

This is an investigation report issued by the Bermuda Department of Maritime Administration (DMA), into a fire on the cruise ship Royal Princess off Port Said, Egypt on 18 June 2009. The DMA conducted the investigation pursuant to the IMO Code for the Investigation of Marine Casualties and Incidents (Resolution A.849(20)).

**Extract from
The Bermuda Merchant Shipping
(Accident Reporting and Investigation)
Regulations 1999 – Regulation 4**

“The fundamental purpose of investigating an accident under these Regulations is to determine its circumstances and the causes with the aim of improving the safety of life at sea and the avoidance of accidents in the future. It is not the purpose to apportion liability, nor, except so far as is necessary to achieve the fundamental purpose, to apportion blame.”

Further printed copies can be obtained via direct application in writing, to the Chief Surveyor of the Department of Maritime Administration

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GLOSSARY OF TERMS

AMOS	Asset Management Operating System. A comprehensive commercially available computer based planned maintenance system.
Bridge Team	Ship's Personnel who have bridge navigational watch duties
Company	Princess Cruise Lines Ltd.
DMA	Department of Maritime Administration, Bermuda
ECR	Engine Control Room, located on deck 3
Fleet Regulations	PCCL Safety Management System
GT	Gross Tons
IMO	International Maritime Organization
kW	Kilowatt – The measure of power output for shipboard machinery
LOA	Length over All
LBP	Length between Perpendiculars
OOW	Officer of the Watch
PCCL	Princess Cruise Lines Ltd.
SOLAS	International Safety of Life at Sea Convention. Made at the International Maritime Organization.
VDR	Voyage Data Recorder – Maritime version of the airline industry “black box”

SECTION 1 - SUMMARY

On the evening of 18th of June 2009, a few minutes before 20:00 hours Royal Princess departed from Port Said, Egypt having spent the day alongside there as a planned call on her cruise itinerary. On board were 733 passengers and a crew of 393 giving total number of persons on board of 1126.

As the vessel passed between the breakwaters leaving Port Said a fire broke out on diesel generator No.4. This unit and unit No. 2 were both in operation providing power for the ship. A number of alarm conditions alerted the automation system of a pending loss of power from No.4 and diesel generator No.1 started automatically and took up the electrical load in conjunction with No. 2. Propulsion was maintained and the Captain made for the first available anchorage.

Crew fire parties were mustered and an attempt was made to enter the engine room but the team were beaten back by smoke and heat. Passengers were called to muster stations and looked after there by the passenger services teams. A decision to tackle the fire with the CO₂ total flooding system was quickly made and as soon as the vessel was in a position to anchor the engine room was sealed, machinery stopped and CO₂ injected.

Boundary cooling was maintained where necessary and temperatures were seen to reduce quite quickly after the CO₂ injection. Passengers were held at muster stations until just after midnight when they were allowed more freedom to access open decks in view of the heat in muster stations in June in Egypt with no air conditioning and limited ventilation. At about 0041 hours an entry was made to the engine room which confirmed that the fire was extinguished and shortly afterwards passengers were allowed to return to their cabins to rest.

Later that morning (Friday 19th June 2009) the vessel was able to re-start units No.1 and No. 2, restore power and make her way back to Port Said where passengers could be disembarked and the investigation commenced.

Throughout this report times are given in Local Time which was GMT +3

SECTION 2 - GENERAL PARTICULARS

2.1 Royal Princess (RP) is a passenger cruise liner which was constructed by Chantiers Atlantique, San Nazaire, France in 2001 and delivered as “R8” She subsequently changed name to “Minerva II” before being purchased by PCCL and re-named Royal Princess. She is registered in Bermuda.

2.2 The general particulars of the vessel are as follows:

Length Overall (LOA)	180.45 metres
Length Between Perpendiculars (LBP)	157.85 metres
Breadth (extreme)	28.30 metres
Breadth (moulded)	25.46 metres
Depth (moulded)	8.40 metres
Load draught	5.965 metres
Air draught (at Load Draught)	40.94 metres
Gross Tonnage (GT)	30277
Net Tonnage (NT)	11481
Maximum Speed	18 knots
Call Sign	ZCDV2
IMO Number	9210220
Crew (normal)	373
Passengers Max	777
Maximum Persons on board	1150

2.3 The vessel has diesel electric propulsion with the prime movers being four diesel main engines located in an engine room aft. The engines are installed with the flywheel end facing forwards and connected to the generator units by shafts penetrating the forward bulkhead to the propulsion motor room. The aft boundary of the engine room is formed by a watertight bulkhead and aft of this on deck 1 (the lowest deck) is an evaporator room. Above this on deck 2 are the engine room workshop and a selection of other service spaces. A power operated sliding watertight door leads into the engine room through this bulkhead at deck 2 level. The door is on the centreline and faced by a lobby with access from both the access stairwell down from deck 3 and the workshop to port.

2.4 The engine room deckhead is formed by deck 3 above and the space is divided into two levels by a deck at the deck 2 level. This deck has two large openings over the main engines on each side so that it forms a platform around the engine room at the deck 2 level from which it is possible to have an overhead view of each pair of engines. On this platform deck are various items of ancillary machinery. Casings extending upwards to the funnel provide space for the exhausts from the four engines, the two boilers and the incinerators to reach open air. They also provide space for the ventilation trunks that supply fresh air to the engine room.

- 2.5 The forward engine room bulkhead is a main vertical zone bulkhead separating Zone 4 from Zone 5. It is penetrated by a sliding watertight door at Deck 1 between the engine room and the next space forward which is the propulsion motor room. This is the only direct opening between the engine room and the propulsion motor room. The shaft from each diesel main engine penetrates through this bulkhead to an alternator situated in the propulsion motor room. The alternators, in turn, supply power for all ship's services and for two Main Electric Propulsion motors.
- 2.6 The propulsion motors are situated in the propulsion motor room immediately forward of the four alternators. They are rated to 6750 kW at 170 RPM and drive the propellers via two shafts that run back aft between the two alternators on each side, back through the bulkhead to the engine room and between the two main engines on each side then through the aft engine room bulkhead.
- 2.7 The system is controlled by a comprehensive power management system that monitors a variety of critical values. The intention is to avoid "black outs" by ensuring that whenever power demand approaches the maximum available power at any time, another main engine and alternator set is started automatically and synchronised to the main switchboard to meet the demand. An automatic diesel generator start in this situation takes about 1 minute from initiation until the unit is synchronised and supplying electric power to the system. Additional generators may also be started manually on demand to meet an anticipated load. Whenever demand exceeds available load, as well as the ability to start and add in additional diesel generator units, the system is equipped with a number of preference trips that will selectively cut off electricity consumers in an order of reverse priority to maintain power supplies to critical functions.
- 2.8 In the event of a black-out there is an emergency generator located outside the engine room that will come on load automatically within a few seconds to supply key emergency features such as emergency lighting, emergency fire pump and others. A transitional power supply system operated by batteries supplies lights and other critical functions in the interval between the power failure and the emergency generator supplying power.
- 2.9 The engine room extends to two decks high on the centreline where the two boilers are located on the deck above and aft on each side casings extend upwards from the engine room to the funnel. Air for the engines is supplied by fans taking their supply from intakes at Deck 10 under the funnel and ducting it down the trunks and exhaust air from the engine room is via outlets into the funnel casing at Deck 11. All the outlets and inlets are protected by louver type dampers capable of remote operation. Each main engine has an exhaust trunk extending up through the casing on the appropriate side to emerge separately at the funnel top along with the incinerator outlets and the boiler exhausts.

- 2.10 Fire detection is provided by a comprehensive addressable fire detection system with smoke detectors, heat detectors and manual call points dispersed all through the ship. In the engine room as well as smoke detectors there are flame detectors. The fire detection system alarms on the bridge, which is manned 24 hours/day, at the central panel from where the location of any activated head can be read off the screen and where a print-out provides a permanent record of all alarms.
- 2.11 A repeater panel for the fire detection system is located in the engine control room.
- 2.12 For fire fighting in the engine room there are three fixed systems;
- a bilge area foam system which supplies fire fighting foam to the bilges under each engine;
 - a water mist system that can provide a high pressure water mist from heads located over each engine; and
 - a total flooding CO₂ system that can fill the engine room with CO₂.
- 2.13 Engine exhaust gases are monitored for smoke by an obscurity meter that records in the engine control room and additionally by a camera trained on the funnel and visible on a screen over the main console in the ECR. The recording system for smoke obscurity failed during the day of the fire and no records are available for the time of the incident.
- 2.14 The four main engines are Wärtsilä “Vasa 32” type units each developing 4680 kW at 720 RPM to give a total available power of 13,500 kW. These units are 12 cylinder “V” type four stroke medium speed diesel engines installed with the flywheel end facing forward and connected at the forward end to a shaft through the bulkhead to an alternator in the propulsion room. Each side of each engine has an exhaust gas turbo charger located at the aft end. The exhaust outlets from each cylinder lead to an exhaust header for each side positioned over the top of the engine between the two cylinder banks taking the exhaust along the top of the engine to the appropriate turbo charger. The two exhaust lines are enclosed in an insulated metal box running down the top centreline of the engine protecting them from contact with flammable materials. The normal exhaust gas temperature, and by necessity, the temperature of the exhaust gas headers is in the region of 400 degrees C. The normal ignition temperature of the fuel oil used in the engines is about 220 degrees C.
- 2.15 The engine banks are labelled A and B with bank A being the left bank of cylinders looking towards the turbo charger end and the cylinders are numbered 1 to 6 on each bank with No. 1 at the forward end and No. 6 at the turbo charger end.



View of engine No. 1 (undamaged) taken from deck 2 looking aft and showing the central cover over the exhaust headers, leading to the two turbo chargers and the uptakes with the rocker covers for each side visible. Also visible are the two crankcase breather pipes rising vertically just in front of the uptakes.

2.16 Fuel supplies for each pair of engines are delivered by a fuel treatment unit situated in the separator room, the compartment immediately forward of the propulsion motor room, and separated from it by another watertight bulkhead. Here are located the service tanks, fuel circulating pumps, separators and other fuel treatment facilities. The fuel system is separated into two equal sides, port and starboard, and each can operate independently. Cross over arrangements allow for flexibility in terms of which side is used to provide fuel to which side but in normal operation the port side unit delivers fuel to engines 3 and 4 and the starboard side unit delivers fuel to engines 1 and 2.

2.17 The service tanks are all equipped with quick closing valves operated from a cabinet near to the engine control room. These valves are a SOLAS requirement and, when triggered, close almost instantly and are designed to allow fuel supplies to a fire area to be remotely cut-off .

- 2.18 The fuel system delivers low pressure fuel at about 7 bars to each engine. The fuel arrives through a filter unit located between each pair of engines and then is delivered to the fuel rails in the “hot box” on each side. The “hot box” is a containment area on each side of the engine. It houses the injector pumps for each cylinder as well as the low pressure fuel circulating pipes and the feed and return pipes from each injector.
- 2.19 The design is intended to achieve two purposes; firstly to prevent any fuel leakage from a fractured pipe from impinging on any hot surface and secondly to maintain the temperature of the fuel piping and injection systems in order to maintain fuel viscosity, hence the term “hot box”. The fuel supply line runs along the hot box on each side and back again to the fuel unit in the separator room. It is kept pressurised with hot fuel oil circulating around the system by the fuel circulation pumps and booster pumps so that each injector pump can draw on a constant supply of hot clean fuel at about 7 bars. Unused fuel returns back to the fuel treatment unit. A pressure sensor constantly monitors the pressure in the fuel line and gives an alarm condition if the pressure falls below 5 bars. An additional Low-Low Pressure alarm is triggered at 4 bars. A drop in fuel oil pressure could indicate a number of faults, including a leakage of fuel. In any case a significant loss of fuel pressure signals a potentially imminent loss of power in the affected engine.
- 2.20 Given the possible consequences of a loss of pressure in the fuel oil system this is one alarm condition, amongst others, that automatically initiates the starting of another diesel generator through the power management system and its synchronization so that overall required electric power is maintained.
- 2.21 The vessel regularly operates on two main engines only for voyages where full speed is not required and this is a normal condition for routine harbour manoeuvring. If high speed is required at sea she can make use of three or four main engines but it is much more normal to operate on 2, occasionally 3, leaving one unit for maintenance and one on standby. This also saves fuel. With two diesel generators in service under normal conditions power available is about twice the total demand provided ship speed is not pushed too high. A sudden loss of one engine, however, would mean the other suddenly taking a load close to 100% of its capability with a consequently very high risk of a blackout.
- 2.22 The ship can operate on one main engine but that unit is then operating close to its limits to supply the whole ship and in this configuration propulsion loads must be minimised and some large electrical consumers are not available. Clearly in this mode any failure would lead to an immediate black out and loss of propulsion.
- 2.23 The hot box on each side of each engine is covered by an aluminium cover. This is easily opened by hand by removing a few bolts fitted with thumbwheels. The cover is designed to seal the fuel pipe and injector pump area from the rest of the engine to the extent that any fuel pipe failure in the hot box cannot spray fuel onto a hot surface. This is a SOLAS requirement to prevent engine fires, many of which have previously occurred from this cause.

