



Danish Maritime Accident
Investigation Board

MARINE ACCIDENT REPORT

April 2016



CAROLINE MÆRSK

Fire in containers on 26 August 2015

The Danish Maritime Accident Investigation Board
Carl Jacobsens Vej 29
DK-2500 Valby
Denmark

Tel. +45 91 37 63 00
Email: dmaib@dmaib.dk
Website: www.dmaib.com

Outside office hours, the DMAIB can be reached on +45 23 34 23 01.

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Front page: Fire nozzle in container on CAROLINE MÆRSK. Source: Maersk Line.

The marine accident report is available from the website of the Danish Maritime Accident Investigation Board www.dmaib.com.

The Danish Maritime Accident Investigation Board

The Danish Maritime Accident Investigation Board is an independent unit under the Ministry of Business and Growth. It carries out investigations as an impartial unit that is, organizationally and legally, independent of other parties. The board investigates maritime accidents and occupational accidents on Danish and Greenland merchant and fishing ships, as well as accidents on foreign merchant ships in Danish and Greenland waters.

The Danish Maritime Accident Investigation Board investigates about 140 accidents annually. In case of very serious accidents, such as deaths and losses, or in case of other special circumstances, either a marine accident report or a summary report is published, depending on the extent and complexity of the events.

The investigations

The investigations are carried out separately from the criminal investigation, without having used legal evidence procedures and with no other basic aim than learning about accidents with the purpose of preventing future accidents. Consequently, any use of this report for other purposes may lead to erroneous or misleading interpretations.

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1. SUMMARY

In the afternoon of 26 August 2015, a fire broke out in a container in a cargo hold on board the container ship CAROLINE MÆRSK. At the time of the accident, the ship was positioned approximately 50 nm from the coast of Vietnam, underway from Chiwan, China to Tanjung Pelepas, Malaysia.

The fire broke out as a result of charcoal self-igniting in a cargo container below deck. Despite a number of challenges related to knowledge about the contents of the cargo container and the nature of the formal fire emergency preparedness, the crewmembers managed to successfully contain the fire for several days and prevent it from spreading excessively. This achievement was the result of the shore and shipboard organization's ability to adapt to the unfolding emergency situation by filling the gaps between the formal emergency preparedness and the actual emergency scenario. In other words, the organization 'finished the design' of the emergency preparedness to match the situation they faced.

Following the accident, the shipping company has implemented a number of preventive measures related to the firefighting systems and emergency procedures.

2. FACTUAL INFORMATION

2.1 Photo of the ship



Figure 1: CAROLINE MÆRSK

Source: ©Jan Svendsen – www.containership-info.com

2.2 Ship particulars

Name of vessel:	CAROLINE MÆRSK
Type of vessel:	Container ship (fully cellular)
Nationality/flag:	Denmark
Port of registry:	Faaborg
IMO number:	9214903
Call sign:	OZWA2
DOC company:	MÆRSK Line A/S
IMO company no. (DOC):	5808451
Year built:	2000
Shipyard/yard number:	Odense Staalskibsværft/Lindoe, #178
Classification society:	American Bureau of Shipping
Length overall:	346.98 m
Breadth overall:	42.80 m
Gross tonnage:	92,198
Deadweight:	110,387 t
Draught max.:	14.941 m
Engine rating:	54,840 kW

Service speed:	25.0 knots
Hull material:	Steel
Hull design:	Single hull

2.3 Voyage particulars

Port of departure:	Chiwan, China
Port of call:	Tanjung Pelepas, Malaysia
Type of voyage:	Merchant shipping, international
Cargo information:	General cargo in containers
Manning:	22
Pilot on board:	No
Number of passengers:	0

2.4 Weather data

Wind – direction and speed:	ESE 3.4-5.5 m/s
Wave height:	0.5-1.0 m
Visibility:	Clear
Light/dark:	Daylight

2.5 Marine casualty or incident information

Type of marine casualty/incident:	Fire
IMO classification:	Serious
Date, time:	26 August 2015 at 16.00 LMT
Location:	South China Sea
Position:	14°51.2' N – 109°54.5' E
Ship's operation, voyage segment:	En route
Place on board:	Cargo hold
Human factor data:	Yes
Consequences:	Damage to containers Damage to reefer cargo Damage to ship (CO ₂ room)

2.6 Shore authority involvement and emergency response

Involved parties:	Svitzer Fire Team. Port of Tanjung Pelepas (PTP). Company crisis team.
Resources used:	Firefighting team, port personnel and equipment.
Actions taken:	Firefighting assistance on board (Svitzer). Unloading of burning container (PTP). Planning and coordination (Company).

Results achieved: Fire contained, burning container unloaded.

2.7 The ship's emergency management team

Master
Held an STCW II/2 master unlimited certificate.
Had served 25 years at sea, 14 years with the company, and had served on CAROLINE MÆRSK for two months.

Chief engineer
Held an STCW III/2 chief engineer certificate.
Had served 22 of his 23 years at sea with the company, 8 of which on CAROLINE MÆRSK.

2.8 Scene of the accident

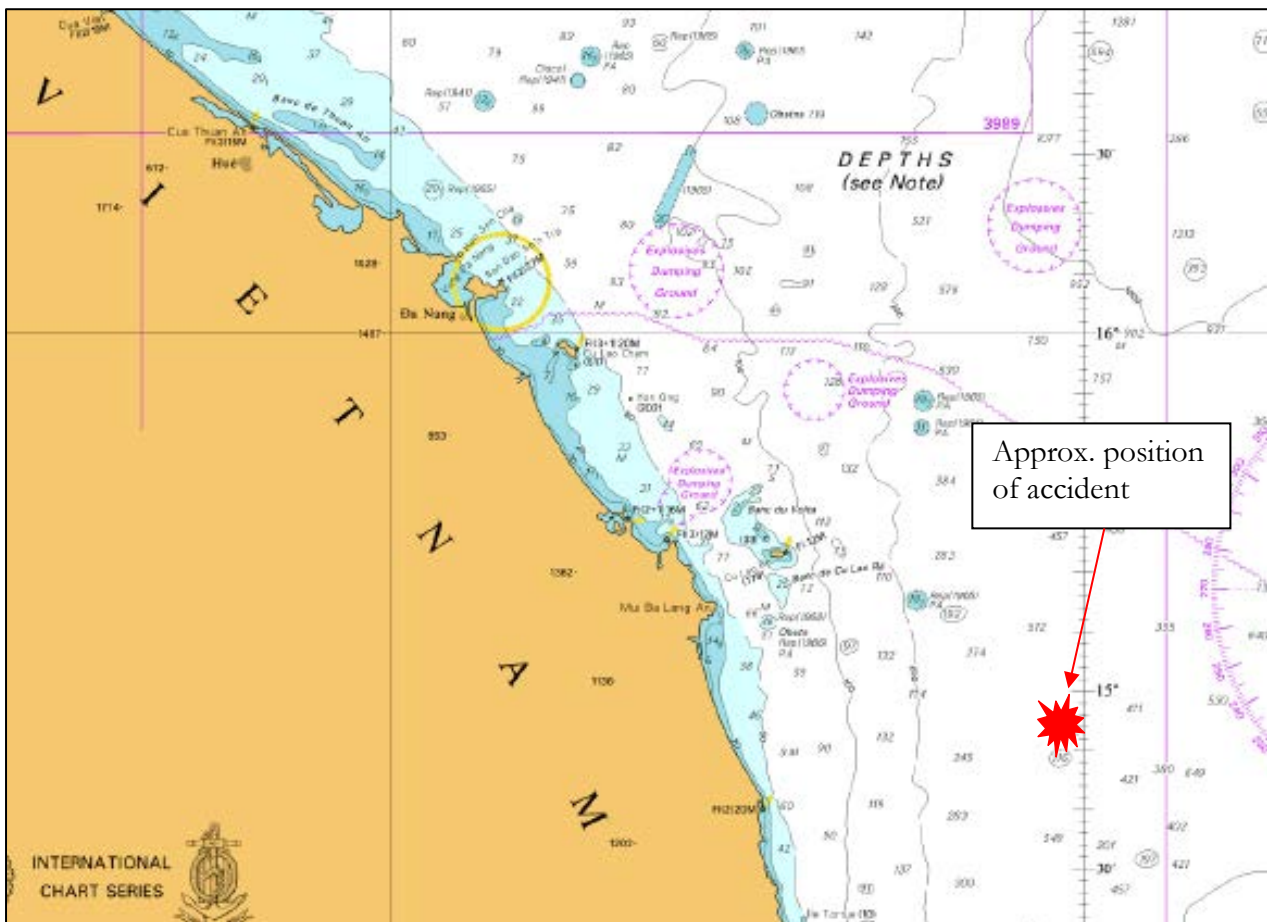


Figure 2: Scene of the accident. Off the coast of Vietnam.

