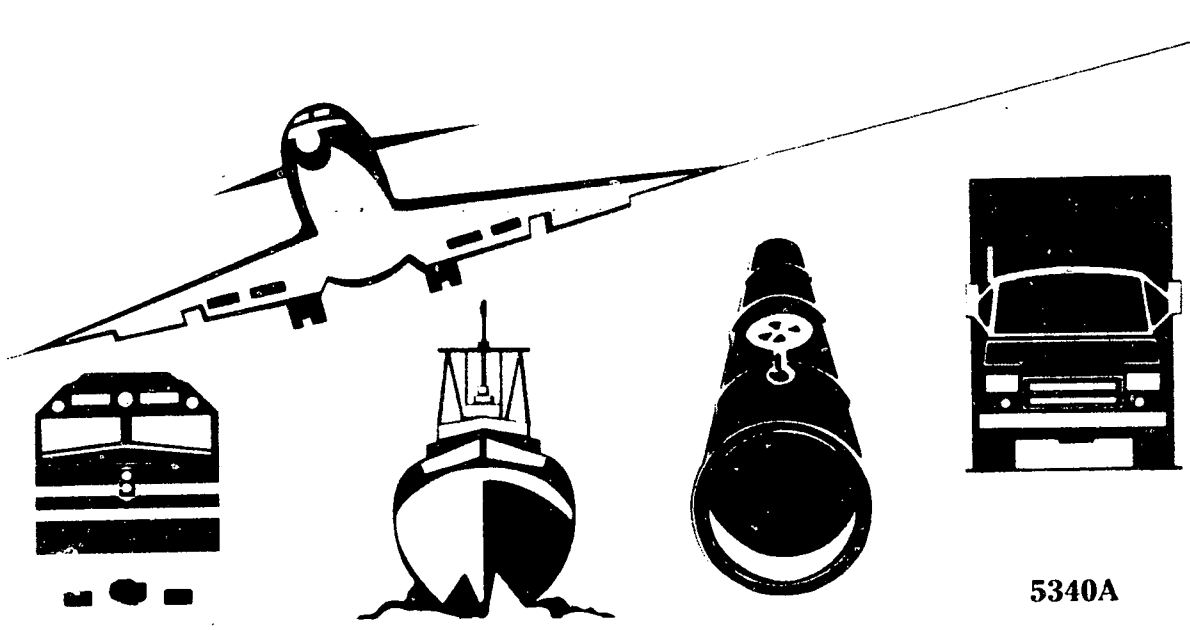
PB92-916402
NTSB/MAR-92/02

NATIONAL TRANSPORTATION SAFETY BOARD

MARINE ACCIDENT REPORT

EXPLOSION AND FIRE ON THE U.S. TANK SHIP SURF CITY PERSIAN GULF FEBRUARY 22, 1990



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WASHINGTON, D.C. 20594

MARINE ACCIDENT REPORT

EXPLOSION AND FIRE ON THE U.S. TANK SHIP SURF CITY PERSIAN GULF FEBRUARY 22, 1990

ADOPTED: MARCH 31, 1992
NOTATION 5340A

Abstract: On February 22, 1990, the reflagged 760-foot-long U.S. tank ship SURF CITY, loaded with naphtha and automotive diesel oil, exploded and burned in the Persian Gulf. The fire burned for 2 weeks and 196,985 barrels of the 606,215 barrels of cargo were lost. The damage loss resulting from this accident was $31.53 million. The safety issues discussed in this report are the ballast tank entry procedures; extension of the inert gas system to include the ballast tanks; ballast system integrity; repeated stress related fatigue fracturing in cargo/ballast tanks; location of fire foam monitor; and retrofit or replacement of primary lifesaving equipment. The Safety Board made recommendations addressing these issues to the U.S. Coast Guard, the International Chamber of Shipping, the International Association of Classification Societies, the Gleneagle Management Company, Inc., and through the U.S. Coast Guard to the International Maritime Organization.

CONTENTS

EXECUTIVE SUMMARY

On February 20, 1990, the reflagged 760-foot-long U.S. tank ship SURF CITY, loaded with naphtha and automotive diesel oil, departed Kuwait en route to discharge ports in southern Europe. At 1012 on February 22, the master and the chief mate were standing at the No. 4 starboard water ballast tank access trunk when an explosion occurred in the tank. The tank and area aft to the deckhouse on the starboard side were immediately engulfed in flames. The crew abandoned ship in the port liftboat and were rescued by the U.S. Navy guided missile frigate USS SIMPSON (FFG-56) at 1053. U.S. naval vessels recovered the master's remains but the chief mate is missing and presumed dead. The fire burned for 2 weeks and 196,985 barrels of the 606,215 barrels of cargo were lost. The damage loss resulting from this accident was $31.53 million.

The safety issues discussed in this report are:

- Ballast tank entry procedures.
- Extension of the inert gas system to include the ballast tanks.
- Ballast system integrity.
- Repeated stress related fatigue fracturing in cargo/ballast tanks.
- Location of fire foam monitor.
- Retrofit or replacement of primary lifesaving equipment.

The Safety Board made recommendations addressing these issues to the U.S. Coast Guard, the International Chamber of Shipping, the International Association of Classification Societies, and the Gleneagle Management Company, Inc., and through the U.S. Coast Guard to the International Maritime Organization,

The National Transportation Safety Board determines that the probable cause of the explosion and fire on the U.S. tank ship SURF CITY was the lack of adequate industry standards regarding ventilation and entry procedures into ballast tanks. Also causal to the accident was the failure by the master and the chief mate to secure the forced ventilation and close the tank after becoming aware of the naphtha in the ballast tank.

NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D.C. 20594

MARINE ACCIDENT REPORT

EXPLOSION AND FIRE ON THE U.S. TANK SHIP SURF CITY PERSIAN GULF FEBRUARY 22, 1990

INVESTIGATION

Events Before The Accident

At 1752[1] on February 17, 1990, the reflagged[2] 760-foot-long U.S. tank ship SURF CITY arrived in ballast at the Kuwait National Petroleum Company (KNPC), Mina Abdulla Refinery Terminal, Kuwait. The SURF CITY had 13 cargo tanks and 2 slop tanks configured as shown in figure 1. At the Mina Abdulla Refinery Terminal,

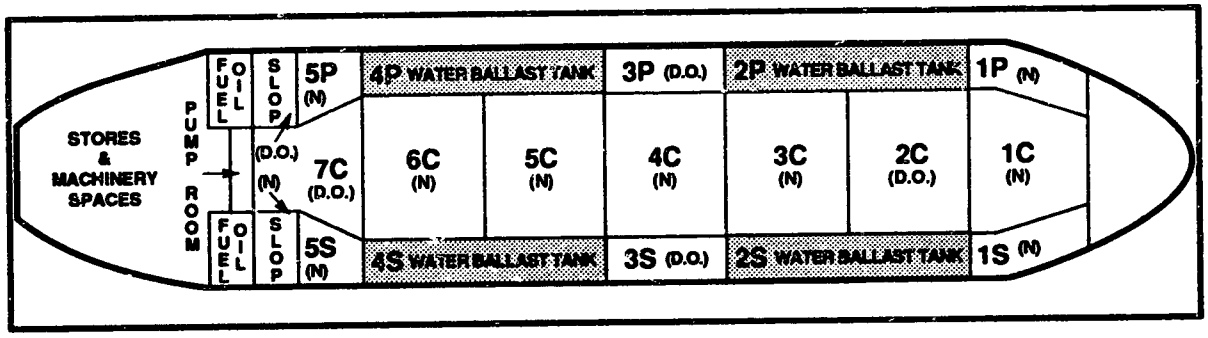

Figure 1.--Cross section of SURF CITY cargo area.

220,736 barrels[3] of naphtha were loaded into the following tanks: Nos. 1 port and starboard (1P and 1S), 4 center (4C), 5P, 5S, 6C, and the starboard slop tank. After completing the loading of these tanks on February 18, 1990, the vessel shifted about 10 miles north to KNPC's Mina Al Ahmadi Refinery Terminal. (See figure 2.) At this terminal, crewmembers loaded 206,768 barrels of naphtha into go tanks Nos. 1C, 3C, And 5C, and 178,711 barrels of automotive diesel oil into cargo tanks Nos. 2C, 3P, 3S, 7C, and the port slop tank. Records show that the SURF CITY was fully loaded on February 20, 1990. As the SURF CITY took on cargo at the two terminals, crewmembers simultaneously discharged all salt water ballast from the segregated ballast tanks Nos. 2P, 2S, 4P, and 4S. Before the tank ship departed for ports in southern Europe, crewmembers closed all cargo tank openings and ballast tank

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[1]All times are based on the 24-hour clock and are local times in the International Time Zone "C," which is 3 hours later than Universal Time.

[2]The vessel was reflagged from Kuwait to United States on August 28, 1987. (See Vessel Information.)

[3]One barrel equates to 42 gallons.

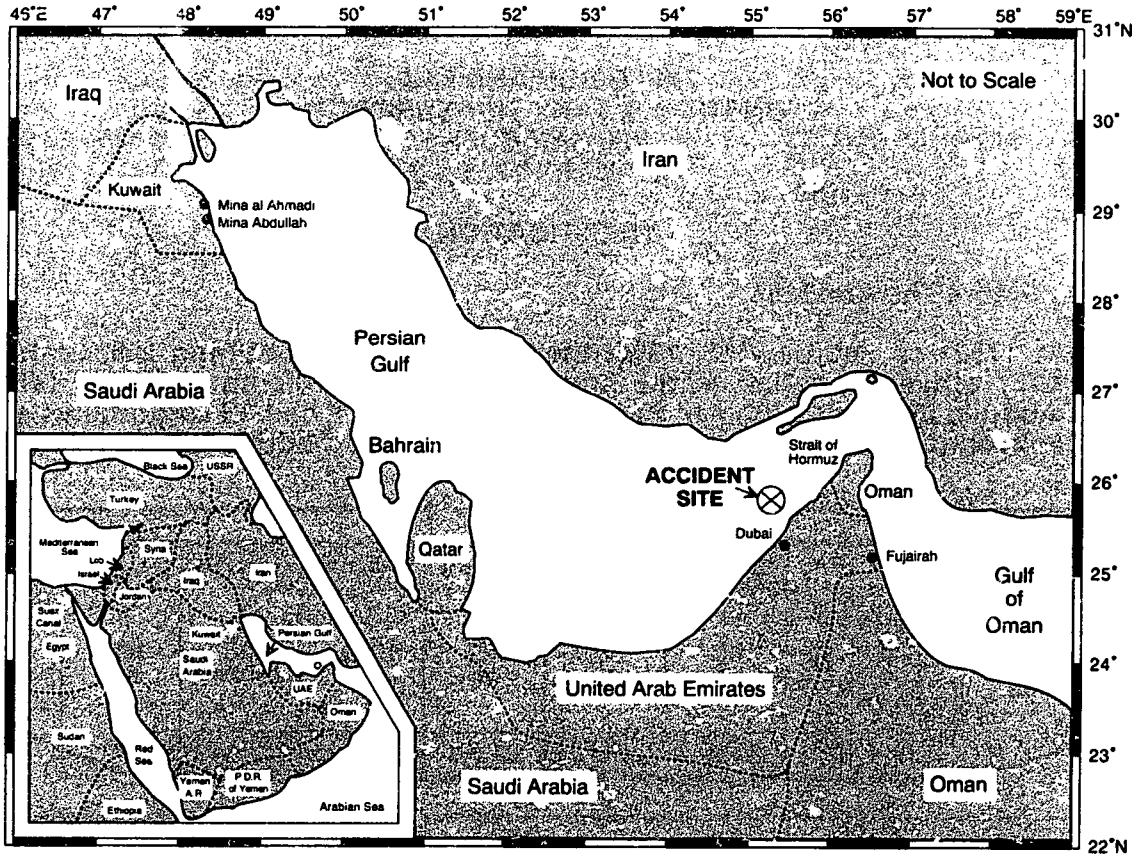

Figure 2. Location of terminals and accident site.

ullage openings[4] and inerted[5] the cargo tanks as required by the International Convention for Safety Of Life At Sea (SOLAS) 1974 and U.S. Coast Guard regulations. Inert gas was not provided to the SURF CITY's fuel oil tanks, double bottom tanks, cofferdams, or the four ballast tanks, nor was it required by U.S. or international regulations.

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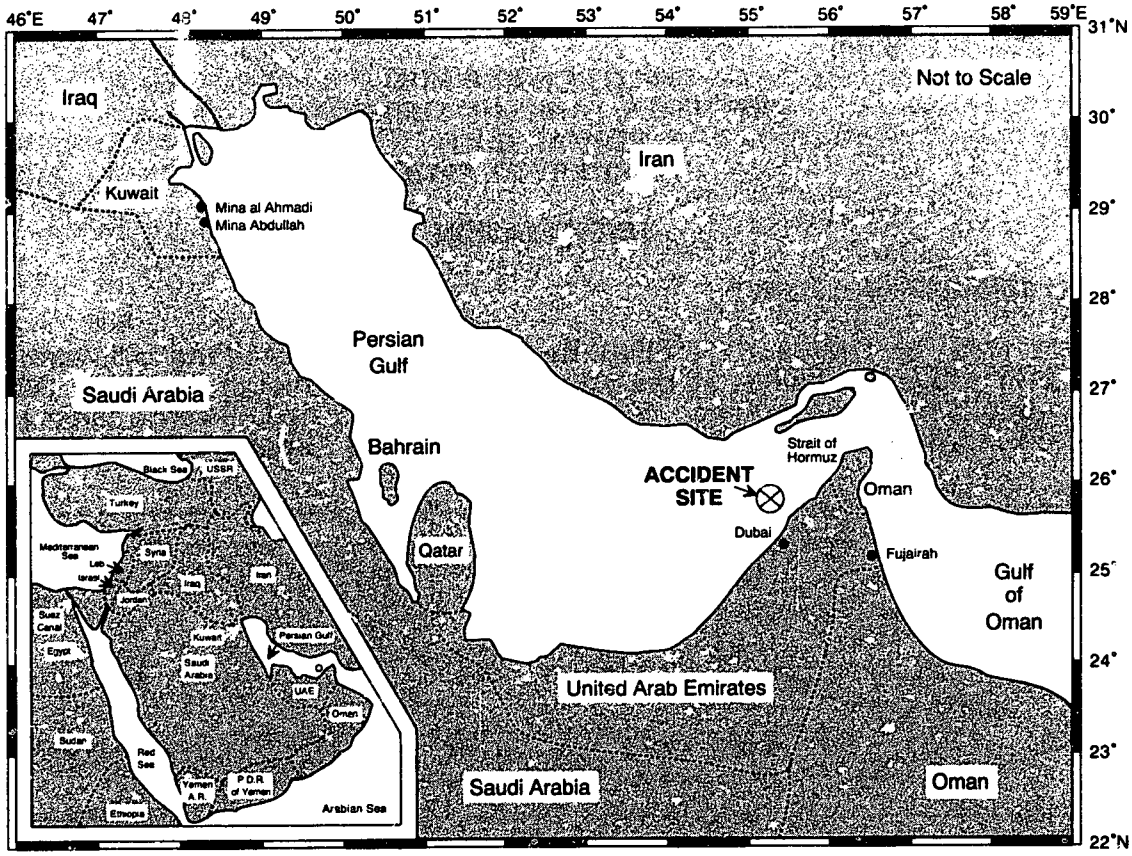
[4]An ullage opening is a penetration into the tank through which a device can be inserted to determine the tank's ullage, i.e., the measurement of the space between the surface of the liquid in the tank and the deck (or ullage) opening. To determine the volume of liquid in the tank, this measurement is cross referenced with ullage tables derived for the vessel.

[5]SOLAS '74, as amended, Chapter II-2, Part D-Fire Safety Measures for Tankers, Regulation 62, stipulates that the oxygen content in a tank may not exceed 8 percent of the volume. U.S. Coast Guard regulations at 46 Code of Federal Regulations (CFR) 32.53 contain the same restriction. To maintain a low oxygen content in a tank, crews replace the existing atmosphere of a cargo tank by introducing an inert gas.



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The Accident

On February 22, 1990, the chief mate and two able seamen (AB) were standing the 0400 to 0800 bridge navigation watch.[6] One AB testified that the chief mate said that he "wanted to inspect the automatic draft gauges that were located in each of the ballast tanks to see if he can get them to work again." The SURF CITY was equipped with a remote draft measuring system that had sensors in the forepeak, Nos. 4P and 4S ballast tanks, and propeller shaft alley in the engineroom.[7] According to the AB, "The gauges hadn't been used on the ship for as long as I was aboard [about 3 months]." The AB said that the chief mate told them that after their watch, they were to place water-driven air blowers on the Nos. 4P and 4S water ballast tanks.

About 0745, after they were relieved from their 0400-0800 watch, one of the ABs went out on the main deck about 0755 and removed the forward and center tank cleaning (Butterworth) cover plates, which were bolted to the main deck tank top of the No. 4S water ballast tank. From the starboard midships deck storage house, he retrieved two Model 125 Dasic Jetfans, high-speed/high-volume ventilation fans. He also picked up two electrically bonded hoses, which were used to connect the fans to the fire main seawater supply.

About 0815, the AB inserted a Jetfan into each of the 12-inch diameter Butterworth openings. He next opened the No. 4S access trunk cover. The AB connected one end of the bonded hose to a Jetfan and the other end to a valved outlet on the fire main piping.

As the first AB finished placing the Jetfans in the Butterworth openings on the starboard side (see figure 3), the second AB, who had stood watch with him, and an ordinary seaman (OS) arrived on deck. They took the tools that the first AB had used to install the Jetfans on the starboard side over to the port side in order to remove the covers on the center and forward Butterworth openings of the No. 4P water ballast tank. The first AB remained on the starboard side to clean up his area.

The OS obtained two Jetfans from the port midships deck storage house to install on the port ballast tank. However, only one grounded hose was in the storage house. The OS and the second AB used the one available electrically bonded hose on the Jetfan installed in the center Butterworth opening. To connect the Jetfan on the forward port Butterworth opening to the fire main, they used an ungrounded fire hose. According to the second AB, the chief mate inspected the ungrounded hose and "said. . .it was okay."

The first AB at the starboard ballast tank stated that he noticed "a very clear naphtha smell on deck" but added that it was not strong enough to cause him to become alarmed. He said that he assumed that the smell was vapors from cargo vents being blown across deck from the port bow to the starboard quarter by the relatively light wind. He said that he mentioned to his watch partner that he smelled

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[6]While in the Persian Gulf, the two ABs were used as helmsman/lookout and lookout. Outside the Gulf, only one seaman, who served as a helmsman/lookout, was on watch; the other seaman normally on watch was assigned to day work.

[7]The draft measuring system indicators were located in the cargo control room in the deckhouse forward on the "A" deck.

Figure 3.--Dasic Jetfan 125 at Butterworth opening on the SEA ISLE CITY, sister vessel to the SURF CITY.

fumes on the starboard side but did not advise the chief mate. He testified that he did not note any fumes coming from the port tank, and that it only smelled "like dirt, algae or something."

The crewmembers installing Jetfans on the port side opened the access trunk cover to the No. 4P ballast tank. The second AB then telephoned the engineroom watch and asked that they put water pressure (start the fire pump) to the fire main on deck. About 0900, an AB opened the valves to the main deck fire main branch lines, which provided pressurized sea water to the Jetfans. The two ABs and the OS stated that the Jetfans appeared to be operating at full speed, blowing air into the tanks, whereupon they departed the main deck about 0910, and entered the accommodation house.