2.24 As an additional required safety feature at each end of the hot box there is a fuel oil leakage drain leading to a small collection vessel. This contains a float switch and is connected to the main alarm system, and designed to give an immediate alarm if any quantity of leaked fuel in the hot box runs down the drains. From the drain collection vessels any spilt fuel is diverted to a spill tank.

SECTION 3 - SEQUENCE OF EVENTS

- 3.1 This sequence of events has been compiled from interviews with members of the crew, an examination of the physical evidence, alarm printouts and other records and from experimentation on board. Not all the times are exact but where they are expressed as “about” or in similar terms they are the best estimate that can be made.
- 3.2 The vessel was on local time Egypt (GMT +3) and this was the time frame used by the bridge team to log events on the bridge but various items of recording equipment on board are set to differing times, some to GMT, some to UK time and some to European Time. Copies of data attached to this report therefore show various times but for consistency all times in the report are converted to, and reported in, local time.
- 3.3 Royal Princess arrived in Port Said in the morning of Thursday 18th June. Engine No. 4 had been started the previous day in Alexandria and operated all day Thursday. No. 2 was started prior to departure Port Said so that No. 4 and No. 2 were the two units on load for departure from Port Said.
- 3.4 Departure time was set for 20:00 and at about 19:00 the Chief Engineer signed off a positive ready to sail report confirming that the engineering, power and propulsion systems were in all respects ready for sea. This is a requirement of the Company Safety Management System (Fleet Regulations) and is to be completed an hour before sailing.
- 3.5 Sailing from Port Said is often delayed due to traffic but on this occasion the traffic conditions in the harbour allowed an early unberthing and Royal Princess left the berth a few minutes before 20:00. A local pilot provided assistance to the bridge team.
- 3.6 At this time the disposition of key duty personnel was as follows:

Bridge:

Captain, (Navigator)
Staff Captain, (Operations Director)
Senior First Officer, (Co-Navigator)
Second Officer, (Administrator)
Helmsman,
Lookout.

Engine Control Room:

Chief Engineer,
1st Engineer, (Watch Engineer)
Senior Electro Technical Officer, (SETO)

Engineering spaces:

Motorman.

3.7 A few minutes before 20:00 the Second Engineer arrived in the ECR to take over the watch at 20:00. He took the handover from the 4-8 watchkeeper, a process that took about 5 minutes. At this time (20:03 approximately) all indications were normal, no alarms were in evidence and the vessel appeared to be operating normally in manoeuvring mode with control from the bridge and power being supplied to both propulsion motors, thrusters and ship services from diesel generators 2 and 4. Total load was well within the total available power level. The Engineering Watch Officer normally mans the station to the left of the console where he can see the alarm panels clearly and from where he has a keyboard that allows him to access different information screens and initiate actions to control the engineering plant. He can also monitor total power available and total power demand. He can communicate by VHF portable radio with the motorman who has a similar radio equipped with a headset allowing him to hear in noisy machinery spaces.



ECR control panel looking forward towards the port side showing (centre of picture) the position for the watch engineer and to the right the central part of the panel which has the engine controls. Above the engine controls can be seen the first screen of the camera monitoring system.

3.8 The Chief Engineer was standing to his right at the centre of the console facing the main engine controls and also monitoring the overall status of the plant. The Senior Electrical Officer was also in the control room to be ready to deal with electrical issues. The motorman was in the evaporator room on a routine task. A few minutes earlier he had passed through the engine room and noticed nothing out of the ordinary as he passed through.

- 3.9 At 20:08 an alarm came up on the main engine room alarm panel in front of the 2nd Engineer. The alarm indicated low fuel oil pressure at main engine No. 4. (A low pressure alarm is triggered at 5 bars). Fifteen seconds later the fuel oil pressure low-low level alarm came up for No. 4 (fuel pressure below 4 bars) The 2nd Engineer acknowledged the alarm several times and a few seconds later the automatic system began the start up sequence for engine No. 1. This process takes less than a minute from initiation to the stand-by alternator being synchronised and on-load.
- 3.10 About half a minute after the fuel oil low pressure alarm a fire detector (Smoke Detector Head No. 19) located in the engine room Port Side at Deck 2 activated. 9 Seconds later this alarm was muted by Second Officer on the bridge while he checked; 2 seconds later another alarm activated this time from a smoke detector on deck 1 port side engine room (head No. 46). This was closely followed by detector 15 (Deck 2 engine room port side) and detector 67 (Deck 8 port side engine room casing,). A few seconds before 20:09 the Second Officer again muted the alarm panel but alarm conditions continued to come up. The first set were quickly followed by Casing (deck 4) port side, Casing (deck 6) port side, Casing (deck 7.) Thereafter activations came up every few seconds. All were from smoke detectors in the port side of the engine room and in the machinery space casing and the overall progression was rapidly upwards from Deck 2 suggesting smoke and combustion products rising into the casing from the port side. The first flame detector alarmed at 20:10 for a flame detector at Deck 2 port side engine room.
- 3.11 The Second Officer realised very quickly that the indications suggested a serious situation in the engine room and called the engine control room to tell them that they had multiple fire indications from the engine room. Receiving this call the 2nd Engineer called the motorman on his radio to ask him to investigate reports of fire alarm activation from the engine room casing.
- 3.12 At this time the ship was heading northwards in the buoyed channel parallel to the Port Said western breakwater and had just dropped the pilot. She was close to where the eastern breakwater ends and the channel continues open to the east following the western breakwater on the port side. In this position there was no room to turn to port to leave the channel to the west because of the breakwater and to starboard the depths are too shallow for the ship; leaving her confined at this time to the buoyed channel.
- 3.13 The Motorman was in the evaporator room aft of the engine room. He had passed through the engine room a few minutes earlier and noticed nothing out of the ordinary. When he received the radio call he returned to the engine room via the watertight door at deck 2 and saw a fire on the aft end of engine No. 4. As he watched he saw the water mist system start. He reports seeing a second smaller fire at the forward end of the engine at this time. This cannot be confirmed and was not seen by anyone else but it remains possible that a fire had ignited here at this time.

- 3.14 As the second engineer was dealing with the alarms and calling the motorman the Electrician noticed an unusual amount of very black smoke from the exhaust stacks visible on the television monitor. Realising that the motorman might have to travel some distance and open a watertight door, which takes time, to reach the engine room he went out of the engine control room into the alleyway on the port side. His emergency role in a machinery space emergency is as a part of the assessment team, in any case. This alleyway is known as the “M1” on board and it leads along most of the ship’s length on deck 3. It is a major crew working thoroughfare. A few metres aft from the control room in this alleyway is an escape door that leads directly from the engine room. A stair leads directly up from deck 2 in the engine room at the port side outboard (very close to the forward end of engine No. 4) to this door. He went down and as he emerged onto deck 2 in the engine room he saw flames at the aft end of main engine No. 4 extending up to about the top of the turbo chargers. The engine was still running. He left immediately via the same route.
- 3.15 He went straight back towards the control room intending to report a real fire. At just about exactly the same time the Chief Engineer saw the fire on the camera monitors as they cycled through and went immediately across to the control panel for the water mist system and activated it. This system is capable of providing a very fine water mist discharge over any selected engine or over either of the two separator units in the separator room. It is necessary only to select the desired target area then a simple button press activates the system. At the same time, having seen that No. 1 was on-load, he ordered the Second Engineer to stop No. 4. The Second Engineer initiated this process and a normal shut down was completed at 2014 for No. 4. At the same time the emergency stop for No. 3 was pressed.
- 3.16 The bridge team realised that they had a serious emergency and used the PA system at 20:10 to announce “assessment Party to the ECR¹”. This is the normal planned first response to an identified emergency and involves a small team of senior personnel with the right mix of skills to reach an area quickly and make an immediate assessment of the threat and the scale of the problem. The assessment party for an engine room emergency includes the Staff Engineer, the Senior Electrical Officer and the Senior First Engineer.
- 3.17 The Master had charge of navigation (designated “Navigator” in the Princess/P&O Bridge Team Command and Control System BTCC) and was fully involved in the handling of the ship and keeping her on a safe track and away from other vessels. The pilot had already disembarked. He was concerned about the risks of a black out and resulting loss of propulsion in the ship’s situation just then. She was accelerating after dropping the pilot and had reached a speed of approximately 12.5 knots at this point but if he were to anchor in her present location there was a risk that the ship would block the channel for all other vessels entering or leaving Port Said. The Staff Captain took command of the emergency centre on the bridge and the Master remained in charge of the navigation until the ship eventually anchored except for a very short period when he handed charge of the ship to the Second Officer while he was briefed on the emergency.

¹ ECR - Engine Control Room

- 3.18 The Staff Engineer had finished duty for the day and was on deck 11 in the crew area beside the funnel relaxing and watching the departure. He was with the Doctor. His attention was drawn by the Doctor to an unusual amount of black smoke issuing from the exhaust. From this position it is not possible to see the individual exhaust pipes but it was clear that one engine at least was emitting much more smoke than was normal.
- 3.19 It was sufficiently abnormal to cause him concern and he headed for the stair but before he reached it the Assessment Party announcement was made. This was at or very close to 20:10, about two minutes after the initial fire detector alert and at about the same time the Senior Electrician was looking into the engine room. Shortly after the Staff Engineer left the Doctor noticed a very heavy rush of black smoke from the funnel just before the crew alert was called.
- 3.20 The Senior First Engineer was in the dining room on deck 9 when the assessment party call was made, he left immediately for the engine control room. Both he and the Staff Engineer arrived together within about 30 seconds of the announcement and collected their radios.
- 3.21 The Chief Engineer informed them of a fire on No. 4 and they went immediately to the escape door leading into the engine room and down to deck 2 following the same route that the Electrician had taken. On the way they met him in the alleyway and he turned to join them. The three officers entered together. None of them noticed any smoke in the stairwell as they entered. Turning aft from the bottom of the stair and past the two tanks positioned here on deck 2 just outboard of engine No. 4 they had a good view of the tops of both engines 3 and 4. They saw that there was clearly a fire at the aft end of No. 4 in the area of the turbo chargers. At this stage it was not particularly large and they didn't see any others.
- 3.22 The Senior First Engineer thought it could be tackled with a portable extinguisher and he turned forwards to get the nearest one which was located just under the stairs that they had come down. He had some trouble getting its protective cover off but managed it and turned again towards the fire. The water mist system was operating and appeared to be holding down the fire to some extent. At this stage there was little obvious smoke and the three officers could see clearly and breathe easily.



Looking to starboard on deck 2. This is about the position from where the Staff Engineer and Senior First Engineer saw the fire when they entered. The turbochargers are to the right. In the gap between the deck edge and the first safety rail can be seen the top of No.4 engine.

- 3.23 As they watched the fire appeared to flash forwards and increase dramatically with a very high plume of flame rising from the forward end of the engine right up to the deckhead. It was accompanied by heavy smoke and a blast of heat and smoke coming from forward and all three officers retreated back the way they had come. The Senior First Engineer dropped his extinguisher realising that it would be ineffective now. At this time No.4 was running and sounded quite normal. They retreated via the same door to the M1 and returned to the control room. This fits in well with the Doctor's observation that a few minutes after the Staff Engineer left there was a very substantial increase in black smoke from the funnel. The Senior Electrician was badly affected by the smoke as they made their way out and shortly afterwards reported to the medical centre suffering from smoke inhalation.
- 3.24 In the control room the Chief Engineer had seen the flare up on the camera monitor, he immediately reported a "Big Fire" to the bridge using the talkback. When the Staff Engineer returned he recommended a crew alert. At 2014 the bridge ordered a crew alert which activated all the fire and emergency parties.

