ACCIDENT REPORT

MAIB
MARINE ACCIDENT INVESTIGATION BRANCH

Report on the investigation into carbon monoxide poisoning on board the motor cruiser *Arniston* on Windermere 1 April 2013 resulting in two fatalities

VERY SERIOUS MARINE CASUALTY REPORT NO 2/2015 JANUARY 2015

Extract from

The United Kingdom Merchant Shipping

(Accident Reporting and Investigation)

Regulations 2012 – Regulation 5:

"The sole objective of the investigation of an accident under the Merchant Shipping (Accident Reporting and Investigation) Regulations 2012 shall be the prevention of future accidents through the ascertainment of its causes and circumstances. It shall not be the purpose of an investigation to determine liability nor, except so far as is necessary to achieve its objective, to apportion blame."

NOTE

This report is not written with litigation in mind and, pursuant to Regulation 14(14) of the Merchant Shipping (Accident Reporting and Investigation) Regulations 2012, shall be inadmissible in any judicial proceedings whose purpose, or one of whose purposes is to attribute or apportion liability or blame.

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

ABYC	-	American Boat & Yacht Council
AINA	-	Association of Inland Navigation Authorities
APPCOG	-	All Party Parliamentary Carbon Monoxide Group
BIS	-	Department for Business, Innovation and Skills
BSI	-	British Standards Institution
BSS	-	Boat Safety Scheme
CCTV	-	Closed-Circuit Television
CE	-	Conformité Européenne
CO	-	Carbon Monoxide
CoGDEM	-	Council of Gas Detection and Environmental Monitoring
COHb	-	Carboxyhaemoglobin
CORGI	-	Council for Registered Gas Installers
CPR	-	Cardio-Pulmonary Resuscitation
EA	-	Environment Agency
EEA	-	European Economic Area
EU	-	European Union
g/kWh	-	Grams per kilowatt hour
GRP	-	Glass Reinforced Plastic
hp	-	horsepower
ISO	-	International Organisation for Standardisation
kg	-	kilogram
kW	-	kilowatt
LDNPA	-	Lake District National Park Authority
LOA	-	Length overall
MGN	-	Marine Guidance Note
NMMA	-	National Marine Manufacturers Association

ppm	-	parts per million
RCD	-	Recreational Craft Directive
RYA	-	Royal Yachting Association
SLDC	-	South Lakeland District Council
UKAS	-	United Kingdom Accreditation Service
UKLPG	-	United Kingdom Liquefied Petroleum Gas
USA	-	United States of America

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

SYNOPSIS

On Monday 1 April 2013, the emergency services attended the motor cruiser *Arniston* on Windermere, Cumbria, where a mother and her daughter had been found unconscious.

The two females were taken by air ambulance to Lancaster Royal Infirmary where they were pronounced deceased. A postmortem concluded that the cause of death was carbon monoxide poisoning.

The subsequent MAIB investigation identified that:

- The carbon monoxide poisoning had resulted from the inhalation of fumes emitted from a portable generator installed in the boat's engine bay.
- The external exhaust system fitted to the portable generator had been modified to incorporate a silencer that had become detached from both the generator and the outlet pipe to the vessel's side.
- The portable generator's engine exhaust fumes filled the engine bay and spread through gaps in an internal bulkhead into the aft cabin where the mother and daughter were asleep.
- The portable generator was not intended by its manufacturer to be installed into an enclosed space, nor was it intended to be modified in any way.
- The improvised exhaust system attached to the generator was constructed from materials and using methods that were not appropriate for this application.
- The boat's occupants were not alerted to the danger because two carbon monoxide sensors fitted to the boat at build were out of date and had been disconnected from the power supply.

A recommendation has been made to the Department for Business Innovation & Skills, which is intended to ensure that new recreational craft are fitted with carbon monoxide alarms. A recommendation has also been made to the Boat Safety Scheme, Maritime and Coastguard Agency, Royal Yachting Association, British Marine Federation, Council of Gas Detection and Environmental Monitoring and the Association of Inland Navigation Authorities, aimed at raising the awareness of recreational boaters to the dangers of carbon monoxide and promoting the use of carbon monoxide alarms through a co-ordinated and concerted campaign.

A further recommendation has been made to the Boat Safety Scheme, which is aimed at identifying and highlighting the risks of carbon monoxide poisoning during boat examinations. A recommendation has also been made to the Lake District National Park Authority to improve safety on its waters.

SECTION 1 - FACTUAL INFORMATION

1.1 PARTICULARS OF *ARNISTON* AND ACCIDENT

SHIP PARTICULARS	
Vessel's name	*Arniston*
Flag	N/A
Type	Motor cruiser
Registered owner	Privately owned
Construction	GRP
Length overall	8.70m
Build	2002
Weight	3654kg
Engine power and type	300hp – 350 MAG Mercruiser petrol stern drive
MARINE CASUALTY INFORMATION	
Date and time	1 April 2013 between 1400 and 1600
Type of marine casualty or incident	Very serious marine casualty
Location of incident	Ferry Nab public jetty - Windermere
Place on board	Accommodation
Fatalities	2
Persons on board	3
Environment	Light wind. Temperature high 5°C, low -1°C

Arniston

1.2 NARRATIVE

During the morning of Sunday 31 March 2013, the motor cruiser *Arniston* was collected from Windermere Aquatics **(Figure 1)**, a Bayliner dealer and service agent in Bowness, Windermere, by its owner. The owner was accompanied by his partner Kelly Webster and Kelly's 10 year old daughter, Lauren Thornton. He then navigated the boat on Windermere to the Ferry Nab public jetty **(Figure 1)**, where his work van was parked. The group's intention was to spend the remainder of the bank holiday weekend on board *Arniston.* This was their first trip and overnight stay on the boat in 2013.

Image courtesy of South Lakeland District Council

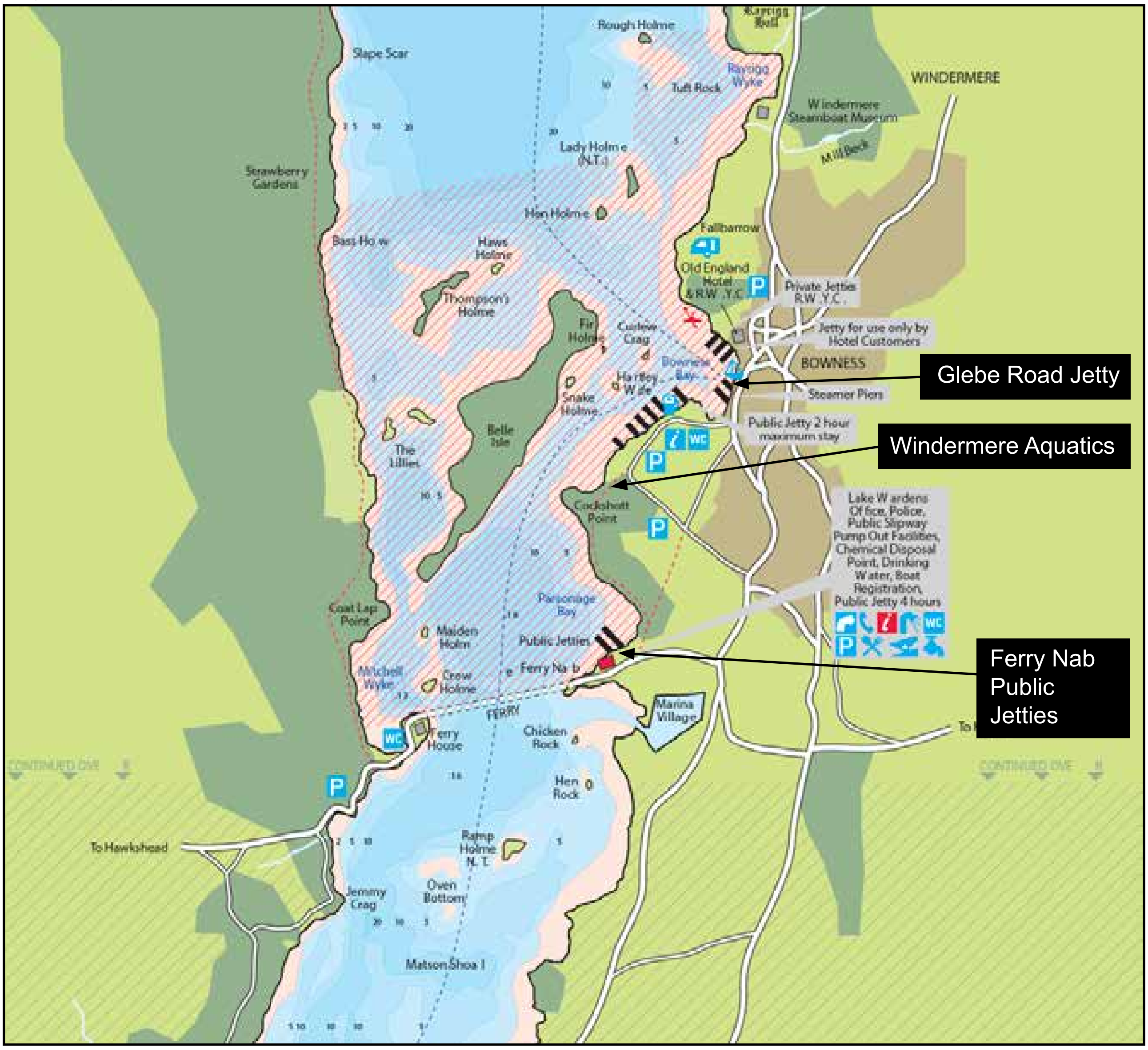

Figure 1: Windermere - Northern section

After *Arniston* had been secured alongside the public jetty, its owner removed a small "suitcase" type generator **(Figure 2)** from his work van and installed it into *Arniston*'s engine bay **(Figure 3)**. The owner had extended and modified the generator's exhaust, which he connected to an outlet in the boat's hull.

Image courtesy of The Test House

Figure 2: Hyundai generator

Image courtesy of Brunswick Boat Group

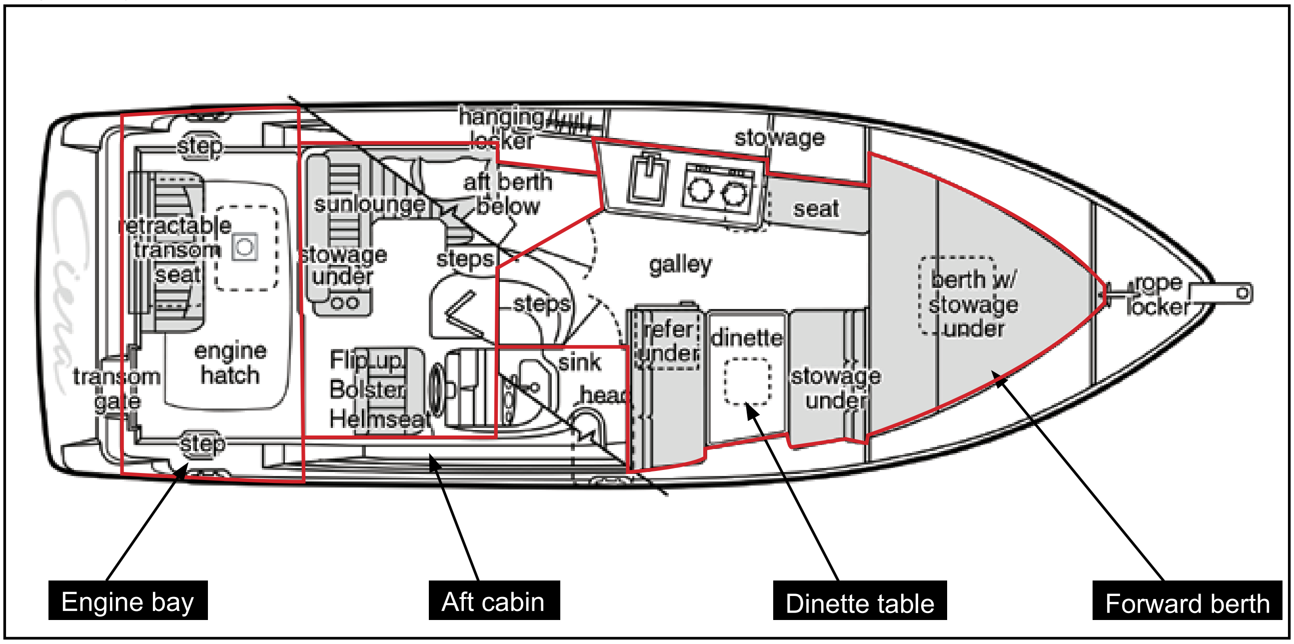

Figure 3: Layout of *Arniston*

During the evening, the group met up with other boat owners and friends at the Ferry Nab jetty to celebrate a birthday. The portable generator on board *Arniston* was running, and the exhaust was seen to be working as intended. The weather was very cold for the time of year so the owner and a friend warmed their hands with warm air flowing from *Arniston*'s side vents produced by fans in the boat's engine bay.

