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REPORT ON THE INVESTIGATION OF A MARINE ACCIDENT NORDLYS LHCW - FIRE ON BOARD DURING APPROACH TO ÅLESUND 15 SEPTEMBER 2011

AIBN has compiled this report for the sole purpose of improving safety at sea. The object of a safety investigation is to clarify the sequence of events and root cause factors, study matters of significance for the prevention of maritime accidents and improvement of safety at sea, and to publish a report with eventually safety recommendations. The Board shall not apportion any blame or liability. Use of this report for any other purpose than for improvements of the safety at sea shall be avoided.

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This report has been translated into English and published by the Accident Investigation Board Norway (AIBN) to facilitate access by international readers. As accurate as the translation might be, the original Norwegian text takes precedence as the report of reference.

Photo of ferry on the Norwegian west coast: Bente Amandussen

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NOTIFICATION OF THE ACCIDENT

At 10:09 on Thursday 15 September 2011, the Accident Investigation Board Norway (AIBN) received a call from the Norwegian Maritime Authority (NMA), notifying of a fire on board the coastal express steamer *Nordlys*. According to the notification, there were 262 persons on board, two of whom were injured. At the time, the AIBN had already become aware of the incident through the media. At 10:43, after having followed the developments, the AIBN informed the shipping company and the NMA of its intention to initiate an investigation. From then on, the AIBN stayed in regular contact with the shipping company, and it became clear that the situation was serious. Among other things, information was received that two persons had died and several were injured.

At 11:05 the same day, the AIBN was contacted by the Norwegian Fire Research Laboratory (SINTEF NBL AS), which offered to assist in connection with the investigation. This resulted in an agreement under which SINTEF would assist the AIBN in connection with the preliminary investigations. At 12:05, the AIBN was contacted by the police operations centre in Ålesund. The police were informed that the AIBN would arrive in Ålesund that same afternoon, and contact information was exchanged. The AIBN received a telephone message about the accident from the Joint Rescue Coordination Centre (JRCC) at 17:10. It was stated that the JRCC had concluded its rescue operation.

Two accident investigators arrived in Ålesund in the afternoon on 15 September, while one accident investigator, one assistant accident investigator and two SINTEF staff arrived in the morning on 16 September 2011. Another two AIBN staff arrived in the evening of 16 September. On 16 and 17 September, interviews were conducted with the ship's crew and the local fire service. An inspection was also carried out of the ship, including of the engine room, and logs were confiscated. The AIBN left Ålesund on 18 September 2011.

Figure 1: The fire started on 15 September 2011, as the northbound coastal express steamer Nordlys was approaching Ålesund.

Four accident investigators, one assistant accident investigator and three SINTEF staff returned to Ålesund in the evening of 21 September, after *Nordlys* had been towed to Fiskerstrand shipyard, and the circumstances facilitated further on board investigations. Detailed on board investigations were carried out on 22 and 23 September 2011. In the course of these two days, factual information was collected in collaboration with personnel from Ålesund police station and the National Criminal Investigation Service (Kripos).

SUMMARY

During the approach to Ålesund on the morning of 15 September 2011, a fire broke out in the engine room of the northbound coastal express steamer *Nordlys*. Two crew members died and two suffered serious injuries. Seven other crew members suffered minor injuries. There were 207 passengers on board, all of whom were evacuated without any physical injuries. *Nordlys* lost all engine power as both the main and auxiliary engines stopped as a consequence of the fire. The ship was towed to Ålesund harbour, and as *Nordlys* was being berthed, the starboard stabiliser fin was pressed through the hull's side so that the cargo holds became flooded with water. As a result of the flooding, *Nordlys* developed a 20 degrees list. The situation was clarified during the evening of 16 September when the leakage in the hull had been located and temporarily sealed.

The AIBN's investigation concludes that the fire probably started when a diesel leakage was ignited coming into contact with an un-insulated indicator valve on the starboard main engine. The most probable cause of the diesel leakage is fatigue fracture in the feed pipes for a fuel injector pump, due to the pump being loose. The fuel injector pump was loose because the fastening bolts had probably not been sufficiently tightened during replacement of the pump 12 days prior to the accident. The AIBN believes that an insufficient job specification for the replacement of the fuel injector pump was a contributory cause. Likewise, inadequacies in the job specification for inspection of the insulation of hot surfaces contributed to explaining why hot surfaces in the engine room were not sufficiently insulated.

The water-based local application fire-extinguishing system was not immediately released because it was set to manual mode. According to the safety management system, the water-based fire-extinguishing system should have been set to automatic mode. However, the crew had set the system to manual mode without conducting a risk assessment and without notifying the onshore organisation of the nonconformity. The CO_2-based main fire-extinguishing system was not released as the master did not have an overview of where all members of the engine crew were.

Due to limited evacuation possibilities from the engine room workshop, three crew members had to evacuate through the fire. They received no protection from the local application fire-extinguishing system as that system had not been activated at the time.

The emergency generator started as intended when the main and auxiliary engines stopped, but shortly afterwards it also failed as a result of insufficient cooling. This resulted in loss of power to the emergency switchboard, and fire-water pumps and other electrical equipment became inoperative. Prior to the accident, the crew had discovered a failure in the control mechanism for the dampers in the emergency generator room that were designed to ensure supply with cooling air to the generator, but no sufficient corrective actions were taken. Nor was the onshore organisation informed about this.

The management system lacked procedures for training to deal with loss of personnel. The personnel also lacked training for such situations, which to a certain extent explain why safety-

critical tasks were not attended to in connection with the fire. Among other things, the air supply and fuel supply were not shut off.

The stabiliser fins were not retracted before *Nordlys* was berthed, and the starboard fin was pressed through the hull when the ship came alongside the quay. Initially, this led to water ingress into cargo hold no 2. Because a watertight sliding door between cargo holds no 2 and no 1 leaked or was open, cargo hold no 1 was also flooded. As *Nordlys* was only designed to withstand damage between the main transverse bulkheads, the flooding became critical and *Nordlys* came close to capsizing alongside the quay.

The requirement for insulation of surfaces with temperatures exceeding 220 °C became applicable to *Nordlys* on 1 July 2003, but due to an insufficient overview of what surfaces might exceed 220 °C, lead to the fact that both *Nordlys* and two of its sister ships operated with several un-insulated surfaces in the engine room.

Both the NMA and Det Norske Veritas (DNV) had conducted inspections without finding any defects relating to the insulation. They had chosen somewhat different methods to follow this up, but common to them both was that they normally checked the insulation of hot surfaces while the ship was in port and the engines were cold. The absence of a documented overview of what surfaces require insulation, places great demands on the competence and experience of the inspectors. The AIBN believes that the lack of such an overview may have been an underlying factor that helps to explain why the inadequacies were not identified during inspections. Inadequate updating of the NMA's checklists for inspection of passenger vessels may also have been a contributing factor. Insulation of hot surfaces was not in focus in connection with any of the NMA's inspections of *Nordlys* in 2003, 2005, 2006, 2008 and 2010. Insulation of hot surfaces was a topic during the NMA survey in 2011, the most recent survey prior to the fire, but it was left to the shipping company to check the insulation through self-inspection.

The supervisory authority had conducted ISM audits without identifying the deficiencies in the content and compliance with the shipping company's safety management system. The supervisory authority had also approved the emergency generator arrangement without any comments. Following the accident, the NMA has consulted with DNV and concluded that the arrangement for controlling the dampers in the emergency generator room must be altered.

The shipping company has implemented several measures after the accident. This includes the installation of a new water-mist system as the main fire-extinguishing system. In addition, new emergency exits from the engine room have been installed, the arrangement for opening/closing the dampers in the generator room has been altered and new dry tanks have been arranged around the stabiliser fins. In addition to design changes to its ships, the shipping company has through management development programmes and officers' conferences focused on attitudes and challenges relating to the crew's compliance with procedures, and cooperation with the University of Bergen has been initiated to map the safety culture on board the shipping company's ships.

The AIBN proposes seven safety recommendations in this report. These recommendations are submitted to the NMA for them to propose requirements for all vessels to have prepared an overview of hot surfaces in the engine room, to propose prohibitions in the use of extinguishing agents that can pose a risk to human life on board vessels, and to propose requirements for automatically released fire-extinguishing systems. Furthermore, the AIBN recommends that the NMA increase its focus on insulation of hot surfaces in connection with future inspections of passenger ships. The shipping company is advised to revise its maintenance system so that the crew can rely on the job specification for correct performance of the task, and to introduce routines for training to deal with loss of key personnel. The shipping company is also advised to consult with the NMA with a view to implementing measures to ensure the watertight integrity of the main transverse bulkhead between the cargo holds.

FACTUAL INFORMATION

1.1 Details of the vessel and the accident

Details of the vessel

Name of vessel	:	*Nordlys*
Call signal	:	LHCW
Owner	:	Kirberg Shipping KS Conrad Mohrs veg 29 C/O Rederiet Odfjell AS NO-5072 Bergen
ISM responsible company	:	Hurtigruten ASA Havnegata 2 NO-8514 Narvik
Vessel type	:	Passenger/cargo ship
Year/place built	:	1994 / Volkswerft, Stralsund, Germany
Flag state /register	:	Norway / NOR
Classification society	:	DNV
Port of registry	:	Tromsø
Hull material	:	Steel
Length overall	:	121.80 metres
Breadth	:	19.20 metres
Gross tonnage	:	11 204
Type of main engine	:	2 x MaK 6M552C
Engine power, main engine	:	2 x 4 500 KW / 2 x 6 114 GHP
Type of auxiliary engine	:	2 x Ulstein Bergen KRG – 8
Engine power, auxiliary engine	:	2 x 1 265 KW / 2 x 1 719 GHP

Figure 2: The coastal express steamer Nordlys during the fire 15 September 2011. Photo: Thomas Molnes

Details of the accident

Time and date	:	09:13, local time (UTC+2), 15 September 2011
Accident location	:	N 62° 28.6´ E 006° 07.0´
Persons on board (POB)	:	262, of whom 55 crew and 207 passengers
Number of fatalities	:	2 dead
Number of injured persons	:	2 seriously injured and 7 less seriously injured
Damage to the vessel	:	Considerable fire damage in the engine room, smoke and soot damage in corridors forward of the engine room, in the midship stairwell and in the midship accommodation area on deck 4. Gash in the ship's side aft of the starboard stabiliser fin. Water damage in the engine room, cargo hold and aft and midship accommodation areas.

1.2 The course of events

1.2.1 The approach to Ålesund

Nordlys left Bergen on its northbound route to Kirkenes at 20:00 on 14 September 2011. The northbound voyage took its normal course with calls in Florø and Måløy in accordance with the timetable. *Nordlys* was slightly delayed leaving Torvik at 08:11, but it was back on schedule for calling at Ålesund at 09:30. An eyewitness working on the quay in Torvik reported that he had saw black smoke rising from *Nordlys* at approx. 08:50 or 08:55, when the ship passed Flørauden. The ship's crew had not registered anything out of the ordinary on board the ship during this period, however.

Breakfast was served from 07:00, and as the morning progressed, many passengers came to occupy the restaurant aft on deck 4. At the time, the crew were preparing for the approach to and call at Ålesund. Forward and aft moorings were made ready as part of the preparations. The main engines were still in combinator mode, but preparations were being made to switch to constant revolutions as this mode was normally used when manoeuvring the ship alongside or leaving the quay. The stabiliser fins were still out on both sides.

The master and the safety officer went on bridge duty at 08:00. The deck crew that went on duty held a morning meeting in a room next to the car deck (deck 2) at 08:00.

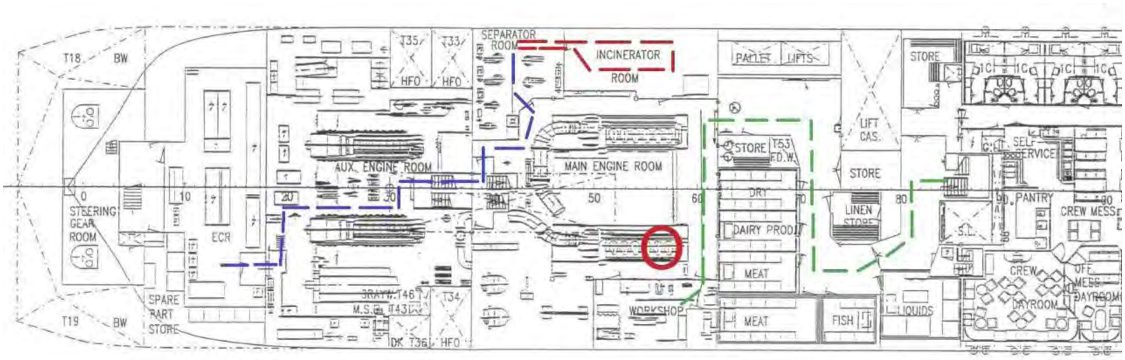
The engine crew held a morning meeting in the control room at 08:00 to plan their working day. One of the matters focused on was the work on installing a new lube oil separator in the separator room.

After the morning meeting, the crew members took up their respective duties. During the period preceding the fire, the chief engineer, first engineer, motorman, repairman, apprentice engineer and apprentice electrician all paid visits to the main engine room passing in the immediate vicinity of the main engines, without observing anything out of the ordinary. The motorman who went off duty made a routine check of the technical rooms at approx. 07:30, and the motorman who came on duty at 08:00 did the same just after the morning meeting.

1.2.2 The fire and the crew's actions

The first engineer and apprentice engineer were working on the lube oil separator. During the period immediately preceding the fire, they were in the workshop together with the repairman adapting a pipe. Suddenly, the apprentice, who was standing closest to the door, notified that there was something wrong outside the workshop. Through the workshop window, they observed thick black smoke and flames at the forward part of the starboard main engine. They opened the door and left the workshop, passing by the starboard main engine. The space was filled with black smoke. The first engineer, who went first, fell over in front of the port main engine. He got up again and escaped together with the repairman through the watertight door on the port side of the forward engine room bulkhead. They do not remember seeing the apprentice as they evacuated the engine room.

The motorman was present in the separator room during the period immediately preceding the fire. The chief engineer entered the separator room from the incinerator room and started up a conversation with the motorman. After approximately one minute, the chief engineer turned around, called out and wondered what was happening. Through the door they observed that the incinerator room was filled with dense, black smoke. The chief engineer ran out of the separator room and into the incinerator room. The motorman ran in the opposite direction and looked into the engine room through the aft door of the separator room. There was less smoke in that area. He ran back to the incinerator room to look for the chief engineer, but was unable to see anything because of the dense smoke. He ran back to the aft door of the separator room and into the engine room. Immediately outside the door, he went down on his knees and looked underneath the exhaust pipe. He observed dense smoke above the starboard main engine. He observed flames immediately above the engine, between the engine and the smoke. He entered the stairwell aft of the engine room and climbed down onto the tank top. There were no flames there, but plenty of smoke, particularly in front of the engines. He then escaped into the auxiliary engine room through the watertight door on the port side at the aft end of the engine room. From there, he was able to reach the control room and call the bridge.



Legend:
O: Observed flames
---: The first engineer and repairman's escape route
---: The motorman's escape route
---: The chief engineer's movements

Figure 3: Sketch of the aft part of deck 1, showing the movements of the chief engineer, first engineer, motorman and repairman.

The fire alarm was released on the bridge at 09:13, without the bridge crew having received any prior warning. The safety officer checked the alarm panel and saw that the alarm indicated fire in the engine room above the starboard main engine. The detectors indicated that smoke was also rising to the decks above. The safety officer looked out from the bridge wing and registered smoke pouring out from the ship's stern. Before they had time to call the engine room, the motorman called the bridge, reporting that the engine room was under full fire. The starboard main engine stopped, causing *Nordlys* to change its course to starboard. Then the port main engine also stopped, and the vessel completely blacked out. The vessel's emergency power supply was working, so that the radar and the emergency systems were operative. Without engine power, *Nordlys* came very close to Steinvåggrunnene (shallows) in the Valderhaugfjord at that point in time. The vessel passed a green navigation mark on the starboard side, but managed to manoeuvre clear of the marker.

The master deemed the situation to be very serious and called up Florø radio. The time was then 09:17. The master considered ordering activation of the fire-extinguishing system (CO_2 system) in the engine room, but decided to wait, since there was uncertainty about whether any crew members were present in the engine room.

The first engineer and the repairman, who had escaped through the watertight door at the forward end of the main engine room and reached the stairwell, climbed up to deck 2 and into the corridor in the crew quarters, which was free of smoke. From there, they proceeded to the reception on deck 3.

The motorman, who had evacuated through the watertight door at the aft end of the main engine room and into the auxiliary engine room, was able to reach the aft control room, which proved to be empty. All the while, the main engines were running with full revolutions. He called the bridge and notified of the fire in the engine room, and told them to either reduce the speed or stop the engine. The speed was quickly reduced, and then the starboard main engine stopped. The power blacked out and the starboard auxiliary engine started. However, it did not take long before that engine also stopped. The port auxiliary engine started up and the power returned. Shortly afterwards, however, the port auxiliary engine also stopped.

The emergency generator started up and activated the panel as expected, but it also stopped after a while.

The apprentice electrician, who had been in the electrical workshop and was heading for the separator room, was walking down the corridor aft of the engine control room, when the lights went out. He immediately headed for the control room, where he ran into the motorman. The motorman told the apprentice electrician to go and fetch the electrician. On his way up to deck 7 where he was to muster at the fire station, the apprentice called the electrician.

The electrician was working on deck 7 when the lights went out. He ran down to the control room where he met the motorman. Together they acknowledged the alarms and remained on standby pending instructions from the bridge. They turned the switch for the local application fire-extinguishing system in the engine room and think they remember switching from manual to automatic. At the time, smoke had seeped into the control room and the motorman had put on the smoke-diving equipment that hang in the control room.

The electrician was concerned about the emergency generator as he knew there had been problems with the air dampers. He ran up to deck 7 in order to open the door to the emergency generator room and secure an air supply in case the air vents were to close. However, due to the large volumes of smoke in the area, the emergency generator room was inaccessible. Nor could he see whether the air vents were still open.

The tour leader, who was about to announce the arrival in Ålesund in the usual manner, observed smoke pouring out from the area of the galley and saw many people running. Without being prompted, the tour leader immediately announced full evacuation over the PA system, requesting everybody to assemble on deck 5. The bridge crew registered calls from the purser in the reception stating that there was much smoke in the area, and the off-duty crew were mustered to ready the lifeboats.

After that, the focus was entirely on the evacuation of passengers. Since it was breakfast time, it did not take long to assemble the passengers. The crew did not have the time to carry out a full search of the whole ship, though the reception crew carried out a search of the cabins for the disabled.

1.2.3 The rescue operation

At 09:17, Florø radio received a call from *Nordlys* notifying of a fire in the engine room. Florø radio notified the JRCC immediately. *Nordlys* called Florø again at 09:18, requesting the assistance of a rescue vessel. At 09:19, *Nordlys* stated that it was without engine power. At the same time, an eyewitness notified Ålesund fire service, which issued a major incident alarm. Full mobilisation was initiated of the marine stand-by rescue team (RITS), crisis team and other rescue personnel in Ålesund.

The rescue vessel *Emmy Dyvi*, which was docked alongside the quay in Ålesund, had overheard the call and reported back that it was starting the engines and would proceed to *Nordlys* as soon as possible. *Emmy Dyvi* departed at 09:23 and reached the accident vessel at 09:27. *Nordlys* had prepared a tow line on the forecastle, and the line was aboard *Emmy Dyvi* at 09:31.

The steering engines were still powered when *Emmy Dyvi* arrived to take the tow line aboard. However, the crew on *Emmy Dyvi* registered that the lights on board *Nordlys* went out immediately after they had fastened the towline.

At 09:31, Florø radio issued a Mayday Relay to all vessels, stating that *Nordlys* was on fire. At that time, *Nordlys* had confirmed that there were 207 passengers and 55 crew on board, two of whom were injured by fire. Several vessels had now arrived at the scene, and others, including passenger vessels with great capacity, stated that they would be able to arrive in a matter of minutes. In addition, SeaKing helicopters had been requisitioned from Florø and Ørlandet.

Smoke was now developing rapidly on board *Nordlys*. It was pouring out of the stack and casing, preventing use of the starboard side boat deck to which the smoke gravitated. *Nordlys*, which had lost all engine power at this stage, turned against the wind and ended up in a position where only the lifeboats on the port side were available. The passengers and most of the crew put on life jackets, and were counted and taken aboard the lifeboats on the port side. Lifeboat no 3 was filled up first, followed by lifeboat no 5.

At 09:42, *Nordlys* stated that a MOB boat had been launched, carrying two injured crew. The injured crew were transported ashore, where health personnel overlapped and took them to hospital.

The fire service called *Nordlys* at 09:44 and informed the vessel that the fire service, paramedics and police were present and ready on the quay. It was agreed that priority would be given to the evacuation of passengers. A search would then be carried out of the smoke-filled areas on board.

1.2.4 Berthing of *Nordlys* alongside the quay

Nordlys arrived at the quay at 09:48 and was berthed with starboard side alongside. Before *Nordlys* was moored, the first lifeboat (lifeboat no 3) was lowered and released on the port side at 09:50. While *Nordlys* was being moored, the other lifeboat (lifeboat no 5) was also launched, at 09:58. Both lifeboats proceeded to the inner harbour and were moored to a floating stage where the passengers and crew were attended to and later taken to a hotel in Ålesund for accommodation.

At the same time as *Nordlys* was being berthed alongside the quay, the JRCC informed the Coast Guard vessel *Nornen* of the situation and requested *Nornen* to take the role as on-scene coordinator.

Emmy Dyvi started to cool down the hull on *Nordlys's* port side with sea water. The fire line aboard *Nordlys* was without pressure at the time, and the emergency fire-pumps did not work.

The Coast Guard vessel *Nornen* notified of its time of arrival and capacity, at the same time as the crew and equipment were being prepared.

1.2.5 Smoke diving and fire-extinguishing

The marine stand-by rescue team and regular crew from Ålesund fire service arrived at the quay at 09:28, where they were met by two smoke divers from the ship's crew, who were prepared to provide further guidance. Using the fire service's personnel lift, the rescue team boarded the ship from the aft end of deck 3 at 10:04.

According to the fire service personnel, there were no lights in the corridors aft on deck 3 when they boarded the ship. They were also informed that the fire hoses on board were without pressure. Since the fire-pumps on board were not working, hoses were deployed for feeding from fire fighting vehicles ashore.

The smoke divers started to search deck 3. On completing their search of that section, they proceeded to search decks 2, 1, 5 and 6, without any result. The smoke divers then went on to search deck 4. During that search, one person was found dead in the passage next to the hot kitchen in the galley. The person was later identified as the apprentice engineer.

At the same time as the accommodation was being searched, smoke divers made their way down into the engine room aft. The door between the engine control room and the auxiliary engine room was closed and cold. The auxiliary engine room was dark, the temperature was acceptable, visibility was reasonable and it contained some smoke. The watertight door between the auxiliary engine room and the main engine room was closed. Since there was no power for operating the door, it had to be opened by manual pumping.

Inside the main engine room, the smoke was dense and visibility was very poor. Most of the flames were observed on the starboard side of the starboard engine, in the area furthest away from the auxiliary engine room. This was also where the heat was mostly concentrated. The flames were spread out, emanating from separate points.

The smoke divers continued to the upper part of the engine room, on level with deck 1. In this area it was very hot, and zero visibility. The door between the main engine room and the incinerator room was open. Inside the incinerator room, flames emanated from several places, particularly on top of a workbench. Immediately next to the workbench stood an acetylene cylinder. Burning residue, which had dropped onto and around the cylinder, was extinguished by the smoke divers.

They moved onwards into the separator room. The door between the incinerator room and the separator room was open. There were no flames inside the separator room. On the floor in the middle of the separator room, they found a lifeless person, who was brought up and out onto the poop deck. The person was later identified as the chief engineer.

The smoke divers then continued to search the workshop on the opposite side of the main engine room. The door from the main engine room to the workshop was closed. No open flames were observed inside the workshop, but the heat was intense, and they had to pull back.

There was some confusion with regard to the correct number of passengers, as *Nordlys* had previously stated that there were 207 passengers on board. The shipping company had counted 209 passengers on the passenger list, and the reason for this was that two passengers had booked their ticket ashore without booking a cabin. When they came on board, they wished to book a cabin, which meant that an additional booking was made on board. Consequently, the two passengers were registered twice on the passenger list, but the correct number of passengers (207) had been entered at the bottom of the list. This was clarified by the shipping company and the ship together, and, at 12:32, *Nordlys* was able to reaffirm that the correct number of passengers was 207.

At 13:16, the SeaKing helicopter completed its search of the area where *Nordlys* had been when the fire started, without any result. At 13:45, the police concluded that there were no more missing persons.

At 11:28, *Emmy Dyvi*, which, after towing *Nordlys* to the quay, had positioned itself on *Nordlys*'s port side in order to cool down the hull, reported that *Nordlys* was laying 'heavier' in the water. Later on it was also observed that *Nordlys* was listing to port. At 12:16, *Nornen* reported that *Nordlys* had two metres of water in the cargo hold and that pumping had been initiated. At 12:20, *Emmy Dyvi* was requested to end cooling down the ship's side and prepare to take part in a diving operation.

At 13:28, it was reported that the fire service had extinguished the fire in the engine room. The diving operation was started by *Emmy Dyvi* at the same time. It had now become clear that *Nordlys* was taking in more water than the pumps were able to handle. It had also become clear that they were pumping salt water, while it was fresh water that had been used for extinguishing the fire.

1.2.6 Water ingress and the salvage operation

The focus eventually shifted to providing more pump capacity. Measures in that connection included the requisitioning of two bilge pumps with a capacity of 500 and 350 m^3 per hour, respectively, that were available in the Ålesund area.

It was not clear where the water ingress came from, but the divers initially focused on the seawater intakes. At 14:18, *Emmy Dyvi* reported that the divers had not found any seawater intakes where it could be detected any suction.

The Coast Guard now assumed command of the diving, and leak mats were prepared for covering the seawater intakes. The work was stopped at 15:15, however, due to uncertainty about the ship's stability. At 15:27, the bridge on board *Nordlys* was evacuated due to the heavy list.

One focus area was now to get the ship's emergency generators going, so that priority could be given to emptying the ship of water. In addition to the fact that the dampers, that were designed to ensure air supply to and cooling of the air in the emergency generator room, had closed; a cooling water hose proved to be leaking. When a hose of the right dimension was procured, it was still impossible get the emergency generators to work. It has subsequently become clear that the engine had seized.

At that point in time, no water had been found in cargo hold no 1, but water in cargo hold no 2 had been confirmed. While the bridge was being evacuated, a message was received that a leakage had developed through the door between cargo hold no 1 and cargo hold no 2. DNV was assigned the task of carrying out stability calculations to ascertain how much water ingress *Nordlys* would be able to withstand before the danger of capsizing became a reality.

At 16:19, the rescue operation was concluded, and the shipping company initiated efforts to salvage the ship.

At 18:46, professional divers were in place and took over the diving operations.

At 20:36, the intermunicipal pollution control committee deployed booms around *Nordlys*, with the assistance of the Coast Guard vessel. As the evening progressed, possible measures were considered how to deal with the situation should it deteriorate and *Nordlys* capsize. This included an assessment of the possibility of beaching *Nordlys* on Ellingsøya island. It was concluded, however, that *Nordlys* should remain alongside the quay.

The effort to empty the cargo holds of water continued. Practical problems, including that the pumps clogged, were dealt with as they arose. At approx. 23:00, a hole was cut in the hull next to the side gate on the starboard side, to provide easier access for the pumps. The initial hole proved to be too high up, however, and a new hole had to be cut lower down in the ship's side. A small fire occurred on the car deck as a result of the work on cutting the first hole. At the same time, two divers from a civil company continued to seal the seawater intakes with the aid of *inter alia* magnetic mats, and to inspect the hull to detect any further leakage points.

Just after midnight, a new and larger hole was cut aft of the first holes in the starboard ship's side, to make it easier for personnel to board the ship. The hole was ready at 02:31, but it proved to be too high up the ship's side, and a new hole was cut slightly lower down. At 03:04, fire service personnel boarded the ship and inspected the engine room, which proved to be dry. At 04:10, water was found to have entered the elevator shaft in addition to the cargo holds, but it was not possible to find the route by which the water entered.

The list became heavier as the night progressed and the morning broke. At 05:49, the list was measured at 19.7 degrees, at 07:40, it was measured at 20.3 degrees and at 08:39, it was measured at 21.78 degrees.

On Friday 16 September at 09:00, a coordination meeting was held in the harbour master's offices in the quay area in Ålesund. Present at the meeting were representatives of all those involved, including the port authority, the shipping company, the police, the fire service, the rescue crew, the Norwegian Coastal Administration, the NMA and the AIBN. Information was exchanged at the meeting, and decisions were made as necessary for the salvage operation to proceed. It was also decided to hold regular coordination meetings.

Salvage specialists from Smit Salvage had arrived in Ålesund that morning, and they boarded *Nordlys* at 09:08.

By that time, more than sufficient pumping capacity had been put into place and the pumps were working well. At the same time, divers discovered a hole in *Nordlys*' hull, located aft of the starboard stabiliser fin.

As the day progressed, divers worked to seal the hull damage using wedges of wood, magnetic mats and margarine. The rescue crew were thus able to eventually gain control over the water ingress, and the list was little by little reduced through the evening and night.

The next coordination meeting was held at 09:00 on Saturday 17 September. The list had now been reduced to approx. 10 degrees, and it was decided that the ship could now be boarded by others in addition to the salvage crew. The AIBN, together with the master and representatives of the shipping company, the police, the insurance company and the NMA, boarded the ship just before 12:00 Noon. The first preliminary investigations were carried out.

In the course of the day and evening of 17 September, the list was further reduced and the situation clarified.

1.3 Weather conditions

According to the Norwegian Meteorological Institute, a fresh to strong breeze was blowing in the area during the period in question. The weather was cloudy with some light rain, but visibility was mostly good.

1.4 Extent of damage

1.4.1 Injuries to persons

Two crew members – the chief engineer and one apprentice – died, while two others – the first engineer and the repairman – were seriously injured in connection with the fire.

Those who were seriously injured were sent to Haukeland Hospital for treatment of burn injuries. Another seven crew members sustained light injuries. They were sent to Ålesund Hospital for treatment and observation. Two of them were hospitalised for four weeks, while the other five were discharged after a few hours.

None of the passengers were injured.

1.4.2 Damage to the vessel

The fire caused extreme heat development in the main engine room. In addition, the auxiliary engine room was damaged by smoke and soot, as was the corridor forward of the main engine room, the stairwell and the area of the galley on deck 4.

Figures 4, 5, 6 and 7 show the extent of damage to the main engine room and adjacent rooms (workshop and incinerator room). Figures 8 and 9 show the extent of damage to the corridor forward of the main engine room and the midship stairwell.

Figure 4: Starboard side of the main engine room looking aft from the forward gallery. The top of the starboard main engine can be seen in the foreground. The bulkhead dividing the workshop from the engine room can be seen in the background, with the aft entrance door in the middle of the photo. Photo: The police.

Figure 5: The interior of the workshop on the starboard side, where the first engineer, repairman and apprentice were standing when the fire broke out. Photo: The police.

Figure 6: The port side of the main engine room looking aft from the forward gallery. The top of the port main engine is included in the photo. The door to the incinerator room can be seen on the right. Photo: The police.

Figure 7: The interior of the incinerator room where the chief engineer came from when he met the motorman in the separator room. Photo: The police.

Figure 8: Outside the cold provision stores between the midship stairwell and the main engine room on deck 1. The temperature was so high that it melted the plastic wrapping around the toilet paper rolls. Photo: SINTEF NBL.

Figure 9: On the landing between decks 2 and 3 in the midship stairwell. Photo: SINTEF NBL.

While *Nordlys* was being berthed alongside the quay, the starboard stabiliser fin was forced back and into the ship's side aft of the stabiliser room. This tore a gash in the ship's side, which in turn resulted in cargo hold no 2 filling up with water.

1.4.3 Environmental damage

No pollution or other form of environmental damage was registered in connection with the accident.

1.5 Shipping company and fleet

Nordlys is owned by Kirberg Shipping KS and is operated by Hurtigruten ASA. Hurtigruten ASA, with offices in Narvik and Tromsø, is a merger between the former Ofoten og Vesterålen Dampskibsselskap (OVDS) and Troms Fylkes Dampskibsselskap (TFDS). The two companies merged in March 2006, and the core activities are operation of the Hurtigruten coastal express service, travel and tourism. Hurtigruten ASA currently operates 13 ships, 11 of which are used in the coastal service between Bergen and Kirkenes. The shipping company's fleet consists mainly of ships built in the 1990s and 2000s.

The sailing pattern for the 11 ships in the coastal service consists of 11-day round trips between Bergen and Kirkenes with 34 calls en route each way. This amounts to approx. 24 000 port calls per year.

The company is certified under the International Safety Management (ISM) Code and had a valid Document of Compliance (DOC) at the time of the accident.

The shipping company has been forthcoming and has contributed information during the AIBN's safety investigation after the accident on board *Nordlys*.

1.6 The crew

Nordlys had a total crew of 55, consisting of 10 deck crew (including one apprentice), 9 engine crew (including 2 apprentices) and 36 hotel crew (board and accommodation) (including 1 apprentice). The bridge crew consisted of the master, chief mate, safety officer and navigation officer. The engine officers consisted of the chief engineer, first engineer and second engineer.

The ship had an 8 – 4, 4 – 8 watch system, i.e. 8 hours on, 4 hours off, 4 hours on, 8 hours off. This is the normal watch system used by the shipping company. In addition, some crew members worked as daymen at the time of the accident. Among the maritime crew members, this included the chief engineer, repairman and electrician. The purser also worked as a dayman.

1.7 Passengers and cargo

Nordlys had 207 passengers on board when the accident occurred. In addition, it had a cargo of private cars and miscellaneous mixed cargo. The passengers came from 16 different nations.[1]

1.8 The ship

Nordlys was built as Build No 102 by Volkswerft Stralsund VEB in 1994. The ship was built to carry 691 passengers and 50 cars.

At the time of the accident, it was registered in the Norwegian Ordinary Ship Register (NOR) and classified by DNV with class designation +1A1 ICE-1C Car Ferry A RM E0. Applicable regulatory and classification certificates were valid, and *Nordlys* was approved to carry 681 persons, or 622 passengers and 59 crew. The Passenger Ship Safety Certificate had been issued by the NMA on 1 April 2011, with validity until 31 March 2012. The ISM certificate had been issued by the NMA on 27 March 2009, with validity until 27 September 2012. The class certificate had been issued by DNV on 20 May 2009, with validity until 31 March 2014.

Nordlys has a manned engine room. According to the minimum manning requirements issued by the NMA on 5 November 2007, the minimum safe manning for operation with a manned engine room is chief engineer, first engineer, engineer, electrician and three motormen.

1.9 The ship's engines, power supply and fuel oil system

1.9.1 <u>The main engines</u>

The main propulsion engines were two six-cylinder, four-stroke diesel engines of the type MaK 6M552C, each with an output of 6 114 BHP (4 500 KW). The engines were manufactured in 1992 by MaK Motoren GmbH & Co. KG in Kiel in Germany.

[1] NO, US, DE, CH, AU, BE, FR, IT, DK, AT, SE, RU, EE, NL, ES and GB

Each main engine is connected to a shaft generator, which can also be operated as an electrical propulsion engine. They can be operated in combinator mode at around 48–52 Hz. Before arrival in port, it is normal to switch to constant revolutions while the shaft generators continue as the primary suppliers of electricity. The auxiliary engines are operated when necessary.

1.9.2 The auxiliary engines

The auxiliary engines are of the type Ulstein Bergen KRG-8. Each of the two engines has an output of 1 719 BHP (1 265 KW). The engines were produced in 1992 by Ulstein Bergen AS in Bergen in Norway.

1.9.3 The emergency generator

The emergency generator is placed in the emergency generator room on the starboard side aft on deck 7, and it is operated by a water-cooled Detroit 6V-92TA diesel engine with an output of 275 kW. The engine is connected to a dedicated 3 000-litre diesel tank. The cooling water for the engine is cooled in a radiator placed immediately aft of the engine. In order to provide sufficient air for cooling, dampers in the bulkhead open when the generator is started. The dampers on board *Nordlys* were air-operated, and the design of the spring-loaded open/close mechanisms meant that the dampers depended on a supply of compressed air from a compressed air accumulator to open. The compressed air is produced by a working air compressor placed in the auxiliary engine room. The compressor is in turn dependent on power from the ship's main electricity supply. After weaknesses in this system had been identified in connection with the grounding of the sister ship *Richard With* in 2009 (see the AIBN's report MARINE 2010/03), a check valve was installed on the air supply line in the emergency generator room, so as to prevent loss of air pressure in the event that the power supply failed.

The function of the emergency generator is to produce power for the emergency switchboard in the event that the main power supply fails. During normal operation, the emergency switchboard is supplied with power via a contactor that is activated from the main switchboard. If the main power supply fails, loss of voltage at the emergency switchboard will trigger a signal for start of the diesel engine for the emergency generator. The emergency generator starts, and, when the speed and voltage is right, the emergency generator breaker will close and energise the emergency switchboard. The emergency switchboard then takes over and ensures that power is distributed to the connected systems; see Appendix C.

1.9.4 The power supply system

Nordlys can operate in different power supply configuration modes. When sailing in normal service, it usually operates in mode 3, which was also the case at the time of the accident. In mode 3, the ship is supplied with power from the shaft generators, and the main switchboard is split. Each section of the switchboard is supplied with power from its own shaft generator, and each shaft generator has an auxiliary engine on standby (see Figure 10). Duplicated equipment is distributed between the two main switchboard sections, so that e.g. a fuel injector pump connected to the port side switchboard will have a dedicated standby pump connected to the starboard switchboard.

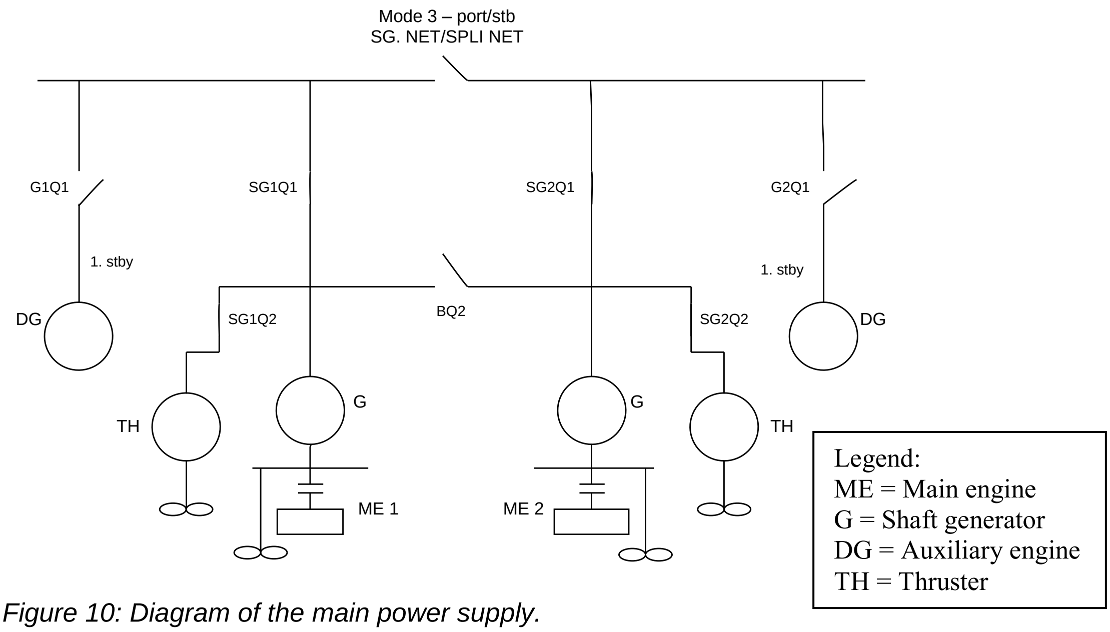


Figure 10: Diagram of the main power supply.

The emergency switchboard is supplied with power from the main switchboard 1 (port), and any loss of power to this switchboard will trigger a signal for automatic start of the emergency generator. A list of equipment supplied with electricity from the emergency switchboard is enclosed as Appendix C.

1.9.5 Fuel oil system

Nordlys was initially designed for use of both heavy fuel oil and diesel, but, since autumn 2009, it has only used a special distillate that can be described as 'waxed diesel'. This was used to fuel both the main and auxiliary engines. The emergency generator used conventional diesel.

Booster pumps are used to feed fuel to the main engines at a pressure of approx. 5–5.5 bar. In addition, each cylinder has its own fuel injector pump that pumps fuel from the engine's fuel rack and discharges it into the cylinders at a pressure of approx. 350 bar. The booster pumps circulate approx. 3 m^3 of fuel per hour, which is more than double the maximum consumption. The surplus is collected at the end of the fuel rack and returned to the mixing tank. The closed circuit (mixing tank – main engine – mixing tank) is set to a pressure of approx. 5 bar and is continually topped up from the daytank.

When the high-pressure pumps open and close towards the low-pressure side, pressure pulses arise in the low-pressure system. Piping, components and fixings can be damaged if the pulses are sufficiently strong or if self-oscillations arise in the system. Immediately before and after the fuel rack, the fuel passes through pressure compensators whose function is to dampen such pressure pulses. The mixing tank also has a dampening function in that it is pressurised using an air bag that will help to dampen pulses/oscillations in the system.

All fuel tanks have quick-closing valves located in the emergency station on deck 2. Lube oil and booster pumps as well as fans and separators can be shut down from an emergency panel just outside the control room.

Figure 11: Panel for emergency shutdown of pumps, fans and engine room equipment. Photo: AIBN.

1.10 The engine room fire-extinguishing system

Two types of fixed fire-fighting systems are installed in the engine room on *Nordlys*. The main system is a CO_2 system. In addition, a water-based local application fire-extinguishing system has been installed above the two main engines and in some other special areas.

1.10.1 The CO_2 system

The CO_2 system in the engine room on *Nordlys* was delivered by Minimax. It was required to have the capacity to flood the engine room with sufficient gas to create an inert atmosphere in which all fire would eventually be extinguished. In practice, that meant that the gas was supposed to fill 40% of the room's gross volume or 35% of its net volume. It was assumed that 85% of this gas could be released into the room within two minutes after activation of the system. As CO_2 concentrations of this strength are life-threatening for people who occupy the room, it is required that the rooms must be evacuated before the system is released, and it must not be possible to release the system from inside the room.

CO_2 was stored in pressure cylinders of 45 kg: 55 cylinders for the main and auxiliary engine rooms, 2 for the separator room and 4 for the control room. The panel for release of the CO_2 was placed in the stairwell on deck 2, and the pressure cylinders were kept in a separate room at the aft end of deck 2.

A separate procedure was in place for releasing CO_2 into the engine room. The procedure required the CO_2 cabinet to be opened prior to activating the system, which would automatically release an alarm and stop the ventilation fans. Next, it must be ensured that everyone had left the room, that all openings were closed and that the fuel oil supply was closed. The safety pin in the time delay box would then have to be removed, then to open a flap once the time delay had expired, open for the CO_2 pilot cylinders, open the steering valve for the CO_2 valve and, finally open the steering valve for the CO_2 cylinders. Manual release of CO_2 was also possible from the CO_2 room.

1.10.2 Local application fire-extinguishing system

In addition to the CO_2 system, the engine room on board *Nordlys* was protected by a local application fire-extinguishing system of the type Novenco Hi-Pres Water Mist System. The system, installed in 2002, was water-based and divided into six sections: one section with three nozzles above the boiler, one with six nozzles above each main engine and auxiliary engine, and one with five nozzles in the separator room. All nozzles were located on deck 1 (under deck 2). There were no nozzles at the tank-top level.

The system is called a 'high-pressure system', but it was operated at approx. 10–12 bar, which places it in the 'medium pressure' category according to the terminology used to describe water mist systems. The nozzles had a k-factor of 5, giving a water rate of approximately 13.5 l/min at 7.3 bar pressure. They were made of brass alloy and had a protective cap of stainless steel that, on account of the pressure, would fall off automatically on release of the system. They had a spray angle of 120 degrees. The system was connected to a dedicated pump capable of delivering 6 m^3 per hour, and it was supplied with water from a freshwater tank of 3 m^3. A valve to the fire-water line had to be opened before the freshwater tank was emptied, in order for extinguishing to continue using seawater.

Connected to the system were UV flame detectors and combined smoke and heat (ionization) detectors. The local application fire-extinguishing system was fully automatic and set to be released on activation of the smoke and flame detectors for the section. The system could also be released manually at each section or from the pump system in the stores room on the port side aft of the engine control room.

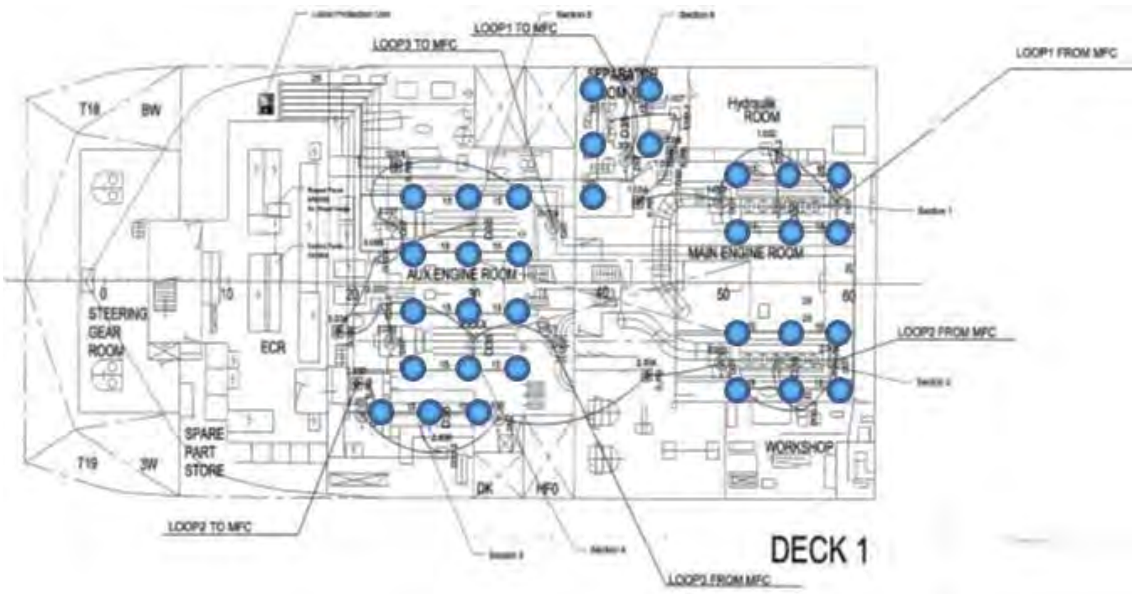


Figure 12: Sketch showing the position of the nozzles in the local application fire-extinguishing system. The nozzles (marked as blue bullet points) are placed above each main engine (six per engine), in the separator room (five), above each auxiliary engine (six per engine) and above the boiler (three). This add ups to a total of 32 nozzles on deck 1 (under deck 2). There are no nozzles at the tank-top level.

The local application fire-extinguishing system is supplied with power via the emergency switchboard.

For automatic release of the system, the control panel on the port side in the engine control room must be set to 'auto', and fire must be indicated by at least two detectors connected to the system.

1.11 Fire doors

Nordlys is divided into three main zones that can be separated by fire doors in an emergency situation. The fire doors are designed to limit the spread of fire and smoke, and to reduce the supply of oxygen to the fire.

The doors can be closed from the bridge, either zone by zone or all at the same time. The doors can also be closed manually in a location close to each door. The doors can also be connected to the fire alarm system so that they will close automatically in the event that a fire alarm is not acknowledged within two minutes.

1.12 Watertight subdivision

To be able to survive damage that leads to flooding through the hull, *Nordlys* is divided into several watertight divisions by transverse bulkheads. Such transverse bulkheads are arranged on frames 18, 38, 62, 86, 134 and 166 (the 'collision bulkhead'). As a minimum, the transverse bulkheads extend to deck 2, which is defined as the 'bulkhead deck'. The spaces between the watertight bulkheads are referred to as 'watertight compartments'.

1.13 Watertight doors

Watertight sliding doors have been arranged in all the transverse bulkheads with the exception of the collision bulkhead. At tank-top level, a watertight sliding door has been arranged in the bulkhead on frame 86, between cargo hold no 2 and cargo hold no 1. On deck 1, watertight sliding doors have been arranged on frame 18 (between the engine control room and the auxiliary engine room), in the bulkhead on frame 38 (between the auxiliary engine room and the main engine room), in the bulkhead on frame 62 (between the main engine room and the provision stores), in the bulkhead on frame 86 (between the provisions stores and crew accommodation) and in the bulkheads on frames 110 and 134 (inside the crew accommodation).

The watertight doors were installed during the construction of *Nordlys*.

All watertight doors shall be kept closed during sailing, but they can be opened if it is necessary to pass through them or if work is being carried out in the immediate vicinity of the doors. The doors shall be closed again as soon as they have been passed through or the work is completed. The doors can be operated locally, from the safety central and from the bridge. From the bridge, it is possible to close the doors one by one or all at once. If all doors are closed from the bridge, they will automatically re-close if they have been opened individually at location.

1.14 The shipping company's safety management system

The shipping company has established a safety management system in line with the ISM Code[2]. The system is designed to ensure safety at sea, prevent personal injuries and loss of human life, and avoid harm to the environment and property.

Important in relation to the shipping company's vessels are the safety manual and the ship manual, which contain both general and vessel-specific instructions and procedures, including responsibility and job descriptions, documents describing training requirements and instructions relating to emergency situations.

The safety management system, which was prepared in cooperation with the employees, is based on national and international rules and regulations in addition to internal requirements defined by the shipping company. The system contains routines, procedures and instructions for day-to-day operation and how to act in emergency situations. The system is continually revised by the shipping company through internal audits, system reviews by the shipboard management and system reviews by the shipping company's management. Regular audits of the system are also carried out by the NMA.

Policy and overriding governing documents form the basis for manuals, and the shipping company's manual forms the basis for ship manuals. The policy also forms the basis for instructions and the instructions are detailed in procedures. When the need arises, checklists are prepared to ensure compliance with the procedures. Documents in the safety management system are distributed via Docmap, the company's electronic document management system.

[2] International Safety Management Code, IMO Res. A 741 (18)

Figure 13 shows the structure of the management system.

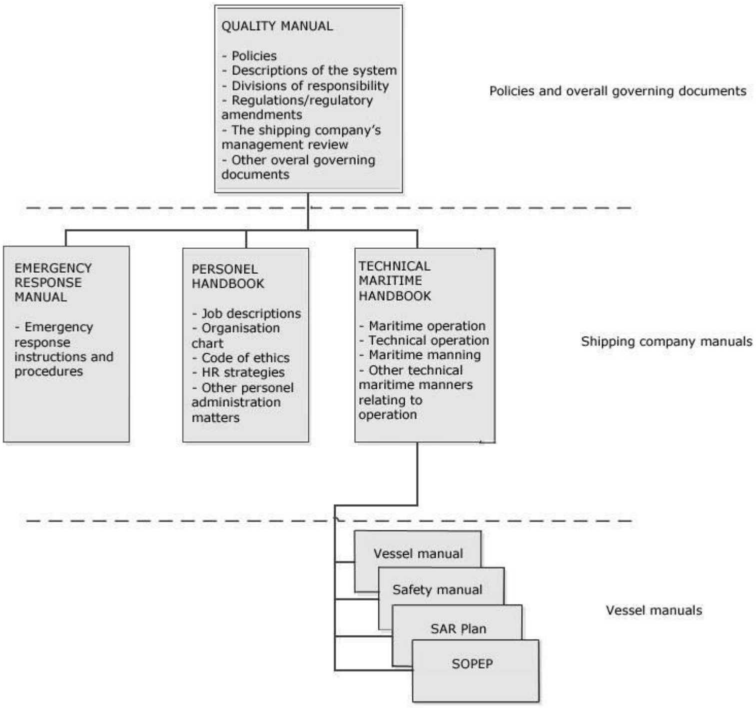


Figure 13: Schematic presentation of the shipping company's management system. Source: Hurtigruten ASA.

1.14.1 Responsibility and job descriptions

Responsibility and job descriptions have been prepared for each individual position on board. According to the master's job description,[3] he is obliged to take such action as he considers necessary to avoid undesirable incidents. The master has overriding authority on board and is responsible for making decisions related to safety and pollution prevention and for requesting assistance from the company as necessary. According to the chief engineer's job description,[4] he has the authority to ensure day-to-day operation in his department within a defined framework.

According to the alarm instructions, the chief engineer has the function of chief fire officer / incident commander and shall muster to the bridge in an emergency situation. The alarm instructions also describe who is to stand in for key personnel if the latter are unavailable. The chief mate is stand-in for the master and the chief engineer, while the second engineer is stand-in for the first engineer etc.

1.14.2 Shipboard training

Crew training is described in a separate procedure.[5] The procedure is meant to ensure that new recruits receive necessary training through the completion of training programmes adapted to each individual position on board. The master is responsible for ensuring compliance with the training procedures on board, while the head of each department is responsible for ensuring that necessary training is given to personnel in his/her section.

[3] Job description SB0001 Job Description Master
[4] Job description SB0013 Job Description Chief Engineer
[5] Procedure PR0001 Shipboard training procedures

The ship's safety officer is responsible for ensuring that necessary safety training is carried out. Drills shall be conducted on board in accordance with a specified safety training programme.

1.14.3 Procedure in the event of fire[6]

According to the fire procedure, the bridge shall be notified immediately and in the fastest possible way of any fire or event posing a similar danger to the ship. When the alarm button closest to the place of the fire is depressed, the call point is displayed on the control panel on the bridge. The person discovering the fire shall do his/her utmost to extinguish the fire using the closest fire extinguisher.

Doors and hatches from which smoke is seeping out must not be opened until the fire extinguisher has been readied for use. The procedure warns against spitting flames that may flare up when doors are opened. If it proves impossible to extinguish the fire with the available means, an attempt shall be made to close all openings that feed air to the fire, and the person in question shall then remain at the place of the fire pending the arrival of a fire-fighting team. That person shall then report what happened and whether anyone is trapped in the area of the fire, before proceeding to his/her station in accordance with the alarm plan.

According to the procedure, the navigator on watch shall first notify the master. On the master's orders, the navigator on watch shall:

- close fire doors/watertight doors;
- start the fire-water pumps;
- check that the ventilation has been shut down;
- if necessary, change course so that the location of the fire is protected from the wind.

In the event of a fire in the engine room, the engineer on duty shall:

- on detection, notification or suspicion of fire in the engine room or adjacent rooms, release the fire alarm, and then inform the bridge and chief engineer of the situation;
- seek to extinguish an incipient fire using available extinguishing equipment. The ship also has a local application fire-extinguishing system. If the engineer is not convinced that the fire can be extinguished by means of available equipment, orders shall be issued for evacuation of the engine room;
- start the alarm for the main extinguishing system by opening the door to the release cabinet. (The fans will stop). THE ACTUAL SYSTEM MUST NOT BE RELEASED! It must only be released after control mustering and on receiving an express order to do so;

[6] Procedure PR0065 Fire

- Remain next to the release cabinet until the chief engineer arrives and inform him of the situation. Then act in accordance with the alarm instructions and on the orders of the chief engineer.

It is also clear from the procedures[7] that the main extinguishing system (the CO_2 system) must only be released by the ship's management on the master's orders.

The fire procedure contains no instructions for shutting off the fuel supply. This is, however, dealt with in the procedure for release of the CO_2 system.

1.14.4 Instructions relating to fire-fighting and accident teams[8]

Three fire teams (fire team, technical team and assistance team) have been established to participate in the response efforts in a fire/accident situation and to search areas that are not immediately accessible due to smoke etc. The fire teams can be assigned tasks relating to fire-fighting, air supply, damage control, evacuation, pollution, helicopter landing assistance, search and rescue operations etc. The fire teams muster in accordance with the emergency plan.

1.14.5 Procedure for engine-room local application fire-extinguishing system[9]

The system is described as a fully automatic system that will be released on activation of a smoke detector and a flame detector for the section that give simultaneous indication. The procedure also describes the location of manual release points next to each component, and of the possibility of manual release from the pump system in the stores room. The system is also described as being connected to the ship's fire-water line via a stop valve. The system is not under pressure.

1.14.6 Checklist for the bridge on approaching port (normal operation)[10]

The ship manual contains a number of checklists to be used during normal operation. According to the checklist to be used on approaching port, the bridge crew shall check *inter alia* that the stabiliser fins have been retracted.

1.14.7 Procedure for preparing job specifications[11]

The procedure is designed to ensure that, on preparing job specifications, necessary and sufficient information is included for the job to be carried out in an expedient and safe manner. Among the factors to be assessed are previous experience, matters requiring special attention, operational adjustments and whether safe and expedient performance of the job requires additional personnel and/or special tools. References to risk assessments shall be included where relevant. A similar assessment shall also be carried out when the job is completed in order to determine whether the job specification is satisfactory.

[7] Procedure PRO116 CO_2 alarm
[8] Instructions IN0043 Fire-fighting and accident teams
[9] Procedure PRO182 Engine-room local application fire-extinguishing system
[10] Checklist SL0163 Checklist for the bridge on approaching port
[11] Procedure PR0006 Preparing job specifications

1.14.8 Handling of nonconformities

Handling of nonconformities is part of the company's safety management system and is carried out with the aid of the Docmap electronic document management system. Each employee is instructed in his/her job description to inform his/her immediate superior of any non-conformities. The shipping company has prepared a separate procedure for processing of observation reports (including nonconformities) between the individual ship and Technical Maritime Operation (TMO). The purpose of the instructions is to ensure that observation reports are processed, investigated and analysed with a view to improving safety and preventing pollution. Reporting is done using as specific 'Nonconformity' observation report in Docmap. The master has overall responsibility for shipboard processing of observation reports. TMO's director has overall responsibility for processing of observation reports by TMO. The instructions state that, as far as possible, observations reports prepared by the ship should be handled on board the ship.

Nonconformity reports from the individual ships are subject to consideration/review in various forums, including:

- Internal ship meetings
- The ship's operational meetings with the administration
- The shipboard management's annual system review
- TMO’s department meetings
- The shipping company's management reviews

1.15 The shipping company's maintenance system

Hurtigruten ASA uses a computer-based maintenance system of the type STAR IPS. The system describes the routines for maintenance of ships and equipment.

In 2009, the shipping company issued an 'ERFA notice' (experience report) to its vessels stating that, in connection with an audit, the NMA had identified inadequate job specifications in the maintenance system, including the absence of references to the manufacturer's maintenance specifications. The ERFA notice described various actions to be taken by the vessels as a consequence of this. All work orders should include an unambiguous job specification in accordance with the manufacturer's instructions and references to the manufacturer's instruction manual where appropriate. It was also made clear that risk assessments should be carried out of the tasks involved and that they should be linked to the job. On completion of a job, a complementary report should be made on the execution of the work.

At the time of the accident, the maintenance system included, *inter alia*, the following job specifications:

1.15.1 Maintenance of the main engines

The fuel injector pumps for the main engines were to be replaced at intervals of 24 000 hours. In the maintenance system, the job was described as 'overhaul fuel injection pump'. The job specification included neither details on how the job should be done nor references to user manuals or other supporting documents. It was clear from the system that, prior to the accident, the most recent job relating to the fuel injector pumps was the replacement of the fuel injector pump for cylinder no 5 on the starboard main engine on 3 September 2011, without any noteworthy comments having been entered.

1.15.2 Insulation of hot surfaces

The instructions prescribed annual inspection of the insulation of the exhaust manifold and exhaust pipes. The job was described as 'inspect insulation and exhaust pipes'. According to the system, prior to the accident, this job was most recently reported to have been carried out on 14 April 2011, and the comment 'inspected together with Veritas/ the NMA's Bergen office 26.03 – 02.04, ok.' had been entered.

1.15.3 Maintenance of the emergency generator

The maintenance system included a job that prescribed weekly testing of the emergency generator. This job involved inspection of water, oil and engine heater, and start-up of the engine. A three-monthly job was also included, prescribing a test run of the emergency generator under load conditions. The alarms connected to the emergency generator were to be tested annually, and a minor overhaul job was to be carried out on an annual basis. The system included a major overhaul job at five-year intervals. The above-mentioned jobs were reported as having been carried out without any major non-conformities during the period before the accident.

Another job that was included was described as 'test automatic air dampers for the emergency generator. Also check that the dampers do not close on loss of air pressure'. This job was carried out on 2 July 2011, and the following comment entered: *'tested and the check valve does not work as intended – the damper goes in closed position after a while. Working on getting hold of new air cyl. with opposite action. Until then, the dampers are to be set blocked open at black-out.'* According to the shipping company, the results of the tests were neither conveyed to the onshore organisation nor to the sister ships. Nor were any temporary measures implemented to secure the air supply pending the modification work.

There were no scheduled jobs in the maintenance system relating to inspection and replacement of flexible tubing, including cooling water hoses, for the emergency generator.

1.16 Regulations

1.16.1 Overriding requirements for the design, construction and fitting out of ships

Pursuant to the Norwegian Ship Safety and Security Act,[12] a ship shall be so designed, constructed and equipped that it, according to its purpose and trade area, provides for the satisfactory protection of life, health, property and the environment. The Ministry issues regulations relating to how vessels shall be designed, built and fitted out in order to meet the above requirements.

Section 6 of the Act states that the shipping company has an overall duty to ensure that the construction and operation of the ship is in accordance with the rules laid down in or

[12] Act no 9 of 16 February 2007 relating to ship safety.

pursuant to the Act, including that the master and other persons working on board comply with the legislation.

1.16.2 Requirements for construction and outfitting

Nordlys, whose keel was laid on 16 October 1992 and handed over from the construction yard to the shipping company on 1 January 1994, was subject to the building requirements laid down in the Norwegian Shipbuilding Regulations[13] that applied when the keel was laid. *Nordlys* is also required to comply with the provisions of Regulations No 305.[14] The Regulations implement the amendments to Council Directive 98/18/EC, and include requirements for upgrading of existing ships in accordance with the provisions set out in each section and annex.

1.16.3 Requirements for a safety management system

Requirements for safety management systems are regulated by the ISM Regulations.[15] The international norm for the safe management and operation of ships and the prevention of pollution (the ISM Code) is appended to the Regulations.

1.16.4 Requirements for a maintenance system

The ISM Regulations require establishment of a system for maintenance of ships and follow from the ISM Code Section 10: Maintenance of the Ship and Equipment. The Company should establish procedures to ensure that the ship is maintained in conformity with the provisions of the relevant rules and regulations and with any additional requirements which may be established by the company. Equipment and technical systems, which may lead to hazardous situations due to a sudden operational failure shall be identified, and specific measures aimed at improving the reliability of such equipment or such systems shall be implemented.

Records of maintenance shall be kept, and inspections and measures shall be an integrated part of the ship's operational maintenance procedures. Maintenance systems are not required to be electronic or to be approved by the authorities. In the case of classed ships, it is clear from the ship's class status whether it has an approved maintenance system. In the case of classed ships without an approved maintenance system, control of the ship's machinery is carried out in the form of direct onboard inspections. In the case of classed ships with an approved maintenance system, control is based on audits of the systems and self-inspections by the shipping company.

1.16.5 Requirements for stand-ins for key personnel

Pursuant to Regulations No 305, the muster list and alarm instructions must meet the requirements of the SOLAS Convention.[16] Among other things, this means that stand-ins must be appointed to replace key personnel in the event that the latter are unavailable. Account must be taken of the fact that different actions may be required according to the nature of the emergency situation. The Regulations do not prescribe training to deal with

[13] Regulations of 15 June 1987 No 504 relating to the construction of passenger ships, cargo vessels and lighters
[14] Regulations of 28 March 2000 No 305 relating to inspection, construction and fitting-out of passenger ships in domestic service
[15] Regulations of 14 March 2008 No 306 relating to safety management systems on Norwegian ships and mobile facilities
[16] International Convention for the Safety of Life at Sea

situations in which key personnel are un-available, with the exception of a general reference that crew on board are required to be familiar with their tasks in an emergency situation before the voyage commences.

1.16.6 Requirements for insulation and hot-surface protection in the engine room

When *Nordlys* was constructed, there were no provisions with explicit references to temperatures relating to the insulation of hot surfaces in the engine room. Such requirements were introduced with Regulations No 305 and applied to *Nordlys* as from 1 July 2003.

Pursuant to the requirements set out in Regulations No 305,[17] surfaces in the engine room that may reach temperatures exceeding 220 °C and that may come into contact with combustible liquids in the event of a leakage shall be insulated. Fuel oil lines are also required to be screened or otherwise suitably protected to prevent oil from splashing or leaking onto the hot surface as far as practically possible.

The Norwegian ASH Regulations[18] also contain provisions on screening of hot surfaces with a view to protecting the crew against the risk of sustaining burns if they come into contact with such surfaces. The Regulations contain no explicit temperature references, however.

1.16.7 Requirements for fire-extinguishing systems in the engine room

Pursuant to Regulation 305, *Nordlys* is required to have at least one of the following fixed fire-extinguishing systems:

- A gas system or an equivalent water-based system that meets the applicable provisions.
- A low-expansion foam system that meets the applicable provisions.
- A water-mist system that meets the applicable provisions.

Pursuant to the FSS Code,[19] the gas system mentioned in the first bullet point may be a CO_2 system or an equivalent gas-based system based on the IMO[20] guidelines and approved by the Administration.[21]

In addition, *Nordlys* was required to have installed a fixed water-based or equivalent local application fire-extinguishing system in the engine room by 1 October 2005. Continually manned engine rooms are only required to have a device for manual release of the system. The fire-extinguishing agent used must not endanger human life.

The local application extinguishing system shall not require shutting down of the engines, evacuation of personnel or sealing of the room, and the system shall protect, *inter alia,*

[17] Annex I pt. II-2 to Regulations No 305, and DNV Rules for Ships of January 2011, Pt. 7 Ch. 2 Sec. 2 C203 and C204.
[18] Regulations of 1 January 2005 No 80 relating to the working environment, safety and health of employees on board ships
[19] International Code for Fire Safety Systems
[20] International Maritime Organization
[21] The Norwegian Maritime Directorate for ships sailing under the Norwegian flag

fire-hazardous machinery parts with combustion chambers used as the ship's main means of propulsion and power supply.

Activation of the system shall trigger a visual and clearly audible alarm in the protected space and at the continuously manned stations. The alarm shall indicate which system has been activated.

Components used in the fire-extinguishing system in the protected space shall be able to withstand the higher temperatures that can arise in connection with a fire. The nozzles shall be placed so as to take account of any obstacles in the space between the nozzles and the area to be protected.

It must be possible to manually release the local application fire-extinguishing system both locally and from outside the protected area, and it must be easily accessible.

1.16.8 Requirements for an emergency power supply

Pursuant to rule II-1/D/3 on sources of emergency electrical power in Appendix I to Regulations No 305, all ships must have an independent source of emergency electrical power, with an emergency switchboard placed above the bulkhead deck and as close as possible to the source of the emergency power. In the case of Class B ships, the emergency source of electrical power (the emergency generator) must be able to operate for a minimum of 12 hours. The emergency generator must be capable of supplying power for the emergency bilge pumps, one of the fire-water pumps, the emergency lighting, the navigation lights, communication equipment, the general alarm system, the fire detection system, the emergency signals and the pumps for the sprinkler system. In addition, it must be capable of supplying power to the watertight doors and pertaining control, indicator and alarm circuits for at least 30 minutes.

1.16.9 Requirements for emergency exits from the engine room

Pursuant to Regulations No 305, engine rooms under the bulkhead deck shall have two escape routes consisting of either:

- two sets of steel ladders placed as far apart as possible, leading to doors in the upper part of the room that are correspondingly far apart and that provide access to the appropriate lifeboat and life-raft embarkation deck, or

- one steel ladder leading to a door that provides access to the embarkation deck, and additionally, in the lower part of the room and in a position well separated from that ladder, a steel door that can be opened and closed from both sides and that provides access to a safe escape route to the embarkation deck from the lower part of the room.

1.16.10 Requirements for stability and watertight subdivision

The requirements for stability set out in the Norwegian Shipbuilding Regulations that applied when *Nordlys* was built were based on the requirements in the SOLAS Convention. This was the case even though *Nordlys* only required certification for domestic service (small coastal trade). Pursuant to the Regulations, the ship must have sufficient intact stability to withstand what is known as 'one-compartment damage', i.e. damage leading to penetration of the skin between the watertight transverse bulkheads.

Hence, it was not necessary to assume damage to the transverse bulkheads when considering the ship's stability in relation to the minimum requirements in the Regulations.

Following the *Herald of Free Enterprise* accident in 1987, new requirements were introduced relating to stability in a damaged state. The requirements, which, in the case of ships like *Nordlys*, were still based on one-compartment damage, were applicable to new ships built after 29 April 1990 and to existing ships with effect from a date to be specified. *Nordlys* already met all these requirements, however.

After the *Estonia* accident in 1994, new requirements for stability with water-flooded car deck were introduced for ro-ro ships through an agreement[22] between the Nordic countries, the Republic of Ireland, the UK and Germany. The requirements were applicable to new ships in international service built after 1997, and to existing ships in international service with effect from a date to be specified. *Nordlys*, which was certified for domestic service, did not need to satisfy these requirements.

At the same time, the SOLAS Convention was amended so that ro-ro ships, which had previously been assessed on the basis of one-compartment damage, were now to be assessed on the basis of two-compartment damage. The provision applied to ships built after 1997 and certified to carry 400 or more passengers and crew. Existing ships were to satisfy this requirement by a date to be specified. *Nordlys* is required to satisfy the requirement by 2014. As an alternative, it must reduce the number of passengers and crew to 400 in 2014.

The current requirements relating to stability are set out in Chapter II-1 in Appendix I to Regulations No 305. Pursuant to these provisions, which implement the amendments to Directive 98/18/EC, *Nordlys* is required to have sufficient intact stability to withstand one-compartment damage. One of the specific requirements in the Regulations is that damage leading to asymmetric flooding shall not lead to a list of more than seven degrees on flooding of one compartment. In addition, *Nordlys* should have met the requirement for stability with flooded car deck by 1 October 2010. Alternatively, *Nordlys* could have retained its existing standard, provided that it is removed from service in 2015. The Regulations also introduce a long-standing requirement in the SOLAS Convention, namely that there must be no doors in bulkheads between the cargo holds. In the case of *Nordlys*, this prohibition entered into force on 1 July 2010.

1.17 Supervision

Pursuant to the Norwegian Ship Safety and Security Act, § 42 and § 43, ships and management systems shall be subject to supervision. The purpose of the supervision is to establish whether the ship satisfies the requirements laid down in or pursuant to the Act. Supervision of the management system may include a system audit of the documentation confirming that the shipping company has established necessary and appropriate systematic measures, and a verification confirming that the systematic measures are implemented, and that the implemented activities are in accordance with requirements laid down by law and regulations.