About 0930, the chief mate was in the engineroom and asked the dayworking first assistant engineer "if it was okay for him to trace the [pipe] line for the aft draft indicator sensor." The first assistant engineer directed the third assistant engineer to guide the chief mate to the aft draft sensor located in the propeller shaft alley. After being shown the sensor, the chief mate left the engineroom.

According to two members of the 0800-1200 navigation watch, they observed the master and the chief mate on deck near the No. 4S ballast tank access trunk at about 0945. The helmsman/lookout stood his watch primarily inside the navigation bridge and the lookout (boatswain)[8] stood his watch on the starboard bridge wing. They testified that they saw the master and the chief mate lean over and peer into the access trunk to No. 4S and then jerk their heads back and hurriedly back away. The boatswain testified that he "could see the fumes coming out of the ballast tank" access trunk and he could smell them on the bridge wing and that the fans were operating. These witnesses further stated that the master and the chief mate next moved over to the starboard rail (about 15 feet outboard of the access trunk), where they spoke together for a short time. The chief mate then went aft to the accommodation house.

About 0950, the third mate on watch testified that he received a telephone call from the chief mate, who asked him where a breathing apparatus was located. Because he did not know, the third mate gave the telephone to the boatswain who told the chief mate. The third mate and the boatswain stated that the chief mate did not tell them why the ballast tanks had been opened or why he wanted a breathing apparatus.

According to witnesses, when the chief mate rejoined the master at the No. 4S access trunk, he brought with him a 10-minute Emergency Life Support Apparatus (ELSA). (See figure 4.) An off-watch AB testified that when he looked out his porthole that he "noticed something in the chief mate's hand." The AB guessed that it was "a gas analyzer." The boatswain said that the master assisted the chief mate in putting on the ELSA, which had an air bottle in a back pouch. The boatswain added that the chief mate was holding something yellow, which he was "pretty sure" was a meter gauge for detecting fumes. He said that the chief mate entered

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[8]The boatswain/senior AB was the supervisor of the deck seamen and was the interface between the chief mate and the crew. Working with the boatswain, the chief mate schedules day work for the deck seamen.

Figure 4.--Gleneagle Company representative wearing an ELSA at the No. 4S ballast tank trunk on the SEA ISLE CITY. (Demonstrator is facing to port and the vessel's centerline; forward is to his right.)

the access trunk[9] to the 4S ballast tank with the blowers operating. After about 5 minutes, the chief mate climbed out of the access trunk, "panting for air," and sat on the deck to catch his breath.

The boatswain on the bridge said that the master and the chief mate next shut off the sea water to all four Jetfans. They removed the two Jetfans from the No. 4S ballast tank Butterworth openings and laid the blowers on the deck. The boatswain testified that the master and the chief mate then stood forward of the access trunk and used a mirror [generally made of steel] to reflect sunlight down and aft through the Butterworth openings and the access trunk into the ballast tank. The third mate and the helmsman/lookout testified that only the chief mate used a mirror to look into the tank. The boatswain explained that tanker personnel who carry a mirror usually keep it in their back pocket on a string to ensure that they do not drop it into a tank, but that he did not notice where the master and the chief mate put the mirror that the mate had been using when he was finished with it.

The boatswain said the master was standing adjacent to the access trunk and that the chief mate was apparently preparing to reenter the tank when an explosion erupted from the No. 4S ballast tank. Almost immediately, the deck area from the No. 4S ballast tank aft to the deckhouse on the starboard side of the vessel was engulfed in flames. (See figure 5.)

Abandon Ship and Rescue

With the exception of the master and the chief mate and three crewmembers on the bridge, all of the crew were within the accommodation area and protected from the explosion, fragmentation, and fire. Off-watch crewmembers were asleep or resting in their rooms and dayworking crewmembers were in the middle of their 1000 coffee break.

According to the boatswain who had been standing on the starboard bridge wing, the explosion "instantly blew up" the chief mate, the master, "and the deck around them." He further stated:

> I saw them disappear in a vast fireball as I was knocked over by the shock [of the blast]. It was raining shrapnel. The noise and blast were tremendous; the heat was intense as the ball of fire and smoke rushed over me.

The concussion of the blast blew the bridge front windows[10] inward, sending shards of glass and other debris across the wheelhouse. Glass fragments struck the

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[9]The trunk measured about 36 inches high by 34.3 inches in diameter. The opening in the deck inside the trunk was oval shaped and measured 22.8 inches by 27.6 inches. Inside the access trunk, a vertical ladder extended about 10 feet down to the first platform. An angled steel stairway welded to the after transverse bulkhead of the No. 4S ballast tank led down in a zigzag pattern in three sections from the first platform to the bottom of the 62-foot-deep tank.

[10]All forward-facing glazing on the bridge was 1/2-inch thick by 4-feet high by 8-feet long and was held in place by rubber gasket material.

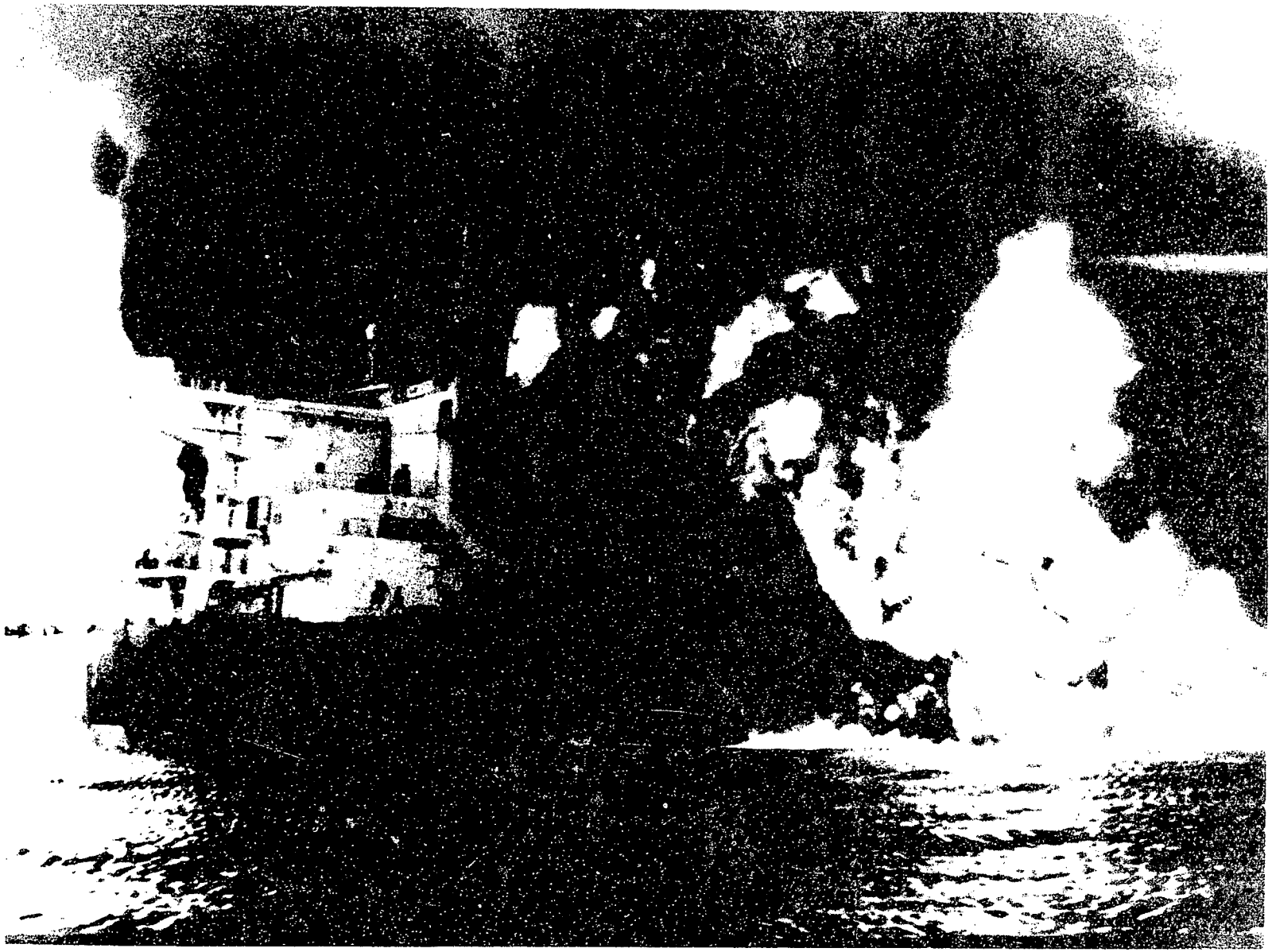

Figure 5.--SURF CITY on fire following the explosion.
Photograph taken by M. J. Muniz, second engineer, from the tank ship's lifeboat and provided by the Gleneagle Ship Management Company.

helmsman/lookout on the right side of his head. The force of the blast knocked the boatswain to the bridge deck, where he was shielded from the flames by the bridge wing windbreak. The third mate, who was bending over the chart table in the aft section of the wheelhouse, was partially shielded from the explosion and flying glass.

The boatswain said that immediately after the explosion, he ran into the wheelhouse and found the interior a shambles of glass and debris. The boatswain said that the third mate appeared to be dazed and in shock. The third mate asked him, "Where's the captain and the mate?" The boatswain replied, "They're gone," and advised the third mate that they could do nothing except get out before another blast occurred. The boatswain said that he grabbed the helmsman/lookout, whose head was bleeding profusely, and led him to an interior stairway to evacuate the bridge.

As they proceeded to the port lifeboat, the boatswain stopped at his room to retrieve his life preserver. The third mate then assisted the helmsman/lookout to the port lifeboat while the boatswain ran through the upper decks of the house telling people to abandon ship.

Witnesses said that immediately after the explosion, the vessel took about a 5 degree starboard list and the fire alarm sounded. Crewmembers who were up and about the decks checked to make sure all others were up and out of their rooms. According to a crewmember who was assigned to the starboard lifeboat, "There was no chance [to get] there [to the starboard lifeboat]" because of the intensity of the fire on the starboard side. Therefore, not only the crewmembers who were assigned to the port lifeboat, but also crewmembers who were assigned to the starboard lifeboat, proceeded to the port lifeboat embarkation area on "A" deck.

Before they left the engineroom, the engineer-on-watch and the first assistant engineer stopped the main engine and allowed the generator to continue operating. An off-watch engineering officer, awakened by the explosion, went down into the engineroom and found it empty. He checked the indicator panel for the fire pump and found that it was operating.

Some SURF CITY crewmembers went to the port side main deck to try to fight the fire with the deck fire monitors. They reported, "The hot deck and heat forward of the deck house was too intense." One of the crewmen assigned to the fire control room on the main deck testified:

> I started down [the port side exterior stair] toward the foam room to turn on the foam supply from the foam tank, but I checked the deck at that point and it was too hot. I moved forward [on the port main deck] up toward the front edge of the deckhouse and it was too hot.. . .We couldn't turn on any monitors or anything. It was radiant heat. I don't recall seeing flames on the port side then . . . then I just went back up towards the lifeboat.

The radio officer, who had been in the radio room at the time of the explosion, went to the bridge and the master's room. He said that when he did not find anyone, he gave up the search because of the intensity of the heat and flames on the bridge. About 1018, he returned to the radio room and sent a distress message to

the U.S. Navy warship, USS SIMPSON.[11] The SIMPSON radioed, "SURF CITY . . .we see you. . . . Were you hit or did you have an accident?" The radio officer responded that he did not know and told them that the crew was abandoning ship.

On the USS SIMPSON, which was about 3,000 yards astern of the SURF CITY, the bridge watch sighted and logged the time of the explosion as 1012 and the position as latitude 25°45.6'N and longitude 55°18.6'E, about 32 nmi north of Dubai, United Arab Emirates (U.A.E.). According to the bridge watch on the USS SIMPSON, "A massive explosion was immediately proceeded by two small explosions." They also reported "tremendous heat and flame from the burning tanker, along with a burning slick developing behind the SURF CITY that appeared to be fed by the fuel leaking out of the hole created by the explosion."

On board the SURF CITY, a crewmember who was among the first to reach the port lifeboat recounted that he unhooked the forward gripe and released the lifelines[12] from their stowed position. (See figure 6.) He added that at the same time, other crewmembers had the aft gripe free and were starting to lower the boat down to the 'A' deck [embarkation deck]. He said that the third mate was "more or less" the overall coordinator of the embarkation activity and that the boatswain, who was on ['A'] deck at the brake [lifeboat winch], was "more or less" in charge [of the boat lowering]. The crewman testified, "We went down to the embarkation deck. The crew got on, all except a few guys."

The boatswain eased the winch drum brake and lowered the lifeboat to the embarkation deck. While the boatswain remained on board the SURF CITY to lower it, 20 crewmembers boarded the lifeboat. However, when the boatswain attempted to lower the lifeboat, it hung in place because no one had released the aft tricing pendant.[13] When a crewmember did release the tricing pendant, the lifeboat quickly dropped the short length of the paid out fall line and an OS was thrown overboard.

As the lifeboat was being lowered, the chief engineer started its engine. After the lifeboat was released from the wire falls, the third mate steered the lifeboat away from the ship. The boatswain estimated that the flaming tank ship, with fire trailing on the sea, was moving about 7 to 8 knots when the lifeboat was launched. Before the engineer on watch stopped the ship's main propulsion engine, the SURF CITY had been moving about 12.5 knots according to the third mate on bridge watch.

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[11]The USS SIMPSON (FFG 56), a guided missile frigate assigned to protect U.S. commercial vessels in the Persian Gulf during the Iran/Iraq war, was escorting the SURF CITY through the Gulf to the Strait of Hormuz.

[12]A safety line attached to the davit span wire between the lifeboat davits. Regulations require a minimum of two lifelines.

[13]A line secured to the gravity davit and hooked to the lifeboat block at each end of the lifeboat. It pulls the lifeboat to the side of the ship as the boat is lowered to the embarkation deck, making it easier for people to board. Before people embark and the tricing pendants are released, the frapping lines should be in place around the lifeboat falls and manned on the embarkation deck. After all individuals are in the lifeboat, the tricing pendants are released; and the frapping lines are adjusted to keep the lifeboat from swinging as it is lowered to the water.

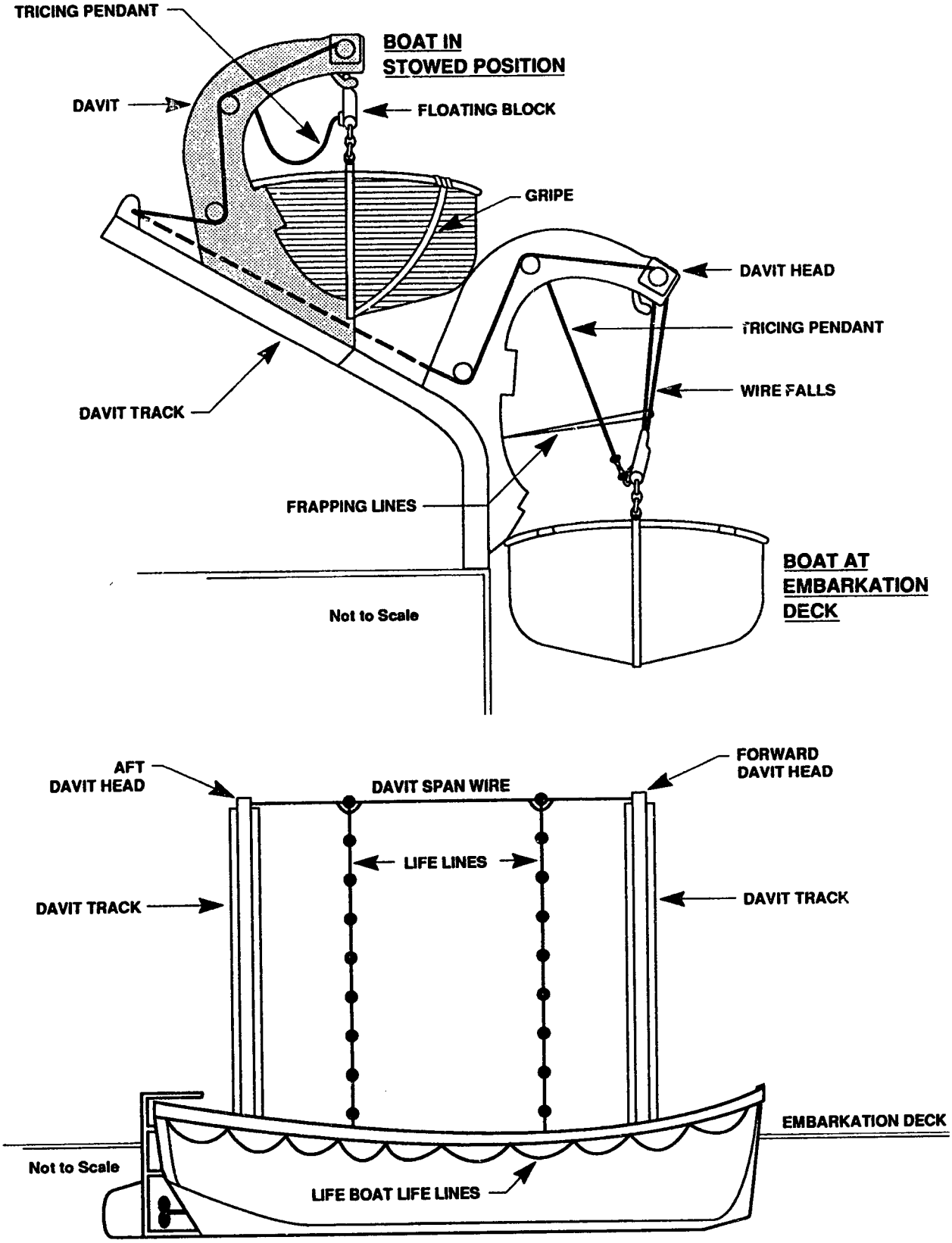

Figure 6.--Lifeboat and gravity davit nomenclature.

Before the lifeboat was lowered, the second mate went back into the accommodation house to search for crewmembers. He found only the radio officer. They proceeded to the port lifeboat embarkation area only to discover that the lifeboat had already been launched and was moving away from the ship. With life preservers donned, the second mate and radio officer jumped into the sea. The boatswain, who had remained on board to lower the lifeboat, attempted to use a lifeline that was attached to the davit span wire to climb down to the water but his life preserver became entangled in the line. He freed himself from the line and fell into the sea wearing his life preserver.

The crew stated that the tank ship was still moving and it seemed to be traveling in an arc, slightly to port. The crew added that the fire was intense and continued flaring up. One crewmember stated that the lifeboat "wasn't getting away from the fire quite fast enough. We seemed to be moving very slowly. . . .It was getting extremely hot, so at one point most of us jumped [from the lifeboat] into the water to hold on to the side of the lifeboat to be clear of the heat." As the lifeboat moved further away from the heat of the fire, the crew climbed back in. The third mate turned the lifeboat toward the tank vessel and rescued the four crewmen: the second officer, the radio officer, the boatswain, and the OS who had fallen from the lifeboat.