At about 2330, *Arniston*'s owner returned on board his boat, accompanied by Kelly and Lauren. He had consumed more alcohol than usual but he was not drunk. Once on board, the generator was turned off, and the owner, Kelly and Lauren went to their beds.

The following morning, on 1 April, *Arniston*'s owner, Kelly and Lauren woke up feeling sick and suffering with headaches. Both the owner and Lauren were physically sick; the owner attributed his illness to the over-consumption of alcohol.

At about 1130, *Arniston*'s owner moved his boat 0.75 mile to the Glebe Road public jetties **(Figure 1)**, which had a number of commercial outlets, including fast-food shops, nearby. At about 1300, the owner walked to a fish and chip shop and bought lunch for the group. Kelly and Lauren stayed on the boat.

The weather was fine with clear skies and light winds, but the temperature was only about 5°C. Kelly and Lauren were cold when the owner returned from the chip shop. To heat the boat's accommodation the portable generator was started remotely using a fob, in order to power a fan heater **(Figure 4)**. The fan heater had recently been purchased and could be set to either 1kW or 2kW. On this occasion it was on the 1kW setting.

Image courtesy of Cumbria Constabulary

Figure 4: *Arniston* accommodation

The group ate their lunch at the dinette table **(Figure 4)**. Shortly after lunch, the owner fell asleep at the table. When he awoke, he felt very unwell; his fingers were numb and he had pains in his chest. The owner was extremely disorientated and was not fully conscious. He struggled onto the upper deck and laid down on the seating area to recover. After an unknown period of time the owner started to feel better and he made his way back down below. The door to the aft cabin was ajar, Kelly and Lauren were both inside and appeared to be unconscious. Neither Kelly nor her daughter responded to the owner's attempts to wake them.

At 1558, the owner called 999 on his mobile telephone to raise the alarm. He then made his way onto the jetty to direct the emergency services to *Arniston* as soon as they arrived. Between waking and leaving *Arniston*, the owner also stopped the generator, again using the remote fob.

A paramedic in a rapid response vehicle and a police constable were stationed close to the Glebe Road jetty and were on scene within minutes. Other emergency service assets and two Windermere lake wardens arrived shortly afterwards.

Kelly and Lauren were taken onto the jetty, where cardio-pulmonary resuscitation (CPR) was commenced. CPR was continued while they were transferred to Lancaster Royal Infirmary in separate air ambulances. The owner was given oxygen on the jetty before he was also taken to hospital.

1.3 HOSPITAL ADMISSION AND POSTMORTEM

The levels of carboxyhaemoglobin[1] (COHb) in Kelly and Lauren's blood on admission to Lancaster Royal Infirmary were 48.5% and 53.6% respectively. The level of COHb in the owner's blood was 16%.

Despite the extensive efforts by paramedics and hospital staff, both Lauren and Kelly were pronounced life extinct by 1755. Postmortem examination confirmed that the cause of Kelly and Lauren's deaths was carbon monoxide (CO) poisoning. The owner was treated for CO poisoning.

1.4 BOAT HISTORY AND LAYOUT

Arniston was a Bayliner 285 motor cruiser that was built in 2002 in the United States of America (USA) by the Brunswick Boat Group, the largest manufacturer of leisure boats in the world. The company builds up to 45 brands of boat including *SeaRay, Bayliner* and *Maxum.*

The motor cruiser *Arniston* was 8.7m length overall (LOA) and was driven by a Mercury Mercruiser 350 MAG, 8 cylinder V8 inboard engine supplying up to 300hp through a steerable outdrive. The main engine incorporated a "wet" exhaust system that vented exhaust gases and cooling water through the outdrive.

Arniston was divided into four underdeck compartments **(Figure 3)** comprising an engine bay, an aft cabin, heads, and a galley/dinette area that led to a sleeping berth in the forepeak. The engine bay and aft cabin shared a common bulkhead, which was not gas tight (see 1.6.4).

[1] Carboxyhaemoglobin (COHb) describes the combination of carbon monoxide (CO) and haemoglobin that forms in red blood cells when carbon monoxide is inhaled or produced in normal metabolism.

When built, *Arniston*, in common with all Bayliner boats, was certified by the National Marine Manufacturers Association (NMMA). The NMMA website[2] provides the following information on industry standards in the USA:

> *"Many — but not all — boats are required to meet a set of minimum manufacturing regulations established by the U.S. Coast Guard. In the U.S., NMMA Certification goes beyond the minimum USCG standards to ensure adherence to the American Boat & Yacht Council (ABYC) Standards.*
>
> *Manufacturers of NMMA Certified boats benefit from:*
>
> - *Assurance their boats meet the industry standards for the United States (ABYC Standards)*
> - *A detailed inspection and verification process*
> - *Improved Consumer Confidence*
> - *Increased brand respect*
> - *Liability protection and product liability insurance discounts".* [sic]

The NMMA certification required that CO alarms and stickers to warn of the dangers of CO were fitted when a boat was built.

Arniston was first registered in the USA in March 2003. It was used in the USA for 4 years before being imported into the UK in March 2007. The importation process involved a post-construction assessment and a Conformité Européenne (CE) marking to comply with the Recreational Craft Directive (RCD)[3]. This work was conducted by Human Performance Improvements verification services, a notified body based in Oxford.

After arrival into the UK, *Arniston* was used for 2 years in the Solent before being sold in June 2008. The vessel was then kept in the Poole area but was used infrequently.

In May 2012, the current owner purchased *Arniston* through a broker based in Poole. He then had the boat transported by road to Windermere, where it was launched in June 2012. The owner, Kelly and Lauren used the boat most weekends on the lake during the summer of 2012.

In late August 2012, *Arniston* was stolen from its swinging mooring on Windermere and was vandalised. Seat covers and canopies were slashed and unsecured items were thrown out of the boat into the lake. The boat was partially repaired at Windermere Aquatics over the winter.

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2 'Benefits of NMMA certification' - NMMA website

3 A European Union directive which sets out minimum technical, safety and environmental standards for boats between 2.5m and 24m being traded in Europe. (See paragraph 1.10.3)

1.5 *ARNISTON*'S OWNER

Arniston's owner was 39 years old. After leaving school he completed a heating and ventilation apprenticeship, during which he gained City and Guilds qualifications in pipe-fitting and welding. He was also on the 'Gas Safe Register'[4], which is the official gas registration for the United Kingdom. In 2007, the owner started a business installing and servicing heating and ventilation systems in commercial premises.

The owner had a long association with Windermere. He had enjoyed boating activities on the lake from early childhood on a variety of craft including sailing yachts, small speedboats and larger cruisers. The owner did not hold any formal boating qualifications.

1.6 MODIFICATIONS

1.6.1 Generator

Arniston's owner purchased the "suitcase" type *Hyundai HY3000sei* generator **(Figure 2)** from an online tool supplier in June 2012. The generator was a 4-stroke, petrol-driven, air-cooled engine which was capable of producing 230V power with a maximum output of 2.8kW. It could be started and stopped remotely using a fob and it was fitted with an integral fuel tank. The technical specification of the *Hyundai HY3000sei* is shown at **Table 1**.

Watts:	2800W Peak Power, 2600W Running Power
Outlets:	2 x 230V UK 3-pin plug
Type:	OHV/Forced-Air Cooling, Single Cylinder, 4 stroke petrol
Engine:	5.3hp 5500rpm 149CC Hyundai Motor
Start:	Electric Start or Manual Recoil
Fuel Capacity:	4.5 Litres
Fuel type:	Unleaded Gasoline
Dimensions:	550x310x500 millimetres
Weight:	35kg

Table 1: Specification of Hyundai HY 3000SEi generator set

The Hyundai generators were usually supplied with a number of warnings about the dangers of CO if the units were used in unventilated spaces. The warnings **(Figure 5)** were attached to the units and detailed in the user manuals and other information supplied by the manufacturer.

The user manuals also warned that the generator should not be modified **(Figure 6)**.

[4] The Gas Safe Register replaced the Council for Registered Gas Installers (CORGI) as the gas registration body in Great Britain and Isle of Man on 1 April 2009 and Northern Ireland and Guernsey on 1 April 2010.

