Report of the Chief Inspector of Marine Accidents

into the explosion on the Motor Tanker

ESSO MERSEY

on 4 September 1991 resulting

in the loss of two lives

Marine Accident Investigation Branch
5/7 Brunswick Place
SOUTHAMPTON
Hants SO1 2AN

London: HMSO

First published 1993
Second published 1994

ISBN 0 11 551166 0

Marine Accident Investigation Branch
Department of Transport
5/7 Brunswick Place
Southampton
Hants SO1 2AN

10 December 1992

The Right Honourable John MacGregor OBE MP
Secretary of State for Transport

Sir

In pursuance of Regulation 9 of the Merchant Shipping (Accident Investigation) Regulations 1989, I submit my Report following the Inspector's Inquiry into the explosion on the tanker ESSO MERSEY on 4 September 1991 resulting in the loss of two lives.

I wish to place on record appreciation for the co-operation which was extended by the Esso Petroleum Company to the Inspectors who carried out the Inquiry.

I am, Sir,
Your obedient servant

Captain P B Marriott
Chief Inspector of Marine Accidents

CONTENTS

1. SUMMARY

The 1972 built, UK registered motor tanker ESSO MERSEY was discharging cargo at the Esso Fawley Refinery Marine Terminal on 4 September 1991 when an explosion occurred in the pump room. The products of the explosion passed up through the pump room, burst into the cargo control room, and exited through the forward starboard door at poop deck level. The Chief Officer suffered severe burns from which he later died while an Able Seaman was killed outright in the blast.

The discharge operation ceased immediately and, due to the action taken by ship's staff, only minor leakage occurred in the pump room. Minor fire damage occurred in the pump room with severe blast and fire damage to the cargo control room.

A "Category 2" incident (a situation beyond the scope of Esso site personnel, which requires back-up facilities) was declared under the Esso Emergency Plan. Onsite and offsite emergency services then co-ordinated successfully to safeguard the vessel, prevent further explosions and protect the environment against pollution.

The investigation established that the explosion was caused by a vibration-induced failure of a cargo pump, leading to the loss of cargo through the top mechanical seal and eventual ignition by contact between the drive shaft and the shaft guard.

Deficiencies have been identified in the maintenance work carried out on the cargo pump involved in the explosion, and in the supervision of that work together with a low appreciation of the inherent dangers of vibration despite the vessel being manned with experienced tanker officers. Along with the positive steps already taken by Esso, recommendations have been made in the Report with a view to preventing the recurrence of a similar incident.

PART I FACTUAL ACCOUNT

2. PARTICULARS OF SHIP AND CREW

2.1 Description and Construction of Vessel

ESSO MERSEY is a steel hulled, single screw motor tanker with 13 cargo tanks, 2 segregated water ballast tanks, and 2 dedicated ballast tanks (fore peak and fore deep) occupying the forward part of the ship, with 1 dedicated ballast tank (aft peak), the pump room, engine room and accommodation aft (see Figure 1). The vessel operates in the "clean oil" trade round the UK coast and Continent.

Official No	:	358496
Owners	:	Esso Marine UK Ltd
Managers	:	Esso Petroleum Co Ltd, Marine Division
Registered	:	London, UK
Built	:	1972 Cammell Laird & Co, Birkenhead
Gross Tonnage	:	11,898
Deadweight	:	20,510 tonnes
Length	:	166.50 metres
Beam	:	22.84 metres
Draft	:	9.21 metres
Classification	:	Lloyd's Register +100A1, + LMC, UMS
Cargo Pumps	:	4 x Weirs Vertical 2 stage, twin impeller centrifugal type, electrically driven. 720 m^3/hr @ 1750 rpm

2.2 Cargo Pump Room

The cargo pump room is situated between the forward engine room bulkhead and the after bulkheads of No 5 Port, Centre and Starboard Cargo tanks and extends upwards from keel plate to poop deck level (see Figure 2).

At lower floor plate level, recessed into and immediately forward of the engine room bulkhead are four main cargo pumps; No 1 on the port side and No 4 on the starboard side. Each pump is driven by a vertically mounted electric motor situated in the engine room. The motor and pump are connected via a deck head bearing and gas seal to a cardan shaft driven through a universal coupling (Figure 3).

Forward of the cargo pumps at this level are the cargo valves. Outboard of the cargo pumps on the starboard side is a cargo tank ballast pump whilst the port side is used as a small work space. Rising through the space to the main deck are the discharge pipes from the individual pumps, extract ventilation trunking and the hydraulic and pneumatic control lines for the cargo and pump valves.

The cargo discharge lines pass through two openings at main deck level into the deck house and run forward to the discharge manifold on the open deck. On the starboard side of the deck house is the exhaust fan whilst at the rear of the space are four VAC strip pumps with their water seal tanks. The hydraulics room, situated at main deck level, aft of the pump room and within the accommodation block, contains the electric motors driving the exhaust fan and VAC strip pumps. Each drive shaft is fitted with a bulkhead gland.

Eight openings, each of 1m x 0.6m, in the deck head at the after end of the deck house provide access through which the hydraulic control lines for all valves, both in the pump room and on deck pass through to the control desk in the cargo control room above. Access from the pump room to the main deck is provided by doors at the port and starboard side.

Ventilation is by induced draught via twin intakes on the port forward side of the poop deck into the top of the pump room deck house. One is fitted with a movable cowl; the other is blanked off. The exhaust fan takes in air from a number of inlets at lower floor plate level and discharges on deck at high level on the starboard side, poop deck.

2.3 Cargo Control Room

The cargo control room is recessed into the front of the accommodation block at poop deck level. Access is direct from the poop deck forward via weathertight doors, one port and one starboard.

The cargo control room contains an integrated control desk and mimic panel, cargo and ballast pump control panels, cargo tank ullage control panel and pump monitoring systems. Office equipment, tank status board and various test, safety and communication equipment had also been fitted.

2.4 Pump Room Machinery Instrumentation

Each cargo pump and the ballast pump are fitted with the following temperature sensors:

- Top and bottom bearing

- Casing

- Gas seal at the pump room/engine room penetration

These sensors are fitted in excess of both statutory and Classification Society requirements.

The cargo pump bearing and casing sensors are set to alarm at 60°C with the pump trip operating at 65°C. These alarms sound in the cargo control room. The pump room/engine room gas seals and the ballast pump sensors do not have an alarm point but are set to trip the individual pump which they protect at 65°C.

The pump room extraction fan is fitted with a rotational failure and a power failure alarm.

There is no statutory requirement for continuous gas monitoring of the cargo pump area although sampling tubes are installed to enable gas tests to be carried out on demand from the cargo control room.

2.5 Fire Fighting Equipment

The equipment installed is in excess of the requirements of the Safety of Life at Sea (SOLAS) Convention 1974 and the Merchant Shipping (Fire Protection) (Ships Built Before 25 May 1980) Regulations 1985.

The cargo pump room is fitted with a fixed CO_2 smothering system in addition to a fixed multispray water system fed from the deck fire main.

An approved fire and smoke detection and alarm system is fitted covering both the cargo control room and the cargo pump room, the alarm sounding initially on the bridge and in the engine control room. Lack of response switches the alarm into a general alarm situation.

2.6 Certification

All of the certificates for the vessel, including the Cargo Ship Safety Equipment Certificate and Cargo Ship Safety Construction Certificate, were found to be in order and fully up-to-date.

2.7 Crew

The vessel carried a total complement of 16: the Master, three deck officers, four engineer officers, the Pumpman, four able seamen, the Chief Steward and two engine room ratings. All the officers were experienced in tanker operations and were properly certificated.

3. NARRATIVE

3.1 Events Prior to Cargo Discharge

The vessel departed from Amsterdam in a loaded condition at approximately 1415 hrs on 2 September 1991 bound for the Esso Fawley Refinery Marine Terminal, Southampton. The cargo consisted of 5,358.5 tonnes of premium grade petrol and 12,511.7 tonnes of naphtha.

After an uneventful passage, the vessel arrived at Fawley with "Finished with Engines" ordered at 1636 hrs on 3 September. She berthed starboard side to at No 3 Berth and commenced the various safety checks. The Esso Vessel Inspection Officer boarded and, after consultation with the Chief Officer, the ship/shore safety check list was completed satisfactorily. The "EEC Tanker Check List" was also approved. A cargo surveyor took samples, ullages etc and agreed with the refinery the cargo discharge plan previously prepared by the Chief Officer, and approved by the Master in accordance with Esso's established procedures.

