Transportation Safety Board of Canada
Bureau de la sécurité des transports du Canada

MARINE TRANSPORTATION SAFETY INVESTIGATION REPORT M23C0104

ENGINE ROOM FIRE

Bulk carrier *Cuyahoga*
Lake Erie
Kingsville, Ontario
23 May 2023

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Summary

On 23 May 2023, the self-unloading bulk carrier *Cuyahoga*, with 20 people on board, experienced a fire in the engine room while proceeding north on Lake Erie off Kingsville, Ontario. The crew closed the quick-closing fuel valve for the main engine day tank and then attempted to use the vessel's carbon dioxide fixed fire suppression system. The vessel anchored north of Pelee Island, Ontario, and the fire went out shortly after the main engine stopped. On 25 May 2023, the vessel was towed to Kingsville, Ontario. No injuries or pollution were reported.

1.0 FACTUAL INFORMATION

1.1 Particulars of the vessel

Table 1. Particulars of the vessel

Name of the vessel	*Cuyahoga*
International Maritime Organization number	5166392
Transport Canada official number	815560
Flag	Canada
Port of registry	Port Dover, ON
Type	Self-unloading bulk carrier
Gross tonnage	10532
Length	188.98 m
Breadth	18.29 m
Draft at time of occurrence	Forward: 5.85 m / Aft: 5.88 m
Built	1943, Lorain, Ohio, U.S.

Propulsion	One diesel engine of 2530 kW driving 1 controllable-pitch propeller
Crew	20
Registered owner and authorized representative	Lower Lakes Towing Ltd.
Classification society / recognized organization	Lloyd's Register
Issuing authority for International Safety Management certification	American Bureau of Shipping

1.2 Description of the vessel

The bulk carrier *Cuyahoga* (Figure 1) was built in 1943 in Ohio, U.S., by the American Ship Building Company. It was built as a steam-propelled vessel and was converted to diesel in 2000. The *Cuyahoga* had a steel hull, and its forward and aft superstructures were separated by 8 cargo holds.

Figure 1. The *Cuyahoga,* shortly after the fire (Source: TSB)

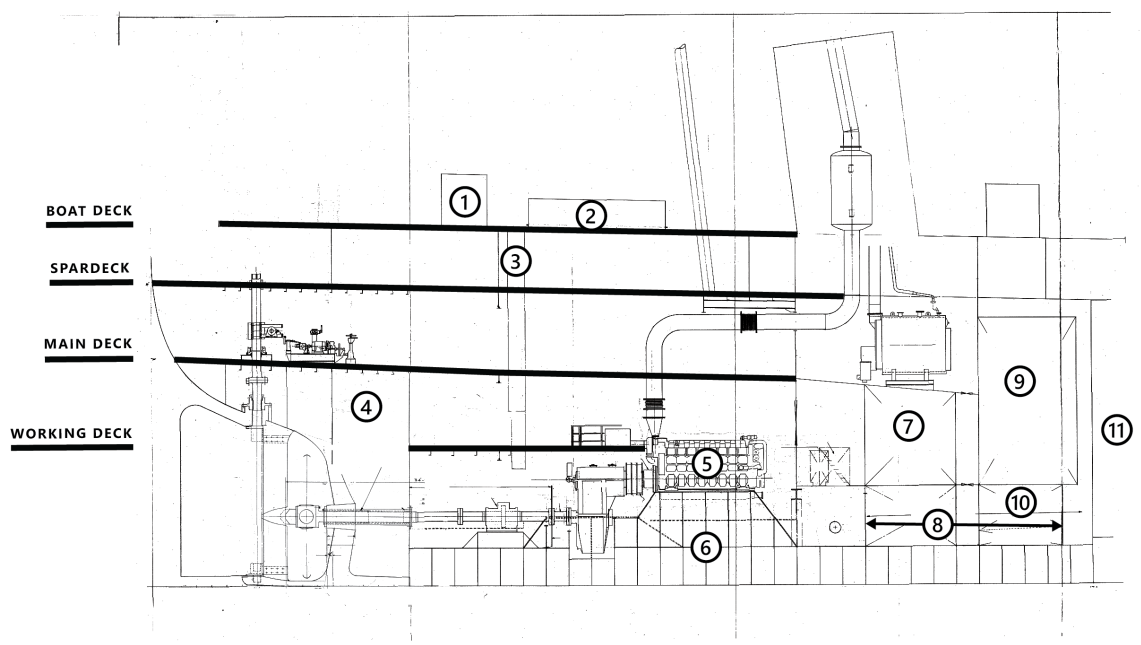
The main deck spanned nearly the entire length of the vessel. The spardeck, above the main deck, was the uppermost deck over the cargo holds. The tank top ran from the engine room along the lowest part of the unloading tunnel below the cargo holds to the forward structure.

The forward structure contained cargo conveyor and elevator machinery between the tank top and main deck. At the main deck level, the forward structure contained crew accommodations, workshops, storerooms, and the electrical control room for the cargo machinery. Above the spardeck, 2 partial decks contained additional crew accommodations, stores, and the forward deck machinery. The bridge was in the pilot house at the top of the forward structure.

The aft structure (Figure 2) contained the main machinery spaces, separated from the aft deckhouse and cargo hold by bulkheads and decks that were rated as A-class divisions. The engine room comprised 3 levels: the tank top, the working deck, and the main deck. The engine control room, electric bus board, and auxiliary machinery were located on the working deck.

The vessel's steering gear, diesel generator compartment, boiler room, workshops, and storage areas were located on the main deck. Fuel storage tanks for the main engine were located in the machinery spaces just forward of the main engine below the main deck. The engine and boiler rooms were protected by a carbon dioxide (CO_2) fixed fire suppression system and the diesel generator compartment was protected by a similar, independent system. The vessel carried portable fire extinguishers, as required.

Figure 2. Profile view of the aft structure of the *Cuyahoga* (Source: TSB, based on machinery arrangement drawings (Lower Lakes Towing Ltd.))



1 CO_2 room, **2** Skylight, **3** Vent, **4** Aft peak, **5** Main engine, **6** Tank top, **7** Water ballast, **8** Unloading tunnel (to cargo hold), **9** Fuel oil bunker, **10** Fuel oil day tank, **11** Cargo hold.

The aft deckhouse, which was on the spardeck and above the vessel's main machinery spaces, contained crew accommodations, the galley, and the mess. The engine and boiler room casings ran through the accommodations to the deckhouse top on the boat deck. The engine room casing had a steel skylight and the boiler room casing housed the machinery exhaust piping that led into the exhaust gas funnel. The engine and boiler rooms could be accessed through a door inside the accommodations in the aft deckhouse or through 2 doors outside the aft deckhouse on the spardeck.

The skylight had an opening of approximately 2.4 m by 1.8 m. The opening was covered by a steel-hinged hatch that could be opened and closed by a power-operated winch mounted outside on the skylight next to the hatch opening. The remote control for the winch was in the engine room on the working deck.

The emergency generator compartment, the cylinder room for the CO_2 fixed fire suppression system, the fuel tank for the ship service generator, the life rafts, and a rescue boat were located on the boat deck.

Conveyor belts on the tank top ran underneath the cargo holds between the forward and aft sections of the vessel to carry cargo forward to the elevator. The cargo was carried up to the boom by the elevator and discharged to shore. An unloading tunnel that ran along the vessel's centre line gave the crew access to the conveyor belts and associated machinery for operation and maintenance.

The vessel's emergency fire pump was located approximately 2.4 m forward of the bulkhead that separated the engine room from the cargo hold on the tank top. The isolation valve on the discharge side of the pump was located in the boiler room on the main deck, aft of this bulkhead.

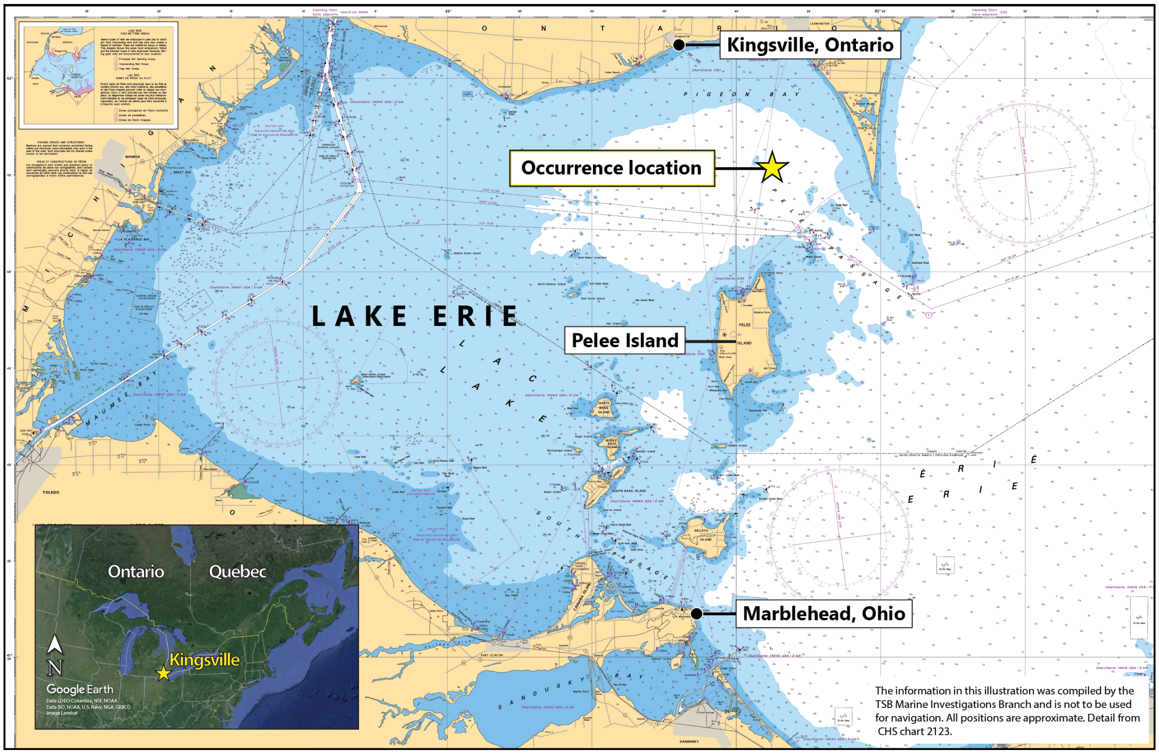
There were 4 muster stations. These were located forward of the aft deckhouse on the boat deck, aft of the forward deckhouse on the forecastle deck, in the engine control room, and on the bridge. The firefighter outfits and self-contained breathing apparatuses (SCBAs) on the vessel were stored in lockers at the forward and aft deckhouse muster stations. One outfit and 1 SCBA with spare bottles were located in each locker.

1.3 History of the occurrence

On 23 May 2023 at 1914,[1] the *Cuyahoga* left Marblehead, Ohio, U.S., bound for Kingsville, Ontario (Figure 3), a voyage of approximately 4 hours. The vessel was loaded with 11 400 metric tonnes of granular A crushed stone.

1 All times are Eastern Daylight Time (Coordinated Universal Time minus 4 hours).

Figure 3. Area of the occurrence (Source of main image: Canadian Hydrographic Service chart 2123, with TSB annotations. Source of inset image: Google Maps)



At 2000, the fourth engineer began his 4-hour watch in the engine room. The chief engineer, second engineer, third engineer, and the master were in their cabins. The chief officer was the officer of the watch on the bridge along with the helmsperson and a deck officer cadet. At 2045, the chief engineer conducted a routine round of the engine room, then returned to his cabin to rest in preparation for cargo operations at Kingsville.

At 2159, the fourth engineer was carrying out a routine round of the engine room. From the port side of the main deck, he observed that a fire had ignited on the top of the main engine between cylinders 7 and 8. He attempted to descend to the control room working deck to stop the main engine, but he could not reach it because of heat and flames from the rapidly expanding fire.

The fourth engineer left the engine room through the access door in the aft accommodations and notified the chief engineer of the fire. He then activated the general alarm from a pull station outside the engine room and called the officer of the watch on the bridge to inform them of the fire location. The master heard the general alarm and immediately went to the bridge.

At 2201, the master arrived on the bridge and observed flames and smoke coming from the engine room's open skylight hatch. He relieved the chief officer and ordered him to proceed to the forward muster station. The helmsperson and the deck officer cadet remained on the bridge with the master. At approximately 2203, the chief officer arrived at his muster station at the forward deckhouse and reported that all crew who were required to be at this muster station were present.

At the same time, crew members were reporting to the muster station at the aft deckhouse. They began closing the machinery space ventilation openings and preparing fire hoses for use. A deckhand at the forward muster station and the general-purpose crew member at the aft muster station began donning firefighter outfits and SCBAs.

At 2204, the third engineer started the emergency generator and connected it to the emergency bus, ensuring that emergency lighting and essential machinery, such as the emergency fire pump, steering gear, and controllable-pitch propeller, would continue to function. At the same time, the chief engineer stopped the engine room fans.

At 2206, the master attempted to contact the second engineer, who was in charge of the aft muster station, on a portable very high frequency (VHF) radio. However, the second engineer was not at the muster station and there was no response. Consequently, the master ordered the chief officer to go aft to take charge of the aft muster station.

At 2207, the master contacted Lower Lakes Towing Ltd. (LLT) and Marine Communications and Traffic Services Sarnia, informing them of the fire, and then made a Mayday call on very high frequency (VHF) channel 16. Canadian and U.S. Coast Guard vessels and aircraft and 2 cargo vessels were tasked through the Joint Rescue Coordination Centre in Trenton, Ontario, and the U.S. Coast Guard in Detroit, Michigan, U.S., and stood by ready to render assistance, if necessary.

The chief engineer, who was unable to reach his muster station in the engine control room because of the fire, went to the boat deck and attempted to reach the skylight hatch to close it. He observed that the winch's electric motor was running, and the skylight hatch was opening wider. When he heard the master's attempt to contact the second engineer by radio, he became aware that the second engineer was absent. The chief engineer then re-entered the aft deckhouse accommodations on the port side to search for the second engineer, but he encountered heavy smoke and abandoned the attempt.

At 2208, the third engineer reported to the aft muster station, where he found that the second engineer was absent. He then entered the aft deckhouse on the starboard side and went to the second engineer's cabin, where he found the second engineer still asleep and woke him. The 2 engineers then escaped the accommodations area. Soon after, the chief officer reported to the master that all crew aft had been accounted for.

At approximately 2209, concerned that the fire would cause an explosion, the master ordered all crew not involved in fire containment to move to the forward muster station, including the crew member from the aft muster station wearing a firefighter outfit. The chief engineer, second engineer, third engineer, and fourth engineer remained aft.

Following an order from the chief engineer, the second engineer activated the quick-closing fuel valves for the main engine and ship service generators, which were located behind the emergency generator compartment on the boat deck of the aft deckhouse. The chief engineer then started the emergency fire pump from the emergency generator compartment.

Soon after, the chief engineer reported to the master that they were still unable to close the skylight hatch and the engine room vents behind the skylight to finish sealing the engine room. The heat and smoke coming from the opening prevented them from approaching the winch. Nevertheless, although the room had not been fully sealed, the master ordered the chief engineer to activate the engine room CO_2 fixed fire suppression system to put out the fire.

At 2211, despite the presence of smoke, the chief engineer entered the aft deckhouse, intending to activate the CO_2 fixed fire suppression system by pulling the release cables at the remote operating station outside the access door to the engine room. When the chief engineer pulled the remote release cables, approximately 3 to 4 m of cable came out of the conduits. The chief engineer did not feel any resistance in the wire when he pulled.

At 2212, the chief engineer reported to the master that the remote release cables for the CO_2 fixed fire suppression system had failed.

At approximately 2214, the fourth engineer succeeded in manually closing the skylight hatch and engine room vents and reported this to the chief engineer, who relayed this information to the master. After a brief discussion, the master then ordered the chief engineer to attempt to activate the CO_2 fixed fire suppression system locally at the CO_2 cylinder room on the boat deck.

At 2215, the chief engineer entered the CO_2 cylinder room accompanied by another crew member. He began the sequence to trigger the release of CO_2 into the engine room by pulling the manual operating levers on the control heads of the 2 cylinders closest to the entry door. Almost immediately, the cylinder room flooded with CO_2. The chief engineer and the crew member were forced to evacuate the room and closed the door behind them.

At the same time, the master ordered the 2 crew members who had donned firefighter outfits and SCBAs and who were at the forward muster station to go aft to assist the engine room crew.

At 2216, the master ordered the wheelsman to steer hard to starboard so that the easterly wind would blow the smoke aft and away from the life raft stations, and then to reduce the propeller pitch to zero. He ordered the second officer to drop the forward anchors when the vessel stopped.

At 2217, the crew remaining at the forward muster station began to drop the forward anchors.

At 2218, the chief engineer reported to the master that the 2nd attempt to activate the CO_2 fixed fire suppression system had failed and that he could not confirm that CO_2 had been released into the engine room.

At 2221, the chief engineer reported to the master that there was no water available in the fire main, even though the emergency fire pump had been confirmed to be running.

At 2222, the master ordered the crew to launch the life rafts and rescue boat and to stand by to abandon the vessel. Soon after, the starboard life rafts on the forward and aft deckhouses were deployed by the second officer and chief officer.

At 2224, the chief officer reported that the port life raft and the rescue boat on the boat deck were inaccessible due to smoke but the crew continued to try to reach them. By 2230, the chief officer reported that all 3 life rafts and the rescue boat had been successfully launched. The master ordered the crew to pull the life rafts to the vessel's midship section and deploy the embarkation ladders.

At 2231, the chief engineer reported to the master that he had observed a reduction of smoke coming from around the skylight hatch and surrounding steel structure. He told the master that he believed that the CO_2 was taking effect. The master ordered the crew to ensure that the engine room remained sealed.

At 2244, the chief engineer returned to his cabin to retrieve an infrared thermometer so that the crew could begin monitoring boundary temperatures on the aft structure.

At 2316, the chief engineer and a cargo maintenance crew member entered the unloading tunnel from the forward end of the vessel. They proceeded aft to troubleshoot the emergency fire pump. The chief officer remained at the opening of the emergency escape hatch on the spardeck to relay communications between the chief engineer and master, because the steel structure impeded radio transmissions.

Believing that the fire pump was airlocked, the chief engineer attempted to drain air from the pump casing and discharge pipe through valves installed for this purpose. He observed what was considered a normal pressure on the discharge pressure gauge. Having confirmed that the pump was not airlocked, he was unable to do more to rectify the lack of flow to the fire main and he and the other crew member left the unloading tunnel.

By 2328, no more smoke was observed coming from the skylight hatch and surrounding structure.

On 24 May at 0147, 8 crew members who were not required to remain on the vessel to maintain control of the fire were evacuated to the Canadian Coast Guard Auxiliary vessel *Colchester Guardian* and brought to Kingsville.

At 1002, LLT advised Marine Communications and Traffic Services Sarnia that they had contacted McKeil Marine Ltd. for tug assistance and T&T Marine Salvage Inc. for assistance with the fire.[2]

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[2] Under the U.S. *Oil or Hazardous Material Pollution Prevention Regulations*, 33 CFR, Part 155.4035, paragraph (b)(2), vessels such as the *Cuyahoga* are required to prepare a marine firefighting pre-fire plan in accordance with the U.S. National Fire Protection Association, NFPA 1405, *Guide for Land-Based Firefighters that Respond to Marine Vessel Fires*. The plan must identify a marine firefighting resource provider that is

On the following day, at 1445, the tugs *Ecosse* and *Stormont* arrived on site and prepared to tow the *Cuyahoga*. At 2050, the vessel was secured alongside at Kingsville. A team from T&T Marine Salvage Inc. entered the engine room and confirmed that the fire had been extinguished.

1.4 Damage to the vessel

The *Cuyahoga*'s engine room and associated machinery sustained heat and smoke damage from the fire. The main engine and various electrical cables and equipment sustained moderate to severe fire damage.

