MAIB
MARINE ACCIDENT INVESTIGATION BRANCH

ACCIDENT REPORT

VERY SERIOUS MARINE CASUALTY | REPORT NO 4/2021 | APRIL 2021

Carbon monoxide poisoning on board motor cruiser *Diversion*, resulting in two fatalities at the Museum Gardens quay, River Ouse, York on 4 December 2019

SUMMARY

At about 2000 on 4 December 2019, the bodies of two men were discovered in the forward cabin of the 9.14m motor cruiser *Diversion*, which was moored to a quay on the River Ouse **(Figure 1)** in the centre of York, England. The bodies were those of the vessel owner and his friend who had spent the previous evening in the city centre socialising with former work colleagues and were spending the night on board. Both men had died as a result of carbon monoxide poisoning.

The MAIB investigation concluded that:

- The carbon monoxide had leaked into the cabin from the boat's diesel-fuelled cabin heater exhaust.
- The cabin heater's exhaust silencer was not designed for marine use. Its connection to the exhaust pipe system was not gas tight, the installation had not been checked by a professional heater installer, and it had not been serviced.
- The cabin ventilation system did not meet the requirements of the Boat Safety Scheme and this might have increased the rate at which the carbon monoxide accumulated in the boat's cabin space.
- The owner and his friend were not alerted to the danger because a carbon monoxide alarm had not been fitted.

Figure 1: *Diversion* moored in York

As a result of the investigation's initial findings, the MAIB issued safety bulletin number SB2/2020, highlighting the importance of having diesel-fuelled cabin heater installations checked and regularly serviced, and also the requirement to have a carbon monoxide alarm fitted. The safety bulletin has been referenced in Boat Safety Scheme publications and has been featured in the 2020 Carbon Monoxide awareness week.

FACTUAL INFORMATION

Narrative

At about 1200 on 3 December 2019, the owner and two of his friends made their way onto the motor cruiser *Diversion* at its mooring in York Marina. Once on board, they readied the boat for a 4 mile trip upriver to York city centre, where they had arranged to attend a pre-Christmas social gathering with former work colleagues. They left the marina at about 1230 for York, where the owner and one of his friends planned to sleep on board *Diversion* overnight.

During the trip the owner used the stove in the main cabin to make coffee while one of his friends steered the boat. It was a cold, clear day so the owner also turned on the boat's diesel-fuelled cabin heater. At about 1330, they arrived in the city centre and moored *Diversion* on the northern bank of the river, adjacent to Museum Gardens.

At about 1400, the three men went ashore, and spent the afternoon drinking and socialising with their former colleagues in several city centre pubs. One of the owner's two friends had to return home in the early evening and left them at about 1930 to catch a train. The owner and his remaining friend had a meal with some of the group then returned to *Diversion* at about 2200, and prepared to go to bed.

At about midday on the following day, the families of the owner and his friend became concerned that they had not heard from either man. They made several telephone calls to try to locate them, but without success, and later in the afternoon they reported their concerns to the police. A police officer was dispatched to the quayside and confirmed that the boat was still moored there, and that its accommodation was in darkness and no one appeared to be on board. The officer was then instructed to continue on patrol. With no further contact from the two men, the families contacted the police once again to express their increasing concern.

At about 2000, another police officer boarded *Diversion* and found the main cabin door unlocked, with all lights switched off. The police officer entered the boat and found the bodies of the owner and his friend in the forward cabin bunk space; one was lying on the floor, the other was seated on the forward cabin entrance steps, and it was apparent that they had prepared themselves to go to bed. The police officer immediately called for backup and, at 2045, the Fire and Rescue Service arrived on the boat. They tested the atmosphere in *Diversion*'s accommodation and declared it safe for entry. Paramedics entered the boat and at 2115 the owner and his friend were declared deceased.

Diversion was towed back to York Marina on 7 December 2019, where it was secured by the police.

On 9 December post-mortems were carried out, which found that the primary cause of death for both men was carbon monoxide (CO) poisoning; both also had caffeine and alcohol in their system.

The accident was not reported to the MAIB until June 2020; the investigation started shortly afterwards.

The casualties

Diversion's owner, Ronnie Holmes, was 60-years-old and had worked as a power station engineer for over 30 years. He retired in 2015 and spent his time carrying out home improvements, fixing motorcycles and boating. Before retirement he had enjoyed scuba diving with friends.

Stephen Jewitt had retired around the same time as Ronnie, was 63-years-old and had worked as an engineer at the power station, where he met and became friends with Ronnie. Stephen also owned a boat which he had used for diving trips with Ronnie.

