**Report on the investigation**

**of a rupture of the port economiser on board**

***Island Princess***

**resulting in two deaths**

**on 7 December 1997**

Marine Accident Investigation Branch
First Floor, Carlton House
Carlton Place
Southampton
SO15 2DZ

**Report No 37/2000**

**Extract from**

**The Merchant Shipping**

**(Accident Reporting and Investigation)**

**Regulations 1999**

The fundamental purpose of investigating an accident under these Regulations is to determine its circumstances and the causes with the aim of improving the safety of life at sea and the avoidance of accidents in the future. It is not the purpose to apportion liability, nor, except so far as is necessary to achieve the fundamental purpose, to apportion blame.

# CONTENTS

## GLOSSARY OF ABBREVIATIONS AND ACRONYMS

| | | |
|---|---|---|
| AOTC | - | Associated Offices Technical Committee |
| CP | - | Controllable pitch |
| DNV | - | Det Norske Veritas |
| DOC | - | Document of compliance |
| GL | - | Germanischer Lloyd |
| HAZ | - | Heat affected zone |
| HSE | - | Health and Safety Executive |
| IACS | - | International Association of Classification Societies |
| IMO | - | International Maritime Organization |
| ISM Code | - | International Safety Management Code |
| kW | - | kilowatt |
| LRS | - | Lloyd's Register of Shipping |
| MAIB | - | Marine Accident Investigation Branch |
| MCA | - | Maritime and Coastguard Agency |
| MCR | - | Machinery Control Room |
| NDT | - | Non-destructive testing |
| P&O | - | Peninsular and Oriental |
| PSC | - | Passenger safety certificate |
| PTFE | - | Plastic material - phenolic tetrafluoroethylene |
| SAFed | - | Safety Assessment Federation |
| SMC | - | Safety Management Certificate |
| SOLAS | - | Safety of Life at Sea Convention |