1.5 Environmental conditions

At the time of the occurrence, the sky was overcast and the visibility was about 25 nautical miles. The wind was from the east at 10 knots. The air temperature was 16 °C.

1.6 Personnel certification and experience

The master held a Master Mariner certificate of competency that was first issued in 2017. He had been the master on the *Cuyahoga* since December 2020. He had graduated from a marine school in 2011 and had joined the company's fleet in 2016. The master completed Marine Emergency Duties (MED) Advanced Firefighting training in 2011 and MED for Senior Officers training in 2013. He completed the Advanced Firefighting training refresher course in 2016.

The chief officer held a Watchkeeping Mate certificate of competency but was exempted by Transport Canada from holding a Chief Mate, Near Coastal certificate of competency, which was otherwise required on board the *Cuyahoga.* He had worked on the vessel previously and had recently been promoted to chief officer. He graduated from a marine school in 2017 and had joined the company's fleet in 2018. The chief officer had completed MED Advanced Firefighting training in 2017.

The chief engineer held a Second-class Engineer, Motor Ship certificate of competency, which was first issued to him in 2016. He had been chief engineer on the *Cuyahoga* since 2017. He graduated from a marine school in 2005 and began sailing with the LLT fleet. The chief engineer had completed MED Advanced Firefighting training in 2007 and MED for Senior Officers training in 2011.

The fourth engineer had the sea time and required training but had not yet obtained a Fourth-Class Engineer, Motor Ship certificate of competency. He had taken all examinations except the oral examination.

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under contract to respond as required. To comply with this regulatory requirement, Lower Lakes Towing Ltd. had contracted T&T Marine Salvage Inc.

All 16 remaining crew members on the *Cuyahoga* held the required certificates for their positions on board.

1.7 Vessel certification

The *Cuyahoga* held an inspection certificate for Near Coastal, Class 1 voyages, limited to trading in the Great Lakes and St. Lawrence River basin. The certificate was valid until 01 April 2028. The *Cuyahoga* was classed with Lloyd's Register and inspected on behalf of Transport Canada by Lloyd's Register under the Delegated Statutory Inspection Program (DSIP).

The vessel's safe manning document required the vessel to carry a minimum of complement of 1 master, 1 chief mate, 1 watchkeeping mate, 1 chief engineer, 1 watchkeeping engineer, 2 bridge watch ratings, and 4 additional ratings. Also, the document indicated that the vessel had a 2-watch arrangement. In this occurrence, the vessel met the requirements of the safe manning document.

1.8 Operations and crew workload

1.8.1 Vessel operations

The *Cuyahoga* transported dry bulk commodities, such as coal, salt, grain, and crushed stone, typically between March and December.[3] Outside of this navigation season, the vessel was placed into winter layup. Some of the crew remained on board for at least part of the layup period to carry out repairs to machinery, vessel structure, and cargo equipment and to supervise contractors. Class and statutory inspections were also normally carried out toward the end of this period.

During the navigation season, *Cuyahoga* crew members operated in rotations of approximately 6 to 8 weeks. The vessel's trading pattern followed a planned schedule between various ports on the Great Lakes. While the vessel was in transit, crew followed work/rest schedules to support essential maintenance and the inspection of equipment before cargo operations at port. Voyages were sometimes as short as 4 hours. While the vessel was alongside, cargo operations created additional tasks for the crew, such as loading and unloading freight, pumping ballast, shifting the vessel, and adjusting moorings. During this time, additional maintenance and inspections of machinery necessary for navigation were conducted regularly, as were navigation planning activities and the training and familiarization of new crew members. The result was a marked increase in the crew's workload during these intensive periods, which invariably disrupted established work/rest schedules.

Marine industry members acknowledge that more crew are needed when a vessel is operating in a complex environment, with frequent port calls or fast turnarounds in port,

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3 After another serious fire (Marine Transportation Safety Occurrence M24F0001), the *Cuyahoga* was declared a total constructive loss.

and that increased maintenance is needed for older vessels.[4] Crew prioritize tasks that are immediately pressing, such as navigation tasks, repairs needed to maintain navigability, and cargo operations. Given that voyages between ports on the Great Lakes are often short, the time spent on mooring and cargo operations on these vessels is significantly higher than on deep-sea vessels. The tight operational schedule of the *Cuyahoga* left little, if any, time for crew to catch up on other tasks, such as routine inspections or documentation of maintenance work.

On the vessel, the officers and crew communicated regularly, and senior officers communicated with shore staff as needed.

1.8.1.1 Sleep-related fatigue

Sleep-related fatigue is widely reported in marine operations. Sleeping conditions on board bulk carriers like the *Cuyahoga* are not conducive to restorative sleep, given short turnarounds that interrupt sleep periods, noise and vibration from cargo machinery, and variable lighting conditions. The risk of sleep-related fatigue is increased by long shift durations, standby duties, and missed sleep opportunities during mandatory daytime rest periods. In acknowledgement of these operational challenges, the company has a fatigue policy, fatigue management training for employees, and fatigue management strategies.

The TSB conducted a predictive analysis of the work and rest schedules[5] for the days leading up to the occurrence. According to this analysis, although some fatigue was likely present, there was no evidence that fatigue unduly influenced crew performance.

1.8.2 Deck operations

The deck crew navigated the vessel and operated deck machinery. They supervised the loading of cargo and operated the machinery to discharge the cargo. Deck crew inspected deck and cargo machinery, and safety equipment, including the fixed fire suppression systems, and kept records.

The deck crew normally worked on a 3-watch arrangement (4 hours on, 8 hours off) plus overtime as required for mooring and cargo work. On the occurrence voyage, there was no third officer on board, so the chief officer and the second officer worked a 2-watch system (6 hours on, 6 hours off),[6] plus overtime as required.

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[4] International Maritime Organization, MSC 109 /INF.3, *Study on the Effective Implementation of the International Safety Management (ISM) Code* (23 September 2024), p. 64.

[5] TSB Guide to Investigating Sleep-Related Fatigue 2022: A Component of the TSB Operations Framework (unpublished).

[6] Six hours on, 6 hours off shift work is recognized as contributing to fatigue; the amount of restorative sleep available in a 6-hour shift is much less than 6 hours, given the need to do personal things and the noise and other shipboard conditions. For this reason, 6 hours on, 6 hours off shifts are no longer a common industry practice.

1.8.3 Engine room operations

The engine room crew maintained the propulsion and other operational machinery, such as the conveyor belts and other machinery used to unload cargo. The engine room crew also kept records, both in the planned maintenance system for coordination with the technical shore staff and in various documents used on board for crew handovers for coordinating work among themselves.

The engine room crew worked on a 3-watch arrangement (4 hours on, 8 off), plus an additional 2 to 3 hours of overtime on most days. At the time of the occurrence, the fourth engineer had not yet completed the requirements for his watchkeeping engineer licence and he was on watch with the chief engineer on call.

1.8.4 Shore operations

Shore-based support for the *Cuyahoga* included a vessel manager and a designated person ,[7] who worked together to coordinate technical and safety matters.

The vessel manager oversaw the *Cuyahoga* and 2 other vessels. He was responsible for compliance, technical oversight, and maintenance planning and was a primary point of contact for emergencies. The chief engineer and the master worked closely with the vessel manager.

The designated person provides a link between the company and those on board the 6 vessels owned by LLT. The primary functions of the designated person are to act as a primary contact for emergencies and to coordinate response, to monitor the safety and pollution prevention aspects of the operation of each vessel, and to ensure that adequate resources and shore-based support are provided.

1.8.5 Operating environment

Marine shipping operates in an environment defined by a complex relationship between production and safety. Production includes delivering cargo on time and safety includes safe work practices.[8] Given the hazards involved in production, companies must balance the need to produce against the need to operate safely by being aware of hazards and managing risks to levels as low as reasonably practicable.

Cargo vessels transporting bulk materials on short voyages operate in a competitive environment with short-term pressures. TSB research has demonstrated that commercial success in a competitive environment results, in part, from operating at the edges of usual accepted practices.[9] In other words, success depends on trading off financial efficiency, workload pressures, and safety, which may involve simplifying procedures, working faster,

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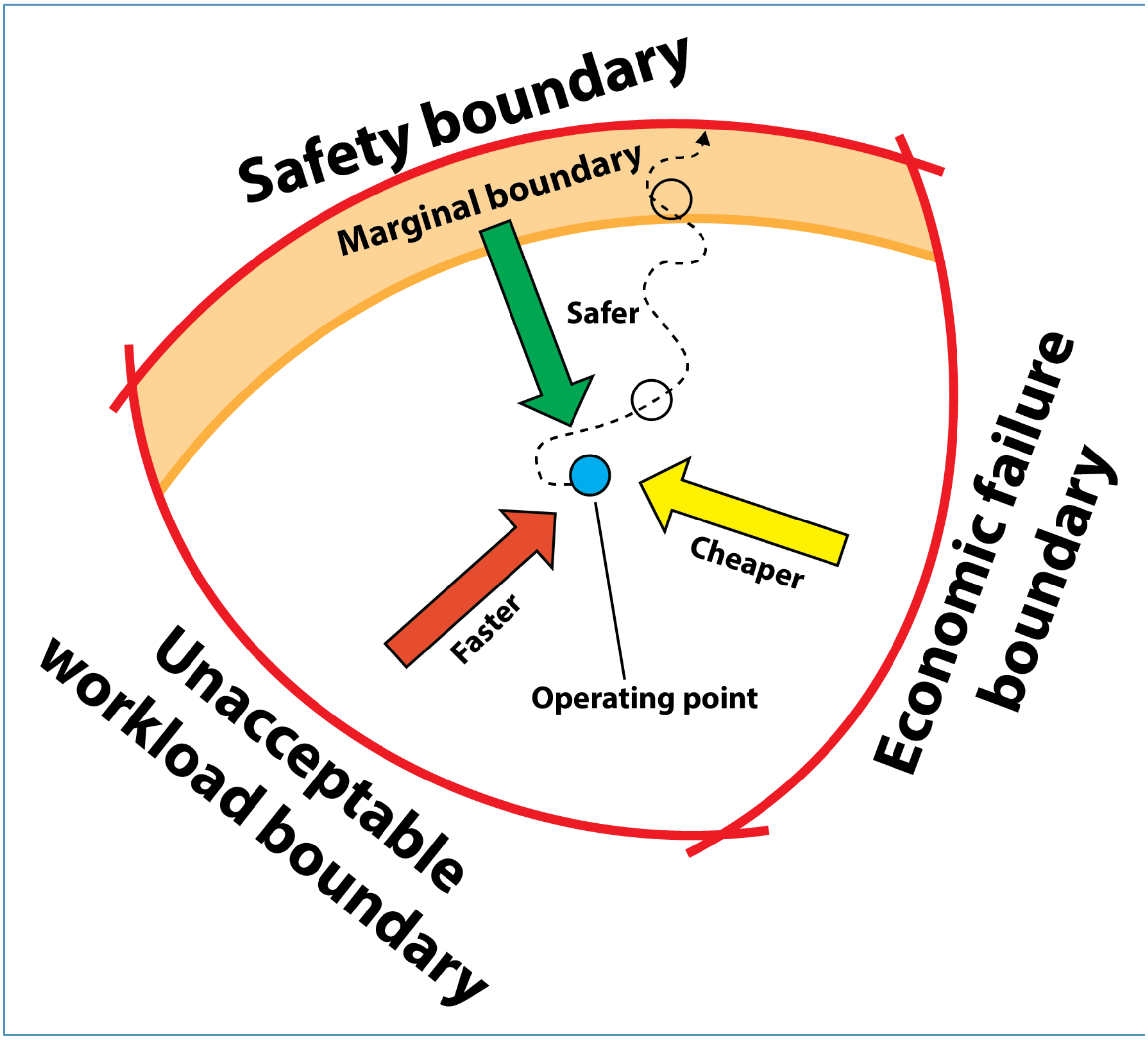
7 The ISM Code requires a designated person (Part A, section 4).

8 J. Reason, *Managing the Risks of Organizational Accidents* (Routledge, 1997), pp. 4–5.

9 TSB Air Transportation Safety Issue Investigation A15H0001.

or reducing costs. How these themes interact is represented in the operating envelope model (Figure 4).

Figure 4. The operating envelope model (Source: TSB, adapted from S. Dekker, *Foundations of Safety Science* (2019), p. 254)



The boundaries are

- the economic failure boundary (beyond this boundary, the financial costs become unsustainable);
- the unacceptable workload boundary (beyond this boundary, not enough time or resources are available); and
- the safety boundary (beyond this boundary, there may be harm to workers, passengers, or the public).

The marginal boundary delineates where the safety of an operation begins to break down. The safety margin is that part of the safe operating envelope between the marginal boundary and the safety boundary.

In the model, the operating point represents the marine industry or individual operator and is constantly moving. The arrows inside the boundaries represent the competing pressures that push the organizational performance away from or toward a boundary. The adaptations made locally by individual workers, under the pressures of workload and financial constraints, are incremental and largely unseen by individuals. Left unchecked, organizational performance drifts toward the marginal boundary and eventually can cross over the safety boundary. As the operating point crosses the marginal boundary, the safety of the operation diminishes. When the operating point crosses the safety boundary, an accident or incident is increasingly likely to occur.

1.9 Main engine

The *Cuyahoga*'s propulsion was provided by a Caterpillar 3608 DITA 8-cylinder in-line type, turbocharged, aftercooled diesel engine. The engine was coupled to a reduction gearbox via a flexible elastomeric coupling and a pneumatic clutch. The reduction gearbox drove the single propeller shaft and controllable-pitch propeller.

Vibration is inherent in all diesel engines due to alternating combustion forces, torque reactions, movement of the unbalanced mass of rotating parts, clearance between parts due to manufacturing tolerances, and pressure pulses in fuel and exhaust piping. The *Cuyahoga*'s main engine systems showed the effects of excessive engine vibration.

1.9.1 Fuel system

The engine operated on marine diesel oil. This fuel was supplied from the day tank forward of the engine. The fuel supply system consisted of fuel filters, a single engine-driven booster pump mounted on the engine, hard supply and return piping with threaded connections mounted on the engine, and a mechanical unit injector for each cylinder. Mechanical unit injectors may contribute to vibration more than electronic unit injectors.

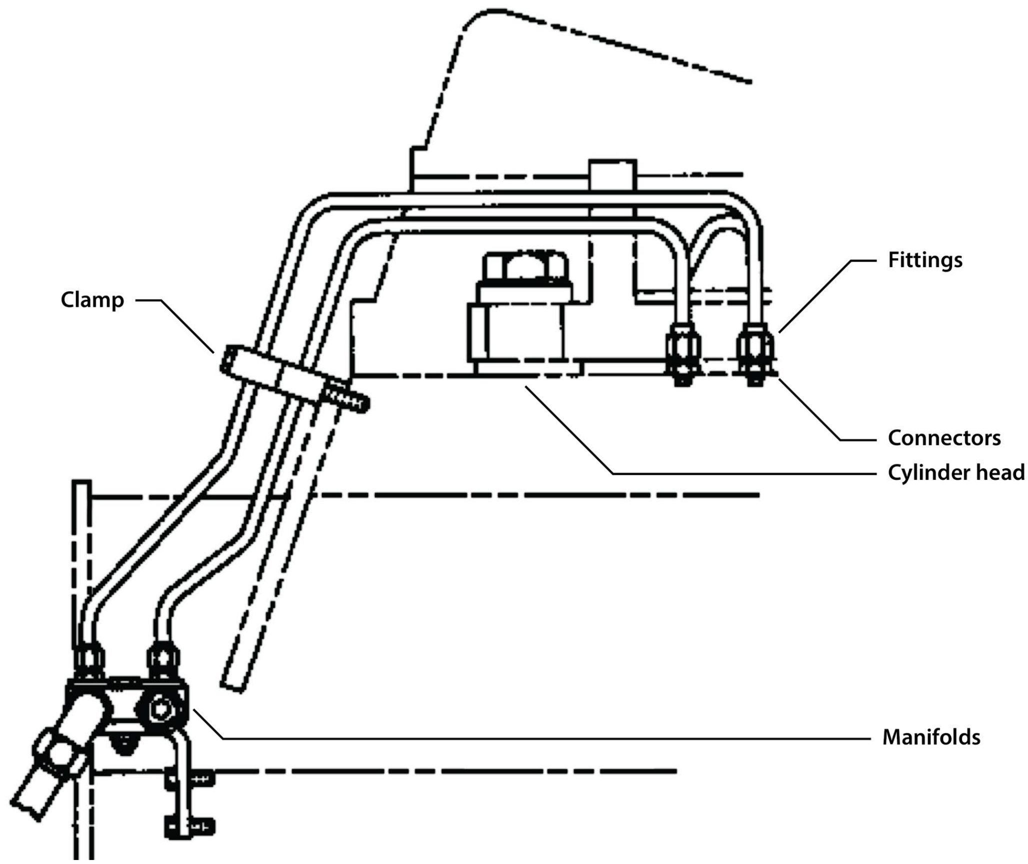
The fuel supplied to the injectors also provided cooling. Surplus fuel was returned to the day tank after having been cooled by a plate-type heat exchanger. The TSB calculated that at the maximum continuous rating, fuel pressurized to 550 kPa would flow to the injectors at a rate of approximately 37 L/min, and that surplus fuel would flow back to the day tank at 27 L/min at 350 kPa. The temperature in the return manifold after the injectors and before the cooler was approximately 91 °C.

The working level of the fuel in the day tank was lower than the engine-mounted fuel supply and return manifolds connected to the injectors.

1.9.1.1 Fuel injection lines and retaining clamps

Fuel injection supply and return lines between manifolds and injectors were connected at the cylinder heads (Figure 5). The lines were ½-inch diameter steel tubes. The fuel injection lines were comprised of −08 steel tube with a brazed steel flat end, a 13/16-16 UNC (unified national coarse) threaded connector, and an O-ring face seal (ORFS) fitting.[10,11,12]

Figure 5. Fuel injection supply and return lines showing positions of clamps, connectors, and fittings (Source: Manufacturer's specifications with TSB annotations)



ORFS fittings typically provide reliable leak-free connections. However, the tightening sequence and clamping force between the sealing faces of the fittings on the fuel injection lines are critical to ensuring adequate sealing against leaks, and the majority of leaks that do occur are due to loose fittings.[13] Typical causes for loose fittings are[14]

10 International Organization for Standardization, ISO-8434-3:2005, *Metallic tube connections for fluid power and general use — Part 3: O-ring face seal connectors* (Edition 2, 2005).

11 International Organization for Standardization, ISO-6149-2:2006, *Connections for hydraulic fluid power and general use — Ports and stud ends with ISO 261 metric threads and O-ring sealing — Part 2: Dimensions, design, test methods and requirements for heavy-duty (S series) stud ends* (Edition 2, 2006).

12 SAE International, Hydraulic Tube Fittings Committee, SAE J1453-3, *Specification for O-Ring Face Seal Connectors: Part 3 – Requirements, Dimensions, and Tests for Steel Unions, Bulkheads, Swivels, Braze Sleeves, Caps, and Connectors with SAE J1926-2 Inch Stud Ends* (revised August 2009).

13 SAE International, Hydraulic Tube Fittings Committee, SAE J2593-202201, *Information Report for the Installation of Fluid Conductors and Connectors* (21 January 2022).

14 Ibid.

- excessive strain caused by an incorrect tightening sequence;
- improper use of tools;
- failure to apply the specified torque;[15] and
- vibration.

Manufacturers often supply general torque specifications for fittings based on type, size, and application. When the amount of torque is different for a particular application, it is specified in either a separate technical bulletin or in the disassembly/reassembly procedures for fittings.

To reduce the effects of vibration on the fuel injection line fittings, retaining clamps secure the fuel injection lines to the cylinder heads, making the lines more rigid and reducing mechanical vibration in the fuel injection lines.