- 3.25 The Staff Engineer went out again and started the bilge foam system. The operating station for this is located in a locker just aft from the control room nearly opposite to the escape door to the engine room that they had used earlier. This is the same locker that houses the CO₂ system remote controls. At this time there was smoke issuing from around the edges of the access door to the engine room and building up in the alleyway. Clearly the route they had used a few minutes earlier to assess the situation was now smoke logged. In the locker there was some smoke coming from the scupper but otherwise the atmosphere was fine. This locker is located almost directly over the seat of the fire. It took only seconds to open the foam valve and the appropriate water valve to start foam delivery to the bilge area. Fire pump No. 1 situated forward in the chiller room was the set standby pump and this pump started as soon as the system detected the drop in fire main pressure when the hydrant was opened.
- 3.26 From the control room the Senior First Engineer went towards the engine room fire locker located off the M1 forward of the control room. Here the fire team was already getting ready. Having checked on his team the Senior First Engineer went back to the control room in time to see the Staff Engineer switch all the emergency stops for the port side of the engine room and the port side Fuel Oil treatment. This was just before 20:17. These stops are on a set of switches located on the starboard side of the main console. There are switches for general areas such as Evaporator Room or Emergency Generator Room and switches for each side of the engine room and fuel oil treatment. Operating the two switches for the port side diesel generator room and port side fuel oil treatment stops:
- Port Fuel Transfer pumps,
 - Port purifiers,
 - Port Fuel Oil Module,
 - Port Circulating pumps,
 - Port pre-lubrication pumps,
 - Diesel Generators 3 and 4,
 - Port ventilation supply fans to engine room,,
 - Port ventilation exhaust fans ,
 - Port separators,
 - Port fuel transfer pumps,
 - Boilers.
- 3.27 The Staff Engineer asked the Senior First Engineer (as commander of the engine room fire party) to bring the fire team to the workshop. As “on scene commander”, he was planning an entry from the workshop area through the watertight door on deck 2 into the aft end of the engine room. This is the most direct route to the fire scene at a low level and allows fire teams to prepare at the door. It was an evolution which the teams had practised during drills.

- 3.28 The Senior First Engineer went back to the fire locker and directed the team to take hoses and equipment to the workshop area. He stayed until the three man breathing apparatus team were fully dressed then accompanied them to the area just inboard of the workshop on deck 2 from where the Staff Engineer was planning to attack the fire. At this stage conditions aft of the watertight door were good with no smoke. The Senior First Engineer realised that they needed another foam inductor and sent one member of his party back to the fire locker on deck 3 to get one.
- 3.29 This man returned and reported that the alleyway on Deck 3 in the area near the control room and the engine room escape door² was now full of smoke, dense enough to prevent passage without breathing apparatus. The Senior First Engineer went quickly up to check and verified the same thing.
- 3.30 The Master had been informed at 20:17 when the Staff Engineer operated the port side stops. He considered this to mean that port propulsion was off and that only the Starboard propeller was available so extra attention to steering was required. In fact only the port side of the ER had been isolated and there was still ample power available to both propulsion motors and both propellers from No. 1 and 2 generators. It did, however, concern him as the ship does not steer well at very low speed and on one propeller only manoeuvring is even harder.
- 3.31 The Staff Captain took charge of Command and Control of the fire incident. He was mainly in a reactive role as he considered that the engine room team appeared to be covering all aspects of the situation and did not need additional input from him. The crew alert muster was considered to be going well. He was informed of smoke in various parts of the ship. On contacting Port Said authorities the ship was allocated the nearest available anchorage C1 which is located just past the end of the Western breakwater. The passage plan was amended to make for that anchorage.
- 3.32 At this time, the two starboard engines No's 1 & 2 were running and providing power to ships services and to both propulsion motors. The port side engine room fans were off and the port side fuel system was shut down, including separators, circulating pumps, etc. Engine No. 4 was now stopped, however the valves in the fuel system were still open and some fuel was probably draining by gravity from the separating tank to engine 4 albeit at a very low pressure head. The ship was still in the buoyed channel heading outwards. To port the western breakwater prevented any turn to port but there was now sufficient depth to starboard for her to leave the channel if necessary keeping outside the 10m depth contour. The ship's maximum load draft is 5.965m. However the area to starboard is encumbered by the two other buoyed approach channels to the Suez Canal and the El Bahar Light Tower.

² The same door that the Staff Engineer, Senior 1st Engineer and Electrician had used to enter and check on the situation earlier.

- 3.33 The staff engineer organised the fire team at the fire doors leading to the lobby immediately outside the watertight door leading to the engine room aft at deck 2. He directed a two man team in fireman's outfits to move forward enter and make an assessment. The team checked for heat on the door and concluded that it was not excessive. They opened the door a little at 20:19 and a lot of very hot smoke emerged under some pressure, but no flames. They opened the door further and could not see any fire but heat and smoke were still pouring out. They opened the door about half way and entered. Visibility was poor but a few steps into the engine room on deck 2 they were able to see flames on No. 4 engine showing bright red through the smoke. They saw flames at both ends of the engine with the largest blaze at the forward end. They withdrew back through the WT door.
- 3.34 When the team entered the engine room the outrush of thick black smoke and heat drove the rest of the fire team back from the lobby and up the stairs to the stair lobby at deck 3.
- 3.35 The two fireman's outfit wearers came out and closed the WT door again. They lost contact with each other in the smoke but the team leader managed to check that his hose was clear and that the door was fully shut before he made his way out. The outrush of heat had also triggered the sprinkler head just outside the watertight door and this head delivered water until the end of the emergency when the sprinkler pump was switched off.
- 3.36 Smoke at this time was issuing strongly from around the engine room access door on deck 3 and making conditions in the alleyway near the control room untenable. The large volume of smoke that emerged from the engine room when the fire party tried to enter also moved up from Deck 2 to add to the overall level of smoke in zone 5 at decks 2, 3 and 4. The fire party retreated up the stairwell to deck 4 as the Staff Engineer closed the fire doors from the stair well to the gun port area on deck 3 before he left. Other fire doors in this area were still open at this stage and generally remained open. The various members of the fire party made their way by different routes back to the engine control room and noted that they were followed by thick smoke as they went. By this time the area in the alleyway outside the ECR which is designated as the CO₂ muster point was fully smoke logged. The engine room fire party was missing one man who had become separated in the withdrawal from the engine room entry. A call on radio prompted a report from another team that he was accounted for.
- 3.37 At this time, approximately 20:27, the ship was just clear of the buoyed channel. A call was made to Port Control to advise that the ship was making for anchorage C1. The first fire team had made their withdrawal from the engine room and the Chief Engineer considered that the only recourse now was to use the fixed CO₂ system. He advised the Master and the Staff Engineer who made ready to initiate the release while a CO₂ Muster was called. The CO₂ muster station is located in the M1 on deck 3 just aft of the control room door. However because of the volume of smoke in the alleyway in this area the muster point was shifted to the starboard alleyway which was clear of smoke.

- 3.38 At this time the Master estimated that he had about four minutes to run to the anchorage and, though he was now in safe water, he did not want to anchor in the approach zone to the Suez Canal. He appreciated that to seal the engine room preparatory to CO₂ release would cause a black out and a total loss of propulsion. He wanted to be in a position to “coast” into the anchorage area without power. He was also still waiting for the passenger muster to complete and he wanted a PA safety announcement to be made prior to the blackout so all on board were aware of the situation prior to black out in case communications were affected.
- 3.39 At 20:30 the General Emergency Signal was sounded calling passengers to their muster stations. The 1st Officer on the bridge made an announcement to passengers to explain the situation and that the ship was going to anchor. He also explained that in a few minutes the ship would “black out” but that lights would remain on and did his best to reassure passengers that the situation was under control and that there was no need for alarm.
- 3.40 At 20:39 the CO₂ muster roll call was signalled as complete and at 20:44 the Captain authorised an engine room shut down and CO₂ injection and the Chief Engineer operated all the remaining emergency stops to close off fans, dampers, pumps, engines and effectively seal the engine room preparatory to CO₂ release. This stopped the two remaining engines and caused an immediate black-out. He also operated the fuel quick closing valves from their operating locker.
- 3.41 The transitional power systems maintained lighting for the few seconds before the emergency generator started automatically and took up the designated emergency supplies. The ship was still making way through the water and was short of the designated anchorage, steering was still available from the emergency generator as were lights but no thrusters or propulsion. The Master allowed the way to come off the ship naturally as obviously no astern power was available. She arrived in “C1” anchorage with less than 2 knots of headway and successfully anchored at 20:58.
- 3.42 The Staff Engineer collected a breathing apparatus set and two men in fireman’s outfits to assist him. He was aware that the alleyway between the control room and the CO₂ release locker was heavily smoke logged. With the two men providing cooling water where necessary he made his way to the release locker. Once inside he opened the control box for the diesel generator room and operated the correct valve lever. Then he took the key for the master control box which is stored in the first box, to open the master box ready to fire the CO₂ system. He called the control room and said he was ready to release. He was asked to wait. Conditions in the locker were rapidly becoming untenable due to heat and he advised the control room of this. After a few minutes, at approximately 20:45, he received the order to release. He pulled the correct levers and quickly exited back to the control room with the two hose men.
- 3.43 He had heard nothing as he operated the release and as he retreated from the locker he realised that he may have forgotten to open the pilot cylinder valves. He deemed it impossible to return and accompanied by the Senior First Engineer and the deck Petty Officer who was equipped with a full fireman’s outfit he made his way up through the messroom and aft to the CO₂ room to make sure the system had discharged.



Looking forward on the "M1". The door on the left is the engine room escape door through which the first entrances were made. On the right is the CO₂ release locker and directly ahead through the (closed) fire doors is the door to the Control Room situated on the right hand side of the alleyway in this view. Heavy smoke was jetting out from around the engine room door through most of the emergency leaving this area smoke logged. The engine room fire locker is further ahead in this alleyway.

- 3.44 The Staff Engineer and the Senior First Engineer accompanied by the deck Petty Officer made their way aft on the starboard side. On the way they stopped at the Chief Engineer's office to pick up the Chief's keys from him as the Staff Engineer had dropped his in the CO₂ locker. The Senior First Engineer stayed in the alleyway leading to the messroom to maintain a communications link while the Staff Engineer and the deck Petty Officer made their way aft. At the galley they were forced to use their breathing apparatus again to get through due to the amount of smoke there. They emerged on the aft mooring deck at 20:56 and entered the CO₂ room. The Staff Engineer called the engine control room to advise them to evacuate just in case as it is a CO₂ protected space, then he manually opened the valve to the diesel generator room, fitted the manual operating handles for the pilot cylinders and operated the system. It was immediately clear that it was discharging and equally that it had not, in fact, operated earlier. This final release is estimated to have been at 20:50.