At 1036, the SIMPSON launched a helicopter, Proud Warrior (PW) 432, on a search and rescue mission for survivors. The SIMPSON reported that the burning slick created a wall of flame and smoke that initially prevented the helicopter crewmen from seeing the lifeboat. As soon as they spotted the lifeboat, PW432 hovered above it and deployed a rescue swimmer to assess the condition of the survivors and assist in their recovery. At 1053, after securing the lifeboat alongside the SIMPSON, the 23 SURF CITY crewmembers boarded the Navy vessel. Shortly after boarding, the SIMPSON's helicopter flew the boatswain and the helmsman/lookout to the Rashid Hospital in Dubai, U.A.E. On February 23, 1990, the remaining survivors were transported ashore by SHIP VI, a Gulf Agency Company ship, and on February 26, they were flown to the United States.

After the SIMPSON's helicopter returned from Dubai, it joined seven other helicopters from other Navy warships in searching for the master and the chief mate. A helicopter from the USS DEWEY (DDG 45) recovered the partial remains of the master and the shoes that he was wearing as well as the ELSA vest (see figure 7) and a sneaker that the chief mate was wearing. The ELSA vest was missing its steel air bottle.

Injuries to Persons

Injuries[14]	Crew
Fatal	2
Serious	2
Moderate	3
Minor	4
None	15
Total	25

[14]Injuries in this accident have been coded according to the revised 1990 Abbreviated Injury Scale (AIS) of the Association for the Advancement of Automotive Medicine.

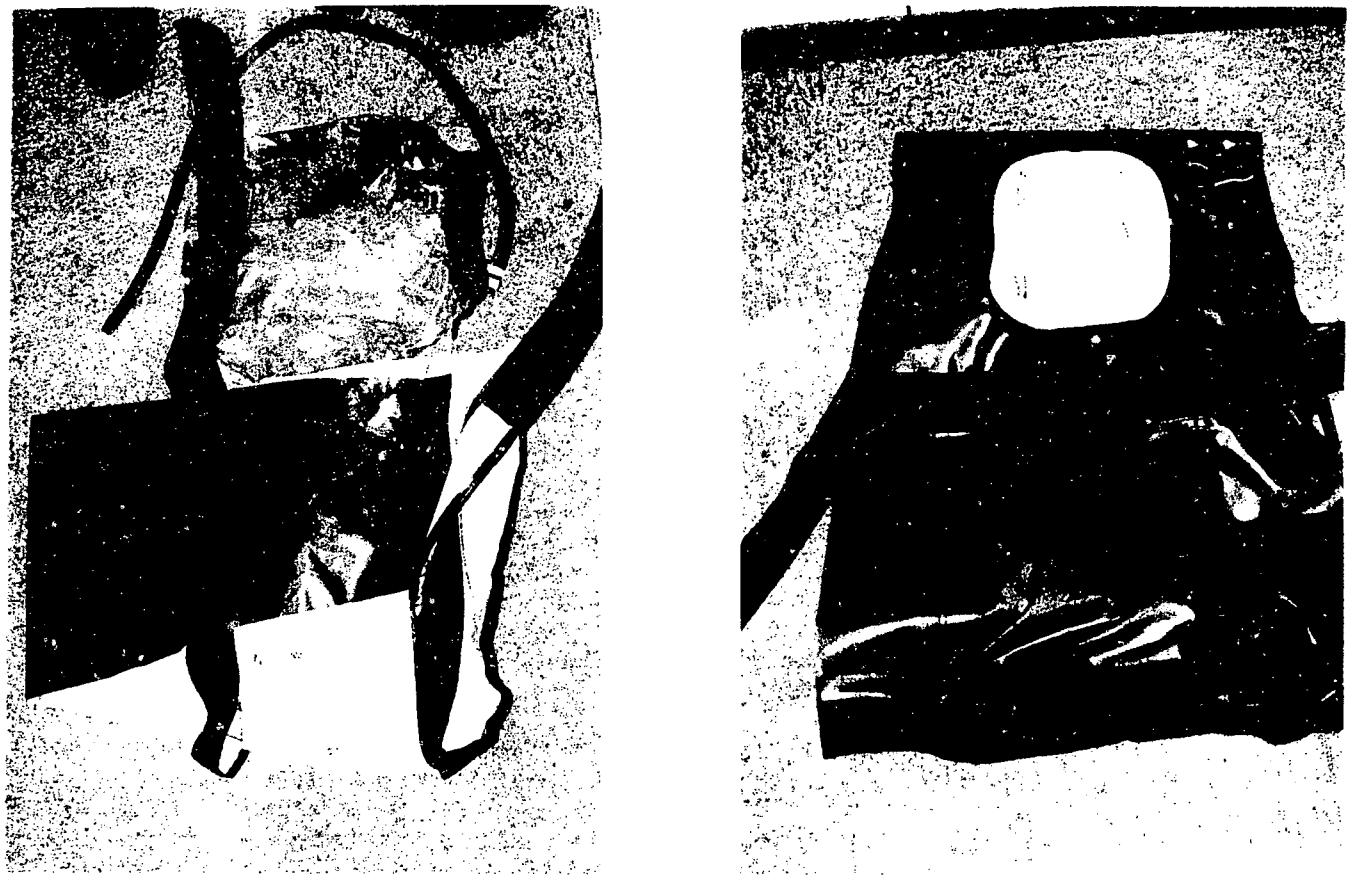

Figure 7.--ELSA recovered by the USS SIMPSON.

Damage

The explosions and fire aboard the SURF CITY damaged the vessel's aft accommodations house and the aft six tanks in the cargo block.[15] The vessel, valued at $30 million before the accident, was sold in its damaged condition for $4.85 million. The cargo, valued at $12.88 million before the accident, had a salved value of $6.5 million. Thus, total cost of vessel and cargo damages from this accident was $31.53 million.

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[15]The vessel area between the forward bulkhead of the forward cargo tank and the aft bulkhead of the aft cargo tank and all intervening spaces within, between, below, or outboard of these tanks, and the deck area above these tanks or spaces.

Crew Information

The SURF CITY's 25-man crew comprised 10 licensed officers and 15 certificated seamen. The vessel's Coast Guard Certificate of Inspection (COI) required a minimum of 21 crewmembers: 9 licensed officers (1 master, 3 mates, 1 chief engineer, 3 assistant engineers, and 1 radio officer), and 12 certificated seamen (3 oilers, 6 able seaman, and 3 ordinary seaman). In addition to the required crew, the SURF CITY had a third assistant engineer, a cook, a second cook, and a steward/utility. Two of the ABs held unlimited third mate licenses, another held a limited mate license (1,600 gross tons), and a fourth AB held a limited master license (less than 100 gross tons).

Before February 11, 1990, at the request of the U.S. Department of Defense, the U.S. Department of Transportation had waived U.S. citizenship requirements for all crewmembers except the master and the radio officer of reflagged Kuwaiti tankers transiting the Persian Gulf. Following that date, all officers and at least 75 percent of the unlicensed crewmembers were required to be U.S. citizens and the remainder legally admitted U.S. resident aliens. The SURF CITY's 25-man crew comprised 24 U.S. citizens and one Canadian citizen. The Canadian citizen was the chief engineer and held a British Board of Trade first class certificate for steam or motor vessels, which is equivalent to a U.S. chief engineer license. The first assistant engineer held a U.S. chief engineer license and was scheduled to relieve the Canadian chief engineer after the voyage.

The master, 38, graduated from the State University of New York Maritime College in 1973 and had 8 years of sea service. He was issued his first master license by the Coast Guard on March 12, 1982, qualifying him to serve as master of ocean steam and motor vessels, of any gross tons, with a radar observer's endorsement. He had been employed in various licensed positions up to and including master on fleet oilers (replenishment tank ships) and combat stores vessels operated by the Military Sealift Command (MSC) between 1975 and 1989. He had also been assigned various rotational duties ashore before he resigned from Federal civilian service and MSC at the end of 1989. On January 11, 1990, he was hired as the SURF CITY's master and boarded the tanker in Spain.

The chief mate, 34, graduated from the Massachusetts Maritime Academy in 1977 and had less than 3 years of sea service, half of which was on tankers. He was issued his first license as chief mate by the Coast Guard on September 8, 1989, qualifying him to serve as chief mate of ocean steam and motor vessels, of any gross tons, and master of ocean steam and motor vessels, of not more than 1,600 gross tons, with a radar observer's endorsement. On April 20, 1984, he completed a tanker course in Crude Oil Washing and Inert Gas Operations at the Maritime Institute of Training and Graduate Studies (MITAGS) in Maryland. Before serving as chief mate on the SEA ISLE CITY, the sister vessel of the SURF CITY, from December 16, 1989, through January 31, 1990, he had last sailed on a tanker in 1982. On February 3, 1990, he was assigned as the SURF CITY's chief mate and boarded the vessel in Egypt. (See appendix B for additional crew information.)

Vessel Information

The SURF CITY, O.N. 916258, originally named UMM AL AISH (Mother of Life), was delivered to its first owners, the Kuwait Oil Tanker Company (KOTC), in June 1981. The first of two sister tank ships built by Mitsubishi Heavy Industries in

their shipyard at Nagasaki, Japan, the SURF CITY was a single-hulled tank ship (see figure 8) built from plans approved by the American Bureau of Shipping (ABS). The vessel met ABS's Rules for Building and Classing Steel Vessels, receiving ABS's highest class rating of A1, which it retained until the accident. On August 28, 1987, the tank ship was reflagged from Kuwait to U.S. flag and certificated by the Coast Guard for carriage of crude oil products and flammable liquid cargo rated Grade B[16] and lower.

The tank ship met the construction and equipment requirements of SOLAS 74, as amended, and the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 (MARPOL '73/'78). The MARPOL standards require protectively located segregated ballast tanks and installation of a cargo tank inert gas system.

Principal characteristics of the SURF CITY were:

Length overall	760.5	feet
Beam	144.5	feet
Depth	62.3	feet
Gross Tonnage	44,542	
Net Tonnage	29,883	
Deadweight Tonnage	81,283	
Cargo Capacity	613,628	barrels
Horsepower	12,720	

A typical modern tank ship, the SURF CITY was constructed of welded high-strength steel. It had a single continuous main deck, straight-raked stem, bulbous bow, and a transom-type stern. A deckhouse was located aft on the main deck at the stern above the engineroom, and the navigation bridge had standard navigation equipment for a vessel of its size. The ship was a single-screw motor vessel, powered by a five-cylinder, reversible, Sulzer marine diesel engine.

Segregated Ballast Tanks.--Tank ships operate on a voyage cycle of ballast (without cargo) and cargo (without ballast) trips. During a ballast voyage to a cargo loading terminal, the cargo and slop tanks are empty, and the ballast tanks are filled with seawater to increase the vessel's seakeeping ability. When necessary, cargo tanks are cleaned during the ballast voyage and the resulting dirty fluids (slops) are pumped into the slop tanks. The slops are discharged to shoreside facilities before cargo loading because the slop tanks can also be used to carry cargo.

Segregated ballast tank regulations were enacted to reduce contamination of the marine environment. In accordance with U.S. and international requirements, ballast water is not permitted to be carried in empty cargo tanks. The regulations also require that the ballast piping system and tanks be segregated from the cargo piping system and tanks. The SURF CITY's segregated ballast tank system provided dedicated tanks for the carriage of water ballast not contaminated by cargo tank residue.

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[16]Grade B liquid is any liquid that gives off flammable vapors at or below 80°F and has a Reid vapor pressure of at least 8.5 psi, but less than 14 psi.

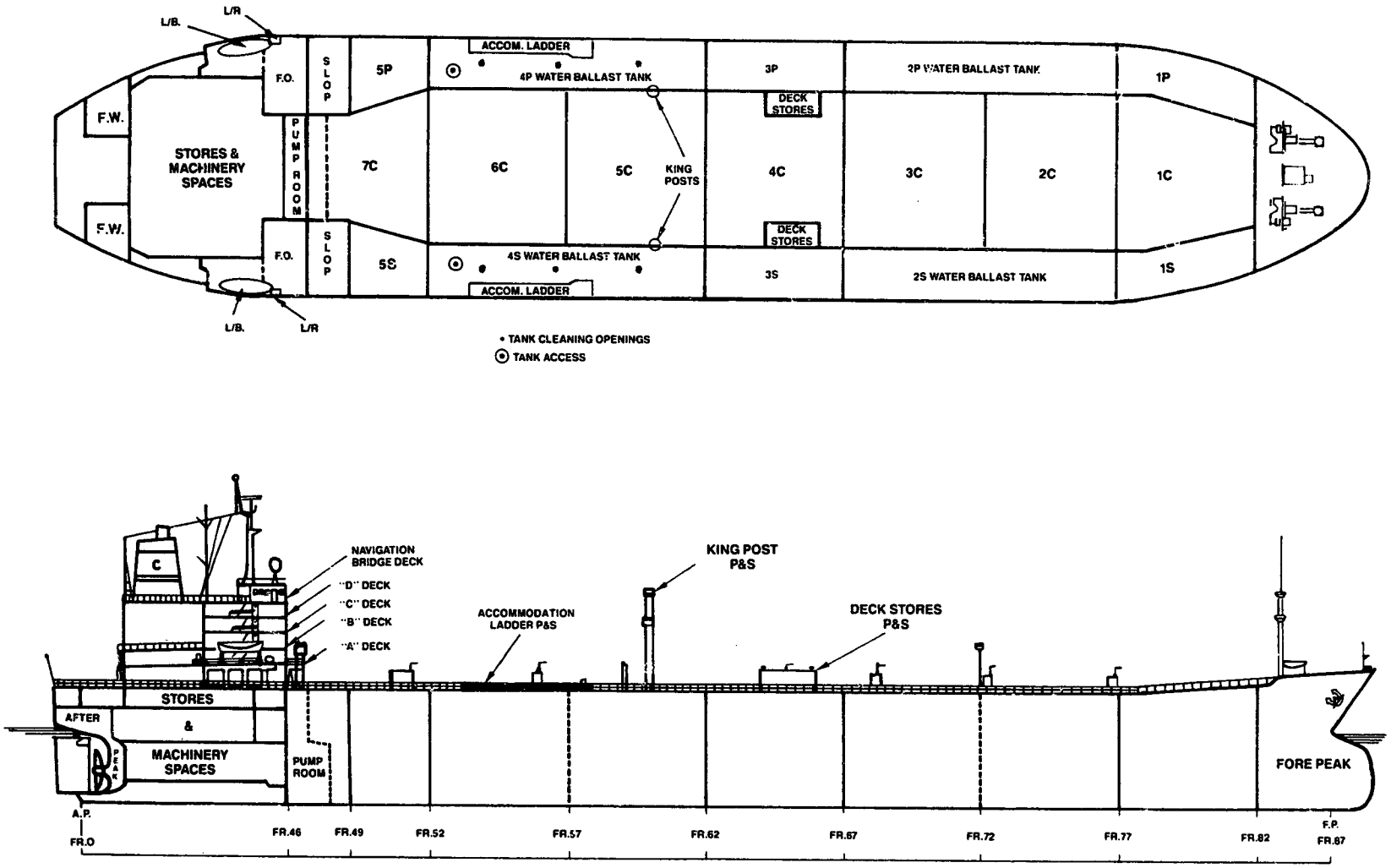

Figure 8.--Plan and side view of the SURF CITY.

Each of the SURF CITY's four large segregated ballast tanks, Nos. 2P, 2S, 4P, and 4S, was bordered on three sides (fore, aft, and inboard) by adjacent cargo tanks; cargo pressed against the ballast tank bulkheads when the cargo tanks were loaded. The outboard side and bottom of each of the wing ballast tanks were adjacent to the sea. The top of each ballast tank formed a part of the main deck. Tank top/main deck openings and entries to each ballast tank included three Butterworth openings with threaded studs and a bolted steel plate cover; two permanent air vents with flame screens that permitted air flow out from the ballast tank when ballasting and air flow into the tank when deballasting; and penetrations for a remote tank level indicating system. In addition, the Nos. 4P and 4S ballast tanks each had tank top penetrations for a remote draft gauge.

The SURF CITY's main ballast suction and fill pipeline comprised flanged pipe sections bolted end to end with gaskets and routed forward from the pumproom through the center cargo tanks near the tank bottoms. Valved branch pipelines connected the main ballast pipe line to the port and starboard wing ballast tanks and to the forepeak tank. When the tanks were loaded, cargo surrounded the main ballast pipeline, putting cargo head pressure on the conduit.

All internal structural steel members (see figure 9) of the ballast tanks, such as longitudinals, transverse web frames, horizontal girders, and ladders (stairs), were coated to protect the steel of the tank from the corrosive effects of seawater salts and other elements. With the exception of the tank level indicator float guide piping, tank penetration piping was also coated.

Inert Gas System.--While the SURF CITY loaded or unloaded cargo, the tankship's inert gas and cargo tank venting system produced inert gas pressurization of the cargo and slop tanks to displace cargo vapors and oxygen, thereby reducing or eliminating the risk of fire or explosion. The system distributed inert gas from the main deck inert gas pipeline to cargo and slop tanks via individual branch pipelines to each tank access trunk. Each branch line was fitted with a tank isolation valve and a pressure/vacuum relief valve atop a riser. Inert gas was extracted from the auxiliary boiler exhaust, cleaned, cooled, and injected under low pressure into the cargo tanks.

Draft Gauges.--The SURF CITY had a remote reading draft gauge system. Sensors installed near the bottom hull plating at the bow (forepeak tank), the stern (shaft alley aft), and midships port and starboard ballast tanks transmitted a pneumatic signal of the vessel's draft from each sensor location to a corresponding draft indicator (manometer) located in the cargo control room. The signal represented the difference between the atmospheric air pressure at sea level and the sea water pressure on the vessel's bottom hull.

Tank Level Indicating System.--The SURF CITY had a closed remote tank level indicating system installed with floating level sensors, designed to be intrinsically safe,[17] located in each cargo, slop, and ballast tank. This was the only permanent

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[17]Under normal or abnormal conditions, equipment and wiring that is incapable of releasing sufficient electrical or thermal energy to ignite a flammable atmospheric mixture even in its most volatile concentration.