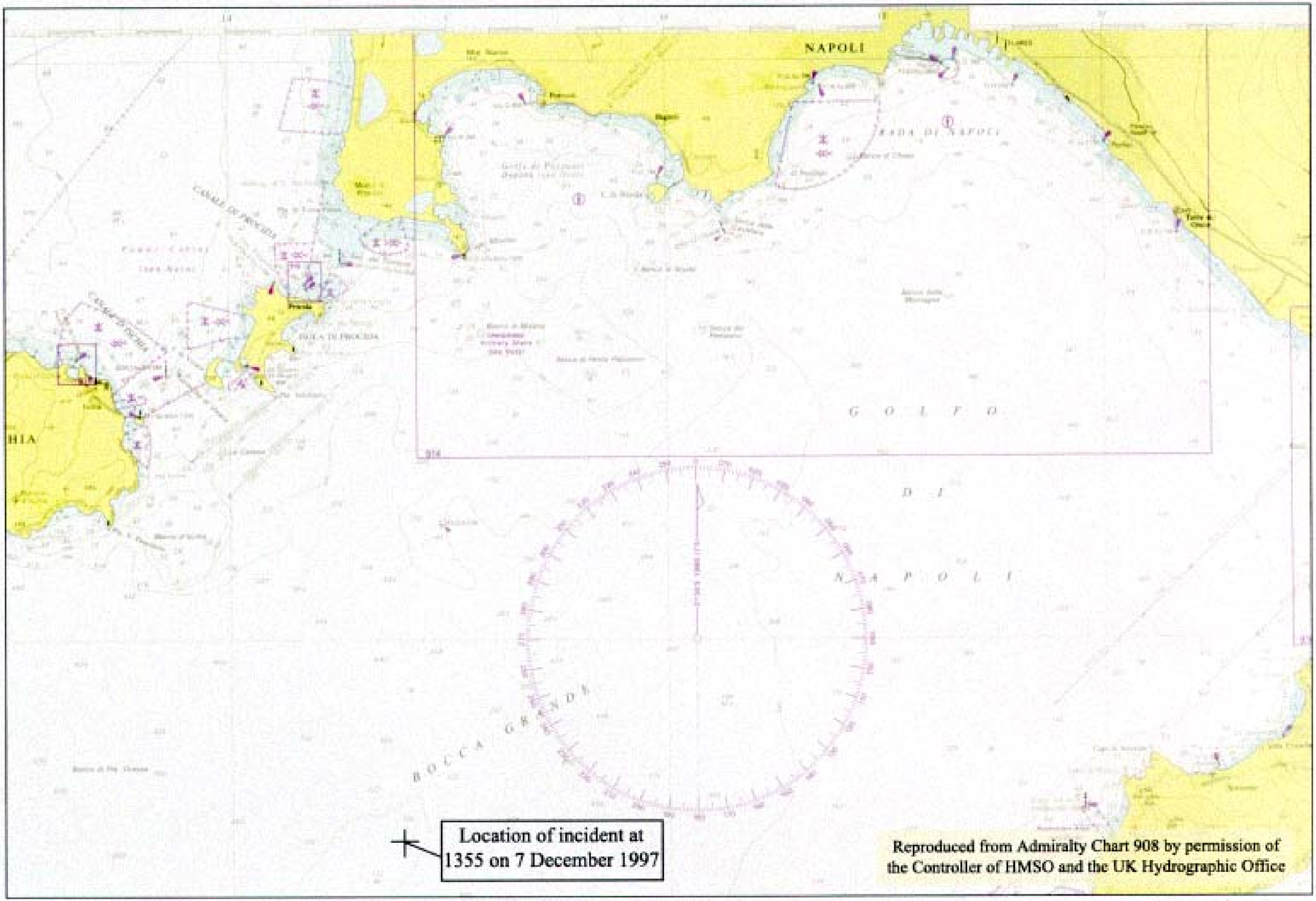
| | | |
|---|---|---|
| STCW | - | International convention on standards of training, certification and watchkeeping for Seafarers, 1978 as amended in 1995 |
| TDS | - | Total dissolved solids |
| TEI | - | Thermal Engineering International Ltd |
| TRD | - | Technical rules for steam boilers |
| UTC | - | Universal Co-ordinated Time |

**Footnote**

Over the period covered by the report the name of the UK Government's marine survey organisation, now known as the Maritime and Coastguard Agency (MCA), changed a number of times.

The Marine Safety Agency (MSA) and the Coastguard Agency (TCA) merged in April 1998 to form the MCA. The MSA was established in 1993 as a government agency of the Department of Transport.

For convenience, the report refers to the MCA, irrespective of the period in question.



NAPOLI
CANALE DI PROCIDA
ISOLA DI PROCIDA
RADA DI NAPOLI
G O L F O
D I
N A P O L I
BOCCA GRANDE
HIA
Location of incident at
1355 on 7 December 1997
Reproduced from Admiralty Chart 908 by permission of
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## SYNOPSIS

The port exhaust gas boiler (economiser) of the United Kingdom registered Princess Cruises liner *Island Princess* ruptured killing two people and injuring three others during sea trials in the Bay of Naples on 7 December 1997. No passengers were on board.

The Marine Accident Investigation Branch (MAIB) was notified of the accident on the same day. The investigation was undertaken by Mr J Stuart Withington, Principal Inspector.

Because it occurred in the territorial waters of Italy, the accident was also investigated by the Italian authorities.

The victims and two of those injured were contractors working on a boiler below the economiser when the accident occurred. Without warning, the economiser ruptured and discharged hot water and steam. A seaman working above the economiser was also injured by the escaping steam.

The economiser, a shell-type flat-ended pressure vessel heated by main engine exhaust gas, was not in use at the time, but had been left full of water. It was isolated from the steam plant system, but not vented to atmosphere. The economiser pressurised as the main engine exhaust heated the water but, because the safety valves had seized in the closed position, it overpressurised. Three and a half hours after the vessel put to sea, the economiser ruptured along its lower circumferential weld joint.

