Report on the investigation of the

inadvertent release of carbon dioxide and disabling of

Figaro

off Wolf Rock

6 December 2007

Marine Accident Investigation Branch
Carlton House
Carlton Place
Southampton
United Kingdom
SO15 2DZ

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Extract from

The United Kingdom Merchant Shipping

(Accident Reporting and Investigation)

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

2/O	-	Second Officer
2E	-	Second Engineer
3/O	-	Third Officer
3E	-	Third Engineer
AB	-	Able Seaman
AIS	-	Automatic Identification System
ALB	-	All Weather Lifeboat
BA	-	Breathing Apparatus
C/O	-	Chief Officer
CE	-	Chief Engineer
CO_2	-	Carbon Dioxide
COG	-	Course Over Ground
CPA	-	Closest Point of Approach
CPSO	-	Counter Pollution and Salvage Officer
DPA	-	Designated Person Ashore
EE	-	Electrical Engineer
EEBD	-	Emergency Escape Breathing Device
ETV	-	Emergency Towing Vessel
FSS	-	Fire Safety Systems (Code)
gt	-	gross tons
HMPE	-	High Modulus Polyethylene (rope)
ISM	-	International Safety Management (Code)
kg	-	kilogramme
Kts	-	Knots
kW	-	kilo Watts
MCA	-	Maritime and Coastguard Agency
MCU	-	Master Control Unit
MPA	-	Maritime and Port Authority of Singapore

Nm	-	Nautical miles
PMS	-	Planned Maintenance System
RAF	-	Royal Air Force
RCC	-	Rescue Co-ordination Centre
RNAS	-	Royal Naval Air Station
Ro-Pax	-	Roll on Roll off (passenger ship)
RoRo	-	Roll on Roll off (ship)
rpm	-	Revolutions per minute
SMS	-	Safety Management System
SOLAS	-	Safety of Life at Sea (International Convention)
SVDR	-	Simplified Voyage Data Recorder
TSS	-	Traffic Separation Scheme
TTI	-	Tension Technology International (Ltd)
VDR	-	Voyage Data Recorder
VHF	-	Very High Frequency

All times used in this report are UTC and all courses are true unless otherwise stated

SYNOPSIS

Figaro was preparing to pass through the Traffic Separation Scheme between Lands End and the Isles of Scilly with a cargo of vehicles on 6 December 2007. The weather was poor and the sea was the roughest that the vessel had encountered for some weeks. At 1629, *Figaro* landed heavily in the swell, causing the vessel to shudder. At the same time, CO_2 gas from the fire smothering system was released into the engine room and three of the four cargo zones. Crew in the affected compartments were able to escape without injury, but the CO_2 gas caused the main engine and auxiliary generator to shut down.

The vessel began to drift towards Wolf Rock and the master requested the Coastguard to provide tug assistance. It was apparent that there was a risk of *Figaro* striking Wolf Rock, and the Coastguard mobilised the local lifeboat, an Emergency Towing Vessel (ETV) and put two rescue helicopters on standby.

After an early unsuccessful attempt, the engineers on board *Figaro* were able to restart an auxiliary generator. However, without the main engine, the master decided to accept a tow from the ETV. Maintenance work was being conducted on the forward mooring equipment, which meant that it could not be used to help rig the tow. The ETV was unaware of this and had prepared a heavy steel wire. This could not be handled by *Figaro*'s crew, and the ETV had to move off to re-rig the tow with a lighter man-made line. The lighter tow line was attached successfully, but parted early on in the tow. Fortunately, *Figaro*'s main engine was restarted and the vessel proceeded under its own power.

It was determined that a routine test had been conducted on the CO_2 fire smothering system 2 weeks earlier. This had not been successful and the system had not been properly reset. It was left in an unstable condition, such that movement of only one valve was needed to release 46,000kg of CO_2 to all the protected compartments on board. This valve had been partially activated during the unsuccessful test and was of a type, and in a position, that made it particularly vulnerable to moving under the influence of the ship's motion. It is most likely that the movement of the ship in rough weather caused this valve to open, triggering release of the gas.

The investigation identified that the maintenance instructions for the CO_2 system were contradictory and vulnerable to misinterpretation. The crew of *Figaro* were unfamiliar with the equipment and were unable to recognise the problem that occurred during the routine test, or realise the risk posed by leaving the system in an unstable condition.

The incident also highlighted some areas where ETV procedures could be improved to help maintain the successful reputation that this service has gained.

In view of the actions taken by the managers of *Figaro* and the Maritime and Coastguard Agency (MCA), following the incident, no further recommendations have been made as a result of this investigation.

Figaro

SECTION 1 - FACTUAL INFORMATION

1.1 PARTICULARS OF *FIGARO* AND ACCIDENT

Vessel details

Registered owner	:	Wallenius Lines Singapore Pte Ltd
Manager(s)	:	Wallenius Marine Singapore Pte Ltd
Port of registry	:	Singapore
IMO No.	:	7917563
Flag	:	Singapore
Type	:	Ro-ro Vehicle Carrier
Built	:	1981
Classification society	:	Lloyd's Register
Construction	:	Steel
Length overall	:	198.12
Gross tonnage	:	50681
Engine power and/or type	:	Single, 13500kW B&W 7L80GFCA, driving a single, fixed pitch propeller
Service speed	:	18.2 kts
Other relevant info	:	Single, 1100kW bow thruster

Accident details

Time and date	:	1629 on 6 December 2007
Location of incident	:	49° 53.2 N, 005° 54.6 W, 5nm off Wolf Rock, South of the Traffic Separation Scheme between Lands End and the Isles of Scilly
Persons on board	:	30
Injuries/fatalities	:	None
Damage	:	Release of 46,000kg of CO_2 causing failure of main engine and generators

1.2 BACKGROUND

The vehicle carrier *Figaro* was on passage from the Far East to Europe, via the Suez Canal, with a cargo of cars. The vessel was fitted with a low pressure CO_2 fire smothering system to protect the machinery and cargo spaces. 46,000kg of pressurised and refrigerated CO_2 liquid was stored in two large tanks which, on release, would 'boil off' and expand to generate 25,760m^3 of CO_2 gas to smother fires. A planned test of the CO_2 remote operating system had been conducted some weeks before the incident, but this had not been successful and the system had been partially reset so that it could be operated manually in the event of a fire.

1.3 EVENTS LEADING UP TO THE ACCIDENT

Figaro had transited through the Suez Canal on 26 and 27 of November and called at Alexandria on 28 November. The vessel had then called at Santander on 5 December before passing across the South Western Approaches heading for Avonmouth (Bristol) with an estimated time of arrival of 0600 on 7 December.

1.3.1 Environmental conditions

Weather at the time of the accident was poor, with *Figaro* recording true wind speeds of over 30 kts coming from 245^o. Sea conditions were rough and wave heights of 5.5m from west south west were recorded on board. The tidal stream was initially setting south west at 0.5 kt, but the direction altered during the incident, backing to a south, south westerly set.

1.3.2 Navigational situation

Making good a course of 003^o at a speed of 17.5 kts, *Figaro* was heading for the north bound TSS lane between Lands End and the Isles of Scilly. Traffic was relatively light, and at the time of the incident there were two vessels ahead of *Figaro*, sailing on similar courses. Study of the Automatic Identification System (AIS) data showed that *Figaro*'s speed began to drop at 1629, and by 1637 speed had reduced to 6 kts. Port rudder was used to turn the ship into the prevailing sea and wind, but steerage became less effective as the speed fell and the vessel settled diagonally across the wind, yawing about 15 degrees either side of an average heading of 330^o.

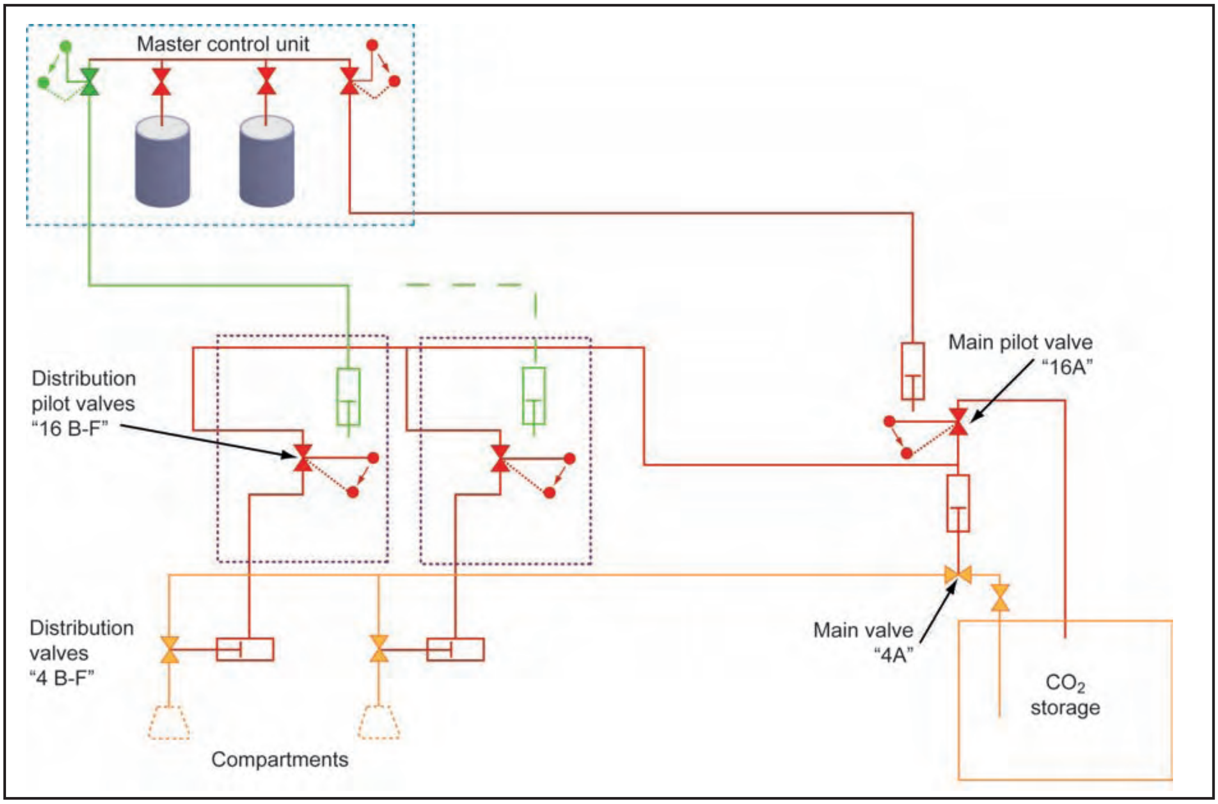
1.4 RELEASE OF CO_2

1.4.1 Routine testing

A routine test of the remote release valves for the CO_2 system was conducted on 22 November 2007 as required by the vessel's Planned Maintenance System (PMS), with the main stop valves on the CO_2 tanks shut. The Chief Engineer's (CE) experience on other vessels, was with high pressure systems, and this was the first time that he had tested a low pressure system. The test was conducted by the electrical engineer (EE), second engineer (2E) and third engineer (3E). The EE operated the Main Control Panel on deck 14, witnessed by the 2E. The 3E was stationed in the CO_2 room on deck 5, to report the movement of system valves. The 2E was new to the vessel and, although the EE and 3E had both worked on specific parts of the system before, neither of them had operated the controls themselves.

A simplified schematic diagram of the CO_2 system is at **(Figure 1)**. The Master Control Unit (MCU) was situated in a compartment on Deck 14 giving remote operation of the CO_2 system. The control panel **(Figure 2)** consisted of five cabinets, each of which

Figure 1



Simplified CO_2 System Schematic Diagram

Figure 2

Master Control Unit (MCU) panel on Deck 14 contained two levers, one for the operation of the main release valve and the other to operate the appropriate distribution valve to divert the gas to the desired compartment. Opening the cabinet door released a micro switch which activated the ship's CO_2 alarm. Two CO_2 pilot cylinders provided gas to operate the remote release system. A third, spare cylinder, was connected to the remote system via a blanking plate for testing and maintenance.

The EE opened all five of the cabinets in sequence and operated the main and distribution valve remote controls. The 3E, stationed in the CO_2 compartment on deck 5, reported via radio that he could not see any of the corresponding valves in the system operating. The CE, EE and 2E went to the CO_2 compartment on deck 5 and attempted to move the valves manually. The distribution valves moved freely, but the main valve was stuck in the closed position. The CE, EE, 2E and 3E inspected the position of the local control levers. These were arranged differently to the remote controls, and only the distribution valve controls were housed inside cabinets. There was a single control lever to operate the main pilot release valve and this was mounted on the panel with no form of enclosure **(Figure 3)**. On inspection, the distribution valve controls were all found in the 'down' position. The main release valve control lever was found in the 'up' position.

Figure 3

Main release valve in the CO_2 room on Deck 5

There were no markings on the operating levers to indicate what the different positions signified, and there was little guidance in the manufacturer's manual to assist in diagnosing the problem. The CE concluded that the remote system had malfunctioned, but considered that in the event of a fire he could still release the CO_2 by opening the main and distribution valves manually. He was not sure what position the levers should be in and decided to leave them as they were found. The main stop valves on the CO_2 storage tanks were re-opened so that gas was immediately available in an emergency.

The CE sent a message to the vessel managers' purchasing department, asking them to arrange a service agent to attend the vessel at the next port of call to make repairs. There was no service agent available in either Alexandria or Santander, and the earliest opportunity was expected to be in Avonmouth.

The vessel continued on passage, with the CE believing that the CO_2 system was in a stable condition, and that it could be operated manually if needed.