3.2 Start of Cargo Discharge

As there were two Second Officers (Deck) on the ship, for clarity they are referred to in this part of the Report as the "8-12 Second Officer" and the "12-4 Second Officer".

At 2000 hrs when the Chief Officer handed over the watch to the 8-12 Second Officer and an Able Seaman, all checks had been completed and the vessel was ready to discharge. No valves had been opened at that time.

The standard Company "Enclosed Space Entry Permit" system had been put into operation by the Master with the then current permit having been validated from 1630 hrs that day. This permit required a hydrocarbon gas test to be taken at least every 4 hrs in the pump room.

The agreed discharge plan was as follows:

Nos 1 and 2 cargo pumps discharging naphtha via No 2 manifold.

No 3 cargo pump discharging premium grade petrol via No 3 manifold.

The line up sequence of valve opening and cargo line flooding from tank to pump was started with No 1 and No 2 pump lines proving satisfactory. The sequence of valve opening to No 3 pump line was also satisfactory until the suction valve to the pump itself was opened. At this point, the Pumpman who was monitoring the situation from the pump room whilst the Second Officer operated the valves from the cargo control room, advised that the pump separation chamber was leaking. The line was shut down and the Chief Officer called.

As the last gas test on the pump room had occurred at 2030 hrs, prior to the leak, the space was re-tested before the Chief Officer entered to inspect the pump and authorise a change in the discharge plan. It was subsequently decided that due to this leak, additional testing over and above the permit requirements should be carried out on the pump room before entry to the space, and that the cargo control room should also be tested at intervals.

The revised discharge plan was approved and implemented utilising No 4 cargo pump rather than No 3 cargo pump. This required additional valve changes on deck to allow discharge via No 3 manifold. Discharge started at 2048 hrs and continued according to the revised discharge plan.

At 2400 hrs the watch was taken over by the 12-4 Second Officer together with another Able Seaman. During the next four hours two visits were made to the pump room: the small leak from No 3 pump separator chamber was confirmed and an additional small leak from No 4 pump top mechanical seal noted.

The pump room entry permit was again revalidated at 0030 hrs and an acceptably low hydrocarbon gas reading obtained in the pump room. Two further tests were carried out prior to entry for inspection visits during the watch, also giving acceptable readings.

The cargo pump temperatures had been monitored as usual during the watch without a suggestion of any problem, all temperatures being well below the alarm point.

3.3 Events Leading up to the Explosion

The Chief Officer together with a different Able Seaman took over the watch at 0400 hrs and a decision was made to alter the discharging sequence in order that a slight port list could be applied to the vessel to assist in the stripping of the cargo tanks which were nearly empty.

A pump room gas reading was taken at 0430 hrs and recorded as being acceptable (less than 1% of the lower explosive limit - LEL). At this time it was decided that to further assist the tank stripping operation, the vessel's stern trim would be increased by changing the discharge sequence. As tank valves on deck required opening for this operation and the Able Seaman on duty was new to the vessel, the Chief Officer went forward with him to identify the correct valve.

On their return aft to the poop deck at approximately 0500 hrs, the Chief Officer smelt a very strong concentration of petroleum vapour just outside the cargo control room. He said to the Able Seaman that something was not right and then told him to get ready to go forward and close the manifold valves. The Chief Officer took a gas reading on deck just outside the cargo control room using the meter stowed on the starboard side of the mimic panel and obtained a reading of 20% LEL.

Moving back into the cargo control room, he took another reading with a different meter by the desk and again noted a reading of 20% LEL. Deciding to shut down all cargo operations, he called to the Able Seaman to shut the manifold valves. Turning towards the stop button for No 4 pump, there was a rattle, an orange flash, a very loud bang and he found himself on the deck in the cargo control room.

3.4 Events After the Explosion

At about 0505 hrs the 12-4 Second Officer, heard the explosion and quickly went down to the starboard side of the poop deck intending to go to the cargo control room. As he opened the door to the deck, he met the Chief Officer who was just entering, severely burned and in a state of shock. He was immediately led to the nearest cabin for cold water treatment before being taken by the Second Engineer and the Electrician to the hospital for immersion in a cold bath.

The Second Officer in the meantime had gone out onto the poop deck to check the situation in the pump room. He found debris all over the deck with thick black smoke coming out of the cargo control room doors. The exhaust fan failure alarm was operating followed shortly afterwards by the general alarm. He then made his way up to the bridge to report to the Master.

The Master, who had been awakened by the explosion, went immediately to the bridge and found both the pump room fire and smoke detection and exhaust fan failure alarms ringing. Whilst the Master was contacting Southampton Vessel Traffic Service (VTS) (recorded at 0508 hrs) and the Esso Marine Control via VHF radio, the Second Officer went back down on the forward deck to secure the cargo system. He advised the Master that the explosion in the cargo control room had badly burned the Chief Officer and that the on-duty Able Seaman was missing.

On his return to the deck, the Second Officer briefly looked into the cargo control room, could see nothing, noted that the vent intake cowlings were missing and continued forward finding the missing Able Seaman slumped over the flying bridge rail and apparently dead. He shut all three manifold entry block valves using the remote controls on the flying bridge (the hydraulics still operated at this time) before passing down onto the main deck in order to manually shut Nos 2 and 3 manifold valves.

On picking up the gangway hand-held radio (located in this position in port for visitors to advise the Officer on watch of their arrival), he advised the Master of the situation and that he was going to shut all deck valves; he also confirmed to the shore personnel that discharge was stopped.

Esso Marine Control having been advised by the Master that an explosion had occurred in the pump room and that one man was dead and another badly injured, notified the Esso Emergency Control Centre. All cargo operations on other berths were stopped and under the Esso Emergency Plan the incident was classified as "Category 2" - a situation that required back-up facilities beyond the scope of Esso site personnel. VTS advised all ships via a general broadcast that traffic movements past Esso Fawley Marine Terminal were suspended until further notice.

The Master in the meantime had instructed the engine room to check the temperature of the pump room bulkhead, rig for boundary cooling and to keep him advised of any temperature variations. The engine room staff shut down the hydraulic system and electrically isolated the cargo pumps.

On deck forward, the 12-4 Second Officer together with an Able Seaman had shut all deck cargo tank valves and cargo tank vent valves. Whilst this was in progress, the 8-12 Second Officer, who had been mustering the crew aft for a personnel check, had obtained a hand-held radio and had been instructed by the Master to lower the port lifeboat to the embarkation deck as well as to activate the bridge front water wall. The 12-4 Second Officer had by this time advised the local shore personnel of the situation regarding the explosion, injuries suffered etc, as well as instructing an Able Seaman to shut the pump room doors. On his return the Able Seaman advised that the port door of the pump room was closed, with the starboard door partly closed on two "dogs" only.

Esso Marine Control put the on-station standby fire tug CLAUSENTUM on full alert, and called the Marine Terminal Superintendent. In the meantime, an incident room had been set up ashore and Esso Petroleum Marine Division Managers contacted.

At 0525 hrs, the Master instructed the engine room to flood the pump room with CO_2 but not to operate the multispray at that time.

Hampshire Fire and Ambulance services arrived at approximately 0527 hrs and took the Chief Officer ashore and to hospital. The Hampshire Fire team met the Master and Terminal representatives on the bridge to discuss the situation and for an update on cargo position. At 0555 hrs the Fire Brigade injected foam into the pump room as a precautionary fire measure as well as to contain any gas emission.

At 0600 hrs VTS advised all ships that traffic could now resume but that it should pass Esso Fawley Marine Terminal with extreme caution and give it a wide berth. At 0720 hrs VTS advised all shipping that normal conditions passing Esso Fawley Marine Terminal could be resumed.

3.5. Containment and Recovery Operation

At approximately 0800 hrs three firemen, the 12-4 Second Officer, the Chief Engineer and the Esso Ship Operations Manager entered the pump room wearing Self Contained Breathing Apparatus (SCBA) sets. Gas readings taken at the first and second levels proved high and the team retreated back on deck. About an hour later, the same team less the Chief Engineer re-entered and confirmed that three leaks were present, two of seawater from the ballast system and one of cargo from the bottom of No 4 cargo pump.