[22] The 'Stockholm Agreement'

1.17.1 Supervision by the authorities

1.17.1.1 *Supervision of ships*

Pursuant to § 6 of Regulations No 305, new and existing passenger ships shall be surveyed by the NMA. The survey shall include approval of construction drawings, follow-up of the ship during construction and periodic inspections during the ship's service life. Surveys shall be carried out insofar as they are deemed necessary, and shall be based on available drawings, among other things.

For classed ships, a copy of the master drawings of machinery, approved by the classification society, shall be submitted for review and, if applicable, follow-up by the NMA. In practice, the NMA relies on the classification society for approval of construction drawings of hull and machinery.

After conducting an initial survey of the ship, the NMA shall issue a passenger ship safety certificate. The certificate is issued for a maximum of 12 months. Before a new certificate is issued, the NMA shall carry out a survey for renewal of the certificate. The NMA's inspectors use checklists in connection with such surveys.

The Norwegian Maritime Directorate has prepared a checklist for verification of compliance with the requirements set out in Regulations No 305. This checklist,[23] which, according to the Maritime Directorate's internal instructions,[24] is to be used for the initial survey of the vessel after the entry into force of Regulations No 305, includes a check of hot surfaces. As far as subsequent (ordinary) surveys for the renewal of certificates are concerned, the AIBN has been informed that there are no available checklists adapted to Regulations No 305. For that reason, checklists[25] based on the Survey Regulations[26] are still used for surveys relating to the renewal of certificates. According to the NMA's internal instructions, checklists for renewal of certificates (PSF) shall be used every five years, while the checklist for annual inspection (PSÅ) shall be used for the four intervening years. Even though it is not adapted to Regulations No 305, the PSF checklist includes inspection of hot surfaces. Inspection of hot surfaces is, however, not included in the PSÅ checklist.

According to the NMA, it carried out an extended survey of *Nordlys* in 2002 in connection with the entry into force of Regulations No 305. In addition to the annual checklist (PSÅ), the KS-0104B report form was also used. According to the NMA, the background to using the annual checklist (PSÅ) on this occasion was that *Nordlys* had a valid[27] passenger ship safety certificate at the time. In connection with the renewal surveys in 2003, 2005, 2006, 2007, 2008 and 2010, the annual checklist (PSÅ) was used, while the checklist (PSF) was used in connection with the renewal surveys in 2004, 2009 and 2011.

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[23] *Rapport KS-0104B for eksisterende passasjerskip på 24 meter og derover, klasse B* ('Report KS-0104B for existing passenger ships of 24 metres and more, class B' – in Norwegian only)

[24] The Station Manual's Chapter 3 concerning safety certificates for passenger ships in domestic service was replaced by a procedure for surveying of and issuing of safety certificates to passenger ships in domestic service on 22 November 2011.

[25] Checklist KS-0151B for PSSC renewal surveys (PSF) and checklist KS-0157B for annual inspection (PSÅ)

[26] Regulations of 15 June 1987 No 506 concerning Survey for the Issue of Certificates to Passenger Ships, Cargo Ships and Lighters and concerning other Surveys etc.

[27] Valid until 2004

The PSF checklist was used during the renewal survey carried out 29 March–1 April 2011 (the most recent inspection prior to the fire). In that connection, it was left to the shipping company to check insulation and hot surfaces through self-inspection.

According to the NMA's vessel history, on 16 April 2007, the shipping company was required to insulate indicator valves and hot pipes. On 20 April 2007, the shipping company confirmed that it had acted on these requirements. After that, no instructions have been issued relating to the insulation of hot surfaces.

The CO_2 fire-extinguishing system that was available on board during the fire in 2011 had been installed on *Nordlys* as a newbuild and approved in connection with the initial survey in 1994.

The local application fire-extinguishing system had been installed[28] and approved in connection with the entry into force of Regulations No 305. At the time when *Nordlys* was built, there were no requirements for a local application fire-extinguishing system in the engine room. Relevant documentation relating to the local application fire-extinguishing system was addressed in the NMA's letter of 25 January 2002. In its letter, the NMA pointed out that the placement of the aft nozzles above the auxiliary engines was not quite in accordance with the type certificate issued by DNV. The letter also made it clear that the arrangement was not deemed to have been finally approved until it had been subject to a full-scale test in the presence of a representative of the NMA. During the test, which was carried out in connection with the installation of the system and in the presence of representatives of the NMA and DNV, the system was first pressure-tested by applying a pressure of 15 bar for 24 hours, and then tested through activation of the nozzles in the separator room.

The emergency generator on board *Nordlys* had been approved by the supervisory authority before the *Richard With* accident occurred. The modifications that were carried out on board *Nordlys* after the *Richard With* accident had likewise been approved. After the fire on board *Nordlys*, the NMA has confirmed in a safety notice[29] that the arrangement for opening and closing of the dampers in the emergency generator room was in accordance with both the NMA and DNV's regulations, provided that a check valve was installed between the emergency generator's compressed air accumulator and the ordinary compressed air arrangement.

Concerning the prohibition on having doors in the bulkhead between cargo holds, the NMA has stated that this was made known to the industry through a circular of April 2000[30] informing about the entry into force of Regulations No 305. Because *Nordlys* and other Hurtigruten ships had a sliding door at tank-top level in the watertight bulkhead on frame 86 between cargo holds nos 1 and 2, the problem was subsequently specifically brought to the attention of Hurtigruten ASA in a letter from the NMA of 23 June 2009. Since then, there has been an ongoing process in which the problem surrounding the door between the cargo holds has been considered along with the other upgrading requirements.

[28] The system was installed during a yard stay at Fiskerstrand Verft during the period from 31 January 2002 to 9 February 2002

[29] Safety Notice SM-03-2011 of 19 October 2011

[30] Circular – Series F No 7/2000, dated 25 April 2000

The other requirements for upgrading in accordance with Regulations No 305 have primarily been related to ro-ro passenger ships, and the shipping company has wanted to reclassify *Nordlys* as an ordinary passenger ship. If the ship is reclassified, the requirement for two-compartment standard and flooding of the deck will no longer apply.

The prohibition on having a door between the cargo holds at the tank-top level will still apply, however, even if *Nordlys* is reclassified from a ro-ro ship to a passenger ship. In a letter from the NMA of 28 October 2010, the shipping company was granted temporary dispensation so that the door could be retained until 1 April 2011. Temporary dispensation was granted on the same terms as those used as the basis for granting *Nordlys* dispensation from the provisions relating to doors between cargo holds in a letter of 22 January 1996. At that time, the terms included a requirement that the door in question must be kept closed when the ship was under power.

Though the shipping company's dispensation has not been extended in writing, the NMA states that the company has been verbally informed that it would be possible to extend the deadline pending the NMA's processing of the case.

The most recent correspondence in the case is a letter from the NMA of 5 June 2012, in which the NMA, in principle, accepts the shipping company's proposed solution.

Concerning the supervisory authority's inspection of the tightness of the door in question, it is evident from the PSF checklist used during the renewal survey 29 March–1 April 2011, that, as in the case of hot surfaces, it was left to the shipping company to check this through self-inspection. However, judging by the PSÅ checklist, a check of the tightness of doors through self-inspection is not carried out as part of the annual inspection. The most recent annual inspection prior to the fire had taken place on 10 and 11 March 2010.

1.17.1.2 *Control of management systems*

Pursuant to the ISM Regulations, the NMA is also the supervisory authority in relation to the shipping company and ship's safety management systems. This supervisory role means that the NMA is responsible for conducting audits of the shipping company's safety management systems, both in the onshore organisation and on board the ships. The NMA is furthermore required to check that the company and shipboard management operate in accordance with the safety management systems. According to information from the NMA, it conducts ISM audits in accordance with IMO's guidelines as described in Res.A.1022(26), 'guidelines on the implementation of the international safety management (ISM) code by administrations' as well as internal procedures for planning and implementation of ISM audits.

When an audit shows that the requirements set out in the ISM Code have been met, a Document of Compliance (DoC) is issued to the shipping company and a Safety Management Certificate (SMC) is issued to the ship.

The most recent audit of the safety management system prior to the fire on board *Nordlys* on 15 September 2011 was carried out on 16 and 17 June 2010, when the system was found to be in compliance with the ISM Code. According to the audit report, the management system was well implemented and was being used on board. The shipboard management, particularly the master, had a good understanding of the management system, used it actively and motivated the crew. The interviewed crew members demonstrated a good understanding and knowledge of the system and Docmap.

Some nonconformities were also identified during the audit, however. In that connection, it was pointed out that the 'System review by shipboard management' report form included no requirements for minimum content of the review. The following items were not included in the shipboard management's system review:

- Review of governing documents
- How the management system worked in practice on board
- Evaluation and review of critical shipboard systems and components
- Evaluation and review of the ship's maintenance system

Other findings included that the training programme for the apprentice electrician was not adequately followed up and that the maintenance system lacked a definition of 'critical equipment'. The column for critical equipment contained no entries for any components with associated jobs. Equipment units capable of causing hazardous situations in the event of failure had been identified through analyses, but not integrated in the maintenance system.

1.17.2 Classification inspections

Nordlys has been classed by Det Norske Veritas since the ship was new. This means that *Nordlys* should also satisfy the classification rules. In that connection, DNV has carried out inspection and approval of construction drawings, follow-up of the ship during construction and all subsequent periodic class inspections of hull and machinery during the ship's service life.

During the ship's service life, the classification society conducts periodic inspections. The class certificate is renewed every five years. Periodic inspections include annual inspections, intermediate inspections and surveys relating to renewal of the class certificate. The inspections include verification that the hull and machinery are in accordance with applicable class requirements.

1.17.2.1 *Supervision of ships*

The most recent survey for renewal of the class certificate was carried out in May 2009. On the basis of that survey, the certificate was renewed until 31 March 2014. DNV carried out annual inspections in 2010 and 2011. The most recent annual inspection of *Nordlys* prior to the fire was carried out on 28 March 2011.

Inspection of hot surfaces is included on DNV's checklists both for renewal of certificates and for annual inspections. In addition, DNV's internal instructions for inspectors include guidelines on how to carry out inspections of hot surfaces. The guidelines go some way towards dealing with the challenge that such inspections are almost always carried out of cold machinery, in that they describe typical problem areas and visual indicators of high temperatures. They also include advise on the assessment and handling of nonconformities. The instructions recommend immediate repair of hot-surface insulation, subject to the possibility of setting a deadline until the ship's next call in port or of one month, if necessary.

No orders for insulation of hot surfaces were issued in connection with the most recent annual inspection of *Nordlys* prior to the fire. According to DNV's reports, nor did any comments emerge relating to the condition of hot-surface insulation during the most recent annual inspections of the sister ships prior to the fire on board *Nordlys*, carried out on 9 November 2010 (*Richard With*) and 21 March 2011 (*Kong Harald*).

1.17.2.2 *Control of the maintenance system*

The shipping company's maintenance system has been approved by DNV in accordance with DNV's rules for planned maintenance systems (PMS).[31] This means that DNV has approved the electronic system and conducted an onboard audit to verify that the system has been implemented in accordance with the regulations. DNV also conducts annual audits of the maintenance system on board and the machinery is continually accredited on the basis of historical data presented by the ship's chief engineer.

1.18 Technical examinations after the fire

1.18.1 Diesel leakages next to the starboard main engine

Detailed examinations of the main engine room after the accident showed that there had been an intense fire at and around the starboard main engine, and that the fire had been most intense in the area around the forward part on the starboard side of the engine. Melted aluminium components and deformed steel structures showed that the temperature had been extremely high in this area.

The AIBN's examination of the engine room after the accident focused, *inter alia*, on determining whether there had been any leakages of combustible liquids, and some particularly interesting observations were made in that connection. The observations described in the following relate to the fuel system for the starboard main engine or, more precisely, to the low-pressure pipes for fuel injector pump no 5 (numbered from aft to fore) on the starboard side of the engine and the ball valve on a drainage pipe on the starboard side at the front of the engine; see Figure 14.

The AIBN's investigation also found that the quick-closing valves for the fuel oil tanks were not activated and that the fuel injector pumps were not stopped in connection with the fire.

[31] DNV Rules for Ships, July 2008, Pt. 7 Ch. 1 Sec. 8

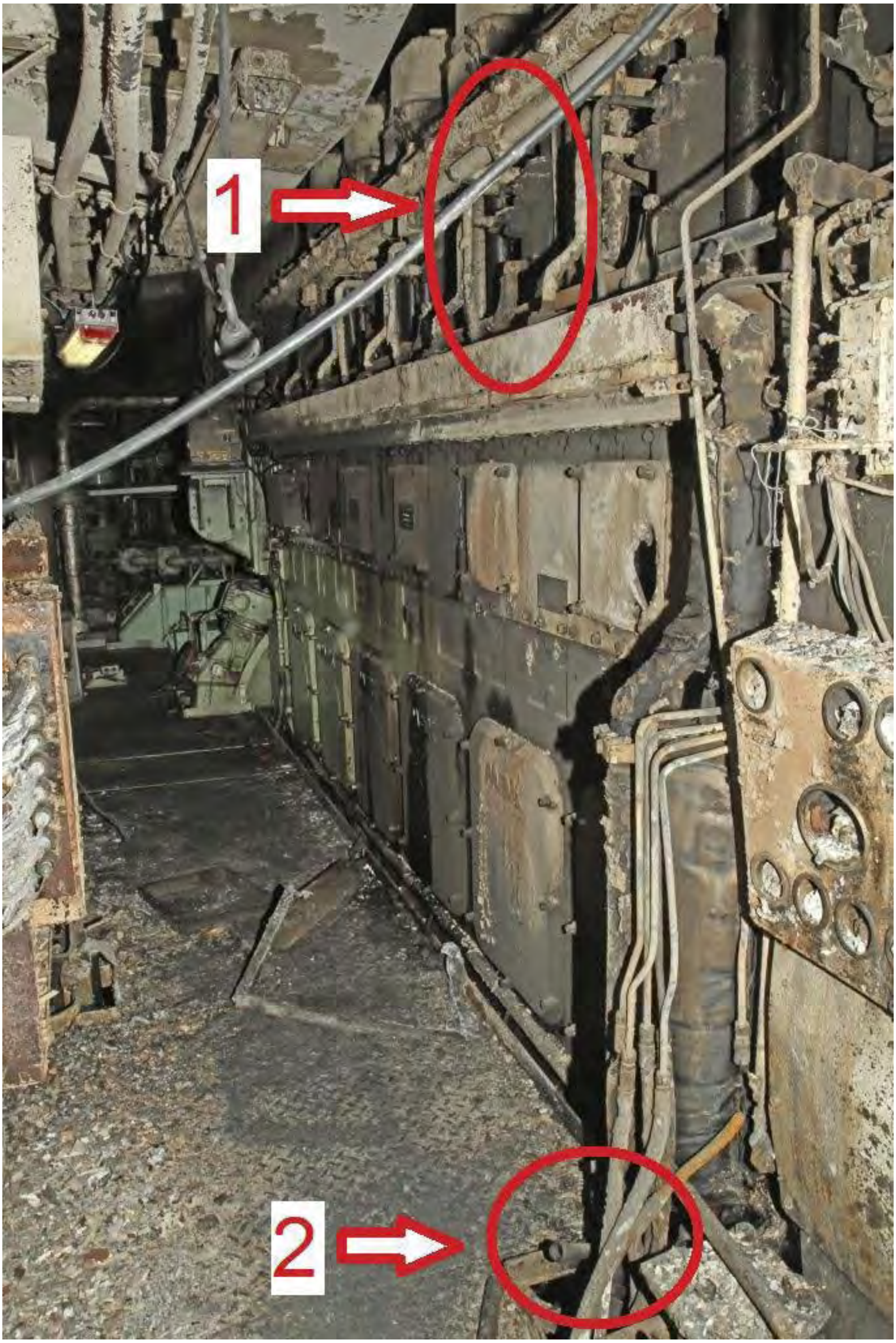

Figure 14: Starboard side of the starboard main engine viewed from above and looking aft at tank-top level. The numbers denote: 1) fuel injector pump for cylinder no 5, and 2) drainage pipe on fuel return line. Photo: The police.

The initial investigations on board showed a breakage in the low-pressure fuel-return pipe from the fuel injector pump for cylinder no 5. The breakage was found where the line was welded to the upper flange (see Figures 15 and 16).

When the pipes were removed, another breakage was discovered in the supply pipe, in addition to one in the pipe feeding lube oil to the pump. There was some doubt as to whether the feed pipe was already broken or whether it broke during removal, as a breakage may have been concealed by the insulation material.

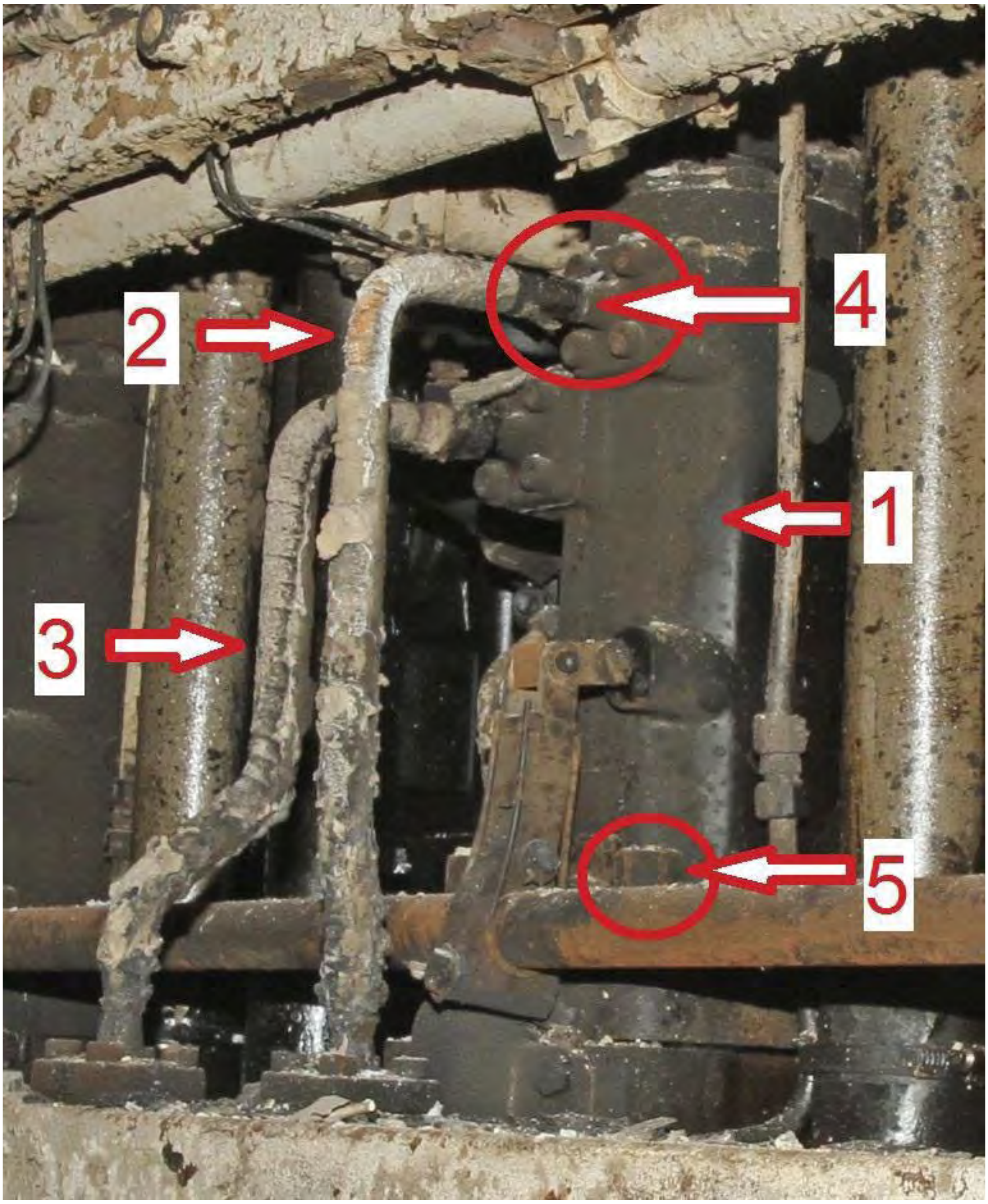

Figure 15: The fuel injector pump for cylinder no 5. The numbers denote: 1) The pump, 2) Return pipe, 3) Feed pipe, 4) Breakage, 5) Fastening bolts. Photo: The police.

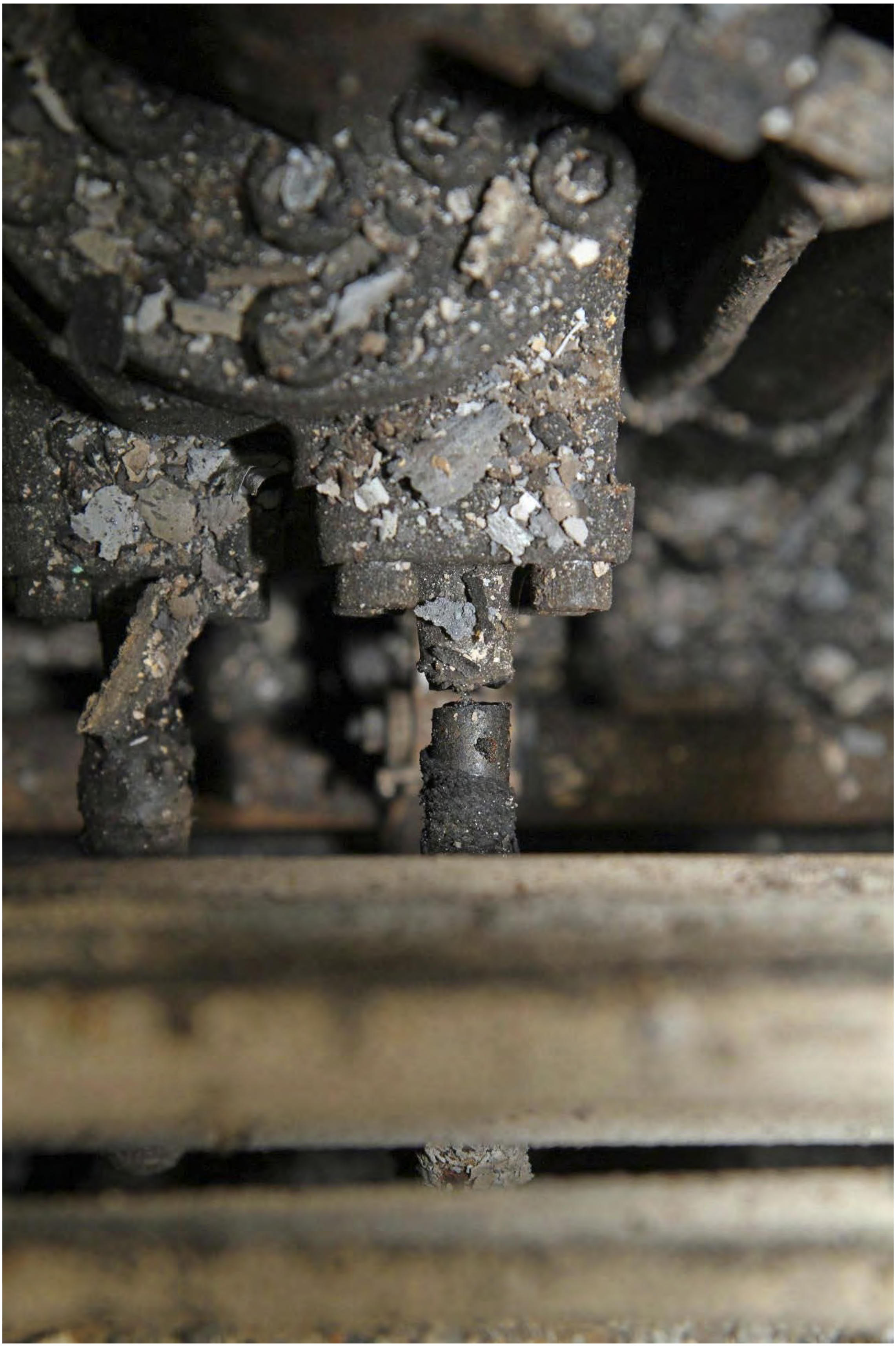

Figure 16: The breakage in the fuel return pipe (see ref. 4) in Figure 15) where it was attached to pump no 5, viewed from above. Photo: The police.

In connection with further on board examination of fuel injector pump no 5, it was observed that the bolts holding the pump were so loose that they could be unscrewed by hand. Because the bolts were loose, the pump was able to move approximately 2–3 mm up from the base on which it rested, i.e. the whole pump may have been pressed upwards every time the camshaft revolved, a movement that would impose cyclical stresses on the low-pressure pipes. At nominal revolutions, the camshaft rotates at approximately 250 revolutions per minute. On average, the main engines are in operation for approximately 20 hours in every 24 hours, which means that the system will have been exposed to approximately 3.6 million such movements from 3 September 2011, when the pump was last replaced, until the fire occurred.

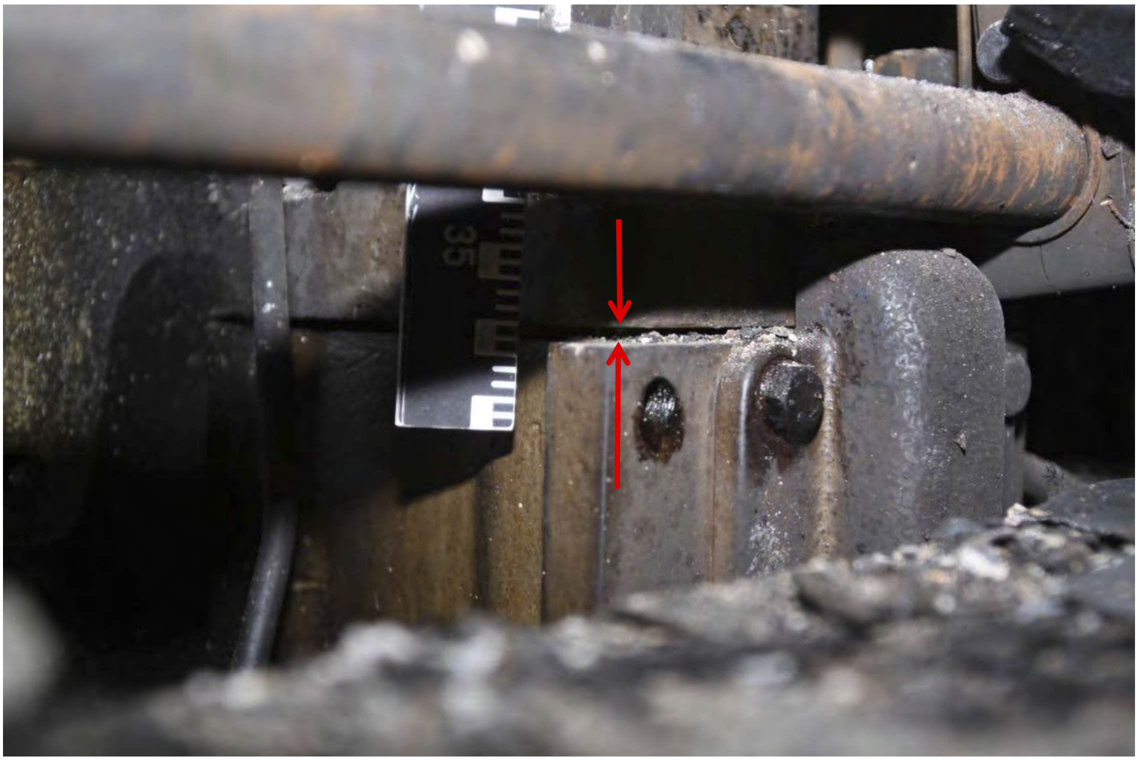

Figure 17: The gap between fuel injector pump no 5 and the base. Photo: The police.

In addition to the fastening bolts for fuel injector pump no 5 being loose, it was observed that the seals on the low-pressure pipes had been incorrectly installed.

According to the engine manufacturer's specifications, the lower flange should be fitted with a rubber seal ring, while the upper flange should have a steel seal ring (see Figure 18). After the pump in question had been replaced 12 days prior to the accident, leakages were observed at the flanges on the low-pressure pipes for this pump. The engineers assumed that the seals had been incorrectly installed, so they switched the seals and refastened the pipes. Since the leakage stopped, they left it at that.

After the fire, when the AIBN removed the pump, it found that the seals between the fuel pipes and engine, on the one hand, and between the fuel pipes and the fuel injector pump, on the other, had been switched around.

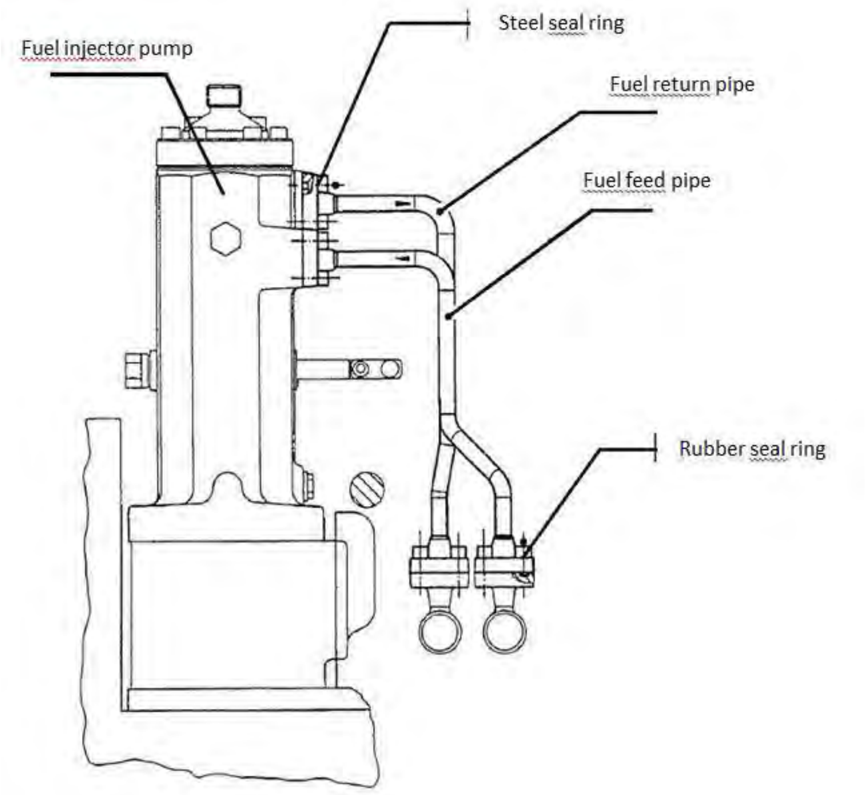

Figure 18: Schematic drawing of a fuel oil injector pump. According to the engine manufacturer's specifications, steel seal rings shall be used on the upper flanges while rubber seal rings shall be used on the lower flanges.

Another observation in connection with the preliminary on board investigations concerned the fuel line for return of fuel from the cylinders. The aforementioned fuel return pipes from each individual cylinder are connected to a single pipe that carries the fuel back to a tank. This pipe follows the main engine on the starboard side and runs down the front of the engine, where a drainage pipe is connected via a T-coupling. The drainage pipe has been closed with a ball valve and plugged with a threaded plug (see Figure 20). The AIBN has been informed that this pipe was probably designed to have a drainage function, but nobody was able to remember whether it had ever been in use. There was no corresponding solution on board the sister ships *Kong Harald* and *Richard With*. When the AIBN conducted its investigations on board *Nordlys* after the fire, only the threaded nipple was left on the pipe. The rest of the valve, ball and end plug were found close by. The lowest point of the fire appears to have been in this area.

Figure 19: Drainage pipe on starboard main engine, without valve. Photo: The police.

Figure 20: The drainage valve from the starboard main engine held next to the drainage pipe with valve on the port main engine. Photo: The police.

The relevant fastening bolts, fuel pipe on the low-pressure side, lube oil pipe and drainage valve were sent for metallurgical examination for analysis by an external laboratory.[32] Fuel injector pump no 5 was examined by a service representative[33] of the engine manufacturer, who also arranged examination of the engine block after the fire.

1.18.1.1 *Examination of bolts and bushings for fuel injector pump no 5*

The laboratory examination of the bolts and bushings for the fuel injector pump was unable to confirm that they had been tightened with the prescribed torque, as the bolt heads had left no clear marks on the bushings, which are considerably softer than the bolts. The original machining grooves were not deformed and appeared to be intact on all bushings; see Appendix B.

Since the first laboratory examination, the AIBN has performed trials in which a torque key was used to tighten the bolts/bushings that were on board *Nordlys* during the fire and a set of completely new and unused bolts/bushings to 190 Nm. The bolt/bushing sets were then examined by the laboratory, yielding the same results as the first examination.

1.18.1.2 *Examination of the feed pipes and lube oil pipe for fuel injector pump no 5*

The laboratory examination led to the conclusion that the feed and return pipes for fuel injector pump no 5 had very probably suffered fatigue cracking, whereby crack propagation in the pipes had finally resulted in a leakage. The fatigue cracking appeared to have been initiated on the underside of the pipes where they were connected to the fuel injector pump, suggesting that the pipes had been exposed to an upward force. Another

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[32] The Norwegian Armed Forces' chemistry and material technology laboratory services (FLO) at Kjeller

[33] Pon Power AS

conclusion of the examination was that the lube oil pipe for fuel injector pump no 5 had broken as a result of excessive exposure to external loads; see Appendix B.

1.18.1.3 *Examination of the drainage valve for the starboard main engine*

The laboratory examination showed local, apparently penetrating, corrosion in the valve. This may have caused a minor leakage, an assumption supported by discolouring on the outside of the valve housing. It was not possible to determine whether that valve had been functional, as the valve ball and stop cock were missing. The examination also showed that the drainage valve for the starboard main engine had very poor thread alignment and that the valve housing was oval with worn threads; see Figure 21 and Appendix B.

Figure 21: Drainage valve disconnected from the starboard engines. Photo: The Norwegian Armed Forces' laboratory service.

As an aid to examining the drainage valve for the starboard engine, the laboratory was given the corresponding valve for the port engine. When compared with the reference valve from the port engine, it was concluded that the valve from the starboard engine had considerably poorer thread alignment; see Figure 22 and Appendix B.

The AIBN has examined the thread alignment of the two valves in more detail. Disconnection of the port valve required several full turns, while one turn was sufficient to disconnect the starboard valve.

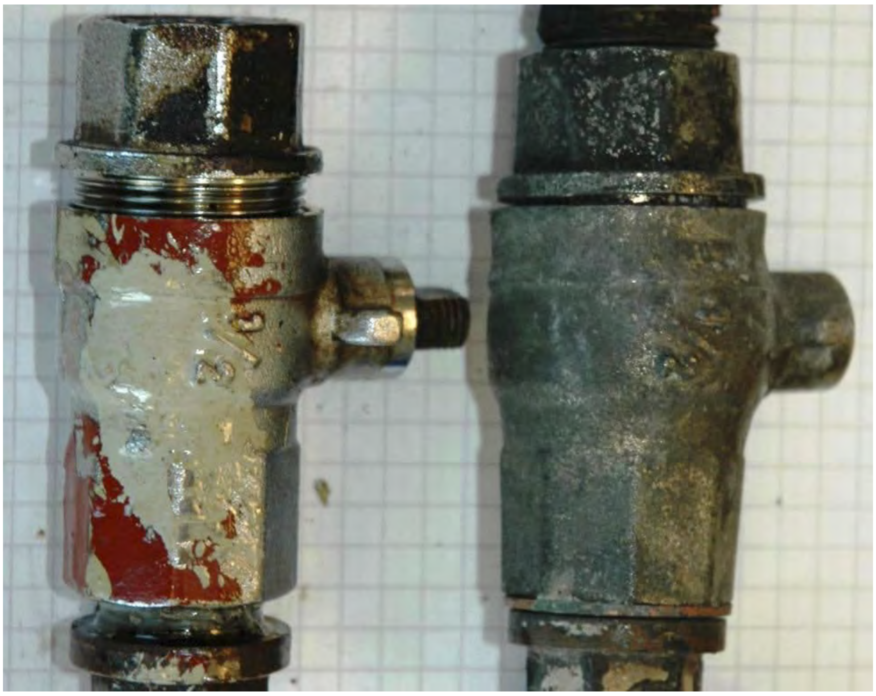


Figure 22: Ball valve from drainage pipe. The reference valve on the left was installed on Nordlys' port main engine, while the valve on the right was installed on Nordlys' starboard main engine. Photo: The Norwegian Armed Forces' laboratory service.

The examination also found that the seal ring of the reference valve's end plug was damaged, suggesting that excessive torque had been applied when it was fitted.

As shown in Figure 22, the valves are also asymmetric because of the stop cock, which means that there is a certain turning moment in the valve itself.

1.18.1.4 *Examination of the fuel injector pump for cylinder no 5 on the starboard engine*

No damage to the pump was found during the examination conducted by the service representative, which included removal of the pump. The piston, cylinder and O-rings were all found to be in order; see Appendix D.

1.18.1.5 *Examination of the starboard engine block*

No damage to the engine block was found during the examination carried out by DNV on assignment for the engine manufacturer's service representative, which included structural and material hardness testing; see Appendix F.

1.18.2 Fuel specifications

According to the receipt issued by the supplier,[34] *Nordlys* filled 224,476 tonnes of type MSD diesel in Bergen on 14 September 2011. According to the supplier's material safety data sheet, the product has a spontaneous ignition temperature of approx. 225 °C and a flash point of approx. 60°C.

[34] A/S Norske Shell

1.18.3 Hot surfaces – potential sources of ignition in the main engine room

After the fire, several of the indicator valves on the starboard engine were found to have inadequate insulation. Such valves are connected to the top of the cylinders so that combustion can be diagnosed through measuring cylinder pressure. The closest indicator valve that lacked sufficient insulation was less than 30 cm from the broken pipe.

The AIBN had a meeting with Hurtigruten ASA on 13 October 2011, in which the discovery of un-insulated hot surfaces was discussed. The AIBN pointed out that this had probably been the source of ignition of the fire on board *Nordlys*, and requested that SINTEF NBL, on behalf of the AIBN, be given access to one of the sister ships in order to measure the actual temperatures of these surfaces under operating conditions.

SINTEF NBL carried out measurements on board *Richard With* on 17 October 2011 and found the insulation to be in a similar condition to that observed by the AIBN on board *Nordlys*. Temperatures of up to 274 °C were measured on the indicator valves. Other un-insulated hot surfaces were also found, including on the exhaust manifold and flange for the turbocharger. Measurements on the exhaust manifold showed temperatures as high as 360 °C.

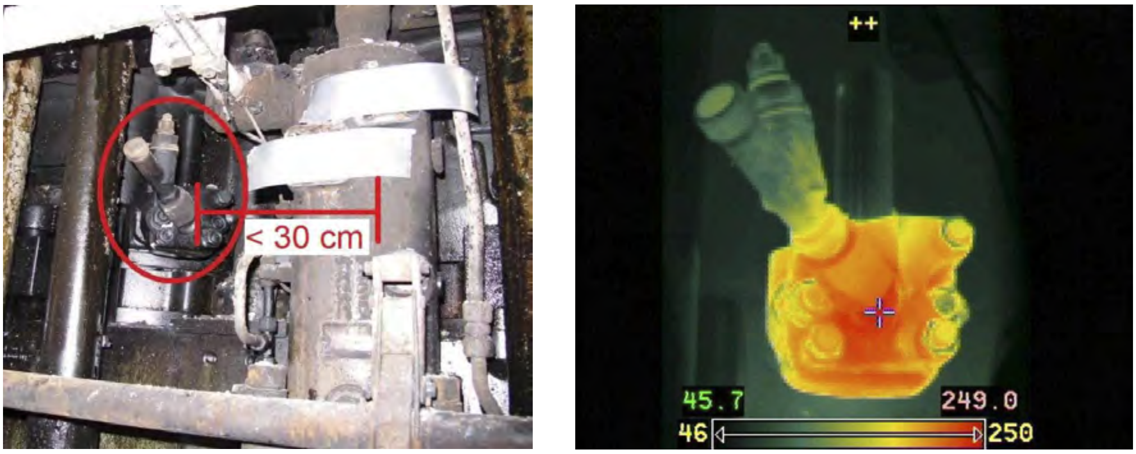


Figure 23: The photo to the left shows the indicator valve between cylinder no 4 and cylinder no 5 on the starboard main engine, and the distance to fuel injector pump no 5 (with the pipes removed). The indicator valve was found to have no insulation. The thermographic image on the right is of the same valve on board Richard With. Left photo: AIBN. Right photo: SINTEF NBL.

The AIBN is aware of the police and DNV having carried out independent measurements on board *Kong Harald*, the other sister ship, on 2 and 15 –16 November, respectively. These measurements showed similar conditions with temperatures of up to 300 °C on the indicator valves and more than 400 °C on the exhaust manifold.

1.18.4 Cover plates on the main engines

The main engines had originally been delivered with cover plates in front of the fuel injector pumps; see Figure 24. These were not in place when the AIBN examined the main engine room after the accident. According to the crew, the cover plates had been removed in order to facilitate inspection of the engines and, *intern alia*, detection of minor leakages at an early stage. The cover plates were kept on board. Removal of the cover plates has not been reported as a non-conformity to the shipping company's onshore organisation.

The engine manufacturer has informed the AIBN that all M552C engines are delivered with such cover plates in order to protect people and equipment within the area from any leakages from fuel injector pumps and pertaining pipes.

Figure 24: The main engines are delivered by the engine manufacturer with cover plates covering the upper part of the starboard side of the engine. These plates had been removed on board Nordlys. The photo shows the cover plates on the starboard side of the starboard engine on board the sister ship Kong Harald. Photo: SINTEF NBL.

1.18.5 The alarm log

After the accident, the AIBN has reviewed the log for the engine control system. It is normal to set alarm system delay times so that unnecessary alarms are not triggered by alarm conditions of short duration that are quickly restored to the norm. The exact delay times to which the system on board *Nordlys* had been set at the time of the accident have not been available to the AIBN, but a back-up of the system was made on 5 September 2011 (ten days prior to the accident), and the investigation has assumed that the delay times corresponded to those that were set for that date.

The fire caused extensive damage to large parts of the control system, and a number of alarms were triggered in the course of a very short period. The system is subject to certain limitations in terms of communication speed and transmission capacity, and the exact times and order in which the alarms were triggered according to the alarm log may deviate somewhat from the order in which they were actually triggered.

Prior to the fire, no alarms had been registered by the engine control system for nearly two hours. At the time of the accident, however, 9 alarms were triggered during the first minute, followed by a further 120 alarms during the next minute, and another 14, 6, 16, 12 and 6 alarms, respectively, during the minutes that followed.

The very first alarm to be triggered was 'Ground failure bus bars'. This is a general alarm, indicating earth fault in the 220V main switchboard or its connected equipment.

The second alarm was triggered four seconds after the first one and showed an indicator error on the temperature sensor for the starboard engine's fuel intake.

The third alarm, triggered eight seconds after the second alarm, showed low pressure in the fuel supply for the port main engine. The fuel circuit is shared by both main engines, and a leakage on the starboard engine will thus cause a drop in the pressure to both engines. After another 37 seconds, an alarm was triggered indicating that a stand-by fuel injector pump had started up. After a further 15 seconds, the low-pressure alarm returned to the normal condition.

Approximately 70 seconds after the first alarm, alarms were triggered that signalled that a control cabinet designated as 'SAU 8' had lost contact with the main system. In the course of the next 30 seconds, ten or so alarms were triggered connected to the 'SAU 12' control cabinet. Immediately afterwards, further alarms indicated that this control cabinet had also lost contact with the main system. The cabinets mentioned are located to starboard of the starboard main engine, on the same level as the fuel injector pumps and at a horizontal distance of about one metre from fuel injector pump no 5.

The alarm log also shows that an alarm from the provisions stores compressor was triggered about two minutes after the first alarm. This compressor is located immediately opposite the lowest forward leakage point (the ball valve). The alarm is a general alarm and does not indicate exactly what the fault condition is.

The alarm log shows that several alarms connected to the emergency generator were triggered about one minute after the first alarm. The first alarm indicated low pressure in the starting air for the emergency generator. The alarm for low fuel level in the fuel tank for the emergency generator was triggered at the same time. The sensor is located high up in the tank to ensure that it is continually topped up, and during the investigations after the fire, the tank was found to be almost full with the level slightly below the upper sensor. The alarm for charging the starter batteries for the emergency generator was triggered after another eleven seconds. A general alarm from the local control system for the emergency generator was triggered four seconds after the alarm for charging the starter batteries.

The alarm log, with corrections for set delay times, is enclosed as Appendix I.

1.18.6 <u>The emergency generator</u>

The AIBN's investigations suggest that the emergency generator started as it should in connection with the main switchboard failure and that it supplied power to the ship's emergency systems. Before long, the emergency generator also failed, however, so that the ship lost all electric power.

When the AIBN boarded the ship after the accident, the air dampers for the emergency generator room were found to be in the closed position. They are designed to ensure that the engine that operates the emergency generator is supplied with fresh air for cooling and combustion. One of the engine's cooling water hoses was also found to be broken. The AIBN has carried out a more detailed examination of the engine, cooling water hose and dampers.

1.18.6.1 *Examination of the engine*

After the accident, the engine that operates the emergency generator was examined and overhauled by an external engine firm.[35] The engine had clearly been overheated. The engine block had turned blue because of the heat and ruptures were discovered in several of the cylinders, so that all the cylinders had to be replaced; see Appendix H.

1.18.6.2 *Examination of the cooling water hose*

After the accident, the AIBN arranged for the ruptured cooling water hose to be examined by an independent hose manufacturer.[36] The hose was assessed as being of a 'standard' quality and type often used in cooling water systems to connect the pipe arrangement and thus achieve some flexibility and protect against possible vibrations. This type of hose will normally be exposed to working pressures of 3–4 bar and it has a rupture pressure of approximately 9–12 bar. The rubber quality used will be either ethylene propylene diene monomer (EPDM) or neoprene, both of which are resistant to cooling fluids containing glycol and other corrosion inhibitors.

The examination showed that the hose was most probably the original one, but there were evident signs of fatigue, with crack formation on both the inside and the outside.

Figure 25: The photo shows the ruptured cooling water hose. Photo: AIBN.

[35] Maritim Motor AS
[36] Tess AS

1.18.6.3 *Examination of the dampers*

Nordlys had previously had a system whereby the air dampers would close automatically when the compressor in the auxiliary engine room stopped and the air pressure dropped. After weaknesses were discovered in this system following the grounding of the sister ship *Richard With* in 2009, *Nordlys* and the other sister ships were modified: A check valve was mounted on the air duct carrying air to the emergency generator room so as to ensure that the air pressure would not disappear in the event that the electricity supply failed.

Figure 26: The photo on the left shows the aft damper in the generator room, viewed from the outside. The photo on the right shows the starboard damper viewed from inside the emergency generator room. Photo: AIBN.

However, during testing, the crew on board *Nordlys* had experienced leakages and that the system was still not satisfactory in that the dampers did not always stay open as intended. *Nordlys* had therefore ordered parts in order to modify the system so that the dampers would stay open on loss of air pressure. The parts received proved not to be the correct ones, however. They were therefore returned, and a new order was placed. The new parts had not yet been received at the time of the fire.

The fact that the dampers in the emergency generator room continued to close unintentionally as a result of leakages in the compressed air system had not been reported as a non-conformity, but it had been commented on in the maintenance system. The crew on board *Nordlys* had neither discussed the danger they perceived relating to the system nor the planned modification with the shipping company or the crew on board the other ships with corresponding systems.

1.18.7 <u>The engine room fire-extinguishing system</u>

The AIBN's technical on board examinations and interviews with the ship's crew confirm that the CO_2 system was not released in connection with the fire. The local application fire-extinguishing system was, however, released manually some time after the fire had started to develop.

1.18.7.1 *The CO_2 system*

The nozzles for supplying CO_2, which look similar to the nozzles in a deluge or sprinkler system, are made of cast brass or bronze alloy. Figure 27 shows that parts of the CO_2 nozzle immediately above the centre of the fire had disappeared, probably due to the impact of heat. Right next to that nozzle, we can see a local application nozzle. This nozzle, which was also made of a brass alloy, was found to be intact.

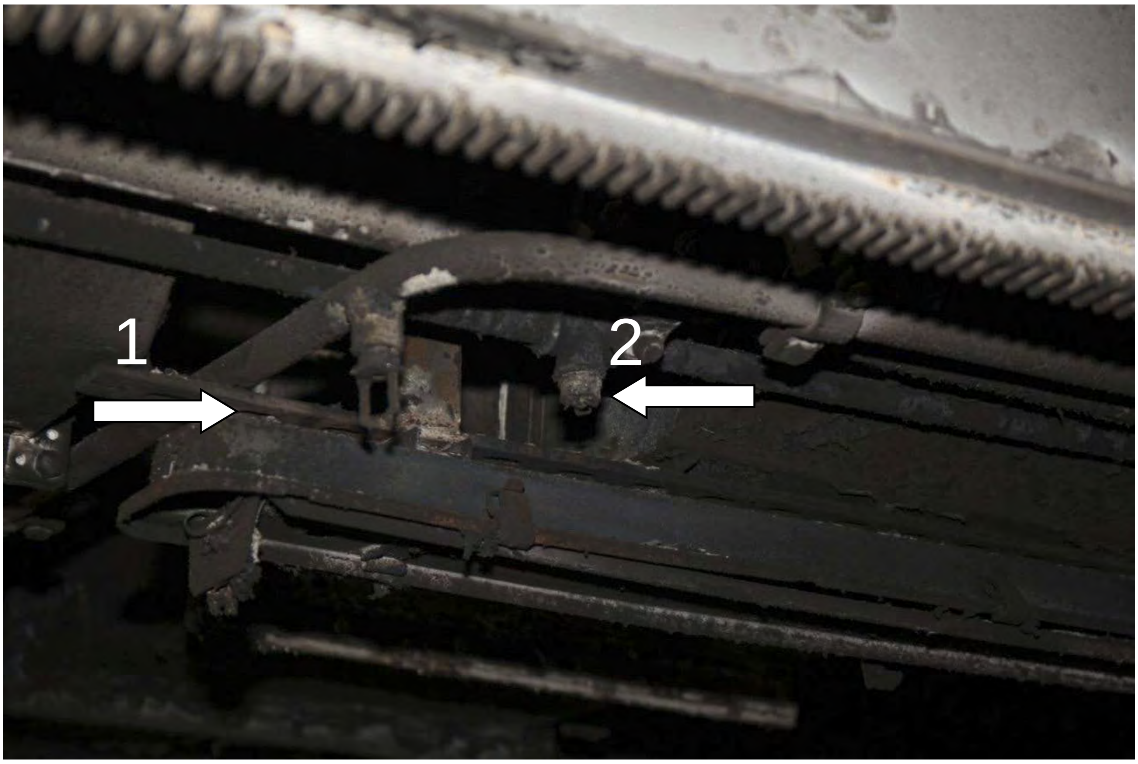


Figure 27: Arrow no 1 points to the CO_2 nozzle, while arrow no 2 points to a water mist nozzle. Photo: SINTEF NBL.

The AIBN's investigations show that preparation for CO_2 release had been initiated, but that it was interrupted, probably when it was decided that all persons on board were to be evacuated because of the list and the risk of capsizing.

One of the items in the user instructions for release of the CO_2 system is to 'close all openings'. Among the most important openings are the air intake dampers, installed in the smokestack on deck 7. The investigation has shown that the dampers in the smokestack were not closed during the fire, and that fresh air was supplied to the engine room, including via these dampers.

Figure 28: One of the dampers on the air inlet in the smokestack building on deck 7. Photo: SINTEF NBL.

1.18.7.2 *Local application fire-extinguishing system*

Even though only manual release of the local application fire-extinguishing system is required for ships with manned engine rooms, the system on board *Nordlys* was arranged with options for both manual and automatic release.

In interviews with the engine crew, the AIBN was informed that, in connection with the fire, the local application fire-extinguishing system was released manually by switching the system from manual to automatic mode. The AIBN's investigations on board found that the panel for the fire extinguishing system was set to manual mode. There was no key in the switch for switching between manual and automatic extinguishing. The AIBN has no information about who switched the system back to manual mode after the fire.

The local application nozzles above the main engine were intact, which suggests that water has flowed through the nozzles. None of the local application nozzles were deformed, and there were no visible soot deposits in the nozzle openings. The freshwater tank connected to the system was also confirmed to be empty after the fire.

According to the procedures, the local application fire-extinguishing system should have been set to the automatic mode. If hot work was carried out involving a risk of accidental release of the system, the system could, however, be set to manual while the work was in progress. In connection with hot work, special requirements for posting an additional fire watch were specified. However, according to the information obtained by the AIBN, the system was always set to manual on board *Nordlys*, because of previous incidents involving accidental release of the system. The problems relating to the local application fire-extinguishing system and the decision to leave the system in manual mode despite the requirement in the safety management system that it should be set to automatic mode, had not been reported as a nonconformity to the shipping company's onshore organisation. As far as the AIBN has been able to ascertain, nor had any procedures been established for taking compensatory action over and above a verbal message instructing the crew to remember to release the system in the event of fire.

The freshwater tank was emptied during the fire, but no attempt was made to open the main fire-water line. When both the main and the emergency power supply failed, it would not in any case have been possible to operate the pumps for adding freshwater to the tank.

Figure 29: The photo shows the panel for the local application fire-extinguishing system. When the AIBN conducted its on board investigations, it was observed that the panel, which is located in the engine control room, was set to manual mode. There was no key in the switch for switching between manual and automatic extinguishing. Photo: AIBN.

1.18.8 The spread of smoke

Examinations to register the spread of smoke[37] were carried out on board *Nordlys* on 22 and 23 September 2011 while the ship was alongside the quay at the Fiskerstrand verft shipyard. Starting in the engine room, the spread of smoke was registered deck by deck.

1.18.8.1 *Deck 1*

Some soot deposits were found in the auxiliary engine room, aft of the main engine room, predominantly on horizontal surfaces.

The corridor forward of the engine room is directly connected to the engine room by a watertight door. The corridor had clearly contained large volumes of smoke, as most

[37] Carried out by SINTEF NBL on assignment from the AIBN.

vertical and horizontal surfaces were covered in a thick, black layer of soot. Of the adjacent rooms, only the room marked as the 'linen store' had the same amount of soot deposits as the corridor. The door to that room had probably been open during the fire. Traces of soot were also found on the inside of an exhaust air vent in the linen store, which may indicate that the smoke has spread through the ventilation system.

Slightly less soot was found in the adjacent room marked 'store'. Traces indicate that the door to that room remained closed during the fire, but that there was ingress of smoke via an open ventilation duct from the corridor.

The corridor is also connected to a stairwell through which the smoke escaped, leaving clear traces on both vertical and horizontal surfaces.

In the crew cabins, a thin layer of soot was found on some of the horizontal surfaces, even though the smoke had left no traces around the doors.

Figure 30: Registered soot deposits on deck 1 (green: no spread of smoke; orange: some spread of smoke; red: spread of moderate to heavy smoke; white: uninspected area).

1.18.8.2 *Deck 2*

On deck 2, clear traces of smoke were found in the stairwell and on the stair landing.

There was a fire door between the stair landing and the car deck. There were no clear traces of smoke on the car deck, apart from a thin layer of soot on the cars.

The ventilation room on deck 2 contained no traces of smoke, with the exception of a small area of soot deposits in a joint between two ventilation ducts, indicating that there may have been smoke in the ventilation system.

Figure 31: Registered soot deposits on deck 2 (green: no spread of smoke; red: moderate to heavy spread of smoke; white: uninspected area).

1.18.8.3 *Deck 3*

On deck 3, clear traces of smoke were found in the stairwell and on the stair landing. Heavy soot deposits were also found above the ceiling in passenger cabin 332 (no checks were carried out above the ceilings in other cabins). There was also a thin layer of soot in the rest of the cabin.

Figure 32: Registered soot deposits on deck 3 (green: no spread of smoke; orange: some spread of smoke; red: moderate to heavy spread of smoke; white: uninspected area).

1.18.8.4 *Deck 4*

Deck 4 contains the ship's dining areas, galley and passenger mingling area. This is a large, open space, divided into three zones. There were generally clear signs that large volumes of smoke had been present in Zone 2 (the middle section) while the two other zones had been free of smoke, indicating that the fire doors had remained closed and kept Zones 1 and 3 free of smoke during the fire.

The soot deposits indicate that most of the smoke has risen up through the stairwell and welled out through two doors, namely the door to the galley and the door to the passenger mingling area. Soot deposits were also found inside a goods lift in the galley, which indicates that it may also have been filled with smoke. At the centre of the ship, in a cupboard-like room next to the space marked 'preparation room', the soot deposits on deck and other horizontal surfaces were relatively much heavier than outside the door to the room. In this room, too, heavy soot deposits were observed in the hollow space above the ceiling.

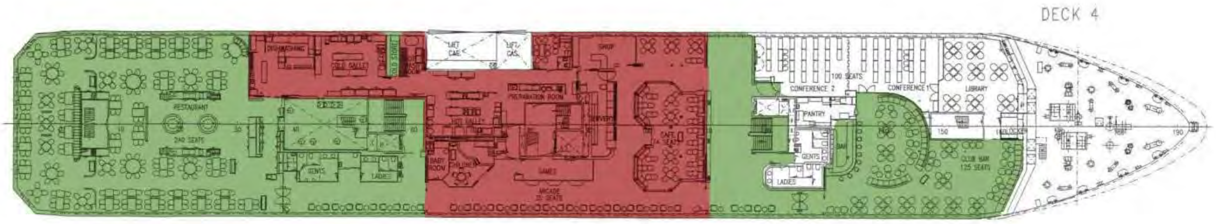


Figure 33: Registered soot deposits on deck 4 (green: no spread of smoke; red: moderate to heavy spread of smoke; white: uninspected area).

1.18.8.5 *Deck 5*

In addition to the soot in the stairwell, a thin layer of soot was found to cover the landing aft of the main stairs. Sample observations were made in some of cabins, but no traces of smoke or soot were found.

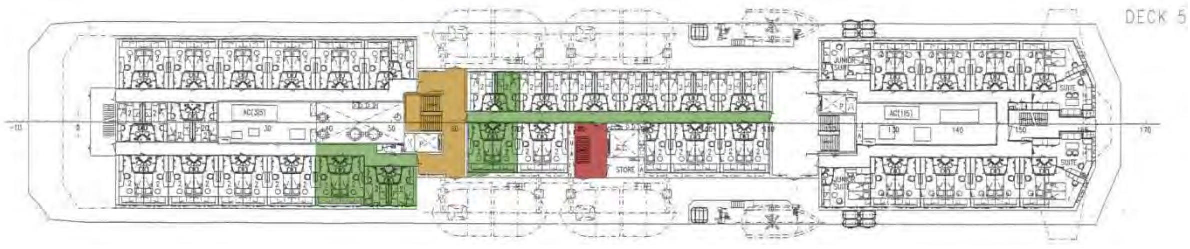


Figure 34: Registered soot deposits on deck 5 (green: no spread of smoke; orange: some spread of smoke; red: moderate to heavy spread of smoke; white: uninspected area).

1.18.8.6 *Deck 6*

In addition to the soot in the stairwell, a thin layer of soot was found in the corridor just outside the stairwell, and in a cabin adjacent to the corridor.

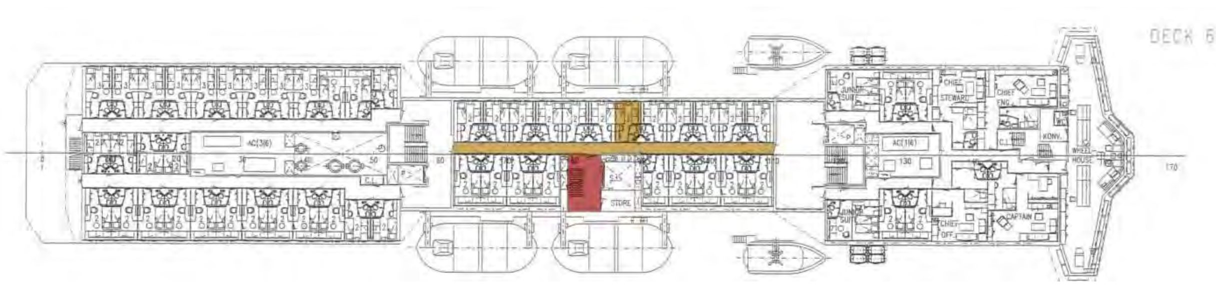


Figure 35: Registered soot deposits on deck 6 (orange: some spread of smoke; red: moderate to heavy spread of smoke; white: uninspected area).

1.18.8.7 *Deck 7*

There were clear traces of large volumes of smoke having been present in the stairwell. Deck 7 contains an open space with several bars. A thin layer of soot was found in this area.

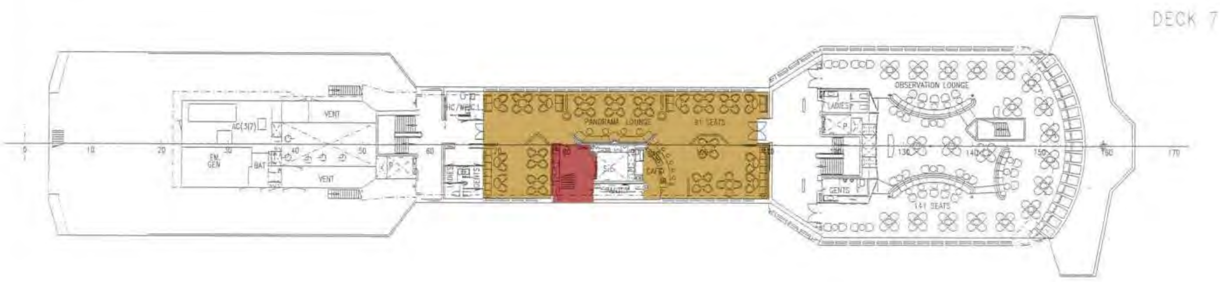


Figure 36: Registered soot deposits on deck 7 (orange: some spread of smoke; red: moderate to heavy spread of smoke; white: uninspected area).

1.18.9 Hull damage during berthing and subsequent ingress of water

After *Nordlys* had been towed to quay by the rescue vessel *Emmy Dyvi*, the ship's stern was observed to lie deeper and deeper in the water and *Nordlys* listed more and more to port. The engine room was found to contain water, which turned out to be freshwater used by the fire service to extinguish the fire. The water was first assumed to come in through the seawater intakes. Actions were therefore initiated to seal them.

Not until the morning of 16 September 2011, more than 24 hours after the fire had broken out, was the leakage found in the area aft of the starboard stabiliser fin. *Nordlys* had both stabiliser fins extended when the ship was towed to quay.

Not only were the stabiliser fins included in the checklist to be used on approaching port; they were also set to be retracted automatically on start-up of the bow thrusters to ensure that the ship would not go alongside quay with extended fins. The fins are operated hydraulically and controlled electrically in that they are connected to the emergency switchboard and operated from a panel on the bridge. The fins could also be operated using an emergency pump supplied with electricity via the emergency switchboard, or using a manual pump, but none of this was done.

When colliding with the quay, the starboard fin was pressed towards the ship's aft end and penetrated the skin in the area of cargo hold no 2. The damage led to flooding of cargo hold no 2; see Figure 37.

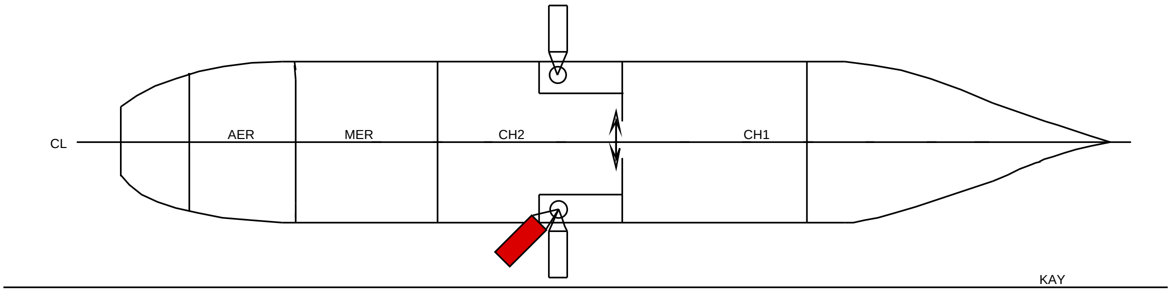


Figure 37: Schematic drawing showing how the starboard stabiliser fin (highlighted in red) was pressed towards the aft of the ship when Nordlys was towed to quay during the fire. This caused the stabiliser fin to penetrate the hull and led to flooding of cargo hold no 2.

Figure 38: The photo shows the marks/damage sustained on the starboard stabiliser fin, at the end closest to the hull, after it penetrated the skin. Photo: DNV.

According to the NMA, the stabiliser room is not defined as a part of the ship's watertight compartments. As the stabiliser room is located in the compartment by cargo hold no 2, any damage to the stabiliser room should only lead to ingress of water in cargo hold no 2. The AIBN's review of logs etc. also indicates that water ingress was initially limited to cargo hold no 2. In the course of the evening of 15 September, water accumulated in cargo hold 2, and, sometime during the night, the water pressure became so great that leakages probably occurred in the watertight sliding door towards cargo hold no 1, whereby cargo hold no 1 was also flooded with seawater.

1.18.10 Stability calculations

After the accident, stability calculations[38] were carried out for different scenarios involving a flooded ship. The calculations were based on the intact loading condition of *Nordlys* at the time the fire broke out, and on water ingress in the spaces that the investigation found to have contained water. This applied to the following spaces:

At the tank-top level:

- Cargo hold no 1, cargo hold no 2, port lift shafts and the space for the port stabiliser fin.

[38] Carried out by DNV on assignment from the shipping company.

On deck 1:

- The accommodation above cargo hold no 1, stores room above cargo hold no 2 and port lift shafts.

On deck 2:

- Car deck, port lift shafts and stores room aft of the car deck (aft end of deck 2)

The amount of water in each individual space was calculated on the basis of marks left by the water on the bulkheads, and the first stability calculations were based on the assumption that the flooded spaces were not open to the sea. In this theoretical intact condition, *Nordlys* had a list of 19 degrees to port and an acceptable residual stability, i.e. an acceptable survival capability.

The calculations that follow are based on the assumption that the water-filled spaces were opened to the sea, one by one. The calculations show that the list did not change dramatically, but that the residual stability was reduced as more spaces were opened to the sea. If cargo hold no 2, the stores room above cargo hold no 2, the car deck and the stores room at the aft end of deck 2 were opened to the sea while there was water in cargo hold no 1, in the accommodation above cargo hold no 1, in the port lift shafts and in the space for the port stabiliser fin, *Nordlys* would capsize. The stability calculations are enclosed as Appendix G.

1.18.11 Position and tightness of doors

1.18.11.1 *Watertight doors*

The investigation showed that the watertight doors were set to local control after the accident, and there is nothing to suggest that they were closed from the bridge in connection with the fire.

After the accident, the AIBN made a visual inspection of the watertight sliding door at the tank-top level in the transverse bulkhead on frame 86, between cargo hold no 1 and cargo hold no 2. The door appeared to be intact, and it had not been pushed out of its frame; see Figure 39.

A more detailed investigation of the door in question was carried out by the door manufacturer,[39] which was assigned by the shipping company to upgrade the door after the fire. The upgrade included replacement of the seals, and, according to the door manufacturer, the seal on the underside of the door was worn. The seal was a lip seal, and wear had produced an open gap of 8–10 mm below the door along its whole width of 2.2 m. According to the door manufacturer, this was damage from wear and not the result of the fire and water ingress. The door was installed when *Nordlys* was built in 1994, and the seals have not been replaced since then.

[39] IMS AS

Figure 39: The photo shows the watertight sliding door between cargo hold no 1 and cargo hold no 2. The investigation found wear on seals on the underside of the door. Photo: AIBN.

1.18.11.2 *Fire doors*

The key switch used to connect the fire doors to the fire alarm system so that the doors close automatically if a fire alarm is not acknowledged within two minutes was in manual mode after the fire. Moreover, the investigation shows that fire doors were not closed from the bridge on *Nordlys*. Those fire doors that were closed during the fire were closed locally.

1.19 Notification of safety-critical factors

Following the initial investigations, the AIBN issued a notification of safety-critical matters on 20 October 2011. The purpose was to provide information about matters that had been discovered so far in connection with the investigation, and to facilitate rapid action by the shipping industry, the maritime authorities and the classification societies as applicable. The following notifications were issued:

1.19.1 Notification of safety-critical factors No 5/2011 AIBN

After the fire on *Nordlys*, a fuel injector pump was found to have loose fastening bolts, and breakages were found in the fuel and lube oil pipes for the same pump. The loose bolts appear to have caused cyclical stresses and fatigue cracking in these pipes, which in turn led to a fuel leakage.

1.19.2 Notification of safety-critical factors No 6/2011 AIBN

Several insufficiently insulated surfaces were found on the main engines on board *Nordlys*. During operation, the temperatures on these surfaces may exceed 220°C, and they should therefore have been insulated. The AIBN finds it highly likely that the above-mentioned fuel leakage caused fuel to come into contact with such surfaces and was thus the cause of the fire.

1.19.3 Notification of safety-critical factors No 7/2011 AIBN

The main power systems were quickly put out of action during the fire in the engine room. The emergency generator, which is designed to take over and supply power to the ship's emergency systems, failed shortly afterwards. During the on board investigations, the dampers that are designed to ensure a supply of fresh air to the emergency generator for cooling and combustion were found to be in the closed position. This has probably caused the engine to seize and stop due to overheating.

1.20 Implemented measures

1.20.1 Measures implemented by the shipping company

According to information received from the shipping company, it has implemented several measures in relation to *Nordlys* and the other Hurtigruten vessels after the accident:

- Insulation and hot-surface protection have been installed on main engines and auxiliary engines.
- All ships have been inspected as regards the design of the fuel return pipe.
- New procedures for inspection and re-tightening of fuel pipe connections have been introduced.
- It has been decided to install a new water-mist system as the main fire-extinguishing system. The existing CO_2 system will be retained as a back-up system. This will also be done on the other ships having CO_2 systems.
- The procedures for testing and maintenance of oil and water hoses on the emergency generator have been revised.
- The compressed air arrangement for opening/closing of dampers in the emergency generator room has been replaced by electrical opening/closing on ships with the same design as *Nordlys*.
- New escape routes from the workshop and a new exit to the car deck from the incinerator room have been arranged on *Nordlys* and *Kong Harald*. The same will be done on *Richard With* in autumn 2013.
- On board *Nordlys*, the watertight door between the engine room and the provisions corridor has been replaced by a bolted hatch. The door will be retained on the sister ships, but use of the door shall be subject to approval by the chief engineer in each case.

- On ships that have the same design as *Nordlys* as regards the consequences of the stabilisers penetrating the ship's side, a dry tank will be built around the damage-prone area. This has been done on *Nordlys* and *Richard With,* and will be done on the other ships in connection with their docking in shipyards.

- A group has been appointed to look at fire-fighting equipment and clothing in order to assess whether the ships have adequate equipment and procedures on board. Measures will be implemented in accordance with the group's recommendations.