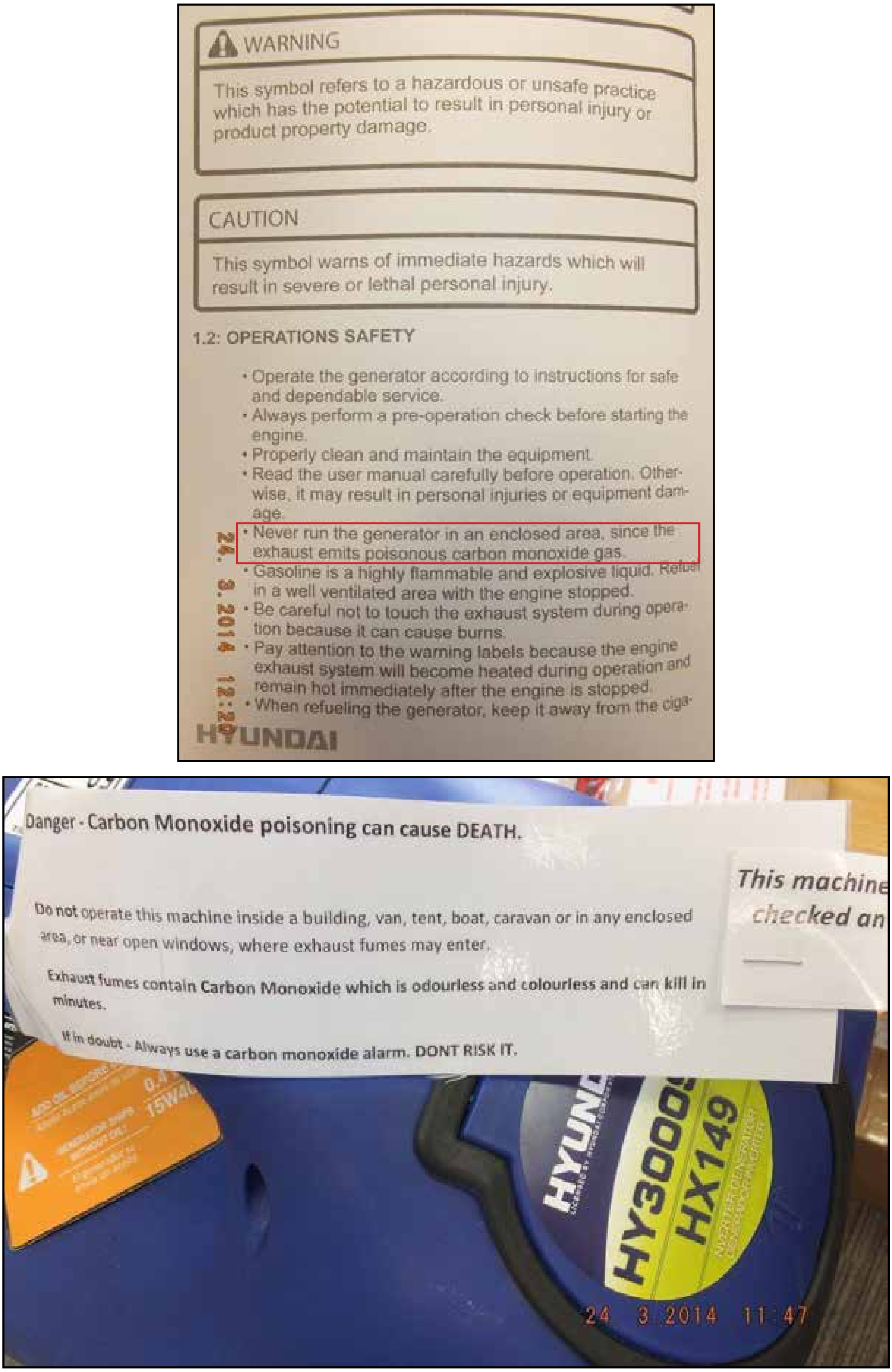

Figure 5: CO warnings

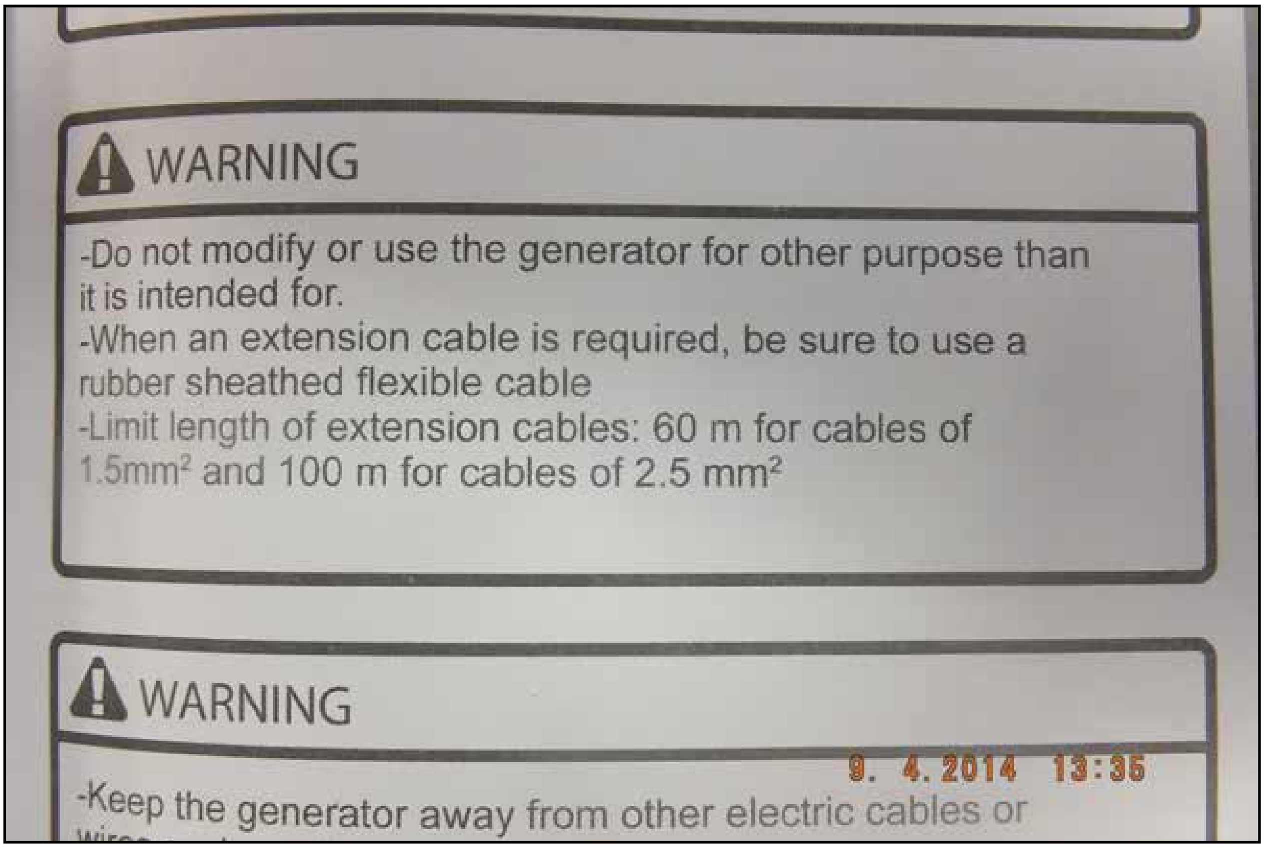

Figure 6: Warning against modification

When the generator was bought and first fitted into *Arniston*'s engine bay in 2012, the owner connected a piece of flexible stainless steel pipe from the generator's internal exhaust to a through-hull fitting using a 'jubilee clip' at each end. The generator was used on board *Arniston* during the summer of 2012 without incident, but was removed during the winter.

On 31 March 2013, the owner re-installed the generator on the port side of the boat in the enclosed engine bay; it was placed on an anti-vibration mat but was not secured to the engine bay deck.

The owner had removed the integral fuel tank from the generator and, in its place, he had fitted a rubber fuel pipe through *Arniston*'s aft bulkhead in order to supply petrol from a portable tank sited in a locker above the swim platform.

Due to light-hearted comments from other lake users regarding the noise created by the generator during 2012, the owner modified the system for the 2013 boating season by adding a silencer into the exhaust line.

1.6.2 Exhaust system

The owner purchased a *Webasto 86450C* silencer **(Figure 7)**, which was specifically designed for use with *Webasto* 5kW diesel heaters and was not approved for any other application. The exhaust line incorporating the silencer was then assembled by the owner and fitted to the generator at his home prior to the trip to Windermere on 31 March. He had tested the combined generator/exhaust system by running the engine in fresh air. No electrical load was applied.

Figure 7: Webasto silencer

The external exhaust system **(Figure 8)** was constructed as follows:

- A 22mm diameter straight copper fitting was secured to the generator's engine exhaust pipe with three screws **(Figure 9)**. No sealant was used.
- The straight copper fitting attached to the engine exhaust was connected to a 45° copper elbow using soft soldered joints and a short section of copper pipe **(Figure 9)**.
- A further length of straight copper pipe and another 45° elbow joint were then used to connect to the silencer. The elbow joint was attached to the silencer by a single screw and jointing compound **(Figure 10)**.
- The silencer was connected to the through-hull fitting by a 24mm flexible steel hose, which had 'jubilee clips' at each end **(Figure 11)**.

On 31 March, when installing the generator, the owner coupled the end of the modified silencer onto the flexible steel hose positioning the jubilee clips where the hose overlapped the silencer's outlet.

1.6.3 Wiring

Arniston was designed and constructed to use a 120V shore power supply, which is used throughout North America. The boat's distribution panel **(Figure 12)** housed the breaker switches for the electrical appliances and lights and was located in the aft cabin. To enable the *Hyundai* generator to supply electrical power, the owner had modified the as-built wiring system by cutting the two cables supplying the distribution panel. In effect this disabled the USA shore power connections. The

