ACCIDENT REPORT

Report on the investigation into

carbon monoxide poisoning

on board the motor cruiser

Love for Lydia

on Wroxham Broad, United Kingdom

between 7 and 9 June 2016

resulting in two fatalities

MAIB
MARINE ACCIDENT INVESTIGATION BRANCH

VERY SERIOUS MARINE CASUALTY REPORT NO 9/2017 MAY 2017

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

AINA	-	Association of Inland Navigation Authorities
APPCOG	-	All-Party Parliamentary Carbon Monoxide Group
BIS	-	Department for Business, Innovation and Skills
BM	-	British Marine (formerly BMF)
BMF	-	British Marine Federation
BSS	-	Boat Safety Scheme
CE	-	Conformité Européenne
CFOA	-	Chief Fire Officers Association
CO	-	Carbon Monoxide
CoGDEM	-	Council of Gas Detection and Environmental Monitoring
COHb	-	Carboxyhaemoglobin
CPR	-	Cardio-Pulmonary Resuscitation
DC	-	Direct Current
EEA	-	European Economic Area
EU	-	European Union
HSE	-	Health and Safety Executive
ISO	-	International Organisation for Standardisation
MCA	-	Maritime and Coastguard Agency
NBYC	-	Norfolk Broads Yacht Club
ppm	-	parts per million
RCD	-	Recreational Craft Directive
rpm	-	revolutions per minute
RYA	-	Royal Yachting Association
UKLPG	-	United Kingdom Liquefied Petroleum Gas
UTC	-	Universal Coordinated Time

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

SYNOPSIS

Between 7 and 9 June 2016, the two occupants of the motor cruiser *Love for Lydia* died from carbon monoxide poisoning. The boat was moored alongside Wroxham Island, River Bure, Norfolk, and their bodies were found during the afternoon of 9 June in the boat's forepeak cabin.

The MAIB investigation identified that:

- The source of the carbon monoxide was exhaust fumes from the boat's eight-cylinder petrol engine, which contained high levels of the gas even when the engine was 'idling'.

- The engine was probably being run to charge the boat's 12v batteries and the occupants did not recognise the danger from the exhaust fumes.

- The carbon monoxide from the 'wet' exhaust at the stern of the boat spread under the canvas canopy on the aft deck and then into the forepeak cabin, where it quickly reached lethal concentrations.

- The boat's habitable spaces were not adequately ventilated; the forepeak cabin's deck hatch and port holes were shut.

- The boat's occupants were not alerted to the danger because a carbon monoxide alarm was not fitted.

In January 2015, the MAIB made several recommendations in an attempt to improve carbon monoxide safety on board recreational craft following its investigation into the double fatality on board the motor cruiser *Arniston* on Windermere. It is disappointing that a recommendation intended to require new recreational craft to be fitted with a carbon monoxide alarm was not accepted and that the action that resulted from a recommendation aimed at providing a co-ordinated and focused awareness campaign was short-lived.

A number of organisations continue to raise the awareness of leisure boaters to the dangers of carbon monoxide, but more needs to be done. A recommendation has been made to the Maritime and Coastguard Agency intended to re-energise various industry bodies into agreeing a co-ordinated and concerted campaign. Recommendations have also been made to the Boat Safety Scheme and British Marine which are intended to realise the mandatory fitting of carbon monoxide alarms on board new recreational craft and on board existing recreational craft using inland waterways.

SECTION 1 - FACTUAL INFORMATION

1.1 PARTICULARS OF *LOVE FOR LYDIA* AND ACCIDENT

SHIP PARTICULARS	
Vessel's name	*Love for Lydia*
Flag	Not applicable
Type	Motor cruiser
Registered owner	Privately owned
Construction	Glass reinforced plastic
Year of build	2000
Length overall	7.62m
Weight	2910 kilogrammes
Engine power and type	300hp – 350 MAG Mercruiser petrol stern drive
MARINE CASUALTY INFORMATION	
Date and time	Between 7 and 9 June 2016
Type of marine casualty or incident	Very Serious Marine Casualty
Location of incident	Wroxham Broad, River Bure, Norfolk
Place on board	Accommodation
Fatalities	2
Persons on board	2
Environment	Light variable wind. Temperature high 14°C, low 10°C.

Love for Lydia

1.2 NARRATIVE

During the morning of 9 June 2016, an ice cream vendor manoeuvred his boat alongside the motor cruiser *Love for Lydia* that was moored port side alongside to Wroxham Island on the River Bure, Norfolk **(Figures 1** and **2)**. The maximum time permitted at the mooring was 24 hours and the vendor was aware that the boat had been there for 2 days. The ice cream vendor banged on *Love for Lydia*'s stern to attract the attention of its occupants but there was no response. The vendor then continued his passage upriver.

The ice cream vendor returned downriver in the afternoon and saw that *Love for Lydia* was still at the mooring and decided to investigate further. The vendor moored his boat ahead of the motor cruiser and then banged on the motor cruiser's accommodation roof and shouted. Again, there was no response, so he looked through a window and saw a person lying motionless on the bed in the forepeak cabin. The vendor attracted the attention of the occupants of a passing barge, who then moored their boat nearby. The ice cream vendor and the barge's owner then went to *Love for Lydia*'s stern. The boat's aft deck was fully covered by a canvas canopy, apart from an entrance on the port side of the transom where the canopy was unzipped, rolled up and secured **(Figure 3)**.

The two men entered the canopied area. They could see a woman and a dog on the bed in the forepeak cabin and a man slumped in the foot well at the bottom of the steps leading from the cabin to the helm area. All three appeared to be lifeless. The police were alerted by mobile telephone at 1557.

Police officers were transferred from the Norfolk Broads Yacht Club (NBYC) to the scene in the ice cream vendor's boat, arriving at 1628. They were soon joined by a volunteer community first responder, more police officers, officers from the Norfolk Fire and Rescue Service (FRS) and an ambulance crew who had been transported by Broads Authority rangers.

Courtesy of Google Maps

Figure 1: Wroxham Broad

Figure 2: *Love for Lydia* alongside Wroxham Island

Figure 3: Configuration of *Love for Lydia*'s canvas canopy

The first responder unfastened the poppers securing the canopy at *Love for Lydia*'s stern. The FRS then tested the atmosphere on board the vessel and no carbon monoxide (CO) was detected. At 1653, the ambulance crew examined the boat's occupants, Alan Frost and his partner Tina Wilkins, and confirmed that they were

deceased. At 2034, *Love for Lydia* was towed a short distance to the NBYC and moored on a pontoon. The deceased were removed from the boat later in the evening.

On admission to the Norfolk and Norwich University Hospital, the levels of carboxyhaemoglobin[1] (COHb) measured in Alan's blood was 68.7%, and in Tina's blood 67.4%. Postmortem examinations identified that both died from CO poisoning.

1.3 OWNERSHIP

Love for Lydia was purchased by Alan Frost in March 2016. Alan was a 64-year-old retired carpenter who had previously hired boats on the Broads with his long term partner, Tina Wilkins, aged 51. Neither Alan nor Tina held any boating qualifications.

Love for Lydia was the first boat the couple had owned and Alan had spent a few days at weekends preparing it for use. The couple collected the boat from its mooring at Sabena Marine on 6 June 2016 for their first holiday on board. The following morning, *Love for Lydia* was seen alongside the mooring on Wroxham Island with its engine running.

1.4 THE BOAT

1.4.1 History

Love for Lydia was a Doral 250SE sports motor cruiser that was built in 2000 by Doral Boats International in Quebec, Canada. Doral Boats International specialised in manufacturing sports boats, mainly for export, and ceased trading in 2012.

Love for Lydia was used in North America until it was imported into the UK in October 2007. It was first registered with the Broads Authority in June 2008 as *Nouveau* and changed ownership about 1 year later. The boat remained based on the Broads and was renamed *Love for Lydia* by Alan Frost after he bought it in March 2016.

1.4.2 Layout

Love for Lydia's length overall was 7.62m and the boat was divided into four underdeck compartments: an engine bay aft, a small aft cabin, heads and a forepeak cabin **(Figure 4)**. The forepeak cabin could be ventilated by a small oval shaped porthole on each side and a skylight/escape hatch leading to the foredeck **(Figure 5)**.

