Norwegian Safety
Investigation Authority

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REPORT MARINE 2022/08

Fire on board ‘MS Brim’ in the outer Oslofjord on 11 March 2021

The Norwegian Safety Investigation Authority (NSIA) has produced this report exclusively for the purpose of improving safety at sea.

A safety investigation is conducted in order to determine the sequence of events and causal factors, study factors of importance for preventing marine accidents and improving safety at sea, and publish a report and any safety recommendations. It is not the NSIA's task to apportion blame or liability under criminal or civil law.

This report should not be used for purposes other than preventive maritime safety work.

Photo: NSIA

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Notification of the incident

The Norwegian Safety Investigation Authority (NSIA) was notified of the accident by the Norwegian Maritime Authority (NMA) at 18:05 on 11 March 2021. Previously that day, at 15:45, the vessel had issued a MAYDAY distress message following smoke development in one of the battery rooms. As a result of the accident, the crew of four were evacuated and the vessel was towed to Vallø in Tønsberg. Figure 1 shows where the accident occurred.

The NSIA decided to conduct a safety investigation into the accident. Representatives of the owners and members of crew who were board when the accident occurred were interviewed and, on 18 March 2021, NSIA inspectors were deployed to Vallø in Tønsberg to examine the vessel.

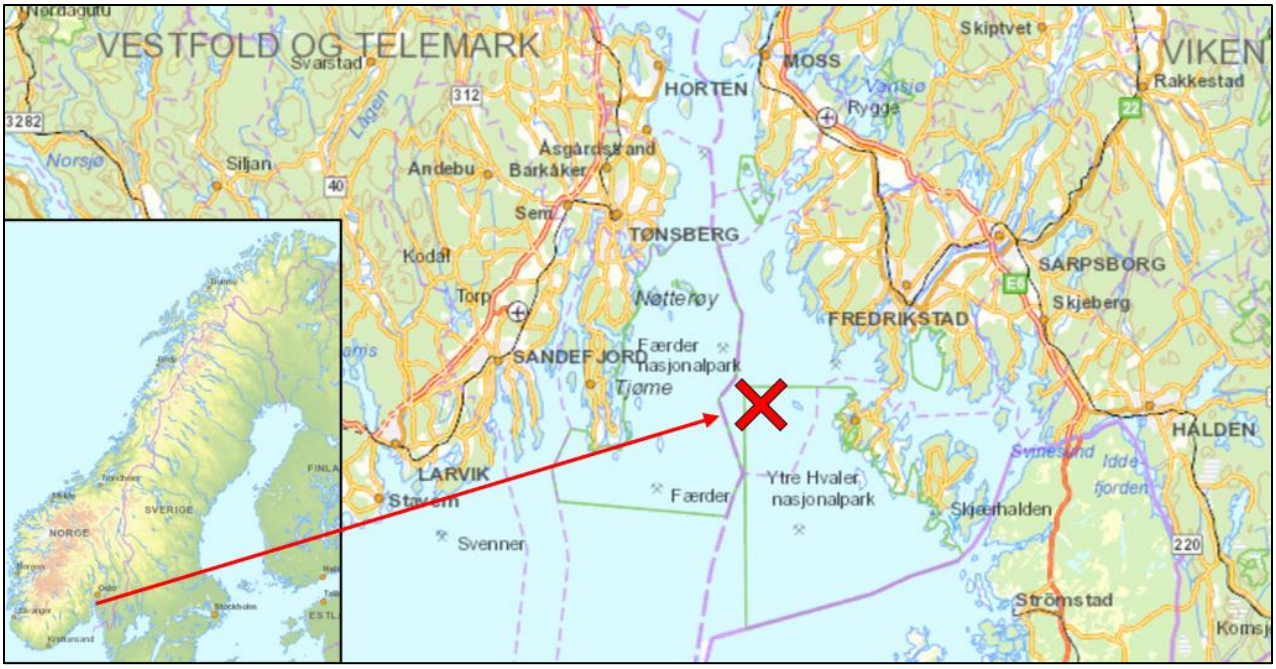

Figure 1: The accident occurred near the mouth of the Oslofjord during a voyage from Sarpsborg to Sandefjord. Map: Kystinfo online map service/NSIA

Summary

On Thursday 11 March 2021, the hybrid vessel 'Brim' was passing through the outer Oslofjord, when the fire alarm went off and the fire alarm panel indicated fire in both the starboard battery room and the starboard engine room. The engineer therefore opened the door to the starboard engine room and confirmed the development of smoke, which was also observed by the skipper via camera surveillance. Novec fire suppression agent was first released into the engine room and then into the battery room. It had the effect of temporarily slowing down the smoke development. A SAR vessel arrived on the scene and assisted with evacuation of the crew and towing the vessel to shore. Extinguishing efforts and control of the vessel continued for several days before the vessel was considered safe enough to board.

Technical examinations showed that the fire started in module 1 in battery stack 6. It is highly likely that seawater ingressed through the ventilation outlet in the tunnel as a result of waves slamming against the tunnel top, and then leaked through the ventilation fan and down onto the batteries. This caused short-circuits and electric arcs and subsequent outbreak of fire.

The NSIA's investigation has shown that the positioning of the ventilation outlet in the tunnel was unfavourable and that measures to prevent water ingress were insufficient. Neither the shipyard, nor DNV or the Norwegian Maritime Authority (NMA) identified the fan as a leakage point with regard to ingress of seawater. Important information about flooding points from the ventilation system to the battery room was missing from the freeboard plan. This meant that the NMA personnel responsible for approving the freeboard plan were unaware of the ventilation outlet being placed in the tunnel. After the accident, the owners have made several changes to the ventilation system.

The investigation also showed that the low IP rating of the battery system enabled seawater to enter battery modules and high-voltage components.[1] A higher IP rating (degree of protection) would have reduced the consequences of seawater ingress to the battery room. In the NSIA's opinion, the regulations do not sufficiently address the need for ingress protection of battery systems.

The fire wall did not prevent smoke from spreading from the battery room to the engine room, which was one reason why the crew did not understand where the fire had started. Because the fire was incorrectly understood to be in the engine room, approximately seven minutes passed before Novec was released to the battery room. In order to be effective, the fire suppression agent needs to be released quickly and automatically. The NSIA considers the lack of adequate means of extinguishing fires in lithium-ion batteries to be a safety problem.

The risk assessment relating to the battery system does not reflect the real risks associated with the system. In the NSIA's opinion, a risk assessment should address all relevant risks identified by the various disciplines, the sum of which constitutes the total risk posed by the battery system.

Battery safety as a whole was not adequately addressed in the regulations and nobody identified the risk of seawater ingress through the ventilation arrangements. Based on current rules and regulations, the same error may be made again. The NMA does not have separate regulations relating to battery safety, but relies on the classification rules. The classification societies may have different requirements for battery safety, which can result in different vessels having different standards of battery safety. The NMA has the administrative authority to ensure safety and must exercise this authority, regardless of the classification rules used.

The NSIA submits a total of seven safety recommendations as a result of the investigation.

[1] *In this report, the NSIA refers to voltages of 500–770 VDC as high voltages.*

About the investigation

Purpose and method

The NSIA has classified the incident as a near accident. The purpose of this investigation has been to determine what caused the fire on board. The NSIA has also considered what can be done to improve safety and thus prevent the recurrence of accidents of a similar nature and scope in future.

The accident and the circumstances surrounding it have been investigated and analysed in line with the NSIA's framework and analysis process for systematic safety investigations (the NSIA method[2]).

Focus and delimitation of the investigation

The investigation has focused in particular on understanding why the fire broke out, how it was handled, and operational and design factors in the shipboard battery system that may have contributed to the accident.

Sources of information

The factual information is based on interviews with the vessel's crew, technical investigations on board, the battery system log, the log from the Norwegian Coastal Administration's Automatic Identification System (AIS) and information and reports from the NMA, the police and fire service and insurance company, and from relevant parties in connection with the design and construction of the vessel.

The investigation report

The first part of the report, 'Factual information', describes the sequence of events, related data and information gathered in connection with the accident, what the NSIA has investigated and related findings.

The second part, the 'Analysis' part, contains the NSIA's assessment of the sequence of events and contributing causes based on factual information and completed investigations/examinations. Circumstances and factors found to be of little relevance to explaining and understanding the accident are not discussed in any depth.

The final part of the report contains the NSIA's conclusions and safety recommendations.

[2] *See https://www.nsia.no/About-us/Methodology*

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1. Factual information

1.1 Sequence of events

1.1.1 THE ACCIDENT

On Wednesday 10 March 2021, the hybrid vessel ‘Brim’ was berthed in Fredrikstad to charge her batteries overnight. The next morning, the vessel was scheduled to sail to Sarpsborg for a planned event. On Thursday 11 March, after the event, the vessel set course for Sandefjord. The crew of four were prepared for some bad weather in the Oslofjord, and they had readied the vessel for the voyage and checked the battery and engine rooms before departure. The navigating officer, who also had the role of engineer on board, used electric power for propulsion while sailing down the Glomma river. On leaving Glomma, the diesel engines were started in order to charge the batteries.

On entering the Oslofjord at approximately 15:00, the skipper increased the speed to initiate charging, but he reduced the speed again at 15:25 due to the sea becoming rougher. Southeasterly winds and waves hit the vessel on the port side, and the crew were under the impression that the waves were slapping against the catamaran’s tunnel top. Figure 2 shows the AIS track of ‘Brim’ on the day of the accident.

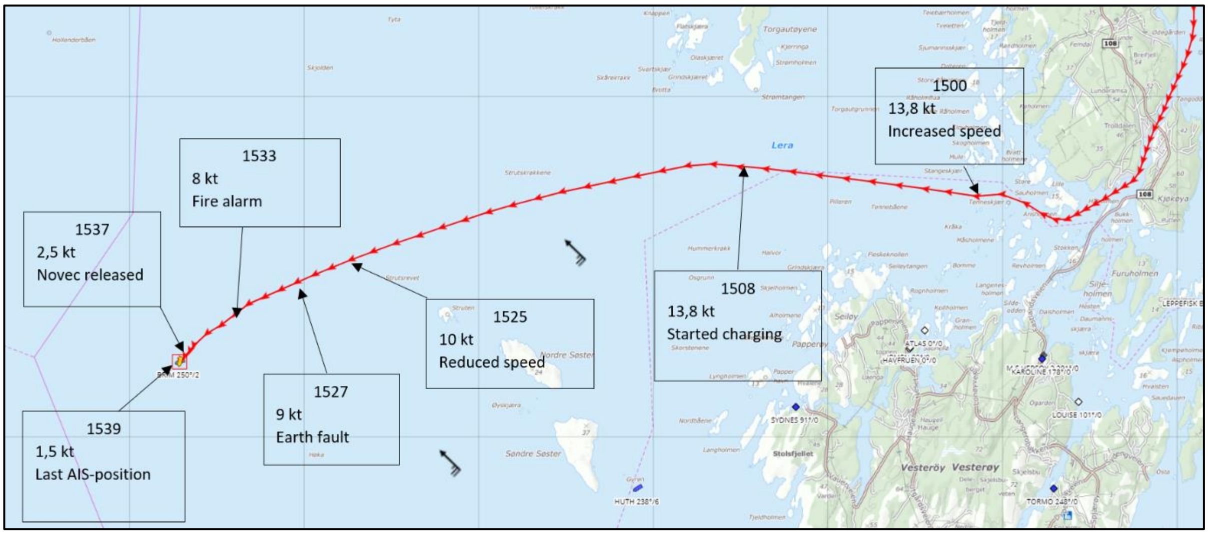


Figure 2: AIS track of the vessel’s voyage. The times are those observed by the crew, based on interviews and the EMS log, but differ from the times registered by the battery management system (BMS). Map: The Norwegian Coastal Administration/NSIA

At approximately 15:27, after approximately 20 minutes’ charging of the batteries, all 12 battery stacks[3] were disconnected and an alarm was transmitted to the EMS[4] panel on the bridge. The skipper and engineer assessed this as being due to a ground fault in the panel. The skipper started troubleshooting from the bridge, but understood all systems to be in working order. Furthermore, he assumed that the ground fault was not critical, as they had experienced such faults several times on previous voyages. After troubleshooting for approximately two minutes, the skipper

[3] The battery system consists of 12 stacks, each holding 6 battery modules. The stacks are distributed equally between the starboard and port battery rooms.
[4] EMS = energy management system. The system receives information from the battery management system (BMS) and displays it on the bridge.

relieved the engineer at the wheel, so that he could go down into the port engine room, where the BMS[5] panel was located, to further investigate the fault message on the panel.

The skipper reduced the speed when the EMS system also issued the warning ‘BMS serious’. The BMS system registered overheating of a module in battery stack 6, which, on the bridge, was displayed as a serious fault. Figure 3 shows the six battery stacks that make up the battery pack in each battery room. The alarm provided no further details and therefore had to be investigated by checking the BMS panel in the port engine room.

Shortly after, at approximately 15:33, the fire alarm sounded on board. The skipper observed that the fire alarm panel on the bridge indicated fire in both the starboard engine room and starboard battery room.

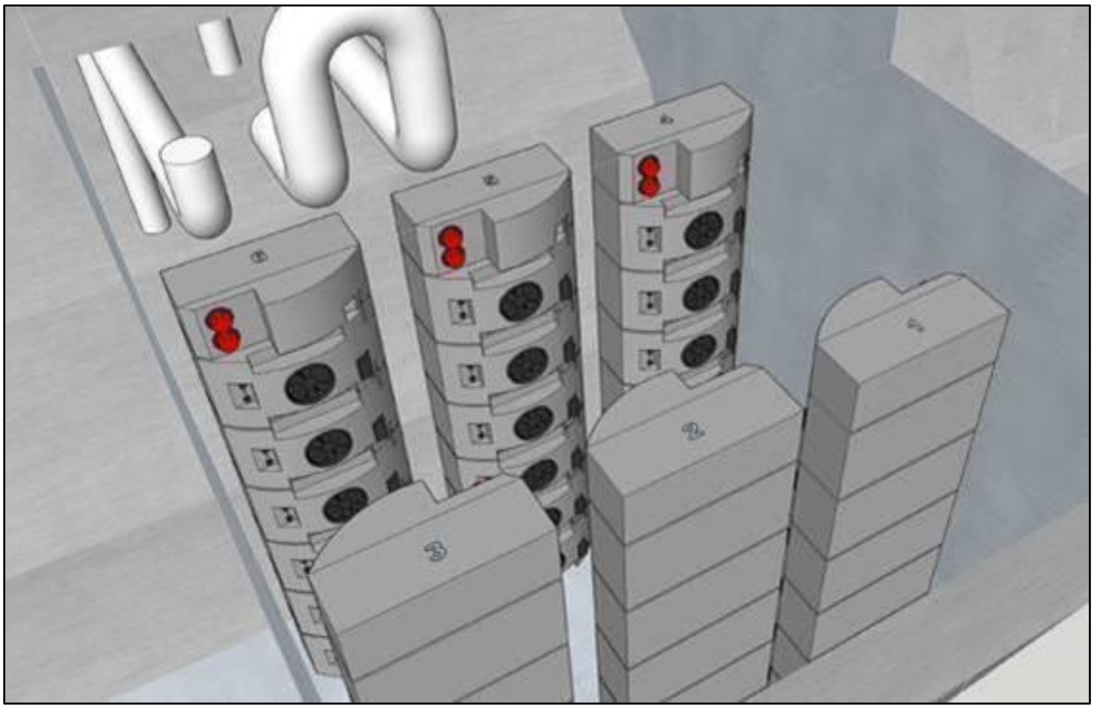


Figure 3: Six stacks of battery modules in one of the battery rooms. Illustration: The battery contractor

The skipper also checked the engine status on the control panel and monitored the engine room via a camera installed in the room. The pressure and temperature readings for the diesel engines were normal.

The able seamen on the main deck called the skipper to find out why the fire alarm had sounded. They were told that the engineer was going down into the engine room to investigate. While they were on their way to the engine room, the power failed, but it came back after approximately one minute. There was no indication of battery pack consumption on the EMS panel on the bridge. On the main deck, one of the able seamen ran into the engineer, who was on his way to the engine room. The engineer found that, while many alarms had been triggered on the BMS panel, everything looked normal on the 230V panel. He registered that the light indicating that the emergency generator had started was on. The engineer found that use of the communication system to communicate with the bridge from the engine room was challenging, because of the noise from the alarms.

[5] *BMS = battery management system. The system is designed for control, monitoring and protection of the battery system. The panel is located in the port engine room.*

The engineer then went over to the starboard side to check the situation there, and opened the door to the engine room. He saw smoke emanating from the direction of the emergency generator. The smell indicated an electric fire and the smoke was brownish or yellowish. At about the same time, the skipper observed via the camera that smoke was developing in the starboard engine room. No camera was installed in the battery room, so the skipper was unable to verify whether it also contained smoke. The engineer quickly closed the door to the engine room, ran to the bridge and notified the skipper of having seen smoke development, but no flames, in the engine room. The skipper concluded that there was a fire in the engine room, based on camera observations of smoke, the triggering of the fire alarm and information from the engineer.

At 15:35, the skipper therefore took action in accordance with the procedure that applied in the event of fire. The able seamen were told to ready the fire hoses on the aft deck. The engineer switched off the ventilation and closed watertight doors and fire dampers on the starboard side. The skipper activated the emergency stop on the starboard main engine.

After that, the engineer helped the able seamen to connect the fire hoses. One of the able seamen notified the skipper that the fire hoses were ready and that the skipper could start the fire pump to pressurise the water, but the pump did not work. At that point in time, the crew observed a lot of smoke emanating from the air vents on the starboard side; see Figure 4. One of the able seamen felt unwell and nauseated after inhaling the smoke. The crew on the main deck therefore ascended to the bridge.

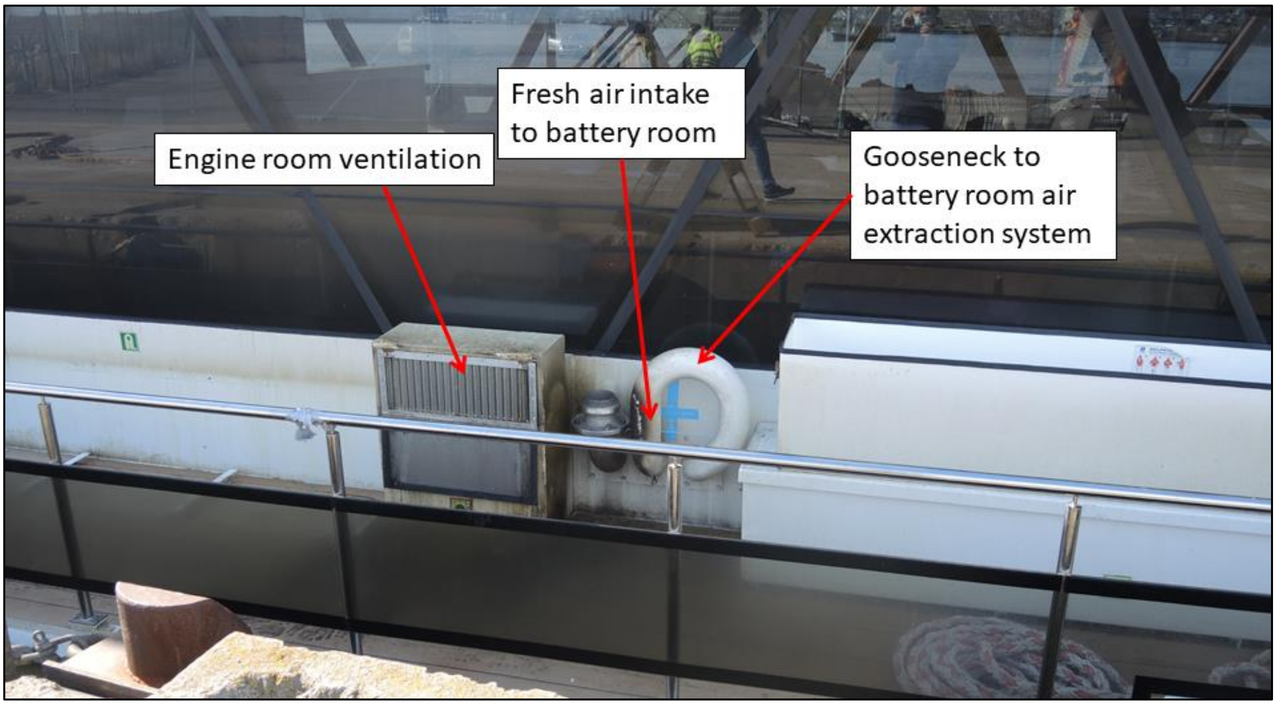


Figure 4: Ventilation for engine room and battery room on starboard side of 'Brim'. Photo: NSIA

In consultation with the engineer, the skipper decided to close off the fuel supply on the starboard side, fearing that diesel fuel was on fire in the engine room.

The various alarms on the bridge made a lot of noise, and one of the able seamen acknowledged the alarms to reduce the noise. At 15:37, the skipper activated the fire suppression system in the starboard engine room. Two of four cylinders of Novec fire suppression agent were released, but the smoke continued to develop. This caused the skipper to conclude that the smoke came from the battery room, and he therefore released the last two Novec cylinders into the battery room at approximately 15:40. This caused some reduction of the smoke development.

Because the fuel supply was shut off, the emergency generator, located on the starboard side, eventually gave up, so that control of navigation was lost and the screens and panels went black. At 15:39, emergency power was activated and only the most important electrical components were in operation. The skipper tried to steer the vessel towards Tjøme, using the port engine and the wave direction for directional stability.

At 15:41, the skipper sent a distress message on VHF channel 6. The distress call was answered by the Joint Rescue Coordination Centre (JRCC) and the skipper explained the situation. The engineer took over navigation of the vessel. The skipper continued to observe the situation and communicate from the bridge, while the able seamen readied the vessel's immersion suits.

1.1.2 THE RESCUE OPERATION

At 15:50, the crew were unable to control the vessel's course and the engineer stopped all propulsion pending the arrival of the rescue service. A cargo ship and a pilot boat arrived soon thereafter. There appeared to be less smoke along the hull side, and the crew therefore assumed that the situation had improved and informed the JRCC. The pilot boat was requested to stand by for evacuation, and preparations were made for taking the vessel in tow.

At approximately 16:10, more smoke developed once again, and the engineer informed the skipper and went back up to the bridge.

Rescue vessel 'RS 172' arrived at the scene at approximately 16:13, and was told that a fire had probably broken out in the battery room on the starboard side. The rescue vessel started to cool the hull by the battery room using a fire monitor.

The crew donned their immersion suits and prepared for evacuation. The pilot boat was told to take the able seamen on board, and they evacuated to the boat at approximately 16:15. The skipper and engineer wanted to stay on board the vessel so as to keep the situation under observation and implement control measures.

The remaining crew evacuated to the pilot boat at 16:38, and were looked after by Red Cross personnel. The engineer was taken to hospital for further checks.

Personnel from Fredrikstad fire and rescue service made an attempt to board the rescue boat at 17:08, but heavy seas prevented them from doing so. The tow wire was brought on board the rescue vessel at 17:32, and 'Brim' was towed to Vallø near Tønsberg, where she was moored alongside at 19:34. Personnel from Vestfold Intermunicipal Fire Service entered the vessel shortly afterwards.

1.1.3 FIRE SUPPRESSION

The vessel was alongside in Vallø at approximately 19:40, and chemical diving was carried out in the vessel to detect gas, measure temperatures and gain a better overview of the situation inside the starboard hull. In the engine room, the gas detector showed the presence of carbon monoxide (CO) and explosive gases, and the temperature of the door to the battery room was measured to be approximately 30 °C.

In the early hours of Friday 12 March, it was decided that fire personnel would enter the vessel to take relevant measurements, including of hydrogen fluoride concentrations. The chemical divers withdrew when their instruments registered enough CO and hydrogen sulphide (H_2S) in the salon for the alarm to be triggered.

Friday morning, an operation staff team was set up at the fire station. The police and health service incident commanders, along with representatives of the Norwegian Coastal Administration (NCA), the Norwegian Defence Research Establishment (FFI), the shipping company, the battery contractor, the insurance company and consultants from Oslo Fire and Rescue Service participated in the meeting. At the time, the risk of explosion was seen as the greatest risk. A 300-metre safety zone was established (see Figure 5) and booms were deployed to reduce the possibility of polluting the fairway.

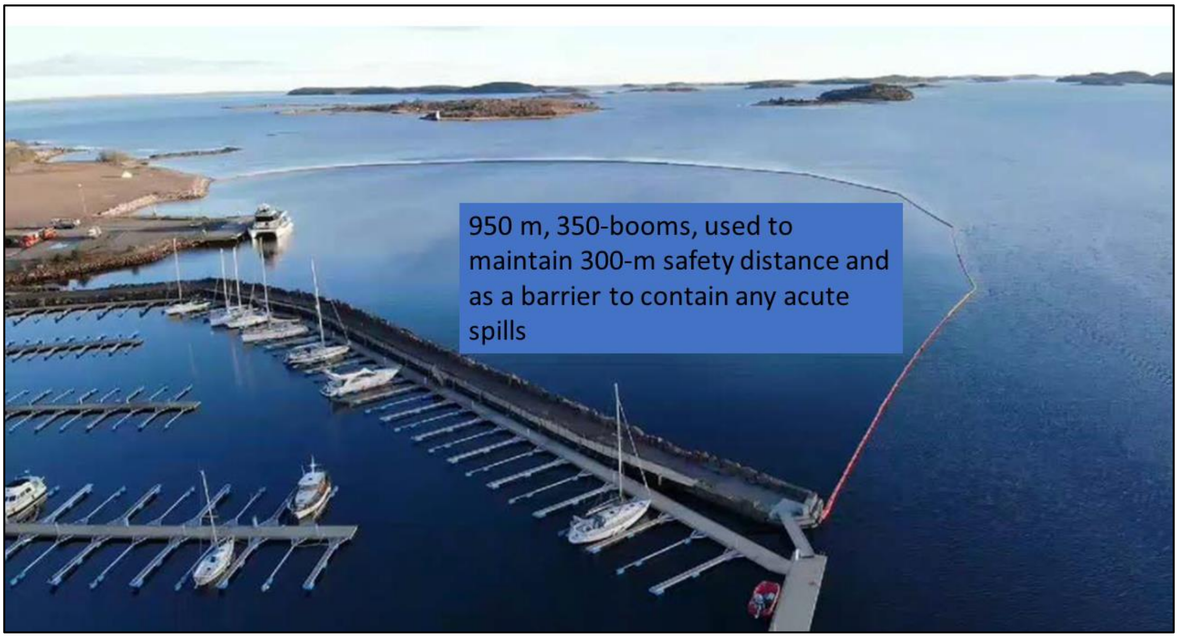


Figure 5: The area in the vicinity of 'Brim'. Photo: Vestfold Intermunicipal Fire Service

It was decided to remove hazardous gases from the vessel using suction, while using nitrogen to displace the oxygen in the air and prevent the formation of an explosive gas mixture in the hull. The vessel was not designed to facilitate the proposed solution. Practical solutions therefore had to be found whereby gas could be removed from the battery room by suction through the ventilation system.