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3. NARRATIVE ABOUT THE ACCIDENT

3.1 Background

CAROLINE MÆRSK was a container ship with an official capacity of 9,578 TEU, owned and operated by MÆRSK Line A/S in Copenhagen, Denmark, and managed by MÆRSK Co. Ltd. in Newcastle upon Tyne, UK. The ship was deployed on MÆRSK Line's 'Safari' route, calling at 11 ports in East Asia, one in Mauritius, and two ports in South Africa.

The crew comprised 22 persons of six nationalities: Filipino, Indian, British, Swedish, Norwegian and Danish. The working language on board was English.

The master had joined the ship in Hong Kong, China, on the evening of 23 August 2015, three days before the accident. He relieved his colleague after a short handover. In the early morning of 24 August, CAROLINE MÆRSK departed for Chiwan, China, where the ship was subjected to a Port State Control, lasting until 2100 in the evening when the ship departed for Tanjung Pelepas (TPP), Malaysia. The company had postponed the planned arrival in TPP by 3 days, and as a result the master updated the voyage plan accordingly. The change of plans also allowed for drills, management meetings and a review and distribution of the master's standing orders.

Times given in this report are the ship's local time (UTC+8) on the day of the accident.

3.2 Sequence of events

The sequence of events aims to describe the events as the involved persons on board perceived them and thereby also aims to reflect the information available to the crew at the given moment.

The narrative consists of several parallel viewpoints and describes the events from the day of the accident, 26 August 2015, until the ship arrived in Singapore, three days later.

The description falls in three sections: Section 3.2.1 covers the discovery and firefighting measures, section 3.2.2 describes the containment of the fire, and section 3.2.3 the external assistance and arrival in port.

3.2.1 Discovering and fighting the fire

On the day of the accident, 26 August, the master and chief officer of CAROLINE MÆRSK were doing paperwork in the master's office. At 1600 the 3rd officer, who was the watchkeeping officer on the bridge, called the master in his office to inform him that there was a smoke detector alarm indicating smoke in cargo hold 9 (figure 3) and that crewmembers working on deck had reported seeing smoke coming from the hatch in the same area. The 3rd officer then activated the general alarm, the master ordered the chief officer to muster at the ship's control centre, and he rushed to the bridge to take command. From the bridge, he kept in radio contact with the chief officer who was the fire team leader, organizing the firefighting efforts from the ship's control centre.

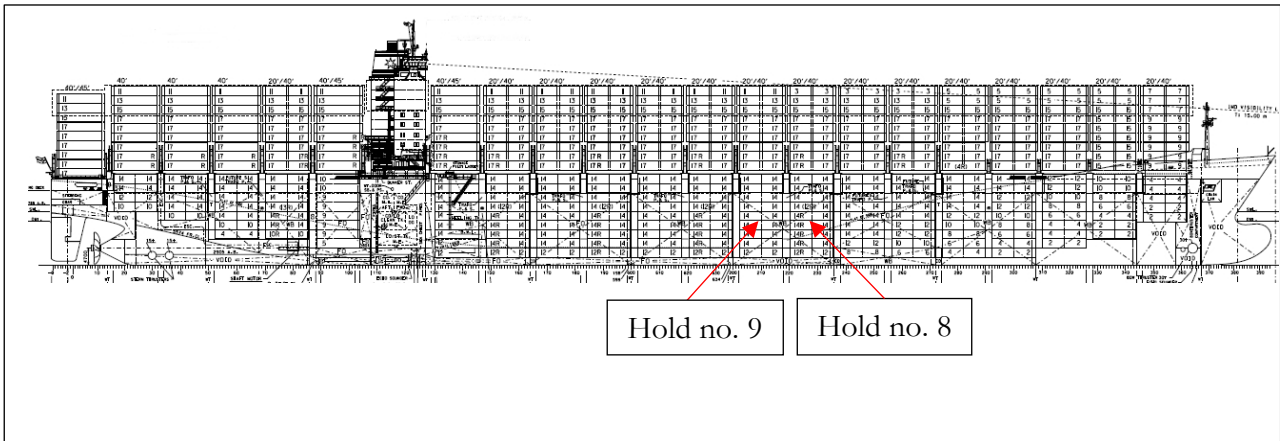


Figure 3: Section of general arrangement CAROLINE MÆRSK

Source: MÆRSK Line

From the bridge, it was not possible for the master to visually assess the situation, as the location of the suspected fire was roughly 100 metres forward of the bridge and obstructed by the container cargo on deck. The master, therefore, considered it essential that a deck officer was appointed on-scene commander to function as his eyes on site, and to organize the efforts assessing and fighting the fire locally, while the chief officer as the fire team leader coordinated the firefighting efforts from the ship's control centre. The crewmembers mustered according to the muster list: the 2nd engineer took over the watch in the engine control room, and the remaining crewmembers reported to the ship's control centre on the A-deck.

One of the two 3rd officers was appointed on-scene commander and went to the side passageway at container bay 34, above cargo hold no. 9. She quickly confirmed that smoke was emerging from under the starboard side of the hatch cover at cargo hold 9, most likely originating from a container in the hold.

The master reduced the ship's speed and altered its course to direct the smoke away from the deck area. All electrical power was switched off, including the reefer transformers in the hold, and ventilation to the hold was stopped. The crew checked the cargo manifests to establish if the hold contained any dangerous cargo, which it did not. Dangerous cargo of various categories¹ was, however, stowed on deck, directly above the fire. The master was in constant radio contact with the chief officer (fire team leader), the 3rd officer (on-scene commander), and the chief engineer, who all were continuously keeping each other updated on the situation.

16 minutes after the alarm, as soon as they had been briefed and equipped, one of the two two-man teams of BA-equipped² firefighters entered the cargo hold to find the location and extent of the fire. They entered through an access hatch on the port side, aft of cargo hold 9. From the hatch

¹ Cargo of categories 2.1 (flammable gases), 6.1 (toxic substances) and 8 (corrosive substances) according to the International Maritime Dangerous Goods Code (IMDG Code) was located above deck.

² Firefighters equipped with breathing apparatus.

on deck, they first had to descend a 5 metre vertical ladder, then pass through the transverse gallery decks one by one, passing numerous narrow manholes, while searching for the fire (figure 4).