The cargo valves still open to No 4 pump were the suction valve, deck discharge valve and No 4 centre bulkhead valve. Due to concern over the condition of the hydraulic system, these valves and others upstream were closed progressively during the day using a portable hydraulic jack. Gas checks carried out at the engine room/pump room gas seals gave nil readings.

Whilst the valve closing operation was under way, a decision was made by the Fire Chief and the Master to shut the vessel down due to the danger from high gas levels still present in the pump room. At about 1000 hrs, the ship's power system was shut down and all sources of electrical power isolated, including the batteries.

The cargo and gas containment operations continued over the next two days with the Hampshire Fire services remaining in attendance. Esso and Hampshire Fire Brigade co-operated in the removal of the mixture of cargo, water and foam in the pump room to a slop tank on the berth.

At 0305 hrs on the 6 September, after the vessel was cleared of personnel, gas freeing of the pump room started. At 1045 hrs the vessel was advised that the resumption of the cargo discharge to shore would be delayed whilst cargo samples were tested. At 1930 hrs the emergency generator was brought back into operation. Venting of the pump room continued with a gas reading taken at 2330 hrs giving a reading of 1% LEL.

At 0630 hrs on the 7 September the Hampshire Fire services, considering the situation safe and under control, left the site. Specialist equipment and expertise under the direct control of the Esso Marine Incident Team, commenced inerting the cargo system at 0210 hrs on 8 September. Cargo discharge of the vessel resumed at 0640 hrs the same day with completion at 1940 hrs on 10 September.

3.6 The Chief Officer died in hospital from his injuries on 7 September 1991.

PART II CONSIDERATION OF POSSIBLE FACTORS

4. CARGO PUMP INSPECTION AND EXTENT OF DAMAGE

4.1 General Damage

Damage sustained to the vessel due to the explosion was essentially restricted to the pump room and cargo control room. There was minimal damage to the adjacent accommodation and service areas and only relatively minor damage to the deck area immediately forward of the cargo control room.

The cargo control room had suffered quite severe damage, principally on the starboard side, with the decking beneath the control panel ruptured and all mimic and control desk access panels blown off. The cargo pump control face panels had been forced into a concave shape, the ventilation trunking had been squashed and the after bulkhead distorted. The starboard bulkhead was also distorted causing damage to furniture in the adjacent crew cabin.

Various items had been blown out on deck. A desk normally fitted on the after bulkhead, starboard side, was thrown forward and partially scorched. No hydraulic valve control or indicator lines were ruptured and there was only minor heat damage to instruments.

On the poop deck forward, a fire valve handle was shattered and the vent cowls for the pump room ventilation blown off. Apart from some blast marking and damaged paintwork the deck area was undamaged.

At the main deck level, in the top of the pump room, there was very little fire damage although on the starboard side aft, immediately under the control desk, the hydraulic lines were badly scorched. The exhaust trunking in this area was squashed. There was also minor damage to the sight glass of one of the priming pump water seal tanks and a hole found at an elbow in the vent line from the seal tanks to the deck. The elbow showed signs of severe internal corrosion/erosion, which together with numerous pipe pieces within the pipe, suggested that the collapse was due to an external pressure wave from the explosion.

Very little fire or smoke damage was evident in the upper reaches of the pump room, moderate damage occurring only in the immediate vicinity of No 4 cargo pump on the starboard side.

Preliminary Examination of No 4 Cargo Pump

Relatively little external damage to the pump was visible but the preliminary examination identified the following points: (see Figures 3 and 4)

- Bottom mechanical seal leaking.

- Top mechanical seal totally failed.

- All 4 top bearing housing pedestal securing bolts missing.

- One locating dowel (outboard) inoperative and one very loose (inboard).

- Cardan shaft guard upper bracket securing bolt missing.

- Cardan shaft guard lower bracket failed.

- Cardan shaft guard securing bolts to pedestal, two missing with centre one loose.

Internal damage to No 4 cargo pump was suspected but this could only be ascertained once the pump was removed from the vessel.

4.3 **Detailed Examination of No 4 Cargo Pump**

A further detailed examination of No 4 cargo pump when the pump had been removed ashore revealed the following: (see Figure 4)

- The pump coupling locknut was tight but did not have locking grub screws fitted.

- The coupling was a loose fit. Good engineering practices would have required an interference fit of 0.001-0.0015".

- The top bearing was well lubricated and fitted well in the housing but it was a poor fit on the shaft and had been fretting on the shaft. This caused the mechanical looseness seen before the strip down.

- The top bearing pedestal had not been securely fixed for a period of time. This was indicated by the elongation in the hole which contained the one remaining dowel. There was evidence that the fixing bolt second from starboard side was the last bolt to vibrate free. This was shown by the heavy thread marks in the pedestal clearance hole.

- The starboard pedestal fixing hole in the pump body was damaged with threads stripped. Only the bottom 2 threads were still there.

- The second fixing dowel had at some time been drifted through the pedestal into the pump casing and not been re-fitted. The dowel was protruding slightly above the flange face.

- The top mechanical seal had totally failed. The primary seal had large pieces of its face material missing and some chips out of the carbon face. The seal face was a hard compound sprayed on to a brass alloy base and machined/lapped flat.

- The secondary seal had broken up and disappeared completely.

- The seal sleeve had been rubbing on the seal plate and seal carrier causing heavy grooving in the sleeve. Some of the seal drive screws had worked loose and one had dropped out, this screw was found on the pump casing while the pump was in the ship.

- The bottom bearing was in a heavily rusted condition and the outer track was running $^1/4$" axially out of position to the inner race. The grease point was fitted and although no lubricant remained on the bearing itself, grease was found in the "O" ring groove in the bearing end cap. This indicated that the bearing was grease packed during assembly on the last occasion that the bearing had been replaced/ renewed. The threaded plugs were found to be missing from the two tapped holes situated at the top of the bearing carrier. Brass sleeves in these holes formed an isolation barrier between the lubrication groove and tapped hole. These holes facilitate drifting the outer bearing clear of the carrier. The outer bearing cavity would have had to be full of grease and under pressure before any lubricant could have escaped through these openings.

- The "O" ring seal to the bottom bearing cover was not fitted.

- The lip seal protecting the bottom bearing had swollen when the bottom seal had leaked product onto it and caused it to fail.

- The bottom mechanical seal was severely damaged with sections of the primary seal face chipped off. The secondary containment carbon seal had totally disintegrated and particles of carbon were found in the bottom seal leak chamber. All drive screws etc were intact in this seal.

- The first stage impeller outer locking nut had backed off $^7/32$" from its mating nut. This locking nut should have been fitted with 2 locking grub screws. Both were missing. These may not have been fitted, or if fitted vibrated out and disappeared, or they were fitted and corroded away completely.

  The inner lock nut, against the impeller, was only hand tight. There were indentations in the mating locknut indicating that on three occasions there had been grub screws fitted in the locknuts.

- The inter stage sleeve, between impellers, was free to move. This should have been an interference fit.

- The top, second stage, impeller lock nuts were tight and the locking grub screws were fitted but were severely corroded as they were mild steel.

  Like the first stage, there were indentations in the mating locknut indicating that on three occasions there had been grub screws fitted in the locknuts.

- The wear rings had all rubbed and the clearances which should have been approximately 0.022" were:

  lower wear ring 1st stage - 0.085"
  upper wear ring 1st stage - 0.105"
  upper wear ring 2nd stage - 0.108"

  The lower wear ring on the 2nd stage impeller had come off the impeller and was resting in the intermediate piece. With this ring off there was a clearance of $^{7}/_{16}$" between impeller and case wear ring.

- All inter stage and neck bushes had excessive clearances with the PTFE liners missing. There was a thin section of liner remaining in the lower neck bush.

- The shaft had been spray metal repaired in four locations; this metal had lifted in all locations with only a small percentage left in two of the areas. The areas spray metalled were:

  2 areas under the top neck bush
  1 area under the bottom neck bush
  1 area under the bottom mechanical seal sleeve

- The impellers were a good press fit on the shaft. Three of the impeller keys were manufactured from mild steel and had badly corroded. The fourth key was stainless steel and in good condition.

- The shaft was checked for straightness and the maximum error was 0.0035" TIR (Total Indicated Reading).

- The general condition of the impellers was good showing only slight signs of cavitation and erosion.

- The general condition of the pump casing was good apart from a small crack in the second stage volute web. This was an original casting flaw which had been highlighted by product erosion.