On Saturday 13 March, a pump vehicle and a nitrogen vehicle were in place. On Sunday 14 March, a risk assessment of the plan and task procedure was conducted together with the personnel who would be carrying out the work and others.

Organisation of the incident command centre started Monday morning, 15 March. At start-up of the operation, the equipment that had been constructed was found to not fit the ventilation system leading to the battery room, and adjustments needed to be made. Injection of nitrogen started at approximately 17:00. The measurement results showed that explosive gases were being sucked out and that the explosiveness of the atmosphere was reduced over the next three hours.

Continuous measurements on Tuesday 16 March showed that large volumes of flammable and explosive gases were being removed, so that the levels were reduced and the atmosphere finally became non-explosive. It was therefore considered safe enough for the fire fighters to enter the vessel.

Fire personnel measured gas levels in the engine room and battery room several times, and the readings were eventually found to be within the norm. They therefore opened up the space to allow for natural ventilation, before concluding their efforts and removing the safety zone. The vessel was now considered safe and was handed over to the police.

Approximately five days after the fire broke out, the vessel was made safe and the investigative work could start.

1.2 Damage to the vessel and equipment

It was largely the battery room and adjacent rooms that had sustained the greatest fire damage. There was a lot of soot and a strong smell throughout the vessel.

The battery room was a total loss; see Figure 6.

Figure 6: Fire damage to starboard battery room. Photo: Kripos

The adjacent cabin at the fore was damaged by smoke penetrating the bulkhead via pipe feedthroughs from the greywater tank located under the sole of the battery room; see Figure 7 and Figure 8.

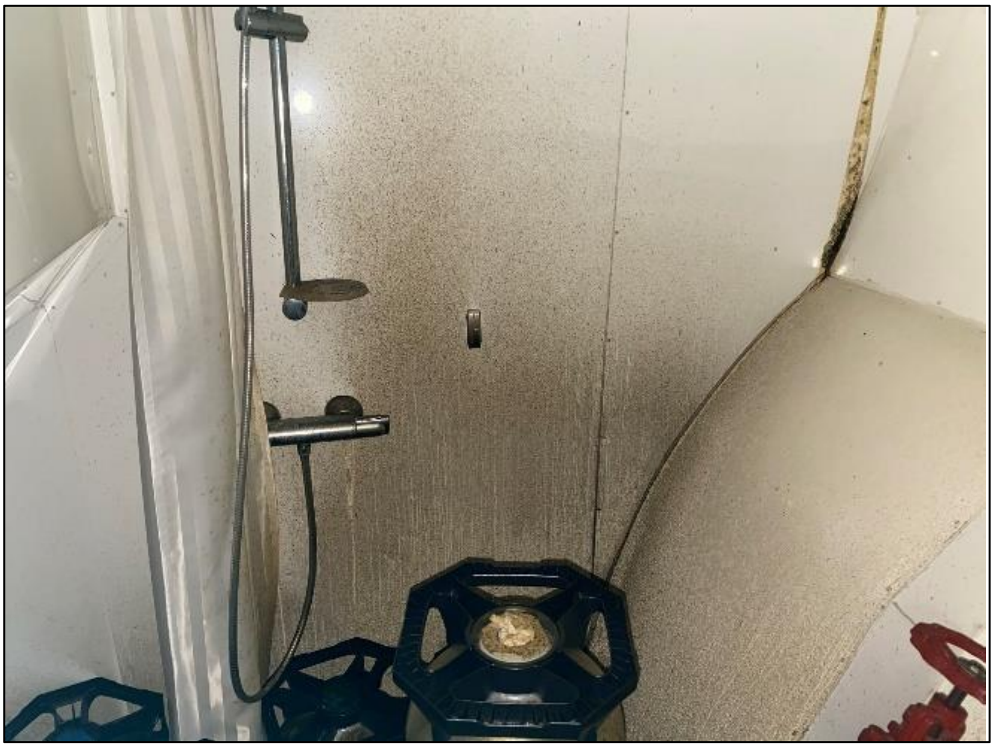


Figure 7: Clear traces of high temperatures having damaged the wall adjacent to the battery room. Photo: The insurance company

Figure 8: The greywater tank was located under the sole of the battery room. Photo: The insurance company

The engine room, the adjacent room at the aft, bore traces of both smoke and acid damage; see Figure 9.

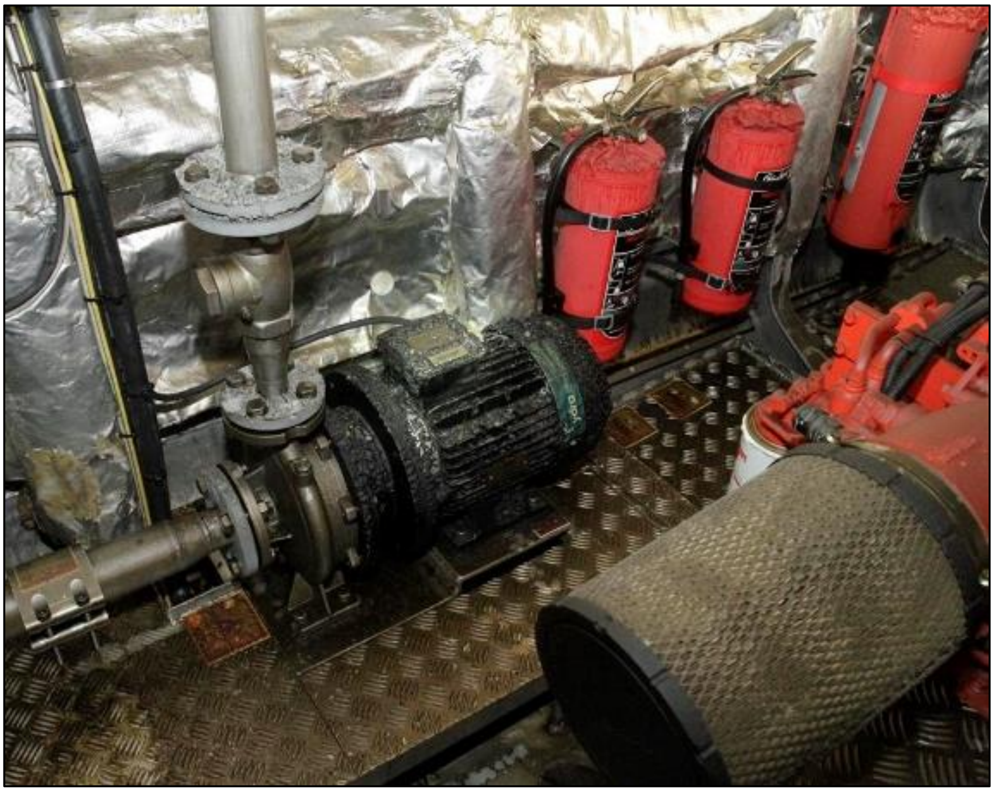


Figure 9: Smoke and acid damage to equipment. Photo: Kripos

1.3 Weather and sea conditions

The meteorological service for the inner Oslofjord forecast south-easterly winds up to 12 m/s (strong breeze). In the afternoon, the wind would weaken to a southerly breeze, turning westerly in the late evening. Sleet and snow turning into rain were forecast, with locally heavy precipitation entailing moderate to poor visibility.

Measurements from the weather station at Strømtangen lighthouse show a southeasterly wind of 8.5 m/s during the period from 15:00 to 16:00, with gusts of up to 12.2 m/s. Measurements from the weather station at Færder lighthouse showed winds of 12–14 m/s, with gusts of up to 18.5 m/s. The temperature was around 2 °C. The forecast wind direction in the area at the time of the accident is shown in Figure 10.

When the wind is southerly, the wave height can increase according to the prevailing wind force over a relatively long stretch of open waters. Based on the wave model for the area between Hvaler and Tjøme in the Oslofjord, the significant wave height was estimated to be 3–4 m. Until around 15:00, the dominant wave direction was southerly, after which the waves came from the south-west.

According to the skipper, the significant wave height was 1.3–1.4 m.

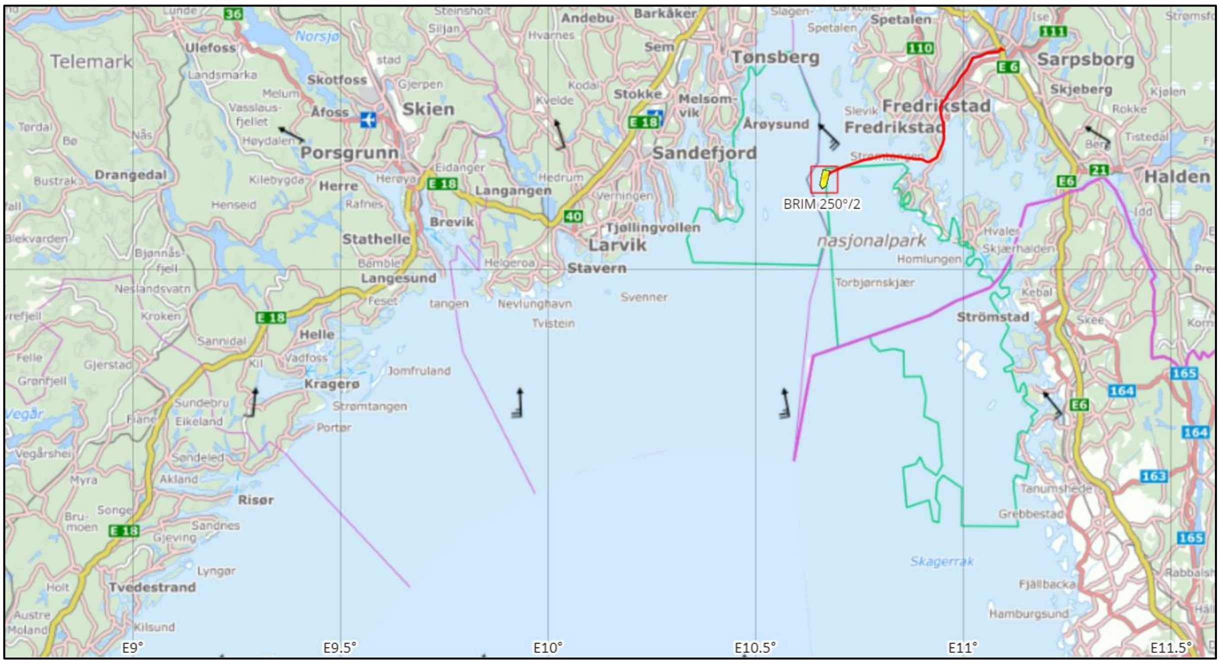


Figure 10: On passing west of Hvaler, the vessel was exposed to the waves from the open waters. Map: The Norwegian Coastal Administration

1.4 Description of waters

From late May 2020, the vessel had sailed in relatively sheltered waters in the inner Oslofjord. When the voyage started on 11 March 2021 from the Glomma river and onwards to the outer Oslofjord north of the island district of Hvaler, the vessel was more exposed to open waters. Until she reached Sandefjord, there was no protection against the open sea.

1.5 Vessel

1.5.1 GENERAL INFORMATION

The shipyard handed over the vessel on 10 October 2019. She had room for 146 passengers, and was designed to use electricity as the main source of power. To provide backup or increase the distance she could sail, a diesel-fuelled propulsion system had been installed.

The vessel had an overall length of 25.2 m, a moulded breadth of 11.2 m and a maximum draught of 1.5 m. Figure 11 shows the vessel’s general arrangement.

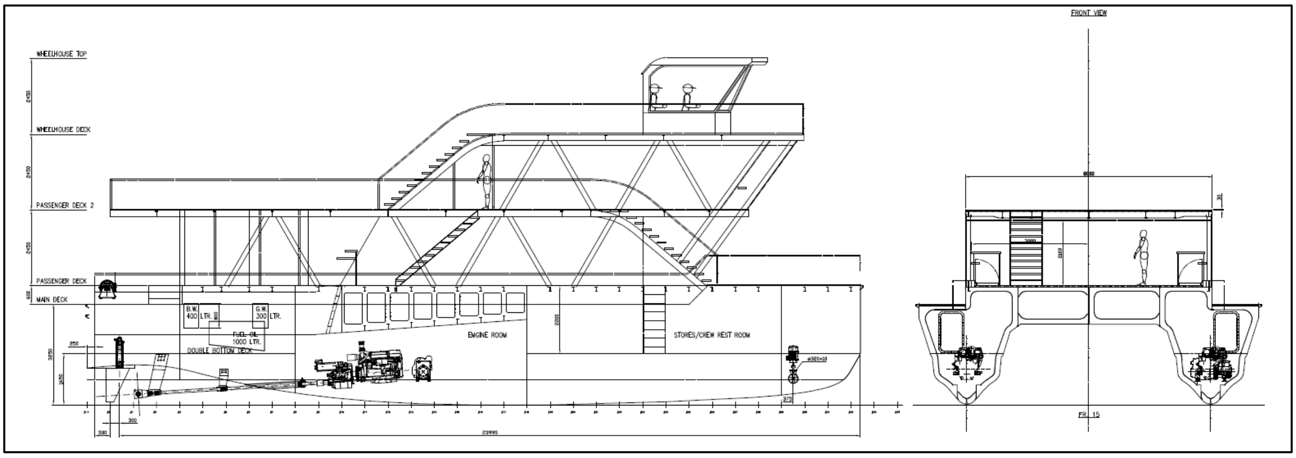


Figure 11: GA drawing of the vessel. Technical drawing: The shipyard

1.5.2 PROPULSION SYSTEM

1.5.2.1 General information

The vessel had a hybrid propulsion system consisting of two propulsion trains, each with a diesel engine, gears, propeller and electric motor; see Figure 12.

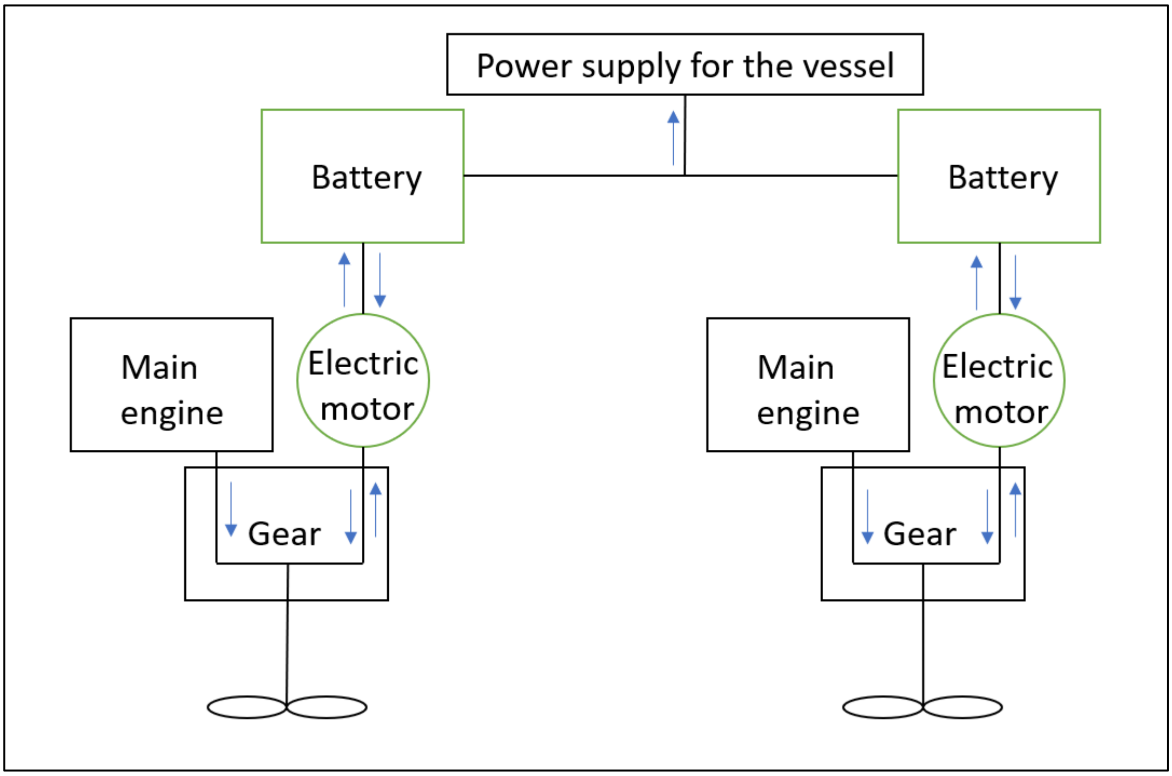


Figure 12: Hybrid propulsion system. Illustration: NSIA

1.5.2.2 Operating modes

The vessel had multiple operating modes, which can be described as follows:

- Diesel-mechanical mode:

  Both main engines available for propulsion. In this mode, the electric motors were not connected to the propulsion system, but both motors could be used as generators to charge the batteries.

- Electrical mode:

  Both main engines were disconnected, and propulsive power was provided by the electric motors using power from the batteries.

- Hybrid mode:

  One propeller was operated by the main engine, and the pertaining electric motor was used as generator to charge the batteries. The other propeller was operated by the pertaining electric motor using power from the batteries. Only one main engine and one electric motor were used in this operating mode.

- Stop mode:

  The propulsion system was switched off, and the electricity was used exclusively for other shipboard systems. Electricity could be supplied from shore or from the batteries. Neither the main engines nor the electric motors were connected in this operating mode.

1.5.3 BATTERY ROOMS AND BATTERY PACK DESIGN

1.5.3.1 General information

The battery rooms were located below deck, one in either hull; see Figure 13. Each room was adjacent to the engine room at the aft and to a cabin at the fore. The battery rooms were accessed through the engine room.

A battery pack was installed in each of the two hull sections. Each battery room had bulkhead throughfeeds for the ventilation system, for pipes supplying water under pressure to the cabin, and for cable trays.

According to the battery contractor's safety specifications, the battery rooms were to be protected against harmful amounts of seawater insofar as this was practically possible. A water level alarm and a bilge pump were installed in each battery room, with alarm indication for high water level.

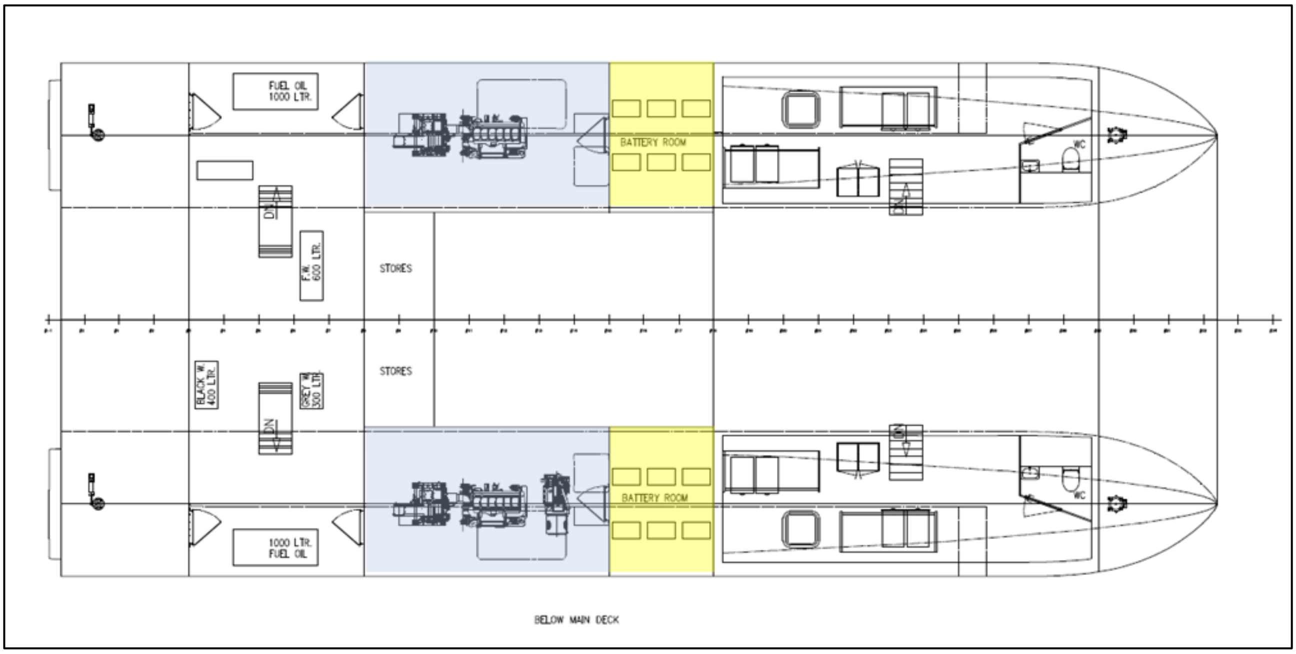


Figure 13: GA drawing showing the location of the engine rooms (blue) and battery rooms (yellow) below the main deck. Technical drawing: The shipyard

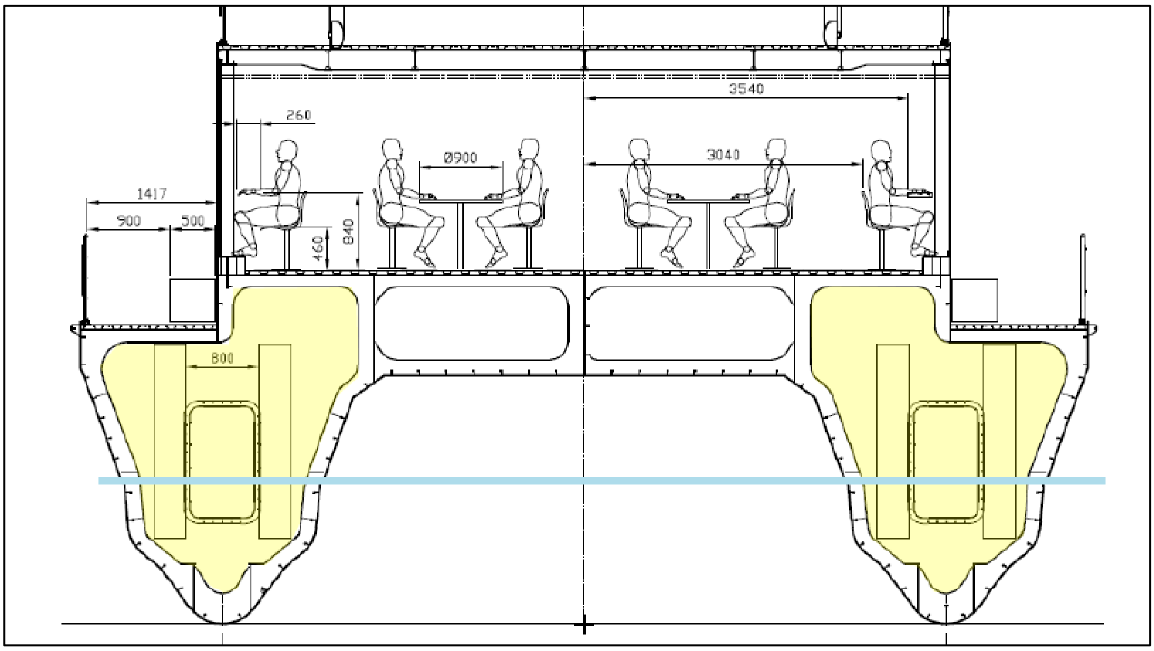


Figure 14: The battery rooms (yellow) seen in relation to the waterline (marked in blue). Technical drawing: The shipyard

1.5.3.2 Throughfeeds from the battery rooms

The battery rooms were located at the very bottom of the hull sections; see Figure 14. A sole had therefore been built in the middle of each room. A greywater tank was located below the sole. The wastewater pipe from the wash basin in the cabin at the fore was routed through the double bottom to the greywater tank.

Two cable trays were routed through the battery room. One went through the bulkhead to the cabin at the fore, while the other went into the empty tunnel space. Feedthroughs for the ventilation system are described in section 1.5.4.

1.5.3.3 Battery system design

The battery packs were made up of lightweight lithium-ion batteries of the type Corvus Dolphin Energy. The system was module-based and primarily designed for maritime use. The system consisted of a total of 12 battery stacks, distributed between two battery rooms. Each stack consisted of six battery modules with a stack controller at the top. The stack controller controlled how much energy the battery stack supplied to the main switch. The stack controller was connected to and received voltage and temperature data from each battery module.

All the battery stacks were connected to a joint DC bus with voltages of between ~600 and 770 VDC. The battery packs could be charged from shore or using the diesel generators. The battery system had a total capacity of 792 kWh.

