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NATIONAL TRANSPORTATION SAFETY BOARD

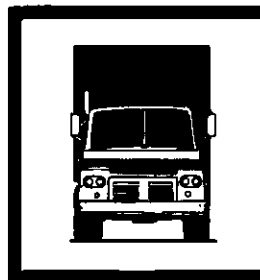
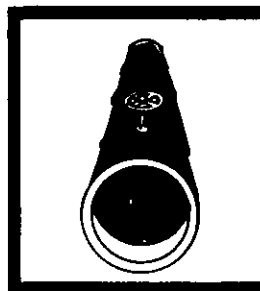
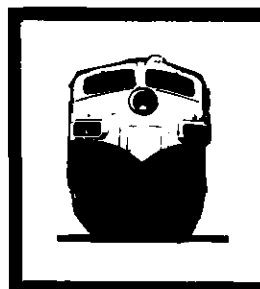
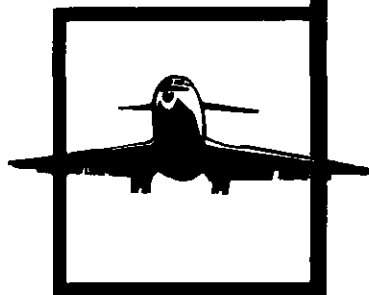
WASHINGTON, D.C. 20594

MARINE ACCIDENT REPORT

**EXPLOSION AND FIRE ONBOARD
THE U.S. MOBILE OFFSHORE DRILLING UNIT
GLOMAR ARCTIC II IN THE NORTH SEA,
130 NAUTICAL MILES EAST-SOUTHEAST
OF ABERDEEN, SCOTLAND
JANUARY 15, 1985**

NTSB/MAR-86/03

UNITED STATES GOVERNMENT



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<p>16. Abstract On January 15, 1985, the US semi-submersible mobile offshore drilling unit (MODU) GLOMAR ARCTIC II was conducting well testing operations 130 nautical miles east-southeast of Aberdeen, Scotland, in the North Sea. About 2030, the drilling unit experienced an explosion in the port pontoon pumphoom. The chief engineer and third assistant engineer were killed in the blast. Damage to the drilling vessel was estimated to be \$2.3 million dollars.</p> <p>The National Transportation Safety Board determines that the probable cause of the accident was the misassembly of the No. 3 crude oil burner nozzle assembly by the well test crew, which resulted in the fracture of the No. 3 crude oil burner tip. The fracture allowed flammable crude oil and gas hydrocarbons to be released into the port pontoon pumphoom, creating an explosive hydrocarbon atmosphere which was subsequently ignited by an electrical component in the pumphoom. Contributing to the fracture of the No. 3 burner tip was the improperly manufactured burner tip and the lack of adequate Otis Pressure Control Company maintenance and inspection procedures for the well test crew.</p>					
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Adopted: February 12, 1986

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INTRODUCTION

This accident was investigated by both the National Transportation Safety Board and the U.S. Coast Guard. The Safety Board conducted an onscene investigation between January 19 and February 1, 1985. This report is based upon the evidence developed by the investigation and analysis 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's analysis and recommendations are made independently of the Coast Guard. To inform the public of all Safety Board recommendations and the responses thereto, notices regarding the recommendations and the responses are published in the Federal Register.

SYNOPSIS

On January 15, 1985, the U.S. semi-submersible mobile offshore drilling unit (MODU) GLOMAR ARCTIC II was conducting well testing operations 130 nautical miles east-southeast of Aberdeen, Scotland, in the North Sea. About 2030, an explosion occurred in the port pontoon pumproom. The chief engineer and the third assistant engineer were killed in the blast. Damage to the drilling vessel was estimated to be \$2.3 million.

The National Transportation Safety Board determines that the probable cause of the accident was the misassembly of the No. 3 crude oil burner nozzle assembly by the well test crew, which resulted in the fracture of the No. 3 crude oil burner tip. The fracture allowed flammable crude oil and gas hydrocarbons to be released into the port pontoon pumproom, creating an explosive hydrocarbon atmosphere which was subsequently ignited by an electrical component in the pumproom. Contributing to the fracture of the No. 3 burner tip was the improperly manufactured burner tip and the lack of adequate Otis Pressure Control Company maintenance and inspection procedures for the well test crew.

INVESTIGATION

Events Preceding the Accident

The GLOMAR ARCTIC II (see figure 1), operated by Global Marine Drilling Company (Global Marine), had begun drilling its first exploratory oil well in the North Sea

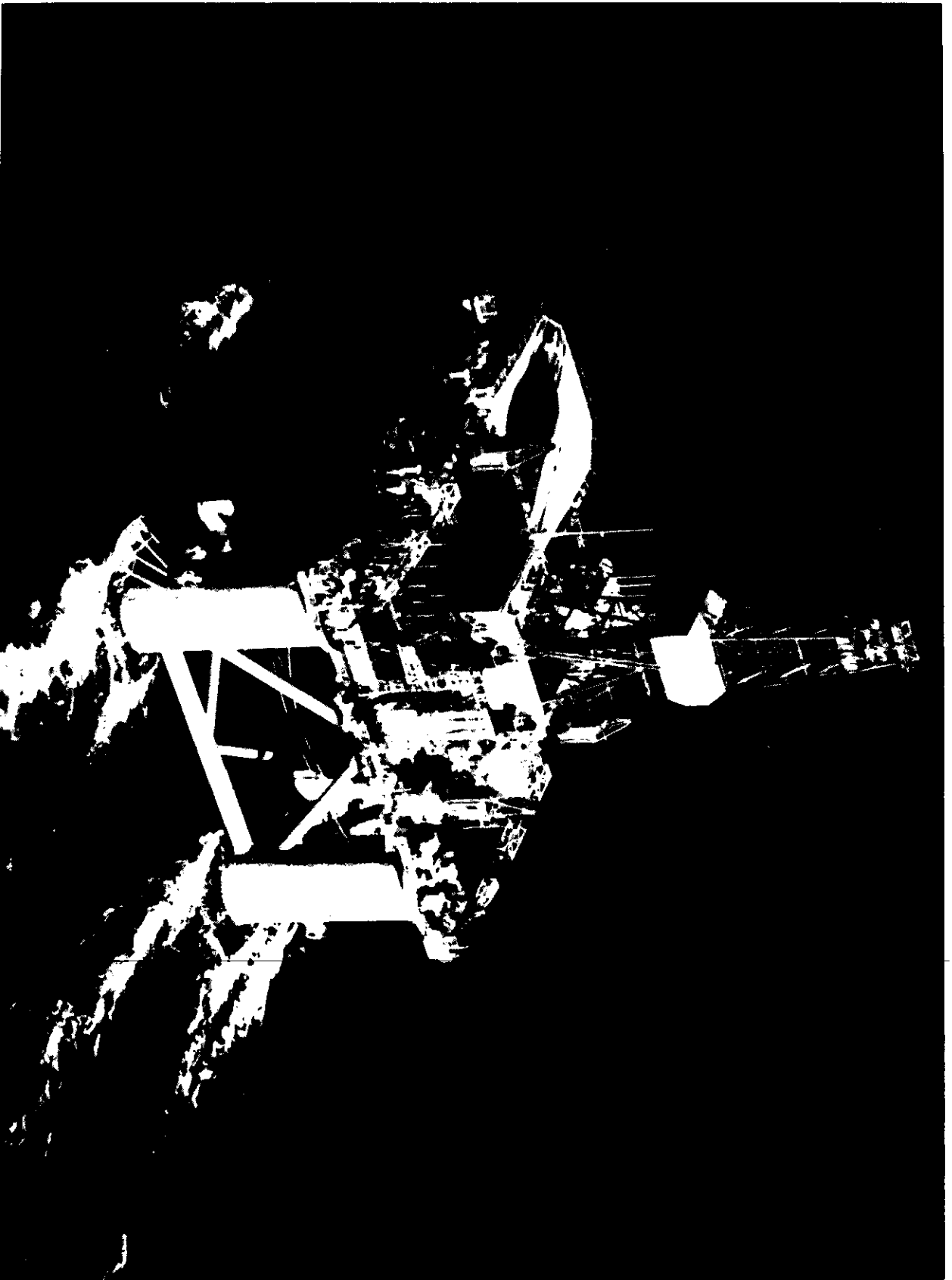


Figure 1.--The U.S. semi-submersible mobile offshore drilling unit
GLOMAR ARCTIC II.

on November 19, 1984, at a location 130 nautical miles east-southeast of Aberdeen, Scotland, under the provisions of a contract with Phillips Petroleum Company United Kingdom, Limited (Phillips). The GLOMAR ARCTIC II was moored in about 265 feet of water at 56°43' north latitude and 02°12' east longitude in an area known as the Joanne Oil Field on the United Kingdom's Continental Shelf. Drilling operations were suspended on December 19, 1984, while well testing was being conducted on an intermittent schedule to determine the production characteristics of the well. The well testing was conducted by Otis Pressure Control Company, Limited (Otis), in accordance with the provisions of a contract with Phillips.

At 1015 on January 9, 1985, well test No. 2 commenced. At 1300 on January 10, a member of the Otis well test crew opened the adjustable choke valve 1/ at the well test area on the drill floor of the MODU to allow the flammable crude oil and gas to flow from the well. (See figure A-1, appendix A.) While well fluid samples were being taken, the flammable crude oil and gas continued to flow under pressure through piping from the choke valve manifold to the port side crude oil burner where the flammable well fluids were ignited and consumed in flames. The port side crude oil burner unit was installed at the outboard end of the port burner boom which extends 70 feet outboard of the MODU. (See figure 2.)

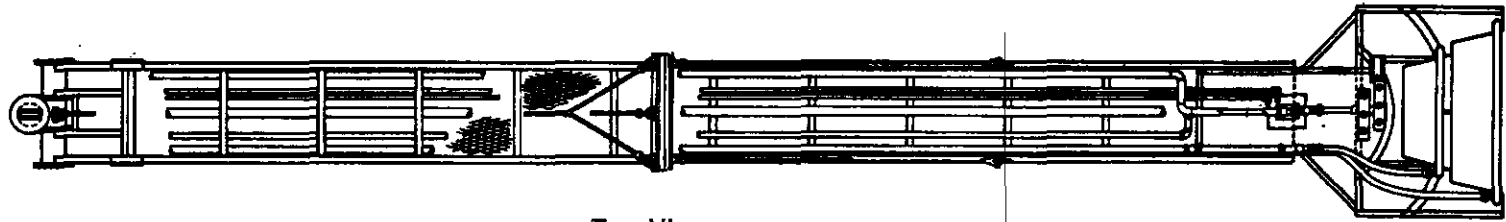
A member of the well test crew said that about 1305 the port crude oil burner oil flow was obstructed. The well test crew closed the choke valve which stopped the crude oil flow and drained the crude oil burner supply pipeline and then cleaned the three burner nozzle assemblies (see figure 3) on the port crude oil burner. Each burner nozzle was unscrewed and removed, including the Flexitallic compression gasket, 2/ and then the 20 atomizing air holes in each burner nozzle were cleaned. (See appendix B.) The burner tips (see figure 3-B), were removed as necessary so that petroleum wax and other well solids could be cleared by hand. Seawater was pumped into the system at the choke valve manifold and flushed through the crude oil supply pipe to the crude oil burners. The burner tips, Flexitallic compression gaskets, and burner nozzles then were reinstalled onto each nozzle assembly and the crude oil burner was ready for use. According to the Phillips Petroleum drilling supervisor, the procedure applied to the crude oil burners is the only maintenance performed by the well testing crew after testing has been suspended or stopped. The drilling supervisor also said that he was not aware of any user manual applicable to the burner nozzle assembly and that there was none aboard the GLOMAR ARCTIC II. Well test No. 2 resumed at 1700 on January 10 and continued until January 12 when an equipment malfunction caused the test to be terminated. At 2100 on January 13 well test No. 2A was begun.

The Accident

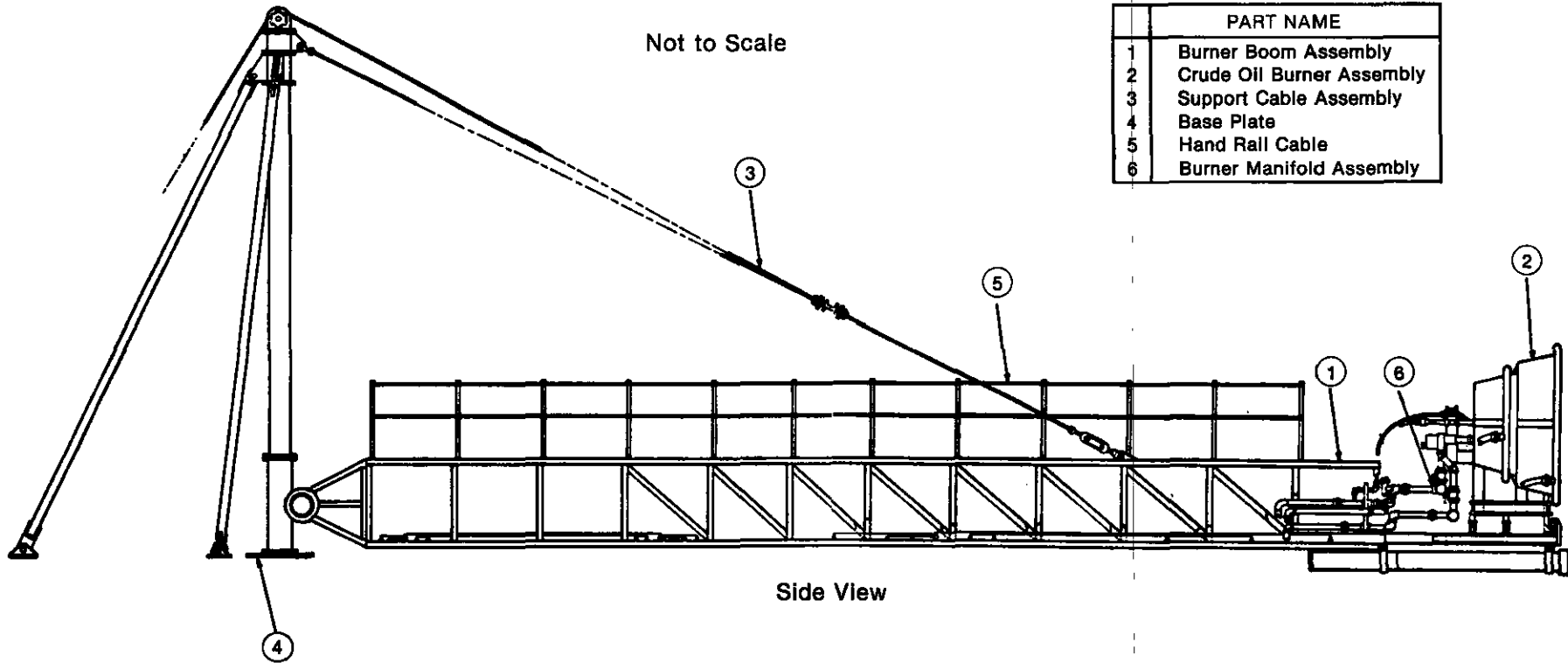
On January 15, well test No. 2A was still in progress. As instructed by the drilling supervisor, at 1950 the well test crew opened the adjustable choke valve from 1/4 inch to fully open at 1 inch in a 3-minute time span. The drilling supervisor stated that there was an extraordinary amount of noise caused by gas passing through the choke system. The drilling supervisor also stated that this well test (the crude oil/gas) was flowing fast compared with other tests on this well. Crude oil and gas flowed to the port crude oil

1/ Adjustable choke valve - a valve attached to the well piping which allows flow and pressure control of well fluids during well test operations.