The TSB found that the fuel injection return line for cylinder 7 was disconnected, which resulted in a spray of marine diesel oil. At the time of the occurrence, all the retaining clamps on the fuel injection lines were missing (figures 6 and 7). The investigation found that the retaining clamps were most likely removed in 2021, when the crew replaced the fuel supply and return manifolds.

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15 Ibid.

Figure 6. Cylinders 2, 3, and 4 on the main engine before the occurrence, with retaining clamps (enlarged) securing the fuel injection lines (Source: Lower Lakes Towing Ltd.)

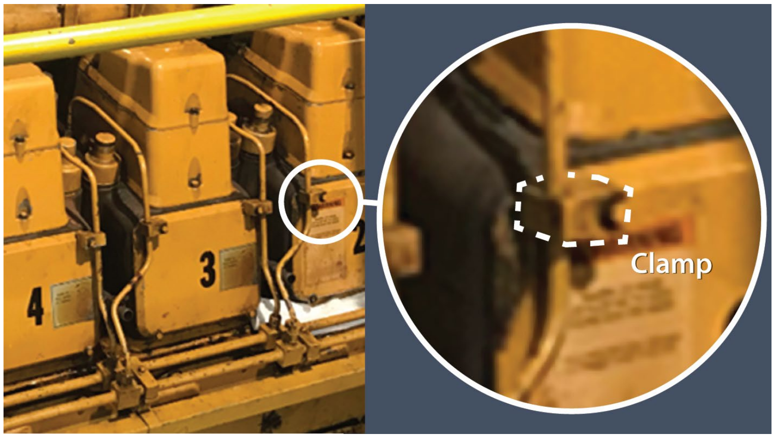
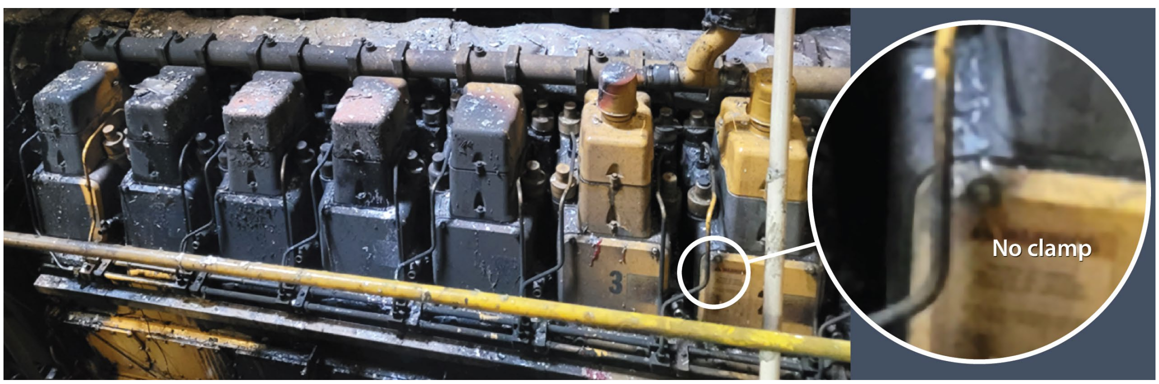


Figure 7. Main engine after the occurrence showing fuel injection lines with only bolts at the location for the retaining clamps (1 enlarged) (Source: TSB)



The investigation could not determine whether the fuel injection lines had been replaced since the engine was installed in 2000; wear at the position of the retaining clamps indicated that the fuel injection lines had been in use with the clamps in place.

1.9.1.2 Fuel injection line maintenance

Following the 2021 replacement of the fuel supply and return manifolds, several instances were recorded where the fuel injection line fittings had developed observable leaks (Table 2). Whenever leaks were observed, the crew removed the fuel injection lines to inspect and replace the O-rings, then reinstalled the lines. During the investigation, TSB laboratory personnel examined the no. 7 fuel injection return line that disconnected and determined that its connection would visibly leak when it was only finger-tight.

Table 2. Fuel injection line and manifold issues and maintenance work documented in the engine room records

Date	Action
2020-04-28	The crew observed a crack on the main engine fuel supply manifold. They removed and temporarily repaired both the supply and return manifolds and ordered replacement

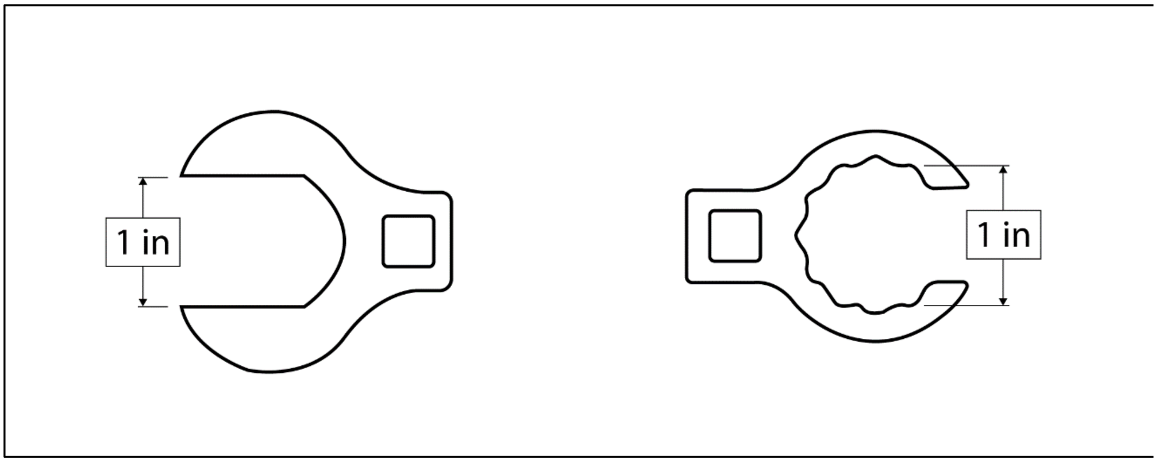
	parts from the engine manufacturer. The cause of the crack was attributed to excessive vibration.
2021-01-24	Replacement fuel supply and return manifolds were received and the manifolds were replaced by the crew. The connecting points for the fuel injection lines likely shifted when the new manifolds were installed. To protect against the effects of vibration, pieces of welding blanket were inserted between the manifold pipes and the clamps that secured them.
2021-08-26	The crew observed a fuel leak on a fuel injection line on cylinder no. 2. The leak was repaired by tightening the fitting.
2021-10-23	The crew observed a fuel leak on a fuel injection line on cylinder no. 2. The leak was repaired by tightening the fitting. The crew retightened all the fuel injection line fittings as a precaution.
2021-10-25	The crew observed a fuel leak on a fuel injection line on cylinder no. 2. The leak was repaired by tightening the fitting.
2022-01-03	The crew observed that the fuel injection lines on cylinder no. 6 had been retightened to correct leaks on an unidentified date in December 2021.
2022-08-01	The crew observed a fuel leak on an injection line on cylinder no. 6. They removed all the fuel injection lines to investigate and then reinstalled them with new O-rings.
2023-04-16	The crew observed fuel leaks on the fuel injection lines on cylinder no. 7 and cylinder no. 8. They removed the fuel injection lines to investigate and then reinstalled them with new O-rings.
2023-05-05	The crew observed a fuel leak on a fuel injection line on cylinder no. 4. They removed the fuel injection lines to investigate and then reinstalled them with new O-rings.
2023-05-21	The crew observed a fuel leak on an injection line on cylinder no. 6. They removed the fuel injection lines on cylinder 6 to investigate and then reinstalled them with new O-rings. The crew then checked the torque of the fittings on all the remaining fuel injection lines, as a precaution.

1.9.1.3 Fuel injection line installation

The location of the fuel injection line connections between the cylinder heads was difficult to access, both for installation and for in-service inspections and maintenance. During operation, surface temperatures of engine components ranged from 60 °C to 80 °C and touching these components required the use of gloves. To reach the connections, a crew member had to stand on a ladder, then reach up and fully extend their arms. This made it physically difficult to use the necessary tools and it was difficult for a crew member to see what they were doing.

The fittings required the use of a crow's foot attachment at the end of a ratchet extension that was approximately 30 cm long and connected to a torque wrench. The manufacturer's installation and maintenance instructions state that a double hex flare nut crow's foot attachment should be used (Figure 8, right) and that the full specified torque should be applied to each fitting in a single step. In this occurrence, the crew used the open-ended crow's foot (Figure 8, left) attachment that they had on board the vessel, and torqued the fittings in multiple steps. Torquing bolts in a flange connection in multiple steps maintains relative positions during the process and ensures the gasket is sealed. For fittings such as the fuel injection line connections, torquing in multiple steps is unnecessary.

Figure 8. Crow's foot attachments. A double hex flare nut attachment (right) gives a better fit than an open-ended attachment (left) for applying the correct torque (Source: TSB)



1.9.2 Engine mounting arrangement

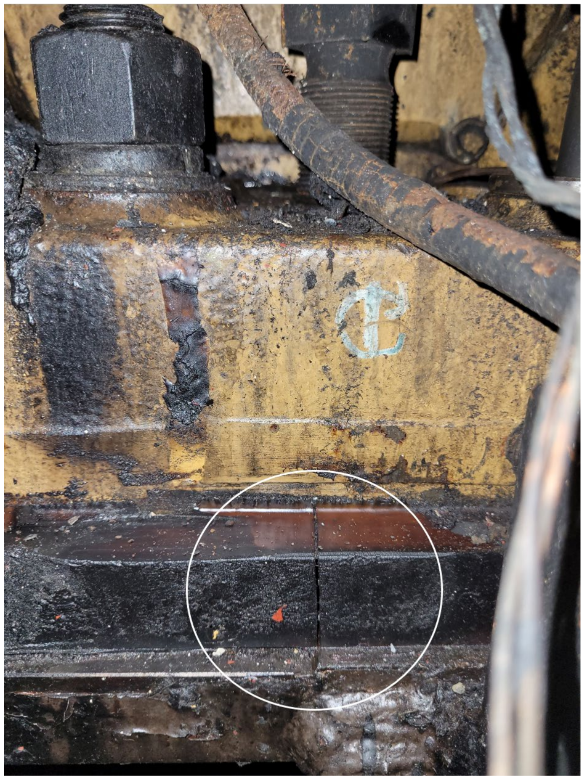
The engine was secured to the bedplate via 4 mounts, with cast epoxy chocks separating each mount from the bedplate to retain the vertical alignment of the engine relative to the reduction gearbox. To ensure alignment is maintained, and to prevent relative movement between an engine mount and the bedplate, the chocks must maintain surface contact between the mount and bedplate. The forward mounts were secured to the bedplate by a fitted bolt and a bolt with a clearance fit. The fitted bolt controlled the horizontal angular alignment between the engine and gearbox; the bolt with a clearance fit provided the clamping force necessary to secure the engine in place. The aft mounts were secured to the bedplate by 2 clearance bolts. The manufacturer's instructions indicate that insecure mounting causes increased levels of vibration, and that the levels will increase with higher engine loads.

In 2020, the reduction gearbox was removed from the *Cuyahoga*'s engine room for repairs and reinstalled during the winter layup. The alignment between the engine and gearbox was outside of the maximum tolerance for vertical and angular misalignment specified by the manufacturer of the coupling. During the 2021 layup period, the engine was realigned to the gearbox to correct the misalignment. The engine's epoxy chocks were repoured during the realignment. During the TSB examination of the mounting arrangement, cracks in 2 chocks were noted (figures 9, 10, and 11). The presence of oil and debris in the cracks indicated they predated the occurrence.

Figure 9. Close-up photo of engine mounting, showing a crack on the forward port engine mount near the bolts (Source: TSB)

Figure 10. Close-up photo of engine mounting, showing a second crack on the forward port engine mount near the bolts (Source: TSB)

Figure 11. Close-up photo of engine mounting, showing a crack on the aft port engine mount near the bolts (Source: TSB)



The *Cuyahoga*'s planned maintenance system generated a maintenance task after every 900 hours of engine operation that included a check of foundation bolt tightness. The task did not include any instructions for inspecting the engine mounts or epoxy chocks for damage, nor did it provide the torque for the bolts. When the task was last completed, on the day of the occurrence, the cracks in the epoxy chocks were not recorded.

1.9.3 Technical documentation updates

The engine manufacturer makes updates to its technical documentation available for purchase via an annual subscription. In 1999, the manufacturer published a technical bulletin[16] reminding users to use proper tooling and torque when servicing fuel injection lines on the 3600 series engine. The document listed the original torque of 45 newton-metres for the 13/16-16 size ORFS fitting. In 2020, the manufacturer updated its general torque specification for all of the ORFS fittings used on its products, increasing the torque for this size fitting to 65 newton-metres. Subsequently, the manufacturer consolidated references to the torque values into the general torque specifications.

LLT received some of the manufacturer's documentation updates from authorized service providers when these service providers were on the vessel performing maintenance on the

16 Caterpillar Inc., *Use Proper Tooling and Torque When Servicing Fuel Injection Lines* {1252, 1380} (SEB9278-00) (1999, revised 09 April 2019).

engine. LLT technical management staff were aware of the manufacturer's paid subscription service but expected that authorized service providers would give the updates to LLT for free as they became available. At the time of the occurrence, the documentation on board the vessel comprised the original paper copies of the manual and technical bulletins that specified the original torque of 45 newton-metres.[17]

1.9.4 Spray protection for fuel systems

The *International Convention for the Safety of Life at Sea* (SOLAS) requirements related to spray protection for fuel systems first came into effect in 1998 but were open to different interpretations. In 2003, the International Maritime Organization (IMO) issued a circular stating that all vessels were required to comply with the regulation by 01 July 2003 and clarifying the regulations as follows:

> Spray shields should be fitted around flanged joints, flanged bonnets and any other flanged or threaded connections in fuel oil piping systems under pressure exceeding 0.18 N/mm^2 [newtons per square millimetre] which are located above or near units of high temperature, including boilers, steam pipes, exhaust manifolds, silencers or other equipment required to be insulated by SOLAS regulation II-2/15.2.10.[18]

In response, the manufacturer developed shields for fuel injection line fittings for installation at the manifolds and on the cylinder heads for its 3600 series engines. The manufacturer also recommended that class-approved metallic tape be used on all fuel and oil line connections.

When the *Cuyahoga*'s engine was installed in 2000, shields for the fuel injection line fittings were not installed. At that time, the Canadian *Marine Machinery Regulations*[19] applied and they did not require spray protection for fuel systems.

1.9.5 Exhaust system insulation condition and installation

The *Vessel Fire Safety Regulations* incorporate SOLAS requirements by reference. SOLAS regulation 4 requires surfaces above 220 °C to be "properly insulated."[20] Associated SOLAS standards specify material performance requirements; there are no specific installation guidelines or requirements for crew or inspectors and "properly insulated" is not defined. Given that insulation is used in many industries, standards and practices from outside of the marine industry may also be applicable.

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17 Caterpillar Inc., *3600 Diesel Service Pocket Guide* (October 1999), p. 183.

18 International Maritime Organization, MSC/Circ.1083, *Unified Interpretation of SOLAS* [Safety of Life at Sea] *Regulation II-2/15.2.11, in Force Before 1 July 2002* (13 June 2003).

19 Transport Canada, SOR/90-264, *Marine Machinery Regulations* (as amended 23 June 2021). The *Vessel Construction and Equipment Regulations* (SOR/2023-257) now require cargo vessels to comply with SOLAS requirements.

20 International Maritime Organization, *International Convention for the Safety of Life at Sea* (SOLAS), 1974, as amended 2016, Chapter II-2, Regulation 4, paragraph 2.2.6: Protection of high temperature surfaces.

On the *Cuyahoga*, when the main engine was running at full load, exhaust gas temperature before entering the turbocharger was typically 520 °C, and exhaust gas temperature after exiting the turbocharger was typically 350 °C. The engine's turbocharger was housed in an insulated metal casing. The bellows and the turbocharger connection were covered with removable insulation blankets. The inner insulating material was a composite of aluminized fibreglass and fibre wool made of calcium, magnesium, and silica that was held in place by a stainless-steel mesh. The outer surface was a silicone-impregnated fibreglass material that acts as a fluid barrier. The blankets were attached using lock wire that was wrapped over tabs riveted into the blanket. To ensure that insulation acts as an effective barrier, gaps and seams must be eliminated to the extent possible; if gaps or seams are present, they must face away from potential fluid sprays.

During the TSB examination of the insulation (figures 12 and 13), the following was observed:

- Notches were worn into the lower edge of the lagging covering the bellows where previously there had been support brackets. These notches formed openings that exposed the exhaust gas piping.
- Gaps between sections of lagging and the insulation encased in sheet metal left piping exposed.
- Flanges in the exhaust gas piping between the reducer, expansion bellows, and main piping section were uncovered.
- Gaps were left for exhaust gas turbocharger temperature sensors.
- The lagging over the opening in the turbocharger casing for the engine manifold piping was loose fitting.

The TSB found no maintenance or inspection records or reported deficiencies related to the condition of the exhaust thermal insulation of the main engine turbocharger outlet pipe and expansion bellows.

The sections of insulation covering the turbocharger outlet had been in use for several years, were occasionally removed and replaced during engine maintenance, and had deteriorated over time.

Figure 12. Insulation on turbocharger showing gaps in the way the insulation had been installed on the turbocharger outlet from the side (Source: TSB)

Figure 13. Insulation on turbocharger showing a notch in the way the insulation had been installed on the turbocharger outlet (Source: TSB)

1.9.6 Remote control system

The main engine speed and propeller pitch were controllable from the bridge using the engine control system. The system on the bridge included an emergency declutch button to disengage the propeller shaft from the engine in an emergency. Current regulations also require a remote stop control for the engine on the bridge.[21] This was not a requirement

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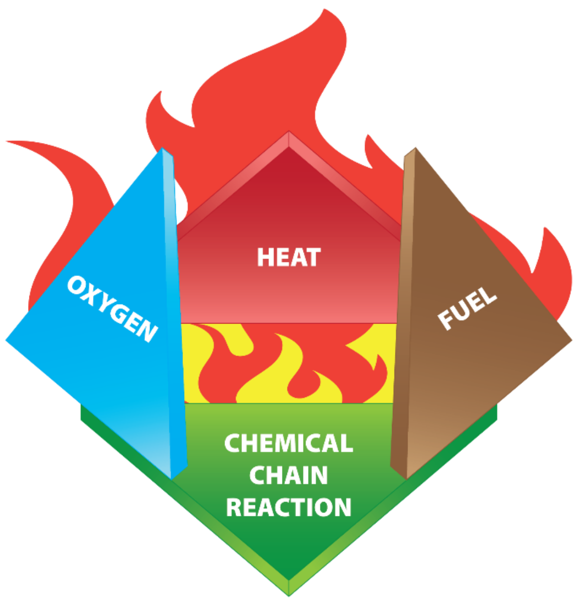
[21] The *Vessel Construction and Equipment Regulations* (Transport Canada, SOR 2023-257, Part 1 Requirements, Construction – Structure, Subdivision and Stability, Machinery and Electrical Installations, section 100) incorporate SOLAS regulations by reference. The SOLAS regulations (International Maritime Organization,

when the *Cuyahoga*'s engine was installed; thus, the only means to stop the engine outside of the engine room was to use the main engine day tank quick-closing fuel valve. In this occurrence, the engine continued to run. When it did stop, it was either because the engine had exhausted the fuel in the supply piping connecting the day tank to the engine, or because of the damage to the engine caused by the fire.

1.10 Engine room fires

Fire is an exothermic chemical reaction where fuel rapidly oxidizes. Fires require fuel, an oxidizing agent (air), heat, and a continuous chemical chain reaction to continue burning (Figure 14).

Figure 14. The fire tetrahedron: fuel, heat, air, and a chemical chain reaction (Source: TSB)



A serious shipboard fire is one that

- generates large amounts of heat and smoke within a vessel;
- is in a location that is difficult to access;
- can spread rapidly; and
- can lead to other consequences, such as an explosion or flooding.