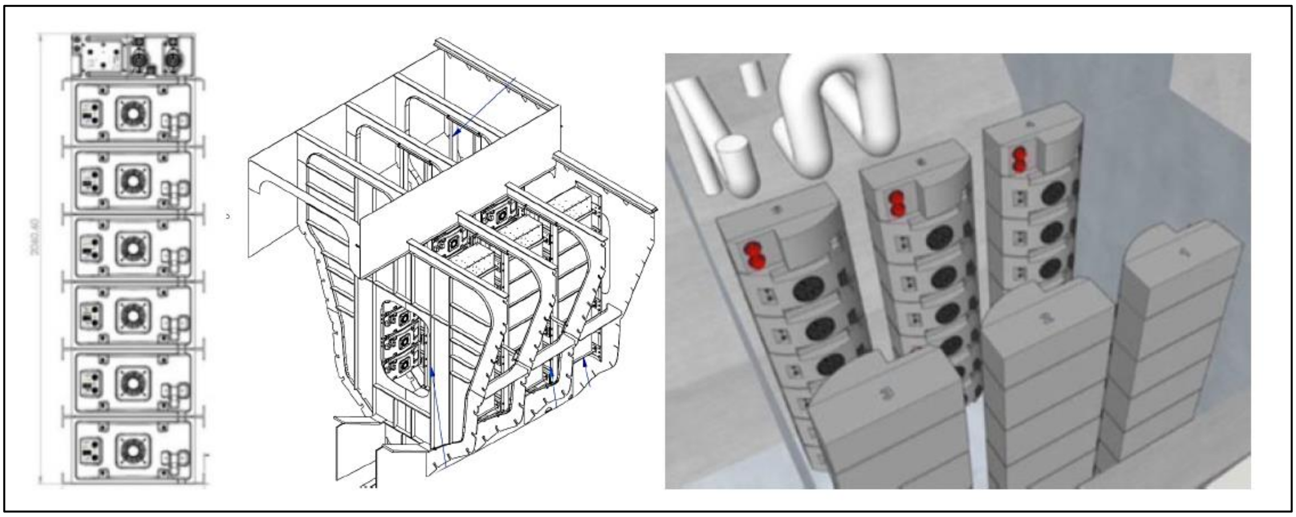


Figure 15: The drawing on the left shows a stack of six battery modules with a stack controller at the top. The middle and right-hand drawings show six battery stacks in one battery room. Illustration: The shipyard

The sub-modules were connected with copper strips to form a module as shown in Figure 16.

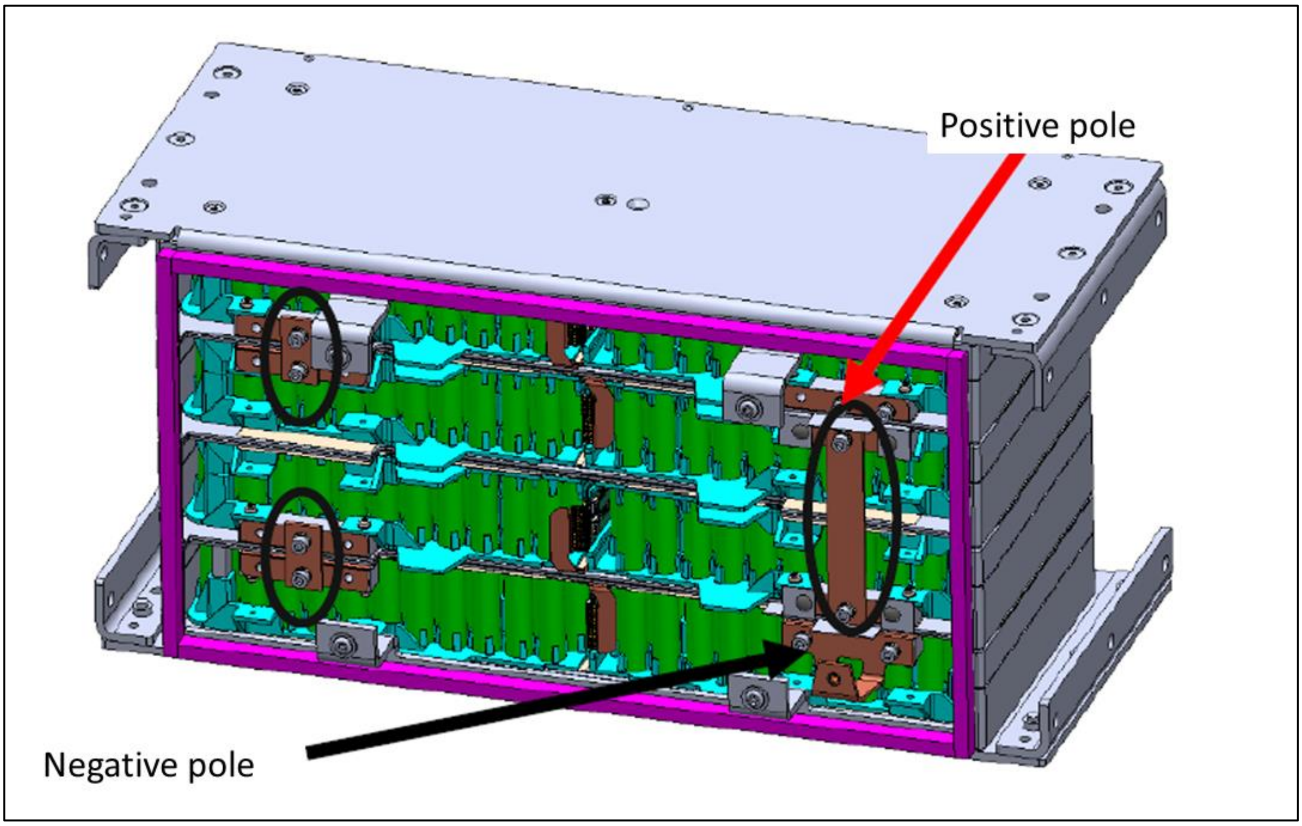
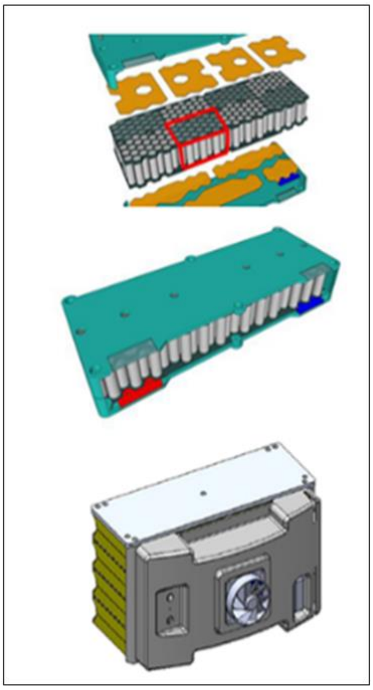


Figure 16: Connection of the sub-modules with indication of the connection points, the module's positive and negative poles. The copper strips are shown as vertical rectangles and marked with a black circle. The negative and positive poles are marked with arrows. Illustration: FFI/NSIA/The battery contractor

The modules were connected in series with copper strips between the modules and up to the stack controller. The negative pole on the lower-most module was connected to the pack controller with a cable. A fuse was installed on every connection between one module's negative terminal and the next module's positive terminal. Each lithium-ion cell had external mechanical protection and a built-in current interrupt device (CID). Figure 17 provides a general overview of the battery module design.



Eight cell blocks, each comprising 27 battery cells. The battery cells and a cell blocks had a voltage of 4 V.
To increase the voltage, several blocks of cells were connected in series.

A sub-module. Each battery module consisted of 4 sub-modules.

A battery module consisted of:

- 4 BMS cards, measuring 8 voltages and 16 temperatures for each sub-module. Data from these cards were transmitted to the main BMS in the string controller.
- 864 LG MJ118650 lithium-ion cells

Cooling air was drawn in at the back of the module and blown out through the fan at the front of the module. Module housing with open back, closed sides and front.

Total voltage of 80–134 V DC per module.

Figure 17: Battery module design. Illustration: The battery contractor

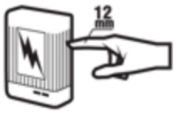
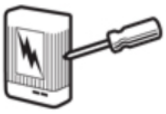
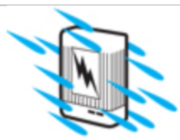
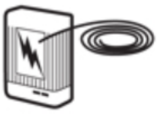
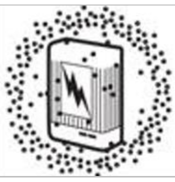
Figure 18: Battery module with battery cells, from the port battery room. Photo: NSIA

1.5.3.4 Battery IP rating

The IP rating[6] defines the battery modules' degree of protection against ingress of water, dust and particles. The letters IP are followed by two numbers denoting the degree of protection against solid particles and water, respectively. See Table 1 for a description of relevant IP ratings.

The battery modules installed in the vessel were designed and tested to IP44 on all sides, except for the front (rated IP23), and the back (rated IP2X). IP2X meant no protection against the ingress of water. In the battery's production certificate, it was rated as IP23 by DNV, which the investigation subsequently found to be an error; it should have been rated as IP2X.

Table 1: Requirements for ratings IP00–IP68. Source: The battery contractor

IP – Ingress Protection				
IP rating	Protection against solid particles		Protection against water	
0/X		No protection		No protection
1		Protected against solid object greater than 50 mm such as a hand.		Protected against vertically falling drops of water. Limited ingress permitted.
2		Protected against solid object greater than 12.5 mm such as a finger.		Protected against vertically falling drops of water with the enclosure tilted up to 15 degrees from the vertical. Limited ingress permitted.
3		Protected against solid object greater than 2.5 mm such as a screwdriver.		Protected against sprays of water up to 60 degrees from the vertical. Limited ingress permitted for up to 3 minutes.
4		Protected against solid object greater than 1 mm such as a wire.		Protected against water splashes from all directions. Limited ingress permitted.
5		Dust protected. Limited ingress permitted. Will not interfere with the operation of the equipment for 2 to 8 hours.		Protected against jets of water. Limited ingress permitted.
6		Dust tight. No ingress of dust for 2 to 8 hours.		Water projected in powerful jets shall not enter the enclosure in harmful quantities.
7	-	-		Protected against the effects of immersion in water between 15 cm and 1 m for 30 minutes.

[6] *The ingress protection (IP) rating describes a component's capacity for withstanding water, dust and other foreign bodies.*

8	-	-		Protected against the effects of immersion in water under pressure for long periods.

1.5.3.5 Battery management system (BMS)

The system had an integrated battery management system (BMS). The system comprised functions for management, control, monitoring and protection. The BMS panel was located in the port engine room. The panel displayed battery alarms.

1.5.3.6 Securing data from the battery alarm system

Once the fire service had declared that the vessel was safe, the police gathered data from the propulsion system. BMS did not enable data transfer. The terminal in the engine room was started and the process was video recorded.

The EMS and BMS control systems were different, and the times were not synchronised. The EMS system transmitted data to a terminal on the bridge. The EMS log files were saved to a memory stick.

Unlike the sister vessel 'Bard', 'Brim' had no remote monitoring installed. The battery system had a short-term memory, stored locally, and this meant that no historical data from the time of the accident were available. Prior to the accident, work had been carried out on the system on board, and large parts of the historical data were lost. The condition log for the battery system from the time of the accident had already been overwritten, as the system was designed for short-term use.

1.5.3.7 Safety mechanisms

The battery system was equipped with several different safety mechanisms, both mechanical and electrical. The safety mechanisms controlled via the BMS included temperature, voltage, charging and consumption. If the BMS detected a serious alarm, it would disconnect the battery stacks and the batteries would be deactivated.

If the temperature in a battery module became too high, the fan for that module would start. There was also mechanical protection of each cell in the case of high temperatures. Too high voltages would heat up the cell and it would be deactivated automatically.

The battery system was equipped with fuses at several levels, which would melt if overloaded or short-circuited. Each battery stack, module and block of cells had a dedicated fuse.

1.5.4 VENTILATION IN THE BATTERY ROOMS

The purpose of the ventilation system was to supply fresh air (breathing air) and remove waste gases in the event of battery incidents. Both functions were incorporated in a single ventilation system. For requirements relating to the ventilation arrangements in battery rooms, see section 1.9.4.2. A cooling system was also installed to ensure that the temperature in the room was kept at 15–25 °C as recommended.

The ventilation intake for the battery room was located on the main deck. The intake was equipped with a flotation valve that would close the intake automatically to prevent the ingress of water, and a fire damper.

The outlet air from the battery room was routed via a gooseneck to deck, back to the battery room and into the tunnel. The outlet was equipped with a centrifugal fan and a fire damper; see Figure 19 and Figure 20. The design with location of the outlet in the tunnel was chosen on the basis of requirements relating to fire safety and emission of hazardous gases from the battery room. In the interest of crew and passenger safety, it was decided to route the outlet to the tunnel rather than to install a 3.5-metre high vent pipe on deck.

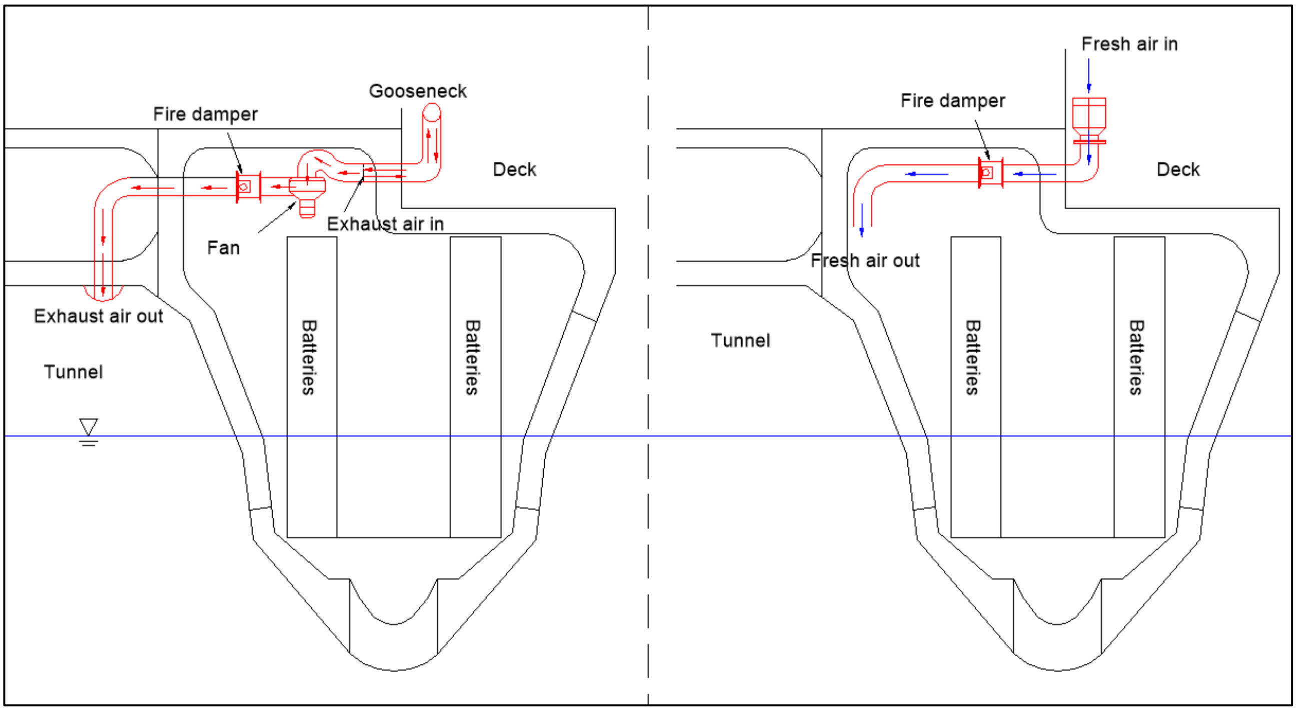


Figure 19: Arrangement drawing of battery room ventilation. Illustration: The shipyard/NSIA

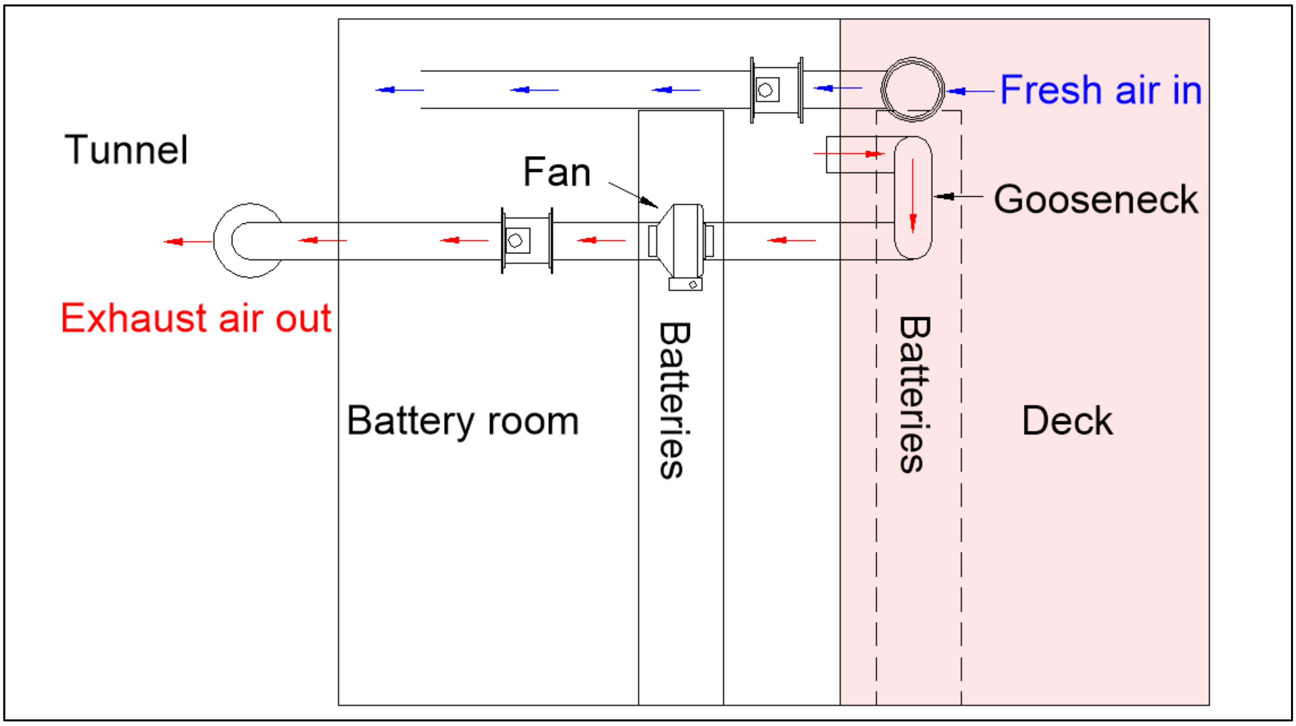


Figure 20: Arrangement drawing of the ventilation system seen from above. Illustration: The shipyard/NSIA

The ventilation fans were EX-approved[7] and in continuous operation, as the battery rooms were not equipped with gas detectors. The fan was located above battery stack 6 in the starboard battery room and, in a corresponding location above battery stack 12 in the port battery room.

[7] *EX = explosion protection*

Each fan discharged air via a gooseneck on the outside of the hull (see Figure 20) to the top of the tunnel; see Figure 21. The gooseneck design had been chosen to ensure sufficient freeboard.

Figure 21: The ventilation outlet from the battery room to the tunnel marked with a red circle. The soot and fire damage inside the tunnel hull came from the cabin at the fore of the battery room. Photo: NSIA

1.5.5 FREEBOARD

Fully loaded, the vessel's midship draught and freeboard were 1.67 m and 1.59 m, respectively. The deck was 3.25 m above the keel. The distance from the freeboard deck to the lower part of the top of the gooseneck was 760 mm. The ventilation intake was located at the same level as the gooseneck, with an automatic flotation valve closing mechanism at the top of the ventilation pipe.

In fully loaded condition, the distance from the waterline to the ventilation fan was approximately 1.8 m and from the ventilation opening in the tunnel top to the waterline approximately 1.04 m. Figure 22 is an illustration of the air extraction system showing distances to the waterline.

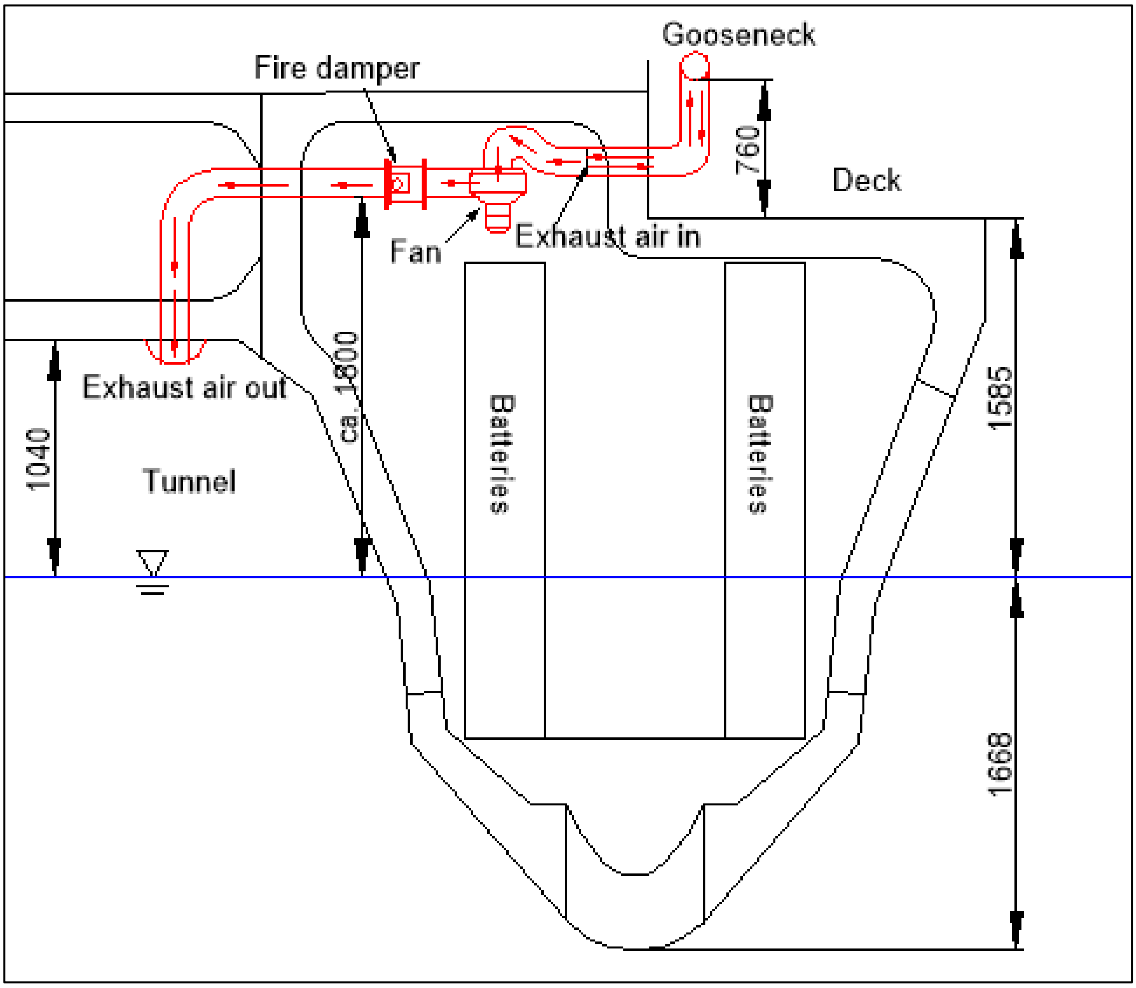


Figure 22: Freeboard measurements (mm) relating to the air extraction system. Illustration: The shipyard/NSIA

The ventilation system for each battery room has two possible flooding points: the ventilation intake located by the superstructure just above the main deck and the ventilation outlet located in the tunnel top.

1.5.6 FIRE INTEGRITY AND FIRE DETECTION

According to the risk assessment[8] conducted by the shipyard, the battery rooms were classified as 'non-hazardous'. This was based on the safety specifications for the installed battery system having concluded that the volume and composition of any gas produced by a faulty cell were far from sufficient to constitute an explosion and fire hazard.

A-60[9] fire insulation was installed in the battery room adjacent to the changing room and toilet forward of frame 18 and the salon on the deck above. A-60 insulation was also installed on both sides of the bulkhead between the battery room and engine room at frame 15.

The bulkhead was installed in extension of the existing frame. This meant that all cutouts (brace throughfeeds) in the original frame had to be closed with small aluminium plates.

In a few areas, use of welding equipment proved impossible and sealing compound of the type SIKA Firestop was used instead. According to the yard that carried out repairs in the starboard battery room after the fire, new 50 mm certified A-60 insulation was used in the same areas as

[8] *Battery installation – risk analysis, rev 02, dated 12 September 2019*
[9] *A-60 insulation remains fire and smoke-tight for 60 minutes.*

previously. The repair yard had installed insulation almost all the way down to the bottom of the vessel. The regulations[10] permitted leaving 100 mm immediately above deck level without insulation for drainage purposes, but the bulkhead had to be smoke-tight. Fire insulation shall be from deck to deck, except along the ship sides; see sections 1.9.2 and 1.9.4.5. Figure 24 shows the fire integrity plan and where fire insulation was to be installed.