1.4.2 Immediate actions

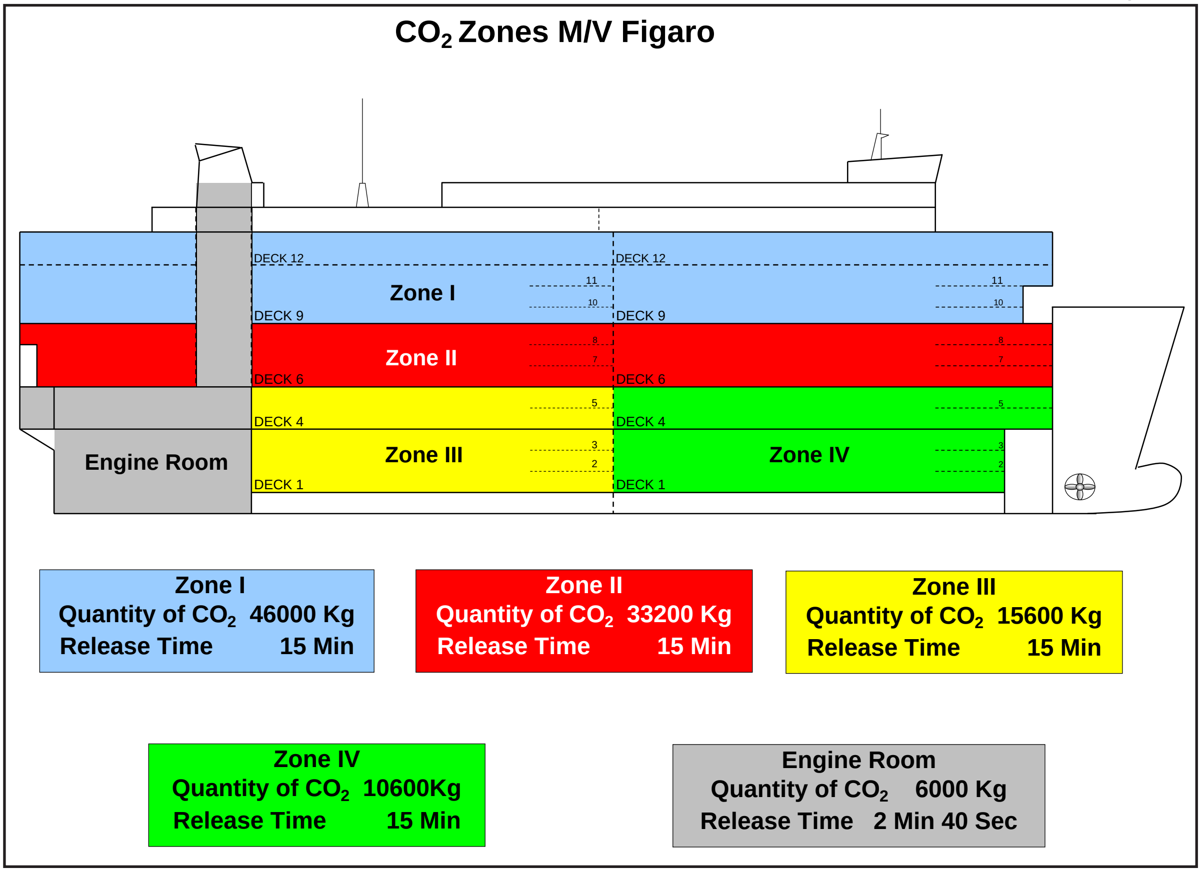
During the afternoon of 6 December 2007, the CE was on the bridge, talking about the expected weather with the chief officer (C/O), who was the officer of the watch. Both the C/O and CE felt the vessel pitch heavily, shaking as it reached the bottom of the wave trough. Immediately after, at about 1630, an able seaman (AB) telephoned the C/O on the bridge, reporting that a dense fog of gas was coming out of the CO_2 drench horns on Deck 6. Very soon afterwards, the fire detection alarm sounded. Both the C/O and CE inspected the control panel and determined that a smoke alarm had been activated in the engine room. This triggered the general fire alarm to sound throughout the ship, which was a pre-arranged signal for all crew to muster at their emergency stations. Both the engine and CO_2 room were fitted with CO_2 detectors. It is not known if these alarms were activated.

The master came to the bridge and relieved the C/O, who went to the ship's office to collect crew lists and then to the muster station to take charge of the crew. The CE went to the CO_2 remote release station on Deck 14 and noted that the CO_2 contents indicator gauge showed 10,000kg and was falling rapidly. The CE then returned to the muster station, where the C/O reported that he had seen white smoke coming from the engine exhaust funnel.

At the muster station, crew reported that fog from the discharging CO_2 gas had also been seen in the engine room and in cargo zone no.1 on deck 9. Sightings of CO_2 being released were confirmed in cargo zones 1, 2 and 3 **(Figure 4)** and in the engine room, the vast majority of the internal volume of the ship. The AB, who had made the initial report, and a cadet escaped from cargo zone 2 on deck 6, the fourth engineer and two engine room ratings had escaped from the engine room and another AB had escaped from cargo zone no.3 on deck 4. No CO_2 was released into cargo zone 4 at the lower, forward end of the vessel.

All crew and passengers were accounted for with the exception of a working party of five personnel who were known to be working on the hydraulic system for the forward mooring equipment.

Figure 4



Schematic diagram of vessel showing CO_2 protected zones

1.4.3 Evacuation of personnel

The electrical engineer (EE), second engineer (2E), the electrical cadet, an engine room wiper and a fitter had been working on the hydraulic system for the forward mooring equipment in a machinery space below the forecastle. The mooring equipment had not worked correctly during the last port call in Santander and the crew were attempting to change one of the hydraulic pumps. They heard the ship's fire alarm, left the machinery space and came through the forecastle store, intending to go to their emergency stations via cargo zone no. 2 on deck 6. The crew crossed the stairwell separating the forecastle store from the forward cargo hold bulkhead and opened the door into the cargo hold. They saw the CO_2 mist in the cargo hold and felt some difficulty breathing. Realising the danger, they climbed the stairs and managed to get into the open air on the forecastle deck.

The only accesses to the forecastle were via an enclosed stairwell, which led down from the forward, open part of deck 14 and had doorways connecting to each of the cargo holds and forecastle store. The crew did not know if the atmosphere in the stairwell was breathable, and decided to stay in safety on the forecastle. The EE was carrying a portable radio, and reported to the C/O the names of the personnel who were trapped on the forecastle.

1.5 RECOVERY ACTIONS

The main engine and No.2 generator had been running, and both engines stopped after CO_2 was released. The vessel's automation systems worked as intended, and firstly No.1 and then No. 3 generator attempted to start automatically to restore electrical power. Neither generator was able to run, and the emergency generator, in a separate compartment on deck 14, started automatically, giving power to emergency equipment.

1.5.1 Initial engine room re-entry

The CE's priority was to get back into the engine room to restart machinery. He and the third engineer (3E), who was with him at the muster station, each took an Emergency Escape Breathing Device (EEBD) from a nearby store and put it on. At 1640, they descended the stairs, to climb down from deck 14 to the engine room on deck 5. The 3E went to prepare No. 2 generator for starting and the CE went into the engine control room to operate the switchboard.

The 3E started the fuel and cooling pumps that were supplied by the emergency generator and attempted to start No. 2 generator. It would not run, and the 3E noted that there was no indication light to show that the fuel pump was running.

At 1648, the C/O called the CE by portable radio to check that both the CE and 3E were all right and to remind them that they only had enough air for 7 minutes left. Shortly afterwards, the CE and 3E left the engine room and began climbing the stairs back up to deck 14. By deck 13, both men were breathing heavily, and the CE was forced to take off his EEBD hood as he could not breathe properly. They both managed to get back to deck 14 unaided, but the CE had to rest for several minutes before he was able to give a report to the master on the bridge. The 3E reported to the CE that he suspected there were problems with the generator fuel pump, and it was agreed that the EE was needed to check the system.

1.6 EXTERNAL ASSISTANCE

With no main engine and only emergency electrical power, *Figaro* began drifting on a course of about 070^{o}. The master plotted the position of the vessel on a paper chart and used one of the radars to plot the range and bearing of Wolf Rock **(Figure 5)**. At 1649, the master contacted Falmouth Coastguard using VHF radio on channel 16. He reported that the vessel had lost main engine power and was drifting in the direction of Wolf Rock. He requested the urgent assistance of a tug, but did not use "Pan Pan" or "Mayday" prefixes.

1.6.1 Coastguard response

Falmouth Coastguard confirmed the position of the vessel, and by 1652 had determined that *Figaro* had Wolf Rock on a bearing of 050, at a distance of 5nm. They estimated that the Closest Point of Approach (CPA) between *Figaro* and Wolf Rock could be as little as 1nm, and took action to assist the vessel and safeguard those on board. At 1655 the Coastguard tasked the Emergency Towing Vessel (ETV) *Anglian Princess* to proceed from its anchorage in Mounts Bay, to intercept *Figaro* and take it in tow.

By 1707 *Figaro* was within 4.4nm of Wolf Rock, which was on a bearing of 047. The vessel was drifting on a course of 080 at a speed of about 2 kts. The Coastguard had made contingency plans to evacuate the 30 people on board and at 1715, a Royal Navy Search and Rescue helicopter, Rescue 193 from RNAS CULDROSE, was put on immediate standby. Rescue 193 was capable, in normal circumstances, of carrying 10 passengers and the Coastguard also tasked Sennen Cove All Weather Lifeboat (ALB) to intercept *Figaro*. Rescue 169, from RAF Chivenor, was called forward to standby at Penzance Heliport. The Coastguard prepared and began broadcasting "Pan Pan" relay messages.

Courtesy of the MCA

Figure 5

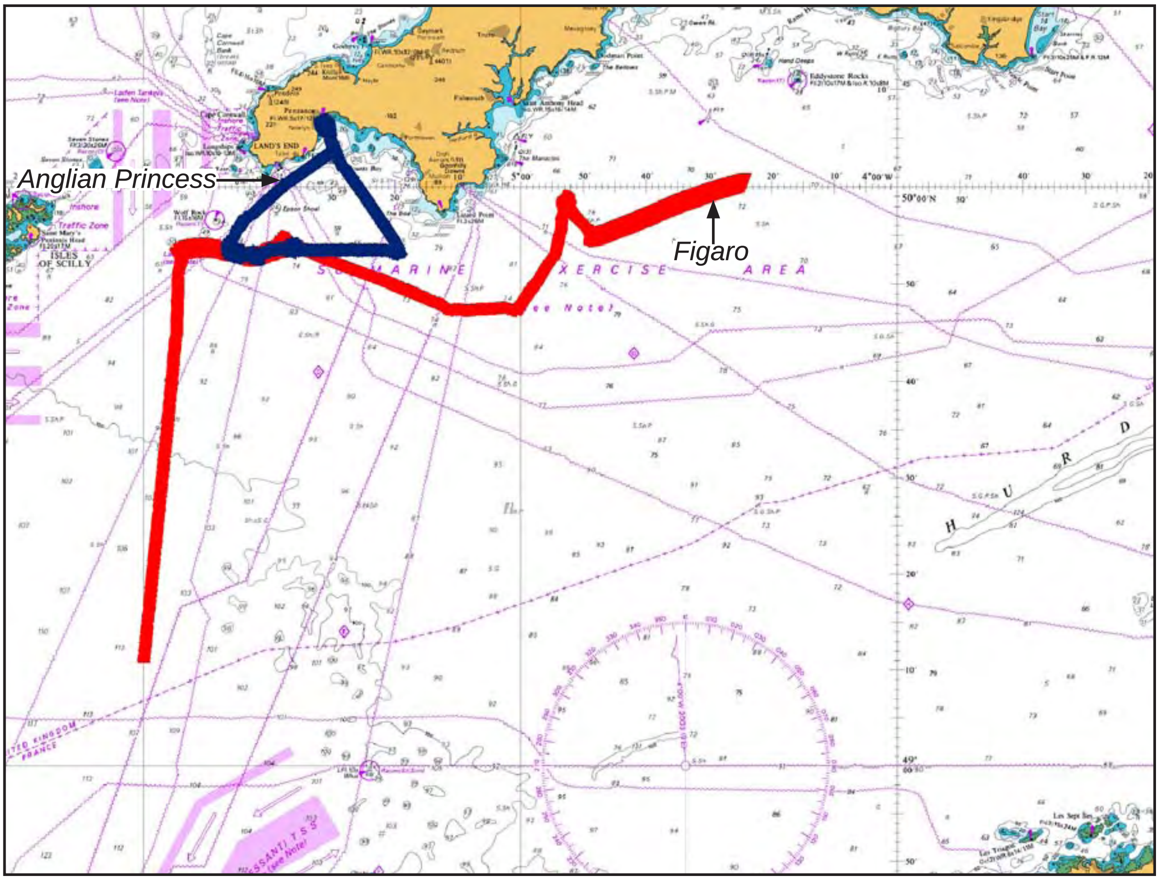


Chart showing AIS data of *Figaro*'s position

At 1724 Coastguard personnel updated the MCA's duty Counter Pollution and Salvage Officer (CPSO) and discussed the rescue options. It was agreed that the options were limited, and the CPSO suggested requesting other tugs in the area to assist in addition to the ETV. At 1725 the duty officer from RNAS CULDROSE telephoned the Coastguard to report that it would take approximately 1 hour and 20 minutes to winch up 10 passengers, and that the transit between the ship and Penzance would take another 20 minutes each way. He requested to be advised as soon as possible if R193 was required to launch.

At 1744 the ETV *Anglian Princess* reported that it had 16nm to run to intercept *Figaro*, and estimated that it would arrive on scene at 1904. At 1813 *Figaro*'s reported position put Wolf Rock 2.7nm away on a bearing of 010. The rate of drift was now 2.6 kts on a course of 084, and the CPA with Wolf Rock was subsequently calculated to have occurred at 1820, at a distance of 2.6nm.

1.6.2 Company response

At 1700, the master of *Figaro* had requested Falmouth Coastguard to contact his Designated Person Ashore (DPA) in Singapore. The Coastguard telephoned the DPA and updated him on *Figaro*'s situation and the actions underway to assist the vessel. The DPA activated the company's emergency response procedures and alerted other members of the management company to standby while he monitored the situation.