Vessel description

Diversion was a 9.14m steel hulled boat **(Figure 2)** that had been built by its owner based on plans purchased from boat designer Bruce Roberts. The owner had started the construction of *Diversion* in 1990 and built it over a period of 11 years on land behind his home. The boat was launched at York Marina in 2001, where it was based for the next 19 years. The owner used *Diversion* predominantly on the River Ouse, and frequently entertained family and friends on board.

During the build, the owner had made several alterations to the design, which included the installation of a second engine and changes to the cabin arrangements. The forward cabin was fitted with twin bunk beds and was wood lined, but it had no thermal insulation to the hull. The steering wheel, engine throttles and engine control console were located on the starboard side of the main cabin, and there was a 4kW[1] twin burner methylated spirit stove on the port side. In 2018, the owner fitted a second-hand diesel-fuelled cabin heater that he had purchased from an auction website. The owner had also purchased a portable petrol generator and coupled it up to a 24V battery charger in the engine space. Two spare back-up batteries had been placed in the engine bay by the owner before they left York Marina.

Diversion was licensed by the Canal and River Trust to operate on the River Ouse and was examined under the Boat Safety Scheme (BSS) as a mandatory requirement of this licence.

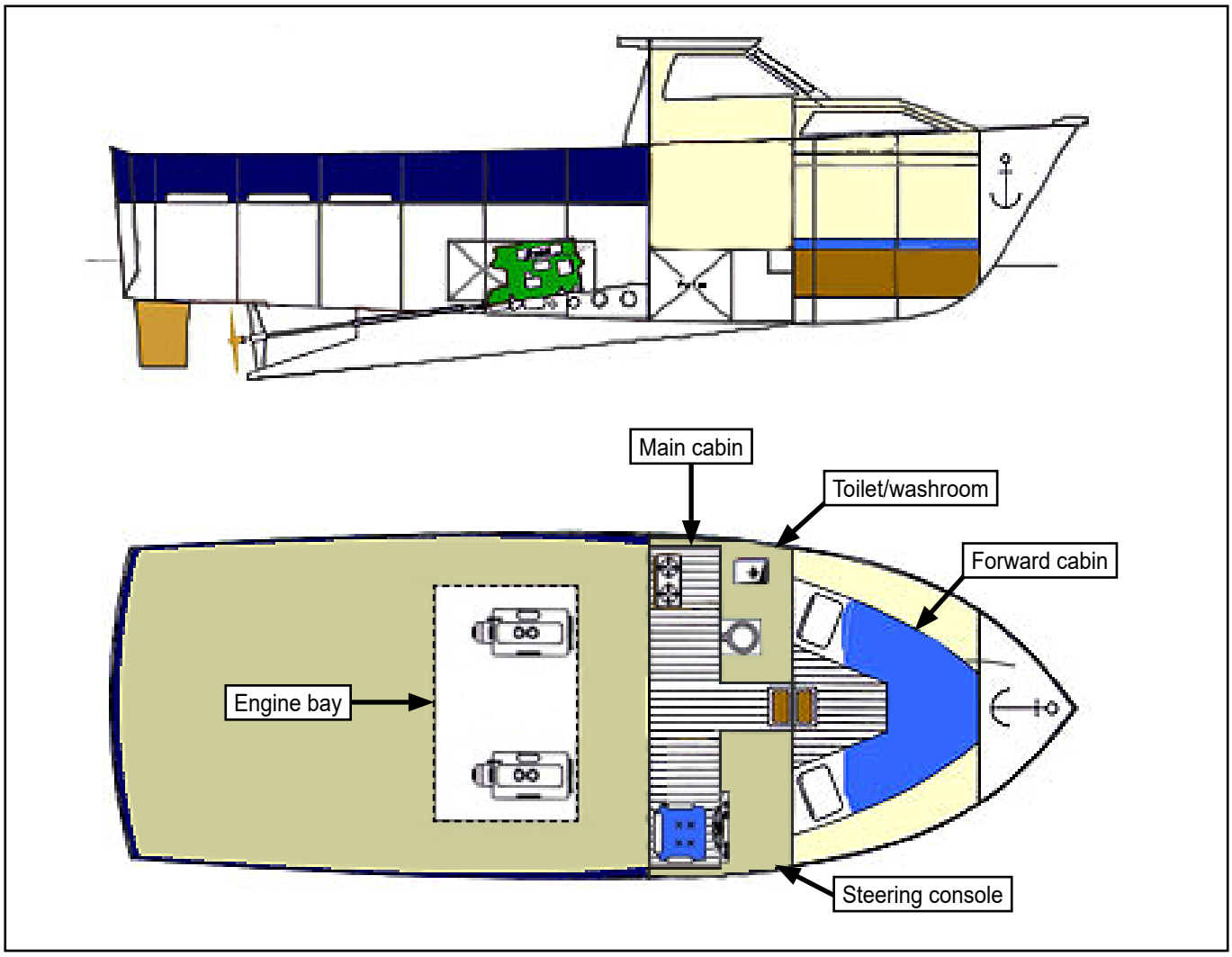

Figure 2: *Diversion* general arrangement

[1] kW – Kilowatt

Boat Safety Scheme

The BSS is a public safety initiative, jointly owned by the Canal and River Trust and the Environment Agency. The purpose of the BSS is to help minimise the risk of boat fires, explosions, or pollution from harming third party users of the waterways.