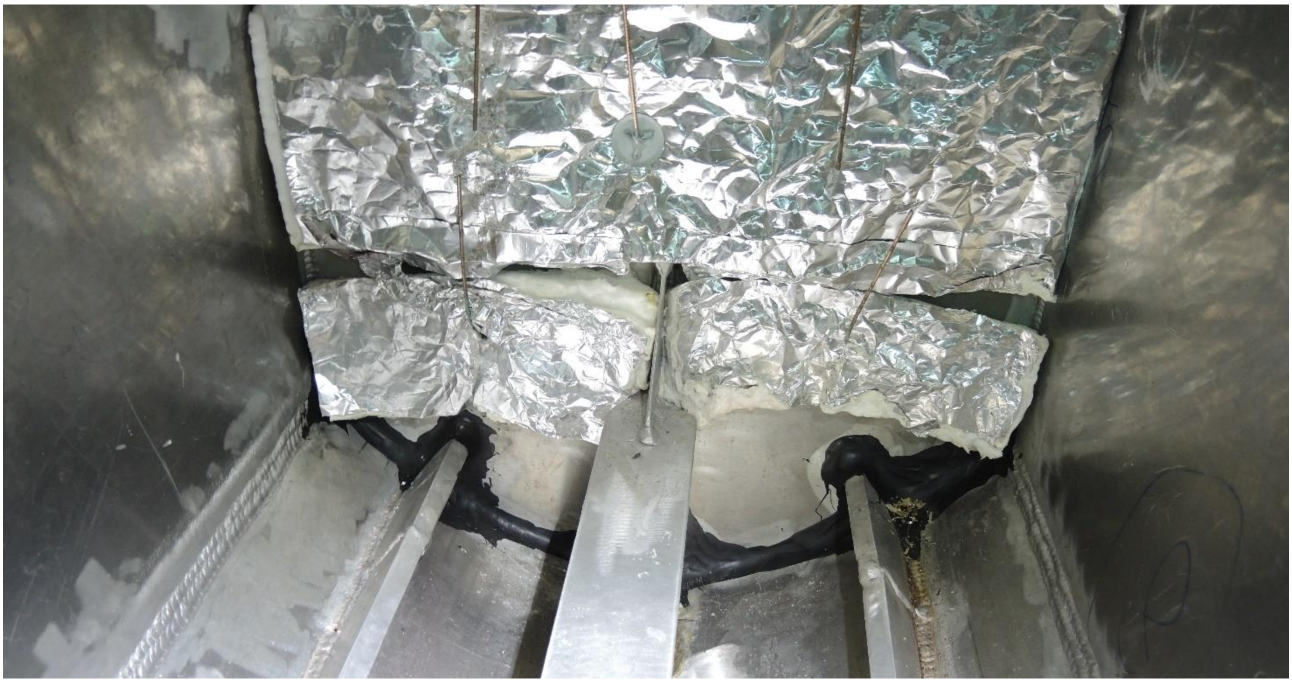


Figure 23: Fire insulation almost all the way to the bottom of the vessel, with SIKA Firestop at the lower end. Photo: NSIA

[10] *MSC/Circ.1120*

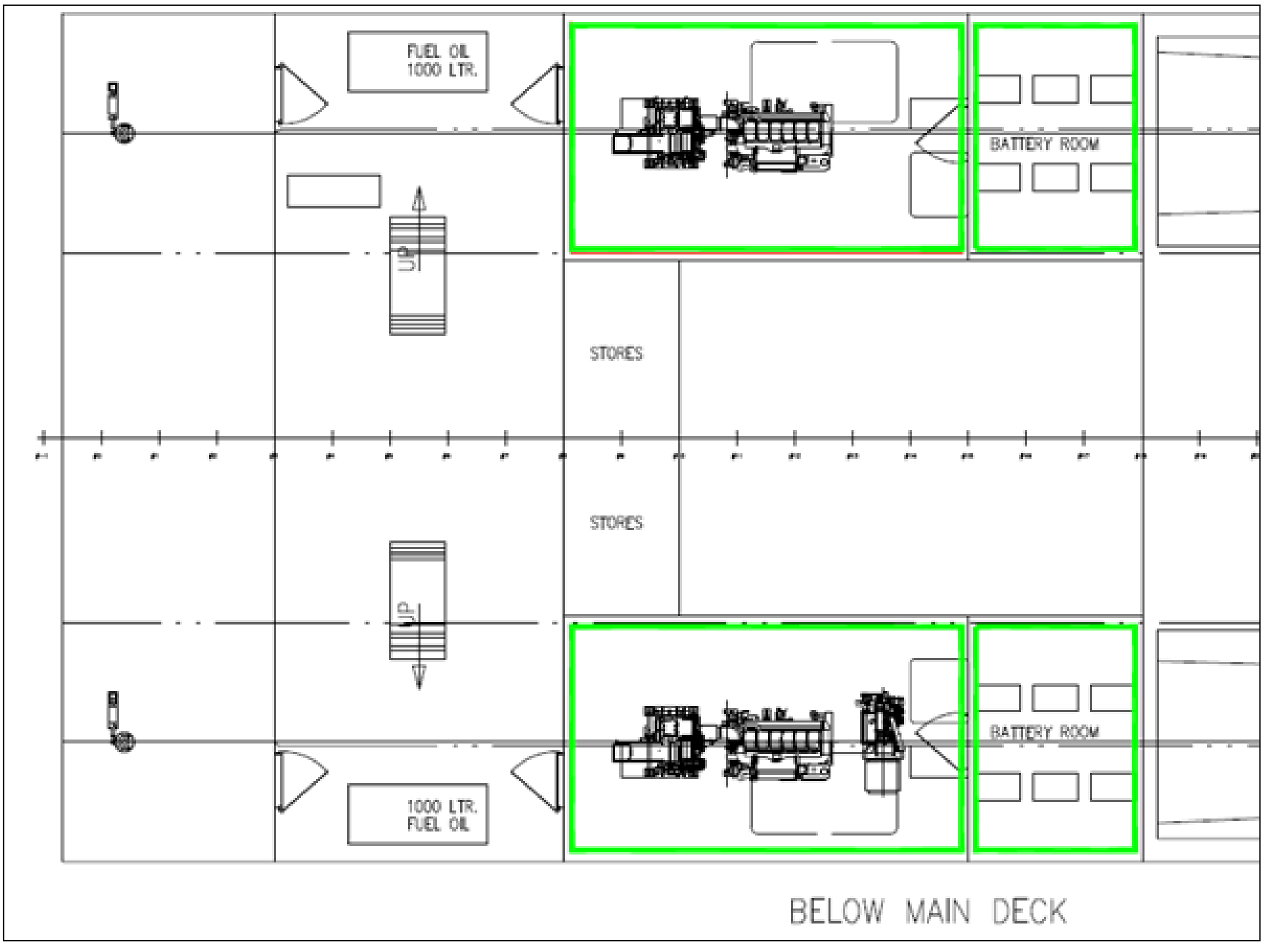


Figure 24: Fire insulation of the engine and battery rooms as presented in the fire integrity plan. Technical drawing: The shipyard

A smoke and heat sensor had been installed in each battery room, and these were integrated in the vessel's fire alarm system. No gas detectors were installed in the battery rooms.

1.5.7 FIRE SUPPRESSION SYSTEM

Lithium-ion batteries burn in an explosion-like manner, with toxic gas formation inside the batteries. The greatest fire risk associated with lithium batteries is the chain reaction known as thermal runaway,[11] which starts when the temperature inside the battery reaches a certain limit. The resulting fire is fed with sufficient oxygen as a result of the chemical reactions inside the battery. Once the process is initiated, the fire is very difficult to extinguish. The critical battery temperature is typically between 175 and 200 °C.[12]

1.5.7.1 Shipboard fire suppression system

A fire suppression system was installed, consisting of four cylinders of Novec 1230 suppression agent. Two cylinders could be released in the battery rooms and two to the engine rooms. It was possible to activate the system manually from the bridge.

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[11] *The process is accelerated because the energy released by the rise in temperature will further increase the temperature.*

[12] https://www.sintef.no/siste-nytt/2021/er-litiumbatterier-brannfarlige/

The Novec 1230 dealer calculated the amount of suppression agent that was needed in each of the battery rooms. The concentration of suppression agent required for the starboard battery room was calculated to be between 9.35 and 9.99% per dose, depending on the room temperature.

According to the owners' procedure in the event of an engine or battery room fire, before releasing Novec, the fire panel must be checked to determine which room the fire was located in. In the case of a fire in one of the battery rooms, the ventilation would stop automatically when the Novec key was turned; see Figure 25. Before releasing Novec, fire doors and dampers must be closed. As a rule, Novec should be activated from the Novec panel on the bridge, but it could also be activated manually from the technical room on either side of the vessel.

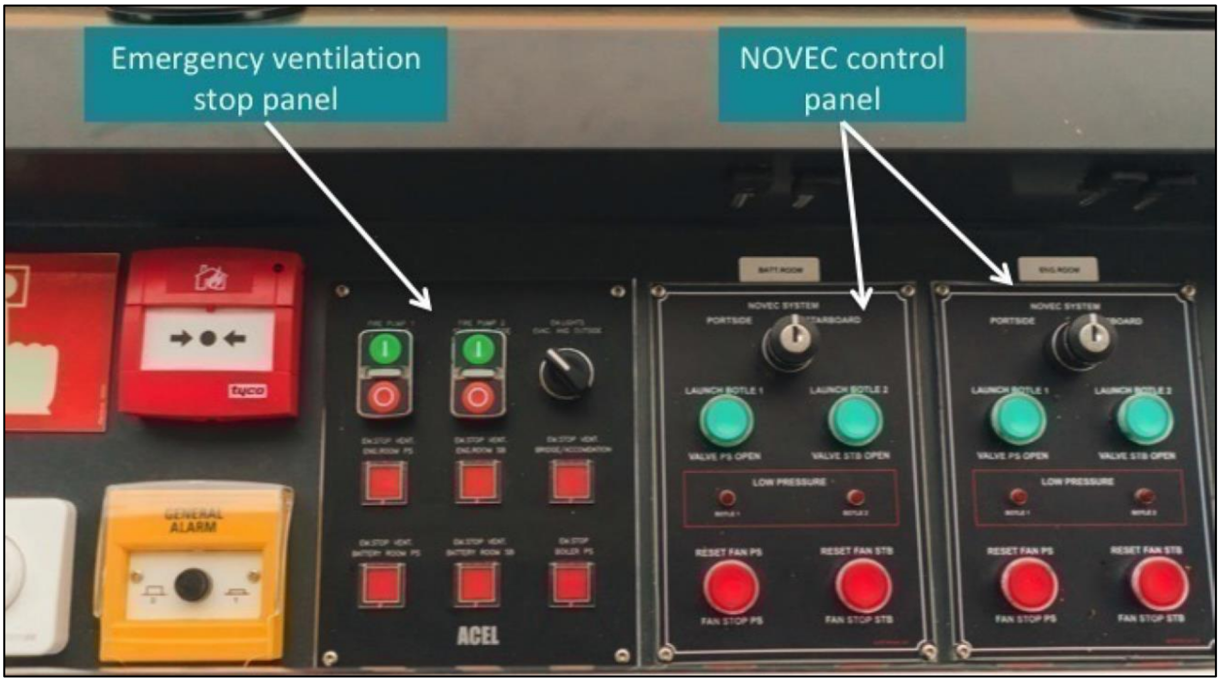

Figure 25: Novec panel on the bridge. The key on the right controls the fire suppression system in the engine rooms, while the key on the left controls the system in the battery rooms. Photo: Shipping company

Whether Novec would be released in one of the battery rooms or one of the engine rooms depended on which key was turned on the Novec panel and in what direction. Turning the key to the right would activate the system on the starboard side, and vice versa. After that, one or two doses of Novec could be released to the room in question.

According to DNV's classification rules, as from January 2018, Novec was approved for use in category A engine rooms in accordance with the International Code for Fire Safety Systems (FFS Code), and thus also approved for use in battery rooms containing lithium-ion batteries.

1.5.7.2 Fire suppression gases

According to the Norwegian Fire Protection Association,[13] a distinction is made between inert and halocarbon suppression agents. Inert gases are clean and harmless, while halocarbon gases break down into hazardous gases. Novec is a halocarbon gas.

Novec 1230 is a fluorine-based gas that decomposes into hydrogen fluoride (HF) and carbon fluoride (COF_2) at temperatures exceeding 500 °C. Hydrogen fluoride is a colourless toxic gas. At 20 °C, it condenses into liquid hydrogen fluoride, an acidic liquid emitting highly toxic fumes.

[13] *https://brannvernforeningen.no/slokkeanlegg/ulike-slokkeanlegg/gass/generelt-om-gass/*

(anhydrous hydrofluoric acid). This can be harmful to health and, in high concentrations, HF is corrosive and will damage sensitive components.

Fire suppression gases have no effect on electric arcs,[14] heat sources or 'fires' in metals and materials that contain chemically bonded oxygen, and are therefore unreliant on oxygen from the air.[15] Fire suppression gases affect combustion (oxidation in air) only, whereby they are effective against flames and can slow down the development of smouldering fires that oxidise.

Halocarbon gases can be effective in lower concentrations, but require rapid filling of the room. The need for pressure relief must always be assessed on the basis that the combination of pressure resistance of the room, discharge time and design concentration shall prevent blasting on activation. Halocarbon gases produce underpressure, followed by overpressure. Inert gases produce overpressure.

Figure 26: Novec cylinders in the port technical room. The smallest cylinder on the left is for the battery room while the cylinder on the right is for the engine room. Gas from both cylinders was released. Photo: NSIA

In 2019, DNV produced a report on the effect of different fire suppression agents in battery rooms. It emerged from the report that a Novec fire suppression system would be capable of extinguishing flames, but would have less cooling effect than water mist. Water mist would have a good cooling effect and was recommended with a view to classification rules.

In its documentation, the Novec manufacturer had advised against use of the fire suppression agent in battery rooms containing lithium-ion batteries. The NMA was aware of the problems associated with the use of Novec, but has stated that, at present, no fire suppression system is available that would effectively extinguish a lithium-ion fire.

[14] An electric arc leads to the formation of plasma with a very high temperature (close to 20,000 ºC). Plasma has negative resistance and its conductive capacity increases with increasing current. In a battery where the short-circuit current is high, rapid heating will lead to rapid and explosive expansion of the gas in the arc.
[15] DNV: Technical Reference for Li-ion Battery Explosion Risk and Fire Suppression, Report No. 2019-1025, Rev. 4

The battery contractor recommended a gas fire suppression system for its batteries as a result of the battery modules' low IP rating.

1.5.8 RISK ASSESSMENT OF THE BATTERY SYSTEM

During the design phase, the shipyard submitted a risk assessment of the battery system, prepared by a consultant. It was, in turn, based on a risk assessment conducted by the battery contractor. The regulations require a safety assessment to be conducted, including that all risks be identified, to ensure the safety of passengers, crew and vessel; see section 1.9.4.6. It was concluded in the assessment that none of the identified scenarios entailed a high risk, and the assessment was approved by DNV.

It was assumed in the assessment that the battery system would be approved by the NMA or DNV on the basis of safety mechanisms having been implemented to limit thermal runaway, and that the battery room was defined as a non-hazardous space.

Concerning the assessment of risks relating to fire and explosive gases from the battery system, reference was made to the safety descriptions. An event in one battery cell would not entail escalation to another battery cell. Accordingly, the volume and composition of the gas produced by a defective cell would be well below the level that entailed a risk of explosion or fire; the battery rooms could thus be defined as non-hazardous spaces.

The assessment went on to describe that seawater is conductive, and that a single battery cell was sufficient to initiate electrolysis. Early detection of seawater ingress was therefore described as critical with a view to avoiding prolonged electrolysis. Hydrogen and oxygen formation could result in an explosive mixture.

The risk assessment identified several scenarios in which water ingress could entail a risk of flammable gases, fire and explosion. One of the risk reduction measures described was the ventilation intake's freeboard height of 4.5 m, which was intended to reduce the risk of seawater ingress to the room. The risk of seawater entering through the ventilation system was therefore assessed as low.

1.5.9 TYPE APPROVAL

Both the BMS and the batteries used had DNV type-approval. That meant that the batteries had been found to meet safety requirements and technical specifications in various tests, and it simplified the battery installation approvement process. Type-approval meant that predefined tests had to be completed, including a propagation test. This is described in section 1.7.2.3.

1.5.10 PREVIOUS INCIDENTS IN THE BATTERY ROOMS

Since the vessel was put into operation, the owners had registered several problems relating to the battery system.

On 14 October 2019, the owners reported of water ingress to both battery rooms, most probably from the pressurised greywater tank below the sole. In connection with the incident, the battery contractor pointed out that it was important to keep the rooms dry.

In March 2020, the vessel departed from Tromsø for relocation to Oslo. A yard stay had been planned en route. The vessel arrived in April and stayed at the yard for some time in the month of May. She left Ålesund on 13 May to continue the voyage to Oslo; see Figure 27.

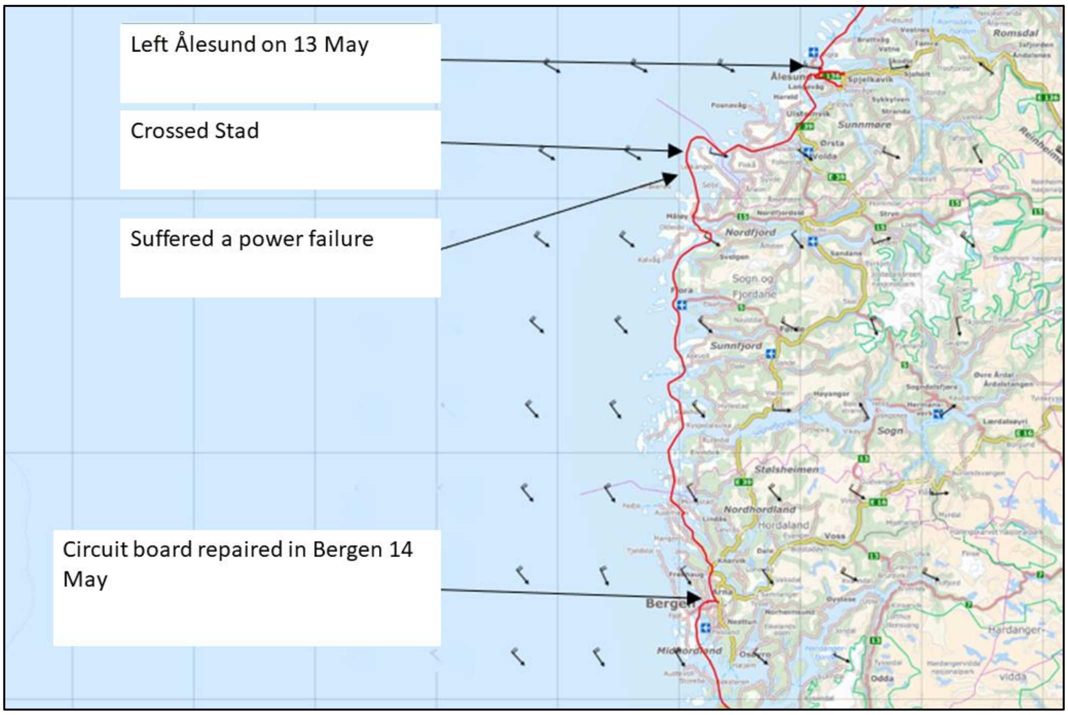

Figure 27: AIS track from Ålesund to Bergen. Map: The Norwegian Coastal Administration/NSIA

The vessel crossed the Stadhavet sea on 13 May exposed to westerly winds and waves to starboard. Shortly afterwards, the power failed, but the vessel continued the voyage to Bergen on the same day, with the batteries disconnected. The battery contractor came on board the vessel to troubleshoot the battery system. The service report concluded that the circuit board for the stack controller in the port battery room was damaged by water. The damaged circuit board was replaced; see Figure 28. Communication between the owners and the shipyard on 14 May 2020 made it clear that the circuit board had been exposed to water and bore clear signs of corrosion and fire damage.

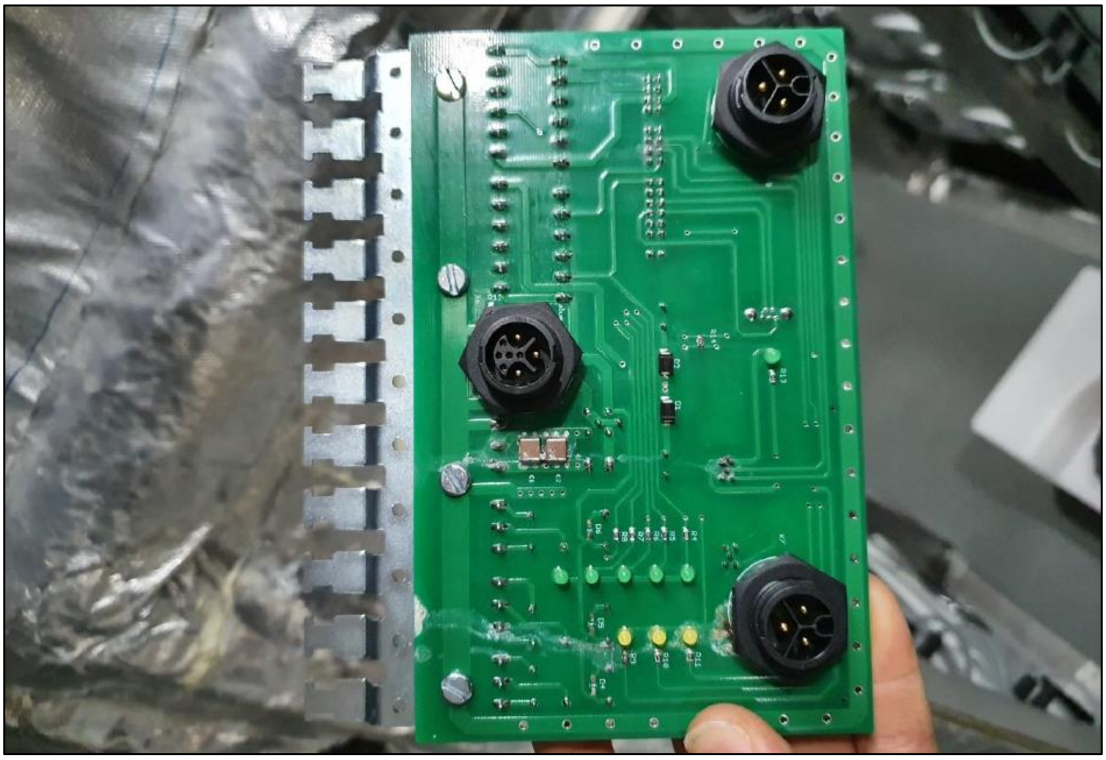

Figure 28: The damaged circuit board that was replaced in stack 12. Photo: The battery contractor

Once the circuit board had been replaced, the vessel continued her voyage and arrived in Oslo on 15 May 2020.

A few days after that, it was discovered that the fan in the port battery room had overheated and gave off a burning smell. The yard was notified, ordered a new fan and replaced it. As a consequence of the leakage from the fan, which was assumed to be condensation, the yard proposed making a drip pan for drainage into the keel. The yard sent drainage covers to lead the 'condensation water' away from the stacks and down to the soles of the battery rooms. The owners installed the drainage cover on the port side; see Figure 29. The fan was not replaced and no drainage cover was installed on the starboard side.

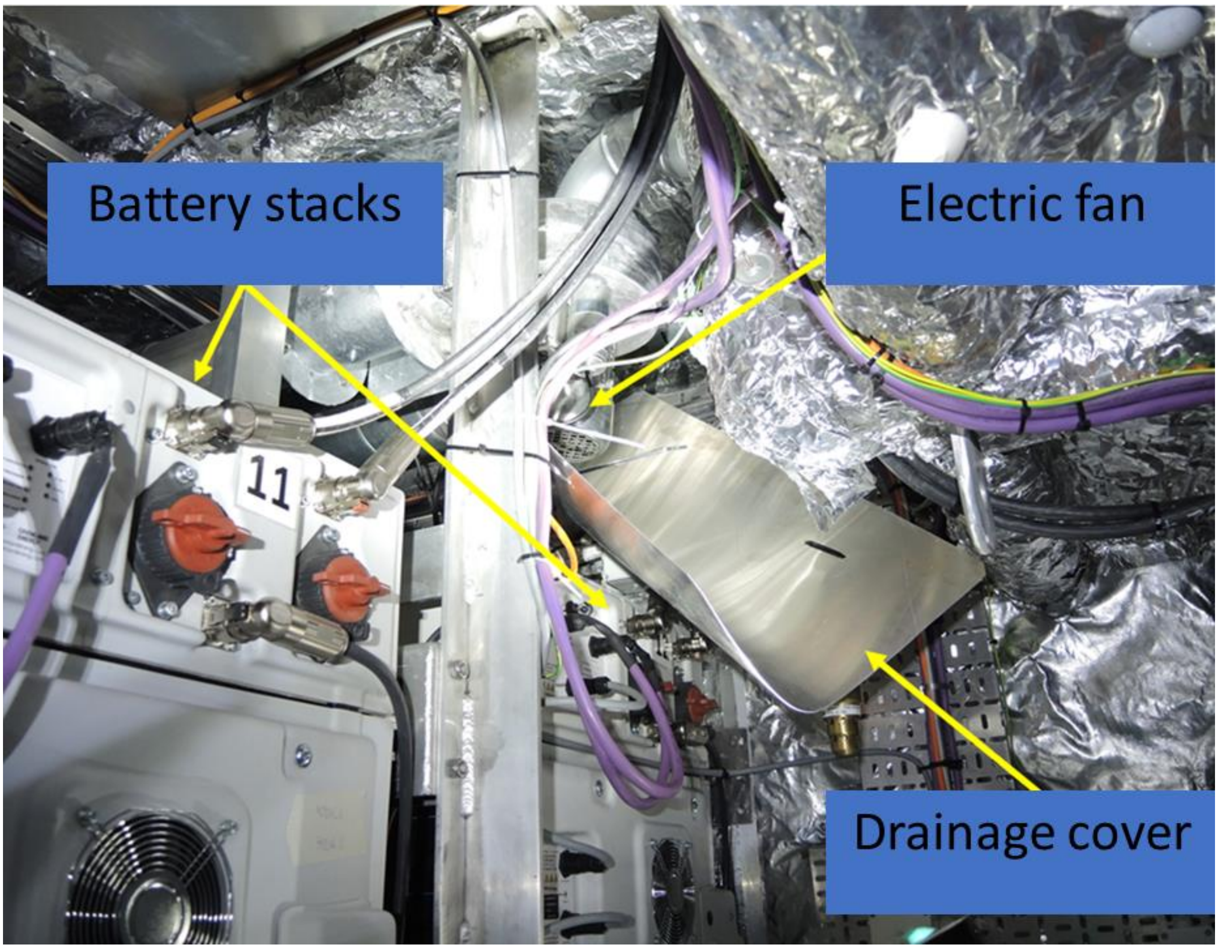

Figure 29: Electric fan above battery stack 12 with temporary drainage cover installed in port battery room to lead water away from the battery system. Photo: NSIA

In August 2020, the battery contractor came on board the vessel once again, this time to troubleshoot a ground fault in stack 12 in the port battery room. A first inspection showed no sign of water ingress to the battery stacks, and the cause of the ground fault was not identified. The ground fault alarm notifies of a ground fault, but does not indicate its source. A final inspection and test conducted by the battery contractor did not explain the ground fault either, but the ground fault message disappeared. It was stated that the battery would have to be deactivated to remove the fault, but that it would probably recur.

The NSIA has been told that two owner representatives were present during the troubleshooting and effort to detect the problem. The owners had observed water marks on the fan directly above the battery stack and believed that they were probably left by condensation and had most likely caused the ground fault.