- A review has been carried out of all procedures relating to use of fire fighting equipment, fire doors, watertight doors, hospital, bridge organisation in connection with incidents, and training. The shipping company will also review the organisation and training of fire teams, together with the marine rescue team.

- The content of drills and training on board has been reviewed. A project has also been established to review the management system, including its technical platform, structure and content. Representatives of the crew also participate in this project.

- As part of the effort to ensure that the shipping company's ships learn from each other's audits/nonconformities, the reporting system has been made more transparent in that all ships have been given access to view audit reports from the other ships and thus have access to all reported nonconformities.

- Management development programmes and officers' conferences have been organised, focusing on attitudes and challenges related to the crew's compliance with procedures.

- Cooperation with the University of Bergen has been initiated to map the safety culture on board the shipping company's ships.

1.20.2 Measures implemented by the authorities

The Norwegian Maritime Directorate held a follow-up meeting with the shipping company on 11 October 2011. The agenda for the meeting was as follows:

- Information about status relating to the *Nordlys* accident and any immediate actions implemented by the shipping company.

- Discussion of matters relating to the cause of the fire, the fire, fire alarms, fire extinguishing and evacuation of the engine room, as well as oil systems, emergency shutdown of oil and ventilation, closing of fire doors and operation of auxiliary engines and emergency generators etc.

- Discussion of matters relating to the operation and control of watertight doors/gates, and logging.

- Discussion of matters relating to the ship's and the shipping company's implementation of ISM and self-inspection.

At the meeting, the NMA informed Hurtigruten ASA that it must expect unannounced inspections to follow up the items discussed.

Concerning the issue relating to the dampers in the emergency generator room, the NMA issued a safety notice on 19 October 2011, after the fire on board *Nordlys*, based on experience gained in connection with the grounding of *Richard With* in January 2009. In that safety notice, the NMA stated that the installation in connection with control of the dampers on board *Richard With* was permitted pursuant to Norwegian regulations and DNV's rules, provided that a check valve was installed between the compressed air accumulator in the emergency generator room and the ordinary compressed air system.

However, the NMA and DNV has subsequently assessed and found that the arrangement comes into conflict with the regulations.

1.20.3 Measures implemented by the classification society

After the fire on board *Nordlys*, DNV carried out an assessment of fire safety in the engine room and ventilation of the emergency generator room, and, based on that assessment, the following measures have been or are scheduled to be implemented:

- Inspections have been carried out of *Nordlys'* s sister ships and, together with crew, possible improvement measures have been identified regarding thermal insulation of hot surfaces and protection of potential sources of fuel oil leakages. Plans are being prepared for a meeting with Hurtigruten ASA to further discuss matters relating to fire safety.

- It has been decided to organise an internal workshop in DNV to thoroughly elucidate issues relating to insulation of hot surfaces and protection of fuel pipes, and DNV's follow-up of these matters during the approbation, CMC, NB and SiO phases in general. The purpose is to identify possible measures that address challenges in the different phases (work processes), and to establish the order of priority for these measures. Simpler improvement measures will be initiated by DNV. Should the mapping of issues and related improvement proposals uncover a need for more extensive amendment of regulatory requirements, it is natural to raise this through IACS.

- On a principal basis, the dampers in ventilation openings in emergency generator rooms have been discussed along with how DNV should follow up that such dampers do not close accidentally, causing emergency generators to stop. DNV has concluded that such dampers must be designed on the basis of the 'fail to open' principle. Among other things, this means that an open damper will not close as a result of a simple fault. This will be reflected in internal instructions for use during the approbation phase and in connection with inspections/surveys on board.

- A DNV 'Casualty Information' was issued following the *Richard With* incident, addressing weaknesses relating to the compressed-air operated dampers in the emergency generator room.

1.21 Statistics related to fires on board ships

According to a survey conducted by DNV, based on 165 fires on board DNV-classed vessels in the period 1992–1997, 63% of the fires started in the engine room, 27% in a cargo hold and 10% in the accommodation.

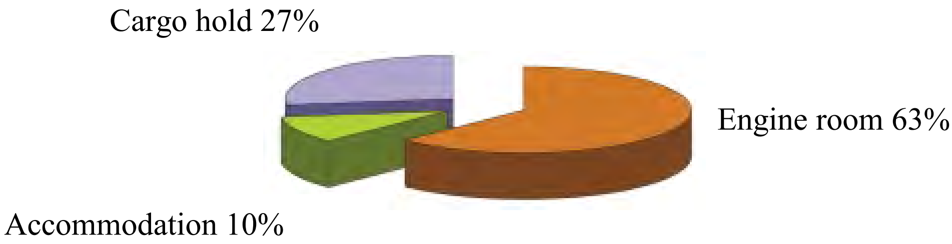


Figure 40: Fires on board vessels broken down by category.

The survey found that 56% of fires in engine rooms were caused by oil leakages onto hot surfaces, 14% were boiler incidents, 14% were caused by component failure, and 9% were due to faults in the electrical system.

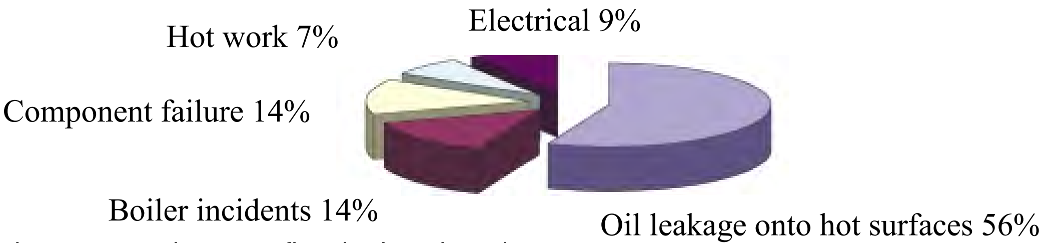


Figure 41: Engine room fires broken down by cau

According to the survey, a shipping company with 20 vessels could, statistically speaking, expect a serious engine room fire every ten years. After DNV conducted the survey, explicit requirements have been introduced, *inter alia* for insulation of hot surfaces.

1.22 Other relevant accidents

On the morning of 6 January 2009, *Nordlys*'s sister ship *Richard With* ran aground as it was about to call at Trondheim. It was reported that there was water ingress in the engine room, and the captain issued orders to start the bilge pumps. The water ingress meant that the main and auxiliary engines had to be stopped. The bilge pumps were then powered by the ship's emergency generator and a shoreside generator. During the course of the day, the engines for the emergency generator overheated as a result of the ventilation dampers for the emergency generator room having closed accidentally. The crew were able to force the dampers open, thereby ensuring a supply of cooling air so that the emergency generator could continue to generate power.

The AIBN's investigation of the incident found that the vessel's emergency power system was not self-contained. In that connection, the AIBN proposed the following two safety recommendations in its report:[40]

[40] Report Marine 2010/03 dated 12 April 2010

1.22.1 Safety recommendation MARINE No 2010/12

The NMA's and DNV's design approval and follow-up during construction and during the ship's service phase failed to verify to a sufficient degree that the emergency power system was self-contained. This could have been critical in other circumstances and entailed an unacceptable risk for the passengers and crew, as it could have caused the ship to be without power in an emergency situation.

The AIBN recommends that the NMA and DNV work together to consider measures to ensure that supervision by regulatory bodies and follow-up by the classification society of existing vessels and vessels under construction verify the functional requirement of a self-contained emergency power system.

1.22.2 Safety recommendation MARINE No 2010/13

The NMA's and DNV's design approval and follow-up during construction and during the ship's service phase failed to verify to a sufficient degree that the emergency power system was self-contained. The same may be the case for other vessels.

On this basis, the AIBN recommends that the NMA, together with DNV, consider measures for making the issue known to the owners of any other vessels that may have the same construction weaknesses and which are subject to supervision by the NMA and follow-up by DNV.

2. ANALYSIS

2.1 Introduction

The analysis begins by discussing the probable starting point and cause of the fire, and the fire damage situation, witness statements, alarm log, fuel leakages and potential sources of ignition are assessed in that connection.

The analysis then aims to clarify details surrounding the chain of events. Issues considered in that connection are the fire development, activation of the local application fire-extinguishing system, evacuation of the engine room, release of the CO_2 system, loss of the emergency generator, the spread of smoke, operation of the stabiliser fins and the water ingress, and the damage potential.

Through the analysis, the AIBN also wishes to draw attention to the safety challanges that were identified during the investigation. Issues considered in that connection relate to the replacement of fuel injector pumps, insulation of hot surfaces, activation of the local application fire-extinguishing system and shutting off of the air and fuel supply. The suitability of CO_2 as an extinguishing agent is also considered. The same applies to the options for evacuating the engine room, and the spread of smoke, as crew members who were present in the engine room died or were injured. A further topic is the emergency generator that failed.

The analysis also aims to identify factors that contributed to the fire itself, and organisational factors that caused important barriers to fail. The shipping company's safety management system and maintenance system, as well as the authorities' and the classification society's regulations and supervision will also be discussed and assessed.

The chain of events after *Nordlys* was taken under tow has not been thoroughly investigated and assessed, but the evacuation of passengers and crew, and the stabilisation problems that arose after *Nordlys* was berthed alongside the quay, are commented on.

2.2 Assessment of the chain of events and damage potential

The northbound voyage from Bergen had taken its normal course, and the crew and passengers had not observed any forewarnings of the problems that would cause a fire on board. In the AIBN's view, the observation of black smoke that an eyewitness on the quay in Torvik believed came from *Nordlys* can probably not be linked to the fire. According to the master, *Nordlys* was southwest of Hoggstein at the time, and it is unlikely that smoke from the vessel could be seen from Torvik.

2.2.1 <u>Assessment of the starting point and cause of the fire</u>

The AIBN's assessments relating to the starting point and cause of the fire are based on interpretations of the fire damage and alarm log, in addition to witness statements and findings in the engine room.

2.2.1.1 *Interpretation of the fire damage*

The fire damage in the main engine room was clearly greatest around the starboard side of the forward part of the starboard main engine. The lowest point of the fire appears to have been by the lowest leakage point (the ball valve), which was at the forward end of the starboard side of the engine on the same level as the floor plates on the tank top. The fire had deposited a 'fire fan' (a V-shaped mark) from that point and up along the starboard side of the engine; see Figure 42. Corresponding deposits were also found on the workshop bulkhead opposite the engine on deck 1; see Figure 43.

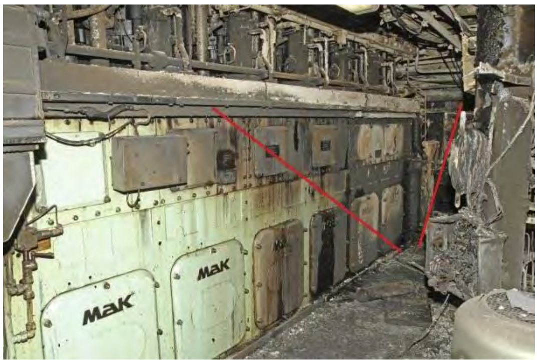


Figure 42: Looking forward along the starboard side of the starboard main engine at tank-top level. The fire has left a V-shaped mark from the floor upwards ('fire fan'). Photo: The police.

Figure 43: The top of the starboard engine looking aft at an angle. The bulkhead with the aft door to the workshop can be seen in the background. The fire has left an upward V-shaped mark. Photo: The police.

As mentioned, the lowest 'fire fan' starts at the lowest leakage point (the ball valve), while the upper 'fire fan' seems to start at the highest leakage point (fuel injector pump no 5). In other words, both leakages seem to have contributed during the fire.

There were clear signs that the area around the lowest leakage point (the ball valve) had been exposed to intense heat. The cooling compressor for the provisions stores, placed further away in the same area, was highly contaminated by diesel oil; see Figure 44. This was probably due to diesel splashing out from the drainage pipe after the ball valve had fallen off. The cooling compressor had not been burnt 'clean', as the AIBN believes would have been the case had the whole area been on fire.

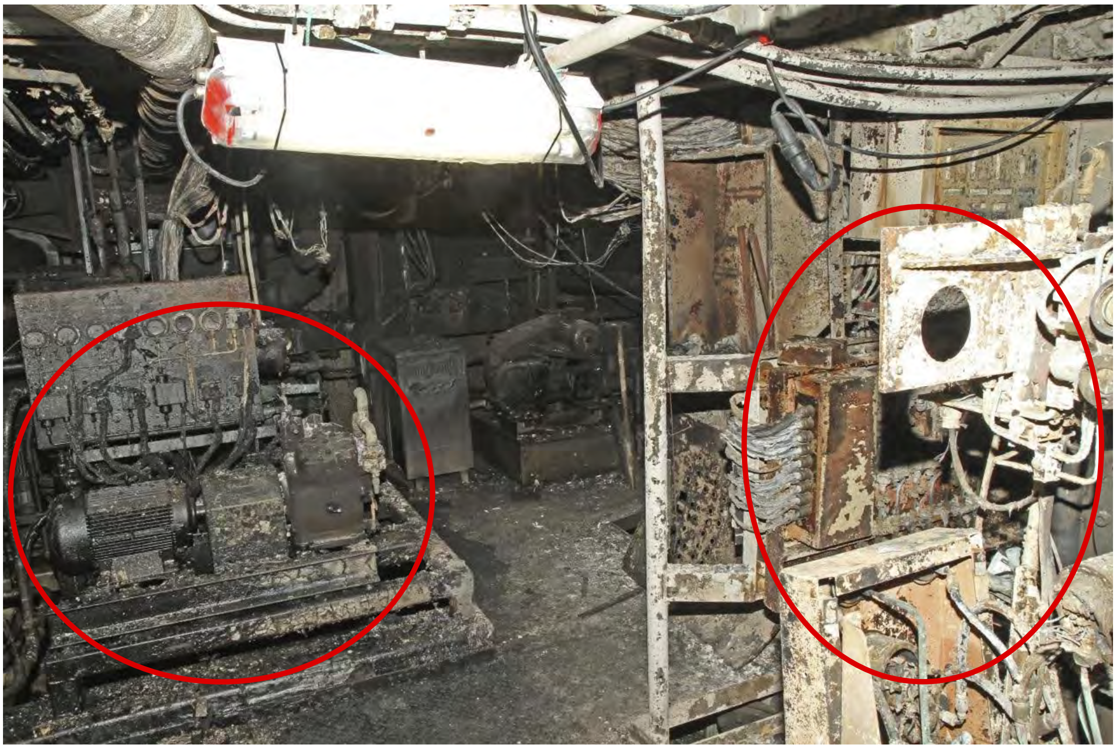


Figure 44: The photo shows the cooling compressor on the left. The cooling compressor was contaminated by diesel oil that had not been burnt away in connection with the fire. Components fitted to the starboard main engine can be seen on the right. The combustible material had been burnt away. Photo: The police.

2.2.1.2 *Witness statements*

The crew members who were in the workshop have told the AIBN that they first became aware of the fire when they observed smoke and flames. They have described thick, dark smoke and an immediate development of extreme heat even before they heard the fire alarm. The motorman, who evacuated from the separator room, had also observed thick smoke pouring in from the incinerator room as the first sign that something was very wrong. As he made his way out into the main engine room, there was thick smoke above the starboard main engine, and he could see flames just over the top of the engine. The descriptions are compatible with a fire resulting from ignition of a sudden leakage of combustible liquid.

2.2.1.3 *Interpretation of the alarm log*

The alarm log from the engine control system confirms the impression that the fire developed rapidly. At the time of the accident, 9 alarms were triggered during the first minute, followed by a further 120 alarms during the second minute, and another 14, 6, 16, 12 and 6 alarms, respectively, during the minutes that followed. The number of alarms during the second minute is remarkably high. After that, it was reduced to a relatively low number per minute. Many of the alarms that went off during the first two minutes indicate communication failure between the different control units. Many alarms have probably gone off as a consequence of burnt sensors, cables and control cabinets. The AIBN considers that large parts of the engine control room were put out of action shortly after the fire started.

The very first alarm to be triggered was 'Ground failure bus bars'. This is a general alarm, indicating earth fault in the 220V main switchboard or connected equipment. It is neither possible to tell from the alarm log which equipment caused the fault, nor to establish whether it caused a blackout. It cannot be ruled out that this alarm went off because of a leakage or the fire had an impact on the electrical equipment, e.g. that a burnt cable caused an earth fault.

The second alarm that was triggered four seconds after the first one, showed an indicator error on the temperature sensor for the starboard engine's fuel intake. Alarms for indicator faults are typically activated due to a fault in a sensor or cable, such as a broken cable or other contact failure. The sensor was in the immediate vicinity of both the aforementioned leakage points, on top of the fuel rack (supply and return); see Figure 45. It was also connected via the 'SAU8' control cabinet, which was directly opposite the uppermost of the leakages and which was quickly completely destroyed by fire (see separate section below). Hence, this alarm was probably activated as a result of fire damage to the sensor or its cable immediately after the fire started.

Figure 45: Position of the temperature sensor, ringed in at the top right of the photo, on top of the fuel rack. In other words, the sensor was placed in the immediate vicinity of both leakage points, ringed in at the top and bottom of the photo, respectively. Photo: The police.

The third alarm, that triggered eight seconds after the second alarm, showed low pressure in the fuel supply for the port main engine. The fuel circuit is shared by both main engines, and a leakage on the starboard engine will thus cause a drop in the pressure to both engines.

A possible interpretation of the three above-mentioned alarms is that a fuel leakage arose first. It probably ignited immediately (see section 2.2.1.5 on the source of ignition) and damaged nearby cables and equipment, causing the first two alarms to go off. After 12 seconds, the pressure in the fuel system has dropped below the alarm limit as a result of the leakage and triggered the low pressure alarm.

Approximately 70 seconds after the first alarm, alarms were triggered that signalled that a control cabinet designated as 'SAU 8' had lost contact with the main system. In the course of the next 30 seconds, ten or so alarms were triggered connected to the 'SAU 12' control cabinet. Immediately afterwards, further alarms indicated that the latter control cabinet had also lost contact with the main system. The cabinets mentioned are located on the starboard side of the starboard main engine, opposite and about one metre from fuel injector pump no 5; see Figure 46. The fact that these cabinets were completely damaged in such an early point of time indicates intense fire in this area from the very start of the fire.

Figure 46: The SAU8 and SAU12 control cabinets, ringed at the top left of the photo, were at a horizontal distance of about one metre from the leakage at fuel injector pump no 5, ringed in at the top right of the photo. Photo: The police.

The alarm log also shows that an alarm from the provisions stores compressor was triggered about two minutes after the first alarm. This compressor was placed all the way down on the tank top on the starboard side in front of the starboard main engine; see Figure 44. The alarm is a general alarm and does not indicate exactly what the fault condition is. It suggests, however, that the leakage from the drainage pipe may have occurred at this point in time and triggered the alarm on the compressor. The position of the compressor would otherwise suggest that it would not be much affected by a fire in the area of cylinder no 5.

2.2.1.4 *The fuel leakages*

After the fire, two different leakages were found in the fuel system, one in the fuel return pipe from fuel injector pump no 5 and one in a drainage valve at the forward end of the starboard engine.

The AIBN's on board investigations found that all four fastening bolts for fuel injector pump no 5 were loose. Subsequent metallurgical examinations of the fracture surfaces showed that the pipes by fuel injector pump no 5 most probably broke as a result of fatigue fracturing caused by cyclical vertical loads. The camshaft imposes a vertical upward force on the pump with each revolution as it activates the fuel injector pump. If the pump is loose while the pipes are fastened to the pump and engine, respectively, the pipes will be exposed to cyclical loads with each revolution of the camshaft. Considering that the fuel injector pump was replaced 12 days before the fire, the camshaft would have completed approximately 3.6 million revolutions since the pump was replaced. This is a relevant number of cycles with respect to fatigue damage. The places in which the pipes had broken are also compatible with such a theory, and the metallurgical examinations show that the force had most likely been imposed from below.

The ball valve that was found on the floor plates came from a drainage pipe on the joint return pipe for fuel from the engine. This also accounts for a considerable leakage. Worn, tapered threads with very poor alignment were found on the ball valve. The valve could be taken apart simply by turning it once from the fully tightened position.

The AIBN finds it highly unlikely that the two leakages have occurred at the same time and independent of one another. A key question is therefore how they may be connected; which leakage occurred first and which arose as a consequence of the fire.

In the AIBN's view, the ball valve may have become unscrewed as a result of vibrations over time, causing diesel to splash onto the cooling compressor on the opposite side. However, the AIBN considers it unlikely that a diesel leakage from the drainage pipe could have been ignited by the cooling compressor, as the compressor was covered in uncombusted diesel oil after the fire. Nor can the AIBN see how a fire caused by a leakage from the drain valve could have caused the bolts on fuel injector pump no 5 to come loose. It is also not possible to explain why fuel injector pump no 5 would have been particularly exposed in such a scenario. None of the fastening bolts for the other fuel injector pumps were found to be loose.

The AIBN believes, on the other hand, that the breakage of both diesel pipes and the lube oil pipe for fuel injector pump no 5 may have been a result of the bolts having been loose in the first place. The diesel leakage, the smoke and a lack of fresh air for combustion may then have caused poor, uneven combustion resulting in greater engine vibrations. The AIBN assumes that the ball valve coupling had been secured with thread tape or hemp. The thread tape or hemp may have melted or burnt in the fire, and the abnormal vibrations may have caused the ball valve to become 'unscrewed'.

Moreover, the alarm log indicates that the fire at an early stage became very intense in the area around fuel injector pump no 5, as the 'SAU8' and 'SAU12' control cabinets lost all contact after 1–1½ minutes. The alarm from the cooling compressor opposite the lower of the two leakages was activated after approximately two minutes, which suggests that this may have been when the second leakage occurred.

There are also arguments that speak against such a theory. Crew members and others have claimed that the bolts on the fuel injector pump could not have been loose for 12 days, as this would then have been discovered at an earlier stage. They point out that such a condition would probably have been both visible and audible and would have affected the exhaust temperatures. The AIBN cannot say for certain whether this is the case, and no simulations or tests have been carried out that could shed light on the matter or on how loose the bolts would have had to have been to cause such a fatigue breakage after 12 days. It is therefore assumed that the bolts may have appeared to have been completely tightened, though not with the prescribed torque, and that they have gradually come loose during the period leading up to the fire – and also during the fire – to end up in the position they were in when they were found after the fire with approximately 2–3 mm clearance.

In other words, the AIBN cannot say for certain which of the leakages occurred first or for what reason, but finds it most probably that loose fastening bolts for fuel injector pump no 5 have caused fatigue cracking and a breakage in the return pipe from the pump. The ball valve has then probably come unscrewed as a consequence of the fire and the temperature and engine vibrations it has caused.

2.2.1.5 *The source of ignition*

There are in principle several possible sources of ignition in an engine room. Both electrical systems and hot surfaces are typical potential ignition sources.

The investigation uncovered that several indicator valves on the starboard engine were inadequately insulated. Measurements conducted by SINTEF NBL on board *Richard With* show that the indicator valves reached temperatures of up to 274 °C under operation. Independent measurements conducted by the police and DNV on board the sister ship *Kong Harald* found similar conditions, and temperatures of more than 300 °C were measured on the indicator valves. Based on the distance to the indicator valve and other potential ignition sources, and the assumed spread of diesel in connection with the broken pipe, the AIBN considers that the most likely ignition point was the indicator valve between fuel injector pumps nos 4 and 5.

2.2.1.6 *Probable starting point and cause of fire*

The alarm log, witness statements, findings in the engine room and the fire damage indicate that the fire was due to immediate ignition of a sudden fuel leakage that came into contact with uninsulated hot surfaces on the starboard main engine. The AIBN considers it most likely that the primary leakage came from a fatigue breakage in the return pipe from fuel injector pump no 5 as a result of loose bolts, and that the fire started in the indicator valve between fuel injector pumps nos 4 and 5.

2.2.2 Fire development

Both the alarm log and witness observations confirm that the fire developed rapidly and led to the development of intense heat and thick smoke in a short space of time.

Interviews with the crew have revealed that the local application fire-extinguishing system was in manual mode and was not activated until some time after the fire started. This, and the fact that the main fire-extinguishing system was not released, have clearly been decisive for how the fire developed.

The AIBN's onboard investigations found that the quick-closing valves before the fuel oil tanks were not activated and that the booster pumps were not shut down. The control panel for the quick-closing valves on the fuel oil system was located in the midship emergency station on deck 2, and the control panel for the booster pumps was located in the corridor aft of the engine control room. As regards the air supply, the air intake dampers in the smokestack on deck 7 were among the most important openings. They were not closed during the fire, and the engine room was supplied with fresh air, *inter alia*, from these dampers.

The main engines had originally been delivered with cover plates in front of the fuel injector pumps to limit the spread of diesel in the event of a leakage. These plates had been removed from the main engines on board *Nordlys*, and the AIBN is of the opinion that this may also have affected the development of the fire. Without the plates, the fuel was able to spread under the platform and workshop on deck 1 to a greater extent, as shown in Figure 47. All the water nozzles in the local application fire-extinguishing system were located under the ceiling above deck 1, and the AIBN cannot rule out that the missing cover plates on the starboard engine made the local extinguishing system less effective when it was finally released.

Pursuant to regulations, the local application fire-extinguishing system shall protect the fire-hazardous areas around the combustion engines. The missing cover plates on the main engines meant that the spaces under the workshop were more exposed to fire hazards, and the AIBN consequently believes that nozzles should have been arranged in that area if *Nordlys* was to operate without the cover plates.

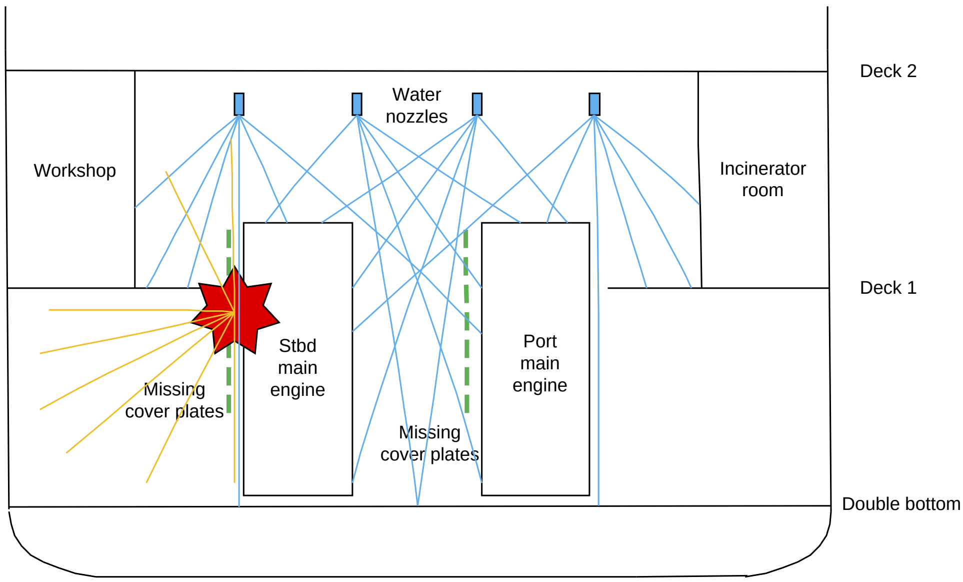


Figure 47: Schematic drawing showing the spread of diesel and the location of water nozzles looking aft in the engine room. The spread of diesel would most likely have been reduced had the cover plates on the starboard side of the main engines not been removed.

The local application fire-extinguishing system draws water from a freshwater tank, but it can also be supplied with seawater via the fire pumps. The valve for supplying seawater to the system was not opened. The freshwater tank was found to be empty after the fire, which indicates that the extinguishing system ran out of water at some point as a consequence of not being supplied with seawater. The AIBN cannot say for certain what role this played, since the emergency generator failed at an early stage and the fire pumps would quickly have stopped.

The AIBN believes that the main factors that led the fire to develop the way it did were that the local application fire-extinguishing system did not activate immediately, that the main extinguishing system was not released and that the supply of fuel and air was not shut off.

2.2.3 Activation of the local application fire-extinguishing system

The AIBN's on board technical examinations and interviews with the ship's crew confirm that the local application fire-extinguishing system was activated in connection with the fire. As the system was in manual mode when the fire started, however, the system was not activated until the engine crew did so manually sometime after the fire started. The AIBN has not been able to establish the exact time at which the system was activated, but the investigation indicates that it had not been activated at the time when the crew evacuated the engine room. On this basis, the AIBN believes that the local application fire-extinguishing system was activated approximately 2–3 minutes after the fire started.

2.2.4 Evacuation of the engine room

The chief engineer and the motorman were in the separator room when the fire started. When interviewed by the AIBN, the motorman explained that the chief engineer moved out into the incinerator room when they realised that smoke was emanating from that room. At some point, he must have turned back, as his body was found in the separator room. The AIBN cannot say for certain whether he moved out into the incinerator room with the intention of evacuating the engine room through the watertight door at the forward end of the engine room, or whether he intended to investigate what was wrong. The AIBN assumes that he turned back because of the smoke. The motorman escaped through the exit in the aft end of the engine room; see Figure 48.

The first engineer, the repairman and the apprentice engineer were in the workshop on the starboard side of deck 1 when the fire started. From there, they had two alternative escape routes: either through the aft door in the workshop and then through the exit at the aft end of the workshop, or through the forward door of the workshop and then through the watertight door at the forward end of the engine room. Both alternatives meant that they would have to pass close by the fire. The first engineer and the repairman have explained to the AIBN that they chose the latter alternative, and then made their way up to deck 3. Both sustained major burn injuries and had to receive treatment at Haukeland Hospital after the accident. The apprentice engineer, whose body was found next to the stairwell on deck 4, has probably followed the same escape route as the first engineer and the repairman.

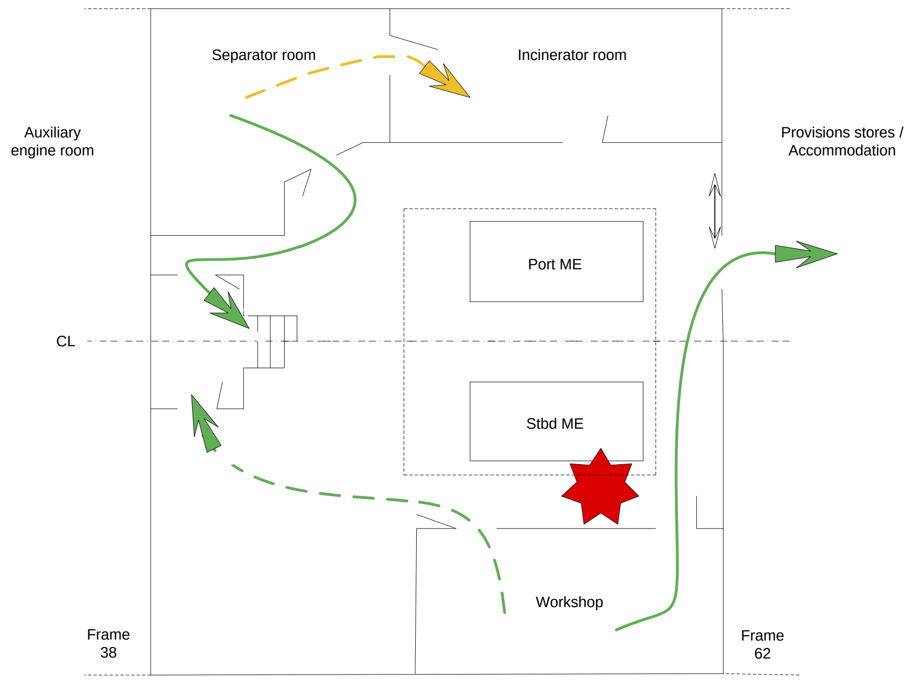


Figure 48: Sketch showing the alternative escape routes from the workshop, which both entailed passing the fire at close range. The solid green line shows the escape route chosen by the first engineer, the repairman and probably the apprentice. The dotted green line shows the alternative escape route. The motorman's escape route from the separator room is marked with a solid green line, and the likely movement of the chief engineer from the separator room is marked with an orange dotted line.

2.2.5 Release of the CO_2 system

During the fire, an assessment was made of whether to release the CO_2 system, but preparations for release were not carried out. The reason why it was not released during the first phase of the fire was that, at that time, the crew did not have a complete overview of who, if anyone, was still in the engine room. After *Nordlys* had arrived at the quay, and the fire service had boarded the ship, the possibility of and need for releasing the CO_2 system was reassessed. The fire had not yet been extinguished, and although it was considered likely that crew members might still be in the engine room, it was considered that there was no longer hope of finding anyone alive. A decision to release the CO_2 system was therefore made in consultation with the fire service. Preparations were made to initiate the release, but orders to the contrary were issued before the system was activated, probably because of the ship's increasing list and orders to abandon ship.

In the AIBN's view, the decisions made in relation to release of the CO_2 system were well founded. It was difficult to get an overview of the situation, and there was a risk that releasing the system would endanger human life.

2.2.6 Failure of the emergency generator

The alarm log shows that four alarms connected to the emergency generator were triggered approximately one minute after the first alarm went off at 09:12:35. The alarm that indicates low pressure in the starting air for the emergency generator was triggered after 57 seconds. The alarm for low fuel level in the fuel tank for the emergency generator was triggered at the same time. The sensor is located high up in the tank to ensure that the tank is continually topped up, and during the investigations after the fire, the tank was found to be almost full with the level slightly below the upper sensor. The third alarm, which was triggered 11 seconds later, was the alarm for charging the starter batteries for the emergency generator. This alarm is triggered if the starter batteries lose power from the main power system and it is therefore a typical indication of a blackout situation that confirms a message to start up the emergency generator. The fourth alarm, which was triggered after another four seconds, was a general alarm from the local control system for the emergency generator.

Logically, the alarm that indicated the blackout situation and confirmed the message to start the emergency generator should have been triggered first. However, approximately 120 alarms were triggered in the course of one minute, and the heavy load on the control system may have caused some alarms to be delayed. The AIBN believes that the above-mentioned alarms together indicate that the emergency generator started during the first minute after the first alarm. This is consistent with witness observations.

The AIBN cannot say exactly when the emergency generator stopped. However, the crew on *Emmy Dyvi* registered that the lights on board *Nordlys* went out immediately after they had fastened the towline. The line was aboard *Emmy Dyvi* at 09:31.

When the engine was examined after the accident, it showed signs of overheating. The dampers that are meant to ensure that the engine has access to fresh air for cooling and combustion were found in the closed position, and a cooling water hose was found to be broken. The hose showed clear signs of fatigue, with both interior and exterior crack formations.

As described above, *Nordlys's* sistership *Richard With* had experienced problems with unintended closing of the air dampers for the emergency generator room in connection with an incident in 2009. Certain modifications had been carried out, but the crew on board *Nordlys* had nonetheless experienced unintended closing of the dampers when they were tested after the above-mentioned improvements had been made.

The AIBN therefore considers it likely that the dampers, in connection with the fire, either opened and quickly closed again, or failed to open, and that the temperature in the emergency generator room increased as a result of insufficient air cooling. This then caused a rapid increase in the cooling water temperature, so that the cooling water line was exposed to high temperatures and probably a considerable increase in pressure when the cooling water reached boiling point. The hose probably ruptured under the strain and cut off the last remaining cooling effect for the engine, which then seized.

2.2.7 The spread of smoke

Mapping of the spread of smoke after the accident found moderate to dense smoke in the main and auxiliary engine rooms, in the corridor forward of the engine room, in the midship stairwell and in the midship passenger mingling area on deck 4. Some spread of smoke was also found, inter alia, in the aft crew cabins on the port side on deck 1, and in the open bar area on deck 7. Little or no spread of smoke was otherwise found to have taken place on board.

Deck 4 contains the ship's dining areas, galley and passenger mingling area. This is a large open space, divided into three zones. There were generally clear signs that dense smoke had spread to zone 2 (the middle section) while the two other zones had been free of smoke, indicating that the fire doors had remained closed and kept zones 1 and 3 free of smoke during the fire.

The soot deposits indicate that most of the smoke has risen up through the stairwell and welled out through two doors, namely the door to the galley and the door to the passenger mingling area. The AIBN sees this in conjunction with the escape routes chosen by the first engineer, the repairman and the apprentice engineer. The first engineer and the repairman evacuated the engine room through the watertight door in the forward engine room bulkhead, and made their way through the corridor and up the stairwell to the reception area on deck 3. The apprentice engineer probably followed the same escape route, but instead of stopping on deck 3, he continued to deck 4, where his body was found just inside the door to the stairwell.

The density of smoke in the engine room contributed to two deaths, and serious injuries to two crew members. In the AIBN's view, the smoke in the corridor forward, in the midship stairwell and in the midship passenger mingling area on deck 4 also constituted a safety problem. The crew have also described the density of the smoke in the crew cabins on deck 1 as problematic. In the AIBN's view, the internal spread of smoke was mainly due to the fact that the watertight door forward of the engine room was opened and not closed again, during the evacuation of the engine room. Had the watertight doors been closed from the bridge, the door would have automatically returned to the closed position after the engine crew had passed through it.

In addition to the internal spread of smoke, the black heavy smoke that poured out through the smoke stack and casing and gravitated down to the starboard boat deck, also constituted a safety problem. Among other things, the smoke prevented use of the lifeboats on the starboard side. The relatively low number of passengers on board *Nordlys* carried on this trip meant that everyone could be evacuated by using the lifeboats on the port side, but this could have posed a major safety challenge had the ship carried the maximum number of passengers. The smoke also meant that the emergency generator room was inaccessible.

The combustion of oil and other materials generated large volumes of smoke that rose through the casing and escaped through the ventilation openings on the aft side of the smoke stack. The fire also led to a reduced content of oxygen in the engine room, which in turn resulted in the engines not getting enough oxygen to be able to maintain good combustion. Normally, a slight overpressure is kept in the engine room to secure enough oxygen for the engines. The incomplete combustion that took place in the engines generated thick, black smoke that rose through the exhaust ducts and escaped through the smoke stack as long as the engines were running.

2.2.8 Operation of the stabiliser fins

Nordlys had both stabiliser fins extended when the fire started, and they were still extended when the ship was berthed alongside the quay. On colliding with the quay, the starboard fin was pressed through the hull and caused ingress of water.

As described in section 1.18.9, several barriers had been established to ensure that the fins were retracted, and the fins could also be operated in emergency situations. The fact that the stabiliser fins were not retracted in connection with this accident was probably due to the special conditions before and during arrival at the quay. The situation on the bridge had been hectic and stressful ever since the fire alarm was triggered. A lack of focus on important operations can also be seen in conjunction with loss of key personnel and the fact that a decision regarding release of CO_2 demanded too much attention from the master.

2.2.9 The ingress of water

After the accident, an assessment was made of what spaces had been filled with water. This applied to cargo hold no 1, cargo hold no 2, the port elevator shafts and the space for the port stabiliser fin, the accommodation above cargo hold no 1, the stores room above cargo hold no 2, the car deck and the stores room aft of the car deck (at the aft end of deck 2).

The damage and ingress of water were initially in the compartment that included cargo hold no 2, and it is likely that the compartment forward of this was filled through the watertight door in the bulkhead on frame 86, between cargo holds nos 2 and 1. The AIBN cannot say for certain whether this door was closed or open when the fire started. However, the investigation conducted after the fire showed that the seal on the underside of the door was not watertight. A gap of 8–10 mm across the width of the door results in an opening of approximately 200 cm^2. With the door closed, it is therefore probably that a leakage would occur as a result of the static pressure of the water in cargo hold no 2. In order to illustrate the potential flow of water through such an opening, we will use Bernoulli's equation, which assumes a frictionless flow:

$Q = A * V$,

where Q = the flow rate, A = the area of the opening and V = the velocity of the water.

The velocity of the water can be found using the formula $V = \sqrt{(2*g*h)}$,

where $g = 9.81 \ m/s^2$ and h = the water level on one side of the opening.

If the water level in cargo hold no 2 is assumed to be 0.1 m, the flow rate will be:

$Q = 0.01 * 2.2 * \sqrt{(2*9.81 * 0.1)} \ m^3/s = 0.0308 \ m^3/s = 110.9 \ m^3$ per hour.

If the water level in cargo hold no 2 is assumed to be 1 m, the flow rate will be:

$Q = 0.01 * 2.2 * \sqrt{(2*9.81 * 0.1)} \ m^3/s = 0.0974 \ m^3/s = 350.6 \ m^3$ per hour.

The above calculations are based on several simplifications in relation to the actual chain of events. Firstly, the flow of water through the gap under the door was not frictionless. Secondly, the pressure difference between the two rooms was gradually balanced out as the water flowed into cargo hold no 2. The situation is further complicated by the fact that the door in question was adjacent to the centre (from the centre to the port side) and that *Nordlys* listed (to port) and had an aft trim. Without assessing the corrections that follow from this, the AIBN is of the opinion that the water that flooded cargo hold no 1 may have come from cargo hold no 2 through the watertight door even if the door was closed.

As a result, *Nordlys* had a two-compartment damage when the ship lay alongside the quay after the fire in Ålesund, and the damage caused a list of more than the maximum 7 degrees that the ship is assumed to list as a consequence of a one-compartment damage. At most, the list was nearly 22 degrees.

The calculations carried out by DNV after the accident show that *Nordlys* had very limited survival capability given the degree of flooding. Had not emptying of the ship been initiated at the time it was done, and had not the leakage been stopped, *Nordlys* would probably have capsized alongside the quay in Ålesund during the night following the accident.

2.2.10 Damage potential

The accident occurred during the approach to Ålesund. The sea was calm and the weather was fair. The traffic in the area meant that many vessels quickly arrived at the scene and were ready to provide assistance. The rescue vessel *Emmy Dyvi* arrived only 14 minutes after the alarm went off on board *Nordlys*. *Emmy Dyvi* was on its way to an exercise and happened to be in the harbour. The proximity to Ålesund harbour also meant that the police, fire service, health personnel and other rescue crew could be mobilised in a short space of time.

Furthermore, the accident occurred at a time when many of the passengers were assembled around in the mingling areas on decks 4 and 7. In addition, *Nordlys* only carried 33% of the maximum permitted number of passengers.

The AIBN is of the opinion that, under different circumstances, the consequences of the accident could have been far greater. If *Nordlys* had carried the maximum permitted number of passengers, the evacuation would probably had been more challenging as the lifeboats on the starboard side were inaccessible because of smoke. If, in addition, the fire had started earlier, for example while the passengers were sleeping, the evacuation would in all probability have been more problematic. If the fire had started while the ship was at a greater distance from established, good infrastructure, and during extreme weather conditions, it would also have taken longer for external assistance to get there.

On the other hand, the serious situation that arose when the stabiliser fin penetrated the hull and led to water ingress in the cargo holds would probably not have occurred if the fire had started while *Nordlys* was further away from port.

The consequences of the water ingress meant that the situation became very critical, and *Nordlys* would probably have capsized alongside the quay had not measures been initiated in the form of emptying and temporary sealing of the hole in the hull. The AIBN does not necessarily believe that human life would have been at risk, but the incident had the potential to cause considerable environmental damage.

2.3 Assessment of safety problems and underlying factors

The chain of events as it is described in section 1.2 consists of a number of undesirable incidents. A summary of these incidents is provided in figure 49:

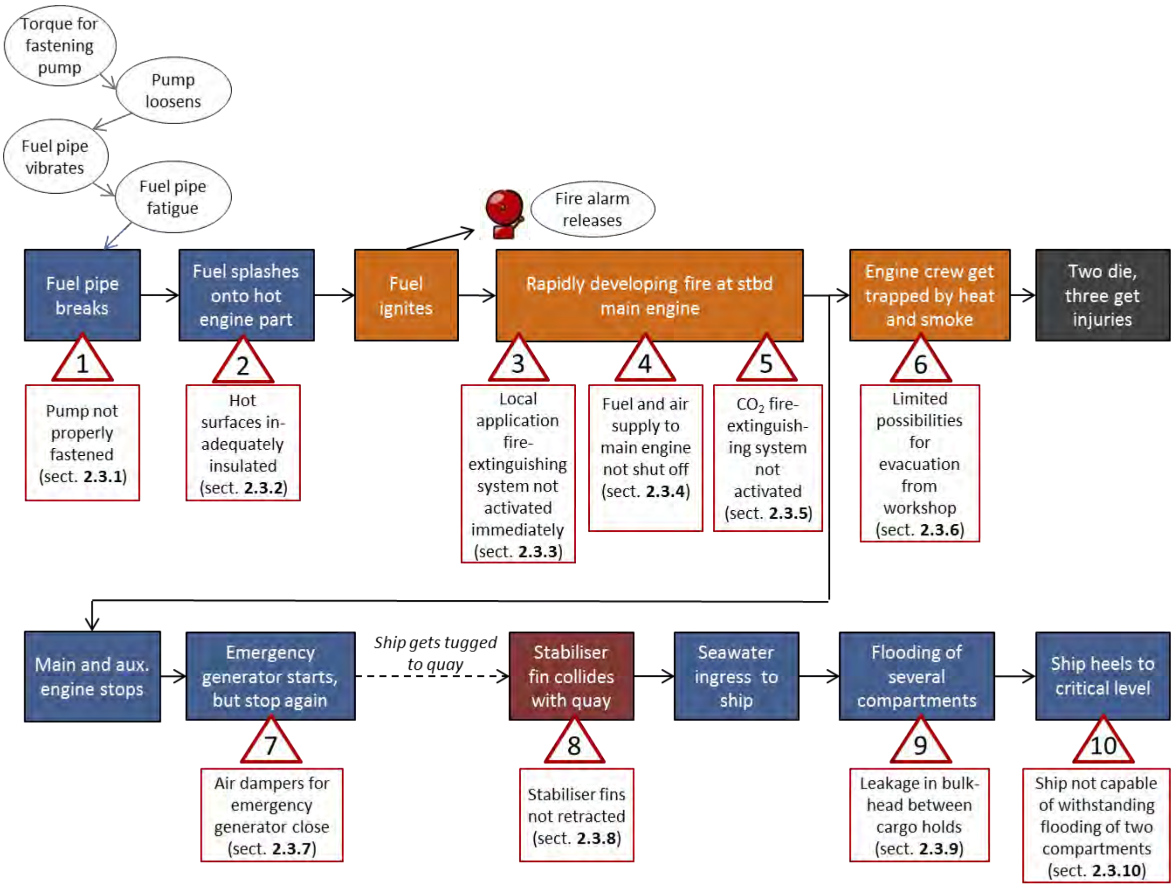


Figure 49: Rough description of the chain of events with description of safety problems.

2.3.1 Tightening of bolts in connection with replacement of fuel injector pumps

As described in the assessment of the chain of events in section 2.2.1.4, the AIBN assumes that the primary fuel leakage was probably related to the broken pipes by fuel injector pump no 5 and that the breakages were probably caused by fatigue as a result of the pump's fastening bolts having been loose already before the fire.

2.3.1.1 *Why were the bolts loose?*

In principle, there are two possible reasons why the fastening bolts were loose. The bolts were either fastened with the correct torque when the pump was last replaced and came loose during operation, or they were not fastened with the correct torque when the pump was last replaced.

The pump in question had been replaced by the crew in Bergen 12 days before the fire, and all four fastening bolts for the pump were found to be loose after the fire. None of the fastening bolts for the other fuel injector pumps were found to be loose.

The job specification on the relevant job card provided no guidance for how the job was to be carried out. Nor did it contain any reference to the manufacturer's maintenance manual or other relevant documentation. The reported history after the pump replacement provides no details on how the work was carried out, only that the pump had been replaced by a newly overhauled one.

The AIBN's interviews with the engine crew found that the replacement of fuel injector pumps was regarded as an easy job. The statements differ on whether the manufacturer's maintenance manual was used and whether there was a requirement for a given torque for tightening the pump's fastening bolts. The interviews did not provide clear answers to whether the maintenance manual was consulted in connection with the job in question, whether a torque key or a given torque was used or who fastened the bolts.

When the pump was removed after the fire, the seals between the fuel pipes and the engine and between the fuel pipes and the fuel injector pump were found to be switched around. After the pump in question had been replaced 12 days prior to the accident, leakages were observed at the flanges on the low-pressure pipes for this pump. The engineers assumed that the seals had been incorrectly installed, so they switched the seals and reconnected the pipes. Since the leakage stopped, they left it at that. In other words, the seals had been correctly installed in the first place, but they were switched around, so that they were not installed in accordance with the engine manufacturer's specifications. The AIBN cannot see that this has made a significant contribution to the bolts coming loose or to fatigue in the pipes, but it shows that the job was not correctly executed. It also suggests that the maintenance manual was probably not consulted in connection with this job.

The AIBN has examined the fastening bolts and bushings, and the results have been compared with examinations of identical bolts and bushings fastened with the prescribed torque. The examinations have not been able to confirm or disprove that the fastening bolts were fastened with the correct torque in connection with the pump replacement on 3 September 2011.

In the AIBN's view, the above-mentioned factors suggest that the replacement of the fuel injector pump in question was probably not correctly performed and, consequently that the bolts were loose because they had not been fastened with the correct torque. There are no grounds for assuming that the bolts had been fastened with the correct torque and subsequently came loose during operation.

2.3.1.2 *Why were the bolts not fastened with the correct torque?*

As mentioned above, the job specification on the job card contained no details on the job and had no reference to the maintenance manual. Nor did the maintenance system describe the job as particularly critical. The engine crew knew that the manual contained detailed instructions, but considered the job in question to be uncomplicated.

In the AIBN's view, the shipping company has failed to provide the crew with reasonable guidance relating to the job or its criticality through the ship's maintenance system. The fact that the job is regarded as uncomplicated may also have led to the crew not finding it necessary to retrieve the correct instructions from the maintenance manual.

As mentioned, the reported history after the pump replacement contains no details on the job done. The AIBN believes that better procedures for history reporting could have led the engine crew to check the maintenance manual to be able to report back that the job had been carried out correctly.

The AIBN is of the opinion that the maintenance system largely had the potential to ensure that the job was done correctly. This would, however, have required a more detailed job specification and history reporting. A criticality assessment of systems, components and jobs, as required by the ISM Regulations, could also have made a positive contribution. All these elements are described in the shipping company's safety management system, though they were not implemented on board. In the AIBN's view, a lack of compliance with the shipping company's safety management system is therefore the most important organisational factor contributing to incorrect fastening of the fastening bolts for fuel injector pump no 5. The content of the maintenance system and compliance with the procedures in the safety management system are discussed in more detail in sections 2.4 and 2.5, respectively.

2.3.2 Insulation of hot surfaces

The AIBN considers it probable that diesel leaking from the pipes connected to fuel injector pump no 5 was ignited when it came into contact with the nearest indicator valve, which was insufficiently insulated.

2.3.2.1 *Why were the hot surfaces of the engine insufficiently insulated?*

Insulation must regularly be removed and reinstalled, for example in order to perform inspections or maintenance work. Some wear and tear is naturally associated with such removal and reinstallation. Machinery movements, high temperatures, various types of leakages and cleaning also produce wear in the insulation. This entails a need for regular maintenance of the insulation to keep it in satisfactory condition.

The investigation has shown that the insulation was not in satisfactory condition on *Nordlys* after the fire. The insulation on board the sister ships *Richard With* and *Kong Harald* has also been found to be in a correspondingly poor condition.

Interviews with relevant crew and employees of the shipping company's onshore organisation have revealed insufficient knowledge about hot surfaces in the engine room and the insulation of such surfaces. The ship's maintenance system prescribed annual inspection of the insulation of the exhaust manifold and exhaust pipes. The job specification did not, however, include any details on where to install insulation or on how any necessary repairs should be carried out. In addition, the maintenance system did not describe the job as particularly critical. The engine manufacturer has not prepared any information about what surfaces become hot, nor has the shipping company tried to obtain such an overview. In the maintenance system, the job was most recently reported to have been carried out on 14 April 2011, and the comment 'inspected together with DNV/ NMA Bergen 26.03 – 02.04, ok.' had been entered.

The AIBN is of the opinion that the maintenance system had a far greater potential to serve as guidance for the crew than was the case. This would, however, have required a far more detailed job specification and requirements for more detailed history reporting. A criticality assessment of systems, components and jobs could also have made positive contributions. All these elements are described in the shipping company's safety management system, but not implemented on board.

In the AIBN's view, the lack of an overview of hot surfaces to be insulated was an important organisational factor that contributed to insufficient insulation of the engine's hot surfaces. The content of the maintenance system and compliance with procedures in the safety management system are discussed in more detail in sections 2.4 and 2.5, respectively.

2.3.2.2 *Why was insufficient insulation not uncovered by the supervisiory authority?*

The NMA and DNV are both charged with conducting supervisory activities to ensure that vessels comply with the requirement for insulation of hot surfaces. They both normally check this while the vessels are in port and the engines are cold. This places great demands on the competence and experience of the inspectors, insofar as there is no documented list of what surfaces need insulation.

Inspection of hot surfaces is included on DNV's checklists both for renewal of certificates and for annual inspections. In addition, DNV's internal instructions for inspectors include guidelines on how to carry out inspections of hot surfaces. The guidelines go some way towards addressing the challenge that such inspections are almost invariably carried out of cold machinery in that they describe typical problem areas and visual indicators of high temperatures. They also include advice on the assessment and handling of nonconformities. Checklists are also used by the NMA, but no detailed instructions have been prepared how to conduct inspection of hot surfaces. In principle, it is left to the shipping company to check hot surfaces through self-inspection.

No orders for insulation of hot surfaces had been issued, neither by the NMA nor DVN, in connection with the most recent annual inspection of *Nordlys* prior to the fire. Nor had the state of the insulation of hot surfaces on the sister ships been commented on in connection with the most recent annual inspection prior to the fire. Despite this, the AIBN's investigation shows that the condition was unsatisfactory on board all three ships in autumn 2011. The AIBN finds it unlikely that the condition of the insulation on board all three ships was satisfactory in connection with the above-mentioned supervisory inspections and had subsequently deteriorated to the same degree and to such an extent in less than one year. In the AIBN's view, this suggests that the supervisory authority's inspection procedures have been inadequate in this respect. This is due to three factors. In light of the fact that the inspections are normally carried out when the engine is cold, the AIBN believes that the lack of overview of the surfaces to be insulated is probably one of the reasons why the supervisory authority failed to uncover the matter when insulation of hot surfaces was physically inspected on board. A safety recommendation is submitted to the NMA in this connection.

The other two factors relate to the NMA's inspection regime, which is discussed in section 2.6 on supervision by the authorities.

2.3.3 <u>Activation of the local application fire-extinguishing system</u>

The chain of undesirable events could have been broken shortly after the fire started had extinguishing been initiated immediately.

The local application fire-extinguishing system was in manual mode, however, and seen in relation to the consequences of the fire, the AIBN believes that this constituted a major safety problem. Although the AIBN cannot say whether the fire had been put out immediately had the fire-extinguishing system been released immediately, it considers that the outcome would have been very different with regards to the survival aspect and the injuries suffered by the survivors. This, in turn, would have had a major impact on the further handling of the fire and on the consequential damage that it caused. The water from the extinguishing system would probably have contributed to limiting the fire to the area between the tank top and the top grating and contributed to cooling down the area.

Exhaust gases and particles would have bonded with the water. Those who were present in the engine room would probably have been less affected by the smoke and heat, and it would have been easier to orientate oneself in order to evacuate quickly.

The way the AIBN sees it, the requirement for a local application fire-extinguishing system in the engine room is intended to enable immediate activation of a fire-extinguishing system without having to consider whether there are still people in the area, to protect the most fire-hazardous areas and have sufficient capacity to extinguish or supress a fire. The system is intended to allow people enough time to take other action to extinguish the fire should the first attempt be unsuccessful.

It is somewhat unclear when the main switchboard failed, when the emergency generator started, for how long it was in operation and whether equipment that is supplied with power via the emergency switchboard had a constant supply of power until the emergency generator stopped. Whether the local application fire-extinguishing system worked as intended from the time it was activated until the emergency generator stopped has been impossible to ascertain, but the tank that is connected to the system was empty after the fire, indicating that extinguishing must have continued for some time. The main fire-water line had not been opened to secure a continued water supply, however, so continued extinguishing would not have been possible until it was opened even if there was power to operate the fire-pumps. The AIBN cannot say whether anyone would have opened the valve later had the emergency generator continued to run, or whether not opening the valve was in any way connected to the loss of personnel or other circumstances.

Pursuant to Regulations No 305, only manual operation of the extinguishing system is required for vessels with a manned engine room such as *Nordlys*. The installed extinguishing system was, however, arranged for both manual and automatic release though the shipping company's procedures stated that the system was to be set to 'auto' mode and that it would be activated if the smoke detector and flame detector activated. The crew had not communicated to the shipping company that they had decided to set the system to the manual mode on a permanent basis, neither through nonconformity reporting nor in any other way. Effective compensatory measures had not been established to reduce the risk entailed, and no risk assessments had been carried out in this connection. The issue of inadequate risk assessments and the lack of nonconformity reporting are discussed in more detail in section 2.5 about the safety management system.

The two crew members who died due to smoke injuries and the two who were badly injured had also been exposed to large amounts of smoke in addition to burn injuries. They had been in the immediate vicinity of the area where the fire started and managed to get out of the engine room in a relatively short space of time. The local application fire-extinguishing system had not been activated at the time they evacuated the engine room. It did not take long from the fire started until they sustained injuries from the heat and smoke. Even though the local application fire-extinguishing system was activated approximately two to three minutes after the fire was discovered, this was not sufficient to limit the scope of injuries to personnel. The crew in the workshop were prevented from reaching a manual trigger point due to smoke and heat. In the AIBN's view, this shows that it is not expedient to allow manual activation of a local application fire-extinguishing system unless another automatic extinguishing system has been activated that does not endanger human life. If the system had been activated automatically, the chances of extinguishing the fire at an early stage would have significantly improved. Not only would the water have a cooling effect, it would also have bonded with smoke particles so that the evacuation could have taken place in a more safe and secure way.

No procedures had been established for manual release of the system. However, the AIBN believes that this would not have been sufficient to solve the challenges relating to manual release in a satisfactory manner. Even in the best case scenario, it would in all probability take significantly longer for someone to reach a trigger point to release the system manually than it would for the system to be activated automatically. This accident has highlighted challenges relating to the performance of manual actions and compliance with procedures in an emergency situation, especially in the event of loss of personnel in complex, chaotic situations. The regulations should therefore, as far as possible, prescribe automatic operations where this can be done without adding other and greater risk factors. A safety recommendation is submitted to the NMA in this connection.

2.3.4 Shutting off of the fuel and air supply

If the supply of fuel and air had been shut off, the fire would probably gradually have died down by itself. The decision-support system on the bridge included a checklist in the event of fire that, among other things, entailed shutting off the fuel and air supply. The chief engineer was to muster to the bridge in an emergency situation, and he would normally be the one to follow up the checklist. However, the chief engineer was put out of action as a result of the fire, and the fuel and air supply were not closed off. The fire was consequently fed by a continuous supply of fuel.

The issue relating to the performance of safety-critical tasks in the event of loss of personnel, and training and drills in that connection, are discussed in more detail in section 2.5 on the shipping company's safety management system.

2.3.5 Use of CO_2 as a fire-extinguishing agent

The main fire-extinguishing system did not either work as a barrier in relation to preventing escalation of the accident. The captain was responsible for deciding whether to release the system. The situation on the bridge was hectic and challenging in the minutes after the alarm was triggered. The fire caused a blackout, and the loss of engine power was assessed as critical because *Nordlys* was near Steinvåggrunnene (shallows) at the time. The AIBN believes the focus on clarification of this situation may have led to a postponement of the decision as to whether the CO_2 system in the engine room should be released. When the situation had been clarified, and the captain was able to address the issue of whether to release the CO_2 system, however, he did not know whether there were any crew in the engine room. He therefore chose not to release the system. In the AIBN's view, this is a difficult, but safety-critical, dilemma that will often be relevant in such situations.

In hindsight, we cannot draw the conclusion that release of the system would have changed the scope of the accident in relation to loss of human life. The chief engineer and the apprentice, who both died, sustained burn and smoke injuries while they were present in the engine room. The consequences would have been the same had the CO_2 system been released, although it is uncertain whether they would have died from smoke injuries sustained during an early stages of the fire or from CO_2. The first engineer and the repairman, who were both seriously injured, also sustained burn and smoke injuries while they were in the engine room. Depending on when the CO_2 had been released, they could both have died had the system been released immediately. The other crew members who were lightly injured sustained smoke injuries in other areas of the ship that filled up with heavy smoke. For these injuries to be avoided, the CO_2 system would have had to be released and stopped the fire and smoke from developing at a very early stage, and procedures in connection with the release of CO_2 would have to have been followed, including for shutting down the ventilation and closing all openings to the engine room.

Hurtigruten ASA has special training requirements for crew who must be prepared to release CO_2. For release in the engine room, this applies to the whole engine crew, the deck officers and the fire teams. Despite the fact that a large part of the engine crew was out of action, there were still available crew with sufficient knowledge to prepare and to conduct a release of the system. At the time when the crew were ready to release the CO_2 system, however, all openings to the engine room had not been closed in that dampers and doors were still open. In order for a CO_2 system to be effective, the gas must be released into a confined space, without a supply of fresh air and without the possibility of gas escaping through openings to other parts of the ship or the atmosphere. The AIBN has not been able to establish whether the crew planned to close the openings and had insufficient time to do so, whether they attempted to close all openings but were unable to do so, or whether they forgot to close all openings. Releasing the system without closing the openings would have reduced the possibility of extinguishing the fire, at the same time as it could have posed a risk to anyone without breathing equipment occupying the spaces into which the CO_2 escaped.

In the event of fire, it is up to the captain to decide whether to release the CO_2 system to limit the extent of damage or not release the system to avoid endangering the lives if anyone who could still be in the area. Not only does this impose mental strain on the captain; it is also a dilemma that can reduce or remove the focus on making other decisions and carrying out required actions. Several actions that should have been implemented from the bridge were not initiated during the fire, such as the closing of fire doors and watertight doors.

In the AIBN's view, this shows that CO_2 is not particularly suitable as an extinguishing medium in extinguishing systems on board ships. This type of fire will probably often develop rapidly, and it will be difficult to maintain a full overview at all times of the scope of the fire and where crew members are in relation to the fire zone. On some types of vessels, indication panels on the bridge show which doors, ventilation ducts and fire dampers are open, but this requires good knowledge of the ship's detailed layout and regular training to deal with different fire scenarios. In general, the challenges related to releasing a CO_2 system in a sufficient quick way increase with the size of the vessel and the number of engine crew.

In practice, the Petroleum Safety Authority Norway (PSA) no longer allows CO_2 to be used as an extinguishing agent on board installations on the Norwegian continental shelf. In its guidelines to the Facilities Regulations[41] Section 37 on permanent fire-extinguishing systems, the PSA states that CO_2 used as an extinguishing agent in spaces that may be occupied by personnel is incompatible with the requirement for rapid, effective fire-fighting.

[41] Regulations of 29 April 2010 No 634 relating to design and outfitting of facilities etc. in the petroleum activities

There are currently alternative extinguishing systems that do not pose an immediate health hazard, which can therefore be activated regardless of whether anyone is in the room. Many choose to install water-mist systems or what are known as inert gas systems instead of CO_2.

No major modifications or adjustments are needed to switch from a CO_2-based system to a system that uses another form of inerting gas, such as Argonite or Inergen. According to SINTEF NBL, only minor modifications are needed before such gases can be used in existing systems, such as the replacement of nozzles and the installation of reduction valves. Such gas mixtures have about the same density as air, which means that they blend more efficiently with the air and the concentration is maintained for a longer period than with CO_2. These gas mixtures are stored under pressure in the same way as CO_2, and can also be released in the same way as CO_2 in a dead ship situation.

Given the alternatives that are currently available to replace CO_2 as the main extinguishing agent, it seems like financial considerations are the most important argument for allowing the continued use of CO_2 as an extinguishing agent in permanent facilities in spaces where personnel may be present. The AIBN therefore recommends that CO_2 be phased out as an extinguishing agent on vessels, and submits a safety recommendation to the NMA in that connection.

2.3.6 Evacuation options from the engine room

The AIBN believes that the limited possibility of evacuating the engine room, and the workshop in particular, contributed to the outcome of the accident. First of all, the first engineer, the repairman and the apprentice had to move through intense heat and smoke in order to get out, which caused the apprentice to die and the first engineer and the repairman to be seriously injured. Furthermore, the watertight door through which they evacuated was left open when they passed through it, which caused smoke to spread to parts of the accommodation.

After the accident, *Nordlys* has been modified in that new emergency exits have been arranged that lead directly up to the car deck from both the workshop and the incinerator room. In addition, the watertight sliding door through which the first engineer, the repairman and probably also the apprentice evacuated through, has been replaced by a bolted hatch. The same modifications will be done on the other vessels with the same design as *Nordlys*.

2.3.7 The air dampers in the emergency generator room

As described in section 2.2.6, the emergency generator probably overheated and seized as a consequence of not getting enough air for cooling when the air dampers in the emergency generator room closed unintended after a short period of time, or as a consequence of the dampers failing to open as intended when the emergency generator started.

The AIBN believes that the underlying issue concerning the dampers on board both *Nordlys* and *Richard With* had to do with the fact that the dampers were in the closed position, i.e. in an undesirable position in relation to safe operation of the emergency generator, when they were not influenced by power/energy. In the event that the power/energy that was to open the dampers and keep them open failed, the dampers would revert to the closed position. Furthermore, in the AIBN's opinion, an unstable source of power was used. A possible drop in pressure in the compressed air system caused by e.g. a leakage would not be compensated if the main switchboard failed and the compressor lost its power supply. The AIBN therefore believes that the arrangement on board *Nordlys* at the time of the accident did not satisfy the requirement for the emergency power system to be an independent source of emergency power capable of supplying power to the emergency switchboard so as to maintain safety-critical functions in an emergency situation.

After the sister ship *Richard With* ran aground in January 2009, the dampers in the emergency generator room on *Nordlys* and the other sister ships were modified by installing a check valve to prevent a drop in pressure if the compressor were to stop. However, during testing, the crew on board *Nordlys* had experienced leakages and that the system was still not satisfactory in that the dampers did not always stay open as intended. The problems experienced by *Nordlys* despite the modification, were neither conveyed to those of the other ships that had similar arrangements nor to the shipping company, and sufficient compensatory measures were not implemented to secure the air supply.

In the AIBN's view, the supervisory authority failed to follow up the problems that were emphasised in connection with the *Richard With* accident in a satisfactory manner. The modification that was carried out on board *Nordlys* and its sister ships was approved by both the NMA and DNV. Furthermore, after the fire on board *Nordlys*, the NMA confirmed in a safety notice that the modified arrangement that included an additional check valve was in accordance with both regulatory and class requirements.

Following the fire on board *Nordlys*, the shipping company has altered the compressed air arrangement for opening/closing the dampers in the emergency generator room to electrical opening/closing with the aid of an electric motor that is supplied with power from a network connection between the emergency generator and emergency switchboard. New routines have also been introduced for test runs and maintenance of the oil and water hoses on the emergency generator. The AIBN believes that the new opening/closing arrangement based on electrical power from a network connection between the emergency generator and the emergency switchboard is more stable than the previous arrangement based on compressed air produced by a compressor connected to the main switchboard. The dampers are controlled by the 'run' signal to the motor. When the motor stops, the dampers close. The damper arrangement includes a pin that can be manually removed, and the dampers will then go into open position.

The AIBN takes the view that it is up to the supervisory authority to decide whether the new arrangement is satisfactory. Supplementary comments on the role of the supervisory authority are included in section 2.6.2.

2.3.8 Operation of the stabiliser fins

Despite several technical and operational barriers that had been established to ensure that the stabiliser fins were retracted, the fins were still extended when *Nordlys* was berthed. When the ship docked alongside the quay, the starboard fin was pressed through the hull and caused ingress of water.

Following the accident, the shipping company has built dry tanks around the stabiliser fins on both *Nordlys* and its sister ships with a similar design to *Nordlys* as regards the consequences of stabilisers penetrating the ship's side. Damage to the stabiliser fin will thus be the only consequence of a similar incident in future.

In the AIBN's opinion, there are greater safety benefits from focusing on reducing the consequences of the stabiliser fins being pressed against the hull than from introducing further operational barriers to ensure that they are retracted when berthing at the quay. The background to this is that other measures to reduce the consequences will also improve safety in situations other than when calling in port, for example during navigation through narrow channels and in shallow waters.

2.3.9 Openings in bulkheads between cargo holds

As mentioned in the assessment of the chain of events in section 2.2.9, the flooding of cargo hold no 1 may have been a consequence of a leak through the door between cargo holds nos 2 and 1. The door was not watertight as the seal along the underside of the door was worn. The issue of inspection and replacement of seals around watertight doors is discussed in more detail in sections 2.4 and 2.6.

Regulations No 305 do not permit doors between cargo holds, and this prohibition became applicable to *Nordlys* from 1 July 2010. Had the watertight door been removed before the accident on 15 September 2011, the flooding caused by the starboard stabiliser fin penetrating the hull would probably not have had any dramatic consequences. The AIBN therefore takes a serious view of the shipping company's failure to comply with the prohibition.

According to the NMA, the shipping company was informed about the prohibition through a circular informing the industry about the entry into force of the Regulations. The NMA subsequently specifically informed the shipping company of this problem in a letter dated 23 June 2009. Since then, a process has been under way to find a solution; in the AIBN's view, however, the NMA has also been too lax in its follow-up of a prohibition of such importance to safety.

In consultation with the NMA, the shipping company has now found a solution whereby alteration work will be carried out on board *Nordlys*, to move the forward cargo hold up to deck 1 and use the original cargo hold no 1 as a provisions store. The watertight bulkhead at frame 86 will thus be between a cargo hold and a provisions store, and the prohibition on openings in this bulkhead will no longer apply. This means that the shipping company has obtained acceptance from the NMA for retaining the door in question.

The AIBN finds it difficult to see how the planned alterations will solve the fundamental safety problem related to possible water ingress from cargo hold no 2 to the adjacent space in front of this. The AIBN therefore submits a safety recommendation to the shipping company to ensure watertight integrity in the bulkhead between the two compartments.

2.3.10 Damage stability standard

The calculations carried out by DNV after the accident show that, during the night following the accident, *Nordlys* came close to capsizing alongside the quay in Ålesund. The reason for this was that *Nordlys* experienced water ingress to two compartments, while the ship was basically only designed to withstand a one-compartment damage, i.e.

damage between the watertight transverse bulkheads. This damage stability standard was in accordance with the regulatory minimum requirements in 1994, when *Nordlys* was constructed.

However, as a consequence of, *inter alia*, the *Herald of Free Enterprise* accident in 1987 and the *Estonia* accident in 1994, the authorities have introduced more stringent requirements for existing passenger ships' survival capabilities following damage involving water ingress. In that connection, requirements have also been introduced for survival capability following damage to watertight transverse bulkheads, i.e. two-compartment damages, and these will become applicable to *Nordlys* in 2014.

Since the issue of damage stability standards is being addressed through regulatory amendments as regards both new and existing ro-ro passenger ships, and since the shipping company has a dialogue with the NMA on how to meet the new requirements, the AIBN does not see any need to make further safety recommendations relating to damage stability standards.