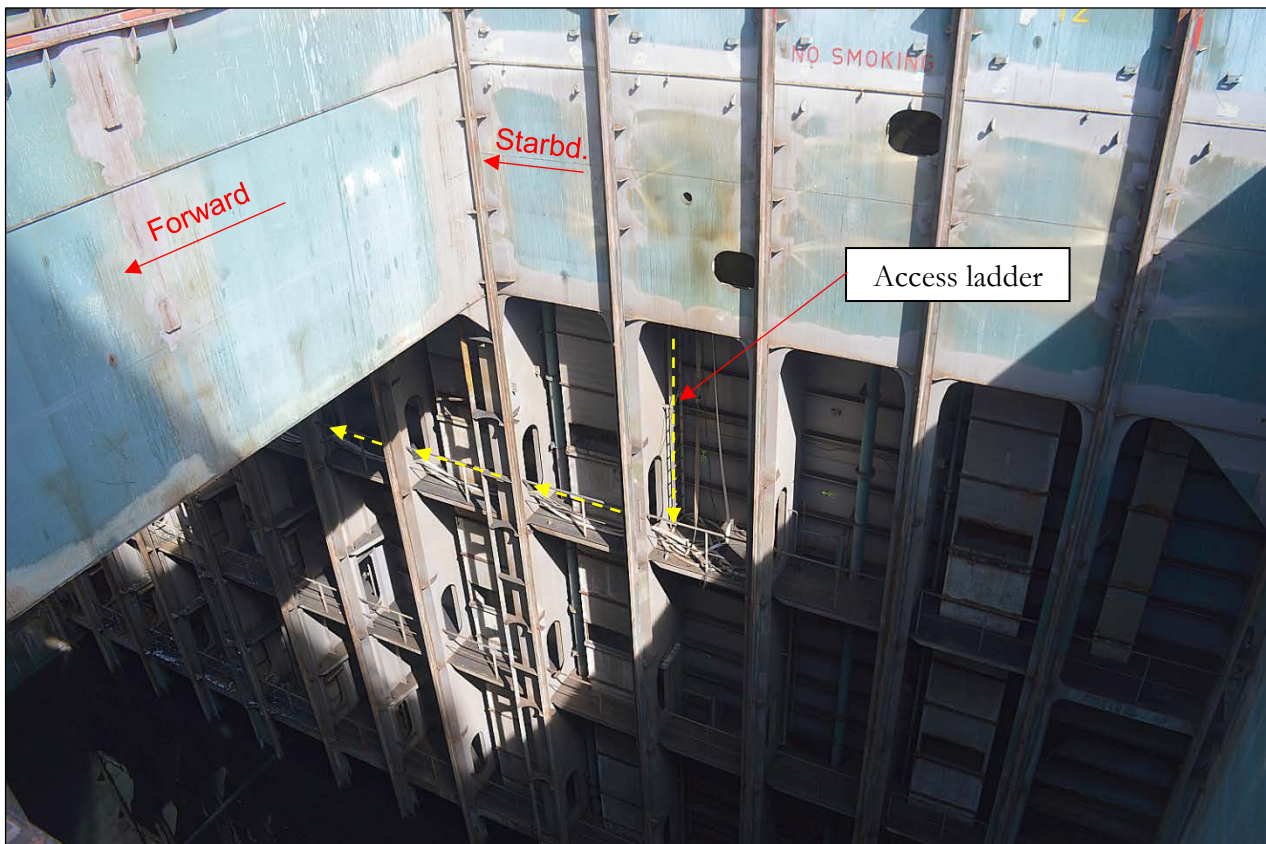


Figure 4: Cargo hold 9, transverse gallery decks, firefighters' access route to fire indicated in yellow
Source: DMAIB

The team made their way down into the hold in darkness and heavy smoke with very limited visibility, and uncertain about the scenario they would meet.

Equipped with firefighter's outfits, breathing apparatuses and fire hoses, the two firefighters had great difficulties entering and manoeuvring in the hold, struggling with dragging the pressurized fire hoses with them through the steel structure, mainly because the hose couplings kept getting stuck whenever passing a manhole. The firefighters saw no flames and felt no significant heat while searching for the fire, and when the air supply was running out after about 20 minutes, they made their way back up, without having been able to locate the source of the fire. Having returned to the deck, they briefed the second firefighting team.

The second firefighting team then entered the hold to continue the search and identified a container located between three and four levels down, at the starboard side (stowage position 340710³) as the probable source of the smoke. At this point in time, the crew still had no knowledge of the

³ Stowage position 340710 indicates loading bay 34, 4th container position from centre on starboard side, 5th level from the bottom.

extent and severity of the fire, nor the contents of the containers affected. While the firefighting teams were deployed in the hold, their colleagues on deck had established boundary cooling of the adjacent areas.

With the information provided by the firefighting teams, the master considered his options and decided to deploy the ship's CO₂ extinguishing system. In preparation for releasing the CO₂, the crew withdrew from the cargo hold area, and the ventilation to the accommodation was switched off. To be safe from any potential leaks from the system into the ship's control centre, the crew mustered on the open deck outside, at the starboard side of the A-deck, above the CO₂-room (figure 5).

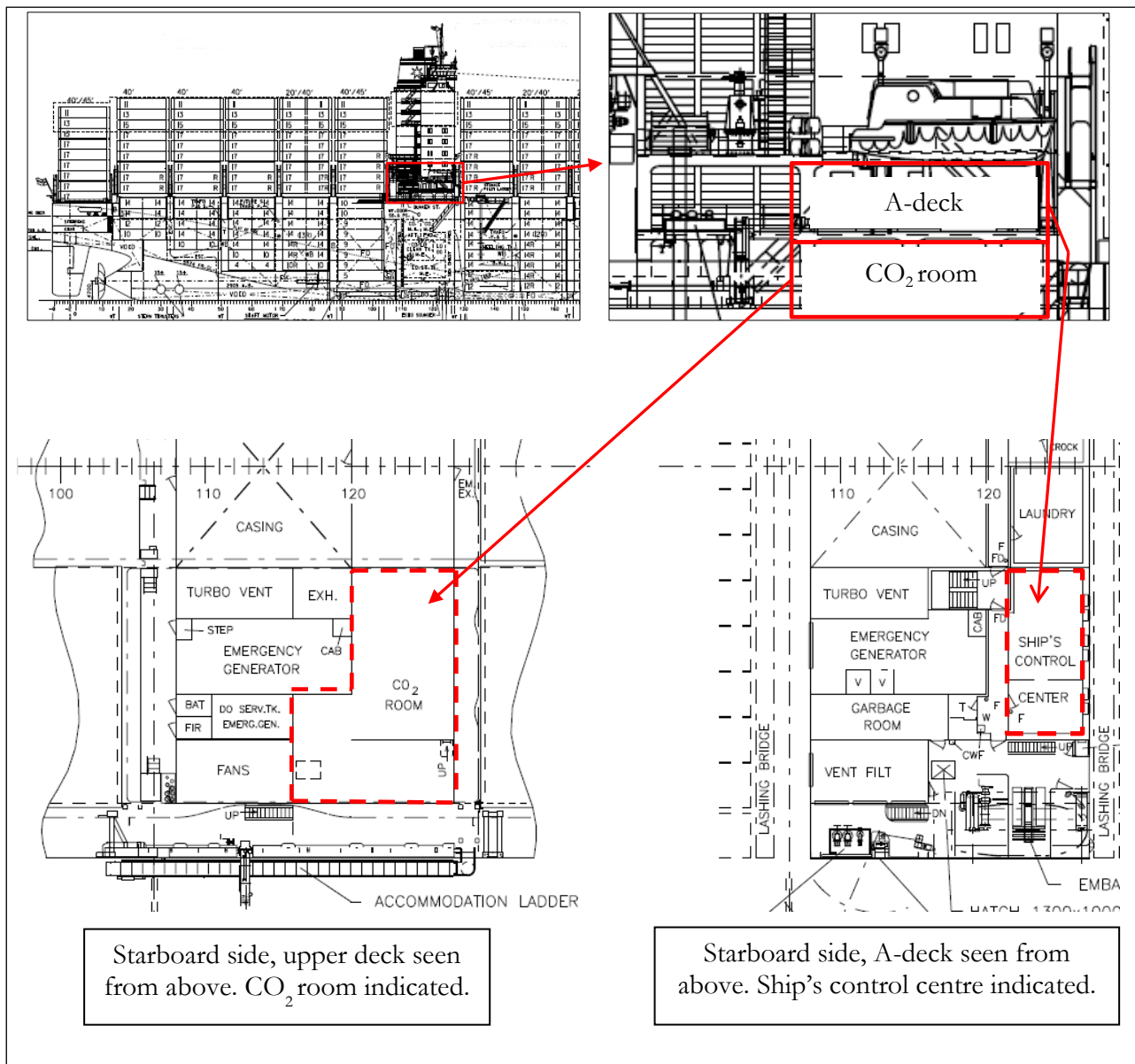


Figure 5: Excerpts from general arr. and capacity plan. A-deck and CO₂ room indicated.