In general, the crew of a vessel must fight a fire themselves, as support is often unavailable due to the location of the vessel or the specialized nature of marine firefighting. When the fire is in the engine room, a large fuel load is available for the fire in the form of engine fuel,

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International Convention for the Safety of Life at Sea (SOLAS), 1974, as amended 2016, Chapter II-1: Construction – structure, subdivision and stability, machinery and electrical installations, Regulation 31: Machinery controls, paragraph 2.3) state that "the main propulsion machinery shall be provided with an emergency stopping device on the navigation bridge which shall be independent of the navigation bridge control system."

hydraulic fluids, oils, cleaning equipment, power tools, cardboard, and other flammable materials.

Research has found that approximately 60% of shipboard fires worldwide originate in the engine room and more than ⅔ of these fires have fuel oil as the primary fuel.[22] An important source of fuel is leakage from fuel system failures attributed to vibration and errors in the reassembly of fuel piping components, like fuel injection lines, and insulation on hot surfaces.[23]

In this occurrence, the fire expanded rapidly: the flames were approximately 4 feet high when the fire was first detected and grew to close to 40 feet in the time it took the fourth engineer to travel between the main deck and the working deck.

1.10.1 Fuel and heat

Whether the fuel source is solid, liquid, or gaseous, only a vapour burns; that is, to burn, solids and liquids must be heated to temperatures that cause them to emit vapours. The temperature at which a material emits enough vapour to momentarily ignite in air with an ignition source is called its flashpoint.

The temperature at which an ignition source is not required for combustion is a material's auto-ignition temperature. If the temperature of the vapour of a flammable material is beyond the material's auto-ignition temperature, hot surface ignition can occur.[24]

The flashpoint of the marine diesel oil used by the *Cuyahoga* was 76 °C,[25] and a typical auto-ignition temperature for marine diesel oil is approximately 250 °C.[26]

1.10.2 Effects of ventilation in a compartment fire

Flame and heat paths start and end at ventilation openings. At the early stage of a fire in a large compartment, the fire's intensity is determined by the amount of fuel available. Hot gases created by fire rise and circulate, and heat is radiated from the layer that is subsequently formed. Depending on the level of ventilation and the amount of heat radiated, other flammable materials may ignite. When this happens, the entire compartment becomes involved, intensifying the fire and increasing the risk that the fire spreads to other compartments as the heat is transferred by conduction.

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[22] Gard AS, "Engine room fires are still a major concern" (13 February 2025), at https://gard.no/insights/engine-room-fires-are-still-a-major-concern/ (last accessed 16 July 2025).

[23] A. Charchalis and S. Czyż, "Analysis of fire hazard and safety requirements of a [*sic*] sea vessel engine rooms," *Journal of KONES Powertrain and Transport*, Vol. 18, No. 2 (2011), at https://kones.eu/ep/2011/vol18/no2/6.pdf (last accessed 16 July 2025).

[24] The geometry of the surface and the air flow close to the surface are also factors (Source: V. Babrauskas, "Ignition of gases, vapors, and liquids by hot surfaces," *Fire Technology,* Vol. 58, No. 2 [2022], pp. 281–310).

[25] Sterling Fuels, Product loading ticket (16 May 2023).

[26] W. Tang, D. Bahrami, L. Yuan, et al., "Hot surface ignition of liquid fuels under ventilation," *Mining, Metallurgy & Exploration*, Vol. 39 (2022), pp. 961–968.

The intensity of a fire in its later stages depends mostly on the amount of oxygen available. If a compartment is sealed, the fire may extinguish when all available oxygen has been consumed.

1.10.3 Guidance on preventing engine room fires

Chapter II-2 of SOLAS contains regulations intended to reduce the probability of ignition by containing fuel sprays and preventing contact with surfaces at temperatures above 220 °C. This is accomplished by shielding connections of low-pressure fuel piping, containment of leaks, and the insulation of hot surfaces.

In 2000, Transport Canada (TC) circulated a ship safety bulletin[27] intended to remind mariners of the fire hazards posed by fuel and oil piping systems. The bulletin identified areas where attention should be paid, but it provided little specific guidance for use by owners or crew.

In 2009, the IMO published a circular[28] that highlighted measures to prevent engine room fires and provided specific guidance on the maintenance and design of engine rooms with respect to fire prevention. The IMO distributed the circular to flag state administrations, including Canada, with the intention that the information would be distributed widely to vessel owners, operators, builders, designers, and other parties. This information was not distributed through TC's ship safety bulletin system because TC determined that the information was not applicable to non-SOLAS vessels.

Among other things, the IMO guidelines identify:

- Causes for fuel system failures
- Design and installation considerations for piping systems
- Methods for shielding piping system joints
- Design and installation considerations for the insulation of hot surfaces

For example, guidance is provided to ensure that pipe flanges and expansion joints are completely insulated.

In 2021, the International Association of Classification Societies (IACS) provided guidance to classification societies on measures to prevent fires in machinery spaces. The IACS guidance highlights classification society experience and is intended to improve owner awareness by referencing the IMO circular.[29]

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27 Transport Canada, *Ship Safety Bulletin* (SSB) 08/2000: "Fire Precaution with Respect to Fuel Oil, Lubricating Oil, Hydraulic Oil Piping and Fittings" (22 June 2000).

28 International Maritime Organization, MSC.1/Circ.1321, *Guidelines for Measures to Prevent Fire in Engine-Rooms and Cargo Pump-Rooms* (11 June 2009).

29 International Association of Classification Societies, IACS Rec. 1999/Rev.2 2021, No. 58, *Fire Protection of Machinery Spaces*.

In Canada, the *Vessel Fire Safety Regulations* require that measures be put in place to prevent oil from contacting heated surfaces. The existing Canadian regulatory requirements provide only qualitative guidance. The *Cuyahoga* was required to insulate surfaces of over 220 °C.

1.11 Fire protection in machinery spaces

Given the risk posed by fires, vessels must meet requirements for structural fire protection. Vessels such as the *Cuyahoga* must also be equipped with fixed fire suppression systems and other equipment for fighting a fire, such as firefighter outfits and fire pumps.[30]

The following are the basic principles for setting fire safety requirements for machinery spaces:

- Limitation of contact between flammable material and hot surfaces
- Detection of fire
- Containment of fire
- Provision of means of control and extinguishment
- Provision of means of escape

1.11.1 Ventilation

Machinery spaces are ventilated to supply fresh air and to exhaust fumes and excess heat. On the *Cuyahoga*, both the ventilation intakes and exhaust outtakes were located on the boat deck, aft of the skylight, and were fitted with dampers to isolate the engine room in case of a fire.

1.11.2 Portholes and fire doors

On the main deck level of the engine room, there were 17 portholes that opened from the inside. Each porthole was equipped with a cast steel-hinged cover intended to prevent water ingress in rough weather if the porthole glass breaks.

Before the fire started, 3 of the portholes in the main engine room had been secured open to improve air circulation. The fire doors between the boiler room, main engine room, and diesel generator compartment were also secured open; fire doors are intended to be kept closed when the vessel is under way. After the machinery spaces had been evacuated, there were no means to close the portholes or fire doors from outside the spaces because there were no remote closing devices.

1.11.3 Skylight hatch

The skylight hatch was used to move equipment and material in and out of the main engine room (Figure 15). The hatch was often left open to improve the circulation of air in the main engine room.

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30 Transport Canada, SOR/2017-14, *Vessel Fire Safety Regulations* (as amended 23 November 2022).

Figure 15. Skylight hatch and winch (circled) (Source: TSB)

The skylight hatch was opened and closed using a power-operated winch. Normally, this winch was controlled remotely from the engine room, but it could also be opened and closed locally by using a manual crank.

Marine electrical standards[31] on vessels such as the *Cuyahoga* require the use of electrical cables that meet minimum fire- and flame-resistance requirements. In Canada, cable for marine use must meet the standards set out in Transport Canada TP 127, *Ships Electrical*

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[31] For applicable standards, see also Transport Canada, TP 13585, Marine Safety Management System (Online Manual), Tier I – Policies, *Acceptance of Marine and Offshore Electrical Cable*.

Standards (2018). Additional protection is provided by routing exposed electrical cables in metal conduits. The electrical cable for the remote control was not approved for marine use and did not have the required flame rating. From the working-deck level to the skylight, approximately 10 m of cable ran vertically along the inside of the engine room casing without any mechanical protection, such as metal conduit. The exposed section of cable was destroyed in the fire and the insulation behind it was damaged.

The switch in the engine room was inaccessible once the engine room had been evacuated. From the boat deck, both the chief engineer and fourth engineer observed the hatch opening wider during the 1st attempt to close it. It is likely that a temporary short was created by the thermal degradation of the conductor insulation, so that the winch motor contactor was energized.

Heat and smoke coming from the skylight hatch and the temperature of the surrounding steel structure initially prevented the crew from approaching the winch to use the manual crank to close the hatch. Similarly, the crew were also unable to approach the engine room ventilation fan dampers.

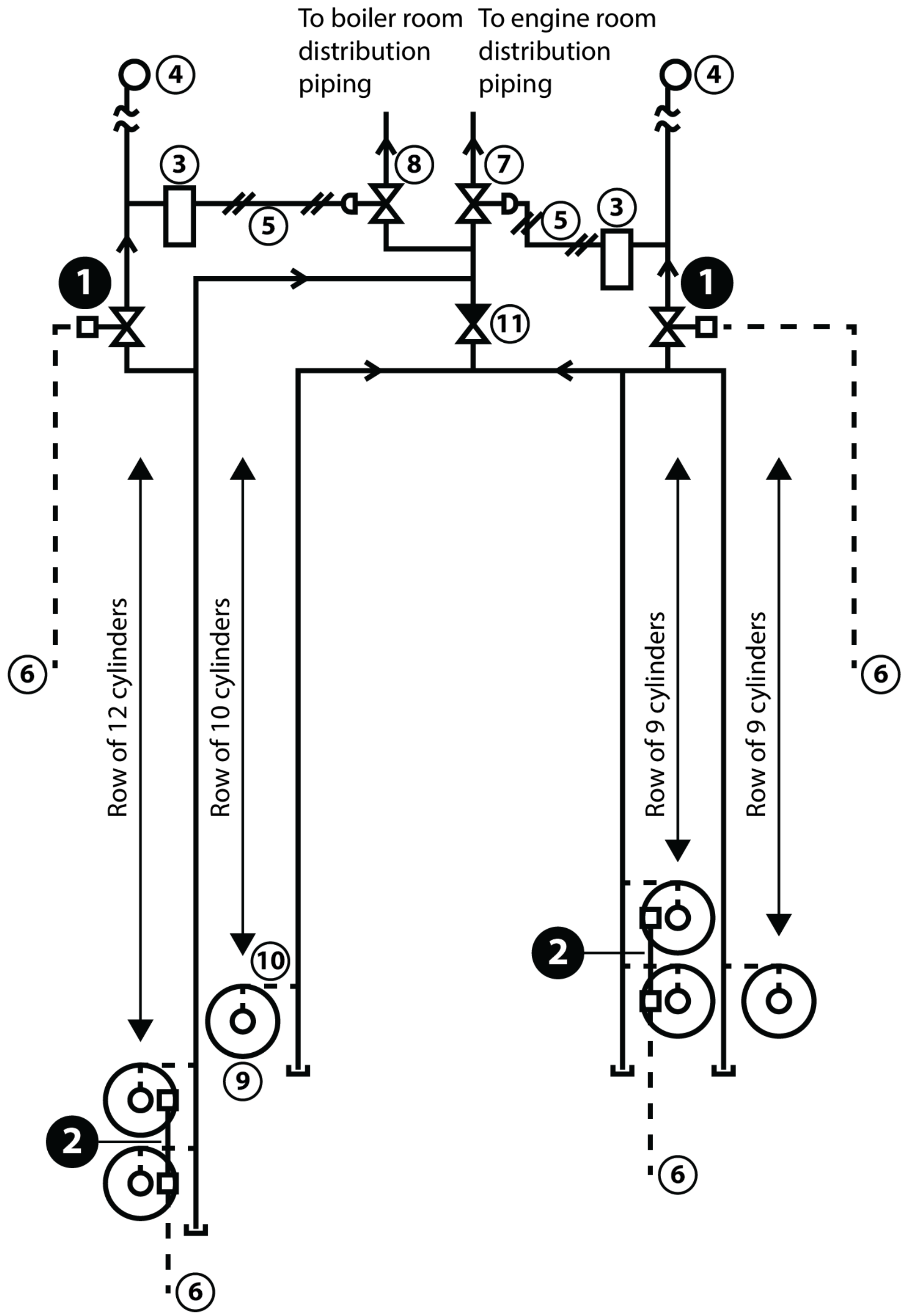
Consequently, it was approximately 15 minutes before the fourth engineer was eventually able to reach the winch and the dampers by using several portable CO_2 extinguishers to temporarily cool the deck enough to walk on it.

1.11.4 Carbon dioxide fixed fire suppression systems

CO_2 is colourless, odourless, non-flammable, and non-conductive, and is often used for fire suppression in machinery spaces. Exposure to high levels of CO_2 can cause fatal injury. Because CO_2 is stored as a liquid, the pressures and temperatures involved during release pose additional safety hazards.

The *Cuyahoga* was fitted with a CO_2 fixed fire suppression system to protect the engine and boiler rooms. The system was installed in 2002 as part of an upgrade to the vessel. The system comprised 40 CO_2 cylinders of a nominal 45 kg capacity for a total of 1800 kg (Figure 16). The CO_2 could be released into either the engine or boiler rooms in stages or all at once.

Figure 16. Layout of the CO_2 fixed fire suppression system as installed on the *Cuyahoga* (Source: TSB)



1 Cable-operated directional stop valve, **2** Tandem cable-operated control head, **3** 30-second discharge delay, **4** Pressure-operated siren, **5** Flexible actuation hose, **6** Stainless steel pull cable, **7** Engine room stop valve, **8** Boiler room stop valve, **9** One of 40 CO_2 cylinders, **10** Flexible discharge hose, **11** Check valve.

On each side, 2 discharge cylinders were connected by a cable-operated tandem control head. When activated, the tandem control head caused the contents of both cylinders to pressurize the manifold, which then opened the valves of the rest of the cylinders. The system used directional stop valves to direct the flow of some of the CO_2 to a control circuit. Downstream of the directional stop valves, the control circuit contained a discharge delay device in the cylinder room and pressure-operated sirens mounted in the protected spaces to alert crew members that the system had been activated. When the 30-second delay had passed, CO_2 pressure opened the main stop valve for the space into which the CO_2 was being directed.

1.11.4.1 Remote release

A recognized industry standard for CO_2 fixed fire suppression systems published by National Fire Prevention Association, to which the *Cuyahoga's* system was designed, states that ''[a]ll devices shall be located, installed, or protected so that they are not subject to mechanical, chemical, or other damage that would render them inoperative.''[32] Neither SOLAS nor Canadian regulations specify where remote release cables can be routed. IACS member rules also make no specification on routing. However, additional guidelines for general use in the marine industry, published by the American Bureau of Shipping, recommend that "…cables and other operating mechanisms should never be installed in locations where they will be subject to the effect of weather, corrosion, etc. In addition, actuation cables and tubing should not run through the protected spaces."[33] On the *Cuyahoga*, individual remote release cables ran through 4 zinc-galvanized steel conduits that were attached together to form a continuous run so that no individual stainless steel cable was exposed.[34] All 4 conduits ran through the top of the engine room, near the skylight (Figure 17).

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[32] U.S. National Fire Protection Association, NFPA 12, *Standard on Carbon Dioxide Systems*.

[33] American Bureau of Shipping, *Guidance Notes on Fire-Fighting Systems* (May 2005; updated February 2015), section 4, subsection 3.1.10: Location of Controls for Extinguishing Medium Release.

[34] The installation plan for the CO_2 system was approved by TC in 2002. The plan stated that the exact location of the cables was to be "site-verified."

Figure 17. The conduits for the remote release cables passed close to the skylight and the cables were damaged in the fire (circled location). The insulation on the boundary between the engine room and accommodation spaces was partially destroyed. (Source: TSB)

The *Cuyahoga*'s system used 4 stainless steel cables to trigger the CO_2 release remotely. Two were connected to the control heads on the directional stop valves and 2 were connected to the tandem control heads for the discharge valves on the cylinders. The order of operation depended on which space the CO_2 was to be released in but, in any case, the directional stop valve was to be operated before the tandem control valve (Figure 16).

The remote CO_2 release station was located next to the engine room access door in the aft deckhouse accommodations. Instructions for remote release were posted at the release station. The posted instructions, developed by the crew, gave information about how to confirm the CO_2 had been released and what to do after the release (for example, safety precautions and boundary cooling).[35]

[35] This information was developed after an earlier fire on board another Lower Lakes Towing Inc. vessel, the *Tecumseh* (TSB Marine Transportation Safety Investigation Report M19C0403).

Finding: Other

Following an earlier fire on board another LLT vessel, instructions at the *Cuyahoga*'s remote CO_2 release station were revised to give accurate information about how to confirm that a release was successful and describe post-release safety precautions.

The chief engineer attempted to use the remote release during the fire but felt no resistance on the cables when he pulled them. The cables failed and 3 to 4 m of cable were pulled out of the conduit.

Personnel at the TSB laboratory examined the cables. This examination found the stainless steel cables to have been exposed to elevated temperatures and molten zinc during the occurrence fire, which caused liquid metal embrittlement of the cable. The zinc originated from the conduit that housed the cable.

1.11.4.2 Local release

A CO_2 release can be triggered locally by accessing the CO_2 cylinder room and manually activating the control heads. A local CO_2 release carries higher risks for the operators due to the potential for CO_2 to leak into the cylinder room.

Each CO_2 system is installed in a vessel-specific arrangement and the physical placement of the elements in the arrangement may differ. The instructions for local CO_2 release should help ensure that the system functions as intended and that risks to a crew member in the cylinder room are minimized by clearly indicating the correct order of operation. The directional stop valve (Figure 16, annotation 1), which allows the CO_2 to enter the protected space, should be opened first; the control head (Figure 16, annotation 2), which controls discharge of the gas from the cylinders, should be opened next.[36] This order of operation minimizes the chance that pressure will build up and CO_2 will leak into the cylinder room.

Instructions for local release were attached to the pilot cylinders in the *Cuyahoga*'s CO_2 cylinder room. The instructions for local release directed the operator to first trigger the release of the CO_2 by activating the control heads and then to activate the directional stop valve. The instructions were based on an example in the manufacturer's manual for a simpler system that was configured differently.