1.6 Crew

At the time of the accident, the vessel carried a crew of four: the skipper, engineer and two able seamen. This was in accordance with the owners' procedure for safe manning.

1.7 Technical investigations

1.7.1 TECHNICAL FIRE INVESTIGATION

The NSIA, as well as the National Criminal Investigation Service (KRIPOS), conducted several investigations to determine where and why the fire broke out. The Norwegian Defence Research Establishment (FFI) assisted with the interpretation of the results. A summary of the findings from the technical investigation is given below.

1.7.1.1 Traces of short-circuiting

The investigation after the fire showed that the starboard battery room was completely burnt out. Figure 30 and Figure 31 show the damage to the battery room, seen from the battery room door. Figure 30 shows the left part of the battery room, showing battery stacks 6, 5 and 4 (from left to right). Figure 31 shows the right part of the battery room with battery stacks 2 and 3. The battery modules on the left were more intact than those on the right.

Figure 30: Damage to the battery room, seen from the battery room door. From left to right: battery stacks 6, 5 and 4. Photo: Kripos

Figure 31: Damage to the battery room, seen from the battery room door. From left to right: battery stacks 3 and 2. Battery stack 1 (next to battery stack 2) cannot be seen in the photo. Photo: Kripos

At the lower end of battery stack 6, differences were observed between battery module 2 (second module from the bottom), shown in Figure 32, and battery module 1 (bottom module), shown in Figure 33. The findings showed that, on the right-hand side of module 1 (red circle), the copper strips were missing, probably as a result of electric arcs having burnt off the attachment points. The module above (module 2), on the other hand, showed intact components in the same area. Module 1 stood out from the other modules in battery stack 6 (the differences can be seen in the areas encircled in red in Figure 32 and Figure 33).

Figure 32: Remnants of battery module 2 in battery stack 6, with the copper strip encircled in red. Photo: Kripos

Figure 33: Remnants of battery module 1 in battery stack 6, with the area of the missing copper strip encircled in red. Photo: Kripos

On examination, several battery cells showed signs of rupture in the cell walls; see Figure 34 and Figure 35.

Figure 34: Signs of rupture in the cell wall are encircled in red. Photo: Kripos

Figure 35: Signs of rupture in the cell wall are encircled in red. Photo: Kripos

Some of the missing connecting strips from module 1 were collected and re-constructed; see Figure 36. Electric arc damage to the copper strips in module 1 can be seen in the photo (marked with red arrows).

Figure 36: Debris from battery modules 1 and 2 in battery stack 6. The red arrows point to electric arc damage. Photo: Kripos

Figure 37 shows the copper strips with short circuit damage and their possible position in battery module 1 (red arrows). The short circuit damage encircled in black corresponds to where the 60 VDC connections between the cell modules were insulated with somewhat 'thin insulation material'. Ingress of seawater to the locations encircled in black would very likely short-circuit the battery pack. This tallies with the damage to the copper strips in module 1. The vertical copper strip shown in the middle of the photo had been burnt off, as a result of either high short-circuit current or electric arcs.

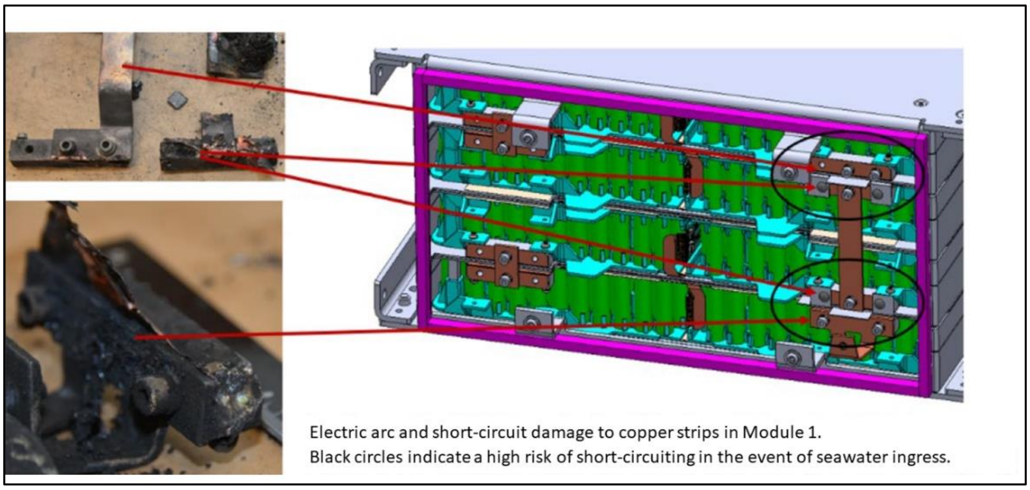

Figure 37: Position of copper strips with short-circuit damage in a drawing of module 1 with the copper strips intact. Photo: Kripos. Drawing: Kripos/The battery contractor/FFI

1.7.1.2 Fan motors

The fan motors in both battery rooms were taken down and examined. The port fan motor had suffered corrosion, and rust was found in the fan housing and on the motor shaft. The yard had replaced the motor in May 2020.

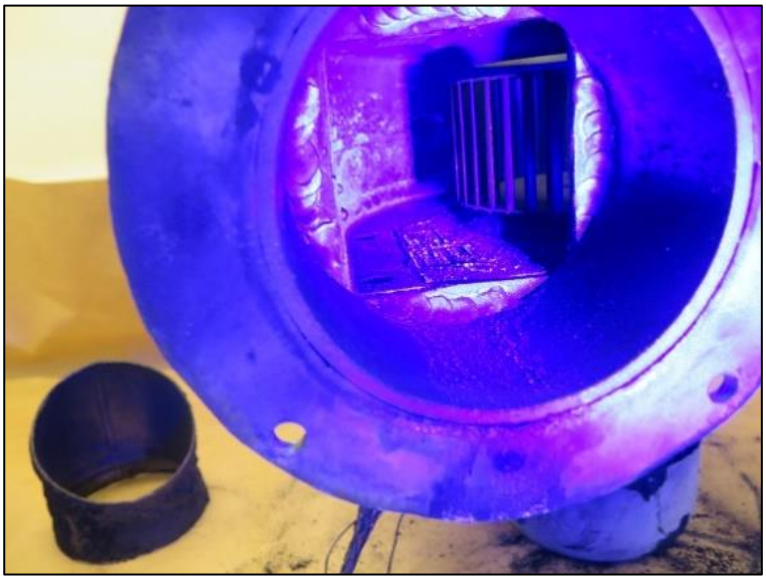

Figure 38: The inside of the starboard fan housing. UV light was used to identify traces of splashes and moisture. Photo: NSIA

1.7.1.3 Stack controllers

The stack controllers for battery stacks 6 and 12, below the fan motors, were taken down and examined.

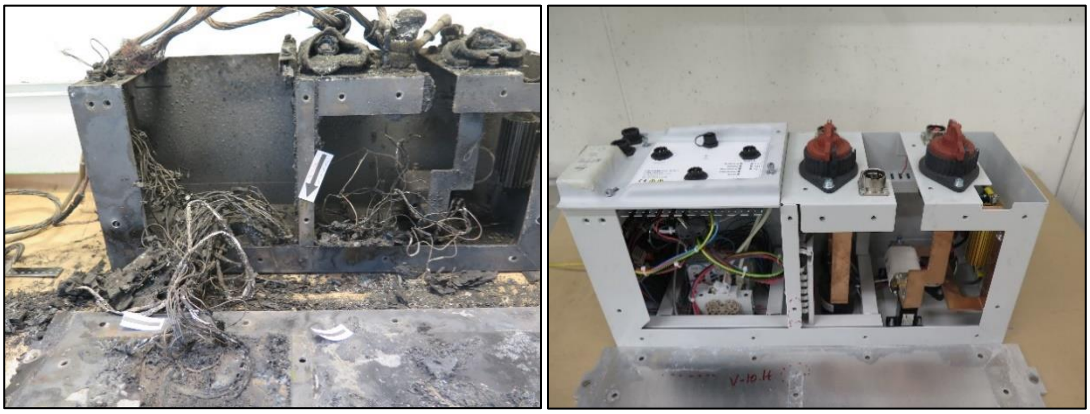

Figure 39: The photo on the right shows the module from the starboard side. The photo on the left shows the module from the port side. Photo: NSIA

The module from the starboard side was examined for traces of short-circuiting, along with the circuit board and fuses found inside the module. The main fuse was intact.

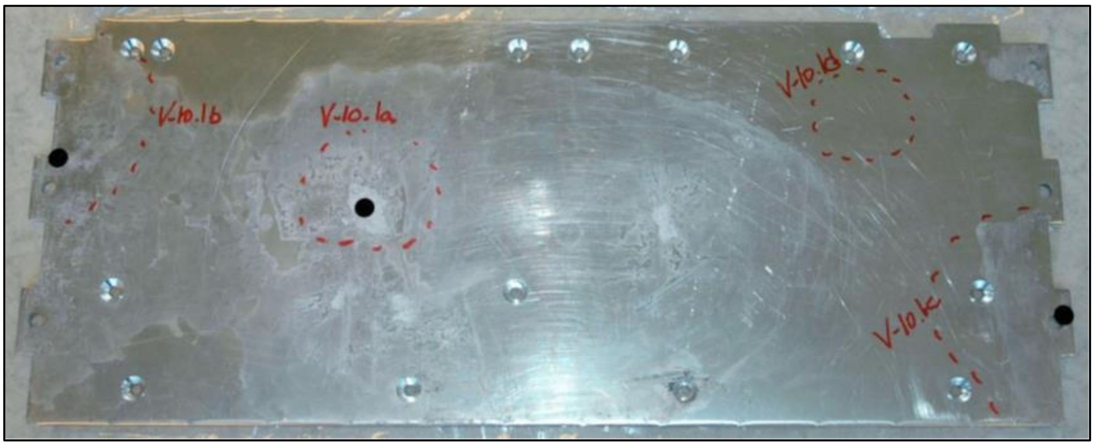

Figure 40: The stack controller's bottom plate. Scraped-off material from the marked areas was sent for analysis. Photo: NSIA

Salt was found to have been deposited in several places of the stack controller's bottom plate, on the port side. The bottom plate on the starboard side was not sent for analysis.

1.7.1.4 Examination of the port battery room

The two battery rooms were identical, and the port battery room was therefore used for purposes of comparison.

The cover for battery stack 12, located below the fan in the port battery room, was removed to get a view of the inside of the battery modules. Corrosive stains were found on the top module's copper strip; see Figure 41.

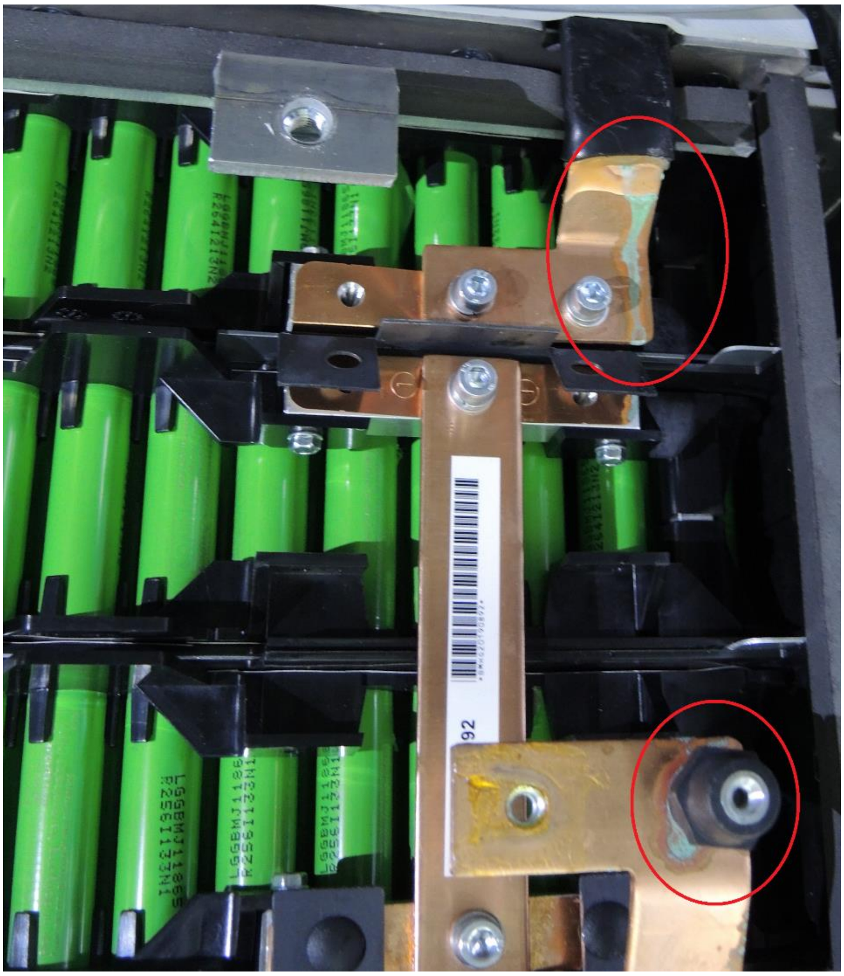

Figure 41: Corrosive stains on the topmost copper strip in battery stack 12, which was located below the fan in the port battery room. Photo: NSIA

Salt was found to have been deposited on the flange for the fire damper installed in the ventilation outlet; see Figure 42.

Figure 42: Salt deposit at the bottom of the flange for the fire damper in the ventilation outlet. Photo: NSIA

1.7.2 ASSESSMENT OF THE BATTERY INSTALLATION BY THE NORWEGIAN DEFENCE RESEARCH ESTABLISHMENT (FFI)

FFI was commissioned to help the NSIA assess the battery system and to consider the following factors:

- interpretation of the findings;
- probable sequence of events relating to the fire in the battery pack;
- the execution of the propagation test;
- the risk assessment;
- the significance of the IP rating;
- consequences of the ventilation system arrangement;
- comparison with the accident on board 'MF Ytterøyningen';
- the fire suppression method.

1.7.2.1 Interpretation of the findings

Based on the findings made after the accident, FFI has submitted the following opinion[16]:

> *On the basis of findings, saltwater ingress and associated short-circuiting/electric arcs between two to four submodules in module 1 of battery pack[17] 6 can be assumed to be the most probable cause of the incident. Depending on short-circuit resistance, this can generate moderate currents that will not cause the fuse to blow, but heat up the battery pack. If the whole module is short-circuited, the risk of electric arcs increases as the voltage exceeds 100 VDC. Several ground faults in the battery pack could also result in electric arc damage. Electric arc damage can be seen on the middle copper strip in module 1/Figure 37[18].*
>
> *Figure 43 shows how seawater can enter battery module 1 through an open protective cover.*

[16] *The report from FFI was in Norwegian only, but has been translated by NSIA. The content may differ slightly from the original version.*
[17] *In the NSIA's report, battery packs are referred to as battery stacks.*
[18] *The references to figures in the quote have been changed to the NSIA's report format.*

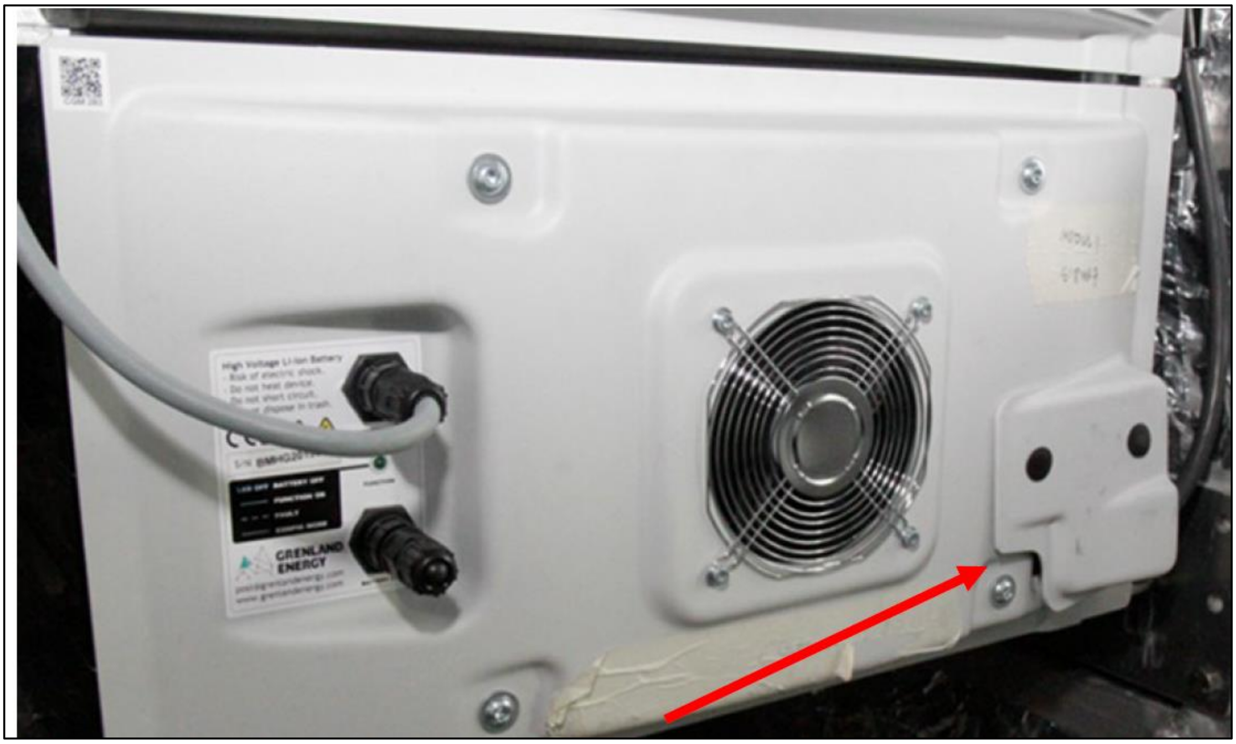

Figure 43: Module 1 in a battery stack from the port side. Note that the protective cover on the right is open. Photo: NSIA/FFI

‘MS Brim’ was put back into operation on completion of the repairs. The NSIA inspected the vessel in Svolvær on 31 August 2021, and material was scraped off the surfaces and analysed by the Norwegian Armed Forces Laboratory Services. Sea salt was found on all surfaces in the battery room. This is only to be expected in an air-cooled system in a maritime atmosphere requiring six air changes per hour. Salty residue was also found inside the battery modules on the port side, which were examined by the battery contractor after the incident. Sea salt is hygroscopic[19] and will give rise to a conductive surface film when humidity exceeds a certain level.

1.7.2.2 Probable sequence of events in the battery module

Seawater probably entered through the air duct and fan motor in the battery room, dripping down on the top of stack controller 6. The stack controller has a continuous top plate, and this will cause seawater to move (somewhat randomly) to the side of the stack controller and probably seep down along the battery module’s front sealing gasket. Weaknesses in the sealing strip probably admitted water to the copper strip between modules 1 and 2. Figure 44 shows the initial short-circuit point in module 1 in battery pack 6, where there would have been a potential of approximately 60 VDC across the copper fuse. This is supported by findings of short-circuit damage and electric arc traces on copper strips inside module 1; see Figure 37. The initial short-circuit will reduce the voltage and raise the temperature across sub-modules 3 and 4.

[19] The ability of a substance to readily take up and retain moisture.

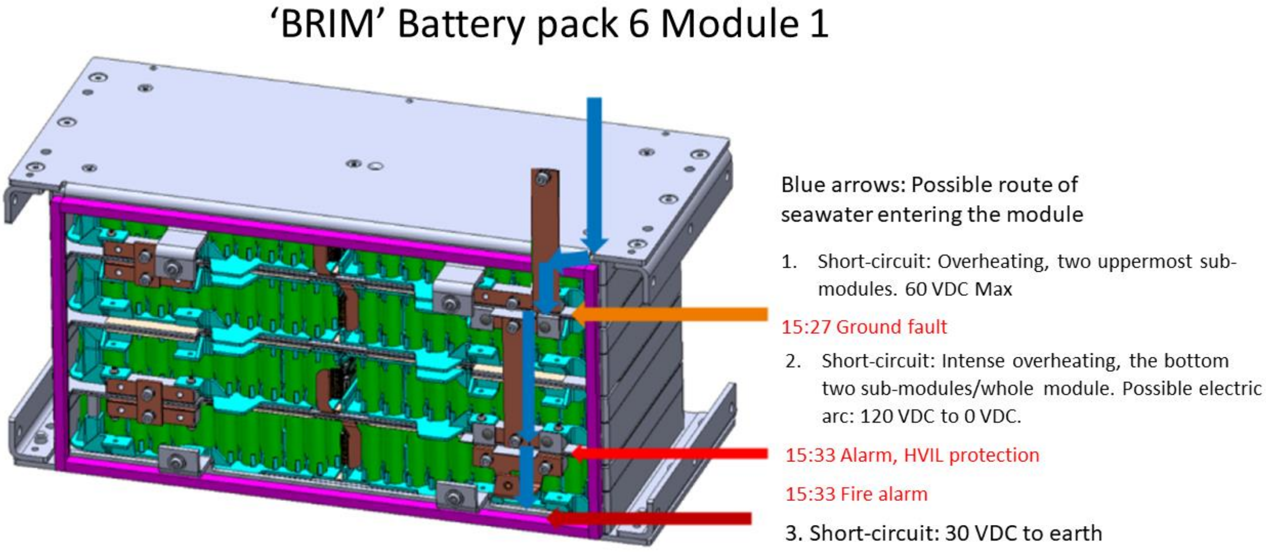

Figure 44: Possible sequence of events on ingress of seawater to module 1 in battery stack 6. The blue arrows show how seawater may have ingressed and short-circuited the modules in several places. Illustration: The battery contractor/FFI

The seawater would be able to move onwards via the vertical copper strip in the module and short-circuit sub-modules 1 and 2 (possibly the whole module). This could give rise to overheating in the lower sub-modules/whole module and to the possible formation of electric arcs when a charge of 120 VDC is short-circuited. It can also be assumed that the BMS system detected faults in battery pack 6 and implemented safety actions: Alarm, HVIL protection on all battery packs at 15:33, at the same time as the alarm is triggered. High-voltage interlock loop (HVIL) protection means that the stack controller disconnects the current from all the battery packs (a message to that effect was issued for all the battery packs). The water will probably drip down from the lower-most copper strips and short-circuit the lower-most sub-module to the casing, i.e. 30 VDC to earth. It was probably an electric arc that broke the vertical copper strip in the middle of the battery module and started the fire. It is improbable that short-circuit current would have been capable of melting a copper strip of this kind.

Figure 45 shows a possible sequence of events (based on electric arcs) whereby the fire spread to the battery modules in battery packs 4 and 5, and the times of corresponding fault messages from the respective battery packs (listed below the respective battery packs). The stated times show that the fire spread rapidly to battery pack 5. It took 3–4 minutes (from the time the fire alarm was triggered) until the BMS system warned of high temperature in battery pack 5, and 20 seconds afterwards, the data line to the battery pack was lost. The warning of high temperature in battery pack 4 was issued 6 minutes after the fire alarm. Six minutes after the fire alarm was triggered, the Novec™ 1230 fire suppression system was activated, by which time it can be assumed that the battery fire had spread to up to 50% of the modules on one side of the battery room. The battery modules have an open back, and a fire will spread quickly upwards through the battery packs. After a while, the temperature in the battery room will increase to a level whereby the battery pack on the other side of the room is ignited by the high temperature. This can explain the differences between the damage to the battery packs on the two sides of the battery room.

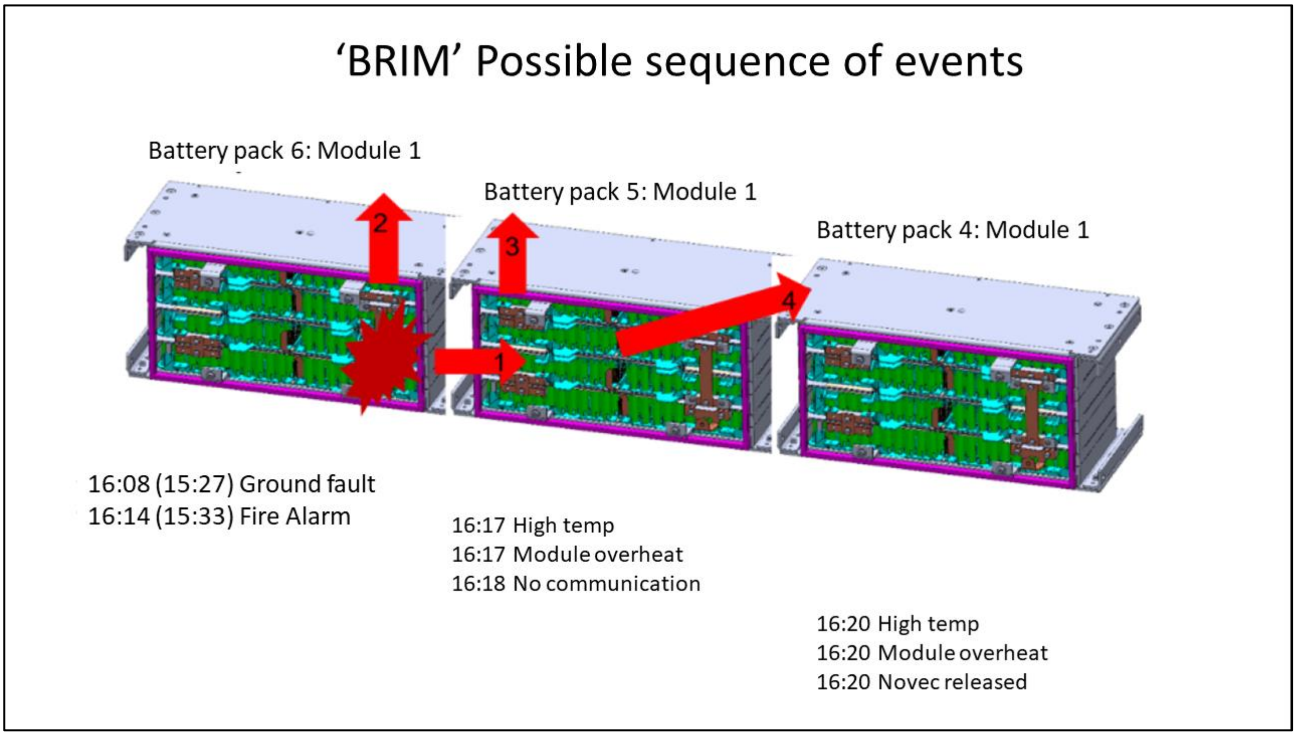

Figure 45: Possible spread of fire between battery packs 4, 5 and 6 in the battery room.[20] Illustration: The battery contractor / FFI

1.7.2.3 Propagation test

An evaluation of the propagation test was carried out to verify that it was in accordance with applicable regulations; see section 1.9.4.9. Based on FFI's assessments, it was concluded that the battery contractor's propagation test had been conducted in accordance with the regulations,[21] but, based on the picture of the battery module, it was impossible to ascertain whether propagation had taken place.