5. CAUSE OF EXPLOSION

5.1 Preliminary Investigation

The conclusions reached after the preliminary examination were:

- The fire damage in the pump room at plate level was consistent with the combustion of a pocket of rich gas (at the upper explosive limit) at or above head height in the vicinity of No 4 cargo pump and the propagation of a flame front away from this area.

- The damage in the upper parts of the pump room and in the cargo control room was consistent with the passage of unburned product mixture followed by the flame front and combustion products into the cargo control room via the epoxy partition below the control console and mimic panels before finally venting out forward through the control room doors.

5.2 Report of Failure Sequence

The detailed examination of No 4 cargo pump, suggests a probable sequence of events from pump failure leading to release of product and eventual explosion:

The lower impeller, 1st stage outer locknut came loose and backed off. This allowed the locknut holding the 1st stage impeller to free sufficiently to allow the 1st stage impeller to move on the shaft and allow free movement of the interstage sleeve between the impellers. The cause of the initial slackness in the impeller outer locking nut was not positively identified. However, it was noted that the locking grub screws were absent and that the products of corrosion was evident in the 1st stage impeller lock nut grub screw holes. The debris found in the threaded holes was such that it was not possible to say whether grub screws had been refitted after a 1989 overhaul and the material had corroded away or simply that the screws had not been replaced.

The resultant mechanical looseness in the rotating unit made it less stiff and brought the critical running speed of the rotor close to the actual running speed of the machine. This looseness caused imbalance in the rotor and increased the vibration levels. Discolouration of the faces of the locknuts indicated that they had been loose for some time.

One of the top bearing pedestal dowels was not fitted; this was likely to mean that the pump shaft was not running through the centre of the casing. This being the case it caused instability through the centre bush and affected wear ring clearances, thus further increasing vibrations.

The lower wear ring on the 2nd stage impeller most likely came into contact with the casing wear ring, heated, expanded and started to move off the impeller. This caused further rubbing and heat until it finally came off and rested in the intermediate piece. This put the rotor further out of balance.

The high vibrations in the machine were sufficient to loosen the bolts in the cardan shaft guard and the top bearing pedestal. It would appear that these bolts came out over a lengthy period of time with the last remaining bolt being the second from the starboard side.

The final bolt in the top bearing pedestal worked its way out allowing the pedestal to swing about the remaining dowel. This movement then shattered the seal secondary containment carbon and severely chipped the primary seal faces on both the top and bottom seal causing major seal leakage.

The edges of the 16 bolts clamping the cardan shaft Hardy Spicer swivel joint to the pump drive coupling, protruded over the edge of the coupling periphery. Following the release of the cardan shaft guard restraining bolts and the pedestal retaining bolts, the pump would have been vibrating severely. At this time, movement of the assemblies would have been such that the coupling bolts and nuts would come into contact with the cardan shaft guard. Evidence of the impact was clearly visible inside the guard and is considered to be the ignition source.

6. PUMP MAINTENANCE

6.1 General

The mechanical condition of this cargo pump prior to the incident gives rise to concern as some of the defects noted in the examination have their origin in quality control of contractor overhauls as well as the standard of maintenance and supervision on board the vessel.

6.2 Planned Maintenance System

In 1981 an incident involving the failure of a cargo pump and fire raised the question of maintenance of these frequently utilised pumps which are required to operate in a harsh marine environment across a wide range of conditions. The Esso report of that incident noted that the then current maintenance system based on elapsed time overhauls and defect rectification should be reviewed and concluded that "a need exists for an effective planned maintenance system to be introduced onboard".

That report was acted upon with the result that modifications were carried out to the rotating element of the pumps, the type of mechanical seal used was changed and a planned maintenance system introduced.

The records on ESSO MERSEY showed that routine work required under the Planned Maintenance system had been carried out at the frequency specified.

6.3 Previous History of Cargo Pumps

The repair and maintenance history of each cargo pump was essentially contained within two sources:

- The "Blue Book" or On-board Work Record Book in which all repair work involving the use of replacement parts was recorded.

- The Computerised Maintenance List from which evolved the routine maintenance as to greasing, cardan shaft movement, alarm and trip testing etc.

The "Blue Book" showed the following work carried out from 1983 onwards in respect of No 4 cargo pump:

1983

February	Top seal leaking, parts renewed.
April	Top seal leaking, carbon broken, renewed.
April	Top seal leaking, renewed. Ran on test for 5 minutes but vibration shook bolts loose and broke seal. New bearing and seal, and refurbished cardan shaft fitted. Because of vibration, pump used for ballasting only.
June	Top bearing hot, clearances of clamping sleeve found to be excessive, compensating ring fitted with new bearing. Still runs warm with slight vibration.

1984

January	Top seal leaking, renewed in drydock, still leaking on leaving drydock.
February	Top seal and bearing renewed.
February	Top seal failed. Outside firm called in with new rotating element. Top and bottom bearing carrier faces machined in-situ with dummy rotor. Not successfully machined, firm reported it cannot be done in-situ.
March	Pump re-assembled with new rotor but vibrates.

1985

April	Top seal failed, new bearing and seal, still vibrating. Pump on ballast only.
December	Cargo pump bottom bearing probe renewed.

1986

November	Overhauled cardan shaft fitted, still vibrating.
December	Various extra clamps fitted to pipework, and broken clamps repaired, vibration reduced, pump taken into normal service.

1987	No work recorded.

1988

August	Bellows renewed.

1989

August — Top seal leaking so decided to do a complete overhaul. Parts used were:

Cardan shaft.
Rotating element.
Both bearings and seals.

Top bearing pedestal had sheared and loose bolts. These were renewed and tightened up.

1990 — No work recorded.

1991

February — Vibrating excessively. Top and bottom bearings renewed. Old seals put back.

The records showed that all four cargo pumps suffered vibratory problems over the years with a succession of bearing and seal failures.

The "Work Meetings Book" for the period September 1987 onwards included references to the following:

1988

June — Top seal bearing

October — Cardan shaft

1989

October — Pump bearing

No details of what or if any work was carried out were given in this book and nothing corresponding to these dates were shown in the "Blue Book".

The overhaul of No 4 cargo pump in August 1989, which was carried out by members of the ship's crew, included the complete replacement of the rotating element with a reconditioned spare. This rotating element, previously removed from No 3 cargo pump in November 1988, had been rebuilt by a specialist contractor as it required metal spraying, new bushes and wear rings along with dynamic balancing of the assembled rotating element. No 4 pump was put back into service in September 1989.

Further checks were carried out on No 4 cargo pump in June/July 1991 due to further vibration but other than the shaft being 0.004" out of true nothing significant was found. As this work was of an investigative type, no spares being used, details were not recorded within the machinery condition monitoring system.

6.4 The Quality of Maintenance and Supervision

The "Blue Book" recorded all repair work involving the use of replacement components but not maintenance work of an investigatory nature. The computerised maintenance list covered items not covered by Classification Society requirements but in so far as the cargo pumps were concerned, it was essentially of a routine maintenance nature.

The record system therefore had no apparent provision for recording investigative work of any type or the actual condition of the pump. Handover notes on crew changes included references to the operating conditions of the pump in so far as they might affect discharge operations, but these notes did not form part of the machinery condition monitoring system.

Esso Marine Division Management's maintenance system was based on a mixture of condition monitoring and periodic inspections with overhaul guideline adjustments depending upon the experience and judgment of both sea staff and shore management.

The absence of details relating to investigative work from the records made the exercise of judgment difficult and could make any trend analysis upon which variations to the planned maintenance system were to be judged or implemented heavily dependent upon the individual Chief Engineer and/or Chief Officer. The Divisional management ashore, lacking access to complete records, would become dependent upon the resident Chief Engineer and Chief Officer and less able to exercise independent judgement.

Although it is accepted that the main thrust of onboard management lies with the Master and Chief Engineer through the Shipboard Management Team, the Marine Division management ashore have a responsibility to ensure that the vessel is maintained in a safe and efficient manner. For that to be possible, not only must records be held but they must be complete, kept preferably within one file and readily available for reference. This investigation has shown that such records were neither complete nor readily available.

The records showed a continuing history of vibratory problems on all pumps at differing times, generating on at least two occasions loose or broken bolts and clamps. That vibration had been a continual problem was evident from the fact that Esso Marine Division management commissioned a vibration study of the cargo pump in 1981 following a pump failure and pump room fire. That resulted in a re-design of the rotating element to ensure that the critical speed did not coincide with the operating speed, and a change in the type of mechanical seal. It did not, however, totally eradicate the vibration problem.