2/ The Flexitallic compression gasket is a spiral-wound metallic asbestos gasket composed of alternate layers of dovetailed stainless steel ribbon, and strips of asbestos. Once the gasket has been compressed (crushed) in use it should not be re-used (Flexitallic Gasket Co., Bellmawr, New Jersey).



Top View



PART NAME	
1	Burner Boom Assembly
2	Crude Oil Burner Assembly
3	Support Cable Assembly
4	Base Plate
5	Hand Rail Cable
6	Burner Manifold Assembly

Side View

Figure 2.--Burner boom.

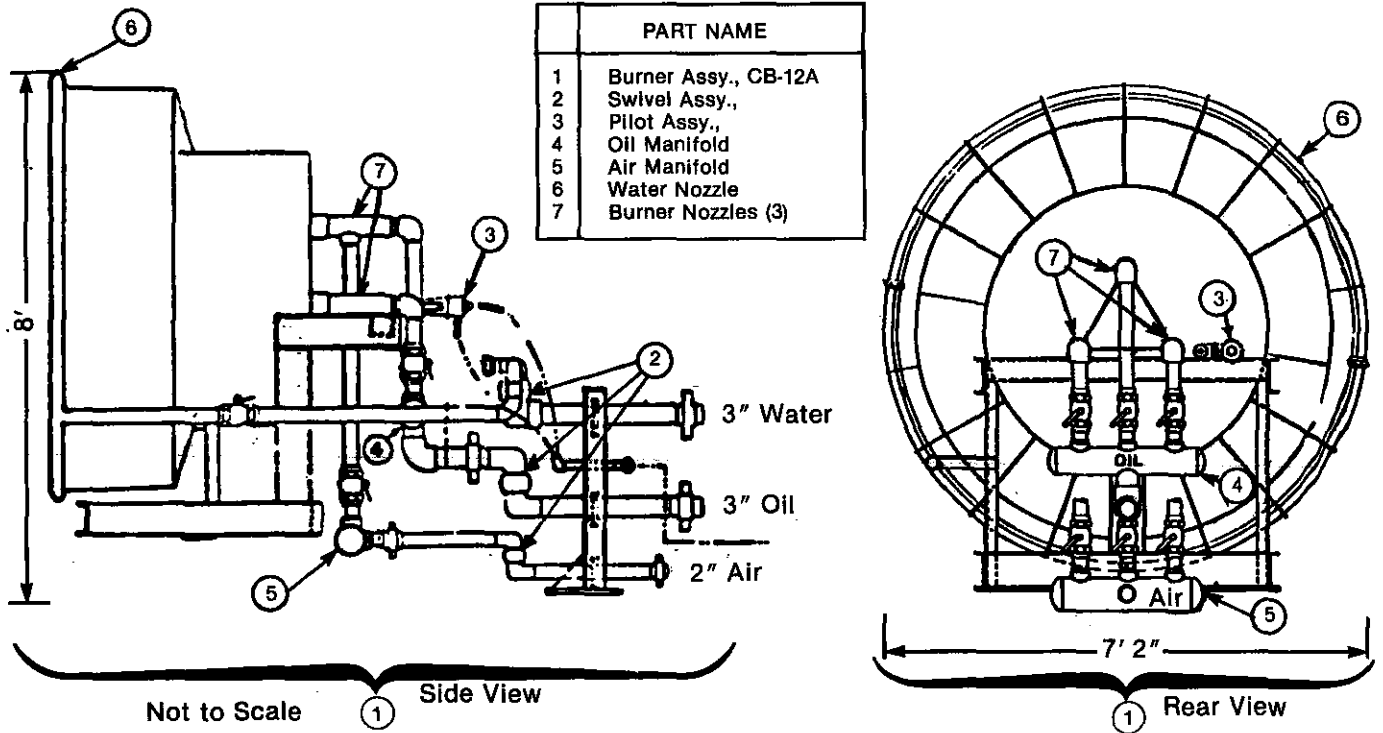


FIGURE 3-A—CRUDE OIL BURNER ASSEMBLY

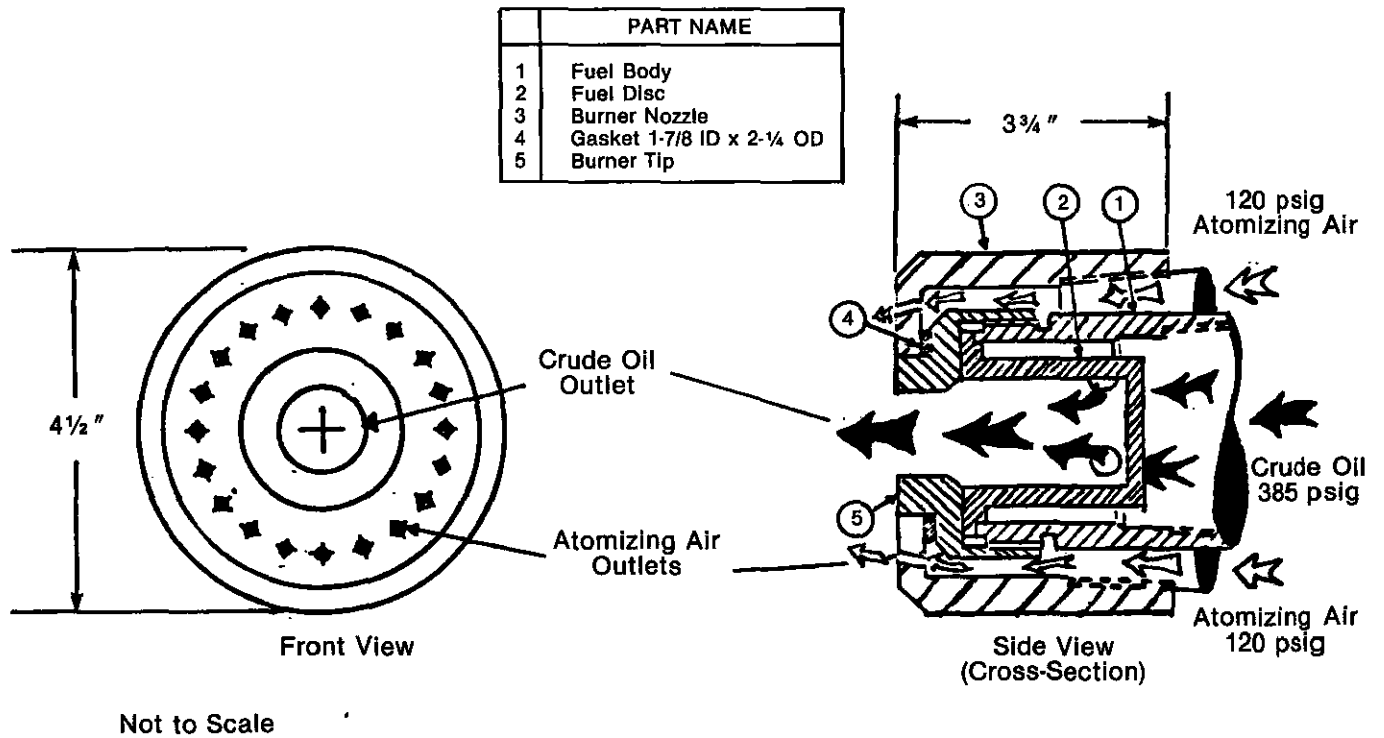


FIGURE 3-B—BURNER NOZZLE ASSEMBLY

Figure 3.--Crude Oil Burner & Nozzle Assembly.

burner where the fluids were ignited but soon went out. The drilling supervisor left the drill floor and went to the port crude oil burner to determine the problem. The well test crew re-lit the crude oil burner and the well test continued in the normal fashion. Crude oil pressure in the well was 2,450 psig. This pressure was reduced to 385 psig flowing to the burner. Atomizing air pressure to the burner was 120 psig. The drilling supervisor returned to the drill floor and, upon entering the drillers house, he could smell the odor of hydrocarbon gas. At 2010, a low-level automatic methane gas alarm ^{3/} in the drillers house sounded and within 2 minutes, the high-level alarm sounded. The automatic methane gas alarm was installed in the exhaust vent duct in the overhead of the drillers house and had sensed methane gas in the drillers house atmosphere. However, none of the other eight methane gas alarms located on the main deck, the cellar deck, or the drill floor had sounded. The drilling supervisor said that he left the drillers house and attempted to locate the source of the gas, but he could not. He then climbed onto a platform (cellar deck) under the drill floor and did not smell any gas. Suspecting that gas was coming from the crude oil burner, he went to the portside main deck near the burner boom but still did not smell hydrocarbon gas. The drilling supervisor said that when he returned to the drillers house, the odor of hydrocarbon gas was still present. (See figures A-1 and -2, appendix A.)

Also at 2010, a methane gas alarm monitor on the ballast control room console (see appendix A-2) was activated indicating the active alarm in the drillers house. The ballast control operator immediately telephoned the master's office and informed the master of the low-level methane gas alarm. The master left his office and, as he passed by the Global Marine toolpusher's office, asked the toolpusher if he was experiencing any problems with the well testing program. The toolpusher responded that he was not aware of any problems. The master and the toolpusher then proceeded to an emergency squad locker to get a portable gas detector/explosimeter. From there, the two men went directly to the drillers house on the drill floor. The master and toolpusher met the drilling supervisor at the drillers house, and they entered the drillers house where they smelled the hydrocarbon gas. The master sampled the atmosphere in the drillers house with the gas detector/explosimeter, and the meter immediately indicated an explosive atmosphere. The master stated that it appeared the gas was coming from an overhead air vent located directly above him.

At 2026, the drilling supervisor instructed the well test crew to close the adjustable choke valve and to check around the drill floor area for a gas leak. The master climbed onto the roof of the drillers house, located the vent, and proceeded to sample the air outside the vent. (See figure A-1, appendix A.) No reading was indicated on the gas detector/explosimeter until the master inserted the explosimeter sampling tube into the vent, and the explosimeter immediately indicated the presence of explosive gas in the vent. The master told the toolpusher that a very serious situation existed and to discontinue all well testing operations until the source of the gas was determined.

Meanwhile at 2020, an automatic smoke detector in the port pontoon pumproom sounded (see figure A-3, appendix A), and the smoke detector monitor on the ballast control room console activated. At the time, no one was in the port pontoon pumproom. The last person in the port pontoon pumproom had been the engineering watch oiler who

3/ The low-level methane gas alarm is activated when the percentage of gas is 15 to 20 percent of the Lower Explosive Limit (L.E.L.). The high-level methane gas alarm is activated when the percentage of gas is 50 to 60 percent of L.E.L. (L.E.L is the smallest percentage of gas or vapor that will make an ignitable air-vapor mixture.)

had made an inspection round at 1800; nothing unusual had been reported at that time. The ballast control operator informed the third assistant engineer on watch in the engine control room of the smoke alarm in the port pontoon pumproom. The third assistant engineer then went directly down to the pontoon pumproom to investigate. At 2025, the third assistant engineer telephoned the ballast control operator and reported that a brown substance was flowing from an air line and that the air in the port pontoon pumproom smelled foul. The ballast control operator asked if there was smoke present, and the third assistant engineer responded that there was no smoke but there was a thick brown haze in the air.

At 2026, the chief engineer and the storekeeper entered the ballast control room. The chief engineer spoke briefly on the phone to the third assistant engineer in the port pontoon pumproom. The chief engineer and the storekeeper then left the ballast control room and proceeded toward the port pontoon pumproom. As he passed through the engineroom, the chief engineer instructed the oiler on watch to hurry ahead to the 100-foot flat (level) of the port center column and start the ventilation exhaust fan for the port center column and pumproom. The oiler went directly to the electrical controller for the exhaust fan and depressed the start button but could not hear the exhaust fan motor running. (The exhaust fan is located on the main deck level directly above the 100-foot level and should have been audible if it were in operation.) When the chief engineer arrived at the 100-foot level, he also attempted to start the exhaust fan, but was not successful. The chief engineer then told the oiler to return to his duties in the engineroom. (The ventilation supply and exhaust fans which serviced the port pontoon pumproom and the port center column had been shut off at their electrical feeders as a precaution against circulating cold, damp, salty air which could damage electrical control equipment and other components located in those spaces.)

As the chief engineer and the storekeeper continued down the stairs in the port center column to the 85-foot level, there was no indication of smoke, haze, or the odor of hydrocarbon gas. At the 85-foot level, the storekeeper asked if the chief engineer wanted him to unlock the storeroom to gain access to the electrical feeders to the supply and exhaust fan motor controllers. The chief engineer responded, yes. The storekeeper turned to go as the chief engineer approached the elevator trunk watertight door and depressed the elevator call button. About 2030, when the storekeeper went around the elevator shaft toward the stairs he heard a rumble and then an explosion.

Events Following the Accident

The master said that he was on top of the drillers house when he heard and felt the shock of the explosion (about 20 minutes after the methane gas alarm sounded) and that, at the time, he saw a large cloud of smoke rising from the port center column area. A fire had ignited on the port side of the main deck in a fuel oil spill containment tray adjacent to the elevator trunk. The drilling supervisor ordered the toolpusher to secure the well and then he went to the port side fire location where he waited for the emergency squad to arrive before he proceed to the bridge. The master left the drill floor and went directly to the navigation bridge, where the master manually sounded the signal for fire and emergency (intermittent ringing of bells) from the pilothouse general alarm station. The master then momentarily left the pilothouse and went to the port side of the helicopter deck and looked aft toward the damage but only could see large volumes of smoke. Suddenly, at 2035, the general alarm bell started ringing continuously, indicating an abandon rig alarm. The master knew immediately that the abandon rig alarm was erroneous and probably had rung because of a general alarm system malfunction since he had not authorized an order to abandon the rig. The master returned to the pilothouse and

attempted to stop the ringing by actuating the bridge general alarm switch on and off. However, all attempts to abort the abandon rig alarm failed.

About 2040, the master contacted by walkie-talkie the leaders of the emergency squads and asked for a condition report. The No. 1 squad leader reported that the squad was in the engine control room responding to the fire alarm and expressed concern about the chief engineer and the third assistant engineer who were thought to have been in the pumproom. The master instructed the No. 1 squad leader that his first priority was to extinguish all fires, and the squad leader acknowledged the order and proceeded toward the fire at the port side fuel oil spill containment tray. The master instructed the leader of emergency squad No. 2 to take his squad and assist emergency squad No. 1.

The master then went to the radio room and told the radio operator to establish and maintain radio contact with the United Kingdom (U.K.) Coast Guard Maritime Rescue Coordinating Center in Aberdeen, and to inform them that the GLOMAR ARCTIC II had suffered an explosion and fire. A sister vessel, the GLOMAR ARCTIC I, had been drilling at a location 5 miles away from the GLOMAR ARCTIC II. The master radioed the GLOMAR ARCTIC I's standby vessel, the M.V. WADDINGTON, which also was about 5 miles away, to come alongside the GLOMAR ARCTIC II. At 2050, the master returned to the pilothouse and contacted the emergency squads for an update. The leader of emergency squad No. 1 reported that the fire main water pressure was lost due to a break in the fire main piping caused by the explosion. The squad leader went on to report that the fire in the port side fuel oil containment tray had been extinguished with dry chemical extinguisher and that emergency squad members were isolating the damaged section of fire main piping. At 2055, the fire main water pressure was restored.