The aft deck and helm area, which was above the engine bay and aft cabin, was fitted with seating and a table **(Figure 6)**. A movable bench seat was fitted at the aft end of the deck. The gap between the underneath of the seat and the top of the transom was approximately 5cm **(Figure 7)**. In common with many sports motor cruisers, the aft deck and helm area was fitted with a canvas canopy **(Figure 3)** that was attached to the superstructure with press studs. The canopy's configuration was adjusted by zips and twist lock fastenings. The canopy was last replaced in 2011 by a Broads-based supplier at a cost of £2200. No warnings on the dangers of CO poisoning accompanied the canopy.

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

1.4.3 Propulsion and power

Love for Lydia's propulsion was supplied by a naturally aspirated, 5.7 litre, eight-cylinder (V8) Mercury Mercruiser inboard engine. The engine had an output of up to 300hp through a steerable outdrive and could drive the boat at cruising speeds of 20-25 knots and a top speed of 40 knots. The engine incorporated a 'wet' exhaust system that vented non-catalysed[2] exhaust gases and cooling water through the outdrive under the water on the stern transom **(Figure 8)**.

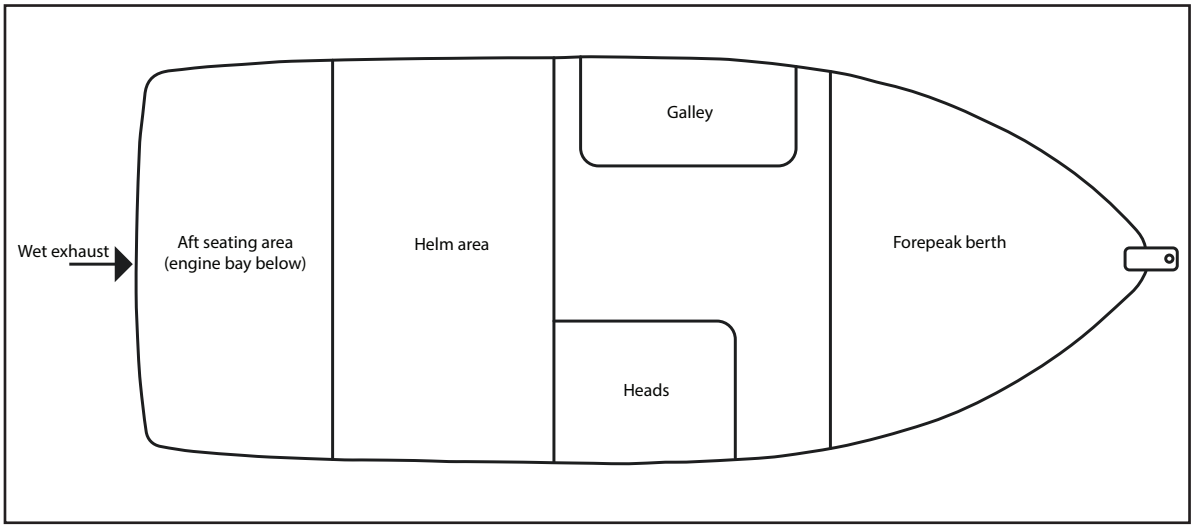

Figure 4: *Love for Lydia* - layout (not to scale)

Figure 5: Forepeak cabin hatch/vent

[2] Modern exhaust systems incorporate a catalytic converter, which substantially reduces the amount of pollutants by converting harmful gases into water vapour and less harmful gases via a series of chemical reactions. A catalytic converter converts three harmful substances into harmless ones: CO into carbon dioxide, nitrogen oxides into nitrogen and oxygen, and hydrocarbons into carbon dioxide and water. Catalytic converters are used with internal combustion engines, fuelled by either petrol or diesel - including lean-burn engines, as well as kerosene heaters and stoves.

Figure 6: Aft deck area

Figure 7: Gap under aft bench seat

Figure 8: 'Wet' exhaust

Data from tests on similar engines, conducted by the manufacturer in 2002, showed that the concentration of CO in the engines' emissions with the engines idling was between 44099ppm and 48206ppm **(Table 1)**.

Engine serial #	engine description	test #	test date	idle CO concentration (ppm)	idle CO mass emissions (g/hr)
0M321484	350 MAG Bravo	2054	1/16/2002	44099	1072.26
0M321484	350 MAG Bravo	2055	1/16/2002	44242	1053.66
0M300179	350 MAG Bravo	2087	2/25/2002	48257	1408.61
0M300179	350 MAG Bravo	2090	2/28/2002	48206	1374.33

Table 1: 350 MAG Bravo CO emissions data

The primary electrical circuit on board *Love for Lydia* was 12v Direct Current (DC) supplied by batteries to power navigational equipment and some lighting. A 220v Alternating Current circuit, supplied either from converted 12v DC supplies or via a shore connection, provided power to domestic electrical appliances that included a TV, DVD player, microwave, hob and fridge. The 12v batteries could be recharged from a shore connection or through an alternator driven by the main engine.

1.4.4 Examination and survey

When *Love for Lydia* was imported into the UK in 2007, the boat underwent a post-construction assessment and Conformité Européenne (CE) marking to comply with the Recreational Craft Directive (RCD)[3] as part of the importation process. This work was undertaken by HPI Verification Services Ltd in July 2007.

On 18 May 2012, *Love for Lydia* was examined in accordance with the requirements of the Boat Safety Scheme (BSS) (see paragraph 1.11). The boat met the requirements of the examination and was issued with a BSS certificate that was valid until 10 June 2016.

Love for Lydia was next inspected in March 2016 during a pre-purchase survey conducted for Alan Frost by an independent marine surveyor to establish the boat's condition with regards to structure, damage, maintenance and safety. The survey report made several recommendations to address deficiencies. It also noted that there was no CO alarm on board, but it did not recommend that one be fitted.

1.5 BOAT CONDITION

1.5.1 'As found'

When *Love for Lydia*'s occupants were found deceased on 9 June 2016, the following was observed:

- The boat was moored port side alongside to Wroxham Island with its bow heading towards the north-east **(Figure 2)**.
- An extinguished 'kettle' type charcoal fuelled barbecue was on the riverbank approximately 1.5m from the boat's side **(Figure 2)**.
- The canopy was covering the aft deck and helm area but the access panel on the port quarter door was unzipped and secured open **(Figure 3)**.
- The cabin port holes and the foredeck hatch were shut.

1.5.2 Subsequent inspection

On 10 June, MAIB inspectors examined *Love for Lydia* at the NBYC and also identified:

- The ignition key was in the ignition and engine run switch was in the 'run' position **(Figure 9)**.
- The engine throttle was set to between 2400 and 3000 revolutions per minute (rpm)[4] **(Figure 9)**.
- The fuel tank was empty.

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[3] A European Union (EU) directive which sets out minimum technical, safety and environmental standards for boats between 2.5m and 24m being traded in Europe (see paragraph 1.8.2).

[4] *Love for Lydia*'s throttle lever had a degree of 'play' in its movement. Consequently, when it was positioned 'as found' the engine speed varied between 2400 and 3000rpm.

- The fuel filler cap located on the starboard side had been unscrewed **(Figure 10)**.
- A ‘shore power’ lead was coiled on the port side of the aft seating area. The ‘inboard’ end of the lead was plugged into the boat’s supply socket **(Figure 10)**.
- The switches on the electrical distribution panel in the galley for the fridge, internal lights and domestic water pressure pump were in the ‘on’ position **(Figure 11)**.
- The boat’s batteries were in a discharged condition.
- There were no carbon monoxide alarms on board.

Figure 9: Helm position

- A folder of documents was carried that contained a Mercury Mercruiser Operation, Maintenance and Warranty Manual that highlighted the dangers associated with CO poisoning from engines **(Annex A)**. The manual stated:

  Under certain running and/or wind conditions, permanently enclosed or canvas enclosed cabins or cockpits with insufficient ventilation may draw in carbon monoxide. Install one or more carbon monoxide detectors in your boat.