Image courtesy of The Test House

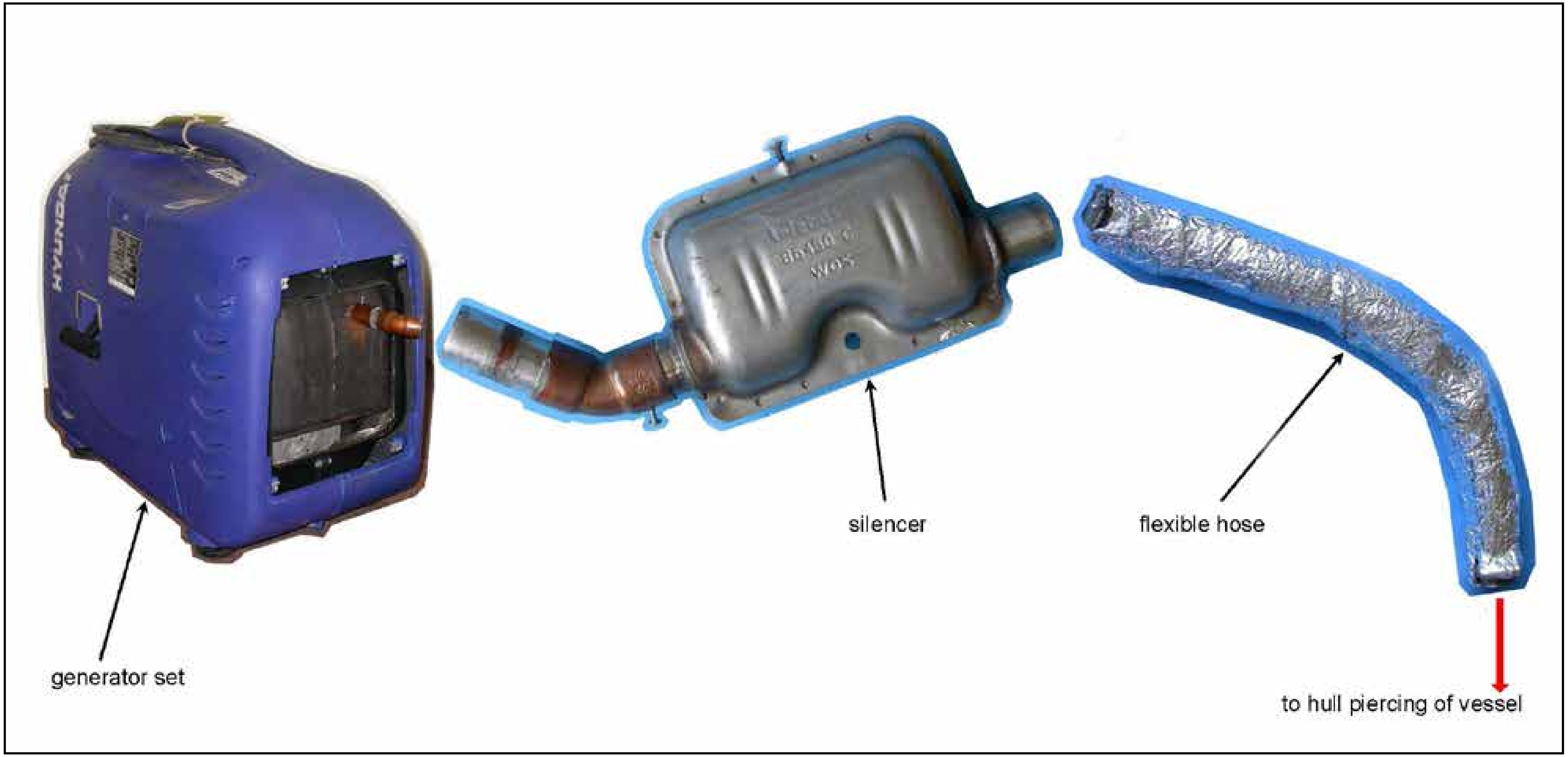

Figure 8: General arrangement of the generator, silencer and pipework

Image courtesy of Cumbria Constabulary

Figure 9: Straight copper fitting to exhaust pipe

Image courtesy of Cumbria Constabulary

Figure 10: Failed soldered joint

Image courtesy of Cumbria Constabulary

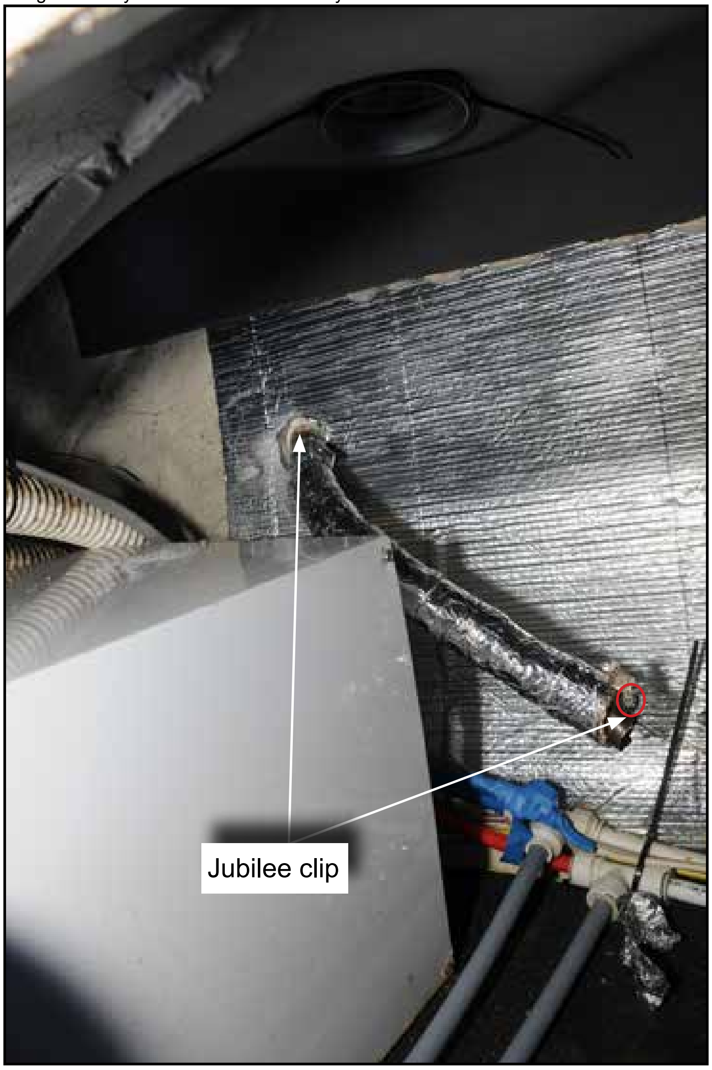

Figure 11: Silencer to through hull fitting

Image courtesy of Cumbria Constabulary

Figure 12: Electrical distribution panel

owner then connected two wires, each fitted with a standard UK 3-pin plug, to the cables supplying the distribution panel. The wires were connected using plastic terminal blocks that were wrapped in insulating tape **(Figure 13)**. The 3-pin plugs were then connected to the generator to enable 240V power to be supplied to the boat's appliances via the distribution panel.

Figure 13: Electrical wire joints

1.6.4 Fan system

When *Arniston*'s owner installed the generator in 2012, he also fitted two 240V electrically powered fans that were intended to circulate fresh air around the engine bay in the area of the generator.

A 23W supply fan was installed, which drew air from vents on the port side of the boat through a 4" flexible hose to the area of the generator. An 85W extraction fan was also fitted to draw air from above the generator and expel it via a similar flexible hose and vents, also sited on the port side of the hull.

The fan system was wired into a breaker switch on the distribution panel in the aft cabin. The same switch also controlled the boat's battery charger.

The supply and extraction hoses associated with the fan system, and the 240V electrical supply cables, were routed from the engine bay through a large opening **(Figure 14)** in the top corner of the common bulkhead between the engine bay and the port side of the aft cabin.

Figure 14: Bulkhead penetration

1.7 POST-ACCIDENT EXAMINATION AND TECHNICAL INVESTIGATIONS

1.7.1 Post-accident examination

On 2 April 2013, the day following the accident, MAIB inspectors and police officers examined *Arniston*, its fittings and associated equipment. Findings included:

- The silencer fitted to the generator's modified exhaust system had completely detached at both ends and was lying on the engine bay deck **(Figure 15)**.
- 'Scorch' marks **(Figure 16)** and evidence of solder 'splash' **(Figure 17)** were found on the heat resistant bulkhead lining adjacent to the exhaust outlet pipe on the generator.
- The breaker switch on the electrical distribution panel, controlling the engine bay fans and the battery charger, was in the 'off' position.
- *Arniston* was fitted with two *SAFE-T-ALERT* CO alarms, model number 60-541 **(Figure 18)**. One located on the deck head in the aft cabin and the other fixed on the deck head above the dinette table. Information shown on both alarms indicated that they had been due for renewal in 2005 and had been date-stamped as being manufactured or fitted on October 8 2002 **(Figure 19)**.
- Both CO alarms had been disconnected from the power supply **(Figure 19)** and were not fitted with internal batteries.
- *Arniston* was also fitted with several stickers **(Figure 20)** that warned of the hazards of CO. The stickers were required in order for the boat to comply with the NMMA build standard in the USA.

