drawn into the engine room and for CO_2 to escape due to thermal currents in the atmosphere caused by the fire. Any additional air entering the space would only have had the effect of increasing the available oxygen for the fire.

The partial failure of the CO_2 system on board *Finnmaster* did not achieve the designed volumetric discharge quantity. This resulted in a concentration of oxygen in the engine room that remained able to support combustion and did not extinguish the fire in the AER.

Effect of system defects on CO_2 system ability to extinguish cargo hold fires

Analysis of the effect of the position of the flexible hose assembly blockages in the cargo hold pilot system showed that neither the upper cargo hold nor lower cargo hold systems would have operated as required in the event of their use.

As the CO_2 from both the time delay unit and booster systems in the cargo hold pilot systems both entered at the same end of the pilot system in the CO_2 room, the blockage between cylinders C207 and C208 would have prevented the activation of all the CO_2 cylinder valves downstream of that blockage[96]. The number of cylinders opening automatically in the event of an activation of either system would have reduced by the amount shown in **Table 3**.

Compartment	Cylinders configured for automatic release	Actual operational cylinders (due to blockage)	%	Achievable oxygen concentration %
Upper cargo hold	179	118	66	17
Lower cargo hold	100	39	39	19

Table 3: Effect of a cargo hold flexible pilot hose assembly blockage on CO_2 injection

[96] See **Figure 23**.

The pilot system defects meant that it was very unlikely that a concentration of CO_2 sufficient to extinguish a fire in either of the cargo holds would have been achieved by the automatic injection of CO_2 from the main fixed high-pressure system on *Finnmaster*.

The system allowed for the manual release of CO_2 from the main cylinders. In all cases, were the need identified, it would have been possible for the appropriate amount of CO_2 to be released into the protected space using the manual handles provided for the purpose. This would reduce the level of oxygen in the space to one where combustion would not have been possible.

2.4.2 System service

Flexible hose assembly production and oversight

The components used in the manufacture of the flexible hose assemblies installed in the CO_2 system on board *Finnmaster* were required to be produced in line with RINA type approval standards.

Geeve held an approval of manufacturer certificate issued by DNV. The certificate permitted Geeve to manufacture flexible hose assemblies for installation on ships under DNV's responsibility. Geeve did not hold any authorisation issued by RINA for the production of flexible hose assemblies and RINA had no oversight of Geeve's assembly production process.

Geeve made two deliveries of flexible hose assemblies to Viking that were used in the installation on board *Finnmaster*. The flexible hose assemblies in both deliveries were supported by test certificates stating the applicable DNV type approvals and referencing the DNV rules. The DNV type approvals referenced in the Geeve test certificates included the requirement for the couplings used in the manufacture of the flexible hose assemblies to be of a type produced by Parker. Geeve had amended its purchasing procedure and instead sourced the couplings for the flexible hose assemblies from HSR.

As HSR was distanced from the maritime regulations governing the use of the flexible hose assemblies, it is very unlikely that the company was aware of the couplings' intended use or any type approval requirement. Consequently, the couplings used in *Finnmaster*'s CO_2 system flexible pilot hoses were not manufactured to the standard that the type approval process was intended to deliver.

The quality assurance procedure used by Geeve did not ensure that the type approval requirement for each flexible hose assembly to be subject to a pressure test was met. Only 20% of each batch of hose assemblies was actually tested and the test procedure would not necessarily identify any blockages or pressurise the entire flexible hose if a blockage was present.

DNV did have oversight of Geeve's flexible hose assembly manufacturing procedures through the tests conducted for the issue of the *approval of manufacturer certificate*. The initial survey for this certificate in 2017, and its subsequent renewal in June 2020, did not indicate any identified issues with the Geeve systems. This conflicts with the findings of the DNV survey of Geeve in April 2022 that was undertaken following concerns raised during this investigation.

This audit identified multiple failings in the management of the production process sufficient for the approval of Geeve as a manufacturer of flexible hose assemblies to be rescinded.

Geeve did hold a responsibility to inform DNV of any changes to the procedures used in the manufacture of flexible hose assemblies, which would include changes to the components used in production. Without receiving any such notification, DNV did not have the opportunity to assess the Geeve procedures against the type approval standards until the next scheduled renewal of the approval of manufacturer certificate.

Viking did not have the ability to exercise control over the manufacturing process, nor the system of assurance leading up to the delivery from Geeve, so relied on the certification accompanying the delivery of flexible hose assemblies to verify their quality.

The purchasing systems for Viking LSE in the Netherlands and Viking in Finland did not identify the lack of appropriate RINA certificates for the manufacturer of the flexible hose assemblies or type approvals accompanying the flexible pilot hoses supplied for use on *Finnmaster*.

The oversight of the manufacture and supply of the flexible hose assemblies by DNV, RINA and the Viking Group was not robust enough to prevent them entering the supply chain and being installed in *Finnmaster*'s CO_2 system.

Regardless of DNV's oversight of Geeve, flexible hose assemblies produced under the DNV approval of manufacturers scheme were not valid for installation on *Finnmaster* after 1 January 2016, when the ship's classification transferred to RINA.

Servicing procedures

The March 2021 service by Viking technicians of *Finnmaster*'s high-pressure CO_2 system used checklists that referenced the example service chart in MSC.1/Circ.1318. The example checklist contained the entry, *servo tubing/pilot lines pressure tested at maximum working pressure and checked for leakages and blockage*. The onboard CO_2 system manual and the manual available to the Viking technicians provided methods to test the operation of the pilot system. The service report indicated that a test of the cylinder valves and pilot system had been completed, including a test for both leakage and blockage. The blocked flexible hoses were in position at the time of the service, and this combined with pilot system leaks would have prevented the operation of some cylinder valves. The defects were not identified during the test.

It is very likely that the test conducted during the service of the CO_2 system on board *Finnmaster* differed from the contents of the manuals held on the ship and by Viking. The test did not therefore wholly align with either of the minimum recommended maintenance methods set out in section 6.2 of MSC.1/Circ.1318.

It is possible that the CO_2 system on *Finnmaster* was not fully operational from the initial replacement of flexible hose assemblies in July 2020. The tests of the system carried out in March 2021 failed to identify this deficiency.

Survey oversight

The guidance in MSC.1/Circ.1318 recommended that specific servicing tasks on the CO_2 system be carried out at periodical and renewal surveys. The statutory oversight of the maintenance was reliant on the scheduled surveys required by SOLAS Chapter I. SOLAS required an examination of the CO_2 system at the time of the survey but did not dictate the need for survey when maintenance was undertaken. Further, the survey procedures referenced by SOLAS and contained in the RINA procedures did not require the presence of a surveyor to witness the conduct of the service or testing of the CO_2 system on *Finnmaster*.

The periodical survey of *Finnmaster* was carried out in July 2021 leading to the endorsement of the SEC. While it could not be verified that the documents related to the service of the CO_2 system in March 2021 were presented to the RINA surveyor, the report of the service was available on board. The report stated that a satisfactory service had been completed. In reality, the CO_2 system had non-compliant components installed, loose connections and was not fully operational. These defects were not identified at time of survey. It is likely that the attending surveyor accepted the service report in good faith.

Without any oversight of the servicing of the CO_2 system on board *Finnmaster*, the surveys completed for the certification of the ship relied almost entirely on the quality assurance procedures used within the component supply chain, and the documentation produced by the service provider undertaking the maintenance.

Approval of service suppliers

The audit of Viking by Finnlines focused on business risk and its scope did not include any examination of the Viking maintenance or purchasing procedures. Though the audit provided the opportunity to identify potential shortfalls in the supply of components for installation in the CO_2 system on board *Finnmaster*, it was limited in its ability to do so.

TRAFICOM had delegated the responsibility for the approval of service suppliers for a range of activities undertaken on ships registered in Finland, but this did not extend to the acceptance of training of service technicians undertaking maintenance of fire-extinguishing systems. Information on the lack of approval by the flag administration was available to the RINA surveyors but, as Viking held a valid approval from RINA as a service supplier under the well-established IACS UR-Z17 framework, it is unlikely this would be identified.

The flag state administration did not set out its criteria for the acceptance of standards for the training of technicians servicing fire-extinguishing systems as required by MSC.1/Circ.1318.

Training of service suppliers

The Viking technicians undertaking the service on *Finnmaster* were trained under the Viking Group system, using centralised training facilities in the Netherlands. They were experienced in the servicing of high-pressure CO_2 systems but it is very unlikely that they followed the procedure contained in the available system manuals to perform service tests of the CO_2 system on board. Had they done so, it is likely that the system faults would have been identified.

The local supervision and lack of independent oversight of the maintenance carried out allowed the service technicians to complete a service of *Finnmaster*'s CO_2 systems that did not ensure it was operational on completion.

International Maritime Organization guidance

Section 6.2 of MSC.1/Circ.1318 provided two means of testing the pilot system intended to assure its integrity and function following a service. One test procedure only tested the activation heads and pilot system pipework without the heads being attached to the cylinders. The second test procedure only provided for a pressure test of the pilot system pipework and did not effectively test for a blockage in the system or the operation of the cylinder valves. The two tests were not equivalent, though their inclusion in the same section of the circular might imply this was the case. Neither test had the capability of ensuring that the system was fully operational at the point the system was returned to service as required by 6.2.3 of the circular.

The IMO guidance in MSC.1/Circ.1318 for the servicing of CO_2 systems allowed for a test procedure that did not explicitly prove that the activation system was fully operational on completion of maintenance.

International Association of Classification Societies unified requirements

Viking undertook servicing of the CO_2 systems throughout the Finnlines fleet. It was approved to inspect and maintain fire-extinguishing equipment in line with the IACS UR-Z17 procedures by four IACS member classification societies, including RINA. As the surveying of CO_2 systems depended on the work of approved service suppliers, the application and content of IACS UR-Z17 procedures was critical.

The September 2018 investigation report on the unintentional releases of CO_2 on board *Eddystone* and *Red Eagle* highlighted the reliance placed on companies servicing CO_2 systems. In its report the MAIB made a recommendation (2018/125) to two IACS members proposing that an investigation be carried out into the application of UR-Z17. Subsequent amendments to UR-Z17 did not update the requirements for the assessment and approval of companies engaged in inspections and maintenance of fire-extinguishing equipment and systems. The response to the recommendation did not generate any effective change to improve the performance of service providers. Many elements of the *Finnmaster* investigation raised similar concerns to those highlighted in the *Eddystone* and *Red Eagle* report.

It is apparent that the content and application of UR-Z17 continues to not deliver a satisfactory level of service from the approved service suppliers that maintain the safety of CO_2 systems on board ships.

2.5 ELECTRICAL SYSTEM FAILURES

2.5.1 Loss of power

AE1 continued to function for 4 minutes after the fire started. It stopped when the fire impinged on its shutdown control circuits. When AE1 stopped, the main and emergency switchboards lost power and *Finnmaster* consequently lost propulsion.

2.5.2 Circuit breaker failure

When AE1 stopped providing power to the main switchboard, the interconnector circuit breaker between the main and emergency switchboards opened and the EDG automatically started. When the voltage supplied by the EDG stabilised, the circuit breaker connecting it to the emergency switchboard failed to close correctly and the power from the EDG was unable to reach the emergency switchboard.

It is likely that the defective soldered connections identified by Schneider Electric caused an intermittent break in the circuit to the undervoltage coil. This disrupted the logic of the internal control circuits of the motor module. This likely resulted in the motor module repeatedly opening and closing the circuit breaker until the ratchet pawl detached, fell into the circuit breaker switch mechanism and jammed it. The continued action of the motor on the jammed mechanism resulted in the plastic circuit breaker switch handle and the SD lever breaking, preventing the subsequent circuit breaker closure by the motor module.

The dislodged pawl in the ratchet mechanism also made it impossible for the crew to charge the control unit spring using the manual lever. The failure of the circuit breaker switch handle would have prevented a manual closure of the circuit breaker, even if the crew had managed to charge the spring.

The location of the defective soldered connections within the EDG circuit breaker meant that it was very unlikely they would have been identified in any of the inspections or surveys carried out on board *Finnmaster*.

It is likely that the defective solder connections had been present since the manufacture of the EDG circuit breaker and its installation into *Finnmaster* when the ship was built. The circuit breaker worked as intended when operated up until the time of the accident.

2.5.3 Power loss consequences

Finnmaster's loss of power impacted the crew's ability to respond effectively to the emergency because:

- The loss of main propulsion, steering gear, and the bow thruster in the early stages of the emergency, reduced *Finnmaster*'s manoeuvrability.
- The cooling fan for the EDG radiator was unable to start and the ventilation dampers on the radiator duct remained closed. This caused the EDG engine cooling water temperature to rise.
- The lack of power supply to the emergency fire pump prevented it from pressurising the fire main.
- The mooring winches were unavailable to assist with securing the tug lines and mooring lines when *Finnmaster* was eventually brought alongside the berth.
- The UHF radio system became inoperable, restricting communication between the crew as they dealt with the emergency.

The loss of power on board *Finnmaster* caused a consequential loss of critical safety equipment needed to support the efforts of the crew in fighting the fire and to safely moor the ship.

2.5.4 Emergency power supply testing

Finnmaster's SMS identified the emergency generator and emergency switchboard as *critical equipment* necessary for the safe operation of the ship that required routine testing to ensure their reliability. The weekly EDG off-load tests, the frequency of which exceeded that set out in the PMS, provided assurance that the engine driving the emergency generator was operational and that the EDG was able to produce the required frequency and voltage.

Finnmaster's EDG circuit breaker would only have operated when the emergency generator was put on load, supplying the emergency switchboard. With a 6-monthly periodicity under Finnlines management, it is possible that the circuit breaker had only operated less than 25 times in the preceding 5 years, with possibly as few as 100 operations in total since it was installed. The opportunity for any defect to the EDG circuit breaker to become apparent was limited.

Classification society surveys provided assurance that the vessel complied with the standards required for the issue and maintenance of the relevant certificates. The tests conducted during the surveys confirmed that *at the time of the survey* the ship's equipment and systems met those requirements. As such, the surveys only formed part of the overall scheme of assurance.

The EDG testing regime on board *Finnmaster* did not identify the latent defect with the EDG circuit breaker and promote the reliability of the system to ensure it was operational during emergency situations.

2.5.5 Emergency sources of power testing requirements

The ISM code required specific measures aimed at promoting the reliability of safety-critical equipment, noting that the measures should include the regular testing of standby arrangements and equipment that is not in continuous use. The 2017 SIAF safety study report highlighted these requirements, identifying that the fast-ageing of automation systems was a problem and that tests were intended to detect deficiencies.

In the year before the fire on *Finnmaster*, the failure of an emergency source of power was a factor in almost 10% of detentions in the Paris MOU region, raising the concern that onboard testing procedures were not identifying faults in emergency power systems.

None of the relevant statutory requirements set out a schedule for the testing of emergency sources of power. SOLAS Chapter II-2 required the provision of a means to test the emergency source of power but was silent on the expectations for doing so. Though SOLAS Chapter V included the need for a 3-monthly test of alternative power supplies while testing the emergency steering system, it was not explicit in the requirement to test the full extent of the emergency power supply including the EDG. The IMO produced no guidance on the expectations for testing EDGs to clarify the extent of the test anticipated by SOLAS, and TRAFICOM did not produce any national guidance similar to that of MGN 52 (M+F).

With no guidance from the IMO or TRAFICOM, *Finnmaster*'s emergency power supply was only tested once between annual surveys, which was insufficient to identify the latent defects in the EDG circuit breaker.

2.5.6 Fire party communication equipment standards

The loss of power supply to *Finnmaster*'s UHF repeater unit significantly compromised the ability of the master to monitor or exercise control over the activities of the crew during the emergency.

With no functional standards to apply for the handheld radios carried on board to meet the requirement for two-way communication, surveys were limited to noting the presence and operation of the UHF radio units but did not consider their effectiveness in emergency situations. Consequently, the implications of the loss of power to a UHF radio repeater unit were not identified at survey.

The SOLAS requirements were not supported by guidance setting out the performance expectations of the equipment to ensure it was able to function during emergency situations.

2.6 EMERGENCY PROCEDURES

2.6.1 Safety management system

The contents of the emergency procedures for responding to fires contained in *Finnmaster*'s SMS and training manual met the requirements of the flag state administration. The muster list set out the response required from the crew on hearing the fire alarm sound. The procedures described the actions to be taken in the event of a fire in the machinery space and the procedure for the release of CO_2 to extinguish it. Fires drills were undertaken as part of the routine operation of the ship. However, in the 11 months before the fire a video shown to the crew was the only content specific to a machinery space fire, and only one of the senior officers on board at the time of the fire had been on *Finnmaster* when the video was shown.

2.6.2 Command and control

When the fire started in the AER the master and 2/O were already at their assigned muster station on the bridge. The remainder of the crew were either off duty or at their assigned stations for the departure from Hull.

No formal muster was carried out to ensure everyone, including the single passenger was accounted for; however, given that the muster list did not include all of the crew, some might anyway have been unaccounted for.