The master then telephoned the ballast control operator and was told that the explosion had severed all the cables installed in a large multiple electric cable raceway and disabled the computer control and monitoring for the ballast system. At the same time a crewmember reported to the navigation bridge that rig personnel were boarding the lifeboats and were preparing to launch them to abandon the rig. The master ran from the pilothouse to the lifeboats and explained that there had been a malfunction in the general alarm system and that there was no abandon rig order in effect. The master ordered those persons assigned to "active emergency duties" to go to their stations and service personnel (subcontractor) to remain at their lifeboat stations.

The master contacted the emergency squads about 2100 and asked if anyone in the squads had gone into the port pontoon pumproom. The leader of emergency squad No. 1 told the master that no one had gone below the 100-foot level of the center port column due to extensive debris blocking the path. The master ordered emergency squad No. 1 to enter the aft port column and to enter the port pontoon propulsion room by way of the escape trunk in order to investigate the portside column and pontoon spaces for fire or flooding. The squad leader acknowledged the order and proceeded as directed by the master.

The master and the drilling supervisor surveyed the portside of the main deck for explosive hazards and damage. They found the elevator trunk blown apart by the force of the explosion. They quickly surveyed the fire damage, the broken fire main piping, and the many electric power, control, and alarm system cables severed by the blast, and then returned to the navigation bridge. The U.K. Coast Guard reported at 2117 that they had two rescue helicopters en route to the GLOMAR ARCTIC II. At 2125, the MODU's main electric power went off the line. The emergency diesel generator started automatically

within seconds and provided emergency electric power to the MODU. The master decided to evacuate those crewmembers whom he considered to be nonessential personnel to the GLOMAR ARCTIC I.

At 2135 the leader of emergency squad No. 1 reported to the master that there were no fires or flooding in the port pontoon propulsion room, pumphoom, or the center and after port columns. The squad leader went on to report that they had found the body of the third assistant engineer in the port pontoon propulsion room which is adjacent to the pumphoom.

At 2138, the GLOMAR ARCTIC II radioed a Phillips-owned offshore installation in the Ekofisk oil field in the Norwegian sector, about 40 nautical miles southeast of the MODU's site and requested helicopter assistance for evacuation. About the same time, the main diesel generators' cooling water, which was interrupted by the explosion, was restored and the main generators were restarted. The emergency diesel generator was shut down, and computer monitoring of the starboard pontoon pumphoom ballast system was regained. Remote control of the port and starboard pumphoom valves was not possible because of the discovery of flammable hydrocarbon contamination of the rig air system, although the valves could be operated manually.

Two Ekofisk helicopters arrived aboard the GLOMAR ARCTIC II at 2207 and 2237. By 2300, the two helicopters had transported 46 nonessential personnel to the GLOMAR ARCTIC I.

Two Royal Air Force (RAF) helicopters, Rescue 37 and Rescue 31, which had been dispatched by the Maritime Rescue Coordination Center at Aberdeen, arrived onscene about 2320. The RAF helicopters landed at nearby offshore installations and remained in a standby status. The chief engineer of the GLOMAR ARCTIC I was transported to the GLOMAR ARCTIC II to assist in damage repairs.

Following the partial evacuation of the MODU, the master surveyed the damage. He said that the entire port pontoon pumphoom was blackened by smoke and had a noxious odor and that the damage to the pumphoom was extensive due to heat and pressure of the explosion. When the master returned to the main deck level he was told that the body of the chief engineer had been discovered in the port center column at the 85-foot level just outside of the elevator doorway. The elevator trunk watertight door had been torn from it's fittings and weldments by the force of the explosion. The two bodies were brought to the helicopter deck for transport ashore.

Beginning at 0030, on January 16, continuous inspections were conducted throughout the MODU in an effort to locate gas sources and locations of gas buildup. Samples taken from the rig's compressed air outlets in many locations contained a brownish liquid which crewmembers stated was crude oil and was indicative of how thoroughly the crude oil had contaminated the compressed air system. Of the two Ekofisk helicopters used during the evacuation, one remained onboard the GLOMAR ARCTIC I and the other was released by the GLOMAR ARCTIC II and departed for Ekofisk at 0100. At 0150, Rescue 37 transported two injured crewmembers ashore to a hospital near Aberdeen.

At 0330, the master reported to the U.K. Coast Guard, Phillips Petroleum offices ashore and shoreside offices of Global Marine that the rig was stable, that it appeared structurally sound, and that no portion of the underwater hull or any column was opened to the sea by the explosion. The master requested that portable air compressors be sent to the MODU by supply boat because the MODU's compressed air was unavailable for use due to hydrocarbon contamination of the system. The portable air compressors would be

used to furnish uncontaminated compressed air needed onboard the MODU. He also requested bottled nitrogen gas to be used in purging the contaminated compressed air system.

On January 25, 1985, the GLOMAR ARCTIC II was towed to a shipyard in Rotterdam, the Netherlands, for repairs.

Injuries to Persons

<u>Injuries</u>	<u>Crew</u>	<u>Other</u>	<u>Total</u>
Fatal	2	0	2
Non-fatal	2	0	2
Minor/None	48	32	80
Total	52	32	84

Damage to Vessel

The effects of a fairly uniform overpressurization, due to the explosion, were evident in the pumphoom. Most of the electric motor starting boxes, control boxes, cabinets, and ventilation ducting had been crushed inward by the force of the explosion. The only exception to this general pattern of overpressurization was the High-Level Process Interface Unit (HLPIU), a component of the MODU's computer controlled ballast system. The HLPIU comprised a large steel cabinet housing multitude of electrical relays and pneumatic (compressed air) lines. After the explosion, the HLPIU was found with its steel cabinet panels blown outward, the cabinet interior was coated with the waxy residue of crude oil, and the internal fittings were greatly disarrayed.

The excessive pressures created by the explosion were vented from the port pontoon pumphoom into the bottom of the elevator trunk, upward about 100 feet through the top and out the sides of the port elevator trunk at the main deck to the atmosphere, and into the port center column from the elevator trunk into the 50-, 85-, and 100-foot levels through blown-off watertight doors and supply ventilation openings. Electrical cabling inside the elevator trunk was damaged and the elevator cabin, the elevator motor, and the rack and pinion gear were destroyed. Additional explosive venting occurred from the port pontoon pumphoom into the pontoon propulsion room via the passageway connecting the pumphoom and propulsion room and then up the escape trunk in the port aft column to the atmosphere.

Extensive damage was sustained in the port pontoon pumphoom. The port side automatic ballast control system was damaged severely. Electric power, alarm, and control cables were severed by the explosion, and lighting fixtures and gauges were destroyed. The rig compressed air system and the valve remote control compressed air system were contaminated beyond use by hydrocarbons from the well. The valve remote control compressed air tank in the port pontoon pumphoom was found to contain flammable liquid and gas hydrocarbons. The compressed air tank was fitted with a pressure relief valve to protect the tank against overpressurization by releasing the excess pressure to the pumphoom atmosphere.

The principal damage in the port pontoon propulsion room and escape trunk included the ventilation ducting, lighting fixtures, ladders, rails, and floor plates.

At the main deck level, the fore and aft main engineroom bulkheads were damaged and the double-doors to the engine room were blown out of their frames. The atomizing compressed air pipeline to the port crude oil burner was damaged. The fire main piping and electric power, control, alarm and communication cables which were attached to the port elevator trunk exterior bulkheads were severed by the blast. A fire on the main deck port side adjacent to the destroyed elevator trunk burned bulkheads and the severed electric cables which included the general alarm cable.

Crew Information

At the time of the accident, 84 persons were onboard the GLOMAR ARCTIC II; 52 were Global Marine employees, 2 were Phillips' employees, and 30 were subcontractor employees, including 7 Otis Pressure Control Company well testing personnel. Pursuant to the provisions of the drilling contract between Global Marine and Phillips, Global Marine provided the semi-submersible drilling vessel GLOMAR ARCTIC II and personnel to man and operate the vessel while in transit and during drilling operations. These personnel served a deck department, an engineering department, a stewards department, and a drilling department. The GLOMAR ARCTIC II's master, also designated as the Offshore Installation Manager in accordance with U.K. law, was the highest authority on the MODU and responsible for all activities aboard the vessel. In addition, the master supervised the deck department, which included a stability technician who also was a U.S. Coast Guard (USCG) licensed second mate, two ballast control operators (a USCG licensed second mate and a USCG licensed third mate), two USCG licensed radio operators, two able seamen, and one medical doctor.

A USCG licensed chief engineer headed the engineering department, which included two USCG licensed assistant engineers and two oilers. The stewards department, headed by the chief steward, included two cooks.

The Global Marine drilling department was headed by two toolpushers and included two drillers, two assistant drillers, two derrickmen, one rig mechanic, two crane operators, six roughnecks, five roustabouts, five utility men, two storekeepers, one subsea engineer, one welder, one electronics technician, and one electrician.

Phillips' representatives on the MODU included a senior drilling supervisor and a reservoir engineer. Phillips also employed contractors who provided support services, i.e., standby vessels, helicopters and subcontractors, such as mud loggers, mud engineers, divers, and a well testing crew. Well testing operations were routinely conducted on an intermittent schedule at various drilling depths. The well testing company, Otis, was under contract to gather well pressure data and fluid samples and other information from the well to determine the well's production potential.

At the time of the accident, the two emergency squads onboard the GLOMAR ARCTIC II consisted of the following:

Emergency Squad No. 1

Stability Technician	In Charge
Crane Operator	2nd In Charge
Roustabout	Provide Breathing Apparatus
Roustabout	Provide Fire Axe
Roustabout	Provide Fire Suits
Able Bodied Seaman	Provide Breathing Apparatus and Lifeline

Emergency Squad No. 1 (cont'd)

Rig Mechanic Electronics Technician	Provide Fire Extinguisher Communications
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Emergency Squad No. 2

Crane Operator (Off Duty)	In Charge
Roustabout (Off Duty)	Provide Breathing Apparatus
Roustabout (Off Duty)	Provide Fire Axe
Roustabout (Off Duty)	Provide Fire Suits
Able Bodied Seaman	Provide Breathing Apparatus and Lifeline
Welder	Provide Fire Extinguisher
Storekeeper	Communications

Vessel Information

Description.--The GLOMAR ARCTIC II is a self-propelled, twin hull, column stabilized semi-submersible mobile offshore drilling unit and is owned and operated by Global Marine North Sea, Inc., of Houston, Texas. (See figure A-4, appendix A.) The MODU was built in 1984 by Rauma-Repola Shipbuilding, Offshore Division at Mantyluoto, Finland, and it was delivered to Global Marine on July 2, 1984. The vessel is U.S. registered and constructed to meet the classification requirements of Det Norske Veritas and the regulatory requirements of the USCG, the U. K. Department of Trade, and the U. K. Department of Energy.

Arrangements.--The forward half of the main deck, (see figure A-2, appendix A), had accommodation spaces (quarters) for 100 persons, a six-person hospital, a galley, messrooms, offices, recreation rooms, an engineroom, engine control room, a ballast control room, a drilling mud pumphouse, and storage areas. The after half of the main deck contained the auxiliary machinery room, drilling mud processing space, an emergency generator room, a diving equipment area, a well test equipment area, a machine shop, a welding shop, a storeroom, and workshops for the engineers, electricians, and seamen.

The upper deck was located one deck above the main deck. (See figure A-1, appendix A) An 87-foot-long by 85-foot-wide helicopter landing pad was located at the forward port corner. The navigation house at the forward starboard corner housed the pilothouse, the chart room, the radio room, the auxiliary ballast control room, the captain's stateroom, the radio operator's stateroom, and a lounge. The drilling pipe storage area was situated aft of the helicopter pad and the navigation house. The drilling mud logging unit, the battery charger room, and the emergency battery room were located on the after half of the upper deck.

The drill floor, a 72-foot-wide by 48-foot-long platform deck, was located 22 feet above the upper deck. (See figure A-1, appendix A.) The drillers house, the drillers office, well choke valve manifold, and a 40- by 40- by 160-foot-high derrick structure were located on the drill floor.

The main deck and upper deck were supported by three vertical columns arranged longitudinally on each side of the MODU which, in turn, were supported by the port and starboard pontoon hulls. (See figure A-4, appendix A.) The columns were subdivided horizontally into compartments. Inclined ladders within the column compartments provided access from one level to the next. Each port and starboard center column contained an elevator with stops at the pontoon pumproom, the 50-foot level, (50 feet above the pontoon keel), the 85-foot level and the 100-foot level.

Two pontoon hulls, one port and one starboard, constituted the underwater portion of the MODU and provided support for the columns and decks. (See figure A-3, appendix A.) The pontoons were symmetrical in the compartment arrangement, but mirror opposite in configuration. Each pontoon was divided into 24 separate compartments, consisting of 11 ballast tanks, 4 drillwater tanks, 2 portable water tanks, 2 freshwater tanks, 2 fuel oil tanks, a cofferdam, a pumproom, and a propulsion room.

Hazardous (Classified) Locations.--There are various areas on MODUs that are designated as "hazardous" locations. These are locations where the presence or the probability of a flammable atmosphere requires the use of specially designed machinery and electrical equipment due to the potential hazards of fire or explosion. Current USCG electrical engineering regulations refer to the National Electrical Code (NEC) for the classification of hazardous locations.

According to the NEC, "Class I locations are those in which flammable gases or vapors are or may be present in the air in quantities sufficient to produce explosive or ignitable mixtures." Class I is divided into two divisions: Class I, Division 1 and Class I, Division 2. A Class I, Division 1 location is one in which ignitable concentrations of flammable gases or vapors can exist under normal operating conditions or one in which such gases or vapors may exist frequently because of repair, maintenance, or the breakdown or faulty operation of equipment. A Class I, Division 2 location is one in which flammable liquids, gases, or vapors are handled or used but the liquids, vapors, or gases are confined within closed containers or systems from which they can escape only in cases of accidental rupture of the closed containers or systems or the abnormal operation of equipment. Locations that are adjacent to Class I, Division 1 locations and to which ignitable concentrations of gases or vapors might occasionally be communicated are also designated as Class 1, Division 2 locations.

An unclassified location is a location not classified as Division 1 or Division 2. The pontoon pumprooms and propulsion rooms were neither Class I, Division 1 nor Class I, Division 2 hazardous locations and did not require specially designed machinery or electrical equipment.

Survival Systems.--Two davit-launched, fully enclosed motor lifeboats, each equipped with a VHF radio transceiver, were installed at the forward end of the main deck level at the centerline. Each lifeboat had a capacity of 58 persons. Four davit-launched inflatable liferafts were installed at the aft end of the main deck port and starboard of the centerline. Each liferaft had a capacity of 25 persons. One eight-person capacity motorized rescue boat was installed on the aft edge of the main deck at the centerline. The MODU was outfitted with 125 exposure suits and 150 life preservers.