Image courtesy of Cumbria Constabulary

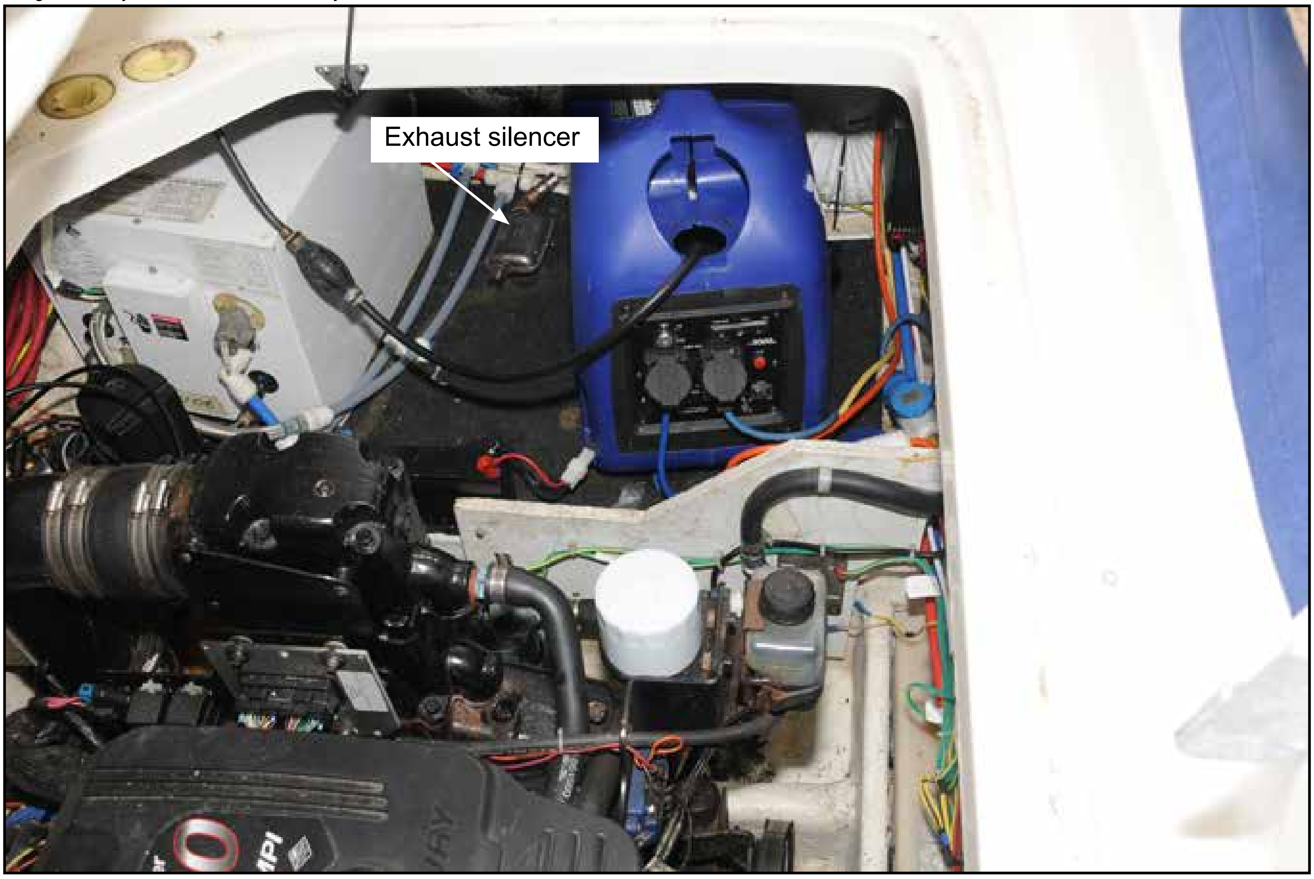

Figure 15: Showing approximate position of detached exhaust silencer

Image courtesy of Cumbria Constabulary

Figure 16: "Scorch" marks engine bay on bulkhead

Image courtesy of Cumbria Constabulary

Figure 17: Solder splash on engine bay bulkhead

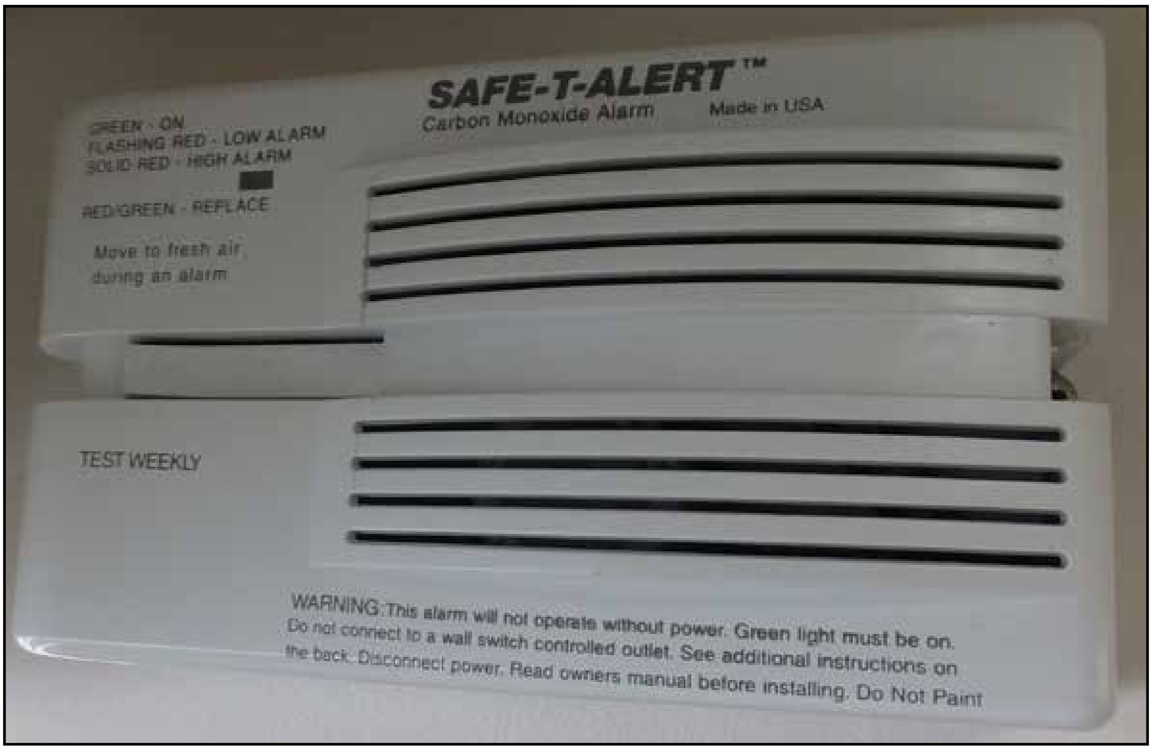

Figure 18: CO alarm

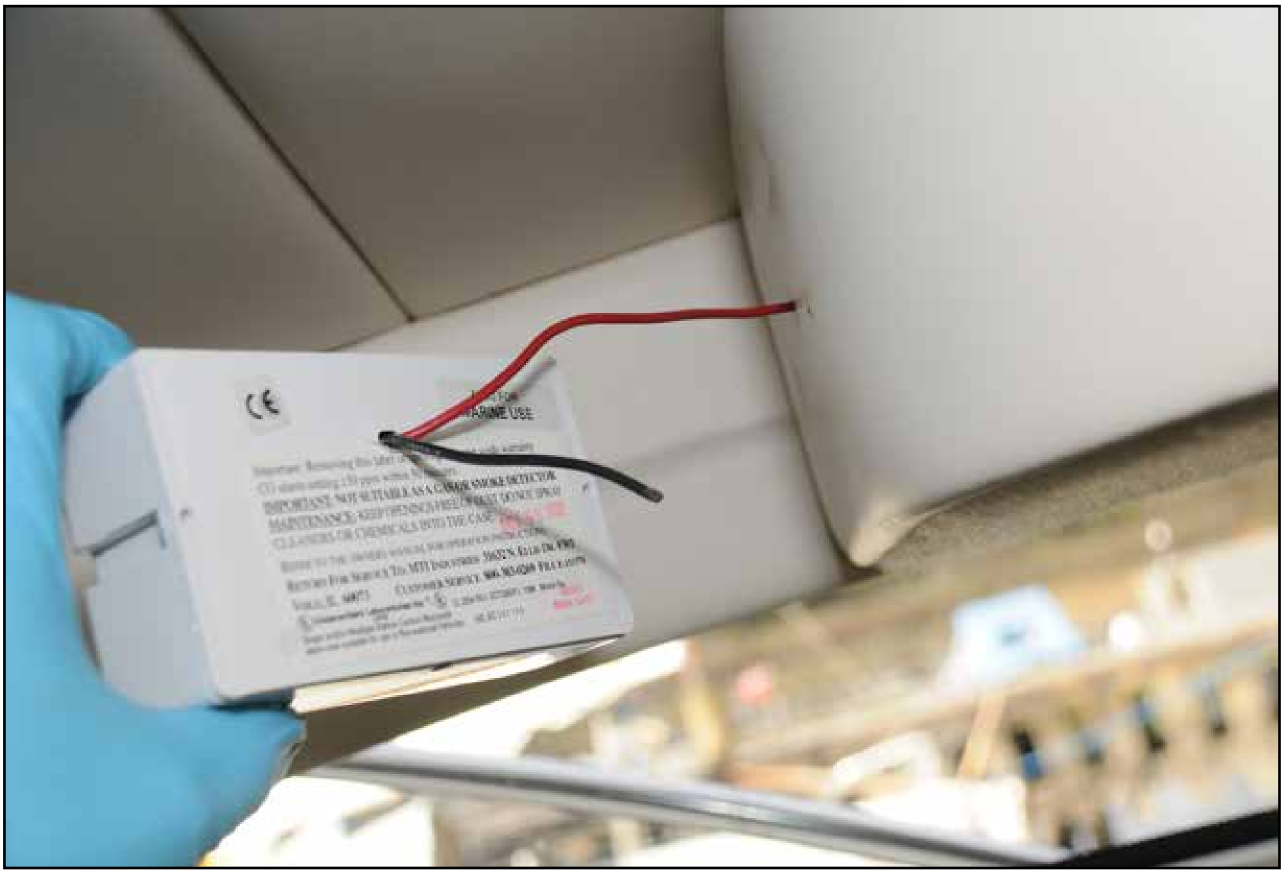

Figure 19: Disconnected CO alarm

Figure 20: Warning of CO hazard on accommodation door

1.7.2 Test House examination

The Test House, a United Kingdom Accreditation Service (UKAS) accredited independent commercial testing laboratory, was contracted in June 2013 to perform a laboratory examination and analysis of the mechanical construction of the components that made up the exhaust system fitted to the generator.

The aims of the tests included:

1. To establish the method of fixing each of the joints.

2. To establish the type and characteristics of the solder used.

3. To establish the effect of the engine running temperature on the joints.

Accordingly, each joint was examined and the method and quality of fixing was evaluated. It was established that the gas tight properties of each joint varied considerably. Of note, the flexible hose joints secured by the 'jubilee clips' were never able to be gas tight. The Test House report **(Annex A)** noted:

> *"The bore of the hose at the vessel piercing end exhibited significantly less evidence of sooting, which served to confirm that most, if not all the exhaust, had leaked out of the silencer and flexible hose joint before getting to the outlet end of the hose".*

The quality of the soldering on the soldered joints that survived was assessed as adequate for a plumbing application. However, the joints showed signs of having started to melt and open up due to the temperature of the exhaust gases.

The solder was analysed and was found to have a high lead content (71.7%). The lead content indicated that the solder would reach a semi-molten pasty state at a temperature of between 183°C and 259°C. Its melting point was 259°C.

1.7.3 Accident reconstruction

Between 23 and 25 September 2013, a reconstruction of the failure of the generator exhaust was conducted on board *Arniston*. The external exhaust used in the reconstruction was fabricated by the Council for Registered Gas Installers (CORGI) Technical Services. CORGI used similar components and materials to those used by *Arniston*'s owner.

The reconstruction aimed to:

- Establish the failure mechanism of the external exhaust.

- Monitor and record the levels of CO throughout the internal spaces of the boat using calibrated CO sensors placed in the engine bay, aft cabin and galley areas of the boat.

For the reconstruction:

- The original generator with the identical external exhaust system attached was placed back into *Arniston*'s engine bay.

- The main accommodation door was open, the aft cabin door and skylight were ajar, and the awning was down but not secured.

- The generator was started remotely using the fob.

- The generator was subjected to a 1kW electrical load.

- The engine bay circulation fans were on.

- The generator was observed and recorded via closed-circuit television (CCTV).

Key findings of the reconstruction were:

- The soldered section of the external exhaust adjacent to the silencer was observed to fail after 4 minutes 54 seconds.

- The generator exhaust fumes then began to discharge directly into the enclosed engine bay.

- CO levels in the aft cabin reached 743 parts per million (ppm) after 120 minutes.

- After the generator was stopped, the concentration of CO in the aft cabin was seen to ‘spike’ and reach 1,239ppm after a further 20 minutes.

- Another set of measurements was taken with the doors closed. A CO concentration in the aft cabin, of 1,458ppm, was noted after 45 minutes.

- It was noted that the CO emissions from the generator appeared to be high.

The reconstruction replicated the physical aspects of the accident as closely as possible with the exception of the ambient temperature which was 5°C on the day of the accident and 17°C on the day of the reconstruction. For this reason, readings from the reconstruction must be taken as very close approximations.

The CORGI Technical Services report on the reconstruction is at **Annex B**.

1.7.4 Mechanical examination

Following the discovery during the reconstruction of events **(1.7.3)** that the generator appeared to be emitting high levels of CO, the generator was examined in January 2014 by an expert in combustion, emissions and fuels. A generator of the same model was also examined for comparative purposes.

The examination established that both of the generators were set up with a rich air/fuel mixture[5] that resulted in a CO concentration of over 3% in the exhaust gases, but the emissions still met the type approval requirements for use in Europe. The European standard for the issue of type approval for this class of engine requires that the CO emissions should not exceed 610 grams per kilowatt hour (g/kWh). The CO emissions from the *Hyundai* generator were 248.3 g/kWh.

[5] The concentration of carbon monoxide in the exhaust gas will depend on the air fuel ratio. If the ratio is greater than 14.7:1 the mixture is said to be *lean*. The concentration of carbon monoxide will be low. If the air fuel ratio is less than 14.7:1 the mixture is said to be *rich*. There will be only a small amount of oxygen but potentially high concentrations of carbon monoxide.

The examination also determined that on both generators the choke to assist cold start was unable to open fully. The main jet of the carburettor fitted on *Arniston*'s generator was also 0.05mm oversize. Both of these factors would have made the fuel mixture richer and would have resulted in higher concentrations of CO in the exhaust gases. The problem with the choke and the oversize carburettor jet were assessed to have been present at the point of sale as there was no evidence of tool marks. There was also no evidence to suggest that *Arniston*'s owner had made any modifications that had had an adverse effect on CO emissions from the generator.

The report into the condition of the *Hyundai* generator and its emissions is at **Annex C**.

1.8 CARBON MONOXIDE POISONING

CO is a poisonous gas with almost the same density as air. It is a by-product of combustion appliances fuelled by oils, solid fuel or gas. Fossil fuelled cookers, heaters, combustion engines and even barbeques all have the potential to cause CO poisoning, particularly if they are incorrectly installed, poorly maintained or used inappropriately.

CO poisoning occurs by inhalation. The gas has no smell or taste and for this reason it is sometimes referred to as the 'silent killer'. Once inside the respiratory system CO binds tightly to haemoglobin[6] to form COHb, and reduces the body's ability to transport oxygen in the bloodstream.

CO binds to haemoglobin approximately 240 times more effectively than oxygen. While a person continues to inhale CO, the levels of COHb in the blood will continue to rise. Only once exposure ends will the body begin to rid itself of CO by exhaling. COHb will then revert back to oxyhaemoglobin, which is the form of haemoglobin that can carry oxygen. It can take approximately 5 hours to remove half of the CO in the blood, although breathing pure oxygen or the use of a hyperbaric chamber can quicken the process.

In high concentrations, the effect of CO poisoning is death. However, in lower concentrations, CO poisoning causes illness. The effects of CO poisoning on adults is shown at **Table 2**. The most recognisable symptoms are:

- headaches
- vomiting
- tiredness and confusion
- stomach pain
- shortness of breath and difficulty breathing.

[6] Haemoglobin in the blood carries oxygen from the lungs to the rest of the body.

Effects of carboxyhaemoglobin on human beings			
% CO	Parts per million (ppm)	Effects on adults	% Saturation of CO in blood stream
0.01	100	Slight headache in 2-3 hrs.	13%
0.02	200	Mild headache, dizziness, nausea and tiredness after 2-3 hrs.	20% - 30%
0.04	400	Frontal headache and nausea after 1-2 hrs.; risk to life if over 3hrs exposure	36%
0.08	800	Severe headaches, dizziness, convulsions within 45 minutes; unconsciousness and death possible after 2-3hrs	50%
0.16	1600	Headaches, dizziness and nausea within 20 minutes; collapse, unconsciousness and death possible within 1-2hrs	68%
0.32	3200	Headache, dizziness and nausea within 5-10 minutes	70% - 75%
0.64	6400	Severe symptoms within 1-2 minutes; death within 15 minutes	80%
1.28	12800	Immediate symptoms; death within 1-3 minutes	85% - 90%

Table 2: Symptoms of carbon monoxide poisoning[7]

It is estimated that 40 people in the UK are killed by CO poisoning each year. At least a further 4,000 people are treated for CO poisoning in hospital. However, the number of people poisoned by CO is likely to be much higher than these figures indicate, as CO poisoning is very difficult to diagnose because symptoms are often similar to common illnesses like flu and food poisoning.