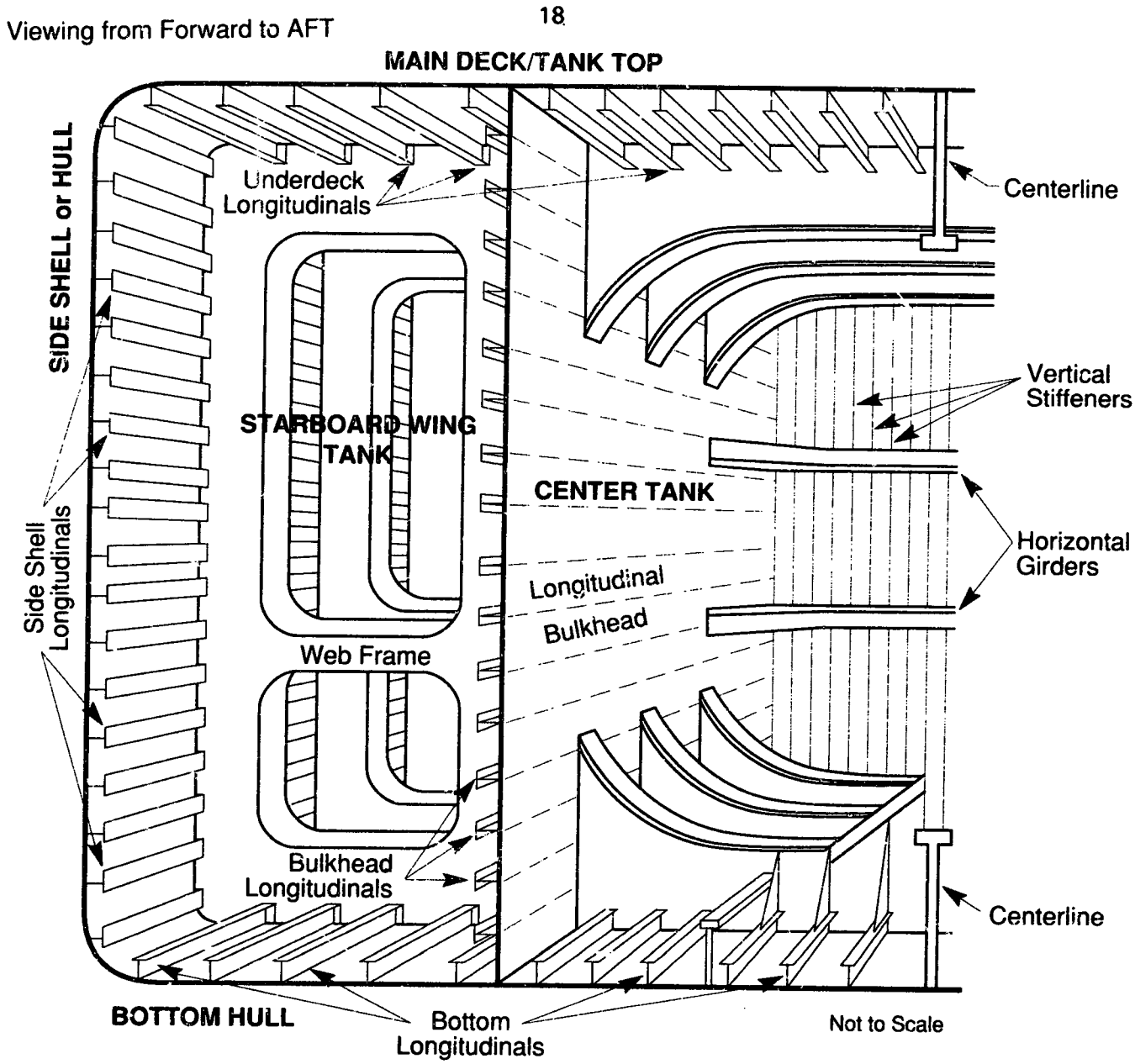


Figure 9.--Typical wing tank structural configuration.

electrical device in the tanks. The system design was based on variations in electrical resistance relative to the vertical position of a floating sensor on a guide pipeline. An unpainted stainless steel guide pipeline, secured to a bulkhead in each tank, maintained the float's vertical position relative to the tank.

Handover Notes.--After the accident, investigators found handover notes,[18] dated March 7, 1989, typed by a previous chief mate (foreign crew), in the SURF CITY's cargo control room. The notes stated that mercury had been removed from the port and starboard midships draft gauge manometers' 'U' bend tubing installed

[18]Handover notes are shipboard operational procedures passed on or handed over from the relieved chief mate to the relieving chief mate.

in the cargo control room. The notes gave no reason for the action, which would have disabled the midships draft gauges installed in the Nos. 4P and 4S ballast tanks.

Firefighting Systems.--In accordance with regulations at 46 CFR Part 34, the SURF CITY had a variety of firefighting systems and equipment, including a fire main system, a fixed-foam system, and a fixed-Halon system. For firefighting, the vessel had on board 4 CO_2 and 32 dry chemical portable fire extinguishers and two fireman outfits, four self-contained breathing (30-minute) apparatus, and four (10-minute) ELSA's.

In the engineroom, two electrically driven fire pumps supplied pressurized seawater to the fire main piping system. The tank ship had control stations for starting and stopping the fire pumps in the engineroom, on the bridge, and in the fire control room. The fire main piping distributed pressurized seawater to 49 fire hose stations (hydrants) located in and around the accommodations house and engineroom and on the main deck. The fire main also supplied pressurized seawater to the accommodation house-front spray system and to the firefighting foam system via a common header in the fire control room.

The vessel's firefighting system had nine fire foam monitors, seven of which were spaced along the centerline on a raised platform above the cargo tanks and two of which were on the tank tops of the port and starboard slop tanks on the main deck. The foam room contained the foam proportioner pumps and all the valves which directed foam to the fire monitors and to the pumproom. The open/close valve on each fire monitor was kept in the closed position when not in use.

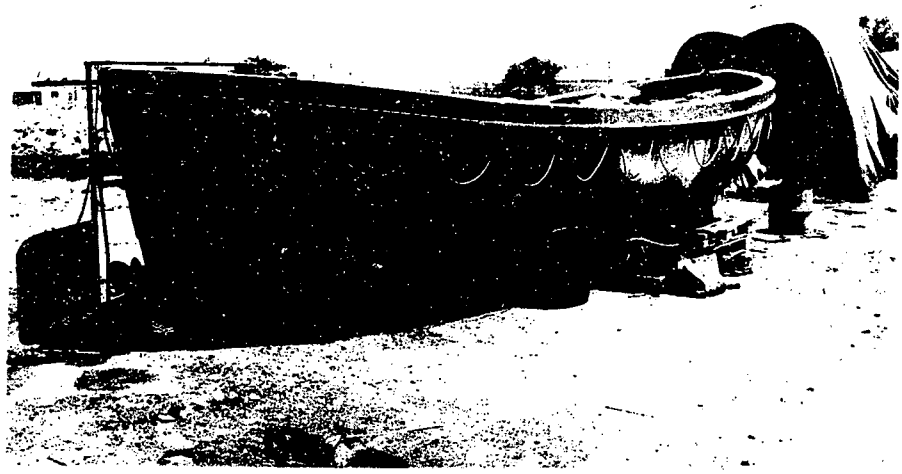
Lifesaving Equipment.--The SURF CITY carried two 28-foot-long, fiberglass, open, motorized lifeboats manufactured by Shigi of Japan and outfitted for 60 persons each. The gravity davits used to launch, recover, and stow the lifeboats were manufactured by Tsuji Heavy Industries Co. Ltd., Japan. The vessel's lifeboats were stowed on each side of the deckhouse on B deck. Because the SURF CITY was built before July 1, 1986, its lifeboats were not enclosed and the propulsion system on each lifeboat was not protected from debris in the water. Coast Guard inspectors examined both lifeboats as part of the tank ship's mandatory annual inspection on September 26, 1988, and found no deficiencies.

The blaze on the SURF CITY consumed the starboard lifeboat. On May 2, 1990, Safety Board and Coast Guard investigators inspected the port lifeboat at the Gulf Agency Company Terminal, Dubai, U.A.E. They found that a "gripe" or steel cable used to secure the lifeboat in its stowed position was tightly wound around the propeller drive shaft. (See figure 10.)

Wreckage

From April 22 to May 2, 1990, Safety Board investigators, a Coast Guard investigator, and representatives from Gleneagle Ship Management examined the SURF CITY while the tank ship lay at anchor in the Gulf of Oman, about 40 nmi off Fujairah, U.A.E. (See figures 11 and 12.)

The examination showed that fire and intense heat had completely gutted the navigation bridge and wheelhouse. Most of the windows were missing, all equipment was incinerated, and the bridge deck plating and bulwarks were warped. Fire also consumed all combustible contents in the accommodation house compartments located port to starboard in the forward area of D, C, and B decks and



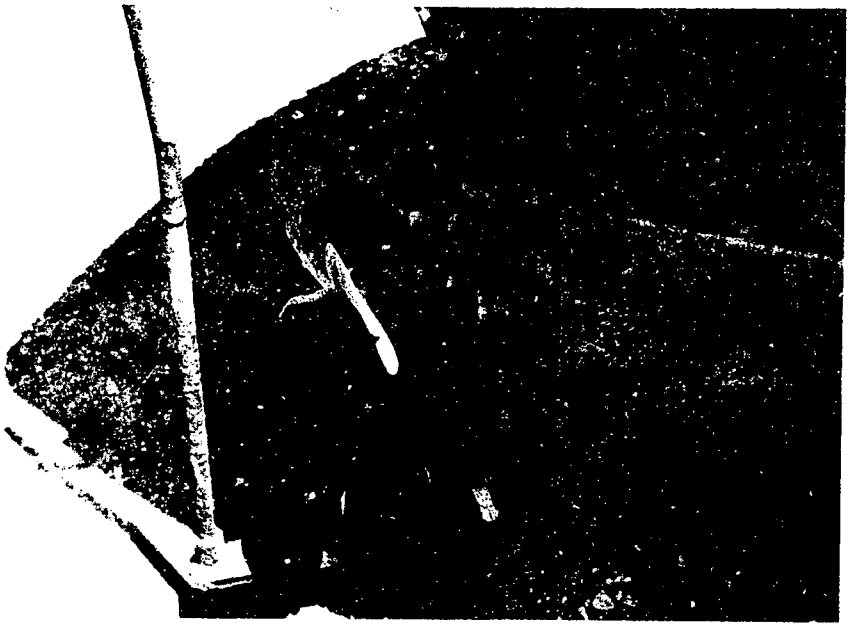


Figure 10.--SURF CITY's port lifeboat
with gripe wrapped around propeller shaft.

the accommodation house compartments located aft on the starboard side of D, C, and B decks. Compartments on the A deck, such as the cargo control room, sustained smoke damage and soot deposits. Main deck areas, including the foam room and the fire control room, sustained minor damage. Investigators found that the interior aluminum access doors to the athwartships passageway had melted away; the steel watertight doors were secured in the open position.

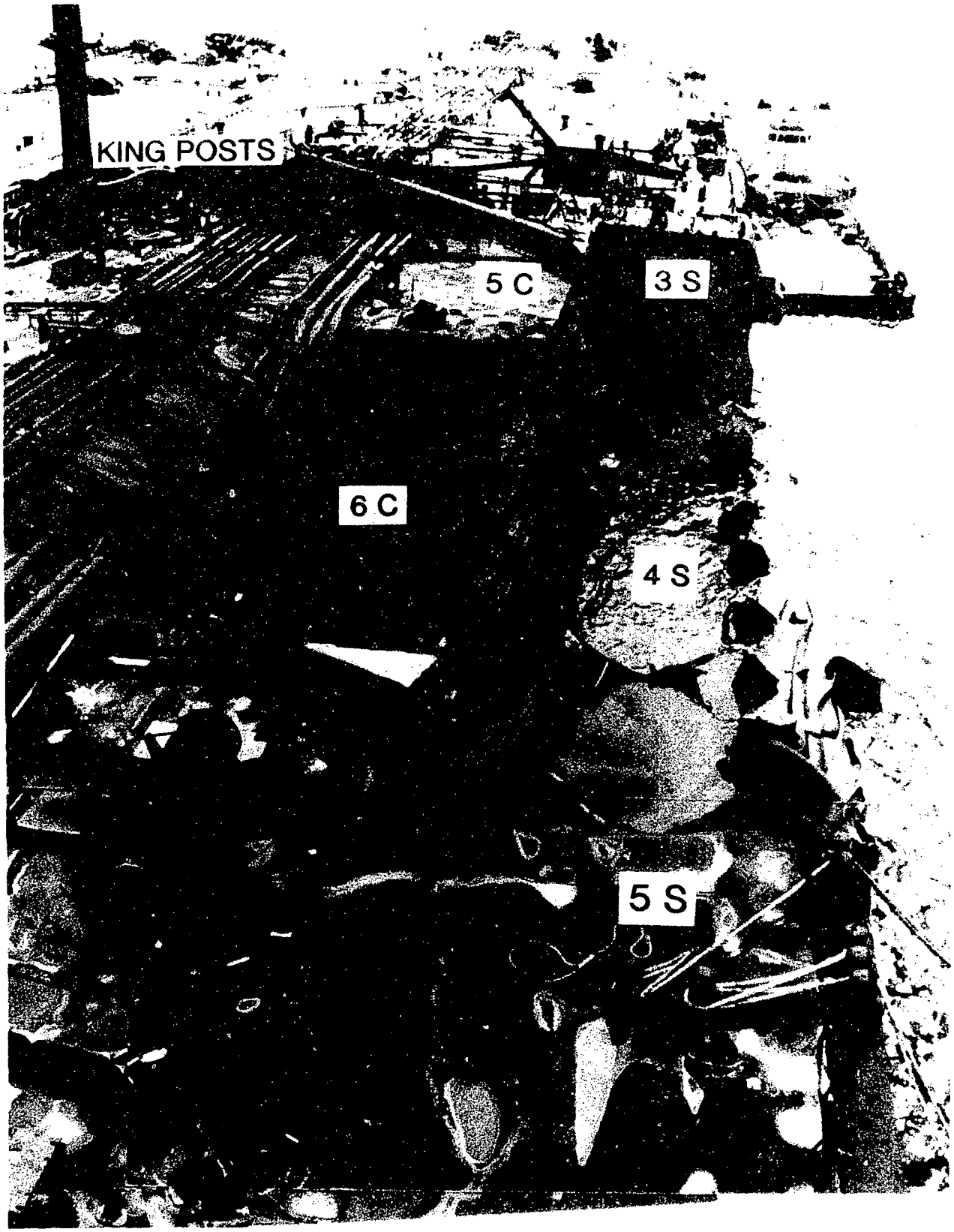


Figure 11.--Looking forward on the starboard side into the damaged tanks.

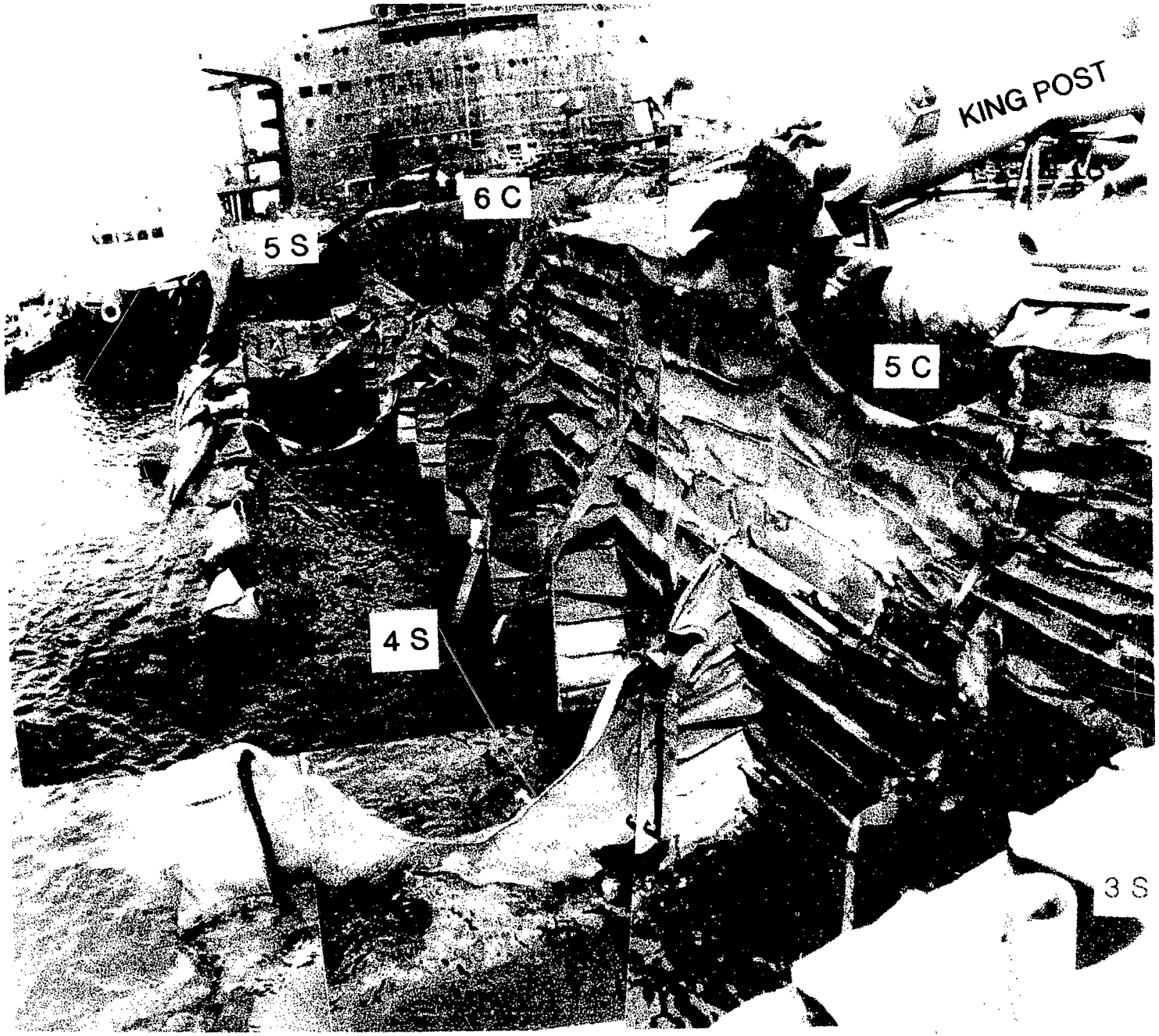


Figure 12.--Looking aft on the starboard side into the damaged tanks.

The main deck plating forward from the accommodation house to the midships storage deck houses was warped heavily from the port to the starboard side. Investigators found the starboard king post lying transversely across the main deck piping and the stainless steel pipeline from the No. 4S ballast tank remote tank level indicating system lying on the main deck. The 60-foot-long pipeline was bent in several places over its span. A 1-foot-long section of the pipeline bottom section was separated from the remaining pipeline.

During the first week that investigators were examining the damage, the remaining cargo (about 60 percent) was being transferred from the damaged tank ship to her sister vessel, the SEA ISLE CITY. As the cargo transfer proceeded, the lightened SURF CITY rose in the seaway, exposing additional areas of damage. On April 29, 1990, investigators found three previously submerged buckets in the No. 4S ballast tank adjacent to the inboard longitudinal bulkhead, just aft of transverse web frame No. 59. The buckets were hanging from a 6-foot-long, 1/4-inch-diameter polyethylene line that was attached to a vertical section of the midships remote draft gauge pipeline in the ballast tank. (See figure 13.) Pipe clamps bolted the pipeline to steel angle iron brackets that were welded to the longitudinal stiffeners on the inboard bulkhead of the ballast tank.

Investigators found one 12-inch-diameter by 16-inch-deep steel bucket hanging at the end of the polyethylene line. A smaller plastic bucket, also attached to the line, was inside the steel bucket. Another slightly larger plastic bucket hung immediately above the steel bucket, tied to the other end of the line. Neither the buckets nor the line showed evidence of flame exposure or other damage.

Because of the vessel's damaged condition, salvors prohibited the opening of any piping, including the piping in the pumproom. Investigators therefore could not verify the structural integrity of the main and branch ballast pipeline while the vessel lay at anchor in the Gulf of Oman but had to wait until the tank ship was drydocked.

The SURF CITY was sold at its anchored location in the Gulf of Oman and the new owners, Alandia Shipping, had the vessel towed to Sembawang Shipyard, Singapore, for drydocking and repairs. According to an Alandia Shipping captain who was on board during the tow to the shipyard, all tanks surrounding the No. 4S ballast tank were dry at the start of the tow. He said that he noted a fracture, less than 1 meter long, in the transverse bulkhead between the No. 4S and No. 5S tanks about 6 meters from the tank bottom and 4 meters outboard of the longitudinal bulkhead. He noted another fracture, less than 1 meter long, in the longitudinal bulkhead between No. 4S ballast tank and No. 6C cargo tank near frame No. 56, about 7 meters above the tank bottom. The Alandia captain stated that by the time the SURF CITY arrived at the drydock, each tank surrounding No. 4S had taken on about 7 meters (about 23 feet) of water.