Ballast System.--Identical port and starboard ballast systems consisting of ballast water tanks, one ballast pump, and appropriate valves and piping were located in each pontoon. The starboard pontoon and port pontoon ballast systems were interconnected with a crossover pipe. All the ballast valves and pumps in the port and starboard ballast

system were remotely controlled by the ballast control operator through the operation of the ballast control computer from either the ballast control room (see figure A-2, appendix A) or the auxiliary ballast control room in the navigation house. The ballast control computer also monitored the status of remotely operated valves (open/closed) and pumps (running/stopped), tank liquid levels, vessel inclination (list/trim), and the status (open/closed) of watertight doors in the pontoons and columns. The ballast control system also monitored alarms for fire, smoke, hydrogen sulfide gas, and methane gas at various locations throughout the vessel.

The ballast valves were remotely operated from the ballast control console and utilized an electric/pneumatic valve actuating process. When operated, electricity activated a solenoid valve which admitted compressed air from the valve remote control compressed air system to tubing connected to the ballast valve operating gear in the pumphoom. Installed in each pumphoom was a valve remote control compressed air receiver to supply compressed air to the ballast valve actuators. The starboard and port side ballast systems normally functioned independently. Additionally, the ballast valves and pumps could be manually operated locally from the pontoon pumphooms.

Firefighting Equipment.--A fire main firefighting piping system was installed throughout the MODU with water pressure supplied by the main fire pump located in the starboard pontoon pumphoom and the emergency fire pump, located in the port pontoon pumphoom; both fire pumps were identical. The fire pumps could be controlled both remotely from the ballast control console and manually from their respective pumphooms. Both the port and starboard fire main pipelines were connected to a common header which supplied all firehose stations with water pressure. Fifty-one firehose stations were situated in the pontoons, columns, exterior decks, and interior spaces. For the use of the emergency squads, there were two emergency squad lockers. Each locker contained two fireman outfits, two oxygen breathing apparatus (OBA), two safety harnesses with lifeline, nonconducting boots and gloves, and a portable gas detector/explosimeter.

Fire Detection.--There were 73 thermal detectors, 75 smoke detectors, and 7 flame detectors for fire detection. The detectors were grouped in fire zones, and each zone was connected to the fire alarm monitor panel in the ballast control room. Upon detection of heat, flames, or smoke, the appropriate detector would illuminate on the panel to indicate the affected area, and a buzzer would sound at the detector location.

Gas Detection.--Eleven methane gas detectors/alarms and 10 hydrogen sulfide gas detectors/alarms were connected to a central monitoring unit in the ballast control room. Upon detection, an alarm sounds at the sensor location to warn personnel in the area and a light is illuminated on the ballast control room monitor indicating the type and location of the alarm. It is the responsibility of the ballast control officer to notify the master immediately of any alarm situation.

The gas detectors were installed on the MODU in the following locations:

<u>Location</u>	<u>Type and No. of Gas Detector</u>
Inlet ventilation duct to accommodations	1 methane and 1 hydrogen sulfide
Welding shop	1 methane
Shale shaker area	1 methane and 1 hydrogen sulfide
Cellar deck below the drill floor	1 methane and 1 hydrogen sulfide
Mud pit room in the exhaust duct	2 methane and 2 hydrogen sulfide
Mud pumphoom	2 methane and 2 hydrogen sulfide
Driller house in the exhaust duct	1 methane and 1 hydrogen sulfide
Test separator area (at the drill floor)	1 methane and 1 hydrogen sulfide
Diesel engine generator room	1 methane

Section 3 of the American Petroleum Institute's (API) recommended practice for Fire Prevention and Control on Open Type Offshore Production Platforms states, in part:

An important role in preventing fires or minimizing their effect can be performed by the platform surface and subsurface safety systems. The purpose of a surface safety system is to detect abnormal conditions and initiate appropriate action to prevent the creation of situations that could result in an accidental fire. The action normally initiated by the surface safety system is to shut off process flow, thus eliminating the major fuel source on a platform.

* * *

The concentration of a combustible gas can be determined by detection devices which may initiate alarms or shutdowns. The usual practice is to activate an audible and/or visual alarm at a low gas concentration and to initiate action to shut off the gas source and/or ignition source if the concentration reaches a preset limit below the lower explosive limit (LEL).

A review of Global Marine's GLOMAR ARTIC II Critical Procedures Manual and Operations Manual indicated that there were no instructions directing Global's personnel to shut off the well flow when the low-level automatic methane gas alarm sounded. The Safety Board was unable to locate any Phillips Petroleum procedures on shutdown of well flow when the automatic low-level methane gas alarm sounds.

Compressed Air Systems.--Three main independent compressed air systems were arranged throughout the MODU: the starting air system, the bulk air system, and the rig air system. The rig compressed air system also furnished compressed air to the sub-systems of instrument air, valve remote control air, purge air and atomizing air.

The starting air system consisted of two air compressors, two compressed air receivers (tanks), piping, and valves which distributed compressed air at 200 psig to start the main diesel engines.

The bulk air system consisted of one air compressor, one compressed air receiver, piping, and valves which distributed the compressed air at 40 psig to the bulk material handling system. This system transferred dry bulk materials, such as drilling cement, barite, and bentonite, by compressed, pressurized air.

The rig air system was extensive and consisted of one air compressor, one moisture separator, one air dryer, and three rig air receivers. Piping and associated valves located throughout the MODU distributed compressed rig air at 125 psig to an air receiver located on the drill floor which furnished compressed rig air to the MODU's air operated equipment, i.e., winches and various air operated hand tools. Rig compressed air also supplied atomizing compressed air for the crude oil burners, the purge air system and the two valve remote control compressed air receivers, one located in each pumphouse. These two receivers provided compressed air for the remote operation of the ballast, bilge, saltwater service, drill water, fuel oil, and fire and potable water remote valve actuators. The purge air system distributes compressed air at 3 psig to the interior of designated electrical enclosures, such as equipment control consoles, motor housings and other spaces. This is done to slightly overpressurize the interiors and prevent flammable or explosive gases entering or being drawn into the equipment and spaces.

Although each compressed air system is independent, interconnecting valves and piping were permanently in place to maintain compressed air requirements in emergencies. All the air compressors operate automatically to maintain preset air pressure levels in the respective air receivers.

Burner Booms.--The GLOMAR ARCTIC II was fitted with two 70-foot-long steel burner booms, one each on the port and starboard sides of the main deck (see figure A-1, appendix A, and figure 2) with one end of the boom attached to a pivot point at midships. The booms were fabricated and installed during the MODU's construction and were a part of the vessel's permanent equipment. Each burner boom provided support for the crude oil, atomizing air and water pipelines and the crude oil burner assembly located at the boom's extreme outboard end. With the use of the pivot, the boom could be oriented to suit the wind direction and keep the flame's heat and smoke away from the MODU. When the burners were not in use, the booms could be brought in and secured alongside the MODU's main deck.

Crude Oil Burners.--The Otis crude oil burners, model CB-12A (see figure 3), were portable (about 1,600 pounds), temporary equipment and had been installed on the GLOMAR ARCTIC II on October 15, 1984. The main components of each burner unit included three burner nozzle assemblies, a crude oil manifold, an atomizing air manifold, the frame and can assembly, and a water ring. Each burner nozzle assembly (model 80 B 190) included a fuel body, fuel disc, burner tip, Flexitallic gasket, and a burner nozzle. The crude oil burners were designed by National Airoil Burner Company (NAO) of Philadelphia, Pennsylvania, and manufactured, with the exception of the nozzle assemblies, by Merpro Ltd. of Montrose, Scotland in 1983.

Prior to 1978, the complete nozzle assembly was manufactured by NAO and fabricated entirely of nitrolloy. Since 1978, the nozzle assembly has been manufactured of ASTM 304 stainless steel by Otis or by an Otis contracted vendor using Otis supplied specifications. Of the three nozzle assemblies in use on the port side burner at the time of the accident, the No. 1 nozzle assembly was made entirely of 304 stainless steel and was manufactured by Otis or a vendor contracted by Otis, the No. 2 nozzle assembly was made entirely of nitrolloy and was manufactured by NAO, and the No. 3 nozzle assembly contained a nitrolloy burner tip and burner nozzle (NAO manufacture) and a 304 stainless steel fuel disc and fuel body (Otis manufacture or vendor).

The crude oil burner assemblies were mounted on the outboard end of the burner booms. Pipe connections at the outboard end of the burner boom were fastened interconnecting the port and starboard crude oil burner units to permanent MODU piping systems which furnished crude oil/gas from the well, sea water for cooling, and compressed atomizing air.

The crude oil supply piping and the atomizing compressed air supply piping of the burners were designed to keep the crude oil and the atomizing air separated. The crude oil was atomized by the atomizing compressed air only after the crude oil had exited the burner tip and the atomizing air had exited the burner nozzle. Crude oil burners have been used by the offshore industry for many years. Crude oil cannot be dumped into the sea, and there is not enough space onboard the MODU for storage of the well products. The burning of the flammable well products eliminates the need for large storage space and the danger of pollution. Once crude oil burner units are installed onboard a MODU, they usually remain in place until completion of the drilling contract between the MODU's owners and the oil company.

Waterway Information

The North Sea is located between the British Isles and the mainland of northwestern Europe. (See figure 4.) The sea is about 700 miles long and 420 miles wide at its widest point, covering a 220,000-square-mile area. Water depths in the North Sea range from less than 100 feet in the southern extremity to about 600 feet in the north. The North Sea is bordered by the United Kingdom and the Orkney Islands to the west, the Shetland Islands to the north, Norway and Denmark to the east, and West Germany, the Netherlands, Belgium, and France to the south.

In 1958, oil was discovered beneath the North Sea. The development and exploitation of these resources has been carried out by the United Kingdom, Norway, Denmark, West Germany, the Netherlands, and France. In 1958, these nations, under the auspices of the United Nations, created a treaty which divided the North Sea into national sector economic zones for the the development of offshore oil and natural gas. Foreign, primarily U.S., companies under lease license agreements have been responsible for much of the development of the North Sea hydrocarbon resources. At the time of the accident, 100 mobile offshore drilling units were active in the North Sea, the world's fifth largest producer of oil and natural gas.

Meteorological Information

The weather conditions experienced by the GLOMAR ARCTIC II at the time of the accident were easterly winds at 22 knots and a temperature of 35° F. Visibility was 5 to 8 miles with snow flurries and a cloud ceiling of 2,700 feet. The sea conditions were waves of 3 to 4 feet and swells of 8 to 10 feet, both from an easterly direction.

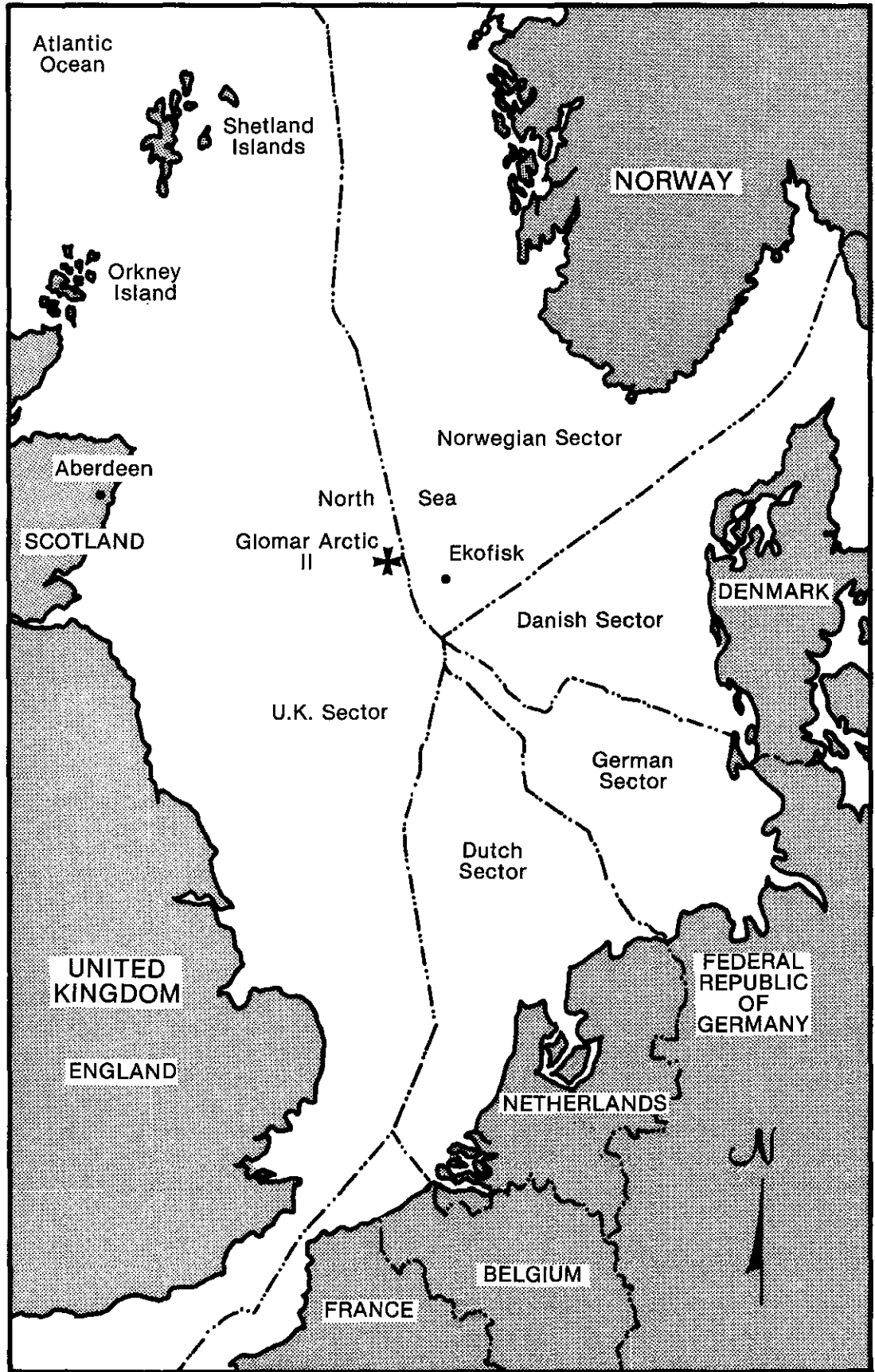


Figure 4.--North Sea.

Inspection Requirements

During all phases of construction, the GLOMAR ARCTIC II was inspected by the USCG as part of its overseas inspection program for vessels to be registered in the United States. The inspections assured adherence to U.S. regulations concerning standards for welding, material specification, electrical installations, piping systems, safety and survival systems, and machinery installation for both shipboard marine and industrial systems. The Norwegian classification society, Det Norske Veritas, also conducted construction inspections to verify adherence to its rules for the Classification of Mobile Offshore Units. Additionally, in order to conduct drilling operations on the United Kingdom's continental shelf, all aspects of the construction process were subjected to examination by a U.K. Department of Energy authorized Certifying Authority, which, in this case, was Det Norske Veritas.

After successfully completing all the required USCG inspections during construction and the operational tests of the dock trials and sea trials following construction, the GLOMAR ARCTIC II was issued an original Certificate of Inspection by the USCG on July 1, 1984. The GLOMAR ARCTIC II also satisfied the classification requirements of Det Norske Veritas and was approved for classification by that society. Det Norske Veritas, acting as a Certifying Authority on behalf of the United Kingdom issued a Certificate of Fitness to the GLOMAR ARCTIC II for the U.K. Department of Energy.