Approximately 60,000 BSS boat examinations are carried out by BSS accredited examiners every 4 years. Their checks are visual and do not involve disassembly of equipment. The BSS states on its website that its examinations are not a full condition survey and that owners should ensure boats and appliances are competently installed and serviced according to manufacturer's instructions.

On 1 April 2019, BSS had amended its requirements to include a working CO alarm[2]. The BSS extensively publicised this requirement on its website and in boating publications but found that about 10% of the boats presented for examination in the year April 2019 to April 2020 did not have a CO alarm fitted.

Diversion did not have a CO alarm fitted at the time of the accident or when it was last presented for a BSS examination in February 2019. The owner was not present at the BSS examination and was not advised of the imminent requirement to install a CO monitor in the examination report. Documentary evidence indicates that a CO alarm had been fitted previously, but the reasons for its subsequent removal prior to the survey in February 2019 are unknown.

On board investigation and tests

MAIB did not become aware of the accident until June 2020, consequently testing of equipment onboard was carried out under warm summer conditions. It is possible, therefore, that the performance of the cabin ventilation during the wintery conditions at the time of the accident differed from those found during testing. Four potential sources of CO were found on board *Diversion* when the boat was inspected. These were the main engines, portable generator, cabin stove and cabin heater; all were subject to onboard examination and testing.

The boat's engines and portable generator were not running when the police first boarded the boat. The evidence indicated that they were not running at the time of the accident. When they were tested, no exhaust gas leaks were found, and no CO was measured within the boat's accommodation.

The methylated spirit fuelled stove was found turned off and both burner reservoirs contained fuel. When the stove was lit, the CO emissions measured in the main cabin initially exceeded 20ppm[3] but dropped to approximately 10ppm once the burners were warm.

When the emergency services arrived on board the boat, the diesel-fuelled heater was found to be powered up, but it had switched itself into the standby mode and was not operating. When tested on board, the heater was observed to emit approximately 20ppm of CO from its external exhaust, and CO was detected in the cabin spaces after the heater had been run for extended periods. CO levels in excess of 50ppm were measured in the main cabin more than 16 hours after the heater had been shut down.

The cabin heater

Diversion's cabin heater was an Eberspächer 1.8kW D1LC air heater. It was installed in a cabinet in the main cabin beneath the steering console and was operated from a panel mounted on the top of the console. Circulating air was drawn from inside the cabinet, warmed by the heater, and discharged to the boat's main cabin via a nozzle mounted at deck level next to the steering position **(Figure 3)**. The cabin temperature was set by means of an adjustable control knob, and the heater started and stopped thermostatically. The heater also drew its combustion air from inside the cabinet, and a pump supplied diesel fuel from the boat's port side fuel tank. The fuel/air mixture was burned in the heater,