1.7 ACTION ON BOARD

1.7.1 Anchoring preparations

Meanwhile, on board *Figaro*, the master, CE and C/O gathered on the bridge to discuss what action to take while waiting for the ETV to arrive. The depth of water was 60m, and with 11 shackles on each anchor it was agreed that the anchors could be let go if needed. However, as a faulty pump had just been removed from the forward hydraulic equipment and none of the equipment on the forecastle could be operated, there would be no way to recover the anchors, if let go.

Five crew members were still trapped on the forecastle and, apart from the immediate concerns of rescuing them, the EE was needed to assist restarting machinery and restoring power to the vessel. The third officer (3/O) took an EEBD to the forward part of deck 14 and was going to lower it on a line to the EE on the forecastle below so that he could escape. Before the 3/O was able to lower the EEBD, the crew men trapped on the forecastle escaped up the stairs one by one, and went to the muster station. They had held open the door from the forecastle into the stairwell, allowing the wind to ventilate the area.

The C/O and bosun went forward to clear away the anchors and standby for the order to slip if needed. The C/O wore the EEBD while he opened up doors in the stairwell to ventilate the forecastle store and No.s 1 and 2 cargo holds. Both then went down the stairs and onto the forecastle. The second officer (2/O) and two ABs went to the after mooring station, to prepare in case the tug needed to secure the tow aft.

After about 30 minutes of waiting on the forecastle, the C/O asked the master for an update on their situation. The master replied that the direction of the tide had changed and the vessel was now beginning to drift clear of Wolf Rock. The master had been listening to communications between the ETV and the Coastguard, and passed on to the C/O that he expected the tug to arrive on scene in about 1 hour. The C/O asked the master to send more crew members to the forecastle to assist with handling the tow line. At 1830 the second officer (2/O) and the remainder of the deck crew arrived, making ten people in total on the forecastle.

1.7.2 Restarting No.2 generator

The CE and 3E discussed why there had been difficulty starting no. 2 generator. The 3E reported that there was no indication on the control panel to show that the fuel pump was running, and he thought that there might also be an electrical safety interlock preventing the engine from starting.

The EE had now returned from the forecastle. At 1832, he and the 3E went back down to the engine room, wearing Breathing Apparatus (BA). The third officer kept a record of the pressures in the BA cylinders, the times that personnel started using breathing air and used radio sets built into the BA equipment to give updates on the amount of time remaining.

The EE found that the lamp on the control panel for no. 2 generator, which showed that the fuel pump was running, did not work; the pump was running correctly and there were no interlocks to prevent the generator from starting. The 3E attempted to start the generator, but it would only run up to between 150 and 200 rpm. He attempted this several times, with the engine speed improving each time. The normal starting air reserves were used up and the connection to the emergency supply was opened. Finally, the generator reached its normal running speed of 720 rpm and was put on load at 1842. Ventilation fans, cooling and lubrication oil pumps, were all restarted and the EE and 3E used the passenger lift to return to deck 14, returning safely at 1845.

1.8 EMERGENCY TOWING VESSEL

1.8.1 Background and requirement

The Maritime and Coastguard Agency (MCA) has a well established system to provide Emergency Towing Vessels (ETV), under the National Contingency Plan for Marine Pollution from Shipping and Offshore Installations. Four chartered ETVs operate all year round from stations in the Minches, Dover Strait, South Western Approaches and the Fair Isle Channel.

1.8.2 Procedures

The ETVs are funded by the MCA under a charter agreement with the ETV operator. Operational tasking of the ETVs is delegated to Coastguard Rescue Co-ordination Centres (RCC). They have the authority to task the ETV in their geographical area, to respond to an incident where it is considered that there is a serious risk of harm to persons or property, or a serious risk of pollution.

1.8.3 Preparations

On 6 December, the ETV *Anglian Princess* was on station in the South Western Approaches, at anchor in Mounts Bay off Penzance. This anchorage is often used as it is relatively central in the operating area and provides good shelter from the prevailing weather. At 1655, *Anglian Princess* was tasked by Falmouth Coastguard, using the channel 0 VHF frequency, to proceed to *Figaro*.

Anglian Princess's crew knew that they were sailing to intercept a large vessel and prepared one of their 64mm diameter steel wire rope pennants and attached it to their main, 76mm diameter, towing wire.

Anglian Princess continued to sail to intercept *Figaro*, making good around 12 kts though the water. At about 1800, *Anglian Princess*'s master called *Figaro*'s master and informed him of his estimated time of arrival. *Anglian Princess* was taken off contract to the MCA, and contractual terms between the ETV operator and Wallenius Lines were arranged.

Visual contact between the two vessels was established at some time after 1845, the master of *Anglian Princess* reporting that he could see deck and accommodation lights, in addition to the navigation lights. He interpreted this to mean that *Figaro* had restarted her generators and assumed that power would be available to operate the mooring equipment.

Sennen Cove ALB had arrived on scene before the ETV, and stood by acting as a safety boat.

1.9 EMERGENCY TOW

1.9.1 Establishing the tow

Anglian Princess manoeuvred her stern close to *Figaro*'s bow and a heaving line was passed at about 1900. This was attached to a messenger line, connected to the 64mm wire pennant. The ten members of crew on *Figaro*'s forecastle heaved up the messenger by hand, but were unable to heave up any more of the messenger as the weight of the pennant came on to the line.

Figaro's master informed *Anglian Princess* that there was no power to the deck machinery on the forecastle and that the crew were unable to heave up the weight of the steel towing pennant. Although there had been a number of communications between the two vessels previously, this was the first time that *Anglian Princess*'s crew became aware of this limitation. The messenger was recovered and, at about 1920, *Anglian Princess* moved off to prepare a Dyneema towing line.

The steel wire pennant was disconnected from the main towing wire and the Dyneema line was unwound from its storage drum and connected. At 1950, *Anglian Princess* moved back into position and prepared to pass the tow.

1.9.2 Main machinery

On board *Figaro*, No. 2 generator had by now been running for 45 minutes and the CE was confident that the ventilation fans would have reduced the CO_2 concentration in the engine room. At 1936, the CE, 2E, 3E and EE all re-entered the engine room wearing BA. The 4E joined them 2 minutes later. The engineers restarted the auxiliary boiler to generate steam to heat heavy fuel oil for the main engine and recharged the starting air cylinders. The fuel system was configured for the main engine to run heavy fuel oil and, as it began to warm through, pumps and purifiers were started in preparation for starting the main engine.

The bow thruster was electrically powered and was available to help manoeuvre the vessel once all three generators were running and on load. It can not be determined precisely when the bow thruster was first available, but it is likely that this occurred at about 2000. Similarly, it was not recorded when the main engine was restarted, however it can be estimated that the <u>earliest</u> that it could have been restarted was between 2010 and 2025.

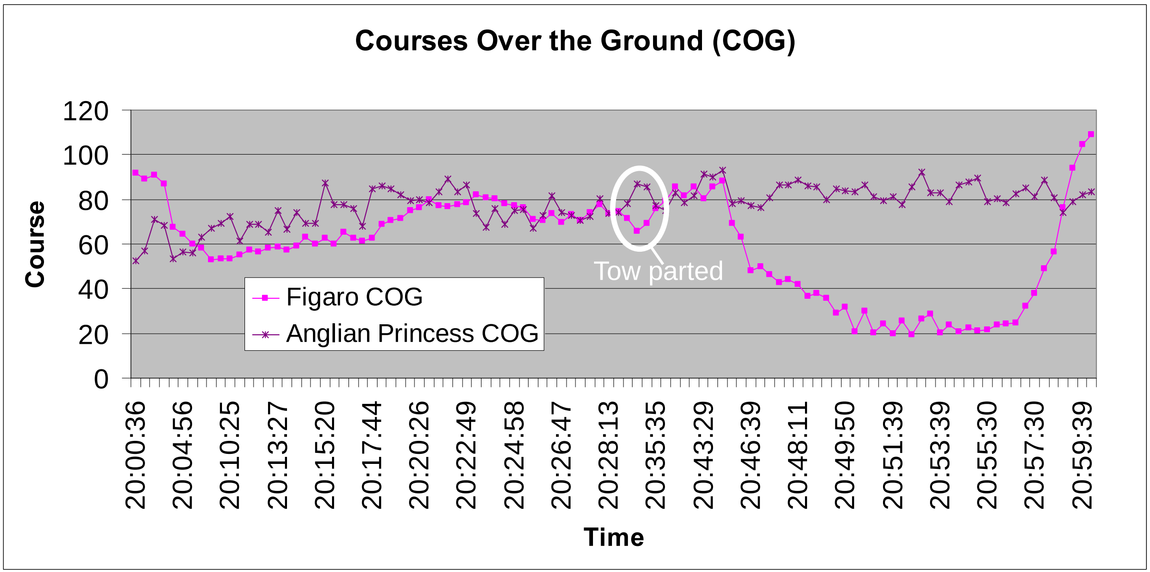
1.9.3 Parting of the tow

Figaro's rate of drift had increased to over 3 kts, and *Anglian Princess* had difficulty keeping station upwind and stern onto *Figaro,* using its normal manoeuvring mode. The master of *Anglian Princess* decided that the only alternative was to turn through 180 degrees and run before *Figaro*, matching his speed to the rate of drift to keep ahead of the bow.

The 68mm Dyneema tow line was passed and secured at 2000 without any further difficulties. Satisfied with the securing arrangements, the CO stood down his crew from the forecastle and went to the bridge to report to the master. At 2020, *Anglian Princess* reported to Falmouth Coastguard that the tow was underway and that they were attempting to turn *Figaro* to the east, with the intention of making for shelter.

Study of AIS data shows *Anglian Princess* making good a course to the east at about 3.5 kts. At 2026 *Figaro*'s heading begins to alter to starboard, turning through north and reaching 007º at 2029. The courses over the ground (COG) for *Anglian Princess* and *Figaro* begin to converge at around 074º. The next AIS data sample for *Figaro*, 3 minutes later at 2032, shows that the heading has altered, through 29º to port, to 338º. *Anglian Princess*'s speed drops sharply from 3.7 to 1.4 kts and the courses over the ground diverge, *Figaro* altering to port to make good 065º and *Anglian Princess* to starboard to make good 085º **(Figure 6)**.

Figure 6



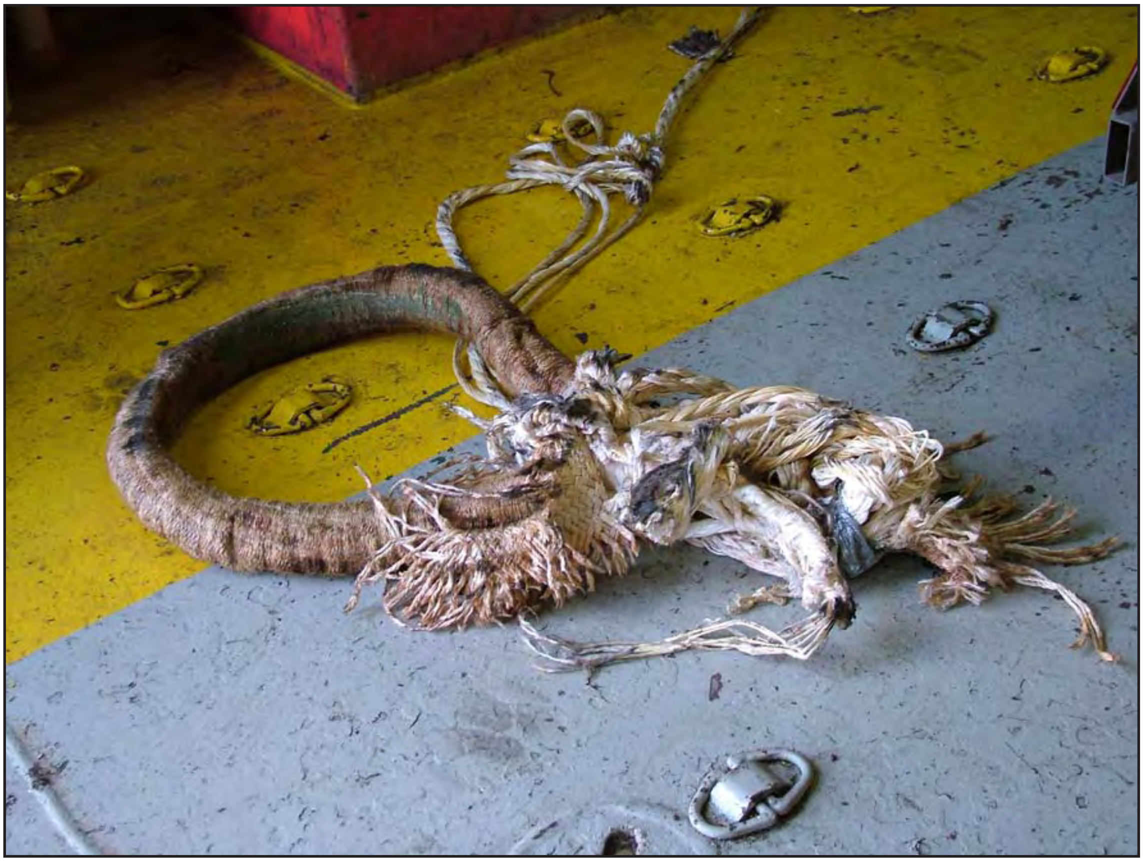
Graph of *Figaro* and the ETV's courses over the ground

The crew of *Anglian Princess* saw the Dyneema tow line part. At 2034, Coastguard officers recorded that they had overheard Sennen Cove ALB reporting to *Anglian Princess* that the line had parted, making a loud crack as the line went slack. *Anglian Princess* recorded in their log that the tow line had parted at 2015, but the Coastguard had also recorded *Anglian Princess*'s report that the tow was underway at 2020. It has not been possible to determine why there is a discrepancy between Coastguard and ETV timings.