The master was aware of the location of the initial smoke detection in the AER, confirmed by the C/E, but was likely focused on the safe navigation of the vessel in collaboration with the pilot. The master was unaware of the efforts being made to extinguish the fire and the risk of key crew members becoming casualties. The decision to release CO_2 into the engine room was made without verifying that the space had been evacuated, posing a potential risk of asphyxiation to anyone who might have been inside.

2.6.3 Communication

The crew were accustomed to being able to coordinate an effective emergency response using the internal UHF radio system and the loss of the UHF radio repeater proved a significant barrier to this. The communications breakdown between the main parties substantially affected their understanding of the situation and the management of their response to it. Decisions were made and actions taken without a full understanding of the circumstances, placing crew members at risk.

The crew's methods to mitigate for the loss of the UHF repeater, the use of runners to pass messages, and the distribution of the handheld VHF radios showed recognition of the equipment available and provided a means of restoring a proportion of the communications necessary to deal with the emergency.

2.6.4 Carbon dioxide system activation

Any entry by crew into the AER once the fire was established would have placed them at significant risk. The use of the CO_2 system provided the safest and potentially most effective means of fighting the fire on board *Finnmaster*.

When the CO_2 system was activated the crew had not been fully accounted for. Further, the manual machinery space fire dampers had not been closed and the remotely operated fuel valves had not been shut so it was likely that the fire in the AER continued to be supplied with oxygen and fuel.

When the 2/E checked the CO_2 system had operated correctly, the ventilation fans in the CO_2 room had stopped due to the loss of power. The pilot system of the CO_2 system on *Finnmaster* contained leaks, and a quantity of CO_2 had discharged into the compartment during the system activation. Consequently, the 2/E risked being overcome by the atmosphere in the compartment. Further, as the 2/E was working in isolation there was a risk of their absence going unnoticed for a significant period of time. The entry was carried out without recognition of the risk posed by the possibility of CO_2 leakage into the space when the system was activated.

The manual release of CO_2 cylinders was not initiated when it became known that the CO_2 system had only partially operated. Consequently, the opportunity to inject the correct amount of CO_2 was missed and the operation of the system did not extinguish the fire. The *Arco Avon* report highlighted the benefits of operating CO_2 system cylinders manually when necessary to ensure the correct quantity of gas is injected when a system fails to operate as intended.

The senior engineers had undergone advanced firefighting training and were familiar with the operation of the CO_2 system and the precautions to take to ensure it was done safely. Further, *Finnmaster*'s training manual provided explicit guidance on the need to ensure all personnel had left the area and to close the space down to prevent the ingress of air.

Despite an understanding of the procedure for the release of CO_2, it is likely that speed of response, compounded by the limited communication between the teams, was prioritised over aspects of the activation process. In this instance, a trade-off was made between the thoroughness of the structured procedure for the system activation against the time it would have taken to complete all the necessary stages.

The crew response on board *Finnmaster* was similar to that of the senior officers on board *The Calypso*, whose actions also deviated from the onboard procedures and good practice. This led to a risk that the response might have been ineffective, and placed people at risk. The report highlighted the importance of drills, practical exercises and crew taking the required actions following the activation of CO_2 systems.

With the desire to act quickly to extinguish the fire, the procedure used for the activation of the high-pressure CO_2 system departed from established practice and risked being both hazardous to crew and enabling an escalation of the fire.

2.6.5 Crew firefighting response

At the onset of the emergency, two attempts were made to fight the fire using portable fire extinguishers. The first, using a 6kg CO_2 extinguisher, was made when both AEs and the engine room supply fans were still running. In these circumstances, it was very unlikely that the extinguishing effect of the limited amount of CO_2 would have been successful. The lack of a cooling effect from a CO_2 extinguisher, the flow of air into the space, and that being drawn into the adjacent turbochargers almost certainly dispersed the gas to an extent that made it ineffective as a means to extinguish the fire. The second attempt was made by the C/E, who entered the AER with a dry powder extinguisher and without wearing CABA. This entry placed the C/E at significant risk and was unlikely to have been successful given the extent of the fire. The use of a dry powder extinguisher would neither provide cooling effect nor the protection of a charged fired hose.

After CO_2 was injected into *Finnmaster*'s engine room the situation stabilised and there was a pause in the emergency response while the ship was brought alongside the berth. This provided an opportunity to assess the effectiveness of the initial firefighting response and determine the next course of action. With the focus switching from immediate response to system restoration, no decision was made to consolidate the CO_2 procedures and secure the engine room openings, isolate the fuel supply, or inject additional CO_2 to the space to achieve the desired concentration.

Finnmaster's training manual advised that, once CO_2 had been injected into a compartment, the area must be allowed to cool before any doors were opened to prevent oxygen being admitted to the affected space and reigniting the fire. A two-person fire team wearing CABA entered the AER 19 minutes after the CO_2 injection. It is unlikely that this period of time would have been sufficient for all the material in the space to have cooled enough to prevent reignition. The decision to enter the AER so soon after the CO_2 was injected was probably based on the belief that the fire had been extinguished and a desire to confirm that this was the case. The risk posed due to the possibility of reignition of the fire, and the limited protection for the fire party members making the entry, likely outweighed any benefit.

It is apparent that, although well-intentioned, *Finnmaster*'s crew response to the fire did not follow the guidance in the training manual and therefore increased the risk of casualties and the possibility of reignition.

2.6.6 Crew emergency training

At the time of the fire all of *Finnmaster*'s senior officers except the master had participated in most of the recent drills conducted on board. Three of these drills contained elements relevant to the fire, including the use of local CO_2 systems[97]; the closure of fire dampers; and the use of CABA.

With the exception of the engine room ventilation exhaust fire dampers at the rear of the funnel, the crew had a good knowledge of the firefighting systems, their operation and the procedures for their use. However, the following risks had not been identified during drills:

- The UHF repeater unit was always supplied with power and able to support communication throughout the ship. The effect of a power failure on the system and its consequential impact on the crew's ability to communicate during an emergency had not been identified as a risk.

- The shortcomings in the muster list instructions led to the possibility that missing crew members might be overlooked, and that key tasks might not be undertaken in an emergency.

Exercises embed common practice between team members and mitigate the risk of skills diminishing over time. They also assist in the development of strategies to deal with emergencies on board and enable the evaluation of decisions made when managing complex fire scenarios in a training environment.

In the 11 months before the fire, the drills on *Finnmaster* included a single exercise related to an engine room fire: the presentation of a video on engine room fire hazards. The introduction to this video noted that the engine room was a high fire risk area, but training for such a fire was limited in the ship's drills schedule.

Exercises in the use of the local CO_2 systems had been carried out and the need to close fire dampers for the use of these systems was recognised and included. The frequency of fire exercises completed on board *Finnmaster* met the regulatory requirements.

None of the emergency training reports completed on board indicated anything other than satisfactory drills being conducted. It is likely that the conduct of the drills did not test the limits of the organisation as a means of assessing opportunities for improvement. It is therefore unlikely that the exercises completed on board *Finnmaster* met the intent of SOLAS that exercises *as far as practicable, be conducted as if there were an actual emergency*.

There was a marked contrast between the conduct of the response to the fire on *Finnmaster* and that on *Oscar Wilde*. While the scale of the impact of the breakdown in UHF communication differed, the ability of realistic crew drills to influence the outcome of an emergency on board was clear. Similarly, the report on the fire on board *Pride of Canterbury* provided an example of how an effectively trained and motivated crew were able to respond to an emergency they had not specifically practised dealing with.

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[97] The ship's local CO_2 systems were separate from the main installation used to fight the fire in the AER and the procedures for their operation differed.

It is probable that the crew's response to the fire on *Finnmaster* relied more on the senior officers' experience and knowledge derived from their professional training rather than the drills conducted on board. It is also likely that the training schedule for exercises carried out on *Finnmaster* did not provide regular practice in fighting engine room fires that reflected the high level of risk posed.

2.6.7 Summary

The crew of *Finnmaster* were faced with an engine room fire scenario for which they had received very limited training. Further, their response to the emergency was hindered by the failure of critical systems that should have supported their efforts. It is apparent that some of the actions taken placed some crew members and the ship at risk, and that emergency drills had not been wholly effective in preparing the crew to respond to the emergency.

2.7 FIRE EXTINCTION

The volume of CO_2 injected into the engine room was insufficient to reduce the oxygen content of the atmosphere to a level that would extinguish the fire. The combustion was further supported as air was able to enter the machinery spaces through the open fire dampers.

The measurements of the level of MGO in the service tank and the height of the failed flexible fuel hose where it passed over the top of the flywheel cover of AE2 indicated that there was a height difference of 50cm. When *Finnmaster* lost power, the fuel feed pump supplying the two AEs stopped. The remote closing valve on the outlet from the service tank remained open. The route from the service tank to the point of leakage was restricted by the system components and the small diameter of the pipework.

It is almost certain that the pressure in the flexible hose, due only to the head of MGO from the service tank and the restrictions in the system, reduced the flow of MGO from the failed flexible hose, lessening the extent of the fire. When the fire team entered the AER the fire had diminished to a point it could be extinguished using a portable fire extinguisher.

The principal reason that the fire was able to be extinguished was the loss of power to the fuel feed pump and the consequential reduction in the flow of fuel to the fire.

SECTION 3 – CONCLUSIONS

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

1. Historic AE fuel injection pump coupling faults were not addressed, and were not reported to the company. This prevented concerns being raised with the OEM to enable it to consider further design or procedural amendments to reduce the risk of failure. [2.3.1]

2. The incorrect maintenance procedure to AE2's exhaust allowed high temperature exhaust gas to leak into the insulated box structure, below which the flexible fuel hose was positioned. [2.3.2]

3. The monitoring, approval and assurance of work carried out during the major overhaul of AE2 was ineffective and this put the safe operation of *Finnmaster* at risk [2.3.3]

4. The original modification to the AE's alarm and monitoring systems did not meet the requirements set out in SOLAS Chapter II-2 or the classification society rules, was unapproved, and exposed the flexible hoses to elevated temperatures, increasing the risk of failure and the potential for a fire. [2.3.4]

5. Throughout the period that the flexible fuel hoses were in place on *Finnmaster*'s AEs, none of the inspections or surveys conducted by classification surveyors and the ships engineers identified the noncompliance or potential risk from such an installation. [2.3.6, 2.3.7]

6. The surveys and examinations conducted by C/Es under delegation from the classification societies through the life of the vessel were not effectively managed, supported or controlled by the operating companies or classification societies. [2.3.7]

7. The flag state administration and ship's classification society did not effectively disseminate or apply the critical safety information in IMO Circular MSC.1/Circ.1321 on the prevention of fires in machinery spaces. [2.3.8]

3.2 SAFETY ISSUES NOT DIRECTLY CONTRIBUTING TO THE ACCIDENT THAT HAVE BEEN ADDRESSED OR RESULTED IN RECOMMENDATIONS

1. *Finnmaster*'s CO_2 system failed to operate as designed due to a combination of leaks and a blocked flexible hose assembly installed in the pilot system. As a result, the amount of CO_2 discharged to the engine room was insufficient to extinguish the fire in the AER. [2.4.1]

2. The defects in the CO_2 system meant that it was unlikely that a fire in either of the cargo holds on *Finnmaster* would have been extinguished by the automatic activation of the CO_2 system. [2.4.1]

3. The oversight of the manufacture and supply of the flexible hose assemblies was ineffective resulting in defective flexible hose assemblies entering the supply chain and being installed in *Finnmaster*'s CO_2 system, making the system non-operational and placing the ship at risk. [2.4.2]

4. It is very likely the system test completed as part of the service of the CO_2 system carried out in March 2021 did not follow the system manual procedure and consequently failed to identify the faults, placing the ship at risk. [2.4.2]

5. The IMO guidance in MSC.1/Circ.1318 for the servicing of CO_2 systems allowed for a test procedure that did not explicitly prove that the activation system was fully operational on completion of maintenance. [2.4.2]

6. The flag state administration did not set out its criteria for the acceptance of standards for the training of service technicians undertaking servicing of fire-extinguishing systems as required by the IMO. [2.4.2]

7. The content and application of the IACS UR-Z17 procedure continues not to deliver the required level of service by approved service suppliers necessary to maintain the safety of CO_2 fixed fire-extinguishing systems on board ships. [2.4.2]

8. The loss of all power on board *Finnmaster* caused a consequential loss of critical safety equipment required to support the efforts of the crew in fighting the fire and safely moor the vessel. [2.5.3]

9. The testing regime of the EDG on board *Finnmaster* did not identify the latent defect with the EDG circuit breaker nor promote the reliability of the system to ensure it was able to supply power to the emergency switchboard during emergency situations. [2.5.4]

10. SOLAS Chapter II-1, regulation 43.7 required only the provision of a facility to periodically test the emergency generator on load. The frequency of such tests was not defined in the convention. No guidance was provided by the IMO or the flag state administration on the expectations for the conduct of such tests. [2.5.5]

11. The two two-way portable radiotelephone apparatus required by SOLAS Chapter II-2 for firefighters' communication were not supported by functional requirements that would ensure their operation in an emergency. [2.5.6]

12. Some elements of the on board emergency response placed crew members and the ship at risk, and the emergency drills had not been wholly effective in preparing the crew to respond to the emergency. [2.6.7]

SECTION 4 – ACTION TAKEN

4.1 MAIB ACTIONS

The **MAIB** has:

- Issued MAIB Safety Bulletin 1/2022 **(Annex K)**, highlighting the potential for manufacturing defects existing within flexible hose assemblies installed in the pilot systems of CO_2 systems.

- Issued MAIB Safety Bulletin 1/2023 **(Annex L)**, highlighting potential fire hazards from flexible hose installations.

4.2 ACTIONS TAKEN BY OTHER ORGANISATIONS

In response to the two recommendations made to it in MAIB Safety Bulletin SB1/2022, **Geeve Hydraulics B.V.** has:

- Provided a copy of MAIB Safety Bulletin SB1/2022 to all customers supplied with flexible hose assemblies fitted with couplings supplied by HSR Hydraulics BV that did not meet the required type approval requirements, drawing attention to the safety issues raised and the need for immediate action to identify and rectify any defects found in safety critical systems[98].

- Amended its purchasing, production and quality control procedures, presenting them to DNV for recertification to ensure that flexible hose assembly components are procured, and flexible hose assemblies are manufactured in line with the relevant type approval requirements[99].

Viking Life-Saving Equipment B.V., Netherlands has:

- Issued a group-wide safety bulletin to its marine fire service providers to highlight the initial findings in the CO_2 system on board *Finnmaster*.

- Revised the group-wide test procedure contained in its management system to incorporate:

    - a function test of all cylinder discharge valves;

    - a leak test of the pilot system incorporating a manometer installed at the furthest point in the system from the location of the applied pressure; and

    - a requirement for service stations in the group to check flexible hose assemblies for blockage on receipt from third party suppliers.

Finnlines PLC has:

- Updated its supplier audit process to include people with knowledge of specific areas in the auditing of service suppliers and the review of inspection reports.

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[98] MAIB recommendation S2022/105.

[99] MAIB recommendation S2022/106.

- Arranged for Viking Life-Saving Equipment Oy Finland to inspect and test all fixed CO_2 systems in the Finnlines fleet and confirmed that these were in good condition and working as designed.

- Issued two fleet circulars requiring:

    - an inspection of the high-pressure CO_2 system's remote and manual release systems on all vessel in the Finnlines fleet.

    - confirmation that the instructions for manual release of the CO_2 systems are correct on all vessels in the Finnlines fleet.

    - the conduct of a risk assessment on preparations for entering the CO_2 room in an emergency.

    - the conduct of a drill on the procedure for manual release of CO_2 cylinders.

    - that any service by an external service company be reported to the respective ship superintendent and safety manager in advance and, if conducted, for it to be closely monitored by a competent crew member.

    - the completion of a risk assessment for the conduct of tests carried out on the CO_2 system.

    - The inclusion of procedures for checking the release status of the CO_2 system in a safe way and for manually releasing CO_2 cylinders in the fire drill scenario framework on board the ships in the Finnlines fleet.

    - confirmation that fire drills conducted on the ships in the Finnlines fleet include training in operating quick-closing valves, fire dampers and emergency communication systems.

- Installed a UPS for the UHF repeater system on *Finnmaster* to ensure its availability in the event of a loss of power from the emergency power supply to the system.

- Provided training to the crew on the configuration and use of the UHF radio system.

- Replaced the EDG circuit breaker and motor module and demonstrated its operation to the satisfaction of a RINA surveyor.

Mitsubishi Turbocharger and Engine Europe B.V. has:

- Updated its service instructions for the S12R series of engines to incorporate cautionary notes on the assembly of the fuel injection pump couplings to reduce the likelihood of coupling slippage.

- Updated its training curriculum for its service partners on the SR series of engines, to incorporate specific training on the risk of fuel injection pump slippage and the procedure for disassembly, inspection and assembly of the fuel injection pump couplings.