The rupture pressure is uncertain but would have been affected by the weakening effect of corrosion fatigue cracks around the circumferential joint.

By jacking open the economiser safety valves using the easing gear, the ship's engineers thought they had taken adequate steps to vent the system. They did not realise they had failed to do so.

The investigation found that the safety valves on the port economiser had remained shut throughout the entire episode, and did not lift under pressure because the spindles had seized in their guides. This was due to an accumulation of corrosion products, corrosive boiler sludge deposits and other extraneous products at the spindle/guide interface. Poor quality boiler water and leaking safety valves created the conditions that weakened the spindles' corrosion resistance.

The investigation revealed a previous history of safety valve seizures and economiser overpressure and rupture. Such a record demanded particular care and attention when operating and maintaining them. This need was not satisfied.

## SECTION 1 - FACTUAL INFORMATION (All times UTC + 1)

### 1.1 PARTICULARS OF VESSEL AND INCIDENT (Figure 1)

| | | |
|---|---|---|
| Previous name | : | *Island Venturer* (until 1974) |
| Name at time of accident | : | *Island Princess* |
| Type of ship | : | Passenger cruise ship |
| Managers | : | Princess Cruises Inc |
| Flag | : | United Kingdom |
| Port of Registry | : | London |
| LR number | : | 7108514 |
| Classification Society | : | Lloyd's Register of Shipping |
| Construction | : | Steel |
| Year keel laid | : | 1971 |
| Place of build | : | Rheinstahl Nordseewerke GMBH, Germany |
| Gross tonnage | : | 20186 |
| Length overall | : | 168.76m |
| Breadth | : | 24.60m |
| Propulsion | : | Four Fiat 4 stroke single acting turbo charged diesel engines geared to two CP propellers, providing 13423kW (18000 hp) and a service speed of 21.5 knots |
| Passenger capacity | : | 751 |
| Time and date of accident | : | 1355 on 7 December 1997 |
| Injuries | : | Two people killed and three injured |
| Location of accident | : | Bay of Naples, Italy |
| Damage | : | Rupture of port exhaust gas boiler (economiser) |
| Passenger Safety Certificate | : | Valid at the time of the accident |


Figure 1 - *Island Princess*

## 1.2 BACKGROUND

Built in 1971, the passenger ship *Island Princess* came under P&O Cruises management in 1974 when she changed from Norwegian to United Kingdom registry. Her classification society was changed from Det Norske Veritas (DNV) to Lloyd's Register of Shipping (LRS) about one year later.

At the time of the accident, *Island Princess* was managed by Princess Cruises of Los Angeles, part of the P&O Group, and was operating a winter cruise schedule. During one of these cruises she damaged her starboard propeller while manoeuvring at Civitavechia, Italy on 17 November 1997.

Because the propeller damage required the ship to be dry-docked she proceeded to Naples for repairs and a cruise had to be cancelled. The accident occurred during the sea trials in the Bay of Naples that followed the repairs. There were no passengers embarked at the time but 124 shore-based contractors were on board.

## 1.3 NARRATIVE

### 1.3.1 Preparing the ship for sea trials

*Island Princess* was due to leave dry-dock mid-morning of 7 December 1997 for trials in the Bay of Naples. Preparations to leave started the previous evening when the dock was flooded to about 5.5m of the ship's draught. She remained on her blocks overnight, and checks were made for leaks in the hull as the ship's services were started up.

A seagoing engine room watchkeeping routine started at 0600 on 7 December. Flooding of the dock resumed at about 0645, and the ship was afloat by 0729. The undocking was supervised by the owner's technical superintendent.

The watch was manned by both a third and fourth engineer officer. As part of the transition from port to sea watches, the 8 to 12 fourth engineer came on duty at 0600. Having had breakfast the incoming third engineer relieved his opposite number at 0830.

Because of the additional work required for leaving dry-dock and undertaking sea trials, the chief, first and second engineers went on standby duty at 0620. The daywork third engineer joined the engine room team at 0800.