The master of *Anglian Princess* called *Figaro* and informed them that the line had parted. *Figaro*'s master had been using his bow thruster and rudder to assist with the turn and was concerned that a loose end might foul his bow thruster, so stopped it immediately. He then instructed the CO to go to the forecastle and recover any loose parts of the tow line. The CO found that the tow line had parted at the splice forming the soft eye **(Figure 7)** that had been secured to *Figaro*'s bitts, and reported to the master that there was no line to foul the bow thruster.

With *Figaro* clear of Wolf Rock and out of immediate danger, the crew of *Anglian Princess* started to discuss why the Dyneema line might have parted and alternative methods of re-establishing the tow. It was not clear why the tow line failed; it had a certified minimum breaking load of 360 tonnes and the towing winch strain gauge had shown a consistent load of around 130 tonnes.

Figure 7



Remains of the soft eye of the tow line attached to *Figaro*

At 2042, *Figaro*'s heading had reached 330º. The master reported to the Coastguard that main engine had been restarted and propulsion was now available. The heading came back to starboard, reaching 345º by 2045.

Anglian Princess confirmed that *Figaro* was underway at 2046, and AIS data shows the vessel gathering headway by 2048. *Figaro*'s master reported his intention to make for Falmouth at 2108 and the rescue helicopters and lifeboat were stood down. *Anglian Princess* stayed nearby, providing an escort.

1.9.4 Data records

Anglian Princess was not fitted with a Voyage Data Recorder (VDR) or any other form of data recording device, and it has not been possible to determine the precise circumstances (e.g. strain on the tow line, engine outputs, voice communications, navigational situation or environmental conditions) leading up to the tow parting. Although *Figaro* was fitted with a Simplified Voyage Data Recorder (SVDR), the computer files were not saved and had been overwritten by the time MAIB Inspectors were able to intervene. AIS data for both vessels was obtained and plotted to determine the relative positions, headings, courses and speeds.

1.9.5 Technical investigation

It was not readily apparent why the tow line had parted, but the soft eye had been kept on board *Figaro* and was taken for further analysis. The remainder of the tow line had been recovered on board *Anglian Princess*, but the damaged part was cut off and discarded. The remainder of the tow line remained in service and was used the following week, with a bowline tied to form a soft eye, to tow a 130m general cargo vessel that had also suffered an engine failure.

The soft eye was sent for detailed inspection and dissection by a specialist company, Tension Technology International (TTI) to determine why it had failed. TTI noted that the soft eye had become very stiff and, by comparing the rope core with the protective jacket, that it had contracted to approximately half its original length. This was caused by a combination of the rope cores pulling through the splices under extreme tension and compaction of the rope under recoil after it parted. The rope cores had failed at the splice, in two principal methods; four of the ten individual splices had slipped, causing the remaining strands to be overloaded. There was evidence of overheating with rope cores becoming fused together and further damage consistent with violent recoil. TTI concluded that the rope *"had been subjected to a severe load that had occurred quite quickly"* [sic].

Further work was done to establish the strength of the tow line and the suitability of the splicing method. The line was manufactured out of HMPE[1], which has a low friction coefficient. Although the splice had been done in accordance with the manufacturer's instructions, TTI reported that they and another major manufacturer recommended using 24 to 26 splices in this material to prevent the strands from slipping.

Undamaged rope yarns were taken from the sample and subjected to tensile testing. An analytical method was then used to estimate that the rope's residual strength after it had parted was in the order of 230 tonnes. It was also estimated from the general condition of the rope, that its minimum breaking load before the accident would have been about 75% of its value when new, giving 270 tonnes. The effect of the four slipped splices was considered to have reduced the actual breaking load by 25% and so it was concluded that the tow line would have parted at a load of about 200 tonnes.

A substantial yawing movement, in the opposite direction to the tow, was recorded on *Figaro*'s AIS data immediately prior to the tow line parting. The possibility of modelling the environmental loads on *Figaro* was investigated to determine if these forces would have been sufficient to generate this movement and overload the tow line. Unfortunately there was insufficient data available on the wind speed and direction to support robust calculations.

1.10 POST-ACCIDENT ACTIONS

1.10.1 Initial intentions

It was agreed between Falmouth Coastguard and *Figaro*'s master that the vessel should sail to Falmouth for repairs. *Figaro*'s managers appointed an agent and made arrangements with a local ship repair yard to repair and refill the CO_2 system. However, the weather deteriorated, and it transpired that there was not enough room for *Figaro* to berth in Falmouth. An option of securing to the Cross Roads buoy was explored, but conditions were considered too rough for both a pilot to board the vessel and for buoy jumpers to operate. Furthermore, many vessels were at anchor, taking shelter in Falmouth bay, and there was not enough room for *Figaro* to anchor safely.

It was confirmed during the morning of 7 December, that there was no service agent for the CO_2 system available in Avonmouth, but an agent and a supply of CO_2 had been identified in the next scheduled port, Zeebrugge. *Figaro* remained off Falmouth Bay throughout the morning, unable to seek shelter, but remaining in the area while in

[1] High Modulus Polyethylene rope

conversation with the MCA's duty CPSO. The duty CPSO was concerned that *Figaro* should not transit the Dover Straits without the fixed fire-fighting system in operation, and wanted the vessel to be inspected by MCA surveyors. *Figaro* was not given any formal instructions.

1.10.2 Onward passage

Figaro's master was increasingly concerned for the safety of his vessel and his crew, and was anxious either to take shelter or to proceed to a port where he could get the necessary technical support. A water mist system had recently been fitted in the engine room, and additional personnel had been posted to keep a fire watch in machinery and cargo spaces. On this basis, the master considered that the risk of fire was acceptable and that further machinery breakdown was unlikely, so he decided to continue on passage to Zeebrugge.

The duty CPSO discussed the situation with the French maritime administration and it was accepted that *Figaro* could transit through Dover Strait. The remainder of the passage went without incident and *Figaro* berthed in Zeebrugge early in the morning on 8 December 2007.

1.11 VESSEL OPERATIONS

1.11.1 Ownership

Wallenius Lines has divided its fleet of vessels between Swedish and Singapore registered ownership and registry. *Figaro* was owned by Wallenius Lines Singapore Pte Ltd, a wholly owned subsidiary of the Swedish based Wallenius Lines group.

1.11.2 Management

Figaro was managed by Wallenius Marine Singapore Pte Ltd, part of the Wallenius Marine ship management group. The vessel was on the Singapore Registry and met the requirements of the Maritime and Port Authority of Singapore. The managers held the appropriate Document of Compliance for the type of vessel and were the International Safety Management (ISM) Code registered 'company' on behalf of the vessel's owners. A Safety Management Certificate had been issued for *Figaro* in January 2007 by the classification society on behalf of the Flag State.

Wallenius Marine Singapore Pte Ltd operated a computer based safety management system which described the high level company policies for operations, safety and environmental protection. Further detail was provided in each section of the Safety Management System (SMS) manual with procedures and specific instructions for different activities. The working language on board, and throughout the company, was English.

The SMS manual included a section on fire-fighting apparatus, which set out the responsibilities of the senior officers. These stated that the master, chief engineer and chief officer were to make themselves, "*thoroughly conversant with the fire detection and fire extinguishing installations onboard the vessel by personal inspection and careful study of the plans, etc."* [sic]. Maintenance instructions for the CO_2 system were also included, but the following tasks were at different periodicities to those in the PMS:

- CO_2 lines and nozzles to be blown through annually (instead of 3 monthly in the PMS);
- Test of remote release system to be done annually (instead of 3 monthly in the PMS).

The company required crew to complete familiarisation training on board its vessels. This was conducted in two parts, a checklist for essential instructions, fire-fighting and lifesaving appliances, and a record for on the job training. On the job training records included a section on the fixed fire-fighting system, with the requirement for engine room crew to explain the operation (and safety devices) of the CO_2 system. Records showed that the CE, EE and 3E had all successfully completed this training.

A list of critical equipment was included in the SMS manual; this covered main engine failure, auxiliary machinery failure and steering gear failure. Neither the CO_2 system nor VDR were listed as critical equipment.

A Permit to Work system was in place, but was only required to be used for hot work and entry into confined spaces.

Technical and internal ISM audits were both conducted annually, but at separate times. The last technical audit of the vessel was completed on 16 March 2007 and noted that one of the seats for the CO_2 storage tanks was buckled. This was subsequently repaired. ISM audits had not identified any shortcomings with the operation and maintenance of the CO_2 system.

1.12 CREW

There were 30 people on board *Figaro* during the incident, 27 members of crew (including 4 cadets), 2 passengers and a service agent for the stern ramp machinery. The manning was in excess of that required by the vessel's Safe Manning Certificate.

The master was Swedish and aged 58. He had worked at sea for 40 years and was promoted to master in 1981. He had wide experience of many different ship types, and further experience of search and rescue operations through work at the International Maritime Organization on behalf of the Swedish Maritime Administration.

The chief engineer was also Swedish and was aged 50. He had worked at sea since 1977 and began his first post as chief engineer in 1989. The majority of his experience was on Ro-Pax vessels and he was on his third, 10 week contract on board vehicle carriers. These were the first ships fitted with low pressure CO_2 systems that he had worked on.

The chief officer was aged 30 and from Sweden, he had started his career at sea in the Swedish Navy and, on leaving, had joined the merchant fleet.

The remainder of the officers and ratings were from Myanmar and the Philippines. Both the electrical engineer (EE) and the third engineer (3/E) were from Myanmar and had long experience of *Figaro* and her sister vessels, which gave them detailed knowledge and was used to good effect in re-starting machinery after the incident.

The vessel's managers encouraged detailed handovers between key personnel. Three to five days were allowed for handovers between technical officers.

1.13 CO_2 SYSTEM

1.13.1 System description

Figaro was fitted with a fixed fire-fighting system capable of smothering fires in the engine room and cargo holds. The low pressure CO_2 system was capable of storing the volume of CO_2 needed to be able to smother a fire in the single, largest cargo holds. The equipment fitted to *Figaro* was manufactured by a Danish company "Ginge Brand A/S Technik". The company no longer trades in its original form, but it is estimated by former employees that about 200 similar systems were manufactured from the late 1970s through to 1997.

The system was designed to store liquid CO_2 at a pressure of 21 Bar and a temperature of -18^{o}C. Two interconnected cylindrical tanks, one holding 22,500 kg and the other holding 23,500 kg were fitted on deck 5, at the after end of the vessel. The tanks were insulated and fitted with a refrigeration system to maintain the temperature and therefore control the pressure of the CO_2. Once released, the pressure would fall and the liquid CO_2 would rapidly expand, evaporating or 'boiling off' into a vapour. As the vapour was distributed in pipes throughout the ship, it would gain heat from the surroundings and would expand further until it reached the distribution horns fitted at the deckhead of each protected compartment. As CO_2 gas is denser than air, it would then fall to the deck, displacing oxygen and smothering the fire.

By installing different sizes of distribution pipe and using electronic timers to control the amount of time the release valves opened, sufficient gas could be released to achieve the required 35% CO_2 concentration in the engine room or 45% in the cargo holds. These concentrations reduced the relative proportion of oxygen in the compartment, so that it could no longer support combustion.

1.13.2 Modes of operation

(Refer to System Instruction Plan **(Figure 8)** in conjunction with this section.)

SOLAS FSS[2] Code regulations require that the controls for all fixed gas fire extinguishing systems have two distinct operations:

> "*two separate controls shall be provided for releasing carbon dioxide into a protected space and to ensure the activation of the alarm. One control shall be used for opening the valve of the piping which conveys the gas into the protected space and a second control shall be used to discharge the gas from its storage containers*" [sic]

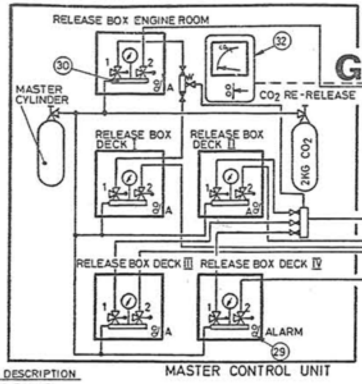
On the system fitted to *Figaro*, this was achieved by providing separate control levers, one to operate the main release valve and the other to operate the distribution valve to divert gas to the desired compartment.