An assessment was also carried out of whether an alternative method to the nail penetration test would have led to a different conclusion. Some of FFI's considerations are copied in below:

> *In the event of a fire in a lithium-ion cell, it is necessary to deal with the heat emanating from the side walls, heat expulsion from the cell and the flame path from the cell. The heat in a 18650 cell can be expelled in three directions, i.e. through the bottom, top and side walls. Most 18650 lithium-ion cells will release 20–30% of their energy through the side walls, and the rest through the top or bottom of the cell. NASA[22] has demonstrated that use of cells with an energy density greater than 230 Wh/kg is associated with side-wall rupture problems in 18650 cells. The cells used in 'MS Brim' have an energy density of 260 Wh/kg. Side wall rupture entails heat expulsion trough the side wall rather than through the top or bottom of the cell. This sends burning gas/material directly into the neighbouring cell, so that the fire propagates easily between the cells. In most circumstances, side wall rupture will cause propagation in an air-cooled battery module (air-separated cells) of 18650 cells having high*

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[20] *The texts below the module are taken from the HMI/BMS logs of alarms from the relevant battery packs. The time of the incidents correspond to the times recorded in the HMI/BMS logs, with the times in brackets having been corrected in accordance with the sequence of events described in section 1.1.*
[21] *Rules for Classification: Ships (RU-SHIP), Part 6 Additional class notations, Ch.2 Propulsion, power generation and auxiliary systems, sections 4.1.2.7 and 4.2.2, Edition 2021-07 and IEC 62619:2017, Appendix B, B.1-B.3.*
[22] *Source: NASA NESC Task Report. TI 14 00942 'Assessment of ISS/EVA Lithium ion Battery TR Severity Reduction Measures', May 2017*

energy density.[23] The modules on board 'MS Brim' have not been tested in that respect. Propagation tests should use nail penetration tests as a last resort only, where overcharging or cell heating is not possible. Today, there is a free choice of methods of propagation testing. Consideration should be given to changing the rules in this respect. If it is necessary to use nail initiation as a test method, all elements of risk associated with thermal runaway in a cell must be correctly presented, i.e. a nail penetration test should give rise to the same response as a heating test. The module should not be modified so that the flames leave the module in the wrong direction.

Nail penetration tests can easily been seen to provide false security, given all their weaknesses. The photos taken by Kripos also show side wall ruptures in some of the cells. Low charges have most likely prevented side wall rupture in many of the cells. The results of the propagation test can thus create the impression that the system is safe and that the room may be classified as a non-hazardous area.

The number of parallel propagation attempts is also important. The current requirement is for three tests. That means there is low probability of identifying an infrequent event such as side wall rupture.

1.7.2.4 Risk assessment

FFI has evaluated the risk assessment. The following is a summary of its assessment.

The risk assessment that had been conducted had failed to identify all elements of risk associated with lithium-ion batteries. Risk assessment of lithium-ion batteries should be carried out by somebody who is well acquainted with the elements of risk associated with lithium-ion batteries. Furthermore, using a propagation test that does not produce side wall rupture or convert the energy from the cell in the same way as in a module will leave the impression that the system is non-hazardous based on the definition of 'non-hazardous area'. A risk assessment must be approved by an expert committee consisting of a battery expert, boat expert and high-voltage DC expert. Only the aggregate knowledge of these discipline areas will be able to identify weaknesses in the risk assessment. In connection with new incidents / the emergence of new information, the risk assessment should be updated using a quality assurance system.

1.7.2.5 Consequences of the ventilation arrangements

FFI has assessed the significance of the ventilation system arrangement. Its considerations are reproduced below.

The ventilation system in the battery room was required by DNV-GL for the purpose of removing thermal runaway gases from a cell without creating an explosive zone in the battery room. That required six air changes per hour. Continuous operation was chosen rather than use of a detector for flammable gases to control the ventilation. Note that this is a general recommendation from DNV-GL. The ventilation inlet to the battery room was placed behind battery pack 6 and the extraction fan was placed above battery pack 6, which is assumed to be where the incident started. Humid sea air would thus enter behind battery pack 6, and the battery modules had an IP rating of 2X.

The humid air was then drawn through the battery modules to the front of the modules. That could cause problems on warm days when the temperature of the outside air exceeded the temperature in the battery room. It meant that humid sea air could condense on cold

[23] *Darcy, Eric, et al., Guidelines for Safe, High Performing Li-ion ion Batteries with 18650 cells, JRC Exploratory Research Workshop, JRC Petten Netherlands, 8 March 2018*

surfaces (lithium-ion cells) and cause short-circuiting. The air in a maritime environment contains some salt, and if salty air is drawn in through the ventilation system, salt will be deposited and eventually produce ground faults in systems that have a low IP rating.

The combination of air cooling, high voltages and an unpurified maritime atmosphere is not favourable. Air-cooled batteries are not suitable for use on board ships having continuous ventilation using air from an unpurified maritime atmosphere.

1.7.2.6 Significance of IP rating

FFI has assessed the significance of the battery system's IP rating. The following is a summary of the assessment.

General learning points from the incidents on 'MS Brim', 'MF Ytterøyningen' and 'Volt' include inadequate IP rating of high-voltage components, and liquid ingress entailing subsequent short circuiting/electric arcs and fire. IP-44 would have prevented direct ingress of seawater to the battery and electronic modules. It would clearly have been better, but would not have excluded the possibility of salt being deposited. The combination of air cooling, high voltages and an unpurified maritime atmosphere is not favourable.

An upper voltage limit should be defined for lithium-ion battery modules. The limit should be based on the possible formation of electric arcs. Such a limit probably lies somewhere between 50 and 100 VDC. In the case of voltages exceeding the electric arc limit, a high IP rating should be required to prevent moisture penetration. It must apply to all components/connections with voltages above the limit. Where the voltage is below the electric arc limit, lower IP ratings may be permitted. There should also be a method for isolating battery modules in the event of an incident, i.e. switches or similar.

In order to reduce the probability of electric arcs, the module voltage should not exceed 100 V. Note that the exact limit for DC electric arc formation is unknown. IEEE[24] has recommended that the electric arc limit be set to 100 VDC.

1.7.2.7 Comparison with the accident on board 'MF Ytterøyningen'

Common to both incidents were that conductive liquid came into contact with a high-voltage DC system causing short-circuiting / electric arcs, and that the fire suppression system was used incorrectly.

1.7.2.8 Fire suppression method

FFI has conducted an assessment of Novec 1230 fire suppression agent, which was used to put out the battery fire on board. The following is a summary of the assessment.

The application of Novec 1230 will soon lower the temperature in the room and put out any flames. A rapid temperature decrease will also create underpressure in the room, which can harm the room's fire barriers. When using Novec 1230, the ventilation system must therefore be open so as to compensate for any underpressure. After application, the ventilation system must be closed. This was not done on board 'MS Brim'.

Note also that the manufacturer TM, in its Novec 1230 brochure from January 2018, advised against use of Novec for putting out battery fires. One important reason for this could be that thermal runaway in lithium batteries causes external temperatures far higher than 500 ºC. Novec 1230 will be capable of supressing the flames and lowering the temperature in the

[24] *Stephen McCluer Schneider Electric Presentation DC Systems Battery Safety Evolution through Codes Government Regulations IEEE.pdf*

battery room, but will not lower the temperature in the battery packs. At temperatures above 500 ºC, Novec 1230 will decompose into HF and COF_2 compounds on the hot surfaces of the battery modules. These compounds are toxic and stable in stable environmental conditions. In addition to the above, Novec 1230 lacks a cooling effect whereby heat propagation between cells and modules could be prevented.

The Novec 1230 system was activated manually about six minutes after the fire alarm had been triggered. By that time, the fire had caught on and was emitting a lot of smoke. Fire or thermal runaway can be assumed to have developed in large parts of three battery packs at temperatures of between 500 and 1,000 ºC in the battery modules. The application of a fire suppression agent without cooling effect would probably not stop, but only temporarily halt the reaction in the battery modules. Toxic and corrosive decomposition products would form instead, potentially creating problems for the fire service. Novec 1230 is dependent on an advanced control system with opening and closing of valves to prevent underpressure and broken fire barriers. Control was not correctly exercised and this may have destroyed fire barriers and accelerated the process.

Regardless of suppression agent, it is important to act quickly. Fire suppression systems in rooms with lithium-ion battery installations must be quick-acting and automatic. Use of water mist in a high-voltage system without a high degree of ingress protection (for example 'MS Brim') will cause flashovers / electric arcs and is not recommended.

FFI cannot recommend any specific suppression agent for lithium-ion fires in boats, as it depends on the systems installed.

1.7.3 LEARNING POINTS FROM THE JRCC

The JRCC has reviewed the incident under consideration and other incidents of fire in electric and hybrid vessels. The following points emerged from the review:

1. The development of toxic gases creates risks for rescue personnel.
2. Risk of explosion.
3. The vessel type bears no marks to inform response personnel of the risks to which they may be exposed.
4. The ship design is not adapted to the elements of risk.
5. Extremely difficult to extinguish, and the temperature is sustained by the energy in the battery packs.
6. Finding a suitable place for mooring and further extinguishing can be a challenge – wide safety zone required.
7. Limited access to suitable/competent fire personnel for this type of assignment. Only Oslo and Bergen have marine response teams with chemical expertise for this type of assignment.

1.7.4 EVALUATION REPORT FROM FREDRIKSTAD FIRE AND RESCUE SERVICE

The evaluation report following the incident summed up with the following points for improvement:

- We wanted to obtain more information about risks on board the vessel before entering, meaning that we wanted more information about the vessel. The response team leader was in contact with the 110 communication centre to obtain drawings of the vessel by email, but they never arrived.

- Early on in the communication with the 02 police/JRCC, information should be provided about what resources we have available for getting to the vessel. Distance, weather and sea conditions must be considered in that connection. The plans must include that we inform the JRCC of what seagoing resources we need to get to the vessel.

- We would like a better tool for assessing what risks we will be exposed to on entering a vessel, particularly a hybrid vessel. Splash suits should be worn, but there is uncertainty about whether this provides enough protection against hydrogen fluoride/anhydrous hydrofluoric acid.

- We need better training relating to fires in lithium batteries, whether on land or at sea. There is a need to appoint a battery team in our brigade.

- Questions are raised about early dismissal of the shore-based health service. In our experience, it is the JRCC that makes the decision. It does so at a point in time when we may be expected to engage in response efforts on board the vessel, and, in that connection, we would like to have the health service standby as close as possible to the scene.

- In light of this being an incident in open waters, with the challenges that entails, we realise that the marine response team should have been mobilised, given that it has special expertise and training in providing assistance to vessels.

- DMO[25] must be used for smoke diving on board ferries, because of poor UHF coverage.

1.7.5 EVALUATION REPORT FROM VESTFOLD INTERMUNICIPAL FIRE SERVICE

Vestfold Intermunicipal Fire Service's evaluation report describes the seven-day response effort from the time that the vessel entered its service area at Vallø.

1.7.5.1 Learning points from the report

Some of the learning points from the report are reproduced below:

Battery fires develop chemicals that are hazardous to health and explosive. Hence, a battery fire can potentially develop into a CBRNE[26] incident.

Batteries are increasingly being used as energy sources in cars, buses and boats, and, in other contexts, for the purpose of energy storage. This means that the intermunicipal fire service must increase the organisation's competence to tackle challenges relating to fire, effective suppression methods, risks, personal protective equipment, measuring instruments and governing documentation.

The risk of explosion and hydrogen fluoride/anhydrous hydrofluoric acid represent the greatest challenges associated with such incidents, and the incident must be tackled on that basis.

In connection with accidents at sea, the Norwegian Government has entered into an agreement with seven fire services with particular expertise in responding to incidents on board ships. Fire safety shall primarily be ensured through preventive actions and the ship's own emergency preparedness. Assistance from shore will only constitute a secondary

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[25] Direct Mode Operation

[26] CBRNE is an acronym for chemical (C), biological (B), radiological (R), nuclear (N) and high yield explosives (E).

response. All fire services that cover areas with a coastline have a duty to assist in the event of fire or an accident at sea.

We believe that the chemical response scheme[27] and intervention competence are suitable for fighting fires in large battery packs. We believe that this emergency preparedness should have been deployed as an initial first response. That would also have ensured that we gained a better understanding of the risks associated with the incident. The scheme was not used. The scheme does not appear to have been properly implemented by the emergency services or the JRCC.

One of the battery rooms was on fire, and the solution that was chosen was to introduce nitrogen and balanced ventilation to eliminate the risk of explosion. If such a solution is appropriate to adequate and effective intervention by the fire service in connection with an incident, it must be facilitated on all vessels with large battery packs on board. Connections must be standardised and a standard for execution should be developed.

1.7.6 EXAMINATION OF 'BRIM' AFTER THE ACCIDENT

The NSIA boarded the vessel in September 2021 to see what measures had been implemented after the accident and obtain answers to some additional questions. In that connection, particle samples were collected from both battery rooms to find out whether they contained traces of salt. The samples were analysed by the Norwegian Armed Forces' laboratory service.

Six samples were taken from the port battery room and two from the starboard battery room. The samples were taken from different places in both battery rooms, from both new and old components. The particle samples included samples taken from the inside of the hull at the ventilation intake in both battery rooms, and from the bottom of the new fan in the starboard battery room; see Figure 46.

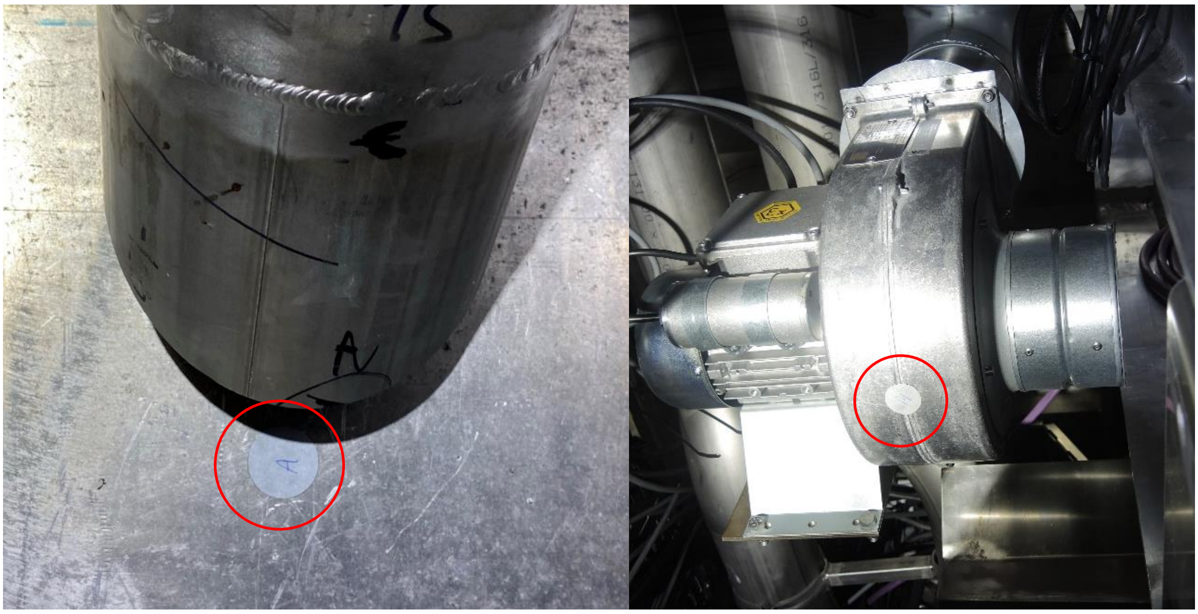

Figure 46: Particle samples from the hull at the ventilation intake (left) and from the bottom of the ventilation fan on the port side (right). The red circles mark the areas from which the samples were taken. Photo: NSIA

Traces of chlorine and salts were found in all eight samples. In addition to chlorine, other elements that may be present in a maritime environment were also found, including magnesium, sulphur,

[27] *Rescue effort at sea – chemical intervention crew (RITS-Kjem)*

calcium and potassium. The samples primarily contained particles of aluminium oxide and glass fibre. According to the battery contractor’s guidelines, the battery rooms must be free of salts.

1.7.7 THE BATTERY CONTRACTOR’S EXAMINATION OF THE PORT BATTERY ROOM AFTER THE INCIDENT

After the incident, the battery contractor conducted an examination of the port battery stack. Among other things, it was described in the report that water ingress to the battery room had been identified previously. All cell modules were inspected. In stack 12, traces of saltwater ingress were found in all modules, both internally and on visible plastic and metal components; see Figure 47 and Figure 48.

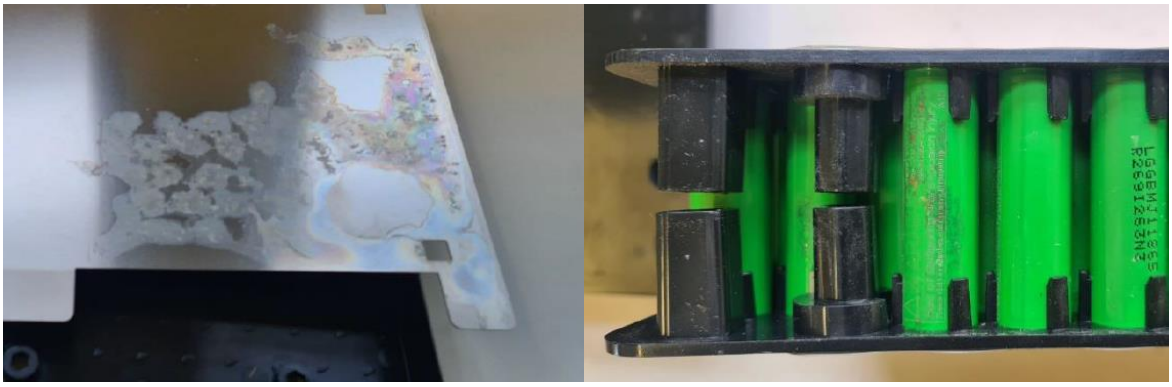

Figure 47: On the left: traces of dried-up saltwater on metal components in stack 12, module 2, cell module 2. On the right: corrosion on cell box and salt residue. Photo: The battery contractor

Figure 48: On the left: dried-up crystallised salt inside stack 12, module 5, cell module 2. On the right: visible corrosion and saltwater residue on data bus and cell module cover in stack 12, module 4, cell module 4. Photo: The battery contractor

No saltwater residue was found on the other stacks (7–11) in the port battery room. Stack 12 had to be replaced because of the severity of the findings. After testing, it was decided that use of the other stacks could continue.

1.8 Shipping company and safety management

1.8.1 GENERAL INFORMATION ABOUT THE OWNERS

The vessel and her sister vessel are owned and operated by Brim Explorer AS. The two vessels were purpose-built for experience trips with minimum impact on the environment, and are intended for trips in the Lofoten, Tromsø and Svalbard areas.

1.8.2 SAFETY MANAGEMENT

The owners have prepared a safety and nonconformity management system using the Smartsea platform. The system includes procedures, risk assessments, actions, exercises, nonconformities, ship documentation etc.

Separate procedures have been prepared for handling different emergency situations, including fire, emergency battery room ventilation and the Novec fire suppression system.

In the fire procedure, the crew are assigned dedicated tasks, including to localise and extinguish the fire, either by traditional fire-fighting using a hose from deck or by activating the Novec fire suppression system, which comes under the skipper's area of responsibility.

The procedure for fire suppression with Novec contains a detailed description of different methods of releasing the suppression agent to the engine and battery rooms on the port or starboard side.

1.9 Rules and regulations

1.9.1 INTRODUCTION

Relevant regulatory requirements are presented in the sections below.

1.9.2 THE NORWEGIAN MARITIME AUTHORITY

1.9.2.1 Regulations relating to fire safety on board

Important regulatory requirements for fire safety are set out in the Regulations of 1 July 2014 No 1099 on fire protection on ships. The regulations apply to ships for which a passenger certificate is required, among others.

SOLAS 74 Chapter II-2 Construction – The regulations incorporate fire protection, fire detection and fire extinction and describe requirements for fire divisions, among other things. Definitions of fire divisions in accordance with Regulation 3 Definitions no 2:

> *'A' class divisions are those divisions formed by bulkheads and decks which comply with the following criteria:*
>
> *1) They are constructed of steel or other equivalent material.*
>
> *2) They are suitably stiffened.*
>
> *3) They are insulated with approved non-combustible materials such that the average temperature of the unexposed side will not rise more than 140 °C above the original temperature, nor will the temperature, at any one point, including any joint, rise more than 180 °C above the original temperature, within the time listed below:*
>
> *Class 'A-60' 60 min*
>
> *Class 'A-30' 30 min*
>
> *Class 'A-15' 15 min*
>
> *Class 'A-0' 0 min*

4) They are constructed as to be capable of preventing the passage of smoke and flame up to the end of the one-hour standard fire test, and

5) The administration required a test of a prototype bulkhead or deck in accordance with the Fire Test Procedures Code to ensure that it meets the above requirements for integrity and temperature rise.

1.9.2.2 Regulations on supervision and certificates for Norwegian ships and mobile offshore units

The NMA adopted the Regulations of 22 December 2014 No 1893 on supervision and certificates for Norwegian ships and mobile offshore units in pursuance of the Act of 16 February 2007 No 9 relating to ship safety and security (the Ship Safety and Security Act).

1.9.2.3 Circular

The NMA has published several circulars relating to battery installations as a consequence of accidents with vessels with large battery packs.

The intention behind the circular from 2016 about guidelines on chemical energy storage in maritime battery systems was to facilitate the same level of safety in ships with battery installations as in conventionally fuelled ships.

The NMA issued guidelines to the effect that ships shall comply with recognised classification rules relating to batteries, and that these rules shall have been approved by the NMA.

A propagation test is required in order to determine the damage potential of a thermal incident in a specific battery system. In 2016, the use of nail penetration tests was accepted because the cells are equipped with a current interrupt device (CID), and it was argued that it was not possible to heat them up.

The NMA considered that DNV's rules from 2018 met the requirements of RSV 12-2016. In retrospect, it has been acknowledged that the need to exclude the option of using nail penetration tests was not recognised.

The DNV rules refer to IEC 62619 7.3.3, where heating is described as one method of initiating thermal runaway, while other possible methods of initiating the process are also mentioned (IEC 62619 Appendix B).

In a circular from 2019, the NMA recommended that all owners of vessels with battery installations should update their risk assessments relating to the risk of explosive gas accumulation in connection with undesirable battery system incidents.

The risk assessment should identify possible emergency situations on board, for example fire, flooding, collision etc., and procedures should then be introduced for responding to emergency situations, and training and exercises to handle such situations administered.

In a circular published in January 2022, training of the person who will be in charge of control, inspection and maintenance of maritime battery systems for use on board ships is described as an important precondition for the safe execution of such tasks.

The training is intended to help ensure that work relating to the battery system can be safely executed by the shipboard crew. The requirement will increase their knowledge of how to handle equipment, risks and safety issues.

For vessels of less than 24 m in length, the NMA published a circular in May 2022, stating that the guidelines for electrical energy storage systems on board Norwegian vessels may be used as an alternative to relevant rules for battery systems adopted and announced by an NMA-approved classification society.

1.9.3 DIRECTORATE FOR CIVIL PROTECTION

The NMA's administrative area does not include electro-technical rules for or supervision of maritime electrical systems. This comes under the administrative area of the Directorate for Civil Protection; see the Regulations relating to Maritime Electrical Installations.

1.9.3.1 Regulations relating to Maritime Electrical Installations

Regulations of 4 December 2001 No 1450 relating to maritime electrical installations. The purpose of these regulations is to achieve a satisfactory level of electrical safety in maritime electrical installations and in the operation of electrical equipment connected to these installations.

Section 24. Protection against external influences

The installation and its equipment shall be appropriate to the external influences that can be expected.

1.9.4 DNV

1.9.4.1 Requirements relating to battery installations

Requirements relating to battery installations on battery-operated vessels are described in DNV's 'Rules for Classification': Ships (RU-SHIP), Part 6 Additional class notations, Ch.2 Propulsion, power generation and auxiliary systems'. Relevant requirements as presented in DNV's classification rules (version 2018-1) are described in the sections below.

Among other things, the rules state that the class notation 'Battery Power' shall be used for vessels where battery power is used for propulsion during normal operation. The notation applies to both purely electrical and hybrid propulsion systems.

1.9.4.2 Ventilation

Requirements for ventilation arrangements for battery installations are described in section 2.3.1 of the classification rules. The section describes requirements for mechanical ventilation to ensure an adequate number of air changes per hour as well as dilution of explosive gases in the event of a battery failure incident.

The fan is required to start automatically upon detection of off-gas from the batteries, and remote activation of the fan must be possible. The rules also state that it must be possible to activate the fan locally.

The July 2021 edition of the rules includes additional requirements for closing mechanisms in ventilation openings for battery rooms, with reference to *inter alia* the requirements of the International Convention on Load Lines.

1.9.4.3 Area classification and gas detection

The classification of battery rooms and requirements for gas detection are described in section 2.3.2 of the classification rules. It is stated, among other things, that classification of the battery room shall be based on the safety description defined in section 4.1.2.1 of the rules. It is also stated that, if a failure can give rise to flammable gases, the space shall be subject to zone 2[28] classification. The classification shall be used for selecting equipment for use in hazardous areas.