  Although the occurrence is rare, on a very calm day, swimmers and passengers in an unclosed area of a stationary boat that contains or is near a running engine may be exposed to a hazardous level of carbon monoxide. [sic]

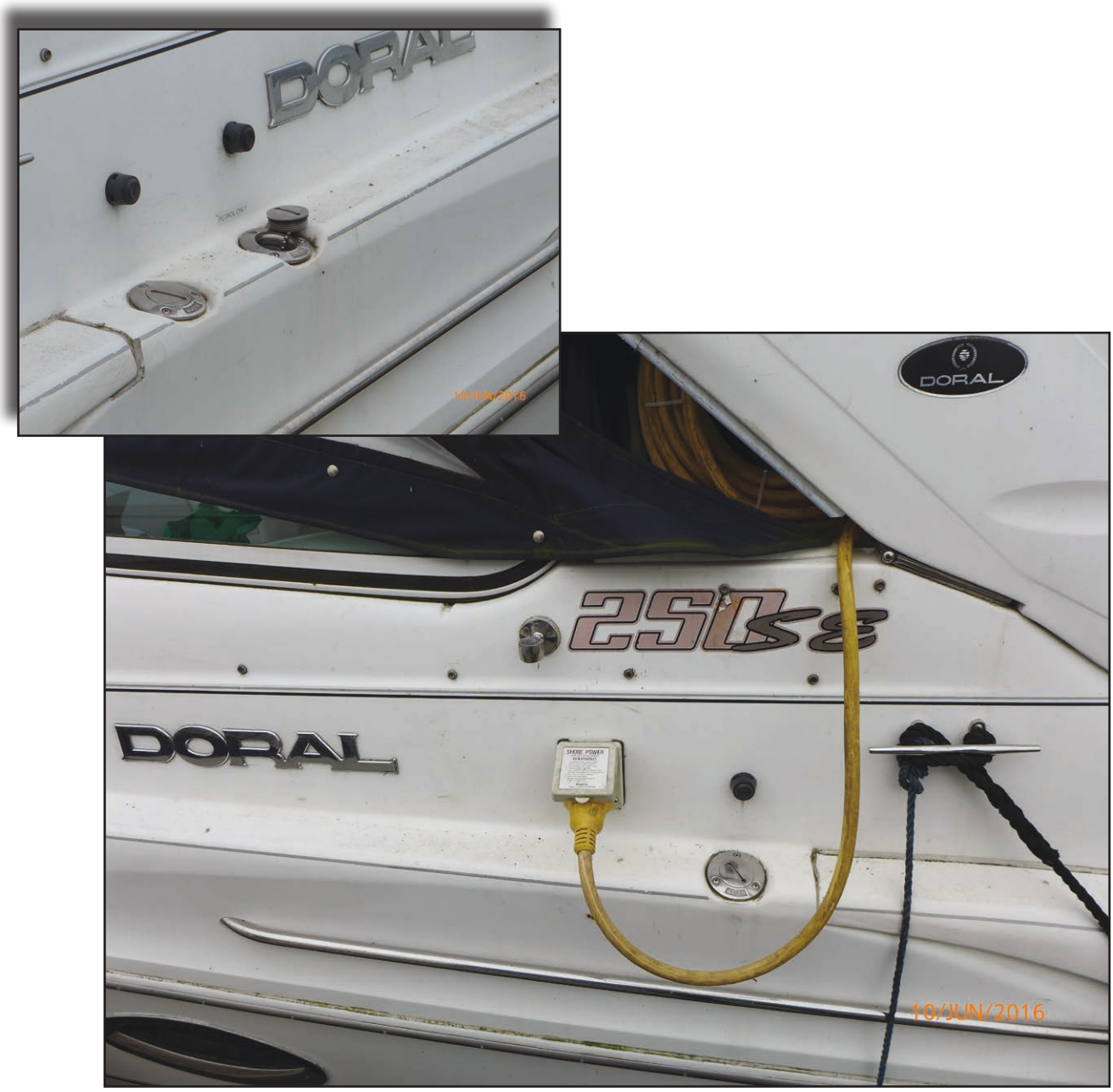


Figure 10: Shore cable and fuel tank cap

Figure 11: Power distribution panel

1.6 PRACTICAL TESTS

1.6.1 Initial assessment

In order to establish the condition and operation of *Love for Lydia*'s onboard electrical systems and main engine, MAIB inspectors charged the vessel's batteries using its shore power supply lead. Unleaded petrol was put into the vessel's fuel tank and the main engine was started. Almost immediately a *MicroClip XT* personal gas monitoring detector placed in the helm area alarmed. This indicated that the concentration of CO had exceeded 200ppm. Two minutes and 32 seconds later, another *MicroClip XT* detector in the forepeak cabin also alarmed.

A second test with the engine running was conducted with a *MicroClip XT* personal gas monitoring detector also placed in the engine bay. The engine bay hatch was closed. The detectors by the helm position and in the forepeak again alarmed within 3 minutes of the engine being started; the device in the engine bay did not alarm until 2 minutes later. No exhaust leaks were found.

1.6.2 Further tests

Between 12 and 14 September 2016, further tests were conducted on board *Love for Lydia* at the Broads Authority boatyard near Norwich **(Figure 12)**. In addition to MAIB inspectors, representatives from the BSS and the Broads Authority also attended. The purpose of the tests was to:

- Accurately measure the concentrations of CO in the helm and forepeak cabin while the engine was running.

- Monitor the passage of CO from the external ‘wet’ exhaust to the boat’s interior.
- Identify the consequences of different canopy configurations on the accumulation and retention of CO inside the boat.
- Examine the effect of ventilation[5] on the levels of CO present in habitable areas.

For the tests, Dräger X-am 5600 Multi Gas Monitors with data-logging capability[6] and *Fireangel CO-9D*[7] domestic CO alarms were placed in the helm area and the forepeak cabin. A Dräger monitor was also placed external to the boat, either on the jetty or on an adjacent boat. In addition, a forward looking infrared camera (FLIR)[8] was used to monitor and record the flow of the CO and a remote stop switch was fitted for the main engine.

Figure 12: Set-up for field tests

[5] Ventilation in the context of this report means the configuration of openable windows, port holes, hatches and canopy side screens etc

[6] Supplied and operated by Inspectahire Instrument Company Ltd. The monitors recorded levels up to 2000ppm.

[7] The *FireAngel CO-9D* alarm will sound; between 60 and 90 minutes when exposed to a minimum of 50ppm of CO. Between 10 and 40 minutes when exposed to a minimum of 100ppm of CO. Within 3 minutes when exposed to a minimum of 300ppm of CO (see **Table 2**).

[8] The FLIR was supplied and operated by FLIR Systems Ltd. FLIR OGI (Optical Gas Imaging) cameras use advanced thermal camera technology to be able to visualise gas. Many gases absorb infrared radiation at different wavelengths and FLIR OGI cameras are tuned and filtered to visualise this absorption specific to different gases. The background infrared energy is absorbed by the gas and the camera is able to visualize the absorption and the motion of the gas. The greater the energy background difference, the more efficient the technique. Motion of the gas is very important and utilising the camera’s HSM (High Sensitivity Mode), which is a real time frame subtraction technique, greatly enhances the gas visualisation and how it disperses in atmosphere.

Fifteen independent tests were conducted with the engine running at different engine speeds up to 3000rpm and with various canopy, ventilation and relative wind configurations. Between the tests, *Love for Lydia*'s internal spaces were mechanically vented to 0% CO baseline. The results of the tests are at **Annex B**.

The key findings were:

- In the 'as found' condition with an engine speed of 3000, the concentration of CO in the helm position reached over 2000ppm within 39 seconds. Similar levels were recorded in the forepeak cabin within 8 minutes **(Figures 13)**. At 600rpm, the concentration of CO reached 600ppm within 50 seconds in the helm area and 450ppm in the forepeak cabin within 10 minutes.

- Ventilation was fundamental in ensuring that levels of CO in the habitable spaces were kept to a minimum **(Figures 14)**.

- The spread and accumulation of CO were influenced by the canopy and ventilation configurations and by the relative wind direction.

- Moderate to high levels of CO were recorded on the adjacent jetty and in the boat moored astern **(Figure 13** and **14** and **Annex B)**.

- The *Fireangel CO-9D* domestic alarms accurately warned of the presence of CO before a potentially fatal concentration had accumulated.

- The FLIR camera was able to visualise the passage of CO from the wet exhaust into the boat. A recording taken during the tests can be viewed at https://youtu.be/ko77jFmGurA.

1.7 CARBON MONOXIDE POISONING

1.7.1 Sources of CO

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 barbecues all have the potential to cause CO poisoning, particularly if they are incorrectly installed, poorly maintained or used inappropriately.

1.7.2 Mechanism

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[9] to form COHb, and this 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.