- Implemented a procedure for the evaluation of service personnel undertaking maintenance of Mitsubishi engines.

Det Norske Veritas Group AS has:

Completed an additional audit of Geeve Hydraulics B.V. and reinstated the certificate of manufacturer held by the company.

The **Maritime and Coastguard Agency** has:

Issued a safety bulletin[100], referencing that of the MAIB, advising owners of the need for the testing of CO_2 systems in a manner to ensure that the system remains fully functional on the completion of maintenance work on the system. It also reinforced the need for crew to be fully familiar with the manual operation of CO_2 systems.

[100] https://www.gov.uk/government/publications/safety-bulletin-26-co2-fire-suppression-installation-testing/safety-bulletin-26-co2-fire-suppression-installation-testing

SECTION 5 – RECOMMENDATIONS

The **Finnish Transport and Communications Agency** is recommended to:

2025/132 In consultation with the UK's Maritime Administration, draft and submit to the appropriate International Maritime Organization sub-committee a paper proposing the production of a circular providing guidance on the conduct and frequency of routine testing of on board emergency power supplies.

2025/133 In consultation with the UK's Maritime Administration, draft and submit to the appropriate International Maritime Organization sub-committee a paper proposing functional requirements for systems supporting the operation of the two-way portable radiotelephone apparatus required by SOLAS Chapter II-2 Regulation 10.4.

2025/134 In consultation with the UK's Maritime Administration, propose an amendment to International Maritime Organization Circular MSC.1/Circ.1318 Revision 1 to include procedural requirements to verify that a fixed fire-extinguishing system is fully operational on completion of the servicing activity required by section 6.2.1 of the circular.

2025/135 Define its requirements for the acceptance of the training of service technicians for CO_2 fixed fire-extinguishing systems in line with section 6.2 of International Maritime Organization Circular MSC.1/Circ.1318 Revision 1.

2025/136 Disseminate the contents of International Maritime Organization Circular MSC.1/Circ.1321 to the Finnish maritime industry to raise awareness of guidance on the prevention of fires in machinery spaces.

Finnlines Plc is recommended to:

2025/137 Provide guidance to its fleet on the identification and reporting of machinery failure trends in order to recognise and address recurring issues in equipment.

2025/138 Update the ship familiarisation and training programmes within its safety management system to encompass all equipment critical to the emergency response procedures and provide a framework for the conduct of realistic drills to ensure crew can react effectively to emergency situations.

2025/139 Ensure that the muster lists used on its ships accurately reflect the response procedures in use on board and that all crew members are included.

RINA S.p.A is recommended to:

2025/140 Propose guidance to the International Association of Classification Societies to improve the acceptance, training and guidance for chief engineers authorised to conduct classification-related surveys and inspections.

2025/141 Provide guidance to its surveyors, restating the requirement for the examination of type approval certificates where surveys of safety critical equipment are carried out.

2025/142 Disseminate the contents of International Maritime Organization Circular MSC.1/Circ.1321 and related rule requirements to its surveyors to raise awareness of guidance on the prevention of fires in machinery spaces.

2025/143 Noting that the response to previous recommendations has been ineffective in improving the performance of service suppliers conducting servicing of CO_2 systems under the provisions of Unified Requirement Z17 – *Procedural requirements for service suppliers*. Propose to the International Association of Classification Societies that an urgent review and revision of UR-Z17 is undertaken to deliver the necessary improvements in the services provided by such suppliers.

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

Annex A

United States Coast Guard Marine Safety Alert 06-17

UNITED STATES COAST GUARD
U.S. Department of Homeland Security

MARINE SAFETY ALERT

Inspections and Compliance Directorate

June 6, 2017
Washington, DC

Safety Alert 06-17

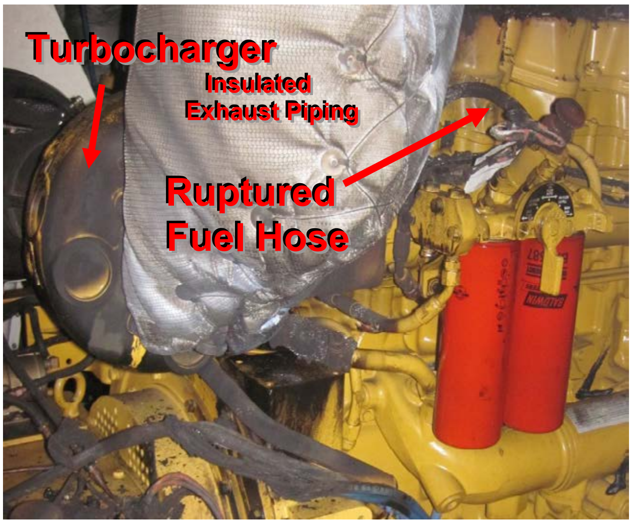
Fuel Spray Fire - Déjà Vu

Prepare and Prevent it from Happening to You!

This safety alert addresses yet another fuel spray fire onboard a commercial vessel. These types of incidents, involving fuel leakages contacting hot surfaces and igniting, happen too frequently and have been a focus of various marine safety organizations such as the IMO for many years. One recent marine casualty involved a 194 GRT inspected offshore supply vessel with an unmanned engine room. This engine room fire led to significant damage, operational down time of the vessel and lost company revenues. Fortunately, no one was injured during this event.

Investigators learned that the master received a main engine low fuel pressure alarm on the bridge which was then investigated by the crew. The crew member on watch entered the engine room and identified a high pressure fuel leak spraying over and upon the port engine's turbocharger. He also reported a large quantity of diesel fuel in the bilge. The master then went down into the engine room and witnessed the ignition of the fire. Using a hand held portable fire extinguisher he quickly attempted to extinguish the fire without success. The master activated the general alarm, secured the hatches, had crew members secure the ventilation dampers and closed the remote fuel shut-off valves to the engine room. The fire then quickly self extinguished.

During the post-casualty inspection of the engine room, the source of the fuel leak was identified to be a rupture on a flexible fuel hose connected to the fuel filter assembly. Additionally, it was noted that the fuel filter assembly and its components were installed in relatively close proximity to the turbocharger on the inboard side of the engine. Although components of the turbochargers may be insulated, temperatures on some surfaces typically exceed the fuel's ignition point. In this instance, the heat radiating from the turbo charger components was very high and likely led to the degradation of the flexible rubberized hoses nearby. However, the installation was confirmed to be in accordance with an accepted location on the manufacturer's marine engine manual.



Following the casualty, the owner/operator of the vessel enacted fleet-wide changes and relocated the fuel filter assemblies away from the turbochargers on the outboard side of the engines in the vicinity of the fuel pumps.

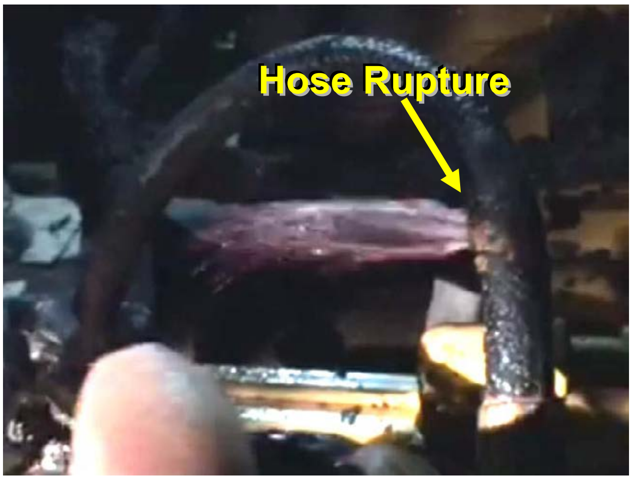
Image courtesy of United States Coast Guard

The U.S. Coast Guard **strongly recommends** vessel owners and operators to regularly:

- Avoid an "out of sight, out of mind mentality." Unmanned machinery spaces should be inspected at least daily, but preferably several times per day. Those who perform such activities should develop an eye for detail by tracing out and inspecting all equipment, systems, and components. Such spaces should be well lit as good lighting will benefit mindsets of those within the spaces and enhance the ability to detect anomalies.

- Inspect fuel and lubricating systems closely from source tanks to system end points. Think about system vulnerabilities, loose or missing pipe clamps and securing devices, wear or chaffing due to vibration impacting hoses, and piping or tubing which may be insufficiently secured. Make sure plastic piping is not close to hot spots. Examine fuel supply pumps, noting shaft sealing for leakages and bearings when fitted, for overheating and indications of wear. Pay similar attention to the pumps and motors associated with other systems.

- Regarding hot spots; examine all heat sources particularly with respect to engine exhausts. Look closely at areas where exhaust piping may exit the space and proceed through other spaces. Numerous fires onboard vessels have occurred in these areas. Ensure all insulation, blankets, and lagging are maintained and kept tight. Look for areas where released fluids may make contact. Check that spray shielding is kept in place where used and consider adding such shielding around gasketed flanges and other areas if helpful.



- Minimize the use of nonmetallic flexible hoses in systems carrying flammable liquids particularly around engine areas where failures leading to leakage or spray may find hot spots capable of igniting the fluids. Consult with engine representatives if modifications are needed to minimize the risk of fuel spray fires.

- In this instance the installed engines and components were about three years old. It may be beneficial for vessel owners to consult with engine manufacturer representatives to determine if a replacement schedule is necessary taking into account hose exposure to heat sources, vibration, and other factors that may degrade the hose strength internally or externally.

This safety alert is provided for informational purpose only and does not relieve any domestic or international safety, operational, or material requirements. Developed by Marine Safety Unit Morgan City and distributed by the Office of Investigations and Casualty Analysis. Questions or comments may be sent to HQS-PF-fldr-CG-INV@uscg.mil. Similar alerts are available at the following links:

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IMO Circular MSC.1/Circ.1318 – Guidelines for the Maintenance and Inspections of Fixed Carbon Dioxide Fire-extinguishing Systems

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Ref: T4/4.01

MSC.1/Circ.1318
11 June 2009

GUIDELINES FOR THE MAINTENANCE AND INSPECTIONS OF FIXED CARBON DIOXIDE FIRE-EXTINGUISHING SYSTEMS

1 The Committee, at its eighty-sixth session (27 May to 5 June 2009), having considered the proposal by the Sub-Committee on Fire Protection, at its fifty-third session, approved Guidelines for the maintenance and inspections of fixed carbon dioxide fire-extinguishing systems, as set out in the annex.

2 Member Governments are invited to apply the annexed Guidelines when inspecting fixed carbon dioxide fire-extinguishing systems on board all ships and bring them to the attention of ship designers, shipowners, equipment manufacturers, and other parties concerned.

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ANNEX

GUIDELINES FOR THE MAINTENANCE AND INSPECTIONS OF FIXED CARBON DIOXIDE FIRE-EXTINGUISHING SYSTEMS

1 General

These Guidelines provide the minimum recommended level of maintenance and inspections for fixed carbon dioxide fire-extinguishing systems on all ships, and are intended to demonstrate that the system is kept in good working order as specified in SOLAS regulation II-2/14.2.1.2. These Guidelines are intended to supplement the fire-extinguishing system manufacturer's approved maintenance instructions. Certain maintenance procedures and inspections may be performed by competent crewmembers, while others should be performed by persons specially trained in the maintenance of such systems. The onboard maintenance plan should indicate which parts of the recommended inspections and maintenance should be completed by trained personnel.

2 Safety

Whenever carbon dioxide fire-extinguishing systems are subjected to inspection or maintenance, strict safety precautions should be followed to prevent the possibility that individuals performing or witnessing the activities are placed at risk. Prior to performing any work, a safety plan should be developed to account for all personnel and establish an effective communications system between the inspection personnel and the on-duty crew. Measures to avoid accidental discharges such as locking or removing the operating arms from directional valves, or shutting and locking the system block valve should be taken as the initial procedure for the protection of personnel performing any maintenance or inspections. All personnel should be notified of the impending activities before work is begun.

3 Maintenance and inspection plan

Fixed carbon dioxide fire-extinguishing systems should be kept in good working order and readily available for immediate use. Maintenance and inspections should be carried out in accordance with the ship's maintenance plan having due regard to ensuring the reliability of the system. The onboard maintenance plan should be included in the ship's safety management system and should be based on the system manufacturer's recommendations including:

.1 maintenance and inspection procedures and instructions;

.2 required schedules for periodic maintenance and inspections;

.3 listing of recommended spare parts; and

.4 records of inspections and maintenance, including corrective actions taken to maintain the system in operable condition.

4 Monthly inspections

4.1 At least every 30 days a general visual inspection should be made of the overall system condition for obvious signs of damage, and should include verification that:

.1 all stop valves are in the closed position;

.2 all releasing controls are in the proper position and readily accessible for immediate use;

.3 all discharge piping and pneumatic tubing is intact and has not been damaged;

.4 all high pressure cylinders are in place and properly secured; and

.5 the alarm devices are in place and do not appear damaged.

4.2 In addition, on low pressure systems the inspections should verify that:

.1 the pressure gauge is reading in the normal range;

.2 the liquid level indicator is reading within the proper level;

.3 the manually operated storage tank main service valve is secured in the open position; and

.4 the vapour supply line valve is secured in the open position.

5 Annual inspections

The following minimum level of maintenance and inspections should be carried out in accordance with the system manufacturer's instructions and safety precautions:

.1 the boundaries of the protected space should be visually inspected to confirm that no modifications have been made to the enclosure that have created uncloseable openings that would render the system ineffective;

.2 all storage containers should be visually inspected for any signs of damage, rust or loose mounting hardware. Cylinders that are leaking, corroded, dented or bulging should be hydrostatically retested or replaced;

.3 system piping should be visually inspected to check for damage, loose supports and corrosion. Nozzles should be inspected to ensure they have not been obstructed by the storage of spare parts or a new installation of structure or machinery;

.4 the manifold should be inspected to verify that all flexible discharge hoses and fittings are properly tightened; and

.5 all entrance doors to the protected space should close properly and should have warning signs, which indicate that the space is protected by a fixed carbon dioxide system and that personnel should evacuate immediately if the alarms sound. All remote releasing controls should be checked for clear operating instructions and indication as to the space served.

6 Minimum recommended maintenance

6.1 At least biennially (intervals of 2 years ± 3 months) in passenger ships or at each intermediate, periodical or renewal survey* in cargo ships, the following maintenance should be carried out (to assist in carrying out the recommended maintenance, examples of service charts are set out in the appendix):

.1 all high pressure cylinders and pilot cylinders should be weighed or have their contents verified by other reliable means to confirm that the available charge in each is above 90% of the nominal charge. Cylinders containing less than 90% of the nominal charge should be refilled. The liquid level of low pressure storage tanks should be checked to verify that the required amount of carbon dioxide to protect the largest hazard is available;

.2 the hydrostatic test date of all storage containers should be checked. High pressure cylinders should be subjected to periodical tests at intervals not exceeding 10 years. At the 10-year inspection, at least 10% of the total number provided should be subjected to an internal inspection and hydrostatic test**. If one or more cylinders fail, a total of 50% of the onboard cylinders should be tested. If further cylinders fail, all cylinders should be tested. Flexible hoses should be replaced at the intervals recommended by the manufacturer and not exceeding every 10 years; and

.3 the discharge piping and nozzles should be tested to verify that they are not blocked. The test should be performed by isolating the discharge piping from the system and flowing dry air or nitrogen from test cylinders or suitable means through the piping.

6.2 At least biennially (intervals of 2 years ± 3 months) in passenger ships or at each renewal survey* in cargo ships, the following maintenance should be carried out by service technicians/specialists trained to standards accepted by the Administration:

.1 where possible, all activating heads should be removed from the cylinder valves and tested for correct functioning by applying full working pressure through the pilot lines.

In cases where this is not possible, pilot lines should be disconnected from the cylinder valves and blanked off or connected together and tested with full working pressure from the release station and checked for leakage.

In both cases this should be carried out from one or more release stations when installed.

* Refer to Survey guidelines under the Harmonized System of Survey and Certification, 2007 (resolution A.997(25)).

** Refer to standard ISO 6406 – Periodic inspection and testing of seamless steel gas cylinders.

If manual pull cables operate the remote release controls, they should be checked to verify the cables and corner pulleys are in good condition and freely move and do not require an excessive amount of travel to activate the system;

.2 all cable components should be cleaned and adjusted as necessary, and the cable connectors should be properly tightened. If the remote release controls are operated by pneumatic pressure, the tubing should be checked for leakage, and the proper charge of the remote releasing station pilot gas cylinders should be verified. All controls and warning devices should function normally, and the time delay, if fitted should prevent the discharge of gas for the required time period; and

.3 after completion of the work, the system should be returned to service. All releasing controls should be verified in the proper position and connected to the correct control valves. All pressure switch interlocks should be reset and returned to service. All stop valves should be in the closed position.