Source: MÆRSK Line/DMAIB

The chief engineer, equipped with an emergency escape breathing apparatus (EEBD), entered the ship's control centre, ready to release the required amount of CO₂ when he got the go-ahead from the master. At about the same time, the master called the company crisis team to update them on the status of the situation, following up on an email briefing he had submitted earlier on.

The moment the CO₂ was released, the crew, from their position on the A-deck, heard noise coming from the CO₂ room and immediately saw a big white cloud oozing out of the CO₂ room. There was a loud bang, the door to the room was blown open, and CO₂ gushed through the door and the fire dampers. Realising that the situation could be fatal, the crewmembers quickly drew a breath of fresh air and rushed for the stairs to the deck below, to get away from the risk of suffocation. After some congestion at the narrow stairway, all crewmembers made their way aft to around bay 70, where a headcount was done to ensure everybody was safe.

The chief engineer wanted to investigate the cause of the failed attempt to release the CO₂, and try to fix the problem, but in the hurry to get away from the hazardous area, the BA equipment had been left behind by the firefighters on the deck outside the ship's control centre. An additional EEBD was retrieved from the engine room entrance on the aft part of the accommodation, which allowed the chief engineer to collect a breathing apparatus from the A-deck and enter the CO₂ room.

Once inside, he found the room covered in ice from the leaked CO₂, and with paint peeled off by the freezing. He quickly established that there were no defects on the hoses connecting the cylinders, noted that the main distribution valve for the cargo holds was not open, and that a gasket on the main pipeline had burst. He reported to the master that no CO₂ could have reached the cargo hold. He manually opened the main distribution valve to the cargo hold and left the room. The chief engineer then returned to the ship control centre from where he released a second section of CO₂ cylinders, while keeping his hand on the pipes to check that it was in fact flowing to the cargo hold this time. When he went outside to the deck, he also saw that CO₂ was still leaking out of the room. From the bridge, the master confirmed that some CO₂ had likely reached the hold as he could see an effect on the smoke coming from the hold.

During the various ongoing efforts, the master was in contact with the company crisis team, and the possibility of calling a nearby port in Vietnam was discussed. The ports of Vung Tau and Da Nang, located on the southern and eastern coast respectively, were considered but were both ruled out due to lack of water depth and shore facilities. It was tentatively decided to proceed towards the original port of call, Tanjung Pelepas, at full speed while keeping Vung Tau as an option since this was on the same route. The company crisis team also contributed with information about the declared contents of containers in the concerned area, and advise on the possible firefighting measures.

In the early evening on the first day, around 1845, while preparations were made to enter the hold again, the crew reported that the compressor for filling breathing apparatus (BA) bottles had a breakdown. Although relatively simple, the defect was crucial to the continued efforts. As it turned out, the problem was that a pressure relief valve was broken. This meant that while the compressor was still able to pressurize the bottles, the bottles could not safely be disconnected afterwards. Over the next hours, the engine crew was able to work out a makeshift solution, bringing the compressor temporarily back into working order. With the compressor working again, teams of firefighters prepared to enter the hold again shortly before midnight on 26 August.

The first team was able to confirm that the burning container was blackened to a degree that made it unidentifiable. Just after, a second team entered, carrying the ship's special container firefighting equipment, consisting of a cordless power drill, a hole saw bit and a spike nozzle. The idea was that the drill should be used for drilling a hole in the burning container, into which the spike nozzle would be driven, allowing water to be sprayed directly into the container. However, the special equipment proved ineffective as the power drill was not able to penetrate the container door. The team returned from the hold feeling demotivated by the fact that the gear supposed to help them in a crisis situation proved inadequate.

It was decided to close the hold, maintain the cooling, and allow the crew some rest and time to consider alternative approaches. The company crisis team advised the master to make another attempt at placing the spike nozzle in the burning container, this time using an angle grinder. The 2nd officer volunteered for the task. To pre-empt unnecessary difficulties once he was in the hold, the chief engineer instructed the 2nd officer in effective use of the angle grinder by practicing on containers on deck, well away from the constrictions of wearing the firefighter's outfit, and operating in darkness, heat, noise, and a limited amount of time. Just after 0400 on the second day, the 2nd officer had managed to cut a hole, place the spike in the container (figure 6), and turn on the water flow inside it. Soon after, the fire was considered under control.



Figure 6: Burning container with spike nozzle inserted.

Source: MÆRSK Line

3.2.2 Containment of fire

Later in the morning of the second day, smoke and steam in increasing amounts were observed coming from the cargo hold. A firefighting team entered to investigate and evaluate the situation. When they returned, they reported elevated temperatures (65°C as compared to the surrounding temperature of approximately 45°C) in the containers adjacent to the burning one. During the following 12 hours, the situation was kept under observation, and another three teams entered the hold during that period to measure temperatures and check the water level in the hold. Based on these evaluations, it was decided to cut holes in the two adjacent containers and flood them with water as well. Since only one special container spike nozzle was available, the crew instead inserted standard fire nozzles into the two containers (figure 7).