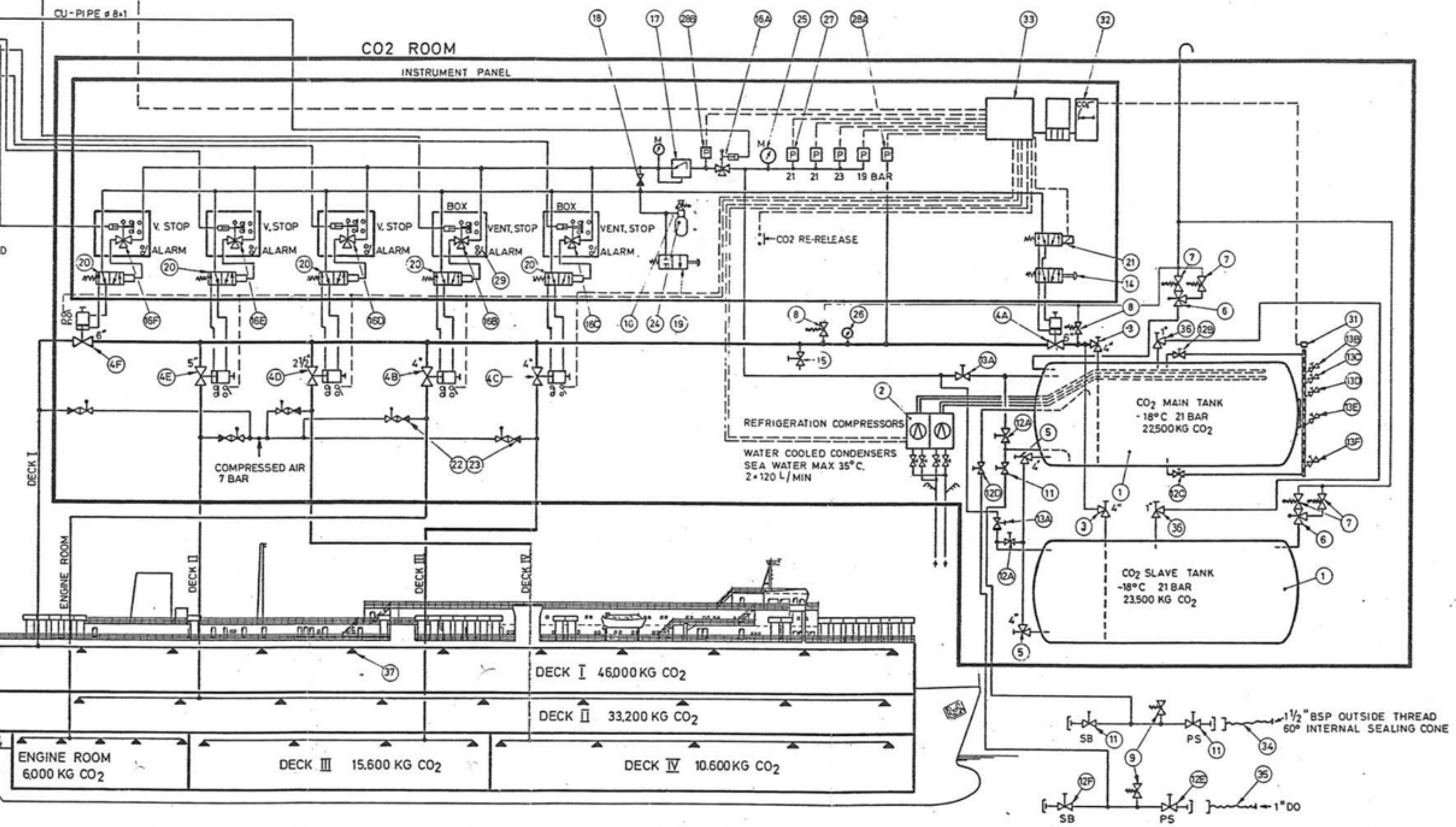
In addition, two operating stations had been provided, the MCU, situated on deck 14, and the CO_2 room control unit, mounted on a panel next to the storage and distribution equipment in its own compartment on deck 5. The MCU was effectively a remote operating station, which used low pressure CO_2 to drive pistons to move the valve levers on the CO_2 room control unit. The MCU had five cabinets, each containing a control for the main valve and a control for the appropriate distribution valve. Each control in the MCU was operated by pulling a vertical lever towards the operator, down through 90^{o} to a horizontal position **(Figure 9)**. This allowed the valve seat to open,

[2] International Convention on the Safety of Life At Sea, Fire Safety Systems Code

GINGE LOW PRESSURE CO_2 FIRE EXTINGUISHING PLANT.

INSTRUCTION PLAN.





ITEM DESCRIPTION

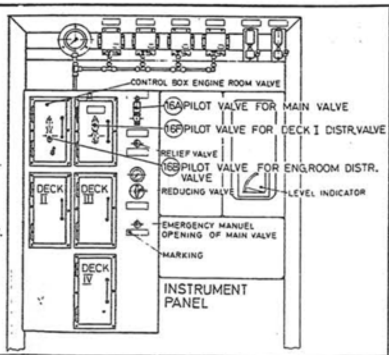
1. CO_2 TANKS
2. COOLING COMPRESSOR TWIN
3. 4" STOP VALVE. NORMALLY OPEN
4A. 6" PRESSURE OPERATED VALVE. NORMALLY CLOSED. (MAIN VALVE)
4B. 4" DISTRIBUTION VALVE FOR ENGINE ROOM. NORMALLY CLOSED
4C. 4" DISTRIBUTION VALVE FOR DECK III. NORMALLY CLOSED
4D/E/F. 2½", 5", 6" DISTRIBUTION VALVES FOR DECK IV, II, I. NORMALLY CLOSED
5. 4" STOP VALVE. NORMALLY OPEN
6. 3-WAY VALVE
7. SAFETY VALVE 24.5 BAR
8. SAFETY VALVE 35 BAR
9. SAFETY VALVE 35 BAR
10. SAFETY VALVE 10 BAR
11. 1½" LIQUID FILLING VALVE. NORMALLY CLOSED
12A. 1" EMERGENCY LEVEL INDICATOR VALVE. NORMALLY CLOSED
12B. 1" LIQUID LEVEL ISOLATION VALVE. NORMALLY OPEN
12C. 1" LIQUID LEVEL ISOLATION VALVE. NORMALLY OPEN
12D. 1" VAPOUR BALANCE VALVE. NORMALLY CLOSED
12E. 1" VAPOUR BALANCE VALVE. NORMALLY CLOSED
12F. 1" VAPOUR BALANCE VALVE. NORMALLY CLOSED
13A. 3/4" PILOT PRESSURE VALVE. NORMALLY OPEN
13B. 3/4" LEVEL VALVE 100 %
13C. 3/4" LEVEL VALVE 95 %. (100 % AT 14 BAR)
13D. 3/4" LEVEL VALVE 75 %
13E. 3/4" LEVEL VALVE 50 %
13F. 3/4" LEVEL VALVE 0 %
14. EMERG. MANUAL PILOT VALVE FOR MAIN VALVE
15. 1/2" RELIEF VALVE MAIN DISTRIBUTION PIPE
16A. MANUAL/PRESSURE OPERATED PILOT VALVE
16B. MANUAL/PRESSURE OPERATED PILOT VALVE
16C/D/E/F. MANUAL/PRESSURE OPERATED PILOT VALVE
17. REDUCING VALVE. SET POINT 7 BAR
18. 1/4" NON RETURN VALVE
19. PILOT SYSTEM RELIEF VALVE
20. PRESSURE OPERATED PILOT VALVE
21. 1/4" 4-PORT SOLENOID VALVE
22. 3/4" NON RETURN VALVE
23. 3/4" BALL VALVE
24. CO_2 GAS RESERVOIR
25. MANOMETER 0-40 BAR
26. MANOMETER 0-60 BAR
27. PRESSURESTAT
28A. PRESSURE SWITCH
28B. PRESSURE SWITCH
29. SWITCH
30. REMOTE RELEASE UNIT
31. LIQUID LEVEL SENSOR
32. LIQUID LEVEL INDICATOR
33. INSTRUMENT PANEL
34. 1½" FILLING HOSE
35. 1" FILLING HOSE
36. 1" STOP VALVE. NORMALLY OPEN
37. CO_2 NOZZLE

RELEASE FROM MASTER CONTROL UNIT

RELEASE TO ENGINE ROOM AND DECKS

1. OPEN DOOR TO REMOTE RELEASE BOX TO DECK ON FIRE.
2. CHECK THAT EVERYBODY HAS LEFT THE ROOM.
3. OPEN SCREW VALVE ON ONE OF THE MASTER CYLINDERS.
4. OPEN MASTER CONTROL VALVE MARKED NO 1.
5. OPEN MASTER CONTROL VALVE MARKED NO 2.
   THE 6" MAIN VALVE (4A) WILL CLOSE AUTOMATICALLY AFTER CALCULATED RELEASE TIME.
   TO DECK I THE TANKS WILL BE EMPTIED.
6. ADDING MORE CO_2 TO DECK II, III AND IV:
   PRESS BUTTON "CO_2 RE-RELEASE."

CALCULATED RELEASE TIME TO ENGINE ROOM IS 2MIN 40SEC.
CALCULATED RELEASE TIME TO DECKS IS 15 MIN.



RELEASE FROM CO_2 ROOM

RELEASE TO ENGINE ROOM

1. OPEN DOOR FOR "CONTROL BOX ENGINE ROOM VALVE" (16B).
2. CHECK THAT EVERYBODY HAS LEFT THE ROOM.
3. OPEN "PILOT VALVE FOR MAIN VALVE" (16 A).
4. OPEN PILOT VALVE FOR ENGINE ROOM DISTRIBUTION VALVE (16 B.)
   THE 6" MAIN VALVE (4A) WILL CLOSE AUTOMATICALLY AFTER CALCULATED RELEASE TIME.
5. ADDING MORE CO_2:
   PRESS BUTTON "CO_2 RE-RELEASE".

CALCULATED RELEASE TIME IS 2 MIN 40SEC.

RELEASE TO DECKS

1. OPEN DOOR FOR CONTROL BOX TO DECK ON FIRE. BOXES ARE MARKED "CONTROL BOX DECK I", "CONTROL BOX DECK II" ETC.
2. CHECK THAT EVERYBODY HAS LEFT THE ROOM.
3. OPEN "PILOT VALVE FOR MAIN VALVE" (16A).
4. OPEN PILOT VALVE PLACED IN THE OPENED CONTROL BOX IN ITEM 1
   THE 6" MAIN VALVE (4A) WILL CLOSE AUTOMATICALLY AFTER CALCULATED RELEASE TIME.
   TC DECK I THE TANKS WILL BE EMPTIED.
5. ADDING MORE CO_2 TO DECK II, III AND IV:
   PRESS BUTTON "CO_2 RE-RELEASE".

CALCULATED RELEASE TIME IS 15 MIN.

DECK NO.	QUANTITY OF CO_2 [KG]	RELEASE TIME [MIN]
I	46.000	15
II	33.200	15
III	15.600	15
IV	10.600	15
ENGINE ROOM	6.000	2MIN 40 SEC.