APPENDIX

EXAMPLE SERVICE CHARTS

HIGH PRESSURE CO_2 SYSTEM

Date:	Name of ship/unit:	IMO No.:	

Technical description

No.	Text	Value
1	Manufacturer	
2	Number of main cylinders	
3	Main cylinders capacity (each)	
4	Number of pilot cylinders	
5	Pilot cylinder capacity (each)	
6	Number of distribution lines	
7	Oldest cylinder pressure test date	
8	Protected space(s)	
9	Date flexible hoses fitted/renewed	

Description of inspection/Tests

No.	Description	Carried out	Not carried out	Not applicable	Comment
1	Release controls and distribution valves secured to prevent accidental discharge				
2	Contents in main cylinders checked by weighing				
3	Contents in main cylinders checked by liquid level indicator				
4	Contents of pilot cylinders checked				
5	All cylinder valves visually inspected				
6	All cylinder clamps and connections checked for tightness				
7	Manifold visually inspected				
8	Manifold tested for leakage, by applying dry working air				
9	Main valve and distribution valves visually inspected				
10	Main valve and distribution valves tested for operation				
11	Time delay devices tested for correct setting*				
12	Remote release system visually inspected				
13	Remote release system tested				
14	Servo tubing/pilot lines pressure tested at maximum working pressure and checked for leakages and blockage				
15	Manual pull cables, pulleys, gang releases tested, serviced and tightened/adjusted as necessary				
16	Release stations visually inspected				
17	Warning alarms (audible/visual) tested				
18	Fan stop tested*				
19	10% of cylinders and pilot cylinder/s pressure tested every 10 years				
20	Distribution lines and nozzles blown through, by applying dry working air				
21	All doors, hinges and locks inspected*				
22	All instruction and warning signs on installation inspected				
23	All flexible hoses renewed and check valves in manifold visually inspected every 10 years				
24	Release controls and distribution valves reconnected and system put back in service				
25	Inspection date tags attached				

* If fitted as part of the CO_2 system.

LOW PRESSURE CO_2 SYSTEM

Date:	Name of ship/unit:	IMO No.:	

Technical description

No.	Text	Value
1	Manufacturer	
2	No. of tanks	
3	Tanks capacity (tonnes)	
4	Number of pilot cylinders	
5	Pilot cylinder capacity (each)	
6	Number of distribution lines	
7	Protected space(s)	

Description of inspection/Tests

No.	Description	Carried out	Not carried out	Not applicable	Comment
1	Tank main service valve closed and secured to prevent accidental discharge				
2	Distribution valves verified closed				
3	Check correct function of level indicator				
4	Contents of CO_2 tank checked by tank level indicator				
5	Contents of CO_2 tank checked by riser tube reading				
6	Contents of CO_2 tank checked by level control valve				
7	Supports of tank inspected				
8	Insulation on tank inspected				
9	Safety valves of tank inspected				
10	Safety valves of tank tested				
11	Contents of pilot cylinders checked				
12	Start/stop function of cooling compressors tested				
13	All connected electrical alarms and indicators tested				
14	Main manifold valve inspected				
15	Main manifold valve tested				
16	Distribution valves inspected				
17	Distribution valves tested				
18	Release stations inspected				
19	Total flooding release mechanism inspected				
20	Total flooding release mechanism tested				
21	Time delay devices tested for correct setting*				
22	Warning alarms tested				
23	Fan stop tested*				
24	Distribution lines and nozzles inspected				
25	Distribution lines and nozzles tested				
26	Distribution lines and nozzles blown through				
27	All doors, hinges and locks inspected*				
28	All instruction plates inspected				
29	Tank main service valve reopened and secured open				
30	System put back in service				
31	Inspection date tags attached				

* If fitted as part of the CO_2 system.

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Geeve Hydraulics B.V. flexible hose assembly test certificate – July 2020

Test Certificate for Hose Assemblies

Certificate No.: GL-30019199

General Data

Geeve Hydraulics B.V.
Manufacturer

30019199
Works Order No.

VIKING LIFE SAVING EQUIPMENT B.V.
Ordered by

4500919656
Order No.

Item No.	No. Of	Hose standard	Type	Type Approval Certificate No.	Fitting Type	Material 1) Ferrule / Nipple	Partnumber	DN	M.A. W.P. Bar	T.P. Bar	Total Length mm
1	220	1SNDN06	1SN	TAP000013G	3/8DR/3/8DR	CS	VIK 6/290	06	225	450	290

1) Carbon steel = CS Stainless Steel = SS Stainless Steel (Free Cutting) = FC Copper alloys = CA

This is to certify that the products described above have been tested in accordance with the Rules of DNV·GL and meet the specified requirements. As per certificate AMT 0000051 / DNVGL - CP - 0183

Rotterdam 02-07-2020

Place / Date **Stamp** **Signature of Manufacturer**

Guidelines for the Inspection of Mechanical and Electrotechnical Products" and is kept under regular auditing by Parker Hannifin.

QUALITY SYSTEM CERTIFICATION
DNV·GL
DNVGL-CP-0183

DNV CO_2 system flexible hose type approval certificate – issued December 2017

DNV·GL

Certificate No:
TAP000013G

TYPE APPROVAL CERTIFICATE

This is to certify:

That the Flexible Hoses of Non-Metallic Material with Permanently Fitted Couplings

with type designation(s)
301SN/301TC, 421SN

Issued to
Parker Hannifin Manufacturing S.r.l.
Veniano CO, Italy

is found to comply with
DNV GL rules for classification – Ships Pt.4 Ch.6 Piping systems
DNVGL-OS-D101 – Marine and machinery systems and equipment, Edition July 2015
DNV GL class programme DNVGL-CP-0183 – Type approval – Flexible hoses

Application :

Product(s) approved by this certificate is/are accepted for installation on vessels classed by DNV GL.

Type:	Temperature range:	Max. working press.:	Sizes:
301SN/301TC	-40 ºC to 100 ºC (dependent on medium)	80 to 400 bar (dependent on size)	DN6, 8, 10, 12, 16, 19, 25, 31, 38, 51
421SN	-40 ºC to 100 ºC (dependent on medium)	40 to 225 bar (dependent on size)	DN6, 8, 10, 12, 16, 19, 25, 31, 38, 51

Issued at **Høvik** on **2017-12-28**
This Certificate is valid until **2022-12-27**.
DNV GL local station: **Milan**

Approval Engineer: [redacted]

for **DNV GL**

[redacted]
Head of Section

This Certificate is subject to terms and conditions overleaf. Any significant change in design or construction may render this Certificate invalid.
The validity date relates to the Type Approval Certificate and not to the approval of equipment/systems installed.

Job Id: **262.1-016585-4**
Certificate No: **TAP000013G**

Product description
301SN and 301TC according to EN 853 2SN – ISO 1436 2SN:
Synthetic rubber inner tube, two braids of high tensile steel wire reinforcement separated by a synthetic rubber layer. Oil, weather fire and abrasion resistant synthetic rubber black outer cover.

421SN according to EN 853 1SN – ISO 1436 1SN:
Synthetic rubber inner tube - one braid of high tensile steel wire reinforcement. Oil, weather , fire and abrasion resistant synthetic rubber black outer cover.

Couplings	Parker couplings series 48 made of carbon or 316 stainless steel (for both types 301SN/TC &421SN)
Hoses made by:	Parker Hannifin, Italy
Couplings made by:	Parker Hannifin, Germany

Application/Limitation
This certificate is valid for the specific assembly of hose and coupling type as specified, assembled and delivered by the holder (named as manufacturer) of this certificate.

The hose may be used for the following application: Petroleum base hydraulic fluids, water glycol and water oil emulsion hydraulic fluids, compressed air & fresh water.

Maximum working pressure:

Hose size (DN)	301SN/TC			421SN	
	Designation		Max working pressure (bar)	Designation	Max working pressure (bar)
6	301SN-4	301TC-4	400	421SN-4	225
8	301SN-5	301TC-5	350	421SN-5	215
10	301SN-6	301TC-6	330	421SN-6	180
112	301SN-8	301TC-8	275	421SN-8	160
16	301SN-10	301TC-10	250	421SN-10	130
19	301SN-12	301TC-12	215	421SN-12	105
25	301SN-16	301TC-16	165	421SN-16	88
31	301SN-20	301TC-20	125	421SN-20	63
38	301SN-24	301TC-24	90	421SN-24	50
51	301SN-32	301TC-32	80	421SN-32	40

Temperature range:

Medium:	Temperature range:
Petroleum base hydraulic fluids	-40 ºC to 100 ºC
Water and water based hydraulic fluids	-40 ºC to 85 ºC
Compressed air	-40 ºC to 70 ºC

Each hose assembly is before delivery to be hydraulic pressure tested to 1.5 times the maximum working pressure and to be delivered with the pressure test report with reference to this type approval certificate.

Flexible hoses are only to be used where it is necessary due to vibrations or flexible mounting of the machinery. The hoses shall not replace/be used where permanent piping is possible/required and must only be fitted in places where they are always accessible.

Flexible hoses of these types are not to be used in boiler fronts.

Hoses covered by this certificate shall not be installed in systems with pressure below atmospheric or vacuum conditions.

The hoses are to be mounted in accordance with the manufacturer's instructions.

The cover of hoses for gaseous applications shall be pin-pricked.

Type Approval documentation

Tests carried out
Dimensional Check, Proof Pressure, Change in Length, Burst, Cold Flex, Oil Resistance, Ozone Resistance, Cover- and Tube- Adhesion Test, Impulse and Fire Test.

Marking of product
For traceability to this type approval the products are at least to be marked with:
- Manufacturer's name or trade mark
- Type designation
- Maximum working pressure
- Size

Periodical assessment
For retention of the Type Approval, a DNV GL Surveyor shall perform periodical assessment after two years (+/- 90 days) and after 3.5 years (+/- 90 days) to verify that the conditions for the approval are complied with. Reference is made to DNVGL-CP-0338.

Geeve Hydraulics B.V. flexible hose assembly test certificate – February 2021

Image courtesy of Geeve Hydraulics B.V.

GEEVEHYDRAULICS
know how *in hydraulics*

SINCE 1996

Test Certificate for Hose Assemblies

Certificate No.: GL-31003656

General Data

Geeve Hydraulics B.V.	31003656
Manufacturer	**Works Order No.**
VIKING LIFE SAVING EQUIPMENT B.V.	4500983359
Ordered by	**Order No.**

Item No.	No. Of	Hose standard	Type	Type Approval Certificate No.	Fitting Type	Material 1) Ferrule / Nipple	Partnumber	DN	M.A. W.P. Bar	T.P. Bar	Total Length mm
1	60	1SNDN06	1SN	TAP00001JV	3/8DR/3/8DR	CS	VIK 6/300	06	225	340	300
2	60	1SNDN12	1SN	TAP00001JV	1/2DR/CO2	CS	VIK 10/330	12	160	240	330

1) Carbon steel = CS   Stainless Steel = SS   Stainless Steel (Free Cutting) = FC   Copper alloys = CA

This is to certify that the products described above have been tested in accordance with the Rules of DNV·GL and meet the specified requirements. As per certificate AMT 0000051 / DNVGL - CP - 0183

Rotterdam 17-02-2021

Place / Date   **Stamp**   **Signature of Manufacturer**

Guidelines for the Inspection of Mechanical and Electrotechnical Products" and is kept under regular auditing by Parker Hannifin.

QUALITY SYSTEM CERTIFICATION
DNV·GL
DNVGL-CP-0183

DNV CO_2 system flexible hose type approval certificate – issued September 2020

DNV·GL

TYPE APPROVAL CERTIFICATE

Certificate No:
TAP00001JV
Revision No:
1

This is to certify:

That the Flexible Hoses of Non-Metallic Material with Permanently Fitted Couplings

with type designation(s)
421TC, 421SN

Issued to
Parker Hannifin Manufacturing S.r.l.
Veniano CO, Italy

is found to comply with
DNV GL rules for classification – Ships Pt.4 Ch.6 Piping systems
DNVGL-OS-D101 – Marine and machinery systems and equipment, Edition January 2018
DNV GL class programme DNVGL-CP-0183 – Type approval – Flexible hoses

Application :

Product(s) approved by this certificate is/are accepted for installation on vessels classed by DNV GL.

Type:	Temperature range:	Max. working press.:	Sizes:
421TC	-40°C to +100°C	See page 2	DN6, 10, 12
421SN	-40°C to +100°C	See page 2	DN6, 10, 12

Issued at **Høvik** on **2020-09-09**
This Certificate is valid until **2025-04-21**.
DNV GL local station: **Italy/Malta CMC**

Approval Engineer: [redacted]

for **DNV GL**

[redacted]
Head of Section

This Certificate is subject to terms and conditions overleaf. Any significant change in design or construction may render this Certificate invalid. The validity date relates to the Type Approval Certificate and not to the approval of equipment/systems installed.

Product description

Synthetic rubber hoses with one braid wire reinforcement designed according to EN 853 1SN.

Materials:

Inner tube: Nitrile rubber (NBR)
Reinforcement: One braid of steel wire
Cover 421SN: Perforated cover of synthetic rubber
Cover 421TC: MSHA approved synthetic rubber, tough cover
Couplings: Parker Coupling Series 48 (material – stainless steel: 1.4571, 1.4404, 1.4401, carbon steel: 1.0718, 1.0715, SAE1137, 1.0765, 1.0581, 1.0255, 1.0303, 1.0504, 1.7225, 1.7131)

Manufacturing location for hose and end fittings:

Parker Hannifin Manufacturing S.r.l
6 Via Giovanni Battista Pirelli
Veniano, CO, 22070 Italy

Application/Limitation

This certificate is valid for the specific assembly of hose and coupling type as specified, assembled and delivered by the holder (named as manufacturer) of this certificate.

Maximum working pressure at room temperature:

Size		421 TC	421 SN
DASH	DN		
4	6	225 bar	225 bar
6	10	180 bar	180 bar
8	12	160 bar	160 bar

Hose assemblies covered by this certificate are approved to be used as flexible connections between bottle valve and manifold in CO_2 fire extinguishing systems.

The cover of the hoses shall be pin-pricked.

This certificate is valid for the specific assembly of hose and coupling type as specified, assembled and delivered by the holder (named as manufacturer) of this certificate.

Flexible hoses are only to be used where it is necessary due to vibrations or flexible mounting of the machinery. The hoses shall not replace/be used where permanent piping is possible/required.

The hose assemblies must only be fitted on places where they are always accessible for inspection and shall be mounted according to the manufacturer's instructions.

The outer end of the pipe coupling (performing the connection to the fixed piping) is not covered by this certificate and shall follow the below requirements:

- Flanged ends shall be according to a recognized standard
- Slip-on threaded joints having pipe threads where pressure-tight joints are made on the threads with parallel or tapered threads, shall comply with requirements of a recognized standard. Limitations stated in DNVGL-RU-SHIP Pt.4 Ch.6 Sec.9 [5.6.2] to be followed.
- If these outer ends are going to be part of a mechanical joint as covered by DNVGL-RU-SHIP Pt.4 Ch.6 Sec.9 [Table 10], then they shall be separately type approved.

Production testing

Each hose assembly shall be hydrostatically tested at a pressure of 1.5 times the maximum working pressure and be delivered with the pressure test report with reference to this type approval certificate.

Type Approval documentation

Tests carried out

Dimensional check, change in length, leakage test, cold flexibility, resistance against liquids, cover adhesion, vacuum test, ozone resistance, fire test, impulse, burst at minimum design temperature, endurance test with liquid carbon dioxide

Marking of product

For traceability to this type approval the products are to be marked with:

- Hose manufacturer's name or trademark;
- Date of manufacture (month/year);
- Designation type reference;
- Nominal diameter;
- Pressure rating;
- Temperature rating.

Periodical assessment

For retention of the Type Approval, a DNV GL Surveyor shall perform periodical assessment after two years (+/- 90 days) and after 3.5 years (+/- 90 days) to verify that the conditions for the approval are complied with. Reference is made to DNVGL-CP-0338.

RINA CO_2 system flexible hose type approval certificate – issued July 2015

TYPE APPROVAL CERTIFICATE
No. **MAC176015CS/004**

This is to certify that the product identified below is in compliance with the regulations herewith specified.

Description	**Non metallic flexible hoses**
Type	**421SN**
Applicant	**PARKER HANNIFIN MANUFACTURING SRL** **VIA G.B. PIRELLI, 6** **22070 VENIANO (CO)** **ITALY**
Manufacturer	**PARKER HANNIFIN MANUFACTURING SRL**
Place of manufacture	**VIA G.B. PIRELLI, 6** **22070 VENIANO (CO)** **ITALY**
Reference standards	**RINA Rules for the Type Approval of Flexible Hoses and Expansion Joints**

Issued in **Genoa** on **July 24, 2015**. *This Certificate is valid until* **July 23, 2020**

RINA Services S.p.A.
[redacted]

This certificate consists of this page and 1 enclosure

RINA Services S.p.A.
Via Corsica, 12 - 16128 Genova
Tel +39 010 53851
Fax +39 010 5351000

TYPE APPROVAL CERTIFICATE
No. **MAC176015CS/004**
Enclosure - Page 1 of 2
421SN

Reference documents

Parker Hannifin specifications nos. Hs-421SN and HS-K48
Test Reports Nos. 1364, 1365, 1366 and 1367 of 03/08/2004.
Test Report No. 2009/CS/4434 of 11/02/2010 of RINA Milan Office.