The chief engineer's role was to direct and co-ordinate work on, and operation of, the main propulsion system, paying particular attention to the part repaired in dry-dock.

Supervised by the second engineer, the watchkeepers had to respond to work arising from these repairs in addition to their normal routine duties of preparing and running the propulsion plant. The daywork third engineer worked under the direction of the second engineer.

The second engineer also worked on problems associated with the steam supply from a temporary oil-fired boiler installed on the open deck outside the engine room.

At about 0800, the chief engineer and his officers met in the machinery control room (MCR) to discuss what was required for leaving dry-dock and the forthcoming sea trials. The meeting included a discussion about what was required to prepare the economiser for seagoing conditions.

The ship had arrived in dry-dock with the port boiler shut down for repairs and the starboard oil-fired boiler coupled to the two economisers. During the time in dry-dock the starboard boiler had been damaged, which meant that when *Island Princess* sailed on sea trials, neither boiler was in action. The economisers could not, therefore, be used. An oil-fired boiler was temporarily installed on the open deck to supply steam to the ship's services.

Both economisers were still full of water from the previous voyage. To prevent them from pressurising as they heated up once the main engines were started, the engineers decided to jack open the safety valves to vent the steam to atmosphere.

During the 8 to 12 watch, the daywork third engineer was told to check that the circulating valves between the economisers and boilers were closed, and to open the economiser safety valves using the easing gear. He operated the easing gear handwheels for both sides until they indicated fully open and reported this to the second and third engineer watchkeepers. They in turn passed this information to the incoming 12 to 4 third engineer watchkeeper when he took over the watch at 1200. The report was noted in the engine room handover book.

The watchkeepers prepared Nos 1 and 2 port engines, and Nos 3 and 4 starboard engines for leaving. Preparation of No 1 main engine was delayed because crankshaft bearing tests had to be made following a survey. These tests were undertaken by the second engineer assisted by the fourth engineer. All main engines were running by 0930.

At a meeting in the MCR at 1000 with the chief and second engineers, the technical superintendent asked if the economisers manhole doors had been removed. The second engineer informed him that the safety valves had been jacked open by the easing gear instead.

A tug manoeuvred *Island Princess* astern out of the dry-dock. Once she was clear at 1030, the tug was let go and *Island Princess* pulled away under her own power. Shortly afterwards the starboard propulsion shaft muff coupling locking ring was found to be slack. The starboard inner and outer main engines were de-clutched and she proceeded with the two port engines driving the port shaft. Once the starboard propeller had stopped turning, the locking ring was secured within 15 minutes.

The watchkeepers changed over at 1200. Neither the 8 to 12 nor the 12 to 4 watchkeepers checked the economisers or the safety valves.

By 1230, *Island Princess* was making way on both shafts with all four engines running.

### 1.3.2 Rupture of the port economiser (Figures 2a, 2b and 2c)

At 1355 the port economiser ruptured. There was a loud bang followed by hot water, steam and insulation material cascading over the port oil-fired boiler and into the engine room below. At the same time the boiler and economiser space smoke detectors activated to sound the fire alarms on the bridge and in the engine control room. Steam surged through the open door of No 2 fan room next to the space above the economiser, knocking over and injuring GP1 Sadullah, a general purpose seaman. Unassisted, he crawled out on to the open deck, where someone helped him to the ship's medical centre.

The rupture had immediate repercussions for a four-man Thermal Engineering International Ltd (TEI) team working on the port oil-fired boiler. They were Messrs Clayton, Marshal, Wilkinson and Pickard. Mr Clayton was inside the boiler preparing the lower tube plate for welding, while the others were outside in support. Showered by hot steam, water and debris, Mr Marshal and Mr Clayton escaped down the boiler room steps into the relative safety of the cross-alleyway outside the boiler space on 'C' deck. From here, they were helped to the ship's medical centre.