PRINCIPLE DIAGRAM FOR CO_2 LOW PRESSURE PLANT

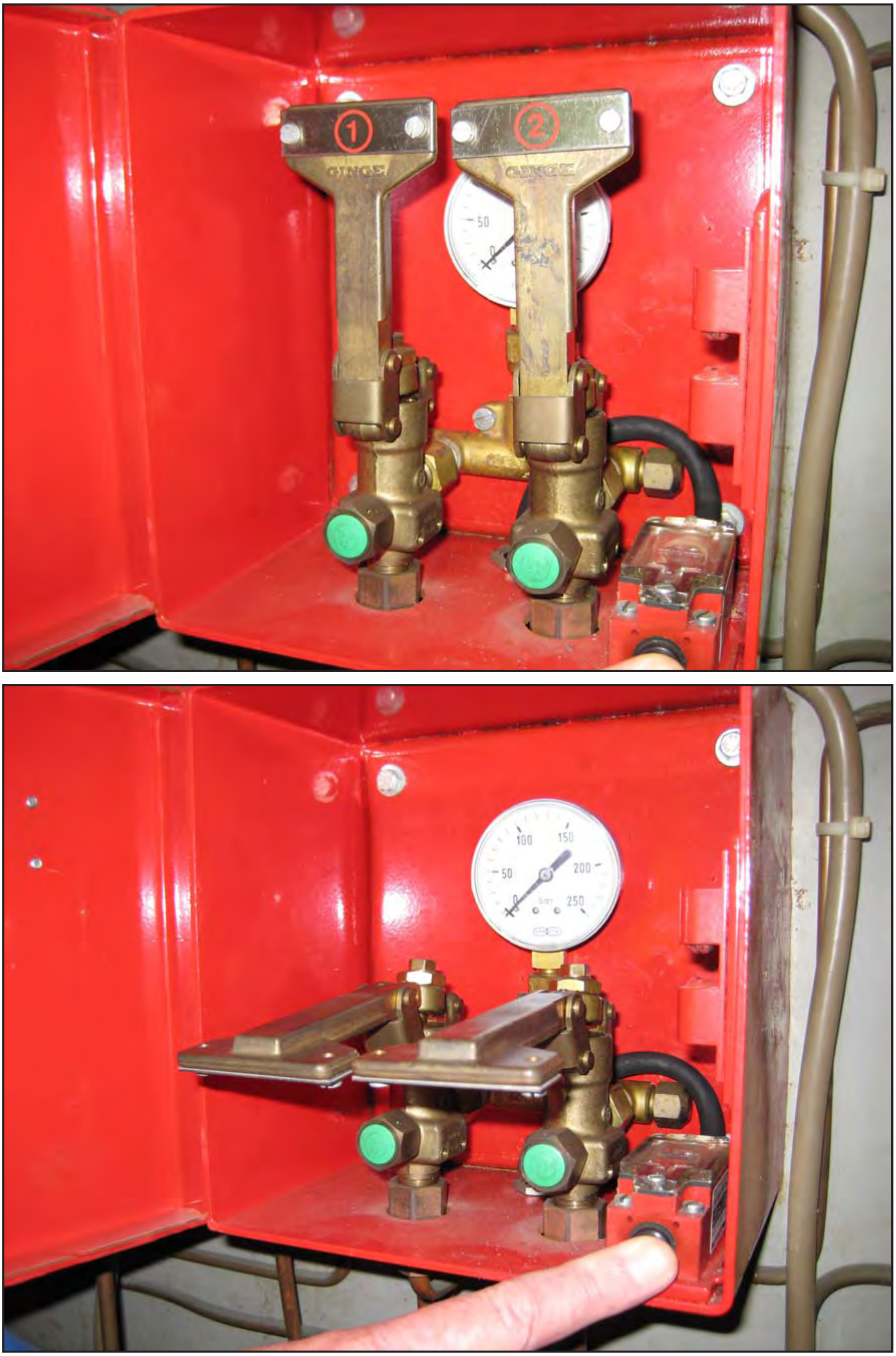
GINGE BRAND & ELEKTRONIK A/S

Tegn. af F.W. Dato 80-08-11
Rev. af T.C. Dato 81-06-18

52-0029 A02

Images courtesy of C.Bevis, Brookes Bell

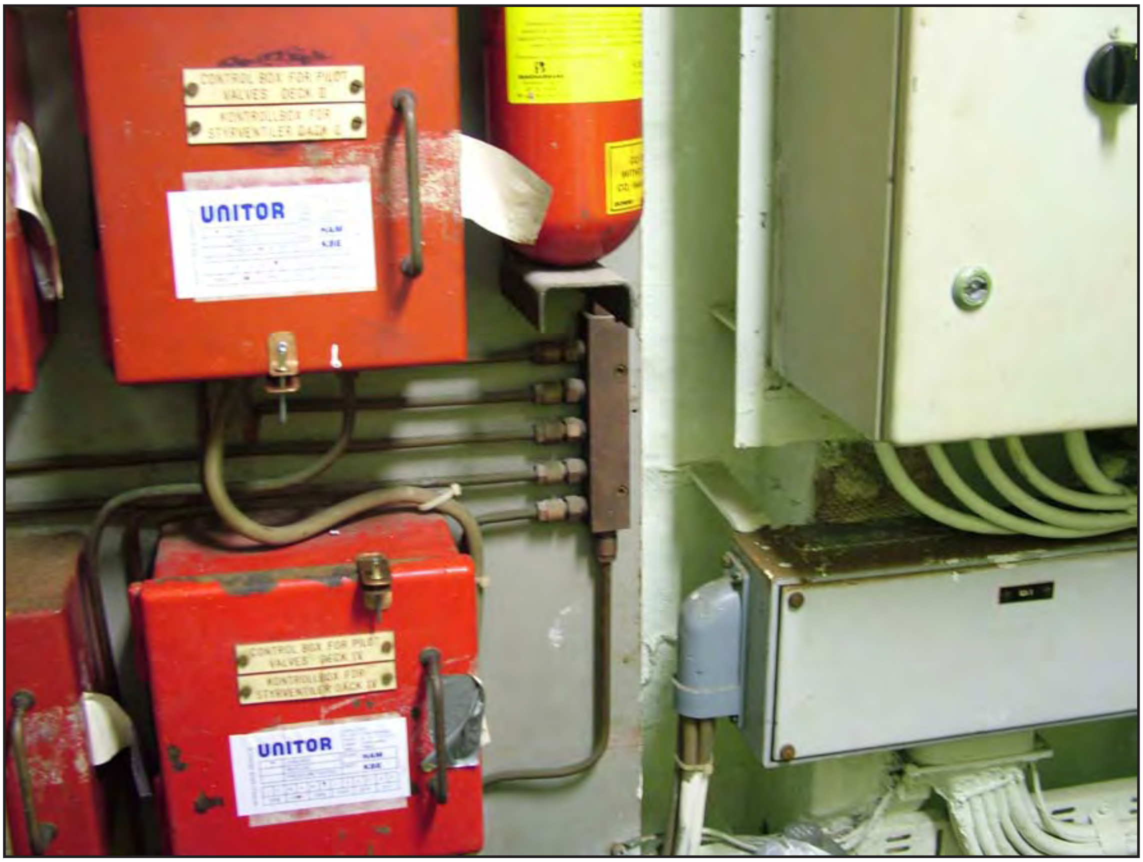
Figure 9



Main Control Unit operating levers

releasing low pressure gas from the small Master cylinders. The distribution controls had separate pipework connecting each of them directly to the respective control in the CO_2 room. However, each of the five different remote controls for the main valve terminated at a non return valve and then joined a common manifold **(Figure 10)**. A single pipe from this manifold then lead down from deck 14 to the main valve controls in the CO_2 room. The control lever valves were self purging, with pipework open to the atmosphere when closed and only sealing once operated. The non return valves were required to prevent gas pressure from an opened control valve escaping back through any of the unused control valves.

Figure 10

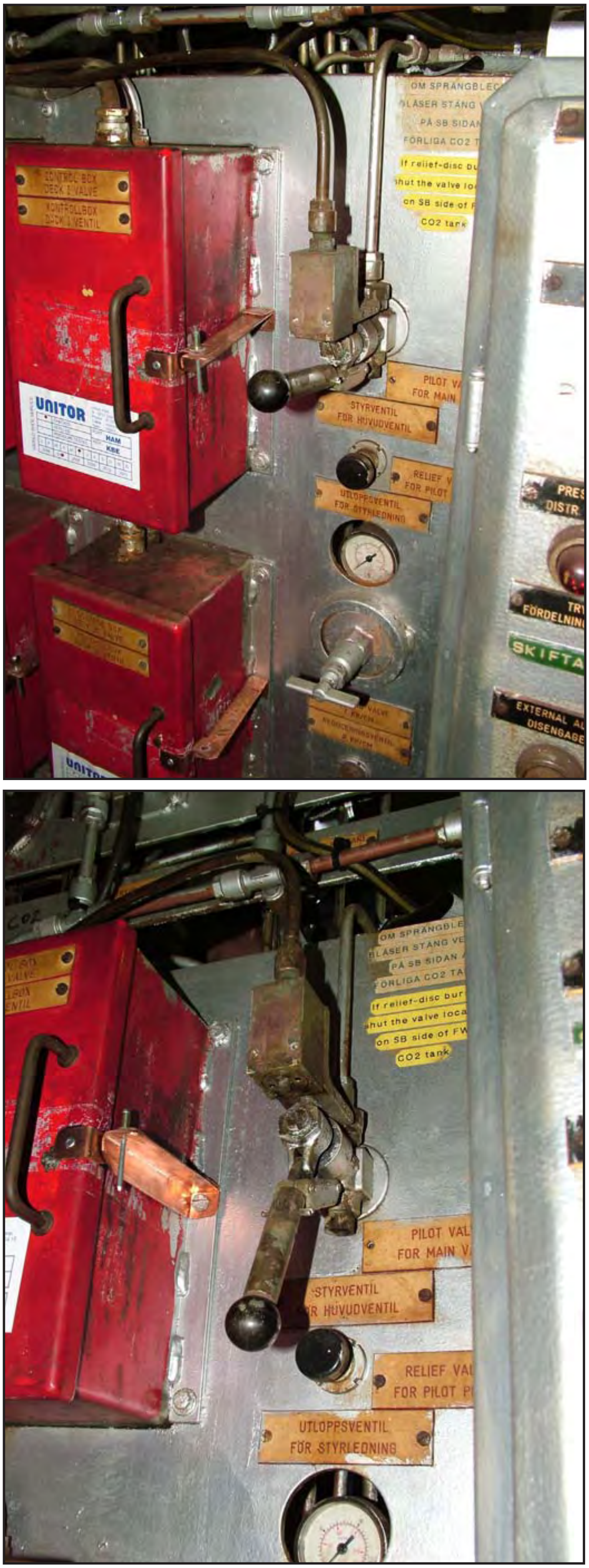


Manifold for MCU main pilot valve controls

The CO_2 room control panel was arranged slightly differently to the MCU, five control cabinets were provided, but these only contained the controls for each distribution valve. There was one control for the main valve, mounted directly onto the control panel without a cabinet. Although the control levers were similar to those on the MCU, they were orientated differently, so that they were normally in a horizontal position and were operated by pushing them down to the vertical position **(Figure 11)**.

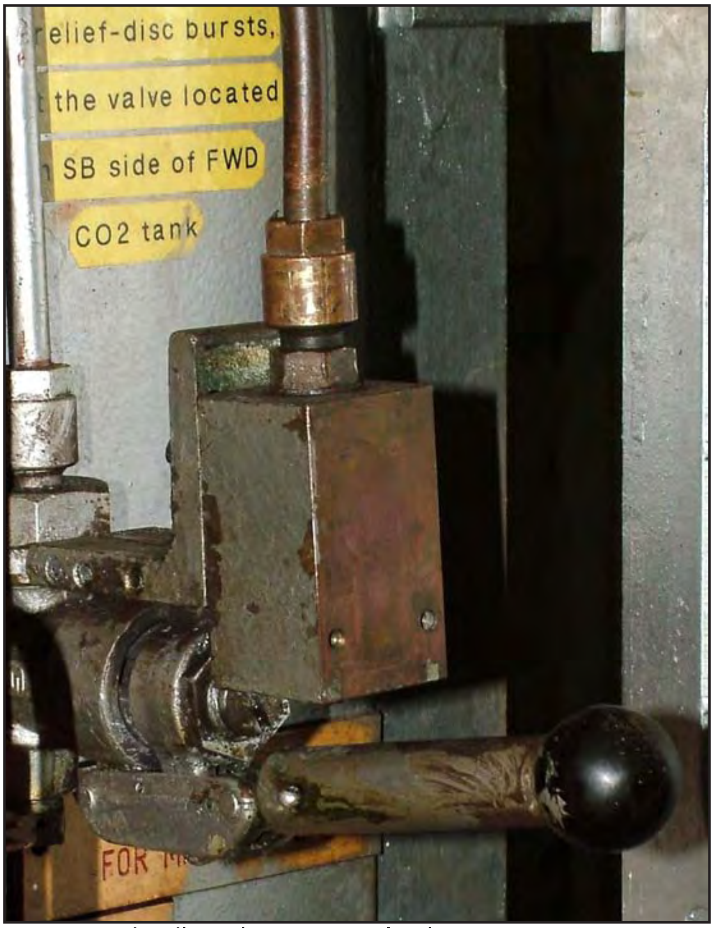
The control valve levers operated on the over centre principle, similar to a clasp found on a travelling case or ski boot. Pressure from the valve pin kept the lever in the closed position. A relatively small movement of the lever compressed the valve pin further, until the fulcrum of the lever hinge changed. Pressure from the valve pin then acted on the lever to move it further, releasing the pin and allowing the valve to open fully **(Figure 12)**.

Figure 11



Main pilot release control valve on the CO_2 room contol panel

Figure 12



Main pilot release control valve arrangement

The valves in the CO_2 room were driven by gas taken from the main storage tank. This was controlled by the pilot valve (16A). Opening this valve allowed gas to flow into the pilot system where it was sensed by a transducer (28B), which provided an electrical signal to the release control timing system. Pilot pressure was also provided to solenoid valve (21), which was kept closed by an electrical signal from the control timing system.

Pressure was then available to all the distribution pilot valves (16B to 16F) which allowed the operator to direct CO_2 to the appropriate compartment. Opening any of these valves, allowed gas in the pilot system to operate one of the solenoid valves (20) which in turn opened the appropriate distribution valve (4B to 4F). Once the distribution valve was fully open, an electrical interlock was completed, opening the solenoid valve (21) and main valve (4A). CO_2 was then released through the main pipework and distributed to the selected compartment(s).

Movement of the pilot valves (16A to 16F) was the principal means of activating the system. The MCU levers gave remote control by operating small pistons which acted directly onto the pilot valve levers, pushing them a short distance past the opening point, after which the levers fell away under gravity.

1.13.3 Condition of system after the routine test

During the routine test on 22 November 2007, all of the operating levers in the Master Control Unit were pulled down from the vertical to the horizontal position, releasing CO_2 gas to extend each of the five pistons on the CO_2 room control panel. The cabinets on the CO_2 room control panel were kept closed and the 3E, witnessing the test, expected to see the large distribution valves operate. When there was no movement of the valves, the cabinets were opened and all five distribution pilot valve levers (16B to 16F) were found in the down (open) position **(Figure 13)**. The main pilot valve lever (16A) was found in the horizontal (closed) position. However, there were no markings to describe what the positions meant. The CE was able to operate the distribution valves (4B to 4F) by hand, but could not open the main valve (4A).

Figure 13

Distribution valve pilot release control lever

1.13.4 Ventilation system

Each cabinet on both the Master and CO_2 room control units was fitted with a micro switch which activated the ship's CO_2 alarm as soon as the door opened. All of these worked correctly. Additional interlocks were fitted inside the distribution valve cabinets to shut down ventilation fans and close ventilation dampers as soon as the control lever was moved. The distribution valve levers on the CO_2 room control panel were left in the down position (open) after the routine test on 22 November, and it was soon reported to the EE that the engine room ventilation was not operating. The temperature was rising and the main and auxiliary engines were beginning to labour. After studying the electrical drawings the EE decided to bypass the CO_2 system interlock, rather than establish a new supply to the ventilation fans from another junction box. This would ensure that other automatic vent stop functions could still be used. He fitted a nylon cable tie to the interlock switches on the CO_2 system distribution valve lever for the engine room and restored ventilation to the engine room.

On 26 November, the EE attempted to start the cargo hold ventilation fans prior to arrival in Alexandria, but none of them would operate. The EE suspected that the problem was caused by the CO_2 system interlocks and asked the CE if he could bypass them. The CE gave his permission, misinterpreting the request as one of the many routine questions that he was regularly asked. The EE fitted nylon cable ties to the interlock switches in each of the cabinets and restarted the cargo ventilation system. The EE did not alter the position of any of the CO_2 system valves or control levers.

1.13.5 Inspection following the discharge of CO_2

Service agents attended *Figaro* on arrival in Zeebrugge on 8 and 9 December and conducted a full survey of the CO_2 system. They determined that both CO_2 tanks had been discharged apart from a small volume of CO_2 that had frozen during the discharge process and was now melting very slowly, giving a small positive pressure in the tanks. The controls had not been moved since the routine test on 22 November and were all found in the same positions as described by the crew during interviews.

1.13.6 Defects found

The service agents found a number of defects with the system which are summarised as:

- CO_2 storage tank high pressure alarm set point too high;
- main valve manifold bracket broken, causing misalignment and leakage from valve flange;
- minor leakage through valve spindles on actuators for distribution valves to Zones 3 and 4;
- leakage in main pilot valve (16A) operating pipework between Main Control Panel and CO_2 room control panel;
    - Two out of five non return valves in the connection between the main valve operating levers and the manifold would not seal properly and allowed gas pressure to relieve to atmosphere via other remaining main valve operating levers;
- actuation piston from Main Control Panel to operate main pilot valve (16A) was partially seized and would not extend to its full range of travel;
- pilot pressure regulator (17) filter assembly partially blocked with fine corrosion products;
- nylon cable ties fitted to all ventilation interlocks.

The defects were repaired and the operating system was tested and found to be working satisfactorily. The tanks were refilled with CO_2 and the system was certified as being in order. Representatives from the classification society attended the vessel, confirmed the circumstances of the incident and satisfied themselves that the CO_2 system had been recommissioned and was functional.