Reference Standard

EN 853 - 1SN.

Materials/components

Lining:
Nitrile based synthetic rubber oil resistant

Reinforcement:
One braid of high tensile steel wire

Cover:
Black synthetic rubber resistant to oils and weathering

End fittings:
Parker 48 series - Material: Steel (9SMnPb28 UNI 4838 or equivalent) - Stainless steel (316).

Technical characteristics

Maximum allowable working pressure at ambient temperature according to the following table:

Item	Nominal Diameter (mm)	Inside Diameter (mm)	Max. working pressure (N/mm^2)
-3	5	4.6	25
-4	6.3	6.2	22.5
-5	8	7.7	21.5
-6	10	9.3	18
-8	12.5	12.3	16
-10	16	15.5	13
-12	19	18.6	10.5
-16	25	25.0	8.8
-20	31.5	31.4	6.3
-24	38	37.7	5
-32	51	50.4	4

Working temperature: -40°C to +100°C

RINA Services S.p.A.
Via Corsica, 12 - 16128 Genova
Tel +39 010 53851
Fax +39 010 5351000

Fields of application

Hydraulic systems with a hydraulic oil having a flash point not less than 150°C.

TYPE APPROVAL CERTIFICATE
No. **MAC176015CS/004**
Enclosure - Page 2 of 2
421SN

Acceptance Conditions

The installation on board of the piping system is to be carried out by qualified personnel in accordance with the manufacturer's instructions.

The flexible hoses are to be installed in order to satisfy the requirements of para. 5.9.3 of Part C, Ch 1, Sec 10 of RINA Rules.

The acceptance of the a.m. products on board ship and other units classified with RINA is subject to the satisfactory outcome of testing as per RINA Rules.

The product (hose and fittings) is to be marked, for traceability, with the following data: nominal diameter, design conditions, Manufacturer's name or trademark, designation type reference.

Remarks

This certificate annuls and replaces the previous certificate No. MAC443409CS/004 issued on 5 March 2010.

Genoa July 24, 2015

RINA Services S.p.A.
Via Corsica, 12 - 16128 Genova
Tel +39 010 53851
Fax +39 010 5351000

RINA CO_2 system flexible hose type approval certificate – issued November 2020

TYPE APPROVAL CERTIFICATE
No. **MAC241320CS/002**

This is to certify that the product identified below is in compliance with the regulations herewith specified.

Description	**Non metallic flexible hoses**
Type	**421SN**
Applicant	**PARKER HANNIFIN MANUFACTURING SRL** **VIA G.B. PIRELLI, 6** **22070 VENIANO (CO)** **ITALY**
Manufacturer *Place of manufacture*	**PARKER HANNIFIN MANUFACTURING SRL** **VIA G.B. PIRELLI, 6** **22070 VENIANO (CO)** **ITALY**
Reference standards	**RINA Rules for the Type Approval of Flexible Hoses and Expansion Joints**

Issued in **Genoa** on **November 23, 2020**. *This Certificate*

RINA Services S.p.A.

This certificate consists of this page and 1 enclosure

[redacted]

RINA Services S.p.A.
Via Corsica, 12 - 16128 Genova
Tel +39 010 53851
Fax +39 010 5351000

TYPE APPROVAL CERTIFICATE
No. **MAC241320CS/002**
Enclosure - Page 1 of 2
421SN

Reference documents

Parker Hannifin specifications nos. Hs-421SN and HS-K48
Test Reports Nos. 1364, 1365, 1366 and 1367 of 03/08/2004.
Test Report No. 2009/CS/4434 of 11/02/2010 of RINA Milan Office.
Catalogue 4400/UK - Cab-9

Reference Standard

EN 853 / ISO 1436 - 1SN.

Materials/components

Lining:
Nitrile based synthetic rubber oil resistant

Reinforcement:
One braid of high tensile steel wire

Cover:
Black synthetic rubber resistant to oils and weathering

End fittings:
Parker 48 series - Material: Steel (9SMnPb28 UNI 4838 or equivalent) - Stainless steel (316).

Technical characteristics

Maximum allowable working pressure at ambient temperature according to the following table:

Item	Nominal Diameter (mm)	Inside Diameter (mm)	Max. working pressure (N/mm^2)
-3	5	4.6	25
-4	6.3	6.2	22.5
-5	8	7.7	21.5
-6	10	9.3	18
-8	12.5	12.3	16
-10	16	15.5	13
-12	19	18.6	10.5
-16	25	25.0	8.8
-20	31.5	31.4	6.3
-24	38	37.7	5
-32	51	50.4	4

Working temperature: -40°C to +100°C

Fields of application

Hydraulic systems with a hydraulic oil having a flash point not less than 150°C.

TYPE APPROVAL CERTIFICATE
No. **MAC241320CS/004**
Enclosure - Page 2 of 2
421SN

Acceptance Conditions

The installation on board of the piping system is to be carried out by qualified personnel in accordance with the manufacturer's instructions.

The flexible hoses are to be installed in order to satisfy the requirements of para. 5.9.3 of Part C, Ch 1, Sec 10 of RINA Rules.

The acceptance of the a.m. products on board ship and other units classified with RINA is subject to the satisfactory outcome of testing as per RINA Rules.

The product (hose and fittings) is to be marked, for traceability, with the following data: nominal diameter, design conditions, Manufacturer's name or trademark, designation type reference.

Remarks

This certificate annuls and replaces the previous certificate No. MAC176015CS/004 issued on 24/07/2015.

Genoa 23/11/2020

RINA Services S.p.A.
Via Corsica, 12 - 16128 Genova
Tel +39 010 53851
Fax +39 010 5351000

DNV approval of manufacturer certificate

DNV·GL

APPROVAL OF MANUFACTURER CERTIFICATE

Certificate No:
AMT0000051
Revision No:
1

This is to certify:

That the Manufacturer
Geeve Hydraulics B.V.
ROTTERDAM, Zuid-Holland, Netherlands

is approved for the
Assembling of type approved hoses and couplings

The approval is granted on condition that
DNV GL class programme DNVGL-CP-0183 – Type approval – Flexible hoses

are complied with in all respect

Type	Size
462TC	DN 6 to DN 48
492	DN 6 to DN 25
387TC	DN 4 to DN 32
301SN, 421SN	DN 6 to DN 51
811	DN 19 to DN 125
372	DN 10 to DN 31
H31	DN 6 to DN 25
H29	DN 19 to DN 51
R42	DN 16 to DN 51
520N	DN 3 to DN 16
421SN	DN 6 to DN 12
2245N	DN 6 to DN 25
787TC, 797TC	DN 6 to DN 51
R35TC	DN 12 to DN 48
471TC	DN 6 and DN 10 to DN 51
701	DN 12 to DN 40

Manufacturer(s) approved by this certificate is/are accepted to deliver according to DNV GL, DNV and GL rules.

Issued at **Høvik** on **2020-11-30**
This Certificate is valid until **2023-07-24**.
DNV GL local station: **Netherlands CMC**

Approval Engineer: [redacted]

for **DNV GL**

[redacted]
Head of Section

LEGAL DISCLAIMER: Unless otherwise stated in the applicable contract with the holder of this document, or following from mandatory law, the liability of DNV GL AS, its parent companies and subsidiaries as well as their officers, directors and employees ("DNV GL") arising from or in connection with the services rendered for the purpose of the issuance of this document or reliance thereon, whether in contract or in tort (including negligence), shall be limited to direct losses and under any circumstance be limited to 300,000 USD.
This Certificate is subject to terms and conditions overleaf. Any significant change in production facilities and methods may render this Certificate invalid.

Approval basis
Geeve Hydraulics B.V. is approved as a hose assembling company to deliver type approved hose assemblies (hose & coupling types as described in this certificate) to DNV GL vessels.

Products
Holder of this certificate is authorized to assemble hoses and end fittings as specified in below type approval certificates with subsequent identical revisions (as long as there is no change in the design of the products):

TAC Holder	Type Approval Certificate	Expiry date	Type	Size
Parker Hannifin Manufacturing S.r.l.	TAP000000E	2022-06-30	462TC	DN 06 to DN 76
			492	DN 06 to DN 31
	TAP000008S	2021-02-11	387TC	DN 04 to DN 32
	TAP000013G	2022-12-17	301SN	DN 06 to DN 51
			421SN	DN 06 to DN 51
	TAP0000158	2022-06-30	811	DN 19 to DN 125
	TAP000016X	2022-12-27	372	DN 10 to DN 31
	TAP000016Y	2022-12-27	H31	DN 06 to DN 25
			H29	DN 19 to DN 51
	TAP000016Z	2022-12-27	R42	DN 16 to DN 51
	TAP00001AR	2023-06-30	520N	DN 03 to DN 16
	TAP00001JV	2025-04-21	421SN	DN 06 to DN 12
	TAP00001M6	2024-01-20	2245N	DN 06 to DN 25
	TAP000013N	2022-11-08	787TC	DN 06 to DN 51
			797TC	DN 06 to DN 51
	TAP00001N8	2023-12-31	R35TC	DN 12 to DN 48
	TAP00001R6	2024-03-10	471TC	DN 06 and DN 10 to DN 51
	TAP00000TU	2022-02-15	701	DN 12 to DN 40

Limitation
The approval is valid by considering all conditions in relevant type approval certificates during the validity of current certificate as well as the relevant type approval certificates & authorization letter.

Production testing
Each hose assembly is to be hydraulic pressure tested to 1.5 times the maximum working pressure before delivery and to be delivered from the certificate holder with pressure test report with reference to the type approval certificate and this certificate.

Approval documentation

Certificate Retention Survey
The AoM certificate is valid for three years with no intermediate assessment unless otherwise requested by the Society.

Annex J

Schneider Electric Fault Analysis Report reference RM22212514

Image courtesy of Schneider Electric

Fault Analysis Report

Report Ref: RM22212514 Customer Ref: Finnmaster

BFO / TEX number:	BFO96175385 / TEX-2023012670432
Customer company name:	Marine Accident Investigation Branch
Customer contact name:	[redacted]
Product reference:	NS400NA = 32756, MT400 = 32641
Product description:	400A 3 Pole Switch, 208/277V AC Motor Mech
Quantity:	1 Each
Reported fault:	Failed to close
Date code(s):	NS400NA = N9805, MT400 = P97464

Expert Assessment Information

Expert centre name and country:	[redacted].
Name of the expert completing the report:	[redacted]
Email address:	[redacted]
Tel:	[redacted]

Inspection

The picture below shows the parts as received.

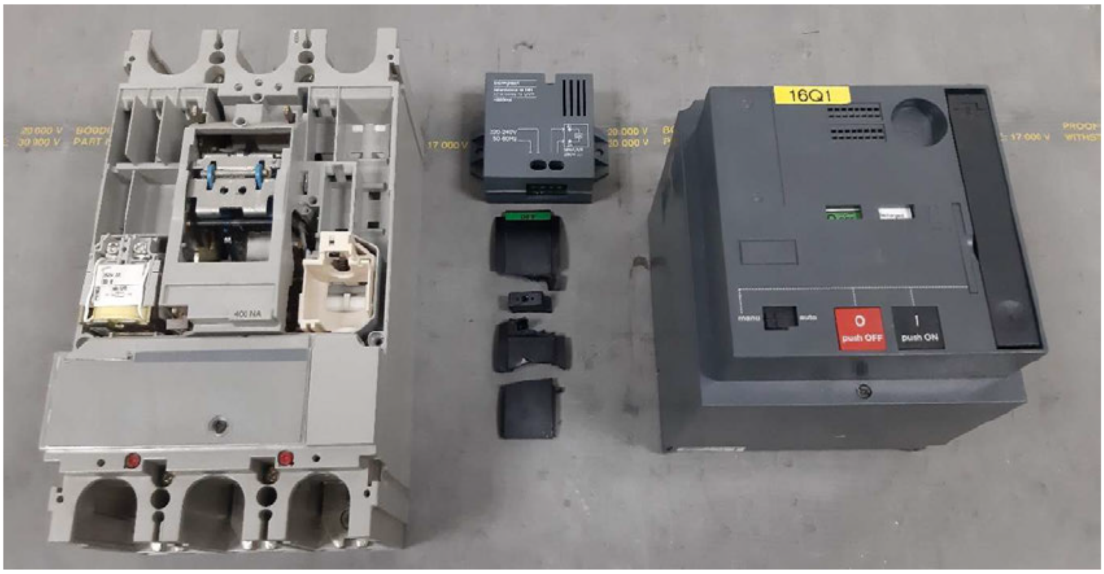
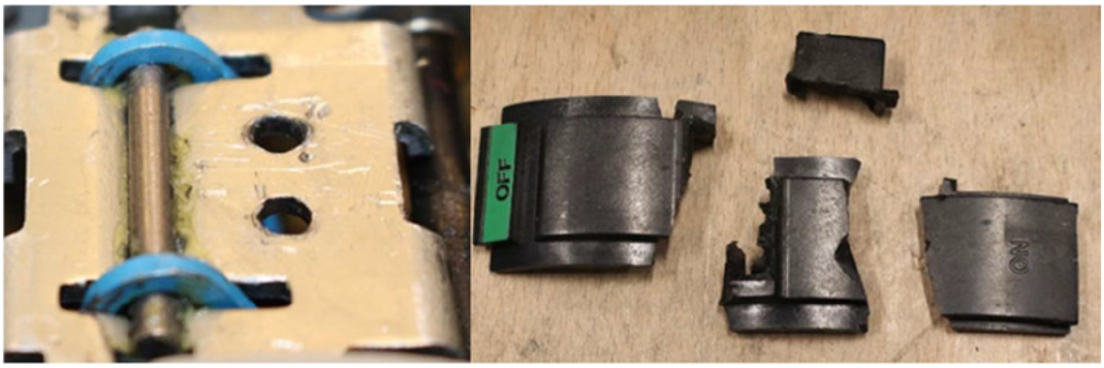
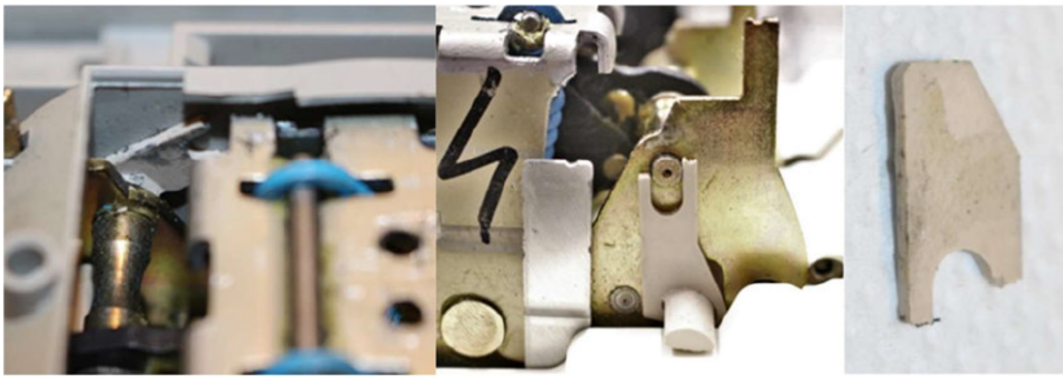


Image courtesy of Schneider Electric

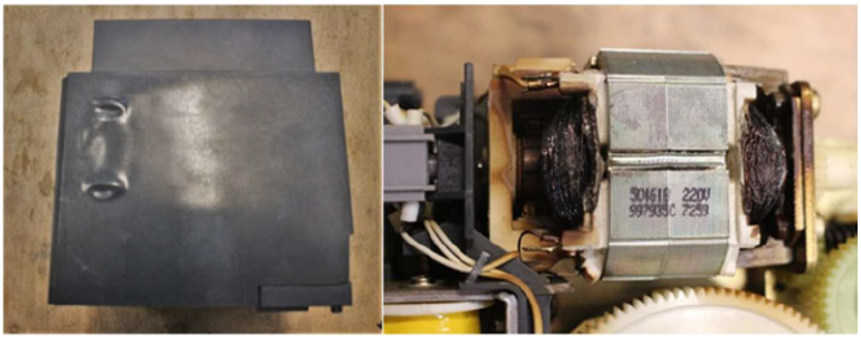
On closer inspection of the switch, we found that the fixing holes of the handle are deformed, and the handle is clearly broken.



We also found parts of the SD lever broken.



The motor mechanism casing showed signs of heat damage. With the cover removed we can see the motor is burnt out, and the charging handle ratchet arm and axle had become detached.