[2] alarm meeting safety standard EN 50291-2:2010,

[3] ppm – parts per million

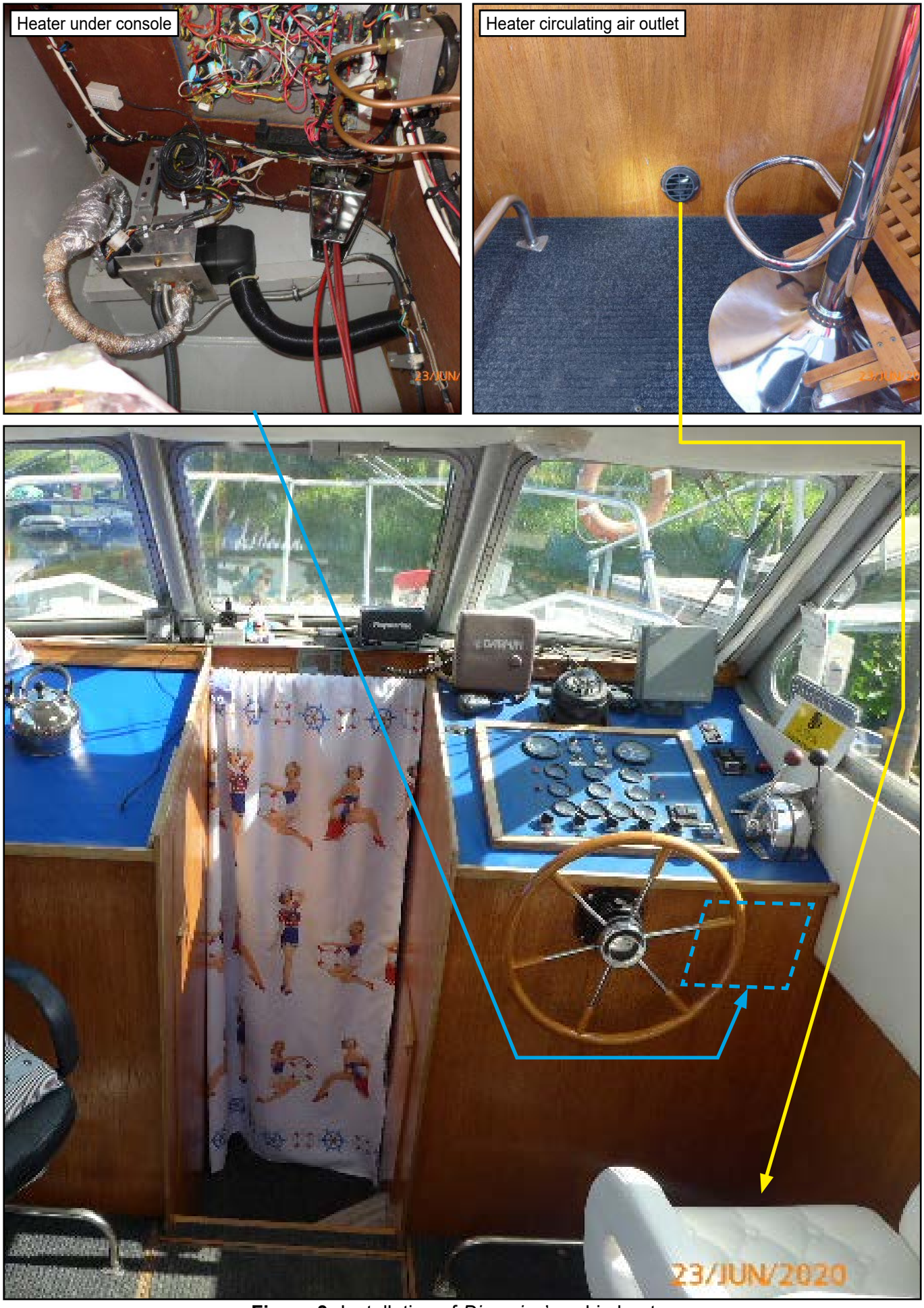

Figure 3: Installation of *Diversion*'s cabin heater

and the exhaust gases containing CO and carbon dioxide (CO_2) were discharged outside via a silencer connected to a through-hull fitting on the starboard side. The exhaust system was fully insulated with heat proof fibreglass and covered by foil tape.

The manufacturer's installation instructions, available via the internet, provided guidance regarding the requirements of the heater's fuel system, exhaust, combustion air, electrical connection and circulating air. It is unknown if the owner read the instructions before he installed the heater and there was no record to indicate the installation was checked by an approved Eberspächer agent, or of the heater being serviced since it was fitted.

The heater's exhaust lagging was removed to enable closer inspection of the system, which comprised of a Webasto exhaust silencer, connected to the heater and boat's side via flexible pipes. The Eberspächer heater exhaust port had a 24mm outside diameter stub pipe, but the Webasto silencer inlet had a 22mm outside diameter stub pipe. This meant that the two sizes were incompatible, and the flexible exhaust that connected the heater to the silencer was loose, and leaked exhaust gas. In addition, the silencer had spot welded seams and a condensate drain hole, which also leaked exhaust gas when the heater ran **(Figure 4)**.