1.14 MAINTENANCE OF THE CO_2 SYSTEM

1.14.1 Planned maintenance system

The management company used a classification society approved, computer based Planned Maintenance System (PMS) for all its vessels. This system detailed the maintenance items that were required and provided work instructions and references to other manuals for individual tasks. Tasks were required at preset periodicities based on manufacturers' recommendations or machinery running hours.

1.14.2 CO_2 system maintenance history

The PMS included maintenance of the CO_2 system at 3 and 12 monthly intervals. The work was assigned a *"low priority"* [sic], defined in the maintenance manual as, *"overdue is not critical"* [sic]. The maintenance manual also gave examples for the classification of maintenance priorities:

- *"High – eg. overhaul of main fire pump*
- *Medium – eg. overhaul of main engine cam shaft pump*
- *Low – eg. maintenance of swimming pool pump*" [sic]

The content of the 3 monthly test has been reproduced at **Annex A**, the main points are summarised below:

- close the main stop valves on CO_2 storage tanks to prevent liquid being released;
- operate the remote release valves to each compartment and check that alarm signals and valves function satisfactorily;
- operate the local release valves to each compartment and check that alarm signals and valves function satisfactorily;
- reset the local and remote operating valves;
- re-open the main stop valves on the storage tanks to restore the system.

The 3 monthly maintenance had last been completed on 4 June 2007 and was due to be next completed on 4 September 2007. This was shortly after the CE had joined the vessel and he overlooked the task until early November, when he conducted a routine check of outstanding maintenance tasks. The CE then planned to complete the 3 monthly test on 22 November 2007.

Examination of the handover notes between previous chief engineers dated 19 May 2007 included the following comments relating to the CO_2 system:

> *"Routines for 3 month test of CO_2 are to be changed.*
>
> 1. *Alarm horn function to be tested by Chief Engineer*
> 2. *Lines in engine room and cargo hold, blow thru by compressed air when cargo hold is empty from cargo*
>
> *CO_2 system complete, Yearly test by certified service from ashore. New company policy to information from DPA. Annual is due this time in Europe."* [sic]

The vessel's managers stated that the notes related to a request from a chief engineer, new to the company, wanting confirmation that maintenance tasks and periodicities should be adhered to. It had been noted that the maintenance schedule was in excess of SOLAS and Flag State administration requirements and the chief engineer had wanted to check the company's policy. The notes made no mention of the three monthly test of the remote operating system and there were no changes to the PMS system.

Service agents were employed to inspect and test the CO_2 operating system on a biannual rotation. The work item for the first year was to "*Survey CO_2 low pressure system*" [sic] and the work item for the second was *"Survey CO_2 plan control system"* [sic]. Both work items referred to service agreements and no other work specifications were held by the company. The most recent inspection and test of the system was conducted in Bremerhaven on 4 June 2007 against the service agent's checklist **(Annex B)**. The inspection and test report includes the following successful tests:

- Item 12: Main valve tested
- Item 14: Distribution valves tested
- Item 17: Total flooding release mechanism tested

There were no references to the remote or pilot release mechanisms, but these items could be interpreted as being included in Item 17. No defects or rectification work was recorded.

1.15 REGULATIONS

The requirement for a fixed gas fire extinguishing system for ro-ro cargo spaces was incorporated into the 1981 SOLAS amendments and entered into force on 1 September 1984. The requirements were included in the 1983 consolidated edition of SOLAS in Chapter II-2, under Regulation 53, which stated that:

> *"2.2.1 Ro-ro cargo spaces capable of being sealed shall be fitted with a fixed gas fire-extinguishing system which shall comply with the provisions of regulation 5*[3]*, except that:*
>
> *.1 if a carbon dioxide system is fitted, the quantity of gas available shall be at least sufficient to give a minimum volume of free gas equal to 45 per vent of the gross volume of the largest such cargo space which is capable of being sealed, and the arrangements shall be such that at least two thirds of the gas required for the relevant space shall be introduced during 10 minutes;"* [sic]

Regulation 54 described special requirements for ships carrying dangerous goods, which includes the carriage of motor vehicles containing fuel for their own propulsion. This referred to other requirements to enhance fire safety, including provisions for:

- The supply and drainage of water for fire-fighting
- Sources of electrical ignition
- Fire detection
- Ventilation

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[3] Regulation 5 referred to general requirements for fixed gas fire-extinguishing systems

- Protective equipment for personnel
- Portable fire extinguishers
- And stipulated that Flag Administrations should provide a document of compliance as evidence that the vessel complied with Regulation 54.

Figaro was issued with a "Document of Compliance – Special Requirements for Ships Carrying Dangerous Goods" in June 2006, which stated that the vessel complied with the requirements of SOLAS II-2/54 and was suitable for the carriage of dangerous goods.

Regulations 53 and 54 have now been incorporated in the 2004 Consolidated Edition of SOLAS in Chapter II-2 / Regulations 10 and 20. Regulation 10 includes the requirement for a fixed fire-fighting system for machinery spaces under Paragraph 5, and for cargo spaces containing dangerous goods under Paragraph 7. The remainder of special requirements for vehicle, special category and ro-ro spaces are included in Regulation 20, which, in the context of this report, are the same as Regulation 53.

The CO_2 installation met the requirements of SOLAS regulations and Chapter 5 of the FSS Code[4] for the arrangement of operating controls. The CO_2 alarm was activated by opening the cabinet door, a method suggested in the FSS code.

Part E of SOLAS Chapter II-2 describes the operational requirements of fire safety systems. Regulation 14 requires that:

> *.1 fire protection systems and fire-fighting systems and appliances shall be maintained ready for use; and*
>
> *.2 fire protection systems and fire-fighting systems shall be properly tested and inspected.*

The detail of these requirements was expanded in Circular 850 from the Maritime Safety Committee (MSC/Circ.850) in June 1998 **(Annex C)**, endorsed and amplified by Singapore MPA circular no. 28 of 2006 **(Annex D)**.

Maintenance of the CO_2 system on *Figaro* had been planned in accordance with the instructions in the manufacturer's manual. Even with the delay in conducting the three monthly tests, maintenance was still conducted in excess of the requirements of MSC Circ 850, Singapore MPA and the classification society's' instructions.

[4] SOLAS refers of the International Code for Fire Safety Systems (the FSS Code) for the technical requirements of fixed gas extinguishing systems

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_2 SYSTEM

2.2.1 Effect of unsuccessful test

During the routine test of the remote operating system on 22 November 2007, all the control levers for the main and distribution valve controls were operated from the MCU on deck 14. The five cabinets housing the distribution controls on the local control panel in the CO_2 compartment were shut and so the 3E did not see the levers move. The control for the main pilot valve (16A) did not appear to move.

None of the valves on the CO_2 system opened as expected, and when the local controls were inspected, it was not clear what position they should be in. There were no markings and none of the engineers knew the system sufficiently well to recognise what had happened.

On the CO_2 room control panel, all the distribution pilot valve levers were opened by the MCU remote pistons, but because the main pilot valve lever (16A) remained shut, there was no gas pressure to operate the rest of the pilot system. The valves were left in this configuration, such that it only needed the main pilot valve (16A) to operate to allow both the main and all the distribution valves to open.

The CE attempted to operate the main and distribution valves by hand. The distribution valves would turn, but because the main valve was controlled by a solenoid valve it could not be moved. A manual pilot valve was also provided to operate the main release valve (4A) in emergency, and the CE considered that the CO_2 system could still be operated manually if needed. He re-opened the stop valves on the storage tanks so that the system was available. In this configuration, it would only require the operation of the main pilot valve (16A) to release CO_2 to all the compartments.

2.2.2 Cause of unplanned release

It is not possible to be absolutely sure why the CO_2 system operated on 6 December, but there was no evidence to suspect that the controls were operated in error or maliciously. The release of CO_2 was coincident with the vessel shuddering as it reached the bottom of a wave trough, and it is most likely that the motion caused the main pilot valve (16A) to open.

The main pilot valve (16A) was mounted so that its operating handle was horizontal when the valve was closed. In normal circumstances, it only needed to be moved a short distance (around 20mm) downwards, before the mechanism released and the valve handle fell to the vertical position under gravity. The valve handle should have been opened by the MCU remote piston during the earlier test, but there were two leaks and the piston was partially fouled, preventing it from moving throughout its full range of travel.

It is most likely, that during the routine test on 22 November, the remote piston moved a short distance, pressing up on the main pilot valve (16A) operating handle, before a combination of the leaks and fouled piston stopped it from pushing the handle fully downwards as intended. The lever would then have stayed in this position, with tension in the mechanism until 6 December.

The valve handle was steel, approximately 120mm long and 16mm in diameter with a plastic fitting on the end. It was horizontal and therefore vertical forces would generate the greatest operating torque. The CO_2 compartment was low down in the vessel, close to the stern and known to suffer from the effects of vibration and ship motion. The momentum gained while the stern fell, and then the sudden deceleration and vibration at the bottom of the wave trough could have generated sufficient vertical force to move the main pilot valve handle. It is likely that it had already been moved a short distance, and that the mechanism had been pre-tensioned during the earlier test and less movement than normal would have been needed to release the mechanism and open the valve.

The distribution pilot valves were already open, and once the main pilot valve (16A) opened, the pilot system was activated. The main release valve and all the distribution valves opened and released the gas from the main storage tank. The valve for Zone 4 did not open, no defects were found and as the system was designed to operate one valve at a time, it is most likely that the gas pressure collapsed too quickly for it to be operated properly.

Alarms to indicate the release of CO_2 were activated by opening the cabinet doors on either the MCU or local control panels, a method suggested in the FSS Code. As none of the cabinets were opened during the incident, the alarms did not sound. Although there were no reports of the CO_2 detectors in the engine and CO_2 room being activated, it is thought most likely that crew had already responded to what was a very obvious problem and had escaped before the CO_2 content was sufficient to activate the alarms.

2.2.3 Design considerations

The CO_2 system operating controls seemed, on first inspection, straightforward and intuitive. This incident however, highlights several simple but fundamental problems:

- none of the operating levers were marked to indicate which was the open or shut position;
- the orientation of the operating levers on the Master and local control units differed by 90^o increasing confusion over whether a lever was open or shut;
- distribution pilot valve operating levers on the local control panel could be operated remotely inside their cabinets without being seen by an observer;
- the main pilot release valve operating lever was positioned horizontally and at the aft end of the ship where the effect from forces generated by wave motion would be greatest.

2.2.4 Effect of CO_2

The storage tanks held 46,000kg, based on the requirement to fill the largest single cargo hold with sufficient CO_2 to achieve a 45% concentration. This was achieved during a 15 minute discharge, controlled by a timer in the control circuit. The other three cargo holds required less gas, and smaller distribution pipes were used to restrict the flow rate in the same 15 minute period. The engine room was a far smaller volume and the required 35% concentration of CO_2 was achieved by a timer shutting the valve after 2 minutes and 40 seconds.

During the incident, it is likely that the engine room reached the design concentration of 35% because of the short time required to fill the relatively small compartment volume. The three cargo holds would have been filled with the remaining CO_2. The concentration of CO_2 can be estimated if the calculation is simplified by assuming that gas flowed to the three cargo holds at the same relative flow rates during the 15 minute discharge. Using this method, it is possible to estimate that the concentration reached 19% in each of the three cargo holds by the end of the 15 minute discharge. From the guidance in the manufacturer's manual, this is sufficient to have caused loss of consciousness, and with continued exposure, death would have occurred after 20 minutes.

The CO_2 release alarm did not sound when the system was activated, but crew in each of the compartments affected were able to see the gas vapour as it was released. They were extremely fortunate to be able to escape before the concentration of CO_2 grew sufficiently to overwhelm them. The ship's fire detection system was activated by CO_2 vapour triggering smoke detectors in the engine room.

2.2.5 Ventilation

After the unsuccessful routine test of the CO_2 system on 22 November 2007, the movement of the distribution valve levers opened the interlocks to shut down the ventilation fans and dampers. It was readily apparent that the fans in the engine room needed to be re-started and, latterly, fans in the cargo hold were needed. Nylon cable ties were fitted to bypass the interlocks, this method being chosen to ensure that other emergency ventilation shut down controls would still work. The EE sought permission from the CE to carry out this modification, but his request was misinterpreted and approved without further thought. If the significance had been appreciated, it might have prompted further consideration about the problems with the CO_2 system, and potentially, the significance of the distribution valve operating levers being left open.

2.2.6 Regulatory compliance

Although the equipment and the maintenance met and even exceeded the regulatory requirements, this incident illustrates that continued emphasis is needed to ensure that CO_2 systems are simple to operate and that crew fully understand them.

2.3 RECOVERY AFTER ENGINE FAILURE

2.3.1 Restarting of machinery

The first priority was to restore electrical power to the vessel, and the CE and 3E attempted to restart No. 2 generator. When the generator did not start, it was first thought that there was either a problem with the fuel pump or with a safety interlock. It took a little time to appreciate that the difficulties in starting the generator were due to the CO_2 that had been ingested into the engine and that it had stopped due to oxygen starvation.

The second attempt to start the generator was about 2 hours after the release of gas. The ventilation flaps had remained open throughout the incident, and a certain amount of natural ventilation would have occurred, helping to reduce the amount of CO_2 in the atmosphere. The generator engine had to be turned over a considerable amount, purging the engine of CO_2 before it would run sustainably. This used large amounts of starting air, including some of the emergency supplies, before the engine ran properly.

Once No.2 generator was running, ventilation fans could be restarted, which helped improve the atmosphere in the engine room further. The fuel systems had been permanently configured so that the main engine could only be run on heavy fuel oil, and the auxiliary boiler was flashed to heat fuel and lubrication oil, before the main engine could be started. Compressors were run to refill starting air reservoirs. It can be estimated from the time needed to heat the fuel that the earliest the main engine could have been started was between 2010 and 2025.