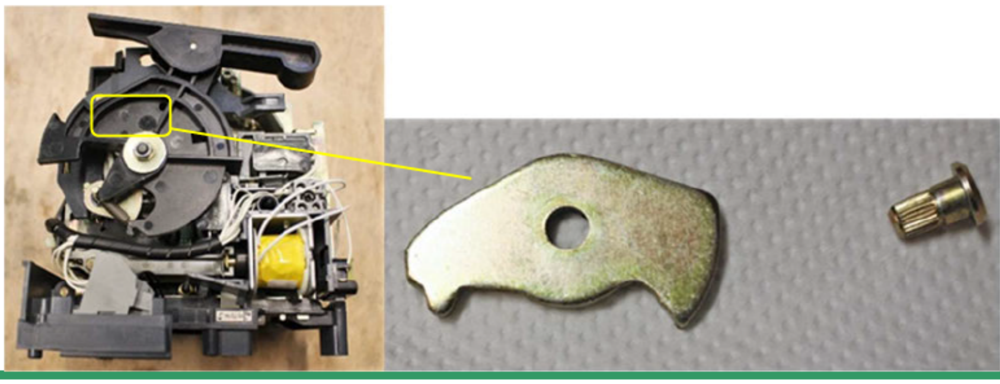
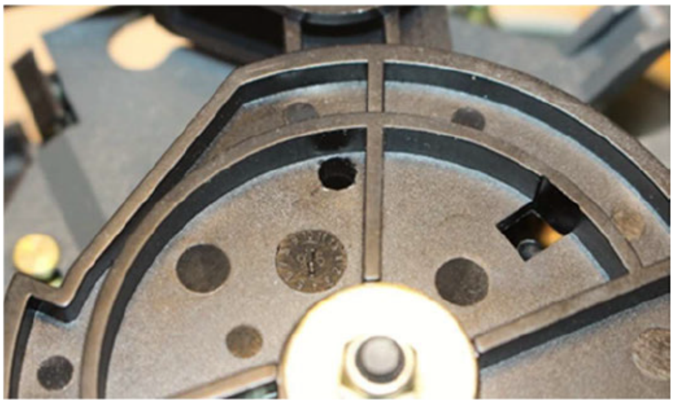
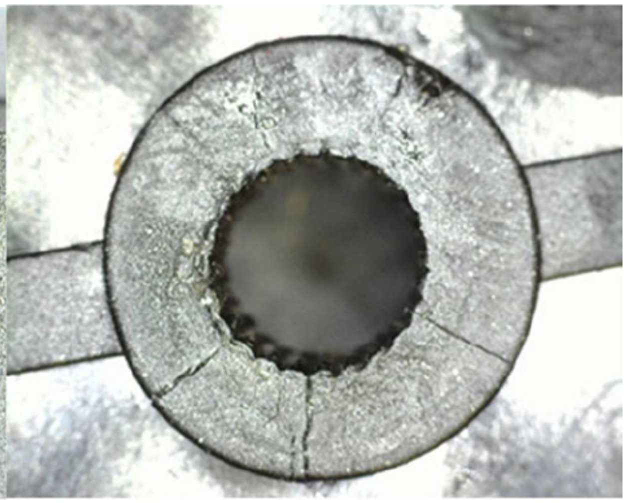


Image courtesy of Schneider Electric

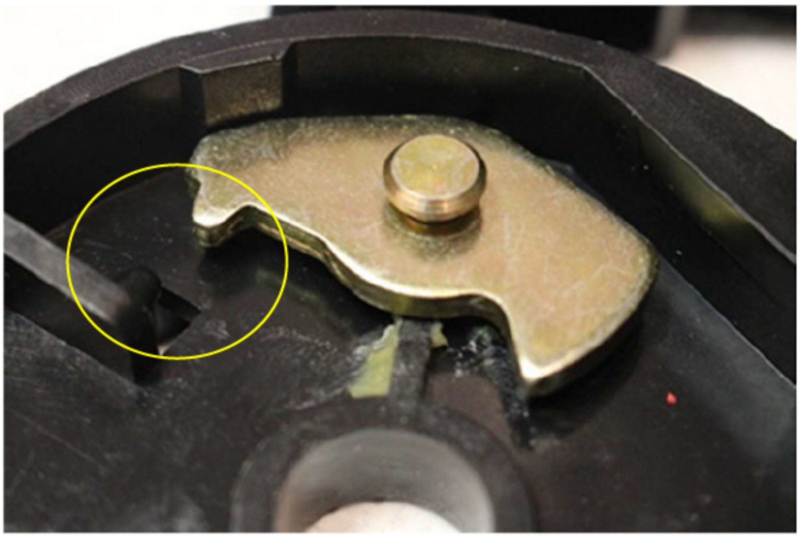
A closer view of the ratchet axle position on the motor mechanism handle, shows cracking and deformation of the plastic.



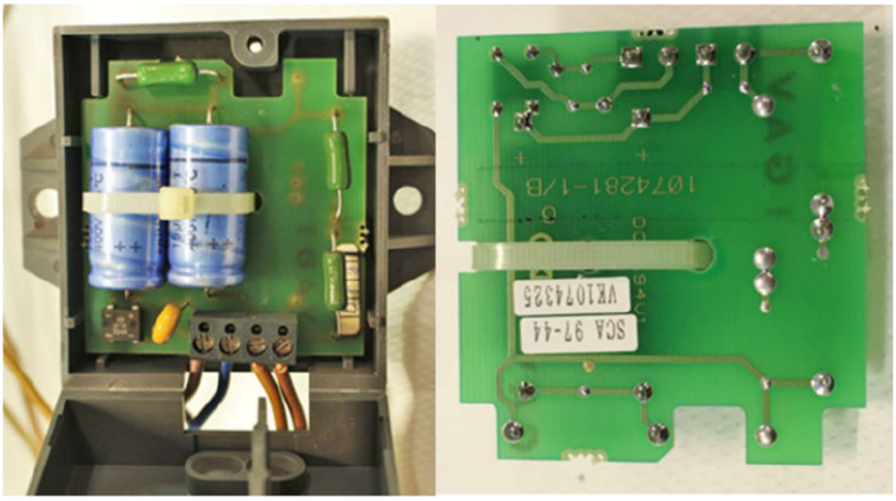


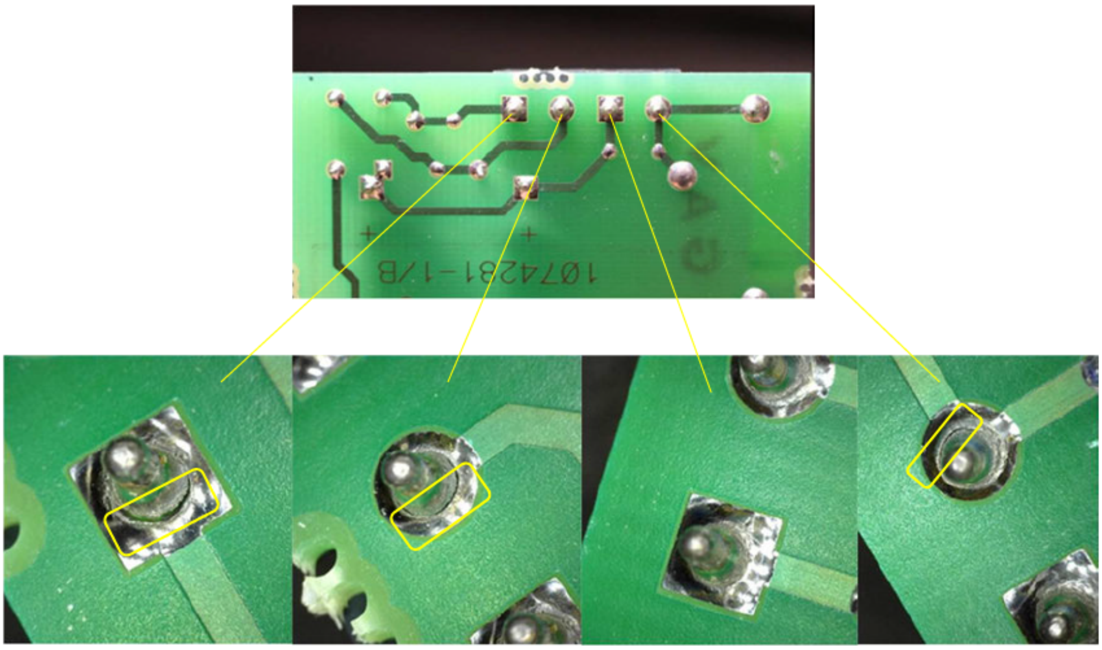
The ratchet and axle could be correctly reassembled, although the ratchet spring could not be found.

Ratchet spring position



When viewing the UVR time delay unit we found internal soldering had cracked on three of the four terminal pins.





The UVR coil was found to be in good condition. When energised directly the UVR coil operated correctly. When energised via the UVR time delay the UVR coil operated only intermittently.

De-energised

Energised

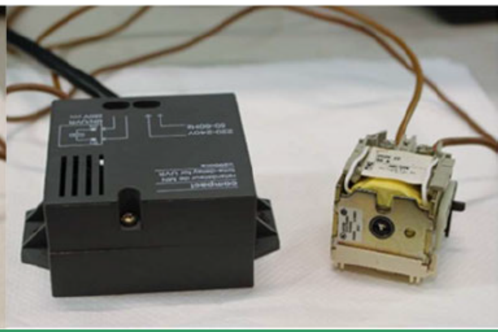


Image courtesy of Schneider Electric

Conclusion

We received a request for the investigation of a Compact NS400NA 3 Pole switch, with a motor mechanism, and a UVR coil with a time delay module. An issue occurred when the motor mech tried to close the switch, and the switch failed to close.

The switch was received with a broken handle, the SD lever broken, and one part of the motor mechanism had fallen into the switch.

The motor mechanism charging handle was inoperable. Microscopic analysis showed cracking and deformation on the axis support of the handle ratchet.

The motor mechanism motor is burnt out, but the gears and sprocket are in good condition. Traces of heat show that the motor mechanism has not moved since the motor burnt out.

When testing the UVR coil in conjunction with the time delay the UVR coil would only operate intermittently. When testing the UVR coil alone, the coil operated correctly every time.

Inspection of the of UVR time delay PCBA showed that three of the four soldering pins, which supply the relay and the UVR coil, were cracked and there was no continuity for one of them.

The control circuit schematic showed that when the motor mechanism was in auto mode, auto-rearming of the motor mechanism is selected, and the SD contact should be wired to close the rearming order. The NS400 was received with no SD contact to ensure this function. We cannot confirm if the contact was present or not.

Our motor mechanisms are designed for four operations per minute maximum. An excessive number of operations per minute will lead to the motor overheating and the degradation of mechanical parts.

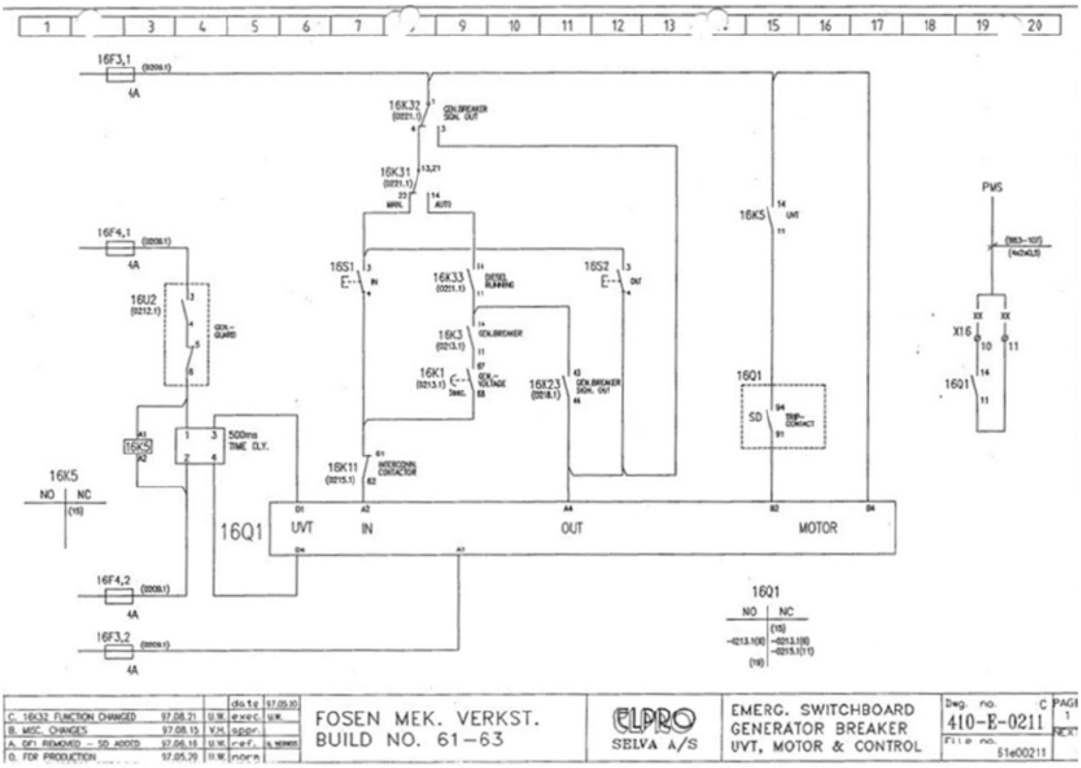


Image courtesy of Schneider Electric

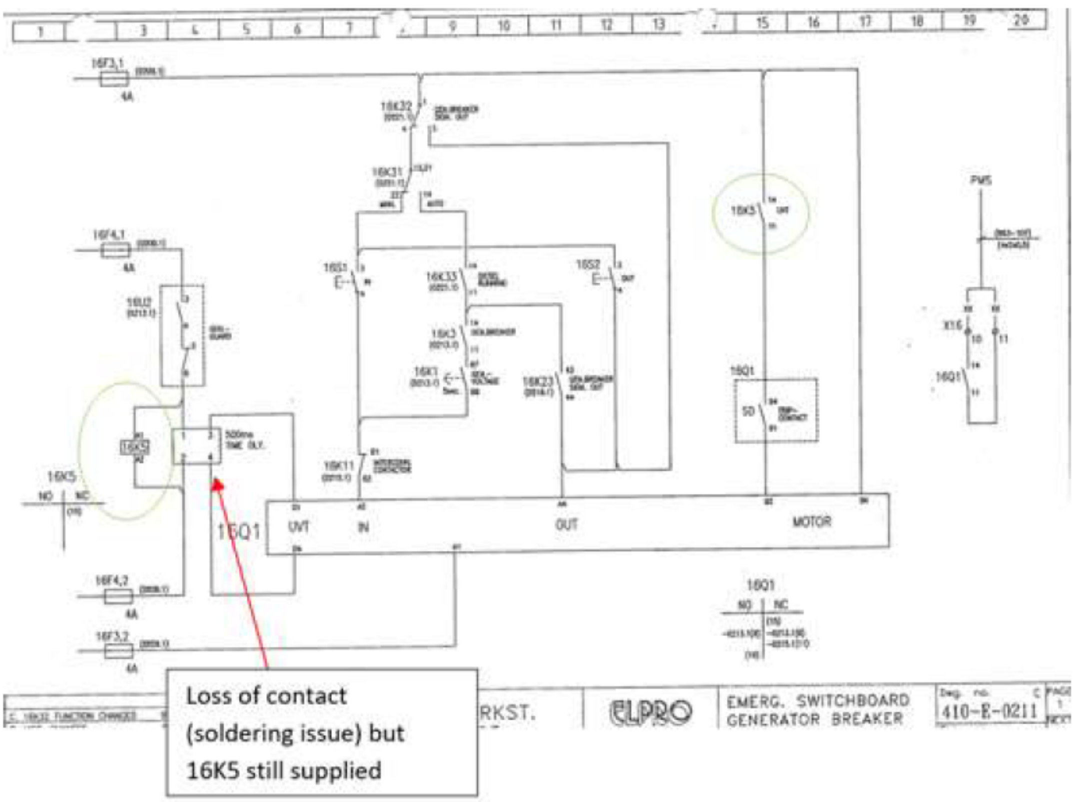
Based on the information supplied, the schematic of the installation and our knowledge of the device, the most probable scenario for the issue is as below:

1. An issue with the supply to the UVR coil is created due to UVR time delay connector soldering cracks. With no supply to the UVR coil, the switch then opens. Even though supply is lost to the UVR coil, relay 16K5 remains energised.

2. Relay 16K5 is energised and the SD contact is closed, keeping a supply on to the rearming order (B2) and auto-run has a constant supply (B4). The motor mechanism repeatedly tries to close the switch (motor mechanism is in auto reset mode), without success as the UVR coil is not energised. This leads to the motor eventually overheating and creating mechanical issues.

3. The ratchet on the motor mechanism handle breaks, the ratchet falls into the switching mechanism of the switch, this results in the handle and the SD lever breaking, preventing the switch closing via the motor mechanism.