- 3.45 Returning to the control room via the same route the Staff Engineer noticed that the indicator lights on the control panel for the water mist system were extinguished. He felt that it was important to keep this system running and taking his breathing apparatus, he considered that it was important to maintain this system in operation to assist in cooling down the fire area and he and the deck Petty Officer headed forward to investigate accompanied by the Senior First Engineer. They left the fire team doing as much as they could with hoses in the deck 3 area to keep boundaries cool.
- 3.46 The pump and local control panel for the water mist system is located in the chiller room forward on deck 1 which they entered via the escape hatch in deck 2 and the Staff Engineer and the deck Petty Officer went to the local control panel for the system. There was a fault light showing and the Staff Engineer tried to reset the system but without success. He checked the water tank for water, found it at the correct level, and then opened the electrical cabinet and made an emergency manual override then started the pump. This time it started correctly and showed the correct pressure. He asked the Senior First Engineer to pass down the two breathing apparatus sets and he and the Deck Fitter made their way back aft on deck 1 towards the propulsion room with the intention of checking on the forward engine room bulkhead. The Senior First Engineer headed back towards the control room on deck 2 but on the way back he overheard a call on his radio from one of the boundary cooling teams to say that they had lost water pressure on the fire main.
- 3.47 He ran back to the control room where he saw that the indicator lamp for pump No. 1 was, in fact, illuminated which should indicate a running condition. He set off again forward as quickly as he could to the pump, which is situated in the chiller room forward. Entering he saw that the pump was in fact stopped and he tried to do a local manual start but without success. Leaving it he turned aft and went through the watertight door to the next compartment aft, the pump room, and manually started pump No. 2. This pump started correctly and indicated 10 bar delivery pressure to the fire main. Returning to the control room he arrived back at just about the same time as the Staff Engineer returned from the propulsion room.
- 3.48 The Staff Engineer had worked his way aft as far as the propulsion room and checked the sector valves for the water mist system which are mounted on the bulkhead just by the watertight door to the engine room. He saw that all four valves were closed and he opened the ones for Nos. 3 and 4 engines and heard water passing through. He and the deck Petty Officer checked the bulkhead using the thermal imaging camera in the deck Petty Officer's helmet. They found a hot spot visible to the camera in the converter room on deck 2 adjacent to the engine room bulkhead but no visible signs of heat transfer. Otherwise they found no problems and they returned to the control room to report.
- 3.49 While this was taking place the deck preparation teams lowered all lifeboats to their embarkation positions and reported them ready at 2110.

- 3.50 At this time the level of smoke in the M1 alleyway was decreasing and the staff engineer sent the deck fire party to try and start boundary cooling in the workshop area on deck 2. He was also able to recover his keys from the CO₂ release locker and he and the Senior First Engineer directed boundary cooling and checking in the area. They found signs of heat in the electrical locker on deck 3 where the deck covering was starting to smoulder and they got the boundary cooling teams to add a little water which was quickly effective in dealing with the problem.
- 3.51 Elsewhere in the ship the passenger services staff were managing the passengers in their muster stations. With the ship on emergency power the lights were on but the toilet system was out of action and there was no air conditioning. They arranged for cold towels to be provided and chilled bottles of water from fridges and chillers wherever they could be reached. Many of the passengers had not long returned from ashore and had not eaten. The passenger services teams used every accessible galley and pantry to collect cold meats, salads fruit, confectionary and other materials to prepare about 1300 rounds of sandwiches and other food for passengers. The main galley, however, could not be accessed because of smoke. The toilets proved to be a problem throughout the night and as the available ones near the muster stations became choked the passenger services teams in consultation with the captain allowed passengers under escort to use toilets further away from the muster stations.
- 3.52 The fire parties operating from the engine control room continued to monitor temperatures and smoke levels using their infra red remote temperature sensor and the helmet thermal imaging units with the fireman's outfits. Cooling was applied where needed. They were able to report signs of temperature decrease in all areas. At 21:13 the Master made a further announcement to passengers to reassure them that the situation was under control.
- 3.53 Temperatures were, however, rising in the muster stations without the air conditioning system or ventilation system, and with the smoke in various decks clearing a bit, limited ventilation was turned back on at 22:05. By 23:22 the passenger services teams were escorting passengers in need of fresh air to the open decks in groups and shortly afterwards the Captain announced that the situation was under control and that it would shortly be possible to allow general access to open decks. Just after midnight the Captain announced free access to decks 9 and 10 only for passengers. This greatly eased the situation in the muster stations and made passengers generally more comfortable.
- 3.54 At 23:38 there was a conference between the Captain, the Chief Engineer, the Staff Engineer and the Senior First Officer to evaluate the situation and plan ahead. After discussions with the Company and an on-board evaluation it was decided to make an exploratory entry to the engine room. The Staff Engineer led a three man team into the space via the watertight door at deck 2 aft at 00:41. They found high temperatures and a reasonably clear atmosphere but no sign of fire and after making a quick evaluation they exited and closed the door again.

3.55 Just after 02:00 the Captain announced that passengers were free to return to their cabins and rest. He stressed that there would only be emergency lighting and no operating toilets. Many of the passengers took advantage of this to return to their cabins and simply lie down. At the same time he allowed the greater part of the crew to stand down from their emergency stations and get some rest. Several other entries to the engine room were made during this period and the atmosphere checked using the ships O₂ measuring equipment. By 08:50 after a period of ventilation main diesel generator No. 2 was successfully started and the ship restored to mains power and full services. Later that morning she was manoeuvred back to Port Said on engines 1 and 2 and berthed alongside where passengers could safely disembark.

SECTION 4 - SOURCES OF EVIDENCE

- 4.1 An investigation was commenced by the DMA on 20th June 2009. Two investigators from the Maritime Administration; Bermuda joined the vessel at Port Said first thing on the morning of the 20th.
- 4.2 The investigators made a thorough physical examination of the affected areas and interviewed all the key personnel, taking depositions where appropriate. In addition they collected evidence in the form of machine generated records – alarm lists and log print outs. Where it was necessary the investigators made trial runs to establish the time required to move from one location to another.
- 4.3 Inevitably there are items of evidence that conflict and recollections vary. This is normal and in preparing this report the investigators have, wherever possible, used only evidence that can be substantiated or backed up from other evidence. Where there is doubt it is stated.
- 4.4 Subsequent to the fire and the initial investigation the vessel was moved to Greece for repairs and further evidence that came to light while engine No. 4 was stripped down was also incorporated.
- 4.5 All of the evidence was then collated to develop the chain of events described in Part 3 of this report which is the best description available based on all the evidence.

SECTION 5 - ANALYSIS OF EVIDENCE

5.1 Aim

The aim of the analysis is to determine the contributory causes and circumstances of the accident as a basis for making recommendations to prevent similar accidents occurring in the future. There is no intention in this to be critical of what must inevitably be seen as a well executed response to a serious emergency that resulted in the ship and her passengers remaining safe and the fire extinguished without any external assistance. However it is also necessary to try and see if anything can be learned from a rare experience that might assist others in the future trying to deal with a similar situation.

5.2 Issues to be addressed.

5.2.1 An analysis of the chain of events set out in Part 3 of this report suggests a number of questions that need to be answered and this section attempts to derive answers to these. They include:

- The timing of events.
- What caused the fire and how did it develop?
- Why did the Hi-Fog system stop and how effective was it?
- Is there a need for any procedural changes?
- How effective were the fire fighting efforts?
- How well did the ship's structural fire protection work to protect against spread of fire?
- How well was the emergency handled in so far as the passenger welfare is concerned?

5.3 The timing of events.

5.3.1 Throughout the investigation it has been difficult to reconcile the timings of important events. The bridge team operated on ship's local time; however the engine room alarm system operated on GMT while the fire detection system was set to GMT+1. More importantly none of the systems appear to be in synchronisation. This is important when attempting to determine the exact sequence of events at a time when several disparate things were happening quickly.

- 5.3.2 During the investigation it was concluded that by comparison with the GPS timing and assuming that all the systems had maintained their internal clocks, the fire detection panel was 1 minute 16 seconds slow of GMT +1, while the engine room alarm system was running at 56 seconds fast of GMT. Making the corrections for time zones it is concluded that the engine room alarm system was running 2 minutes and 12 seconds ahead of the fire detection system. Making this correction the timing of the various alarm indications becomes logical and these corrections are accepted and made wherever necessary throughout this report to compute a report time base set to GMT+3 (local Egyptian time.)
- 5.3.3 It is important in any monitoring system to have a consistent frame of reference and in the systems used in Royal Princess time is the main frame of reference. It is thus important that all the systems use the same frame.
- 5.3.4 **It is recommended that the ship ensure that the time references used by automatic recording systems and by manual monitoring systems are synchronised and maintained synchronised to the same time reference..**

5.4 What Caused the Fire and how did it develop?

- 5.4.1 It is clear from the physical evidence that the main seat of the fire was at the forward end of main engine No.4 on the inboard side. In this area the engine is severely damaged; the aluminium crankcase doors and the cam shaft doors have melted away for units 1, 2 and 3 and wiring and other materials in this area are extensively damaged. On top of the engine the rocker covers for units 1, 2 and 3 have also been melted. The damage decreases further aft on the engine and the aft end is almost undamaged suggesting that the heart of the fire was at the forward end.
- 5.4.2 There is evidence of a smaller fire at the aft end of the engine near the turbo chargers. The rubber connection on the crankcase breather pipe on the inboard side is melted and there is clear evidence of flame damage on the structure in this area with blackening and burning in a fan shaped pattern projected upwards from a point on the inboard side of the top of the engine close to the cylinder head for unit A6 (the aft cylinder on the inboard side.). This fire is also reported by several witnesses.
- 5.4.3 Looking at the area on the inboard forward side of the engine which was the seat of the larger fire there is evidence that suggests fuel leaking down the side of the engine and of fire then burning up from the base of the engine to melt the crankcase doors and the rocker covers. Inside the hot box there is some blackening but little sign of serious fire suggesting that although there may have been some fire inside the hot box, it was small compared to the ferocity of the fire outside the box. The electrical wires adjacent to the failed flange, for example, remained intact³. The hot box cover was only slightly damaged suggesting an external fire with flames rising upwards from below the hot box affecting the side of the engine and the rocker covers but not a fire in the hot box itself.

³ See picture Page 29



Engine No. 4 post fire looking forward on the inboard side towards the seat of the main fire. The hot box cover has been removed in this view and it is possible to see the fuel piping and the injector pumps for each unit.

- 5.4.4 Looking in the hot box there is one connecting flange (between the return fuel pipe from injector pump No.2 to the fuel return line) that is loose. These flanges are normally secured with four bolts and an “O” ring seal. Examining this unit after the fire there was only one bolt in place and that bolt was loose. Two of the other bolts were found intact in the bottom of the hot box. The third bolt had not been recovered at the time of the investigation. This 18mm pipe normally carries unused hot fuel at about 7 bars from the injector pump to the fuel oil return line.
- 5.4.5 There is a regular programme of maintenance and inspection on these flanges and other joints in the fuel system. Engine No. 4 was overhauled in December 2008 by the manufacturers, Wärtsillä. The scheduled maintenance programme on board is controlled through the AMOS Planned Maintenance system and schedules a three monthly “LP Fuel Pipe Inspection” Job No. TEC011 for all the fuel piping systems.

5.4.6 The work order generated from the planned maintenance system states that the scope of the job is:

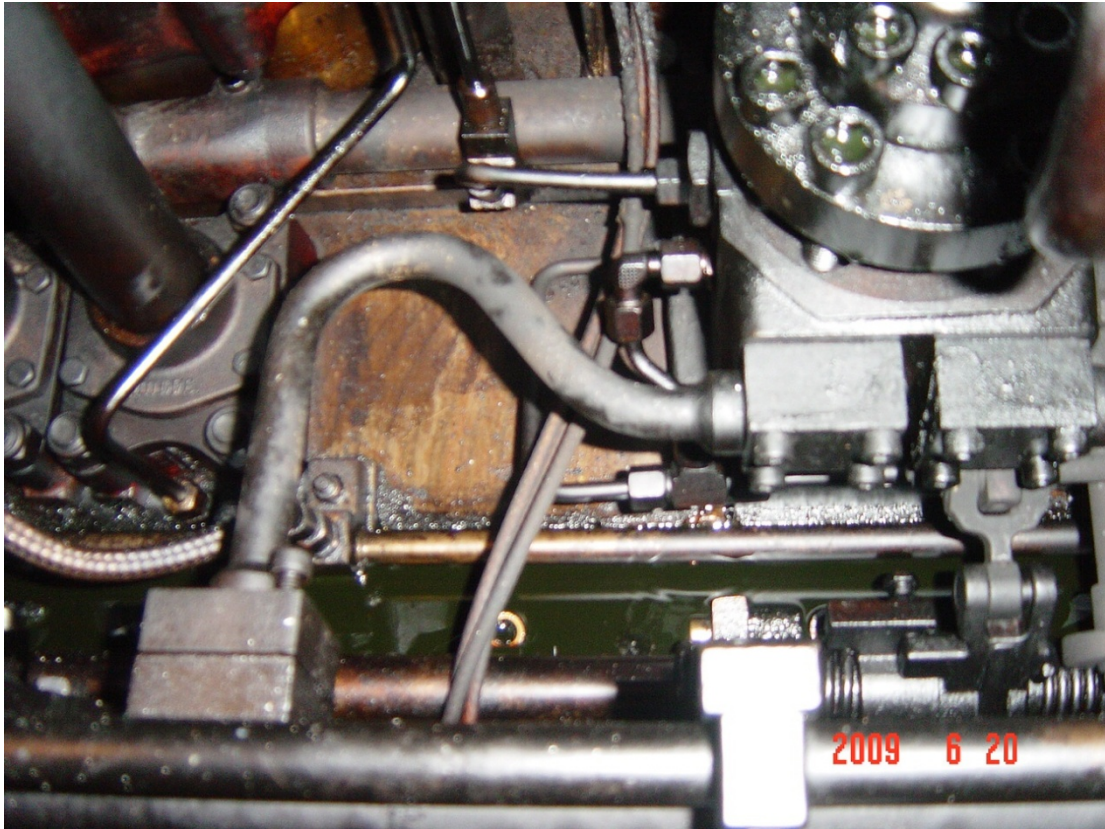
- **Inspection of M.E⁴ Fuel supply and Spill Piping Systems.**
- Inspect all low pressure fuel supply and spill return pipework, to include: check correct torque of all bolts, fittings, and pipework support / clamping arrangements.
- Inspect integrity of all pipework joints.
- Inspect all flexible pipes and hoses.