While the SURF CITY was in the Sembawang Shipyard awaiting repairs, a U.S. Coast Guard resident inspector from Singapore further examined the tank ship. He found that the ballast piping in the center cargo tanks, the ballast branch pipeline to the No. 4S ballast tank, and the branch line valve had not leaked. His examination did not reveal any trace of naphtha in either the ballast main or branch pipelines. The Coast Guard inspector found that the weld around the ballast pipe bulkhead penetration between the No. 4S ballast tank and No. 6C cargo tank was in good condition. He also found the fractures reported by the Alandia captain in the No. 4S

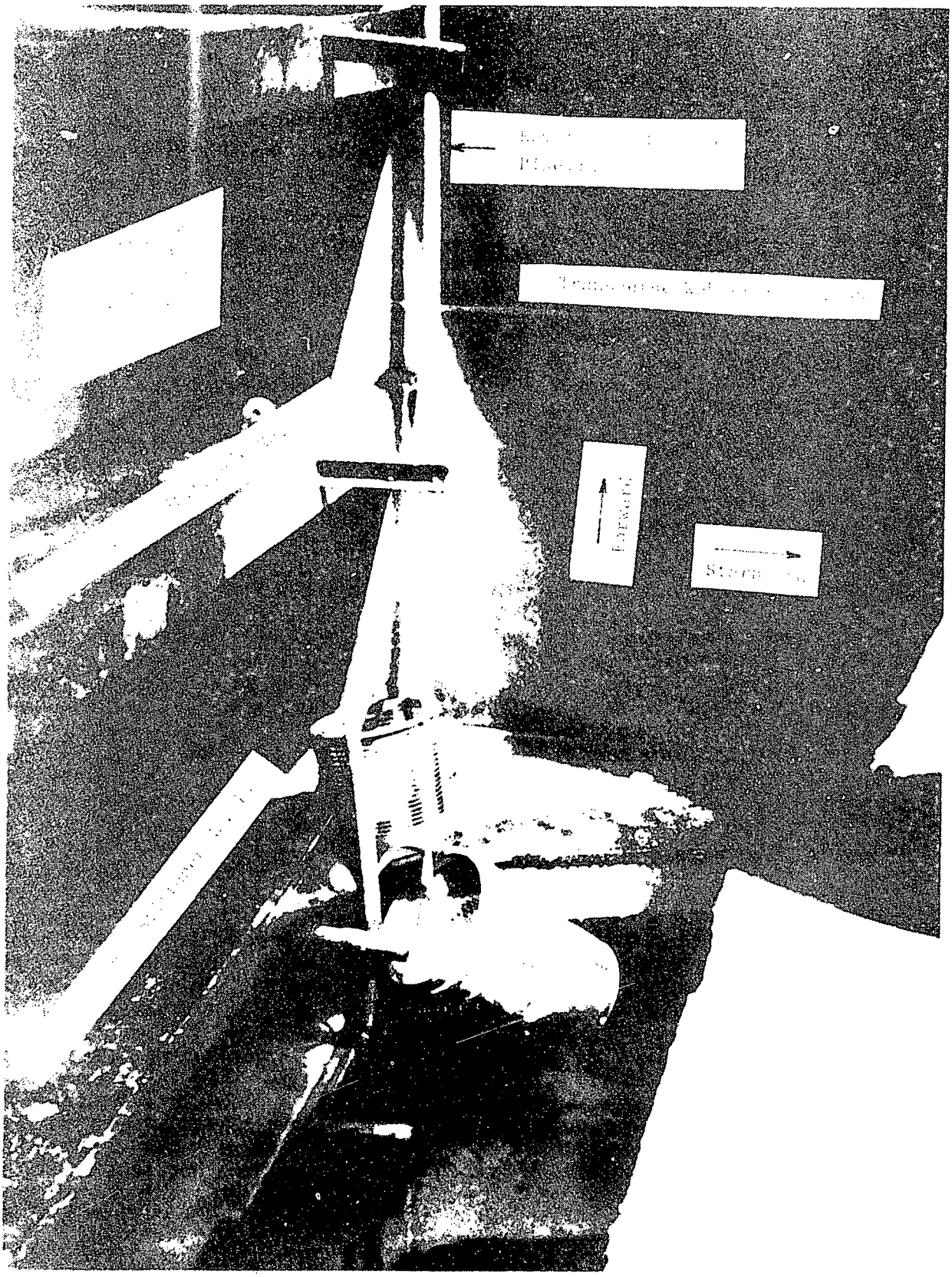


Figure 13.--Buckets recovered from No. 4 starboard ballast tank.

ballast tank aft and inboard bulkheads, as well as other fractures in the lower horizontal girder on the aft bulkhead where the vertical stiffeners intersect.

Waterway Information

The Persian Gulf, also known as the Arabian Gulf, extends from the mouth of the Tigris and Euphrates Rivers in the northwest to the Strait of Hormuz and the Gulf of Oman on the east. The gulf is bordered by Iran to the north, the U.A.E. to the south, Oman to the east, Saudi Arabia and Qatar to the west, and Kuwait and Iraq to the northwest. The waterway is about 600 miles long, ranges in width from about 35 miles to about 200 miles, covers a surface area of about 90,000 square miles, and has an average depth of less than 300 feet.

Meteorological Information

Log entries from the SIMPSON show that at 0955 on February 22, 1990, the surface weather for the area that the SURF CITY was transiting was as follows:

> Wind direction--from 030°T; wind speed--2 knots; air temperature--83°F [figure difficult to read; probably should be 73°F]; visibility--10 nmi; cloud cover--0.4; barometric pressure--29.9" of mercury; sea waves and swell direction--from 000°T; wave height--1 foot; and sea water temperature--75°F.

Medical and Pathological Information

Forty-one minutes after the initial explosion on the SURF CITY, the 23 survivors had been brought on board the USS SIMPSON and examined by Navy medical personnel. According to medical records, the helmsman/lookout sustained burn injuries and "a 2 1/2-inch laceration behind his right ear and the bleeding could not be adequately controlled." The boatswain sustained "head trauma and burn injuries with increasing pain." Navy medical personnel also treated the boatswain for second-degree burn injuries to his scalp and for muscular strain to his mid-back and clavicle. Other crewmembers sustained injuries as follows: the second mate was treated for second-degree burn injuries on his right cheek; the radio officer was treated for second-degree burn injuries to his scalp and face; the chief steward was treated for a first-degree burn injury to his left triceps; a third assistant engineer was treated for a skin contusion on his leg; a wiper/OS was treated for a skin laceration on his leg; and an OS was treated for skin contusions on his leg.

On February 25, 1990, forensic specialists examined the human remains that the Navy helicopter recovered and identified them as the master of the SURF CITY. The chief mate is missing and is presumed to have died in the conflagration.

Firefighting

About 1200, the Smit Tak BV SUMATRA,[19] which was about 32 nmi south-southwest of the SURF CITY in the Persian Gulf, received notification that the tank vessel was on fire. SUMATRA crewmembers stated that when the tug arrived

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[19]An oceangoing salvage tug with foam making apparatus, owned by Smit Tak BV (Rotterdam), was responding from Dubai, U.A.E.

on location between 1500 and 1600, "The wind from the starboard side of the SURF CITY was moving fire and smoke towards the tank ship's accommodations. Ballast tank No. 4S was engulfed in flames and a portion of the deck was missing. Cargo tanks Nos. 5C and 6C were intact." They also stated that "fire engulfed the ruptured area of the tank ship's hull and formed large pools of fire which extended into the sea."

The SUMATRA circled the SURF CITY to survey the tank ship's fire. The SUMATRA then attacked the fire along the exposed forward bulkhead of No. 4S using two water streams at 650 tons/hour[20] capacity. About 1600, the Smit Tak BV IMSALV LION arrived on location and attacked the fire from the port side of the tank ship.

By 1900 on February 22, three local salvage vessels had arrived on scene. When crewmen reported hearing "loud suction noises," the SUMATRA master ordered all vessels to withdraw at least 1/4 mile from the SURF CITY. Salvors stated that between 0300 and 0400 on February 23, 1990, "A large yellow tongue of flame erupted from 5C and 6C and traveled horizontally over the surface of the sea directly between the SUMATRA and the IMSALV LION [at least 1/4 mile from the starboard side of the tank ship]." The salvors said that later "A P/V (pressure/vacuum) [relief] valve let go [separated from the tank] and sprayed fuel on the port side of the SURF CITY, resulting in a running fuel spill fire on the port side and engulfing the port side accommodations."

On the morning of February 23, 1990, four more firefighting tugs arrived and attempted to blanket the fire near the tank ship's No. 4S tank with foam but failed to totally extinguish the blaze. During the next 2 weeks, firefighters allowed the fire to burn until it self-extinguished.

Tests and Research

As part of its investigation, the Safety Board looked into electrostatics as a possible ignition source. Of principle concern were the ventilation fans.

Ventilation Fans.--Dasic Marine Limited had manufactured the four ventilation fans, Jetfan model 125, on board the SURF CITY. The gas-freeing fans are designed to ventilate confined areas and are powered by a water supply, usually at 100 psi. The pressurized water drives a small turbine that is connected to a reversible fan, which can either educt the atmosphere from a tank or induct air into a tank. According to the manufacturer, the Jetfan 125 can produce an air volume of up to 12,500 cubic meters per hour (7,357 cubic feet per minute) with a water supply pressure of 150 psi.

The Dasic Jetfan 125 meets the standards for a Device for the Prevention of Passage of Flame (DPPF) contained in the International Maritime Organization's Maritime Safety Committee Circular 450/Revision 1 (entitled "Revised Factors to be Taken into Consideration when Designing Cargo Tank Venting and Gas-Freeing Arrangements"). The circular requires that a fan used to ventilate a tank have a minimum efflux air velocity of 30 meters per second (about 67 miles per hour) to prevent a flame from passing through the exit air stream.

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[20]A ton of salt water equates to 266 gallons.

In response to the Safety Board's request for additional information regarding the operation of the Jetfan 125, Dasic stated[21] that:

> As far as our records show we did not supply the input hose, but the description of them is normally as follows: The rubber hose is of an electrically bonded nature with a number of separate wires each of approximately 16 strands each being helical wound within the construction of the hose. The helix allows for hose expansion and distortion of shape when in use. The wires are allowed to protrude approximately 6" from each end of the hose and the hose end assemblies consist of a gunmetal nut, shanks and clamps. The nut is entered over the shank and the shank is then pushed into the hose, trapping the earthing [grounding] wires between the inner diameter of the hose and the outer diameter of the shank.
>
> The clamp assemblies are then bolted over the outer diameter of the hose, securing the shank tight into the hose. The nut is free to rotate to be accepted by the hot water line and the input of the fan. Electrical continuity should always be checked and maintained prior to any hose use.

Expert Testimony.--Neither the Dasic Jetfan manufacturer nor any independent source had test data related to electrostatic charge generation by the Dasic Jetfan 125 ventilation blower. The Coast Guard therefore contracted Southwest Research Institute (SwRI) of San Antonio, Texas, to evaluate the Dasic Jetfan 125 Gas-Freeing Fan for electrostatic energy generation and certain vapor ignition factors.[22] Dr. Thomas E. Owen, the SwRI institute engineer who prepared the report, calculated that the amount of naphtha (converted to vapor) required to create a flammable atmosphere in No. 4S ballast tank would range from 105 gallons to produce the Lower Flammable Limit[23] (LFL) of 0.8 percent up to 656 gallons to produce the Upper Flammable Limit[24] (UFL) of 5.0 percent. Dr. Owen testified that in the 45 minutes that they were operating, the fans would have exchanged about 1.6 tank volumes.

From his analysis, Dr. Owen also determined the following:

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[21]Letter dated July 17, 1990, from Mr. R. Owens, Technical Director/Works Manager, Dasic Marine Limited, Hampshire, United Kingdom.

[22]Dr. Thomas E. Owen, Review and Evaluation of Dasic Jetfan 125 for Electrostatic Energy Generation and Certain Vapor Ignition Factors Regarding an Explosion in M/T SURF CITY on February 22, 1990. U.S. Coast Guard Contract No. DTCG84-91-P-7MC117, SwRI Project 15-4117. This report was completed on February 22, 1991.

[23]The concentration of a hydrocarbon gas in air below which hydrocarbon vapor is insufficient to support and propagate combustion. Also referred to as the lower explosive limit (LEL).

[24]The concentration of a hydrocarbon gas in air above which oxygen is insufficient to support and propagate combustion. Also referred to as the upper explosive limit (UEL).

- The minimum electrostatic ignition energy to ignite a flammable mixture of naphtha ranged from 0.25 mJ[25] for the most sensitive concentrations approaching the Lower Flammable Limit to about 15 mJ for very rich concentrations approaching the Upper Flammable Limit.

- Electrostatic charge generation by naphtha spray into the No. 4S ballast tank from a fracture in the tank bulkhead was insufficient to cause ignition of the naphtha vapor.

- The [human] body does not provide an efficient arc discharge path when releasing its stored electrostatic energy. This fact, combined with the low retention of electrostatic charge in a humid atmosphere, makes the possibility negligibly small or unlikely that an electrostatic charge on a man's body might occur with sufficient energy to cause an incendive spark.

- Air flow dynamics within the Jetfan 125 were thought to be sufficient to promote triboelectric[26] charging of some percentage of dust, salt nuclei, and water aerosol particles that may be ingested into the fan intake and to transport these particles, containing a significant electrostatic charge, through the fan outlet and into the tank. Testing of this characteristic of this fan should be conducted to accurately confirm the possibility and magnitude of such effects.

Under a separate contract, the Safety Board and the Coast Guard had SwRI test the Dasic Jetfan 125 fan for electrostatic generation.[27] Safety Board and Coast Guard investigators and a representative of the fan manufacturer attended the testing. Under the test conditions, the fan did not generate sufficient electrostatic energy to ignite the most sensitive naphtha vapor/air mixture. The space charge density produced by the fan was 12 to 40 times less than the ignition energy that would be potentially hazardous.

Other Information

Safety Procedures for Entry and Working in Enclosed Spaces.--International guidelines, the KOTC safety manual, and Coast Guard regulations contain the following procedures regarding entry into confined or enclosed spaces on tankers carrying crude oil and other petroleum products.

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[25]A millijoule is a measure of energy equal to one thousandth of 1 ampere passing through a resistance of 1 ohm in 1 second.

[26]Triboelectric or electrostatic charging is produced by contact when solids or liquids move with respect to one another.

[27]Contract No. NTSB-RFP-91-016 issued on July 12, 1991, (SwRI Project No. 15-4404) "Evaluation of the Dasic Marine Jetfan 125 to Detect and Measure Electrostatic Charge in the Exit Air." This report was completed on December 6, 1991.

International Safety Guide for Oil Tankers and Terminals (ISGOTT)[28].--Chapter 10 "describes the tests to be carried out to determine whether or not an enclosed space is safe for entry." Subsections 1 and 2 advise that hydrocarbon gas and oxygen deficiency should always be suspected in empty compartments such as permanent ballast tanks. ISGOTT states that "Entry into tanks which are known to be nongas free or oxygen deficient can only be permitted in exceptional circumstances and when there is no practicable alternative." In addition, Chapter 10 contains the following precautions:

Chapter 10.2, Gas Tests for Entry or Work.-A decision to enter a compartment where there has been or could be gas should only be made after investigation with approved gas testing equipment . . .Tests should be so arranged that a result representative of the conditions of the entire space is obtained.

10.2.2-To be safe for entry, whether for inspection, cold work, or hot work, a reading of not more than 1 percent LFL [or LEL] must be obtained on a suitable combustible gas indicator.

10.2.5-Before entry is allowed into any compartment, tank, or space which has been closed for any length of time, the atmosphere should be tested with an oxygen analyzer to check that the normal oxygen level in air of 21% by volume is present.

Chapter 10.3, Breathing Apparatus-. . . Breathing apparatus must always be used whenever emergency entry is made into a space which is known to contain toxic gas or smoke, or to be deficient in oxygen. It should be used if there is a possibility that any of these conditions may exist or occur during the period of occupation.

Chapter 10.4.6, Non-Gas Free and Suspect Compartments-When it is necessary to enter a tank or compartment where it is suspected that the atmosphere contains toxic gas or is deficient in oxygen, or that these conditions are likely to occur during the period of occupation, an officer should be responsible for continuous supervision of the operation and should ensure that:

> A permit has been issued by the master stating that there is no practicable alternative to the proposed method of entry and that such entry is essential to the safe operation of the ship.
>
> Ventilation is provided where possible.
>
> Personnel use breathing apparatus and lifeline.

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[28] International Safety Guide for Oil Tankers and Terminals (ISGOTT), Third Edition, International Chamber of Shipping, Oil Companies International Marine Forum, International Association of Ports and Harbors, London, 1988.

> The number of persons entering the tank is kept to a minimum consistent with the work to be performed.
>
> Means of communication are provided and a system of signals is agreed and understood by the personnel involved.
>
> Spare sets of breathing apparatus and resuscitators are available outside the compartment, and a standby party is in attendance in case of emergency.
>
> Any essential work that is to be undertaken is carried out in a manner that will avoid creating an ignition hazard.

In Chapter 9, "Fixed Inert Gas Systems," the ISGOTT stresses that When it is required to gas free[29] a tank ". . . after washing, it should first be purged with inert gas to reduce the hydrocarbon content to 2 percent or less by volume so that during the subsequent gas freeing, no portion of the tank atmosphere is brought within the flammable range."

> **Kuwait Oil Tanker Company Safety Manual**.--Chapter 7, "Entry into Confined Spaces," of the KOTC Safety Manual states that "Toxic vapours or oxygen deficiency may exist in any enclosed space and the precautions laid down in this Chapter are to be strictly observed in All the Company's vessels." When Safety Board investigators reviewed the manual, they found that the guidelines did not provide a warning concerning the use of ventilating fans in flammable atmospheres or the need to properly ground the fans. The manual did contain the following:
>
> Chapter 7.1, GENERAL. The Master in ALL vessels is to ensure that no entry is permitted into any enclosed space until it has been THOROUGHLY VENTILATED and a Responsible Officer has tested the atmosphere with the appropriate equipment and ascertained that it is free from toxic vapors and not deficient in oxygen.

The KOTC safety manual also contains the following additional precautions for entry into an enclosed space:

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[29]According to ISGOTT, a tank, compartment, or container is gas free when sufficient fresh air has been introduced into it to lower the level of any flammable, toxic, or inert gas to that [level] required for a specific purpose, e.g. hot work, entry, etc. At 46 CFR 30.10-29, gas free is defined as free from dangerous concentrations of flammable or toxic gases.

7.3(b) Tests. Tests, from as many sampling points as possible, should be made for:-(i) Oxygen. No entry until 21 percent oxygen has been recorded. (ii) Cargo Vapour. No entry until a zero reading has been recorded with the appropriate instrument. Sampling should continue during entry.

7.3(c) Communications. These must be adequate and foolproof between those inside the space and a responsible person outside. They must be clearly established and understood before entry is permitted. Portable VHF sets and any other means should be used. The person immediately outside the space should form the mid point of the communication system, with the final link being the Navigating Officer of the Watch, or other responsible Officer. The latter must be prepared to raise the alarm in the event of an emergency situation developing. The maximum time interval between messages (4 minutes for example) must be established, and in the event of this time being exceeded, the Emergency Alarm must be raised.