Vibration difficulties continued to be a problem over the years and because they were a contributory factor in the failure of cargo pump mechanical seals and bearings, they became an ongoing feature of vessel operations. In the case of No 4 cargo pump, severe vibration in 1983 shook the top seal bolts loose while in August 1989 the "Blue Book" entry referred to the fact that the top bearing pedestal of No 4 cargo pump had been found with both sheared and loose bolts. Despite the correlation between vibration and its effect on the tightness of bolts etc, neither the shipboard management nor management ashore appear to have considered that systematic and routine checking of bolts on the pump and drive shaft were a necessary feature of maintenance.

The history of vibratory problems on all ESSO MERSEY cargo pumps, as revealed by the rather terse entries in the "Blue Book", was attended by solutions carried out very much on a "trial and error" basis. Apart from the investigation that derived from the 1981 fire, nowhere in the available information was there a reference to the ship's staff seeking advice from management ashore, or the management ashore, having monitored maintenance progress, instigating any technical investigation.

From the evidence to hand it may be concluded that in respect of No 4 cargo pump, the quality of the refurbishment of the rotating element carried out by the contractor and the re-fitting work carried out by ship's staff was not to a sufficiently high standard nor does it appear to have been effectively supervised. New top and bottom bearings were installed in February 1991 and on both there was evidence of lack of attention to detail:

- In the case of the bottom bearing, the "O" ring seal to the bottom bearing cover was not fitted and the plugs preventing the loss of grease from the bearing carrier had been left out.

- In the case of the top bearing one of the fixing dowels had been drifted through and not replaced.

An examination of the bolt securing the support bracket to the top of the drive shaft guard showed considerable wear indicating that there had been movement between the two parts for some time. Together with a finding that the top bearing had not been fixed securely for a period of time, it seems that after an inspection of No 4 cardan shaft in June 1991 by the Chief Engineer, no subsequent recorded mechanical inspections were carried out by engineering personnel. The records showed that greasing of both the top and bottom bearings was carried out on 23 August 1991. The proximity of the top greasing point to the bolts attaching the bottom of the guard to the top of the bearing pedestal were such that it would be reasonable to expect loose bolts to be noticed during routine maintenance.

PART III FURTHER COMMENTS AND DISCUSSION

7. STRUCTURAL INTEGRITY BETWEEN THE CARGO PUMP ROOM AND THE CARGO CONTROL ROOM

7.1 Convention or Classification Requirements in 1972

At the time ESSO MERSEY was built (1972) there were no Safety Convention or Classification requirements for the segregation of the cargo control room from the cargo pump room.

For regulation purposes, the cargo pump room including the cargo pumping control centre was defined as a "Dangerous Space" and therefore had to comply with the various special requirements laid down by the Classification Society in their Rules for these designated areas. All electrical equipment in these areas also had to comply with the regulations for "Dangerous Spaces".

All those requirements were met in the combined cargo pump and control room installed on ESSO MERSEY when built in 1972.

7.2 Current Legislation

The requirement for the separation of the cargo control room and the cargo pump room is contained in the Merchant Shipping (Fire Protection) Regulations 1984 which, under Regulation 129, requires the exterior boundaries of cargo control stations to be insulated to "A-60" standard. This regulation is not retrospective and would therefore not apply to ESSO MERSEY.

7.3 Separation of Cargo Control Room and Cargo Pump Room

The complexity of the remote hydraulic cargo valve actuator system installed on ESSO MERSEY required a large number of small diameter hydraulic pipes to be led to the underside of the cargo control console. To accommodate these pipes, eight rectangular access holes were cut in the steel deck separating the two spaces.

The subsequent use of poured resin panels to provide a gas tight seal beneath the control console was not based on any mandatory requirement but was a reasonable and practical measure to provide a better environment for the operators and to reduce their exposure to a dangerous atmosphere.

Although the presence of this "gas seal" was neither mandatory nor a factor in the cause of the explosion, an examination of the properties of the resin panels was undertaken by Esso. The result of that examination was that the material was flammable, had low thermal conductivity and had poor impact or significant loading characteristics.

8. SAFETY AND EMERGENCY PROCEDURES

8.1 Safety Procedures

In line with Esso's stated Company policy of positively promoting safety, a comprehensive Safety Manual had been issued to all vessels. This manual outlined the responsibilities of both shore and sea based management on Health and Safety legislation and the Company Safety Policy.

The safety advice, policy, rules and procedures given in this manual were of a generalised nature applicable to all vessels. As such, they formed the basis on which individual vessels developed specialised procedures according to the type of vessel and the trade they were operating in. For example, the procedures that were followed in coping with a possible fire in the pump room were developed for ESSO MERSEY and took into account both the position of control switches and valves as well as the fact that the pump room was covered by both a multispray system as well as CO_2 flooding.

The standard of safety training within Esso ensured that the emergency procedures specified both in the Safety Manual and those developed for ESSO MERSEY were all put into effect without delay or confusion.

The section of the Safety Manual dealing with training included specific instructions on the handover requirements between staff and the policy underlying those requirements. That practice was followed on ESSO MERSEY during the handover between Chief Officers in August 1991. In that handover document under "Cargo Pumps" the comments were:

"All four pumps are fully operational with no known problems.

No 4 still a bit noisy - pump shaft's bent. Leaving until major overhaul due.

No 2 pump - new throttle valve fitted last month."

This information is concise and would be read as meaning that the level of noise currently being generated by No 4 cargo pump was normal and acceptable.

The information given was too concise and lacked detail, but it should be seen against the background that the relieving Chief Officer was familiar with the vessel and its cargo system having served continuously on this vessel from February 1989 either as Master or Chief Officer. Prior to taking over on 20 August 1991 after leave, he had sailed as Chief Officer from 1 April to 10 May and then as Master until 20 June 1991. This system of rotating duty as Master or Chief Officer is a common practice within Esso as it is with other companies.

8.2 Execution of Emergency Procedures

Following the explosion, the ship's staff immediately and effectively put into operation their emergency procedures. Both VTS Southampton and Esso Marine Control were informed by the Master whilst an assessment of the damage and the cargo state was carried out by the Second Officer. All cargo tanks were isolated, the procedure for a "Fire in the Pump room" carried out and all non-essential crew mustered aft.

Esso Emergency Control Centre responded and classified the incident as a "Category 2". Hampshire Fire Brigade were therefore called in and arrived on site with 5 tenders and a control vehicle. An Incident Room was established with the Marine Manager assuming overall control. Close co-operation between Hampshire Fire Brigade, Esso Authorities and the ship's staff over the next four days ensured that a hazardous containment and retrieval operation was brought to a safe and successful conclusion.

On the day of the explosion and subsequently, members of the ship's staff and relieving crew members made a number of entries to the pump room wearing SCBA sets to make an assessment of the damage and to carry out valve closures. These personnel, all volunteers, carried out their duties in a known dangerous environment and their actions are to be commended.

The accident highlights the reliance which is placed on hand-held radios particularly in an emergency. The vessel's normal complement of radios was eight portables (with re-charging module on the bridge) and two fixed base stations (one on the bridge and one in the engine control room), though one portable had been lost prior to arrival in Fawley. The hand-held radios were distributed to key personnel so that satisfactory communications could be maintained at all times. Whilst in port one hand-held radio was left at the head of the gangway for visitors to advise the duty officer of their arrival, also another was left in the cargo control room to facilitate ready access in the event of a battery on a radio in use for cargo operations being rundown. The explosion resulted in the loss of two hand-held radios and coupled with the fact that one had previously been lost and another was at the gangway, the availability of these radios was reduced by half. That this did not lead to any delay in organising the emergency procedures is testimony to the value of a substantial provision of hand-held radios, and Esso are to be commended for their foresight in this regard.

The Master's Manual advises that during an emergency the Command Centre, which would normally be the bridge unless it is untenable because of the circumstances of the emergency, should be manned by three persons. On this occasion two of those persons would have been the Chief Officer and the Able Seaman who had been killed by the explosion. This left the Master alone on the bridge. Not only does the Master have to exercise overall control of the situation but he needs to maintain communications on board, has a communication responsibility to those ashore, deal with alarm panel signals, refer to procedures etc. The way in which the emergency procedures were handled on this occasion is testimony that the Master successfully coped with these responsibilities single-handed, for which he is to be commended. However, it might have been different. The Master's Manual does not seem to place sufficient emphasis on the possibility that there may be fatalities in an emergency and that it might be necessary to reallocate personnel to other emergency parties, particularly to the Command Centre.