Section 2.3.2.3 of the rules states that, if a damage of the batteries can lead to release of flammable gases in the battery space, then gas detection shall be arranged. Gas detection sensor(s) shall be positioned to provide as early as possible detection, and gas detection shall give an alarm on the bridge, so that emergency ventilation can be activated.

In the July 2021 edition of the rules, the requirement has been changed to gas monitoring of battery rooms, and that the gas monitoring sensors shall be positioned so that gas is detected at the earliest possible time.

1.9.4.4 Degree of ingress protection

The requirement for IP rating of the batteries depends on the location. As a minimum, IP 44 is required.

The requirement is based on use of a water-based extinguishing system in the battery room. If another extinguishing system is used, the minimum IP rating may be reduced, but must not be lower than IP 2X for voltage systems of less than 1,500 VDC.

The 2021 edition of DNV's classification rules upholds the requirement for IP 44, though with a possibility of reducing the degree of ingress protection based on a risk assessment of the battery installation. The risk assessment shall take account of ingress of seawater, as seawater is the last resort for extinguishing fires on board vessels.

1.9.4.5 Fire integrity and fire detection

Requirements for fire integrity and fire detection are described in section 2.4 of the DNV's rules. That section requires battery rooms to be defined as machinery spaces with respect to structural fire protection.

Section 2.4.1.2 of the rules requires battery rooms to be enclosed by A-0 fire integrity and have A-60 fire integrity towards e.g. machinery spaces of category A and towards muster and embarkation stations for passenger vessels.

Section 2.4.2.1 states that battery spaces shall be monitored by conventional smoke detection within the spaces.

1.9.4.6 Fire fighting

Requirements for fire extinguishing agents are described in section 2.4.3 of the rules. It states, among other things, that battery rooms shall be protected by a fixed total-flooding fire extinguishing system approved for use in machinery spaces of category A as given in SOLAS Reg. II-2/10 and the International Code for Fire Safety Systems (the FSS Code). It also states that a water-based extinguishing system is recommended due to the inherent heat-absorbing capabilities of water.

It is further stated that automatic release of gas extinguishing agents must be approved by the flag administration.

Chapter 5 section 2.1.3.4 of the FSS Code states that automatic release of fire-extinguishing medium shall not be permitted, except as allowed by the administration (The Norwegian Coastal Administration).

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[28] *Area in which an explosive gas atmosphere is unlikely to arise during normal operation, and where, should it arise, it will do so infrequently and for short periods only.*

1.9.4.7 Safety assessment

The DNV rules also require a safety assessment to be conducted so as to ensure the safety of passengers, crew and vessel.

Section 2.5 requires the safety assessment to cover all relevant accident scenarios, including their potential causes and consequences. The risk of such scenarios shall be evaluated, and risk reduction measures to control and reduce the risks shall be identified. Potential hazards include gas development risk, fire and explosion risk and external risks such as exposure to fire or water ingress.

In the July 2021 edition of the rules, the requirement for a safety assessment has been replaced by a requirement for drawing up a safety philosophy. The reason for this amendment was that DNV considered the safety assessments to be of too poor quality. The NMA has stated that it shared DNV's concerns relating to the inadequate quality of risk assessments. It held that DNV's 2020 rules were more prescriptive and would thus reduce the need for risk assessments.

1.9.4.8 Freeboard

Freeboard requirements are described in DNV's 'Rules for Classification': High speed light craft (DNVGL-RU-HSLC-Pt3Ch 6th Edition December 2015). The following section describes relevant requirements for ventilation openings as presented in DNV's classification rules.

Section 3.6.1 describes that the lower edge of the ventilation opening must not be lower than 1.7 m above the waterline. The waterline shall be measured in fully loaded condition. A lower height may be considered for ventilation openings that are not necessary to the vessel's operation at sea. In such case, a closing mechanism must be installed as a permanent solution.

Section 3.6.3 goes on to describe that ventilation openings shall be fitted with screens preventing ingress of water spray and are preferably to be facing aft or athwartships.

1.9.4.9 Propagation

Section 4.1.2.6 states that the design of the battery module should prevent propagation of a thermal event from the first cell to another cell. Alternatively, as a minimum, a system shall be designed such that a fire in one cell may spread within that module, but will not propagate to another module.

Demonstration of the battery's capability to prevent propagation shall be verified by propagation tests as defined in section 4.2.2. The requirements for a propagation test are based on the international IEC 62619 standard (Clause 7.3.3 and Appendix B) and modified to the following two options:

1. The battery system is designed for no propagation between cells within a module.

2. The battery system is designed for no propagation between modules with or without an extinguishing agent.

1.9.5 IEC 62619:2017

Relevant test methods are presented as follows in IEC 62619:2017:

The method used for initiating thermal runaway may include heating, overcharging, nail penetration tests or a combination of said methods, or another theoretically suitable method.

1.10 Supervision of the shipping company and vessel

Supervision of the vessel was carried out by both the NMA and DNV. The NMA does not have specific rules for certification of vessels with battery installations; it relies on a class notation procured by the owners from a classification society, in our case DNV. It includes approval of the battery installation itself and its location on board, including the fire safety of battery rooms.

It is up to the NMA to decide what rules shall apply on Norwegian ships, and it has accepted DNV's classification rules.

Provided that a ship is built in accordance with classification rules, the NMA will not normally perform any document control in areas covered by the class notation, but will acknowledge the documentation as information. If a ship is not built to a class, the NMA will perform document control against the rules of the chosen classification society.

The NMA is responsible for certification of the vessel, a responsibility that has not been delegated even though the NMA normally trusts the classification society's verification of compliance with its own rules.

1.10.1 THE NMA'S APPROVAL OF THE VESSEL

The NMA issued the mandatory certificates, thereby following up tonnage, load line, stability, life-saving aids and general fire safety.

The NMA conducted an initial inspection in 2019 and an annual inspection in October 2020. These were conducted in accordance with the Regulations of 22 December 2014 No 1893 on supervision and certificates for Norwegian ships and mobile offshore units, to verify that the ship meets the requirements for construction and outfitting applicable to passenger ships engaged on domestic voyages.

As part of the initial inspection on, documentation relating to the battery installations was reviewed using a pre-prepared checklist for battery installations. No orders were issued as a consequence of the review.

The annual inspection was conducted on the basis of the NMA's checklists. According to the NMA, the checklists were not reviewed in detail, but spot checks were carried out based on observations on board. Neither the first-time inspection nor the annual inspection resulted in any orders relating to fire insulation or watertight integrity in connection with the battery rooms.

The NMA approved compliance with load line requirements in accordance with the DNV HSLC class rules. Among other things, this entailed approval of the freeboard plan, a drawing that should include all flooding points.

The flooding points associated with battery room ventilation were not marked on the freeboard drawing that the shipyard submitted to the NMA in connection with the approval. The ventilation arrangements were only shown on the detailed ventilation drawings that were submitted to DNV for approval. DNV, on its part, did not consider load line conditions or freeboard requirements, which came under the NMA's area of responsibility. According to the shipyard, the freeboard drawings were submitted before the ventilation arrangements for the battery rooms had been completed, and this was given as the reason why the freeboard drawings lacked this information.

The freeboard and ventilation drawings were approved by different discipline entities and different discipline experts, and the drawings were not cross-checked for consistency. The shipyard's ventilation solution with tunnel outlets and goosenecks was presented to the NMA's fire safety experts. The NMA's discipline personnel with responsibility for load line considerations had not been involved in the discussion and were therefore not aware of the tunnel outlet solution.

According to the NMA, the solution would not have been approved had it been shown on the freeboard drawings. The ventilation arrangement did not meet the requirement of 1.7 m from the waterline to the outlet (see section 1.9.4.8), which, according to the NMA, would have warranted installation of a manual closing mechanism on the outlet. Furthermore, after the incident, the outlet ducts were found not to be watertight, so that the requirement for watertight integrity was not met.

1.10.2 DNV'S APPROVAL OF THE VESSEL

DNV's follow-up of the vessel was limited to following up the requirements in DNV's classification rules.

The vessel was classified in accordance with DNV's 'Classification of High Speed, Light Craft and Naval Surface Craft, July 2017' on 9 October 2019, with the following class notation:

- 1A LC Passenger craft Battery (Power) R2 (nor)

RU-SHIP Pt.6 Ch.2 Sec.1 of January 2018 was used for approval of the battery installations, while the rest of the vessel was approved in accordance with RU-HSLC of July 2017. The reason why the battery installations were in accordance with the 2018 classification rules was that these rules had been harmonised with the NMA's circular RSV 12-2016[29] and that this facilitated follow-up.

Concerning fire safety, DNV's role was limited to following up fire protection of the battery rooms in accordance with applicable classification rules.

DNV approved the ventilation arrangements in the battery rooms in terms of fire integrity and the off-gas function. The approval was based on a review of drawings and specifications by experts on fire protection and electrical installations. There was no dialogue with the NMA's discipline staff with load line expertise when the solution was approved.

In connection with the approval process for the battery system, several comments were issued to the yard relating to, among other things, the ventilation system, risk assessment and fire insulation. According to the yard, these comments were closed by DNV.

1.10.3 SUPERVISION OF THE SISTER VESSEL 'BARD' AFTER THE ACCIDENT

After the accident, the NMA conducted a supervision of the sister vessel 'Bard'. The vessels are not identical, but they had many features in common. Unlike 'Brim', 'Bard' was designed and built in accordance with the load line requirements set out in HSC 2000. The NMA pointed out in its report that the existing solution would allow any water that hit the tunnel top to ingress through the ventilation duct.

On inspection, it was found that water came in through the ventilation duct and leaked into the battery space. In the NMA's opinion, the solution was in contravention of the HSC 2000 regulations. As on 'Brim', the ventilation arrangements were not indicated on the freeboard plan.

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[29] The Norwegian Maritime Authority: The reason for this circular is to facilitate that the same safety level can be maintained for ships with battery installations as for conventionally operated ships.

1.11 Other operators

1.11.1 BATTERY CONTRACTOR

In connection with the battery delivery, the battery contractor was a subcontractor and not physically involved in the installation of the batteries, only commissioning of the system.

1.11.2 SHIPYARD

The shipyard was based in Ålesund and had specialised in the construction of offshore SAR vessels. It mainly constructed speed vessels of between 5 and 25 metres in length of aluminium and composite material. Since production start in 1994, the yard has produced more than 2,000 vessels.

It cooperated with the owners on conceptual development of the vessel for approximately six months before realisation of the project. After that, responsibility for design and construction of the vessel was handed over to the yard.

1.11.3 PROPULSION SYSTEM CONTRACTOR

The propulsion system was supplied by a subcontractor to the yard, whose business was the development, production, sale and servicing of control systems for ship manoeuvring and propulsion.

1.12 Previous accidents involving hybrid vessels

1.12.1 'MF YTTERØYNINGEN'

On 10 October 2019, fire broke out on board 'MF Ytterøyningen', a car ferry that had recently been converted to hybrid propulsion. The ferry was about to enter the ferry dock when the fire alarm was triggered in the battery room. The chief engineer went to check the alarm and observed a lot of smoke and flames. The Novec fire suppression system was eventually activated and, shortly afterwards, the seawater sprinkler system was also released.

Investigations showed that the fire probably started because of a leakage in the water-based battery cooling system. The liquid coolant had probably come into contact with electrical battery components causing short-circuits and electric arcs, and the subsequent outbreak of fire. The fire produced intense heat, which caused thermal runaway in the battery cells. Saltwater from the deluge system triggered more short-circuits, producing further incipient fires.

The next morning, a lot of off-gases from the batteries had accumulated and caused an explosion in the battery room.

After the incident, the NMA prepared a report that included learning points and recommendations for further work. Several of the learning points and findings from the incident are relevant in light of the findings made in the present investigation. They included specific competence requirements for seafarers working on ships with large lithium-ion installations, the importance of early extinguishing and a correct ventilation strategy.

1.13 Implemented measures

1.13.1 SHIPPING COMPANY

After the accident, the shipping company have assessed the risk of fire in the battery rooms and implemented measures, including:

- The owners have introduced weekly fire drills and specific exercises relating to battery room fires;
- The battery room ventilation arrangements have been altered to improve watertight integrity. An automatic non-return valve has been installed in the ventilation duct leading to the tunnel, to prevent ingress of water. The duct diameter has been extended to provide pressure relief should the non-return valve fail. The fan and fire damper have been installed in front of the gooseneck. A fan has been installed to circulate the air in the room, along with temperature-controlled air conditioning;
- The fire damper on the ventilation intake has been closed so that the duct is not used during operation of the vessel, but only opened for a limited period of time in the event of smoke development. Breathing air is therefore supplied from the adjacent engine room by keeping the door open for 10 minutes before entering the room;
- The bulkheads between the battery rooms and adjacent rooms have been made watertight, and the greywater tanks have been removed from the battery rooms;
- The owners have changed the procedure for venting the battery rooms on detection of smoke. The fan is no longer operated continuously, but will start automatically;
- The procedure for controlling the fire dampers has been changed. They are now kept continually closed, unless automatic ventilation is triggered. On activation of the Novec fire suppression system, the fire damper will open and ventilation will stop. The fire damper will close after Novec is released;
- The procedure for inspection of the battery rooms now includes checking for traces of salt and water.

1.13.2 BATTERY CONTRACTOR

After the accident, the battery contractor has prepared a report after examining the batteries on the port side of ‘Brim’. The battery contractor pointed out that it was known from a previous incident on the port side that water could ingress through the ventilation system. It was pointed out, at the same time, that continuous operation of the ventilation system was contrary to the contractor’s recommendations for direct air cooling of the battery system.

The battery contractor has examined all the battery modules. The work included removal, inspection, analysis of the units and testing of the modules, before some of them were reinstalled on board.

1.13.3 SHIPYARD

The shipyard has prepared new checklists for checking general arrangement and system drawings in relation to regulatory requirements. It has also revised all process descriptions of project-related activities from signature of contract until delivery of the vessel, including the description of tasks, responsibilities and capacity requirements. The shipyard has stated that it will give priority to understanding regulatory requirements and clarify any doubts with the relevant parties prior to starting construction.

The yard believes that these measures will make project implementation, particularly the design phase, clearer and more manageable in relation to regulatory requirements.

1.13.4 DIRECTORATE FOR CIVIL PROTECTION

The Directorate for Civil Protection was involved in the investigation of the battery fire incident on board ‘MF Ytterøyningen’ in October 2019. Following that incident, it was decided to prepare guidelines[30] for risk assessment and handling of fires in lithium-ion batteries. The guidelines were completed and published eight months after the incident on board ‘Brim’. Hence, learning points from both incidents were included in the guidelines.

DSB has established an in-house interdisciplinary battery network to focus on safety aspects relating to lithium-ion batteries, and to update its regulations and guidelines.

[30] https://www.dsbinfo.no/DSBno/2021/veiledning/risikovurderingoghaandteringavbrannilitium-ionbatterier/

2. Analysis

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2. Analysis

2.1 Introduction

By way of introduction, the analysis describes the sequence of events from the fire was detected until the vessel was evacuated. It goes on to address battery room design and awareness of the risks associated with exposing batteries to saltwater. It concludes with a discussion of the interaction between the parties involved, the NMA and DNV's roles in connection with the approval of the vessel, and the preparedness of the external fire services.

Electric hybrid or wholly electric propulsion using large battery systems is a relatively recent technology in the maritime sector. The investigation has shown that there is room for improving safety in several areas. In the process of developing technology, it is important that all stakeholders contribute to ensuring a proper level of safety.

2.2 Sequence of events

From May 2020 up until the day of the accident, the vessel had sailed in sheltered waters with limited exposure to rough waters. The accident occurred on the first voyage after arriving in the inner Oslofjord, where the sea was slightly rough. When the vessel encountered waves to port, the waves were crushed against the starboard hull inside the tunnel, which probably caused ingress of water through the ventilation outlet and onward to the battery room. How seawater could enter the battery room is described in more detail in section 2.4.3 on ventilation arrangements.

Immediately before the fire broke out, the battery system was disconnected as a result of a ground fault, which was indicated on the panel on the bridge. Ground faults had been a recurring problem since the vessel was new. The crew therefore perceived the alarm as 'one of many', and did not consider it to be serious. They had no possibility of identifying the point of origin of the ground fault alarm or ascertaining how serious it was.

The fire alarm panel indicated fire both in the engine room and in the battery room on the starboard side. This was probably because smoke had spread quickly through the fire division between the battery room and the engine room, as observed by the skipper via the surveillance camera in the engine room. It was also verified by the engineer when he arrived in the engine room. The battery room had fire insulation and was separated from adjacent rooms by fire walls designed to prevent the passage of smoke and flames for one hour. The incident showed that the fire division did not prevent the passage of smoke, which was one reason why the crew did not understand where the fire originated. The reason why the fire division did not work is discussed in more detail in section 2.4.5.1.

Furthermore, there was no camera surveillance of the battery room. The presence of a camera might have helped the crew to dispel the incorrect perception that it was the engine room that was on fire. The DNV's updated classification rules[31] from 2021 recommend camera surveillance of battery rooms to improve the crew's situational awareness, in addition to gas monitoring for early detection of gases before they develop into smoke. These are deemed to be important aids to rapid detection of smoke development.

The skipper decided to initiate emergency shutdown of the starboard main engine and emergency generator. This led to much reduced redundancy for manoeuvring, instruments and propulsion.

[31] Rules for Classification: Ships (RU-SHIP), Part 6 Additional class notations, Ch.2 Propulsion, power generation and auxiliary systems, Section 2.3.2.1 and 2.8.1, Edition 2021-07

Nonetheless, the NSIA cannot see that the reduction in propulsion and manoeuvring capabilities had a negative impact on the further sequence of events.

Because of the incorrect perception of fire in the engine room, the Novec fire suppression agent was first released to the engine room after approximately five minutes. When that failed to reduce the development of smoke, the crew understood that the fire was in the battery room. Hence, it took approximately seven minutes before Novec was released to the battery room. Too much time passed from the fire alarm went off until Novec was released for the fire suppression agent to have any significant effect on the battery fire. The use of Novec as a fire suppression agent and its effect are discussed in more detail in section 2.4.5.2.

The crew were unable to start the fire pump because the fuel supply for the emergency generator was shut off. It would not have been possible for the crew to use the fire hose in the battery room as the adjacent room was full of smoke. Moreover, use of the fire hose would probably have exacerbated the fire, as the fire pump used seawater. The extinguishing equipment available to the crew could therefore not have helped to put out the fire.

Evacuation and external extinguishing assistance was therefore the only option available to the crew. The Norwegian Society for Sea Rescue helped to cool down the hull with seawater fire pumps. The NSIA believes it could have exacerbated the fire if the water had come into contact with the batteries, which happened in a previous incident involving the car ferry ‘M/F Ytterøyningen’.

The sequence of events has proved that a combination of several factors contributed to the fire developing. The development of smoke through the ventilation outlet on the starboard side also exposed large parts of the vessel to hazardous smoke. Moreover, some of the rescue equipment was located by the ventilation inlet and would have been inaccessible to any passengers on board. The fact that the vessel had no passengers and was close to the shore and that there were other vessels available to help limited the consequences of the incident. The fact that the crew remained calm and carried out their tasks also had a positive impact on the outcome.

2.3 Technical fire analysis

Based on technical examinations of the fallout, scope of damage and short-circuit traces, the fire started in battery stack 6 in module 1. This is also supported by the fact that the attachment points for the thickest copper strips were completely burnt through.

The NSIA considers it highly likely that seawater ingressed through the ventilation outlet in the tunnel as a result of waves slapping against the tunnel top, and then leaked through the ventilation fan and down onto the batteries. The NSIA cannot rule out that condensation combined with salt deposited from sea air have resulted in electrical conductivity. This is nonetheless unlikely because the ventilation fan for the air extraction system extracted room temperature air (15–25 degrees), which makes condensation formation in the fan unlikely, especially in an amount requiring a drainage cover.

In addition, humid sea air from the air inlet has probably entered the space behind battery stack 6, and then been drawn through the battery modules via the fan engines. The fact that the voyage took place in sheltered waters with calm seas may explain why the short circuit did not occur sooner.

The exposure of battery stack 6 to sea air, and most likely seawater over time, caused salt to be deposited, which, combined with humidity, resulted in electrical conductivity; see also section 1.7.2.1. The low IP rating enabled seawater and sea air to enter the battery module. The IP rating, seawater ingress and ventilation system are discussed in more detail in sections 2.4.1, 2.4.2 and 2.4.3.

The investigation has shown that the fire spread quickly because of the high temperature. This will be discussed in more detail in sections 2.4.1.1 and 2.4.1.2 on propagation and IP rating of high-voltage components.

2.4 Battery system and battery room design

2.4.1 DESIGN AND TESTING OF THE BATTERY PACK

2.4.1.1 Propagation test

The fire spread quickly to adjacent modules, and eventually to the whole battery room. The technical examinations have shown that there was uncontrolled ventilation in some battery cells in battery module 1 due to a side wall rupture. A side wall rupture is a rare incident, but, when it occurs, it will be difficult to prevent propagation in an air-conditioned battery system. If the batteries had been fully charged, more cells would most likely have ventilated through the cell wall, and the fire would have developed faster.

DNV's classification rules,[32] based on the IEC 62619 standard, provide for a free choice between the approved methods of propagation testing. The method chosen proved not to be appropriate for this battery type, however, as it failed to identify the risk of side wall rupture. Nail penetration tests are associated with several weaknesses that may change the outcome of the test and give rise to a false sense of security. Among other things, the test is not capable of identifying the likelihood of side wall rupture. Other methods such as local heating of a cell are considered more suitable to identify the battery's likelihood of side wall rupture.

In the NSIA's opinion, the suitability of nail penetration tests to identify the risk of side wall rupture in cylindrical cells with high energy density should be considered. Furthermore, it must be considered whether there should be a free choice of propagation method, as there is a possibility that the choice of method may be at the expense of safety.

The NSIA recommends that the NMA issue requirements for appropriate test methods that reflect the risks associated with the design of different battery types to be chosen for propagation tests; see Safety recommendation Marine No 2022/03T in Chapter 4.

2.4.1.2 IP rating of high-voltage systems

The technical examinations have shown that the fire arose as a result of electric arcs in high-voltage components with insufficient ingress protection (IP rating). The sub-modules were series-connected using copper strips, which meant that the mechanical copper fuse had to be burnt through to be able to isolate one sub-module from another. Burning through the fuse required overheating over time. There was no other way of disconnecting a module in the event of an insulation fault.

Little research has been conducted into the formation of electric arcs in DC systems, and no definite answer has been arrived at for when voltages exceed the electric arc limit. IEEE has recommended that the electric arc limit be set to 100 VDC.

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[32] *Rules for Classification: Ships (RU-SHIP), Part 6 Additional class notations, Ch.2 Propulsion, power generation and auxiliary systems, sections 4.1.2.7 and 4.2.2, Edition 2021-07 and IEC 62619:2017, Appendix B, B.1-B.3.*

If the voltage of each individual module had been below the electric arc limit, thereby enabling automatic isolation from the rest of the system with the use of a rapid current breaker, fire caused by electric arc formation could be prevented. A solution whereby a current breaker was fitted to the battery modules on board would not have prevented fire in this case, however, as the voltage was above the recommended electric arc limit in several of the modules. In the case of voltages exceeding the electric arc limit, a sufficient IP rating should be required to prevent moisture penetration. It should apply to all connections with voltages above the limit.

2.4.2 BATTERY PROTECTION AGAINST SEAWATER

The battery system on board 'Brim' had a low IP rating (IP2X) for protection against seawater exposure. The risk assessment carried out by the yard described the risk of water ingress, but all the measures described were not consistent with the design; see section 1.5.8. Nor was this identified by DNV during its approval of the risk assessment. The issue will be discussed in more detail in section 2.4.3.

The risk assessment described early detection of seawater ingress as critical with a view to avoiding electrolysis. A water level alarm had only been installed to detect large amounts of seawater and activate the bilge pumps. A water level alarm is not capable of detecting small amounts of saltwater that represent a potential risk to a battery system. The NSIA therefore considers a water level alarm to be insufficient as a means of detecting small amounts of saltwater.

Insufficient ingress protection of the battery system and high-voltage components meant that the ingress of salty liquid to the battery modules caused electric arcs and subsequent fire in the battery room. A higher IP rating of the battery modules, contact points and high-voltage components would reduce the likelihood of seawater ingress and possibly prevent a ground fault. Salt may still be deposited from ventilation air in a maritime environment, and this issue will be discussed in more detail in section 2.4.3.

DNV's classification rules[33] from 2021 have been updated to include a minimum rating requirement of IP44, unless a risk assessment indicates that a lower rating may be acceptable. As the regulations are currently worded, they may lead to approval of a lower IP rating and to the risk assessment not reflecting the real risk associated with specific designs, which was the case in connection with the 'Brim' incident. The NSIA believes that the IP-rating requirement must be seen in conjunction with the battery room design and its degree of exposure to external factors. A high IP rating may reduce the effect of fire suppression systems, as the suppression agent will be incapable of penetrating the module. Furthermore, it will not be possible to rule out an internal fault in the module that can lead to short circuiting and fire, regardless of the IP rating. All parameters capable of impacting safety must be considered and approved together in the form of a risk assessment. This is discussed further in sections 2.4.4 and 2.6.

2.4.3 VENTILATION ARRANGEMENTS

The ventilation arrangements were designed with the outlet to the tunnel; see also section 1.5.4. The investigation has shown that it is highly likely that seawater ingressed through the ventilation outlet, leaked down through the fan and down onto the batteries. Neither the shipyard, nor DNV or the NMA identified the fan as a leakage point with a view to ingress of seawater.

The gooseneck, which is part of the ventilation arrangements, was included by the yard to meet the freeboard requirement; see section 1.5.5. The fan, which was a leakage point, was installed before

[33] *Rules for Classification: Ships (RU-SHIP), Part 6 Additional class notations, Ch.2 Propulsion, power generation and auxiliary systems, section 4.1.7, Edition 2021-07*

the gooseneck. This meant that the gooseneck had no function in terms of fulfilling the freeboard requirement or in relation to battery safety.

The yard's risk assessment identified the risk of seawater entering through the ventilation outlet for the air extraction system; see section 1.5.8. This was described as having been addressed by increasing the freeboard to 4.5 m, which proved to be an inherent error in the risk assessment. The error was also not detected by the approval authority.