7.3(e) Breathing Apparatus. This, together with a rescue line and harness, should always be available as precaution.

7.3(f) Control. The last person in the communications link . . . should act as overall Controller, and he must be fully aware of the space being entered and purpose.

7.4 VENTILATION. Ventilation, either natural or forced, must be carried out before entry is permitted into any enclosed space. If forced ventilation is used, a minimum of two air changes must take place before entry is permitted. . . . With ballast tanks, it may be preferable to ensure full ventilation has taken place by filling the ballast tank with clean sea water and pumping out, to ensure adequate air enters the space. Where possible, portable Air/Water fans should be utilized to increase the ventilation in such spaces. . . .The appropriate tests for oxygen and cargo vapour MUST BE TAKEN BEFORE ENTRY IS PERMITTED.

7.5 ENTRY INTO ENCLOSED SPACES FOR NORMAL OPERATIONAL PURPOSES. No one may enter an enclosed space without first obtaining the Chief Officer's permission. An enclosed space will include cargo tank, ballast tank, cofferdam, bunker tank, fresh water tank, duct keel, etc., which may contain either toxic vapours or insufficient oxygen to support life. Before entering the space, the Chief Officer must ensure that the following precautions have been taken:

> (a) . . .Time [required for ventilating the space] will depend on the location and type of space to be entered and the methods available . . . The most effective system must be used before, and during entry.

(b) On each occasion that entry into an enclosed space takes place, an emergency party is to be mobilized as a back-up.

7.6 ENTRY INTO SPACES KNOWN TO BE HAZARDOUS. It may become necessary to enter a space that is not gas free due to defective or inadequate ventilation, mechanical failure of valves, pipeline or pumps or for any other reason when the tests indicate the presence of toxic vapours. Under these circumstances the entry shall be treated as an emergency operation and the Chief Officer will personally supervise the entry. The following procedures will apply:

(i) Ventilation will be provided if available.

(ii) All personnel entering the space will wear compressed air breathing apparatus with full air cylinders.

(iii) A means of communication and a system of signals will be set up and understood before entry takes place.

(iv) Sufficient members of an Emergency Party capable of affecting a rescue from an enclosed space . . . will remain outside the space.

(v) The number of persons entering must be kept to the absolute minimum to carry out the work required.

Chapter 9, "Gas Carrier Cargoes & Safety Procedures," of the KOTC manual states that prior to any gas freeing operations, the chief officer is to ensure that:

1. All external doors and ports are closed.
2. The relative wind over the deck is such that cargo vapor does not approach the accommodation.
3. Smoking restrictions are to be enforced.

Coast Guard Regulations for Tank Entry.--The Coast Guard regulations at 46 CFR 35.01-1 provide for "Inspection and testing required when making alterations, repairs, or other such operations involving riveting, welding, burning, or like fire-producing actions." This regulation incorporates National Fire Protection Association (NFPA) standard No. 306 (1988 edition) as a guide. For pier-side repairs, the regulations require that a certified NFPA marine chemist inspect the area before work is started and issue a certificate attesting to what type of work (hot work or cold work or if the space is safe to enter) is authorized. When the repair work is to be done at a remote location where a chemist is not available, "the inspection shall be made by the senior officer present and a proper entry made in the vessel's logbook." Coast Guard regulations contain no other requirements or guidelines for tank entry.

Cargo Information.--Naphtha is a petroleum distillate; its physical and chemical properties vary between those of gasoline and kerosene. Naphtha consists of saturated aliphatic hydrocarbons, principally pentane and hexanes. The product is

lighter than water and insoluble in water; its vapors are heavier than air. In volume concentrations of 1.1 percent to 5.9 percent, naphtha fumes are generally flammable in air. The auto ignition[30] temperature of the distillate ranges from 450°F to 550°F depending upon its composition.[31]

Automotive diesel oil is a slightly hazy colored liquid that is lighter than water and insoluble in water; its vapors are heavier than air. In volume concentrations of 6.0 percent to 13.5 percent, diesel oil vapors are flammable in air. The oil's auto ignition temperature is approximately 640°F.

Cargo Samples.--When the SURF CITY was loaded at the ports of Mina Abdulla and Mina Al Ahmadi, Kuwait, Kuwait National Petroleum Company (KNPC)/ Societe General de Surveillance S.A.(SGS) took representative samples for laboratory analysis from shore tanks Nos. 50-148, 50-149, 469, 470, and 669. Laboratory personnel tested these samples for specific gravity, flash point, initial boiling point, viscosity, and percentage of water and sediment by volume. After the loading was completed at Mina Abdulla and Mina Al Ahmadi, the terminal chemist had composite samples drawn from each cargo tank that were retained aboard the SURF CITY. Shortly after the February 22, 1990, explosion/fire, investigators recovered these samples from the SURF CITY for laboratory analysis.

The Safety Board contracted Core Laboratories, Houston, Texas, to analyze the recovered cargo samples. The analysis determined molecular weight, flash point, vapor pressure, initial boiling point, and specific gravity. Comparison of the Core and KNPC/SGS test results disclosed that the shore tank samples of naphtha and diesel oil matched the composite cargo samples of naphtha and diesel oil in the broad range of the properties tested.

Emergency Life Support Apparatus.--Sabre Safety Limited, Aldershot, UK, manufactured the four ELSAs (Model No. 10B) on board the SURF CITY. The escape apparatus, a compressed air breathing set, consisted of a clear plastic hood that covered the head and a steel alloy cylinder that contained 14 cubic feet of air (about 10 minutes supply) when charged to about 2,900 psi; the cylinder was carried in a flame retardant polyvinyl chloride sleeveless jacket or vest. The air cylinders had a nickel-plated brass valve and were certified on June 20, 1985, by Sabre. The ELSA polyvinyl chloride clear hood had been approved under a UK Certificate of Approval for Respiratory Protective Equipment to withstand direct flame impingement temperatures of 800°C (1,472°F) for several seconds. Each ELSA had the following instructions imprinted on the front of the jacket:

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[30]Temperature at which a petroleum product self-ignites in air at one atmosphere.

[31]Fire Protection Handbook, Fourteenth Edition, National Fire Protection Association, 1976.

FRONT
Check cylinder is FULL before use

For Escape Use Only
10 Minutes Duration

Instructions

1. Remove Hood from Pouch
2. Open Valve
3. Pull Hood over Head
   (tube to front)
4. GET OUT

According to the Sabre Operating and Maintenance and Instruction Manual (March 1987, Issue A):

> The ELSA is a short duration compressed air breathing set for escape use only and is to be worn at the ready by personnel entering a gas free location but in which isolated pockets of toxic or an irrespirable atmosphere may possibly be encountered. . . . In the event of such an atmosphere being encountered the wearer must operate the apparatus and leave the area immediately. The ELSA should not be used to enter areas already containing an irrespirable atmosphere (except of course during the process of escape), nor for uses generally associated with long duration apparatus, such as firefighting or rescue work.

Remnants of the chief mate's recovered ELSA were later examined at Gulf Agency Company facilities in Fujairah, U.A.E. Other than several small "L" shaped perforations in the vest and the missing steel air cylinder, neither the vest nor the plastic hood showed any thermal or mechanical damage.

Reflagging of the SURF CITY.--In 1987, 11 Kuwaiti tank ships, including 4 liquefied petroleum gas vessels, were reflagged to the U.S. flag. The Coast Guard is the agency responsible for enforcing safety regulations for U.S. commercial vessels and for reflagging vessels to the U.S. flag. The Coast Guard inspectors reviewed the SURF CITY's design and gave the vessel both internal and external inspections, including a drydock inspection to determine whether the tank ship met the requirements for U.S. ownership. As part of the reflagging process, the Coast Guard had to verify that the vessel was of a structure suitable for the service in which it was to be employed; carried proper lifesaving, fire prevention, and firefighting appliances; had suitable accommodations for the crew; complied with appropriate U.S. marine safety laws and regulations; and had installed equipment comparable to a U.S. vessel of the same type.

The Coast Guard's initial regulatory inspection of the SURF CITY for reflagging and certification for U.S. registry began on May 15, 1987, with a review of the vessel's structural plans, the mechanical and electrical systems plans, and installed equipment. During their plan review, Coast Guard examiners identified about 500 items that had to be corrected before the vessel would meet U.S. standards, including overhaul of lifeboat davits and lifeboats, installation of new liferafts, overhaul and/or replacement of all firefighting equipment, replacement of the two electrically-driven fire pumps in the engineroom with new pumps of higher

discharge capacity, installation of nine fire monitors on deck and fixed firefighting systems in the engineroom, enlargement of the concentrated liquid foam supply tank, isolation of potable water piping from other water systems, and installation of new radio equipment. On August 28, 1987, the tank ship was reflagged from Kuwait to the United States and received its first COI from the Coast Guard.

Inspections and Surveys.--In May 1988, while the SURF CITY was anchored off Khor Fakkan, U.A.E., an ABS surveyor conducted special and annual examinations of the vessel's hull, machinery, boilers, and the IGS. He also conducted a survey to "examine and report on hull damage to the Nos. 4 P/S wing ballast tanks, reported to have been caused by corrosion fatigue." The ABS surveyor noted the following conditions in his report:

> No. 4P ballast tank.--The aft section of the 1st [upper] horizontal girder was fractured in two places in way of transverse bulkhead [frame 52] vertical stiffeners 1, 2, and 3 counting out from inboard longitudinal bulkhead. One fracture measured 600 mm[32] and the other 150 mm. The No. 2 longitudinal stiffener under the horizontal girder was detached from bulkhead along the vertical weld. The transverse bulkhead [frame 52] in way of the No. 2 vertical stiffener had a fracture measuring approximately 35 mm.
>
> No. 4S ballast tank.--The aft section of the 1st horizontal girder, in way of the aft transverse bulkhead at frame 52 in the area of vertical stiffeners 2 and 3 from inboard longitudinal bulkhead had fractures in two places, measuring 150 mm and 200 mm respectively.

The ABS surveyor recommended "further examination of the Nos. 4 port and starboard permanent ballast tanks be conducted to ascertain their condition." Gleneagle opted not to have the 4P and 4S ballast tanks examined during the May 1988 survey, and the surveyor recommended that the ballast tank examination be carried out at the vessel's next scheduled drydocking survey [January 1989]. As a result of the May 1988 ABS survey, Gleneagle repaired various fractures in the tank's horizontal girders of the Nos. 4P and 4S ballast tanks. A fracture through the bulkhead between No. 4P ballast tank and the No. 5P cargo tank was welded, and a temporary steel plate was welded over the bulkhead fracture in the No. 4P ballast tank. The ABS surveyor indicated that the temporary plate was to be removed and a permanent steel plate was to be inserted during the next shipyard period.

In September 1988, the Coast Guard reinspected the SURF CITY for recertification and gave the tank ship its second COI on September 26, 1988, with an expiration date of September 26, 1990. An internal and external hull exam was not required as part of the recertification.

Between January 3 and February 15, 1989, Gleneagle, the operator of the SURF CITY, scheduled a shipyard period for the SURF CITY at the Arab Ship Repair Yard (ASRY) in Bahrain to complete modifications required by reflagging to bring the vessel into compliance with Coast Guard regulations, to conduct condition

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[32]One inch equals 25.4 millimeters (mm).

inspections of the exterior hull and the internal structure of the cargo and ballast tanks, and to complete any subsequent repairs required by the attending Coast Guard inspectors.

The Coast Guard inspector who examined the SURF CITY during January and February 1989 stated that while he was examining the exterior hull and the cargo and ballast tank interiors, the tank ship's chief mate brought to his attention a fracture behind the doubler plate[33] in the No. 5P cargo tank bulkhead (frame 52) adjacent to the No. 4P ballast tank. The inspector testified that the chief mate found the fracture when he observed ballast water leaking into the empty cargo tank. The fracture was about 3 1/2 to 4 feet long and about 15 feet from the longitudinal bulkhead. He also said he believed the fracture was diagonal. An area containing the fracture and the doubler plate, about 5 feet by 3 feet, was cut out with an acetylene torch, and an insert was welded in place. The insert extended about 2 1/2 feet above and 2 1/2 feet below the upper [top counting down from the main deck], horizontal girder in the ballast tank.

The Coast Guard hull inspector testified that the two levels of horizontal girders at the ballast tanks' aft bulkhead had many fractures. He also said that the horizontal girder on the No. 4P aft bulkhead was fractured and propagating at the intersection of the vertical stiffener outboard. The fractures had been repaired by drill stopping and welding.

The hull inspector stated, "Evidently . . . the ship 'works'[34] on this vessel" in the No. 2 and No. 4 ballast tanks, port and starboard. He added that during past inspections, he had found damage in the ballast tanks of "all four of the 81,000 [dwt] ton vessels, SURF CITY, CHESAPEAKE CITY, and OCEAN CITY and SEA ISLE CITY" caused by "the ship working" and cracking [fracturing][35] the inboard bulkhead side.

The Coast Guard inspector testified that each of the four tankers had stress cracks ranging in length from 6 to 10 inches that had been there [on the transverse web frames] for quite a while because the cracks were "rusted out." He further stated that the ballast tanks are nine bays deep, and virtually every bay had the same damage on the inboard side [section] of the transverse web frames and the inboard first longitudinal to the watertight [longitudinal] bulkhead.

When the Coast Guard inspector examined the No. 4S tank, he did not find any fractures in the bulkhead at frame 52. When asked about the bulkhead repairs that he discovered during his inspection, he said, "I did not notice any patch in No. 4 starboard ballast tank where the first [upper] horizontal platform [girder] intersected with the second vertical outboard stiffener on the aft bulkhead." He added, "I would say that the cracks in the [horizontal] platform and verticals [stiffeners] . . . on the port side ballast tanks were like a mirror image [laterally

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[33]A doubler plate is a temporary repair; it is a steel plate the same thickness as the bulkhead. A doubler plate is placed on and circumferentially welded to cover a defect or fracture.

[34]Working is the motion of the vessel, in bending and torsion in the seaway; it can produce fatigue cracking of the steel structure. Fatigue is incremental crack growth caused by cyclic stresses; it can substantially reduce the load-carrying ability of the structure.

[35]In the marine industry, crack is a generic term for a fracture. Technically a crack is a defect that may or may not fully penetrate metal plate; a crack does not cause the plate to separate. A fracture penetrates fully through the metal, causing the plate to separate.

symmetrical] to those on the starboard side." He testified that the SURF CITY had an area of concentrated fractures in the floors of the Nos. 4P and 4S ballast tanks in the strength members [web frames]. The Coast Guard inspector added, "One after the other throughout the tank, the fractures were repaired [by welding] and returned to the original structure."

In addition to the Coast Guard inspections during the January-February 1989 shipyard period, ABS surveyors conducted examinations required by the classification society for the SURF CITY. The ABS surveyors filed reports with the vessel owner, the local ABS office, and ABS headquarters in the United States. Gleneagle reported that by the end of the drydock period, all vessel repairs required by the Coast Guard and recommended by the ABS were completed, including the welding of all fractures found and the reapplication of all coatings in the area of the repairs.

Previous Chief Mate's Findings.--The SURF CITY's previous chief mate had reported aboard the tank ship on August 28, 1989, less than 6 months after the drydocking and shipyard repairs had been completed. When he arrived, he examined all of the cargo tanks because they were empty and gas free. He looked for leaks in the bulkheads of the cargo tanks adjacent to the filled ballast tanks.

The former chief mate testified that he did not find any leaks during his examination of the cargo tanks. However, he said that he did find scale (flaked rust), which is the corrosive delamination of surface metal, on the cargo tanks' interior steel plating. He also found that only the top and bottom area of each cargo tank were coated with epoxy which was characteristic of a crude oil carrier but not a product carrier.[36] At the top of the tank, the underdeck and the first 8 feet down were coated with epoxy. The steel bulkhead sections and structural members for 46 feet below this epoxy band were uncoated. The base of each cargo tank and the bottom 8-foot area were also coated with epoxy. In contrast, the structural steel supports and bulkheads in the adjacent ballast tanks had epoxy coating from top to bottom.

Less than 2 months before the SURF CITY accident, while the tank ship was on the cargo leg of a voyage, the former chief mate entered and inspected the tank ship's empty ballast tanks at the direction of Gleneagle. The report of his findings, dated January 10, 1990, was the last inspection of the ballast tanks before the accident.

In this report to Gleneagle, the former chief mate stated that the coating in all ballast tanks had spotty areas of rust along the flange faces of the horizontal and vertical stiffeners where the coating had broken down. When the former chief mate inspected the No. 4S ballast tank, the Nos. 3S, 5S, 5C, and 6C tanks were loaded with cargo. The chief mate noted in his report that in general, the ballast tanks' transverse and longitudinal bulkheads adjacent to the cargo tanks were tight and showed no signs of leaks. The chief mate noted evidence of previous repairs to the tanks and additional new stress fractures.

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[36]The nature and consistency of crude oil protects the steel bulkheads; therefore, a protective coating is only needed at the top and the bottom. A product carrier generally has a protective coating throughout the tank.

The former chief mate found some new fractures along previous weld repairs in the Nos. 4P and 4S ballast tanks. In the No. 4P ballast tank, he found fractures at frame 52 in both the upper and lower horizontal girders near the Nos. 2 and 3 vertical stiffeners. He also found new fractures in transverse web frames Nos. 56, 57, 58, and 59.

In the No. 4S ballast tank, the chief mate found an epoxy "Red Hand"[37] patch at frame No. 52 on the transverse bulkhead separating the No. 4S ballast tank from the No. 5S cargo tank. The patch was near the intersection of the upper horizontal girder and the No. 3 vertical stiffener. The chief mate testified:

> When I inspected the ballast tank aft bulkhead, No. 5 starboard was [loaded] with cargo to about 4 inches below the [main] deck. What I saw was a patch indicating that there was either work done under it or a leak. I don't know which because there was no record indicating that.

The chief mate indicated that the patch was irregularly shaped, approximately 3 inches by 3 inches. He further stated, "I have absolutely no idea how long the patch had been there. There was no evidence of any leak around the patch."

The former chief mate recalled seeing two inserts in No. 4P ballast tank, one in the bottom plating below the bellmouth[38] and the other in bulkhead frame No. 52 between Nos. 4P and 5P tanks. He further testified that the insert in No. 4P "was at the third vertical stringer [stiffener] and it extended above and below the shelf [horizontal girder] by about 2 feet," which mirrored [were laterally symmetrical to] the Red Hand patch in No. 4S.

The former chief mate added, "It is not uncommon to have a bulkhead leak . . . When I looked at the bulkheads, they were fine, but when does a bulkhead leak start?"

When he inspected the No. 4S ballast tank before departing the vessel on January 20, 1990, the former chief mate reported finding three cracks in the 12.5-mm plating of the tank's horizontal girders at frame No. 52. Two were along previously welded fracture repairs to the upper horizontal girder, including one that was 150 mm long at the No. 2 stiffener and another that was 50 mm long at the No. 3 stiffener. The third was a new fracture, 250 mm long, at the No. 2 vertical stiffener of the lower horizontal girder.

ANALYSIS

Explosion and Fire

The explosion and fire on the SURF CITY could have been caused by entry of an external device, such as a mine, missile, or bomb, or by the ignition of a naphtha vapor/air mixture in one of the ship's tanks. However, nearby naval vessels in the

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[37] "Red Hand" is a the brand name of a red-colored epoxy patching material that is applied by hand to stop leaks in small fractures. People in the marine industry commonly use the name generically when referring to any patching material.