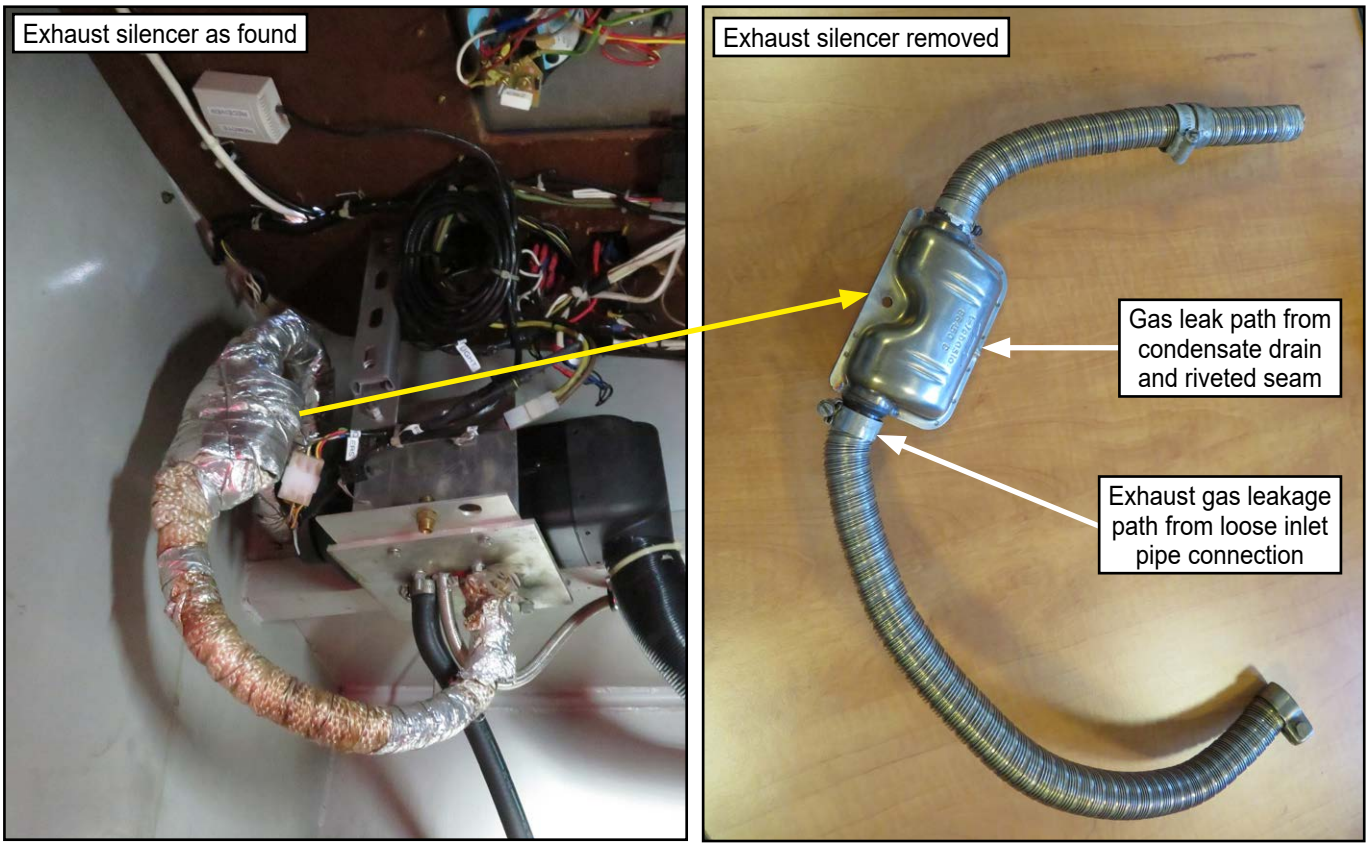

Figure 4: Gas leak path from condensate drain and spot welded seam

The most well-known brands of diesel-fuelled heaters are Webasto and Eberspächer. These are commonly installed into lorries, earth moving machinery, caravans and boats. *Diversion*'s Webasto silencer was not designed to be fitted in marine installations because it was not gas tight and it was incompatible with the exhaust piping. As a result, the leaking exhaust gas was drawn into the heater's circulating air inlet and then blown into the main cabin **(Figure 5).**

The heater would often be left running while the owners were ashore when using *Diversion* on cold days. On one occasion in October 2019, the owner and his wife experienced nausea and sickness after sleeping on board with the cabin heater running.