A post-occurrence examination of the *Cuyahoga*'s manifold layout showed that the directional stop valves (Figure 16, annotation 1) were in the closed position and had not been activated by the remote pull cable or manually. In addition, 7 out of 40 hose connections on the valve heads were found to be only finger-tight. A representative from a third-party service provider who attended the vessel after the occurrence found many other leaks: approximately a third of the cylinder valves had loose swivel nuts at the connection to their discharge heads and, in some instances, the sealing O-rings between the cylinder valves and discharge heads were missing (Figure 18). When the cylinders were weighed

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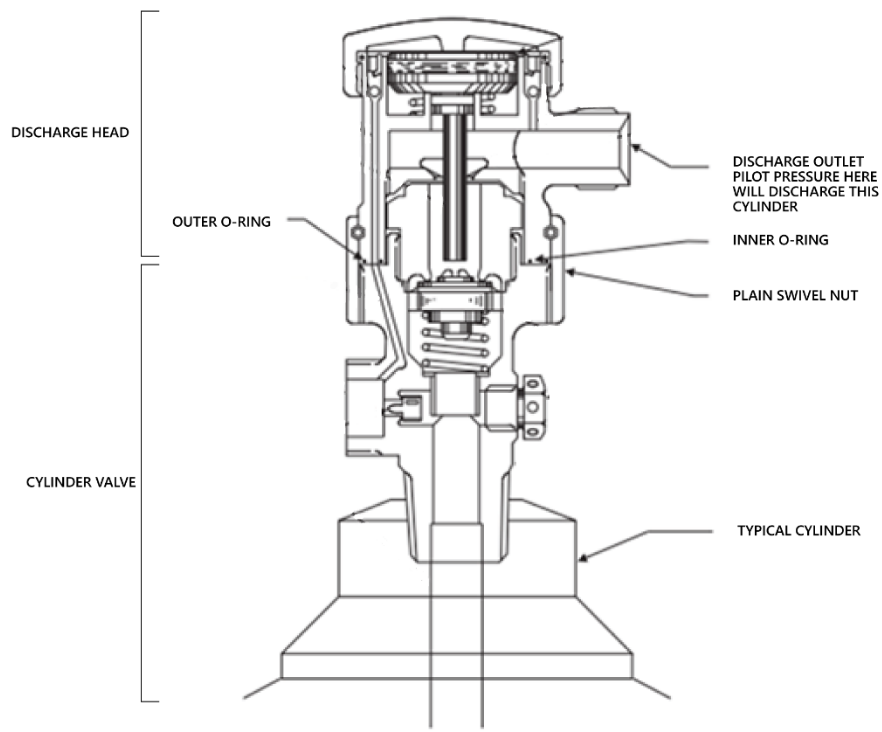
36 International Maritime Organization, *FSS Code: International Code for Fire Safety Systems* (2015), chapter 5: Fixed gas fire-extinguishing systems, section 2.2.2.

during post-discharge maintenance, the weight of each was that of an empty cylinder, indicating that all 1800 kg of CO_2 had been released into the CO_2 cylinder room.

Figure 18. Diagram of the head of a CO_2 cylinder showing the valves and the O-rings that were missing or damaged at the time of use (Source: Manufacturer's manual, with TSB modifications)



1.11.4.3 Inspection and maintenance requirements

Vessel crews, authorized representatives, flag state administrations, recognized organizations (ROs), and classification societies often rely on third-party service providers for annual and periodic maintenance service on fixed fire suppression systems. To ensure that the service providers meet a minimum standard, classification societies issue approval certificates to service providers. To issue an approval certificate, the classification society performs an audit of the service provider's management systems, according to IACS guidelines.[37] In general, to obtain approval, service suppliers must

- demonstrate knowledge of fire theory and firefighting;
- demonstrate knowledge of the basic principles of the systems that they service;
- have access to the manufacturer's instructions and service bulletins and any relevant IMO guidelines;[38] and

37 International Association of Classification Societies, UR-Z17, 1997, Rev.18, Corr.1, *Procedural Requirements for Service Suppliers*.

38 For example, see International Maritime Organization circulars MSC/Circ. 1318 and 1432.

- document procedures for installing and servicing the systems that they are seeking approval for.

Approval certificates from class society auditors outline the scope of the services the provider is authorized to supply. Class approval certificates are renewed at intervals not exceeding 5 years following audits that are conducted to determine whether the original conditions and scope of service have been maintained.

The third-party service provider that performed the last servicing of the *Cuyahoga*'s CO_2 system had been issued an approval certificate in December 2019 that was valid until January 2023. The service provider had changed ownership twice during the certificate validity period. In this occurrence, Lloyd's Register authorized the use of the service provider because the approval certificate was still valid at the beginning of the *Cuyahoga*'s winter layup period. The certificate expired 1 day after LLT issued a purchase order for the annual maintenance of the fire detection and extinguishing equipment. At the time the maintenance was performed on the *Cuyahoga*, and at the time of the occurrence, the certificate had not been renewed.

IACS guidelines state that the training of individuals involved in the installation or maintenance of these fire suppression systems is left to the discretion of the service provider. Under SOLAS and Canadian regulations, there are no minimum training requirements specified for technicians performing maintenance work on the CO_2 fixed fire suppression systems used on vessels.

Unlike technicians for lifeboats and life rafts,[39] technicians performing maintenance on fixed fire suppression systems have no specific regulatory requirement to be factory-trained or trained to a recognized standard. However, the manufacturer's instructions for the *Cuyahoga*'s CO_2 fixed fire suppression system stated that it should be serviced annually and bi-annually by factory-trained technicians. These services are carried out by third-party service suppliers. These suppliers must be authorized by the manufacturer in order to have access to the manufacturer's parts, maintenance training, and technical support.

In January 2023, LLT issued a purchase order for the annual inspection and maintenance of all fire suppression and detection systems on the vessel to a U.S.-based, manufacturer-authorized service provider. In March 2023, technicians boarded the vessel to service the vessel's fixed fire suppression systems and weigh the cylinders. Following the work, the service provider gave the owner a report stating the systems had been serviced and the cylinders weighed according to U.S. Coast Guard regulations.

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[39] Transport Canada, C.R.C., c. 1436, *Life Saving Equipment Regulations,* part II, subsection 114(3).

During maintenance work, defects can be overlooked when technicians are not sufficiently trained in what to watch for or when they do not expect to find a problem. The manufacturer's instructions state that individuals removing and replacing flexible hoses, control heads, or discharge heads must be trained in the maintenance procedures.

The manufacturer instructs technicians to verify the tightness of connections and seals and to look for missing O-rings at every visit to a vessel because missing O-rings and loose connections are known as likely modes of failure. The training instructs technicians to check for these problems when performing maintenance work.

The technicians who serviced the engine room CO_2 fixed fire suppression system had no record of having received installation, inspection, or maintenance training from the manufacturer of the *Cuyahoga*'s CO_2 system or training on any other CO_2 fixed fire suppression system approved for marine use.

An earlier version of the manufacturer's manual (dated 2002) recommends that the monthly inspection should be done by an authorized distributor.[40] In contrast, the manufacturer's training for marine service technicians states that a routine inspection is to be performed monthly by vessel crew members;[41] this is a common industry practice.

Monthly inspection items in the manufacturer's manual include the following (see Appendix A for the full instructions):

> 7. Inspect CO_2 system discharge heads for cracks, corrosion, grime, etc. Ensure that discharge heads are tightly secured to each CO_2 cylinder valve and connected to the discharge manifold with a flexible discharge hose or swivel adapter.
> 8. Inspect flexible discharge hoses for loose fittings, damaged threads, cracks, rust, kinks, distortion, dirt, and frayed wire braid. Tighten loose fittings, and replace hoses which have stripped threads.[42]

The vessel had a copy of the manufacturer's maintenance instructions on board. Electronic versions of the manual are also available at the manufacturer's website and can be downloaded for free. The vessel's planned maintenance system contained tasks for monthly and annual inspections. These tasks did not contain details of the manufacturer's requirements, nor did the tasks refer to the manual. Work orders for monthly inspections generated by the planned maintenance program had been signed off as being completed twice between March 2023 and the day of the occurrence. In each instance, the crew

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40 Kidde Fire Systems (P/N 81-CO2MAN-001), *CO_2 Carbon Dioxide Fire Suppression Systems: Owner's Manual* (January 2002), section 2-5.1 Monthly Inspection, p. 2-4. The manual is now entitled *Engineered Carbon Dioxide (CO_2) Fire Suppression Systems: Design, Installation, Operation and Maintenance Manual*.

41 Carrier, *Kidde Fire Systems Marine Technician Training* (updated November 2022), slides 70-71.

42 Kidde Fire Systems (P/N 81-CO2MAN-001), Engineered *Carbon Dioxide (CO_2) Fire Suppression Systems: Design, Installation, Operation and Maintenance Manual* (September 2013), section 6-3 Inspection Procedures – Monthly, p. 6-2.

completed a rapid visual inspection of the CO_2 cylinder room to ensure that the cylinders and room were clean and free of debris.

The investigation found that vessel managers and the crew members who had been assigned responsibility for completing the monthly inspection were unaware of the manufacturer's requirements. They were also unaware of the manufacturer's annual maintenance requirements. Additionally, they expected that the technicians provided by the third-party supplier had been trained by the manufacturer, without verifying that this was the case.

Inadequate maintenance of fixed fire suppression systems has been identified by other national marine accident investigation agencies as a contributing factor in occurrences. For example, following investigations into 2 occurrences, the United Kingdom Marine Accident Investigation Board found that there is an overreliance on shore-based contractors to perform maintenance on these systems.[43] The U.S. Coast Guard identified technician competency and crew knowledge of operation and maintenance as 2 safety issues in vessel fires.[44]

1.11.5 Water supply to the fire main line

The *Cuyahoga*'s fire main line could be supplied with water by the fire pump, the bilge pump, or the emergency fire pump. Both the fire pump and the bilge pump were in the engine room. The emergency fire pump was located outside of the engine room, as required by regulation,[45] to ensure that the vessel had at least 1 pump available to supply the fire main regardless of the location of the fire. The emergency fire pump was a centrifugal pump driven by an electric induction motor powered by the emergency switchboard. The pump could be started locally or remotely. The emergency fire pump was accessed from the unloading tunnel and from the engine room. The emergency fire pump was connected to the fire main piping by an isolation valve located in the boiler room. This valve was normally left open so that the pump could supply water to the fire main in an emergency. According to SOLAS regulations,[46] isolation valves must not be located in a machinery space. Due to

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43 United Kingdom Maritime and Coastguard Agency, *Safety Bulletin 12: Accidental CO2 Releases Onboard 2 UK Merchant Vessels* (12 September 2018), available at https://www.gov.uk/government/publications/safety-bulletin-12-accidental-carbon-dioxide-releases-onboard-uk-merchant-vessels/safety-bulletin-12-accidental-co2-releases-onboard-2-uk-merchant-vessels (last accessed 30 July 2025).

44 United States Coast Guard, Safety Alert 07-17, *CO_2 Hazards are nothing new, but we'd like to remind you of what not to do!* (20 July 2017) and United States Coast Guard, Notice 02-12, *Servicing of Shipboard CO_2 Fire Suppression Systems, "What you don't know can kill you"* (08 June 2012).

45 Transport Canada, SOR/2017-14, *Vessel Fire Safety Regulations* (as amended 23 November 2022), sections 131 to 134, and International Maritime Organization, International Convention for the Safety of Life at Sea [SOLAS], 1974, as amended 2016, Chapter II-2, Regulation 10, paragraph 2.2.3.2.

46 International Maritime Organization, *International Convention for the Safety of Life* at Sea (SOLAS), 1974, as amended 2016, Chapter II-2, Regulation 10.

the construction date of the *Cuyahoga*, the vessel was exempt from this requirement under SOLAS and Canadian regulations.

When electrical power was supplied by the emergency generator, emergency lights provided low levels of lighting in the unloading tunnel. The emergency generator did not provide power for the mechanical ventilation of the tunnel. Access to and from the tunnel was limited to the entrance at the forward end of the vessel or through the emergency escape hatch located at midship. Communication between the location of the emergency fire pump and the wheelhouse by portable radio was made difficult due to the surrounding steel structure.

The pump was installed below the vessel's light-load waterline. It was not self-priming or fitted with a priming device, and the pump had a history of becoming airlocked.

1.11.5.1 Inspection and maintenance

The vessel maintenance plan required that the emergency fire pump be tested monthly. In the monthly test, crew started the emergency fire pump locally and checked that the pump pressure in the discharge casing reached 70 to 80 psi. If the pressure did not build up, instructions were provided on how to purge air from the pump casing using 2 bleed valves. When the pump was running, crew were instructed to check for unusual noise or vibration before concluding the test. Once these checks were completed, the crew stopped the pump.

The vessel maintenance plan also included conducting a monthly visual inspection of the fire main piping, fire hydrants, and hose stations. However, the maintenance plan for the fire main system did not include the isolation valves or their internal parts. Furthermore, the isolation valves were not included on the classification society's master list of inspection items for the vessel, and there are no records of maintenance, inspection, or replacement of any of the isolation valves in the vessel's fire main.

The emergency fire pump and its electric motor are subject to a regulatory inspection every 5 years. In 2021, a third-party contractor removed the pump and its electric motor from the vessel and dismantled them for a 5-year inspection. The pump components were found to be in satisfactory condition and the pump and motor were reassembled and reinstalled on the vessel. The associated piping and valves were also examined by Lloyd's Register and an operational test was performed, but the isolation valves were not opened.

The emergency fire pump was also checked occasionally during fire drills. During a drill, the pump would be started and the flow of water from the fire hydrants on the forward and aft ends of the vessel would be checked. Records show that during the last fire drill before the occurrence, on 01 May, the pump was run and the flow at the fire hydrants was checked.

The post-occurrence inspection of the emergency fire pump and isolation valve found the pump functioned correctly, but the isolation valve obstructed the flow of water to the fire main. The internal parts of the valve were corroded and the valve spindle was disconnected from the gate. This meant that the gate could no longer be moved and was therefore stuck in the closed position (figures 19, 20, 21). However, the valve spindle was in the open position and the crew was not aware that the gate had disconnected. When operated, the spindle had some resistance, which could give the appearance that the valve was operating normally.

Figure 19. The isolation valve, in position (Source: TSB)

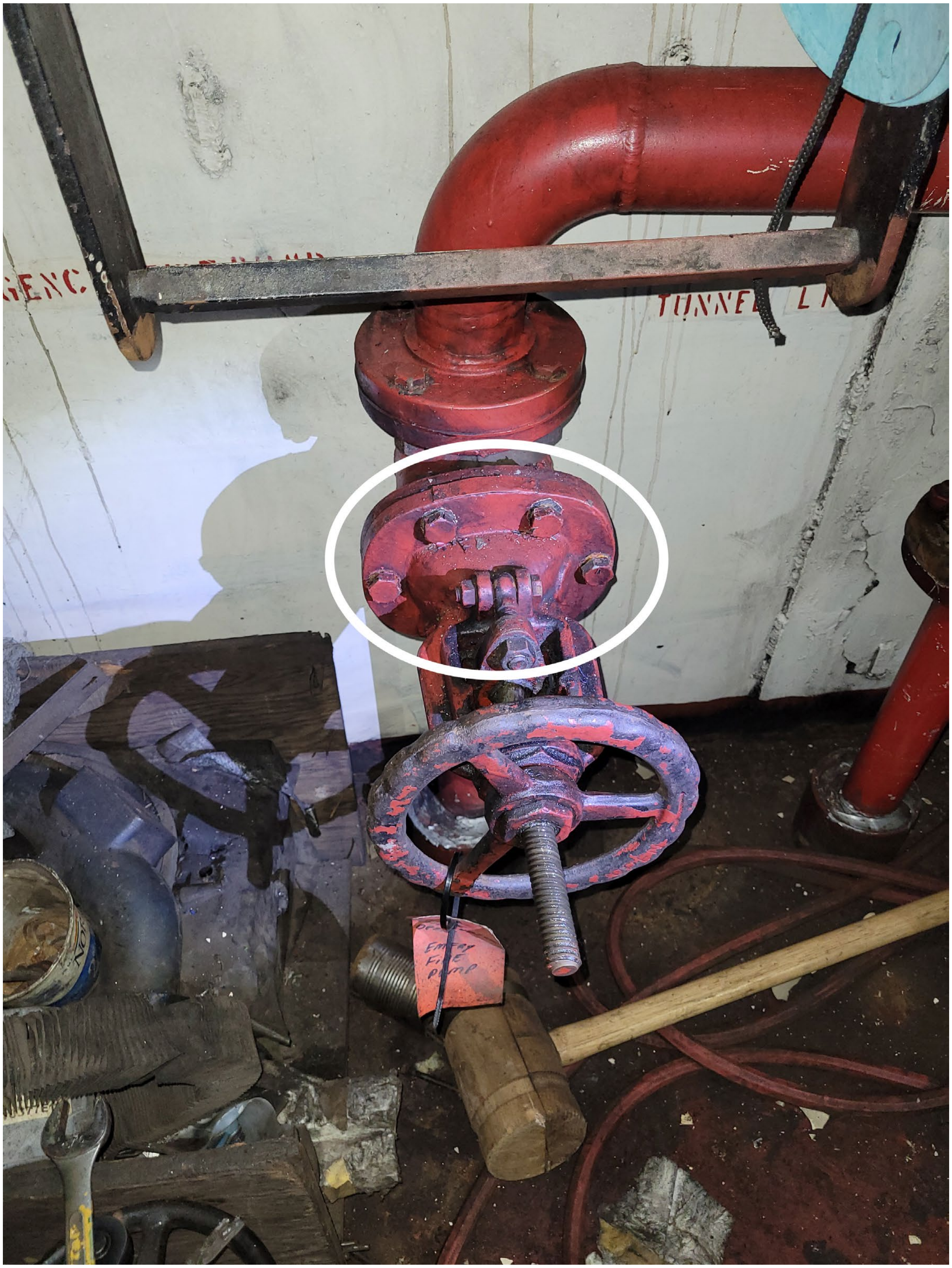

Figure 20. The isolation valve disassembled, showing the disconnected spindle (Source: TSB)

Figure 21. The isolation valve, showing the disconnected gate (Source: TSB)

An isolation valve used to isolate the section of the fire main in the unloading tunnel from the rest of the fire main system failed in the same way in 2022. In that case, the defective valve was replaced by a spare that was on board.

One of the main functions of valves in piping systems in contact with seawater is to prevent accidental water ingress. Valves installed on inlets and discharges connected to the hull below the margin line must be opened for inspection every 5 years during periodic hull inspections. However, other valves in the same piping systems are generally excluded from regulatory inspection. On the *Cuyahoga*, the hull valves were inspected as required, including the emergency fire pump suction valve. The investigation found no record that the isolation valves in the fire main were inspected.

1.12 Firefighting and fire control operations

Steps in shipboard firefighting operations consist of detecting the fire, informing crew, search and rescue, confinement, extinguishing, ventilation, and overhaul. These operations require properly trained and equipped individuals. If the fire is advanced enough, confinement, which includes boundary cooling, may be the best option for control.

To achieve this, the hot compartment must be isolated and all of its boundaries must be monitored and cooled as required. The crew must be able to approach the boundaries safely. Conditions may be unknown before entry; extreme heat and toxic vapour or smoke may be encountered, so crew must be adequately protected. Equipment will protect crew not only from the heat and smoke, but also from any steam generated from water coming into contact with hot steel surfaces during boundary cooling. In any situation where crew enter a space where heat or smoke are present, a second team equipped with firefighting equipment and SCBAs should be available for backup and rescue.[47]

When a compartment is opened, accumulated heat and smoke may exit following the same path that the team is using to enter. Advancing charged fire hoses in interior spaces can be complicated by narrow corridors, bends, corners, ladders, equipment, or furniture, and may require many firefighters. Accessing boundaries or making a direct attack may require passage through vertical and horizontal openings. A firefighter may have to be positioned at each door or hatch to prevent snagging. Firefighting efforts can be strenuous, and firefighters can quickly exhaust air supplies, requiring that relief or intervention teams be assembled for each team making entry. To ensure adequate air for egress, every firefighter inside a compartment should begin to exit before the alarm signalling low air pressure on their SCBA sounds. When temperatures in the compartment are high, firefighters may be limited to only 10 minutes inside.[48]

Canadian vessels of 500 gross tonnes or more are required to carry a minimum of 2 firefighter outfits and 2 SCBAs with 2 spare charged air cylinders;[49] tankers are required to carry additional equipment. Firefighter outfits and SCBAs are required to be stored in "widely separated positions."[50] The TSB has found in other occurrences that when the minimum quantity of equipment is carried onboard, firefighting operations are limited. For example, in an engine room fire on another LLT vessel, the *Tecumseh*,[51] crew entered the engine room to fight the fire, using the fire hose as a lifeline. The crew members became separated and had to exit approximately 20 minutes later, before locating the seat of the fire, because their SCBAs ran low on air. No relief team was available, the crew abandoned firefighting efforts in the engine room, and the fire worsened.

At the time of the occurrence, the *Cuyahoga* was equipped with the required minimum of 2 firefighter outfits and 2 SCBAs with 4 charged air cylinders. On the *Cuyahoga*, 1 firefighting equipment locker was located on the forward deckhouse and the other was located on the boat deck of the aft deckhouse (Figure 22).