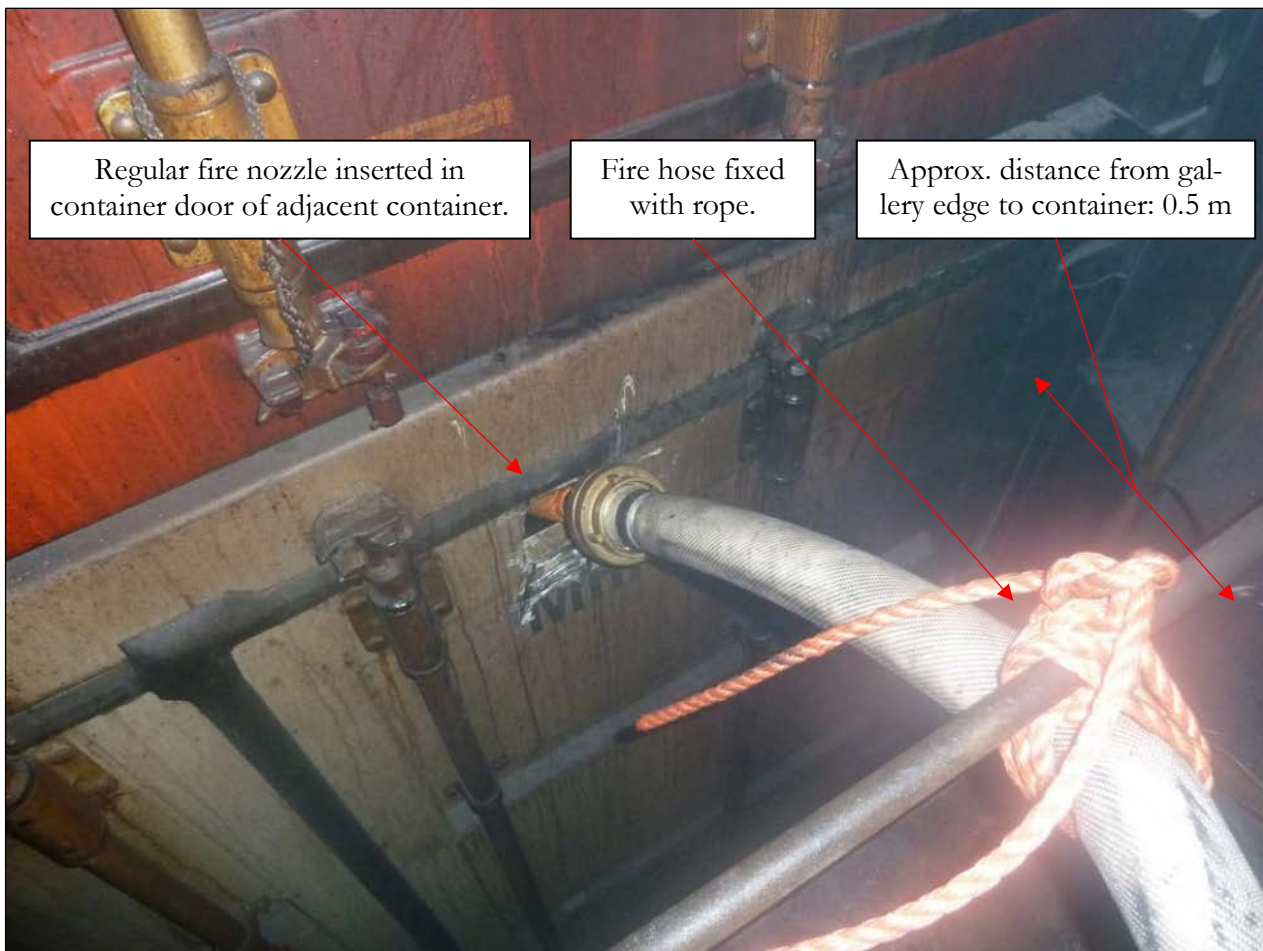


Figure 7: Container with regular fire nozzle mounted.
Source: MÆRSK Line

Just after noon on the third day, 28 August, small amounts of smoke and raised temperatures were reported from cargo hold 8, the hold just forward of hold 9, where the original fire was. Hold 8 was separated from hold 9 by an open transverse bulkhead, so the crew assumed that smouldering material from the burning container had spread from the burning container in hold 9 through the bulkhead. The firefighting teams that entered hold 8 to check reported that they found smouldering charcoal spread around the decks in the hold as well as significantly raised temperatures (80°C) in the containers nearest to where the smouldering charcoal was found. The ventilation and power supply to hold 8 was cut, and the firefighting teams equipped with hoses were able to extinguish the smouldering charcoal within 1½ hours.

3.2.3 External assistance & arrival in port

At approx. 1700, it was decided to request assistance from an external professional firefighting team before arrival at the Tanjung Pelepas pilot boarding position. On the fourth day, 29 August, just after midnight, a salvage team came on board by boat, and was immediately put in charge of the firefighting efforts. At 0155, the pilot came on board along with four surveyors from the port, and at 0358 the vessel was moored alongside in Tanjung Pelepas. The still burning, damaged container was discharged at 2359. On 31 August 2015, the ship proceeded to Singapore for repairs, refitting and cleaning, which lasted until 6 September, when the ship returned to service.

4. INVESTIGATION DATA

4.1 Time, origin and cause of fire

4.1.1 Origin of fire

The contents of the container in which the fire originated were identified as charcoal for water pipes. An independent third party investigation indicated that self-heating of the charcoal tablets was most likely the direct cause of the fire. Charcoal products are susceptible to exothermic oxidation, i.e. they can react with oxygen in the air and produce heat. Under circumstances where there is sufficient oxygen to sustain a reaction, and the area undergoing heating is sufficiently insulated, the heat may be retained, resulting in the temperature of the charcoal product increasing over hours or days until it becomes hot enough to ignite and burn. There was no evidence to suggest that the fire was deliberately started, and examination of the cargo hold showed that the fire was not associated with the ship's electrical installations. Other external sources of fire, such as a discarded smouldering cigarette inside the container, were deemed unlikely due to the time frame – approximately 10 days – between the stuffing and loading of the container, and the fire breaking out.

4.1.2 Container contents

The container in which the fire originated was loaded in Busan, South Korea, 10 days prior to the discovery of the fire, and had been shipped from a manufacturer in China. According to the cargo manifest, the contents were described as *'tablet for water pipe'*. The manifest also referred to HS Code 440290, which is the Harmonized Commodity Description and Coding System's⁴ code for *'wood charcoal'*. The IMDG Code states that charcoal is a Class 4.2 cargo, which covers substances liable to spontaneous combustion; however, the cargo of the burning containers had not been declared as dangerous cargo. These facts indicate that the container contents should have been declared as dangerous cargo from the shipper's side, but they were not.

Undeclared cargo, i.e. containers with contents different from those declared, is an issue that the operator of the ship was aware of. The scale of container shipping, i.e. the high number of containers transported world-wide, means that manual inspection of each individual container is not feasible due to time and personnel restrictions. This means that, with the exception of reefer containers and containers with declared dangerous cargo, shipping containers are only subjected to sporadic spot-checks with regards to contents and stuffing from the time they leave the shipper until the time they arrive at the recipient.

⁴ The Harmonized Commodity Description and Coding System, also known as the Harmonized System (HS) of tariff nomenclature, is an internationally standardized system of names and numbers to classify traded products.

4.2 Firefighting measures

CO₂ extinguishing system, container firefighting equipment and emergency procedures

4.2.1 CO₂ extinguishing system

A CO₂ extinguishing system is designed to extinguish a fire by replacing the oxygen in the protected space with CO₂ which is an inert gas, heavier than air, thus reducing the percentage of oxygen in the area to below what is needed to sustain a fire. Such systems are generally referred to as total flooding systems as they are designed to flood the entire protected area with CO₂. Because CO₂ is an asphyxiant gas and therefore hazardous to humans even in relatively low concentrations, strict safety precautions must be observed when deploying the system.

CO₂ provides a smothering effect on a fire, but has a limited cooling effect. This means that when air is readmitted into the area, there is a risk of the fire re-igniting, which could present a challenge as most CO₂ systems has a capacity of one or two releases. The regulations for container ships require the system to be capable of flooding the largest cargo space covered to 30% by volume. Extinguishing smouldering fires requires a higher concentration of CO₂ (50% by volume) and a longer holding time than container ship CO₂ systems are normally capable of. When a cargo hold is closed before a CO₂ release, some air is still allowed in because ventilation fans, fire flaps and hatch covers are not entirely air tight. Especially when the bilge pumps in the holds are used, air will enter the room to replace the water being removed.

A high pressure CO₂ system (figure 8) consists of a number of CO₂ cylinders, located in a central, separate room. The cylinders are interconnected and connected to a common manifold with main valves for distribution to the areas covered by the system, on container ships typically the engine room and the cargo holds. The cylinder valves and main valves are normally pneumatically operated by means of CO₂ gas from two smaller control cylinders, called pilot bottles. As a safety precaution, the system is manually released from a release cabinet located outside the protected space. Typically, release cabinets are located in the fire control station with an extra release cabinet in the CO₂ room. When opening a release cabinet, micro switches will ensure that CO₂ warning alarms are activated and that the ventilation is shut off. The piping and nozzle arrangement allows the CO₂ gas to spread rapidly to the protected areas.