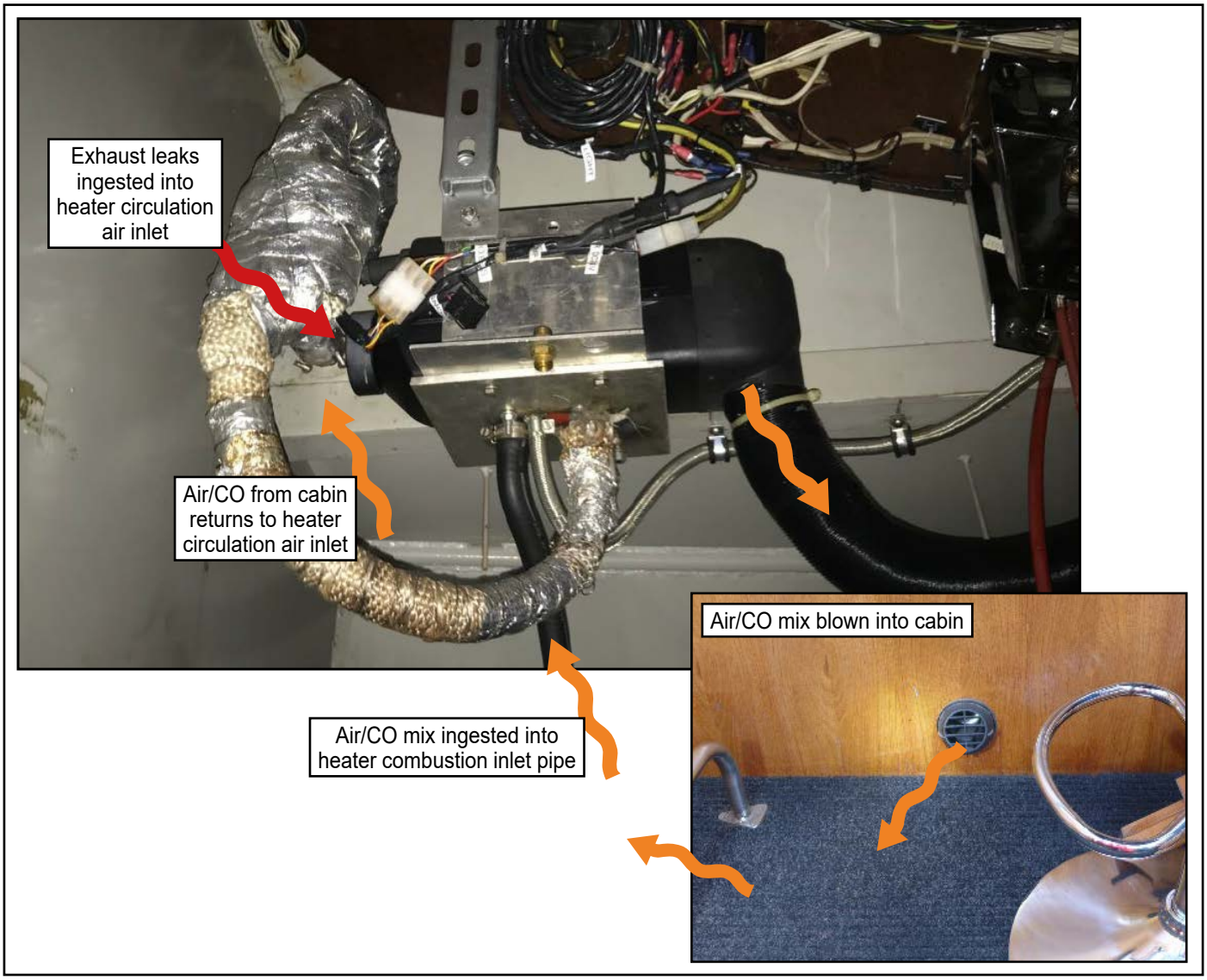

Figure 5: Leakage path of exhaust gas through cabin heater

Examination and testing of the cabin heater

The heater and associated equipment were removed from the boat and taken to an Eberspächer service agent for extensive examination and testing.

The heater's service panel cover was found to have an unbroken seal across it, confirming that it had not been serviced since installation. The heater's internal glow plug was in good condition and there were no soot deposits found.

The heater was found to start and stop thermostatically as per the manufacturer's design, and the low supply voltage cut-out switched the heater to standby mode at 21V. Exhaust gas readings were close to design specifications with no trace of CO found at the circulating air outlet.

The heater was then retested with its exhaust silencer positioned adjacent to the circulating air intake, comparable to the 'as found' arrangement on board *Diversion*. Leaking exhaust gas from the exhaust silencer's seams, condensate drain, and loose inlet connection was sucked into the heater's circulating air inlet and approximately 8ppm CO was then measured at the circulating air outlet.

It was noted that an onboard heater service would include a check of the glow plug, exhaust gas analysis, visual assessment of the installation while the heater was running, and a test of the circulating air for any trace of combustion gas such as CO_2 or CO.

Cabin ventilation

Boat cabins are often fitted with ventilation to provide fresh air for boat users and combustion air for fossil fuel burning cookers, water heaters, wood burners and diesel-fuelled air heaters. Insufficient air supply leads to incomplete combustion within such appliances and a discharge of unburnt fuel and higher than normal levels of CO from their exhaust systems.

Diversion's upper-level ventilation consisted of four mushroom type vents mounted in the roof of the accommodation. The two forward vents provided ventilation to the forward cabin space. These vents were permanently open, had no closing mechanism, and were found to be clear of obstruction. The two aft vents were mounted in the roof of the main cabin and had dampers fitted into them that were found in the closed position.

Low level ventilation was provided via a louvre type grille mounted in the bottom of the cabin door. Holes had been drilled through the door behind the grille, and approximately half of these were found to be blocked with dust. This reduced the effective capability of the ventilator grille **(Figure 6)**.

The BSS used a standard formula[4] for calculating minimum ventilation requirements when they examined *Diversion*. This formula used values based on the thermal output rating of fossil fuel burning appliances installed, and the number of persons for which the accommodation space was designed. There were some errors found in the application of the formula during the 2019 BSS examination of *Diversion*: an incorrect low thermal rating of the stove was used, and the cabin heater was not included. Additionally, there was a miscalculation of the available ventilation on board because the closable mushroom vents were included, in error.