5.4.7 Following the manufacturer's overhaul in December this job came up for engine No. 4 in April 2009. Maintenance jobs such as this one are controlled by the First Engineer. He manages a team of two mechanical fitters and two fitters. He usually prints off the work order, decides who is to be assigned to the job and then in the morning has a brief jobs meeting in the workshop before sending the teams off to undertake their assigned tasks. While they are being done he supervises as necessary.

5.4.8 On completion of a job such as the fuel supply piping systems he normally makes a visual check of the whole system then turns on the fuel circulation system to circulate fuel through it and pressurise the piping to check for leaks. Neither he nor the fitter reported any defects or leaks following the April 2009 check and No 4 was returned to service.

5.4.9 From the manufacturer's data sheets there are approximately 250 bolts in the fuel system for this engine. There are bolts of different sizes and several covers to remove. The engineers claim the job takes about 3.5 hours for two men. Assuming an 08:30 start with a half hour break and allowing 30 minutes each for opening up and closing again on completion this allows about 240 man/minutes for the job which is just under 1 minute for each bolt to place the torque wrench, confirm it is correctly torqued and position the wrench for the next one. This is quite an intensive schedule and given that each flange on an injector supply or return line (48 in total) is identical and given that the staff have never found a loose one it is considered quite likely that one could be accidentally missed. This could explain four failed/loose bolts as opposed to a single one.

⁴ M.E. Main Engine.



The flange on the return fuel line from injector pump A2 on Engine No. 4 The nearest bolt is loose and protruding; the others (one for each corner) are missing. The flange is open 1 to 2 mm.

- 5.4.10 It is also the case that although the personnel doing this job have never found a loose bolt to their knowledge, the normal operation of a torque wrench is such that a bolt might be very slightly loose but remain undetected by a torque wrench user as the normal operation of a torque wrench requires some turning effect until it clicks against the torque setting. It remains very possible that many of the bolts tend to loosen very slightly over time but the regular scheduled torque checks re-set them. However the bolts in a missed flange would continue to loosen until the next inspection or until failure.
- 5.4.11 As well as the 3 monthly checks there is a scheduled visual inspection and clean for the hot box every 150 running hours. Such an inspection would not reveal loose bolts unless they were grossly loose.

- 5.4.12 It remains unclear how or why the four bolts on this pipe came loose. There is no clear evidence to suggest that they were loose in April when they were inspected and none of the other ones were found to be loose. The April inspection concentrated on checking tightness and did not involve loosening any bolts. There are several possible causes ranging from unusual harmonic vibrations for the fuel injector pump to some metallurgical or manufacturing fault in the bolts themselves. Alternatively the possibility that this particular flange was missed out during the April check cannot be ruled out. The staff concerned have no recollection of doing so but they do not recall ever having found a loose bolt while doing this inspection. However it remains possible that, with the need to check over 250 bolts against a time limit in a scenario where the people involved have never knowingly encountered a loose one, one flange out of 24 identical ones could be easily missed, especially if this one was at about break time. It is entirely possible that the two men could resume on the next but one flange. Visually there is nothing to indicate that the bolts have been checked and the tight fit of the flange in situ with its “O” ring would very possibly not immediately show a leak when pressure was restored.
- 5.4.13 As well as running down the length of the hot box, the fuel feed and return lines cross over from one side of the engine to the other. The crossover link is situated at the turbo charger end and runs up from the hot box on each side then transversely across the engine before running down to the opposite hot box. The pipes are protected by bolted on covers to the point where they enter the hot boxes on each side. The subsequent opening up of the engine during repairs revealed that the fuel line on the inboard side of No. 4 engine where it enters the hot box had a small split approximately 1 cm in length aligned across the pipe.
- 5.4.14 Looking at the area it is clear that this split was caused by the edge of the steel cover coming into contact with the pipe and then vibration between the cover and the pipe wearing through the pipe. A bolt that should have held the cover in position was missing allowing it to make contact with the pipe. Fuel leaking or spraying from this split would have both entered the hot box through the space where the pipe enters and would have emerged from around the pipe cover to the area around the aft end of the engine.



View of the fuel line split at the point where the line enters the hot box at the aft (turbo charger) end of engine No. 4

- 5.4.15 Clearly there were two sources of fuel leakage immediately before or during this fire. The small split in the fuel line at the aft end just where the pipe emerges from the hot box, and the open flange at the forward end inside the hot box. There is no direct connection between the two other than the pipe itself. There is no clear explanation as to why the bolts in the flange loosened and no obvious evidence to suggest that they were not correctly tightened when the manufacturer serviced the engine in December or correctly checked when the ship's staff did their inspection in April.
- 5.4.16 The missing bolts in the pipe covers at the aft end have not been found but clearly without them the cover is free to make contact with the pipe and normal vibration of the engine would easily cause fretting between the edge of the cover and the pipe causing the split that was found.

- 5.4.17 It is noted that the motorman, who was closest to the machinery space when the fire started recalls hearing a soft “Phut” sound. He was in the evaporator room at the time having just passed through the machinery space and the sound must have been quite loud for him to have heard anything through the watertight bulkhead. He was the only person close to engine No. 4 at the time.
- 5.4.18 **It is concluded that during the last occasion when the pipe cover was removed, the bolts securing it in position were not all replaced, or were replaced insufficiently tightly so that they subsequently vibrated loose, allowing the cover to drop into contact with the fuel pipe.**
- 5.4.19 **It is concluded that the reason for the fuel line return flange bolts becoming loose cannot be determined with certainty at this stage but of the possibilities that exist, it is concluded that the most likely explanation is that the routine torque setting check on fuel system bolts in April missed this flange and the bolts, already slightly loose, loosened further in the interval.**
- 5.4.20 **It is recommended that the manufacturers Wärtsilä are consulted with a view to analysing the cause from their experience and formulating any changes necessary to prevent a recurrence.**
- 5.4.21 Once the split had opened on the fuel line at the aft end fuel would have sprayed out, some into the hot box and some into the inside of the loose cover plate. The quantities would have been very small, insufficient to trigger the fuel leakage alarm but sufficient to generate a large quantity of fuel vapour in the immediate area as well as some liquid fuel in the area around No A6 cylinder head.
- 5.4.22 This source does not explain the large quantities of fuel that obviously fed the fire at the forward end of the engine. The split is very small. The only source that can be established for this is the failed flange at unit A2 injector pump. Fuel leaking from this in quantity would emerge from the hot box through the opening at the extreme forward end and from there would flow down over the front and side of the engine. The evidence points clearly to an initial fire at the aft end of the engine in the area of cylinder head A6 followed by a much more severe fire centred at the forward end inboard and the pattern of burning clearly suggests fuel pouring down over the inboard forward part of the engine and the forward face of the engine.
- 5.4.23 **It is concluded that a spray of fuel oil from the damaged fuel line at its entry to the hot box at the aft end of the engine provided the fuel for the initial fire and that subsequently leakage of fuel from the loose fuel return line flange at injector pump No. A 2 provided the bulk of the fuel that fed the major fire at the forward end.**

5.4.24 The hot box is designed in part as a system to prevent contact between flammable fuel leaking or spraying from pipe leaks or failed pipes and adjacent hot surfaces. The design of the hot box is such that none of the surfaces inside it can ever be at a high enough temperature to ignite fuel oil or its vapour. In theory a leakage of fuel into the hot box should provide two indications of a problem before a fire starts.

- A fuel spill alarm when spilt fuel drains into the collecting receptacles at each end of the engine and triggers the float switch there. (This should activate to detect a small leak); and,
- A fuel oil low pressure alarm when the pressure in the fuel circulating line drops as fuel leaks out, (This would indicate a major leak).

5.4.25 Both fuel spill alarms for No. 4 operated about 10 seconds after the low fuel oil pressure alarm activated which would have been when large quantities of fuel were released. However from the fire detection system evidence the fire had already started at this time which, in turn, suggests that there was already a leakage of fuel that was not detected by the leakage drain alarms. Assuming that it took a few minutes for the build up of smoke to be detected by the smoke detector on deck 2 (the first one to activate) which is reasonable given that the engine was running and the turbo charger drawing air and smoke inwards while the supply fans at the forward end of the engine delivered a large volume of air and turbulence, it is concluded that the fire ignited a few minutes before the low fuel oil pressure alarm was activated at 20:08.30.

5.4.26 This suggests that the initial fire was at the turbo charger end created by a fine spray of fuel from the damaged pipe. This initial spray would have been small in volume, adequate to generate large quantities of fuel mist and allow some fuel to collect around No. A6 cylinder head but insufficient in volume to activate the fuel leakage alarm or the fuel oil low pressure alarm.

5.4.27 If the oil mist collecting at the aft end, in the hot box, around the cylinder head and around the pipe cover was ignited it is reasonable to assume an explosive effect. This could explain the sound heard by the motorman. If he heard it through the watertight bulkhead it was one with reasonable force. Such an explosion localised on or immediately above the fuel pipe would generate a shock wave affecting all of the fuel pipes running through the hot box including the return line from No. 2 injector pump. If the bolts for this flange were already loose but the flange was still in place a shock loading such as this might have been enough to force out the bolts and open the flange. This would have the effect of quickly dumping a large quantity of fuel into the hot box and triggering a low pressure alarm followed by a low-low pressure alarm. As fuel subsequently built up in the hot box it penetrated to the leakage detection system and triggered a fuel oil leakage alarm forward end followed seconds later by a fuel leakage alarm for the aft end.

- 5.4.28 An examination of the hot box shows that it is not tightly sealed and that at each end there is an opening leading upwards to the cylinder top. These two openings are in the form of slots about 20 cm high and about 5 cm wide. At the aft end of the engine the lower part of the slot is blocked by emerging pipes leading to the fuel cross-over.



The opening at the aft end of the hot box on engine No. 4 partially blocked by pipes passing through. This is looking inwards towards the cylinder heads. Note the missing bolt on the cover and the cover dropped down to lie against the fuel pipe.

- 5.4.29 With the ship on an even keel trim the level of oil in the hot box before any emerged from the two openings would be up to about half full in what is a wedge shaped space. This is not a large volume and any build up would quickly emerge from the forward end opening first due to the pipes blocking the lower part of the aft opening.

- 5.4.30 An ignition source is still needed and it is accepted that by design there is no source in the hot box at a sufficiently high temperature to ignite the fuel oil. The Company has made regular thermal imaging scans of these engines to try and identify and isolate potential hot spots on the engines that could reach the ignition temperature for fuel. Sources are known to exist on the top of the engine. One is the stub pipe for the exhaust gas temperature gauge which could reach the temperature of the exhaust gas at around 400 degrees. Also at the turbo charger end the exhaust headers emerge into the turbo chargers. Insulation is fitted but with the damage on No. 4 it is not possible to identify a possible exposed part of exhaust piping but very little would be sufficient.