2.4 The shipping company's maintenance system

The maintenance system, which describes schedules and procedures for maintenance of ship and equipment, is extensive. The AIBN has limited its assessment to those parts of the system that, directly or indirectly, relate to the accident.

As shown in section 2.3, the investigation has uncovered barrier weaknesses relating to the fastening of fuel injector pumps, insulation of hot surfaces, inspection and replacement of cooling water hoses to the emergency generator, and inspection and replacement of seals around watertight doors.

In the AIBN's opinion, the maintenance system's job specifications relating to fastening of fuel injector pumps and insulation of hot surfaces were inaccurate and lacked references to applicable manuals. For example, the job specification for replacement of fuel injector pumps did not make it clear whether there were any requirements for lubricants or torque. The lack of job specifications was identified by the NMA as early as in 2009, which caused the shipping company to issue an internal ERFA notice in order to resolve the matter. The AIBN cannot see that the matter has been successfully followed up by the shipping company.

Concerning insulation of hot surfaces, insulation of exhaust manifolds and pipes was to be inspected annually. The job was described as 'inspect insulation and exhaust pipes'. The system did not include any information about what surfaces this comprised or procedures for identifying such hot surfaces. Nor was it stated how hot surfaces should be insulated.

Moreover, there was no information in the maintenance system about intervals for replacing cooling water hoses on emergency generators or seals around watertight doors.

The AIBN believes that the deficiencies of the maintenance system contributed to the situation in which the fuel injector pump was loose, that several indicator valves lacked insulation, and that neither the cooling water hose on the emergency generator nor the seals around the watertight doors had been replaced. These deficiencies have thus contributed to the manner in which the accident developed.

Following the accident, the shipping company has introduced new routines for inspection and re-tightening of fuel-system pipe connections, installed insulation and shielding of hot surfaces on the main and auxiliary engines, and revised the routines for test operation of oil and water hoses on the emergency generator. According to the shipping company, it has also improved the work orders relating to inspection of seals around watertight doors.

2.5 The shipping company's safety management system

The company is certified under the International Safety Management (ISM) Code, and, at the time of the accident, it had a valid Document of Compliance (DOC) issued by the NMA. *Nordlys* also had a valid safety management certificate. The safety management system is designed to ensure safety at sea, prevent injuries and loss of human life, and avoid harm to the environment and property.

The management system as a whole may be perceived as somewhat too comprehensive and detailed. It also seems that the same issue are also mentioned in several different procedures, without being harmonised.

Following the accident, the shipping company has established a project to review the management system, including its technical platform, the structure and its content. Representatives of the ships' crews also participate in this project. A review has also been carried out of the content of shipboard drills and training.

2.5.1 Deficiencies in the contents of procedures

The AIBN has limited its assessment of the content of procedures to those parts that directly or indirectly relate to the accident.

2.5.1.1 *Lack of training in how to deal with loss of key personnel*

During the fire, both the chief engineer and the first engineer were put out of action. According to the station bill on *Nordlys*, the chief mate shall take over from the chief engineer and the second engineer shall take over from the first engineer. The investigation showed that several important tasks initially assigned to the chief engineer and first engineer were not carried out in connection with the accident.

In an emergency situation, the chief engineer shall report to the bridge and be responsible for leading and coordinating the fire-fighting and damage control teams. The chief engineer was also responsible for the local application fire-extinguishing system and the CO_2 system, even though the CO_2 system was only to be released on the orders of the master. The decision support system on the bridge included a checklist in the event of fire. The checklist included checkpoints on *inter alia* CO_2, local application fire extinguishing, ventilation, bilge pumping, fire-pumps, and operation of emergency stop functions in the safety central and casing. Emergency stop devices in the safety central and casing included devices for shutting down the fuel supply, ventilation and operation of watertight doors.

The first engineer was to meet in the control room and to assume responsibility for, inter alia, that watertight doors were free of obstructions, for fire- and bilge pumps, for closing fire dampers and shutting down the ventilation as necessary and for ensuring that the fire-fighting and damage control systems were working.

Not only were these specific safety-critical tasks not carried out; communication between the bridge and control room were reduced as a direct consequence of the loss of key personnel.

In the AIBN's view, the fire on board *Nordlys* illustrates some of the challenges facing the crew in a situation of stress. The AIBN believes that, in order to tackle such a situation in an optimum manner, it is essential that the crew, particularly those crew members who have been assigned key roles, are quick to respond. Targeted training is one of the most important tools for achieving this. However, the fire on board *Nordlys* also illustrates the importance of training to deal with situations in which key personnel are put out of action. A lack of training and a lack of awareness about the responsibilities of stand-ins were among the factors that led to inadequate handling of the situation as it developed. In that connection, good drill procedures could have contributed to adapted training covering those factors that are important to address in an emergency situation. The shipping company's management system contained drill programmes, but no drills were specified for attending to safety-critical tasks in the event of loss of personnel.

These factors may also be relevant to the other ships in the fleet, and the AIBN expects the shipping company to address these issues in connection with its review of the procedures for shipboard drills and training.

In addition to training, checklists can also help to ensure that important actions are not left out. The decision support system on the bridge includes a checklist in the event of fire, but it was not used during the fire as that task normally belonged to the chief engineer. Had drills been conducted to deal with the loss of key personnel, the probability that the checklist had been used would also have been greater, and the fact that several safety-critical tasks were not addressed might have been uncovered at a much earlier stage.

2.5.2 Inadequate compliance with procedures

Inadequate compliance with established procedures was probably one of the most important organisational factors that gave rise to the fire in that the maintenance system did not include a job specification for replacement of the fuel pumps, as required by the procedure for preparing job specifications. Likewise, inadequate compliance with management system procedures was probably a contributory organisational factor to explaining why several hot surfaces in the engine room had insufficient insulation and why the local application fire-extinguishing system was set to the manual mode.

Nor had procedures for handling nonconformities been complied with.

2.5.2.1 *Preparation of job specifications*

The ERFA notice issued by the shipping company following the NMA's discovery of deficiencies in the maintenance system in 2009 described various measures to be implemented by the ships. Among other things, all work orders were to include an unambiguous job specification in accordance with the manufacturer's instructions and references to the manufacturer's instruction manual where expedient. It was also made clear that risk assessments should be carried out of the tasks involved and that they should be linked to the job. On completion of a job, a detailed report should be made on the execution of the work.

In the AIBN's opinion, this has not been sufficiently ensured and followed up on board or by the onshore organisation. The investigation found significant deficiencies in the work orders relating to replacement of fuel injector pumps, inspection and insulation of hot surfaces as well as those relating to the emergency generator, and the descriptions of how the job had been executed were inadequate and, in some cases, totally absent. The AIBN believes that it may have been inexpedient to impose these tasks on the ships individually, and that it would have served more of a purpose to facilitate a review whereby it could be ensured that ships having identical systems and equipment prepared harmonised procedures for the execution of jobs, based on both their own experience and the manufacturers' instructions. This would also have made it easier for the shipping company to check that this was done as intended. A safety recommendation is submitted to the shipping company in this connection.

2.5.2.2 *Handling of nonconformities*

According to the management system, the local application fire-extinguishing system should have been set to the automatic mode. The system had been switched to the manual mode, however, as it had been released several times without there being a fire. No nonconformity had been reported, no risk assessment had been carried out and no compensatory action had been taken in that connection.

The cover plates on the main engine had also been removed without this being reported as a nonconformity. No risk assessment had been conducted and no compensatory action taken in this connection either.

According to the maintenance system, the dampers in the emergency generator room were tested on 2 July 2011, and the following comment had been entered: '*tested and the check valve does not work as intended – the damper goes in closed position after a while. Working on getting hold of new air cyl. with opposite action. Until then, we block the dampers open at black-out.'* As far as the AIBN has been able to ascertain, this was not handled as a non-conformity or otherwise reported to the shipping company's onshore organisation or to the sister ships. Nor were adequate measures implemented to secure the air supply pending completion of the modification work.

Several of the job specifications in the maintenance system were not in accordance with the shipping company's procedures, without this having been uncovered and reported as a non-conformity by the crew or the onshore organisation.

The AIBN has reviewed parts of the system for handling nonconformities and assessed nonconformity reports issued by *Nordlys* as well as its sister ships, in order to have a basis for comparison. The AIBN has also reviewed how risk assessments are conducted for the same group of ships. The review shows that the system for reporting nonconformities is being used, but that there is potential for improvement with regards to processing time, the quality of reporting and the work tools used for handling nonconformities. This has also been pointed out by the ships and by the shipping company, and extensive efforts are under way to deal with these challenges. The investigation has, however, been unable to answer the question of why serious nonconformities on board *Nordlys* were not reported. It appears that *Nordlys* may have reported a somewhat lower number of nonconformities and conducted fewer risk assessments, though the AIBN has not been able to find out why that was the case.

Although standard risk assessments seem to be well in place, there is potential for improvements relating to the performance of risk assessments for other conditions that arise during the operational phase. There are also deficiencies in relation to risk assessment of maintenance jobs as provided for by the shipping company's own procedures.

The shipping company has stated to the AIBN that it sometimes feels that the crew have a strong operational focus and wish to deal with their problems there and then, rather than reflect on the fact that their problems/solutions may also be of relevance to the other ships. This is a more general observation, however, and not one that is specific to *Nordlys*. In summer 2012, as part of an effort to ensure that all the ships learn from each other's nonconformities, the reporting system was made more transparent in that all ships were given access to view audit reports from the other ships and look up all reported non-conformities. The shipping company has also focused on attitudes and challenges related to the crew's compliance with procedures, through organising management development programmes and officers' conferences.

After the accident, Hurtigruten ASA has initiated cooperation with the University of Bergen to map the safety culture on board the shipping company's ships. In that connection, the AIBN would like to stress the importance of looking at the differences between the ships as well as the role of the shipping company in relation to influencing the safety culture on board.

2.6 The authorities and classification society's supervisory inspections

Pursuant to the Norwegian Ship Safety and Security Act, the shipping company is responsible for ensuring that ships are built, fitted out and operated in accordance with applicable laws and regulations. Through its investigation, the AIBN has identified several areas in which the shipping company has failed to fulfil these responsibilities in a satisfactory manner. These were not identified through the supervisory inspections that, pursuant to the Norwegian Ship Safety and Security Act, are designed to ascertain whether applicable laws and regulations are being complied with. The areas in which the shipping company did not fulfil its responsibilities and where supervisory inspections could have constituted an extra barrier to ensure compliance with the regulations, is in the AIBN's opinion related to insulation of hot surfaces, the arrangement for operating the air dampers for the emergency generator room and the ship's watertight integrity. ISM audits by the supervisory authority could also have constituted an extra barrier in relation to identifying deficiencies in the contents of and compliance with the maintenance and safety management system.

2.6.1 Inspection of hot surfaces

The AIBN's investigations on board *Nordlys* after the fire showed that both indicator valves and other surfaces were insufficiently insulated. Corresponding observations were made on board the sister ships *Kong Harald* and *Richard With*. In the AIBN's opinion, the fact that there were serious defects in this area on all three ships that were inspected in connection with the accident suggests that the supervisory inspections may not be working as an effective barrier in relation to identifying nonconformities with the requirements for insulation of hot surfaces.

As shown in section 2.3.2.3, the AIBN believes that insufficient knowledge about which surfaces that reaches temperatures of more than 220 °C, and thus need to be insulated, may have contributed to why non-compliance with the requirement was not uncovered. However, the AIBN believes that inadequate updating of the NMA's checklists may also have contributed, both with regards to inspection of hot surfaces and possible other requirements set out in Regulations No 305. With regards to hot surfaces, the consequence of inadequate updating of the checklists is that this point is checked every five years instead of annually.

The requirement for all surfaces with temperatures exceeding 220 °C to be insulated was applicable to *Nordlys* with effect from 1 July 2003. Judging by the NMA's checklists, insulation of hot surfaces was not in focus in connection with any of the supervisory authority's surveys of *Nordlys* in 2003, 2005, 2006, 2008 and 2010. Insulation of hot surfaces was a topic during the survey in 2011, the most recent survey prior to the fire, but it was left to the shipping company to check the insulation through self-inspection. The AIBN submits a safety recommendation to the NMA for them to increase its focus on insulation of hot surfaces in connection with future inspections of passenger ships.

2.6.2 Inspection of the air damper arrangement in the emergency generator room

In connection with the AIBN's investigation after *Richard With* ran aground, problems were identified relating to the emergency power system, which led to the submission of two safety recommendations to the NMA. Approximately 18 months after those recommendations had been issued and more than one month after the fire on *Nordlys*, the NMA issued a safety notice relating to the emergency power system on *Richard With*. The safety notice stated that the damper arrangement on board *Richard With* is permitted pursuant to Norwegian regulations and DNV's rules, provided that a check valve is installed between the compressed air accumulator in the emergency generator room and the ordinary compressed air system. Such a modification had already been carried out and approved by DNV.

The AIBN consider that the NMA may have issued the safety notice on the basis that the modification had already been carried out and approved by DNV, without considering the fact that the modification would not have been sufficient to prevent the dampers from closing during the fire on *Nordlys*.

The AIBN is aware that the NMA in cooperation with DNV have reassessed the design principles and requirements for ventilation dampers in the emergency generator room. In that connection, they have concluded that the new arrangement for opening/closing the dampers on board *Nordlys* and its sister ships, based on the use of an electric motor supplied with power from the emergency switchboard, is not sufficiently robust. The reason for this is that a single fault in the power supply to the damper motor, such as a loose terminal or a broken cable, is enough to cause the dampers to close. Such dampers should normally be open and, in the event of a fault in the power supply to the damper motor, an open damper should remain open, and dampers that eventually is closed when a fault occurs should open automatically. According to the NMA, this interpretation is in accordance with current regulatory requirements.

On that basis, the AIBN will not issue any new safety recommendations relating to the air damper arrangement for the emergency generator room, but refer to the safety recommendations that were submitted after the grounding of *Richard With* in 2009.

2.6.3 Control of watertight integrity

As shown in section 2.3.9, the AIBN believes that, in connection with the certification of *Nordlys*, the NMA has been too lax in extending the shipping company's deadline for compliance with the prohibition on doors in bulkheads between cargo holds. Although the requirement became applicable to *Nordlys* from 1 July 2010, the door had still not been removed on the date of the accident.

In the AIBN's view, the tightness of watertight doors is very important to safety in general, and the supervisory authority should have paid special attention to this door, as it in principle should have been removed. In connection with the most recent inspection (29 March–1 April 2011) prior to the fire, it was left to the shipping company to check the tightness of the door in question through self-inspection. However, in connection with the inspection on 10–11 March 2010, this was checked by the NMA's inspectors. The wear on the seal on the underside of the door was not discovered during either of these inspections.

After the accident, the NMA has accepted that the door in question is retained, provided that the forward cargo hold is moved up to deck 1 and that the original cargo hold is used as a provisions store. The AIBN finds it difficult to see how the planned alterations will solve the fundamental safety problem related to possible water ingress from cargo hold no 2 to the adjacent space in front of it. The AIBN therefore submits a safety recommendation for the shipping company in consultation with the NMA to ensure the watertight integrity of the bulkhead between the two sections.

2.6.4 Control of the contents of and compliance with the maintenance and safety management system

In some instances, positive feedback from the authorities after audits can in some cases be understood by the shipping companies as a confirmation that the safety management system works satisfactory on board and in the shipping company's organisation. The AIBN believes that this may lead to less awareness in the shipping company and among the crew in relation to their independent responsibility for ensuring that the system is actually complied with. The focus on continuous improvement of the system and ensuring shipboard safety may to some extent be replaced by a focus on getting the ISM audit over and done with and to obtain the necessary approvals and certificates.

The NMA has conducted ISM audits of the ships and onshore organisation without uncovering inadequate compliance with the safety management system. In addition to its own procedures, the NMA uses the IMO guidelines described in Res.A.1022(26) when planning and conducting audits. The supervisory authority's audits consist of document reviews in addition to random inspections and examination of focus areas based on previous audits and supervisory inspections, and the time frame and scope is limited. The AIBN believes that such audits are not always appropriate to establishing whether the safety management system is being complied with in the day-to-day operation of the ship, or whether the system is working satisfactorily in relation to improve shipboard safety. It is the shipping company that is responsible for ensuring safe practice in the operation of the ships, and the AIBN believes that in practice it may be difficult for anyone other than the shipping company and shipboard management to conduct a full assessment of whether the safety management system is being complied with.

The issues identified by the AIBN in this connection relating to control and compliance with safety management systems require more extensive investigations and documentation of how they are addressed by the authorities, classification society and shipping companies. Based on the limited scope of the investigation in this area, the AIBN has not pursued this issue any further in connection with the accident.

2.7 Accident chart

The AIBN has presented the most important elements and impact factors relating to the accident in an accident chart; see Figure 50. The areas in which the AIBN has decided to make recommendations are framed in red.

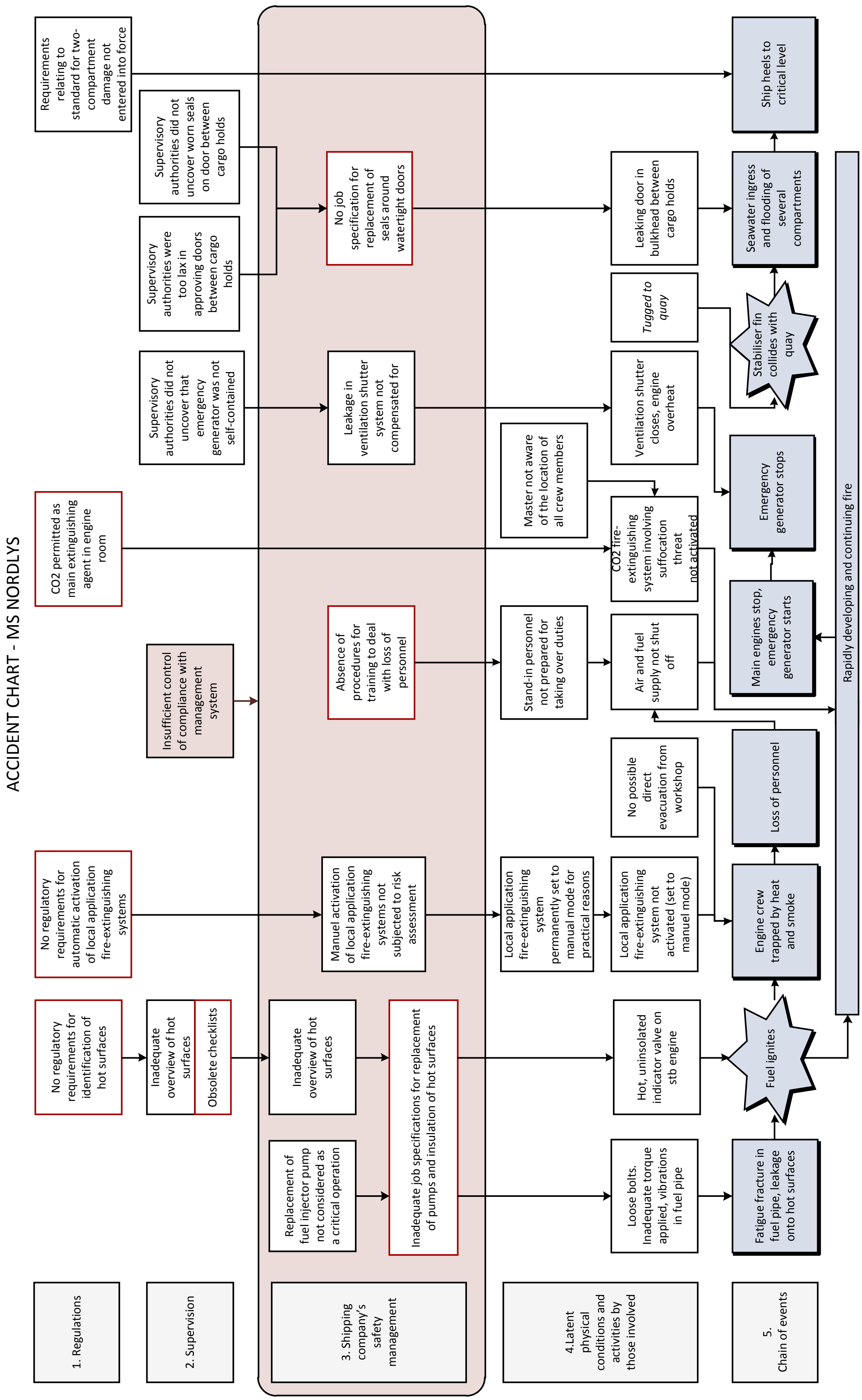


Figure 50: Accident chart of the most important elements of the accident. The areas in which the AIBN has decided to make safety recommendations are framed in red.

3. CONCLUSIONS

The AIBN sums up its investigation of the fire on board *Nordlys* on 15 September 2011 by drawing the following conclusions:

3.1 The start of the fire

- The AIBN's investigations have shown that there were fuel leakages at the starboard main engine and several un-insulated hot surfaces on the same engine. The fire probably started as a result of a diesel fuel leakage at fuel injector pump no 5 on the starboard main engine being ignited when it came into contact with an un-insulated indicator valve installed on the engine less than 30 cm from the leakage point.

3.2 The fuel leakages

- Investigations in the engine room after the fire showed breakages in both the feed pipe to and return pipe from fuel injector pump no 5 on the starboard main engine. Furthermore, all four fastening bolts for the fuel injector pump were found to be loose. Based on technical examinations, the breakages appear to be due to fatigue as a result of cyclical stresses.

- The pump in question had been replaced by the engine crew 12 days prior to the accident. According to the engine manufacturer's maintenance manual, the fasting bolts shall be tightened to 190 Nm using a torque key. The job specification in the shipping company's maintenance system did not provide any guidance on the procedure for replacing the fuel injector pump; nor did it contain any references to the manufacturer's maintenance manual or other documentation. The AIBN believes that the bolts had probably not been tightened in accordance with the specifications set out in the engine manufacturer's maintenance manual, as it has found no other plausible explanation of why all the bolts on this one pump were loose.

- Following the accident, the shipping company has introduced new procedures for inspection and re-tightening of fuel pipe connections.

3.3 Un-insulated hot surfaces

- The investigations following the fire on board *Nordlys* showed that a number of indicator valves had inadequate or no insulation. Such indicator valves can reach temperatures exceeding 300 °C. Measurements on board sister ships have also found a number of un-insulated hot surfaces, including on indicator valves and parts of the exhaust manifolds. Pursuant to both regulatory and class requirements, surfaces in the engine room that may reach temperatures exceeding 220 °C and that may come into contact with combustible liquids in the event of a leakage shall be insulated.

- *Nordlys* and the sister ships that were subject to inspection lacked a documented overview of the surfaces that were required to be insulated. The job specification in the shipping company's maintenance system provided no guidance to the crew on inspection and maintenance of the insulation; nor had the engine manufacturer prepared any such documentation.

- The NMA and DNV are both charged with conducting supervisory activities to ensure that the ships comply with the requirement for insulation of hot surfaces. They had elected to use somewhat different methods to follow this up, but common to them both was that they normally checked this when the ship was in port and the engines were cold. The absence of a documented overview of what surfaces require insulation places great demands on the competence and experience of the inspectors.

- The AIBN is of the opinion that neither the crew nor the shipping company or the supervisory authority have been able to contribute to ensuring that this important barrier against engine room fires was in place and working. To enable the requirement for insulation of hot surfaces to be followed up by all parties concerned, the AIBN believes that a requirement should be introduced for all vessels to have prepared an overview of the surfaces that must be insulated and to keep such documentation on board at all times.

- The requirement for all surfaces with temperatures exceeding 220 °C to be insulated was applicable to *Nordlys* with effect from 1 July 2003. Judging by the NMA's checklists, insulation of hot surfaces was not in focus in connection with any of that authority's surveys of *Nordlys* in 2003, 2005, 2006, 2008 and 2010. Insulation of hot surfaces was a topic during the survey in 2011, the most recent survey prior to the fire, but it was left to the shipping company to check the insulation through self-inspection. The AIBN submits a safety recommendation to the NMA for them to increase its focus on insulation of hot surfaces in connection with future inspections of passenger ships.

- After the accident, the shipping company has implemented measures in cooperation with the classification society to insulate and shield hot surfaces on main and auxiliary engines on all its ships.

3.4 Fire-extinguishing

- *Nordlys* was fitted out with a CO_2-based main fire-extinguishing system as well as a water-based local application fire-extinguishing system. The local application fire-extinguishing system was set to the manual mode when the fire started, and it was only activated some time after the fire had started to develop. Because of uncertainty about whether any persons were present in the engine room, the CO_2 system was not released.

- According to the shipping company's procedures, the local application fire-extinguishing system shall always be set to the automatic mode; on *Nordlys*, however, the system was permanently set to the manual mode without this having been reported to the shipping company and without any assessment having been made of potential consequences. Nor had adequate compensatory measures been put in place.

- The AIBN believes that the fire would probably have had a much less dramatic outcome had the water-based local application fire-extinguishing system been released automatically as soon as the fire started. By all accounts, the water would have protected the engineers who evacuated through the engine room against the flames and heat. At the same time, smoke particles would to some extent have bonded with the water, thus improving visibility and reducing the risk of smoke injuries. The evacuating engineers would probably have got out alive and with only minor injuries.

- The current regulations require that there is an option for immediate activation of a local application fire-extinguishing systems without prior evacuation or sealing of the room, but such applications are not required to be set to the automatic mode. The AIBN believes that the accident illustrates the need for an automatically activated fire-extinguishing system in the engine room, even when it is manned, and submits a safety recommendation to the NMA in that connection.

- Carbon dioxide is deadly, and preparations have to be made before it can be released. All crew must have been accounted for, or one must be willing to risk some people's lives in an effort to save the lives of others. Whether to release the CO_2 system is a serious decision that must be made by the vessel's master. The AIBN believes this puts unreasonable pressure on the master, and that this in turn can reduce the master's focus on other important tasks. Today, other extinguishing agents are available that do not give rise to such a dilemma. The AIBN therefore recommends that CO_2 be phased out as an extinguishing agent on vessels, and submits a safety recommendation to the NMA in that connection.

- After the accident, the shipping company has decided to install a new water-mist system as the main fire-extinguishing system. The existing CO_2 system will be retained as a back-up system.

3.5 Possibilities of evacuation from the engine room

- Two of the five crew members who were present in the engine room when the fire started died and two were seriously injured. The AIBN believes that there is a connection between the consequences of the fire and the possibilities of evacuation from the workshop. The three crew members that were present in the workshop would probably have got out alive and with minor injuries had the workshop had an emergency exit.

- The shipping company has established new escape routes on board *Nordlys* and *Kong Harald* from the workshop and incinerator room, respectively, after the accident. The same will be done on *Richard With* in autumn 2013.

3.6 Failure of the emergency generator

- The emergency generator on board *Nordlys* stopped after a short while and at a critical time when it was meant to ensure the ship's emergency functions. The emergency generator overheated because of accidental closing of the dampers that were meant to supply air to the emergency generator room for cooling and combustion. The design of the closing mechanism meant that the dampers depended on compressed air to open and stay open. The compressed air was produced by the air compressor, which in turn depended on power from the main switchboard.

- Prior to the fire, the crew on *Nordlys* had found that the air dampers were prone to close accidentally. The crew had therefore ordered parts in order to modify the arrangement. Effective temporary measures were not put in place to ensure the air supply in the event of an emergency situation. Nor was the shipping company's onshore organisation or the sister ships with the same design informed about this nonconformity.

- The AIBN believes that the underlying issue concerning accidental closing of the dampers during the fire on board *Nordlys* had to do with the fact that the dampers were in the closed position when they were not powered/energised. When the power/energy that was to open the dampers and keep them open failed, the dampers returned to the closed position. Furthermore, the AIBN takes the view that an unstable source of power was used. There would be no compensation for any pressure drop in the system as a consequence of e.g. a leakage, should the main switchboard fail and the compressor lose its power supply. In the AIBN's opinion, the arrangement was not in accordance with the regulations.

- Based on corresponding problems relating to the unintended closing of dampers when *Richard With* ran aground in 2009, the AIBN submitted two safety recommendations to the NMA relating to air damper arrangements in emergency generator rooms. After the accidents on *Nordlys* and *Richard With*, the NMA issued a safety notice relating to the emergency power system on *Richard With*. The safety notice stated that the damper arrangement on board was permitted pursuant to Norwegian regulations and DNV's rules, provided that a check valve was installed between the compressed air accumulator and the ordinary compressed air system. Such a modification had already been carried out and approved by DNV. The AIBN's opinion, the supervisory authority failed to see that the emergency power supply on board the ships in question still failed to satisfy the requirement for an independent source of emergency power.

- After the fire on *Nordlys*, the shipping company has replaced the compressed-air closing mechanism with an electric motor connected to the emergency switchboard on all its ships that have the same kind of arrangement as *Nordlys*.

- Together with DNV, the NMA has now reassessed the design principles and requirements for ventilation dampers in the emergency generator room. In that connection, it has concluded that the new electrical arrangement for opening/closing of dampers on board *Nordlys* and its sister ships is not sufficiently robust. The reason for this is that a single fault in the power supply to the damper motor, such as a loose terminal or a broken cable, is enough to cause the dampers to close. Such dampers must be open for the emergency generator to work, and in the event of a fault in the damper motor, they should remain open if open and, if closed, they should open automatically when a fault occurs. According to the NMA, this interpretation is in accordance with current regulatory requirements.

- Given that the supervisory authority is reconsidering the problem, the AIBN will not issue any new safety recommendations relating to the air damper arrangement for the emergency generator room, but refers to the safety recommendations that were submitted after the grounding of *Richard With* in 2009.

3.7 Stability and watertight integrity

- When *Nordlys* was berthed during the fire, the stabiliser fins remained extended. When coming up against the quay, the ship's side was penetrated by the starboard fin and the hull damage led to water ingress in cargo hold no 2. Initially, this was not dramatic, as *Nordlys* was designed to withstand such damage. However, the water also ingressed to cargo hold no 1, probably through an opening in connection with the watertight door between the cargo holds. The door was not watertight due to a worn seal along the underside of the door. *Nordlys* was not designed to withstand such a two-compartment damage. It took quite some time to locate and temporarily repair the hull damage, and to establish sufficient pumping capacity. The situation escalated and became critical in that *Nordlys* was close to capsizing alongside the quay.

- As a consequence of amendments to Council Directive 98/18/EC, a prohibition on openings with doors in watertight bulkheads between cargo holds was introduced in March 2000. In the case of *Nordlys*, this prohibition entered into force on 1 July 2010. As a consequence of the amendments to the EU Directive, requirements were also introduced for stability with water flooded car deck and two-compartment damage on board existing ro-ro passenger ships. In the case of *Nordlys*, the requirement for stability with water-flooded car deck became applicable on 1 October 2010. The requirement for stability with two-compartment damage will become applicable in 2014.

- In addition to informing the industry of the new requirements through a circular, the NMA explicitly informed Hurtigruten ASA by a letter of 23 June 2009. Despite this, the door in the bulkhead between the cargo holds on *Nordlys* had not been removed on the date of the accident. The NMA has been involved in the shipping company's process to find overall solutions that meet the new requirements, and the AIBN takes the view that the NMA has been too lax in following up the – in safety terms – important prohibition on doors between cargo holds.

- Following the accident, the shipping company decided to have dry tanks built around the stabiliser fins on ships that are arranged in the same way as *Nordlys*. This has been done on *Nordlys* and *Richard With.* The alteration will be carried out on the other ships during the next yard stay. This will provide additional safety to prevent similar incidents with the shipping company's vessels in future.

- After the accident, the shipping company found a solution whereby alteration work will be carried out on board *Nordlys*, to move the forward cargo hold up to deck 1 and use the original cargo hold no 1 as a provisions store. This means that the prohibition on the opening in this bulkhead will no longer apply, and the shipping company has thus obtained the NMA's acceptance for retaining the door in question. The AIBN finds it difficult to see how the planned alterations will solve the fundamental safety problem related to possible water ingress from cargo hold no 2 to the adjacent forward space. The AIBN therefore submits a safety recommendation to the shipping company to ensure watertight integrity in the bulkhead between the two compartments.

3.8 The contents of and compliance with the safety management system

- When the fire broke out, there were a number of actions that were not taken, including shutting off the air and fuel supply. The AIBN's investigation has shown that several of these actions were normally the responsibility of crew members who were put out of action by the fire. The shipping company had defined who should take over their roles and duties in such a situation, but no specific training had been carried out for such an event, nor had such roles and duties been followed up in connection with the accident. These are circumstances that may also apply to the other ships in the fleet, and the AIBN recommends that the shipping company incorporate and address issues relating to training in the execution of safety-critical tasks in the event of loss of key personnel when reviewing the procedures for shipboard drills and training.

- The safety management system sets out clear requirements for the maintenance system to include good job specifications that provide sufficient guidance for the crew, and for the reported job history to be meaningful and describe the job that was done in sufficient detail. The job specifications in the maintenance system have proved to be of a much poorer standard than prescribed by the safety management system. Relevant examples of this in connection with the accident are the job specifications for replacement of fuel pumps, for inspection of hot surfaces and for maintenance of watertight doors. Nor is the standard of the entered job history in accordance with the requirements of the safety management system, something that the ship's management and onshore organisation have failed to point out.

- The investigation has shown that *Nordlys* had a local application fire-extinguishing system that was permanently set to the manual mode, despite the fact that the safety management system explicitly required it to be set to the automatic mode. This was one of several nonconformities that were not reported to the shipping company. In addition to the unintended closing of the air dampers for the emergency generator, the removal of the plates covering the fuel injector pumps on the main engines is another nonconformity that probably had an impact on the event.

- It is the shipping company that is responsible for ensuring safe practice in the operation of the ships, and the AIBN believes that it is difficult for anyone other than the shipping company and shipboard management to conduct a full assessment of whether the safety management system is being complied with.

- As part of the effort to ensure that the shipping company's ships learn from each other's audits/nonconformities, the reporting system was made more transparent in summer 2012 in that all ships were given access to view audit reports from the other ships and thus access to all reported nonconformities. The shipping company has also focused on attitudes and challenges related to the crew's compliance with procedures, through organising management development programmes and officers' conferences. Following the accident, Hurtigruten ASA has initiated cooperation with the University of Bergen to map the safety culture on board the shipping company's ships.

3.9 The NMA's supervisory regime

- The NMA's checklists for renewal surveys (PSF) and annual inspections (PSÅ) of passenger ships had not been updated in accordance with applicable regulations. This may have contributed to inadequate control of compliance with important safety requirements.

- The NMA uses the IMO guidelines described in Res.A.1022(26) when planning and conducting ISM audits. The supervisory authority's audits consist of document reviews in addition to random inspections and examination of focus areas based on previous audits and supervisory activities. In the AIBN's opinion, such audits can be very appropriate to verifying whether the safety management system is in accordance with the regulations.

  Audits carried out by either the flag state or the classification society have a limited time frame and scope. The AIBN believes that this can sometimes reduce the possibility of finding out whether the safety management system is being complied with in the day-to-day operation of the ship, and whether the system is working satisfactorily in relation to improving safety.

4. SAFETY RECOMMENDATIONS

The investigation of this marine accident has identified the following areas in which the AIBN deems it necessary to submit safety recommendations for the purpose of improving safety at sea.[42]

Safety recommendation MARINE No 2013/03T

The AIBN's investigation of the fire on board *Nordlys* shows that un-insulated hot surfaces were a contributory factor to the fire starting. Explicit requirements for insulation of surfaces with temperatures exceeding 220 °C became applicable to *Nordlys* and its sister ships on 1 July 2003, but the lack of an overview of surfaces that might exceed 220 °C helps to explain why both *Nordlys* and its two sister ships had several un-insulated surfaces in the engine room.

The AIBN recommends that the Norwegian Maritime Authority propose a requirement for all ships to have prepared an overview of surfaces that must be insulated and to keep such documentation on board at all times.

Safety recommendation MARINE No 2013/04T

The AIBN's investigation of the fire on board *Nordlys* shows that un-insulated hot surfaces were a contributory factor to the fire starting. The explicit requirement for all surfaces with temperatures exceeding 220 °C to be insulated was applicable to *Nordlys* with effect from 1 July 2003. Judging by the Norwegian Maritime Authority's checklists, insulation of hot surfaces was not in focus in connection with any of that authority's surveys of *Nordlys* in 2003, 2005, 2006, 2008 and 2010. Insulation of hot surfaces was a topic during the survey in 2011, the most recent survey prior to the fire, but the inspection was carried out by the shipping company as self-inspection.

The AIBN recommends that the Norwegian Maritime Authority increase its focus on insulation of hot surfaces in connection with inspections of passenger ships.

Safety recommendation MARINE No 2013/05T

Manual release of local application fire-extinguishing systems is permitted in manned engine rooms pursuant to national and international provisions, despite the fact that the length of time that passes before it is released may be decisive for the outcome of the fire. The fire on board *Nordlys* illustrates clearly that, even if the engine room is manned, automatic release of the fire-extinguishing system may be very important, not least to protect any crew that is present in the engine room.

The AIBN recommends that the Norwegian Maritime Authority propose requirements for automatic release of local application fire-extinguishing systems in engine rooms, regardless of whether or not the engine room is manned.

Safety recommendation MARINE No 2013/06T

The use of CO_2 as an extinguishing agent is permitted on ships pursuant to national and international provisions, even though the activation of a CO_2 extinguishing system can

[42] The investigation report is submitted to the Ministry of Trade and Industry, which takes necessary measures to ensure that due consideration is given to the safety recommendations.

create a life-threatening atmosphere for anyone who is present in the room where it is released. As a consequence, the fire-extinguishing system may be activated too late or not at all if the situation is unclear, or it may be activated and constitute a threat to human life.

The AIBN recommends that the Norwegian Maritime Authority propose prohibiting the use of extinguishing agents that may threaten the lives of people on board ships.

Safety recommendation MARINE No 2013/07T

The AIBN's investigation of the fire on board *Nordlys* found inadequacies in the job specifications in Hurtigruten ASA's maintenance system. Insufficient job specifications for replacement of fuel injector pumps, insulation of hot surfaces and maintenance of watertight doors were important organisational factors that help to explain why the fire started and had such serious consequences.

The AIBN recommends that Hurtigruten ASA revise its maintenance system so that the job specifications provide the crew with sufficient support for correct execution of the work.

Safety recommendation MARINE No 2013/08T

When the fire on board *Nordlys* started, crew members with key functions were put out of action. Stand-ins had been appointed, but no drills had been organised simulating loss of personnel and the assumption of new roles. As a consequence, several safety-critical tasks were not attended to in connection with the fire.

The AIBN recommends that Hurtigruten ASA prepare procedures for training in the loss of key personnel and implement training in this area on board its ships.

Safety recommendation MARINE No 2013/09T

In connection with the berthing of *Nordlys* during the fire, damage to the hull led to water ingress to cargo hold no 2. However, the water also ingressed to cargo hold no 1, probably through an opening in connection with the watertight door between the cargo holds. *Nordlys* was not designed to withstand such two-compartment damage and came close to capsizing as a consequence of the flooding.

The AIBN recommends that the shipping company consult with the Norwegian Maritime Authority and implement measures to ensure the watertight integrity of the bulkhead in question.

Accident Investigation Board Norway

Lillestrøm, 13 May 2013

APPENDICES

Appendix A:	Relevant abbreviations
Appendix B:	The alarm log
Appendix C:	List of equipment supplied with power from the emergency switchboard
Appendix D:	Report from the examination of fuel pipes, lube oil pipes, drainage valves and bolts
Appendix E:	Report from the examination of fuel injector pump no 5.
Appendix F:	Report from the examination of the starboard engine block
Annex G:	Report from temperature measurements on board *Richard With*
Annex H:	Report from overhaul of emergency generator
Annex I:	Report on stability after damage

APPENDIX A: RELEVANT ABBREVIATIONS

WEHS	:	Working environment, health and safety
BHP	:	Brake horsepower
CMC	:	Certification of Machinery Component
DNV	:	Det Norske Veritas
DG	:	Diesel generator engine (auxiliary engine)
DOC	:	Document of Compliance
ERFA	:	Experience
G	:	Shaft generator
HSE	:	Health, safety and the environment
IMO	:	International Maritime Organisation
ISM	:	International Safety Management
KW	:	Kilowatt
ME	:	Main engine
NB	:	Newbuild
NHD	:	Ministry of Trade and Industry
NIS	:	Norwegian International Ship Register
NMA	:	Norwegian Maritime Authority
MSC	:	Maritime Safety Committee
PA	:	Public address
AIBN	:	Accident Investigation Board Norway
SiO	:	Ships in Operation
SMC	:	Safety Management Certificate
SMS	:	Safety Management System
SSQM System	:	Safety, Security and Quality Management System
TH	:	Thruster
TMO	:	Technical Maritime Operation

APPENDIX B ENGINE ROOM ALARM LOG

Comments:

- The table shows the alarms that went off within approximately nine minutes after the fire started
- The times have been corrected for set delays at the most recent system backup, i.e. on 5 September 2011

Date:	Adjusted time	Alarm ID	Alarm text	Function	Alarm	Status:
15.09.2011	09:12:35	PP065	GROUND FAILURE BUS BARS	XA	OPEN	ALARM
15.09.2011	09:12:39	FO011	ME2 FO INLET ENGINE	TK	IFL	ALARM
15.09.2011	09:12:47	FO001	ME1 FO INLET ENGINE	PAL	LOW	ALARM
15.09.2011	09:12:50	BP012	ME2 EXH GAS BOILER FAILURE	XA	OPEN	ALARM
15.09.2011	09:13:24	HFO PRE 1	HFO PRE BOOSTER PUMP1 FOR ENGINE	PCU1/19	STBY START	ALARM
15.09.2011	09:13:27	SL080	CPP2 GRAVITY TK	LAL	LOW	ALARM
15.09.2011	09:13:32	CA018	EMCY GEN STARTING AIR INLET	PAL	OPEN	ALARM
15.09.2011	09:13:32	FO054	EMCY GEN DAILY SERVICE TK	LAL	OPEN	ALARM
15.09.2011	09:13:34	EG033	ME2 CHARGING AIR ENGINE INLET	PI	IFH	ALARM
15.09.2011	09:13:39	FO001	ME1 FO INLET ENGINE	PAL	LOW	RETURN
15.09.2011	09:13:41	BP012	ME2 EXH GAS BOILER FAILURE	XA	OPEN	RETURN
15.09.2011	09:13:43	PP031	EMCY GEN BATTERY CHARGER H/L		OPEN	ALARM
15.09.2011	09:13:46	COMERR 27	SAU 8 MCU 2		OPEN	ALARM
15.09.2011	09:13:47	PP030	EMCY GEN FALSE START	XA	OPEN	ALARM
15.09.2011	09:13:48	MI048	MAN IN REFRIGER. STORE (R.0403)	XA	OPEN	ALARM
15.09.2011	09:13:48	MI051	SUBSTATION PIPE ESCORT HEAT.FAIL	XA	OPEN	ALARM
15.09.2011	09:13:49	SL080	CPP2 GRAVITY TK	LAL	OPEN	RETURN
15.09.2011	09:13:51	COMERR 8	SAU 8 MCU 1		OPEN	ALARM
15.09.2011	09:13:52	CW016	ME2 FW LT CIRCUIT INLET COOLER	PAL	OPEN	ALARM
15.09.2011	09:13:52	CW017	ME2 FW HT CIRCUIT INLET ENGINE	TIAL	IFH	ALARM
15.09.2011	09:13:52	CW018	ME2 FW HT CIRCUIT OUTLET ENGINE	TIRAH	IFL	ALARM
15.09.2011	09:13:52	ME024	ME2 SPEED	SI	IFL	ALARM
15.09.2011	09:13:52	ME025	ME2 TC SPEED x10	SI	IFL	ALARM
15.09.2011	09:13:53	ME028	ME2 SAFETY CIRCUIT VOLTAGE	XA	OPEN	ALARM
15.09.2011	09:13:54	HT-FWCP1 2	HT-FRESH WATER COOLING PUMP1 ME2	PCU1/21	NO-STB	ALARM
15.09.2011	09:13:54	SY100	IO/FUSE FAIL PCU NO 1	PCU1/126	OPEN	ALARM
15.09.2011	09:13:54	SY200	IO/FUSE FAIL PCU NO 2	PCU2/126	OPEN	ALARM
15.09.2011	09:13:55	ME024	ME2 SPEED	SI	IFH	ALARM
15.09.2011	09:13:57	ME035	ME2 RPM SWITCH FAILURE	XA	OPEN	ALARM
15.09.2011	09:13:57	GCU 229	AE2 LINE FREQUENCY	XI	LOW	ALARM
15.09.2011	09:13:58	AC-2-2-1F	FROST ALARM	PCU6/38	OPEN	ALARM
15.09.2011	09:13:58	ME202	ME2 LO PRESS LOW - SHD	XA	CLOSED	ALARM
15.09.2011	09:13:58	ME206	ME2 FW PRESS LOW - SLD	XA	IFL	ALARM

15.09.2011	09:13:58	PMU 201	SG2 SHUT DOWN	XA	CLOSED	ALARM
15.09.2011	09:13:59	CW012	ME2 FW HT CIRCUIT INLET ENGINE	PIRAL	LOW	ALARM
15.09.2011	09:14:00	AC-2-3-5F	FROST ALARM	PCU6/40	OPEN	ALARM
15.09.2011	09:14:00	AC-3-7-1F	FROST ALARM	PCU7/38	OPEN	ALARM
15.09.2011	09:14:00	AP-2-3-9F	FROST ALARM	PCU6/42	OPEN	ALARM
15.09.2011	09:14:00	AP-3-5-4F	FROST ALARM	PCU7/37	OPEN	ALARM
15.09.2011	09:14:00	AT-2-3-11F	FROST ALARM	PCU6/47	OPEN	ALARM
15.09.2011	09:14:00	AT-3-6-10F	FROST ALARM	PCU7/41	OPEN	ALARM
15.09.2011	09:14:00	AT-3-6-10S	WARM F.W.CIRC.PUMP FOR AC PUMP 2	PCU7/48	NO-STB	ALARM
15.09.2011	09:14:00	GR-II-2-1S	SMOKE ALARM	PCU6/39	OPEN	ALARM
15.09.2011	09:14:00	GR-II-3-1S	SMOKE ALARM	PCU6/41	OPEN	ALARM
15.09.2011	09:14:00	GR-II-3-2S	SMOKE ALARM	PCU6/43	OPEN	ALARM
15.09.2011	09:14:00	GR-II-3-3S	SMOKE ALARM	PCU6/44	OPEN	ALARM
15.09.2011	09:14:00	GR-III5-1S	SMOKE ALARM	PCU7/54	OPEN	ALARM
15.09.2011	09:14:00	GR-III6-2S	SMOKE ALARM	PCU7/50	OPEN	ALARM
15.09.2011	09:14:00	GR-III7-1S	SMOKE ALARM	PCU7/51	OPEN	ALARM
15.09.2011	09:14:00	LO026	ME2 LO LAST BEARING	PIRAL	IFH	ALARM
15.09.2011	09:14:00	ME041	ME2 SLOW DOWN	XA	OPEN	ALARM
15.09.2011	09:14:00	ME040	ME2 SHUT DOWN	XA	OPEN	ALARM
15.09.2011	09:14:00	MI046	MAN IN REFRIGER. STORE (R.0401)	XA	OPEN	ALARM
15.09.2011	09:14:00	PMU 202	SG2 SLOW DOWN	XA	CLOSED	ALARM
15.09.2011	09:14:00	GCU 232	AE2 LINE VOLTAGE	XI	LOW	ALARM
15.09.2011	09:14:01	EG016	ME1 TEMP CONTROLLER CA FAILURE	XA	OPEN	ALARM
15.09.2011	09:14:01	EG036	ME2 TEMP CONTROLLER CA FAILURE	XA	OPEN	ALARM
15.09.2011	09:14:01	PP060	VOLT FAIL MSB 660 V	XA	OPEN	ALARM
15.09.2011	09:14:02	ME HFOBO 1	HFO BOOSTER PUMP 1 FOR ME	PCU1/23	STBY START	ALARM
15.09.2011	09:14:02	ME NOZOIL1	NOZZLE OIL PUMP1 FOR ME 1 AND 2	PCU1/24	STBY START	ALARM
15.09.2011	09:14:02	ME024	ME2 SPEED	SI	IFH	RETURN
15.09.2011	09:14:02	ME025	ME2 TC SPEED x10	SI	IFL	RETURN
15.09.2011	09:14:02	CW006	ME1 FW LT CIRCUIT INLET COOLER	PAL	OPEN	ALARM
15.09.2011	09:14:02	CW010	ME1 HT CIRCUIT CONTROLLER FAIL	XA	OPEN	ALARM
15.09.2011	09:14:02	LO021	ME1 PUMP CONTROL CYL.LO FAILURE	XA	OPEN	ALARM
15.09.2011	09:14:02	LO022	ME1 LO TEMP CONTROLLER FAILURE	XA	OPEN	ALARM
15.09.2011	09:14:02	MI012	FIN STABILIZER, SWITCH-OFF SB	XA	OPEN	ALARM
15.09.2011	09:14:02	MI013	FIN STABILIZ.,FINS NOT RETRACTED	XA	OPEN	ALARM
15.09.2011	09:14:02	PP062	VOLT FAIL MSB 380 V BUS BAR 2.2	XA	OPEN	ALARM
15.09.2011	09:14:02	PP064	VOLT FAIL MSB 220 V BUS BAR 3.2	XA	OPEN	ALARM
15.09.2011	09:14:03	ME024	ME2 SPEED	SI	IFH	ALARM
15.09.2011	09:14:03	ME037	ME2 EL. SPEED CONTROLLER FAIL	XA	OPEN	ALARM
15.09.2011	09:14:05	FO028	ME FO AUTO FILTER	PDAH	OPEN	ALARM
15.09.2011	09:14:05	MI036	STEERING GEARS FAILURE	XA	OPEN	ALARM
15.09.2011	09:14:05	FO088	HFO SEPARATOR 2 FAILURE	XA	OPEN	ALARM
15.09.2011	09:14:07	COMERR 31	SAU 12 MCU 2		OPEN	ALARM
15.09.2011	09:14:08	MI026	24 V POWER SUPPLY 1 (90 A) FAIL	XA	OPEN	ALARM
15.09.2011	09:14:08	MI027	24 V POWER SUPPLY 2 (60 A) FAIL	XA	OPEN	ALARM

15.09.2011	09:14:08	SL101	CPP1, TRANSMITTER FAIL ALARM	XA	OPEN	ALARM
15.09.2011	09:14:08	SL107	CPP2, TRANSMITTER FAIL ALARM	XA	OPEN	ALARM
15.09.2011	09:14:13	COMERR 20	SAU 1 MCU 2		OPEN	ALARM
15.09.2011	09:14:14	ME205	ME2 OIL MIST CONCENT HIGH - SLD	XA	CLOSED	ALARM
15.09.2011	09:14:14	COMERR 21	SAU 2 MCU 2		OPEN	ALARM
15.09.2011	09:14:14	COMERR 22	SAU 3 MCU 2		OPEN	ALARM
15.09.2011	09:14:14	COMERR 23	SAU 4 MCU 2		OPEN	ALARM
15.09.2011	09:14:14	COMERR 24	SAU 5 MCU 2		OPEN	ALARM
15.09.2011	09:14:14	COMERR 26	SAU 7 MCU 2		OPEN	ALARM
15.09.2011	09:14:14	COMERR 28	SAU 9 MCU 2		OPEN	ALARM
15.09.2011	09:14:15	GCU 229	AE2 LINE FREQUENCY	XI	LOW	RETURN
15.09.2011	09:14:15	COMERR 7	SAU 7 MCU 1		OPEN	ALARM
15.09.2011	09:14:15	COMERR 9	SAU 9 MCU 1		OPEN	ALARM
15.09.2011	09:14:15	COMERR 10	SAU 10 MCU 1		OPEN	ALARM
15.09.2011	09:14:15	COMERR 11	SAU 11 MCU 1		OPEN	ALARM
15.09.2011	09:14:15	COMERR 12	SAU 12 MCU 1		OPEN	ALARM
15.09.2011	09:14:15	COMERR 14	LGU 1 MCU 1		OPEN	ALARM
15.09.2011	09:14:15	COMERR 15	LGU 2 MCU 1		OPEN	ALARM
15.09.2011	09:14:15	COMERR 16	PCU 1 MCU 1		OPEN	ALARM
15.09.2011	09:14:15	COMERR 17	PCU 2 MCU 1		OPEN	ALARM
15.09.2011	09:14:15	COMERR 18	PCU 3 MCU 1		OPEN	ALARM
15.09.2011	09:14:15	COMERR 25	SAU 6 MCU 2		OPEN	ALARM
15.09.2011	09:14:15	COMERR 13	SAU 13 MCU 1		OPEN	ALARM
15.09.2011	09:14:17	AC-2-2-1F	FROST ALARM	PCU 6/38	OPEN	RETURN
15.09.2011	09:14:17	AC-2-3-5F	FROST ALARM	PCU 6/40	OPEN	RETURN
15.09.2011	09:14:17	AP-2-3-9F	FROST ALARM	PCU 6/42	OPEN	RETURN
15.09.2011	09:14:17	AT-2-3-11F	FROST ALARM	PCU 6/47	OPEN	OPEN
15.09.2011	09:14:17	AT-3-6-10S	WARM F.W.CIRC.PUMP FOR AC PUMP 2	PCU 7/48	NO-STB	OPEN
15.09.2011	09:14:17	GR-II-2-1S	SMOKE ALARM	PCU 6/39	OPEN	RETURN
15.09.2011	09:14:17	GR-II-3-1S	SMOKE ALARM	PCU 6/41	OPEN	RETURN
15.09.2011	09:14:17	GR-II-3-3S	SMOKE ALARM	PCU 6/44	OPEN	RETURN
15.09.2011	09:14:17	COMERR 1	SAU 1 MCU 1		OPEN	ALARM
15.09.2011	09:14:17	COMERR 29	SAU 10 MCU 2		OPEN	ALARM
15.09.2011	09:14:17	COMERR 3	SAU 3 MCU 1		OPEN	ALARM
15.09.2011	09:14:17	COMERR 30	SAU 11 MCU 2		OPEN	ALARM
15.09.2011	09:14:17	COMERR 32	SAU 13 MCU 2		OPEN	ALARM
15.09.2011	09:14:17	COMERR 4	SAU 4 MCU 1		OPEN	ALARM
15.09.2011	09:14:17	COMERR 5	SAU 5 MCU 1		OPEN	ALARM
15.09.2011	09:14:17	COMERR 6	SAU 6 MCU 1		OPEN	ALARM
15.09.2011	09:14:18	GCU 232	AE2 LINE VOLTAGE	XI	LOW	RETURN
15.09.2011	09:14:18	COMERR 33	LGU 1 MCU 2		OPEN	ALARM
15.09.2011	09:14:18	COMERR 34	LGU 2 MCU 2		OPEN	ALARM
15.09.2011	09:14:18	COMERR 35	PCU 1 MCU 2		OPEN	ALARM
15.09.2011	09:14:18	COMERR 36	PCU 2 MCU 2		OPEN	ALARM
15.09.2011	09:14:19	COMERR 37	PCU 3 MCU 2		OPEN	ALARM

15.09.2011	09:14:25	ME206	ME2 FW PRESS LOW - SLD	XA	IFL	RETURN
15.09.2011	09:14:25	ME205	ME2 FW TEMP HIGH - SLD	XA	BROKEN	ALARM
15.09.2011	09:14:25	ME206	ME2 FW PRESS LOW - SLD	XA	CLOSED	ALARM
15.09.2011	09:14:33	ME205	ME2 FW TEMP HIGH - SLD	XA	BROKEN	RETURN
15.09.2011	09:14:34	ME205	ME2 FW TEMP HIGH - SLD	XA	CLOSED	ALARM
15.09.2011	09:14:34	ME208	ME2 LO PRESS LOW - SLD	XA	CLOSED	ALARM
15.09.2011	09:14:37	RF015	CARGO HOLDS.COMP.PROV.PL.AL.	D0659	CLOSED	ALARM
15.09.2011	09:14:37	RF029	A/C PLANT COMP.2 ALARM	D0758	CLOSED	ALARM
15.09.2011	09:14:40	AP-3-6-6F	FROST ALARM	PCU 7/39	OPEN	ALARM
15.09.2011	09:14:40	GR-III5-2S	SMOKE ALARM	PCU 7/53	OPEN	ALARM
15.09.2011	09:14:40	GR-III6-1S	SMOKE ALARM	PCU 7/49	OPEN	ALARM
15.09.2011	09:14:40	SH-3-5-8F	FROST ALARM	PCU 7/43	OPEN	ALARM
15.09.2011	09:14:40	ME202	ME2 LO PRESS LOW - SHD	XA	IFL	ALARM
15.09.2011	09:14:40	ME206	ME2 FW PRESS LOW - SLD	XA	IFL	ALARM
15.09.2011	09:14:51	GR-II-3-2S	SMOKE ALARM	PCU 6/43	OPEN	RETURN
15.09.2011	09:14:54	PMU 212	SG2 OPERATION INTERLOCKED	XI	CLOSED	ALARM
15.09.2011	09:15:08	ME202	ME2 LO PRESS LOW - SHD	XA	SHORT	ALARM
15.09.2011	09:15:08	ME205	ME2 FW TEMP HIGH - SLD	XA	BROKEN	ALARM
15.09.2011	09:15:11	ME202	ME2 LO PRESS LOW - SHD	XA	IFL	ALARM
15.09.2011	09:15:33	ME202	ME2 LO PRESS LOW - SHD	XA	SHORT	ALARM
15.09.2011	09:15:38	ME205	ME2 FW TEMP HIGH - SLD	XA	BROKEN	RETURN
15.09.2011	09:15:42	RF015	CARGO HOLDS.COMP.PROV.PL.AL.	D0659	CLOSED	RETURN
15.09.2011	09:15:42	ME202	ME2 LO PRESS LOW - SHD	XA	IFL	ALARM
15.09.2011	09:15:48	ME205	ME2 FW TEMP HIGH - SLD	XA	CLOSED	ALARM
15.09.2011	09:16:34	GCU 228	AE2 FREQUENCY	XI	LOW	ALARM
15.09.2011	09:16:34	GCU 229	AE2 LINE FREQUENCY	XI	LOW	ALARM
15.09.2011	09:16:37	GCU 231	AE2 VOLTAGE	XI	LOW	ALARM
15.09.2011	09:16:37	GCU 232	AE2 LINE VOLTAGE	XI	LOW	ALARM
15.09.2011	09:16:39	GR-II-3-2S	SMOKE ALARM	PCU6/43	OPEN	ALARM
15.09.2011	09:16:48	ME205	ME2 FW TEMP HIGH - SLD	XA	BROKEN	ALARM
15.09.2011	09:16:54	ME204	GEAR LO PRESS LOW - SHD	XA	CLOSED	ALARM
15.09.2011	09:17:01	ME208	ME2 LO PRESS LOW - SLD	XA	SHORT	ALARM
15.09.2011	09:17:08	COMERR 19	EXT 1 MCU 1 KVAERNER FRIGO		OPEN	ALARM
15.09.2011	09:17:12	GCU 209	AE2 ERROR MESSAGE	XI	HIGH	ALARM
15.09.2011	09:17:13	AC-2-2-1F	FROST ALARM	PCU6/38	OPEN	ALARM
15.09.2011	09:17:13	AC-2-3-5F	FROST ALARM	PCU6/40	OPEN	ALARM
15.09.2011	09:17:13	AP-2-3-9F	FROST ALARM	PCU6/42	OPEN	ALARM
15.09.2011	09:17:13	AT-2-3-11F	FROST ALARM	PCU6/47	OPEN	ALARM
15.09.2011	09:17:13	GR-II-2-1S	SMOKE ALARM	PCU6/39	OPEN	ALARM
15.09.2011	09:17:13	GR-II-3-1S	SMOKE ALARM	PCU6/41	OPEN	ALARM
15.09.2011	09:17:13	GR-II-3-3S	SMOKE ALARM	PCU6/44	OPEN	ALARM
15.09.2011	09:17:13	AT-3-6-10S	WARM F.W.CIRC.PUMP FOR AC PUMP 2	PCU7/48	NO-STB	ALARM
15.09.2011	09:17:45	COMERR 46	PCU 6 MCU 4		OPEN	ALARM
15.09.2011	09:17:55	ME208	ME2 LO PRESS LOW - SLD	XA	IFL	ALARM
15.09.2011	09:18:09	AC-3-7-1F	FROST ALARM	PCU7/38	OPEN	RETURN

15.09.2011	09:18:09	AP-3-5-4F	FROST ALARM	PCU7/37	OPEN	RETURN
15.09.2011	09:18:09	AP-3-6-6F	FROST ALARM	PCU7/39	OPEN	RETURN
15.09.2011	09:18:09	AT-3-6-10F	FROST ALARM	PCU7/41	OPEN	RETURN
15.09.2011	09:18:09	SH-3-5-8F	FROST ALARM	PCU7/43	OPEN	RETURN
15.09.2011	09:18:09	SY700	IO/FUSE FAIL PCU NO 7	PCU7/126	OPEN	ALARM
15.09.2011	09:19:08	ME207	ME2 LO TEMP HIGH -SLD	XA	SHORT	ALARM
15.09.2011	09:19:17	ME105	ME1 FW TEMP HIGH -SLD	XA	CLOSED	ALARM
15.09.2011	09:19:19	PMU 102	SG1 SLOW DOWN	XA	CLOSED	ALARM
15.09.2011	09:19:33	ME207	ME2 LO TEMP HIGH -SLD	XA	SHORT	RETURN
15.09.2011	09:19:38	ME205	ME2 FW TEMP HIGH - SLD	XA	BROKEN	RETURN
15.09.2011	09:19:39	ME205	ME2 FW TEMP HIGH - SLD	XA	CLOSED	ALARM
15.09.2011	09:19:49	ME207	ME2 LO TEMP HIGH -SLD	XA	SHORT	ALARM
15.09.2011	09:20:10	ME207	ME2 LO TEMP HIGH -SLD	XA	SHORT	RETURN
15.09.2011	09:20:14	ME207	ME2 LO TEMP HIGH -SLD	XA	SHORT	ALARM
15.09.2011	09:20:32	ME205	ME2 FW TEMP HIGH - SLD	XA	CLOSED	RETURN
15.09.2011	09:20:42	COMERR 53	CAB20 MESS ROOM		OPEN	ALARM
15.09.2011	09:20:44	PMU 201	SG2 SHUT DOWN	XA	CLOSED	RETURN
15.09.2011	09:20:44	PMU 202	SG2 SLOW DOWN	XA	CLOSED	RETURN
15.09.2011	09:21:12	GR-1-3-2S	SMOKE ALARM	PCU4/55	OPEN	ALARM

APPENDIX C: LIST OF EQUIPMENT SUPPLIED WITH POWER FROM THE EMERGENCY SWITCHBOARD

380V Emergency swichboard

Load transferred to 380v MSWBD

Consumer
Q201-CHARGER FOR EMERGENCY DIESEL GEN.
Q202-Hydraulic power pack 1 for remote valves
Q203-Hydraulic power pack 2 for remote valves
Q204-FIN STABILIZER 1
Q205-FIN STABILIZER 2
Q206-CONT.CONSOLE FOR FIN STABILIZERS
Q207-AIR COND.DISTR.BOARD 2,FANS FOR STAIRWAY
Q208-AIR COND.DISTR.BOARD 3,FANS FOR STAIRWAY
Q209-PWS,NAUTIC CONS,AND AUTOMATION SYSTEM
Q210-POWER SUPPLY UNIT GENERAL 24V
Q211-Steering gear No.1
Q212-Steering gear No.2
Q213-SPARE
Q214-SPARE
Q215-TYFONS
Q216-TRANSFORMER 380/220V OPERATING ROOM
Q217-FAN DISTR.BOARD 1.1 FAN S53.1 ENG ROOM
Q218-Spare
Q219-Spare
Q220-Spare
Q221-PASSENGER LIFT AFT
Q222-PASSENGER LIFT AHEAD
Q223-SERVICE LIFT
Q224-HYDR.UNIT PASSENGER DOORS/GANGWAY
Q225-AIR COND DISTR.BOARD 1,FANS FOR STAIRWAY
Q226-FAN DISTR.BOARD 1,FAN 255.1 ENGINEROOM
Q227-Fire Water pump,supply 2 / Punktslokking
Q228-Spraying pump for car deck,supply 2
Q229-TO EMERGENCY TRANSFORMER 380/220V
Q001-FROM EMERGENCY GENERATOR
K010-FROM MAIN SW.BOARD 380V,BUSBAR 2.1
Q301-BILGE PUMP
Q302-STARTING AIR COMPRESSOR 2
Q303-BILGE PUMP PISTON TYPE

Q304-EMERGENCY FIRE FIGTHING PUMP
Q305-FILLING PUMP FOR EMERG.DIESEL AND LIFE BOATS
Q306-PRELUBRIC. OIL PUMP FOR AUX ENGINE 1
Q307-PRELUBRIC. OIL PUMP FOR AUX ENGINE 2
Q401-MOTOR FOR HYDR. BULKHEAD DOOR1 RIB 18
Q402-MOTOR FOR HYDR. BULKHEAD DOOR1 RIB 62
Q403-MOTOR FOR HYDR. BULKHEAD DOOR1 RIB 86
Q404-MOTOR FOR HYDR. BULKHEAD DOOR1 RIB 110
Q405-MOTOR FOR HYDR. BULKHEAD DOOR1 RIB 134
Q406-MOTOR FOR HYDR. BULKHEAD DOOR1 RIB 38
Q407-MOTOR FOR HYDR. BULKHEAD DOOR1 RIB 86
Q408-SPARE
Q409-SPARE
TRANSFORMERLoad from UPS 230V ESB

FLO/VEDL/FOLAT
Forsvarets laboratorietjeneste
Kjemi - Material

Oppdragsgiver	Teknisk Rapport
SHT v/ K.H. Brenna **Postboks 213** **2001 Lillestrøm**	
Gjenpart	Oppdragsgivers referanse MS Nordlys Foreløpig rapport: 111012.06

Tittel

Undersøkelse av komponenter etter motorbrann MS Nordlys

Rapportnr	Dato for mottak av oppdrag	Dato for utgivelse
120113.03	2011-09-26	2012-01-25
Jobbnr / Prøvenr	**Antall sider**	**Antall vedlegg**
M-11-255	14	-
Utarbeidet av		**Sjef Analytisk laboratorium**
Øyvind Frigaard		Tor Arne Gustavsen

Sammendrag

Forsvarets laboratorietjeneste, kjemi og material, ble forespurt om å bistå i undersøkelsen av komponenter i forbindelse med motorbrann på MS Nordlys.

Konklusjoner

- De utførte undersøkelsene har vist at tilførselsrørene til drivstoffpumpe til sylinder 5 med stor sannsynlighet har vært utsatt for utmatting og at det har vært initiert gjennomgående utmattingssprekker i rørene med lekkasje som sannsynlig resultat. Utmattingsskadene virker å være initiert fra undersiden av rørene ved innfeste mot drivstoffpumpe, hvilket tyder på at rørene har vært utsatt for en syklisk oppadrettet kraft.
- Undersøkelsen av bolter og foringer til drivstoffpumpen kan ikke bekrefte at disse har vært skrudd til med foreskrevet moment, da foringene som er betydelig mykere sammenlignet med boltene ikke har synlige merker etter bolthodet. Maskineringssporene er ikke klint/deformert og fremstår som intakte på samtlige foringer.
- Rør for smøreolje til drivstoffpumpen til sylinder 5 hadde røket som følge av overbelastning.
- Dreneringsventilen hadde meget lite inngrep, og ventilhuset var ovalt med slitte gjenger. Det kunne observeres lokalt korrosjonsangrep i ventilen som tilsynelatende er gjennomgående. Dette kan ha medført en liten lekkasje, noe som misfarging på utsiden av ventilhuset kan indikere. Funksjonaliteten til ventilen kan ikke fastslås da ventilkule og stengekran manglet. Det kunne også observeres skader på pakningen til referanseventilens endeplugg hvilket tyder på at denne dras til med for stort moment.

Postadresse :
FLO/VEDL/FOLAT Kjemi og Material
Postboks 10
N-2027 KJELLER

Vareadresse
FLO/VEDL/FOLAT Kjemi og Material
Fetveien 80-84
N-2027 KJELLER

Telefon :
+47 63 80 87 41
Mil: 505 8741

Telefax :
+ 47 63 80 87 58
Mil: 505 8758

1 Innledning

Forsvarets laboratorietjeneste, kjemi og material, ble forespurt om å bistå i undersøkelsen av komponenter i forbindelse med motorbrann på MS Nordlys. Oppdragsgiver har ikke forespurt om, og det er derfor ikke utført undersøkelser med tanke på å avdekke materialtype og mekaniske egenskaper til komponenter og sammenføyninger. Før slikt arbeid eventuelt iverksettes må materialstandarder og eventuelle krav til sammenføyninger fremskaffes.

De mottatte komponentene er vist i Figur 1 og omfatter:

C12: Flens til drivstoffrør (retur) drivstoffpumpe til sylinder 5 med brudd.

C15: Flens til drivstoffrør (tur) drivstoffpumpe til sylinder 5 med brudd.

C12 Returrør og C15 Turrør: Drivstoffrør med flens til drivstoffpumpe til sylinder 5 med brudd.