Figure 6: Wheelhouse dour louvre vent

[4] derived from BS 5482—3 Annex G (Code of Practice for the installation of solid fuel heating and cooking appliances – Part 3: Installations in boats, yachts and other boats),

As part of the investigation, the BSS formula was used to re-assess *Diversion*'s ventilation requirement, and to re-calculate the actual available ventilation on board. It was found that the available ventilation was approximately 60% of the minimum required **(Table 1)**.

BSS calculated minimum ventilation requirement Feb 2019	**BSS calculated available ventilation Feb 2019**	**MAIB calculated minimum ventilation requirement**	**MAIB calculated available ventilation**
9200 mm	18469 mm^2	12192 mm^2	7304 mm^2

Table 1: Comparison of ventilation requirement and ventilation availability

Carbon monoxide poisoning

CO is a highly poisonous gas that weighs nearly the same as air and cannot be seen, smelled, tasted or felt by humans. CO readily replaces oxygen in the human bloodstream by forming carboxyhaemoglobin, which prevents oxygen from being supplied to the heart, brain and other vital organs. The blood carboxyhaemoglobin saturation level found during the post-mortem examinations of *Diversion*'s owner and his friend were 58.7% and 61.8% respectively; blood carboxyhaemoglobin saturation more than 50% is lethal to humans.

Common symptoms of low exposure to CO poisoning include headache, nausea, stomach pain, difficulty breathing, or feeling tired or confused. In greater concentrations a person will feel drowsy and lethargic and may have difficulty moving around.

The symptoms of carbon monoxide exposure continue to intensify as the concentration or time frame increases. An exposure at 800ppm can kill the person within a few hours, at 1500ppm it can cause death within an hour, at 3000ppm within half an hour and at 6000ppm death can occur within 15 minutes. Furthermore, exposure at 12,000ppm can result in instant death for the person.

Similar accidents

In November 2016, the owner of pleasure boat *Vasquez*[5] was overcome and died as a result of CO poisoning, which had leaked from the petrol engine's exhaust system. The exhaust system had been extensively modified and the engine had not been regularly serviced. No CO alarm was fitted on board.

In June 2016, two fatalities resulted from CO poisoning on the motor cruiser *Love for Lydia*[6] . The petrol-driven inboard engine had been left running while alongside, probably to charge batteries. The exhaust from the engine filled the cockpit canopy and spread into the cabin. There was no CO alarm fitted on board and the occupants were overcome by the fumes. The MAIB made recommendations to the Maritime and Coastguard Agency regarding the co-ordination of raising CO awareness of the leisure boating community; to British Marine to seek clarification on CO requirements within the recreational craft directive; and to the BSS regarding the compulsory installation of CO alarms in craft participating in the BSS scheme.

In April 2014, two recreational boat users died of CO poisoning while sleeping on board the motor cruiser *Arniston*[7] . The owner had fitted a portable generator in the boat's engine compartment and rigged an exhaust system to discharge combustion gases overboard. The exhaust system failed, and fumes filled the motor cruiser's cabin. The occupants had not been alerted to the presence of CO because the alarms fitted on board did not work.

In January 2014, two fishermen died from CO poisoning on board the scallop dredger *Eshcol*[8] . A butane fuelled cooker grill, which leaked CO, had been left on to warm the boat's cabin as the crew slept. There was no CO alarm fitted and it is believed the cooker had never been serviced.

[5] MAIB report 18/2017

[6] MAIB report 9/2017

[7] MAIB report 2/2015

[8] MAIB report 14/2014

ANALYSIS

Overview

The two men on board *Diversion* died from CO poisoning due to a build-up of exhaust gas within the cabin spaces. The gas leaked from the cabin's air heater exhaust silencer and a loose exhaust pipe connection. The nausea experienced by *Diversion*'s owner and his wife 2 months earlier was probably caused by CO poisoning from the cabin heater exhaust leaks.

The accumulation of carbon monoxide

Because it was a cold day and *Diversion*'s hull was uninsulated, the boat's cabin heater was turned on shortly after leaving York Marina. It is likely that the heater was left running when the friends went ashore so that the accommodation would be warm on their return later that evening.

When the heater was running, small amounts of the leaking exhaust gas were drawn into the heater's circulating air intake and then discharged into the main cabin. Over a period of hours, the air in the main and forward cabins became increasingly polluted with CO and CO_2. As the heater continued to operate, its combustion air drawn from inside the boat also became increasingly saturated with exhaust gases, and as a result the quality of combustion within the heater reduced. This added to the increased amount of CO in the exhaust gas and further polluted the air inside the boat.