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

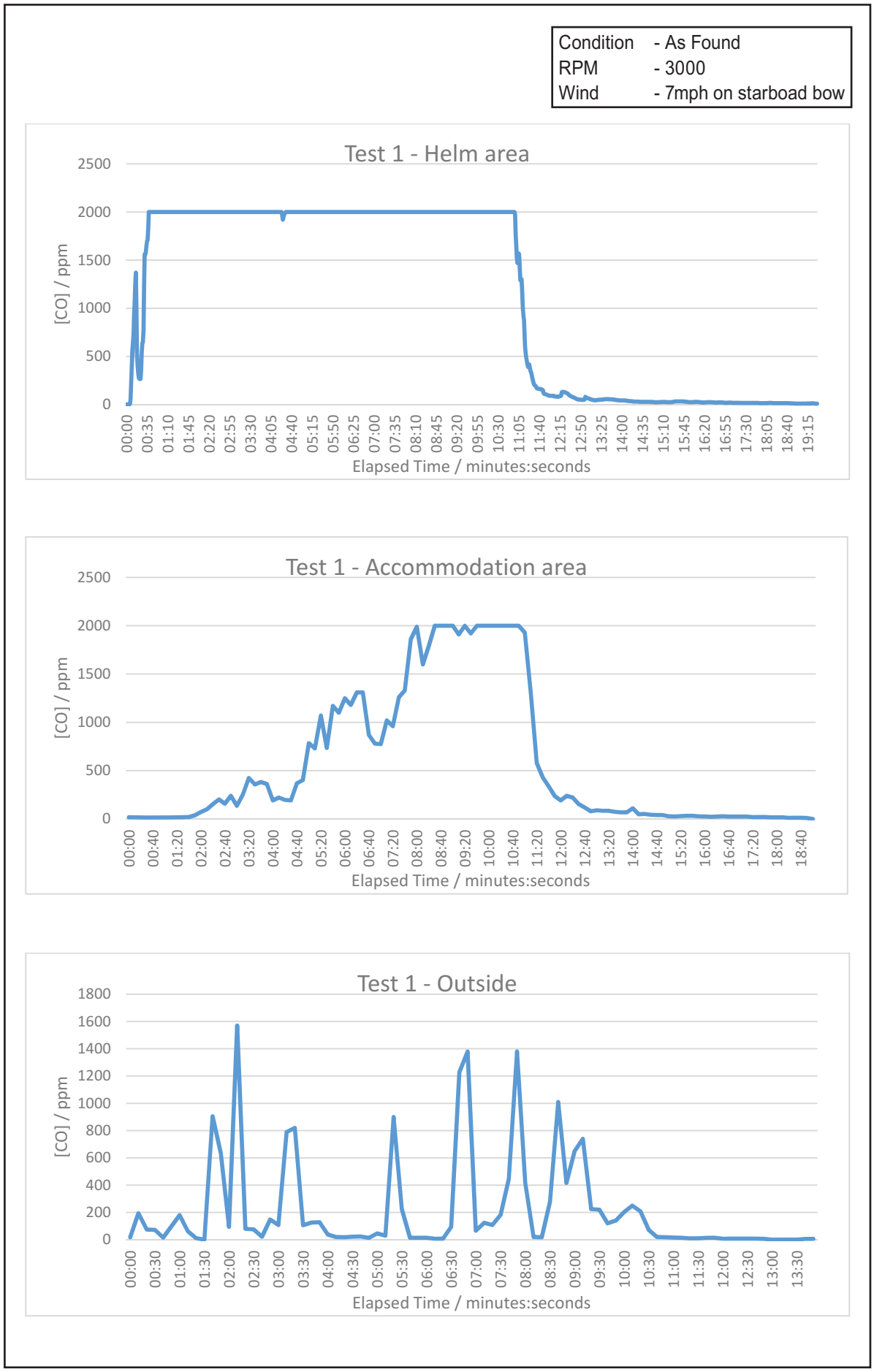
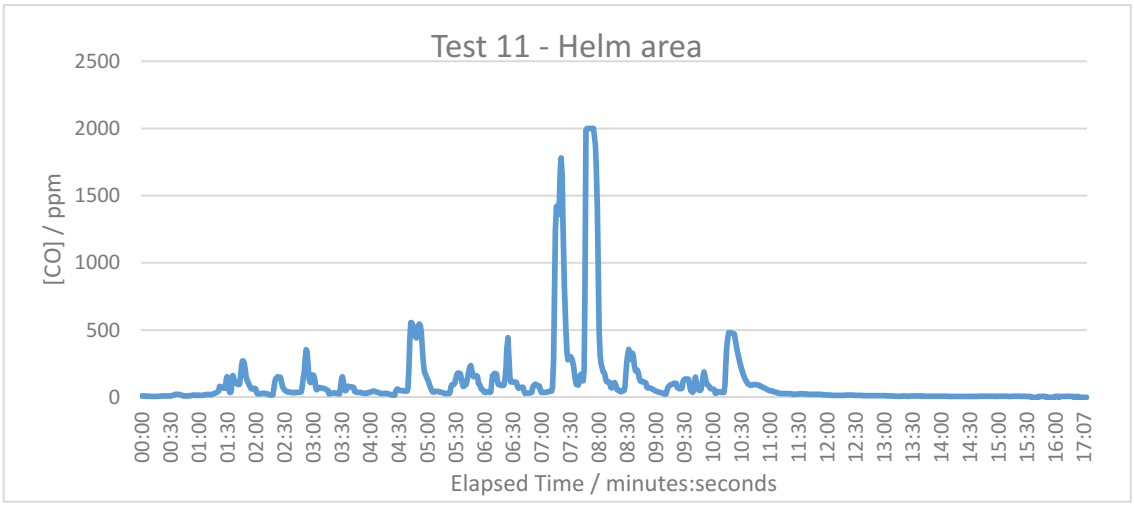
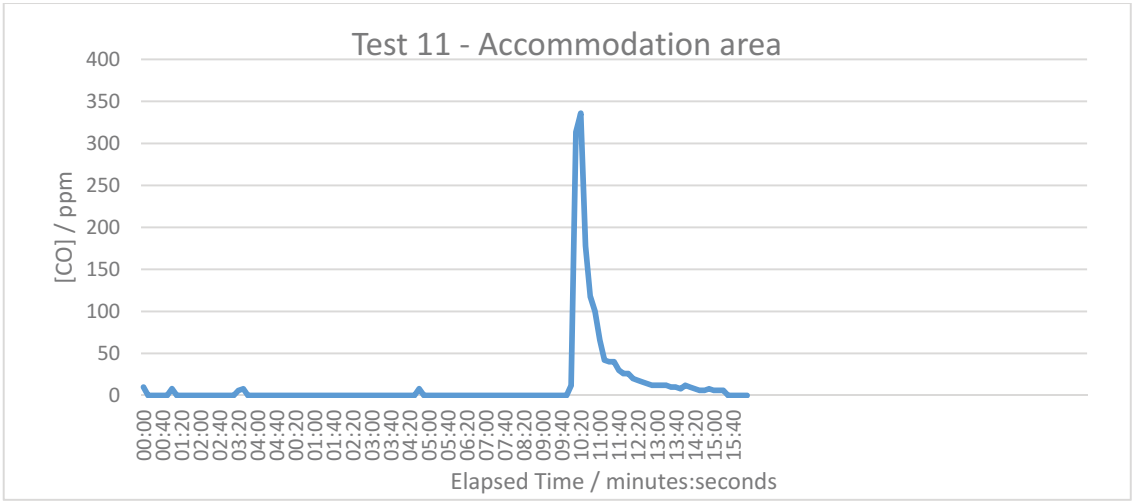


Figure 13: Test result – Test 1

Condition	- Hatch and side vents open
Canopy	- On
Wind	- 5mph fine on port bow





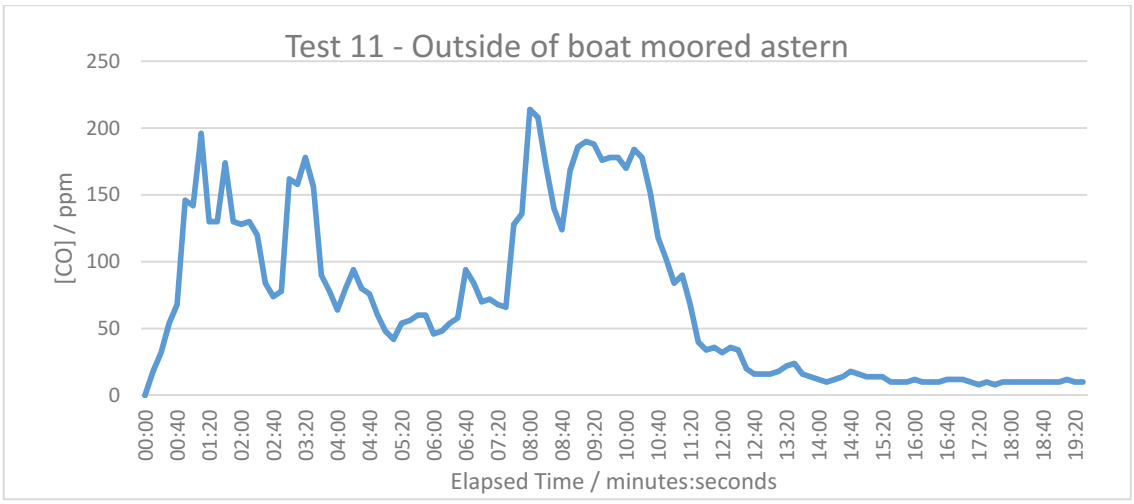


Figure 14: Test result – Test 11

1.7.3 Symptoms

In high concentrations, CO poisoning will result in death. However, in lower concentrations, CO poisoning causes illness. The effects of CO poisoning on adults is shown at **Figure 15**. The most recognisable symptoms are:

- Headaches
- Vomiting
- Tiredness and confusion
- Stomach pain
- Shortness of breath and difficulty breathing.