[38] The bell shaped fitting on the suction end of the piping pumping system at the bottom of a tank.

accident area did not report any mines or missiles or encounter any hostile vessels or aircraft. Moreover, during their examination of the damaged tank ship, investigators determined that the wreckage did not exhibit fragmentation and other characteristics associated with conventional solid-phase "high explosives" such as a mine, missile, or bomb.

Therefore, the Safety Board believes that the accident resulted from a noninstantaneous combustion (vapor phase explosion) of naphtha vapor/air, technically termed a deflagration, in the No. 4S ballast tank. A deflagration occurs in a confined space, such as a ship's tank, when an ignition source is introduced in an atmosphere of accumulated flammable gas/air vapors. A thin flame front forms around the ignition source and propagates outward, consuming the gas-air mixture ahead of it. The flame front causes the temperature in the tank to rise, in turn causing the gases to expand. When the confined space of the tank restricts the gas expansion, pressure in the tank begins to rise at the rate of the speed of sound. When the pressure in the tank reaches a level exceeding the strength of the structure's weakest element, the structure bursts, and the explosion vents itself through the opening(s) it has created.

Examination of the wreckage showed that the initial explosion on the SURF CITY vented through the No. 4S ballast tank top, as evidenced by the fact that the tank top was torn away from the underdeck welds at the web frames and the web frames and the bottom hull plating were pulled upward into the ballast tank. The gas expansion also forced the common longitudinal bulkhead into the No. 6C cargo tank and the after common transverse bulkhead into the No. 5S cargo tank.

Subsequent explosions and fire occurred within the Nos. 5S, 5C and 6C cargo tanks. Explosions destroyed a large part of the No. 6C cargo tank top. The explosion in the No. 5C cargo tank vented itself by forcing a hole through the starboard longitudinal bulkhead toward the 4S ballast tank. Ruptured bulkheads between the No. 4S ballast tank and six adjacent cargo tanks allowed massive amounts of burning naphtha from cargo tanks Nos. 4C, 5C, 6C, 7C, and 5S and diesel oil cargo from tank No. 3S to flood into the open area of the No. 4S ballast tank.

Explosive Conditions

To determine the conditions present on the SURF CITY that resulted in the explosion, this investigation focused on the source of the flammable vapors in the ballast tank, sources that could have ignited the vapors, and the ballast tank entry procedures that the master and the chief mate followed.

Possible Naphtha Paths Into the Ballast Tank.--The naphtha leak into the No. 4S ballast tank began sometime between February 18 and 22, 1990, after the liquid hydrocarbon was loaded into cargo tanks Nos. 5S, 5C, and 6C and/or during the tank ship's passage through the Persian Gulf. Enough naphtha leaked into the starboard ballast tank so that when the vapors mixed with air injected by the Dasic Jetfan ventilation fans, the naphtha atmosphere reached the explosive range.

Naphtha could only have entered the No. 4S ballast tank as a result of either a failure in the ballast system piping or a failure in a ballast tank bulkhead. Postaccident examinations conducted by the Coast Guard revealed that the weld around the ballast pipe penetration into the No. 4S ballast tank, the ballast piping, and the branch valve was tight; no evidence of naphtha was present. Thus, the ballast system piping did not provide a path for naphtha leakage into the tank.

The Safety Board also considered fractures resulting from metal fatigue, stress concentrations, corrosion, and laterally symmetrical damage in the Nos. 4P and 4S tanks as a source of naphtha entry into the ballast tank.

The operation of tank ships in general, including the SURF CITY, generally subjects the cargo block to certain stresses. The motions of the tank ship, in bending and in torsion in a seaway (working), and the tank ship's operational voyage cycle of half the trip in ballast (without cargo) and half the trip in cargo (without ballast) place the steel structure of the cargo block in a constant cycle of alternating loads. This operational cycle of repeated opposing loads and stresses, together with stresses caused by the repeated flexing of the steel structure can lead to fatigue fractures in the bulkheads and the structural strength members within the tanks.

Testimony indicated that in the SURF CITY, working appears to have had the greatest effect in the Nos. 4P and 4S ballast tanks. The conditions of bulkhead and structural strength members in the Nos. 4P and 4S ballast tanks, as reported by Coast Guard inspectors and the ABS surveyor before the accident, indicate that the aft area of the ballast tanks was an area of stress concentration within the cargo block. The Coast Guard hull inspector testified that the fractures he found in the transverse web frames, longitudinal stiffeners, and the upper horizontal girders were stress fractures.

When the former chief mate inspected the SURF CITY's ballast tanks in January 1990, he reported numerous new stress fractures, some along previous weld repairs, in the girders, frames, and stiffeners in the Nos. 4P and 4S ballast tanks. These new fractures had occurred less than 1 year following the previous ballast tank inspections and shipyard repairs in February 1989. He also found a previously unreported bulkhead patch in the No. 4S ballast tank on the aft transverse bulkhead in an area corresponding to the bulkhead fracture found in the No. 4P ballast tank. The testimony and reports from the previous chief mate, the ABs, and the Coast Guard indicate that the type and locations of fracturing found in the No. 4P ballast tank were laterally symmetrical to those found in the No. 4S ballast tank.

The facts concerning the material condition of the tanks, the location of the stress concentration, and the observations of the Coast Guard inspector who found the same condition on "all four of the 81,000 ton [dwt] vessels" (SURF CITY, CHESAPEAKE CITY, OCEAN CITY and SEA ISLE CITY) justify the conclusion that Gleneagle Ship Management Company, operator of the SURF CITY, should monitor the stress levels with strain gauges and determine their impact on the cargo block on the three 81,000 dwt tank ships still in service. Gleneagle should also conduct a detailed assessment of the material condition of the cargo block on board the tank ships CHESAPEAKE CITY, OCEAN CITY, and SEA ISLE CITY to determine the adequacy of cargo block design and implement any repairs or alterations necessary to improve the structural integrity of the cargo block to reduce the stress and the frequency of tank fractures. Furthermore, the Safety Board believes that the International Association of Classification Societies should be made aware of the circumstances of the accident as it relates to ship stress and its effect on the structural integrity of the cargo block.

After the accident, an on-scene examination of ballast tank No. 4S and the three common cargo tank bulkheads bordering the ballast tank disclosed that the upper bulkhead sections were severely damaged or completely destroyed. The severity of the damage sustained by these bulkheads precluded Safety Board

investigators from determining the location of preaccident fractures and potential source(s) of entry for the naphtha into the ballast tank.

During the SURF CITY's tow to Sembawang drydock, the master found fractures in the bulkhead between No. 4S ballast tank and No. 5S cargo tank. When the tank ship was in drydock, a Coast Guard resident inspector identified these same bulkhead fractures and also noted additional fractures in the No. 4S ballast tank stiffeners. Although the Coast Guard inspector could not determine whether the bulkhead fracturing occurred before or after the explosion, he stated that they appeared to be typical stress fractures. Testimony and documentation show that the SURF CITY had a history of such fractures in Nos. 4S and 4P ballast tanks. Therefore, the Safety Board concludes that a fracture in the transverse bulkhead between No. 5S cargo tank and No. 4S ballast tank was the most probable source of entry for the naphtha into the ballast tank.

Possible Ignition Sources.--The explosion and fire on board the SURF CITY did not result from adverse weather. As reported by naval vessels in the area, the weather was clear and seas were calm. Moreover, no lightning had been reported in the area. Safety Board investigators also discounted static electricity as a causal source of combustion because the potential sources of static electricity -- the spraying of naphtha into the tank via a fracture in the internal structural steel or the movement of clothing on the human body -- would not be sufficient to generate an electrostatic incendive spark. Based on findings from laboratory testing, the Safety Board concluded that the Dasic Jetfan was probably not the source of ignition.

Several ignition sources in the No. 4S ballast tank could have created a mechanical spark:

- metal-to-metal impact from an object such as a dropped mirror, tool, or meter striking a structural member in the tank.
- metal-to-metal impact from the steel ELSA air bottle striking the trunk access opening to the tank.
- metal-to-metal impact from the steel bucket striking a structural member in the tank.
- metal-to-metal contact from a detached stiffener which had separated along its weld striking another structural member in the tank.
- metal-to-metal friction from the faces of a structural steel fracture rubbing together and producing heat.
- energy release from fracture development and propagation in the tank's internal structural steel.

The only known electrical source within the No. 4S ballast tank was the tank level indicating system. Investigators could not test the actual system on the SURF CITY because of the severity of damage to the guide pipeline. However, the design and construction of the system indicated that it was incapable of generating sufficient energy to ignite an explosive vapor. Safety Board investigators found no evidence to the contrary.

The Safety Board also considered the following external sources of ignition to the No. 4S ballast tank:

- o spark or flame entry from the cargo control room via the ballast tank remote draft gauge manometer piping.
- o an uncontrolled ignition source from the deckhouse or maindeck.

Possible Scenarios.--Because the master died and the chief mate is still missing and is presumed dead, the Safety Board cannot identify the exact ignition source of the explosion. Based on eyewitness testimony and evidence found during the course of our investigation, the Safety Board offers the following scenarios describing potential causes of explosion from internal ignition sources.

Scenario 1.--During the time that the master and the chief mate first checked the No. 4S ballast tank, witnesses reported seeing them holding a metal mirror and a tool and/or meter. The boatswain, who admitted that he did not continuously watch the chief mate and the master, last saw them close to the access trunk. He stated that he saw the chief mate adjusting his ELSA in preparation to reenter the No. 4S ballast tank. The boatswain could not see whether the chief mate had anything, such as a metal mirror, tool, oxygen analyzer, or explosive meter, in his hands. Although no one actually saw the chief mate or the master lean over the access trunk opening, one of the men could have dropped a metal object into the tank, which could have created a mechanical spark that ignited the naphtha vapors.

Scenario 2.--The opening inside the ballast tank trunk was only 1.9 feet by 2.3 feet. The boatswain stated that he saw the chief mate adjusting the ELSA, which is equipped with a steel bottle, before attempting to reenter the tank. After the accident, Navy divers recovered the ELSA vest without its steel air bottle attached to the back panel. When the chief mate entered the tank through the narrow trunk opening, he could have scraped the ELSA's steel air bottle against bare metal, creating a spark that ignited the tank's atmosphere. Expanding gases that preceded the flame front lifted the tank top, shielding the ELSA vest and plastic hood from flame impingement and heat damage. The force of the explosion threw the chief mate and the master from the ship.

Scenario 3.--The last time the SURF CITY was in the shipyard, a worker inadvertently left a steel bucket in the No. 4S ballast tank. After deballasting, the bucket came to rest on a horizontal stiffener in the tank. On the day of the accident, vessel movement was sufficient to cause the bucket, which was attached to the remote draft gauge pipeline, to fall from the stiffener and strike a structural member in the tank, creating the spark that ignited the explosion. The resulting gaping hole, which spanned the entire length of the ballast tank, and the rapid inrush of sea water into the tank submerged the bucket

and line to which it was attached and protected it from any flame or heat damage.

Scenario 4.--An ABS surveyor discovered during his examination in May 1988 that a vertical stiffener under the upper horizontal girder in the No. 4S ballast tank had separated from the after bulkhead at frame no. 52 along the vertical weld. When the steel faces of a fracture rub together, the friction can generate enough energy to cause a mechanical spark. Gleneagle had the fracture between the longitudinal stiffener and the bulkhead repaired following its discovery. Nonetheless, ABS surveyors and Coast Guard inspectors all noted the propensity of the SURF CITY to develop fractures of the same type and at similar locations. If a new fracture propagated in a location not associated with a bulkhead leak and/or the faces separated and struck one another, the impact could have created a spark that ignited the explosive atmosphere.[39]

In addition to the above metal-to-metal scenarios, the Safety Board discounted two other sources of ignition.

The former chief mate's handover notes stated that the mercury from the Nos. 4P and 4S ballast tank remote draft gauge manometer piping had been removed. The absence of the mercury from the manometer could conceivably have provided a path for flammable naphtha vapor to fill the pipe from the ballast tank to the cargo control room, where it could have been ignited. However, the Safety Board considers it highly unlikely that the ignition originated in the cargo control room because at the time of the explosion, the room was unmanned, locked, and none of the machinery was operating.

The boatswain testified that he saw fumes on deck and that the behavior of the master and the chief mate indicated that they were aware of the presence of naphtha fumes on deck. Also, the direction of the wind from port bow to the starboard quarter would have blown any naphtha fumes from cargo vents and from the No. 4S ballast tank past the deckhouse. Thus, if naphtha vapors had been ignited at or near the deckhouse, there would have been a path for the flame to the open trunk. Neither the No. 4S access trunk nor the two open Butterworths had a flame screen covering the openings that could have prevented flame passage into the tank. Vapors, unless trapped by deck structures, are usually diluted below the LEL within a few feet of travel in the open air, especially if the vapors are venting by natural convection. Except for the two officers on deck and the bridge watch, all other personnel were within the deckhouse and not performing outside work. Therefore, the Safety Board concludes that no uncontrolled flame source from the deckhouse or maindeck caused this explosion. Although the specific ignition source could not be identified, the Safety Board concludes that the most likely source was within the ballast tank.

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[39]The Safety Board recognizes that if the fracture was in a cargo bulkhead and naphtha cargo leakage through the fracture was sufficient to lubricate the fracture faces, the energy release would either be cooled, quenched, or eliminated by the lubricating effect of the naphtha. Further, the weather was calm and probably would not have created the violent movement of the tank bulkheads necessary to generate enough heat from rubbing to overcome the lubrication effect of the naphtha.

Tank Entry

On the morning of this accident, the chief mate indicated to his watchstanders that he intended to check out the inoperable draft sensors in the bottom of ballast tanks Nos. 4P and 4S. The chief mate directed two ABs to install air blowers on the tank openings. When he tasked the seamen to install the ventilators, the chief mate did not advise them to follow any special precautions or be alert for the smell of fumes. Although all the seamen on the work party recalled noticing a faint naphtha odor when the access trunks were opened, they said they discounted the fume smell because they were downwind from the cargo tank vents. As a result, they did not report the naphtha smell to either the master or the chief mate.

Title 46 CFR 35.30-10 requires that the "senior member of the crew on duty" shall be present when cargo tank hatches, ullage holes, or Butterworth plates are opened or remain open without flame screens, unless the cargo tank is gas free. Ballast tanks, cofferdams, or voids are not designated to carry cargo and therefore are not included in the regulation. Thus, the chief mate or the master were not required to be on deck when the crewmembers opened the deck fittings to the Nos. 4S and 4P ballast tanks before ventilating the tanks. Had the chief mate been on deck and present at the No. 4S ballast tank when the Butterworth plates and hatch were opened, he may have been alerted earlier that naphtha fumes were in the tank. Therefore, the Safety Board believes that general safety rules should be revised to require that the senior member of the crew be present when any hatch or Butterworth plate on any enclosed space within the cargo block is opened.

Witnesses could not say whether either the master or the chief mate was aware that the ballast tank was contaminated with naphtha. Neither the chief mate nor the master was on the main deck during the tank opening operations. They did not exercise oversight of the ventilation of the ballast tanks. By his actions, it would seem that the chief mate's initial intent was simply to ensure the tanks had enough oxygen to permit safe entry. The fact that both he and the master quickly withdrew when they peered into the No. 4S ballast tank indicates that they probably first became aware of the contamination at that time.

Although the master and the chief mate recognized that the tank atmosphere was not safe for entry without a breathing apparatus, witnesses did not see anyone test the tank atmosphere for flammability or safe levels of oxygen. After one descent into the tank, the chief mate returned to the deck. He and the master then removed the fans and used mirror(s) to reflect sunlight into the tank in an apparent attempt to locate the naphtha leak.

The KOTC safety manual at Chapter 7.1 provided guidance for preparing a tank for entry, but neither the master nor the chief mate adhered to these procedures. Testimony indicates that the actions of chief mate and the master fostered a casual attitude during the tank opening and ventilation operations. For example, the work party testified that while the two fans on the starboard ballast tank were connected using an electrically bonded rubber hose, one of the two air ventilators on the port ballast tank was connected using two coupled hoses that were not electrically bonded. The work party also stated that they did not use a continuity meter to test any of the blowers or hose arrangements for proper grounding. The work party reportedly told the chief mate about the ungrounded hose, but the chief mate took no exception.

The following actions by the chief mate and the master also showed a lack of knowledge or concern related to safety precautions appropriate when personnel on tankers of crude oil and petroleum products enter confined or enclosed spaces:

- Failure to properly test the atmosphere within the No. 4S tank before using the blowers to determine whether any flammable vapors or sufficient oxygen were present. The chief mate apparently assumed that the tank was deficient in oxygen and did not consider the possibility of a cargo leak into the ballast tank when he ordered the ABs to ventilate it with fans.

- Failure to advise the bridge watch or provide the work party with specific instructions in the event of gas odor during ventilation.

- Failure to immediately stop the fans and seal the No. 4S ballast tank when they detected naphtha odors before taking any further action concerning tank entry.

- Failure to have sufficient personnel on deck during tank entry; the manual required a minimum of three persons. In this accident, it may have resulted in a greater loss of life.

- Failure to have a spare breathing apparatus and a safety line.

- Misuse of the ELSA, which was designed for escape from a nonbreathable atmosphere, not for entry into a nongasfree or suspect tank.

- Misuse of the Jetfan 125, which the chief mate allowed to be operated without adequate grounding; in addition, electrical continuity was not tested prior to use as recommended by Dasic Marine.

Safety Board investigators could not find documentation showing that the master received any formal training in proper tank entry procedures. Tank entry is usually part of the curriculum of other courses concerning inert gas systems, tank cleaning, and inspection of tanks. The chief mate did receive such training in 1984 as part of crude oil washing and inert gas operations training at MITAGS. The master and the chief mate were also tested in tank vessel safety topics by the Coast Guard for their third, second, and chief mate licenses. Whether either of them received additional on-the-job training is not indicated in their employee files. Regardless, they ignored any training and were complacent when opening, ventilating, and entering the ballast tanks. They were quite likely aware of the danger of entering a tank deficient in oxygen, as evidenced by the attempt to ventilate it and the donning of an ELSA breathing device, however inappropriate that device was for tank entry. Furthermore, had they tested the No. 4S ballast tank for explosive levels before ventilating, other actions may have been taken and the accident might have been avoided.

In retrospect, at the first sign of gas odor, the prudent course of action would have been to shut off the blowers and close the tank openings. The master and the chief mate should have contacted the tank ship's offices ashore to alert them of conditions in the ballast tank and awaited instructions. After taking these

precautions, they should not have attempted to enter the ballast tanks until the adjacent cargo tanks were off loaded and the ballast tanks were gas freed.

Guidance for Tank Entry

Guidance in Chapter 7, "Entry into Confined Spaces," of the KOTC Safety Manual discusses oxygen deficiency and toxic vapors but does not state that a person should test for an explosive atmosphere before entering or ventilating a space. Chapter 10, "Entry into and Work in Enclosed Spaces," of the ISGOTT guide discusses gas tests before entry; it also identifies what levels are safe for entry but does not provide any guidance about when to ventilate or not to ventilate a confined space. As this accident demonstrates, these guides would be more useful if both stated clearly and emphatically that prior to entry or ventilation, one should always consider any tank potentially hazardous and test it first for explosive levels and then for oxygen levels. They should also specify what to do, including contacting company management before ventilating, if a tank is found to contain explosive vapors. The guides should also include the rationale for the above procedures.