9. GAS MONITORING

Esso's current permit system for entry to dangerous spaces calls for a manual check to be carried out by the duty officer and/or rating at 4 hourly intervals or at a frequency demanded by the situation. In view of the necessary mobility of the watchkeepers, a build-up of hydrocarbon gas in the pump room could remain undetected for some period of time. To reduce the possibility of a time delay between gas release and detection, the installation of a continuous or automatic hydrocarbon gas monitoring system within the cargo pump room as an added safety measure was considered by Esso in 1989.

ESSO FAWLEY, a sister ship of ESSO MERSEY, was fitted with a continuous gas monitoring system on a trial basis in 1989. This system was eventually disconnected as it could not fully comply with the Classification Society requirements for intrinsically safe circuitry in pump rooms, although its operational advantages were fully demonstrated. As a result of hazard risk analysis performed by Esso in 1991, which confirmed the benefits of continuous gas monitoring equipment, alternative systems were sought. Following identification of a suitable system, Classification Society and Department of Transport type approval was sought and finally obtained from both parties in September 1991. Installation of such a system was scheduled for the ESSO MERSEY at her next dry docking in early 1992 and is in fact now fitted.

International requirements do not provide for oil tankers to be fitted with permanently installed gas detection systems and Esso's initiative in installing such systems in pump rooms is to be commended as it will enhance safety. However the investigation has not been able to determine how quickly the failure of the top seal gland occurred, therefore it is not known whether there was a gradual build-up of hydrocarbon gas to within the explosive limit or whether it was almost instantaneous. This means it is impossible to say whether a continuous hydrocarbon gas monitoring system would have given sufficient warning for the cargo operations to be stopped in time to prevent this accident occurring. Even so an argument may exist for there to be an international requirement for permanently installed gas detectors on oil tankers. Further investigation is necessary to establish the effectiveness of such systems for enhancing safety.

10. ACTIONS TAKEN BY ESSO TO PREVENT RECURRENCE

Following the accident and investigation Esso considered a number of actions to prevent recurrence. These are listed below, with an indication of their implementation status:

- Replace pedestal fixing bolts with studding and secure the studding using "loctite" adhesive. Ensure the studs are bottomed out in the holes. Use "nyloc" (self locking) nuts when attaching the pedestal to the pump body.

  (Complete)

- Identify and install mechanical seals with secondary containment seals and seal leak detection alarms. As part of this work, review the continued use of seals with hard coat sprayed faces in this service. If practicable,the alarm should be routed to the cargo control room.

  (Actioned)

- Fit accelerometers to the top and bottom bearings and install permanent monitors, or set up a data gathering procedure. If permanent monitors are installed, consideration should be given to the provision of an integral alarm system incorporating an initial warning level followed by auto shutdown.

  (Complete)

- Manufacture and install cardan shaft guards from non sparking material.

  (Complete)

- Store spare rotor in vertical rack to avoid distortion during storage.

  (Complete)

- Perform a rotor dynamics study to confirm pump as built does not operate in the critical operating range.

  (Complete)

- Use stainless steel grub screws in impeller locknuts.

  (Complete)

- Complete installation of pump room gas detection systems.

  (Complete)

- Replace the resin panels beneath the control console with steel flooring.

  (Complete)

- Investigate possibility of relocation of pump room gas vent ducting.

  (Review complete, and deemed unnecessary)

- Check other pumps and spare rotor for correctness of repairs.

(Complete)

- Extend Quality Control system and work checklist system to ensure contractor work performed to required standard.

(Actioned)

- Develop check list for pump work performed by Esso personnel to ensure work to correct standard.

(Actioned)

- Include pump room pumps on machinery inspection routines for engineering staff. These should include examining and logging:

  temperatures
  vibration levels
  seal leakage
  critical bolt tightness etc.

(Actioned)

- Extend pump data files to include:

  technical data sheets
  design modifications
  repair details
  failure analyzers etc.

(Actioned)

PART IV CONCLUSION

11. FINDINGS

The Inquiry carried out by the Inspector has covered great detail. It not only covered the immediate events but also took into consideration the history of the cargo pumps and a detailed study of the whole concept of machinery maintenance on board. The co-operation extended by Esso, who carried out their own examination of the circumstances of the explosion and made available to the Inspector the results, helped him considerably in his work. Without that co-operation the Inquiry would have been far more difficult.

The Inspector's findings clearly identify not only the immediate cause of the accident but a number of factors which were contributory to that immediate cause.

I concur with the findings given in this section of the Report and consider they are a true reflection of events.

The immediate cause of the accident was:

11.1 A failure of the top mechanical seal on No 4 cargo pump allowed premium grade petrol to be sprayed forward and upwards whilst at the same time sparks from the mechanical contact between the cardan shaft drive guard and the coupling ignited the fumes causing an explosion and a short duration fire ball.

11.2 An unburned product mixture followed by a flame front and combustion products progressed up the starboard side of the pump room, burst into the cargo control room through the underside of the control console and exited through the control room doors forward onto the poop deck.

11.3 The Chief Officer, who was in the vicinity of the cargo control console, was caught in the flame front causing severe burns from which he later died. The Able Seaman who was standing in the area of the cargo control room doorway was killed instantly.

11.4 Excessive vibration within the body of the pump led to the loss of the pedestal bearing bolts which resulted in significant movement of the top pump bearing pedestal and subsequent failure of the seal. This pedestal movement also caused the cardan shaft drive guard to break loose and make contact with the drive coupling.

11.5 The development of the vibration originated due to the lower impeller, 1st stage, outer locknut becoming loose and backing off. This in turn led to the free movement of other internal components which culminated in excessive vibration.

The principle contributory factors were:

11.6 The movement of the outer locknut was due to the absence of two locking grub screws which secure the locknut to the shaft. Grub screws should have been installed during the 1989 overhaul and rebuild, but there was no evidence to show why they were missing. It therefore seems that:

they were not fitted, or

they vibrated loose and fell out, or

they were of an incorrect material and corroded away.

11.7 Whatever the reason for the absence of the two locking grub screws, the indications are that it occurred as a consequence of a failure on the part of the contractor on this occasion to exercise acceptable quality control procedures during the refurbishment of the rotating element.

11.8 Renewal of both the top and bottom bearings in February 1991 by the ship's staff resulted in the omission of certain parts and the failure to refit integral parts of the assembly; this indicates that the engineering standards practised were below an acceptable level.

Further probable contributory factors were:

11.9 Despite the known work history of this type of pump where it was recorded that vibrations had in the past led to loose and/or fractured bolts, none of the ship's staff felt it prudent to carry out even a visual check prior to operation.

11.10 The absence of details of investigative work in the work records made trend analysis difficult and this may have generated a false sense of security.

11.11 Neither the management ashore nor that on board felt it necessary to establish a discrete system which would have provided a record of all mechanical and test work carried out on the pumps.

Other findings:

11.12 The Operational and Emergency procedures laid down in various onboard publications were carried out in good order and in accordance with Company requirements.

11.13 The actions taken by the Esso Fawley Marine Terminal were in accordance with the procedures laid down in the Esso Marine Emergency Procedures Manual.

12. RECOMMENDATIONS

Based on the Inquiry into the accident and the findings of the Inspectors, a number of recommendations are made which, if implemented, should prevent recurrence of such an accident and generally improve the safety of life at sea.

The recommendations which follow, the first two of which have already been implemented by Esso, and the actions considered and taken by Esso (details of which have been given in Section 10 of this Report) should add significantly to the safety margins of the vessel and should increase the store of engineering and operational knowledge of both sea and shore based staff.

Two of the recommendations are addressed to Esso but all tanker operators should consider them in the context of their own management, operational and training procedures. Therefore Recommendation 4 is addressed to the industry as a whole. There is also one recommendation for research to be carried out, the results of which might have an impact on international regulations; this recommendation is therefore addressed to the Marine Directorate of the Department of Transport.

1. Esso Management should thoroughly review its planned maintenance system currently in use. The review should cover in particular:

    i. the operation and the monitoring of the system by shipboard staff.

    ii. the responsibility of the shoreside Technical Department to monitor the system and ensure that recurring defects are identified and that technical guidance is provided to shipboard staff.