Once the MODU becomes operational, USCG regulations require the successful completion of an annual inspection and a more extensive biennial inspection prior to the issuance of a new Certificate of Inspection. Det Norske Veritas requires that MODUs satisfy the requirements of an annual, biennial, and an extensive survey once every 4 years to retain the MODU in class. The U.K.-authorized Certifying Authority issues Certificates of Fitness annually following a satisfactory inspection of the MODU. At the time of the accident, there were no existing United States or United Kingdom regulatory requirements nor were there any classification society rules concerning the inspection, certification, or approval of portable, temporary industrial equipment, such as crude oil burners and their component parts. USCG regulations contained in 46 CFR 58.60 address only industrial systems and components which are part of the MODU's permanent equipment. The inspection and maintenance of the Otis CB-12A crude oil burner assembly and its component parts was the sole responsibility of Otis Pressure Control and its employees. However, there was no specific Otis inspection procedure in existence for the burner assembly or nozzle assembly and no assembly or inspection records were maintained. It was the practice of Otis personnel before initial installation and between well tests to disassemble the burner nozzle and the Flexitallic compression gasket of each unit, to visually inspect the parts, to clean and repair as required, and to reassemble the units so as to be ready for use. (See appendix B.)

Tests and Research

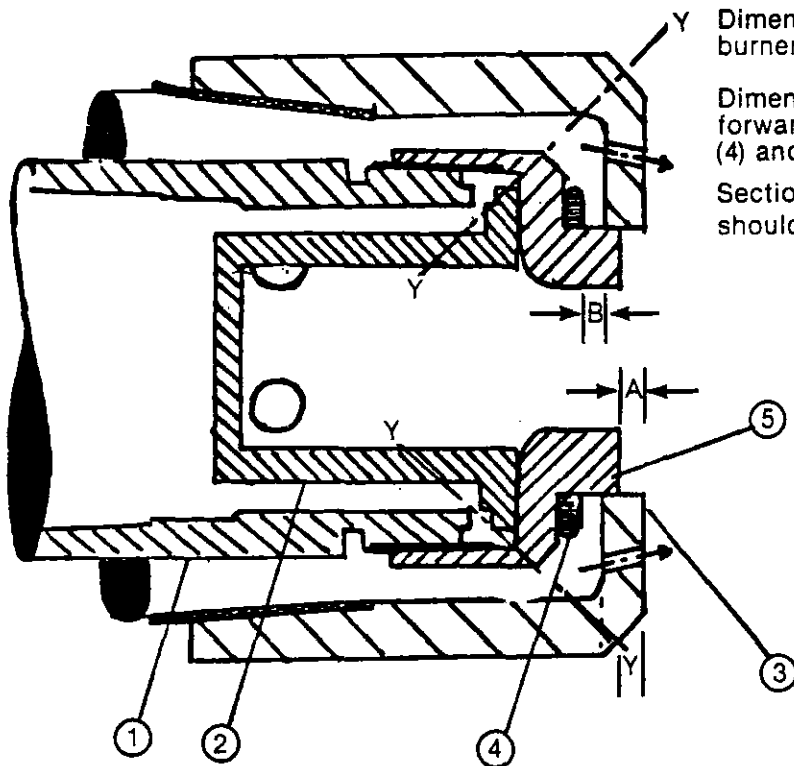
On January 21, 1985, the port side Otis crude oil burner (model CB-12A) was removed from the GLOMAR ARCTIC II and sent ashore to the Robert Gordon Institute of Technology (R.G.I.T.) at Aberdeen, Scotland, for a detailed examination and series of tests. Disassembly of the three nozzle assemblies of the crude oil burner revealed a fracture of the No. 3 burner tip.

Flow Test.--A flow test was conducted to determine if fluid could flow from the crude oil side of the burner nozzle assembly to the normally separated atomizing air side via the fracture in the No. 3 burner tip. To accomplish this test, blanking caps were fitted to the crude oil and atomizing air outlets of nozzle assemblies Nos. 1, 2, and 3. Then compressed air at 80 psig was supplied to the crude oil manifold, and a vent pipe was installed from the atomizing air manifold to a water bath. Two tests were performed:

- (1) The atomizing air and crude oil supply valves to burner nozzle assemblies Nos. 1, 2, and 3 were closed. When the atomizing air and crude oil supply valves to nozzle assembly No. 3 were opened, an immediate full flow of 80 psig laboratory compressed air was exhausted into the water bath from the vent pipe in the atomizing air manifold. However, when the atomizing air and crude oil supply valves to nozzle assemblies Nos. 1 and 2 were opened, there was no air flow to the water bath.
- (2) The atomizing air supply valves to nozzle assemblies Nos. 1 and 2 were closed and the atomizing air valve to nozzle assembly No. 3 was opened. The crude oil supply valves to nozzle assemblies Nos. 1, 2, and 3 were closed. The blanking was removed from nozzle assembly No. 3 and the nozzle was open to the atmosphere. Crude oil supply valve to the No. 3 nozzle assembly was opened, allowing 80 psig laboratory compressed air to flow through the crude oil piping to the No. 3 nozzle assembly. Again, there was an immediate flow of air from the vent pipe in the atomizing air manifold to the water bath, as well as an air flow from the No. 3 nozzle and burner tip.

Dimensional Checks.--The three nozzle assemblies were removed from the crude oil burner, disassembled, and measured.

- (a) Prior to disassembly, Dimension A (see figure 5-A), the clearances from the faces of the burner nozzles to the faces of the burner tips, were measured. Nozzle assembly No. 1 showed a clearance of 0.135 inch, No. 2 showed 0.101 inch of clearance, and No. 3 showed 0.254 inch of clearance.
- (b) The Flexitallic compression gaskets, which were located between the underside of the burner nozzles and the front gasket landing surface (see figure 5-A) of the burner tips, were found to be flattened in nozzle assemblies No. 1 and 3 while the gasket in assembly No. 2 was thicker than the other two. Gaps of about 1/5 inch, Dimension B, were found between the forward face of the compression gasket and the under side of the burner nozzle in the Nos. 1 and 3 nozzle assemblies.
- (c) The burner tip on nozzle assembly No. 3 was found to be only slightly tightened onto the fuel body, which failed to hold the fuel disc in its proper position between the fuel body and the burner tip.
- (d) The general dimensions of the fuel discs, burner tips, and burner nozzles were measured and found to be manufactured within the dimensional tolerances as specified on the Otis engineering drawings, except that the inner fillet radius at section 'YY' (see figure 5-A) of the burner tips on nozzle assemblies Nos. 2 and 3 were found to be 0.014 inch which was a much sharper radius than specified on the drawings. Burner tip No. 1 was found to be 0.060 inch as specified by the drawings.



Dimension A is the clearance measured between the burner nozzle face (3) and the burner tip face (5).

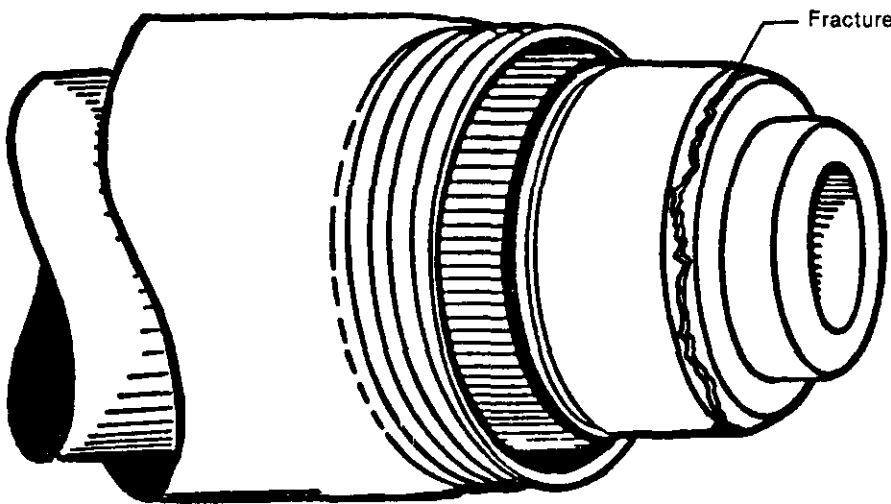
Dimension B is the clearance measured between the forward face of the flexitallic compression gasket (4) and the underside of the burner nozzle face (3).

Section 'Y - Y' is the sharp radius of the inner shoulder of the burner tip

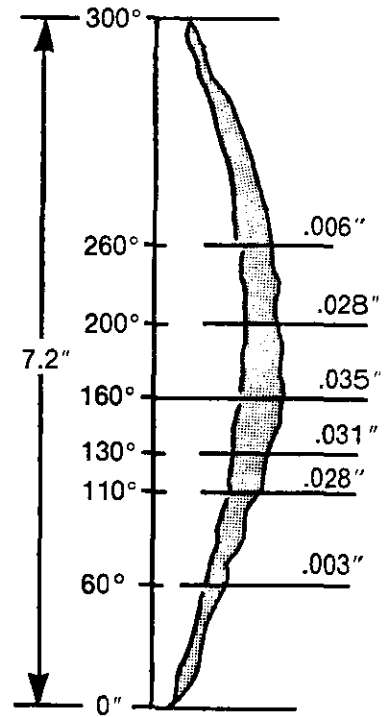
LEGEND	
1.	Fuel Body
2.	Fuel Disc
3.	Burner Nozzle Face
4.	Flexitallic Gasket
5.	Burner Tip Face

(Not to Scale)

Figure 5A.--Nozzle assembly clearances.



Sketch of the No. 3 nozzle assembly (with the burner nozzle and gasket removed) showing the fracture which runs for 300 degrees around the circumference of the burner tip.



Not to Scale

Figure 5-B.--Nozzle assembly dimensions.

- (e) The dimensions of the open crack on the fractured burner tip No. 3 were measured using a micrometer microscope. (See figure 5-B.) The approximate area of the crack opening was 0.15 square inch.

Metallurgical Tests.--Metallurgical tests were confined to the material of the No. 3 burner tip. The metallurgical microstructure was examined and surface hardness values were measured and found to be 800 to 900 VHN (Vickers Hardness Number). Core hardness values were measured in the range of 250 to 320 VHN. The hardness values measured for both the surface and the core were in the appropriate range for nitrolloy 135 M, which is case hardened and has a tempered core structure. The chemical composition of nitrolloy 135 M is designed to produce very high surface hardness by nitriding due to the addition of the nitride-forming elements of chromium, aluminum, vanadium, and molybdenum.

Full chemical analysis of the material was undertaken and the material of each burner tip was checked. Burner tip No. 1 was constructed of type ASTM 304 stainless steel, and burner tips Nos. 2 and 3 were nitrolloy 135 M.

Fracture Examination.--The fracture surfaces were found to have a light deposit of a viscous residue but were otherwise clean and free of corrosion deposits. However, a number of corrosion pits were observed on the surfaces of the inner shoulder radius of the No. 3 burner tip. The fracture was a "fast," or "brittle," fracture which propagated from the inner corner or radius of the No. 3 burner tip shoulder (see section 'YY' figure 5-A). There was no evidence of fatigue or stress corrosion. The burner tip was found to have suffered a complete through-wall fracture, mainly in the chamfered shoulder region with the fracture extremities extending downward into the skirt of the burner tip (see figure 5-B). The fracture ran for approximately 300° of the circumference of the burner tip with the greatest crack opening at the shoulder of about 0.035 inch.

Pressure and Impulse Loads.--When the adjustable choke valve was opened to allow combustible well products to flow to the crude oil burner, pressures and impulse loading conditions were created within the piping system. Knowledge of these conditions was necessary for an examination of the stress applied to the burner tip.

- a. Pressure Loading: According to the RGIT report, during normal well test crude oil flow conditions, a pressure difference of 500 psig existed between the pressure applied to the upstream area of the fuel disc and the pressure within the burner tip.
- b. Impulse Pressure: Impulse pressure conditions were created by liquid/gas and solid slugs traveling inside the crude oil supply piping to the burner assembly at a rate of 350 gallons per minute and impacting on the upstream of the fuel disc. Statements concerning the waxing and slug flow during the well test flow period were taken from well testing crewmembers. Particles of solids were recovered following well test No. 2A, and 9 of the 20 atomizing air orifices in the No. 3 burner nozzle were found to be blocked on visual examination following the accident. The RGIT report suggests that such impulse loads are indeterminate but could reach well head pressure values of 2450 psig.

Stress Calculations.--A simplified finite element analysis ^{4/} stress model was constructed using an internal static pressure difference of 500 psig. The predicted stress at the inner point of section 'YY' (see figure 5-A) of the No. 3 burner tip was 9.21 t/in² (tons per square inch). No exact replica of the geometry of the burner tip could be identified in stress concentration charts, but a similar system was identified and the stress concentration factor at the inner point of 'YY' was conservatively estimated to be 10.6. This would result in a stress of 97.6 t/in² at 'YY' of the burner tip. Also impulse loads impacting on the fuel disc could increase the stress at section 'YY' by a factor of 1.5 to a stress level of 146 t/in² which is very near the ultimate tensile strength of the thin very hard nitrided surface layer of the burner tip and is in excess of the ultimate tensile strength of the core material of the burner tip.

Hydrocarbon Samples.--On January 22, 1985, samples of the brown liquid found in the port pontoon pumphouse bilge, air lines and air receivers were collected for testing. Samples also were taken from the port side crude oil burner, crude oil manifold, atomizing air manifold, crude oil supply pipe and from inside the (fractured) burner nozzle. Additionally samples from the atomizing compressed air supply pipe, the rig compressed air system, and the crude oil sample valve at the choke manifold were collected for testing.

The samples were delivered to the R.G.I.T. for chemical analysis. Each sample was dissolved in benzene and underwent gas chromatographic analysis. In all cases, peaks were produced by each sample at the same corresponding retention value, indicating that all of the oil samples were of the same identity.

Other Information

On January 24, 1985, Global Marine headquarters in Houston, Texas, issued a company "Red Alert" telex addressed to all of its drilling rigs and all areas offices worldwide warning of the possible hazards when operating the crude oil burners. The telex directed that crude oil burners and well test equipment be disconnected from the rig compressed air system, and that compressed air supplied to crude oil burners be furnished by a portable compressed air unit with a nonreturn (check) valve fitted in the compressed air supply piping.

At the time of the accident, Otis had 88 of its crude oil burners installed (with three nozzle assemblies per burner) at 47 offshore installations located throughout the world. Following the accident, Otis advised all of its U.S. and foreign production well testing operations as well as those of its affiliates of the risk of communication between well fluids and atomizing air on their crude oil burners, and instructed that check valves be installed in the compressed atomizing air piping to all crude oil burners.

ANALYSIS

Burner Tip Fracture

At 1950 on January 15, 1985, a member of the Otis well testing crew opened the adjustable choke valve and allowed crude oil from the well to flow through well testing and sampling equipment to the Otis crude oil burner on the port burner boom. Hydrocarbons from the well contaminated the rig compressed air system through a fracture in the No. 3 burner tip on the port side crude oil burner. The rig compressed air

^{4/} Finite element analysis is an advanced computer-aided structural analysis technique which is used to determine the stress at any location in a structure.

system then furnished contaminated compressed air to the purge air system. The automatic methane gas alarm, which was installed in the exhaust vent duct in the overhead of the drillers house, sensed methane gas in a mixture of explosive hydrocarbon gas that was expelled from equipment enclosures pressurized by the contaminated purge air. At 2010, the automatic methane gas alarm sounded at the drillers house. The Safety Board believes that sometime between 1950 when the adjustable choke valve was opened, and 2010, when the automatic methane gas alarm sounded, the No. 3 burner tip fractured.