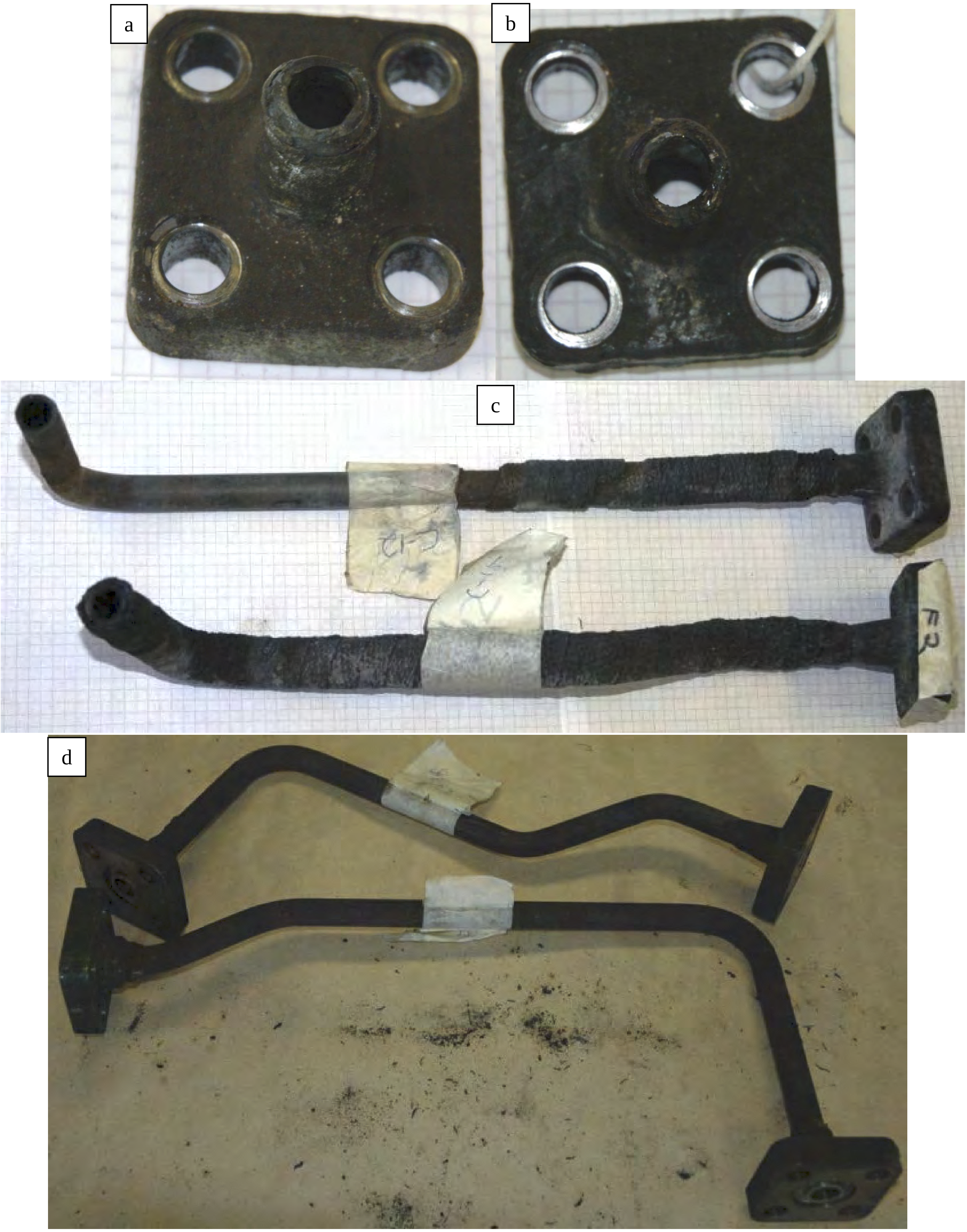
C35 og C38: Drivstoffrør med flenser til drivstoffpumpe til sylinder 1.

C54: Rør for smøring av til drivstoffpumpe sylinder 5 med brudd.

C57, C58. C59 og C60: Bolter med foringer for feste av drivstoffpumpe til sylinder 5.

C39 og C1: Separert dreneringsventil.

C40: Referanse dreneringsventil.



Forts. s.4.

Figur 1 Bilder av deler mottatt for undersøkelse. a: Flens til drivstoffrør (retur) sylinder 5 med brudd merket C12. b: Flens til drivstoffrør (tur) sylinder 5 med brudd merket C15. c: Drivstoffrør med flens til drivstoffpumpe til sylinder 5, C12-returrør og C15-turrør. d: Drivstoffrør med flens til drivstoffpumpe til sylinder 1 mottatt som referanse, C35 og C38. e: Rør for smøring til drivstoffpumpe til sylinder 5 med brudd merket C54. f-i: Bolter med foring for feste av drivstoffpumpe til sylinder 5 merket hhv. C57, C58, C59 og C60. j: Oversiktsbilde av separert dreneringsventil merket (C39 og C1). k: Referanseventil merket C40.

2 Skadeundersøkelse av drivstoffrør til drivstoffpumpe til sylinder 5

Tilførselsrørene til drivstoffpumpe til sylinder 5 hadde brudd slik det fremgår av Figur 1a,b og c. Bruddene hadde oppstått i varmepåvirket sone tett ved sveiseforbindelsen. Røntgen undersøkelser utført ved Luftforsvarets Hovedverksted Kjeller (nå AIM Norway) av sveiseforbindelser på tur og retur rør tilknyttet drivstoffpumpene til sylinder 5 og sylinder 1 viste ikke tegn på sveisefeil.

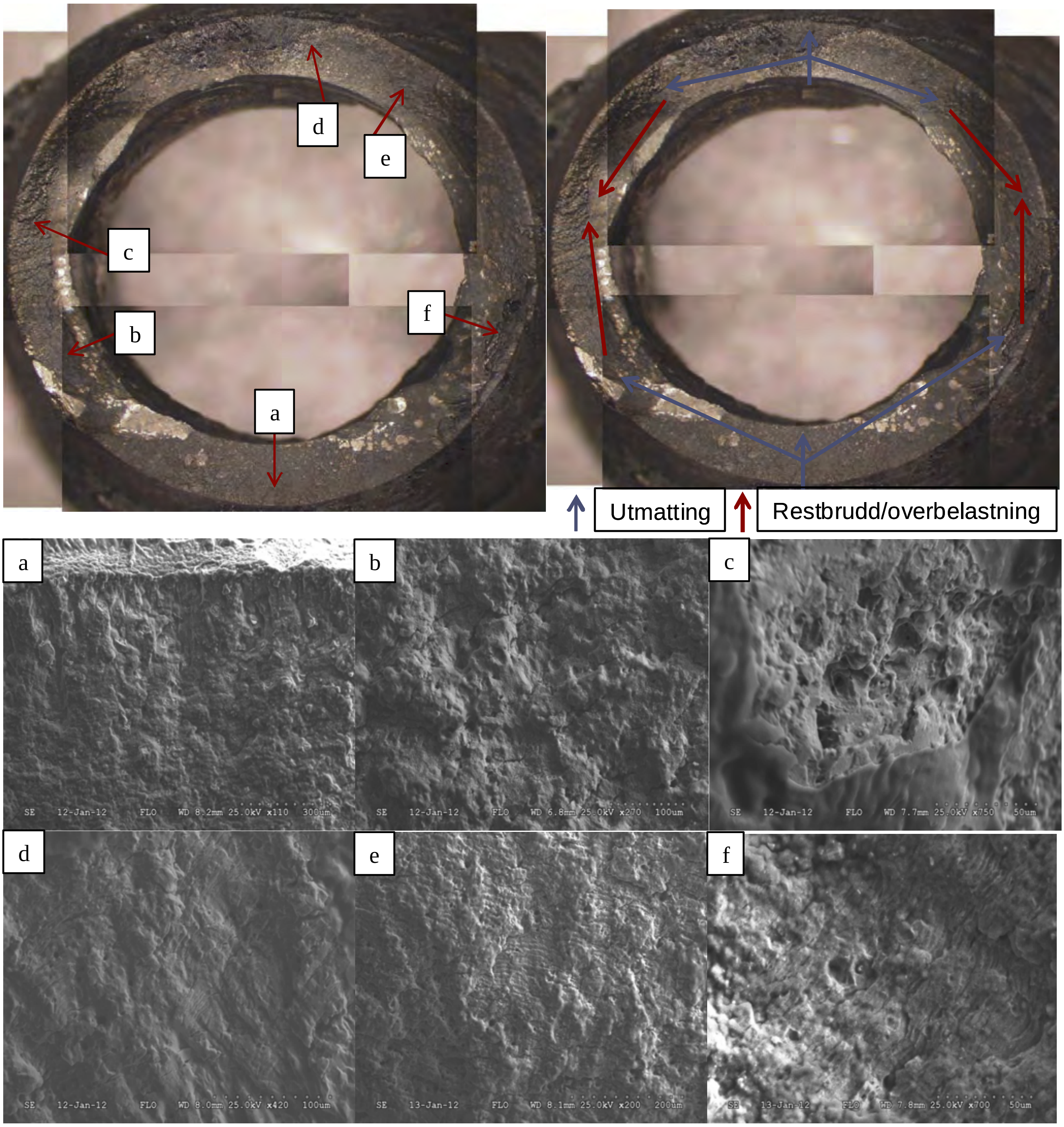
Oversiktsbilder av de undersøkte bruddflatene er vist i Figur 2 og Figur 3, med posisjon til fraktografibilder i SEM angitt i oversiktsbildet. Videre er en oppsummering av observasjonene angitt med piler.

Bruddflaten på innfeste til Returrøret (C12) var oksidert og deler av den opprinnelige bruddflaten var deformert. Bruddflaten ble renset i n-heptan og teknisk sprit, og avsetninger ble forsøkt fjernet med pinsett. SEM undersøkelsen avdekket enkelte områder med tegn på utmatting som vist i Figur 2a,b,d,e og f. Et området med antydning til dimpler er vist i Figur 2c, det kunne i dette området også observeres en ca. 45° skjærleppe forenlig med overbelastning. En tilsvarende skjærleppe kunne observeres på motstående side, og det virker rimelig å anta at dette området også har vært utsatt for overbelasting. Den opprinnelige bruddflaten kunne ikke observeres som følge av klining/deformasjon av bruddflaten.

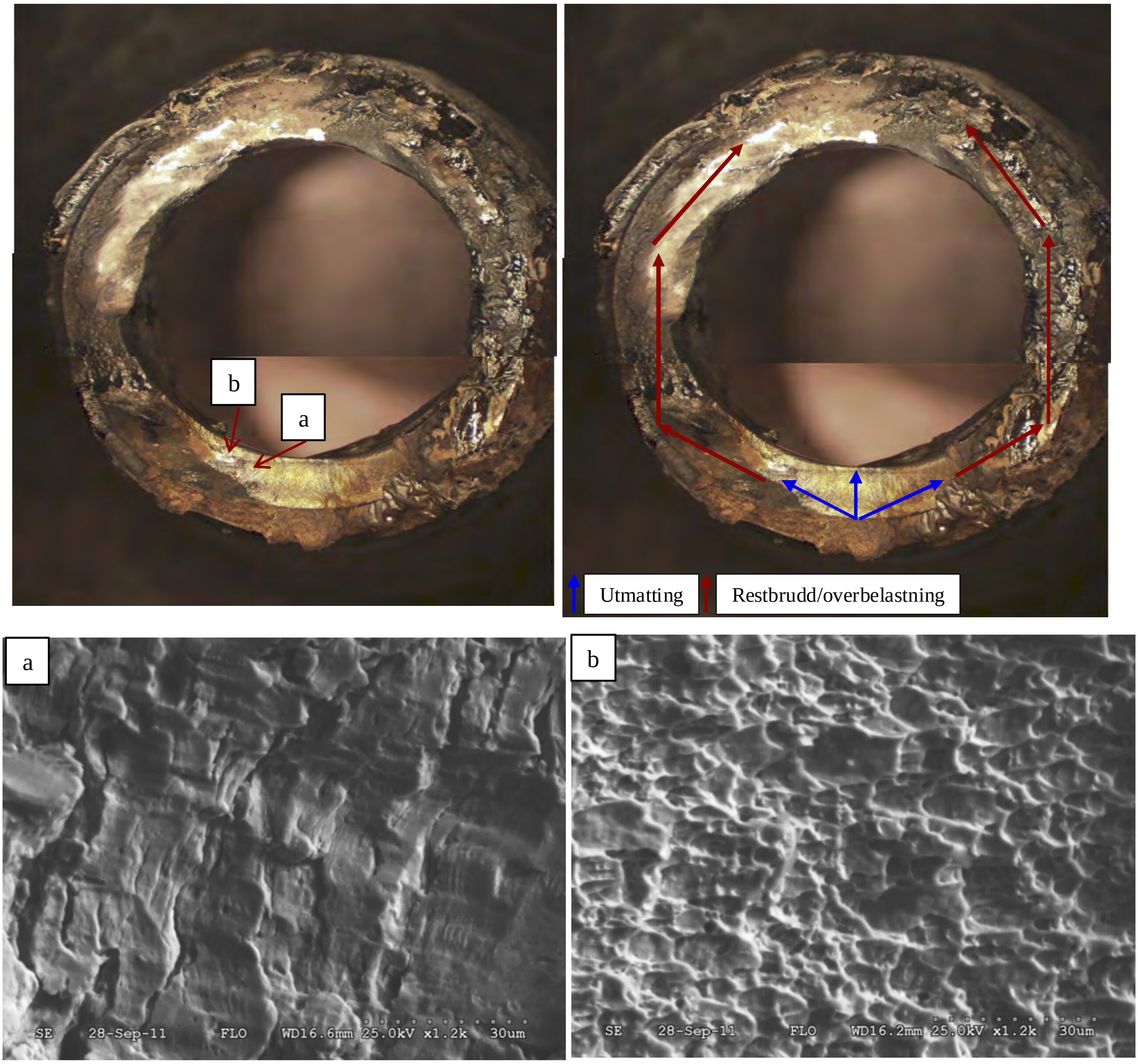
Det kunne gjennomgående observeres antydning til dimpler i områdene med sannsynlig utmatting, hvilket kan tyde på relativt store tøyninger. De eksakte avgrensningene til de ulike bruddforplantningsmekanismene er ikke mulig å bestemme på grunn av deformert og kontaminert bruddflate, men en antydning er gitt med piler i Figur 2, der blå piler representerer utmatting og røde duktil overbelastning.

Bruddflaten på innfeste til Turrøret (C15) viste et område med tydelig utmatting med overgang til overbelastning/restbrudd som vist i Figur 3ab. Den øvrige bruddflaten var svært kontaminert og deformert, slik at observasjoner av den opprinnelige bruddflaten ikke var mulig. Basert på utstrekningen til den observerte utmattingssprekken virker det sannsynlig at bruddet har hatt en betydelig overbelastingsandel, som illustrert med piler i Figur 3, der blå piler representerer utmatting og røde duktil overbelastning. Med bakgrunn i den betydelige kontamineringen av bruddflaten stilles det spørsmål ved om denne kan ha blitt dratt av i forbindelse med demontering etter brannen som tidligere antydet.

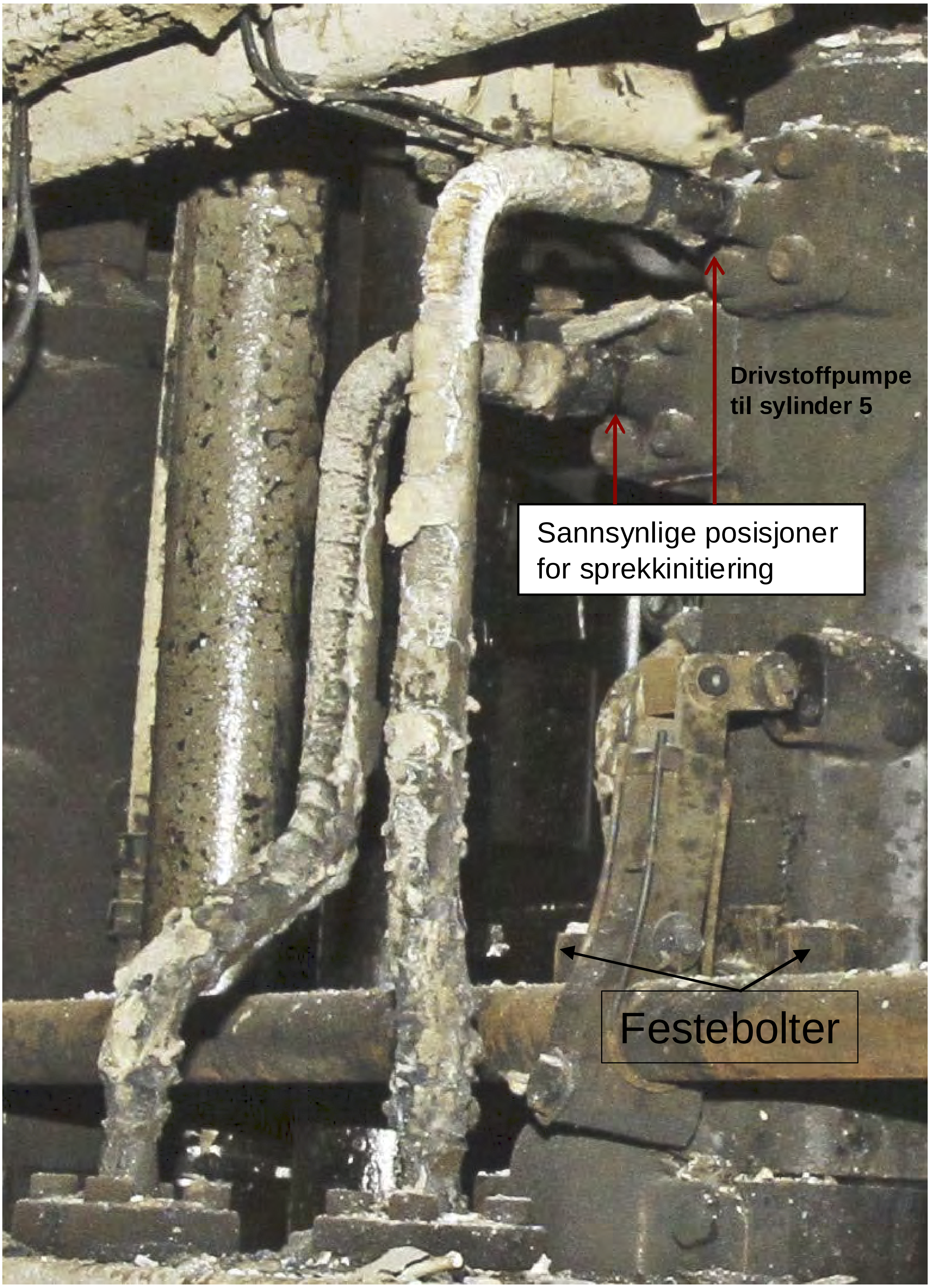
Basert på fraktografiundersøkelsene er sannsynlige sprekkinitieringspunkter angitt i Figur 4.



Figur 2 Oversiktsbilde av bruddflate til drivstoffrør C12 (se Figur 1a). Fraktografibilder: a: Mulig initieringsområde med plan bruddflate og lite topografi, antydning til sprekkstopplinjer, sannsynlig utmatting. b: Mikrosprekker i overflaten med antydning til sprekkstopplinjer, innslag av dimpler tyder på utmatting med relativt store tøyninger. c: I et område med fjernet kontaminering kan det observeres dimpler forenlig med duktil overbelastning. d: Bruddflaten er plan med antydning til sprekkstopplinjer forenlig med utmatting. e: Bruddflaten har mikrosprekker med antydning til striert overflate forenlig med utmatting, innslag av dimpler tyder på relativt store tøyninger. f: Bruddflaten har mikrosprekker med tydelig striert overflate forenlig med utmatting, innslag av dimpler tyder på relativt store tøyninger.



Figur 3 Oversiktsbilde av bruddflate til drivstoffrør C15 (se Figur 1b). Fraktografibilder: a: Mikrosprekker i overflaten med antydning til sprekkstopplinjer forenlig med utmatting. c: Tydelig overgang i bruddflaten til dimpler forenlig med duktil overbelastning.

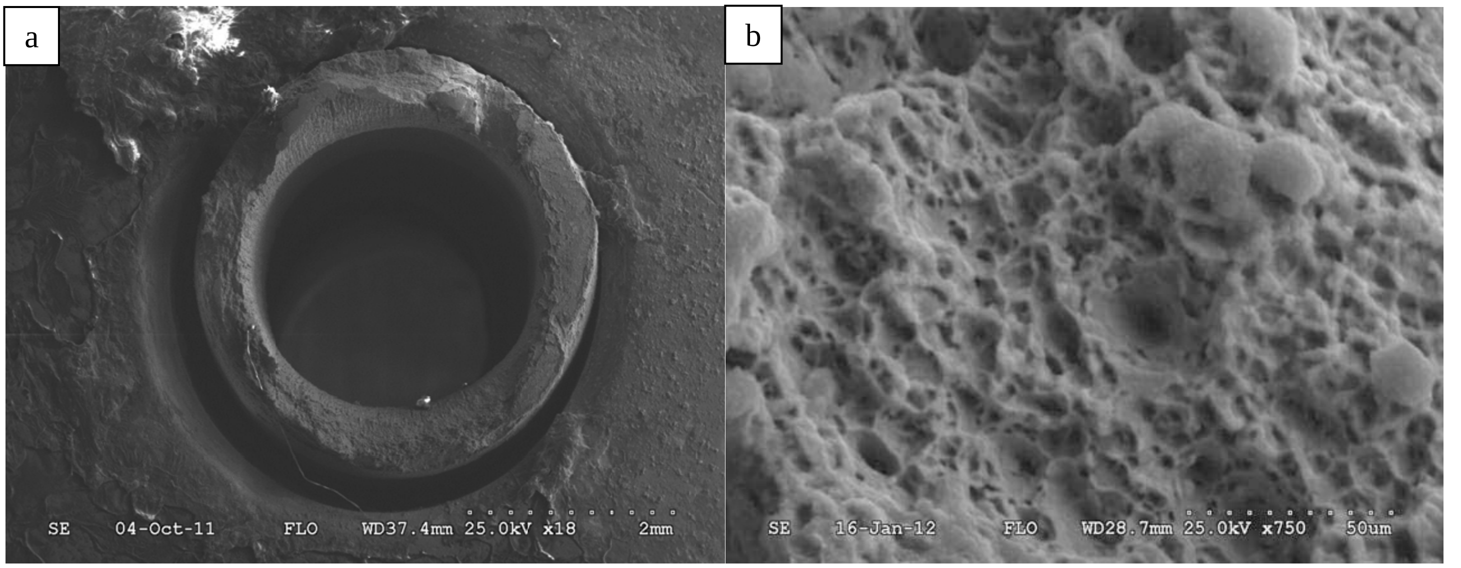


Figur 4 Bilde av drivstoffrør fotografert i motorrom etter brann. Bildet er mottatt fra Politiet via SHT. Bildet angir sannsynlige sprekkinitieringspunkt basert på fraktografiundersøkelsene.

3 Undersøkelse av brudd i rør for smøring til drivstoffpumpe sylinder 5

Oversiktsbilde av rørdelen med brudd merket C54 er vist i Figur 1e. Bruddflaten ble renset i n-heptan og teknisk sprit før fraktografiundersøkelse i SEM.

Et oversiktsbilde av bruddflaten er vist i Figur 5a. Som det fremgår av fraktografibildet vist i Figur 5b bestod bruddflaten av dimpler hvilket viser at røret for smøring av drivstoffpumpe 5 har røket som følge av duktil overbelasting.



Figur 5a: Oversiktsbilde i SEM av bruddflaten til rør ved innfeste. b: Representativt fraktografibilde i SEM av bruddflaten viser dimpler forenlig med duktil overbelasting.

4 Undersøkelse av bolter med foringer for feste av drivstoffpumpe til sylinder 5

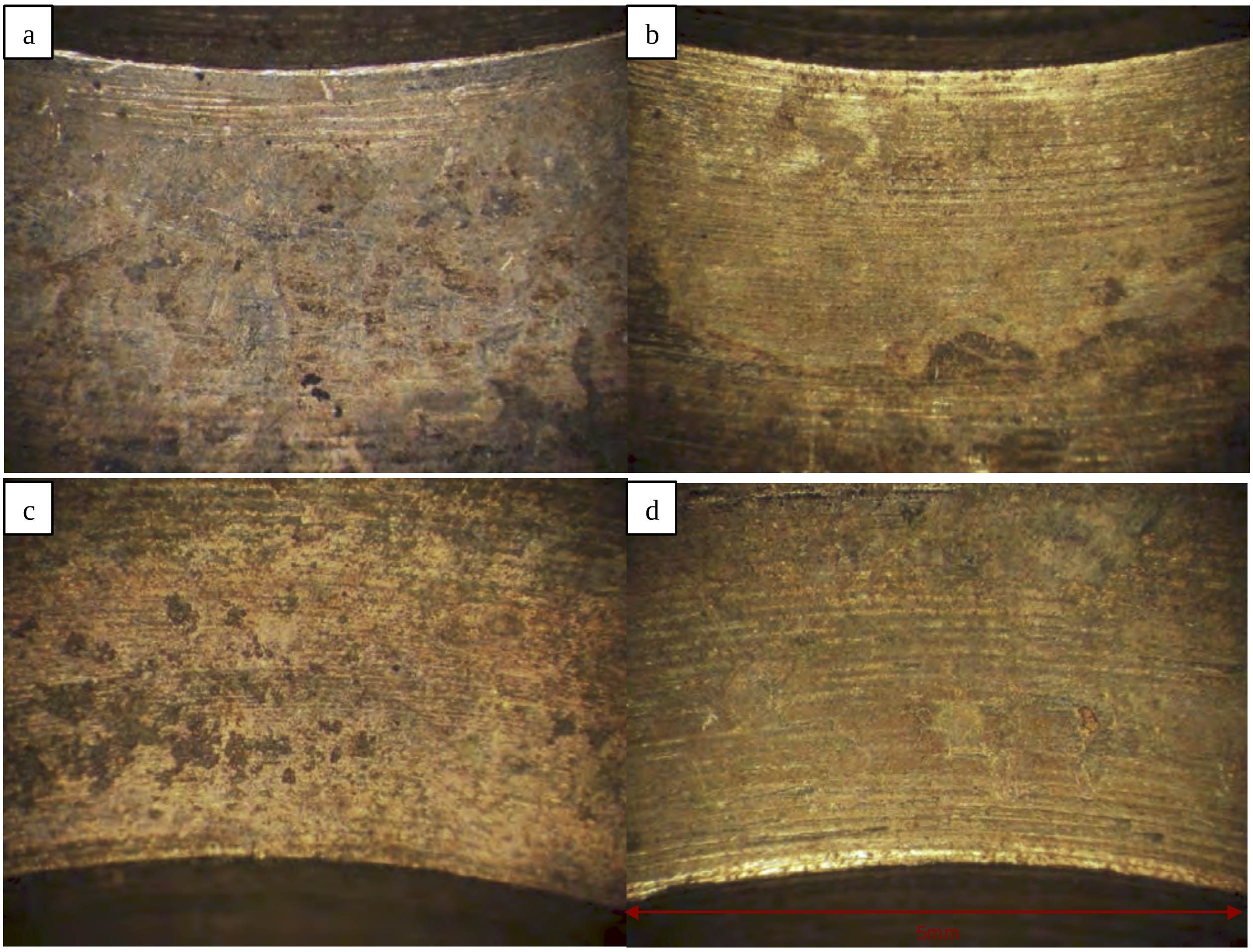
Oversiktsbilde av bolter med tilhørende foringer er vist i Figur 1f-i. Undersøkelse av boltene i stereo lysmikroskop avdekket ingen uregelmessigheter i gjengeparti, stamme eller bolthode. Foringene hadde en plan overflate uten deformasjoner/klining av materialet og overflatene var til dels sotet, slik det fremgår av bildene i Figur 6a-d. Maskineringsspor var synlig på overflatene i stereo lysmikroskop, se Figur 7. Det ble tatt hardhetsmålinger på boltstammene og på overflaten til foringene, resultatene er oppsummert i Tabell 1, og viser at foringene har en betydelig lavere hardhet sammenlignet med bolten.

Tabell 1 Verdier for hardhet til bolter og foringer til drivstoffpumpe, verdier i HRC.

	Bolt	Foring
C57	28	15
C58	29	17
C59	32	15
C60	29	17

Det har vært et sentralt spørsmål å avklare hvorvidt drivstoffpumpen var festet tilstrekkelig eller ikke, basert på observasjonene ovenfor virker det sannsynlig at boltene ikke har vært tilskrudd med moment av betydning. Deformasjon/klining av foringsoverflatene kan ikke observeres hvilket skulle forventes når bolten skrus inn mot den mykere foringen med moment. Dette støttes videre av at sot er avsatt på overflatene hvilket tyder på avstand mellom bolt og foring.
Det ville vært avklarende å montere en bolt med riktig moment mot en tilsvarende foring, for deretter å se på inntrykksgraden for sammenligning med de undersøkte foringene.

Figur 6 Oversiktsbilder av foringer til bolter til drivstoffpumpe til sylinder 5, a: C57, b: C58, c: C59 og d: C60. Bildene viser den siden som møter bolthodet.



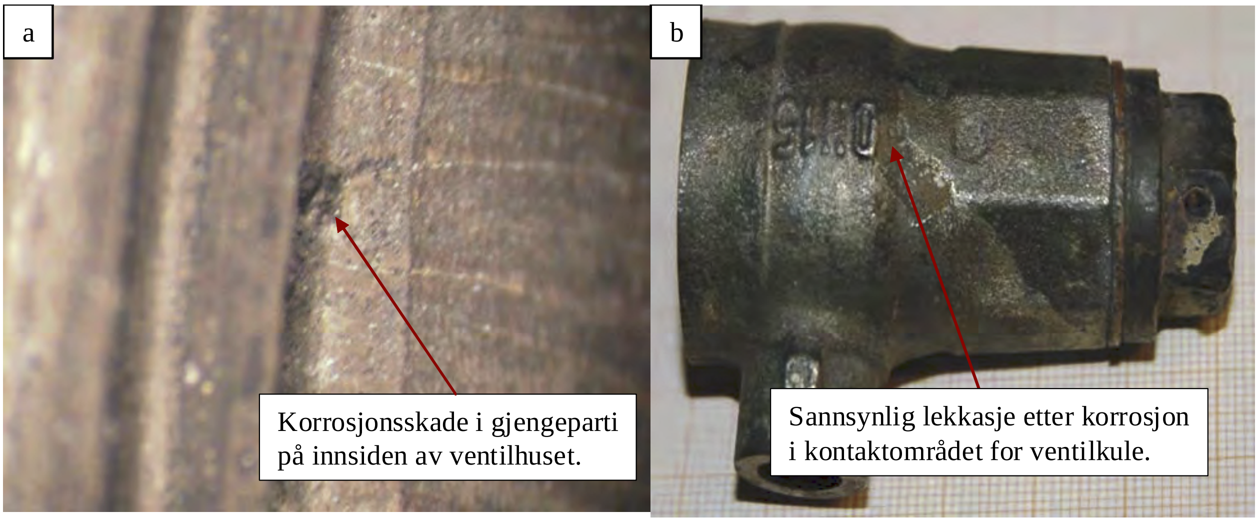
Figur 7 Bilder i stereolysmikroskop av maskineringsspor i overflaten til foringer til bolter til drivstoffpumpe til sylinder 5 som vist i Figur 6a-d, (a: C57, b: C58, c: C59 og d: C60). Bildebredden utgjør ca. 5mm.

5 Dreneringsventil

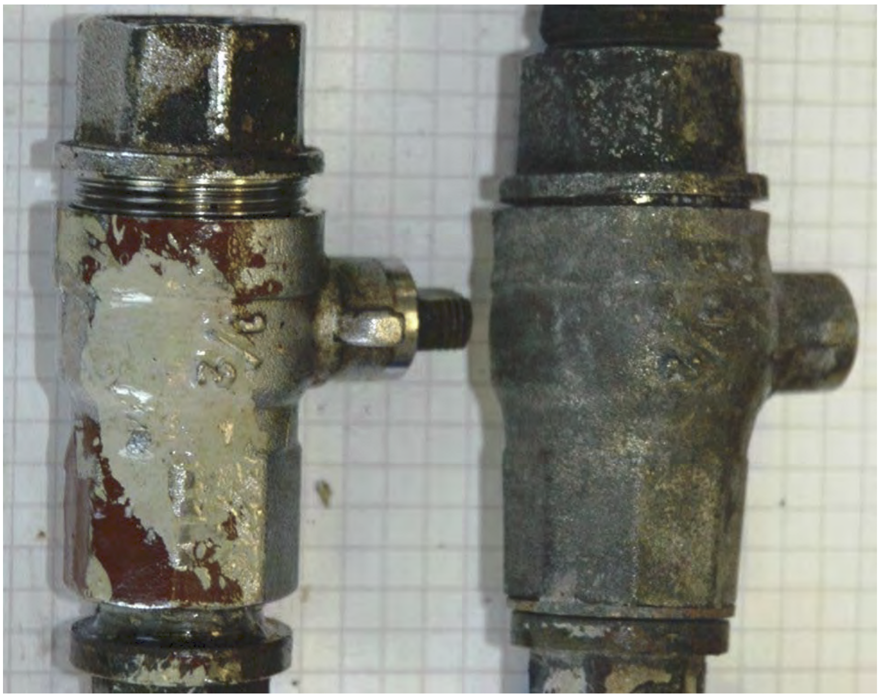
Det ble mottatt en separert dreneringsventil merket C1 og C39 sammen med en referanseventil C40, se Figur 1 hhv. j og k. Den separerte dreneringsventilen ble mottatt uten stengekran og ventilkule. Ventilhuset hadde et meget deformert/slitt gjengeparti og hadde en tilsynelatende gjennomgående korrosjonsskade fra baksiden av gjengepartiet. Tilsvarende korrosjonsskade ble også observert i området hvor ventilkulen skulle ha hatt kontakt med ventilhuset, se Figur 8a og b.

Ved sammenstilling av komponentene C1 og C39 fremkom det en meget liten klaring før inngrep kunne oppnås, dette er illustrert i Figur 9 der ventilen er sammenlignet med referanseventil merket C40. Nøyaktig oppmåling av ventilen var ikke hensiktsmessig på grunn av ovalitet og grov overfalte.

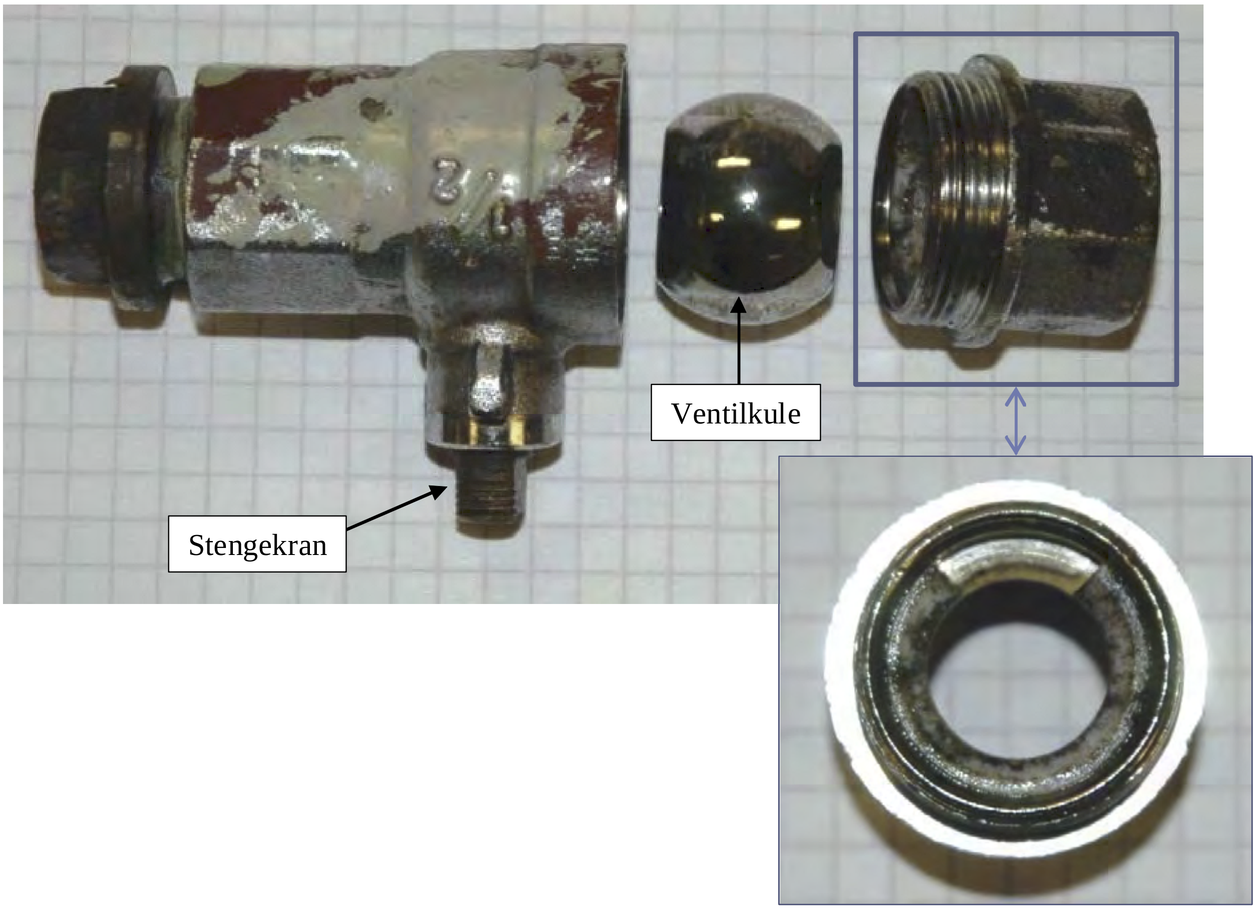
Ved demontering av referanseventilen viste det seg at innvendig pakning var skadet og at deler av denne manglet, Figur 10.



Figur 8ab: Bilder av korrosjonsangrep på ventilhus.



Figur 9 Sammenstilling for å illustrere forskjell i inngrepspunkt mellom referanseventil (C40) t.v. og separert ventil (C1 og C39) t.h.



Figur 10 Bilde av demontert referanseventil med bilde av skadet pakning i endeplugg.

6 Konklusjoner

- De utførte undersøkelsene har vist at tilførselsrørene til drivstoffpumpe til sylinder 5 med stor sannsynlighet har vært utsatt for utmatting og at det har vært initiert gjennomgående utmattingssprekker i rørene med lekkasje som sannsynlig resultat. Utmattingsskadene virker å være initiert fra undersiden av rørene ved innfeste mot drivstoffpumpe, hvilket tyder på at rørene har vært utsatt for en syklisk oppadrettet kraft.
- Undersøkelsen av bolter og foringer til drivstoffpumpen kan ikke bekrefte at disse har vært skrudd til med foreskrevet moment, da foringene som er betydelig mykere sammenlignet med boltene ikke har synlige merker etter bolthodet. Maskineringssporene er ikke klint/deformert og fremstår som intakte på samtlige foringer.
- Rør for smøreolje til drivstoffpumpen til sylinder 5 hadde røket som følge av overbelastning.
- Dreneringsventilen hadde meget lite inngrep, og ventilhuset var ovalt med slitte gjenger. Det kunne observeres lokalt korrosjonsangrep i ventilen som tilsynelatende er gjennomgående. Dette kan ha medført en liten lekkasje, noe som misfarging på utsiden av ventilhuset kan indikere. Funksjonaliteten til ventilen kan ikke fastslås da ventilkule og stengekran manglet. Det kunne også observeres skader på pakningen til referanseventilens endeplugg hvilket tyder på at denne dras til med for stort moment.

SERVICE REPORT

Vessel :	"Nordlys"	**Owner :**	**Hurtigruten**
Engine type :	6M552C	**Total no. of pages :**	1
Engine number :	57113	**Output :**	
Running hours:	Approx 118.000	**Lub.oil type:**	
		Fuel:	MSD
Service order :	5201425	**Service period :**	
Place :	Oslo	**Spoken with :**	
		Service eng :	Karsten Karlsen
Reason for visit : :	**Inspection fuel pump no 5 after fire**		

Inspection of fuel pump no 5, starboard engine "Nordlys" after fire. Attending the inspection:

Norwegian Police, Kripos: Sølvi Harjo and Håvard Arntsen
Hurtigruten: Chief engineer Erling Leiren
Accident Investigation Board Norway: Håvard Bentsen
Pon Power AS: Øystein Skår and Karsten Karlsen

4.11.2011

- Started with visual inspection of pump. There is soot on the pump, but paint seems to be intact.
- Opened up pump, pulled out plunger. Pump plunger is ok
- Inspected pump barrel, this is ok
- O-rings ok

Inspection did not reveal any damage to internal parts in the pump from the fire on board. See picture report for details

Kind regards

Øystein Skår
Service Manager MaK Norway
Pon Power AS

Pon Power AS
Brobekkveien 54
Postboks 133 Vollebekk
N-0520 Oslo, Norway

Telephone: + 47 23 17 05 00
Telefax: + 47 23 17 05 01

www.pon-cat.com

DET NORSKE VERITAS™

REPORT

EXAMINATION OF ENGINE BLOCK MATERIAL, M/S NORDLYS

PON POWER AS

REPORT NO./DNV REG NO.: 2012-3021 / 1-3ZQFB0
REV 00, 2012-01-12

MANAGING RISK

Examination of engine block material, M/S NORDLYS

Det Norske Veritas AS
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For:
Pon Power AS
Postboks 133, Vollebekk
0520 Oslo
Norway

Account Ref.:
Øystein Skår

Date of Current Issue:	2012-01-12	Project No.:	PP030906
Revision No.:	00	Organisation Unit:	BDL Materials Services
DNV Reg. No.:	1-3ZQFB0	Report No.:	2012-3021

Summary:
On request of Pon Power AS, Det Norske Veritas (DNV), section for Material Technology has carried out an examination of the engine block material, stb. main engine, on board M/S NORDLYS. An "explosive" fire in the engine room has affected i.a. a section of the engine block made of nodular cast iron (GGG50). The areas in question were subjected to metallographic examination and hardness measurements including photo documentation.
The main objective of the investigation was to elucidate if the original microstructure (material properties) have been modified as a consequence of the heat affection.

Results:
- A regular microstructure characteristic for nodular cast iron was observed in all examined areas. The microstructure has not been modified as a consequence of the heat affection.
- The hardness measurements were found to meet the received requirements.

	Name and Position	Signature
Prepared by:	Arild Oscar Tjernæs Principal Engineer	Arild O. Tjernæs
Verified by:	Mario Søfferud Engineer	Mario Søfferud
Approved by:	Astrid Holmsen Kjesbu Head of Section	Astrid H. Kjesbu

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- ☒ Limited distribution within DNV after 3 years
- ☐ No distribution (confidential)
- ☐ Secret

Keywords

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
0		First issue signed and verified			

Reference to part of this report which may lead to misinterpretation is not permissible.

Table of Contents *Page*

1 INTRODUCTION

On request of Pon Power AS, Det Norske Veritas (DNV), section for Material Technology has carried out an examination of the engine block material, stb. main engine, on board the vessel M/S NORDLYS. According to received information from the client an “explosive” fire in the engine room has affected i.a. a section of the engine block made of nodular cast iron (GGG50). The areas in question were subjected to metallographic examination and hardness measurements including photo documentation.

1.1 Information received from the client

According to information received from the client the material in the engine block is reported to be of type GGG 50, nodular cast iron.

The hardness shall be in the range of 170 HB – 230 HB.

A drawing (cross section) of the engine was received, see appendix.

1.2 Objectives

The main objective of the investigation was to elucidate if the original microstructure (material properties) have been modified as a consequence of the heat affection.

1.3 Scope of work

- Visual examination
- Photo documentation
- Selection of areas (reference area and heat affected areas)
- Metallographic examination
- Hardness measurements
- Evaluation of results
- Preparation of a technical report including photo documentation

2 EXPERIMENTAL WORK AND RESULTS OBTAINED

2.1 Visual examination

Overview of heat affected areas on the stb. main engine as observed by arrival on the ship/ engine room is shown in Fig. 1. The green framed area on the photo illustrates the hatch covers for the cam shaft consisting of steel plates and hatch ways of aluminum alloy. It was observed that a local area of the one hatch way has melted indicating that the temperature in this area may have been approximately 500 °C to 550 °C. The green framed area was not subjected to further examination.

The red framed area on the photo indicates the section of the engine block which has suffered heat affection during the fire, see close-up in Fig. 2. The area shows that smooth grinding has been carried out at the machined surface. According to information received from the client this is in relation to previously hardness measurements carried out by the manufacturer of the engine. The digit indicates the recorded hardness values. The surface shows that the paint has been removed. It is likely to believe that some of the paint has been burnt off; however, the surface indicates that some paint has been removed by the grinding. The wall thickness was estimated to be 25 mm to 30 mm.

2.2 Metallographic examination

In order to examine the microstructure four different areas labelled by DNV as A, B, C and D were selected within the heat affected area, see Fig. 3. In addition, a reference area for comparison the microstructure and hardness was chosen at the same level as the heat affected area, ref. Fig. 1. Sample A and D including the reference area were selected within an original machined surface carried out by the manufacturing of the engine. The samples B and C were selected in areas where the original casting surface was visible. These two areas were initially rough grinded by use of an angle grinder to approximately 2 mm below surface. All areas were metallographically prepared and finally the microstructure examined in a portable light microscope at magnification 100 X to 400 X. A regular microstructure characteristic for nodular cast iron was observed in all areas, Fig.7 – Fig. 10. However, the areas B and C contain somewhat more ferrite most likely due to shallow grinding into the material.

2.3 Hardness measurements

Hardness measurements were carried out within the metallographically prepared areas by means of a portable Equotip hardness tester and impact device D. The results are given in Table 1 below.

Table 1: Hardness measurements carried out on the surface of the engine block material.

Sample area	Material thickness (approx.) mm	Single values [HB]	Average values [HB]
Reference	30 mm	208 – 198 – 204 – 204 – 199 – 208 – 200 – 202	203
Area A	30 mm	202 – 201 – 197 – 195 – 197 – 202 – 197 – 202	199
Area B	25 mm	176 – 176 – 174 – 177 – 180 – 178 – 180 – 180	178
Area C	25 mm	177 – 177 – 178 – 177 – 180 – 178 – 178 – 179	178
Area D	30 mm	203 – 197 – 187 – 202 – 204 – 205 – 201 – 206	201

The hardness values in area A and D are of the same level as for the reference area. Areas B and C shows a lower hardness, most likely due to a higher content of ferrite. All hardness values meet the specified requirement, (170 HB – 230 HB, ref. appendix).

3 DISCUSSION

Prior to the examination on board the engine room including the heat affected area on the engine block had been cleaned by high-pressure cleaner using water. In addition, some grinding has been carried out at the surface of the heat affected area on the engine. Consequently DNV are not familiar with the original surface condition (appearance) caused by the fire. However, visually the engine surface indicates to have suffered limited heat affection. This is based on observed reminiscences of approximately intact paint and primer adjacent to the affected area.

A regular microstructure characteristic for nodular cast iron was observed in all areas, as expected. It was, however, observed some deviation in the ferrite content compared with the reference area. It is likely to believe that this is not due to annealing caused by the fire, but too shallow grinding. The microstructure and the hardness in area D very close to area B was found similar to the reference area.

4 CONCLUSIONS

Based on the examination carried out the following conclusions have been drawn:

- A regular microstructure characteristic for nodular cast iron was observed in all examined areas. The microstructure has not been modified as a consequence of the heat affection.
- The hardness measurements were found to meet the received requirements.

5 FIGURES

Fig. 1 Overview photo shows the heat affected areas (framed) on the stb. main engine on board the vessel M/S NORDLYS as observed by arrival. The green framed area is the hatch covers for the cam shaft consist of steel plates and hatch ways of aluminum alloy. The red frame indicates the part of the engine block which has suffered heat affection, see Fig. 2.

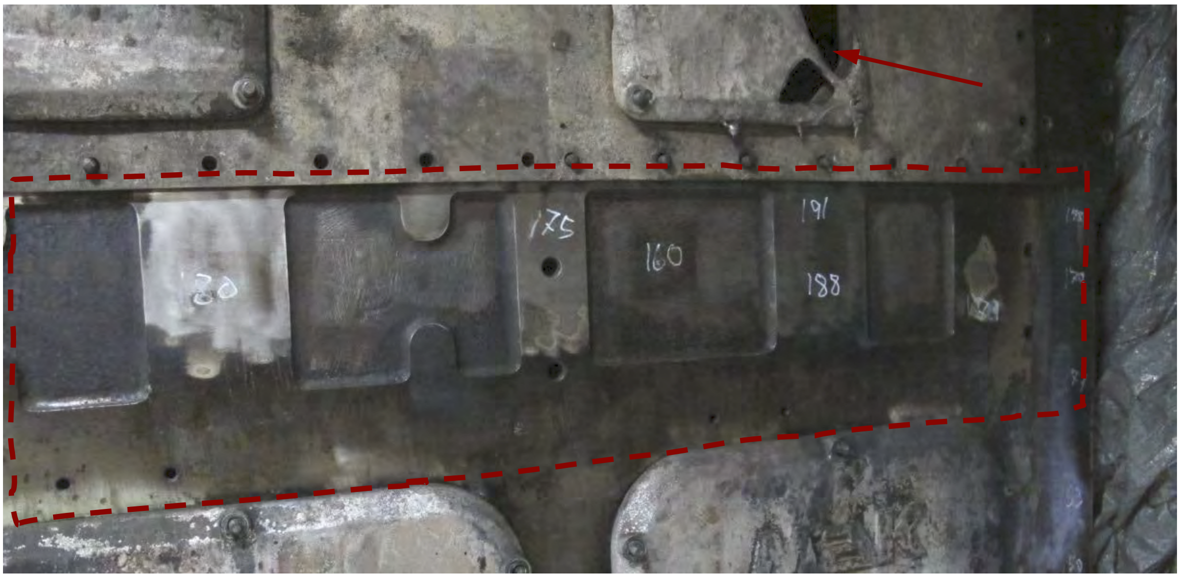


Fig. 2 Close-up of Fig. 1 shows the heat affected area on the engine block. A part of the hatch cover for the cam shaft is visible including the hatch ways of aluminum. A melted area of the hatch way was observed, see arrow. Prior hardness measurements values are indicated by digit.

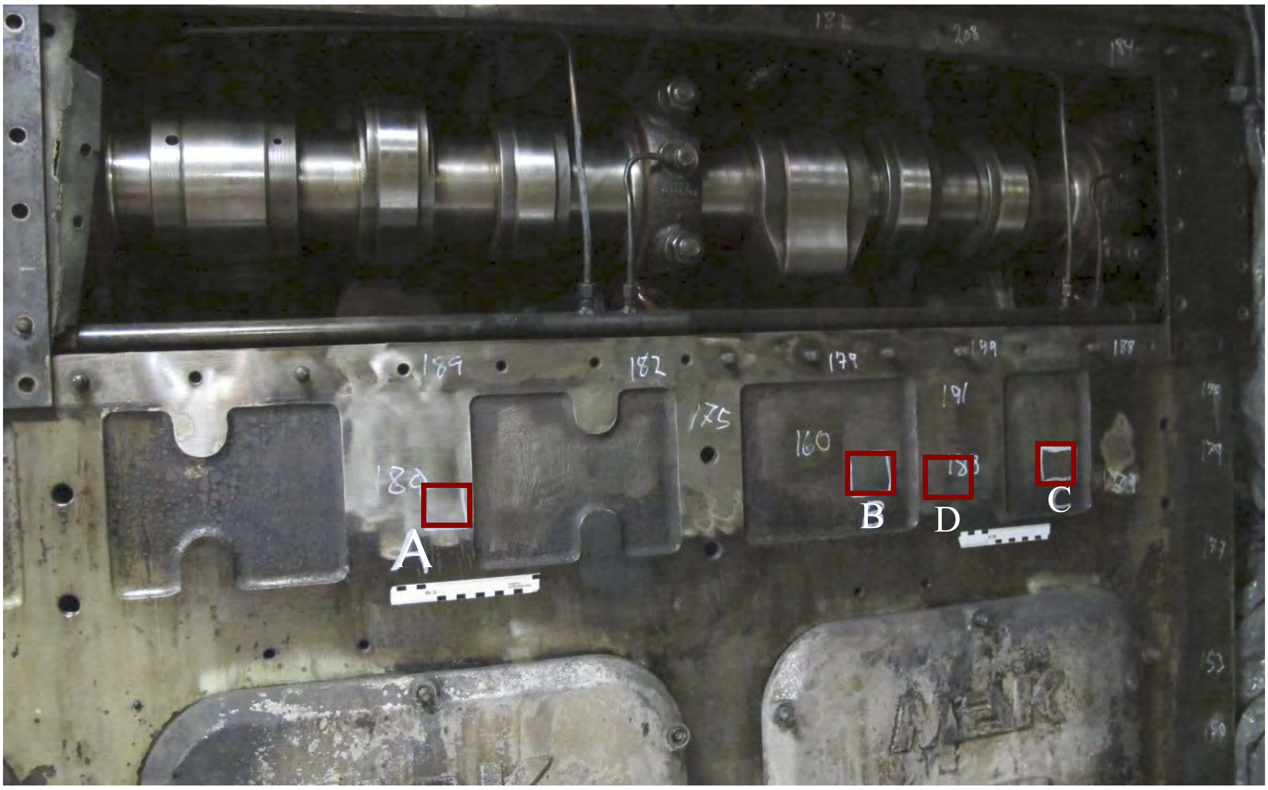


Fig. 3 The same area as shown in Fig. 2, however, the hatch cover is removed. No discoloring was observed at the surface of the cam shaft. The areas labelled A, B, C and D selected for metallographic examination and hardness measurements are indicated by red frames.

Fig. 4 Overview of the prepared areas for examination the microstructure and hardness measurements.

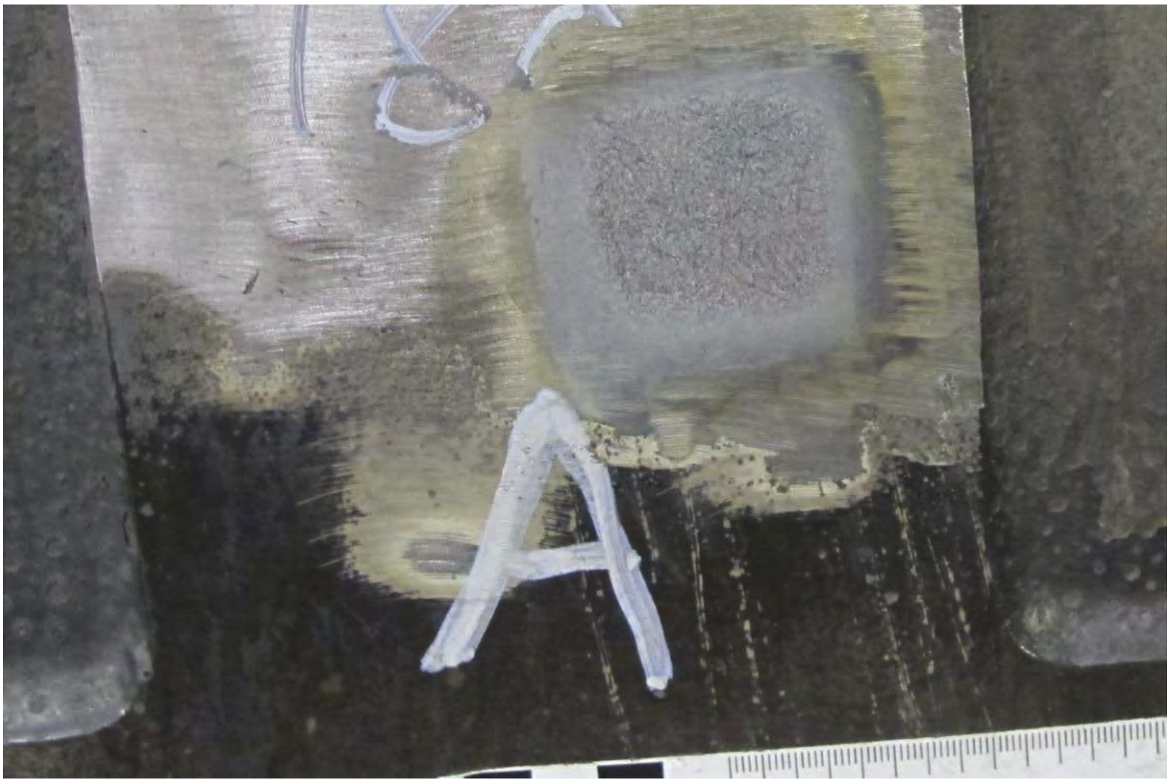


Fig. 5 Close-up of area A prepared and etched for examination in the portable microscope and finally hardness measurements. The area is representative for the areas Ref., B, C and D.

Fig. 6 Close-up of the reference area (ref. to Fig. 1) used for comparison of the microstructure and hardness values.

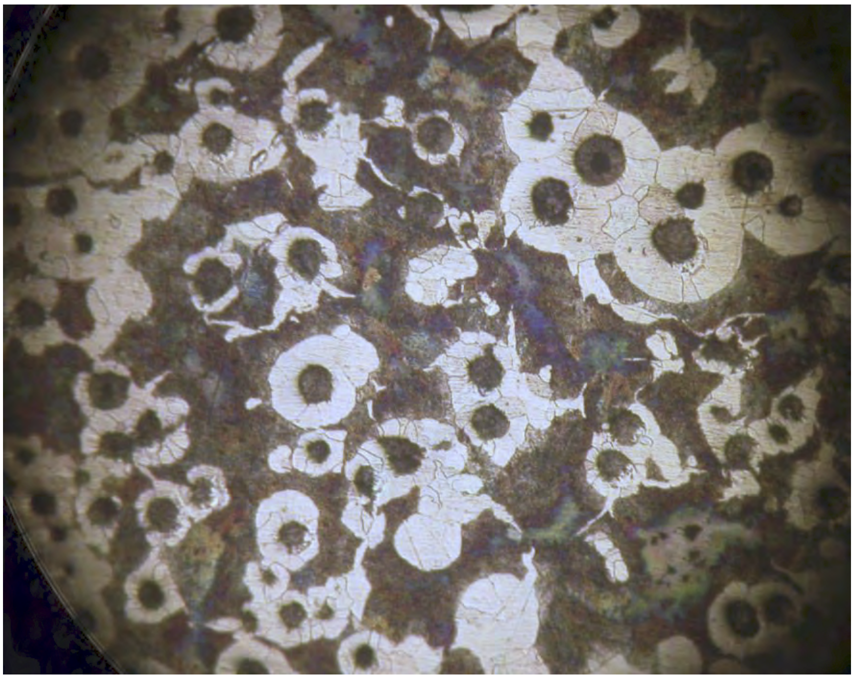


Fig. 7 Reference area. Metallographically prepared area shows a microstructure characteristic for nodular cast iron as expected. The microstructure consists of ferrite and pearlite with spheroidal graphite. Magnification 100 X.

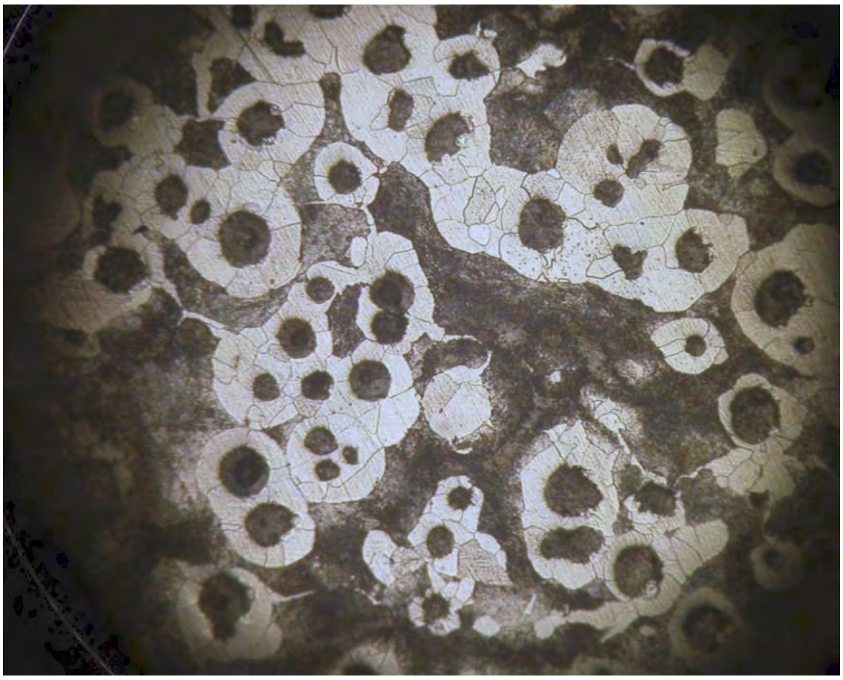


Fig. 8 Area A. The prepared area shows a microstructure characteristic for nodular cast iron as expected. The microstructure consists of ferrite and pearlite with spheroidal graphite. Modification of the microstructure due to heat affection was not observed. Magnification 100 X.

Fig. 9 Area B, representative also for area C. The prepared area shows a microstructure characteristic for nodular cast iron as expected. The microstructure consists of ferrite and pearlite with spheroidal graphite. Compare to the reference area it is observed somewhat more ferrite. Modification of the microstructure due to heat affection was not observed. Magnification 100 X.

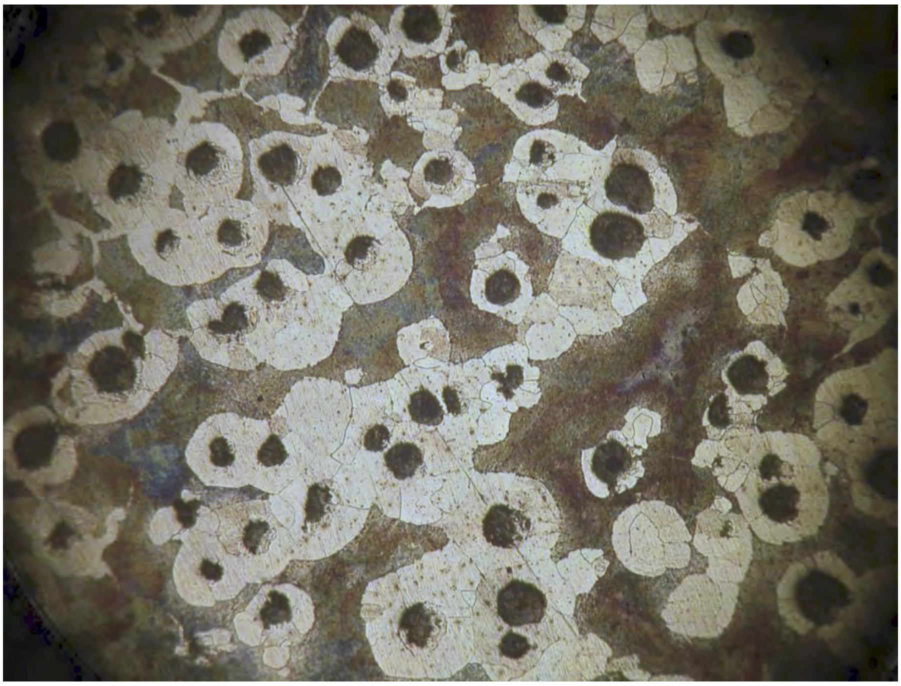


Fig. 10 Area D. The prepared area shows a microstructure characteristic for nodular cast iron as expected. The microstructure consists of ferrite and pearlite with spheroidal graphite. Modification of the microstructure due to heat affection was not observed. Magnification 100 X.

APPENDIX
1
ENGINE CROSS-SECTION

DET NORSKE VERITAS

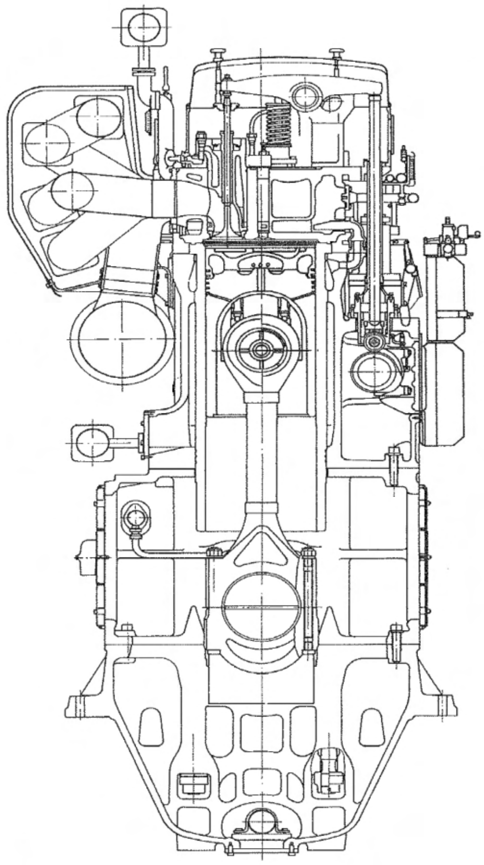
Report for Pon Power AS

Examination of engine block material, M/S NORDLYS

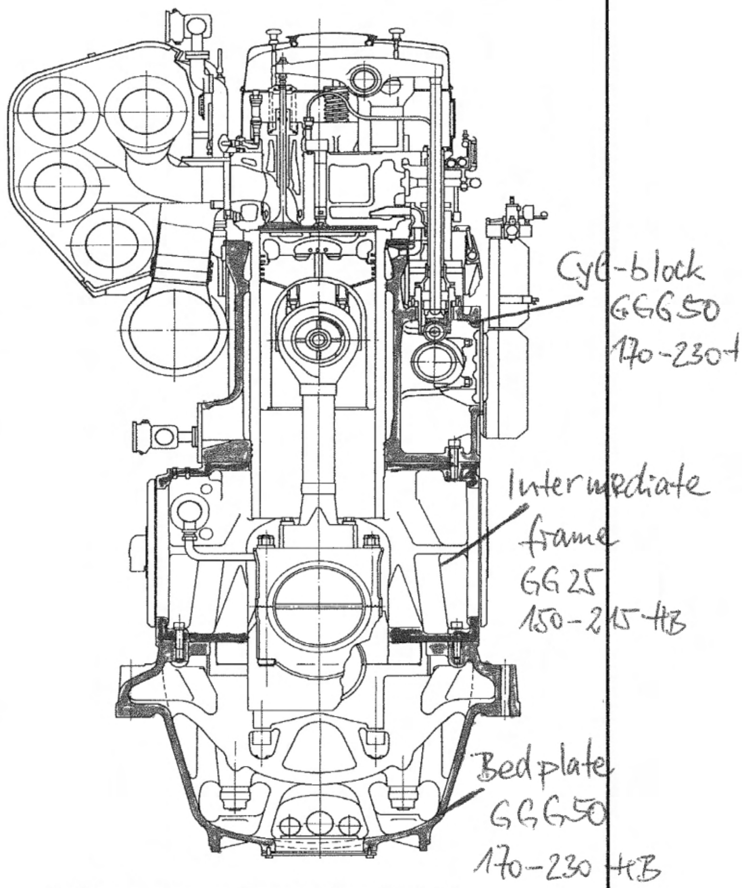
MANAGING RISK

DNV

MaK	Dieselmotor Diesel engine	1.1.1



Reihenmotor/In-line engine M 551



Reihenmotor/In-line engine M 552

M 551/M 552 Viertakt-Schwerölmotor

Grundplattenkonstruktion mit zweiteiligem Motoraufbau

Abgasturboaufladung mit Ladeluftkühlung

Umsteuerbar und nichtumsteuerbar lieferbar

M 551/M 552 Four Stroke Heavy Fuel Engine

Bedplate design with 2-piece engine structure

Exhaust gas turbocharging with charge air cooling

Direct reversible or non-reversible available

Typ	Type		M 551	M 552
Bohrung	Bore	mm	450	450
Hub	Stroke	mm	550	520
Hubvolumen/Zyl.	Swept volume/cyl.	dm^3	87,5	82,7
Drehzahlbereich	Speed range	min^{-1}	375–450	425–514
Zylinderzahl	Number of cyl.		6, 8	6, 8, 9

Querschnitt — Cross section

- o0o -

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DNV is a global provider of knowledge for managing risk. Today, safe and responsible business conduct is both a license to operate and a competitive advantage. Our core competence is to identify, assess, and advise on risk management, and so turn risks into rewards for our customers. From our leading position in certification, classification, verification, and training, we develop and apply standards and best practices. This helps our customers to safely and responsibly improve their business performance.

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DNV is an independent organisation with dedicated risk professionals in more than 100 countries. Our purpose is to safeguard life, property and the environment. DNV serves a range of industries, with a special focus on the maritime and energy sectors. Since 1864, DNV has balanced the needs of business and society based on our independence and integrity. Today, we have a global presence with a network of 300 offices in 100 countries, with headquarters in Oslo, Norway.

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Notat

Temperaturmålinger i maskinrom ombord MS Richard With

SAKSBEHANDLER / FORFATTER
Christian Sesseng

GÅR TIL	BEHANDLING	UTTALELSE	ORIENTERING	ETTER AVTALE
Håvard Bentsen				X

PROSJEKTNR / SAK NR	DATO	GRADERING
10754704	2011-10-25	Fortrolig

Temperaturmålinger ombord Richard With, 2011-10-17.

Først ble motoren undersøkt med IR-kamera, for å lokalisere varme områder. Deretter ble temperaturen målt med IR-termometer. Enkelte temperaturer ble kontrollmålt med IMO-termopar. Sistnevnte målemetode bruker en del tid på å svinge seg inn til rett temperatur, og det er litt vanskelig å komme til på enkelte steder.

IR-kameraet var stilt inn med en emissivitet på 0,90, og IR-termometeret med en emissivitet på 0,95.

Dekselet på styrbord side av styrbord hovedmotor var avmontert. Når det gjelder isolasjon rundt indikatorkranene, kunne en av mannskapet fortelle at de ikke hadde isolasjon på disse.

SINTEF

1 Målinger

Temperaturer ble målt på indikatorkranene, toppen av dekselet som omkapsler eksosmanifolden (Foto 3), flens på eksosrør mellom sylinder 3 og 4 og sylinder 4 og 5 (Foto 7 og Foto 8), på dekselet i overgangen mellom eksosmanifolden og turboladeren (Foto 6), på eksosrør ut fra turboladeren og på hver sylinder (Foto 10).

1.1 Første måling

Første måling ble gjennomført klokken 10:40. Motorene gikk på 100 % pådrag, fordi man skulle sjekke trykket på sylinderne.

Målinger:

	IR-termometer [°C]	Termopar [°C]
Indikatorkran 1	208	
Indikatorkran 2	201	
Indikatorkran 3	231	
Indikatorkran 4	243	
Indikatorkran 5	253	239
Indikatorkran 6	236	224
Eksosmanifold topp	205	189
Eksosmanifold flens 3-4	267	
Eksosmanifold flens 4-5	299	
Overgang mot turbolader	231	164 (målt annet sted enn med IR-termometer)
Eksos ut fra turbolader	153	

Forøvrig ingen høye temperaturer på topptanknivå, bortsett fra indikatorkranene.

SINTEF

1.2 Andre måling

Andre måling ble gjennomført 13:20.

Motorene gikk på ca. 82 % pådrag.

	IR-termometer [°C]
Indikatorkran 1	218
Indikatorkran 2	215
Indikatorkran 3	243
Indikatorkran 4	240
Indikatorkran 5	269
Indikatorkran 6	256
Eksosmanifold topp	195
Eksosmanifold flens 3-4	255
Eksosmanifold flens 4-5	221
Overgang mot turbolader	190
Eksos ut fra turbolader	170
Babord side av sylinder 1	-
Babord side av sylinder 2	265
Babord side av sylinder 3	269
Babord side av sylinder 4	282
Babord side av sylinder 5	260
Babord side av sylinder 6	251

Varmeste overflate på kjølekompressor er ca. 70 grader.

SINTEF

1.3 Tredje måling

Tredje måling ble gjennomført ca. 14:20.

Motorene gikk på ca. 82 % pådrag.

	IR-termometer [°C]
Indikatorkran 1	230
Indikatorkran 2	218
Indikatorkran 3	244
Indikatorkran 4	267
Indikatorkran 5	274
Indikatorkran 6	268
Eksosmanifold topp	206
Eksosmanifold flens 3-4	272
Eksosmanifold flens 4-5	249
Overgang mot turbolader	208
Eksos ut fra turbolader	192
Babord side av sylinder 1	-
Babord side av sylinder 2	291
Babord side av sylinder 3	308
Babord side av sylinder 4	361
Babord side av sylinder 5	316
Babord side av sylinder 6	306

Sylindertemperaturene ble målt ved å holde IR-måleren nærmere enn forrige måling. Får da mer konsentrert målepunkt.