5.4.31 On this evidence and on the accounts of the various eyewitnesses that saw the fire in the very early stages it is concluded that on the balance of probabilities the mechanism and progression for the fire was as follows:

- The loose cover plate vibrating on top of the fuel line where it emerges from the aft end of the hot box to the cross over pipework chafed through the fuel pipe causing a fine spray of fuel. This fed oil into both the hot box and on to the area where the cross over line enters the hot box allowing a build up of fuel mist in the area as well as some collection of liquid fuel. The leakage at this time was insufficient to trigger the leakage alarm or the low pressure alarm
- Vapour or fuel mist reached a hot source near the turbo chargers, possibly the exhaust gas temperature gauge for unit A6, possibly a nearby test cock, or possibly a part of the exhaust line where it leaves its insulated containment and enters the turbo charger. This was enough to ignite the fuel which started a medium sized fire on the engine top near the inboard turbo charger. It was this fire that was seen initially by the motorman and the electrician. Smoke from this fire was drawn into the turbo charger and emerged from the exhaust to be seen by the staff engineer on Deck 11 as an unusually heavy emission of black smoke. The suction of smoke into the turbo charger also delayed the spread of smoke to the smoke detectors for a few minutes.
- The ignition of this vapour caused an explosion which sent a shock wave along the fuel line towards the forward end of the engine. The shock wave opened the flange for the return line to injector pump No. 2 which was already loose due to the missing/loose bolts causing the sudden release of large quantities of fuel into the hot box. This fuel quickly triggered a low fuel oil pressure alarm followed 15 seconds later by a low-low pressure alarm and a fuel leakage alarm, firstly for the forward end (nearest the open flange) then for the aft end as fuel filled up the hot box from forward.
- Fuel began to flow out through the opening at the forward end as the hot box filled up and poured down the side of the engine at the forward end and in the area of units A1 and A2. Oil was also emerging from the cable glands along the bottom of the hot box where rubber grommets seal the emergence of electrical cables. These grommets are not tight and this fuel built up pools of oil along the inboard base of No. 4
- Rising heat and growth of the fire at the aft end triggered a flash over of fuel oil vapour along the engine to ignite the oil spilling from the forward end and starting the major fire there.

- Ample air was being supplied via the ventilation supply trunks adjacent to this part of the engine. This fire burned upwards on the end and forward side of the engine creating the damage visible post fire. This fire created large volumes of smoke and hot gases that drove the assessment party out and as it was drawn into the turbo charger on the running engine the sudden huge increase in black smoke from the funnel was observed by the Doctor after the staff engineer had left.
- When the fuel oil supply was eventually cut off before CO₂ injection the remaining fuel in the hot box drained away through the leakage drains to the collection tank and through the cable grommets leaving the hot box as it appeared post fire; oily but without significant fuel content.



Engine No. 4 looking aft with the exhaust header covers removed. The seat of the initial fire can be seen in the scorching evident on the inboard side of the engine at the turbo charger close to where the cross over fuel lines enter the inboard hot box with evidence of scorching on the beam above.

5.5 Why did the water mist system stop and how effective was it?

- 5.5.1 The water mist system operated correctly as soon as released and was seen to be operating correctly by several observers. All of them were asked for a view on how effective it might have been. All said that it was either having little effect or it was possibly slowing the expansion of the fire but no more. None of the observers felt that it was beating down the fire significantly.
- 5.5.2 The system has only three discharge heads from a single supply line over each engine. It is an additional system installed voluntarily by the Company as an “immediate action” fire suppression system. It is operated by a pump located in the chiller room forward and, when activated, delivers fresh water at about 100 bars to the selected line and discharge heads. The system is sized to deliver to any one line only; although the one fitted to Royal Princess is slightly over-sized and, according to the manufacturer’s service technician, is capable of supplying two lines at once, but no more.
- 5.5.3 It is simple to operate. A control box in the engine control room starts the pump and opens whichever valve is selected. The operator can select each of 4 main engines, or each of the two separator units. Once operated it delivers a very fine water mist into the protected area intended to provide fire suppression mainly through cooling. It has the advantage of being non hazardous to personnel and of creating little damage itself in view of the small quantities of fresh water delivered. Comprehensive systems of this type are now installed in a large number of vessels as a main fire extinguishing system and they have a very good record.
- 5.5.4 The water for the system comes from a small header tank located with the pump and which is automatically topped up from the ship’s technical water tanks which normally hold about 30 Tonnes of fresh water.
- 5.5.5 **It is concluded that, while the system was activated in the first few seconds of this fire, from the descriptions given by eyewitnesses it does not appear that the system was as effective as staff had anticipated.**
- 5.5.6 **It is recommended that the Company, in conjunction with the manufacturers, re-evaluate this system to see if it needs change or enhancement to make it more effective.**
- 5.5.7 The investigation shows that the water mist system failed at some time between the last entry by the assessment team a few minutes after 20:10 and the discharge of CO₂ just before 21:00. The time of failure cannot be established. The Staff Engineer managed to re-start it after the CO₂ discharge by going to its local control panel, which was showing a fault light, and operating the emergency override. Subsequent investigation shows that a fault had developed in the water level sensor in the header tank.

- 5.5.8 This fault would have shut down the pump and required the use of the emergency override to re-start the system. It cannot be determined when it shut down but it could have been very soon after the assessment team observed it working just after 20:10.
- 5.5.9 The sector valves are electrically operated and designed to shut on “no power”. It is accepted therefore that the sector valve to engine No. 4 shut when the power shut down preparatory to using the CO₂ occurred. Whether or not the unit was already shut down from the water level sensor failure cannot be determined. When emergency power was established the pump did not re-start until the staff engineer used the emergency override. He then manually operated the sector valve for engines 3 and 4 and restored the system to operation.
- 5.5.10 It then appears to have operated until close to midnight when another brief blackout about then caused the sector valves to close again. With the valves closed the pump continued to run on recirculation gradually heating up the water in the header tank until the pump finally failed some time in the morning.
- 5.5.11 **It is concluded that the system worked but did not prove as effective as anticipated and that the ship’s crew were not aware of its limitations in terms of how many sectors can be operated at one time and of the need to re-start the system after any power interruption.**
- 5.5.12 **It is recommended that clear guidance on its imitations and the need to reset valves and re-start the system following any power loss are posted at the control box and that crew members are informed of these as part of their induction to this safety system.**

5.6 Is there a need for any procedural changes?

- 5.6.1 The first and obvious direction to look here is in future prevention. Until the analysis of the bolts and the flange is complete and there is an understanding of why this flange came loose it is not possible to suggest any changes in design or practice that might remove the possibility of this happening again. However it is noted that this same fault has occurred before.

In 1994 the passenger ship “Sally Star” suffered a serious engine room fire arising from a failed set of flange bolts on the low pressure fuel line in a very similar Wärtsillä engine. The investigation report in that case looked at the possible cause of the bolt failure and noted that while the normal low pressure fuel line was at about 7 bars –

“Wärtsillä Diesel Company report that transient pressure measurements were carried out on the Vasa 32, the type of main engine installed in SALLY STAR in 1977-78 before the engine was released for production. These pressure measurements have been repeated in response to development changes

since this time. The transient pressure measured in connection pipes of the type used in the SALLY STAR's engines was approximately 45 bar. Rarely are these peak pressures considered when testing low pressure fuel systems for statutory or classification purposes. Test requirements are based on normal working pressure which, in this case, is assumed to be 5bar to 6bar. The type Vasa 32 engine has been in service for more than 15 years and today there are more than 1500 engines in service.”⁵

In 2001 another vessel, the Cruise ship “Nordic Empress” with the same “Vasa 32” main engines suffered a serious engine room fire en route from Bermuda to New York and the investigation traced the original cause to a low pressure fuel line flange bolt failure in a very similar manner to that seen in this case.

5.6.2 The low pressure fuel lines in Sally Star were secured with flanges using two bolts. In 1999 Wärtsillä issued a technical bulletin announcing a change in design to the fuel piping system in response to “*some incidents of serious fuel leakage in the low pressure fuel system.*”⁶ The bulletin notes that the fuel pipes are principally affected by

- Pressure pulses deriving from the fuel injection pump.
- Vibrations initiated by normal engine vibration.
- Static stress caused by heat expansion.

5.6.3 The design modifications aimed to dampen the pressure pulses and vibrations and strengthen the pipes, welding and screw connections. The design changes, amongst other things, modified the flanges from a two bolt design to a four bolt design and these modifications were incorporated in the engines in Royal Princess's engines from new. It is clear that these fuel piping flange joints remain a source of weakness. It is also clear that failure can occur quickly and it seems that it can happen with little or no warning.

5.6.4 In some of the cases investigated bolts had been changed by users and metallurgical investigation as a part of those investigations showed signs of failure cracks from over tightening and similar faults leading to the failure. There is nothing at the time of this report to suggest such faults in Royal Princess.

5.6.5 **It is recommended that the work process for completing the scheduled fuel system inspections include a simple marking system to show each flange that has been checked so that the possibility of one being missed is reduced.**

⁵ Copied from the MAIB report into the Sally Star fire published in 1995.

⁶ Wärtsilä Technical Bulletin ref WNSFI-S 17/08/1999 Doc No. 3217T044GB

- 5.6.6 The Staff Engineer dropped his keys while waiting in the CO₂ release locker for the call to activate the system. This is entirely understandable in the circumstances but it meant that, as it had become impossible due to heat and smoke to return there, he had to obtain another set. The actual CO₂ room door from the aft mooring deck (which is a restricted area) is not fitted with a “break glass” key box, allegedly for security reasons. As a result he would not have been able to enter or to release the CO₂ if he had not obtained the Chief Engineer’s keys en route. The potential delay had he not been able to open this door easily could have had serious consequences, and it is noted that the installation of a “break glass” key box for this door was a recommendation from the last flag state survey.
- 5.6.7 It is also the case that there is considerable risk to ship’s personnel working in CO₂ protected spaces from an unauthorised activation and the consequences of this if access to the CO₂ room was too easy could be catastrophic.
- 5.6.8 It is also the case that once the staff engineer had opened the CO₂ room locker with the Chief Engineer’s keys the padlock is of a design that does not permit the key to be withdrawn from the padlock without re-locking it. As a consequence he had to leave down the padlock with the Chief Engineer’s keys in it while he operated the system. The keys got left behind (quite understandably) when the two men left the CO₂ locker which meant that both the Staff Engineer’s keys and the Chief Engineer’s keys were out of circulation for a while. Fortunately no other locked areas needed opening before the Staff Engineer was able to recover his set.
- 5.6.9 The Staff Engineer and the Senior First Engineer also had difficulties in opening the escape hatch from deck 2 down to the chiller room in order to access the water mist pump and No 1 fire pump. For security reasons again this hatch is secured by a padlock and by special handles that are secured and must be obtained from a locked box before the hatch can be opened.
- 5.6.10 There is an obvious conflict here between the needs of Security and the needs of safety. In every case there is, nevertheless, a need for balance.
- 5.6.11 **It is recommended that a the company should ensure that there are sufficient securely monitored keys available in places such as the engine room control room to provide personnel with keys in an emergency if they have lost or mislaid their own.**

5.7 How effective were the fire fighting efforts?

- 5.7.1 Given that this fire was first detected at about 20:09, confirmed within a few minutes, tackled directly a few minutes later and then extinguished with CO₂ at about 20:50 when the Staff Engineer released the CO₂ from the central CO₂ room it must be stated that fire fighting efforts were entirely effective. At the same time the fact that all the passengers were quickly mustered in their allocated muster stations, looked after, supported, reassured and eventually safely disembarked the next morning clearly demonstrates that the planned responses to emergencies worked well and that on-board training and drills have been effective.**

Nothing in this report should detract from that overall success.