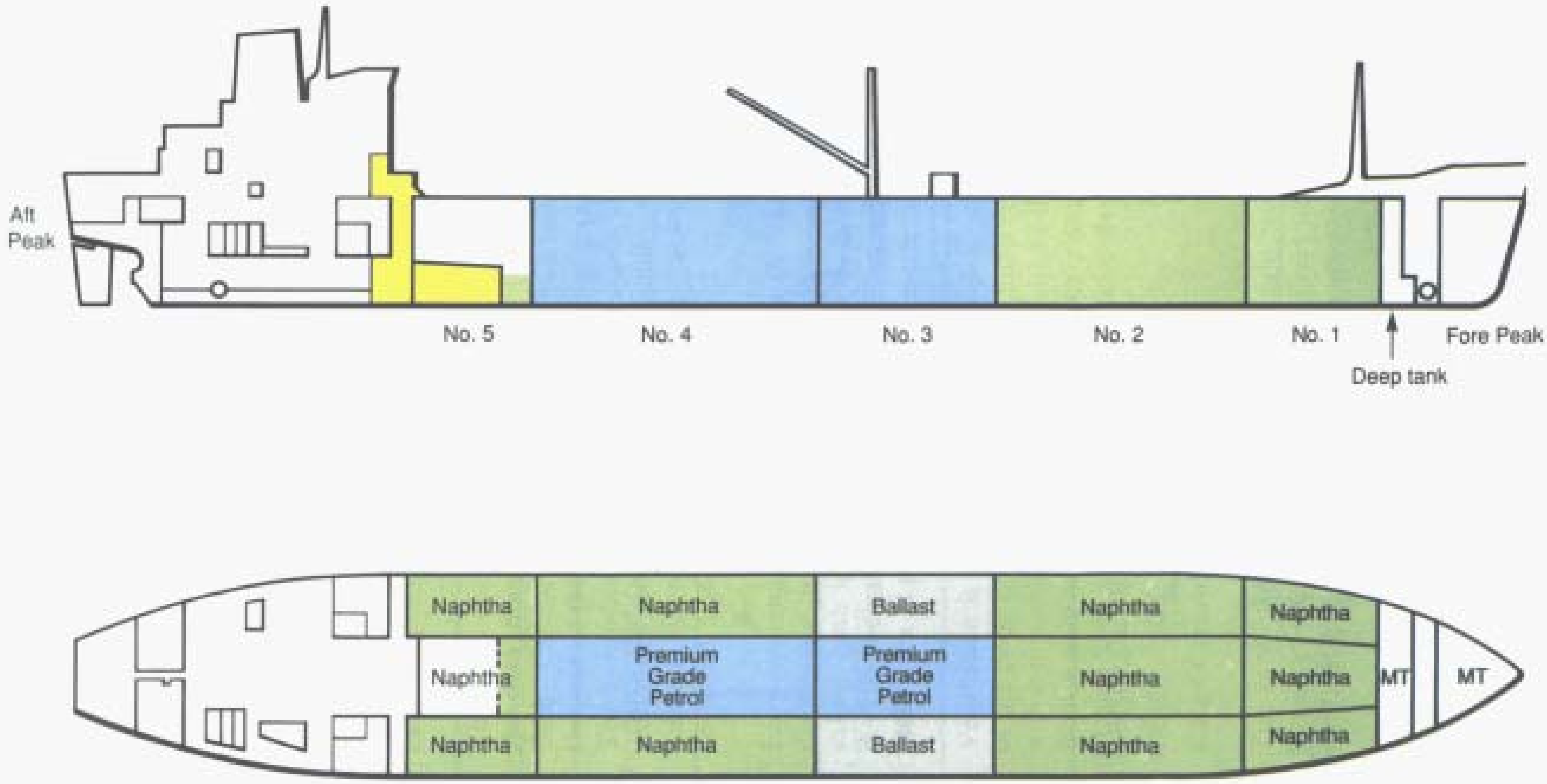
2. Esso Management should review their quality control system in relation to the use of contract maintenance work so as to ensure that material specifications are complied with and that the quality of maintenance work undertaken meets good engineering practice.

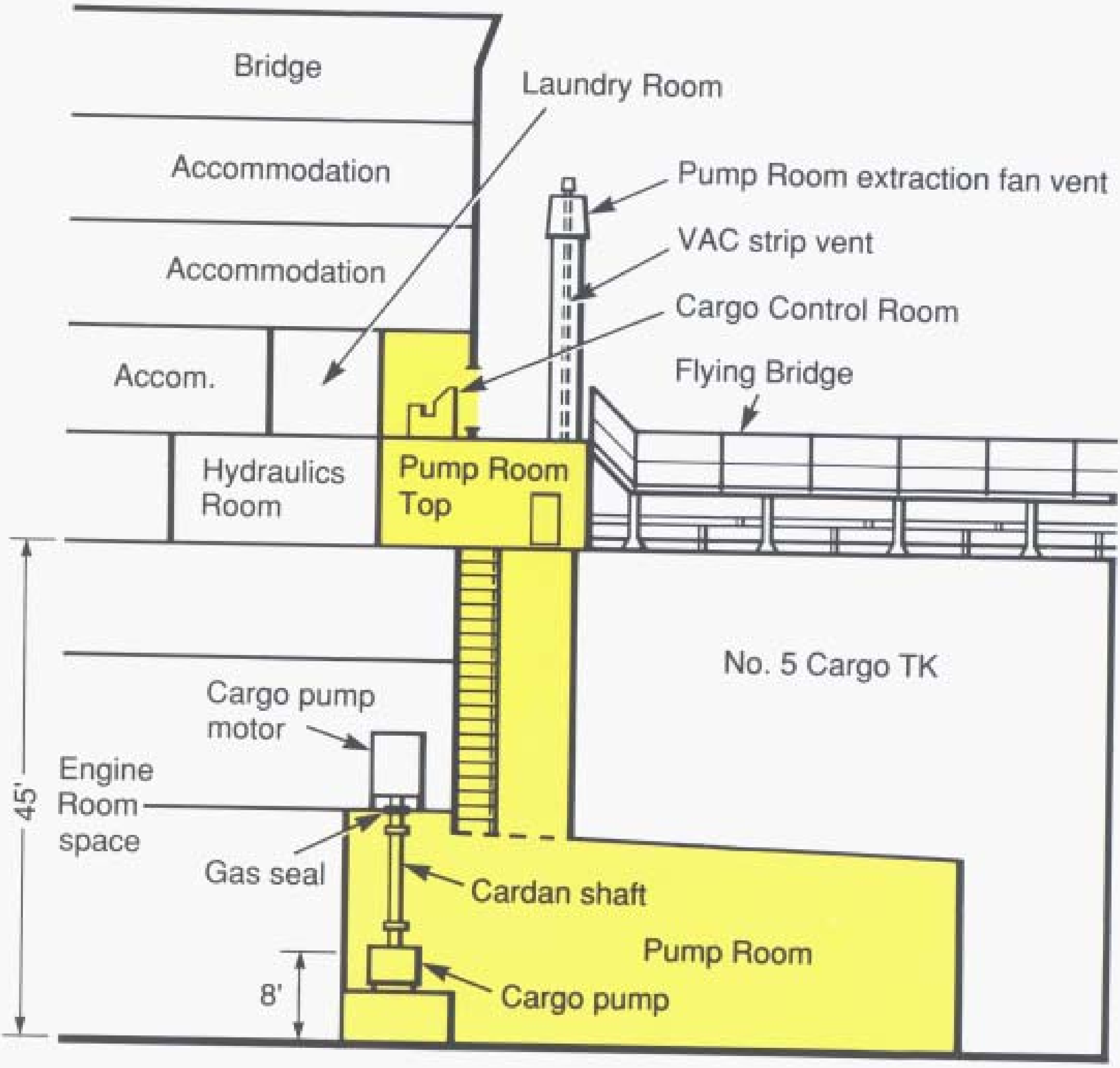
3. The Marine Directorate of the Department of Transport should undertake a research project into continuous automatic hydrocarbon gas monitoring of the atmosphere of pump rooms on oil tankers. The research should be aimed at establishing the effectiveness of such systems to give sufficient warning of a build up of gas so that cargo operations can be stopped before the atmosphere in the space becomes hazardous. The findings of the research, if warranted, should be brought to the attention of the International Maritime Organization (IMO) with a view to an amendment to the SOLAS Convention requiring oil tankers to be fitted with such equipment.