The ventilation arrangement did not meet the requirement of 1.7 m from the waterline to the outlet, and consequently a manual closing mechanism was required. No such mechanism was installed on 'Brim', which meant that there were no barriers against ingress of seawater. The NSIA cannot see that a manual closing mechanism on the outlet would have made a difference, however. The reason for this is that the practical implementation of such a solution could have been installing a cover to be closed in the event of an incident, which would not have prevented water ingress during normal operation.

A ventilation outlet on the ship's side would probably have reduced the likelihood of water ingress, even though it would have been placed less than 1.7 m above the waterline, as it would mean that the ventilation outlet would not have been exposed to slamming loads.

Under the DNV classification rules[34] (see section 1.9.4.2), battery rooms were required to have a ventilation system to extract explosive gases. The solution chosen on 'Brim' was to keep the ventilation system running continuously rather than installing a gas detector to activate the ventilation. This resulted in a continuous supply of sea air to the battery room. Air-cooled batteries combined with continuous fresh-air ventilation is considered an unsuitable solution for battery rooms, as the room should be kept free of salts, particles and humidity. In a maritime environment, the air will always contain a certain amount of salt. If salty air is drawn in through the ventilation system, it will, over time, lead to salt being deposited, which may in turn cause a ground fault.

The NSIA considers that the positioning of the ventilation outlet in the tunnel was unfavourable, and that the measures to prevent water ingress were insufficient. Positioning the ventilation outlet high above deck could have reduced the likelihood of water ingress, but this would required the outlet to be placed at a sufficient distance to prevent possible exposure of passengers. The ventilation system was installed as a safety barrier to remove explosive gases in the event of an incident, but instead it most likely contributed to seawater entering the space. The NSIA cannot see that the load line requirements are adapted so as to prevent small amounts of seawater from entering a battery room and ensure battery safety.

The NSIA recommends that the NMA ensure that battery safety regulations be developed so that ventilation arrangements do not contribute to batteries and high-voltage components being exposed to humid sea air or seawater; see Safety recommendation Marine No 2022/04T in chapter 4.

After the accident, the owners have made several changes to the ventilation system; see section **Feil! Fant ikke referansekilden.**. Among other things, the ventilation arrangement has been m odified to reduce the risk of seawater ingress. The NSIA considers that a solution whereby a ventilation outlet is located high above deck would probably be a better barrier against both seawater ingress and the possibility of passengers being exposed to toxic smoke in the event of an incident. The implemented switch to non-continuous ventilation will also reduce the amount of humid sea air being drawn into the battery room.

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[34] *Rules for Classification: Ships (RU-SHIP), Part 6 Additional class notations, Ch.2 Propulsion, power generation and auxiliary systems, section 2.3 Ventilation, Edition 2018-1*

2.4.4 RISK ASSESSMENT

The investigation has shown that the yard's risk assessment had shortcomings and failed to reflect the real risk associated with the battery system on board 'Brim'.

The battery rooms were defined as non-hazardous areas, which was misleading and gave rise to the misconception that they were safe. It also meant that no gas detection equipment was installed in the battery rooms, and that it took longer before the fire was discovered. In the July 2021 edition of DNV's classification rules,[35] the requirement has been changed to make gas monitoring of battery rooms mandatory; see section 1.9.4.3.

The risks associated with high voltage and electric arc formation were also not reflected in the risk assessment, although the problem was known, among other things as a result of the 'MF Ytterøyningen' incident; see section 1.12.

The NSIA cannot see that the risk assessment reflected the real risk of fire in the battery packs, as neither the weaknesses of the ventilation system nor those of the battery system were sufficiently identified. A risk assessment should address all relevant risks, identified by various disciplines, that together present a risk to the vessel. Taken together, this will potentially uncover weaknesses in the vessel design and identify risks associated with the use of lithium-ion batteries.

In the 2021 edition of DNV's classification rules,[36] the requirement for a safety assessment has been changed to a requirement for drawing up a safety philosophy. The reason for the change was that DNV and the NMA considered the quality of risk assessments to be too poor, and that the updated regulations reduced the need for risk assessments by introducing more prescriptive rules. The NSIA considers that the requirement for a safety philosophy, as worded in the 2021 classification rules, is incapable of uncovering weaknesses through an overall risk assessment of potential risks and how to avoid them by implementing risk reduction measures. DNV has stated that the operators should increasingly contribute to developing the safety of vessels with lithium-ion batteries. The DNV rules provides for the possibility of using batteries with a lower IP rating if a risk assessment is carried out. This further emphasises the importance of conducting a comprehensive risk assessment. The NSIA believes that an overall risk assessment involving different disciplines will contribute to the operators identifying risks and necessary risk reduction measures themselves.

The NSIA recommends that the NMA issue requirements for risk assessments relating to the use of lithium-ion batteries, and that they should contain all relevant risks identified by different disciplines, the sum of which represents the vessel's fire risk; see Safety recommendation Marine No 2022/06T.

2.4.5 FIRE INSULATION AND EXTINGUISHING SYSTEM IN THE BATTERY ROOM

2.4.5.1 Fire integrity of the battery rooms

The fire division between the battery room and the engine room was designed to prevent the passage of smoke and flames for one hour. The incident has shown that smoke and toxic gas quickly spread from the battery room to the engine room, without the fire continuing to spread to adjacent rooms. The smoke in the engine room misled the crew about the location of the fire, and they were thereby unable to release the fire suppression agent in time. The NSIA has not investigated how the smoke spread from the bulkhead between the battery room and the engine room, but nonetheless believes it is essential to maintain the fire and smoke integrity between the

[35] Rules for Classification: Ships (RU-SHIP), Part 6 Additional class notations, Ch.2 Propulsion, power generation and auxiliary systems, section 2.3.2.1, Edition 2021-07
[36] Rules for Classification: Ships (RU-SHIP), Part 6 Additional class notations, Ch.2 Propulsion, power generation and auxiliary systems, section 2.5 Safety philosophy of the onboard installation, Edition 2021-07

two rooms. No follow-up inspection has been carried out of existing or rebuilt bulkheads. The NSIA believes that enhanced quality assurance of the execution of fire insulation of battery rooms is needed.

That the bulkhead was not smokeproof was not uncovered when the drawings were approved, during construction follow-up or in connection with the inspection. The NSIA considers that better quality assurance is needed of the execution of fire insulation of battery rooms through additional measures that ensure that gas and smoke do not pass the fire division.

The NSIA recommends that the NMA introduce additional measures to verify that installations are smokeproof and maintain fire integrity; see Safety recommendation Marine No 2022/05T.

2.4.5.2 Novec 1230 as battery fire suppression agent

In this incident, it took approximately seven minutes from the fire alarm went off until the first dose of Novec was released in the battery room. By then, the fire had probably caught on and thermal runaway had started in several battery modules. In order to be effective against a lithium-ion fire, a fire suppression agent needs to be released quickly and automatically; see section 1.7.2.8. The late release of Novec therefore had little effect on the development of the fire, although it may have had a cooling effect for a short period.

Novec release requires an advanced control system that opens and closes valves to prevent underpressure and broken fire barriers. Novec was released in accordance with the procedure, but the closing of the fire damper before the system was activated may have weakened the fire barriers and accelerated the fire as a result of high underpressure.

In accordance with the regulations[37] (see section 1.9.4.6), automatic activation of gas fire-extinguishing systems is not, in principle, permitted in the maritime sector, among other things because of personnel safety requirements. Some Norwegian vessels have been granted permission to use automatic fire suppression systems, based on safety measures implemented to prevent accidents arising from accidental release. As quick release is vital to the system’s effect, it will be challenging to put out a fire by manual release because of the time it takes. Camera surveillance and gas detection may nonetheless be important aids to early detection.

The NMA was aware of the risks, complexity and effect associated with the use of Novec, but has stated that, at present, no fire suppression system is available that would be capable of extinguishing a lithium-ion fire. The NSIA considers Novec to be unsuited as a fire suppression agent in battery rooms because of the complexity of correct use, its poor effect and the fact that it resolves into toxic gases at high temperatures. Nor are there any other fire suppression agents that work optimally. The NSIA considers the lack of adequate means of extinguishing fires in lithium-ion batteries to be a safety problem.

The NSIA recommends that the NMA introduce compensatory measures to address the safety of passengers and crew in the event of a lithium-ion battery fire; see Safety recommendation Marine No 2022/08T.

After the ‘Brim’ incident, there were clear signs of Novec having resolved into toxic, corrosive products. This may represent a hazard to both passengers and crew, and must be taken into account in an emergency response situation.

The investigation has identified a knowledge gap among the crew as regards the use of and risks associated with Novec. The NSIA considers it important that the user is well aware of the

[37] FSS Code, Chapter 5 section 2.1.3.4

complexities, limitations and risks associated with the use of Novec. Circular 4 issued by the NMA in 2022 introduced new requirements for crew training in maritime battery systems on board Norwegian ships. The NSIA will therefore not submit any safety recommendation on this point.

2.5 Cooperation between the parties in connection with previous incidents

The risk assessment of the battery system, which was based, among other things, on the battery contractor's safety description, identified the risk of seawater in the battery room, and the shipowners, the battery contractor and the yard were thus aware of this type of risk.

As a result of humidity problems, it was decided to replace the circuit board and the fan and to install drainage from the fan housing. At that point in time, the owner and the battery contractor both believed that the humidity problems were caused by condensation, not seawater. The measures that were introduced were simple solutions that did not prevent seawater from entering the battery rooms. Moreover, the drainage solution was not installed in the starboard battery room, where the fire arose. The NSIA believes that the fire could have been avoided if the ingress of seawater and the associated risks had been understood and sufficient measures implemented in both battery rooms.

After the 'Brim' incident, the battery contractor conducted an examination of the port battery pack, where salt deposits were found in several of the modules. The NSIA believes the battery contractor had knowledge of the risks of seawater ingress and had several opportunities to identify the problem. It is unclear to the NSIA why the issue was never identified or addressed by the battery contractor until after the incident.

2.6 Follow-up and approval by the Norwegian Maritime Authority

Responsibility for follow-up and approval of 'Brim' was shared between the NMA, DNV and DSB.

2.6.1 APPROVAL OF VENTILATION ARRANGEMENTS

DNV approved the ventilation arrangements in the battery rooms, but did not consider load line conditions such as freeboard requirements or flooding points from the ventilation system, since these aspects were approved by the NMA.

The freeboard plan approved by the NMA lacked important information about ventilation openings, and thereby also about flooding points.

The purpose of the freeboard requirements is, among other things, to safeguard the vessel's stability and watertight integrity, and requirements are therefore made regarding freeboard to flooding points. However, the NSIA cannot see that the purpose of the load line requirements is to prevent small amounts of seawater and humid sea air from penetrating the battery rooms, and thereby safeguard battery safety.

DNV's regulations for battery safety contained no requirements for how flooding points pertaining to the battery rooms were to be protected against the ingress of seawater. Battery safety as a whole was not adequately addressed, and nobody identified the risk of seawater ingress through the ventilation arrangements. Based on the current rules and regulations, the same error may be made again.

2.6.2 ROLES AND SUPERVISION

Several supervisory bodies may be involved in the supervision of vessels and marine equipment, which was also the case for this vessel. The electric installations on board were required to meet requirements set out in the Regulations relating to Maritime Electrical Installations, which are administered by DSB. The Regulations do not stipulate separate requirements for large battery installations on board vessels.

The NMA does not have separate regulations relating to battery safety, but relies on the classification rules. The classification societies may have different requirements for battery safety, which can result in different vessels having different standards of battery safety depending on which society undertook their classification.

The NSIA considers that the regulatory requirements for vessels of more than 24 metres in length[38] administered by the different supervisory bodies must define a minimum standard that ensures battery safety.

Since the battery system on board was so integrated with other matters regulated by the NMA, the NSIA believes it to be important that the supervisory bodies clarify the division of responsibility between the NMA and DSB to ensure a clear framework in terms of the regulations and pertaining supervisory follow-up.

The regulations refer to standards that do not reflect recent developments. The supervisory authorities must therefore ensure that the rules keep up with developments in technology. In areas where adequate standards have not been established, the supervisory authorities must develop their own regulations to ensure safe operations when new technology is introduced.

The NMA has been assigned overall responsibility for maintaining safety at sea, and it is therefore recommended that it coordinates its activities with other competent authorities.

The NSIA recommends that the NMA, as the administrative authority, cooperate with DSB on stipulating a requirement that all Norwegian vessels, regardless of classification, must be built to a defined standard that ensures battery safety; see Safety recommendation Marine No 2022/07T in Chapter 4.

2.7 Assessment of external fire preparedness

The incident has identified a knowledge gap among the various parties and the fire service tasked with handling the extinguishing operation. The various parties' evaluation of the incident identified several areas for improvement.

The JRCC pointed out that lack of electronic tagging of vessels containing large battery packs presents a problem. Had they been aware of it, they could have engaged in closer dialogue with the fire service to identify necessary safety measures to prevent rescue personnel being exposed to unnecessary danger. This information is important with regard to the choice of resources allocated and how quickly evacuation must be carried out.

Learning points include that, prior to entry, too little information is provided about the risks to which response personnel may be exposed on each individual vessel, and that the fire service's established maritime chemical response scheme (RITS-Kjem) and intervention competence should

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[38] The NMA has published guidelines for energy storage systems on vessels of less than 24 m in length. *https://www.sdir.no/en/shipping/legislation/directives/guideline-for-electrical-energy-storage-systems-maritime-ees-systems-onboard-norwegian-ships-of-less-than-24-meters-in-length-l/*

have been used as a first response. Shortcomings were also identified in relation to standardised solutions for putting out lithium-ion fires on board vessels and the need to study technical solutions where, for example, connections must be standardised on different vessel to allow for an efficient supply of fire suppression agents.

The NMA also identified many of the same learning points after the ‘Ytterøyningen’ incident.

Both incidents have identified a need for more knowledge about the risks response personnel may be exposed to in connection with fires in electric vessels and increase expertise in extinguishing lithium-ion fires.

DSB has prepared and published guidelines for risk assessment and handling of fires in lithium-ion batteries, which is considered positive, but is not on its own sufficient to raise knowledge about how the fire service should approach such missions. Among other things, the fire service has expressed a need for an adapted, pre-defined extinguishing method to put out fires on board vessels with large battery installations. It must be considered whether a standard extinguishing method should be recommended for the sake of predictability and to reduce uncertainty when encountering a lithium-ion fire. Courses must be provided to expand the knowledge of all personnel tasked with dealing with large lithium-ion fires.

The NSIA therefore believes that there is still a need to raise the knowledge and expertise of the parties involved in the first-line response to fires in lithium-ion batteries.

The NSIA recommends that DSB strengthen the knowledge and expertise of the parties involved in the first-line response to accidents involving a fire on board a vessel carrying lithium-ion batteries; see Safety recommendation Marine No 2022/09T in Chapter 4.

3. Conclusion

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3. Conclusion

3.1 Main conclusion

The fire on board most likely arose as a result of seawater entering the ventilation system and coming into contact with the high-voltage components of the battery system, causing short-circuiting, electric arcs and fire. The investigation has also shown that the low IP rating enabled seawater and sea air to enter battery modules.

Late release of the fire suppression agent meant that it had little suppressive effect and did not prevent the fire from developing, but had a cooling effect for a short period. The investigation has shown that a clear extinguishing strategy that would limit the scope of damage in the event of lithium-ion battery fires is lacking.

The investigation has also identified several areas where the risks associated with the use of lithium-ion batteries was not sufficiently identified or addressed in the design. At present, DNV's classification rules for battery safety do not sufficiently address the risks associated with the use of lithium-ion batteries on board vessels.

3.2 Investigation results

3.2.1 SEQUENCE OF EVENTS, OPERATIONAL AND TECHNICAL FACTORS

A. It is highly likely that seawater ingressed through the ventilation outlet in the tunnel as a result of waves slamming against the tunnel top, and then leaked through the ventilation fan and down onto the batteries.

B. When salty liquid came into contact with live components, this led to short-circuiting and electric arc formation in the battery, resulting in intense heat and smoke development.

C. No gas alarm or camera surveillance was installed in the battery room, which made it challenging for the crew to detect the smoke developing in the room at an early stage.

D. Inadequate fire integrity in the battery room caused smoke to spread to the adjacent room. As a result, the crew first believed there was a fire in the engine room, which delayed the release of the fire suppression agent in the battery room.

3.2.2 BATTERY SYSTEM AND BATTERY ROOM DESIGN

A. The technical examinations have shown that there was uncontrolled ventilation in some battery cells in battery module 1 due to a side wall rupture. If the batteries had been fully charged, more cells would most likely have ventilated through the cell wall, and the fire would have developed faster.

B. Under the current regulations,[39] there are several approved methods of propagation testing. Nail penetration tests are associated with several weaknesses that may change the outcome of the test and give rise to a false sense of security.

C. Insufficient ingress protection of the battery system and high-voltage components meant that the ingress of salty liquid to the battery modules caused short-circuiting and subsequent fire in

[39] *Rules for Classification: Ships (RU-SHIP), Part 6 Additional class notations, Ch.2 Propulsion, power generation and auxiliary systems, sections 4.1.2.7 and 4.2.2, Edition 2021-07 and IEC 62619:2017, Appendix B, B.1-B.3.*

the battery room. A higher IP rating of the battery modules, contact points and high-voltage components would reduce the likelihood of water ingress.

D. The fan located just above the batteries had not been identified as a potential leakage point with regard to seawater ingress through the ventilation outlet in the tunnel top.

E. The fan in the port battery room had already been found not to be watertight, but the action taken to remedy the problem was inadequate. No changes were made to the design of the ventilation system in the starboard battery room based on this knowledge.

F. The bulkhead between the battery room and the engine room was not smokeproof, even though the drawings indicated class A-60 insulation.

G. The risk assessment did not reflect the real risk of fire in the battery system. A risk assessment must address all relevant risks identified by various disciplines, that together represent the risk to the vessel.

H. The investigation has shown that Novec had little effect on the development of the fire, and that there are currently no effective suppression agents available capable of preventing fire and propagation in lithium-ion batteries. The lack of effective suppression agents for lithium-ion fires is a safety challenge.

3.2.3 THE ROLES OF THE PARTIES IN CONNECTION WITH APPROVAL OF THE VESSEL

A. Important information about flooding points from the ventilation system to the battery room was missing from the freeboard plan. This meant that the NMA personnel responsible for approving the freeboard plan were unaware of the ventilation outlet being placed in the tunnel.

B. DNV approved the ventilation arrangements in the battery rooms, but did not consider load line conditions such as freeboard requirements or flooding points from the ventilation system, since these aspects were approved by the NMA.

C. DNV's regulations for battery safety contained no requirements for how flooding points pertaining to the battery rooms were to be protected against the ingress of seawater. Based on current rules and regulations, the same error may be made again.

D. Neither the shipyard, nor DNV or the NMA identified the fan as a leakage point with a view to ingress of seawater. Battery safety was thereby not addressed at the overall level, and no one identified the risk of seawater ingressing through the air extraction system.

E. The NMA does not have separate regulations relating to battery safety, but relies on the classification rules. The classification societies may have different requirements for battery safety, which can result in different vessels having different standards of battery safety depending on which society undertook their classification.

F. It is important that the supervisory bodies clarify the division of responsibility between the NMA and DSB to ensure a clear framework in terms of regulations and pertaining supervisory follow-up.

3.2.4 EXTERNAL FIRE PREPAREDNESS

A. It is not possible for the JRCC to identify vessels carrying a large battery pack. If it were, the JRCC would have engaged in closer dialogue with the fire service to identify necessary safety measures to prevent rescue personnel being exposed to danger unnecessarily.

B. The incident has identified a knowledge gap in the fire service tasked with handling the extinguishing operation.

C. The NMA identified many of the same learning points after the ‘Ytterøyningen’ incident. Challenges relating to the extinguishing operation following both incidents have identified a need for raising knowledge about how to put out lithium-ion fires.

D. Courses must be provided to expand the knowledge of all personnel tasked with dealing with large lithium-ion fires.

4. Safety recommendations

4. Safety recommendations

The Norwegian Safety Investigation Authority submits the following three recommendations[40] for the purpose of improving safety at sea:

Safety recommendation Marine No 2022/03T

On 11 March 2021, a fire arose in the starboard battery room of the passenger vessel 'Brim' in the outer Oslofjord. The investigation has shown that there were several weaknesses associated with the propagation test used to identify the battery's likelihood of cell-to-cell propagation and that the test failed to identify the possibility of side wall rupture. DNV's rules, based on the IEC 62619 standard, provide for a free choice between the approved methods of propagation testing. The method chosen was not appropriate for the battery type in question.

The Norwegian Safety Investigation Authority recommends that the Norwegian Maritime Authority issue requirements for appropriate test methods that reflect the risks associated with the design of different battery types to be chosen for conducting propagation tests.

Safety recommendation Marine No 2022/04T

On 11 March 2021, a fire arose in the starboard battery room of the passenger vessel 'Brim' in the outer Oslofjord. The Norwegian Safety Investigation Authority cannot see that the load line requirements are adapted so as to prevent small amounts of seawater from entering a battery room and ensure battery safety. The investigation has shown that the positioning of the ventilation outlet in the tunnel was unfavourable and that measures to prevent water ingress were insufficient. The ventilation should have functioned as a safety barrier by extracting explosive gases in the event of an incident, but instead it contributed to sea air or seawater entering the battery room, resulting in short circuiting / electric arcs and fire.

The Norwegian Safety Investigation Authority recommends that the Norwegian Maritime Authority ensure that battery safety regulations be developed so that ventilation arrangements do not contribute to batteries and high-voltage components being exposed to humid sea air or seawater.

[40] *The Ministry of Trade, Industry and Fisheries has the overall responsibility for following up the safety recommendations.*

Safety recommendation Marine No 2022/05T

On 11 March 2021, a fire arose in the starboard battery room of the passenger vessel 'Brim' in the outer Oslofjord. The investigation has found that the bulkhead between the engine room and the battery room was not smokeproof. Toxic gases spread to adjacent rooms. This was not detected in connection with approval of the drawings, construction follow-up or inspections. There is a need for better quality assurance of the execution of fire insulation of battery rooms through additional measures that ensure that gas and smoke do not penetrate the fire division, as defined in Regulations No 1099 of 1 July 2014 on fire protection on ships.

The Norwegian Safety Investigation Authority recommends that the Norwegian Maritime Authority introduce additional measures to verify that installations are smokeproof and ensure fire integrity.

Safety recommendation Marine No 2022/06T

On 11 March 2021, a fire arose in the starboard battery room of the passenger vessel 'Brim' in the outer Oslofjord. The Norwegian Safety Investigation Authority cannot see that the risk assessment reflected the real risk of fire in the battery packs, as neither the weaknesses of the ventilation system nor those of the battery system were sufficiently identified. A risk assessment should address all relevant risks identified by various disciplines, that together present a risk to the vessel. Taken together, this will potentially uncover weaknesses in the vessel design and identify risks associated with the use of lithium-ion batteries.

The Norwegian Safety Investigation Authority recommends that the Norwegian Maritime Authority issue requirements for risk assessments relating to the use of lithium-ion batteries, and that they should contain all relevant risks identified by different disciplines, the sum of which represents the vessel's fire risk.

Safety recommendation Marine No 2022/07T

On 11 March 2021, a fire arose in the starboard battery room of the passenger vessel 'Brim' in the outer Oslofjord. The Norwegian Maritime Authority does not have separate regulations relating to battery safety, but relies on classification rules. There were shortcomings in the battery safety regulations for the class. Furthermore, the classification societies may have different requirements for battery safety, which can result in different vessels having different standards of battery safety. Different supervisory bodies may be involved in the supervision of vessels and marine equipment, which was also the case for this vessel. In the Norwegian Safety Investigation Authority's opinion, this represents a safety risk that requires better coordination between the different agencies.

The Norwegian Safety Investigation Authority recommends that the Norwegian Maritime Authority, as the administrative authority, cooperate with the Directorate for Civil Protection on stipulating a requirement that all Norwegian vessels, regardless of classification, must be built to a defined standard that ensures battery safety.

Safety recommendation Marine No 2022/08T

On 11 March 2021, a fire arose in the starboard battery room of the passenger vessel 'Brim' in the outer Oslofjord. The investigation has shown that Novec had little effect on the development of the fire, and that there are currently no effective suppression agents available capable of preventing fire and propagation in lithium-ion batteries.

The Norwegian Safety Investigation Authority recommends that the Norwegian Maritime Authority introduce compensatory measures to address the safety of passengers and crew in the event of a lithium-ion battery fire.

Safety recommendation Marine No 2022/09T

On 11 March 2021, a fire arose in the starboard battery room of the passenger vessel 'Brim' in the outer Oslofjord. The investigation has identified a need to raise the knowledge and expertise of the parties involved in first-line emergency response in connection with fires in lithium-ion battery systems on board vessels.

The Norwegian Safety Investigation Authority recommends that the Directorate for Civil Protection strengthen the knowledge and expertise of the parties involved in the first-line response to accidents involving a fire on board a vessel carrying lithium-ion batteries.

Norwegian Safety Investigation Authority
Lillestrøm, 14 July 2022

Appendices

Appendix A Details of the vessel and the accident

Vessel	
Name	'Brim'
Flag state	NOR
Classification society	DNV
IMO Number/Call signal	9862554/LFPS
Type	Passenger catamaran, electric hybrid
Build year	2019
Owner	Brim Explorer AS
Operator / Responsible for ISM	Brim Explorer AS
Construction material	Aluminium
Length	25.05 metres
Gross tonnage	226 BT
Voyage	
Port of departure	Sarpsborg
Planned port of arrival	Sandefjord
Type of voyage	Inshore
Persons on board	4
Information about the accident	
Date and time	10 March 2021 (at 15:27)
Type of accident	Serious marine casualty
Location/position where the accident occurred	The Oslofjord
Place on board where the accident occurred	Starboard battery room
Injuries/deaths	None
Damage to vessel/the environment	Fire damage in starboard battery room and adjacent rooms
At what point in the voyage was the vessel	Under way
Environmental conditions	Moderate south-easterly gale of approximately 12 m/s, wave height of between 1.3 and 1.4 m