The evidence of caffeine found during the post-mortem examinations of both men suggests it is possible that when they returned to *Diversion* and went inside, they had a coffee before going to bed. Once inside the boat, they would have started to breathe in the CO enriched atmosphere, and it is likely that the effects of alcohol consumption made them unaware of the early signs of CO poisoning. As the men prepared to go to sleep in the forward cabin it was apparent that they were both overcome by CO, rendered quickly unconscious, and later died.

The cabin heater would have continued to operate until *Diversion*'s battery voltage dropped to approximately 21V. The heater then automatically shut down to standby mode, which stopped additional build-up of CO inside the boat.

The cabin heater

The undamaged heater glow plug indicated that the heater had not been used frequently. The tests showed that the heater unit had no internal exhaust gas leaks and was in good working order.

It is not known whether the Webasto exhaust silencer was an original fit to a previous heater, was supplied with the replacement Eberspächer heater unit, or was purchased separately. However, the silencer was not approved for marine use and was designed to be fitted externally. The gas leaks from its body, the condensate drain hole, and from the loose pipe connection, were obscured by the exhaust insulation and were probably not noticed by the owner when he installed the heater.

An Eberspächer service agent appraisal of the heater installation, which is recommended by BSS, would probably have highlighted the issues with both of these items. Also, a service agent's circulating air test from the running heater would have shown the presence of CO, and both of these areas of concern would have been pointed out to *Diversion*'s owner for rectification.

Cabin ventilation

Without removing the louvre grille from the door, it was impossible to tell that the drilled holes behind it were mostly blocked. While this did not cause a problem when the door was opened frequently, allowing fresh air into the main cabin, when it was closed for long periods the air flow through the boat was impeded.

Because the calculation used at the time of the BSS examination of the boat was not accurate, the correct level of ventilation required was mis-identified, and the levels of available ventilation were overstated. The situation was made worse, because the ventilation holes in the main cabin door were partially blocked.

Onboard testing in summer conditions demonstrated that CO tended to remain in the boat's atmosphere for extended periods. The impeded air flow through the cabin vents would have increased the likelihood and rate that CO accumulated within the cabin space.

Carbon monoxide alarms

Because a BSS examination is required to be carried out only every 4 years, it is feasible that some boat owners may not comply with the CO alarm installation requirement that came into force in April 2019 until their boat is next examined. This could be as late as 2023; which was the case for *Diversion*. It is surprising that the imminent requirement to have a CO monitor installed to *Diversion* was not highlighted during the last BSS examination.

Taking into account the statistical 10% noncompliance rate at the time of being presented for examination, this could mean that more than 4000 BSS examined boats may not currently have a CO alarm fitted, representing a potential CO poisoning risk to the owners.

On board *Diversion*, because there was no CO alarm fitted, neither the owner nor his friend were alerted to the presence of dangerous levels of CO within the cabin. Since CO in the atmosphere is undetectable by humans until the effects of poisoning start to become apparent, the installation of an alarm may be the final defence available to protect individuals. When a CO monitor goes into alarm, it should never be ignored, or considered to be defective.

CONCLUSIONS

- *Diversion*'s owner and his friend died after being poisoned by CO that had leaked from the boat's cabin heater exhaust system and accumulated in the accommodation spaces.
- *Diversion*'s owner had fitted the cabin heater using some non-marine components which allowed the exhaust to leak.
- The CO leaks had not been identified because the diesel-fuelled heater installation had not been checked by an approved installation engineer, nor had it been serviced.
- CO accumulated in the forward cabin to a lethal level and the cabin ventilation system, which was partially restricted, did not allow the CO to clear.
- The casualties were not alerted to the danger because a CO alarm had not been fitted.

ACTIONS TAKEN

MAIB actions

The MAIB issued Safety Bulletin SB2/2020[9] on 15 October 2020.

Actions taken by other organisations

The BSS has extensively published references to Safety Bulletin SB2/2020 and it has been featured in 2020 CO awareness week, which took place from 23 to 29 November.

RECOMMENDATION

As a result of the actions taken, no recommendations have been made.

[9] MAIB safety bulletin SB2/2020

VESSEL PARTICULARS	
Boat's name	*Diversion*
Type	Motor cruiser
Registered owner	Privately owned
Year of build	1990-2001
Construction	Steel
Length overall	9.14m
Gross tonnage	7 Tonnes (approximately)

VOYAGE PARTICULAS	
Port of departure	York Marina, Naburn
Port of arrival	York City
Type of voyage	Pleasure

MARINE CASUALTY INFORMATION	
Date and time	Overnight 3 to 4 December 2019
Type of marine casualty or incident	Very Serious Marine Casualty
Location of incident	Moored at Museum Gardens quay, York
Place on board	Forward cabin
Injuries/fatalities	2 fatalities
Damage/environmental impact	None
External environment	2ºC Wind southerly 5mph
Persons on board	2