2.3.2 Use of EEBD and BA

It was understandable that the CE wanted to gain access to the engine room as soon as possible, and EEBD sets were close at hand. However, the EEBDs had a 15 minute duration and, crucially, were constant flow rate devices. These provided a constant supply of air, regardless of the user's breathing demands. BA sets are fitted with a demand regulator, which matches the flow rate (within limits) to the user's breathing rate.

It is therefore not surprising that after descending 9 decks by stairs, working in the engine room, and then climbing back up the stairs that the CE struggled to get sufficient air from his EEBD set. EEBDs are intended for escape only and the CE was fortunate that he had reached a safe atmosphere by the time he needed to remove the set.

The C/O also used an EEBD to gain access to the stairwell between the cargo holds and the forecastle. This was a quicker and less strenuous task and he did not experience any breathing problems.

MAIB has investigated a number of fatal accidents where EEBDs have been used inappropriately. EEBDs not only have a very limited duration of air supply, but also have a constant supply air flow, which does not respond to the extra demands that will be made by an individual when working hard. They are intended for escape purposes only. Conventional breathing apparatus (BA) are designed for use in situations where an extended duration of escape is required and have air supply warning devices built in. EEBDs should not, under normal circumstances, be used as an alternative to BA in emergency situations.

BA sets were used for the remainder of the entries into the engine room and worked well. It is commendable that a record of who entered the engine room, at what time and with what cylinder pressure was kept, and the 3/O maintained communications updating users with the remaining duration of their set.

2.4 MAINTENANCE MANAGEMENT

2.4.1 Effectiveness of inspections

The CO_2 system had been surveyed, inspected and/or tested annually by service agents against their own checklist. None of the defects identified in the investigation after this incident were evident from the inspection 6 months previously. The inspection checklist did not specifically refer to the remote or pilot operating systems, and it is possible that defects such as the leaking non return valves and partially blocked filter had been present for some time.

2.4.2 Maintenance policy

The company's maintenance instructions in the PMS and SMS were contradictory. The PMS work orders were confusing and there was no work specification to indicate what the service agents were expected to do at each annual visit. The work orders for 3 monthly tests were listed as being a low priority, evident in the 2 month delay from September to November going unchallenged by technical managers. Annual technical audits were limited to a general survey and there were no recorded observations relating to the function or availability of the CO_2 system.

2.4.3 Management control

The lack of a service specification and publication of contradictory maintenance instructions indicates a lack of management control over the CO_2 system. It was not listed as a critical item in the SMS, despite its obvious importance to fire safety, or as a regulatory requirement. Although the maintenance complied with, and in some cases exceeded, the regulatory requirements, its presentation was confused and vulnerable to misinterpretation. Despite considerable experience on this class of vessel, none of the crew involved in the routine test of the CO_2 system had operated it before. The contrast suggests that familiarisation training and fire exercises should include more detail on the CO_2 system to improve crew knowledge.

2.5 ETV ASSISTANCE

2.5.1 Effectiveness

The ETV *Anglian Princess* was tasked and was underway to intercept the casualty promptly. Despite these best efforts, *Anglian Princess* was unable to reach *Figaro* until 40 minutes after the CPA with Wolf Rock. This emphasises the need for vessels that merit ETV assistance to be identified as early as possible.

The transit took approximately 2 hours, during which time the crew prepared substantial steel wire towing gear. There was minimal communication between *Anglian Princess* and *Figaro* and there was no discussion on the capabilities or limitations of either vessel. The master of *Anglian Princess* was not aware that *Figaro* had no power to assist with heaving up the steel tow line, so the time spent rigging and attempting to pass this tow was wasted. It then took another 30-40 minutes to rig the Dyneema tow line and move back into position. Fortunately the CPA had already passed and there was less of a time pressure to attach the tow.

Both vessels had VHF and telephone communications, and there was ample opportunity to spend a few minutes discussing the towing arrangements while *Anglian Princess* was on passage. If this had been done, it would have saved the time and effort both parties wasted in working the steel wire rope.

2.5.2 Improving response

The ETV service has an excellent record of successful interventions, and has contributed to improving safety and reducing pollution at sea. Equally, it could be interpreted that this operation was a success. However, this was only by chance and it highlights improvements that could be made to improve ETV effectiveness.

There are no standard operating procedures for ETVs either from the operator or charterer, it being considered that every operation is different. While this is understandable to a certain extent, there are fundamental aspects that will occur regularly. It is self evident that an ETV can be expected to tow a casualty vessel and so it would be logical to have standard procedures for:

- Determining the size of the casualty vessel
- Estimating environmental loadings on the tow
- Establishing the casualty's capabilities to handle and rig a tow
- Preparing appropriate towing equipment.

While it would not be appropriate to have lengthy paperwork for each of these activities, there are several methods of providing quick and easy aids to crew to assist them in gathering and processing this basic information. There may be cases where the circumstances prevent this information from being gathered, but these are likely to be in the minority.

2.5.3 Towing line failure

The crew of *Anglian Princess* had logged the tow parting at 2015, but the Coastguard recorded *Anglian Princess* reporting that the tow was underway at 2020. Further communications between Sennen Cove ALB and *Anglian Princess*, reporting that the tow had parted, were also recorded by the Coastguard at 2034. There is no other evidence to suggest that the Coastguard incident log time base was incorrect, and with no VDR record from *Anglian Princess* to corroborate the log, it is considered that the timings of the sequential Coastguard records are most likely to be correct.

The tow line failed at a critical point in the recovery operation, just as *Anglian Princess* was beginning to gain control of *Figaro* and turn it to starboard, towards an easterly heading. *Figaro* had been drifting with a heading of 330^o (+/- 15^o) for several hours, and it is possible that wind forces acting on the ship could have caused the 29^o yaw from 007^o back round to 338^o that was seen between 2029 and 2032. This yaw coincided with a sharp reduction in *Anglian Princess*'s speed from 3.7 to 1.4 kts and it is likely that the tow line came under considerable load during this time. Communications between *Anglian Princess* and Sennen Cove ALB at 2034 reported that the tow line had parted.

Analysis of *Figaro's* and *Anglian Princess*'s courses over the ground shows a converging trend up to 2028 indicating that the tow was taking effect. There is marked divergence from 2028 until 2035, the period which includes the 29^o yaw and the tow parting. From 2035, the heading continues to alter to port, eventually reaching 330, but the courses over the ground are similar until 2042, when *Figaro* declared that main propulsion was restored.

Figaro's bow thruster was available during this time, and it is conceivable that the main engine could also have been running earlier than was declared. These could have been used to cause the yaw to port and change in course that coincided with the tow parting. However, study of the trend over the preceding 3 hours shows several instances of *Figaro*'s heading and course altering by similar amounts, before any machinery was running or the tow was connected. Strain on the tow line was in the order of 130 tonnes under steady conditions, and it is quite possible that the sudden yaw applied more than the 200 tonnes needed to part the line, without the increase on the strain gauge being noted.

It is disappointing that the SVDR on *Figaro* was not saved and that there is no means of recording data on the ETVs. Either vessel could have provided the navigational, weather, propulsion or towing data that is necessary to provide conclusive evidence of why the tow parted. While this is frustrating, the key safety issue is that *Anglian Princess* had no means of predicting whether the towing arrangements would be adequate for such a high sided vessel in strong winds. Although the crew demonstrated considerable skill and experience, it is unrealistic to expect them to be able to judge the effects of the dynamic loads in these extreme circumstances. Sample calculations for more challenging ship types and conditions could be prepared and presented in a simple 'ready reckoning' format to allow ETV masters to make more informed decisions.

ETVs are not fitted with VDR or any other equipment to record their operations. Given that the ETV service regularly involves close quarters manoeuvres, legal interventions on behalf of the MCA, and exchange of commercial and contractual instructions, it is surprising that the benefits of fitting a VDR have not already been identified. Coastguard recordings do not necessarily include the ETV / casualty vessel working channels.

2.6 FATIGUE

There is no evidence to suggest that fatigue was a factor in this incident.

2.7 SIMILAR ACCIDENTS

There have been 11 accidents on vessels of 500gt or more reported to MAIB involving the unintentional release of CO_2 between 1993 and 2007. These did not result in any injuries or fatalities. The principal causes of these accidents is shown in Table 1

Cause	**No of incidents**
Crew inadvertently activated controls	2
During maintenance by shore contractor	2
Equipment fault	2
Incorrect storage of cylinders	1
Unexplained	2
During maintenance by crew	1
During investigation after a fire	1
Total	**11**

Table 1 Similar accidents

SECTION 3 - CONCLUSIONS

3.1 SAFETY ISSUES IDENTIFIED DURING THE INVESTIGATION WHICH HAVE NOT RESULTED IN RECOMMENDATIONS BUT HAVE BEEN ADDRESSED

1. After the routine test of the CO_2 system on 22 November, it was not clear what position the controls should be in. There were no markings and none of the engineers knew the system sufficiently well to recognise what had happened. [2.2.1]

2. It is most likely that the CO_2 system was left in an unstable condition after the unsuccessful test, and that the last remaining control valve needed to release the gas was triggered by the motion of the ship in rough weather. [2.2.2]

3. The alarm to indicate operation of the CO_2 system was activated by opening the operating cabinet doors, and did not sound because no cabinets were opened during the incident. [2.2.2]

4. CO_2 system operating controls should have their normal and operating positions clearly identified and should be arranged in such a way to minimise the effects of external forces from wave motion or vibration. [2.2.3]

5. It is estimated that the CO_2 concentration reached 35% in the engine room and 19% in each of the three cargo holds after the 15 minute discharge. From the guidance in the manufacturer's manual, this is sufficient to have caused loss of consciousness, and with continued exposure, death would have occurred after 20 minutes. [2.2.4]

6. Crew in each of the compartments affected were able to see the gas vapour as it was released. The ship's fire detection system was activated by CO_2 vapour triggering smoke detectors in the engine room. [2.2.4]

7. Continued emphasis is needed by regulatory authorities to ensure that CO_2 systems are simple to operate and that crew fully understand them. [2.2.6]

8. The generator and main engine stopped running due to oxygen starvation and had to be turned over a considerable amount, using large amounts of starting air, to purge the CO_2 before they could be restarted. [2.3.1]

9. EEBDs are intended for escape purposes in an emergency only. They do not have the duration, or the appropriate gas flow characteristics for them to be safely used to enter or work in a contaminated atmosphere and should not be used as an alternative to conventional breathing apparatus (BA), in an emergency situation. [2.3.2]

10. The company's maintenance instructions in the PMS and SMS were contradictory. The PMS work orders were confusing, and there was no work specification to indicate what the service agents were expected to do at each annual visit. [2.4.2]

11. The low priority attached to CO_2 system maintenance, lack of crew familiarity, and attention during internal audits indicates that the subject was not firmly controlled by managers. [2.4.3]

12. The ETV was not able to intercept *Figaro* until 40 minutes after the CPA with Wolf Rock. [2.5.1]

13. The effectiveness of the ETV could be improved by implementing simple standard procedures to obtain basic information about the type and capabilities of casualty vessels. [2.5.2]

14. The sudden yawing of *Figaro* caused the tow line to fail at an approximate load of 200 tonnes. The reason for the yaw cannot be determined. [2.5.3]

15. *Anglian Princess* had no means of predicting whether the towing arrangements would be adequate for such a high sided vessel in strong winds. Sample calculations for more challenging ship types and conditions could be prepared and presented in a simple ‘ready reckoning’ format to allow ETV masters to make more informed decisions. [2.5.3]

16. Fitting VDR equipment to ETVs offers multiple benefits to the operators, the MCA, and for use in accident investigation. [2.5.3]

SECTION 4 - ACTION TAKEN

Wallenius Marine Singapore:

Has undertaken its own investigation into the incident and as a result has taken the following actions on *Figaro* and the three sister vessels:

- published its report of the incident and assessment of the causes and contributory factors to all vessels in its managed fleet;
- re-emphasised existing instructions to crew for requests regarding urgent repairs to be sent to the Designated Person Ashore, as well as the appropriate manager and purchasing department personnel;
- in partnership with the service agent, has clarified the CO_2 system operating and resetting instructions and re-issued them to all vessels in its fleet fitted with this equipment;
- colour coded the controls for each zone;
- fitted an enclosure cabinet to the main pilot valve operating lever such that the open and closed positions are readily apparent;
- added observation windows to the distribution valve operating levers allowing the position of the levers to be easily checked;
- added guards to the CO_2 secondary release (labelled as '*re-release*') control to prevent inadvertent operation;
- deleted the requirement for crew to test the remote operation of the system every 3 months. This has been replaced with a requirement for maintenance, a system test and a crew familiarisation exercise to be carried out by the service agents annually. Senior officers will be permanently assigned to serve either in *Figaro* or the sister vessel, and the annual CO_2 familiarisation exercise will be conducted during a handover period so that both incoming and outgoing officers can be involved;
- issued instructions and advice on the appropriate use of EEBD to all vessels in its managed fleet;
- included CO_2 system training and assessment as an element of internal audits and safety assessments.

Changes to the CO_2 system operating controls are shown at **Annex E**.

The Maritime and Coastguard Agency:

- Has revisited the current CPSO procedures to ensure that the condition of the casualty is known to the crews of the ETVs and other response units. Staff have been reminded to use existing procedures to compile a short report after every casualty response, which includes the critical details and any recommendations and lessons learnt, which can be shared as best practice.
- Will be participating fully in a European Union "Intereg ETOW project". This will include the sharing of best practice between ETV crews in several North Sea Countries. The project will also include a number of workshops, including:
    - Environmental loading on casualty vessels
    - Leeway of large vessels
    - Types and properties of towing gear.
- Is considering the requirement for VDR on board ETVs.

SECTION 5 - RECOMMENDATIONS

In view of the actions already taken, no further recommendations are made as a result of this investigation.

Marine Accident Investigation Branch
August 2008

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