Safety articles in the Coast Guard's bimonthly publication, "Proceedings of the Marine Safety Council," reach a limited audience and do not have a sustained impact over time. Providing guidelines to shipboard personnel in a pamphlet could be ineffective because the booklet could be misplaced. Even though the Coast Guard regulations incorporate National Fire Protection Association (NFPA) Standard No. 306 for pier-side repairs or inspection work, the Safety Board believes that procedures for tank entry should be included in the tank vessel regulations. The regulation should also contain a requirement for the senior responsible officer to make an entry in the vessel's log or other record stating that tests for explosive and oxygen levels have been performed and that rescue equipment and team are in place before tank entry is attempted. Moreover, the regulations should contain guidelines to follow in the event cargo vapors are found in noncargo tanks.

Inert Gas System Protection

Current U.S. and international regulations mandate an inert gas system for cargo and slop tanks only. To date, segregated ballast tanks, cofferdams, and voids are not subject to the same requirements because they do not carry cargo. However, because segregated ballast tanks border cargo tanks within the cargo block, a fracture resulting from corrosion, stress, or fatigue could provide a path for flammable cargo to enter the ballast tank and create an explosive atmosphere.

A tank ship with volatile cargo in its ballast tanks constitutes a very dangerous threat to its crew, other nearby vessels and structures, and the environment. The crew has very few options for removing the threat. If the tank atmosphere is uniformly below the LEL and leakage into the tank remains very small, then continuous ventilation may be sufficient to keep it safe. If the tank atmosphere is flammable or above the UEL, any attempt to ventilate the tank will be very dangerous because the air injected into the tank will bring the over rich hydrocarbon/air mixture into the explosive range.

Because undetected failures in tank boundaries can permit leakage of volatile cargo into adjacent ballast tanks within the cargo block or into areas that are served by ballast piping that passes through cargo tanks, such ballast tanks should be protected by the inert gas system. Installation of the required inert gas system for the cargo tanks is a major construction cost in building a tankship. Inclusion of

ballast tanks in the inert gas system is inexpensive because it requires only the addition of a limited amount of branch line piping and valves. Therefore, expansion of the inert gas system to include the ballast tanks would have minimal economic impact on the vessel owner or operator. The Safety Board believes that the Coast Guard should revise the inert gas regulations to include ballast tanks located within the cargo block. Further, the Safety Board believes that risk to the crew, the vessel, and the environment also exists on tank ships internationally and that the Coast Guard should encourage the International Maritime Organization to include ballast tanks in the inert gas system on tank ships.

As on other tank ships, the SURF CITY's ballast piping was routed through the center cargo tanks, and branch pipe lines extended to port and starboard into the ballast tanks. In the cargo tanks, cargo surrounded the ballast pipeline, which was subject to cargo head pressure. A failure in the ballast pipe line can also provide a path for cargo entry into the ballast tanks. The Safety Board believes that Coast Guard and international regulations should prohibit the routing of ballast piping through cargo tanks and cargo piping through ballast tanks.

Firefighting Equipment Operation and Access

Crewmembers testified that the conflagration was beyond the ability of the fire main/foam system to control. Whether any firefighting attempts by crewmembers would have succeeded is doubtful, considering the rapidly deteriorating survival conditions on deck. Nonetheless, the primary problem in this accident was that the crew could not operate the tank ship's main deck firefighting system because they could not reach the monitors to activate them.

Specifically, the port and starboard fire monitors on the tank top above the port and starboard slop tanks were in a position of risk, subject to damage and heat exposure from an explosion or fire in the area of the after cargo and fuel oil tanks. Had remote controls (open/close valves) been located in the fire control room to supply foam to individual fire foam monitors on deck, the crew could have attacked the fire from a protected position. Fire monitors aft and above the cargo block could have provided the crew with a means to fight the fire and could have allowed the crew to cool the cargo tank tops on the port side and thereby reduce cargo vapors which were feeding the fire. The fire in this accident was too intense for the crew to fight; however, on a smaller fire, remote operation of the fire monitors could be helpful in controlling a fire, preventing further damage, and providing protection to the crew.

Based on a review of the circumstances in this accident, the Safety Board believes that fire control systems on tankships carrying volatile cargoes should incorporate the following elements:

- Individual control valves in the protected fire control room to supply and control water and foam for each fire foam monitor.
- A fire foam monitor on an elevated platform aft of the cargo block on both sides of the vessel.

Survival Aspects

The crew had to abandon the tank ship in a traditional open lifeboat and were exposed to burning cargo, which was being released in the tank ship's wake. As a

result, seven crewmembers suffered radiant heat burns due to lack of thermal protection. When the lifeboat's propulsion system became partially disabled by a steel gripe cable wound around the propeller shaft, exposure time to the burning cargo was increased.

On November 10, 1977, as a result of its investigation of the collision of the U.S. tank ship EDGAR M. QUEENY and the Liberian tank ship CORINTHOS,[40] the Safety Board issued the following recommendation to the Coast Guard:

> M-77-35
>
> Develop and promulgate specifications for an enclosed fire safe, self-contained lifeboat for installation aboard oceangoing vessels of 10,000 or more deadweight tons.

On April 13, 1978, the Coast Guard responded that they agreed with the recommendation and were proceeding with action to achieve such an objective. The Coast Guard's action resulted in the 1983 amendments to the 1974 SOLAS Convention. The Safety Board found this action "acceptable" toward fulfilling Safety Recommendation M-77-35, but the recommendation was never officially closed. The Safety Board now classifies Safety Recommendation M-77-35 as "Closed--Acceptable Action" based on the 1983 amendments to SOLAS '74.

Under the 1983 amendments to the 1974 SOLAS Convention, Chapter III, Regulations 46-1 and 48-1.2 and .4, totally enclosed lifeboats are mandatory on tank ships constructed on or after July 1, 1986, and must be capable of being launched without anyone having to leave the lifeboat. Additionally, under the 1983 amendments to Chapter III, Regulation 41-6.7, "All lifeboats shall be designed with due regard to the safety of persons in the water and to the possibility of damage to the propulsion system by floating debris." The Safety Board notes that under SOLAS '74, as amended, the SURF CITY'S lifeboats were not required to be enclosed or to have propulsion system protection because the SURF CITY was built in 1981 and therefore was not subject to the latest SOLAS lifeboat requirements.

If the boatswain had not remained on the burning tanker and lowered the lifeboat, there would have been no safe means for the craft to enter the water. Because the vessel was built before July 1, 1986, it was not required to have lifeboats that could be launched or lowered from within the craft. The boatswain was apparently injured while attempting to abandon ship after the lifeboat was waterborne. The Safety Board believes that all tank ships, regardless of the date of construction, should be equipped with covered lifeboats that are capable of being lowered to the water from within the craft and without the need for an individual to risk personal harm by remaining on board the ship to actuate the lowering mechanism.

Events that occurred during the lifeboat deployment following the SURF CITY explosion and fire suggest that crewmembers would not have been injured had the lifeboat met those requirements. In view of the large number of tank ships currently equipped with open lifeboats, the risks to crewmembers during an evacuation from

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[40] "SS EDGAR M. QUEENY - S/T CORINTHOS, Collision at Marcus Hook, Pennsylvania on 31 January 1975 with Loss of Life" (USCG/NTSB MAR-77-2(J)).

a burning tank ship will be present until all tank ships are provided with covered lifeboats. This accident suggests that the International Maritime Organization and the Coast Guard need to develop a lifeboat retrofit or replacement program for tank vessels that were built before July 1, 1986, so that older tank ships will have lifeboats that meet current international standards.

CONCLUSIONS

Findings

1. The explosion and fire in the No. 4 starboard ballast tank did not result from adverse weather or from an external incendiary device.

2. Based on three independent crew observations, naphtha vapor was present in the No. 4 starboard ballast tank when the tank accesses were opened.

3. The most likely source of naphtha entry into the No. 4 starboard ballast tank was a fracture in the common bulkhead with the No. 5 starboard cargo tank which contained naphtha.

4. Possible sources of ignition resulting from metal-to-metal impact included a metal mirror, tool, or meter dropping into the tank; a steel Emergency Life Support Apparatus bottle scraping against the side of the access trunk; a steel bucket striking a structural member or side of the tank; or a fracture of a structural member. Because of the extensive damage, the Safety Board could not determine the exact source.

5. Tests, research, and examination of damage indicated that the ventilation fans, cargo piping, ballast piping, draft gauge piping, and tank level piping were unlikely sources of ignition.

6. The inert gas system was effective in preventing the fires and explosions from spreading to the tank ship's forward cargo tanks. If the No. 4 starboard ballast tank had been inerted, this accident might have been avoided.

7. Specific training in tank entry procedures could not be documented for the master; however, the master and the chief mate were aware of tank entry dangers, as evidenced by the attempt to ventilate the tank and donning a breathing apparatus.

8. The Kuwait Oil Tanker Company Safety Manual, International Safety Guide for Oil Tankers and Terminals, and U.S. Coast Guard regulations lack specific guidelines for ventilating and entering ballast tanks.

9. The location of the two fire monitors aft of the cargo tanks on the main deck subjected them to damage and to heat exposure from an explosion or fire.

10. The open lifeboat exposed the crew to burning cargo, which was being released from the ruptured cargo tanks.

11. The repeated fracturing in the aft area of the Nos. 4 port and 4 starboard ballast tanks indicates a structural design deficiency.

12. Despite being advised that the hose was not electrically bonded, the chief mate created a risk when he elected to use the fire hose to power the ventilating fan.

Probable Cause

The National Transportation Safety Board determines that the probable cause of the explosion and fire on the U.S. tank ship SURF CITY was the lack of adequate industry standards regarding ventilation and entry procedures into ballast tanks. Also causal to the accident was the failure by the master and the chief mate to secure the forced ventilation and close the tank after becoming aware of the naphtha in the ballast tank.

RECOMMENDATIONS

As a result of its investigation of this accident, the National Transportation Safety Board made the following recommendations:

--to the U.S. Coast Guard:

Require guidance for crewmembers to use before ventilating or entering cargo tanks, ballast tanks, cofferdams, and voids immediately adjacent to or within the cargo block on tank vessels. (Class II, Priority Action) (M-92-9)

Amend Title 46 Code of Federal Regulations Section 35.30-10, "Cargo tank hatches, ullage holes, and Butterworth plates," to include ballast tanks, cofferdams, and voids in addition to cargo tanks. (Class II, Priority Action)(M-92-10)

Require that the fire control system on each tank vessel have individual controls in the protected fire control room to supply and control water and foam to each fire foam monitor. (Class II, Priority Action) (M-92-11)

Determine the best location, set standards, and implement requirements for port and starboard fire foam monitors aft of the cargo block on tank vessels. (Class II, Priority Action) (M-92-12)

Amend Title 46 Code of Federal Regulations to prohibit the routing of ballast piping through cargo tanks and cargo piping through ballast tanks on tank ships. (Class II, Priority Action) (M-92-13)

Propose that the International Maritime Organization revise SOLAS '74, as amended, to prohibit the routing of ballast piping through the cargo tanks and cargo piping through the ballast tanks on tank vessels. (Class II, Priority Action) (M-92-14)

Revise Title 46 Code of Federal Regulations Section 32.53-5, "Inert Gas System Operation," to require that ballast tanks located within the cargo block on tank vessels be included in the Inert Gas System. (Class II, Priority Action) (M-92-15)

Propose that the International Maritime Organization revise SOLAS '74, as amended, to require that ballast tanks located within the cargo block be included in the Inert Gas System. (Class II, Priority Action) (M-92-16)

For tank ships built before July 1, 1986, develop a lifeboat retrofit or replacement program to require that lifeboats be totally enclosed, have propeller guards, and be launchable from within the craft. (Class II, Priority Action) (M-92-17)

Propose that the International Maritime Organization develop a lifeboat retrofit or replacement program for tank vessels built before July 1, 1986, requiring that lifeboats be totally enclosed, have propeller guards, and be launchable from within the craft. (Class II, Priority Action) (M-92-18)

Disseminate to all Coast Guard marine safety units information about the nature and circumstances of this accident so that they can identify similar safety hazards on other tank vessels. (Class II, Priority Action) (M-92-19)

--to the International Chamber of Shipping:

Revise the 1988 "International Safety Guide for Oil Tankers & Terminals" to include clear instructions that ballast tanks, cofferdams, and voids located in or immediately adjacent to the cargo block should be tested before tank entry for explosive levels and for oxygen levels to determine the condition of the tank atmosphere and procedures to follow before ventilating a tank. (Class II, Priority Action) (M-92-20)

--to the International Association of Classification Societies:

Review the circumstances of this accident as it relates to stress and its effects on the structural integrity of the cargo block on tank vessels and disseminate this information to your member societies. (Class II, Priority Action) (M-92-21)

--to the Gleneagle Ship Management Company Inc.:

Revise the "Kuwait Oil Tanker Company Safety Manual" and relevant safety procedures on all your tank ships to explicitly require that all ballast tanks, cofferdams, and voids located in or immediately adjacent to the cargo block be tested before tank entry for explosive levels and for oxygen levels to determine the condition of the tank atmosphere and procedures to follow before ventilating the tank. (Class II, Priority Action) (M-92-22)

Disseminate to all company tank ship officers information about the nature and circumstances of this accident in order to alert them to potential safety hazards of ventilating ballast tanks. (Class II, Priority Action) (M-92-23)

Develop and implement a program to monitor the stress levels in the cargo block on the CHESAPEAKE CITY, OCEAN CITY, and SEA ISLE CITY; to analyze the information obtained; and to implement any repairs or alterations necessary to improve the structural integrity of the cargo block. (Class II, Priority Action) (M-92-24)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

SUSAN M. COUGHLIN
Acting Chairman

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Member

CHRISTOPHER A. HART
Member

JOHN A. HAMMERSCHMIDT
Member

JAMES L. KOLSTAD
Member

March 31, 1992

APPENDIXES

APPENDIX A

INVESTIGATION

The National Transportation Safety Board was notified of this accident by the U.S. Coast Guard on Thursday, February 22, 1990. Three investigators from the Safety Board's Washington, D.C., headquarters were dispatched on February 25, 1990, to New York, New York, to commence the investigation when the vessel's crew arrived from the Persian Gulf on February 26, 1990.

This accident was investigated jointly by the Safety Board and the Coast Guard. Public hearings were held at the U.S. Coast Guard Marine Inspection Office, Battery Park Building, New York, New York, from February 28 to March 2, March 6 to March 9, and May 9 to May 10, 1990. Testimony was also taken in Tampa, Florida, on March 7, 1991. From April 22 to May 2, 1990, Safety Board and Coast Guard investigators boarded and examined the SURF CITY in its damaged condition while it was anchored off Fujairah, U.A.E. This report is based on the factual information developed as a result of the investigation and on additional analyses made by the Safety Board. The Safety Board has considered all facts in the investigative record that are pertinent to its statutory responsibility to determine the cause or probable cause of the accident and to make recommendations. The Safety Board has made its analyses and recommendations independently of the Coast Guard.

The following parties participated in the investigation: the Chesapeake Shipping, Inc., owner of the SURF CITY; the Gleneagle Ship Management Company, operator of the SURF CITY; the Kuwait Oil Tanker Co., charterer of the SURF CITY (one person represented the owner, operator, and charterer); the International Organization of Masters, Mates, and Pilots, the union representing the vessel's licensed and unlicensed personnel; the estate of the master of the SURF CITY; and the estate of the chief mate of the SURF CITY.

APPENDIX B

CREW INFORMATION

Derric F. Linardich

Captain Derric F. Linardich, 38, master of the SURF CITY, joined the vessel on January 11, 1990, in Spain. Since March 1982, he had held a license issued by the U.S. Coast Guard that qualified him to serve as master of ocean steam and motor vessels, any gross tons, with a radar observer's endorsement. He graduated from the State University of New York Maritime College in 1973 and had sailed since 1973. He obtained his chief mate license on September 5, 1977. He had been employed as master on seven Military Sealift Command (MSC) vessels between 1975 and 1989, when he resigned from Federal service and was hired as master of the SURF CITY.

Steven P. McHugh

Steven P. McHugh, 34, chief mate on the SURF CITY, joined the vessel on February 3, 1990, in Egypt. He held a license issued by the U.S. Coast Guard that qualified him to serve as master of ocean steam and motor vessels, not more than 1,600 gross tons, and chief mate of ocean steam and motor vessels, any gross tons, with a radar observer's endorsement, since September 8, 1989. He graduated from the Massachusetts Maritime Academy in 1977 and obtained a second mate license on April 16, 1984. He had been employed in various licensed positions up to and including second mate on freighters and tankers since 1977. On April 20, 1984, he completed a tanker course in Crude Oil Washing and Inert Gas Operations at the Maritime Institute of Training and Graduate Studies, a Master, Mates, and Pilots Union school in Maryland.

Robert C. Richardson

Robert C. Richardson, 59, chief engineer on the SURF CITY, joined the vessel on November 12, 1989, in Khorfakkan, U.A.E. He held a first class certificate for unlimited horsepower for steam or diesel machinery, issued by the British Board of Trade, that qualified him to serve as chief engineer on steam or motor vessels. He had sailed for about 5 years, including 1 year after obtaining his first class certificate, before going ashore when he was about 26 years old. He went back to sea from the late 1960s until about 1982 and again when he signed on the SURF CITY.

Kenneth N. Gaito

Kenneth N. Gaito, 26, second mate on the SURF CITY, joined the vessel on January 11, 1990, in Spain. He held a license issued by the U.S. Coast Guard that qualified him to serve as master of ocean steam and motor vessels, not more than 1,600 gross tons, and second mate of ocean steam and motor vessels, any gross tons, with a radar observer's endorsement. He was a graduate of the Texas A & M Maritime Academy and had about 3 1/2 years of sea experience, including about 6 months on the SEA ISLE CITY, a sister ship of the SURF CITY.

Douglas J. Nagy

Douglas J. Nagy, 25, third mate on the SURF CITY, joined the vessel on January 11, 1990, in Spain. He held a license issued by the U.S. Coast Guard that qualified him to serve as third mate of ocean steam and motor vessels, any gross tons, with a radar

observer's endorsement. He graduated from the California Maritime Academy in 1989 and had sailed 4 months on another tank ship managed by Gleneagle before joining the SURF CITY.

William W. Sanderson

William W. Sanderson, 64, radioman on the SURF CITY, joined the vessel on January 11, 1990, in Spain. He held a second class radio telegraph issued by the Federal Communications Commission and a radio officer license issued by the U.S. Coast Guard that qualified him to serve as radio officer on board ships. He first sailed as radio officer in 1950 for about 2 years and then changed career. Since returning to sea in 1985, he had served as a radio officer on about two dozen ships before joining the SURF CITY.

Earl A. Washington

Earl A. Washington, 41, boatswain on the SURF CITY, joined the vessel on January 11, 1990, in Spain. He held a merchant mariners document endorsed as able seaman, unlimited, steward department and wiper. He had about 17 years of general at-sea experience and had served on more than a dozen tankers.

Jenriy Lizardo

Jenriy Lizardo, 24, held a merchant mariners document endorsed for the entry ratings of ordinary seaman, wiper, and steward department. He joined the SURF CITY on December 25, 1989, in Kuwait, as a utility steward, and on February 15, 1990, he was reassigned to ordinary seaman. The SURF CITY was the second ship and first tanker on which he had served.