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47 International Fire Service Training Association, *Marine Fire Fighting for Land-Based Firefighters*, Third Edition (2019).

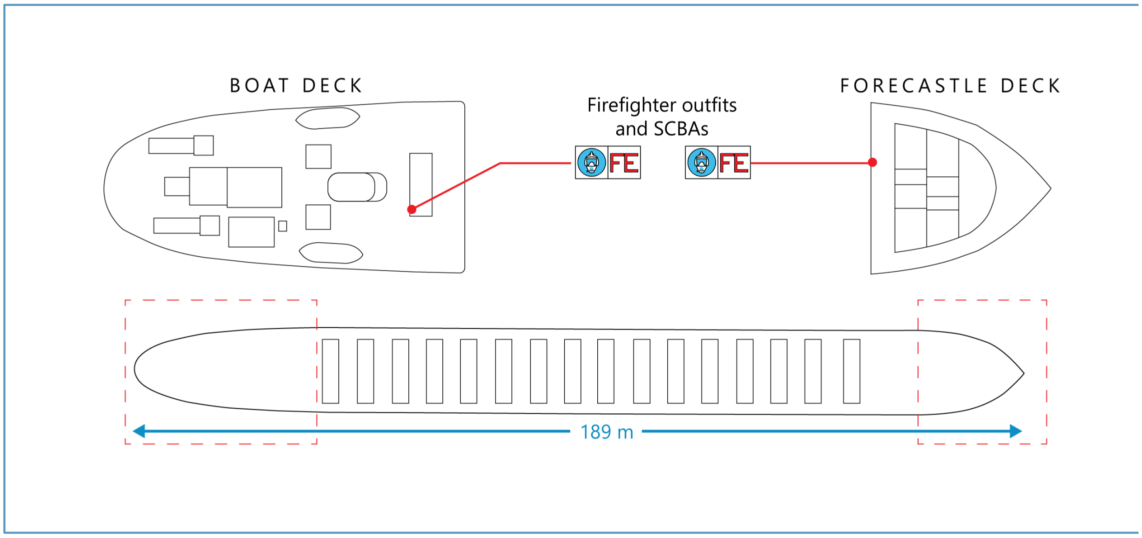
48 Ibid.

49 There is no requirement for the firefighter outfits or self-contained breathing apparatuses to be fitted to the crew members assigned to wear them.

50 International Maritime Organization, *International Convention for the Safety of Life at S*ea (SOLAS), 1974, as amended 2016, Chapter II-2, Regulation 10, paragraph 10.3.1.

51 TSB marine transportation safety investigation report M19C0403.

Figure 22. One firefighter outfit and SCBA was stored on the boat deck and 1 set was stored on the forecastle deck (Source: TSB).



In previous occurrences, a lack of firefighting equipment and a lack of familiarity have led to crew member injuries and placed people in danger when responding to vessel fires.[52] In this occurrence, the decision to use the CO_2 system even though the engine room was not properly sealed was influenced by the fact the *Cuyahoga* carried only enough equipment for 1 team of 2 firefighters, which was insufficient for an engine room fire.

1.13 Human factors issues

1.13.1 Sleep

During sleep, the human body cycles through 4 different stages (Table 3): 3 stages of progressively deeper sleep (stages N1 to N3) and rapid eye movement (REM) sleep, when dreams occur. The 1st episode of stage N3 sleep, the deepest sleep, usually occurs about 30 to 45 minutes after sleep onset and can last as long as 1 hour.

Table 3. Summary of the 4 sleep stages

Sleep stage	Characteristics	Typical duration	Proportion of total (nightly) sleep (%)
N1	Light: some muscle tone, breathing is regular	1 to 5 minutes	5 to 10
N2	Moderately deep: heart rate and body temperature drop	20 to 35 minutes	40 to 50
N3	Deepest: slow wave, fully asleep	Up to 1 hour	10 to 20
R (REM)	When dreams occur	1 to 45 minutes	15 to 20

52 TSB marine transportation safety investigation reports M20A0004, M18P0014, and M02N0007.

The second engineer went to sleep at approximately 2100 on the night of the occurrence. The investigation determined he was likely in deep, stage N3 sleep when the fire alarm was sounded.

1.13.2 Decision making and stress in emergency situations

Emergencies are stressful situations that create high cognitive workloads. In emergencies, people have limited time to process various types of critical information, make decisions, assess the results, and adjust actions accordingly.[53]

Stressful, high-workload situations can affect human performance and may result in people taking inappropriate action.[54] One of the more significant impacts on performance is with respect to a person's attention. For example, attentional tunnelling results when an individual becomes more selective with regard to what they are focusing on, either intentionally or unintentionally. This focused attention can be desirable in certain situations, but it can come at a cost as the person may potentially miss other pieces of information that could be important in managing the situation. For instance, during an emergency, a person may become focused on finding another who is missing, including searching in smoke-filled areas, without considering the risk to themselves. The marine industry's primary method to prepare crew members to manage unexpected situations is via procedures, training, and regular emergency drills.

Being able to make an accurate and comprehensive situation assessment and having good situational awareness[55] are critical for good decision making. In an emergency, a person may face a novel situation that is neither typical nor included in any procedures or any training they may have received. Realistic scenarios in training and drills, and the associated post-drill debriefs, allow crew members to become aware of the variability connected to emergency situations. They can thereby acquire the knowledge and skills necessary to respond effectively to new and unexpected situations and to make rapid decisions.

1.14 Safety in marine operations

Safety in marine operations is the shared responsibility of everyone who interacts with the vessel, from crew to shore staff to regulators. Safety is more than the absence of accidents or even compliance with regulations; rather, it depends on a mature safety culture and documented, systematic processes.

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[53] M. Yu, T. Zhu, and S. Donaldson, "Effects of time pressure on behavioural decision making in natural disasters: Based on an online experimental system," *Journal of Geography & Natural Disasters*, Vol. 8, No. 1 (2018).

[54] C.D. Wickens, W.S. Helton, J.G. Hollands, et al., *Engineering Psychology and Human Performance,* Fifth Edition (Routledge, 2022), p. 492–493.

[55] Situational awareness is a construct that describes how people perceive information about their immediate environment, understand its meaning and, as a result, predict a future state about it, thus creating an awareness of the present situation

The IMO adopted the International Safety Management (ISM) Code in 1993, which came into force in 1998. The ISM Code provides an international standard for the safe and reliable operation of a ship and its equipment and supports compliance with all applicable regulations and requirements. To demonstrate compliance with the ISM Code, external and internal audits are conducted. A vessel is issued a safety management certificate and its operating company is issued a document of compliance once the systems in place have been audited by an accredited organization. Vessel-specific requirements under the ISM Code include the development of plans for shipboard operations and emergency preparedness, and documentation of the vessel's maintenance system. The ISM Code is the basis for Canadian requirements for safety management systems, which, since 2024, have been required for the vast majority of commercial vessels.[56]

An effective safety management system (SMS) accounts for all factors that impact safety, including human and organizational factors. Three elements of safety management that are recognized as being less developed in many SMSs are as follows:

- Reporting of minor incidents
  Reporting, including of accidents, incidents and, more importantly, near misses and non-conformances, is critical to effective safety management. Research demonstrates that seafarers believe that only major near misses should be reported to the company.[57]
- Routine maintenance practices and procedures
  IACS noted in 2001 and again in 2018 that the management of shipboard maintenance is seen as "an entirely technical matter, somehow unrelated to safety and the exclusive responsibility of technical staff."[58] Technical staff here may include shore-side technical managers or simply the engine room crews.
- Systems for improvement that incorporate feedback from crew and others who use the SMS
  Understanding gaps between procedures and work practices is essential for continuous improvement.[59,60,61]

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56 Transport Canada, *Marine Safety Management System Regulations* (SOR/2024-133) and *Fishing Vessel Safety Regulations* (CRC, c.1486).

57 N. Hasanspahić, V. Frančić, S. Vujičić, T. Biočić, "Reporting culture – A prerequisite for safety in shipping," *Journal of Maritime Sciences*, 2023, pp. 91–112.

58 International Association of Classification Societies (IACS Rec. 2001/Rev.2), *A Guide to Managing Maintenance in Accordance with the Requirements of the ISM Code,* 2018, pp. 1–9.

59 S. Dekker, *Safety Differently: Human Factors for a New Era*, Second Edition (CRC Press, 2015), p. 107.

60 J. Reason, *The Human Contribution: Unsafe Acts, Accidents, and Heroic Recoveries* (CRC Press, 2008), pp. 86–87.

61 C. Kuo, *Safety Management and its Maritime Application* (The Nautical Institute, 2007), p. 93.

A recent IMO Maritime Safety Committee (MSC) study[62] on the effectiveness and effective implementation of the ISM Code found that many seafarers are reluctant to report non-conformities and deficiencies or to report hazardous occurrences to management. The study notes that feedback and reporting between ship-based crew and shore-based management is a key requirement for managing safety, and that this is an area of concern.

1.14.1 Lower Lakes Towing safety management system

At the time of the occurrence, LLT was not required to have an SMS; the SMS was voluntarily implemented in 2015. [63] Whether it is required or voluntary, an RO-audited SMS must comply with the ISM Code. Among other things, the ISM Code requires external and internal audits to ensure that the requirements of the code are being met.

External audits of the company and vessel SMS had been carried out by the American Bureau of Shipping since the SMS was implemented. At the time of the occurrence, LLT held a voluntary document of compliance for this type of vessel and the *Cuyahoga* held a voluntary safety management certificate.

LLT's SMS is documented in a manual entitled *Safety Management System: Policies and Procedures*. The company last revised the manual in 2023. At the vessel level, management of the LLT program considers most aspects of vessel operation to be the responsibility of individual masters; most vessel-specific operational procedures are documented on the vessel only and are left to the discretion of the master.

LLT's *Safety Management System: Policies and Procedures* manual is supplemented by documents such as:

- vessel-specific training manuals (for example, a firefighting equipment and training manual, a life-saving appliances manual);
- company training manual;
- printed copies of some Canadian and U.S. regulations;
- safety memos and fleet advisories;
- manufacturer manuals and bulletins; and
- LLT's marine emergency response plan (MERP).

The company's SMS is supported by workplace safety software. This software is used by all crew members and by shore managers for safety planning and for preparation of work permits; identification and assessment of injuries, hazards, and risks; inspection and auditing; corrective action and monitoring; and so on.

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62 International Maritime Organization, MSC 109 INF.3 *Study on the Effective Implementation of the International Safety Management (ISM) Code,* 23 September 2024.

63 Under the updated *Marine Safety Management System Regulations* (SOR/2024-133, last amended on 03 July 2024), vessels such as the *Cuyahoga* are required to have a safety management system.

1.14.2 Lower Lakes Towing maintenance policies and procedures

LLT's policy for the maintenance of its ships and equipment states that the company intends to maintain its vessels to ensure safe, economical, and continued service. It outlines management and crew responsibilities for budget and cost controls and the preparation for drydocks. The policy states that when critical equipment, such as the main engine, becomes defective and requires repair, the situation must be immediately reported to the master and vessel manager, and that the MERP should be utilized, as required. The policy also sets responsibilities for crew members expected to perform planned maintenance and to use the planned maintenance system.

The planned maintenance system software was used to schedule and track routine maintenance, such as manufacturer-required and regulatory maintenance, and to plan maintenance that required a break in operations, was being deferred to a non-operational period, or required additional resources. Planned maintenance tasks based on time or calendar frequency are generated by the software automatically and are intended to provide the instructions and information necessary for maintenance staff to perform the tasks, including references to instructions on the applicable pages of the manufacturer's manual.

1.14.2.1 Reporting and analysis of technical non-conformities and near misses

To establish safety requirements beyond those found in the applicable rules and regulations, and as described in the ISM Code, the company must take into consideration the age of the vessel and its machinery, previous maintenance histories, technical non-conformities, and manufacturer recommendations. Technical non-conformities or deficiencies may be discovered during operations or routine maintenance. Technical non-conformities can lead to hazardous conditions. To mitigate the risk posed by these situations, crew must take corrective action. To choose the best course of action, the defect must be identified and its causes diagnosed. The recording and analysis of the vessel's maintenance history is therefore essential in knowing what tasks need to be done to keep the vessel operating safely, and what ongoing monitoring is needed. LLT's policy for the maintenance of ships and equipment does not contain instructions or guidance for the reporting or tracking of technical non-conformities or deficiencies.

Near-miss incidents are those in which adverse consequences were possible but did not occur. LLT's SMS policy states that all near-miss incidents should be documented and investigated. The policy lists several examples, including events where a fire could have resulted but did not. The policy directs crew members to report near-miss incidents to their immediate supervisor, who is to then complete the near-miss report form before submitting the report to the company designated person for review and follow-up.

The TSB reviewed documented near-miss incidents from the Cuyahoga. These reports typically included occupational health and safety hazards and safety equipment deficiencies. Reports of mechanical problems that meet the definition of near-miss incidents (for example, repetitive leaks on the fuel injection system with the potential to cause an engine room fire) were not documented.

1.14.2.2 Maintenance records

Vessel maintenance records are critical for safety. Detailed and complete maintenance records provide historical data that is needed to analyze equipment failures and determine whether the equipment, scheduled maintenance, or operating procedures require modification. Historical maintenance data also allow for the analysis of trends and enable effective preventive maintenance to be carried out.

Most routine maintenance, whether scheduled or in response to minor problems, is carried out when a vessel is operational. Maintenance records are kept for use by the engine room crew and inspectors. Some maintenance records are also used by shore staff for planning operations and the larger or more costly maintenance tasks.

The planned maintenance system software on the *Cuyahoga* was used to record notes related to such maintenance. For example, the fuel manifold repair was recorded in the planned maintenance system software because replacement parts had to be ordered from a vendor; however, when the work order was completed in the planned maintenance system, details of the replacement work were not recorded. The engine room crew also maintained some records and notes in an informal log on a computer. This informal maintenance log was available to crew during operations and handovers but was not available to shore staff. Crew members also kept some personal, handwritten notes with additional details. Continued problems, leaks, and the retightening of the fuel injection lines were also not recorded. Also, the replacement in 2022 of the defective isolation valve in the fire main was not documented.

1.14.3 Marine emergency response plan

An MERP sets out procedures for common vessel emergencies. In case of a fire, it should set out fire containment measures for fires in various areas of the vessel. This plan would also normally identify fire hazards and set out instructions for specific tasks to be performed during firefighting activities (for example, steps to take when a crew member is missing during a fire, or how to enter the unloading tunnel when the engine room is on fire).

The emergency preparedness section of the LLT SMS manual referred to the MERP. The MERP contained checklists that are intended to be used by vessel masters to document and organize an emergency response to hazardous situations that affect the seaworthiness or safety of the vessel. The MERP checklist for fires and explosions identified what information to collect and to whom it should be reported once the vessel and crew were safe and secure.

1.14.4 Firefighting equipment and training manual

The crew on the *Cuyahoga* had been provided with a manual that contained general information about the emergency equipment available on LLT vessels and the associated regulations. The manual was last revised in March 2018. The contents of the manual were generic and used for all LLT vessels.

Section 4 of the manual provided information on the use and operation of CO_2 fixed fire suppression systems. The manual described the maintenance of a typical system and stated:

> Carbon dioxide systems do not require a tremendous amount of in-depth maintenance. The best thing that can be done to ensure proper operation is regular inspection. Observe operating controls and mechanisms for obstructions or any other conditions that may interfere with their operation.
>
> Pay particular attention to the stowage of materials that may obstruct access to controls or interfere with moving parts. Ensure that nozzles and piping are not clogged with debris, paint, lubricants, or other foreign substances. Most maintenance will be done by a qualified fire equipment technician when a failure has been found or during the annual inspection.[64]

The manual contained no details specific to the *Cuyahoga*'s system installation, operation, inspections, or maintenance.

1.14.5 Emergency drills

The *Fire and Boat Drills Regulations* mandate that vessels conduct drills to ensure that crews are prepared to respond in an emergency. Masters are required to "ensure that drills, in so far as is feasible, are carried out as if there were an actual emergency."[65] Emergency drills that include realistic scenarios increase a crew's preparedness, readiness, and effectiveness in the event of an emergency. Realistic scenarios might include different conditions, such as drilling in the dark or with noise, or drills that deal with a missing member of the team or damaged or inaccessible equipment. Realistic scenarios may also be combinations of individual scenarios and include the potential for escalation, such as a fire on the vessel combined with the risk of an explosion.

Taking the time to debrief after drills and exercises is critical so participants can evaluate the effectiveness of a drill, identify areas for improvement, and discuss comments or concerns regarding roles, equipment, and communications.

There is no requirement to ensure that drills are conducted in specific locations, such as an engine room where the risk of fire is high; regulations leave the planning and content of drills to the discretion of masters. According to LLT's SMS, masters are required to develop drills that encompass different emergency scenarios. The company policy suggests drill scenarios, but masters are given flexibility to choose or change the drill scenarios to meet operational requirements.

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64 Lower Lakes Towing Ltd., *Firefighting Equipment & Training Manual* (January 2015, revised March 2018), pp. 3–4.

65 Transport Canada, SOR/2010-83, *Fire and Boat Drills Regulations* (as amended 23 June 2021), Section 17.

The *Cuyahoga*'s crew regularly conducted drills. After drills were completed, the master completed an emergency drill report. These reports recorded incident details and duration of the drills and included a section for comments. Typically, during the navigation season, drills were held when the vessel was navigating between ports and at times that would disrupt crew rest periods as little as possible, often starting at 1600. Fire and abandon ship drills were combined, and the crew debriefed at the end. Of the 30 drills conducted between May 2020 and May 2023 on board the *Cuyahoga*, the average time of the combined drill and debrief was 25 minutes and drills were always carried out during daylight hours. During this same period, only 1 drill was practised for an engine room fire that required a simulated use of the engine room's CO_2 fixed fire suppression system. No drills included searching for a missing crew member.

The muster list assignments were posted on the bridge. According to the muster list, 3 crew members were assigned to wear firefighter outfits in an emergency.

1.15 Marine Emergency Duties training

A fire on a vessel is a serious event, and crew members are often the best and sometimes the only option for firefighting, particularly in the initial phases of the event. During marine emergency duties (MED) training, students are taught how to respond to vessel fires. The goals of MED training courses are as follows:

1. To help seafarers understand the hazards associated with the marine environment and with their vessel.
2. To provide, through approved shore-based courses, training in the skills that seafarers need to cope with such hazards, to a level appropriate to their functions on board.[66]

The content of MED training courses is defined by TC[67] and approved courses are held at institutions recognized by TC. In basic and advanced firefighting courses, participants are taught the strategies and tactics for controlling fires, how to organize firefighting teams, coordination and communication between teams during firefighting activities, and how to search for and rescue missing crew members. Recognized institutions work to ensure that participants are as prepared as possible to deal with vessel fires in real life, teaching them according to best practices from the firefighting industry.

Recognized institutions are required to have at least 1 firefighting outfit and SCBA for each participant. Before practical exercises, instructors ensure that equipment fits the participants to prevent injury. Fit testing of SCBAs is often a pre-requisite for participation in practical firefighting exercises; fit testing ensures that full face masks form effective seals against participants' faces, thereby conserving air and reducing inhalation of smoke and fumes.

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[66] Transport Canada, TP 4957, *Marine Emergency Duties Training Courses*, 2nd Edition (July 2021), section 1.3.

[67] Transport Canada, TP 4957, *Marine Emergency Duties Training Courses*, 2nd Edition (July 2021).

During practical exercises for fires in engine rooms and accommodation spaces, multiple teams coordinate firefighting efforts:

- An entry team of 3 participants is formed to advance a hose into a space, operate the hose nozzle, and communicate with other parties.
- A relief team of 3 participants remains outside the space, ready to replace the entry team when they have to exit, or for search and rescue should someone on the entry team be injured or lost.
- A 3rd team of 2 or more participants stands by ventilation points, ready to open them immediately prior to the entry team's attack.
- Additional participants perform boundary cooling on exterior spaces.