In his haste to escape, Mr Wilkinson clambered into the starboard boiler furnace. He pushed his cap into his mouth, and placed his hands over his eyes to avoid the effects of the steam and water. The temperature continued to rise and the noise intensified, but, once the initial deluge had subsided, he too managed to escape into the cross-alleyway.

When the economiser ruptured, another contract worker, Mr Hippolyte, was in the cross-alleyway. He also saw the deluge of steam and water, followed by the two TEI contractors emerging from the boiler space. They indicated to Mr Hippolyte that Mr Pickard was still in the boiler space. Elsewhere in the engine room, the daywork third engineer saw steam and water cascading from above. As soon as the initial deluge had subsided, both he and Mr Hippolyte went up into the boiler space and found Mr Pickard lying on the narrow deck between the port boiler and the outer casing bulkhead of the engine room. He was obviously injured and in great distress. The space was too narrow for them to reach him and despite his condition, he was persuaded to manoeuvre himself out of it. Assisted by the daywork third engineer, Mr Hippolyte then carried Mr Pickard on his back, down the boiler room ladders and into the cross-alleyway.

Meanwhile, the first engineer, realising there had been an incident, went to C deck cross-alleyway and thought at first that a steam hose connected to the temporary oil-fired boiler on deck had failed. He went on deck, shut the boiler's steam stop valve, opened the drain, and entered the boiler space above the economisers before going down to the deck level of the economiser safety valves. Here he found the cladding of the port economiser had split with brickwork hanging from it. Inspecting the port economiser safety valves, he found the easing gear wires tight. On pulling one of the