- 5.7.2 It is appreciated that events happened very quickly in this case but nevertheless there are still some factors that should be examined to see if further improvement can be made based on what can be learned from this incident.
- 5.7.3 One of the things that caused difficulties throughout the fire fighting effort was the amount of smoke that escaped the engine room and quickly rendered key locations untenable or unreachable including:
- The CO₂ Muster Station,
 - The CO₂ release locker,
 - The engine room fire locker (not reachable by the fire teams from aft).
- 5.7.4 All of these locations were affected by smoke issuing from the engine room access door on deck 3 opposite the CO₂ locker. This is an A60 rated door with an automatic closer and fitted with a keypad lock for security. Various witnesses saw heavy volumes of smoke issuing from around the edges of this door and it is clear that this was the main source of the smoke that affected the M1 at a critical point.
- 5.7.5 Examination of the door after the fire shows it to be intact and undamaged. It has been clearly exposed to heat and smoke on the inside but otherwise it is in sound condition. However it is also clear that with the engine room fans operational and the resulting positive pressure in the engine room there is considerable pressure tending to open this door. During the investigation it was seen to be passing a large volume of air around the sides of the door but this could easily be stopped with a firm push on the door to actively engage the latch.

- 5.7.6 **It is concluded that when the three members of the assessment team exited through this door having seen the flare up on engine 4, the door was not firmly closed on its latch. As a consequence and with the engine room supply fans still operating for the starboard side there was a positive pressure in the engine room sufficient to drive large quantities of smoke from around the edges of this door which was extremely hot at the time.**
- 5.7.7 There is differing evidence about the fire doors. However the most compelling evidence suggests that all the “held open” fire doors in the control room area and surrounding areas including the decks above were open and remained open. Security camera records show that the doors to the crew stairwell at deck 3 in the gun port area that gives access to the workshop area and upwards to the mess rooms and galley were definitely open until the fire party retreated when the Staff Engineer can be seen closing them manually. There is no other source of smoke in the M1 and it is clear that the smoke that disabled the CO₂ muster area and prevented clear access past this point to the engine room fire locker came from the engine room door. There are several sets of fire doors in the alleyway and the bulkhead between the CO₂ locker and the control room access is the main vertical zone bulkhead between zones 4 and 5 and equipped with double leaf fire doors. Use of a selection of these could have greatly limited the spread of smoke.
- 5.7.8 The spread of smoke to a large volume of the aft part of the ship remains of concern. From an analysis of all the evidence it is concluded that most of the crew stairwell doors and others in zone 5 were open throughout the emergency. This allowed smoke to penetrate aft from the engine room door on deck 3 to the gun port area and forward to the control room area and allowed a considerable volume of smoke from the opening of the watertight door for fire party access to rise up this stairwell and penetrate the galley and other spaces in that area. Small quantities of smoke were reported by staff as far as Deck 8 right aft. While not an immediate threat, the quantity of smoke that penetrated made it impossible, for example, to pass through the galley to the aft mooring deck without breathing apparatus at one time. It denied access to the galley for passenger services teams and it also made access to critical safety systems such as the CO₂ release locker, the Quick Closing valves operating position, and the engine room fire locker extremely difficult. It also restricted movement through crew areas around the boundaries of the fire area.
- 5.7.9 **It is concluded that the spread of smoke around the crew areas in zone 5 hampered fire fighting efforts and boundary cooling efforts and could have been reduced.**
- 5.7.10 **It is recommended that future drills and exercises plan for this sort of eventuality in the case of an engine room fire and for the selective use of fire doors to control and contain smoke spread, possibly by making use of members of the boundary cooling teams or the second fire party.**

- 5.7.11 One of the sources of smoke was the watertight door on deck 2 which was opened to allow the fire party to make an entrance to the fire area. When this was done engines 1 and 2 were running and the starboard side engine room fans were operating creating a strong positive pressure in the engine room. This was a necessary configuration to maintain the two engines running but it meant that smoke was forced out from the edges of the engine room access door and that as soon as the watertight door was opened a large quantity of heat and smoke emerged from there.
- 5.7.12 Traditionally in fire fighting planning, an entrance to an engine room fire is made from as low as possible to try and minimise the effects of smoke and stay below the heat. In Royal Princess there are two watertight doors giving access to the engine room and the escape door giving access to deck 2. The latter was correctly seen as not a good access point, it would emerge directly onto the top of the fire via a narrow stair which would not allow the teams to deploy safely. The choice therefore lay between the two watertight doors, the one aft at deck 2 which gives a clear access to the platform around the engine room at deck 2 level and easy and direct access to what was known to be the seat of the fire and the forward watertight door at deck 1 from the propulsion room. This gives the lowest access point but is more difficult to deploy fire teams to and from this door direct access to the seat of the fire is blocked by engine No. 3 and the shafts on the port side.
- 5.7.13 The Staff Engineer chose to make an initial entrance via the watertight door on deck 2 and this decision cannot be criticised. The following paragraphs are based firmly on hindsight and in no way intended as criticism of the successful efforts made on board or of the skill and determination shown by the ship's personnel.
- 5.7.14 In traditional thinking the plan for engine room fires is to close down the space, isolate fuel supplies and make an attack from as low as possible. That philosophy remains valid but assumes a traditional engine room with a high casing and a large volume. In Royal Princess and similar ships the engine room is confined to 2 decks in height with narrow low volume casings. The result is that the total volume of the space is low, and a large part of the engine room has an overhead deck at a low level. The consequence appears to be that in a fire the space fills with smoke and heat almost instantly, much faster than might be the case in a conventional engine room.
- 5.7.15 In the circumstances of this fire the position of the ship meant that it was crucial to maintain propulsion for as long as possible. That meant that fans had to remain on in order to operate engines 1 and 2. At the same time the port side had been closed down. This meant that the port side exhaust and supply fans were off.
- 5.7.16 The net effect of this configuration was possibly to force smoke and heat to build up very quickly on the port side then start building towards the starboard side with no means of escape other than through the watertight door as soon as it was opened giving the fire fighters a near impossible task. It also contributed to the build up of smoke on deck 3 from the escape door. It is reasonable to consider the situation had the stops been operated slightly differently.

5.7.17 If, for example,

- the quick closing valves for the port side were operated immediately,
- the port exhaust fan was left running, and
- the port side supply fans stopped along with the fuel unit

there might have been a situation where fuel supply to the fire was removed earlier and a substantial percentage of the heat and smoke was vented upwards through the port side exhaust fan. The result might have been a better atmosphere for the fire teams and a higher probability of tackling the fire when they entered.

5.7.18 The situation with the quick closing valves is important. On the evidence available these were not closed until the final order to release CO₂. Only the electrical stops were operated in the early stages and these shut off fans, heaters, and pumps but do not close any valves. The fuel for the engines is supplied from two service tanks located just forward of the propulsion room. These tanks are maintained full and the upper surface of oil in them is higher than the level of the hot boxes on the engines. With the port side pumps stopped there would no longer be any pressurised fuel emerging into the hot box, but with no valves closed there was nothing to prevent a certain amount of fuel from continuing to gravitate to the hot box due to the head of pressure in the tank. The amount supplied by this mechanism is likely to have been small but it would have helped to have stopped it.

5.7.19 This fire occurred at a time when the vessel was navigationally constrained which meant that there was a priority to retain propulsion as long as possible. This in turn meant that the engine room could not be completely closed down until the ship could be manoeuvred to safety.

5.7.20 **It is concluded that there is scope to design a plan to manage the fuel, ventilation and damper controls for the engine room in a situation such as occurred in a manner that could give fire fighting teams a better opportunity in prosecuting a direct attack.**

5.7.21 **It is recommended that the Company in conjunction with the ship's emergency planning teams study potential scenarios in which there are conflicting needs for propulsion and engine room fire fighting at the same time with a view to developing some contingency plans that optimise the conditions for fire fighting by selective management of ventilation and fuel controls.**

- 5.7.22 Once the fire teams had been forced to retreat from the engine room the assessment that only the CO₂ system would now be effective was the correct decision taken in good time. The CO₂ injection, using the full set allocated for the machinery space worked and temperatures were reported to start dropping very quickly. In particular the emission of smoke from around the edges of the access door at deck 3 began to ease improving visibility and conditions in the M1. The crew used all the means available to them to monitor temperatures including the helmet heat sensors and a hand held infra red temperature sensor. All this equipment worked well and proved extremely useful.
- 5.7.23 **It is concluded that the CO₂ injection was immediately effective in extinguishing the fire and that the monitoring of temperatures subsequently and the cooling of boundaries where necessary was effective in establishing conditions in the engine room to the point where it was possible to make a safe exploratory entry.**
- 5.7.24 It is also noted that the ships drills and emergency training is based on mustering crew members, ensuring everyone is accounted for, mustering fire parties, and tackling the fire directly. These activities are practiced for varying scenarios and with varying complications and the crew are undoubtedly good at it. However there appears to be no scenario where the situation is initially assessed as being beyond direct action and where the progression is direct to CO₂ release from assessment. Such a scenario avoids the fire party deployment and the exercise benefits of that, of course. However it is considered that such a contingency should be considered and drilled occasionally. It becomes important when it is considered that on this occasion, within about 10 minutes of the fire detection, the engine room was virtually inaccessible to the fire teams.
- 5.7.25 In this particular case it was not appropriate, the ship could not have been disabled in the location she was in when the fire started. However in other situations there might be benefit in moving directly to CO₂ activation. It is well known that the earlier CO₂ is released the more effective it tends to be. In the case of ships with confined and low overhead height engine rooms such as Royal Princess and other passenger ships such a move might minimise damage and allow a much quicker return to normal operation and could on, analysis, be the better option at times. In any case it should be studied.
- 5.7.26 **It is recommended that the Company and the ship consider preparing contingency plans for a situation where the emergency response to an engine room fire moves directly from alert to assessment to CO₂ release and exercises this plan from time to time.**

5.8 How well did the ship's structural fire protection work to protect against spread of fire?

- 5.8.1 The engine room deckhead is required to be an A60 standard over much of its area in view of the designation of the spaces above. Following the fire it was clear that the insulation remained in place. During the fire there were reports of smoke from the scupper drain in the CO₂ release locker. This feature was identified in the engine room and is located almost directly over the seat of the fire. It is well covered by appropriate insulation and the outlet pipe has an insulation ribband as required. The smoke observed was probably from dirt and water collected in the bottom of the scupper which would invariably become hot.
- 5.8.2 The forward bulkhead between the engine room and the propulsion room is a main vertical zone boundary and insulated to A60. During the fire there was no significant heat transmission detected through this bulkhead and post fire there is no sign of heat transmission. Some of the penetrations for large bundles of electrical cabling show signs of the beginnings of heat transmission to the Propulsion motor side.



View of the engine room deckhead above the fire showing fire insulation intact and secured with only minor damage to covering material. Note cable trays with the cables completely burnt away.

- 5.8.3 **It is concluded that the ship's structural fire protection was fitted as required by regulations and performed as designed. There is no evidence that the level of heat transmission through any of the protected bulkheads exceeded what might be expected from a good A60 boundary.**

5.9 Was there sufficient support in the ECR?

- 5.9.1 During most of the emergency the manning in the control room was the Chief Engineer, and the Second Engineer. The Senior Electrical Officer was at the medical centre from shortly after his second entry to the fire area. The Staff Engineer and the Senior First Engineer were closely involved in the "on-scene" management and in managing fire fighting teams. The Chief Engineer in this case had only been on board for a few days. He was there as a relief Chief and had spent a full day on board before joining with the normal Chief getting familiar with the ship as well as a further day's familiarisation during the actual handover. He is, however, a very experienced Chief Engineer who has worked for the Company in similar, and larger, ships for many years.
- 5.9.2 However, it remains the case that during this emergency the engine control room was manned only by a fairly junior engineer officer and a Chief Engineer with limited experience in this particular ship and its systems. Various things failed that might have been noticed quickly by another experienced officer - the water mist system, the fire pump etc. Additional support for the Chief Engineer might have allowed him to step back and retain a strategic view to support the Staff Engineer on scene.
- 5.9.3 At the same time the build up of smoke in the area suggests that a knowledge of the ship's ventilation systems and capabilities could also have helped. The ship carries a Ventilation Officer who would normally be expected to have an intimate knowledge of the ship's ventilation systems yet this resource skill was not used and the Ventilation Officer spent the emergency at his muster station.
- 5.9.4 Another factor which suggests that ECR manning in an emergency might need re-assessed is the confusion that existed between the actual propulsion plant status and the perception on the bridge. The Master was of the opinion that he did not have access to the port motor on the basis of a message saying the port side had been shut down. The confusion is understandable but might have been avoided with another experienced engineer in the ECR to help with communications between the ECR and the control centre on the bridge. It might also be useful to consider regular machinery status checks with the bridge during the course of any emergency and these could cover a simple check list of critical items such as steering, propulsion motors, maximum power available, etc.