4. The International Chamber of Shipping (ICS), the International Association of Independent Tanker Owners (INTERTANKO) and the Oil Companies International Marine Forum (OCIMF) should bring the details of the investigation into this accident, particularly the findings and the recommendations, to the attention of their members.

Figure 1

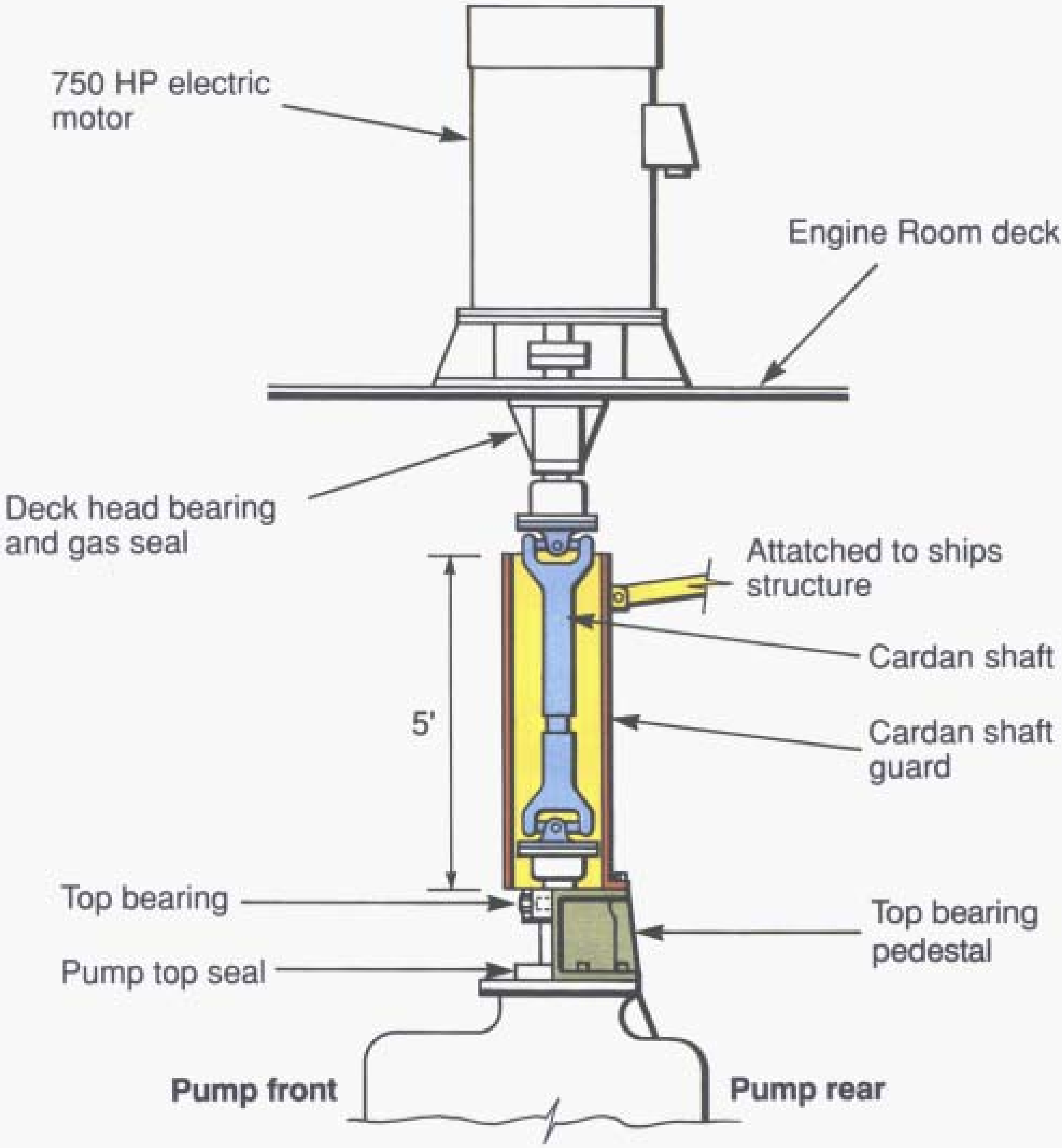
General arrangement of ESSO MERSEY





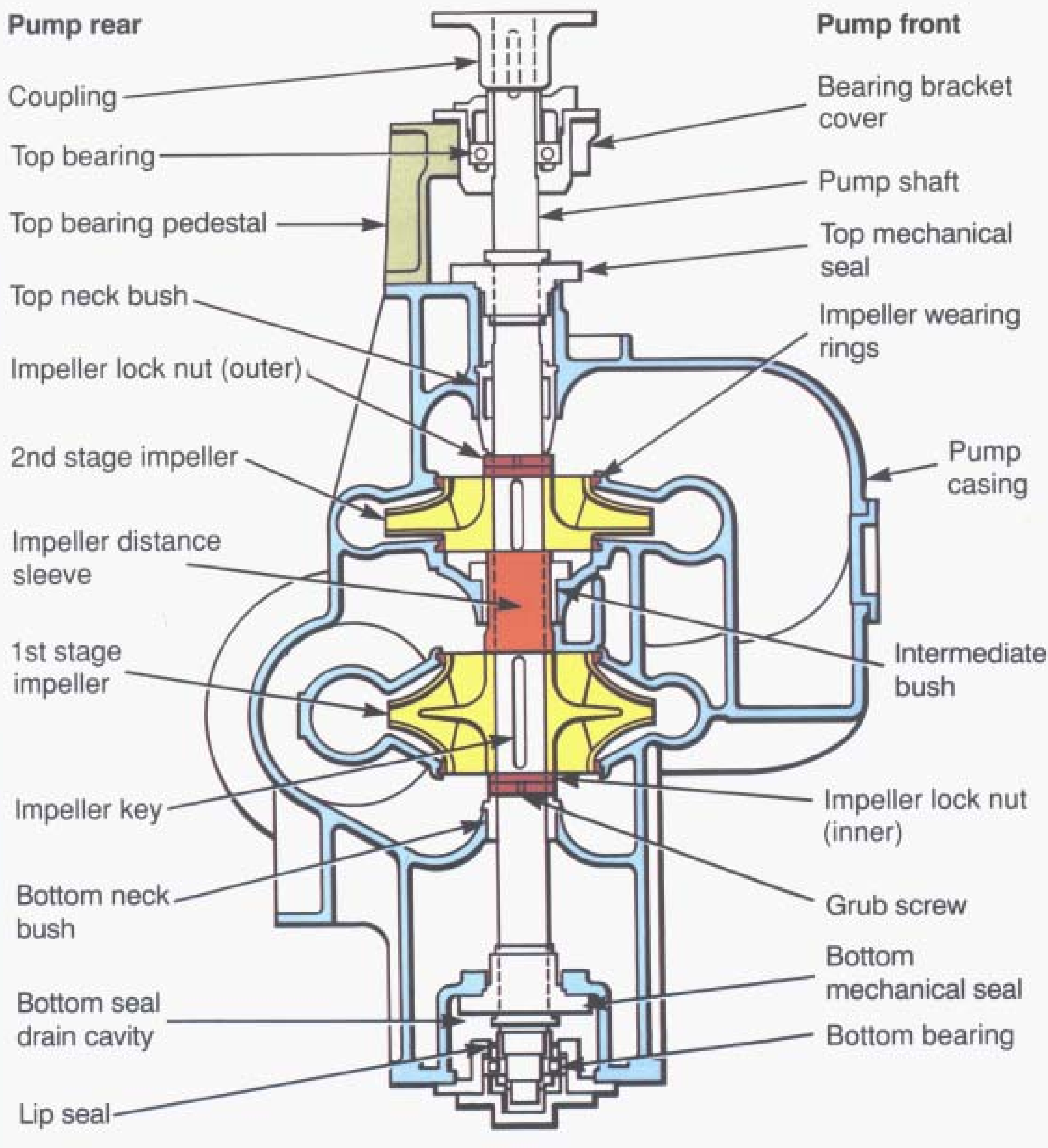
Location of Pump Room

Figure 3



Cargo pump, Cardan Shaft and Guard

Figure 4



Cargo Pump in detail

Printed in the United Kingdom for HMSO
Dd299786 9/94 C1 3400/1 12521