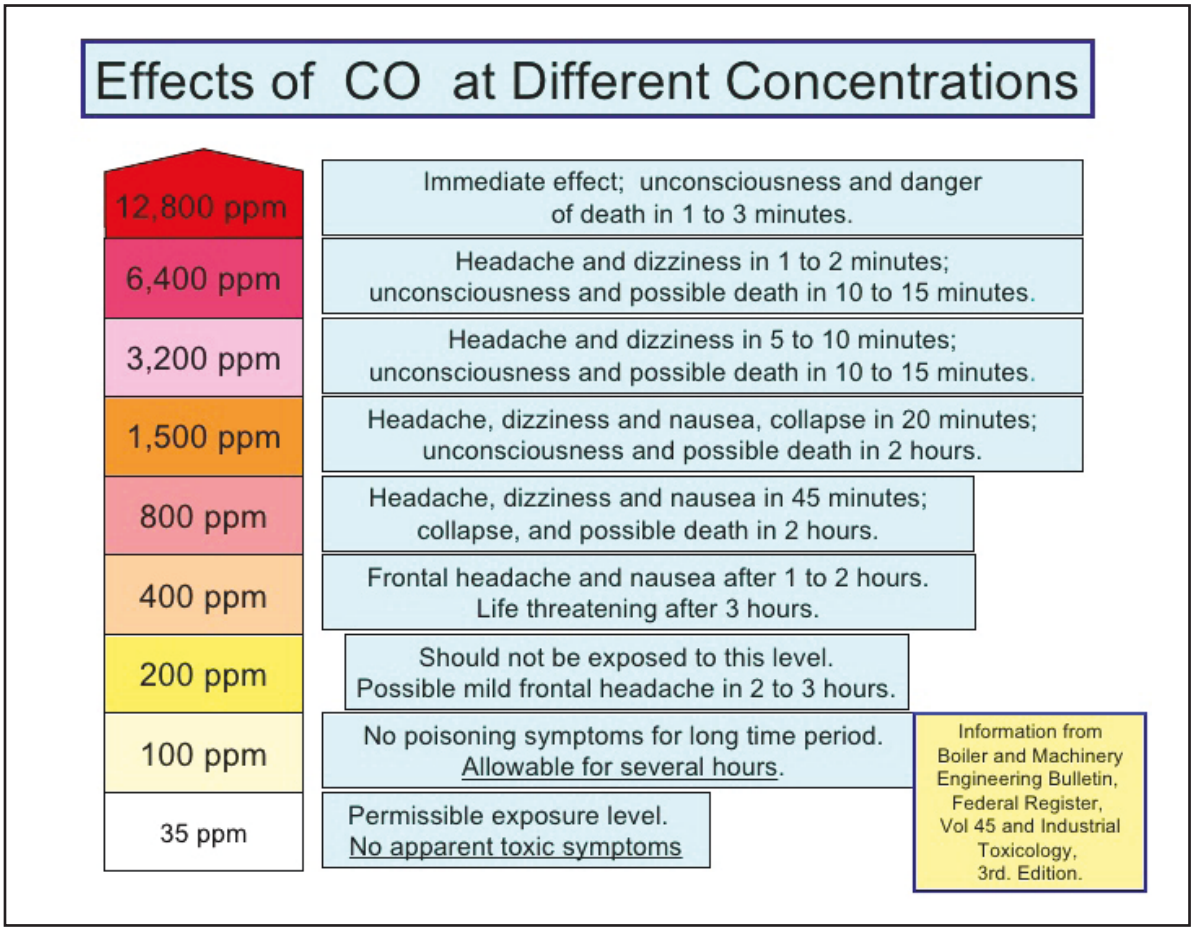


Figure 15: Effects of CO at different concentrations

1.7.4 Incidence

Department of Health statistics from 2013 show that around 40 people in the UK are killed by accidental CO poisoning each year. At least a further 4,000 people are treated for CO poisoning in hospital. In 2013, the Department of Health and Public Health England advised that *"whilst a considerable number of people die from accidental acute CO poisoning, it is now confirmed many more are injured by sub-lethal exposure. It is likely that the true number exposed in this way is even greater than reported."* CO poisoning is very difficult to diagnose because symptoms are often similar to common illnesses like flu, food poisoning or a hangover.

1.7.5 Exposure limits

The Health and Safety Executive (HSE) advises that the time-weighted average CO exposure limits for workers are 30ppm for long term exposure (8 hours) and 200ppm for short term exposure (15 minutes).

1.8 CO ALARMS

1.8.1 Standards and guidance

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 means of: 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[10] standard for CO alarms, only electrochemical sensors are used today. All compliant CO alarms require a continuous power supply so if power is lost, or the batteries fail or are removed, then the alarm becomes ineffective.

The set points at which alarm indicators and audible alarms must operate simultaneously to comply with the safety standard EN 50291-1 are replicated at **Table 2**.

CO concentration	Alarm must **not** activate before	Alarm must activate before
30 ppm	120 min	-
50 ppm	60 min	90 min
100 ppm	10 min	40 min
300 ppm	-	3 min

Table 2 - EN 50291-1 alarm conditions

Once activated the alarm should continue to operate at carbon monoxide concentrations above 50ppm. CO detectors intended for use in a marine environment are required to meet the more rigorous safety standard EN 50291-2[11].

A list of CO alarms that meet EN 50291-2 is provided by the Council of Gas Detection and Environmental Monitoring (CoGDEM) **(Annex C)**. A leaflet produced by the BSS[12] and the CoGDEM titled *'Carbon monoxide safety on boats'* **(Annex D)** is aimed at, among other things, raising the awareness of the dangers and symptoms of CO. It also gives advice on CO alarm placement.

[10] 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.

[11] 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.

[12] See paragraph 1.11.

1.8.2 CO alarm requirements on board recreational craft

In the UK, recreational craft are not required to be fitted with CO alarms. Directive 94/25/EC (known as the Recreational Craft Directive (RCD)) was introduced in 1998 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 2003/44/EC. In November 2013 Directive 94/25/EC was repealed and replaced with Directive 2013/53/EU. 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 waters for touristic reasons. The meeting of the essential safety 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.

1.8.3 CO alarm regulations in dwellings and 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 that 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.

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

[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.

The Smoke and Carbon Monoxide Alarm (England) Regulations 2015 came into force on 1 October 2015 and require private sector landlords to have at least one smoke alarm installed on every storey of their properties and a carbon monoxide alarm in any room containing a solid fuel burning appliance (e.g. a coal fire, wood burning stove). The landlord must make sure the alarms are in working order at the start of each new tenancy.

1.9 STATION WAGON EFFECT

'Station wagon effect' is a phenomenon in which emissions from a boat's exhaust accumulate behind the boat or travel back into the boat due to pressure differential, usually when the boat is underway **(Figure 16)**. As a result, CO spreads into habitable spaces.

Figure 16: Diagram showing 'station wagon effect'

'Station wagon effect' has been extensively researched in the USA by the National Institute for Occupational Safety and Health. In its report of January 2006; *In-depth Survey Report of Carbon Monoxide Emissions and Exposures on Express Cruisers Under Various Operating Conditions*[15] the Institute concluded:

- When the canvas is deployed and boat is underway, CO concentrations exceeded the immediately dangerous to life and health (IDLH) level[16] near the swim platform for many of the evaluated boats.

[15] https://www.cdc.gov/niosh/surveyreports/pdfs/289-11a.pdf

[16] The IDLH concentration tables are values used by the National Institute for Occupational Safety and Health (NIOSH) to aid respirator selection criteria in order to protect workers.
The Occupational Safety and Health Administration defines an IDLH value in its hazardous waste operations and emergency response regulation as follows: *An atmospheric concentration of any toxic, corrosive or asphyxiant substance that poses an immediate threat to life or would cause irreversible or delayed adverse health effects or would interfere with an individual's ability to escape from a dangerous atmosphere* [sic].