The point of interconnection of the industrial crude oil piping system and the marine rig compressed air system was at the crude oil burner. To prevent the possible hydrocarbon contamination of a MODU's rig compressed air system, atomizing compressed air supplied to the crude oil burners should be furnished from a dedicated, separate, compressed air source. Furthermore, steps should be taken to prohibit the backflow of high pressure hydrocarbons that may enter the dedicated, separate, atomizing compressed air piping system. This could be accomplished by installing a device, such as a nonreturn (check) valve, in the atomizing compressed air piping.

Burner Tip Manufacture

The dimensions of the inner fillet radius of the three burner tips from the GLOMAR ARCTIC II's portside crude oil burner were measured. Burner tip No. 1 was found to have been manufactured with an inner fillet radius of 0.60 inch as specified on the Otis engineering drawings. However, burner tips Nos. 2 and 3 were found to have been manufactured with an inner fillet radius of 0.014 inch which is smaller, much sharper, and well below the 0.060 inch radius specified by Otis. A smaller radius is a much higher stress raiser (area of stress concentration) than a large radius. Corrosion pits, which also are stress raisers, were observed on the inner radius of the No. 3 burner tip. The observed corrosion pits in the nitrided case of the sharp inner radius would make section 'YY' susceptible to breakage on impact loading due to the increased stress raisers created by the corrosion pits and the sharp radius. Impulse pressure conditions arising from liquid/gas and wax slugs or solids impacting on the upstream (exterior) side of the fuel disc imparted additional stresses to section 'YY' of the burner tip. Except for an increased fatigue resistance, there appears to be no reason for having a high surface hardness, such as that obtained by a nitrided case. The fracture of the No. 3 burner tip was characterized as being typical of a single load overstress separation in material which is case hardened and has a tempered core, such as nitrolloy 135M. The Safety Board believes that the initiation of the fracture occurred at the point of the highest concentration of stress, that being at or near the location of one or more of the corrosion pits in the sharp inner radius at section 'YY' of the No. 3 burner tip.

Burner Nozzle Assembly

Otis Company drawings of the properly assembled burner nozzle unit clearly show that the faces of the burner nozzle and burner tip are flush and level with each other when assembled properly. (See figure 6-A.) The dimensional checks of the nozzle assembly and its components showed that over 1/4 inch of clearance existed between the No. 3 burner nozzle face and the improperly recessed burner tip face, which should have been an immediate visual indication to the well test crew that the compression gasket was not seated properly within the assembly and that the nozzle assembly was misassembled. (See figure 6-B.) With a misassembled nozzle assembly and an improperly seated compression gasket, crude oil/gas pressure against the fuel disc could transfer tensile and bending stresses to section 'YY' of the underside of the burner tip. Although neither the burner tip material nor the sharp inner shoulder radius separately or together probably

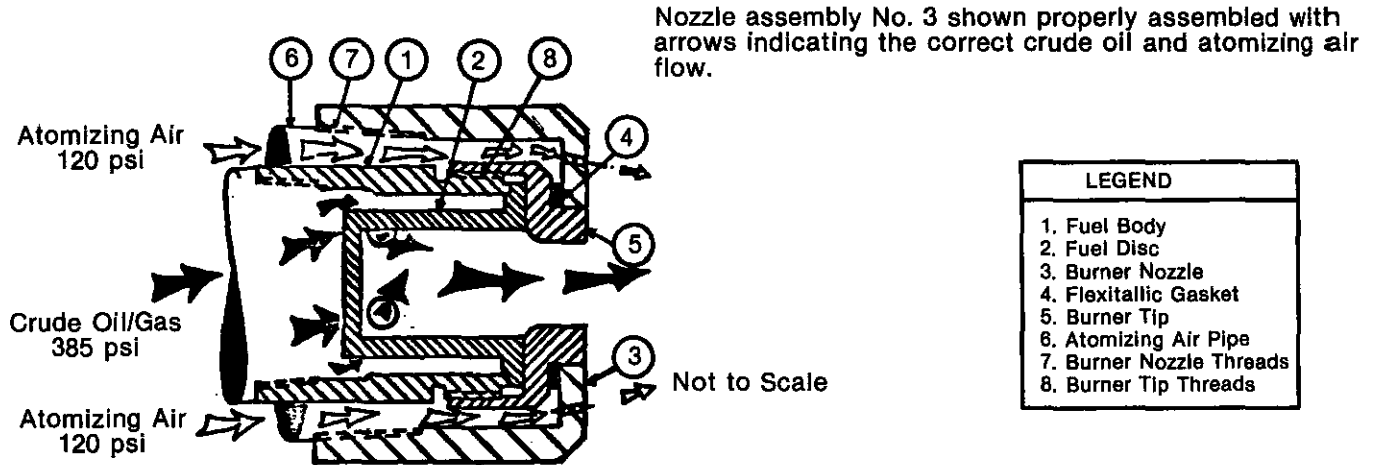
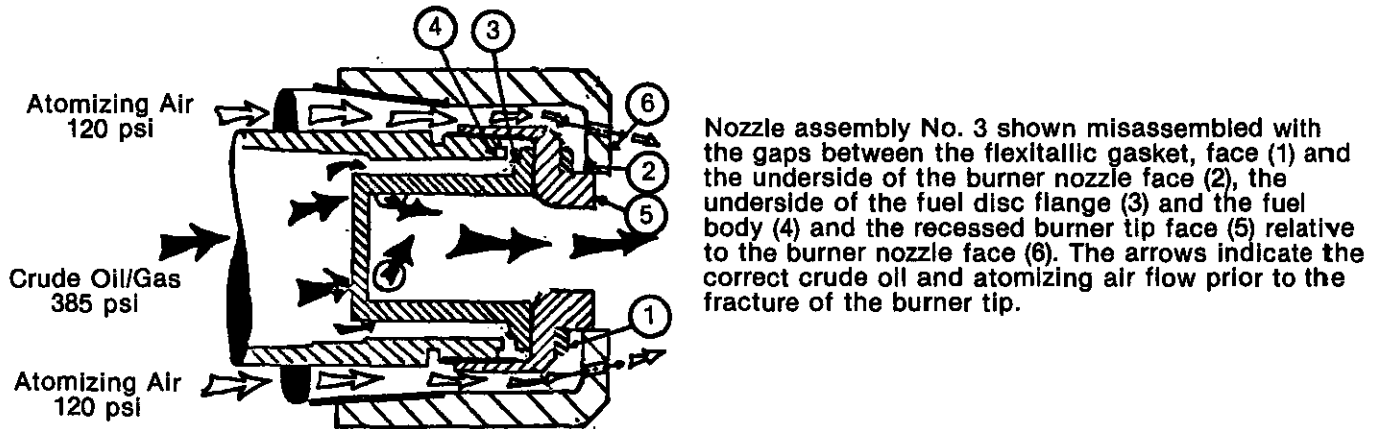
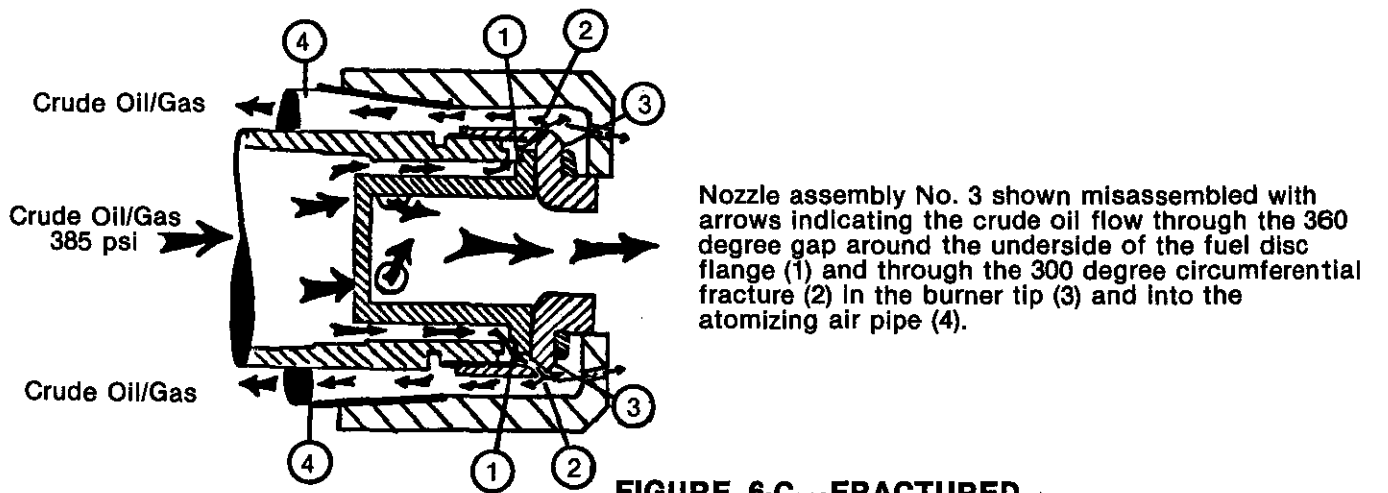


FIGURE 6-A—CORRECTLY ASSEMBLED



Nozzle assembly No. 3 shown misassembled with the gaps between the flexitallic gasket, face (1) and the underside of the burner nozzle face (2), the underside of the fuel disc flange (3) and the fuel body (4) and the recessed burner tip face (5) relative to the burner nozzle face (6). The arrows indicate the correct crude oil and atomizing air flow prior to the fracture of the burner tip.

FIGURE 6-B—MISASSEMBLED



Nozzle assembly No. 3 shown misassembled with arrows indicating the crude oil flow through the 360 degree gap around the underside of the fuel disc flange (1) and through the 300 degree circumferential fracture (2) in the burner tip (3) and into the atomizing air pipe (4).

FIGURE 6-C—FRACTURED

Figure 6.--Nozzle assembly failure sequence.

would have resulted in the failure of the No. 3 burner tip, they each contributed to the high levels of stress experienced by the No. 3 burner tip. Therefore, Otis should establish quality control procedures to ensure that manufacturing defects are identified and that improperly manufactured components are not distributed. The No. 2 nozzle assembly was essentially identical to the No. 3 nozzle assembly; however, it probably did not fail because it was assembled correctly with components tight. The Safety Board believes that the No. 3 burner nozzle and burner tip were improperly assembled which resulted in increased bending loads to section 'YY' and ultimately resulted in the fracture of the No. 3 burner tip.

Crude Oil Flow

The flow test conducted by R.G.I.T. verified the path created by the fracture between the normally isolated crude oil supply piping and the atomizing air piping of the nozzle assembly. (See figure 6-C.) Due to the lightly tightened No. 3 burner tip, the most probable flow path of the crude oil was between the fuel body and the underside of the fuel disc flange and through the fracture. The underside of the fuel disc flange had a clearance created when crude oil supply pressure against the fuel disc exterior moved the fuel disc forward against the underside of the lightly tightened burner tip which opened a flow path from the crude oil supply pipe to the fracture. Once through the fracture, the crude oil entered the atomizing air side of the nozzle assembly where wax and other solids in the crude oil obstructed 9 of the 20 atomizing air outlets in the burner nozzle. The crude oil pressure of 385 psig was more than three times the 120 psig atomizing air pressure. With nearly half of the atomizing air outlets blocked, the route of the crude oil inside the air piping was back through the atomizing air piping and into the rig compressed air piping system leading to various areas, including the purge compressed air system and the valve remote control compressed air (tank) receiver in the port pontoon pumphoom. The excessive crude oil pressure within the air receiver caused the pressure relief valve on the air receiver to open and release the crude oil vapor into the atmosphere of the pumphoom. The crude oil vapors created an explosive hydrocarbon atmosphere in the port pumphoom. This explosive atmosphere could have been ignited by any of a number of possible ignition sources because under the design standards used, the pumphooms and the propulsion rooms were considered as "nonhazardous" unclassified locations and, therefore, did not require explosion-proof enclosures on electrical equipment.

Ignition Source

There were a large number of electrical relays in the port pontoon pumphoom associated with the ballast control equipment. The operation of these relays, which involves the opening and closing of electrical circuits, is often accomplished by electrical arcing. There were numerous such relays within the High-Level Process Interface Unit (HLPIU). The HLPIU was the only item which appeared to have been pressurized internally. Therefore, the Safety Board believes that the ignition of the flammable hydrocarbon vapors in the port pontoon pumphoom probably occurred within this unit.

The analysis of the brown liquid hydrocarbon samples proved that all of the samples were identical. Through this analysis the path of the crude oil could be traced from the well to the crude oil piping, the crude oil manifold, the atomizing air manifold, and atomizing air piping to the port pontoon pumphoom valve remote control compressed air receiver.

Crude Oil Burner Inspection

At the time of the accident, the required United States inspections, examinations, and operational tests of the GLOMAR ARCTIC II addressed the vessel's shipboard and industrial permanent equipment and systems. Crude oil burners are not a part of the MODU's permanent equipment. They are portable, temporary pieces of equipment brought onboard the MODU and installed by a well testing company. In this case, Otis, operating under the provisions of a contract to Phillips, installed two Otis CB-12A crude oil burners on the GLOMAR ARCTIC II. One burner was installed on the port side burner boom, and the other was installed on the starboard burner boom. At installation, the crude oil burners were connected to the vessel's permanent shipboard and industrial piping systems of compressed atomizing air, water, and crude oil/gas.

According to the drilling supervisor, there were no user manuals onboard the GLOMAR ARCTIC II concerning the burners or nozzle assemblies. The Otis maintenance procedures for the crude oil burners and nozzle assemblies were inadequate and permitted the reinstallation of a compression gasket that essentially loses its sealing effectiveness after the initial installation and compression. Onboard Otis inspection procedures for the crude oil burners and nozzle assemblies were nonexistent. Furthermore, at the time of the accident, there were no existing United States or United Kingdom regulatory requirements, and there were no classification society rules concerning the inspection, certification, or approval of portable, temporary industrial equipment, such as crude oil burners and their component parts. The inspection, maintenance, and proper assembly of the Otis crude oil burner and its component parts were left to the discretion and were the sole responsibility of the owner and operator of the equipment, Otis and its employees. In addition, during the manufacturing of the nitrolloy 135M burner tips, Otis failed to establish or require quality control procedures to ensure strict adherence to specifications for the manufacture of the burner tips.

On March 25, 1985, the USCG published CGD-80-071a, an Advance Notice of Proposed Rulemaking (ANPRM), concerning the proposed revisions of the USCG MODU regulations. Paragraph 3 of the ANPRM suggested the addition of new sections to 46 CFR 58.60 concerning the acceptance of portable, temporary industrial equipment and the development of instructions to USCG inspectors pertaining to the acceptance and inspection of industrial systems. The USCG also proposed an additional section to 46 CFR 58.60 pertaining to the installation and interconnection of industrial and shipboard systems. The Safety Board urges the USCG to proceed with its regulatory project and incorporate the proposed changes to 46 CFR 58.60 regarding inspection and interconnection of portable, temporary industrial equipment.