1.9 CO ALARMS

CO detectors are designed to trigger an alarm based on an accumulation of CO over time or a sudden rise in CO. Historically, detectors operated by a chemical reaction causing a colour change, an electrochemical reaction that produced current to trigger an alarm, or a semiconductor sensor that changed its electrical resistance in the presence of CO. To meet the requirements of the EN 50291-1[8] standard for CO alarms, only electrochemical sensors are used today. All compliant CO alarms require a continuous power supply so if the power cuts off, or the batteries fail or are removed, then the alarm becomes ineffective.

[7] Essential Gas Safety Manual-Domestic. Sixth Edition: Published March 2012

[8] BS EN 50291-1:2010+A1:2012 – Electrical apparatus for the detection of carbon monoxide in domestic premises. Part 1: Test methods and performance requirements.

A leaflet produced by the Boat Safety Scheme (BSS)[9] and the Council of Gas Detection and Environmental Monitoring (CoGDEM) – '*Carbon monoxide safety on boats*' **(Annex D)** is aimed at raising the awareness of the dangers and symptoms of CO. It also gives advice on CO alarm placement, including:

> *All cabins with a fuel burning appliance should have a CO alarm fitted. If fuel burning appliances, generators or engines are used whilst people sleep, all sleeping quarters will need their own alarms. If the boat has a single multi-use cabin, one alarm is OK.*
>
> *For the best protection, follow the alarm manufacturer's installation instructions as far as the space and nature of the boat allow.*
>
> *But if the placement directions are difficult to meet on your boat, these are the 'best practice' points.*
>
> *Try to place the alarm:*
>
> - *in living quarters between 1m and 3m (on plan view) from the appliance*
> - *in living quarters fix alarms high up on a wall, but at least 150mm from the ceiling and where the indicator lights can be seen*
> - *in sleeping quarters have the alarm in the "breathing zone", i.e. near the bed head*
> - *before fixing, test that you can hear an alarm from any position in the boat (or buy an additional alarm).*

Although some people may be aware of the early symptoms of CO poisoning, the time when the occupants of a boat are particularly at risk from CO poisoning is while sleeping. For this reason the 'black spot' CO indicators that change colour when CO is present are not suitable for boats that are to be used for overnight sleeping. As CO exposure can cause drowsiness, 'black spot' CO indicators may also be ineffective if people in non-sleeping compartments are overcome by increasing concentrations of CO.

The set points at which alarm indicators and audible alarms must operate simultaneously to comply with the safety standard EN 50291-1 are at **Table 2**. Once activated the alarm should continue to operate at carbon monoxide concentrations above 50ppm.

---

[9] See paragraph 1.11

CO concentration	Without alarm before[10]	With alarm before[11]
30 ppm	120 min	-
50 ppm	60 min	90 min
100 ppm	10 min	40 min
300 ppm	-	3 min

Table 4: EN 50291-1 alarm conditions

CO detectors intended for use in a marine environment are tested to the more rigorous safety standard EN 50291-2[12].

1.10 WINDERMERE

Windermere is 10.5 miles long and is the largest natural lake in England. There are over 4500 powered boats registered on the lake, which is managed by three organisations:

- The Lake District National Park Authority (LDNPA) is responsible for:
    - Byelaw enforcement relating to navigation, lights, sailing, steering, mooring and alcohol use.
    - Registration of powered vessels
    - Lake patrol.
- The South Lakeland District Council (SLDC) is responsible for:
    - Applications for the registration of powered vessels made in person
    - Administration of public jetties and moorings
    - Pump out facilities.
- The Environment Agency (EA) is responsible for:
    - Pollution
    - Water quality.

There are no mandatory safety inspections for boats registered on Windermere and the lake authorities do not participate in the BSS.

[10] Alarm must not activate before

[11] Alarm must activate before

[12] BS EN 50291-2:2010 - Electrical apparatus for the detection of carbon monoxide in domestic premises. Part 2: Electrical apparatus for continuous operation in fixed installations in recreational vehicles and similar premises including recreational craft – Additional test methods and performance requirements.

1.11 BOAT SAFETY SCHEME

1.11.1 Description

The BSS is a public safety initiative owned by the Canal & River Trust and the EA. Its purpose is to help minimise the risk of boat fires, explosions, or pollution harming visitors to the inland waterways, the waterways' workforce and any other users. The remit of the BSS is limited to the condition and use of boats and their equipment.

The majority of the UK's inland navigation authorities (including Canal & River Trust, EA, Broads Authority, Avon Navigation Trust and National Trust) use the BSS to ensure that boats meet reasonable standards of safety. Approximately 70,000 boats on the UK's inland waterways have been certified under the scheme. The authorities that have adopted the BSS require BSS certificates to have been issued to boats over 4 years old before they can be registered for use on their waters. A BSS certificate is valid for 4 years.

A number of inland waterways navigation authorities do not currently participate in the BSS. These include the authorities responsible for navigation in the Lake District, Loch Lomond and the Trossachs, and Waterways Ireland. As a result over 7000 leisure boats on the UK's inland waterways are not certified under the BSS.

1.11.2 Boat examination

BSS boat examinations are conducted only by authorised examiners. Should a boat fail an examination, deficiencies must be rectified before an inland waterways licensing authority will grant a licence to navigate. Deficiencies that are deemed to put people or property in immediate danger or risk are reported to owners. In addition, a warning notice is issued to alert: those responsible for a craft's condition that a hazardous defect has been identified; anyone stepping on board that they could be at risk.

With regard to CO related deficiencies, warnings are supported by the *CO Safety on Boats* leaflet **(Annex D)**. In cases where there is a risk of fire or explosion, examiners will alert the relevant inland navigation authority and mooring managers to enable appropriate control measures to be implemented. Boat examiners also have the authority to disconnect LPG cylinders.

The condition of outboard and portable combustion engines and portable fuel systems are checked during BBS boat examination. Due to its remit, the BSS cannot require boats to be fitted with a CO alarm.

1.12 RECREATIONAL CRAFT DIRECTIVE

In 1998, Directive 94/25/EC (Recreational Craft Directive) was introduced by the European Commission to ensure a uniform level of safety in the design and manufacture of recreational craft throughout the European Economic Area (EEA). The Directive established the free movement of recreational craft within the single market, and was implemented in the UK by the Recreational Craft Regulations 1996 S.I.1996/1353[13]. The Directive was revised in 2003 with the adoption of Directive

[13] The Department for Business, Innovation and Skills (BIS) has policy responsibility for the RCD

2003/44/EC. The RCD applies to all craft (with some exemptions) placed on the market or put into service and intended to be used for sporting and recreational purposes that have a hull length of between 2.5 and 24 metres.

A boat must comply with the RCD by meeting ‘essential safety requirements’ and obtain a CE mark, either at the first point of sale, or when it is first put into service in the EEA, unless it is in transit through, or entering, European Union (EU) waters for touristic reasons. The meeting of the essential requirements is frequently demonstrated by compliance with harmonised standards[14].

None of the RCD’s essential requirements include the provision of CO monitors in the build of a boat nor do they require existing CO monitors, where fitted, to be functional if a boat is imported into the EU. Instead, the RCD relies on other elements of design to prevent CO and other products of combustion reaching accommodation areas, including:

5.1 Engines and engine spaces

5.1.1 Inboard engine – All inboard mounted engines shall be placed within an enclosure separated from living quarters and installed so as to minimize the risk of fires or spread of fires as well as hazards from toxic fumes, heat, noise or vibrations in the living quarters.

5.5 Gas system – Adequate ventilation must be provided to prevent hazards from leaks and products of combustion.

1.13 CO ALARM REGULATIONS IN DWELLINGS AND CARAVANS

The threat of CO poisoning is becoming more widely recognised in the UK, with stricter legislation recently being introduced for new dwellings and new caravans.

Building regulations introduced in 2010 in England and Wales for new dwellings require a CO alarm to be fitted in the same room as a new or replacement fixed solid fuel heating appliance. More recently introduced Building Regulations and Building Standards in Northern Ireland and Scotland are more stringent, and require CO alarms to be fitted in rooms containing heating appliances which burn any fossil fuels (i.e. piped gas, bottled gas, oil or solid fuels).

CO alarms compliant with BS EN 50291 have been required in new touring caravans and motorhomes since 1 September 2011.

1.14 CURRENT CO AWARENESS INITIATIVES

In addition to CoGDEM and the BSS, a number of other organisations have been involved in increasing awareness of the dangers of CO in the marine and domestic environments, and promoting the use of CO alarms.

The Royal Yachting Association (RYA) has published a safety advisory note covering the dangers of CO. The Gas Safe Register, United Kingdom Liquefied Petroleum Gas (UKLPG), and the Camping and Caravanning Club, among others, have promoted the dangers of CO poisoning via poster campaigns.

[14] A harmonised standard is a European Standard elaborated on the basis of a request from the European Commission to a recognised European Standards Organisation to develop a European Standard that provides solutions for compliance with a legal provision.

Such initiatives have had the support of the All Party Parliamentary Carbon Monoxide Group (APPCOG). APPCOG is a cross-party forum for parliamentarians, civil servants and energy industry representatives to research, discuss and address the dangers of CO. The group aims to improve government policy on CO hazards by lobbying on behalf of the public and to work with other stakeholders to raise public awareness.

1.15 PREVIOUS SIMILAR ACCIDENTS

1.15.1 MAIB data

The MAIB is aware of a number of accidents and incidents since 1994 in which vessels' crews have suffered the effects of CO poisoning resulting from the use of petrol driven pumps or generators. These include:

Starlight Rays (MAIB Report 15/2012)

In August 2011, an engineer on board the fishing vessel *Starlight Rays* collapsed while using a portable petrol engine-driven pump inside the vessel's fish hold. He was evacuated from the vessel and taken to hospital by rescue helicopter; the engineer never regained consciousness. He died from CO poisoning.

The pump was being used to remove oily water from inside the vessel's bow thruster space. The pump's petrol engine ran for about 1 hour in a compartment with no mechanical ventilation and little natural air circulation. As a result, very high levels of CO accumulated within the fish hold. Two other crewmen were also poisoned by CO while trying to rescue the engineer; both survived.

This accident demonstrated the ability for high concentrations of CO to quickly incapacitate people in enclosed spaces. It also showed the difficulties posed during rescue efforts in removing an injured crewman from a compartment with a noxious atmosphere without risking the lives of the rescuers.

Unnamed canal boat

In January 2014, a portable generator was used to provide electric power for domestic equipment on board a 40ft long narrow boat being used on inland waterways as a permanent home. The generator was operated under a tonneau cover, which allowed CO to accumulate and enter the accommodation area through unsealed doorways. The boat's owner was found dead on board. Postmortem examination determined that the cause of death was CO poisoning. The boat was not fitted with a CO alarm.

Eshcol (MAIB report 14/2014)

In January 2014, the MAIB issued Safety Bulletin 1/2014 **(Annex F)** after an investigation began into the death of two young fishermen in Whitby harbour. The fishermen had returned from a fishing trip and had slept on board the boat. Before going to bed, the grill of a butane gas cooker was lit in order to warm the accommodation. The following morning the two men were dead in their bunks. The gas grill was still lit and the accommodation was full of fumes. *Eshcol* was not fitted with a CO alarm.

1.15.2 BSS data

The BSS records data of CO related incidents concerning boats on inland waterways and also on coastal boats having similar characteristics to inland craft. **Table 3** shows data for a 20 year period, up to February 2014, in which 30 boat related CO fatalities were recorded, the largest number of fatalities was caused by portable petrol generators.