In other occurrences, the TSB has found that crew attempting to apply techniques using multiple teams with inadequate equipment placed crew at risk. For example, in a fire on the *Newfoundland Lynx,*[68] crew had to don equipment that did not fit them. The crew also attempted a combined attack requiring 4 firefighters with only 3 equipped crew members, placing unequipped crew at risk.

For all TC marine certificates, MED training is the only required training that includes firefighting skills. This training does not include how to respond to a fire with a single team of only 2 equipped individuals.

1.16 Exemptions to mandatory safety requirements

The statutory requirements for maintenance of a vessel define a minimum level of safety. Regulations may contain age-related exemptions (grandfather clauses) that permit authorized representatives to maintain vessels to the original standards of construction unless substantial modifications to systems or equipment are made; nevertheless, existing vessels are typically required to apply new elements that are considered economically feasible. In this context, substantial modifications are those that "substantially alter the vessel's dimensions or passenger accommodation spaces, […] substantially increase the vessel's service life or outfitting […] [or involve the replacement of] machinery, systems, [or] equipment."[69] Some Canadian regulations incorporate current SOLAS requirements by reference; SOLAS regulations contain similar provisions. For example, the *Vessel Fire Safety Regulations* require Canadian vessels to comply with the SOLAS fire regulations (chapter II-2). However, vessels constructed before the July 2002 entry into force of SOLAS II-2 and subsequent Canadian implementation are exempted from the amended requirements; vessels built after this date have to meet new requirements for fire safety. As a result,

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68 TSB Marine Transportation Safety Investigation Report M20A0003.

69 Transport Canada and Natural Resources Canada, SOR/2023-257, *Vessel Construction and Equipment Regulations* (as amended 20 December 2023), section 11(1), subsection (a), paragraphs (i) and (ii) and subsection (d).

vessels of similar sizes operating in Canadian waters have different construction and equipment requirements.[70]

In this occurrence, the investigation identified instances where regulations intended to mitigate fire risks were not applied to the *Cuyahoga* because of age-related exemptions. For example:

- shielding the fuel injection line connections on the main engine;
- having a main engine remote stop on the bridge; and
- not locating an isolation valve in a machinery space.

Finding: Other

Certain regulations to mitigate fire risks did not apply to the *Cuyahoga* due to age-related exemptions.

1.17 Previous occurrences

Over the years, the TSB has been informed of numerous occurrences involving engine room fires. Between May 2018 and May 2023, 180 fires on commercial vessels were reported to the TSB. The TSB and other international accident investigation bodies have investigated similar marine occurrences (Appendix B).

Data on all Canadian marine transportation occurrences since 1995 are available on the TSB website at https://www.tsb.gc.ca/eng/stats/marine/data-6.html. This information is updated monthly.

1.18 TSB Watchlist

The TSB Watchlist identifies the key safety issues that need to be addressed to make Canada's transportation system even safer. The following Watchlist issues are relevant to this occurrence.

Safety management is a Watchlist 2022 issue. Although at the time of the occurrence, an SMS was not required by regulation on vessels such as the *Cuyahoga*, LLT had voluntarily developed and implemented an SMS for its fleet and contracted the American Bureau of Shipping to provide oversight and certification of that system. However, even when operators do have safety management processes in place, they are not always able to demonstrate that hazards are being identified or that effective risk-mitigation measures are being implemented.

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70 The Transport Canada registration database can be queried for a snapshot of currently registered vessels. In a snapshot obtained on 29 April 2024 of 388 self-propelled, Canadian-flagged, registered vessels of 500 GT and over, 179 vessels, or approximately 54%, were built before 2000; this category of vessels includes bulk carriers such as the *Cuyahoga*. For registered vessels of all types and sizes, including barges, this percentage rises to nearly 70%. For comparison, the average age of the vessels in the world merchant fleet is approximately 22 years old (11.6 years old for bulk carriers).

In 2024, the *Marine Safety Management System Regulations* (SOR/2024-133) came into force. Under these regulations, commercial vessels apart from fishing vessels are required to develop, implement, and maintain a documented SMS.

ACTION REQUIRED

The issue of **safety management in marine transportation** will remain on the Watchlist until

- TC implements regulations requiring all commercial operators to have formal safety management processes; and
- operators that do have an SMS demonstrate to TC that it is working—that hazards are being identified and effective risk-mitigation measures are being implemented.

Regulatory surveillance is a Watchlist 2022 issue. For larger vessels (those more than 24 m long) such as the *Cuyahoga*, TC delegates most statutory inspections to third-party recognized organizations and then monitors the regulatory compliance of these vessels through compliance inspections. TSB investigations have shown that the regulatory oversight of delegated vessels is not consistent, resulting in situations where regulatory compliance on board these vessels goes unverified.

ACTION REQUIRED

The issue of **regulatory surveillance in marine transportation** will remain on the Watchlist until TC provides more oversight of the commercial vessel inspection process by demonstrating that its surveillance and monitoring are effective in ensuring that authorized representatives and recognized organizations are ensuring vessel compliance with regulatory requirements; and until TC demonstrates an increase in proactive surveillance.

1.19 TSB laboratory reports

The TSB completed the following laboratory reports in support of this investigation:

- LPO79-2023 – Mechanical systems analysis
- LP097-2023 - NVM Recovery-Computer
- LP119-2023 – Fractographic and chemical analysis of air start fitting and CO_2 release cable

2.0 ANALYSIS

On 23 May 2023, a fire started in the engine room of the bulk carrier *Cuyahoga.* The release of carbon dioxide (CO_2) from the fixed fire suppression system was not successful, but the fire went out because the main engine stopped. The analysis will look at the causes of the engine room fire and its spread. The analysis will also look at installation and maintenance practices for firefighting equipment. Lastly, the analysis will look at emergency response and preparedness with respect to both emergency procedures and firefighting equipment.

2.1 Causes of the engine room fire

2.1.1 Engine vibration and retaining clamps on the fuel injection lines

Fuel system failures associated with engine vibration and the assembly of fuel piping components are a known cause of engine room fires. Fuel injection lines are rigidly connected to the engine's cylinder heads and to the fuel supply and return manifolds. The lines and connecting fittings are therefore subjected to engine vibration. To secure the lines and reduce the effects of vibration, such as loosening fittings, retaining clamps should be installed.

At the time of the occurrence, there were no retaining clamps on the *Cuyahoga*'s main engine fuel injection lines (figures 6 and 7). The retaining clamps had been present before the occurrence but were most likely removed in 2021 when the fuel supply and return manifolds were replaced. The manifold replacement shifted the connecting points for the fuel injection lines. The investigation could not determine the reason for this shift. However, repositioning the manifold to fit the connection points would have required changes to the main engine fuel piping, which would have been time-consuming, especially during layup periods; this was not done. Because retaining clamps are designed to reduce play, they are attached directly to the cylinder heads. Consequently, the position of these clamps could not be changed. Therefore, after the new manifolds were installed, the fuel injection lines could not be secured with the retaining clamps; as a result, the fuel injection lines were unprotected from the effects of engine vibration. As well, the engine vibration was made worse by the cracked epoxy chocks under the engine mounts.

Finding as to causes and contributing factors

The retaining clamps on the fuel injection lines were not in place, increasing the fuel lines' exposure to the effects of engine vibration.

Engine room fires are a serious consequence of fuel injection line leaks. However, even though fuel injection line leaks do occasionally happen, engine room fires are relatively rare. Therefore, throughout their careers, marine engineers accumulate experience with maintenance problems such as fuel injection line leaks that have no adverse consequences, minimizing their perception of the risks.

The fuel injection lines on the *Cuyahoga* had leaked intermittently since the fuel supply and return manifolds were replaced. These leaks were addressed by occasional retightening of fuel injection line fittings, or occasional replacement of O-rings as a precaution. The engine room crew of the *Cuyahoga* focused on the immediate and observable mechanical deficiencies rather than on the underlying nature of the problem. They suspected that the engine vibration was high and they accepted that fuel leaks were frequent.

When crew workloads were high, crew members prioritized operational tasks that were immediately pressing, such as navigation tasks, repairs needed to maintain navigability, and cargo operations. Non-conformities that could be quickly and inexpensively fixed by the crew, such as the fuel injection line leaks, were perceived as minor technical matters. Due to the priorities resulting from vessel operations and workload, tasks related to the safety management system (SMS), such as documenting maintenance work that fit the criteria for reportable events, were not completed. Consequently, minor technical non-conformities were not typically recorded in the planned maintenance system or through the SMS reporting tools.

Although the leaks were corrected when observed, the corrections were not reported. Therefore, the underlying reason for the increased need to retighten the fuel injection line fittings remained uninvestigated, and the crew accepted the increased need for tightening.

Finding as to causes and contributing factors

Rectifying the fuel injection line leaks was incorporated into routine maintenance tasks. Consequently, there was no evaluation of the cause of the repeated leaks.

2.1.2 Fuel spray from loosened fuel injection line connection

Propulsion machinery is critical to the safety of a vessel and its crew. In the event of a failure, a vessel will be unable to navigate, and be placed in a potentially risky situation. A failure of an engine's fuel system or other machinery or components conveying flammable liquids may pose significant safety hazards. The risks associated with such hazards increase if these failures occur near hot surfaces.

The engine manufacturer had specific maintenance instructions for the engine; for example, the torque specification for the fuel injection line fittings and the tools to be used. However, the planned maintenance system did not contain instructions or information related to fuel piping maintenance. There was no process to ensure that crew members were familiarized with the manufacturer's instructions, such as the instruction to use a double hex flare nut crow's foot attachment to tighten the fittings in 1 step, which gives better control of the applied torque. Consequently, each member of the engineering crew carried out their assigned maintenance tasks according to their individual experience. The varied nature of this experience increased the likelihood of deviations from expected maintenance procedures, introducing a higher possibility for error during reassembly.

Because the fuel injection line installation torque was not known to the crew and the installation procedure was an adapted practice, it is also possible that the fittings were inadequately tightened, which would have sped up the vibration-loosening process.

Finding as to causes and contributing factors

Without accurate, documented procedures available to them, crew members developed their own practices for managing fuel injection line leaks; this led to fittings not being adequately tightened to resist the vibration-loosening process. As a result, these deviations from the manufacturer's instructions likely contributed to the loosening of the fittings.

The TSB's analysis of the fuel injection line fittings showed that by the time a leak was visible, a fitting had loosened. Once a threaded connection on a fitting becomes loose, the joint will eventually disconnect. In this occurrence, when the fuel injection return line on cylinder 7 disconnected, the resulting spray produced a mist of droplets that likely covered the engine and exhaust gas piping with fuel.

Finding as to causes and contributing factors

A fitting on a fuel injection return line loosened and disconnected, creating a fuel spray.

Before this occurrence, the company obtained some updates to the manufacturer's engine manuals during service visits. However, the update in which the engine manufacturer changed the torque specification for the fuel injection line fittings to a higher value did not reach the crew. Consequently, each time they attempted to fix a leak by retightening a fitting, they were tightening it to the previous value recommended by the engine manufacturer. As a result, the fuel injection line fittings remained under-torqued and were more susceptible to vibration-induced loosening.

Finding as to risk

If personnel carrying out maintenance work do not have the most current documentation issued by equipment manufacturers, safety updates and corrections will not be available for use. Consequently, poor equipment performance and breakdowns are more likely to occur, increasing the risk to the crew and to the vessel.

2.1.3 Installation of insulation to protect against fire

An important means to mitigate the risk of fire in an engine room is to insulate surfaces that could ignite flammable liquids. The International Maritime Organization (IMO) provides guidelines about fire safety, including high-level installation considerations for insulation; these guidelines are referenced by the International Association of Classification Societies, although they are not distributed by Transport Canada. Given that insulation is used in many industries, standards and practices from outside of the marine industry may also be applicable. However, a standard for installing insulation is not applied in the marine industry.

In this occurrence, the condition and installation of the insulation on the exhaust gas piping exposed steel surfaces that reached temperatures above the auto-ignition temperature of the engine fuel. The deteriorated condition of the insulation was not recorded by inspectors, crew, or vessel management and the insulation remained in place despite its poor condition.

The fuel spray from the disconnected fuel injection return line would have formed a mist that likely reached the nearby exhaust gas piping for the turbocharger and came in contact with the hot steel surface exposed by the gaps in the insulation. The quantity and rate of fuel released from the disconnected fuel injection return line and the abundant supply of air to the engine room contributed to the hot surface ignition of the fuel.

Finding as to causes and contributing factors

Gaps in the insulation exposed hot surfaces on the exhaust gas piping at the turbocharger outlet, and the fuel spray ignited on contact with those surfaces.

2.1.4 Engine room ventilation during fires

Machinery spaces such as engine rooms must be capable of being isolated in the case of fire, both to cut off the air supply and to prevent the fire from spreading. To isolate a space, crew seal off openings. Any openings that cannot be closed will result in an incomplete isolation of the space.

If a space is protected by a fixed fire suppression system, its extinguishing agent (CO_2 in this occurrence) can be released to suppress a fire. However, a period of time is required for the space to cool below the fuel's auto-ignition temperature. If air is introduced into the space during this period of time, either by crew entering or from openings that were not closed, the fire may re-ignite.

In this occurrence, several openings in the boundary of the engine room machinery space were open:

- The skylight hatch was partially closed when the fire began. However, it opened fully when the electrical cable for the winch remote control was damaged in the fire. Consequently, it remained open for 15 minutes after the onset of the fire and during the initial attempt to release CO_2.
- Some portholes and fire doors remained open. These could not be accessed because of heat and smoke in the machinery spaces.

Finding as to risk

If ventilation points and other openings to a compartment on fire cannot be accessed and closed, there is a risk that efforts to control and extinguish the fire will be delayed or unsuccessful.

In this occurrence, the CO_2 from the fixed fire suppression system was not discharged into the engine room and therefore had no effect. However, heat and combustion gases vented out through the skylight hatch and air flowed into the location of the fire through the open portholes and fire doors, becoming entrained in the rising flame plume. This air circulation and entrainment helped cool the space and reduce the heat generated by the fire. As well, separately, the main engine fuel supply was cut off.

The venting of hot gases and the flow of air at the location of the fire, coupled with the stopped main engine, reduced the buildup of heat in the machinery spaces. This prevented other combustible materials in the machinery spaces from igniting, and the fire was contained to the engine room. Consequently, the fire extinguished itself when the spray of fuel stopped.

Finding: Other

Although the CO_2 fixed fire suppression system was not discharged, the ventilation through the skylight likely helped stop the fire from spreading, and the engine shutting down meant that the fuel flow to the fire ceased, allowing the fire to extinguish itself.

2.2 Fixed firefighting equipment maintenance and installation

2.2.1 Carbon dioxide fixed fire suppression systems

Once a fire reaches a certain size, fixed fire suppression systems may be the only means available to a ship's crew to extinguish a fire in a machinery space. These systems must be maintained and inspected according to both industry guidelines and the manufacturers' instructions.

Knowledge of a system's specific maintenance requirements is critical to vessel safety. Lower Lakes Towing (LLT) hired an external service provider to carry out the maintenance on the CO_2 fixed fire suppression system, expecting that the technicians had expert knowledge regarding the system's maintenance. This expectation was supported by the class approval certificate that the contractor had previously held. However, the technicians who performed the maintenance and inspection did not have manufacturer training for the system. As a consequence, maintenance tasks designed to detect and rectify some of the defects that caused the system to fail on the day of the occurrence were not carried out. For example, O-rings were missing from some of the cylinders and some of the discharge hoses had not been tightened. Consequently, the system was left in an unsafe state following the annual maintenance visit. The chief engineer and vessel manager were unaware of the maintenance tasks to be performed and so they were not able to ensure these tasks were being completed according to the manufacturer's requirements during annual maintenance.

Monthly inspection requirements from the manufacturer were not included in the vessel's planned maintenance system or its firefighting equipment and training manual. In part because of this gap, subsequent monthly inspections by the crew failed to identify the loose hose fittings and loose connections at the discharge heads. As a result, the potential for leaks went undetected and the causes of the leaks were discovered only when the system was inspected after the fire during the investigation. Because technicians had performed maintenance on and inspected the vessel's CO_2 system, the crew believed that the system was ready for service and would be effective in suppressing the fire.

Finding as to risk

When individuals involved in inspection and maintenance of fixed fire suppression systems are unaware of the manufacturer's instructions, deficiencies may not be identified and corrected, increasing the risk that these systems will fail in the event of a fire.

Emergency systems are not intended to be regularly used and, for some, their activation in drills is simulated. Consequently, emergency systems require clear, concise, and highly functional instructions for successful use. In particular, CO_2 system installations are engineered for each vessel and protected space; therefore, the instructions for use must be customized.

Customizing instructions, including anticipating problems that may come up during use, requires an understanding of the system. The instructions must provide the steps to be taken to ensure that CO_2 will be released into the protected space. During a local (manually activated) release, the steps taken should also minimize the risk of CO_2 leaks that might affect the crew member performing the task.

In this occurrence, the instructions for the local release of CO_2 were adapted directly from the manufacturer's instructions and were based on its example installation. However, to keep the path for the CO_2 open from the cylinders to the engine room in the *Cuyahoga*'s installation, 2 steps should have been reversed: the directional stop valve should have been opened before the manifold was pressurized. Instead, the instructions specified that the manifold was to be pressurized first, which meant that the gas was blocked from entering the engine room distribution piping. Consequently, high-pressure, low-temperature CO_2 was released into the cylinder room through the leaks in the cylinder heads. With the room full of CO_2, the chief engineer was unable to reach the directional stop valve to open the path to the discharge delay device and the main stop valve for the engine room.

Inspectors and auditors may verify that instructions exist, and that crew know where the instructions are.[71] However, it is beyond the scope of most inspections and audits to verify the instructions themselves. It is the responsibility of the authorized representative to provide instructions and of crew to provide feedback on them. For emergency systems such as CO_2 fixed fire suppression systems, where activation during drills is impracticable, it is especially important to simulate the use of the instructions to identify possible problems and make any needed changes.

Finding as to risk

If instructions for the operation of CO_2 fixed fire suppression systems are not clear, detailed, and specific to the installation, there is a risk that such systems will not be successfully and safely operated in an emergency.

Because of the hazards posed by CO_2 stored under pressure in steel cylinders, the primary means of activating a CO_2 system is by remote control. Protecting and routing the remote

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71 For example, see TSB Marine Transportation Safety Investigation Report M20A0434.

release cables is an important aspect of the system design. Industry guidance documents, such as classification society guidelines, identify a number of factors that affect successful operation, including the location where the cables are installed. To ensure that the cables do not degrade over time, they should be located in areas where they will not be subject to the effects of weather or corrosion. To ensure that they are not damaged by a fire, they should not be routed in exposed locations or in the protected space.

In this occurrence, the remote release cables were subjected to the heat of the fire and made brittle by a reaction between the conduit and cable materials. Consequently, the cables broke when they were pulled. When the system was installed, the cables had been routed near the skylight hatch and above the main engine. In this location, however, they were also inside the protected space at a point where some of the highest temperatures in an engine fire were likely to occur.

Finding as to causes and contributing factors

The remote release cables for the fixed fire suppression system were located in an exposed location in the engine room and were damaged by the fire. Consequently, the cables failed and CO_2 was not discharged into the engine room, requiring a crew member to attempt a local release.

2.2.2 Emergency fire pump isolation valve

Operational tests of emergency equipment are 1 way of ensuring that it will work when needed. However, for components that are seldom used, or where the condition of internal components cannot be thoroughly assessed in operational tests, an important part of preventive maintenance is routine inspection.