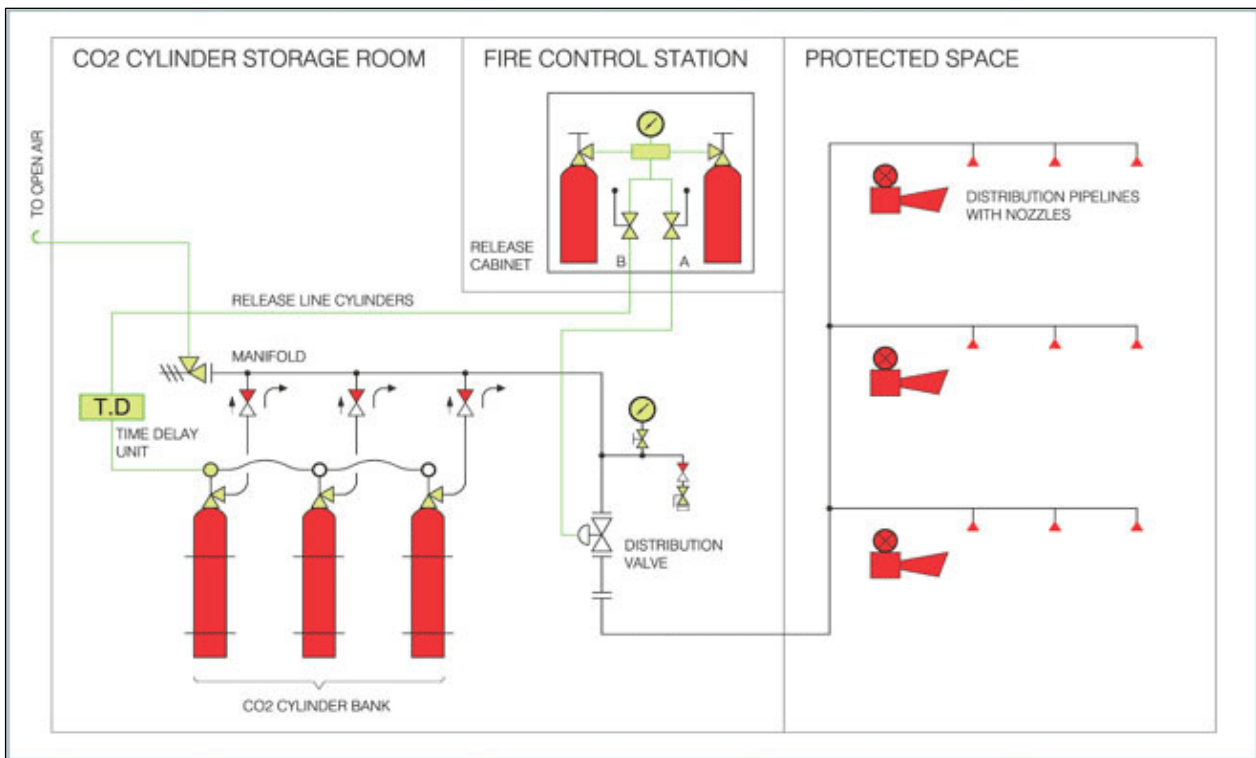


Figure 8: Principal diagram of a high pressure CO₂ system
 Source: FainKorea.com

The CO₂ system on board CAROLINE MÆRSK was place made, i.e. built into the ship during the newbuilding process. It was later modified to meet new regulations. The system was of an industry standard high pressure total flooding type. It consisted of 306 cylinders of CO₂, placed in a dedicated CO₂ room located on the starboard side of the upper deck, with a vertical access ladder from the A-deck. The cylinders were divided into four blocks of 102, 71, 87 and 46 cylinders respectively.

On the day of the accident, with cargo holds 8 and 9 fully loaded, the required number of CO₂ cylinders to be released was 102, corresponding with block no. IV. Normally, the system would be operated from the fire control station in the ship's control centre, but the system could also be operated from within the CO₂ room.

The system had been serviced and recertified approximately six months prior to the accident. The service included visual inspection of all parts of the installation, including a check of valves and actuators. A release test was not part of the survey.

On the day of the accident, although operated in accordance with the procedures, the system failed to release CO₂ into the cargo hold. A subsequent third party examination of the CO₂ system indicated that the cause of failure was that the control valve in the fire control station (ship's control centre) release cabinet was not in the fully opened position. This could have led to the venting of CO₂ from the pilot line causing the distribution valve to not open. The examination showed no signs that the burst gasket in the main pipeline had been of a wrong type or mounted incorrectly. It

is likely that the gasket burst as a result of the sudden blast from the released CO₂ building up high pressure due to the stuck valve. Figure 9 below shows the CO₂ room after the accident.

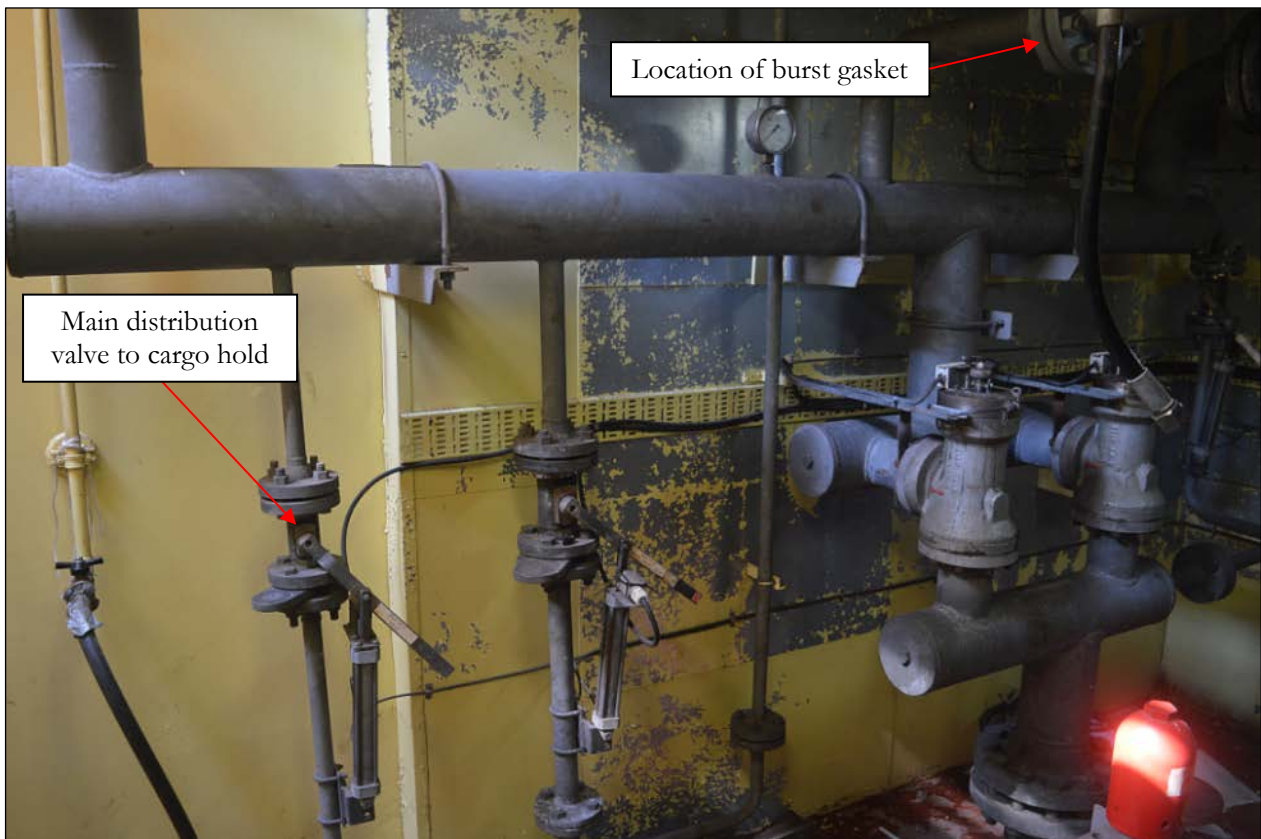


Figure 9: CO₂ room on CAROLINE MÆRSK, main distribution valve indicated
Source: MÆRSK Line/DMAIB

4.2.2 Container firefighting equipment

The special container firefighting equipment that was on board CAROLINE MÆRSK was part of a standard delivery to all the company's container ships. Supplying ships with dedicated container firefighting equipment was not mandatory at the time of the accident. However, the company had for more than 20 years provided all its container ships with such equipment, custom made for the company. The standard package consisted of a box containing the following items:

- 1 spear (spike nozzle) for water (figure 10)
- 2 spears for CO₂
- 1 hammer
- 1 cup drill (hole saw bit)
- 1 cable reel
- Various connection hoses and accessories for CO₂
- Various fittings, spanners and other accessories



Figure 10: Firefighting spear nozzles – Left: Two water spears, one CO₂ spear. Right: CO₂ spear mounted in container. Source: DMAIB

The hole saw was to be used with a power drill, which on CAROLINE MÆRSK was a cordless, rechargeable drill. The general principle is that a hole is drilled in the burning container, into which the spear nozzle is driven by means of the hammer (figure 11), enabling the crew to extinguish the fire from within the container, either by means of water from the fire mains or CO₂ from portable extinguishers, depending on the scenario. No specific training in the use of container firefighting equipment is included in the mandatory shore-based crew training. It was not a part of the on-board training regime on CAROLINE MÆRSK to put the equipment into practical use during exercises.