- 5.9.5 **It is concluded that there would have been advantages to keeping another experienced officer in the control room to assist the Chief Engineer and manage services while the Staff Engineer is deployed “on-scene”. It is also concluded that there could be advantages in making better use of the Ventilation Officer and his skills and knowledge as a back up to the Senior Electrical Officer if nothing else.**
- 5.9.6 **It is recommended that the Company investigate changes to the ship’s emergency plan to provide for another officer, possibly the Senior First Engineer, to be positioned in the control room during engine room emergencies to back up the Chief Engineer and manage services and systems with another Officer leading the engine room fire party.**
- 5.9.7 **It is also recommended that the ship’s emergency plan be amended to make better use of the ship’s Ventilation Officer possibly either in the engine control room for engine room emergencies or on the bridge for other emergencies, depending on where his input could best be used.**
- 5.10 How well was the emergency handled in so far as the passenger welfare is concerned?**
- 5.10.1 The Captain was faced with a difficult situation. He clearly did not want to alarm passengers unnecessarily but he knew that he had an engine room fire.
- 5.10.2 The fire began a few minutes after 20:00 and by 20:14 he knew that the situation was serious. He knew that all his passengers would be up and about, many having just returned from ashore and many starting their evening meal. He decided to hold off a passenger muster for a time. By 20:30 it was clear that only the injection of CO₂ was going to be effective and that meant a black out and a change to emergency power.
- 5.10.3 He made announcements that advised passengers ahead of time of what to expect and then sounded the general alarm signal. A crew alert had already been called and the ship’s emergency teams were in place dealing with the fire. This order of events gave the emergency teams the best opportunity to muster and get started and also gave the passenger services teams ample preparation time for looking after the passengers. From the evidence available the passenger muster proceeded smoothly and quickly with all passengers mustered in the two muster stations within about 10 minutes.
- 5.10.4 **It is concluded that the Master’s decisions on the passenger muster timing and on the advice to passengers were correct and justified.**

- 5.10.5 The passenger services staff had the task of looking after 733 passengers in the two muster stations. They responded quickly to the situation and organised water, face towels, medications recovered from cabins for those needing them and food.
- 5.10.6 Very quickly the toilets became an important concern as the toilet system was inoperative under emergency power. The passenger services team managed this problem by gradually extending the range of available toilets as the communications from the bridge indicated that the situation was coming under control. One issue that emerged was the fact that there is no emergency lighting in the toilets and the available supply of torches was insufficient to cope with demand.
- 5.10.7 Two passengers suffered ill effects from stress and or heat and were admitted to the ships medical centre.
- 5.10.8 Just after midnight the Master authorised the relocation of the muster stations outside to deck 9 which allowed the passengers some fresh air.
- 5.10.9 **It is concluded that the situation with the passengers – alerting them, marshalling them in muster stations, keeping them informed, providing sustenance and eventually stepping down the response as the emergency was dealt with – was handled extremely well.**
- 5.10.10. Prior to the realisation that the ship would not be able to continue her cruise, only four passengers recorded their wish to disembark. Ultimately, of course, it was appreciated that the ship would have to stay at Port Said for some days before moving to a place where permanent repairs could be made and all the passengers were disembarked. The Company arranged for a team of support staff to fly into Egypt to deal with this and all the passengers were very smoothly processed through immigration and to flights home.

SECTION 6 – CONCLUSIONS

- 6 On the basis of the sequence of events developed from this investigation and on the analysis in part 4 of this report the following conclusions are drawn:

It is concluded that;

- 6.1.1 During the last occasion when the covers over the fuel pipework cross-over lines at the aft end of No. 4 were removed, the securing bolts were either not all replaced, or were replaced loosely allowing them to loosen over time due to vibration, in turn allowing the cover to slip and its edge to make contact with the fuel pipe.
- 6.1.2 The reason for the bolts in the return line flange at unit A2 becoming loose cannot be determined with certainty at this stage but the most likely explanation is that the April 2009 checks missed this flange allowing the bolts to slowly loosen due to engine vibration.
- 6.1.3 The fine spray of fuel from the split in the fuel line aft provided the fuel for the initial fire at the aft end and the greater volume of fuel released from the opened flange at the forward end provided the fuel for the major fire that ignited at the forward end.
- 6.1.4 On the balance of probabilities the mechanism and progression for the fire was as follows:
- The loose cover plate vibrating against the fuel line where it emerges from the hot box at the aft end caused a small split in the fuel line. A fine spray of fuel emerged from this into both the hot box and onto the top of the engine in the vicinity of unit A6. The volume was not sufficient to trigger a fuel leakage alarm or a low pressure alarm.
 - Vapour and fuel mist from this split reached a hot source near the turbo chargers, possibly the exhaust gas temperature gauge or a nearby test cock. This was enough to ignite the vapour which started a small sized fire on the engine top near the turbo chargers. This fire scorched the structure above and melted the rubber connection on the crankcase breather line.
 - The ignition of this fuel was accompanied by a small explosion which transmitted a shock wave along the fuel line causing the flange at unit A2 fuel return line which was already loose, to open delivering large quantities of oil to the hot box.
 - As the oil spillage increased the oil leakage drains filled, forward first as closest to the failed flange, then the aft one triggering the fuel leakage alarms but the supply of oil from the pipe was much more than the drains could cope with allowing the hot box to rapidly fill

- Fuel began to flow out through the opening at the forward end of the hot box and poured down the side of the engine at the forward end and in the area of units 1 & 2. Oil was close to emerging from the opening at the aft end. The loss of fuel activated the low fuel oil alarm and then the low-low fuel pressure alarm.
- .At the same time rising heat and growth of the fire at the aft end triggered a flash over of fuel oil vapour along the engine to ignite the oil spilling from the forward end and starting the major fire there.

- 6.1.5 The water mist system worked but did not prove as effective as anticipated.
- 6.1.6 The ship's crew were not fully aware of the limitations of the water mist system in terms of how many sectors can be operated at one time and of the need to re-start the system after any power interruption.
- 6.1.7 The water mist system failed due to a failed tank sensor unit in the header tank but the time of failure cannot be determined.
- 6.1.8 When the three members of the assessment team exited the engine room having seen the flare up on engine 4 the escape door was not firmly closed on its latch. As a consequence and with the engine room supply fans still operating for the starboard side there was a strong positive pressure in the engine room sufficient to drive large quantities of smoke from around the edges of this door.
- 6.1.9 The spread of smoke around the crew areas in zone 5 hampered fire fighting efforts and boundary cooling efforts and could have been reduced.
- 6.1.10 There is scope to design a contingency plan to manage the fuel, ventilation and damper controls for the engine room in a situation such as occurred in a manner that could give the fire fighting teams a better opportunity for a direct attack.
- 6.1.11 The CO2 injection was immediately effective in extinguishing the fire and the monitoring of temperatures subsequently and the cooling of boundaries where necessary was effective in establishing conditions in the engine room to the point where it was possible to make a safe exploratory entry.
- 6.1.12 The ship's structural fire protection was fitted as required by regulations and performed as designed. There is no evidence that the level of heat transmission through any of the protected bulkheads exceeded what might be expected from a good A60 boundary.
- 6.1.13 There would have been advantages to keeping another experienced officer in the control room to assist the Chief Engineer and manage services while the Staff Engineer is deployed "on-scene". It is also concluded that there could be advantages in making better use of the Ventilation Officer and his skills and knowledge as a back up to the Senior Electrical Officer if nothing else.

- 6.1.14 The Master's decisions on the passenger muster timing and on the advice to passengers were correct and justified.
- 6.1.15 The management of the passengers – alerting them, marshalling them in muster stations, keeping them informed, providing sustenance and eventually stepping down the response as the emergency was dealt with – was handled extremely well.

SECTION 7 – ACTIONS BY THE COMPANY.

Following the fire the Company has closely examined the damaged engine and has issued a fleet-wide circular:

- Stressing the importance of checks on the security and tightness of fuel and lub oil system bolts;
- Requiring an immediate inspection of all spaces where there is a risk of oil spray and the tracing of all lubricating oil and fuel oil lines and the fitting of guards and deflectors on any joints that could cause a spray of oil towards a hot surface;
- Reminding all Chief Engineers to emphasise the danger of simple things like missing screws and the importance of replacing covers and securing bolts correctly and completely;
- Requiring all Chief Engineers to personally witness the next scheduled thermographic hot spot inspections of all engines and exhaust systems and report their findings and any corrective action.
- Requiring Chief Engineers to remind their staff of the importance of insulating covers on exhaust pipework and the necessity to replace these correctly after maintenance.

The company has also commenced a modification of the water mist system to allow a more automated activation in line with the systems fitted throughout the fleet. The attendance of the manufacturers has been arranged to re-evaluate the system in Royal Princess and her sister ships in line with the recommendations in this report. In the meantime additional instructions on the operation of the system have been developed and posted.

With regard to the bolts on the fuel system, the company has approached Wärtsillä with a view to the possibility of using bolts with holes to allow the use of locking wires.

The issue of portable illumination available in muster stations for use in toilets in emergency power situations has been examined by the company and chemical light sticks have been provided for this eventuality.

The DMA supports these actions.

SECTION 8 – RECOMMENDATIONS

Recommendations here are derived from the Analysis in Part 5 and the various conclusions reached. Each recommendation is aimed at a person or organisation or group that should study the report and the recommendations with a view to implementing them.

It is recommended that:

- 8.1 The ship ensures that the time references used by automatic recording systems and by manual monitoring systems are synchronised and maintained synchronised.**
- 8.2 The engine manufacturers Wärtsilä are consulted with a view to analysing the cause and formulating any changes necessary to prevent a recurrence.**
- 8.3 The Company, in conjunction with the manufacturers, re-evaluate the water mist system to see if it needs change or enhancement to make it more effective.**
- 8.4 The company_ arrange for clear guidance on the limitations and the need to reset valves and re-start the system following any power loss to be posted at the control box for the water mist system and that crew members are informed of these as part of their induction to this safety system.**
- 8.5 The company_ensure that the work process for completing the scheduled fuel system inspections include a simple system or other arrangement to show each flange that has been checked so that the possibility of one being missed is reduced.**
- 8.6 The Company ensure that there are sufficient securely monitored keys available in locations such as the engine control room to provide essential personnel with necessary keys in an emergency if they have lost or mislaid their own.**
- 8.7 The ship plan future drills and exercises to include the escape of smoke in the case of an engine room fire and for the selective use of fire doors to control and contain smoke spread, possibly by making use of members of the boundary cooling teams or the second fire party.**
- 8.8 The Company, in conjunction with the ship's emergency planning teams, study potential scenarios in which there are conflicting needs for propulsion and engine room fire fighting at the same time with a view to developing some contingency plans that optimise the conditions for fire fighting by selective management of ventilation and fuel controls**

- 8.9 The Company and the ship consider preparing contingency plans for a situation where the emergency response to an engine room fire moves directly from alert to assessment for CO₂ release and exercise this plan from time to time.**
- 8.10 The company investigate the possibility of changes to the ship's emergency plan to provide for another officer, possibly the Senior First Engineer, to be positioned in the control room during engine room emergencies to back up the Chief Engineer in managing services and systems with another officer leading the engine room fire party.**
- 8.11 The company investigate the possibility of changes to the ship's emergency plan to make better use of the ship's Ventilation Officer possibly in the engine control room or on the bridge where his input could be best used.**

SECTION 9 - COMMENTS ON THE DRAFT REPORT

9.1 The draft report was sent to the following persons / organizations for their comments:

The Master, Royal Princess;
The Staff Captain, Royal Princess;
The Chief Engineer, Royal Princess;
The Senior First Engineer, Royal Princess
The Staff Engineer, Royal Princess
PCCL;
Wärtsillä Diesel.

Submissions were received from PCCL and a particularly valuable submission was received from the Staff Engineer which clarified a number of key points. Where considered appropriate they have been incorporated into the report.