Although the crew occasionally performed operational tests of the emergency fire pump in fire drills, the monthly test of starting the pump and checking the discharge pressure could not provide an indication of the condition of the isolation valve. The internal condition of the valve could be observed only by removal and dismantling. Consequently, the corrosion of the isolation valve remained unidentified. Because there was some resistance on the spindle, it is likely that the crew member who last attempted to open the valve believed that the gate had opened.

During the occurrence, the crew observed that there was no water in the fire main. Since the pump had previously become airlocked, and there was no other way to supply water for firefighting, the chief engineer entered the potentially hazardous unloading tunnel to work on the pump.

The corrosion observed in the emergency fire pump isolation valve was the result of several years of use. In fact, the valve had reached the end of its life cycle. Because valves and piping may come into contact with water, they are subject to corrosion, which means they have to be occasionally repaired or replaced. The investigation determined that the guidance for the inspection and maintenance of fire main isolation valves in LLT's SMS and *Fire Fighting Equipment & Training* manual was absent. In Lloyd's Register's master list of inspection items, inspection of fire main isolation valves is not included in the inspection of the emergency fire pump. During this inspection, the emergency fire pump was opened, and the pump and its associated piping and fittings were examined. However, there were no records indicating that the valve had ever been opened for inspection since it was installed.

Finding as to causes and contributing factors

Unknown to the crew, an isolation valve in the fire main piping was corroded and it obstructed the flow of water to the fire main, preventing the use of water to confine the fire.

2.3 Emergency response and preparedness

2.3.1 Drills and procedures

In an emergency, a narrowing of and focusing of attention can occur. This narrowing of and focusing of attention and an accompanying stress response can affect decision making, leading to decisions and actions being taken without an assessment of the risks involved. This focused attention can be desirable in certain situations, but it can come at the cost of potentially missing other pieces of information that could be important in managing emergency situations. Procedures, drills, and training are designed to support crew members in effectively managing emergency conditions, such as an absent or missing crew member in a fire.

As with all types of emergency response, fire and abandon ship drills are most effective if there is a mix of

- activity to develop automatic responses, such as donning firefighter outfits and self-contained breathing apparatuses (SCBAs) or confirming tasks are complete; and
- a wide range of realistic scenarios that represent likely situations, to support decision making.

Additionally, procedures, drills, and training should be carried out with the equipment that will be available in the emergency.

Frequent practice with realistic scenarios provides experience in adjusting to problems or making rapid decisions in an emergency. For example, in this occurrence, crew members needed to make decisions about how to safely access the emergency fire pump when the usual means of access was blocked.

The second engineer, who was named as the leader of the primary fire team, was absent for the first few minutes of the occurrence. His absence delayed some steps in the fire response. As well, the crew members who attempted to locate him did not notify others that they were entering the smoke-filled accommodations and neither of them wore a firefighter outfit or SCBA, putting themselves at additional risk.

The *Cuyahoga*'s muster list assigned 3 crew members to don firefighter outfits for an engine room fire or a fire in a different location. However, only 2 firefighter outfits were available on the vessel. In this occurrence, 2 crew members donned the firefighter outfits. However, the crew members who were the most active in the fire response were not wearing firefighter outfits or SCBAs.

Other TSB investigations[72] have found instances where muster lists were not based on a realistic assessment of an emergency response. Many recent TSB investigations have also found that a lack of varied scenarios in drilling has been a factor in the response to complex emergencies.

Finding as to risk

Realistic scenarios describe events that are likely to occur in an emergency, such as a missing crew member during an engine room fire. If such scenarios are not used for emergency drills, a crew will be less prepared to make rapid decisions, assess the results, and adjust actions accordingly.

Accurate, vessel-specific emergency procedures help the crew develop a shared understanding of the fire emergency response, facilitating the coordination of effort. Without the support of such procedures, masters and senior officers are left to react to all aspects of a fire response while the emergency is occurring. As a result, the fire response may not be well coordinated, reducing the effectiveness of the fire response and increasing risks to crew members.

Procedures should be vessel-specific and complete. For example, fire response procedures should define fire containment measures for different areas of the vessel, especially on a vessel such as the *Cuyahoga* where the forward and aft structures were widely separated.

In this occurrence, the checklist for fires and explosions was not specific to the vessel and primarily described steps for reporting the emergency. Other procedures were high level (not specific to the vessel) or absent.

Finding as to risk

If vessel-specific instructions for fire response are missing or inadequate, there is a risk that the crew will be unable to respond effectively to a shipboard fire.

2.3.2 Firefighting personal protective equipment and training

When a fire breaks out on a vessel, a prompt and coordinated firefighting response, carried out by trained personnel with appropriate equipment, is key to ensuring that the fire is brought under control and extinguished.

In this occurrence, an insufficient number of equipped firefighters limited the crew's ability to respond to the fire effectively and safely. For example, the decision to release CO_2 into the engine room before the space was completely isolated was influenced by the knowledge that it was unnecessarily dangerous for 2 crew members to enter the aft superstructure or engine room without a backup team.

72 TSB marine transportation safety investigation reports M22C0231, M20A0003, and M19C0403.

The 2 crew members who donned the 2 firefighter outfits on board the vessel did so according to the muster list; the engine room team did not don firefighter outfits or SCBAs. Consequently, the members of the engine room team were exposed to smoke and other hazards in responding to events. For example, the chief engineer retrieved the infrared thermometer from the smoke-filled accommodations without an SCBA. As well, the crew members attempting to troubleshoot the emergency fire pump entered the unloading tunnel unprotected.

Previous TSB investigations[73] have shown that the minimum level of required firefighting personal protective equipment may be inadequate.

Finding as to risk

If only the minimum required quantities of firefighting equipment are carried on board, then any response beyond activities such as monitoring and boundary cooling is likely to increase the risk to the crew.

Firefighting training provided by recognized institutions is intended to enable crew to effectively respond to vessel fires safely, following best practices. Participants learn to work in coordinated teams to contain and fight fires.

Vessel crew are not professional firefighters, and for most, Marine Emergency Duties (MED) training provides the sole basis for firefighting knowledge and experience. The lack of firefighting equipment on some vessels will prevent crew from putting into practice what they have learned. Gaps between what crew know how to do and what is possible to do in a real-life emergency due to limitations of available equipment prevent effective use of knowledge and experience gained during MED training. Also, if equipment does not fit the crew donning it, there is an increased risk of injury when entering an affected compartment.

The TSB has found in other occurrences[74] that the lack of access to adequate firefighting equipment prevented crews from safely carrying out combined and coordinated firefighting activities as taught in MED firefighting training courses.

In this occurrence, the fire went out on its own before spreading outside the machinery space because the space was ventilated at the beginning of the occurrence and the fuel flow to the fire ceased quickly. However, the crew were not equipped to employ any of the firefighting knowledge and skills they had learned in MED training and that could have been needed if the fire had spread.

Finding as to risk

If crew only have access to the minimum quantity of firefighting equipment required by regulations, then they will be unable to safely use the firefighting knowledge and skills

73 TSB marine transportation safety investigation reports M20A0003 and M18P0014.

74 TSB marine transportation safety investigation reports M20A0003 and M19C0403.

taught in MED training. Consequently, vessel firefighting and containment activities will be limited and risks to the crew increased.

3.0 FINDINGS

3.1 Findings as to causes and contributing factors

These are the factors that were found to have caused or contributed to the occurrence.

1. The retaining clamps on the fuel injection lines were not in place, increasing the fuel lines' exposure to the effects of engine vibration.

2. Rectifying the fuel injection line leaks was incorporated into routine maintenance tasks. Consequently, there was no evaluation of the cause of the repeated leaks.

3. Without accurate, documented procedures available to them, crew members developed their own practices for managing fuel injection line leaks; this led to fittings not being adequately tightened to resist the vibration-loosening process. As a result, these deviations from the manufacturer's instructions likely contributed to the loosening of the fittings.

4. A fitting on a fuel injection return line loosened and disconnected, creating a fuel spray.

5. Gaps in the insulation exposed hot surfaces on the exhaust gas piping at the turbocharger outlet, and the fuel spray ignited on contact with those surfaces.

6. The remote release cables for the fixed fire suppression system were located in an exposed location in the engine room and were damaged by the fire. Consequently, the cables failed and carbon dioxide (CO_2) was not discharged into the engine room, requiring a crew member to attempt a local release.

7. Unknown to the crew, an isolation valve in the fire main piping was corroded and it obstructed the flow of water to the fire main, preventing the use of water to confine the fire.

3.2 Findings as to risk

These are the factors in the occurrence that were found to pose a risk to the transportation system. These factors may or may not have been causal or contributing to the occurrence but could pose a risk in the future.

1. If personnel carrying out maintenance work do not have the most current documentation issued by equipment manufacturers, safety updates and corrections will not be available for use. Consequently, poor equipment performance and breakdowns are more likely to occur, increasing the risk to the crew and to the vessel.

2. If ventilation points and other openings to a compartment on fire cannot be accessed and closed, there is a risk that efforts to control and extinguish the fire will be delayed or unsuccessful.

3. When individuals involved in inspection and maintenance of fixed fire suppression systems are unaware of the manufacturer's instructions, deficiencies may not be identified and corrected, increasing the risk that these systems will fail in the event of a fire.

4. If instructions for the operation of CO_2 fixed fire suppression systems are not clear, detailed, and specific to the installation, there is a risk that such systems will not be successfully and safely operated in an emergency.

5. Realistic scenarios describe events that are likely to occur in an emergency, such as a missing crew member during an engine room fire. If such scenarios are not used for emergency drills, a crew will be less prepared to make rapid decisions, assess the results, and adjust actions accordingly.

6. If vessel-specific instructions for fire response are missing or inadequate, there is a risk that the crew will be unable to respond effectively to a shipboard fire.

7. If only the minimum required quantities of firefighting equipment are carried on board, then any response beyond activities such as monitoring and boundary cooling is likely to increase the risk to the crew.

8. If crew only have access to the minimum quantity of firefighting equipment required by regulations, then they will be unable to safely use the firefighting knowledge and skills taught in Marine Emergency Duties training. Consequently, vessel firefighting and containment activities will be limited and risks to the crew increased.

3.3 Other findings

These findings resolve an issue of controversy, identify a mitigating circumstance, or acknowledge a noteworthy element of the occurrence.

1. Following an earlier fire on board another Lower Lakes Towing Ltd. vessel, instructions at the *Cuyahoga*'s remote CO_2 release station were revised to give accurate information about how to confirm that a release was successful and describe post-release safety precautions.

2. Certain regulations to mitigate fire risks did not apply to the *Cuyahoga* due to age-related exemptions.

3. Although the CO_2 fixed fire suppression system was not discharged, the ventilation through the skylight likely helped stop the fire from spreading, and the engine shutting down meant that the fuel flow to the fire ceased, allowing the fire to extinguish itself.

4.0 SAFETY ACTION

4.1 Safety action taken

4.1.1 Lower Lakes Towing Limited

During the repairs to the carbon dioxide (CO_2) fixed fire suppression system, the remote cables between the engine room access door and the cylinder compartment were routed outside of the engine room along the deck and skylight on the boat deck.

The instructions for operating the CO_2 system controls were modified, directing the crew to operate the directional stop valve before operating the control heads on the cylinders.

This report concludes the Transportation Safety Board of Canada's investigation into this occurrence. The Board authorized the release of this report on 16 July 2025. It was officially released on 27 August 2025.

APPENDICES

Appendix A – Manufacturer instructions for monthly inspections

6-3 INSPECTION PROCEDURES – MONTHLY

1. Make a general inspection survey of all cylinders and equipment for damaged or missing parts. If any equipment requires replacement, refer to Paragraph 6-7.
2. Ensure that access to hazard areas, remote nitrogen or cable pull stations, discharge nozzles, and cylinders are unobstructed and there are no obstructions to the operation of the equipment or distribution of carbon dioxide.
3. Inspect flexible actuation hoses for loose fittings, damaged threads, cracks, distortion, cuts, dirt and frayed wire braid. Tighten loose fittings. Replace hoses having stripped threads or other damage. If necessary, clean parts as directed in Paragraph 6-6.3. Inspect flexible actuation hose adapters for stripped threads and damage. Replace damaged adapters. Inspect couplings and tees for tightness. Tighten if necessary. Replace damaged parts.
4. Inspect control heads attached to CO_2 cylinders, nitrogen cylinders, stop valves and time delays for physical damage, deterioration, corrosion, distortion, cracks, dirt, and loose couplings. Tighten loose couplings. Replace damaged or missing caps. Replace control head if damage is found. If necessary, clean as directed in Paragraph 6-6.3. Ensure that all control heads, actuation devices, etc. are all in the "set" or "closed" position with the locking pin installed and seal wire intact.
5. Inspect carbon dioxide cylinder and valve assembly for leakage, physical damage such as cracks, dents, distortion, and worn parts. Check safety disc for damage, and replace if necessary. If necessary, clean cylinder and associated parts as described in Paragraph 6-6.3.
6. Inspect cylinder straps, cradles, and attaching hardware for loose, damaged, or broken parts. Check straps and associated parts for corrosion, oil, grease, grime, etc. Tighten loose hardware. Replace damaged parts. If necessary, clean as directed in Paragraph 6-6.3.
7. Inspect CO_2 system discharge heads for cracks, corrosion, grime, etc. Ensure that discharge heads are tightly secured to each CO_2 cylinder valve and connected to the discharge manifold with a flexible discharge hose or swivel adapter.
8. Inspect flexible discharge hoses for loose fittings, damaged threads, cracks, rust, kinks, distortion, dirt, and frayed wire braid. Tighten loose fittings, and replace hoses which have stripped threads. If necessary, clean as directed in Paragraph 6-6.3.
9. Inspect discharge manifold for physical damage, corrosion, and dirt. Inspect manifold support brackets and clamps for looseness and damage. Inspect check and

stop valves, where applicable, for deformation, leakage, cracks, wear, corrosion, and dirt. Secure loose parts. Replace damaged parts. If necessary, clean as directed in Paragraph 6-6.3.

10. Inspect discharge nozzles for dirt and physical damage. Replace damaged nozzles. If nozzles are dirty or clogged, refer to Paragraph 6-6.4. Where frangible discs are used, ensure they are intact and clean. Look for holes or cuts. Broken discs will allow vapors, oils, etc. from the hazard to enter into the nozzles and system piping and seriously effect [*sic*] or block system discharge.

    CAUTION
    Do not paint nozzle orifices. The part number of each nozzle is stamped on the nozzle. Nozzles must be replaced by nozzles of the same part number. Nozzles must never be interchanged, since random interchanging of nozzles will adversely affect proper CO_2 distribution within a hazard area.

11. Inspect pressure switches for deformations, cracks, dirt or other damage. Replace switch if damage is found.
12. Check nitrogen cylinder pressure gauge for proper operating pressure. If pressure loss (adjusted for temperature) exceeds 10%, recharge with nitrogen to 1800 PSIG at 70°F. See Figure 6-1 for pressure-temperature relationship.
13. Inspect lock-out valve (if installed). Valve must be secured and locked in the “open” position.
14. Visually inspect Control Panel/Detection system. Ensure that system is “normal” and free from any “alarm” or “trouble” signals.
15. If any defects are found during the monthly inspection, immediately contact a Kidde Fire Systems Distributor to service the systems.

Kidde Fire Systems (P/N 81-CO2MAN-001), *Engineered Carbon Dioxide (CO_2) Fire Suppression Systems: Design, Installation, Operation and Maintenance Manual* (September 2013), Section 6.3. Monthly inspection procedures vary slightly between different versions of the manual, as one would expect.

Appendix B – Similar occurrences

Transportation Safety Board of Canada

M21A0041 (*Atlantic Destiny*) – On 02 March 2021, the fishing vessel *Atlantic Destiny*, with 31 persons on board, sustained a catastrophic engine failure while the vessel was about 120 nautical miles south of Yarmouth, Nova Scotia. In this occurrence, the vessel's carbon dioxide (CO_2) fixed fire suppression system was used during the response, but crew members re-entered the space after 30 to 40 minutes, reintroducing oxygen before the space had cooled. The Board was concerned that there is insufficient crew knowledge of the necessary pre- and post-release stages in the use of CO_2 fixed fire suppression systems.

M20A0003 (*Newfoundland Lynx*) – On 29 January 2020, the fishing vessel *Newfoundland Lynx* reported a fire in the sauna. There were some difficulties with the firefighter outfits and self-contained breathing apparatuses (SCBAs). The vessel's crew managed to extinguish the fire. The Board issued a safety message stating that it is important that crews perform fire drills on a regular basis to confirm that firefighting equipment is in working order, and to reinforce their knowledge of how to use the equipment and of the assigned emergency duties. It is also important that these drills include varied and realistic scenarios so that crews are prepared to respond effectively to emergencies.

M19C0403 (*Tecumseh*) – On 15 December 2019, the bulk carrier *Tecumseh* sustained a fire in the engine room while transiting the Detroit River off Windsor, Ontario. The TSB investigation determined that the fire was caused by maintenance issues in the engine room.

M18P0403 (*MOL Prestige*) – On 31 January 2018, the container vessel *MOL Prestige* sustained a fire in the engine room, 146 nautical miles south-southwest of Haida Gwaii, British Columbia (BC). The TSB investigation determined that the fire was caused by maintenance issues in the engine room. Also, the vessel's CO_2 fixed fire suppression system failed due to leaks.

M16P0241 (*Ken Mackenzie*) – On 11 July 2016, the tug *Ken Mackenzie* sustained a fire in the engine room while transiting the Fraser River in BC. The TSB investigation determined that the fire was caused by maintenance issues in the engine room of the vessel.

U.S. National Transportation Safety Board

In the U.S., there have been several investigations into fires caused by hot surface ignition. Between 2018 and 2022, the U.S. National Transportation Safety Board (NTSB) investigated

10 occurrences of engine room fires where contact between liquid fuel and the hot surfaces of diesel engines was determined to be the probable cause, including the following:

DCA22FM016 *(Endo Breeze*) – On 29 April 2022, a fire broke out in the engine room of the chemical tanker *Endo Breeze* while it was departing from New Jersey. The investigation determined that the probable cause was a high-pressure fuel spray from a fuel injection pump of 1 of the vessel's main engines that ignited on an engine exhaust component. In its report, the NTSB noted that it has investigated several casualties involving failures of fuel line fittings that led to fires. The report emphasized the importance of following manufacturer assembly procedures during fuel system maintenance and the need to review manufacturers' manuals and guidance regularly.

DCA22FM002 (*Capt. Kirby Dupuis*) – On 09 November 2021, a fire broke out in the engine room of the towing vessel *Capt. Kirby Dupuis* while pushing barges on the Ohio River in Kentucky. The investigation determined that the probable cause was a lube oil tube on the port main engine that had vibrated out of a joint due to a missing retaining ring and mounting bracket, spraying pressurized oil that contacted a hot exhaust surface and ignited.

DCA21FM026 (*President Eisenhower*) – On 28 April 2021, a fire broke out in the engine room of the container ship *President Eisenhower* while it was navigating 17 nautical miles southwest of California. The investigation determined that the probable cause was the spray of fuel oil from a main engine return line onto a nearby unshielded and uninsulated engine exhaust component, and that a fitting had been improperly tightened when installed.

Other international accident investigation boards

Some international investigations also reported problems with the CO_2 fixed fire suppression system.

United Kingdom Marine Accident Investigation Board Report 16/2018 (*Eddystone* and *Red Eagle*) – On 08 June 2016, the roll-on, roll-off cargo vessel *Eddystone* experienced an unintentional release of CO_2 from its fixed fire suppression system while on passage in the southern Red Sea. A similar incident took place on 17 July 2017 on board the roll-on, roll-off passenger ferry *Red Eagle* while on passage from the Isle of Wight to Southampton. In both cases, the engine room distribution valve for the CO_2 gas remained closed and gas leaked out into the compartment where the CO_2 cylinders were stored. The United Kingdom Maritime Accident Investigation Board concluded that the level of service given by service providers regularly failed to maintain the safety of CO_2 fixed fire extinguishing systems on vessels.