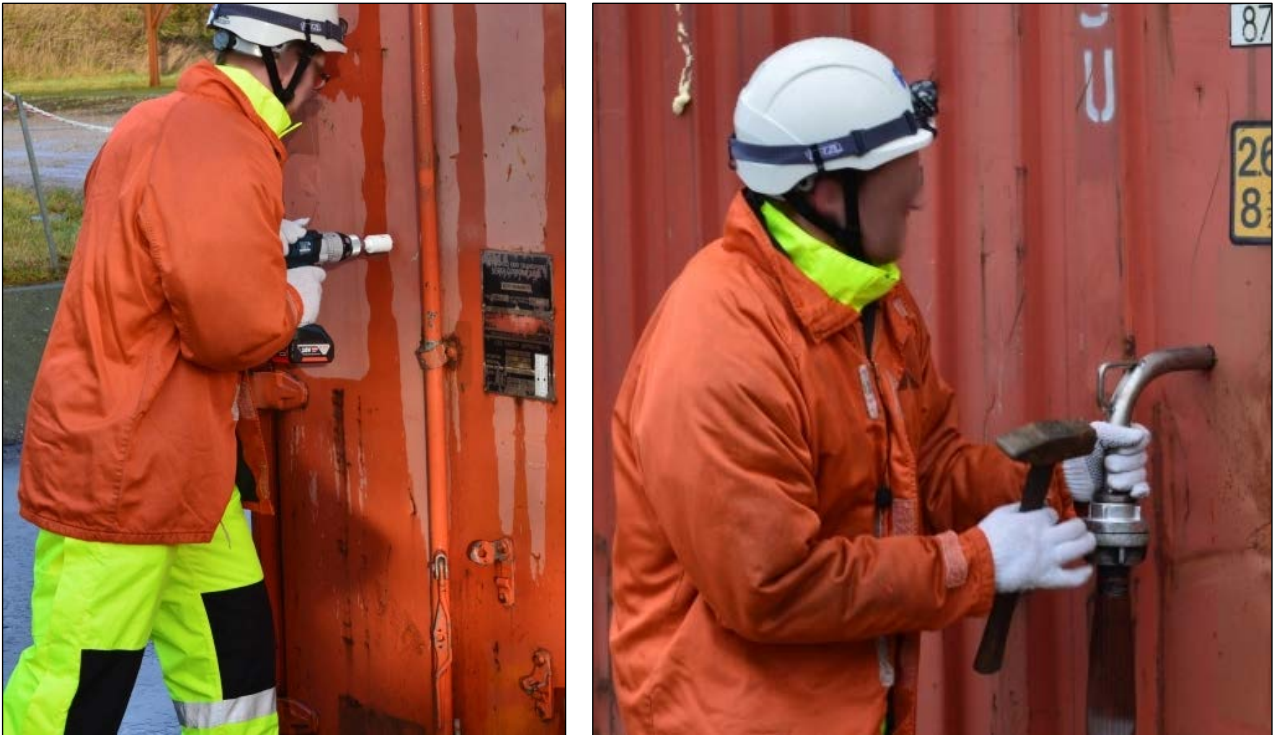


Figure 11: Container firefighting equipment – photos from DMAIB tests
Source: DMAIB

On the day of the accident, the crew of CAROLINE MÆRSK deployed the container firefighting equipment in their attempts to manually extinguish the container fire. The initial attempt was unsuccessful as the drill was not capable of penetrating the container door. The crewmembers that used the equipment reported that the drill was not sufficiently powerful and that the hole saw was too weak, as it was quickly worn down after attempting to penetrate the container. Some crewmembers expressed that the unsuccessful deployment of the equipment was also a demotivating factor that added to an already stressful situation of dealing with a fire on board. Further attempts at penetrating the container were made, using angle grinders, which proved successful, as the crewmember managed to cut holes in a total of three containers, placing fire nozzles inside them and eventually containing the fire.

4.2.3 DMAIB tests

In connection with its investigations of the CAROLINE MÆRSK container fire, and other similar accidents, DMAIB has conducted tests of container firefighting equipment similar to that used on CAROLINE MÆRSK. The aim of the tests was to acquire knowledge about the technical aspects of the equipment to validate the information gathered from interviews with crewmembers on CAROLINE MÆRSK. This section contains a brief summary of the test findings.

Test conditions:

The tests were performed in fair weather during daytime, with optimum working positions, without the test persons wearing breathing apparatus, with limited heat radiation, with no time constraints,

and generally without the stress factors of operating in a real emergency situation. Hence, the test conditions did not simulate actual ship emergency conditions.

Test setup:

The test setup consisted of a standard 20' steel container, subjected to various combinations of fire intensities and durations. The container firefighting equipment tested comprised a new, fully charged power drill, new hole saws (some provided by the company to match those on board and in addition some in high quality, acquired for comparison), new and used spike nozzles, and water pressure similar to ship conditions.

Test results:

From the tests it was found that a good quality, off-the-shelf battery powered drill was capable of drilling several holes in standard container doors and sides, when fully charged.

The hole saw bit similar to the one on board CAROLINE MÆRSK could penetrate a standard container door. However, by coincidence the first attempt with the hole saw was made in a location where there was a structural reinforcement on the inside of the door. After one attempt, the hole saw was worn down and not capable of further attempts. During the attempt, the centre bit (pilot drill bit) fell out and had to be refitted.

Subsequent tests with higher quality bits and hole saws showed that these were capable of drilling several holes in the container without showing significant signs of wear.

The spike nozzles supplied by the company's vendor were effective once placed in the container. Hammering the nozzles through the pre-drilled hole required the operator to use both hands and some manual power. Once placed in the container, the nozzles were able to stay mounted in the drilled hole while pressurized.

Additional factors related to the use of container firefighting equipment:

The DMAIB tests were carried out in a controlled environment. In an actual emergency situation on board a ship, the use of container firefighting equipment can be further challenged by additional factors:

- A limited number of spear nozzles are available, one for water and two for CO₂.
- Using the spears is effective only under certain circumstances when the fire is in a container that is easily accessible. The majority of the containers on deck cannot be reached from deck level or via a lashing bridge. The height, depth and distance to the burning container could mean that it is difficult or impossible to reach and to obtain a good working position.

- Heat radiation. The method requires crewmembers to approach a burning container at very close range, which is often dangerous or impossible due to extreme heat radiation.
- Unknown contents of containers could present a challenge both with regards to physical obstructions within the container, and with regards to the physical and chemical properties of the contents.
- The structural features of a container are not visible from the outside, which can lead to problems with identifying the correct drilling location.
- The quality and durability of the drilling equipment. DMAIB is aware of ship crews reporting that the equipment is virtually useless because of its limited power and durability, or due to problems with getting close to the burning containers.
- Some ship crews have raised concern that there is a risk of demotivating the crew because they place their trust in equipment which is supposed to help them in a crisis situation, and which then turns out not to work as intended.