SINTEF

1.4 Fjerde måling

Fjerde måling ble gjennomført ca. 15:20.

Motorene gikk på ca. 82 % pådrag.

	IR-termometer [°C]
Indikatorkran 1	224
Indikatorkran 2	212
Indikatorkran 3	242
Indikatorkran 4	264
Indikatorkran 5	265
Indikatorkran 6	259
Eksosmanifoldtopp	203
Eksosmanifold flens 3-4	265
Eksosmanifold flens 4-5	243
Overgang mot turbolader	189
Eksos ut fra turbolader	196
Babord side av sylinder 1	-
Babord side av sylinder 2	344
Babord side av sylinder 3	347
Babord side av sylinder 4	360
Babord side av sylinder 5	303
Babord side av sylinder 6	332

Sylindertemperaturene ble målt ved å holde IR-måleren nærmere enn første gang måling. Man får da et mindre og mer nøyaktig målepunkt.

SINTEF

2 Avstandsmålinger

Det ble foretatt avstandsmålinger fra fuelpumpen til forskjellige varme punkt:

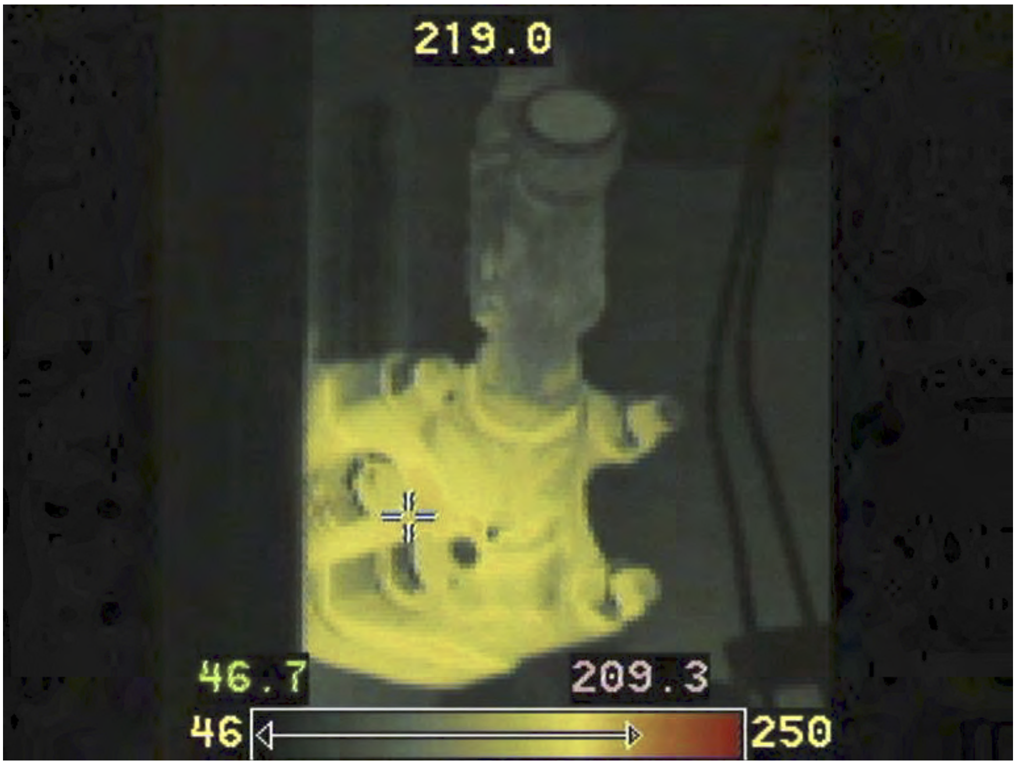
- Fuelpumpe 5 – eksosmanifold flens: Ca. 110 cm horisontalt[1].
- Fuelpumpe 5 – overgang mellom eksosmanifold og turbolader: Ca. 280 cm horisontalt[1].
- Fuelpumpe 5 – indikatorventil 4: Ca. 24 cm horisontalt.
- Fuelpumpe 5 – indikatorventil 5: Ca. 42 cm horisontalt.
- Fuelpumpe 5 – kjøleaggregat: Ca. 300 cm horisontalt, 150 cm vertikalt.

[1] Det er ingen fri sikt mellom disse punktene.

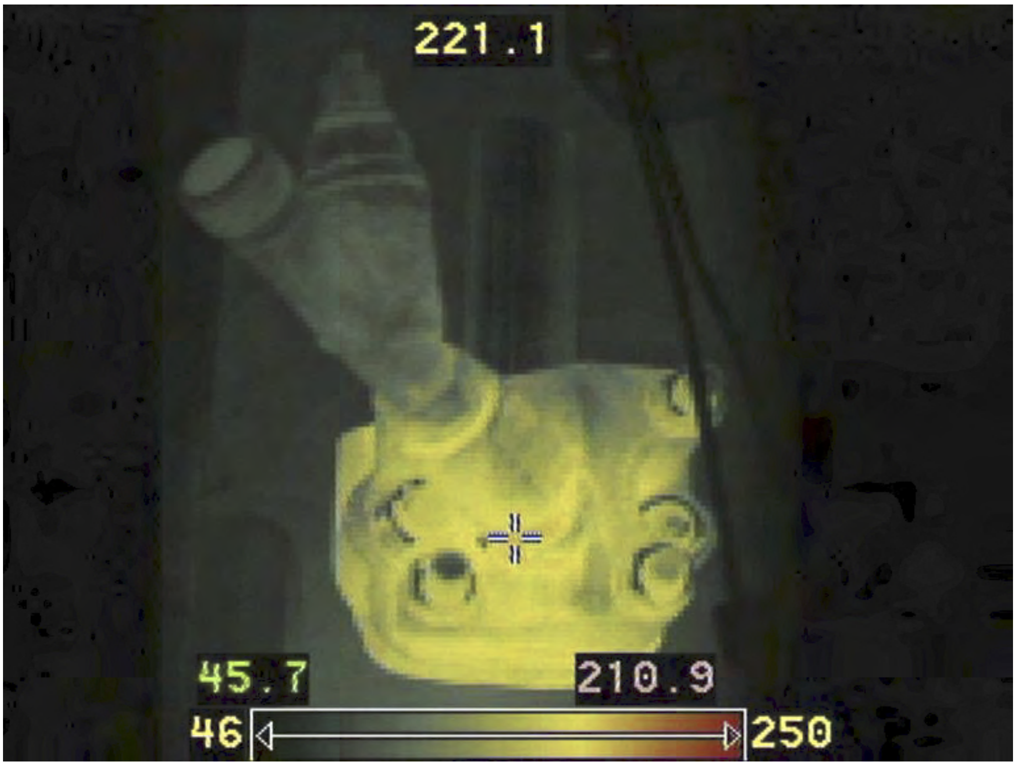
SINTEF

3 IR-bilder

Her følger IR-bilder tatt av enkelte deler av styrbord hovedmotor. Temperaturen vist øverst i midten på bildene, er høyeste temperatur i (krysset på) bildet. Der denne temperaturen viser "++" betyr det at temperaturen har vært høyere enn 250 °C.

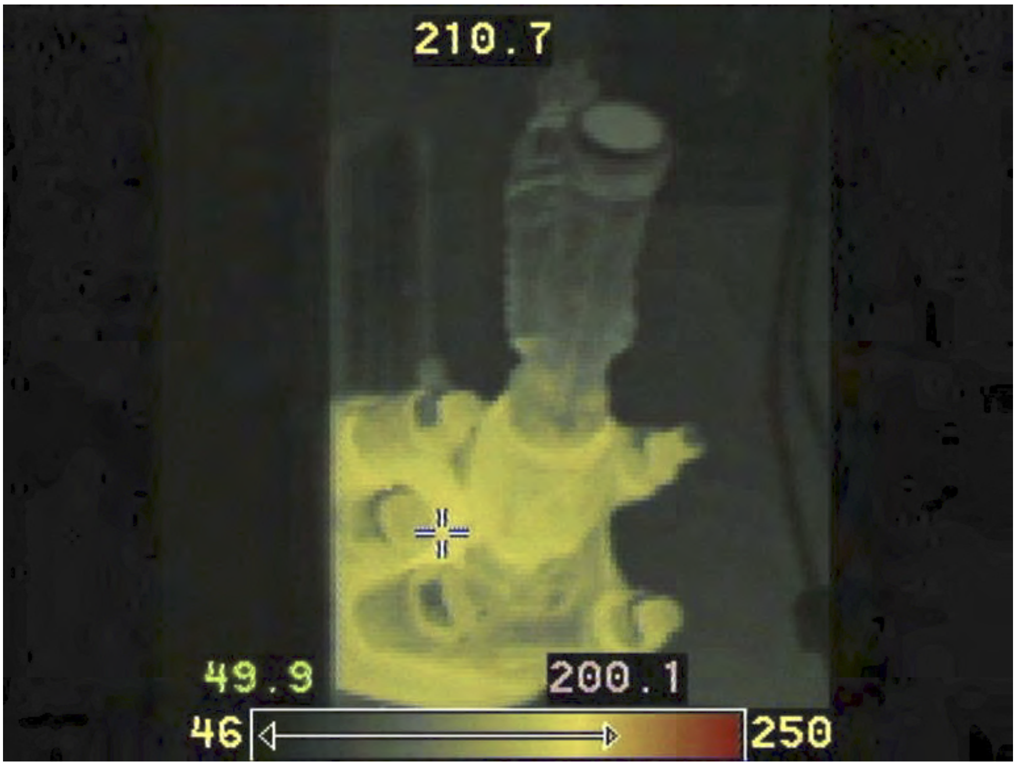


Figur 1 IR-bilde av indikatorkran 1

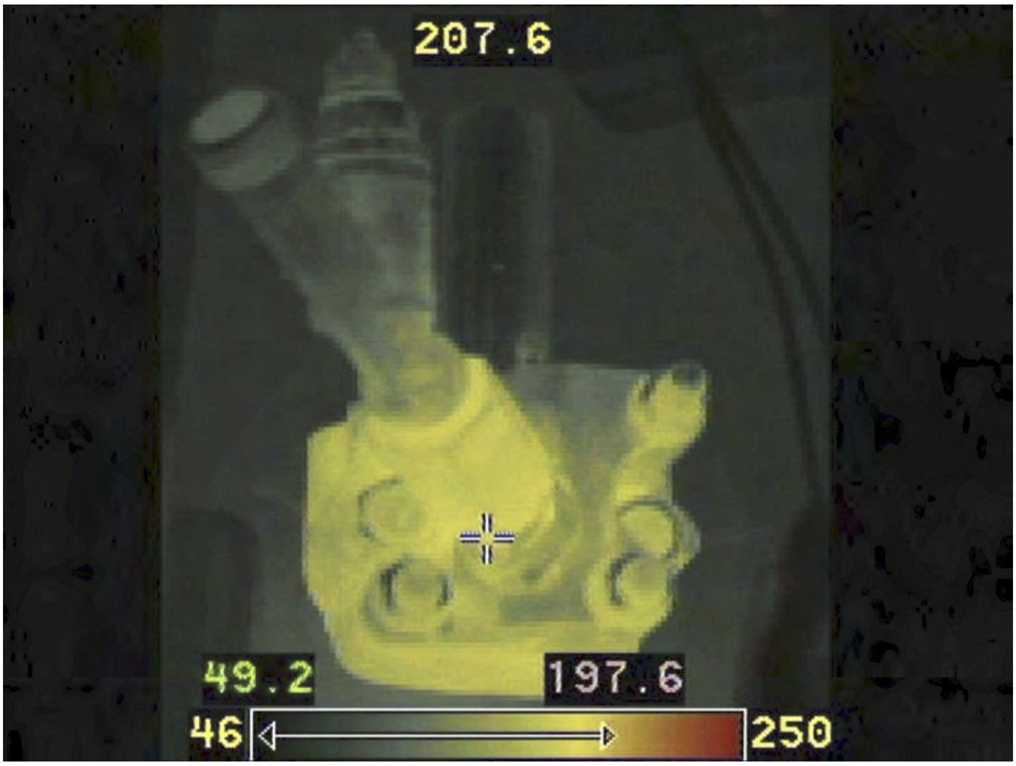


Figur 2 IR-bilde av indikatorkran 1

SINTEF

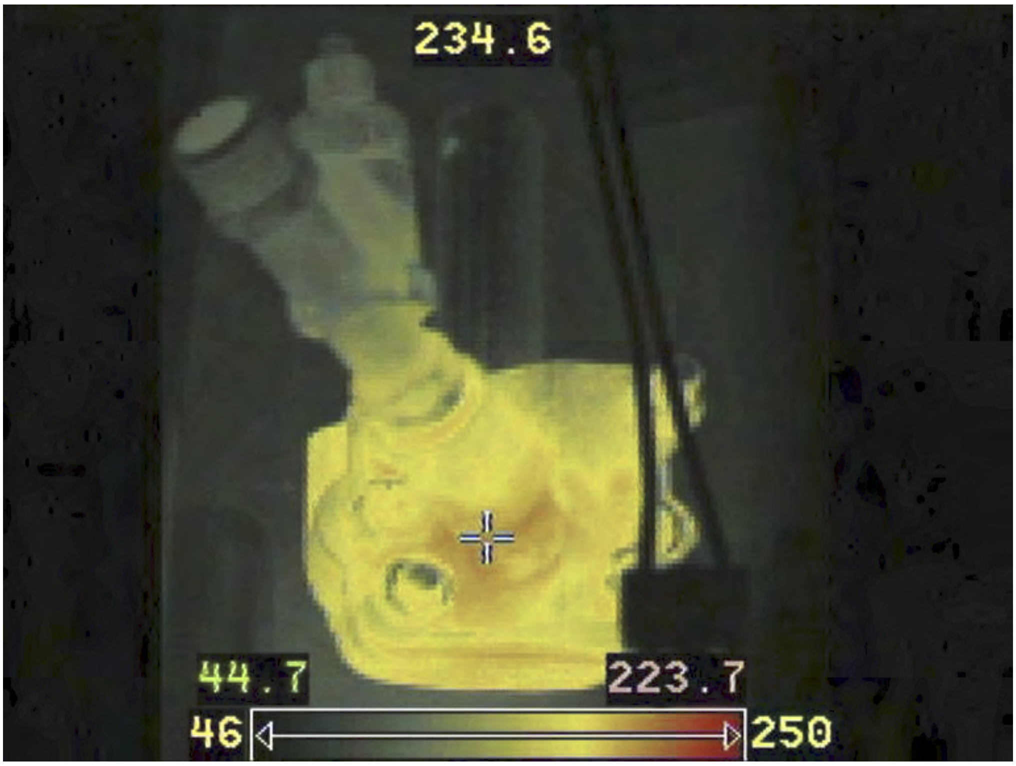


Figur 3 **IR-bilde av indikatorkran 2**

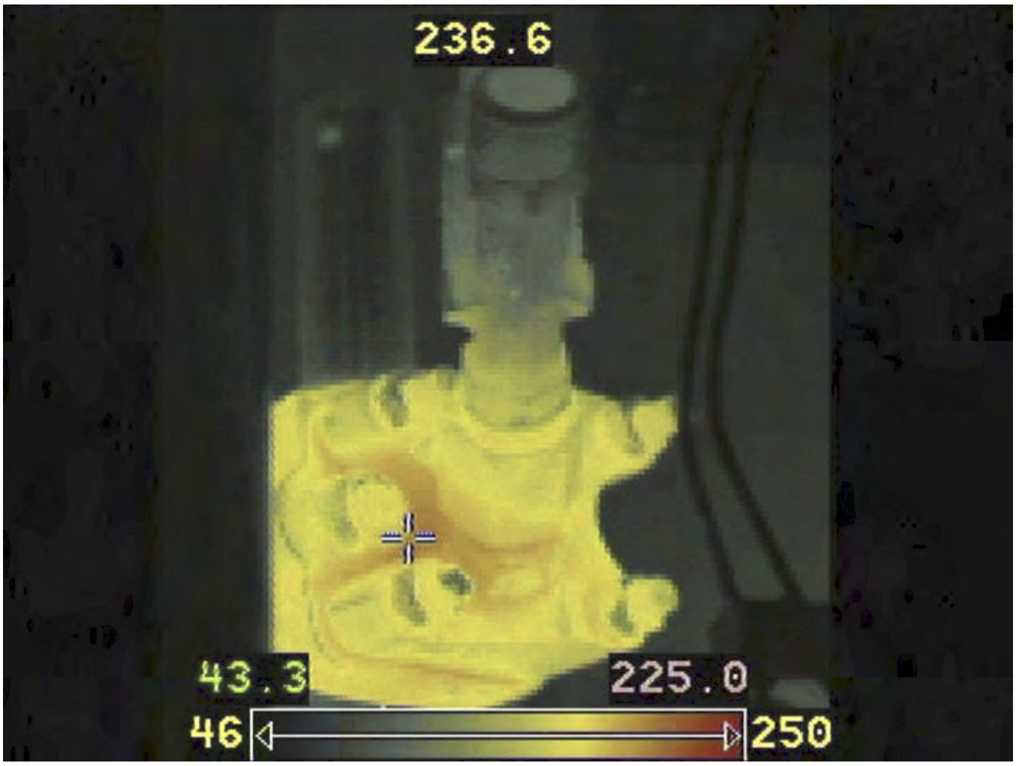


Figur 4 **IR-bilde av indikatorkran 2**

SINTEF

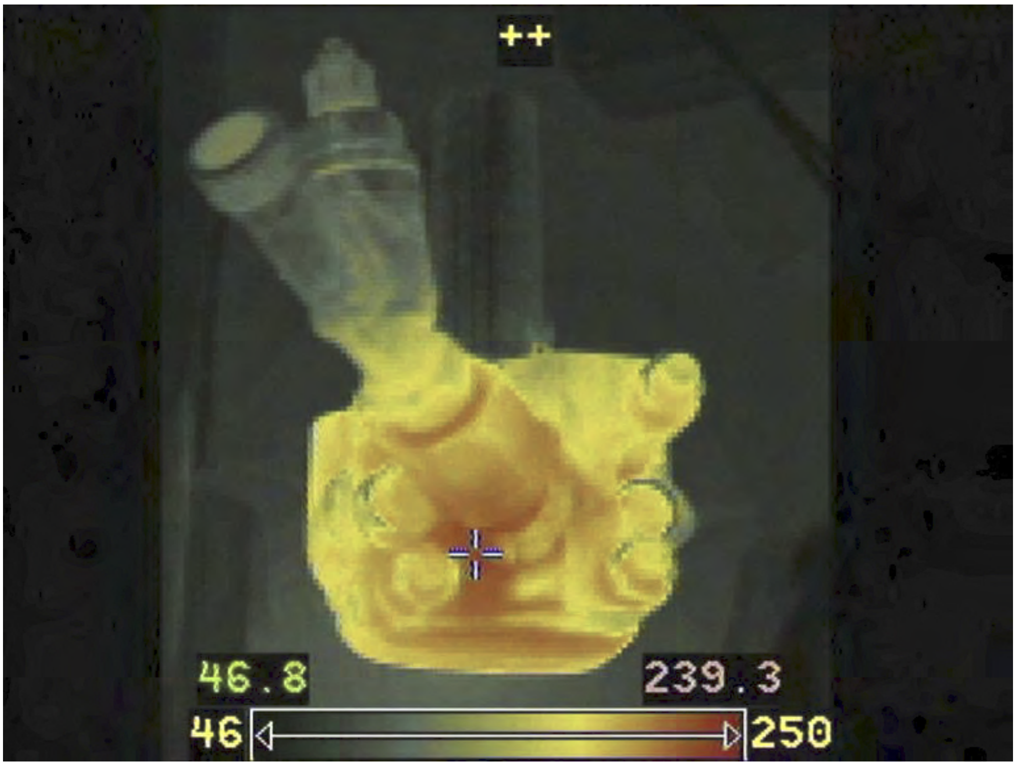


Figur 5 **IR-bilde av indikatorkran 3**

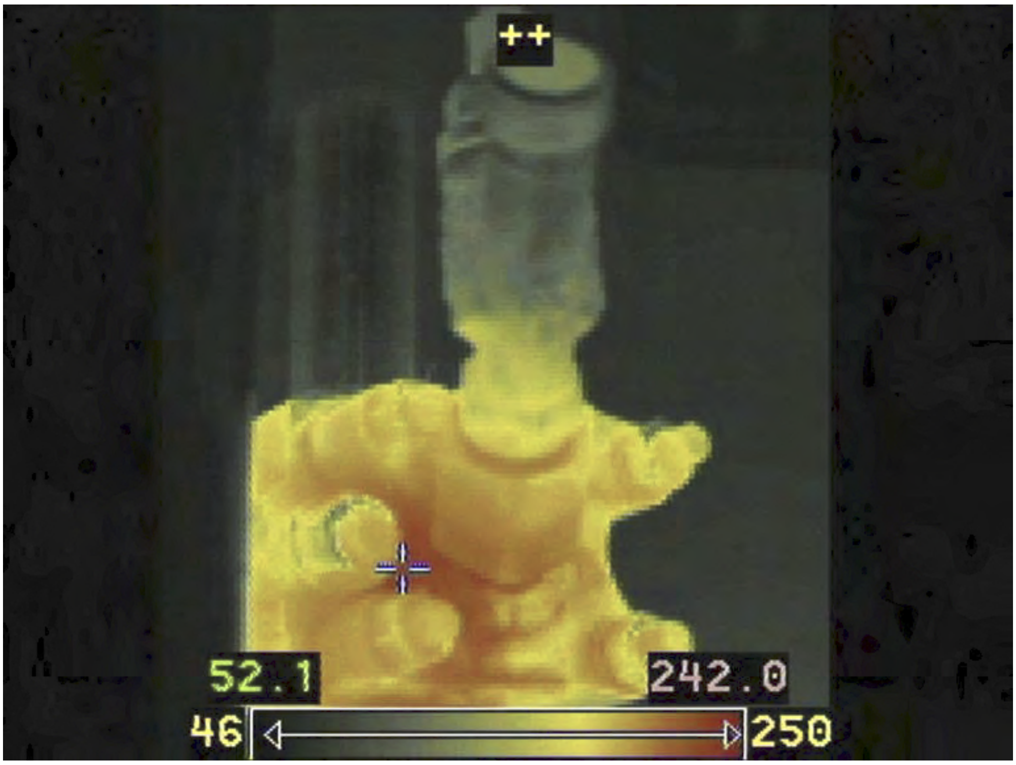


Figur 6 **IR-bilde av indikatorkran 3**

SINTEF

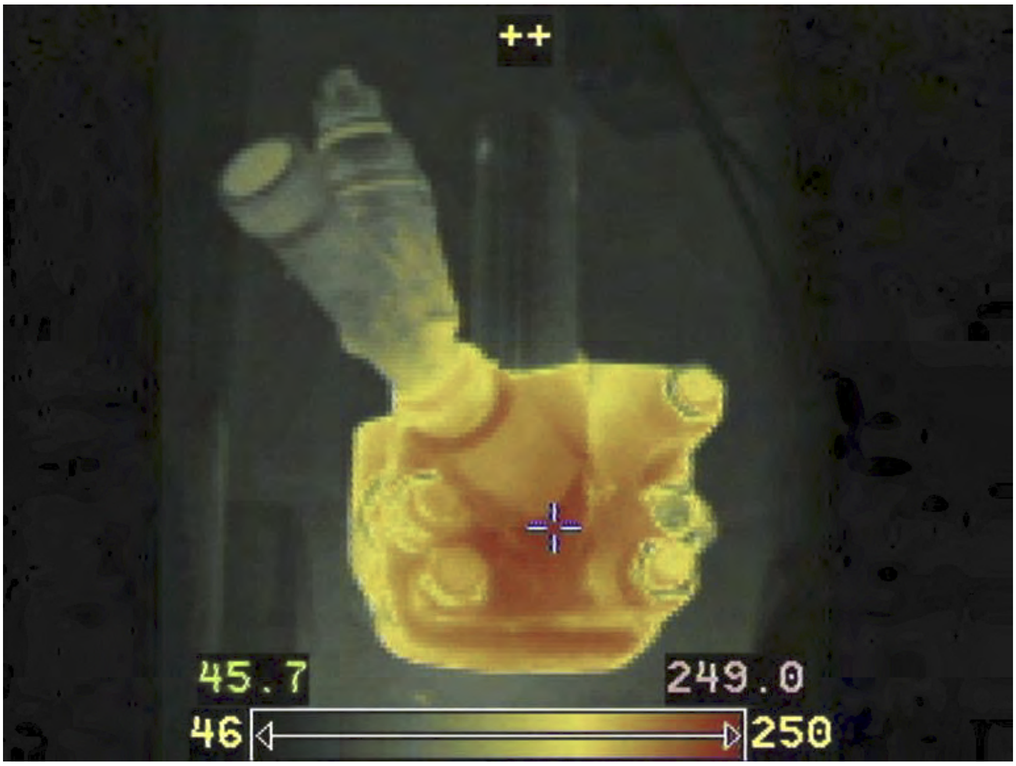


Figur 7 **IR-bilde av indikatorkran 4**



Figur 8 **IR-bilde av indikatorkran 4**

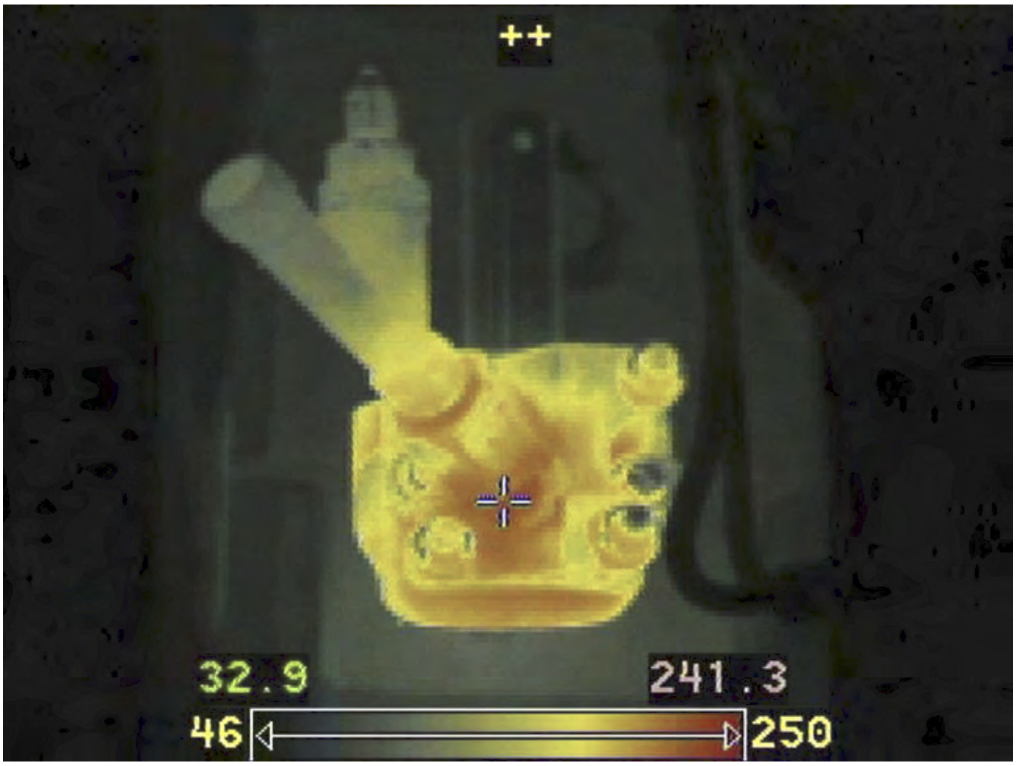
SINTEF



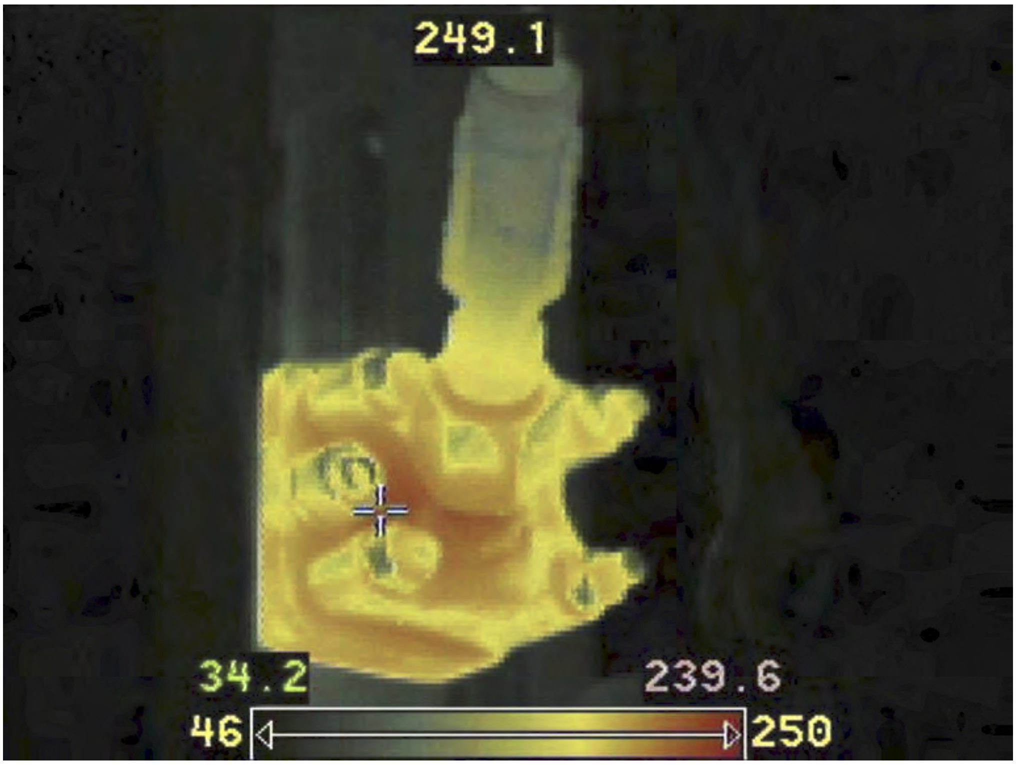
Figur 9 **IR-bilde av indikatorkran 5**

Figur 10 **IR-bilde av indikatorkran 5**

SINTEF

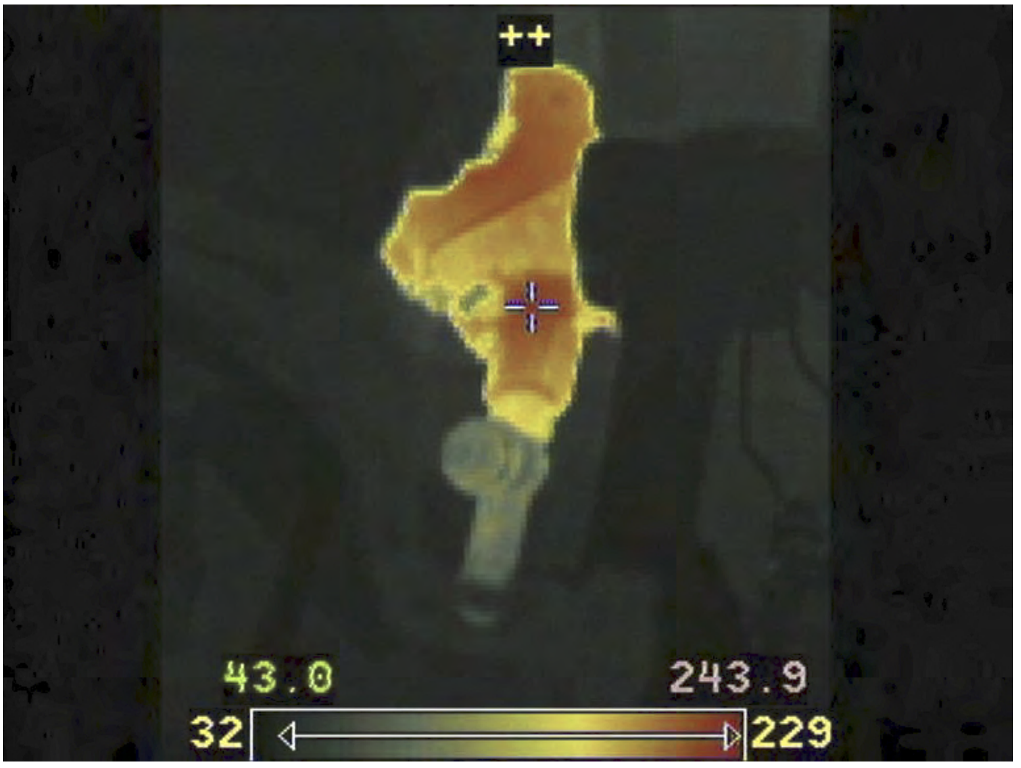


Figur 11 IR-bilde av indikatorkran 6



Figur 12 IR-bilde av indikatorkran 6

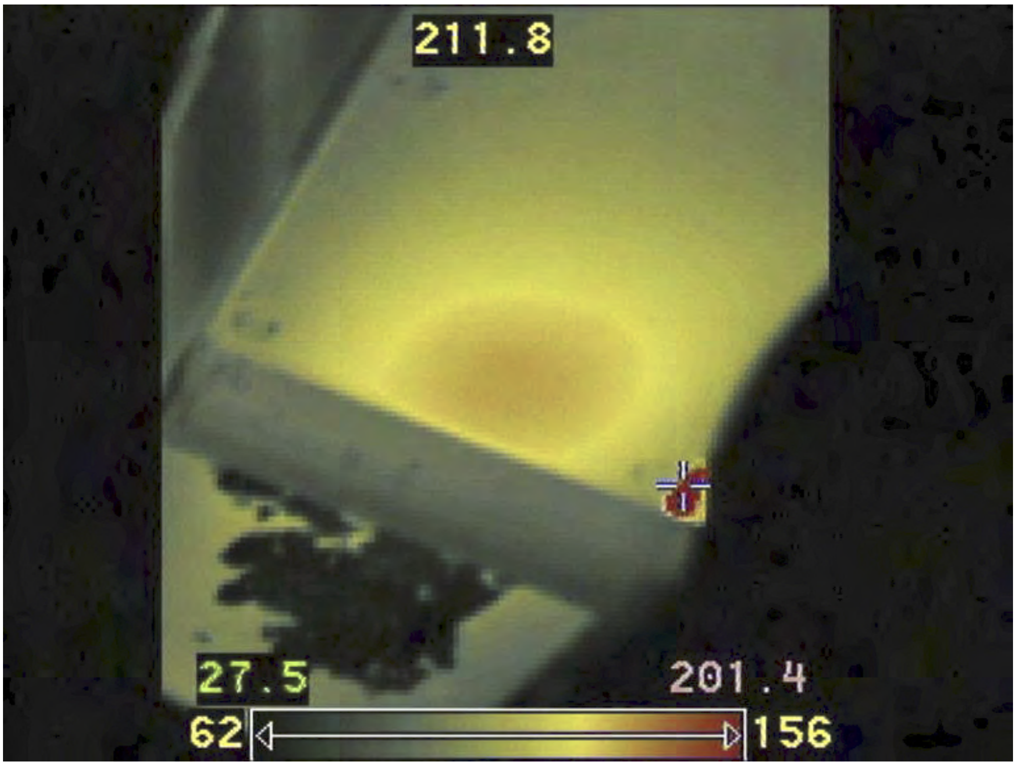
SINTEF



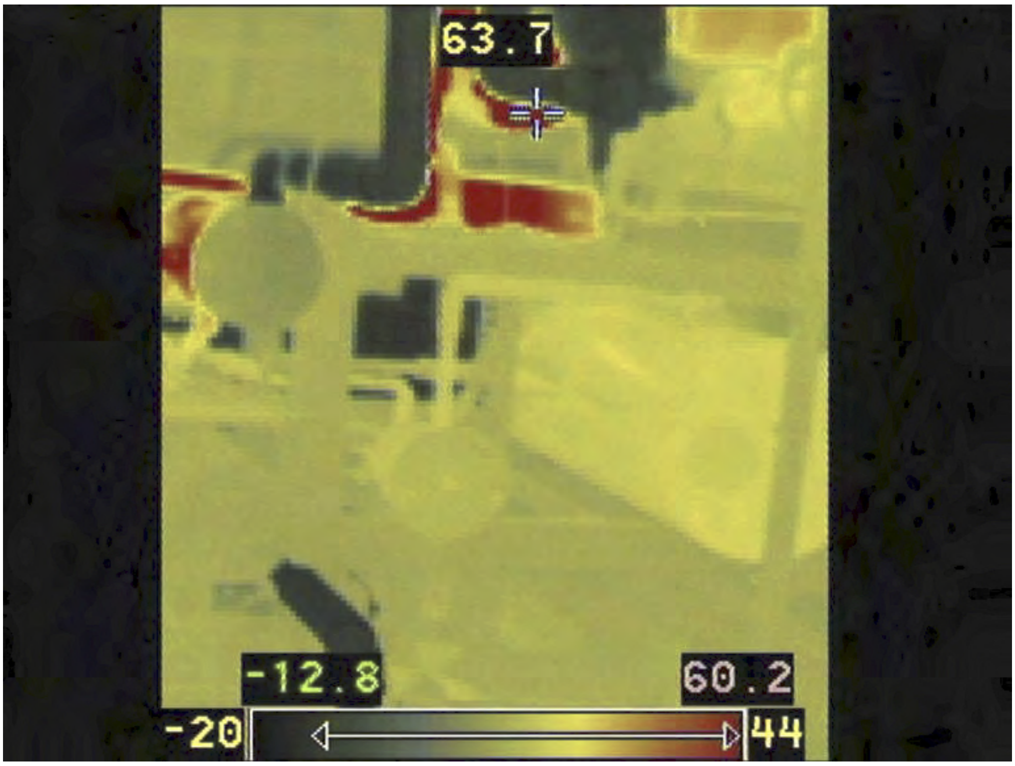
Figur 13 **IR-bilde av indikatorkran 6 sett ovenfra**

Figur 14 **IR-bilde av babord side av styrbord hovedmotor**

SINTEF



Figur 15 **IR-bilde av babord side av styrbord hovedmotor**



Figur 16 **IR-bilde av kjølekompressor**

SINTEF

4 Fotografier

Foto 1 Indikatorkran 6 sett ovenfra.

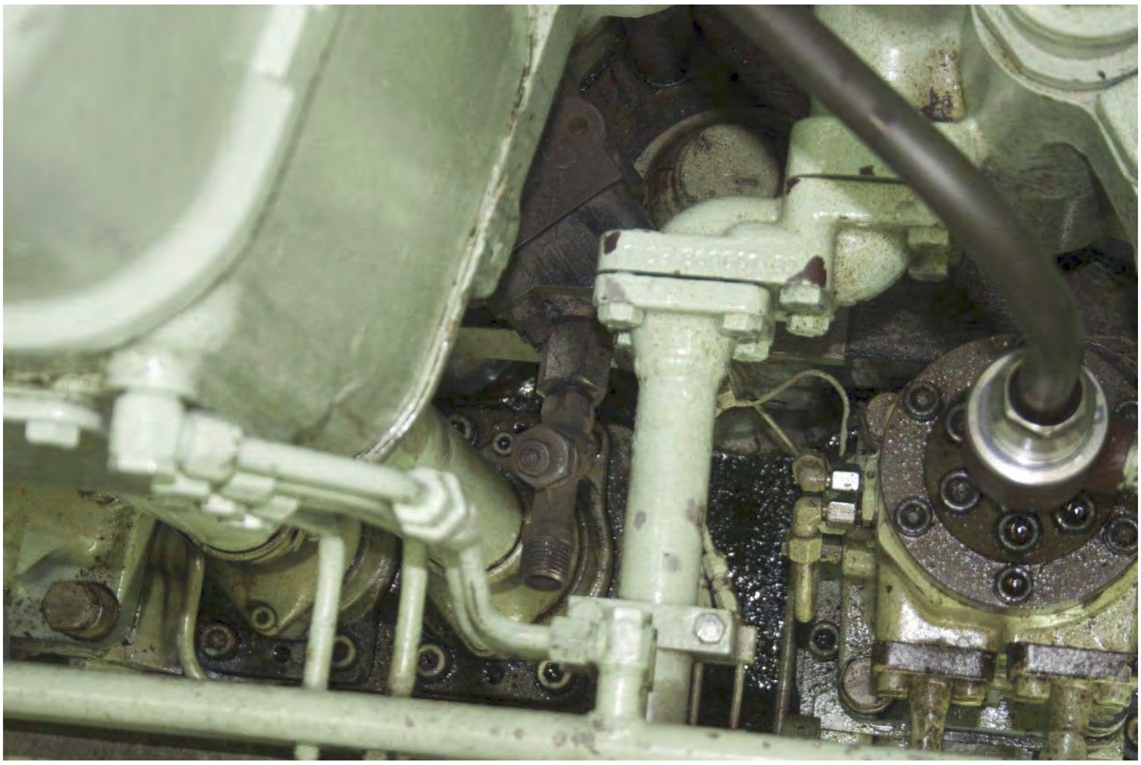


Foto 2 Indikatorkran 5 sett ovenfra.

SINTEF

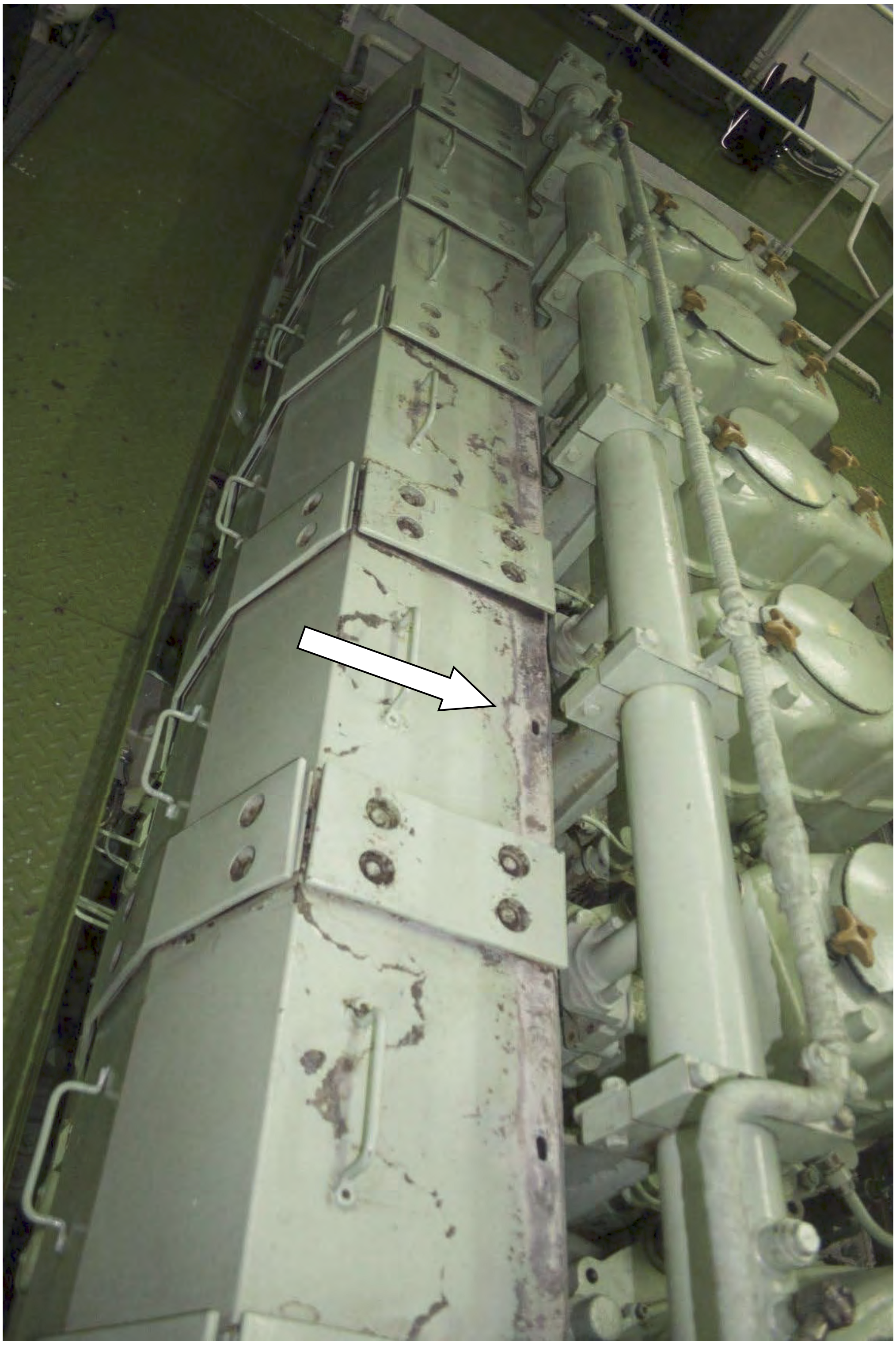


Foto 3 **Deksel rundt eksosmanifold. Lakken ser ut til å være varmepåvirket på aktre halvdel av dekselet, nærmest motorens senterlinje. Pilen peker på punktet som er referert til som "eksosmanifold topp" i temperaturtabellene.**

SINTEF

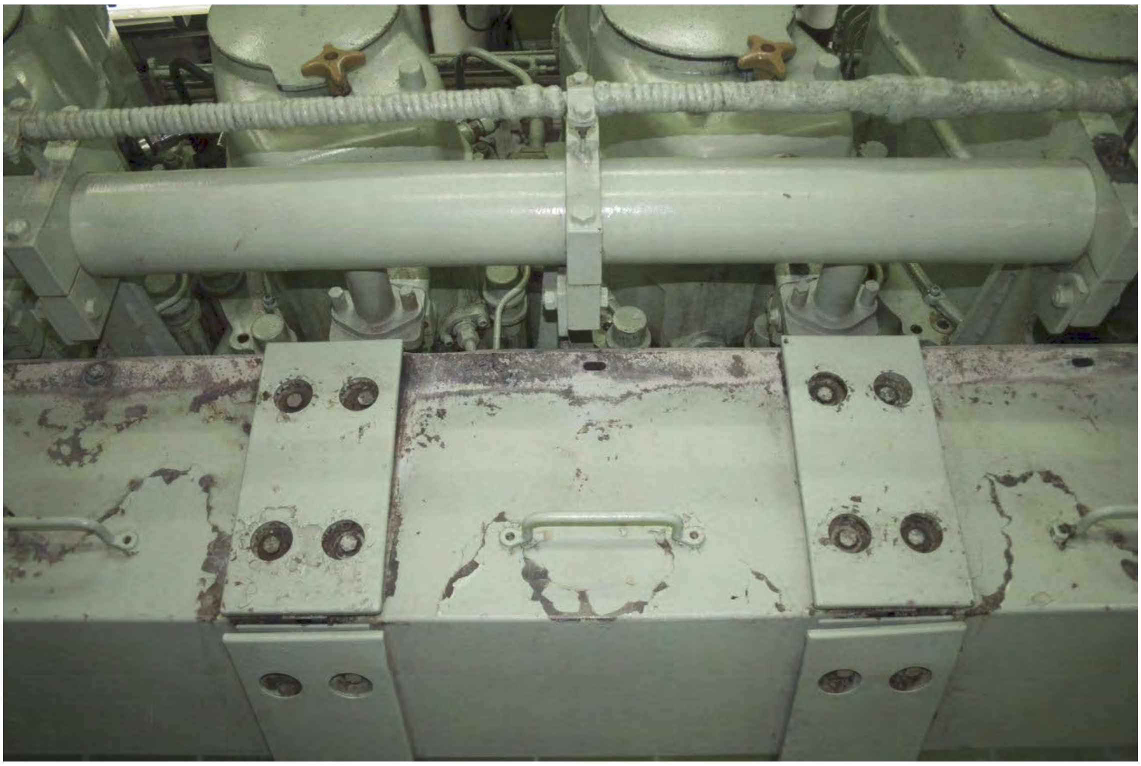


Foto 4 **Deksel rundt eksosmanifold. Lakken ser ut til å være varmepåvirket.**

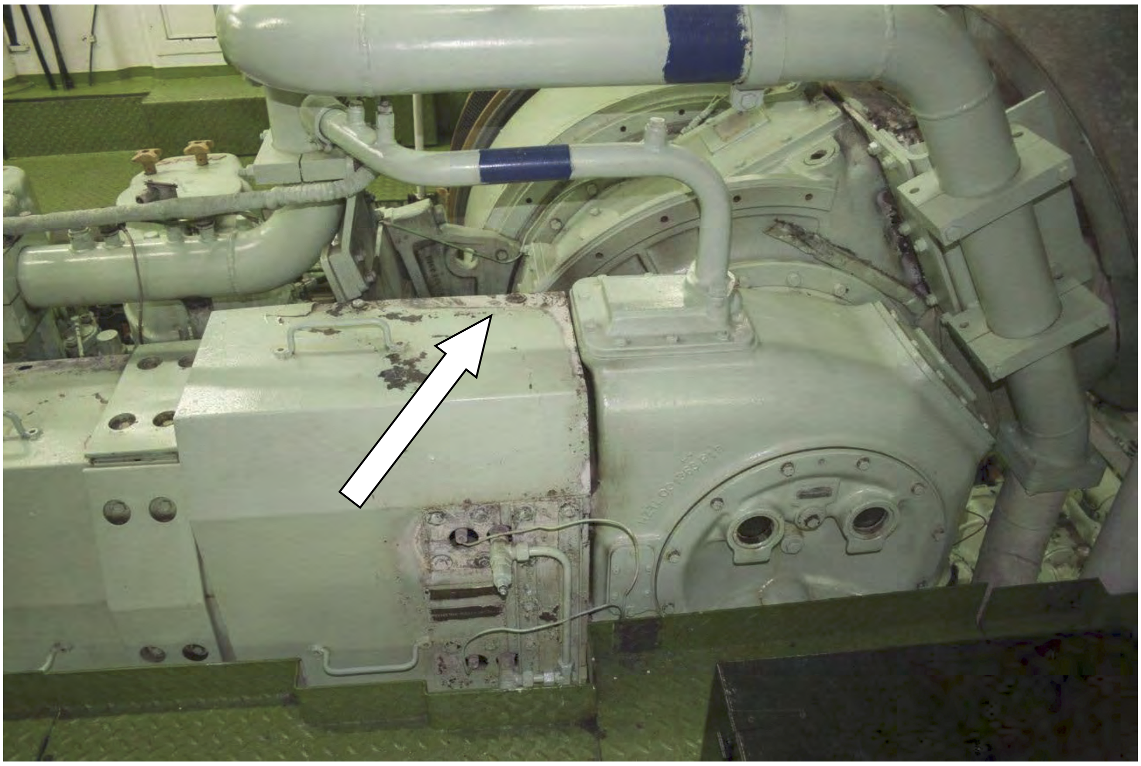


Foto 5 **Overgangen fra eksosmanifolden til turboladeren. Ser tendenser til varmepåvirket lakk.**

SINTEF

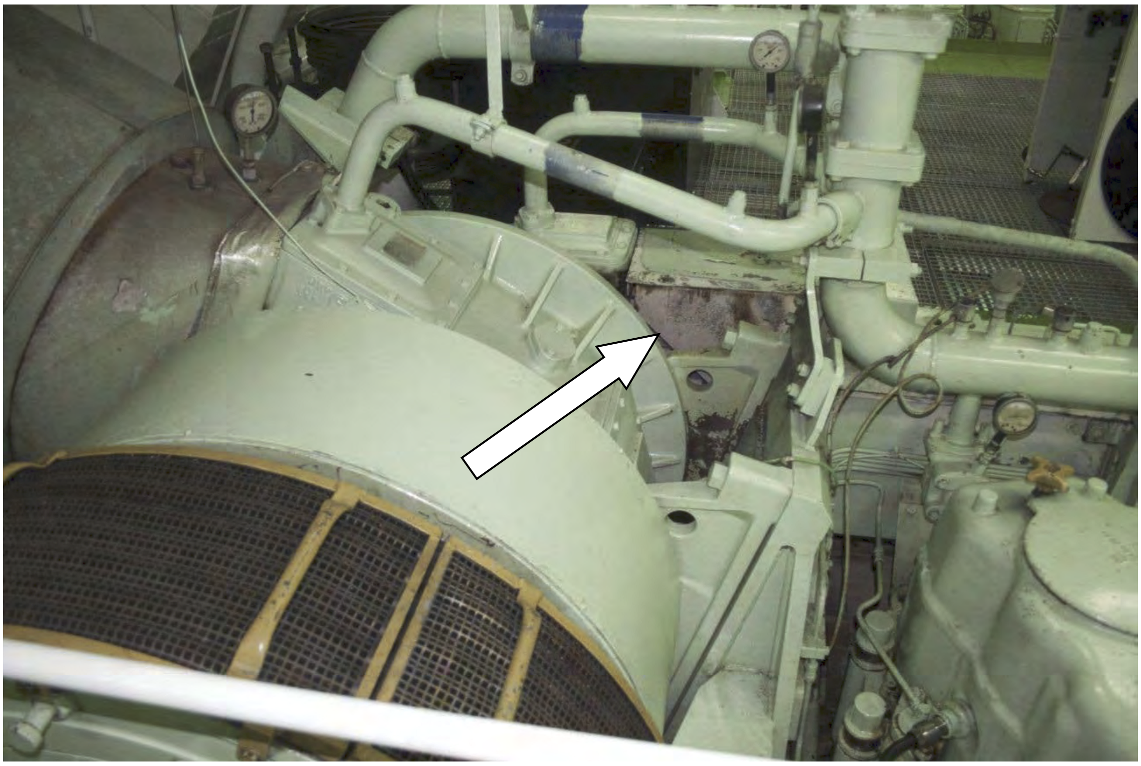


Foto 6 **Overgang fra eksosmanifold til turbolader sett fra motsatt side (fra styrbord) i forhold til Foto 5. Pilen peker på punktet som er referert til "overgang mot turbolader" i temperaturtabellene.**

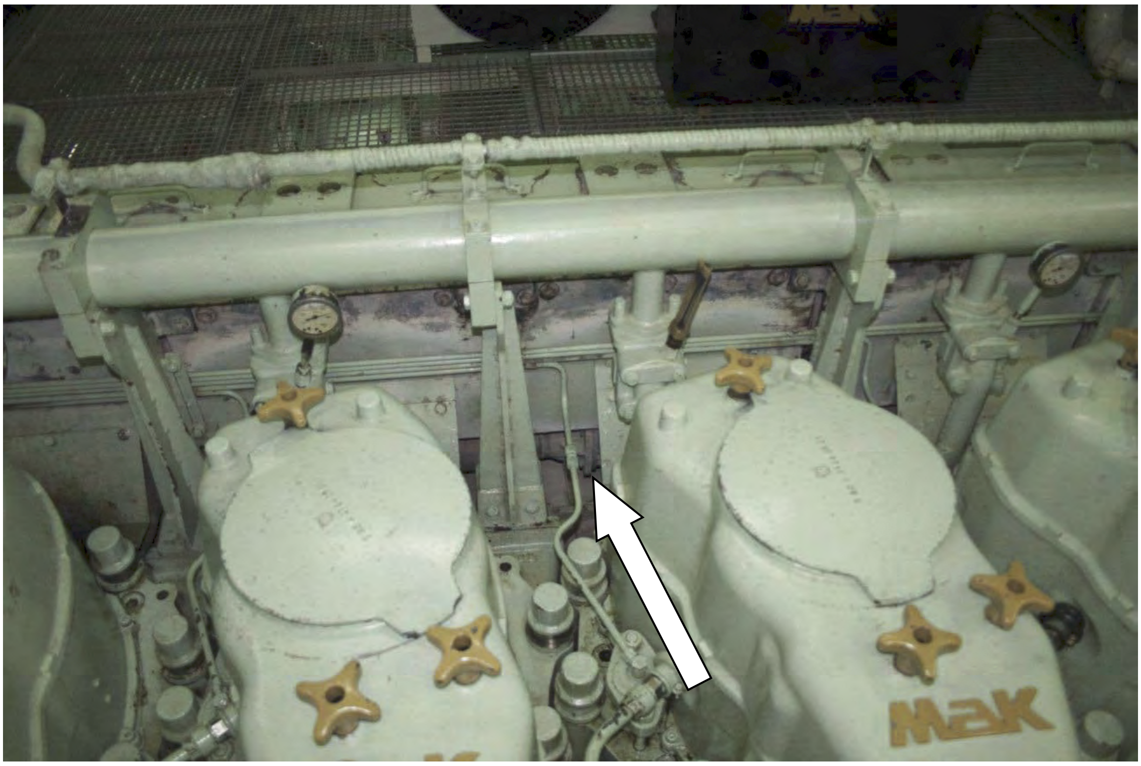


Foto 7 **Eksosmanifold sett fra styrbord side. Pilen peker på punktet som er referert til "eksosmanifold flens" i temperaturtabellene.**

SINTEF

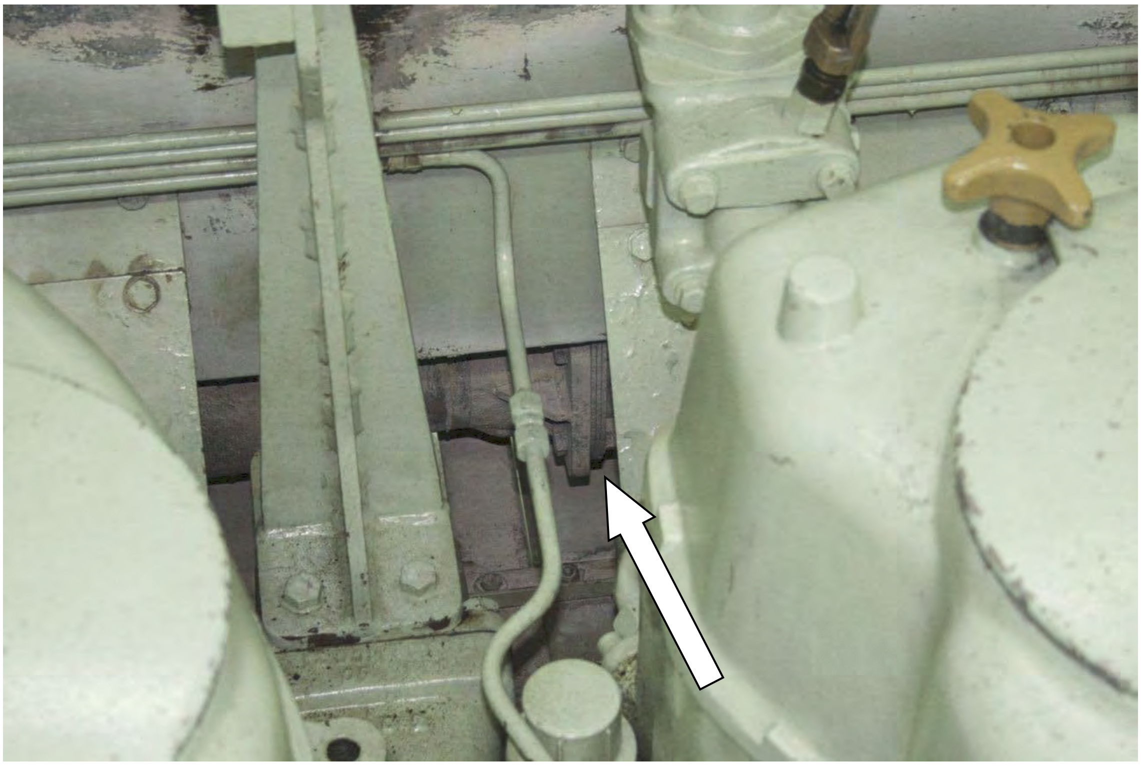


Foto 8 **Pilen peker på punktet som er referert til "eksosmanifold flens" i temperaturtabellene.**

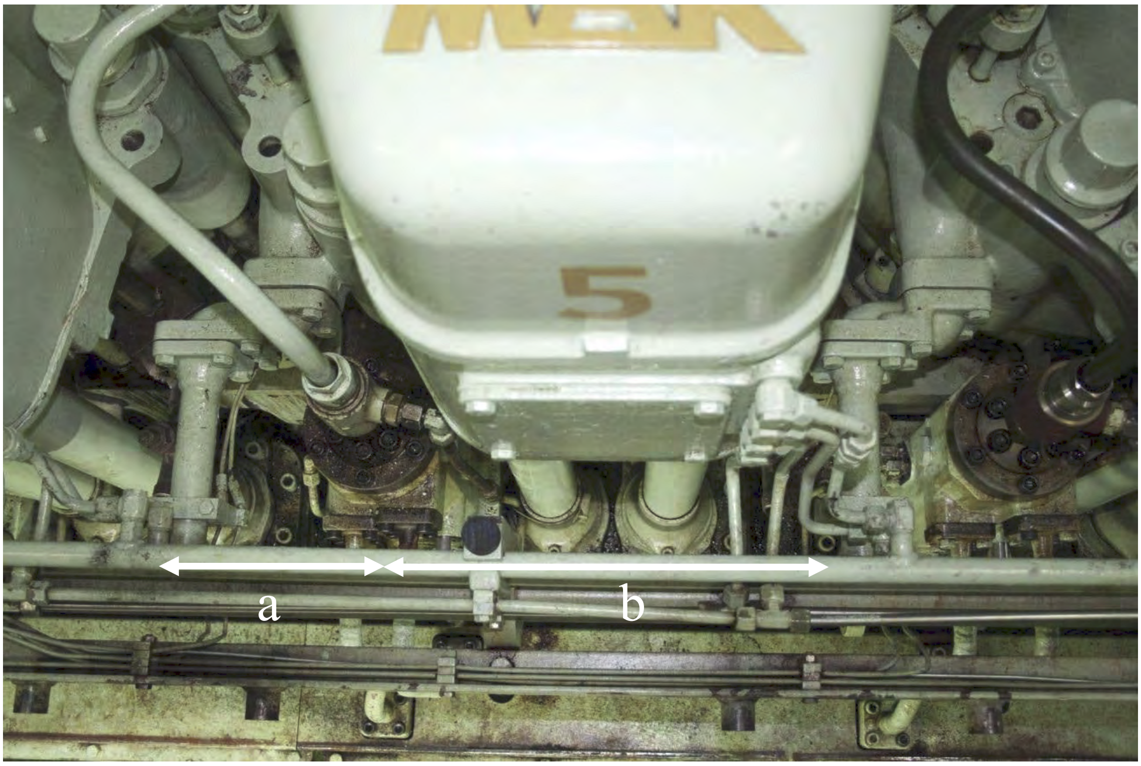


Foto 9 **Sylider, fuelpumpe og indikatorkraner sett ovenfra. Linjestykke *a* angir avstanden mellom fuelpumpe og indikatorkran til venstre (a = 24 cm) og linjestykke *b* angir avstanden mellom fuelpumpe og indikatorkran til høyre (b = 42 cm).**

SINTEF

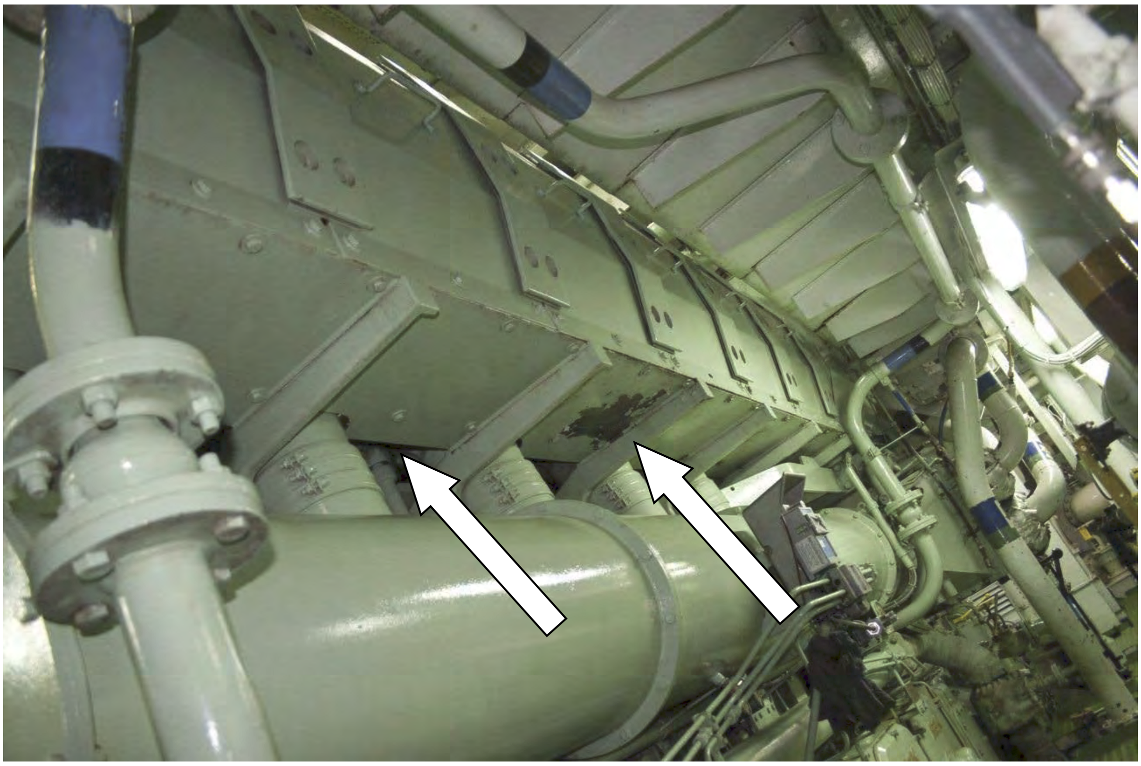


Foto 10 **Bildet viser avskalling av lakk oppunder babord side av styrbord hovedmotor (høyre pil). Venstre pil peker på punktet hvor sylindertemperaturen for hver sylinder ble målt.**

Foto 11 **Detalj av avskalling av lakk oppunder babord side av styrbord hovedmotor.**

Bergen Dieselcontact

SERVICE RAPPORT VF-4639

Fartøy / Objekt	Nordlys
Kunde	Maritim Motor AS
Kontaktperson / Tlf.nr.	Andre Langstein Mob 91644900
Type	6V92TA
Drift	Nød generator
Modell	8063-7405
Serienr.	06VF202175
Gangtid	111,1 timer
Anlegg	Nød generator

	Oppdrag (merk av):	Kort beskrivelse: Overhaling av motor etter varmkjøring.
	Oppstått problem	
	Reklamasjon	
x	Planlagt/avtalt service	

Dato	Beskrivelse	Mek	Ord.	50%	100%	12 t	>12t	Diett
27/9	Reist til Ålesund og Fiskerstrand verft. Demontert stempler, foringer, blåser og ladeluft kjøler. Tatt med deler og reist til Maritim Motor sitt verksted. 4 av stempelstakene var defekt, bestilt nye.	TH	7,5	4,5	1			1
28/9	Satt sammen stempler og foringer, plugget topper og flyttet over endelokk på bytteblåser. Hentet deler på Vigra flyplass og reist til Fiskarstrand verft og fått om bord deler. Demontert vannpumpe.	TH	7,5	4,5				1
29/9	Montert vannpumpe, skiftet rammelager, montert stempler og foringer, montert bunnpanne. Montert topper og blåser+ div. vann og dieselslanger.	TH	7,5	4,5				1
30/9	Montert injektorer med nye rør og justert motor, montert ny turbo og manifoiler, skiftet alle vannslanger og fylt opp motor med vann. Fikk ikke startet motor da vi manglet motorolje. Pakket sammen verktøy og reist tilbake til Bergen.	TH	7,5	4,5	1			1

Besøksadresse: Damsgårdsveien 131 5162 Laksevåg

Postadresse: Postboks 36 Laksevåg 5847 Bergen

Internett: www.bergendieselcontact.no E-post:

Telefon: +47 55 94 78 60 Telefaks:

MARITIM MOTOR A/S

Visitreport

Customer	:	Nordlys
Date report	:	03-10-2011
Location	:	Tomrefjord
Report made by	:	Marius Lyngvær
Copy to	:	Ronny Vik
		Ove Paulsen (Takstmann)
		Jimmy Johansen (Chief)

Starting date of inspection	:	26-09-2011
Place of inspection	:	Fiskerstrand Verft
Reason	:	Havari
Present	:	Marius Lyngvær
		Thor Hermansen
		Ove Paulsen
		Jimmy Johansen

Engine type	:	Detroit 6V-92
Application	:	Gen set
Engine number	:	203173
Engine RPM	:	1800
Engine power output	:	355hp
Running hour	:	111

Nordlys

Telefon	Telefaks	Adresse	Bankgiro	Foretaksnummer
(47) 71 18 22 70 Info@maritim-motor.no	(47) 71 18 20 14	Trohaugen N-6393 Tomrefjord Norway	4060.27.03446	NO 997 114 949 MVA

MARITIM MOTOR A/S

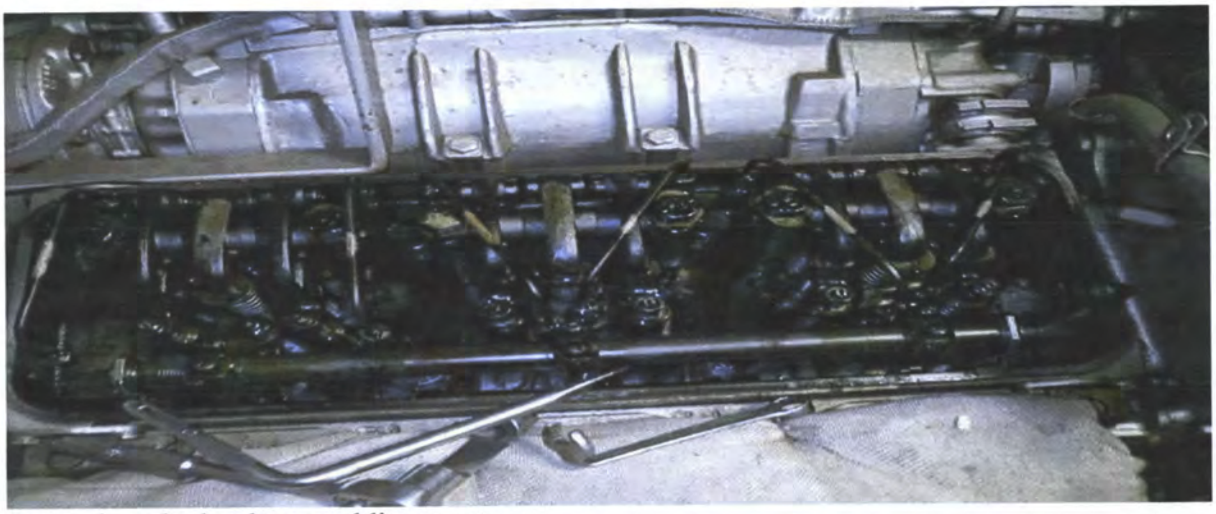
SERVICE DETROIT 6V-92 NØDAGGREGAT MS NORDLYS .