Crew Response

After the low-level gas alarm sounded at 2010, the drilling supervisor began searching for the source of the gas. The toolpusher and the master, who equipped himself with a portable gas detector, proceeded to the drill floor where they met the drilling supervisor. The master began measuring the gas levels in and around the vicinity of the active alarm in the drillers house. After ascertaining that there were high levels of methane gas present, at 2026 the drilling supervisor ordered the well test crew to shut off the well flow. According to the American Petroleum Institute's recommended practice, when the low-level alarm sounded, the well flow should have been shut off immediately to eliminate the major fuel source. However, the Safety Board is not aware of any Phillips procedures directing its personnel to shut off well flow when the automatic low-level

methane gas alarm sounded, and there were no instructions in Global Marine's GLOMAR ARCTIC II Critical Procedures Manual or Operations Manual directing its personnel to shut off the well flow when the low-level automatic methane gas alarm sounded. The Safety Board believes that the Phillips drilling supervisor should have shut off the well flow when the low-level automatic methane gas alarm sounded about 2010. Failing that, the master or toolpusher should have ordered the well flow to be shut off upon their arrival at the drill floor area and then attempted to locate the source of the gas with the portable gas detector. However, even if the well flow had been shut off at 2010, the explosion probably still would have occurred because crude oil/gas had already entered the pumphook before the low-level alarm sounded.

When the explosion occurred in the port pontoon pumphook, the master reacted promptly and appropriately by sounding the fire/emergency alarm. He expeditiously initiated radio communications to the Maritime Rescue Coordination Center at Aberdeen, Scotland, and ordered the standby vessel, the M/V WADDINGTON, to come alongside the GLOMAR ARCTIC II for possible evacuation or rescue of personnel. He mobilized the emergency squads quickly and through radio-communication was kept informed of their progress in fighting the fire and throughout the emergency. His order to the emergency squad leader to insure that extinguishing all fires remained the top priority showed that the master clearly understood his role during the emergency situation and he exercised his command authority assertively.

The master, who was the offshore installation manager (OIM) under U.K. law, took charge of the emergency situation and effectively directed the MODU personnel in fighting the fire, determining the damage and condition of the MODU, and evacuating nonessential personnel in a timely manner. In several of its previous reports, 5/ the Safety Board has addressed the problem of division of authority and responsibility between the master, the toolpusher, and the oil company representative in time of an emergency and has recommended that only one person have ultimate control in time of an emergency. The position of OIM, as demonstrated in this accident where the OIM took full control, appears to be a solution to this problem.

All fires were reported extinguished within 20 minutes of the explosion. The emergency squad's response appeared to be adequate based on the results, although information concerning specific procedures required and actions taken were not available to the Safety Board. Although the abandon rig alarm was activated due to apparent alarm system damage, the statements of the master and crew show that crewmembers responded to the alarm properly and expeditiously.

Abandon Rig Alarm

The Safety Board investigated the false abandon rig alarm but was unable to determine conclusively the cause. However, the general alarm power cable was among the numerous cables severed by the damaged main deck elevator trunk at the time of the

5/ Marine Accident Report--"Capsizing and Sinking of the Self-elevating Mobile Offshore Drilling Unit OCEAN EXPRESS, near Port O'Connor, Texas, April 15, 1976" (NTSB-MAR-79-5); Marine Accident Report--"Capsizing and Sinking of the U.S. Mobile Offshore Drilling Unit OCEAN RANGER, off the East Coast of Canada, 166 Nautical Miles East of St. John's, Newfoundland, February 15, 1982" (NTSB-MAR-83-2); and Marine Accident Report--"Capsizing and Sinking of the U.S. Drillship GLOMAR JAVA SEA in the South China Sea, 65 Nautical Miles South-Southwest of Hainan, Island, Peoples Republic of China, October 25, 1983" (NTSB-MAR-84-08).

blast. The exposed ends of these cables were subjected to the subsequent fire in the oil containment tray. Shorting (contacting) of the two conductors in the cable that are part of a circuit to a general alarm contact maker (switch) will have the same effect as activating the general alarm switch; the alarm will sound continuously. The Safety Board believes that the two exposed conductors in the general alarm cable probably contacted each other and caused the abandon rig alarm to sound. The sounding of the abandon rig alarm probably was terminated by an electrician in the emergency squad who was making temporary emergency repairs to various circuits.

Evacuation

The master's decision to evacuate nonessential personnel from the GLOMAR ARCTIC II showed proper judgment on his part. It is also noteworthy that the master was able to readily identify essential crewmembers who were needed to remain onboard to operate the vessel and prevent further damage to the vessel. The evacuation of non-essential personnel began at 2207 when the transfer by helicopter to the GLOMAR ARCTIC I began; the presence of the M/V WADDINGTON provided an alternative evacuation method had the helicopters been unavailable.

The Safety Board was unable to determine whether the chief engineer or the third assistant engineer were aware of the activation of the methane gas alarm at the drillers house when they proceeded to the port pontoon area. Also, records indicate that the master was not apprised of the smoke alarm in the port pontoon pumproom before the explosion. Had the master, the chief engineer, or the third assistant engineer been aware of both the gas alarm and the smoke alarm before the explosion, a correlation between the two alarms could have been made, possibly resulting in a conclusion not to proceed into the pontoon area until further information was obtained. In any case, the Safety Board believes that the ballast control operator should immediately advise the master of all alarms in order to insure that the master is aware of all significant events as they occurred aboard the vessel.

CONCLUSIONS

Findings

1. The No. 3 burner tip of the port side crude oil burner fractured between 1950 and 2010 on January 15, 1985, during well test No. 2A.
2. The fracture probably initiated at one or more locations on the sharp inner shoulder radius at or near a corrosion pit.
3. The fracture of the No. 3 burner tip allowed well crude oil and gas to enter the atomizing air piping of the port side crude oil burner.
4. Well crude oil and gas flowed from the fuel body pipe, past the underside of the fuel disc flange, and then through the fracture in the burner tip into the rig air system.
5. Well crude oil and gas flowed through the atomizing air piping into the rig compressed air system and was expelled into the atmosphere of the MODU's port pontoon pumproom, creating an explosive condition.
6. The High Level Process Interface Unit ignited the explosive hydrocarbon atmosphere that was created in the port pontoon pumproom.

7. The GLOMAR ARCTIC II had no classification society or regulatory body vessel inspection deficiencies at the time of the accident.
8. Otis failed to establish or require quality control procedures to ensure strict adherence to specifications for the proper manufacture of the nitrolloy burner tips.
9. Otis maintenance procedures for the crude oil burners and nozzle assemblies were inadequate at the time of the accident and inspection procedures were nonexistent.
10. The No. 3 nozzle assembly of the port side crude oil burner was misassembled prior to 1950 on January 15, 1985.
11. The Phillips drilling supervisor should have ordered the well testing operation terminated when the automatic methane gas alarm sounded.
12. The master or the toolpusher of the GLOMAR ARCTIC II should have ordered the well testing stopped when they arrived at the drill floor.

Probable Cause

The National Transportation Safety Board determines that the probable cause of the accident was the misassembly of the No. 3 crude oil burner nozzle assembly by the well test crew, which resulted in the fracture of the No. 3 crude oil burner tip. The fracture allowed flammable crude oil and gas hydrocarbons to be released into the port pontoon pumproom, creating an explosive hydrocarbon atmosphere which was subsequently ignited by an electrical component in the pumproom. Contributing to the fracture of the No. 3 burner tip was the improperly manufactured burner tip and the lack of adequate Otis Pressure Control Company maintenance and inspection procedures for the well test crew.

RECOMMENDATIONS

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

--to the United States Coast Guard:

Amend U.S. Coast Guard regulations for mobile offshore drilling units (46 CFR 58.60) to include a requirement for the inspection of crude oil burners and their component parts to determine the mechanical and electrical conditions and to ensure that the equipment is maintained in a serviceable and safe condition. (Class II, Priority Action) (M-86-18)

Require that compressed air supplied to crude oil burners and well test equipment on all existing and new mobile offshore drilling units be supplied from a dedicated, separate, compressed air source and that the compressed air supply piping to crude oil burners and well test equipment be fitted with a device to prohibit the backflow of well hydrocarbons that may enter the compressed air piping. (Class II, Priority Action) (M-86-19)

--to the International Association of Classification Societies:

Urge its member societies to amend the Rules for Building and Classification of Mobile Offshore Drilling Units to include a requirement for the certification and inspection of crude oil burners and their component parts to determine the mechanical and electrical conditions so that the equipment is maintained in a serviceable and safe condition. (Class II, Priority Action) (M-86-20)

Urge its member societies to require that compressed air supplied to crude oil burners and well test equipment on all existing and new mobile offshore drilling units be supplied from a dedicated, separate, compressed air source and that the compressed air supply piping to crude oil burners and well test equipment be fitted with a device to prohibit the backflow of well hydrocarbons that may enter the compressed air piping. (Class II, Priority Action) (M-86-21)

--to Otis Pressure Control Company, Limited:

Develop and implement comprehensive inspection, maintenance, and assembly procedures for the crude oil burner and its component parts for the use of personnel involved in well testing operations. (Class II, Priority Action) (M-86-22)

Develop and implement quality control standards and procedures so that component parts of the crude oil burner are manufactured as specified. (Class II, Priority Action) (M-86-23)

Revise the operating procedures to require that compressed air supplied to crude oil burners be furnished by a dedicated, separate, compressed air source and that the compressed air supply piping to crude oil burners be fitted with a device to prohibit the backflow of well hydrocarbons that may enter the compressed air piping. (Class II, Priority Action) (M-86-24)

--to Global Marine Drilling Company:

Revise the operations manual for each Global Marine mobile offshore drilling unit to include instructions directing personnel to shut off well flow when the low-level methane gas alarm is sounded. (Class II, Priority Action) (M-86-25)

--to Phillips Petroleum Company:

Develop mobile offshore drilling unit operating procedures to include instructions directing personnel to shut off well flow when the low-level methane gas alarm is sounded. (Class II, Priority Action) (M-86-26)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JIM BURNETT
Chairman

/s/ PATRICIA A. GOLDMAN
Vice Chairman

/s/ JOHN K. LAUBER
Member

February 12, 1986

APPENDIXES

APPENDIX A
GENERAL ARRANGEMENT AND DRAWINGS
GLOMAR ARCTIC II

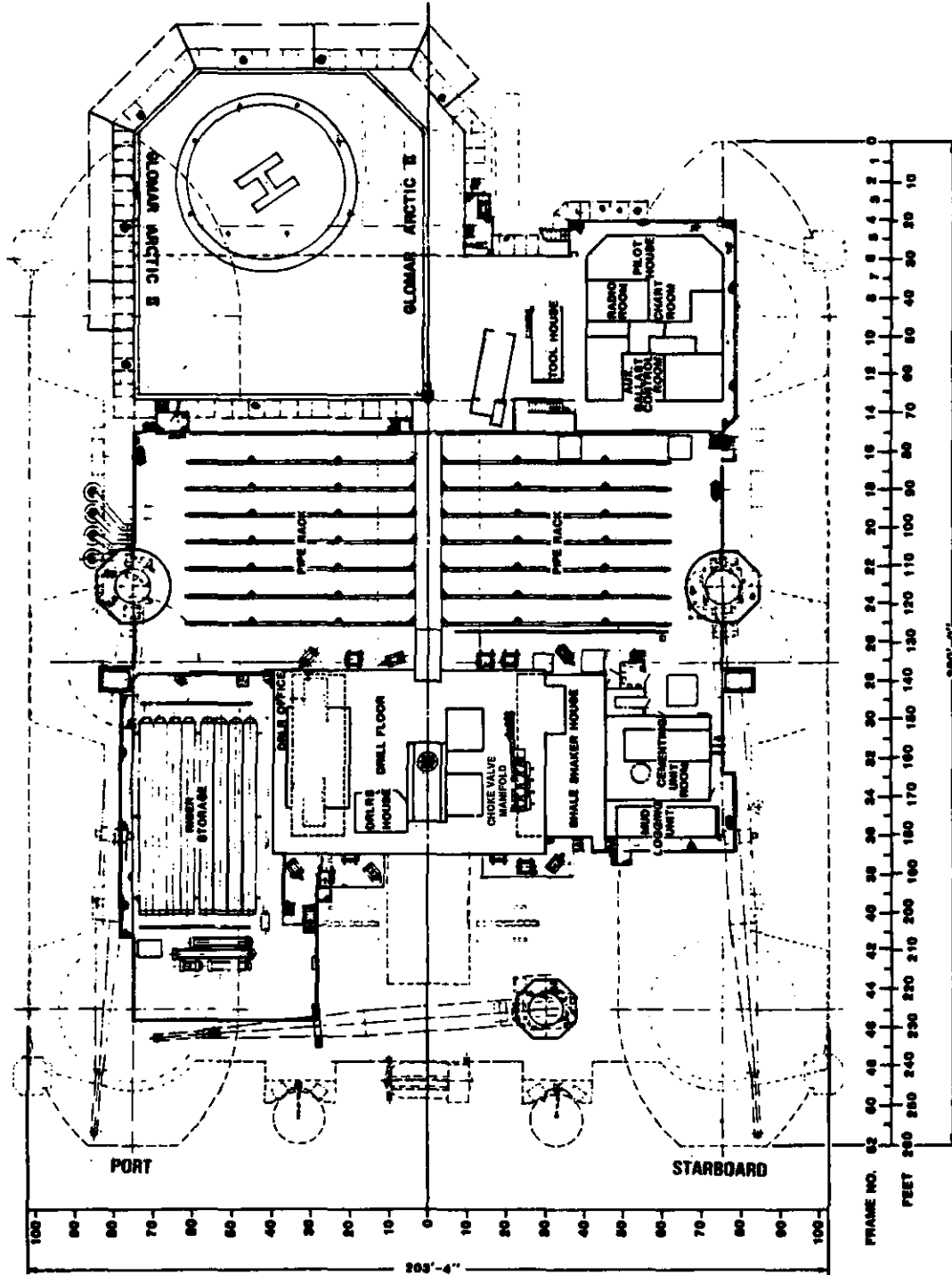


Figure A-1.--Upper decks.

Figure A-2.--Main deck.