- The combination of travel at low speeds into the wind with the canvas fully deployed and no forward hatches, windows or front panels opened maximized the station wagon effect, pulling significant amounts of CO into the cockpit.

- Different exhaust configurations have a major impact on how CO concentrations are entrained into the cockpit and other occupied areas. Accordingly, boats equipped with underwater exhaust exhibited significantly lower CO concentrations than vessels equipped with other exhaust designs.

- CO concentrations are typically higher at the stern of the boat and become gradually lower toward the front of the boat.

- Stationary smoke tests in the engine compartment showed satisfactory sealing of the bulkhead between the engine and adjacent compartments on all boats.

The report also made a number of recommendations including:

- *Because of the station wagon effect, some canvas configurations should not be used while boat is moving or propulsion and/or generator engines are running.*

1.10 RECENT SIMILAR ACCIDENTS

1.10.1 Recreational craft

Drunken Duck

In March 2007, a couple and their dog were found dead on their narrowboat at Norbury Junction, Staffordshire. The cause of death was CO poisoning. At the Coroner's inquest, it was identified that the couple were running the boat's engine to charge the batteries for domestic power and that its air vents had been taped up to conserve heat. The Coroner stated at the inquest, "*I will write to the Boat Safety Scheme to ask if there should be some sort of reminder or warning about ventilation and carbon monoxide when people renew their safety certificates*."

Arniston (MAIB report 2/2015)

On 1 April 2013, a mother and her 10-year-old daughter were fatally poisoned by CO on board the Bayliner 285 motor cruiser *Arniston* on Windermere. The MAIB investigation report identified that the deceased were overcome by fumes from a portable generator which had been started to power a fan heater. The generator was installed in the engine bay and had been modified by the addition of an exhaust that subsequently failed, allowing the small sleeping area to fill with a lethal level of carbon monoxide. The boat's occupants were not alerted to the presence of CO because the alarms fitted on board at build were not working and had been disconnected from the power supply.

The report's recommendations included:

To the Department for Business, Innovation and Skills (BIS):

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.*

To the BSS, Maritime and Coastguard Agency (MCA), Royal Yachting Association (RYA), British Marine Federation (BMF), CoGDEM and the Association of Inland Navigation Authorities (AINA):

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 BSS was also 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.*

BIS did not accept its recommendation on the basis that the RCD would not be revised for some years and that any action would require agreement at a European level.

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.

Unnamed motor cruiser

In March 2016, the owner of a small motor cruiser collected his boat after having a canopy fitted on the aft deck. During the passage home, the CO alarms activated, so the owner stopped and ventilated the boat. It is almost certain that the concentration of the CO was due to the addition of a canopy and 'station wagon effect'. Following the incident, the canopy's manufacturer started to supply a CO alarm free of charge with every canopy it provided.

Vasquez

The MAIB is conducting an investigation of a fatal accident that occurred on the privately owned cabin cruiser *Vasquez* **(Figure 17)** at Cardiff Yacht Club on 12 November 2016. Shortly after midday the boat's owner was found collapsed on the boat and, despite the efforts of fellow club members and emergency services, he did not regain consciousness.

Figure 17: *Vasquez*

The boat was secured to a club pontoon, the inboard petrol engine was running and the canvas cockpit canopy was fully closed except for one zip that was not fastened. Approximately 45 minutes after the owner had started the engine, he was discovered collapsed in the cabin. Two club members boarded the boat and began to administer cardio-pulmonary resuscitation (CPR). Paramedics arrived and immediately recognised that the rescuers were displaying symptoms consistent with CO poisoning. The paramedics removed the canopy and continued to administer CPR to the owner.

The owner was transported to hospital but was later pronounced deceased. Both rescuers were confirmed as suffering from CO poisoning and treated in hospital. Initial MAIB tests showed high levels of CO inside the cockpit with the engine running. The boat was not fitted with a CO alarm.

1.10.2 Fishing vessels

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 how high concentrations of CO can 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.

Eshcol (MAIB report 14/2014)

The MAIB investigated the death of two young fishermen in Whitby harbour in January 2014. The fishermen had returned from a fishing trip and had slept on board their vessel, *Eshcol*. 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.

The investigation report included a recommendation to the MCA to:

120/2014 *At the earliest opportunity, include in the Code of Practice for the Safety of Small Fishing Vessels a requirement for a carbon monoxide detector to be fitted in the accommodation on all vessels.*

The MCA accepted the recommendation. It is anticipated that a requirement for CO alarms to be fitted on board small fishing vessels will be included in the next revision of the Code of Practice, which is scheduled for October 2017.

1.11 BOAT SAFETY SCHEME

1.11.1 Description

The BSS is a public safety initiative owned by the Canal & River Trust and the Environment Agency. 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 the Broads Authority, 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 liquid petroleum gas (LPG) cylinders.

The condition of outboard and portable combustion engines and portable fuel systems is checked during BBS boat examination. Due to its remit, the BSS cannot require boats to be fitted with a CO alarm. However, the BSS and British Marine (BM) (formerly BMF) have agreed that hire boats operating on inland waterways that have a solid fuel stove installed must be fitted with a CO alarm. This requirement is scheduled to become effective from April 2017.

1.12 CO AWARENESS INITIATIVES FOR RECREATIONAL CRAFT

1.12.1 Trusted messenger initiative

In response to the MAIB recommendation 2015/104 contained in the *Arniston* safety investigation report (see paragraph 1.10.1), the BSS has developed a 'Trusted Messenger Initiative', which it intends to introduce on 1 April 2017. The aim of the initiative is for BSS boat examiners to:

- Collect data on CO alarms on board boats being examined.
- Engage with boat owners and share information on CO poisoning and CO alarms in order to try and influence behaviour.

During boat examinations, boat owners will be given a copy of the '*CO Safety on Boats*' leaflet **(Annex D)**, which will incorporate a CO safety checklist for the boat owner to complete. The checklist is intended to raise the awareness of boat owners to the dangers of CO and to identify areas of risk that can be discussed with boat examiners. However, boat examiners are not obliged to carry out additional checks.

1.12.2 Co-ordinated efforts

In response to MAIB recommendation M2015/103 contained in the *Arniston* investigation report (see paragraph 1.10.1) that was intended to raise the awareness of the dangers of CO and the importance of CO alarms among leisure boaters, the MCA, BSS, RYA, BMF, CoGDEM and AINA met on 1 April 2015 to discuss a way forward. The meeting was chaired by the MCA and the attendees identified a number of aims, a potential research project and further partners. The group also discussed a need for a remunerated full-time project leader working to clear terms of

reference. It was agreed that the MCA would continue to chair subsequent meetings but that some of the group's work could be undertaken by correspondence. No further meetings were held prior to the deaths on board *Love for Lydia*.

1.12.3 Bids for funding

To finance the appointment of a project leader to initiate and manage a CO awareness campaign targeted at the owners of recreational craft, the BSS in partnership with the Chief Fire Officers Association (CFOA) applied for a grant of £35,000 from the Gas Safe Charity[17]. The application was rejected on the grounds that the charity's trustees did not feel that enough work had been done to identify those most at risk in the boating community or the most effective means of contacting and advising them.

The BSS also applied to the Gas Safe Trust[18] for funding in support of two further initiatives. The first was for £40,000 to establish a CO monitoring project to collect risk data that could be used to support future research bids. The second was for £80000 to fund a 3-year PhD research project in behavioural science at Reading University to "*help establish and improve the effectiveness of boat CO safety awareness, the methods of delivery and the methods to maintain safe behaviour.*" Neither application has yet been accepted.

1.12.4 Other initiatives

In addition to BSS and CoGDEM, a number of other organisations have been involved in increasing awareness of the dangers of CO and the use of CO alarms in the marine environment. The RYA has published safety advisory notes covering the dangers of CO and has attempted to raise awareness of the membership through its website and magazine. The Gas Safe Register and the United Kingdom Liquefied Petroleum Gas (UKLPG) have also promoted the dangers of CO poisoning via poster campaigns.

1.13 CARBON MONOXIDE GROUP

The All-Party Parliamentary Carbon Monoxide Group (APPCOG) is the leading forum for Parliamentarians from both the House of Commons and the House of Lords and for stakeholders to work together to discuss ways of tackling CO poisoning, to improve government policy on CO safety, and to raise public awareness of the threat posed by CO. In January 2015, APPCOG met and discussed with various industry stakeholders the CO poisonings on board the pleasure craft *Arniston* in 2013 and on board the fishing vessel *Eshcol* in 2014 (paragraph 1.10).