Source of CO	Fatalities
Portable petrol generator	9
LPG Appliance	8
Solid/multi fuel appliance	6
Petrol outboard engine	5
Oil fired(diesel) stove	1
Portable diesel generator	1

Table 3: BSS data – CO fatalities

SECTION 2 - ANALYSIS

2.1 AIM

The purpose of the analysis is to determine the contributory causes and circumstances of the accident as a basis for making recommendations to prevent similar accidents occurring in the future.

2.2 CO POISONING

The postmortem examinations of Kelly and Lauren identified that they died from CO poisoning. It is evident from the reconstruction of the events leading to their deaths **(Paragraph 1.7.3** and **Annex B)** that the source of the CO was the portable generator fitted in *Arniston*'s engine bay. It is also clear that the external exhaust fitted to the portable generator had failed catastrophically **(Figure 14)**, causing the generator's exhaust to vent directly into the engine bay. The exhaust fumes, which contained high levels of CO, then spread from the engine bay into the boat's accommodation through gaps in the engine bay's bulkhead. The only other potential source of CO on board *Arniston* was the boat's main engine, which had been operated for only very short periods on 31 March and 1 April 2014.

Examination of the external exhaust system **(Annex A)** showed that it was not gas tight due to the varying quality of its connections **(Figure 7)**. Consequently, even before its failure, the external exhaust system would have been leaking fumes into the engine bay and possibly beyond whenever the generator was running. The headaches and physical sickness experienced by *Arniston*'s owner and Lauren during the morning of 1 April were possibly the early symptoms of CO poisoning **(Table 2)**, but these went unrecognised.

2.3 GENERATOR INSTALLATION

Portable "suitcase type" generators, such as the *Hyundai HY3000sei*, are reasonably quiet, affordable and small in size. They are becoming widely used in a number of applications. Internal combustion engines should not be installed such that their exhausts vent into enclosed spaces. As shown in the accident reconstruction **(Annex B)**, and further confirmed by examination **(Annex C)**, the *Hyundai* generators, in common with similar generators, operate with a 'rich' air/fuel mixture. The 'rich' mixture is used to enable them to respond to sudden demands for electrical power. A consequence of the 'rich' mixture is that the CO concentration in the generators' exhaust is relatively high, which makes them even more hazardous if used in enclosed or unventilated spaces.

The portable Hyundai generators were usually supplied with warnings that they should not be used in enclosed spaces **(Figure 5)** or be modified **(Figure 6)**. The installation of the portable generator into the engine bay on board *Arniston*, and the extension and modification of its exhaust system indicate that these warnings, if supplied in this case, were not heeded by the boat's owner. It is possible that the owner's decision to fit the generator in this manner was influenced by the need to provide a 240V electrical supply on his boat in a cost-effective way. However, although the owner installed the generator in an enclosed space, and subsequently modified its exhaust, it is evident that he foresaw and tried to mitigate some of the potential adverse consequences of his actions. These included: the fitting of fans in the engine bay; the testing of the generator at home with the silencer attached; and, the connection of the exhaust to a through-hull fitting to ensure that the exhaust gases were expelled into the open air.

Nonetheless, several safety-critical issues were overlooked. In particular, the replacement of the integral fuel tank with a larger external tank, which required the fitting of a rubber hose routed through the aft bulkhead, significantly increased the possibility of fire and/or explosion. More importantly, the materials and the methods used to construct the exhaust system were unsuitable, and the testing of the modified generator without an electrical load was unrealistic and misleading.

2.4 FAILURE OF EXHAUST

2.4.1 Overview

The manner of the failure of the external exhaust fitted by the owner to the portable generator in *Arniston*'s engine bay shows that it was not fit for purpose. It was not gas-tight and was likely to fail in a number of places for differing reasons.

2.4.2 The use of solder

Plumbers' solder is intended to withstand the temperatures experienced during the passage of water of temperatures up to boiling point. It is not suitable for use on combustion engine exhaust systems in which the exhaust gases reach considerably higher temperatures.

The Test House examination of the exhaust **(Annex A)** identified that the soft solder used in the external exhaust's construction reached a semi-molten, pasty state in the temperature range between 183°C and 259°C and that its melting point was 259°C. Therefore, given that the exhaust temperature of the portable generator under a 1KW load was between 250°C and 280°C **(Annex C)**, it is not surprising that the soldered joints failed when the fan heater was switched on. Indeed, solder with a similar melting point failed in less than 5 minutes during the reconstruction. The failure of the external exhaust soon after the fan heater was switched on is also supported by the scorch marks on the heat-resistant cladding inside the engine bay **(Figure 16)**. These marks indicate that hot gases had been exhausted in this area for a prolonged period.

The Test House examination also identified that the failed soldered joint showed signs of having reached a pasty state on a previous occasion **(Figure 21)**. The partial separation of the joint is likely to have occurred when the generator was running during the evening of 31 March. On that occasion, the generator was not under load and therefore its exhaust gas temperatures would have been lower. The semi-molten solder would have cooled and solidified soon after the generator was turned off.

2.4.3 Lack of support

Although the *Webasto* silencer **(Figure 7)** weighed 0.35kg, the external exhaust system was unsupported throughout its entire length. Therefore, when the solder softened and the vibration increased after the generator was put under load, the

Image courtesy of The Test House

Figure 21: Previous partial failure

weight of the silencer would have placed a torsional force on the adjacent soldered joint. Consequently, as shown during the reconstruction **(Annex B)**, the weight of the silencer would have contributed to the external exhaust system's collapse.

2.4.4 Compression joints

The 24mm stainless steel pipe section of the external exhaust system **(Figure 11)** was 'secured' at both its ends by jubilee clips. Due to the characteristics of the steel pipe, it would have been impossible to compress it to effect a gas-tight seal using this method. Consequently, as shown by the evidence highlighted by The Test House examination of the pipe **(Annex A)** and the reconstruction **(Annex B)**, CO was leaking into the engine bay even before the external exhaust system collapsed.

2.4.5 Use of a silencer

The silencer was manufactured to be used only in conjunction with the *Webasto* 5kW diesel heater. No exhaust gas flow rates for the silencer have been found. Therefore, although it is possible that the exhaust gas flow rate from the generator engine's fixed exhaust exceeded that of the *Webasto* silencer, which would have assisted the external exhaust system failure, this has not been verified.

2.5 THE PASSAGE OF CO

2.5.1 Route and concentration

The aft cabin where Kelly and Lauren went to sleep shared a common bulkhead with the engine bay **(Figure 3)**. The bulkhead was not gas-tight. It had large openings **(Figure 14)** through which electric cables and pipework were routed. These openings allowed the exhaust gases from the generator to flow from the engine bay into the aft cabin **(Figure 22)**. The extensive staining found on the deckhead lining of the aft cabin **(Figure 23)** indicates that the atmosphere in the engine bay had been venting into the accommodation for a prolonged period.

Image courtesy of Brunswick Boat Group

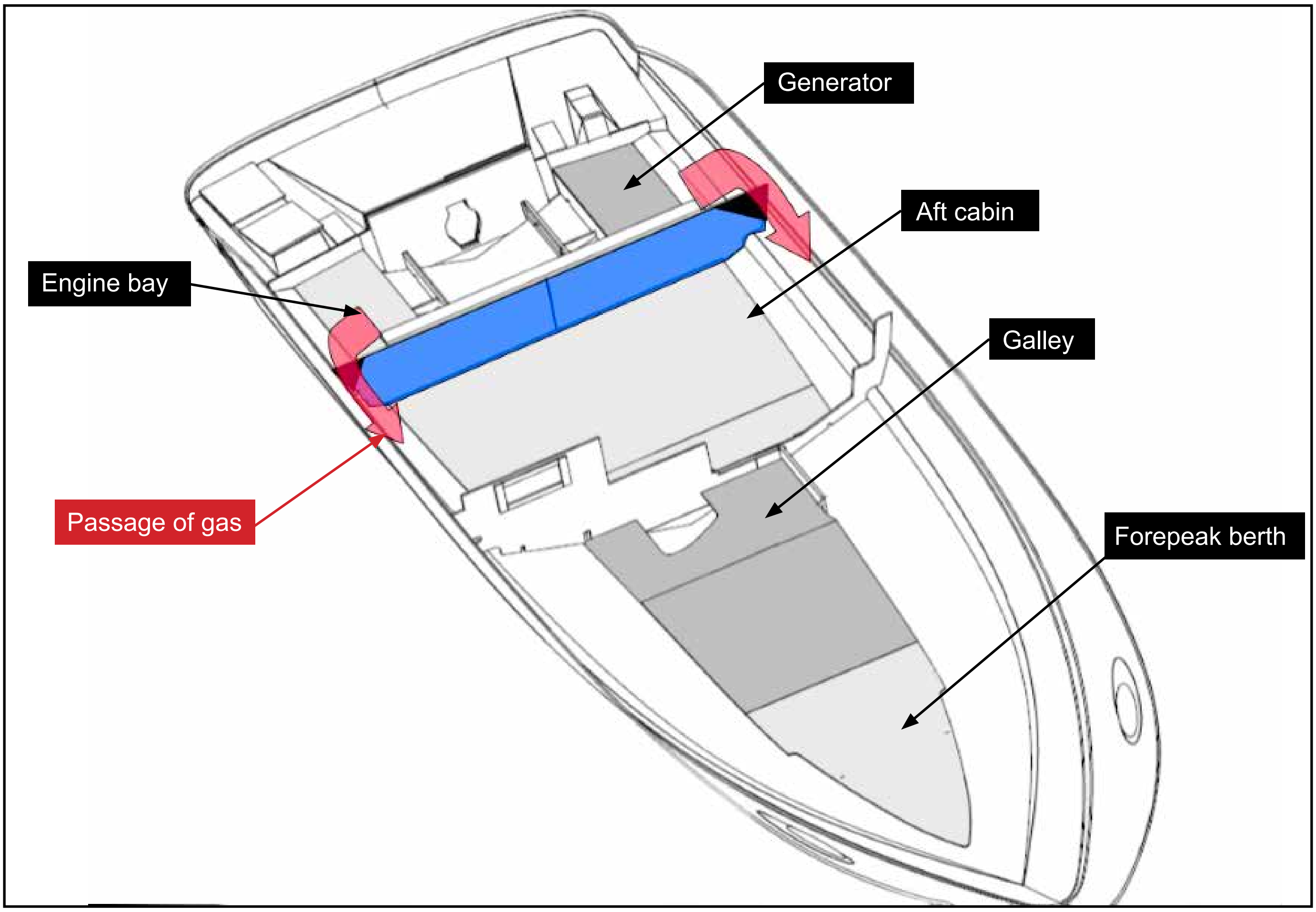

Figure 22: Passage of gas

The accident reconstruction **(Annex B)** showed that the levels of CO in the aft cabin were considerably higher than those in the galley area, which was consistent with the source and the likely passage of the gas. Therefore, as Kelly and Lauren slept in the aft cabin, they would have inhaled higher concentrations of CO for a longer period of time than *Arniston*'s owner, who was asleep at the table in the galley. Nonetheless, the condition and the disorientation of the owner when he awoke indicate that he had also been poisoned by the CO. Even though the owner had mainly been in the open air after waking and had been given oxygen by the attending paramedics and on arrival at the hospital, when tested his CO saturation level was still 16%.

Figure 23: Deckhead lining - gas staining

2.5.2 Effect of fans

The circulation fans in the engine bay were reported to be on during the afternoon of 1 April. However, when MAIB inspectors and police examined *Arniston* on 2 April 2013, the power supply switch to the fans, which was shared with the battery charger, was found to be in the off position **(Figure 24)**. Therefore, there is some doubt whether the fans were operating or not. It is possible that the switch was inadvertently knocked to the 'off' position by the emergency services during the rescue attempt or that the fans were not operating at the time of the accident.