Oppdrag

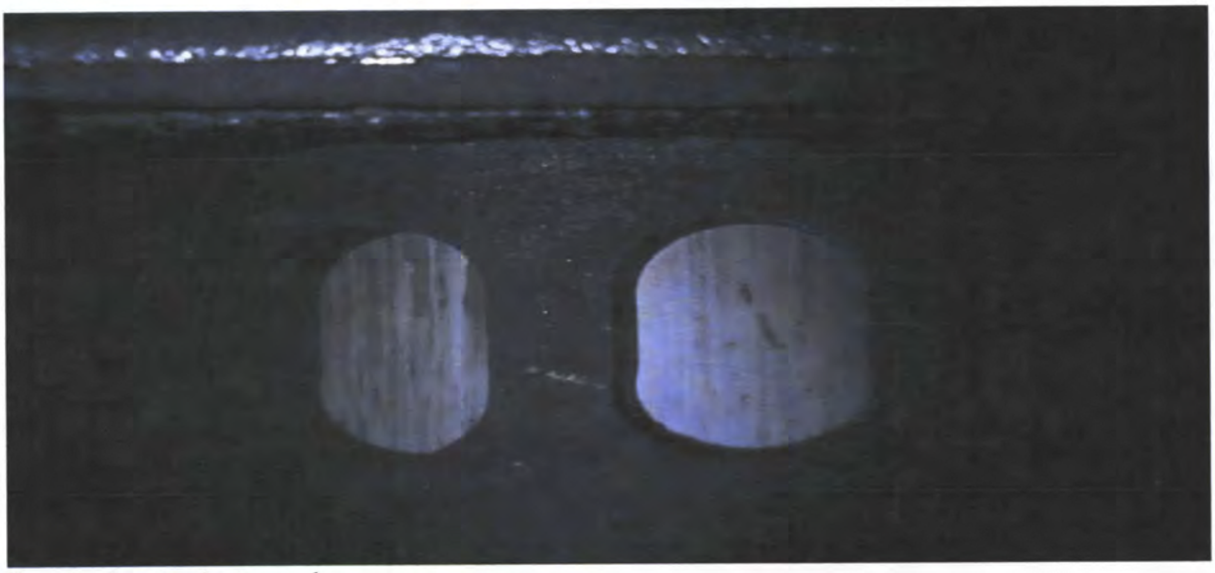
Vegard Eid representant fra Fiskerstrand Verft AS ringte til oss, og ville ha folk til å se på nød aggregatet på Nordlys.
Motoren hadde stoppet, og den var trolig havarert.

26-09-2011

Startet dagen på verkstedet 07.00, reiste deretter ut til fiskerstrand verft. Begynte jobben med og turne motoren, men uten hell. Tok ut injektorene, fortsatt fast. Pratet da med Ove Paulsen, vi ble enige om at bunnpannen måtte ned og topper av.



Ser godt at det har hvert veldig varmt.



Ser rivninger på stempel.

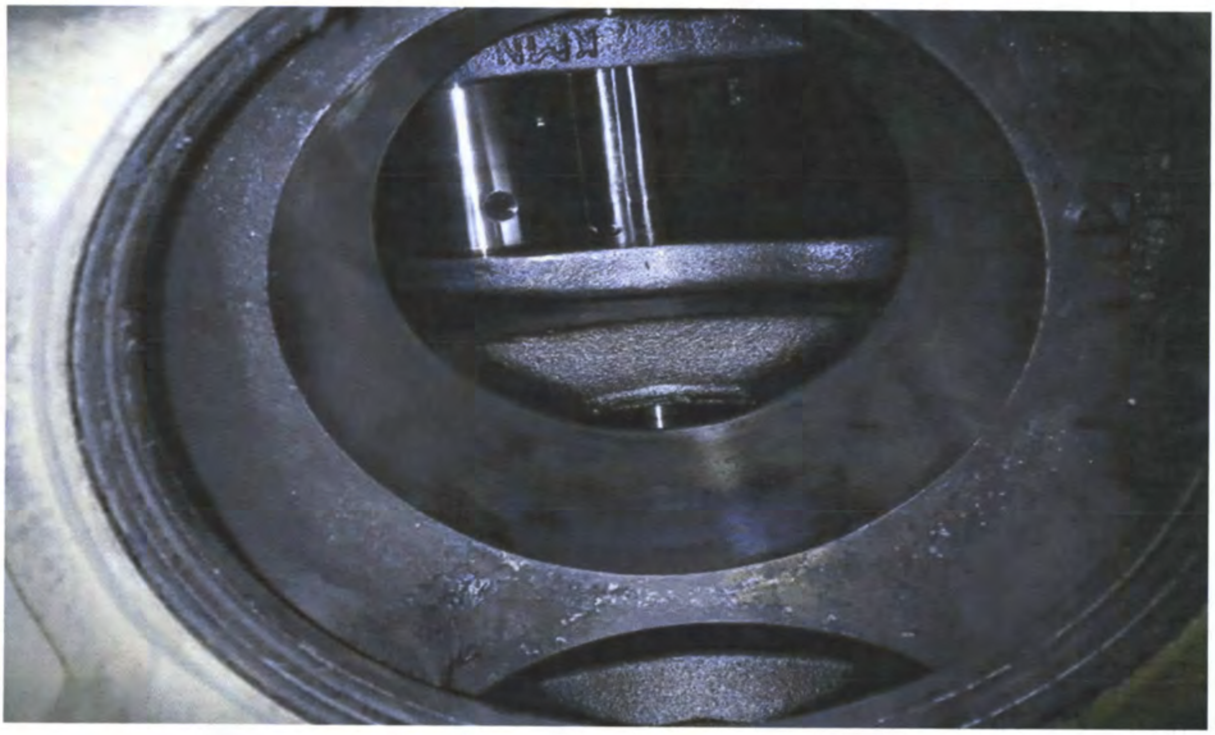
Telefon	Telefaks	Adresse	Bankgiro	Foretaksnummer
(47) 71 18 22 70 Info@maritim-motor.no	(47) 71 18 20 14	Trohaugen N-6393 Tomrefjord Norway	4060.27.03446	NO 997 114 949 MVA

MARITIM MOTOR A/S

Når jeg fikk av toppene var det klart at det hadde revet seg på flere sylindere. Slutt 20.30

27-09-2011

Startet dagen på verkstedet til Maritim Motor AS 07.00, reiste til Vigra for å hente Thor Hermansen fra Bergen Diesel Contact. Ankom verftet og gikk i gang med å dra stempler, så da at alle måtte byttes. Da vi dro foringene så vi at blokken hadde fått blåfarge pga varmen.



Telefon	Telefaks	Adresse	Bankgiro	Foretaksnummer
(47) 71 18 22 70 Info@maritim-motor.no	(47) 71 18 20 14	Trohaugen N-6393 Tomrefjord Norway	4060.27.03446	NO 997 114 949 MVA

MARITIM MOTOR A/S

Da var neste steg å sjekke ramme lagrene, men det var i orden. Etter en telefon til Ove Paulsen ble vi enige om at alle lagrene skulle byttes uansett.

Alt av deler ble pakket i bilen og fraktet til Maritim Motor AS sitt verksted for overhaling
Slutt 20.00

28-09-2011

07.00 overhaling og montering av deler skjedde på verkstedet. Deretter ble delene fraktet til Fiskersrand Verft og tatt ombord. Slutt 20.00

29-09-2011

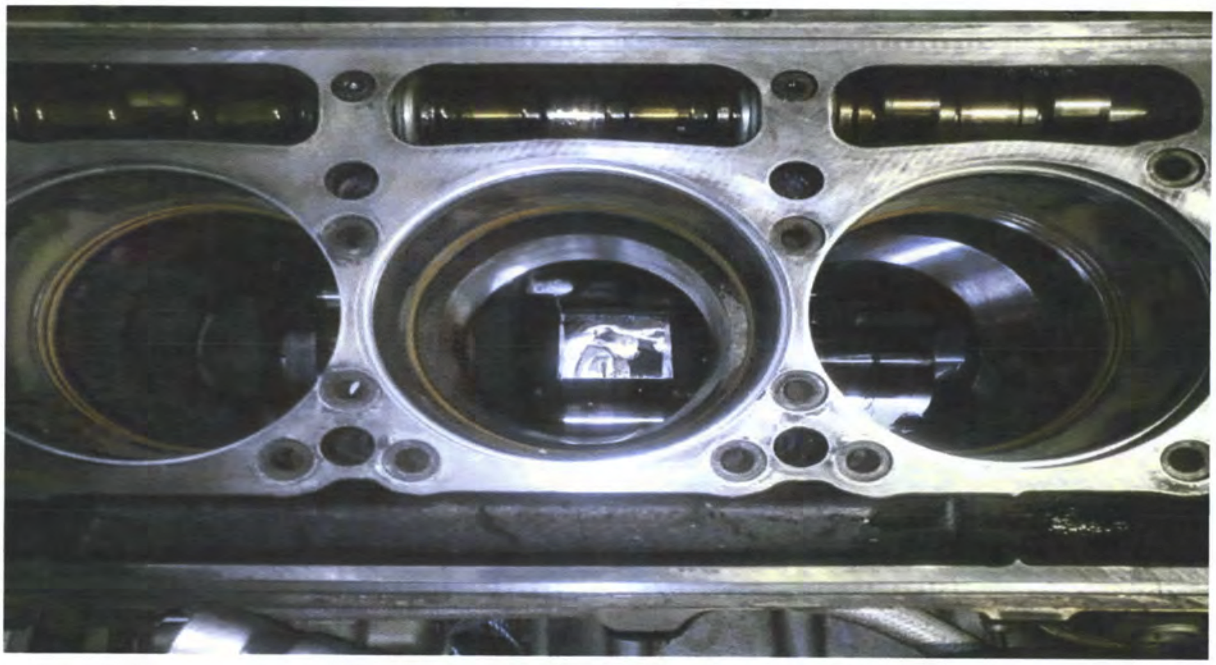
Startet 07.00
Tok bytting av ramme lager, endeseiling ble på 0,12 mm. Så ble vannpumpen montert pluss rengjøring av motor blokka
Slutt 19.30

Telefon	Telefaks	Adresse	Bankgiro	Foretaksnummer
(47) 71 18 22 70 Info@maritim-motor.no	(47) 71 18 20 14	Trohaugen N-6393 Tomrefjord Norway	4060.27.03446	NO 997 114 949 MVA

MARITIM MOTOR A/S

30-09-2011

Startet 07.00



Fortsatte rengjøringen av motor blokken og o-ringer montert, klar for foring og stempler.

Alle stempler mont.

Telefon	Telefaks	Adresse	Bankgiro	Foretaksnummer
(47) 71 18 22 70 Info@maritim-motor.no	(47) 71 18 20 14	Trohaugen N-6393 Tomrefjord Norway	4060.27.03446	NO 997 114 949 MVA

MARITIM MOTOR A/S

Motoren nesten ferdig montert, slutt 20.00

30-09-2011

Startet 07.00 og motoren var ferdig montert ca 15.30, men pga mangel på olje ble oppstart utsatt.

Telefon	Telefaks	Adresse	Bankgiro	Foretaksnummer
(47) 71 18 22 70 Info@maritim-motor.no	(47) 71 18 20 14	Trohaugen N-6393 Tomrefjord Norway	4060.27.03446	NO 997 114 949 MVA

TECHNICAL REPORT

HURTIGRUTEN ASA

NORDLYS
DNV ID 17826
IMO NO 9048914

STABILITY CALCULATIONS AFTER DAMAGE

REPORT NO. 2011-1387
REVISION NO. 0

DET NORSKE VERITAS

DET NORSKE VERITAS

TECHNICAL REPORT

Date of first issue: 2011-11-09	Project No.: PP024830
Approved by: Anne Marie Kristensen Head of Group	Organisational unit: Ship Hydrodynamics and Stability
Client: Hurtigruten ASA	Client ref.: Kurt Grunstad

DET NORSKE VERITAS AS
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Maritime Technical Consultancy
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Fax: +47 67 57 99 11
http://www.dnv.com
Org. No: NO 945 748 931 MVA

Summary:

This report contains damage stability analysis of the vessel based on the damage situation by quay in Ålesund.

It is hard to establish the exact rate of leakage into cargo hold 1 and the accomodation above. A number of intermediate conditions are therefore examined.

The vessel will not reach a stable condition with full flooding of the compartments where sea water entered during the accident. The vessel will be unstable during most of the intermediate flooding stages as well.

The damage, in way of the stabilizer fin, is submerged in all conditions. Any condition with sufficient heel to lift the damage out of the water will not improve the situation since other openings on the port side will be submerged and water will enter the same compartments.

Report No.: 2011-1387	Subject Group:	
Report title: NORDLYS – Stability calculations after damage		
Work carried out by: Ingar Sarnes		
Work verified by: Anne Marie Kristensen		
Date of this revision: 2011-11-09	Rev. No.: 0	Number of pages: 18+appendix

Indexing terms

Key words	Service Area
CAR FERRY STABILITY DAMAGE	
	Market Sector

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Table of Content *Page*

1 INTRODUCTION

DNV’s section Ship Hydrodynamics and Stability was contacted to examine the vessel in damage condition wether the damage would come out of water if the vessel would be further flooded.

During an engine room fire the vessel was put along a quay in Ålesund, Norway, to extinguish the fire with aid from shore. During the docking the starboard stabilizer fin were bent and made a hole in the side shell leading water into cargo hold 2. Progressive flooding occurred and lead to a angle of heel of about 20 degrees which was increasing.

This report examines whether the damage would come out of the water at increased flooding and heel, and whether the vessel would have reached a equilibrium stage in case pumping was not possible.

Any close examination of leakages are not carried out. Some possible means of leakage for the compartments are indicated.

2 PARTICULARS

▪ IMO number	9048914
▪ DNV id number	17826
▪ DNV class	ROPAX (+1A1 Car Ferry A)
▪ LOA=	121.8m / LBP=103.8m / B=19.2m
▪ Max draught =	4.70 m
▪ Maximum number of passengers:	690
▪ Numbers of cars:	45
▪ Keel laid:	1992 / Delivered: 1994
▪ Yard:	Volkswerft – Stralsund, Germany
▪ Flag:	Norway (NOR) Stability approval carried out by NMD Not enrolled in DNV ERS
▪ Damage stability level	One compartment damage

3 CONCLUSIONS

The rate of leakage can not be established with sufficient accuracy. A number of intermediate conditions are therefore examined.

The vessel would not survive full flooding of the compartments who contained sea water during the accident. Nor would the vessel withstand most of the intermediate flooding stages.

The damage is submerged in all conditions. Any condition with sufficient heel to lift the damaged area out of the water will not make any change since other openings on the port side are submerged and let water into the same compartments.

The vessel is designed to withstand damage to one section of the vessel like cargo hold 2 and the compartments above. In this case water had entered 2 sections (cargo hold 2 and upwards, and cargo hold 1 and upwards), and in addition there was water on the car deck. Several levels of free surface occurred due to delay of the leakage into the forward compartments.

Damages examined (compartments open to sea, same level as sea level):

Comp	**D201**	**D202**	**D203**	**D204**	**D204B**	**D205**	**D206**	**D207**	**D208**	**D209**	**D211**
R31										X	X
R32									X		X
R41	X		X	X	X	X	X	X	X	X	X
R42		X	X	X	X	X	X	X	X	X	X
R53				X	X		X	X	X	X	X
R64						X	X	X	X	X	X
STABP					X			X	X	X	X
SURVIVE	OK	OK	OK	???	???	OK	NO	NO	NO	???	NO

- R31 Cargo hold 1
- R32 Accommodation on deck 1
- R41 Cargo hold 2
- R42 Storage room on deck 1
- R53 Car deck
- R64 Nato storage
- Stabp Stabilizer room on port side
- ??? Close to capsize; the uncertainties in the calculations or moderate forces applied like wind or waves will cause the vessel to capsize.

4 INSPECTION

An onboard inspection was carried out 2011-09-28 at Fiskerstrand Verft AS. The purpose of the inspection was to find the floating position and the loading of the vessel at max heel, as exact as possible.

An overview was needed of what compartments were flooded and how much water there was in each compartment. In most compartments this was quite easy to read by the marks left on the bulkheads like in the photo below.

Figure 4-1
Picture of lashing room on car deck (#55 to #62) port side, aft of cargo lifts.

An overview of the tank contents was received from Fiskerstrand Verft AS. The estimated amount of cargo onboard is based on the information given DNV ERS (Emergency Response Service) and by the crew onbord the vessel during the inspection.

5 THE DAMAGE

The damage caused by the stabilizer fin was located at #76 on starborard side in Cargo Hold 2. The vertical centre was approximately 15-20 cm above the tank top. The opening was through the side shell into Cargo Hold 2 only.

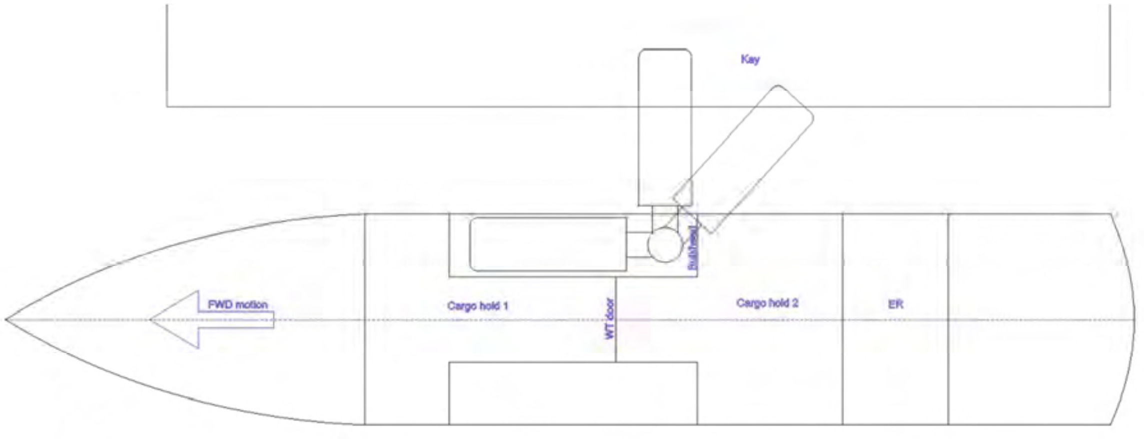

Figure 5-1
Above is a sketch of how the damage occurred. The stabilizer fin was bent backwards causing the trailing edge (Figure 5-2) to cut open the side shell of cargo hold 2.

The size of the hole was reported to be about 30 cm long and 8 to 10 cm high.

Figure 5-2
Trailing edge of stabilizer fin.

Figure 5-3
A repair had been carried out before the inspection, replacing the damaged area with new plating. The exact position of the damage was therefore not attainable. The bottom plating seen on the picture is the tank top.

Figure 5-4
The damage was behind a thick layer of insulation. The water flooded through the damage on the starboard side over to the port side since the vessel had a slight list to port side before the damage.

6 FLOODING

The only source leading sea water into the ship seems to be the damage from the stabilizer fin on starboard side in cargo hold 2. In addition there was some fresh water from fire extinguishing in the engine room.

By increased flooding, the draft increases and the vessel will achieve a greater angle of heel due to increased free surface effect. Non water tight openings on port side, like the loading ramp, will then be submerged.

In addition the scuppers (the drain pipes on the car deck) became submerged and water entered possibly the car deck.

The estimated amount of water in the compartments are based on tracks found on the bulkheads, deck and ceiling. These measurements are indicated on the enclosed drawings. The compartments were applied aft trim of 0,4 meter and the heel as indicated by the drawings.

The measurements were used in NAPA where the model of the compartments were trimmed and inclined to find the volume of water needed to set the corresponding traces.

How water entered each compartment has not been closely examined and only possible accesses is listed in this report.

6.1 Overview of flooded compartments

The marked compartments contained water. The engine room contained 50 m3 of water from fire extinguishing and had no ingress of seawater. The other rooms were partially or fully flooded by seawater.

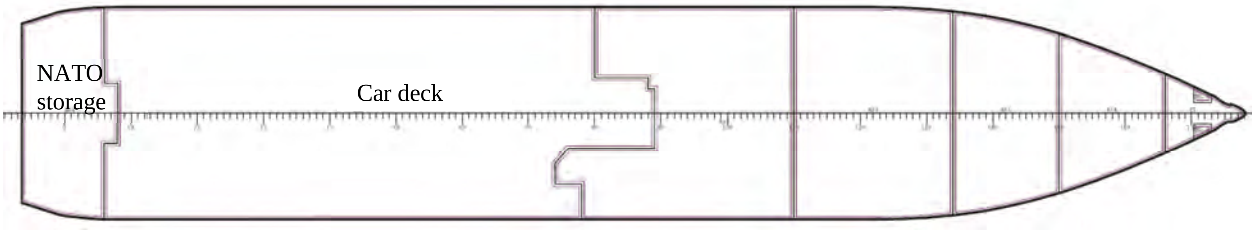

Figure 6-1
Deck 2

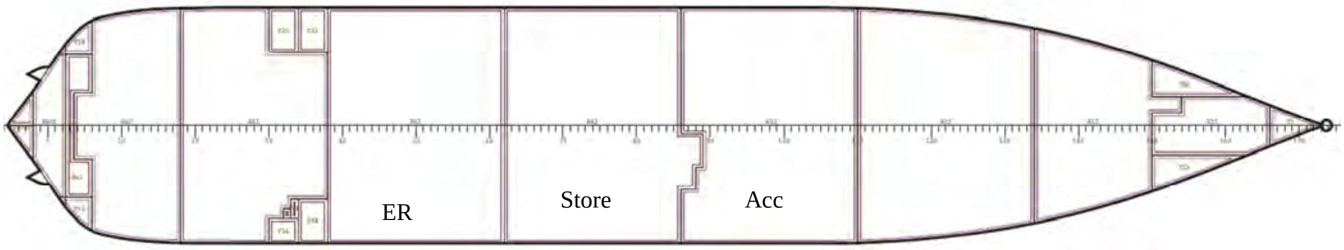

Figure 6-2
Deck 1

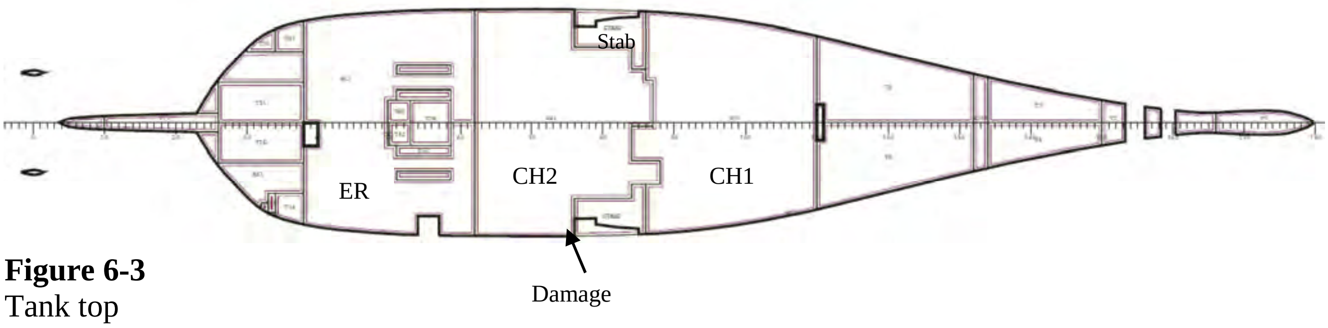

Figure 6-3
Tank top

6.2 Flooded compartments

The following compartments were confirmed to have contained water:

- Refrigerated cargo hold 1 (R31):
  - Sea water
  - Water ingress possible through water tight door at #89,
  - and possible through drop down hatch in accommodation on deck 1 at #88 and #108. These hatches were closed at the inspection and had some water on top. It is therefore not likely they had a significant leak.
  - Estimated volume of water: 151,5 m^3. The angle of heel based on the marks on the bulkhead is approximate 7 degrees. It is presumed that these marks have been set at another stage than the maximum heel. The estimated water level in the compartment is therefore based on the port most mark and an angle of heel of 21 degrees.
  - The hold was close to empty. The permeability is therefore set to 0,9.

Figure 6-4
The arrow shows the level of water. The insulation was dry above the arrow and wet below.

- Refrigerated cargo hold 2 (R41):
  - Sea water. Measured density 1,022 t/m^3.
  - Water ingress from damage in side shell and forward bulkhead at #76.
  - Estimated volume of water: 436 m^3 (including cargo hold 3).

- Partially filled by cargo. The permeability for both cargo hold 2 and cargo hold 3 is set to 0,62.

Figure 6-5
Trace of water is clearly seen on the bulkhead on starboard side of cargo hold 2.

- Refrigerated cargo hold 3 (part of R41):
  - Sea water
  - Not water tight separated from cargo hold 2 therefore treated as part of cargo hold 2 in the calculations.
  - Same water level as in cargo hold 2.
  - Close to full of cargo. See permeability of cargo hold 2.

- Engine room (R51):
  - Fresh water from fire fighting.
  - It was not possible to see marks from the water level.
  - 50 m^3 reported to have been pumped out.

- Lift shaft port side:
  - Sea water
  - Ingress of water possible from Cargo Hold 2, possible through flaps on loading ramp or through drain pipes on Car deck.
  - Estimated amount of water is included in Cargo hold 2 (R41), Stores (R42) and on car deck (R53).

Figure 6-6
Aft part of lift shaft seen from deck 2.

- Accommodation on deck 1 (R32):
  - Sea water
  - Water reached starboard side of the port hallway.
  - The aft and forward cabins has drop down hatches to send water down to Cargo Hold 1. These hatches were closed with water on top at inspection. Unlikely to have had any significant leak.
  - Possible ingress of water through drop down hatches (unlikely) or possible through the water tight door at #86.
  - Estimated volume of water: 88,3 m^3.

- Storage room on deck 1 (R42):
  - Sea water
  - Water ingress possible through the elevator shaft on port side or through the stairway from Cargo Hold 2 on starboard side.
  - It was not possible to find any traces of the maximum water level due to large amounts of soot from the fire in the engine room.
  - Estimated volume of water: 271,6 m^3.

- Stabilizer room on port side (Stabp):
  - Sea water
  - Water ingress possible through the access trunk from Storage room on deck 1 (R42).
  - Estimated volume of water: 12,8 m^3.

- Car deck (R53):
  - Sea water
  - Water has presumably entered from the elevator shaft and the drain pipes.
  - Estimated volume of water: 113 m^3.

Figure 6-7
Car deck looking forward.

- NATO storage (R64):
  - Sea water
  - Estimated volume of water: 14 m^3.

6.3 Sketch of flooding

Continuous red lines indicate clear traces of water. Dashed lines indicate presumed level.

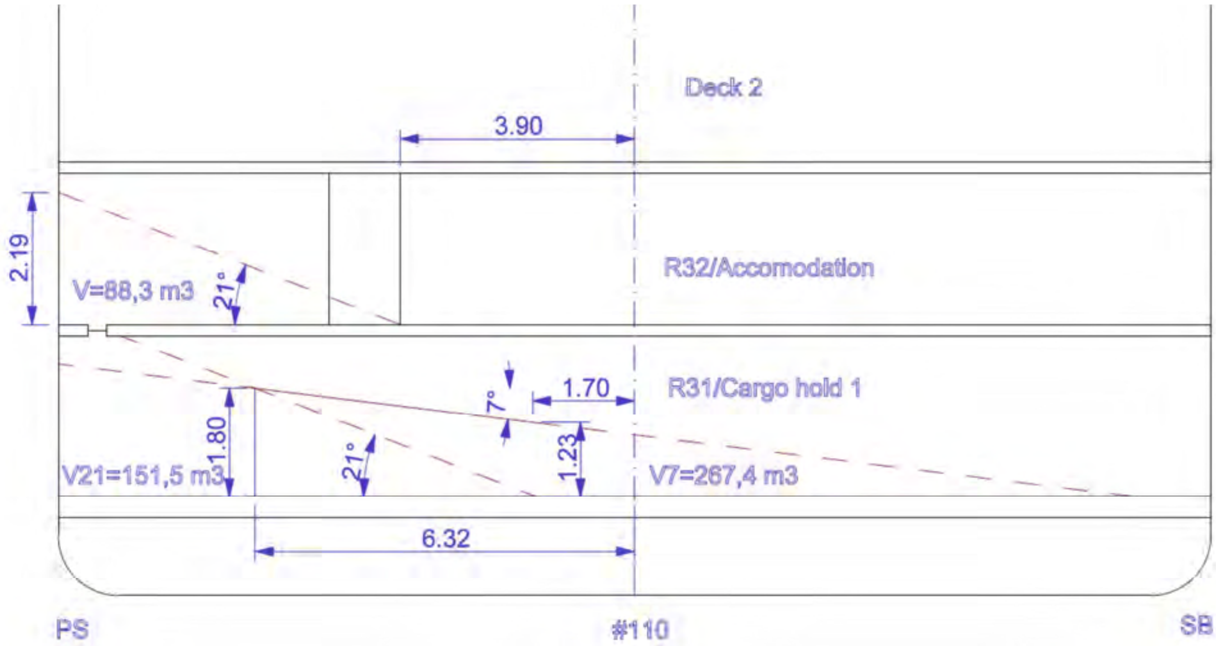

Figure 6-8

In cargo hold 1 were two marks of water detected. As seen on the sketch above, the angle of heel made by the two positions gave a heel of 7 degrees. The port position was an insulated pipe where the insulation was dry above a certain level (see Figure 6-4). It is therefore presumed that this give the highest possible water level at maximum heel.

On deck 1 was water detected on the starboard side of the port corridor in the accommodation. The angle is presumed to be 21 degrees.

Figure 6-9
Marks on the side shell gave the maximum water level. The angle is presumed to be 21 degrees.

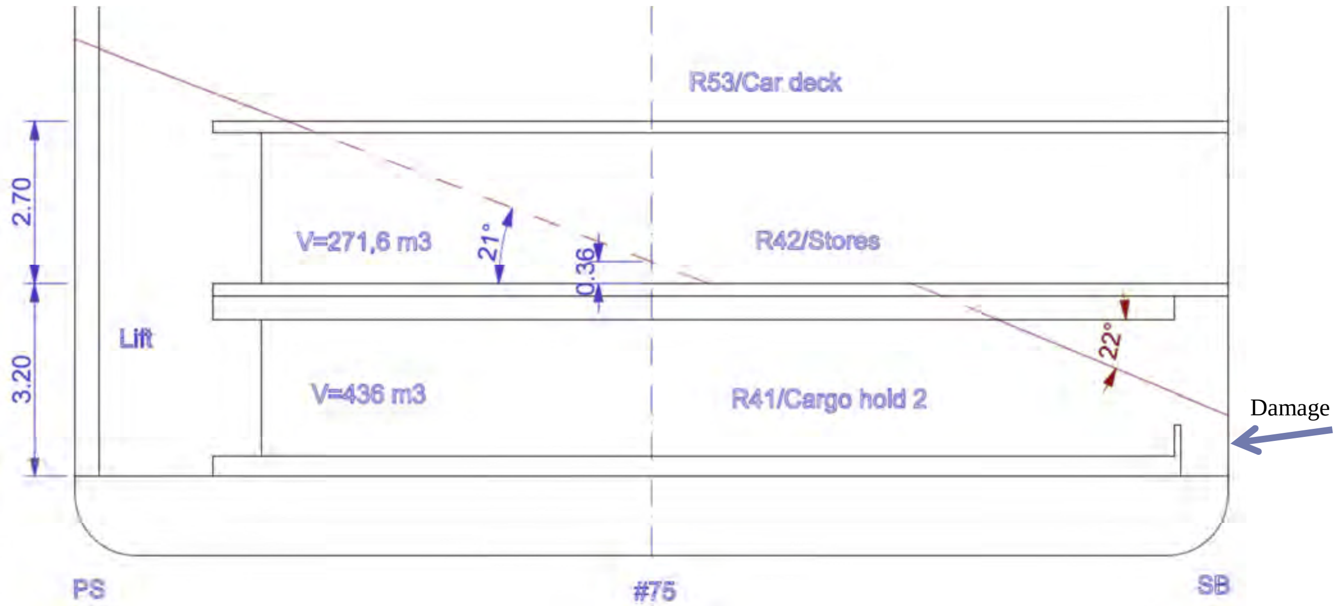

Figure 6-10
Clear traces of water were found on the longitudinal bulkhead in cargo hold 2 (see Figure 6-5). Traces were also found in the ceiling. There was not possible to find any traces in the store room on deck 1 due to a lot of soot. The level is therefore estimated based on the water level above on the car deck.

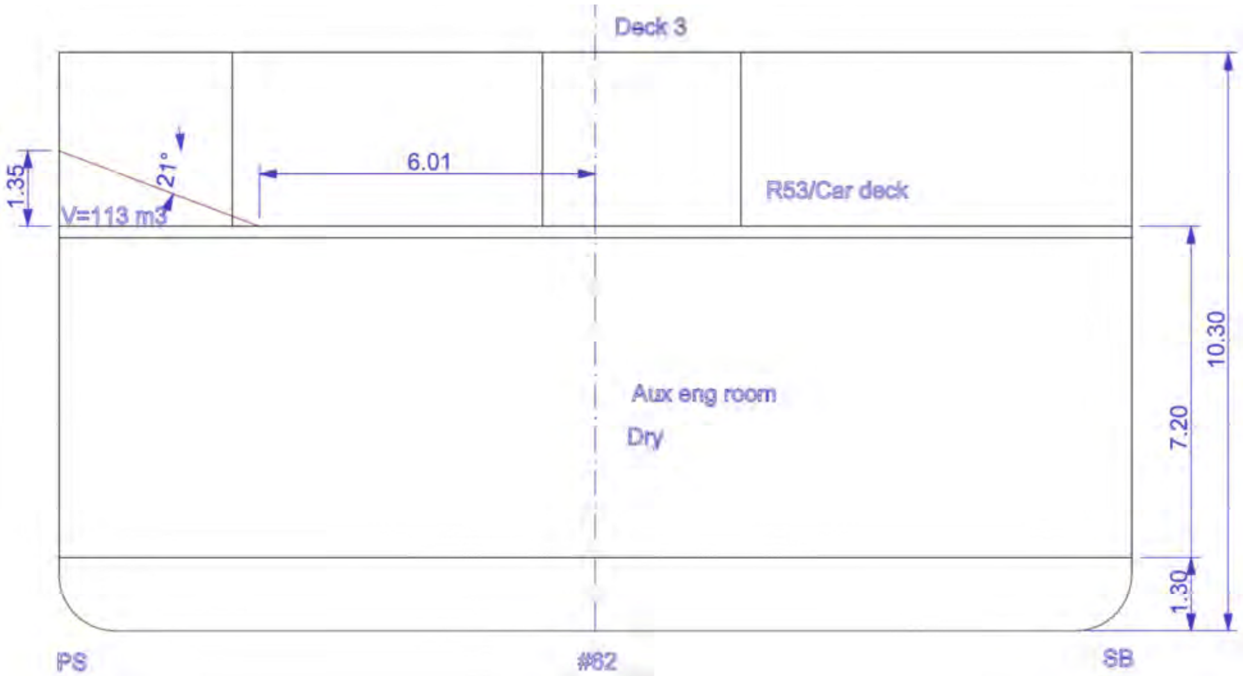

Figure 6-11
Several marks was made by the water on the car deck (see Figure 4-1, 6-6 and 6-7).

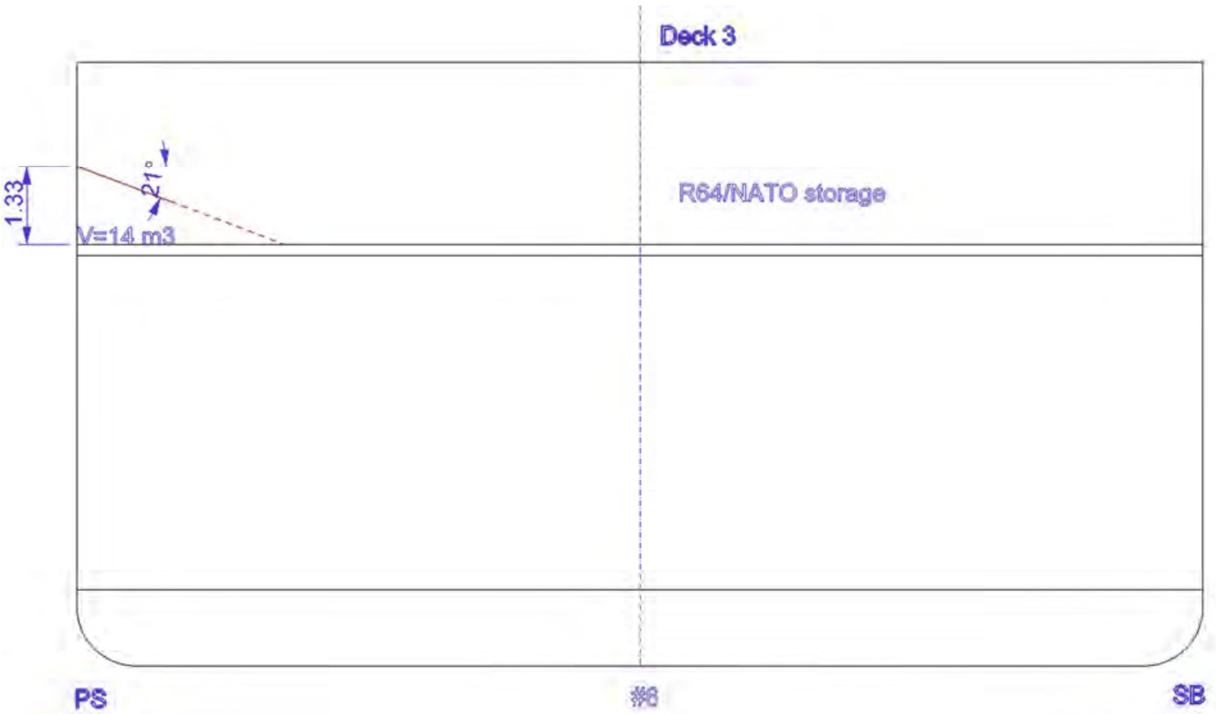

Figure 6-12
Some water was found in the NATO storage aft of the car deck.

7 DAMAGE CALCULATIONS

Damages examined:

Comp	**D201**	**D202**	**D203**	**D204**	**D204B**	**D205**	**D206**	**D207**	**D208**	**D209**	**D211**
R31										X	X
R32									X		X
R41	X		X	X	X	X	X	X	X	X	X
R42		X	X	X	X	X	X	X	X	X	X
R53				X	X		X	X	X	X	X
R64						X	X	X	X	X	X
STABP					X			X	X	X	X
SURVIVE	OK	OK	OK	???	???	OK	NO	NO	NO	???	NO

- R31 Cargo hold 1
- R32 Accommodation on deck 1
- R41 Cargo hold 2
- R42 Storage room on deck 1
- R53 Car deck
- R64 Nato storage
- Stabp Stabilizer room on port side
- ??? Close to capsize; the uncertainties in the calculations or moderate forces applied like wind or waves will cause it to capsize.

Water leaked into cargo hold 1 and the accommodation. The leak delayed the filling of these compartments. The other compartments were either close to or fully flooded. It is therefore presumed that the other compartments would be fully flooded first and then the forward compartments would follow.

8 REFERENCES

/1/ NAPA model of sister vessel Richard With, modified based on measurements onboard Nordlys.

/2/ Damage Control Plan, dwg no. 917.102-11.13.02:3.0.01

/3/ Mounting of fin units, dwg no. SSK:624-0106-500

/4/ Midship section, dwg no. 917.102-10.06:3.0.01

/5/ Tank plan with contents measure by Fiskerstrand Verft AS

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1 AMOUNT OF WATER DETECTED IN THE COMPARTMENTS

Trim is set to 0.4 m aft.
Heel is set to 21 degrees to port side.

These values were reported to DNV ERS (Emergency Response Service) during the accident. The deviations to the values above is commented and based on measurements made onboard.

CARGO HOLD 1 (R31)

At 7 degrees of heel (see sketch in the report).

GAUGE	H	VNET	CGX	CGY	CGZ	AWP	CGXA	CGYA
cm	m	m3	m	m	m	m2	m	m
180	1.03	267.4	58.59	−3.35	2.03	255.0	58.72	−0.95

At 21 degrees of heel (see sketch in the report).

GAUGE	H	VNET	CGX	CGY	CGZ	AWP	CGXA	CGYA
cm	m	m3	m	m	m	m2	m	m
180	−0.72	151.5	58.45	−6.81	2.32	118.2	58.82	−6.35

ACCOMODATION (R32)

GAUGE	H	VNET	CGX	CGY	CGZ	AWP	CGXA	CGYA
cm	m	m3	m	m	m	m2	m	m
219	−1.69	88.3	58.73	−7.71	5.22	87.2	58.77	−8.32

CARGO HOLD 2 (R41)

At 22 degrees of heel (see sketch in the report).

GAUGE	H	VNET	CGX	CGY	CGZ	AWP	CGXA	CGYA
cm	m	m3	m	m	m	m2	m	m
102	4.41	436.0	46.56	−0.46	2.82	34.6	45.93	4.32

STORAGE ROOM (R42)

GAUGE cm	H m	VNET m3	CGX m	CGY m	CGZ m	AWP m2	CGXA m	CGYA m
36	0.01	274.6	44.49	−5.76	5.62	111.3	44.93	−4.40

STABILIZER ROOM PORT SIDE (STABP)

GAUGE cm	H m	VNET m3	CGX m	CGY m	CGZ m	AWP m2	CGXA m	CGYA m
150	−2.11	12.8	48.85	−8.13	1.88	20.8	48.79	−8.20

CAR DECK (R53)

GAUGE cm	H m	VNET m3	CGX m	CGY m	CGZ m	AWP m2	CGXA m	CGYA m
135	−2.71	113.0	24.83	−8.38	7.67	173.1	25.31	−10.09

NATO STORAGE (R64)

GAUGE cm	H m	VNET m3	CGX m	CGY m	CGZ m	AWP m2	CGXA m	CGYA m
133	−2.86	14.0	0.35	−8.21	7.62	25.8	0.05	−9.99

2 INITIAL CONDITION LD200

This condition is based on tank content from the ship yard, loads given by the crew and water level in the compartments from inspection onboard.

The permeability for cargo hold 1 (R31) is set to 0.9. The cargo hold was close to empty containing 1 pallet truck, some ropes and a few collapsible containers.

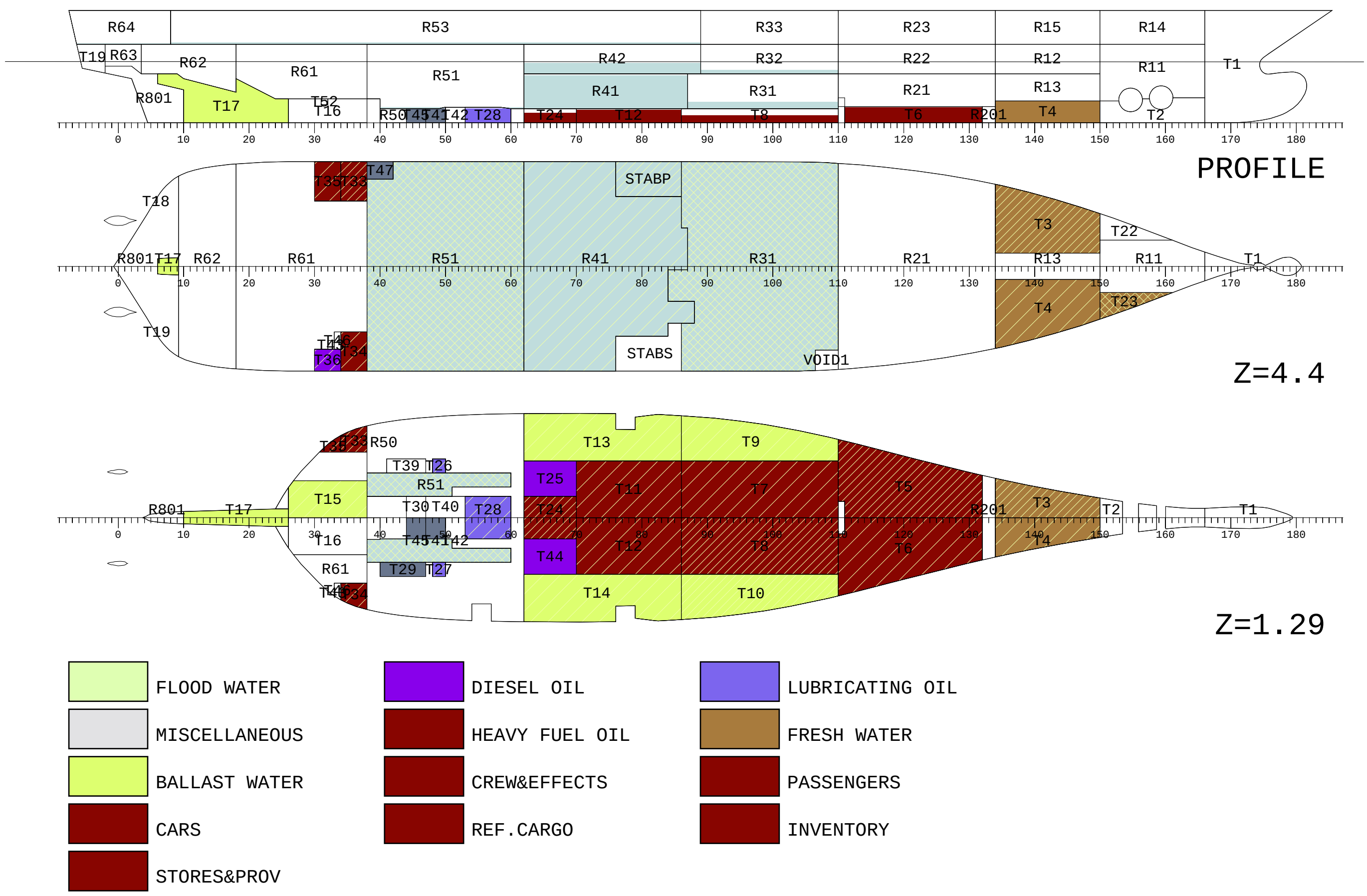
Cargo hold 2 (R41) is set to 0.62. Cargo hold 3, which in these calculations are treated as a part of cargo hold 2 since there is no water tight separation, was close to full leaving a space above the cargo of aproximate 1 meter, while cargo hold 2 were approximately 1/3 full.

The permeability of the storage room (R42) is set to 0.8 based on information about the amount and type of cargo in the compartment.

The car deck (R53) was not full and based on the type of cars and the amount of water and type of cargo in the flooded area, the premeability is set to 0.9.

2.1 Loads initial condition

LOADING CONDITION LD210: Initial damage condition



LOADS

Item	Weight (t)	L.C.G. (m)	T.C.G. (m)	V.C.G. (m)	Frs.mom. (tm)
FLOOD WATER	1167.5	45.41	-0.10	3.73	65371.9
DIESEL OIL	50.4	32.81	2.84	1.79	24.5
LUBRICATING OIL	37.5	32.85	0.00	0.55	27.5
MISCELLANEOUS	22.1	26.50	-0.06	1.37	0.0
HEAVY FUEL OIL	433.3	49.37	-0.34	1.20	875.0
FRESH WATER	185.5	84.83	0.46	2.19	149.0
BALLAST WATER	259.4	36.65	-1.07	0.96	279.0
CREW&EFFECTS	1.0	63.00	0.00	10.00	0.0
CARS	19.0	28.58	0.00	6.56	0.0
REF.CARGO	40.0	50.20	0.00	2.90	0.0
INVENTORY	30.0	45.00	0.00	10.00	0.0
STORES&PROV	60.0	25.00	0.00	6.00	0.0
Deadweight	2305.7	47.09	-0.13	2.85	66726.9
Lightweight	5555.9	47.42	-0.04	9.59	
Displacement (1.025 t/m3)	7861.6	47.32	-0.07	7.61	66726.9

FLOATING POSITION

Mean draught (moulded)	5.17 m	KM about the moulded base	9.60 m
Draught at AP (moulded)	5.15 m	KG above the moulded base	7.61 m
Draught at FP (moulded)	5.19 m	GM0 (solid)	1.99 m
Trim (by stern)	−0.04 m	Free surface correction	−8.49 m
Heeling to port side	−19 deg	GM (fluid)	−6.50 m

Draught	Trim	Minimum GM from damage
5.170	−0.044	9999.900

Calculation arguments:

Speed: 18 knots

Moment by Pass. Crowding: 477.8 m

STABILITY CURVE

_Heel (deg)	5.0	10.0	15.0	19.3	20.0	30.0	40.0	50.0 _
KN (m)	0.78	1.61	2.45	3.16	3.29	4.91	5.98	6.53
KGsin(phi) (m)	0.66	1.32	1.97	2.51	2.60	3.81	4.89	5.83
dGZ (m)	0.42	0.57	0.63	0.65	0.65	0.66	0.62	0.56
GZ (m)	−0.31	−0.27	−0.15	0.00	0.03	0.44	0.47	0.14
e(phi) (mrad)	−0.018	−0.045	−0.064	−0.070	−0.069	−0.026	0.060	0.116

CRITICAL OPENINGS

NAME	TEXT	X m	FR #	Y m	Z m	FLOODING degree
D62P	FLAPS TO PALLET LIFT.	37.20	62.00	−6.60	7.77	−19.2
D62S	FLAPS TO PALLET LIFT.	37.20	62.00	6.60	7.77	−
D74P	OPEN TO CARLIFT CASI.	44.40	74.00	−2.40	7.20	−44.6
D74S	OPEN TO CARLIFT CASI.	44.40	74.00	2.40	7.20	−
D80P	OPEN TO CARLIFT CASI.	48.00	80.00	−2.40	7.20	−44.4
D80S	OPEN TO CARLIFT CASI.	48.00	80.00	2.40	7.20	−
F134P	PARTIAL BULKH FR134P	80.40	134.00	−3.05	7.20	−33.4
F134S	PARTIAL BULKH FR134S	80.40	134.00	3.05	7.20	−
F150P	PARTIAL BULKH FR150P	90.00	150.00	−1.20	7.20	−
F150S	PARTIAL BULKH FR150S	90.00	150.00	1.20	7.20	−
F80P	DOOR TO CARDECK P	48.00	80.00	−1.25	7.20	−
F80S	DOOR TO CARDECK P	48.00	80.00	1.25	7.20	−
F86P	PARTIAL BULKH FR86P	51.60	86.00	−4.50	7.20	−21.4
F86S	PARTIAL BULKH FR86S	51.60	86.00	4.50	7.20	−
F8P	OPEN STAIRCASE FR8P	4.80	8.00	−2.20	7.20	−
F8S	OPEN STAIRCASE FR8S	4.80	8.00	2.20	7.20	−
P108P	STAIRCASE FR108P	64.80	108.00	−0.80	7.20	−
P108S	STAIRCASE FR108S	64.80	108.00	0.80	7.20	−
P118P	STAIRCASE FR118P	70.80	118.00	−2.80	7.20	−37.0
P118S	STAIRCASE FR118S	70.80	118.00	2.80	7.20	−
P154P	OPEN TO STAIRCASE FR.	92.40	154.00	−2.20	7.20	−46.3
P154S	OPEN TO STAIRCASE FR.	92.40	154.00	0.00	7.20	−
P42P	STAIRCASE FR42P	25.20	42.00	−0.90	7.20	−
P42S	STAIRCASE FR42S	25.20	42.00	0.90	7.20	−

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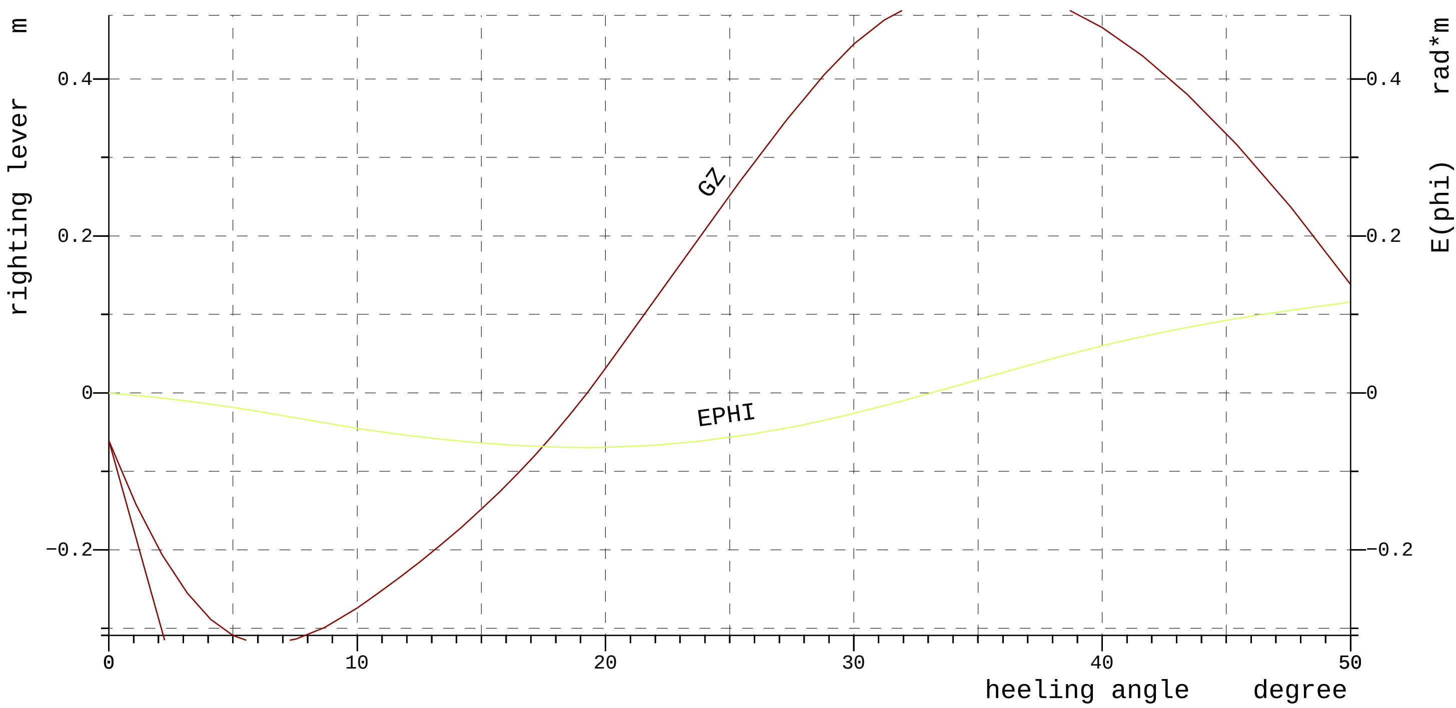
NAME	TEXT	X m	FR #	Y m	Z m	FLOODING degree
P84P	STAIRCASE FR84P	50.40	84.00	-2.10	7.20	-
P84S	STAIRCASE FR84S	50.40	84.00	2.10	7.20	-
DAMAGE	DAMAGE AT CH2	60.80	101.33	8.50	1.50	-



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LOADING CONDITION LD210: Initial damage condition

ID	DES	MASS t	FILL %	LCG m	TCG m	VCG m	FRSM tm
CONTENTS : BW=BALLAST WATER (RHO=1.025)							
T9	BW DB 5 P	38.8	92.1	57.18	−6.60	0.74	49.8
T10	BW DB 5 S	10.8	25.5	56.01	6.32	0.32	24.0
T13	BW DB 6 P	63.2	87.1	44.29	−7.13	0.60	91.2
T14	BW DB 6 S	59.6	82.0	44.28	7.12	0.57	91.2
T17	BW DB 9 skeg	47.5	100.0	10.00	0.00	1.94	0.0
T15	BW DB 8 P	39.5	97.2	19.48	−1.55	1.30	22.8
SUBTOTAL		259.4		36.65	−1.07	0.96	279.0
CONTENTS : MASS=CARS (RHO=1)							
CARS		15.0	0.0	25.00	0.00	7.70	0.0
TRUCKS		4.0	0.0	42.00	0.00	2.30	0.0
SUBTOTAL		19.0		28.58	0.00	6.56	0.0
CONTENTS : MASS=CREW&EFFECTS (RHO=1)							
CREW&EF.		1.0	0.0	63.00	0.00	10.00	0.0
CONTENTS : DO=DIESEL OIL (RHO=0.86)							
T25	DO DB 6 P	16.8	98.3	39.60	−3.57	0.64	11.6
T36	DO DB 8 S	16.8	97.4	19.22	8.53	4.10	1.3
T44	DO DB 6 S	16.8	98.3	39.60	3.57	0.64	11.6
SUBTOTAL		50.4		32.81	2.84	1.79	24.5
CONTENTS : ACC=FLOOD WATER (RHO=1.025)							
R32	Cabin fr.86−110	90.5	12.4	59.09	−0.06	4.67	8623.8
R31	Ref.cargo hold FWD	155.3	18.0	58.55	−0.01	1.60	7057.1
R51	Main eng. rm	50.0	3.1	29.58	−0.08	1.29	7539.9
R41	Ref.cargo hold AFT	446.9	94.4	46.47	−0.03	2.79	3127.2
R53	Car dk.fr6−80	115.8	4.2	26.59	−0.09	7.27	26408.1
R64	Workshop CO2 room	14.3	3.0	0.20	0.00	7.25	3827.1
STABP		13.1	22.6	49.24	−7.32	1.73	28.7
R42		281.5	35.4	44.76	0.06	4.98	8759.9
SUBTOTAL		1167.5		45.41	−0.10	3.73	65371.9
CONTENTS : FW=FRESH WATER (RHO=1)							
T3	FW DB 3 P	80.0	60.1	84.63	−2.14	1.97	62.1
T4	FW DB 3 S	100.0	75.1	84.64	2.40	2.28	85.1
T23	FW TK 2 S	5.5	10.0	91.24	3.09	3.67	1.8
SUBTOTAL		185.5		84.83	0.46	2.19	149.0

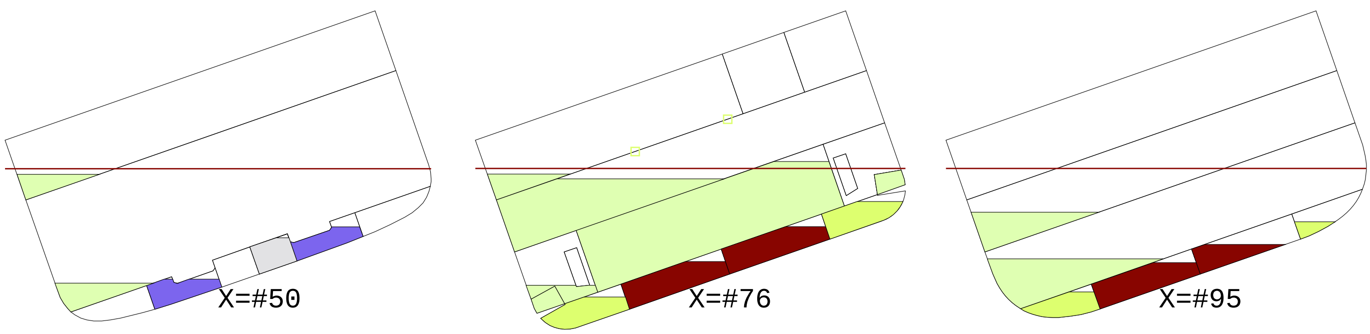
ID	DES	MASS t	FILL %	LCG m	TCG m	VCG m	FRSM tm
CONTENTS : HFO=HEAVY FUEL OIL (RHO=0.96)							
T5	HFO DB 4 P	18.4	24.3	71.57	−1.63	0.32	77.2
T6	HFO DB 4 S	68.4	90.2	71.81	2.32	0.82	220.0
T7	HFO DB 5 P	81.1	89.6	58.73	−2.57	0.59	158.7
T8	HFO DB 5 S	44.6	49.3	58.67	2.55	0.33	158.7
T11	HFO DB 6 P	55.7	91.2	46.80	−2.60	0.59	105.8
T12	HFO DB 6 S	55.7	91.2	46.80	2.60	0.59	105.8
T24	HFO Overflow DB 6	16.0	70.0	39.60	0.00	0.45	22.3
T33	HFO SETTL TK 8 P	24.0	59.8	21.62	−7.63	2.81	8.8
T34	HFO SETTL TK 8 S	34.8	86.8	21.62	7.68	3.49	8.8
T35	HFO Day TK 8 P	34.6	92.5	19.22	−7.68	3.81	8.8
SUBTOTAL		433.3		49.37	−0.34	1.20	875.0
CONTENTS : MASS=INVENTORY (RHO=1)							
INVENTO.		30.0	0.0	45.00	0.00	10.00	0.0
CONTENTS : LO=LUBRICATING OIL (RHO=0.9)							
T26	LO ME Circ DB 7 P	9.3	93.0	31.78	−3.52	0.45	4.7
T27	LO ME Circ DB 7 S	9.3	93.0	31.78	3.52	0.45	4.7
T28	LO DB 7	18.9	93.6	33.90	0.00	0.65	18.0
SUBTOTAL		37.5		32.85	0.00	0.55	27.5
CONTENTS : MIS=MISCELLANEOUS (RHO=1)							
T29	FEEDW DB 7 S	8.2	100.0	26.17	4.19	0.67	0.0
T41	Gear oil DB 7	4.5	99.2	29.11	0.97	0.66	0.0
T45	GAS OIL DB 7	4.4	100.0	27.30	0.97	0.66	0.0
T47	Oper.water tk 7 P	5.0	100.0	24.00	−8.90	3.80	0.0
SUBTOTAL		22.1		26.50	−0.06	1.37	0.0
CONTENTS : MASS=REF.CARGO (RHO=1)							
REF.CAR.		40.0	0.0	50.20	0.00	2.90	0.0
CONTENTS : MASS=STORES&PROV (RHO=1)							
STORES&.		60.0	0.0	25.00	0.00	6.00	0.0
TOTAL		2305.7		47.09	−0.13	2.85	66726.9

2.2 Openings

CRITICAL OPENINGS

NAME	X m	Y m	Z m	IMMA degree	IMMR m
D62P	37.20	-6.60	7.77	-19.2	-0.006
D62S	37.20	6.60	7.77	-	4.349
D74P	44.40	-2.40	7.20	-44.5	0.838
D74S	44.40	2.40	7.20	-	2.422
D80P	48.00	-2.40	7.20	-44.4	0.837
D80S	48.00	2.40	7.20	-	2.420
F134P	80.40	-3.05	7.20	-33.3	0.609
F134S	80.40	3.05	7.20	-	2.621
F150P	90.00	-1.20	7.20	-	1.215
F150S	90.00	1.20	7.20	-	2.007
F80P	48.00	-1.25	7.20	-	1.216
F80S	48.00	1.25	7.20	-	2.041
F86P	51.60	-4.50	7.20	-21.4	0.142
F86S	51.60	4.50	7.20	-	3.112
F8P	4.80	-2.20	7.20	-	0.921
F8S	4.80	2.20	7.20	-	2.373
P108P	64.80	-0.80	7.20	-	1.357
P108S	64.80	0.80	7.20	-	1.885
P118P	70.80	-2.80	7.20	-36.9	0.695
P118S	70.80	2.80	7.20	-	2.543
P154P	92.40	-2.20	7.20	-46.2	0.884
P154S	92.40	0.00	7.20	-	1.610
P42P	25.20	-0.90	7.20	-	1.341
P42S	25.20	0.90	7.20	-	1.935
P84P	50.40	-2.10	7.20	-	0.935
P84S	50.40	2.10	7.20	-	2.320
DAMAGE	60.80	8.50	1.50	0.0	-0.954

2.3 Floating and flooding situation



3 DAMAGE STABILITY ANALYSIS

In the following damage cases have the listed compartments open to sea. This means they have the same water level as the outside sea level.

The remaining compartments are partially filled as in the initial condition.

These sequences are made to illustrate varius ways of progressive flooding and to give the corresponding stability properties.

Please note that due to heel to port side, which is negative in the coordinate system, the sign of the GZ−values are opposite. Positive GZ is listed as negative and negative GZ is listed as positive. The plotted GZ−curves show the actual stability with the right sign.

3.1 D201 Intermediate stage

The following compartments are open to sea:

- R41 Cargo hold 2

Water level in R31, R32, R42, R53, R64 and Stabp is presumed unchanged compared to the initial condition.

3.1.1 Floating position

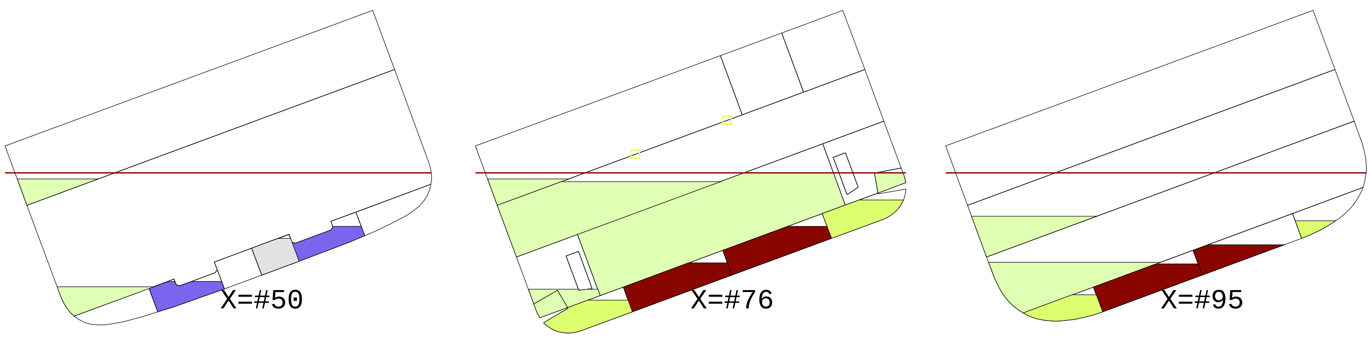
CASE	STAGE	PHASE	SI	T m	TR m	HEEL degree	RESFLD m	OPEN	RESMRG m
ILD210/D201	INTACT	EQ	PS	5.170	-0.044	-19.3	-0.954	DAMAGE	-1.621
ILD210/D201	1	EQ	PS	5.021	-0.040	-20.3	-0.015	D62P	-1.674

3.1.2 Water in damaged compartments

DAMAGED COMPARTMENTS

CASE	STAGE	PHASE	NAME	PERM	VOL	XCG	YCG	ZCG
ILD210/D201	INTACT	EQ			0.0			
ILD210/D201	1	EQ	R41	0.62	254.0	46.58	-0.84	2.77

3.1.3 Floating and flooding situation



3.1.4 GZ−curve

Initial condition : ILD210
Damage case : D201
Stage of damage : 1
Phase of stage : EQ
Azimuth : 0 deg

HEEL degree	GZ m	EPHI rad*m	T m	TR m	OPNAME	IMRES m	RESMRG m
0.0	0.061	0.000	5.517	0.030	F8P	1.67	1.59
−1.0	0.165	−0.002	5.516	0.027	F8P	1.63	1.43
−3.0	0.260	−0.010	5.507	0.027	D74P	1.56	1.09
−5.0	0.299	−0.020	5.488	0.024	D74P	1.47	0.76
−7.0	0.304	−0.030	5.460	0.017	D74P	1.39	0.43
−10.0	0.273	−0.045	5.399	0.005	D62P	1.11	−0.05
−12.0	0.238	−0.054	5.346	−0.004	D62P	0.88	−0.37
−15.0	0.166	−0.065	5.249	−0.016	D62P	0.55	−0.86
−20.0	0.011	−0.073	5.036	−0.039	D62P	0.01	−1.63
−30.0	−0.346	−0.042	4.407	−0.118	D62P	−0.96	−3.06
−40.0	−0.350	0.024	3.645	−0.205	D62P	−1.91	−4.40
−50.0	−0.015	0.060	2.799	−0.284	D62P	−2.82	−5.63

GZ curve
Case: ILD210/D201

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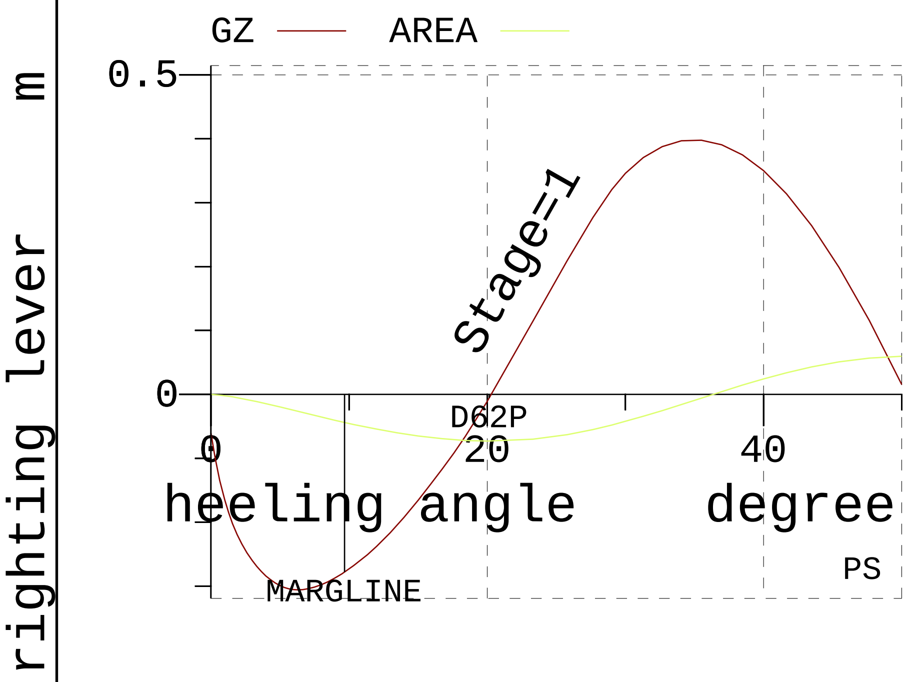


Stage: 1 Phase: EQ

3.1.5 Critical openings

RELEVANT OPENINGS

NAME	TEXT	X m	Y m	Z m	IMMA degree	IMMR m
D62P	FLAPS TO PALLET LIFT P	37.20	−6.60	7.77	20.1	−0.014
D62S	FLAPS TO PALLET LIFT S	37.20	6.60	7.77	−	4.561
D74P	OPEN TO CARLIFT CASING P	44.40	−2.40	7.20	−	0.904
D74S	OPEN TO CARLIFT CASING S	44.40	2.40	7.20	−	2.568
D80P	OPEN TO CARLIFT CASING P	48.00	−2.40	7.20	−	0.903

3.2 D202 Intermediate stage

The following compartments are open to sea:

- R42 Storage room on deck 1

Water level in R31, R32, R41, R53, R64 and Stabp is presumed unchanged compared to the initial condition.