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[17] The Gas Safe Charity awards grants to support gas safety initiatives that can make an impact at local and national levels. Such grants help to fund either gas safety messaging or practical activities. The purpose of the funding is to make more vulnerable people feel safer, and to reduce the causes of gas poisoning, fires and explosions.

[18] The Gas Safety Trust was established in 2005 as a registered charitable body and is the UK's leading gas safety research charity with the key objectives of further improving gas/fossil fuel safety for the public and industry throughout the UK and reducing the incidents of death and serious injury from CO exposure. The Trust does this through the funding of research and data collection relating to CO poisoning. Since 2013, the Gas Safe Trust has awarded £1.5 million in grants to wide-ranging organisations that meet its chosen areas of focus, which includes low level exposure, medics' understanding and awareness, and leisure activities.

Also, in January 2015, APPCOG published a 92-page report, entitled '*Carbon Monoxide: From Awareness to Action*'. The report was the result of a 9-month inquiry chaired by Baroness Finlay of Llandaff and Dr Rachel McCloy, Director of the Centre for Applied Behavioural Science at the University of Reading.

The inquiry found that in order to ensure the effectiveness of CO safety efforts several factors are vitally important, including awareness raising, data collection, context and messengers. These factors heavily influence the extent to which safety messages reach and are understood by those at risk. However, the report warns that approaches towards promoting CO safety that rely too heavily on general public awareness raising may on their own prove 'insufficient' to ensure those at risk are adequately protected. Therefore, to increase the effectiveness of those working hard to prevent CO poisoning incidents the inquiry promotes the use of behavioural science.

The report made more than 20 recommendations, including:

> *The Department for Communities and Local Government should second a full-time staff member to coordinate activity within the department for carbon monoxide, and to provide the Cross Government Group on Gas Safety and CO Awareness with a dedicated person to lead and promote coordination of activity and resources.*
>
> *The Maritime and Coastguard Agency, in line with the 2014 'Eshcol' Marine Accident Investigation Branch Report, should include in the Code of Practice for the Safety of Small Fishing Vessels a requirement for a Standard-compliant carbon monoxide alarm to be fitted in the accommodation on all vessels. Similar requirements should be carried over to vessels used on inland waterways, including those for hire and other purposes, regardless of the fuel type used on board.*

1.14 THE BROADS

The Broads is a network of lakes (broads) in Norfolk and Suffolk formed by flooded peat works and joined by rivers. There are over 120 miles of navigable waterways comprising seven rivers and 63 broads.

In 1989, the Broads Authority was set up as a statutory body and has three primary functions:

- Protecting the interests and safety of navigation.
- Conserving and enhancing the natural beauty, wildlife and cultural heritage of the Broads.
- Promoting opportunities for the understanding and enjoyment of the special qualities of the Broads by the public.

Enforceable byelaws within the Broads include:

- Navigation Byelaws 1995
- Speed Limit Byelaws 1992

- Vessel Dimension Byelaws 1995
- Vessel Registration Byelaws 1997.

The byelaws concern the conduct of navigation and, among other things, measures relating to public moorings, obstructions, navigation by minors, conduct following an incident, navigating under the influence, firearms and weapons in the navigation area and safe speed.

Around 23,000 boats per year use the Broads, which has speed limits in place of between 3mph and 6mph. The speed limits are clearly indicated on riverbanks.

Ten full-time rangers are employed by the Broads Authority to patrol five main areas of the Broads all year round. The full-time rangers are assisted by seasonal rangers and volunteers during the summer period. The Authority has eight patrol launches, a fast rigid inflatable boat (RIB) and two dories. The rangers enforce speed limits, safe navigation and mooring regulations. Rangers also educate Broads users about navigation, safety procedures and tidal conditions. They liaise with local emergency services and respond to issues concerning pollution and oil spills.

All vessels used for more than 28 days on the Broads are required to be registered annually with the Broads Authority. A valid BSS certificate is a condition of registration for vessels with engines and/or cooking, heating, lighting, refrigerating and other domestic appliances.

Norfolk Constabulary's 'Broadsbeat' team are serving police officers who are trained in boat-handling and first-aid; they patrol the Broads from Easter until October each year. The team offer high visibility policing, reassurance and assistance to both local people and visitors to the Broads as well as dealing with a variety of anti-social and criminal activities, and assisting the Broads Authority in enforcing local byelaws.

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

Alan Frost and Tina Wilkins died from CO poisoning; the levels of COHb in their blood were over 67%. The MAIB tests (paragraph 1.6 and **Annex B**) show that the CO came from *Love for Lydia*'s Mercury Mercruiser engine exhaust emissions, which contained high concentrations of the gas **(Table 1)**. The only other potential source of CO was the small kettle barbecue on the riverbank, which was in the open air and 1.5m clear of *Love for Lydia*.

Love for Lydia's empty fuel tank and the positions in which its engine ignition key, engine run switch and throttle were found, indicates that the engine had been running at between 2400rpm and 3000rpm until it ran out of fuel. With the forepeak cabin port holes and hatch closed and the aft deck covered by its canopy **(Figure 3)**, the engine emissions from the 'wet' exhaust were able to propagate through the gap under the bench seat and the open section of the canvas canopy on the port quarter. They then quickly spread through the aft deck to the helm area and into the forepeak cabin **(Figure 13)**. During the MAIB tests, a CO concentration of at least 2000ppm accumulated in the forepeak cabin within 8 minutes. In such conditions, it is likely that the deceased would have been quickly overcome **(Figure 15)**.

2.3 THE RISK FROM ENGINE EMISSIONS

There are typically a number of potential sources of CO on board recreational craft, including gas cookers, gas, oil and solid fuel heaters and internal combustion engines. The risk of CO poisoning from domestic appliances and from engine exhaust leaks inside a boat might be apparent, but the risk from external engine exhausts is less so. The assumption being that the exhaust fumes vent to open air and dissipate.

There was no shore power available on Wroxham Island and it is likely that *Love for Lydia*'s engine was being run in order to charge the boat's 12v batteries. The V8 petrol engine, like those fitted on many other motor cruisers built in the USA, was large and powerful, capable of driving the boat to a top speed of 40 knots. Consequently, its suitability for permanent use on the Broads, where the speed limit was 6mph, was questionable. Moreover, the engine's exhaust gases were also un-catalysed so their CO content **(Table 1)** was higher than usually found in the emissions of diesel and catalysed petrol engines. The level of emissions would have been even higher at faster engine speeds, particularly as the engine was 16 years old.

The circumstances of this case, the MAIB tests **(Annex B)** and the research into 'station wagon effect' (paragraph 1.9) show that there is significant risk of CO poisoning from externally emitted exhaust fumes, particularly from large un-catalysed petrol engines. If the internal spaces of a boat are not adequately ventilated, the risk exists when a boat is stationary or underway and varies

according to the size and fuel type of the engine fitted. In static situations, it also extends to the occupants of boats moored nearby. During the MAIB tests, the concentrations of CO on board the adjacent boat exceeded the long-term exposure limits set by the HSE (paragraph 1.7.5), and had the potential to cause illness.

The risk of CO poisoning from *Love for Lydia*'s engine's exhaust emissions was recognised in the Mercury Mercruiser manual **(Annex A)**, which warned of the dangers when the boat was stationary and underway. The manual also highlighted the need to keep the boat ventilated and the importance of fitting a CO alarm. It is possible that, like many boat owners, the deceased had not read the manual and was unaware of the danger and of the precautions to be taken.

2.4 THE IMPORTANCE OF VENTILATION

The MAIB tests **(Annex B)** showed that good ventilation was pivotal in preventing the harmful concentrations of CO from accumulating in boats' habitable spaces. Indeed, the provision of *adequate ventilation* is an essential requirement of the RCD (paragraph 1.8.2).

However, there is a tendency for the risk of CO poisoning and the importance of ventilation to be overlooked or ignored on board recreational craft, particularly in cold weather. In all of the recent similar CO poisonings on boats that the MAIB is aware of (paragraph 1.10), the spaces in which the deceased were found were poorly ventilated. In addition, in the cases of *Arniston* and *Eshcol*, the sources of the CO had been appliances used to provide heat. Between 7 and 9 June, when *Love for Lydia* was probably moored at Wroxham Island, the air temperature was between 10°C and 14°C. Although this was not cold, it would have discouraged the opening of the forepeak cabin port holes or hatch and made the use of the canopy more likely.