Recently the IMO⁵ has adopted new requirements that entered into force in January 2016, which require large container ships contracted after this date to carry special firefighting equipment, including a piercing nozzle and portable water monitors.

4.2.4 Ship and company procedures

The company and ship safety management system (SMS) contained procedures related to fire emergency situations. An investigation of the usability of the procedures was relevant because they were an integral part of CAROLINE MÆRSK's formal fire emergency preparedness.

Three procedures were found to be particularly relevant on the day of the accident:

- 'Operation and maintenance of CO₂ fire suppression plant' (Doc. ID 0456, located in the SMS section Fire Prevention and Response)
- 'Fire in containers' (Doc. ID 0490, located in the SMS section Fire Prevention and Response)
- 'Damage to property – Fire' (Doc. ID 1147, located in the SMS section Accident, Incident, Near Miss & Safety Observation reporting, Fire)

⁵ International Maritime Organization - Resolution MSC.365(93).

From DMAIB's investigations on board it was found that the checklist and procedures were only partly used during the accident. Investigation of the procedures combined with crew interviews, showed:

- The relevant procedures and checklists were not designed to mitigate the actual emergency scenario.
- The procedures did not take into account a possible breakdown of equipment and/or necessary departures from the formal way of work.
- Some conflicting guidance was identified in the procedures. For instance, the firefighting procedures advised deployment of the CO₂ system without delaying it with attempts at manual firefighting, while at the same time stressing the importance of assessing the situation and consider using the container firefighting equipment.

The investigation of the procedures showed the difficulties of envisaging and describing unpredictable dynamic emergency scenarios in a document offering guidance and/or instructions for generic situations. Seen as a whole, the procedures did not match the conditions faced by the crew and thus offered little practical guidance during the fire.

5. ANALYSIS

The fire on CAROLINE MÆRSK originated from the combustion of charcoal tablets for water pipes stowed in a container below deck. The basic information about the individual containers, such as their contents, was unknown to the crew members on board CAROLINE MÆRSK. The cargo carried in the burned container was of a nature that was not expected to be stowed in that particular position in the hold below deck. The container had not been correctly declared as dangerous goods in accordance with the IMDG Code, which would have prompted a different stowing position or a ban from being transported at all due to its hazardous nature. As the cargo was not declared as IMDG cargo, the crew was not able to immediately identify the contents of the container from a cargo manifest, but relied on assistance from the shore-based organization.

Despite a number of challenges related to knowledge about the contents of the cargo container and the nature of the formal fire emergency preparedness, the crewmembers, aided by the company crisis team, managed to successfully contain the fire for several days and prevent it from spreading excessively. This achievement was the result of the organizations' ability to adapt to the unfolding emergency situation. In DMAIB's analysis, the focus is on the firefighting systems.

The firefighting systems and equipment on board CAROLINE MÆRSK met the regulatory requirements and had been installed, maintained, serviced, certified and operated accordingly. In addition, the company, based on its own experiences, had supplied all their ships with extra equipment to fight container fires.

However, the crew of CAROLINE MÆRSK was faced with some technical challenges during the accident:

The CO₂ system failed as a main distribution valve did not open, resulting in a near-explosion in the CO₂ room, which presented a serious risk to the crew who had mustered in the area. Another consequence was that very little CO₂ actually reached the cargo hold. At the time of the fire discovery, the crewmembers did not know the source of the fire nor the extent and therefore had no way of knowing the most effective way to fight it, before assessing the situation. As they also did not know the contents of the cargo in the containers, they had no chance of knowing whether releasing CO₂ into a cargo hold would be the most effective approach, or if manual extinguishing would be effective or even possible. For some fire scenarios, such as a smouldering fire inside a container, CO₂ is not a particularly effective method, as the fire will often flare up again when oxygen levels in the hold are restored.

During the manual firefighting, the compressor for filling BA bottles broke down and in effect left the crew without any means of fighting or further assessing the fire. Furthermore, the container firefighting equipment did not work as expected. The DMAIB tests showed that a particular set of

preconditions needed to be in place for the equipment to work as intended. These preconditions may not be present in a real-life situation, as on CAROLINE MÆRSK.

What eventually secured a successful outcome, in spite of failing equipment, was the shore and shipboard organization's ability to adapt to the situation, by departing from the formal ways of work and applying their own resourcefulness, i.e. making a temporary replacement valve for the compressor, using an angle grinder instead of an ineffective power drill, using anti-piracy fire equipment⁶ and adapting the formal shipboard organization. Thereby the crew was enabled to fill the gaps between the formal emergency preparedness and the actual emergency scenario.

⁶ Anti-piracy equipment comprised extra fire nozzles, adaptors and fittings that allowed fire nozzles to be mounted on railings etc.

6. CONCLUSIONS

The fire on board CAROLINE MÆRSK broke out as a result of charcoal self-igniting in a cargo container below deck. Despite a number of challenges related to knowledge about the contents of the cargo container and the nature of the formal fire emergency preparedness, the crewmembers managed to successfully contain the fire for several days and prevent it from spreading excessively. This achievement was the result of the shore and shipboard organization's ability to adapt to the unfolding emergency situation by filling the gaps between the formal emergency preparedness and the actual emergency scenario. In other words, the organization 'finished the design' of the emergency preparedness to match the situation they faced.

Firefighting is not the primary function of the crewmembers and actual emergency situations are rare. This means that for most crewmembers such a situation is a once-in-a-lifetime experience. Therefore, seafarers cannot be expected to hold a level of experience equal to that of 'professional firefighters'. These conditions place additional strain on the firefighting preparedness on board ships and need to be carefully considered when designing equipment and work procedures to be used in an emergency situation. Procedures, checklists and decision support systems alone cannot ensure a successful outcome of an emergency situation. Procedures are static tools, whereas emergency situations are dynamic and unpredictable. Many procedures, emergency procedures in particular, bear an inherent assumption that the crew has extensive knowledge of the situation or is able to quickly gain such knowledge, which they in most cases are not. Safety management procedures address a variety of topics besides safety. Often a safety procedure will also contain items relating to insurance issues, internal documentation, general company policies, ordering information, etc., which has no relevance to the crew in an emergency situation.

Over the past decades, container ships have increased considerably in size, enabling contemporary ships to carry significantly larger numbers of containers, stacked higher than earlier. The upscaling of the ships and their cargo capacity has partly been accompanied by corresponding amendments to regulations, procedures, equipment, etc. The subsequent regulation amendments have, however, merely added more of the existing equipment, e.g. an increased number of fire hydrants and hoses for larger ships, but have not included a reconsideration of the strategies and methods used in emergency situations such as fires.

7. PREVENTIVE MEASURES TAKEN

Following the accident, the company has informed DMAIB of the following preventive measures taken:

“A thorough functionality test of the CO₂ release was carried out by Drew Chemicals.

Proper CO₂ release procedures were exercised in the fleet wise annual exercise carried out on Sept 17th 2015.

Tests were carried out with the type of Cup Drills supplied to the fleet. Their cutting capability is all right, but the center drill is rather sensitive with a tendency to break or fall out. On that basis it has been decided to change future cup drill supplies to a model without these weaknesses.

At our next annual drill (on Apr 28th) the cup drills presently on board will be tested in accordance with prevailing procedures. A hole will be drilled through a 3mm steel plate and the result reported to the company.

The CO₂ release procedure “Operation and Maintenance of CO₂ Fire suppression plant” has been revised to emphasize that the released CO₂ quantity corresponds to the vacant volume of the compartment on fire.

Signboard clarification or similar in respect of correct CO₂ release procedure – as per advice from the Fleet Group.”