Although it cannot be determined for certain whether the fans were operating, it is clear from the accident reconstruction **(Paragraph 1.7.3 and Annex B)** that, with the fans operating and the doors open, a CO concentration of 743ppm accumulated in the aft cabin in 2 hours. **Table 2** shows that such a concentration has the potential to be fatal within 2 to 3 hours. Other configurations of the doors and the fans would have led to fatal concentrations of CO being reached much sooner. The sudden rise in the CO concentration to 1,239ppm in the aft cabin, immediately after the generator was stopped during the reconstruction, was almost certainly due to the circulation fans stopping at the same time as the generator.

2.6 CO ALARMS

2.6.1 *Arniston*

The CO alarms fitted on board *Arniston* were over 7 years past their replacement date, and after the accident it was established that they had been disconnected from the power supply **(Figure 19)**. It has not been possible to determine when the detectors were disconnected. However, anecdotal evidence indicates that CO alarms are typically disconnected because they activate as a result of their deteriorating condition (time expired). It is also possible that the alarms were disconnected because they were activating due to the periodic presence of CO in the atmosphere on board and had become an ‘annoyance’. Either way, the absence of at least one functioning CO alarm in *Arniston*’s accommodation meant that a vital barrier to protect the boat’s occupants from the dangers of CO was not in place. Had a stand-alone CO alarm been fitted to *Arniston*, it would have activated within 3 minutes of the hazardous concentration of CO being detected.

Figure 24: Battery charger/fans switch position

2.6.2 Misconceptions

It is a common misconception in leisure boating circles that CO alarms are prone to ‘false alarms’ and that they are therefore not suitable for use in the marine environment. The activating of a CO alarm is nearly always due to the presence of CO in the concentration exceeding those shown in **Table 4**. There are many sources of CO in and around boats, and an alarm could be set off for several reasons, including exhaust fumes from a boat's engine being blown into the accommodation. In such circumstances, these are alarms, not false alarms; the detector is behaving as intended. As CO is invisible, and has no smell or taste, any CO alarm activation should always be treated seriously and appropriate action taken.

CO alarms that are intended for use in recreational craft are now tested to a rigorous standard. Therefore, boaters should be reassured that such alarms are designed to operate effectively in the harsher environments experienced on board.

2.6.3 Fitting requirements

In the UK, there is no requirement for recreational craft, including those intended for overnight sleeping, to be fitted with a CO alarm. Neither the RCD and its associated harmonised standards, nor the BSS certification process, require CO alarms to be fitted to new or existing boats.

CO kills as effectively on a boat as it does in a home or a caravan. Therefore, it should be common sense that measures are introduced to protect recreational mariners on new boats from the danger of CO to the same extent as the protection already afforded occupants of new caravans and new dwellings. Although the RCD relies on other elements of design to prevent exhaust gases reaching accommodation areas, the fitting of a CO alarm is a simple and cost-effective measure that can save lives in the event of material failure or the malfunction of other equipment or fittings. Furthermore, a CO alarm has the potential to play a significant role in fire detection on board all boats (though the presence of a CO alarm should never be used as a reason not to fit a suitable smoke detector).

Mandating the fitting of CO alarms will help to protect an increasing number of boat users over time, as new boats enter service. However, in view of the near 80000 recreational boats currently kept on the UK's inland waterways alone, together with the incidence of CO-related fatalities on UK waterways **(Paragraph 1.15.2)**, it is important that the owners of existing recreational craft also fit CO alarms. Moreover, the alarms fitted must meet the standard EN 50291-2 in order to withstand the marine environment.

Many stand-alone CO alarms currently produced (and compliant with EN 50291-2) have an effective lifetime of between 7 and 10 years, some have sealed-for-life batteries and lifetime warranties. If a boat has CO alarms that rely on its integral power supply, it is good practice to also fit 'stand-alone' alarms as a backup. This will ensure that the occupants are protected should the boat's power supply fail. All alarms should be regularly tested using their push-button test facility to ensure they will operate when required.

2.7 HAZARDS OF 'DIY'

Arniston's owner was a qualified plumber. Therefore, not surprisingly, the soldered joints on the generator exhaust system were of an adequate standard for use in a hot water system. Also, the owner had tested the exhaust system on the generator after its assembly. However, the test was not conducted with the generator under load. It did not produce the temperatures needed to identify that the use of soft solder and plumbers' fittings were totally inappropriate in the generator exhaust system. Consequently, the exhaust fittings did not fail during the test, which gave the owner misplaced confidence in his work.

During the course of the MAIB investigation into this accident, it was found that a number of other boat owners on Windermere had also installed portable generators in enclosed spaces. Many had installed the generators themselves. Do-it-yourself (DIY) work is very popular in the marine leisure sector and is seen as an enjoyable part of boat ownership. It also helps to reduce the costs of running and maintaining a boat.

Nonetheless, there are numerous systems on board boats that, regardless of a boat owner's engineering and mechanical skills, should only be installed, maintained or modified by a qualified marine engineer. In such situations, marine engineers should also follow equipment manufacturers' instructions and use the correct tools and materials. The financial cost of using marine engineers to complete safety-critical work is inevitably more expensive than the cost of 'DIY'. However, where safety critical systems are concerned such expenditure should be factored in to the cost of boat ownership.

2.8 BOAT EXAMINATIONS

The boat examinations conducted by the BSS are useful in identifying and highlighting potentially dangerous CO-emitting installations to enable remedial action to be taken. In this case, had the exhaust not failed so soon after installation and in the meantime *Arniston* had been examined under the BSS certification process, it is possible that:

- The inappropriate use of the portable generator in the confines of the engine bay would have been identified.
- Appropriate warnings would have been issued.
- *Arniston*'s owner would have been advised to replace the disconnected CO alarms.
- *Arniston*'s owner would have been given a copy of the *CO Safety on Boats* leaflet **(Annex D)**.

Given the circumstances of the deaths on board *Arniston*, together with the incidence of portable generators installed on other craft on Windermere, it is evident that the adoption of the BSS or similar by the lake's controlling authority has the potential to prevent similar accidents occurring in the future.

2.9 AWARENESS OF CO

CO is a killer. The gas is produced from a variety of sources, some of which are not as apparent as others. Appliances such as gas fires, cookers, water heaters and open fires that use gas, oil, coal and wood are all sources of CO. Disposable barbeques have also been known to be lethal when used in a confined space.

Although there are many sources of CO on board boats, many boaters are unaware of the risks of CO poisoning. Such risks are probably increased on boats equipped and used for overnight sleeping.

It is likely that numerous cases of CO poisoning are not identified because of this lack of awareness and the symptoms are attributed to other, unspecified illnesses or causes because, in the absence of a CO alarm, the presence of CO is not established.

The work of the BSS, CoGDEM and other organisations to try and raise the awareness of recreational boaters to the dangers of CO, including its sources, the symptoms of CO poisoning and the fitting of alarms, is extremely positive. Nonetheless, given the number of recreational craft and recreational boaters in the UK (the population at potential risk), together with the previous accidents and accident statistics detailed in **Paragraph 1.15**, it is clear that more needs to be done.

SECTION 3 - CONCLUSIONS

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

1. The deceased were poisoned by the CO contained in the exhaust fumes from the portable generator installed in the engine bay. [2.2, 2.3]

2. The generator's external exhaust system had failed catastrophically, causing the generator to vent directly into the engine bay instead of out of the boat's side. [2.2, 2.4]

3. The exhaust fumes contained high levels of CO and spread from the engine bay into the boat's accommodation through gaps in a common bulkhead. [2.2, 2.5]

4. The 'rich' air/fuel mixture used by the generator caused the CO concentration in the generator's exhaust gases to be relatively high. This made the generator even more hazardous if used in an enclosed or unventilated space. [2.3]

5. The portable Hyundai generators were usually supplied with warnings that they should not be used in enclosed spaces or be modified. The installation of the portable generator into the engine bay on board *Arniston*, and the extension and modification of its exhaust system indicate that these warnings, if supplied in this case, were not heeded by the boat's owner. [2.3]

6. The materials and methods used to construct the external exhaust system were unsuitable and the testing of the generator without an electrical load was unrealistic and misleading. [2.4]

7. The external exhaust system fitted to the portable generator was not fit for purpose. It was not gas-tight and was likely to fail in a number of places because of the use of soft solder, unsuitable compression joints and because the system was unsupported. [2.4]

8. The CO concentration in the aft cabin, where the deceased were sleeping, reached life-threatening levels within 2 hours. [2.5]

9. The CO alarms fitted on board *Arniston* were over 7 years past their replacement date and they had been disconnected from the power supply. The absence of a functioning CO alarm in *Arniston*'s accommodation meant that a vital barrier to protect the boat's occupants from the dangers of CO was missing. [2.6]

10. It is a common misconception in leisure boating circles that CO alarms are prone to 'false alarms' and that they are therefore not suitable for use in the marine environment. [2.6]

11. There is no requirement for either new or existing recreational craft, including those intended for overnight sleeping, to be fitted with a CO alarm. It would be common sense for measures to be introduced to protect recreational mariners on new boats from the danger of CO to the same extent as the protection already afforded to occupants of new caravans and new dwellings. [2.6]

12. 'DIY' is very popular with recreational boaters, but there are numerous systems on

board boats that, regardless of a boat owner's engineering and mechanical skills, should only be installed, maintained or modified by a qualified marine engineer following manufacturers' instructions. [2.7]

13. Examinations under the BSS certification process could potentially help to prevent CO poisoning on board recreational craft operating on inland waterways. [2.8]

14. More needs to be done to raise the awareness of recreational boaters to the dangers of CO poisoning. [2.9]

SECTION 4 - ACTION TAKEN

4.1 MAIB ACTIONS

The **Marine Accident Investigation Branch**, in May 2013, issued Safety Bulletin 2/2013 to inform leisure boaters of:

- the hazards of using generators in enclosed spaces
- the dangers of 'DIY'
- the hazards of carbon monoxide.

4.2 ACTIONS TAKEN BY OTHER ORGANISATIONS

The **British Standards Institution** has:

Proposed to the International Organisation for Standardisation technical committee 188 working group 12, that a means of detection to alert craft occupants to the outbreak of fire and the consequential presence of carbon monoxide (CO) is required for craft with more than one habitable space. The proposal was not accepted.

SECTION 5 - RECOMMENDATIONS

The **Department for Business, Innovation and Skills** is recommended to:

2015/102 Explore, through the RCD framework, ways of ensuring that new vessels have a means of detecting toxic gases, particularly carbon monoxide, in habitable spaces, and alerting occupants to their presence.

The **Boat Safety Scheme, Maritime and Coastguard Agency, Royal Yachting Association, British Marine Federation, Council of Gas Detection and Environmental Monitoring** and the **Association of Inland Navigation Authorities**, are recommended to:

M2015/103 Build on current initiatives by engaging with other relevant organisations to conduct a co-ordinated and focused campaign designed to raise the awareness of the leisure boating community of the dangers of CO and the importance of fitting carbon monoxide alarms. Efforts should be focused on, inter alia:

- Raising awareness of the likely sources of carbon monoxide.
- The dangers of using inappropriate or poorly installed fossil-fuel burning equipment.
- The early symptoms of carbon monoxide poisoning.

The **Boat Safety Scheme** is recommended to:

2015/104 Encourage its boat examiners, during the course of periodic boat examinations, to explain to boat users, where present, the risk of carbon monoxide poisoning; highlight the potential sources of carbon monoxide; and promote the use of carbon monoxide alarms.

The **Lake District National Park Authority** is recommended to:

2015/105 Adopt the Boat Safety Scheme as a means of improving safety on inland waterways for which the Lake District National Park Authority holds statutory responsibility.

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

Marine Accident Report

INVESTORS IN PEOPLE