Love for Lydia's canopy extended the boat's enclosed spaces towards its stern. In doing so, it trapped the CO emissions from the 'wet' exhaust and enabled them to spread into the forepeak cabin. Similar consequences could potentially result on board the many other small motor cruisers where canopies are fitted. The 'station wagon effect' experienced on board the unnamed motor cruiser in paragraph 1.10 is a case in point.

2.5 CO ALARMS

2.5.1 Requirement

On board *Love for Lydia*, the benefit of installing a CO alarm was not readily apparent as the engine was the only source of CO and the gas was emitted via the external 'wet' exhaust. The deaths of the boat's occupants and the MAIB tests **(Annex B)** show that these emissions were lethal. The MAIB tests also demonstrated that the domestic CO alarm fitted on board *Love for Lydia* prior to the tests quickly warned of the CO accumulation inside the boat.

In the UK, there is no requirement for recreational craft, including those intended for overnight sleeping, to be fitted with a CO alarm. New craft are built to meet the RCD's essential requirements that rely on elements of design to prevent exhaust gases reaching accommodation areas. However, other than ensuring that habitable spaces can be ventilated and internal exhaust leaks are isolated and contained, the

essential requirements do not protect occupants from other sources of CO such as external exhaust emissions. Consequently, it is regrettable that BIS rejected MAIB recommendation 2015/102 (paragraph 1.10.1) that aimed to address this regulatory deficiency. CO kills as effectively on a boat as it does in a home or a caravan, and 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, new dwellings and rented properties.

The forthcoming initiative from the BSS and BM to require the fitting of CO alarms on board hire craft operating on inland waterways is a positive measure that corresponds with the requirements for rented property. However, the number of CO-related fatalities on UK waterways (paragraph 1.10) indicates that further action is warranted. Mandating the fitting of CO alarms on board recreational craft is currently outside the requirements of the BSS, although the potential for a boat's exhaust emissions to poison the occupants of other boats moored nearby is arguably within its remit (paragraph 1.11.1). A requirement by the BSS to fit CO alarms on all recreational craft with enclosed habitable spaces would help to ensure the safety of the occupants of about 70000 leisure craft on inland waterways within 4 years.

2.5.2 Misconceptions and reliability

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 activation of a CO alarm is nearly always due to the presence of CO. 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 tested to a rigorous standard (EN 50291-2). Therefore, boaters should be reassured that such alarms are designed to operate effectively in the harsher environments experienced on board. Stand-alone CO alarms typically 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.

2.6 AWARENESS

CO poisoning is a continuing cause of fatalities and illnesses in the UK (paragraph 1.7.4), and the action required to reduce its incidence has been identified by APPCOG at the national level (paragraph 1.13). Key among these actions is that of raising awareness. Within the context of recreational boaters, several organisations, notably the BSS, CoGDEM and the RYA have been proactive in this respect. Indeed, the BSS 'Trusted Messenger Scheme', which is due to start in April 2017, has the potential to significantly improve CO safety on inland waterways. However, the fatalities on board *Love for Lydia* and *Vasquez* in 2016 show that the dangers of CO are still not fully understood by all leisure boaters.

The size and widespread nature of the UK's leisure boat sector over inland and coastal waters increases the difficulty of raising awareness about the dangers of CO. Therefore, it is disappointing that industry stakeholders, led by the MCA, met only once in response to recommendation *M2015/103* (paragraph 1.10.1) that was intended to co-ordinate a focused campaign. It is also disappointing that the BSS/CFOA bids to secure charitable grants required to fund the project management of the initiative that was identified at the meeting, as well as further research, were unsuccessful. Organisations working together to collect data, share ideas and develop a common strategy are likely to be more effective than individual campaigns. The need to strive for a more co-ordinated approach to raising CO awareness among leisure boaters remains.

Within the leisure boating sector there are numerous stakeholders who could assist in raising leisure boaters' awareness of CO that have yet not been involved in a co-ordinated manner. For example, independent boat surveyors and canopy manufacturers are well placed to advise boaters on the potential sources of CO, the risk of CO poisoning, the importance of ventilation and the utility of CO alarms. Moreover, the adoption of measures such as recommending during surveys that CO alarms be fitted and providing a CO alarm with new canopies (paragraph 1.10.1) would be highly beneficial.

SECTION 3 - CONCLUSIONS

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

1. *Love for Lydia*'s occupants died from inhaling the CO in the exhaust fumes from the boat's main engine. [2.2]

2. The CO from the 'wet' exhaust at the stern of the boat spread under the canvas canopy and into the forepeak cabin where it quickly reached lethal concentrations. [2.2]

3. *Love for Lydia*'s engine was probably running in order to charge the boat's batteries, but the risk of CO poisoning from the external engine exhaust might not have been recognised. [2.3]

4. The eight-cylinder petrol engine's un-catalysed exhaust fumes contained high levels of CO. [2.3]

5. The risk of engine emissions entering the boat's enclosed spaces was significantly increased by 'station-wagon' effect, which can occur when a boat is stationary or underway. [2.3]

6. *Love for Lydia*'s habitable spaces were not adequately ventilated; the forepeak cabin's deck hatch and port holes were shut. [2.4]

7. A domestic CO alarm would have alerted *Love for Lydia*'s occupants to the presence of CO but the boat was not fitted with one. There is no requirement for recreational craft, including those intended for overnight sleeping, to be fitted with a CO alarm. [2.5.1]

8. Other than ensuring the ability to ventilate habitable spaces, the essential requirements of the RCD do not protect the occupants of recreational craft from the CO contained in external exhaust emissions. [2.5.1]

9. Several organisations continue to raise the awareness of leisure boaters to the dangers of CO and the importance of fitting a CO alarm, but a more co-ordinated campaign is warranted. [2.6]

3.2 SAFETY ISSUES NOT DIRECTLY CONTRIBUTING TO THE ACCIDENT THAT HAVE BEEN ADDRESSED OR RESULTED IN RECOMMENDATIONS

1. In recent similar CO poisonings on board recreational craft, the spaces in which the deceased were found were poorly ventilated. [2.4]

2. Without adequate ventilation, the use of canopies and the 'station wagon effect' increase the risk of CO poisoning from external exhaust emissions. [2.4]

3. 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. [2.5.2]

4. The fatalities on board *Love for Lydia* and *Vasquez* in 2016 show that the dangers of CO are still not fully understood by all leisure boaters. [2.6]

5. There is the potential for a boat's exhaust emissions to poison the occupants of other boats moored nearby. [2.5.1]

SECTION 4 - ACTION TAKEN

4.1 MAIB ACTIONS

In August 2016, the **Marine Accident Investigation Branch** issued Safety Bulletin 2/2016 **(Annex E)** to inform leisure boaters of:

- The importance of fitting a carbon monoxide alarm.
- The risks associated with the build-up of CO associated with the use of canopies.
- The hazards of carbon monoxide.

It also published a video showing the rapid spread of CO during the initial assessment on board *Love for Lydia* (https://youtu.be/ZnITXUVYzUY).

4.2 ACTIONS TAKEN BY OTHER ORGANISATIONS

In December 2016 the **Boat Safety Scheme /CoGDEM** amended the leaflet 'Carbon Monoxide Safety on Boats' **(Annex D)** to include a warning that cockpit awnings can act as a funnel to draw engine fumes inside the boat when underway or alongside.

SECTION 5 - RECOMMENDATIONS

The **Maritime and Coastguard Agency** is recommended to:

2017/112 Continue to build on current initiatives by co-ordinating relevant organisations to focus efforts on raising 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, including from other boats.
- The dangers of using inappropriate or poorly installed fossil-fuel burning equipment.
- Recognising the early symptoms of carbon monoxide poisoning.
- The importance of ventilation in habitable areas.

British Marine is recommended to:

2017/113 Seek clarification from the Recreational Craft Sectoral Group concerning whether a requirement to install carbon monoxide detection systems falls within the scope of the RCD's essential requirements, particularly requirement 5.1.1.

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

2017/114 Make the installation of carbon monoxide alarms a requirement for recreational craft participating in the Boat Safety Scheme, taking into account, among other things, the:

- Potential risk posed to other boat users by carbon monoxide-rich engine emissions.
- Various sources of carbon monoxide on board recreational craft.
- Number of recent deaths of recreational boaters caused by carbon monoxide poisoning.
- Relatively low cost of carbon monoxide alarms.

Marine Accident Report

INVESTORS IN PEOPLE