4. The motor mechanism remains energized locked in position. Causing the motor to overheat and eventually burn out.



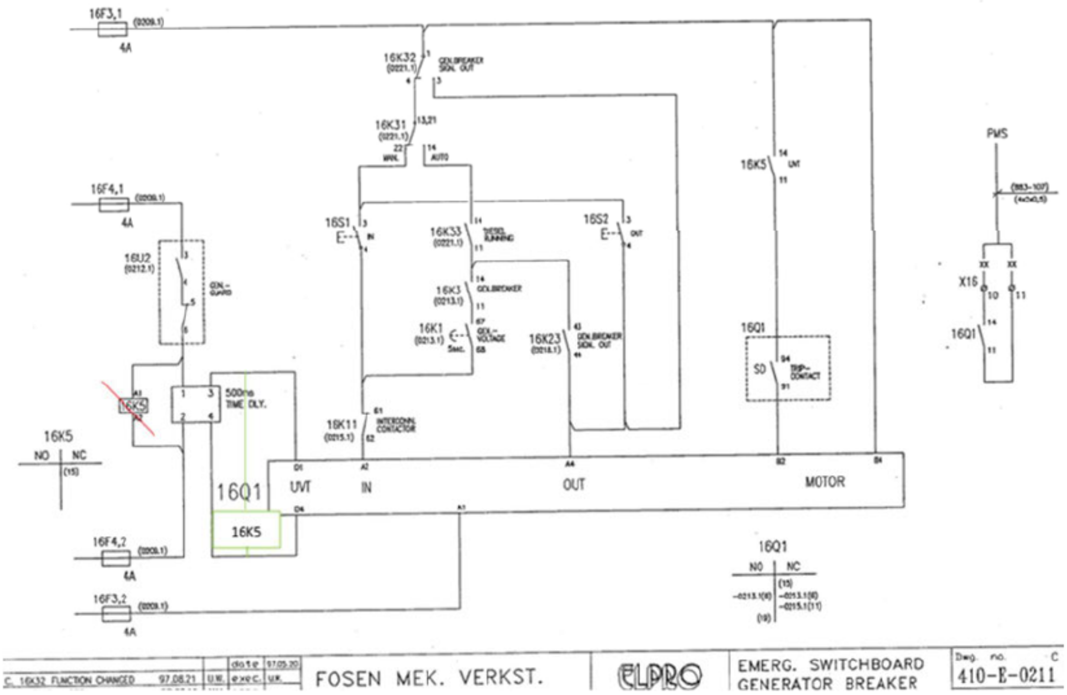
Recommendation

Below is a possible improvement to the schematic to avoid auto rearming of the motor mechanism in case of an issue with the UVR time delay.

1. Use a newer UVR time delay unit, reference 33682 set to 0.5s.

2. Wire relay 16K5 after the UVR time delay directly in parallel with the UVR coil. If there was an issue with the supply to the UVR coil, or an issue with the UVR time delay unit, relay 16K5 will open, preventing constant rearming of the motor mechanism.

In this proposal relay 16K5 must be replaced by a 250VDC low consumption relay, instead of the current 220-240Vac relay.



MAIB Safety Bulletin SB1/2022, issued 10 March 2022

MAIB
MARINE ACCIDENT INVESTIGATION BRANCH

SAFETY BULLETIN

SB1/2022

MARCH 2022

Extracts from The United Kingdom Merchant Shipping (Accident Reporting and Investigation) Regulations 2012 Regulation 5:
"The sole objective of a safety investigation into an accident under these Regulations shall be the prevention of future accidents through the ascertainment of its causes and circumstances. It shall not be the purpose of such an investigation to determine liability nor, except so far as is necessary to achieve its objective, to apportion blame."

Regulation 16(1):
"The Chief Inspector may at any time make recommendations as to how future accidents may be prevented."

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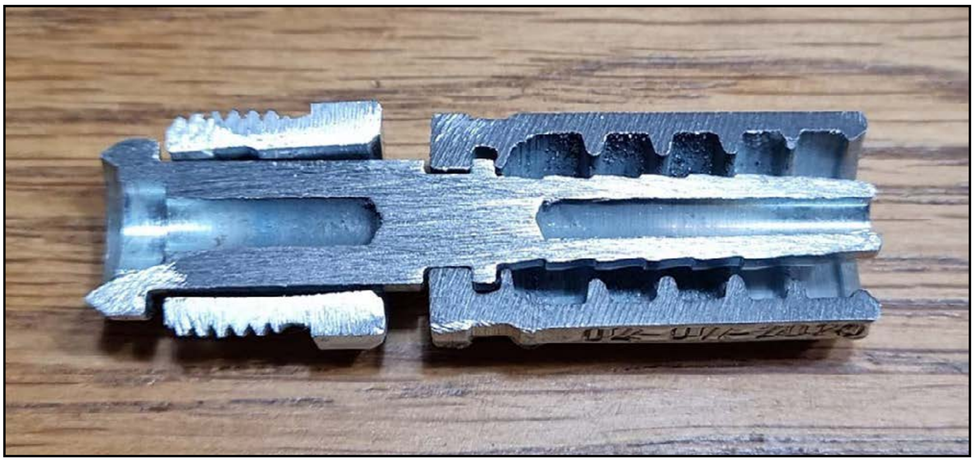
Blockage of fixed CO_2 fire extinguishing system pilot hoses identified following a fire on board the roll-on/roll-off cargo ship *Finnmaster* in Hull, England on 19 September 2021



Section through blocked CO_2 pilot hose coupling showing incomplete bore through the stem

MAIB SAFETY BULLETIN 1/2022

This document, containing safety lessons, has been produced for marine safety purposes only, on the basis of information available to date.

The Merchant Shipping (Accident Reporting and Investigation) Regulations 2012 provides for the Chief Inspector of Marine Accidents to make recommendations or to issue safety lessons at any time during the course of an investigation if, in his opinion, it is necessary or desirable to do so.

The Marine Accident Investigation Branch is carrying out an investigation into the fire on board the roll-on/roll-off cargo ship *Finnmaster* in Hull, England, on 19 September 2021.

The MAIB will publish a full report on completion of the investigation.

Captain Andrew Moll
Chief Inspector of Marine Accidents

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This bulletin is also available on our website: www.gov.uk/maib
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BACKGROUND

On 19 September 2021, a fire broke out in the auxiliary engine room on board the Finland registered roll-on/roll-off cargo ship *Finnmaster* while departing Hull, England. The crew contained the fire and discharged the machinery space's carbon dioxide (CO_2) fire extinguishing system. Only half of the assigned CO_2 cylinders discharged, and the crew had to re-enter the space wearing breathing apparatus to fully extinguish the fire.

Finnmaster was operated by Finnlines Oyj (Finnlines) and was equipped with a fixed high-pressure CO_2 fire extinguishing system that provided protection for the ship's machinery spaces, encompassing the main engine room and the auxiliary engine room, and the two cargo holds. The system was designed to be activated remotely via a network of pilot lines and gas activated cylinder valves **(Figure 1)**.

INITIAL FINDINGS

The initial MAIB investigation identified that one of the auxiliary engine room's CO_2 system pilot hoses was completely blocked. Subsequent examination and testing of *Finnmaster*'s fixed fire extinguishing systems identified two other hoses on the cargo hold pilot line system that were blocked. Radiographic images taken of the blocked hoses **(Figures 2** and **3)** showed that the pilot hose couplings had not been fully bored through during the manufacturing process. The testing process also identified several coupling leaks in the pilot lines.

In March 2021, the pilot hoses had been replaced during a routine service conducted on board *Finnmaster* by the marine fire service section of Viking Life-Saving Equipment Oy Finland (Viking). The tests carried out by Viking during the service did not identify any faults with the system. Following the accident, Viking tested the high-pressure CO_2 fire extinguishing systems on board the remainder of the Finnlines fleet and identified two similar pilot hoses that were blocked on one of the operator's ships.

All the affected hose assemblies had been supplied to Viking by Geeve Hydraulics B.V. (Geeve), based in the Netherlands. The hose assemblies had been produced under the terms of the classification society type approval held by Geeve. Although the type approval required each completed hose assembly to be pressure tested, there was no specific test that gas could pass freely through the hose assemblies.

The hose used in the assemblies was provided in accordance with the type approval held by Geeve. However, Geeve had purchased the couplings from HSR Hydraulics B.V. in the Netherlands, who had sourced the couplings from a different manufacturer.

SAFETY ISSUES

Safety issues identified during the initial stages of the investigation included:

- The quality assurance processes of the pilot hose assembly supplier did not identify that the hose couplings had not been fully bored through.
- Viking's onboard installation testing processes did not identify both that some of the hose assemblies were blocked and that there were leaks in the CO_2 system pilot lines.

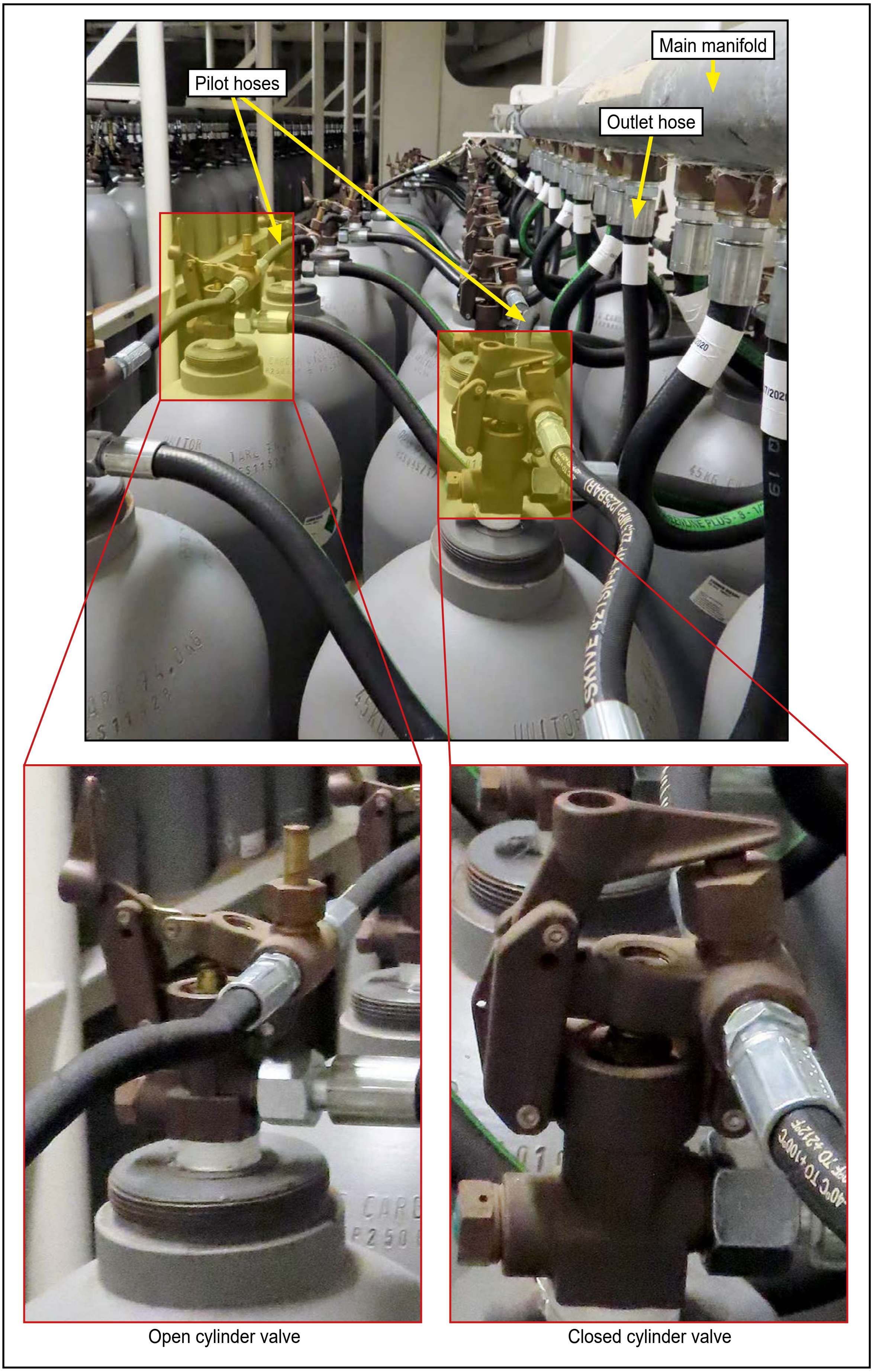

Figure 1: Part of the *Finnmaster* CO_2 fire extinguishing system post-accident

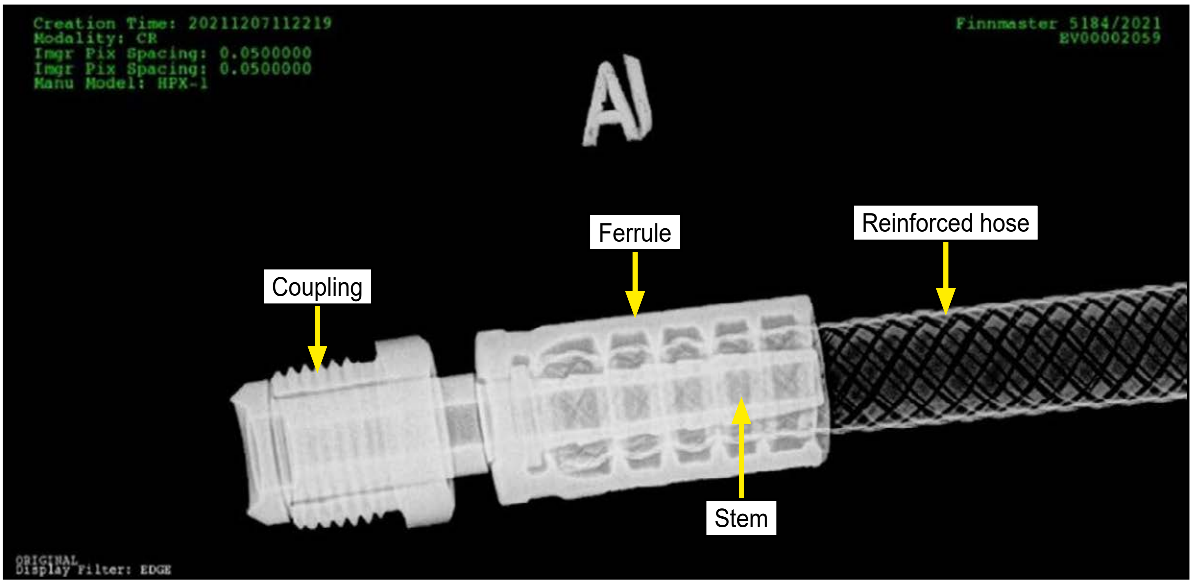

Figure 2: CO_2 pilot hose coupling, showing clear passage through the stem

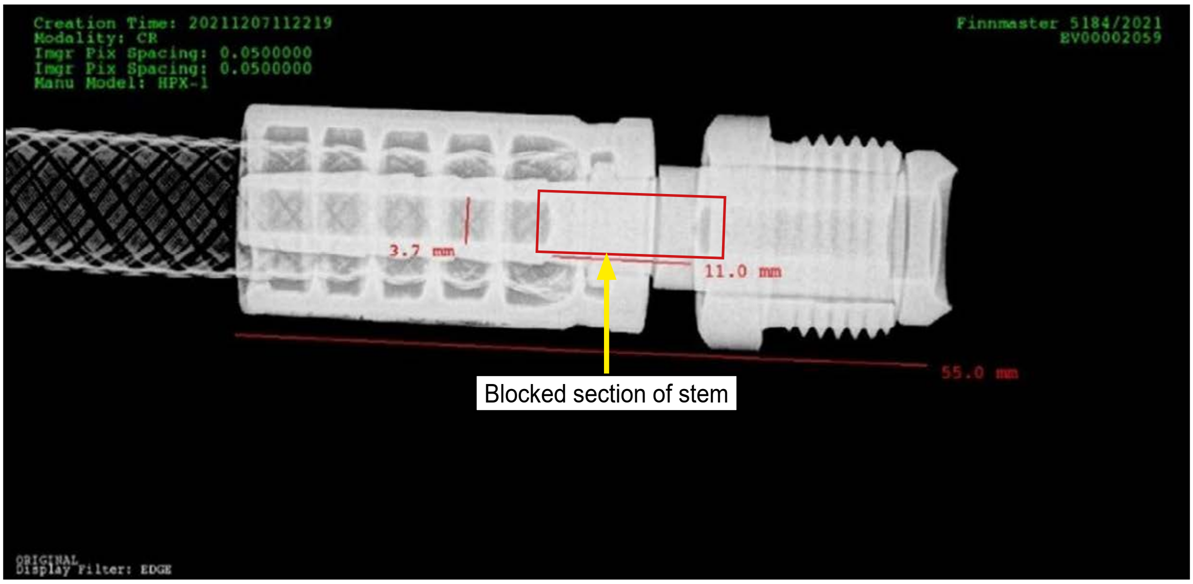

Figure 3: CO_2 pilot hose coupling, showing incomplete bore through the stem

ACTION TAKEN BY THE MAIB

The **MAIB** has:

Contacted the companies identified as having been supplied with the affected hose assemblies to make them aware that these assemblies may be blocked and to recommend that they take immediate remedial action in accordance with recommendation S2022/107M, as detailed below.