3.2.1 Floating position

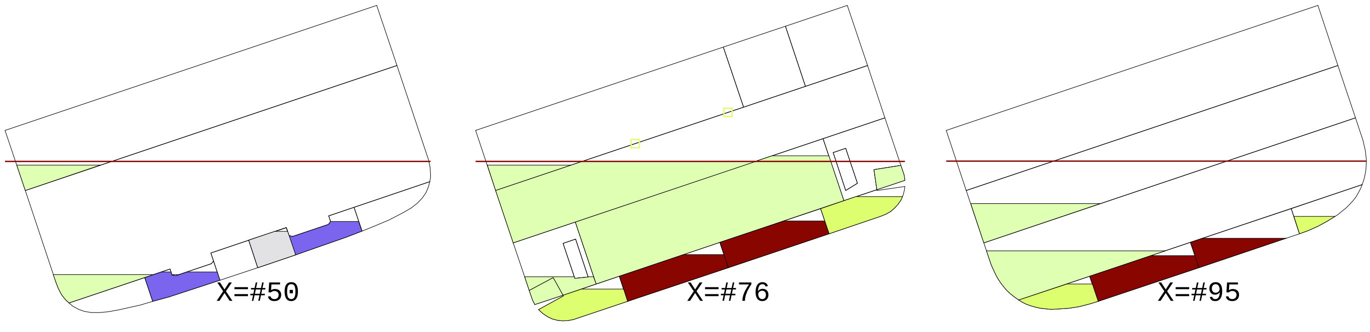
CASE	STAGE	PHASE	SI	T m	TR m	HEEL degree	RESFLD m	OPEN	RESMRG m
ILD210/D202	INTACT	EQ	PS	5.170	-0.044	-19.3	-0.954	DAMAGE	-1.621
ILD210/D202	1	EQ	PS	5.199	-0.035	-18.5	-1.076	DAMAGE	-1.505

3.2.2 Water in damaged compartments

DAMAGED COMPARTMENTS

CASE	STAGE	PHASE	NAME	PERM	VOL	XCG	YCG	ZCG
ILD210/D202	INTACT	EQ			0.0			
ILD210/D202	1	EQ	R42	0.80	268.1	44.63	-4.95	5.62

3.2.3 Floating and flooding situation



3.2.4 GZ−curve

Initial condition : ILD210
Damage case : D202
Stage of damage : 1
Phase of stage : EQ
Azimuth : 0 deg

HEEL degree	GZ m	EPHI rad*m	T m	TR m	OPNAME	IMRES m	RESMRG m
0.0	0.061	0.000	5.588	0.013	DAMAGE	−4.09	1.53
−1.0	0.167	−0.002	5.587	0.011	DAMAGE	−3.94	1.36
−3.0	0.260	−0.010	5.577	0.012	DAMAGE	−3.63	1.03
−5.0	0.291	−0.020	5.557	0.008	DAMAGE	−3.32	0.70
−7.0	0.289	−0.030	5.527	0.002	DAMAGE	−3.00	0.37
−10.0	0.251	−0.044	5.473	−0.008	DAMAGE	−2.52	−0.13
−12.0	0.208	−0.052	5.426	−0.015	DAMAGE	−2.19	−0.46
−15.0	0.122	−0.061	5.335	−0.024	DAMAGE	−1.69	−0.94
−20.0	−0.059	−0.064	5.132	−0.041	DAMAGE	−0.82	−1.73
−30.0	−0.471	−0.016	4.528	−0.105	D62P	−1.08	−3.18
−40.0	−0.489	0.074	3.810	−0.153	D62P	−2.08	−4.55
−50.0	−0.158	0.134	3.003	−0.189	D62P	−3.04	−5.82

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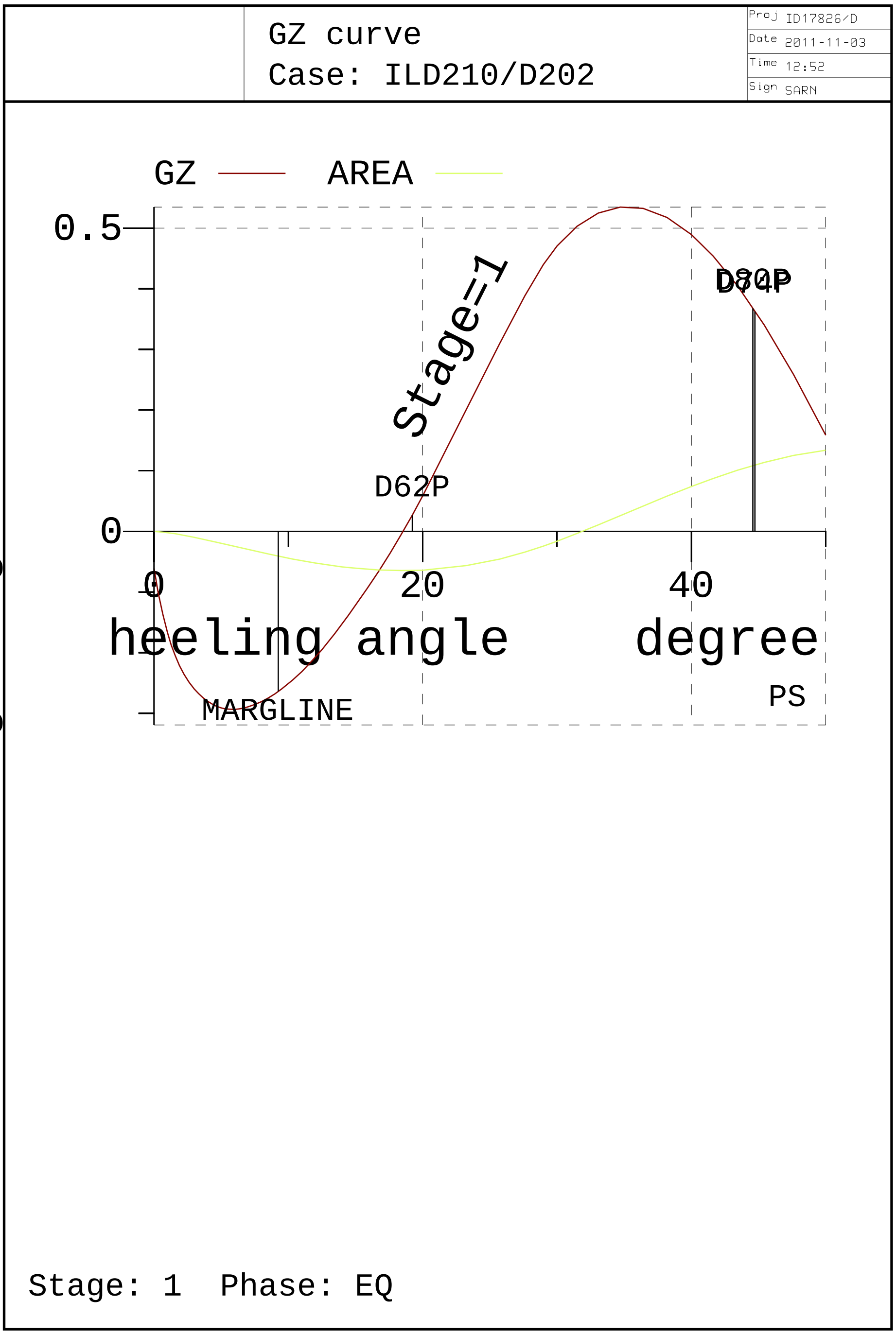
after incident D



3.2.5 Critical openings

RELEVANT OPENINGS

NAME	TEXT	X m	Y m	Z m	IMMA degree	IMMR m
DAMAGE	DAMAGE AT CH2	60.80	8.50	1.50	-	-1.076
D62P	FLAPS TO PALLET LIFT P	37.20	-6.60	7.77	19.2	0.074
D80P	OPEN TO CARLIFT CASING P	48.00	-2.40	7.20	44.6	0.865
D74P	OPEN TO CARLIFT CASING P	44.40	-2.40	7.20	44.7	0.867
D62S	FLAPS TO PALLET LIFT S	37.20	6.60	7.77	-	4.272

3.3 D203 Intermediate stage

The following compartments are open to sea:

- R41 Cargo hold 2
- R42 Storage room on deck 1

Water level in R31, R32, R53, R64 and Stabp is presumed unchanged compared to the initial condition.

3.3.1 Floating position

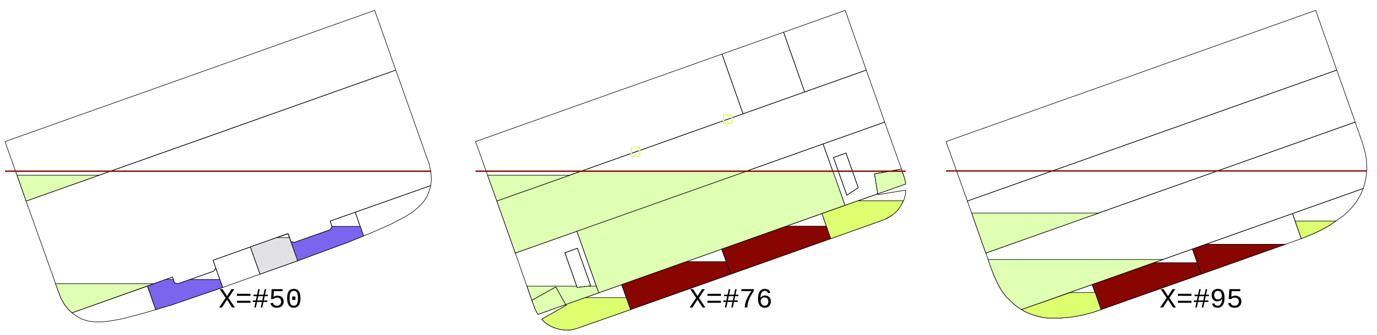
CASE	STAGE	PHASE	SI	T m	TR m	HEEL degree	RESFLD m	OPEN	RESMRG m
ILD210/D203	INTACT	EQ	PS	5.170	-0.044	-19.3	-0.954	DAMAGE	-1.621
ILD210/D203	1	EQ	PS	5.050	-0.040	-19.5	0.072	D62P	-1.553

3.3.2 Water in damaged compartments

DAMAGED COMPARTMENTS

CASE	STAGE	PHASE	NAME	PERM	VOL	XCG	YCG	ZCG
ILD210/D203	INTACT	EQ			0.0			
ILD210/D203	1	EQ	R41	0.62	256.6	46.57	-0.77	2.78
ILD210/D203	1	EQ	R42	0.80	258.2	44.61	-5.13	5.63

3.3.3 Floating and flooding situation



3.3.4 GZ−curve

Initial condition : ILD210
Damage case : D203
Stage of damage : 1
Phase of stage : EQ
Azimuth : 0 deg

HEEL degree	GZ m	EPHI rad*m	T m	TR m	OPNAME	IMRES m	RESMRG m
0.0	0.061	0.000	5.491	0.027	F8P	1.70	1.62
−1.0	0.162	−0.002	5.490	0.024	F8P	1.66	1.45
−3.0	0.250	−0.009	5.480	0.024	D74P	1.58	1.12
−5.0	0.282	−0.019	5.460	0.020	D74P	1.50	0.79
−7.0	0.281	−0.029	5.432	0.013	D74P	1.42	0.46
−10.0	0.247	−0.043	5.378	0.001	D62P	1.13	−0.03
−12.0	0.211	−0.051	5.330	−0.007	D62P	0.90	−0.36
−15.0	0.138	−0.060	5.237	−0.019	D62P	0.56	−0.84
−20.0	−0.017	−0.066	5.027	−0.043	D62P	0.02	−1.62
−30.0	−0.371	−0.030	4.398	−0.124	D62P	−0.95	−3.05
−40.0	−0.374	0.041	3.633	−0.215	D62P	−1.89	−4.39
−50.0	−0.036	0.080	2.787	−0.298	D62P	−2.81	−5.62

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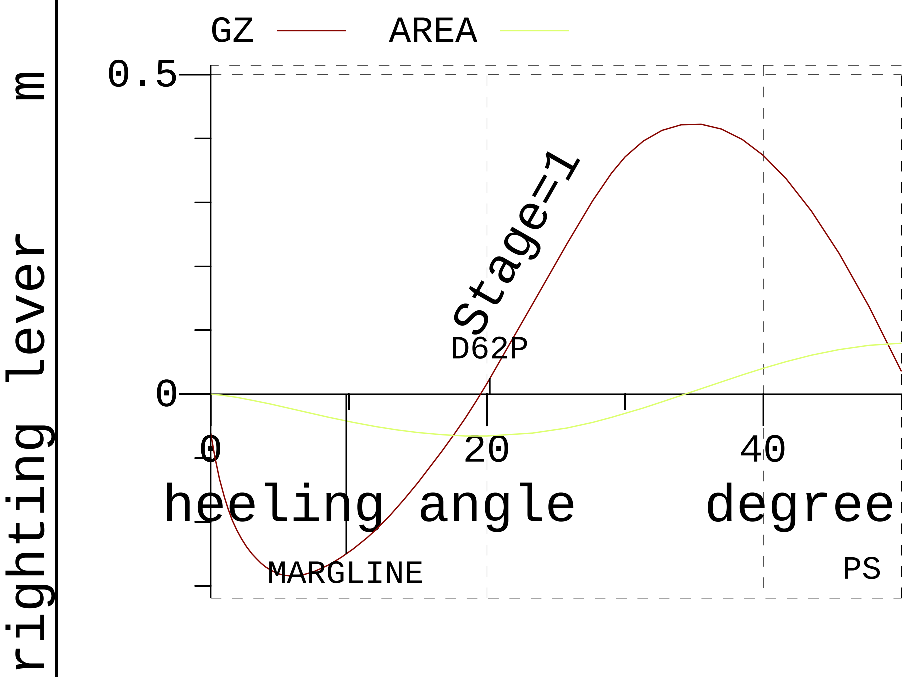
Damage Stability | ID17826
after incident | D

	GZ curve Case: ILD210/D203	Proj ID17826/D Date 2011-11-03 Time 12:52 Sign SARN



Stage: 1 Phase: EQ

3.3.5 Critical openings

RELEVANT OPENINGS

NAME	TEXT	X m	Y m	Z m	IMMA degree	IMMR m
D62P	FLAPS TO PALLET LIFT P	37.20	-6.60	7.77	20.2	0.072
D62S	FLAPS TO PALLET LIFT S	37.20	6.60	7.77	-	4.485
D74P	OPEN TO CARLIFT CASING P	44.40	-2.40	7.20	-	0.937
D74S	OPEN TO CARLIFT CASING S	44.40	2.40	7.20	-	2.541
D80P	OPEN TO CARLIFT CASING P	48.00	-2.40	7.20	-	0.935

3.4 D204 Intermediate stage

The following compartments are open to sea:

- R41 Cargo hold 2
- R42 Storage room on deck 1
- R53 Car deck

Water level in R31, R32, R64 and Stabp is presumed unchanged compared to the initial condition.

3.4.1 Floating position

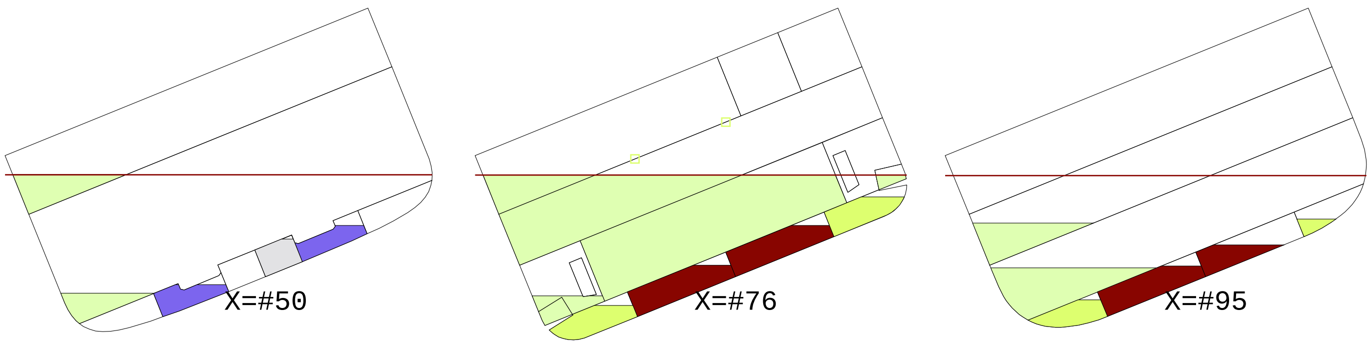
CASE	STAGE	PHASE	SI	T m	TR m	HEEL degree	RESFLD m	OPEN	RESMRG m
ILD210/D204	INTACT	EQ	PS	5.170	-0.044	-19.3	-0.954	DAMAGE	-1.621
ILD210/D204	1	EQ	PS	4.964	0.135	-22.1	-0.267	D62P	-2.036

3.4.2 Water in damaged compartments

DAMAGED COMPARTMENTS

CASE	STAGE	PHASE	NAME	PERM	VOL	XCG	YCG	ZCG
ILD210/D204	INTACT	EQ			0.0			
ILD210/D204	1	EQ	R41	0.62	247.8	46.59	-1.02	2.77
ILD210/D204	1	EQ	R42	0.80	264.3	44.60	-5.11	5.66
ILD210/D204	1	EQ	R53	0.90	215.3	25.58	-7.88	7.90

3.4.3 Floating and flooding situation

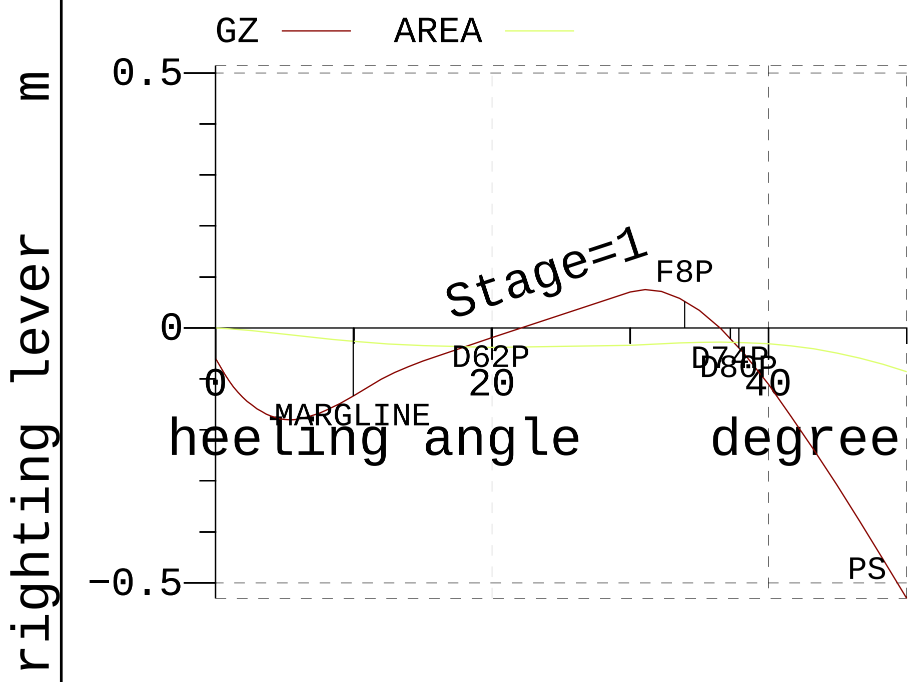


3.4.4 GZ−curve

Initial condition : ILD210
Damage case : D204
Stage of damage : 1
Phase of stage : EQ
Azimuth : 0 deg

HEEL degree	GZ m	EPHI rad*m	T m	TR m	OPNAME	IMRES m	RESMRG m
0.0	0.060	0.000	5.429	−0.151	P108P	1.75	1.63
−1.0	0.105	−0.001	5.428	−0.151	D80P	1.73	1.49
−3.0	0.158	−0.006	5.418	−0.155	D80P	1.65	1.16
−5.0	0.180	−0.012	5.398	−0.161	D80P	1.57	0.83
−7.0	0.172	−0.018	5.370	−0.168	D80P	1.49	0.50
−10.0	0.133	−0.026	5.317	−0.181	D62P	1.21	−0.01
−12.0	0.100	−0.031	5.272	−0.186	D62P	0.98	−0.34
−15.0	0.065	−0.035	5.198	−0.144	D62P	0.62	−0.83
−20.0	0.019	−0.038	5.048	0.026	D62P	−0.01	−1.65
−30.0	−0.071	−0.034	4.594	0.544	D62P	−1.24	−3.47
−40.0	0.111	−0.031	4.049	1.165	D62P	−2.50	−5.29
−50.0	0.530	−0.086	3.421	1.720	D62P	−3.73	−6.98

GZ curve Case: ILD210/D204	Proj ID17826/D Date 2011-11-03 Time 12:52 Sign SARN



Stage: 1 Phase: EQ

3.4.5 Critical openings

RELEVANT OPENINGS

NAME	TEXT	X m	Y m	Z m	IMMA degree	IMMR m
D62P	FLAPS TO PALLET LIFT P	37.20	−6.60	7.77	19.9	−0.255
F8P	OPEN STAIRCASE FR8P	4.80	−2.20	7.20	33.9	0.830
D74P	OPEN TO CARLIFT CASING P	44.40	−2.40	7.20	37.3	0.806
D80P	OPEN TO CARLIFT CASING P	48.00	−2.40	7.20	37.9	0.811
P84P	STAIRCASE FR84P	50.40	−2.10	7.20	41.9	0.927

3.5 D204B Intermediate stage

The following compartments are open to sea:

- R41 Cargo hold 2
- R42 Storage room on deck 1
- R53 Car deck
- Stabp Stabilizer room on port side

Water level in R31, R32 and R64 is presumed unchanged compared to the initial condition.

3.5.1 Floating position

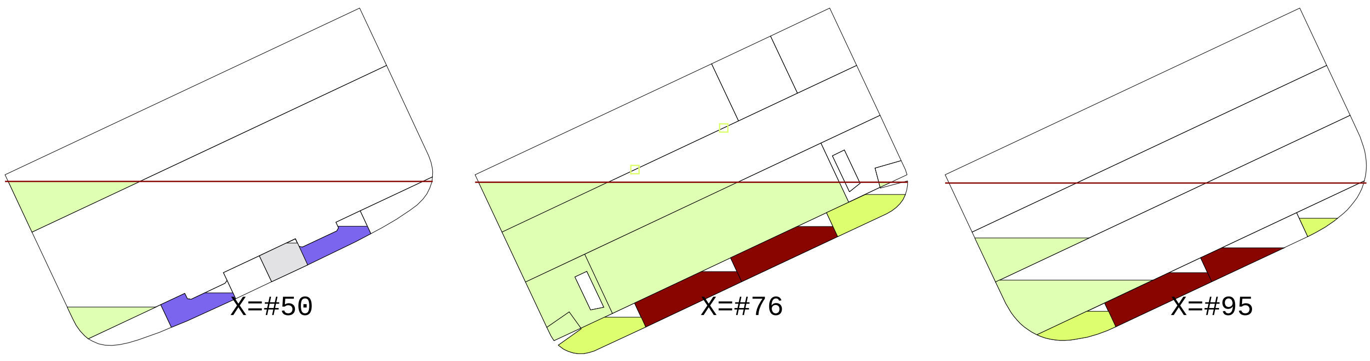
CASE	STAGE	PHASE	SI	T m	TR m	HEEL degree	RESFLD m	OPEN	RESMRG m
ILD210/D204B	INTACT	EQ	PS	5.170	-0.044	-19.3	-0.954	DAMAGE	-1.621
ILD210/D204B	1	EQ	PS	4.854	0.300	-25.2	-0.672	D62P	-2.626

3.5.2 Water in damaged compartments

DAMAGED COMPARTMENTS

CASE	STAGE	PHASE	NAME	PERM	VOL	XCG	YCG	ZCG
ILD210/D204B	INTACT	EQ			0.0			
ILD210/D204B	1	EQ	R41	0.62	236.6	46.60	-1.36	2.77
ILD210/D204B	1	EQ	R42	0.80	270.5	44.59	-5.08	5.69
ILD210/D204B	1	EQ	R53	0.90	323.8	25.42	-7.64	8.12
ILD210/D204B	1	EQ	STABP	0.85	48.0	48.83	-7.86	2.97

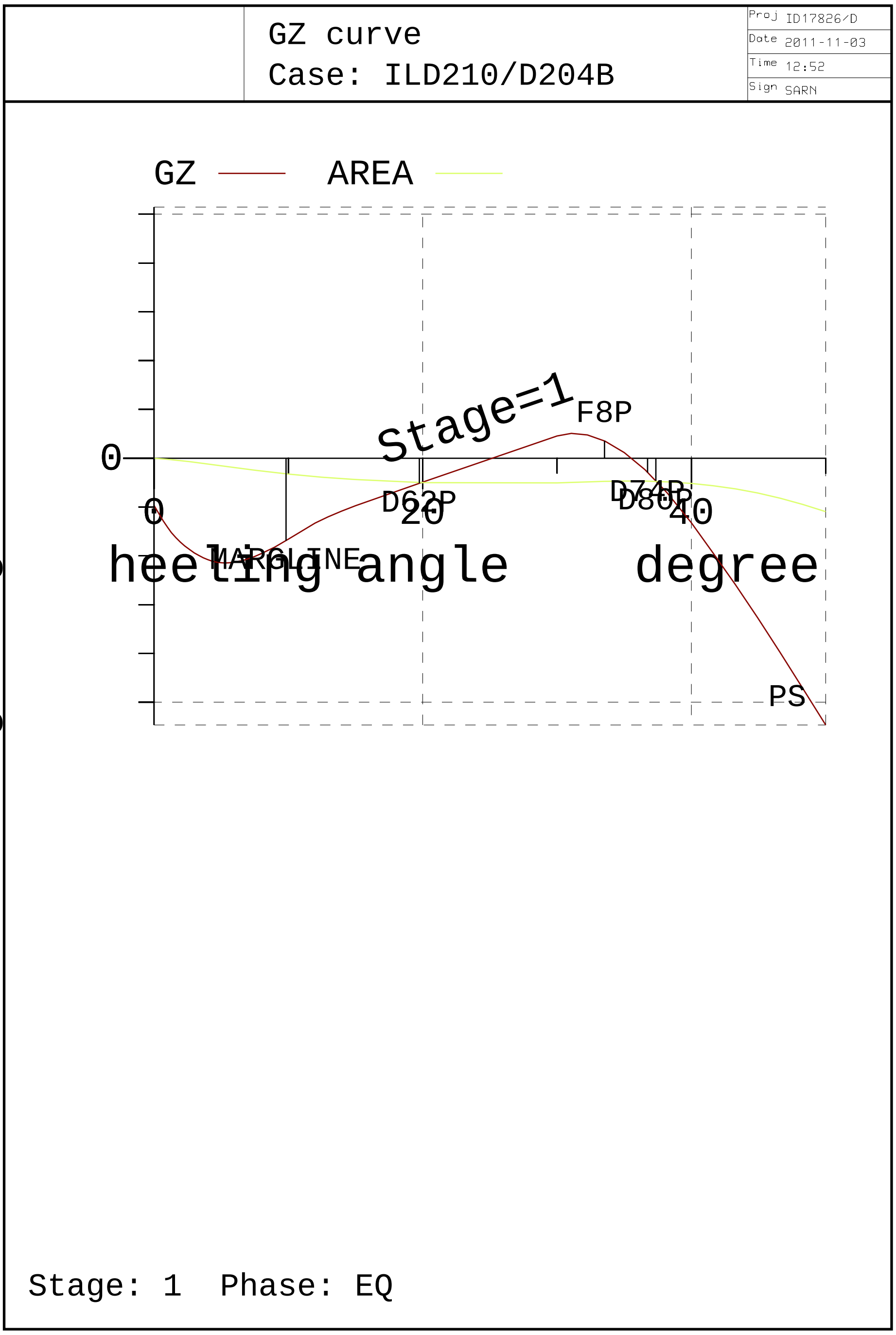
3.5.3 Floating and flooding situation



3.5.4 GZ−curve

Initial condition : ILD210
Damage case : D204B
Stage of damage : 1
Phase of stage : EQ
Azimuth : 0 deg

HEEL	GZ	EPHI	T	TR	OPNAME	IMRES	RESMRG
degree	m	rad*m	m	m		m	m
0.0	0.097	0.000	5.453	−0.159	P108P	1.73	1.60
−1.0	0.141	−0.002	5.451	−0.160	D80P	1.71	1.47
−3.0	0.194	−0.008	5.441	−0.163	D80P	1.63	1.14
−5.0	0.214	−0.015	5.421	−0.169	D80P	1.55	0.80
−7.0	0.206	−0.023	5.393	−0.177	D80P	1.47	0.47
−10.0	0.166	−0.033	5.340	−0.189	D62P	1.19	−0.03
−12.0	0.133	−0.038	5.295	−0.192	D62P	0.96	−0.36
−15.0	0.097	−0.044	5.221	−0.147	D62P	0.60	−0.85
−20.0	0.049	−0.050	5.071	0.028	D62P	−0.03	−1.67
−30.0	−0.045	−0.050	4.619	0.553	D62P	−1.27	−3.50
−40.0	0.132	−0.052	4.079	1.183	D62P	−2.54	−5.33
−50.0	0.546	−0.110	3.456	1.744	D62P	−3.76	−7.02


GZ curve
Case: ILD210/D204B
Proj ID17826/D
Date 2011-11-03
Time 12:52
Sign SARN
GZ
AREA
righting lever m
heeling angle degree
0
20
40
Stage=1
F8P
D62P
D74P
D80P
MARGLINE
PS
Stage: 1 Phase: EQ

3.5.5 Critical openings

RELEVANT OPENINGS

NAME	TEXT	X m	Y m	Z m	IMMA degree	IMMR m
D62P	FLAPS TO PALLET LIFT P	37.20	−6.60	7.77	19.8	−0.655
F8P	OPEN STAIRCASE FR8P	4.80	−2.20	7.20	33.5	0.607
D74P	OPEN TO CARLIFT CASING P	44.40	−2.40	7.20	36.8	0.636
D80P	OPEN TO CARLIFT CASING P	48.00	−2.40	7.20	37.4	0.647
P84P	STAIRCASE FR84P	50.40	−2.10	7.20	41.3	0.781

3.6 D205 Intermediate stage

The following compartments are open to sea:

- R41 Cargo hold 2
- R42 Storage room on deck 1
- R64 Nato storage

Water level in R31, R32, R53 and Stabp is presumed unchanged compared to the initial condition.

3.6.1 Floating position

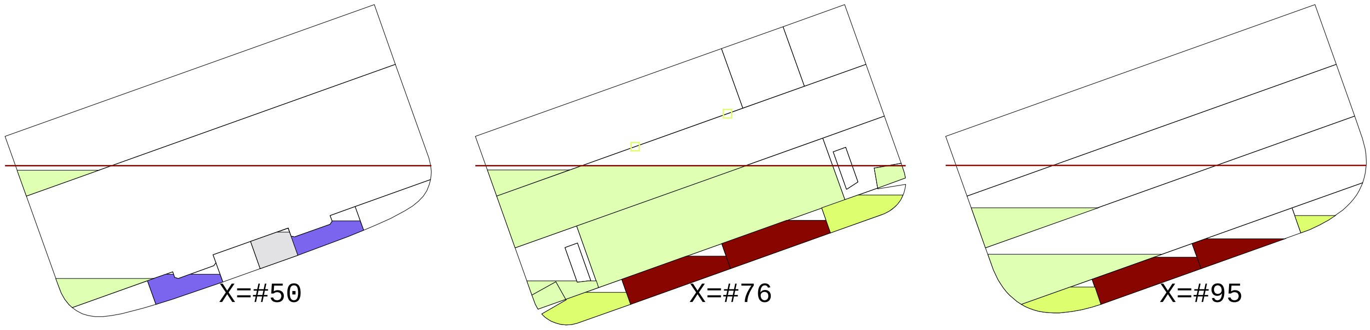
CASE	STAGE	PHASE	SI	T m	TR m	HEEL degree	RESFLD m	OPEN	RESMRG m
ILD210/D205	INTACT	EQ	PS	5.170	-0.044	-19.3	-0.954	DAMAGE	-1.621
ILD210/D205	1	EQ	PS	5.047	-0.024	-19.6	0.058	D62P	-1.567

3.6.2 Water in damaged compartments

DAMAGED COMPARTMENTS

CASE	STAGE	PHASE	NAME	PERM	VOL	XCG	YCG	ZCG
ILD210/D205	INTACT	EQ			0.0			
ILD210/D205	1	EQ	R41	0.62	256.4	46.57	-0.78	2.78
ILD210/D205	1	EQ	R42	0.80	258.5	44.61	-5.13	5.63
ILD210/D205	1	EQ	R64	0.85	18.3	0.25	-7.91	7.70

3.6.3 Floating and flooding situation



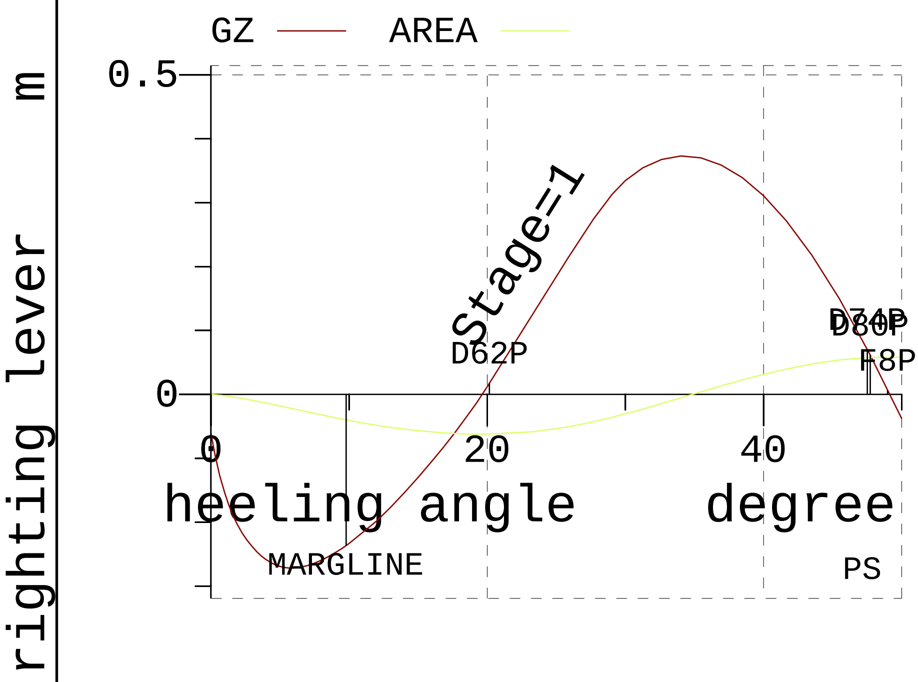
3.6.4 GZ−curve

Initial condition : ILD210
Damage case : D205
Stage of damage : 1
Phase of stage : EQ
Azimuth : 0 deg

HEEL degree	GZ m	EPHI rad*m	T m	TR m	OPNAME	IMRES m	RESMRG m
0.0	0.061	0.000	5.486	−0.031	P108P	1.71	1.62
−1.0	0.154	−0.002	5.485	−0.033	D80P	1.67	1.46
−3.0	0.238	−0.009	5.474	−0.030	D80P	1.59	1.13
−5.0	0.269	−0.018	5.454	−0.033	D80P	1.51	0.80
−7.0	0.268	−0.027	5.426	−0.040	D80P	1.43	0.47
−10.0	0.233	−0.041	5.372	−0.051	D62P	1.14	−0.03
−12.0	0.198	−0.048	5.324	−0.058	D62P	0.91	−0.36
−15.0	0.130	−0.057	5.233	−0.054	D62P	0.57	−0.85
−20.0	−0.012	−0.062	5.029	−0.022	D62P	0.02	−1.62
−30.0	−0.334	−0.031	4.418	0.059	D62P	−1.00	−3.08
−40.0	−0.311	0.031	3.683	0.166	D62P	−2.00	−4.47
−50.0	0.038	0.059	2.868	0.253	D62P	−2.97	−5.76

GZ curve
Case: ILD210/D205

Proj	ID17826/D
Date	2011-11-03
Time	12:52
Sign	SARN



Stage: 1 Phase: EQ

3.6.5 Critical openings

RELEVANT OPENINGS

NAME	TEXT	X m	Y m	Z m	IMMA degree	IMMR m
D62P	FLAPS TO PALLET LIFT P	37.20	−6.60	7.77	20.2	0.058
D74P	OPEN TO CARLIFT CASING P	44.40	−2.40	7.20	47.5	0.930
D80P	OPEN TO CARLIFT CASING P	48.00	−2.40	7.20	47.7	0.930
F8P	OPEN STAIRCASE FR8P	4.80	−2.20	7.20	49.0	1.007
D62S	FLAPS TO PALLET LIFT S	37.20	6.60	7.77	−	4.492

3.7 D206 Intermediate stage

The following compartments are open to sea:

- R41 Cargo hold 2
- R42 Storage room on deck 1
- R53 Car deck
- R64 Nato storage

Water level in R31, R32 and Stabp is presumed unchanged compared to the initial condition.

3.7.1 Floating position

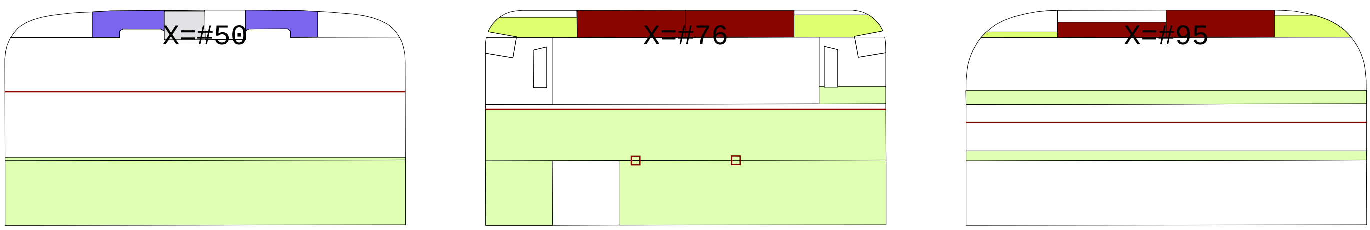
CASE	STAGE	PHASE	SI	T	TR	HEEL	RESFLD	OPEN	RESMRG
				m	m	degree	m		m
ILD210/D206	INTACT	EQ	PS	5.170	-0.044	-19.3	-0.954	DAMAGE	-1.621
ILD210/D206	1	EQ	-	-	-	-	-	-	-

3.7.2 Water in damaged compartments

DAMAGED COMPARTMENTS

CASE	STAGE	PHASE	NAME	PERM	VOL	XCG	YCG	ZCG
ILD210/D206	INTACT	EQ			0.0			
ILD210/D206	1	EQ	R41	0.62	-	-	-	-
ILD210/D206	1	EQ	R42	0.80	-	-	-	-
ILD210/D206	1	EQ	R53	0.90	-	-	-	-
ILD210/D206	1	EQ	R64	0.85	-	-	-	-

3.7.3 Floating and flooding situation



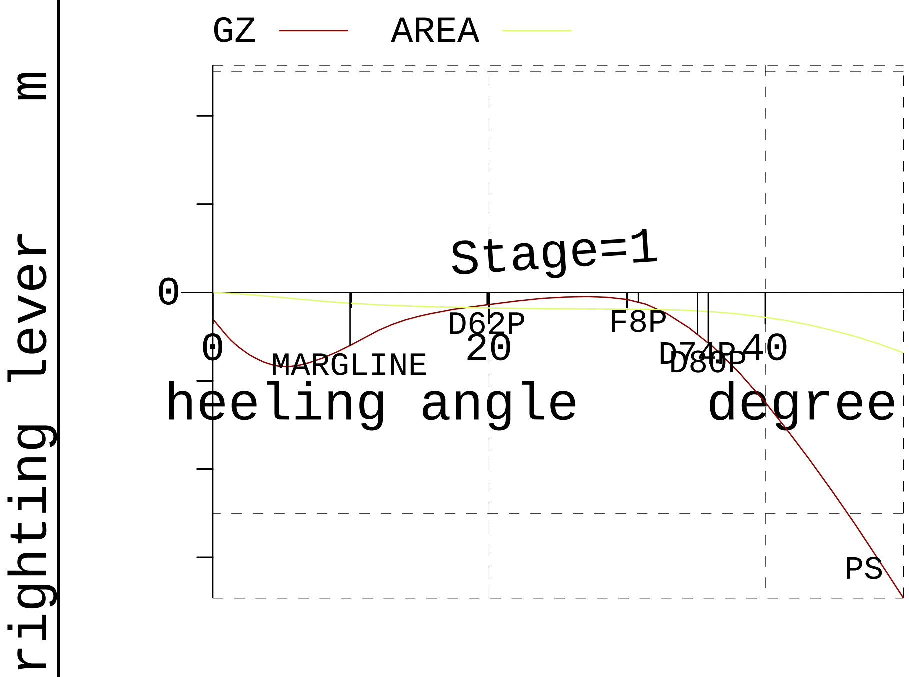
3.7.4 GZ−curve

Initial condition : ILD210
Damage case : D206
Stage of damage : 1
Phase of stage : EQ
Azimuth : 0 deg

HEEL degree	GZ m	EPHI rad*m	T m	TR m	OPNAME	IMRES m	RESMRG m
0.0	0.060	0.000	5.423	−0.203	P108P	1.75	1.61
−1.0	0.097	−0.001	5.422	−0.204	P108P	1.74	1.49
−3.0	0.147	−0.006	5.412	−0.207	D80P	1.66	1.16
−5.0	0.167	−0.011	5.392	−0.213	D80P	1.58	0.82
−7.0	0.159	−0.017	5.364	−0.220	D80P	1.50	0.49
−10.0	0.119	−0.024	5.311	−0.233	D62P	1.23	−0.01
−12.0	0.086	−0.028	5.266	−0.239	D62P	1.00	−0.34
−15.0	0.053	−0.032	5.193	−0.187	D62P	0.63	−0.83
−20.0	0.027	−0.035	5.052	0.059	D62P	−0.02	−1.67
−30.0	0.016	−0.038	4.645	0.904	D62P	−1.34	−3.69
−40.0	0.249	−0.056	4.166	1.893	D62P	−2.72	−5.74
−50.0	0.692	−0.136	3.612	2.757	D62P	−4.06	−7.65

GZ curve
Case: ILD210/D206

Proj	ID17826/D
Date	2011-11-03
Time	12:52
Sign	SARN



Stage: 1 Phase: EQ

3.7.5 Critical openings

RELEVANT OPENINGS

NAME	TEXT	X m	Y m	Z m	IMMA degree	IMMR m
D62P	FLAPS TO PALLET LIFT P	37.20	−6.60	7.77	19.9	−
F8P	OPEN STAIRCASE FR8P	4.80	−2.20	7.20	30.8	−
D74P	OPEN TO CARLIFT CASING P	44.40	−2.40	7.20	35.1	−
D80P	OPEN TO CARLIFT CASING P	48.00	−2.40	7.20	35.9	−
P84P	STAIRCASE FR84P	50.40	−2.10	7.20	39.5	−

3.8 D207 Intermediate stage

The following compartments are open to sea:

- R41 Cargo hold 2
- R42 Storage room on deck 1
- R53 Car deck
- R64 Nato storage
- Stabp Stabilizer room on port side

Water level in R31 and R32 is presumed unchanged compared to the initial condition.

3.8.1 Floating position

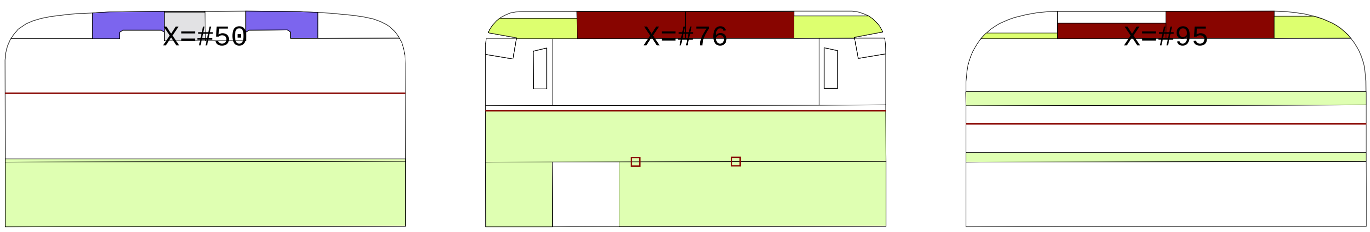
CASE	STAGE	PHASE	SI	T m	TR m	HEEL degree	RESFLD m	OPEN	RESMRG m
ILD210/D207	INTACT	EQ	PS	5.170	-0.044	-19.3	-0.954	DAMAGE	-1.621
ILD210/D207	1	EQ	-	-	-	-	-	-	-

3.8.2 Water in damaged compartments

DAMAGED COMPARTMENTS

CASE	STAGE	PHASE	NAME	PERM	VOL	XCG	YCG	ZCG
ILD210/D207	INTACT	EQ			0.0			
ILD210/D207	1	EQ	R41	0.62	-	-	-	-
ILD210/D207	1	EQ	R42	0.80	-	-	-	-
ILD210/D207	1	EQ	R53	0.90	-	-	-	-
ILD210/D207	1	EQ	R64	0.85	-	-	-	-
ILD210/D207	1	EQ	STABP	0.85	-	-	-	-

3.8.3 Floating and flooding situation

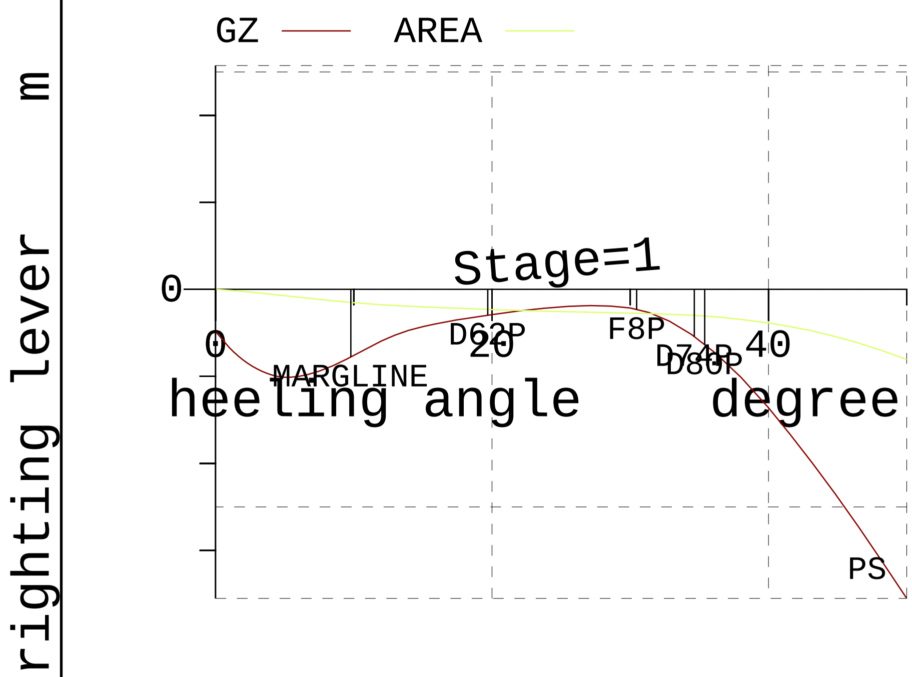


3.8.4 GZ−curve

Initial condition : ILD210
Damage case : D207
Stage of damage : 1
Phase of stage : EQ
Azimuth : 0 deg

HEEL degree	GZ m	EPHI rad*m	T m	TR m	OPNAME	IMRES m	RESMRG m
0.0	0.097	0.000	5.447	−0.211	P108P	1.73	1.58
−1.0	0.134	−0.002	5.445	−0.212	P108P	1.71	1.46
−3.0	0.183	−0.008	5.435	−0.215	D80P	1.64	1.13
−5.0	0.202	−0.014	5.415	−0.221	D80P	1.56	0.80
−7.0	0.193	−0.021	5.387	−0.228	D80P	1.48	0.47
−10.0	0.152	−0.031	5.334	−0.241	D62P	1.21	−0.03
−12.0	0.119	−0.035	5.288	−0.245	D62P	0.97	−0.37
−15.0	0.086	−0.041	5.216	−0.189	D62P	0.61	−0.86
−20.0	0.058	−0.047	5.076	0.064	D62P	−0.04	−1.69
−30.0	0.043	−0.054	4.672	0.920	D62P	−1.37	−3.72
−40.0	0.272	−0.077	4.198	1.918	D62P	−2.76	−5.79
−50.0	0.710	−0.161	3.648	2.793	D62P	−4.10	−7.70

	GZ curve Case: ILD210/D207	Proj ID17826/D Date 2011-11-03 Time 12:52 Sign SARN



Stage: 1 Phase: EQ

3.8.5 Critical openings

RELEVANT OPENINGS

NAME	TEXT	X m	Y m	Z m	IMMA degree	IMMR m
D62P	FLAPS TO PALLET LIFT P	37.20	−6.60	7.77	19.7	−
F8P	OPEN STAIRCASE FR8P	4.80	−2.20	7.20	30.5	−
D74P	OPEN TO CARLIFT CASING P	44.40	−2.40	7.20	34.6	−
D80P	OPEN TO CARLIFT CASING P	48.00	−2.40	7.20	35.4	−
P84P	STAIRCASE FR84P	50.40	−2.10	7.20	39.0	−

3.9 D208 Intermediate stage

The following compartments are open to sea:

- R32 Accommodation on deck 1
- R41 Cargo hold 2
- R42 Storage room on deck 1
- R53 Car deck
- R64 Nato storage
- Stabp Stabilizer room on port side

Water level in R31 is presumed unchanged compared to the initial condition.

At high angles of heel can shifting of the cargo occur. Shifting can happen in both cargo holds and on the car deck. The cars were not lashed.

A shifting of cargo will cause the vessel to heel even more and reducing the margin for progressive flooding.

3.9.1 Floating position

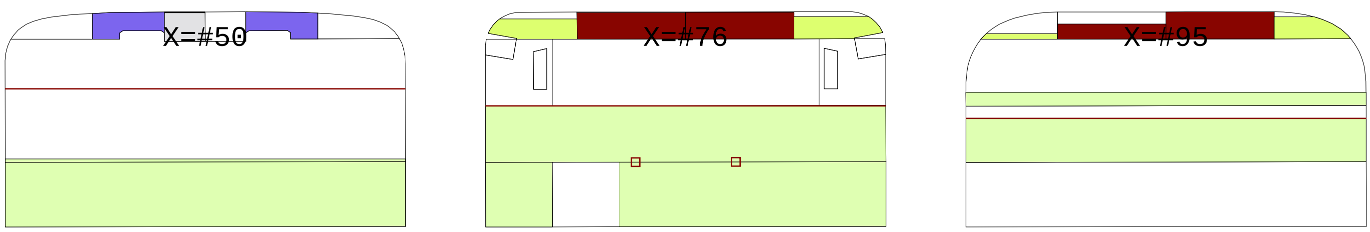
CASE	STAGE	PHASE	SI	T m	TR m	HEEL degree	RESFLD m	OPEN	RESMRG m
ILD210/D208	INTACT	EQ	PS	5.170	-0.044	-19.3	-0.954	DAMAGE	-1.621
ILD210/D208	1	EQ	-	-	-	-	-	-	-

3.9.2 Water in damaged compartments

DAMAGED COMPARTMENTS

CASE	STAGE	PHASE	NAME	PERM	VOL	XCG	YCG	ZCG
ILD210/D208	INTACT	EQ			0.0			
ILD210/D208	1	EQ	R32	0.95	-	-	-	-
ILD210/D208	1	EQ	R41	0.62	-	-	-	-
ILD210/D208	1	EQ	R42	0.80	-	-	-	-
ILD210/D208	1	EQ	R53	0.90	-	-	-	-
ILD210/D208	1	EQ	R64	0.85	-	-	-	-
ILD210/D208	1	EQ	STABP	0.85	-	-	-	-

3.9.3 Floating and flooding situation

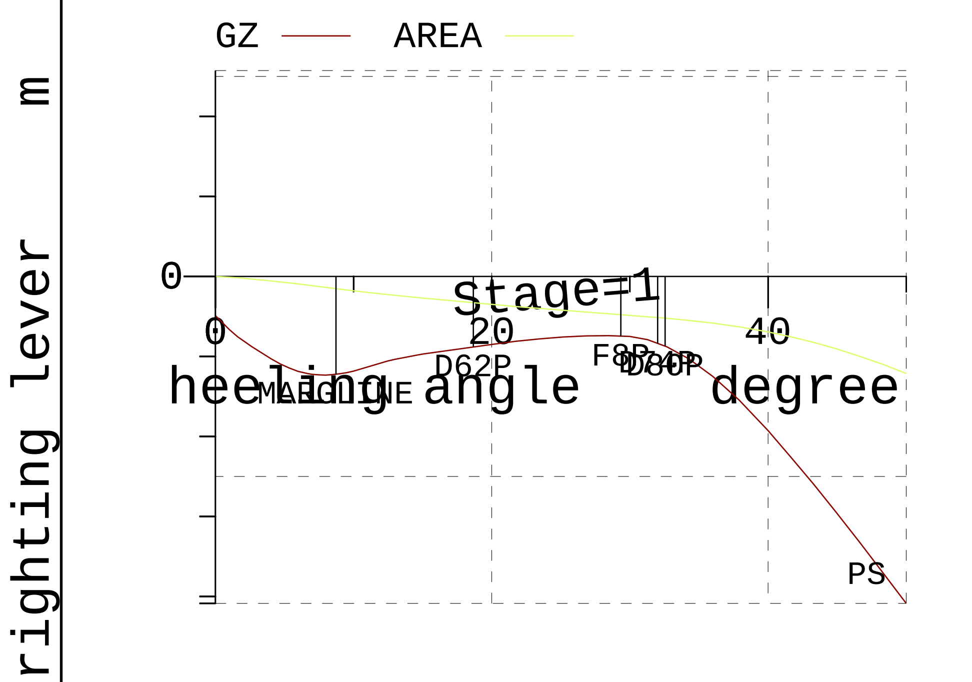


3.9.4 GZ−curve

Initial condition : ILD210
Damage case : D208
Stage of damage : 1
Phase of stage : EQ
Azimuth : 0 deg

HEEL degree	GZ m	EPHI rad*m	T m	TR m	OPNAME	IMRES m	RESMRG m
0.0	0.098	0.000	5.580	−0.413	P108P	1.57	1.35
−1.0	0.133	−0.002	5.579	−0.413	P108P	1.55	1.27
−3.0	0.183	−0.008	5.569	−0.416	D80P	1.51	0.95
−5.0	0.224	−0.015	5.548	−0.420	D80P	1.43	0.62
−7.0	0.244	−0.023	5.518	−0.425	D80P	1.35	0.30
−10.0	0.236	−0.036	5.471	−0.448	D62P	1.10	−0.21
−12.0	0.216	−0.044	5.433	−0.455	D62P	0.86	−0.55
−15.0	0.194	−0.054	5.368	−0.390	D62P	0.48	−1.05
−20.0	0.170	−0.070	5.236	−0.118	D62P	−0.18	−1.85
−30.0	0.150	−0.097	4.846	0.779	D62P	−1.53	−3.83
−40.0	0.385	−0.139	4.410	1.799	D62P	−2.95	−5.94
−50.0	0.817	−0.243	3.896	2.723	D62P	−4.34	−7.92

GZ curve Case: ILD210/D208	Proj ID17826/D Date 2011-11-03 Time 12:52 Sign SARN



Stage: 1 Phase: EQ

3.9.5 Critical openings

RELEVANT OPENINGS

NAME	TEXT	X m	Y m	Z m	IMMA degree	IMMR m
D62P	FLAPS TO PALLET LIFT P	37.20	−6.60	7.77	18.7	−
F8P	OPEN STAIRCASE FR8P	4.80	−2.20	7.20	29.3	−
D74P	OPEN TO CARLIFT CASING P	44.40	−2.40	7.20	32.0	−
D80P	OPEN TO CARLIFT CASING P	48.00	−2.40	7.20	32.5	−
P84P	STAIRCASE FR84P	50.40	−2.10	7.20	35.7	−

3.10 D209 Intermediate stage

The following compartments are open to sea:

- R31 Cargo hold 1
- R41 Cargo hold 2
- R42 Storage room on deck 1
- R53 Car deck
- R64 Nato storage
- Stabp Stabilizer room on port side

Water level in R32 is presumed unchanged compared to the initial condition.

3.10.1 Floating position

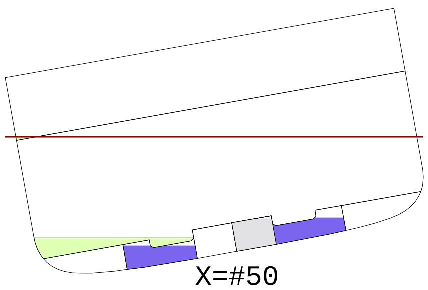
CASE	STAGE	PHASE	SI	T m	TR m	HEEL degree	RESFLD m	OPEN	RESMRG m
ILD210/D209	INTACT	EQ	PS	5.170	-0.044	-19.3	-0.954	DAMAGE	-1.621
ILD210/D209	1	EQ	PS	5.739	-0.815	-10.1	0.866	D62P	-0.586

3.10.2 Water in damaged compartments

DAMAGED COMPARTMENTS

CASE	STAGE	PHASE	NAME	PERM	VOL	XCG	YCG	ZCG
ILD210/D209	INTACT	EQ			0.0			
ILD210/D209	1	EQ	R31	0.90	755.5	58.65	-0.12	2.92
ILD210/D209	1	EQ	R41	0.62	285.1	46.48	-0.06	2.87
ILD210/D209	1	EQ	R42	0.80	293.0	44.81	-3.83	5.46
ILD210/D209	1	EQ	R53	0.90	3.2	38.20	-9.16	7.28
ILD210/D209	1	EQ	R64	0.85	0.0	-	-	-
ILD210/D209	1	EQ	STABP	0.85	48.0	48.83	-7.86	2.97

3.10.3 Floating and flooding situation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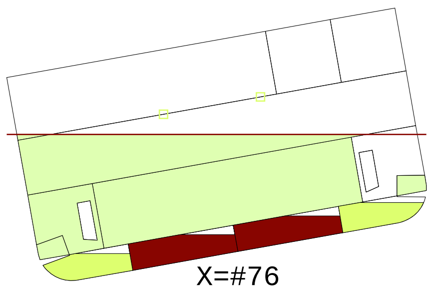
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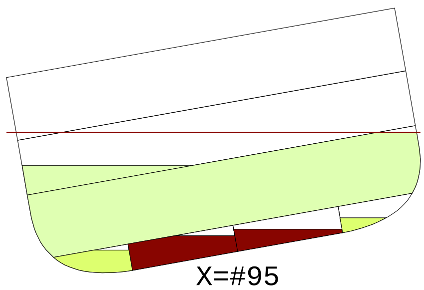
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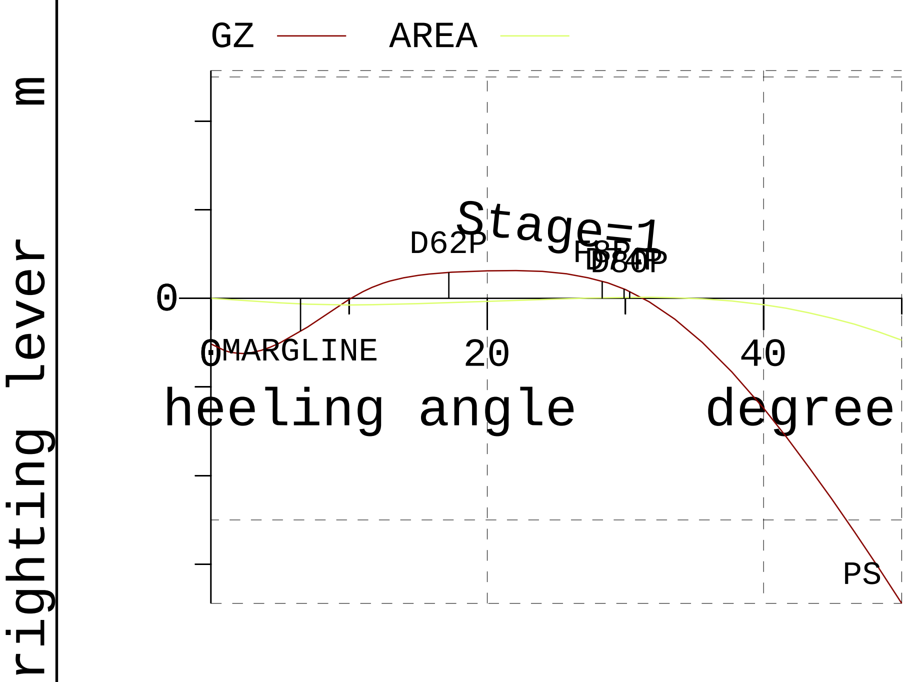
3.10.4 GZ−curve

Initial condition : ILD210
Damage case : D209
Stage of damage : 1
Phase of stage : EQ
Azimuth : 0 deg

HEEL degree	GZ m	EPHI rad*m	T m	TR m	OPNAME	IMRES m	RESMRG m
0.0	0.103	0.000	5.868	−0.808	P108P	1.23	0.89
−1.0	0.118	−0.002	5.866	−0.808	P108P	1.22	0.83
−3.0	0.122	−0.006	5.856	−0.809	P108P	1.19	0.56
−5.0	0.100	−0.010	5.835	−0.812	D80P	1.16	0.24
−7.0	0.065	−0.013	5.805	−0.815	D80P	1.08	−0.08
−10.0	0.002	−0.015	5.741	−0.817	D62P	0.88	−0.57
−12.0	−0.029	−0.014	5.691	−0.788	D62P	0.65	−0.88
−15.0	−0.052	−0.012	5.609	−0.670	D62P	0.28	−1.35
−20.0	−0.062	−0.007	5.444	−0.324	D62P	−0.35	−2.10
−30.0	−0.020	0.002	4.992	0.674	D62P	−1.66	−3.93
−40.0	0.248	−0.014	4.523	1.747	D62P	−3.06	−6.03
−50.0	0.689	−0.095	3.982	2.710	D62P	−4.43	−8.00

GZ curve Case: ILD210/D209	Proj ID17826/D Date 2011-11-03 Time 12:52 Sign SARN



Stage: 1 Phase: EQ

3.10.5 Critical openings

RELEVANT OPENINGS

NAME	TEXT	X m	Y m	Z m	IMMA degree	IMMR m
D62P	FLAPS TO PALLET LIFT P	37.20	-6.60	7.77	17.2	0.866
F8P	OPEN STAIRCASE FR8P	4.80	-2.20	7.20	28.3	1.333
D74P	OPEN TO CARLIFT CASING P	44.40	-2.40	7.20	29.9	0.986
D80P	OPEN TO CARLIFT CASING P	48.00	-2.40	7.20	30.3	0.958
P84P	STAIRCASE FR84P	50.40	-2.10	7.20	33.5	0.992

3.11 D211 Equilibrium in all flooded compartments

The following compartments are open to sea:

- R31 Cargo hold 1
- R32 Accommodation on deck 1
- R41 Cargo hold 2
- R42 Storage room on deck 1
- R53 Car deck
- R64 Nato storage
- Stabp Stabilizer room on port side

These are all the compartmenst where sea water was detected during the inspection after the accident.

3.11.1 Floating position

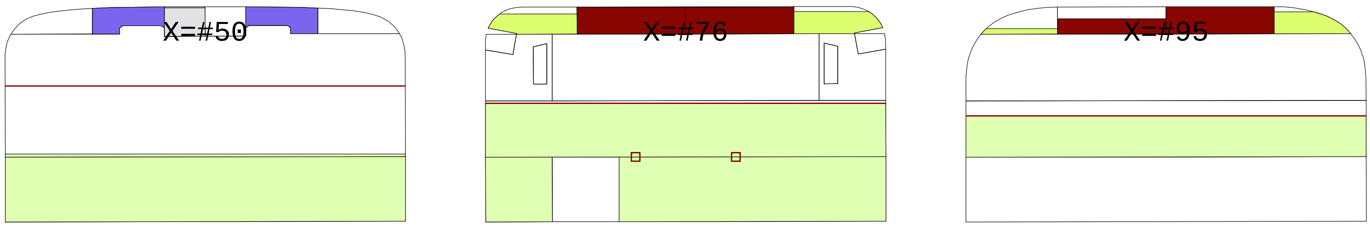
CASE	STAGE	PHASE	SI	T m	TR m	HEEL degree	RESFLD m	OPEN	RESMRG m
ILD210/D211	INTACT	EQ	PS	5.170	-0.044	-19.3	-0.954	DAMAGE	-1.621
ILD210/D211	1	EQ	-	-	-	-	-	-	-

3.11.2 Water in damaged compartments

DAMAGED COMPARTMENTS

CASE	STAGE	PHASE	NAME	PERM	VOL	XCG	YCG	ZCG
ILD210/D211	INTACT	EQ			0.0			
ILD210/D211	1	EQ	R31	0.90	-	-	-	-
ILD210/D211	1	EQ	R32	0.95	-	-	-	-
ILD210/D211	1	EQ	R41	0.62	-	-	-	-
ILD210/D211	1	EQ	R42	0.80	-	-	-	-
ILD210/D211	1	EQ	R53	0.90	-	-	-	-
ILD210/D211	1	EQ	R64	0.85	-	-	-	-
ILD210/D211	1	EQ	STABP	0.85	-	-	-	-

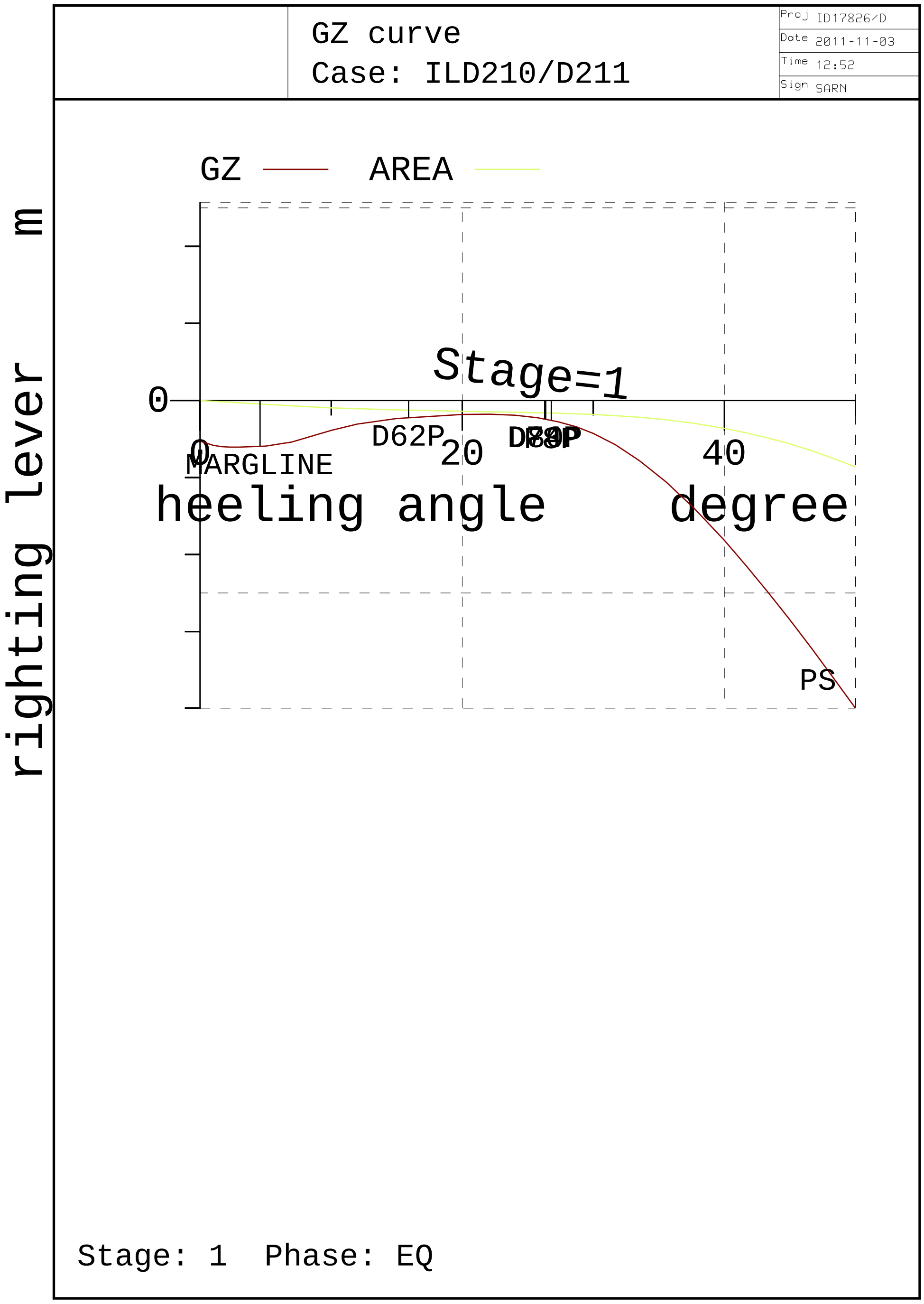
3.11.3 Floating and flooding situation



3.11.4 GZ−curve

Initial condition : ILD210
Damage case : D211
Stage of damage : 1
Phase of stage : EQ
Azimuth : 0 deg

HEEL degree	GZ m	EPHI rad*m	T m	TR m	OPNAME	IMRES m	RESMRG m
0.0	0.105	0.000	6.091	−1.118	P108P	0.97	0.52
−1.0	0.117	−0.002	6.089	−1.118	P108P	0.96	0.46
−3.0	0.121	−0.006	6.079	−1.119	P108P	0.93	0.24
−5.0	0.119	−0.010	6.057	−1.120	P108P	0.91	−0.07
−7.0	0.108	−0.014	6.024	−1.119	D80P	0.87	−0.38
−10.0	0.078	−0.019	5.947	−1.096	D62P	0.71	−0.84
−12.0	0.061	−0.022	5.893	−1.045	D62P	0.48	−1.14
−15.0	0.047	−0.024	5.807	−0.898	D62P	0.12	−1.60
−20.0	0.036	−0.028	5.640	−0.516	D62P	−0.52	−2.33
−30.0	0.085	−0.036	5.202	0.516	D62P	−1.85	−4.07
−40.0	0.363	−0.072	4.769	1.610	D62P	−3.29	−6.21
−50.0	0.799	−0.172	4.266	2.616	D62P	−4.70	−8.24


GZ curve
Case: ILD210/D211
Proj ID17826/D
Date 2011-11-03
Time 12:52
Sign SARN
GZ
AREA
Stage=1
0
20
40
D62P
MARGLINE
PS
heeling angle degree
righting lever m
Stage: 1 Phase: EQ

3.11.5 Critical openings

RELEVANT OPENINGS

NAME	TEXT	X m	Y m	Z m	IMMA degree	IMMR m
D62P	FLAPS TO PALLET LIFT P	37.20	−6.60	7.77	15.9	−
D74P	OPEN TO CARLIFT CASING P	44.40	−2.40	7.20	26.3	−
D80P	OPEN TO CARLIFT CASING P	48.00	−2.40	7.20	26.4	−
F8P	OPEN STAIRCASE FR8P	4.80	−2.20	7.20	26.8	−
P84P	STAIRCASE FR84P	50.40	−2.10	7.20	29.5	−