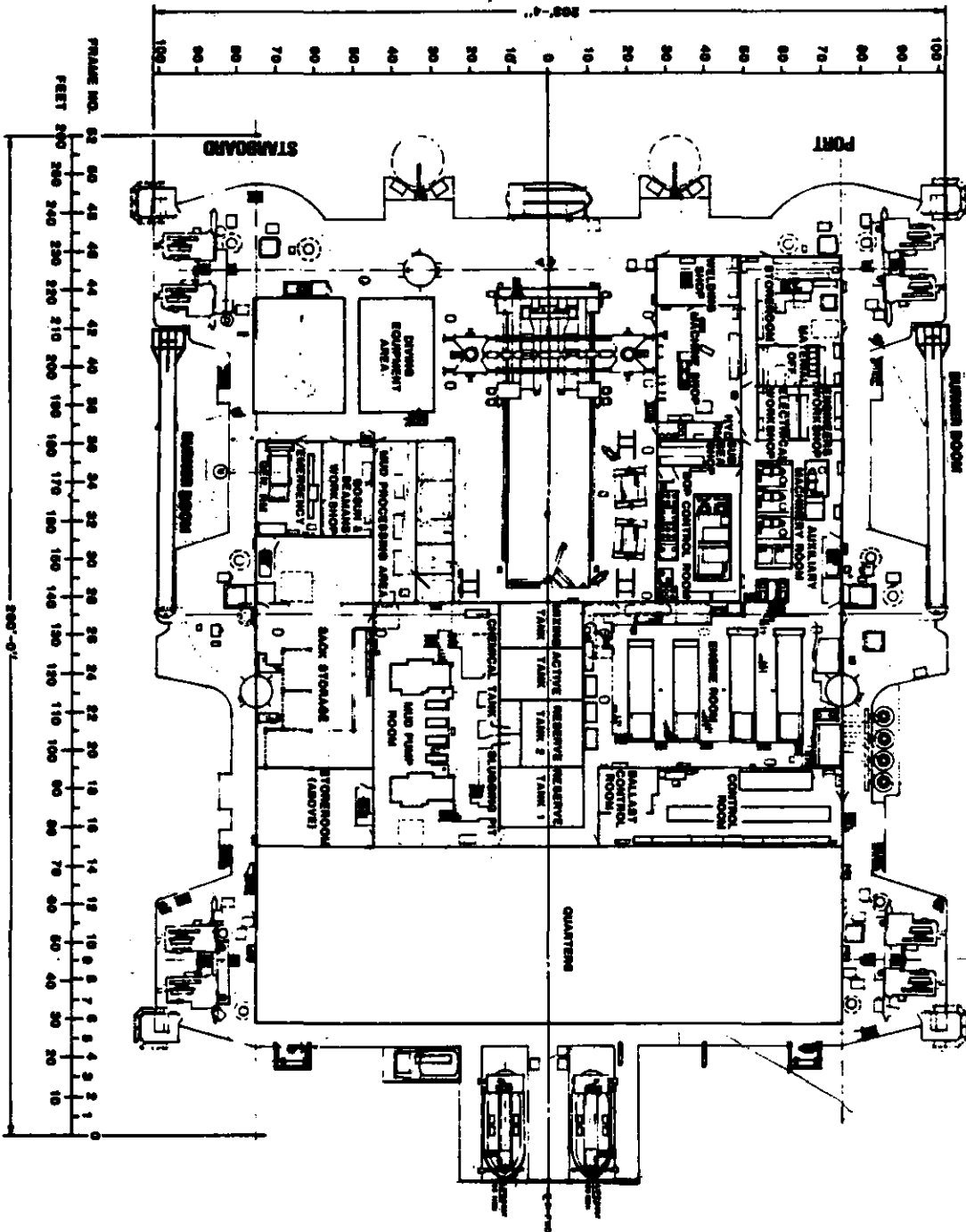


Figure A-3.--Pontoons

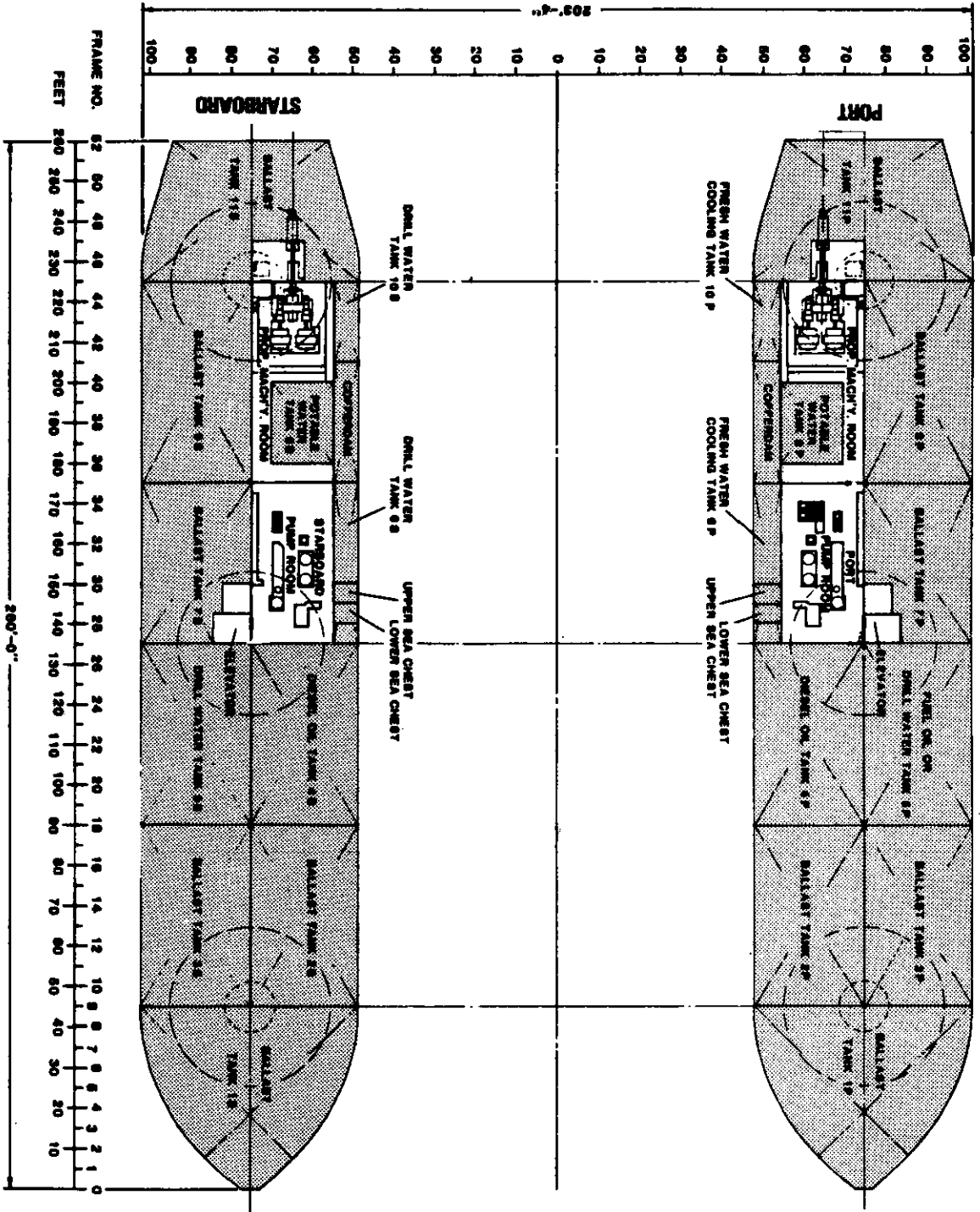
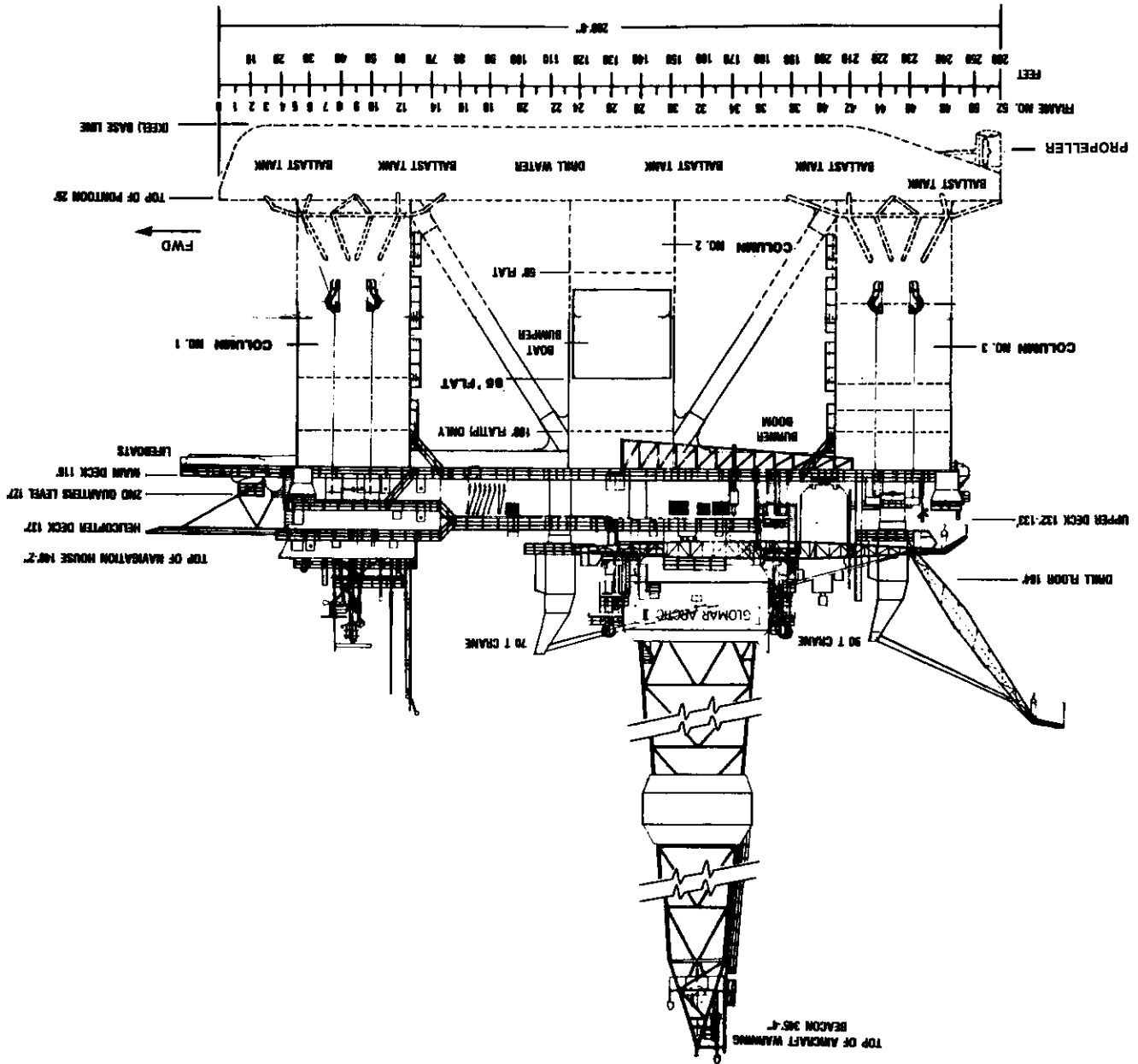


Figure A-4.--Outboard profile, starboard.



APPENDIX B

MAINTENANCE REQUIREMENTS
OTIS CB-12A CRUDE OIL BURNER

OTIS

OTIS CB-12A CRUDE OIL BURNER



3.1 MAINTENANCE REQUIREMENTS

Proper maintenance of the Burner and Manifold assembly will aid in obtaining the maximum efficiency and service life. Inspect all connections and fittings for security.

3.1.1 Pilot and Ignitor System

- A. Inspect plug, high voltage wiring, and ground connections.
- B. Check pilot gas supply for unobstructed flow and security of connections.
- C. Make sure battery pack is kept charged up.

3.1.2 Water Ring

- A. Fresh water should be flushed through the system after each test.
- B. With water spraying, check to see if any nozzles are clogged. Remove any clogged nozzle and either clean or replace it.

3.1.3 Burner Guns (Cleaning and Inspection):

Perform as Required.

- A. Remove outer Burner Nozzle (80B195).

NOTE: Do not lose gasket.

- B. Clear air holes of any obstructions.
- C. Inspect burner tip for clog or wear; clean or replace as condition indicates.
- D. Normally, no further disassembly is required.
- E. Reassemble nozzle assemblies.
- F. If equipment is not to be used for extended periods of time coat with grease to protect against corrosion.

APPENDIX C

PERSONNEL INFORMATION

John Charles Willis, Senior Drilling Supervisor

Mr. Willis was Phillips Petroleum's senior person onboard the GLOMAR ARCTIC II on January 15, 1985. As senior drilling supervisor, Mr. Willis was in overall control of the drilling and well test operations. He coordinated MODU activities to follow a drilling/exploration program devised by Phillips Petroleum shoreside offices. Mr. Willis joined Phillips Petroleum in 1975. He was promoted to staff drilling supervisor in January 1981. In September 1982, he became associate drilling supervisor. In September 1984, he was promoted to senior drilling supervisor. Mr. Willis has actively followed a company training program during his tenure at Phillips Petroleum. He has successfully completed courses in well control, well drilling, offshore survival, and the offshore installation manager (OIM) School.

Bruce Phillip Butterfield, Master/Offshore Installation Manager (OIM)

Mr. Butterfield was hired by Global Marine Drilling Company on September 1, 1984, for the position of master on the GLOMAR ARCTIC II. On November 21, 1985, he successfully completed the offshore installation managers regulations course given by the Scottish Offshore Training Association. Mr. Butterfield had been master/OIM of the GLOMAR ARCTIC II since January 9, 1985, which was also his first experience employed on a MODU. As master/OIM, he was responsible for all activity onboard the vessel. The USCG issued Mr. Butterfield his Master's License, Ocean Steam or Motor Vessels, Any Gross Tons, on October 21, 1980. Prior to joining Global Marine, he worked for the Military Sealift Command-Pacific, for 14 years serving as a third mate, second mate, first mate, and master of a variety of ships on various assignments. While employed by the Military Sealift Command, Mr. Butterfield completed numerous courses in firefighting and damage control. Mr. Butterfield graduated from the California Maritime Academy on July 25, 1970, with a B.S. in Nautical Science.

John P. Traut, Chief Engineer

Mr. Traut was hired by Global Marine Drilling Company in August 1974 as a third assistant engineer on the drillship GLOMAR CORAL SEA. In April 1978, he was assigned as the third assistant engineer onboard the drillship GLOMAR CONCEPTION and in May 1979 he was assigned to the second assistant engineer position on the drillship GLOMAR ATLANTIC where he progressed to first assistant engineer in June, 1980 and chief engineer in April 1982. He was assigned the chief engineer position on the semi-submersible GLOMAR ARCTIC II in March 1984 while the vessel was still in the shipyard in the final construction and testing phase.

Mr. Traut received a B.S. degree in Marine Engineering in 1974 from the United States Merchant Marine Academy at Kings Point, New York. In April 1982, Mr. Traut was issued a license by the USCG as chief engineer on motor vessels of any horsepower and second assistant engineer on steam vessels of any horsepower.

Mark J. Paradiso, Third Assistant Engineer

Mr. Paradiso graduated in 1983 from the U.S. Merchant Marine Academy at Kings Point in New York and was licensed by the USCG as a third mate on steam or motor vessels, unlimited tonnage, and as a third assistant engineer on steam or motor vessels of any horsepower. Mr. Paradiso was hired by Global Marine Drilling Company on April 19, 1984, as a third assistant engineer and was assigned to the GLOMAR ARCTIC II.

Jon H. Wegand, Ballast Control Operator

Upon his graduation from high school, Mr. Wegand enlisted in the USCG where he attained the rank of petty officer second class. Following his discharge from the USCG, Mr. Wegand was hired by Global Marine in 1971 as an ordinary seaman/messman until he left the company in 1975. Mr. Wegand was rehired in 1979 as an able bodied seaman and assigned to the drillship GLOMAR CHALLENGER. In November, 1981 Mr. Wegand was issued a license by the USCG as a third mate steam and motor vessels of any gross tons and Global Marine assigned him as third mate aboard the GLOMAR CHALLENGER. In 1983, he successfully completed Global Marine's on-the-job training courses for seaman and for oiler, and in 1984 he completed Global Marine's fundamentals of Ballast Control Training School. On March 25, 1984, he was assigned to the GLOMAR ARCTIC II as a ballast control operator.