ACTIONS TAKEN BY OTHER ORGANISATIONS

Geeve Hydraulics B.V. has:

- Discontinued the supply of the affected hose assemblies.
- Amended its testing procedure to incorporate a pneumatic flow test of the complete hose assemblies to verify that they are not blocked.

Finnlines Oyj has:

Issued instructions to its fleet to ensure that crews on board its vessels are fully acquainted with the procedures for the manual activation of CO_2 fire extinguishing systems in the event of the pilot actuation system failing.

Viking Life-Saving Equipment Oy Finland has:

Amended its procedures for the servicing of high-pressure CO_2 systems to incorporate a positive test for blockages of the pilot system pipework. It has also issued a health and safety awareness notice highlighting the issues identified.

RECOMMENDATIONS

Geeve Hydraulics B.V. is recommended to:

S2022/105 Provide a copy of this safety bulletin to all customers supplied with hose assemblies fitted with couplings supplied by HSR Hydraulics B.V. that do not meet the required type approval, and draw attention to the safety issues raised and the need for immediate action to identify and rectify any defects found in safety critical systems.

S2022/106 Amend its purchasing and quality control procedures to ensure that hose assembly components are procured in accordance with the relevant type approval requirements.

All companies identified as having been supplied with the affected hose assemblies by Geeve Hydraulics B.V., with couplings sourced from HSR Hydraulics B.V., are recommended to:

S2022/107M Take immediate remedial action to identify and rectify any blocked pilot hose assemblies and pilot system leaks on potentially affected CO_2 fire extinguishing systems.

REQUEST FOR INFORMATION

To assist this investigation, it is requested that service providers, owners and operators pass details of any blocked pilot system hose assemblies that they find to the MAIB.

Email maib@dft.gov.uk with the title ‘CO_2 Pilot System Hose Assembly Issues’ and include the name of the vessel, the date and place of installation of the affected hose assemblies, and details of the defects identified.

This information is for internal use only and will be treated in strict confidence.

Issued March 2022

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

MAIB Safety Bulletin SB1/2023, issued 23 March 2023

Extracts from The United Kingdom Merchant Shipping (Accident Reporting and Investigation) Regulations 2012 Regulation 5:
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Potential fire hazards from flexible hose installations identified following a fire on board the roll-on/roll-off cargo ship *Finnmaster* in Hull, England on 19 September 2021

Finnmaster's fire-damaged compartment

MAIB SAFETY BULLETIN 1/2023

This document, containing safety lessons, has been produced for marine safety purposes only, on the basis of information available to date[1].

The Merchant Shipping (Accident Reporting and Investigation) Regulations 2012 provide for the Chief Inspector of Marine Accidents to make recommendations at any time during the course of an investigation if, in his opinion, it is necessary or desirable to do so.

The Marine Accident Investigation Branch is carrying out an investigation into the fire on board the roll-on/roll-off cargo ship *Finnmaster* in Hull, England, on 19 September 2021.

The MAIB will publish a full report on completion of the investigation.

Captain Andrew Moll OBE
Chief Inspector of Marine Accidents

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[1] A previous safety bulletin, issued by MAIB in March 2022, focused on separate safety issues arising from this accident: https://www.gov.uk/maib-reports/safety-warning-issued-after-discovery-of-blocked-fixed-co2-fire-extinguishing-system-pilot-hoses

BACKGROUND

On 19 September 2021, a fire broke out in the auxiliary engine room on board the Finland registered roll-on/roll-off cargo ship *Finnmaster* while departing Hull, England. The fire was contained and subsequently extinguished without injury to the crew, but the equipment in the auxiliary engine room suffered serious damage **(Figure 1)**.

Figure 1: Damage sustained to auxiliary engine room

Finnmaster's auxiliary engine room was equipped with two main alternators. These were driven by marine gas oil (MGO) fuelled engines and named as auxiliary engine 1 (AE1) and auxiliary engine 2 (AE2). Each auxiliary engine comprised 12 cylinders in a v-shaped configuration and was rated at 1100 kilowatts.

A fuel supply pump supplied the MGO to both auxiliary engines. The fuel supply pipe was then routed to an inboard and outboard set of cartridge filters[2] and a high-pressure fuel injection pump, which were mounted on either side of each engine **(Figure 2)**.

For illustrative purposes only: not to scale

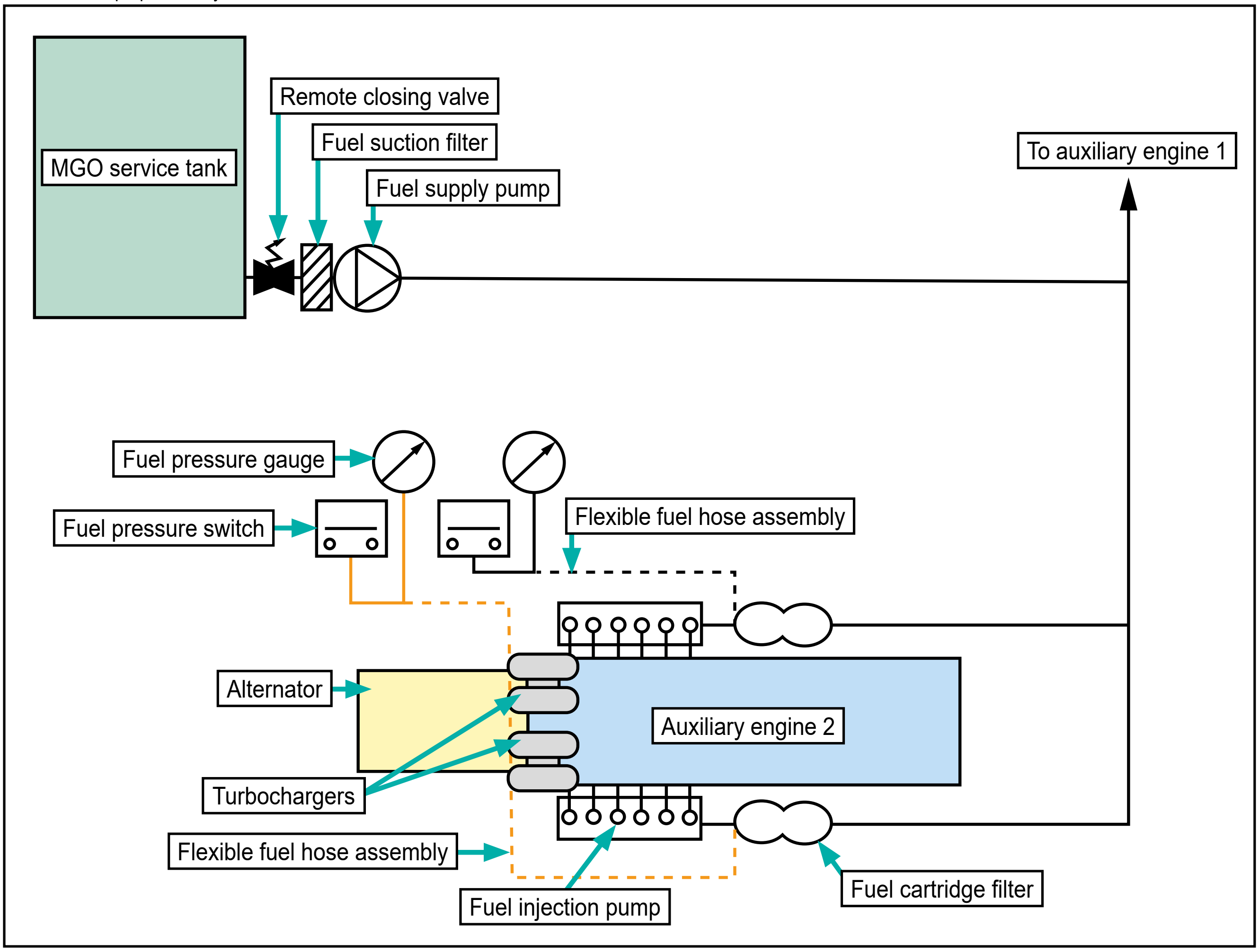

Figure 2: Schematic diagram of auxiliary engine fuel supply system

[2] A disposable filter insert contained within a housing.

INITIAL FINDINGS

The MAIB investigation identified that the fire started below the outboard turbocharger of AE2 when a small-bore flexible fuel hose failed. Exhaust gas had leaked from the outlet of the turbocharger and caused the fuel hose to overheat and fail allowing MGO to spray onto a high temperature surface, where it ignited and a significant fire developed.

Auxiliary engine alarm system modifications

Maintenance records showed that the alarm system for both auxiliary engines had been modified between April 2003 and July 2006, when *Finnmaster* was under different ownership. Low pressure fuel alarm pressure switches and gauges had been installed to both AE1 and AE2 to alert the ship's engineers should the fuel cartridge filters become blocked.

The flexible fuel hose that failed in the accident was connected to the outlet from the inboard set of AE2 cartridge filters **(Figure 3a)**; the hose was routed aft along the engine and passed over the top of the flywheel cover under the turbochargers **(Figures 3b** and **3c)**. It then connected to a pressure sensor on an instrument panel mounted outboard of the AE2 alternator. Both this hose and the matching hose on AE1 were 3.4m in length. No isolation valve was installed at the connection to the cartridge filters.

The thermal insulation that covered the auxiliary engine turbochargers had also been modified by the installation of bespoke insulation pads over the existing insulated box structure. The flexible fuel hose from the AE2 inboard fuel cartridge filters was routed under these insulation pads.

Regulation and guidance

SOLAS Convention[3] Chapter II-2: Construction – Fire protection, fire detection and fire extinction, permitted the restricted use of flexible hose assemblies *in positions where the Administration is satisfied that they are necessary*, and that, *oil fuel lines shall not be located immediately above or near units of high temperature*.

The International Maritime Organization (IMO) provided guidance on compliance with SOLAS on the use of flexible hose assemblies through its Maritime Safety Committee (MSC). In June 1994, the committee issued circular MSC/Circ.647 – Guidelines to Minimize Leakages from Flammable Liquid Systems. This stated that flexible hose assemblies *should be in as short lengths as practicable and only used where necessary to accommodate relative movement between fixed piping and machinery parts*. In June 2009, the MSC consolidated the IMO's guidance on fire safety into circular MSC.1/Circ.1321 – Guidelines for Measures to Prevent Fires in Engine-Rooms and Cargo Pump-Rooms. This circular stated that, in addition to the requirements of MSC/Circ.647, flexible hoses *should not, in general, exceed 1.5m in length*. It further advised that *hoses should be constructed to a recognized standard and be approved as suitable for the intended service, taking into account fire resistance, pressure, temperature, fluid compatibility and mechanical loading including impulse where applicable*.

[3] The International Convention for the Safety of Life at Sea (SOLAS), 1974, as amended.

The IMO guidance on flexible hose installations, including the limitation of length, were incorporated into the rules of the two classification societies that provided oversight of *Finnmaster* during the period that the flexible hoses were in place on the vessel.

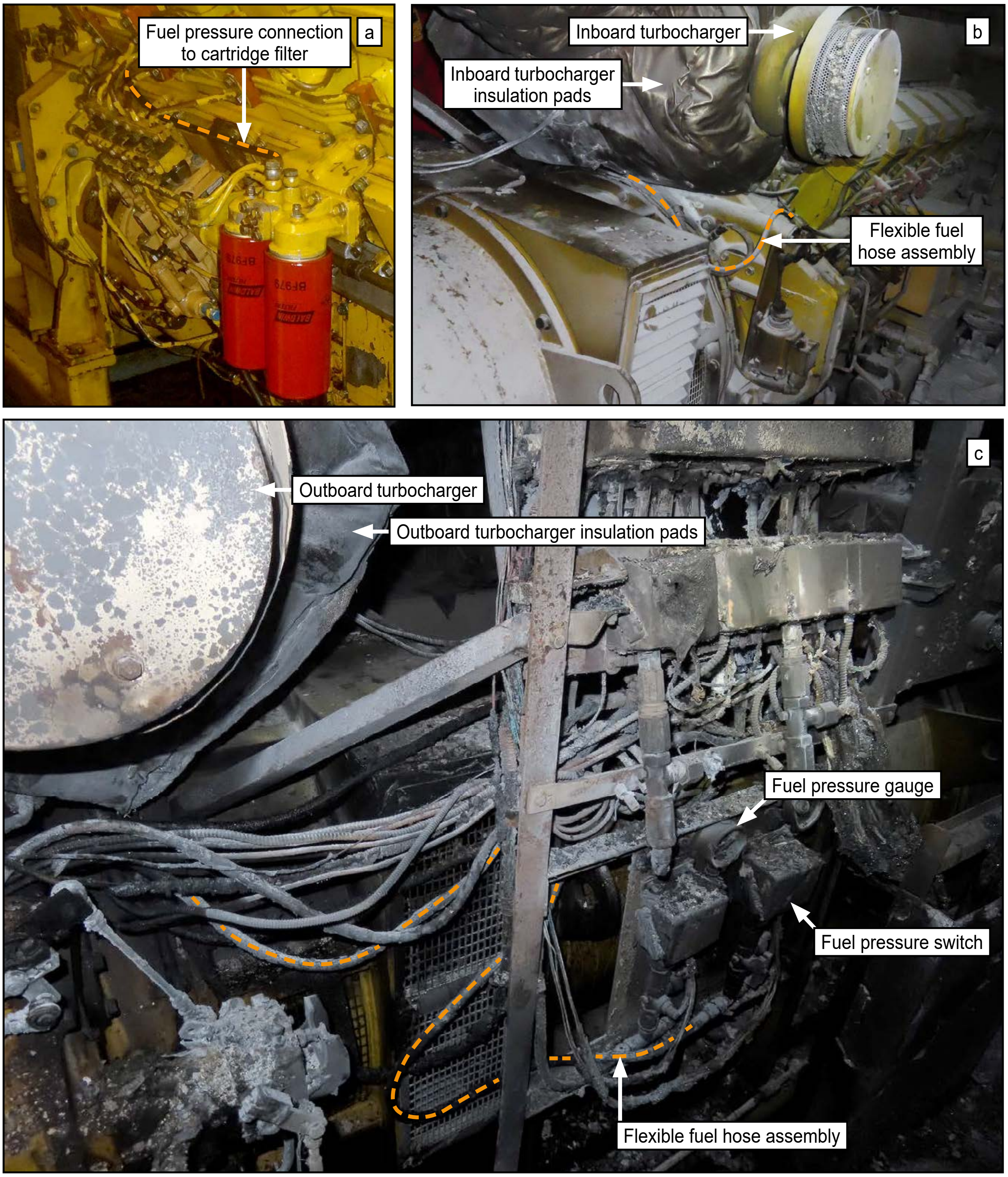

Figure 3: Small-bore flexible fuel hose assembly on AE2, as indicated by dashed orange line

FINDINGS

In this case, the flexible hose assemblies were not needed to accommodate relative movement between fixed piping and machinery parts over their entire length between the cartridge filters and the instrument panel. Furthermore, the routing of the hoses under the turbochargers covered by the insulation pads exposed them to the risk of contact with high temperatures and also made them difficult to inspect.

SOLAS, IMO guidance, and classification society rules all provided the means to ensure that systems are designed, installed and maintained so as to reduce the risk of fires in machinery spaces. The MAIB investigation into the modifications to the auxiliary engine alarm system is ongoing, but has established that the initial proposal to modify the system on board *Finnmaster* had not been submitted to the classification society for approval and the installation was not surveyed on completion. Although the flexible fuel hose was subsequently replaced a number of times during the period of over 15 years before the accident, its material, length and routing had remained the same throughout. Furthermore, the risk that the flexible fuel hoses posed to the safety of the vessel had not been identified or mitigated.

SAFETY LESSONS

- The risks associated with a modification on safety critical equipment should be considered before and during the work being completed. In this case, the positioning of the fuel pressure gauges and pressure switches required the pressure signal to be transferred from one side of the engine to the other. The relocation of the pressure switch closer to the cartridge filters would have removed the need for a long hose; if this was not possible, a rigid metal pipe secured with clamps and routed at an appropriate distance from the engine's exhaust might have been a safer option.
- Flexible hoses are recognised as having a higher risk of failure than a properly fitted metal pipe. An isolation valve fitted at the point of supply allows a flexible hose to be safely isolated in the event of leakage.
- Flag state administrations, ship operators, classification societies, marine surveyors and port state control officers are advised of the risks posed by flexible hose assemblies used in systems that carry flammable liquids if they are not installed and maintained in accordance with IMO MSC.1/Circ.1321.

Issued March 2023

Marine Accident Report

INVESTORS IN PEOPLE