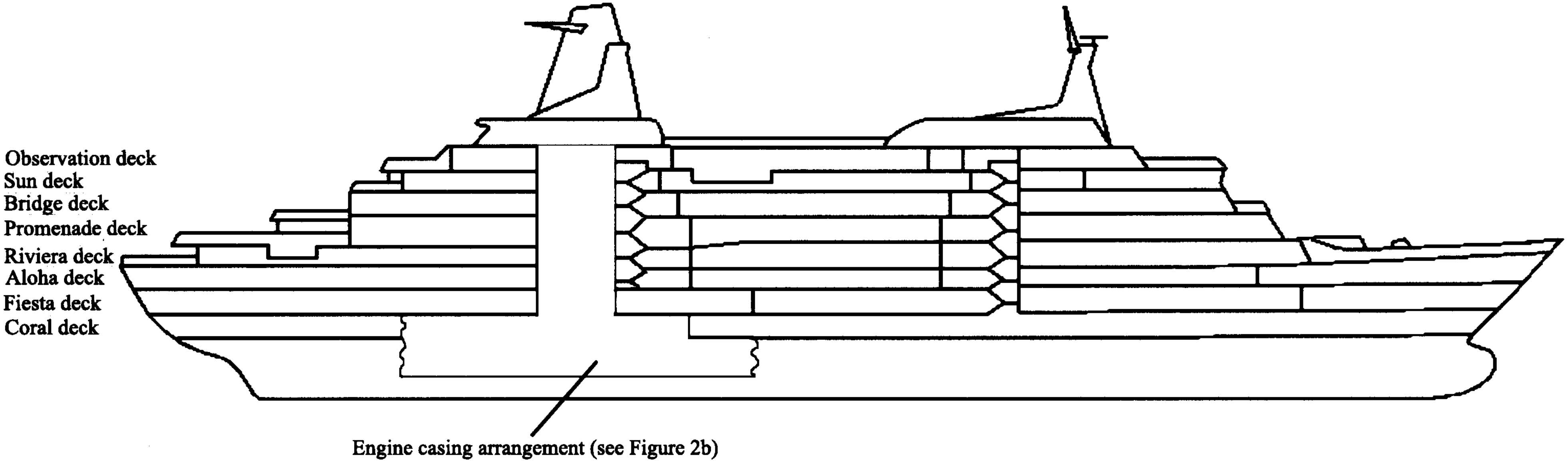



Figure 2a - *Island Princess* Deck Arrangement

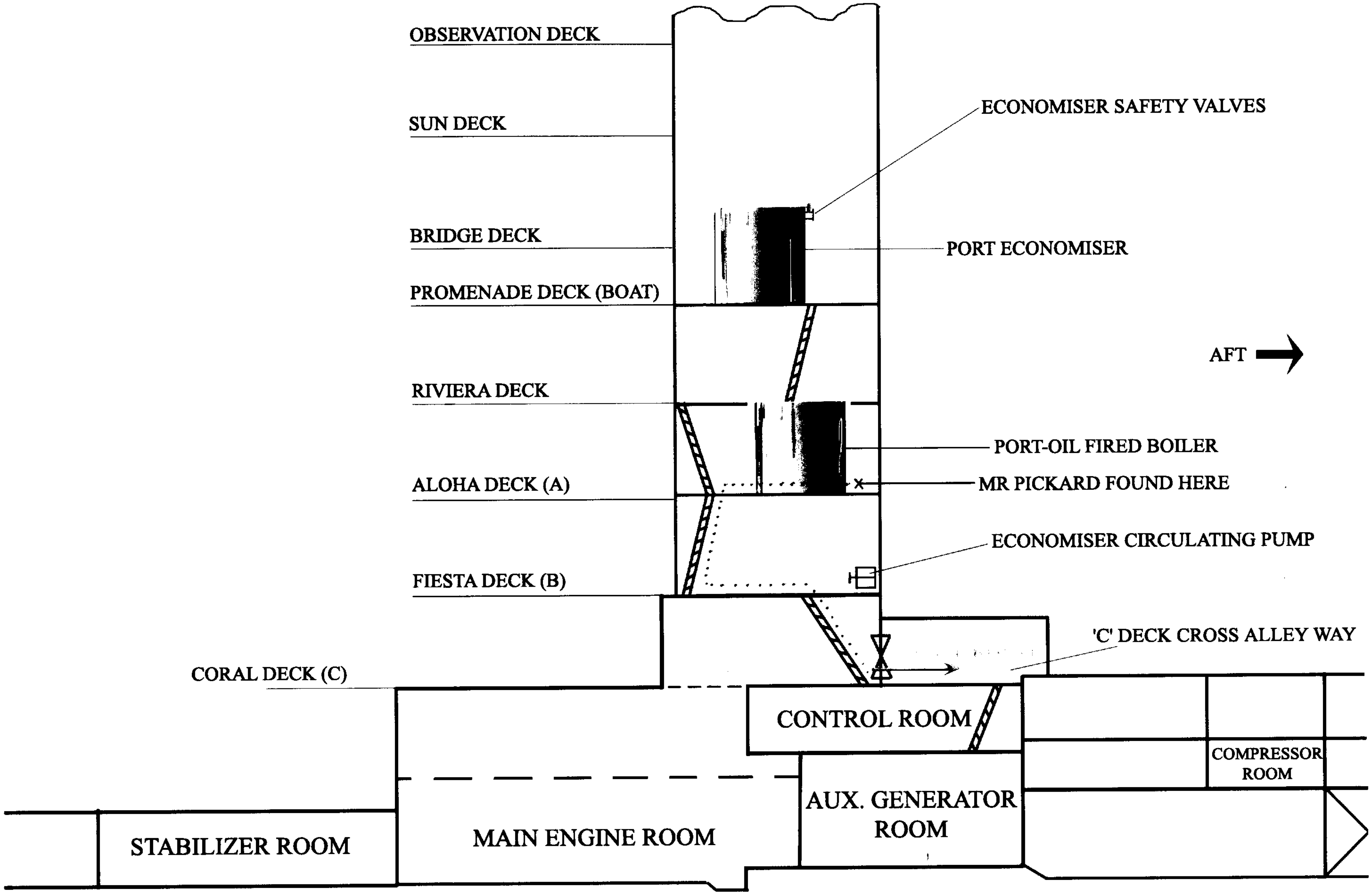



Figure 2b - *Island Princess* engine casing arrangement

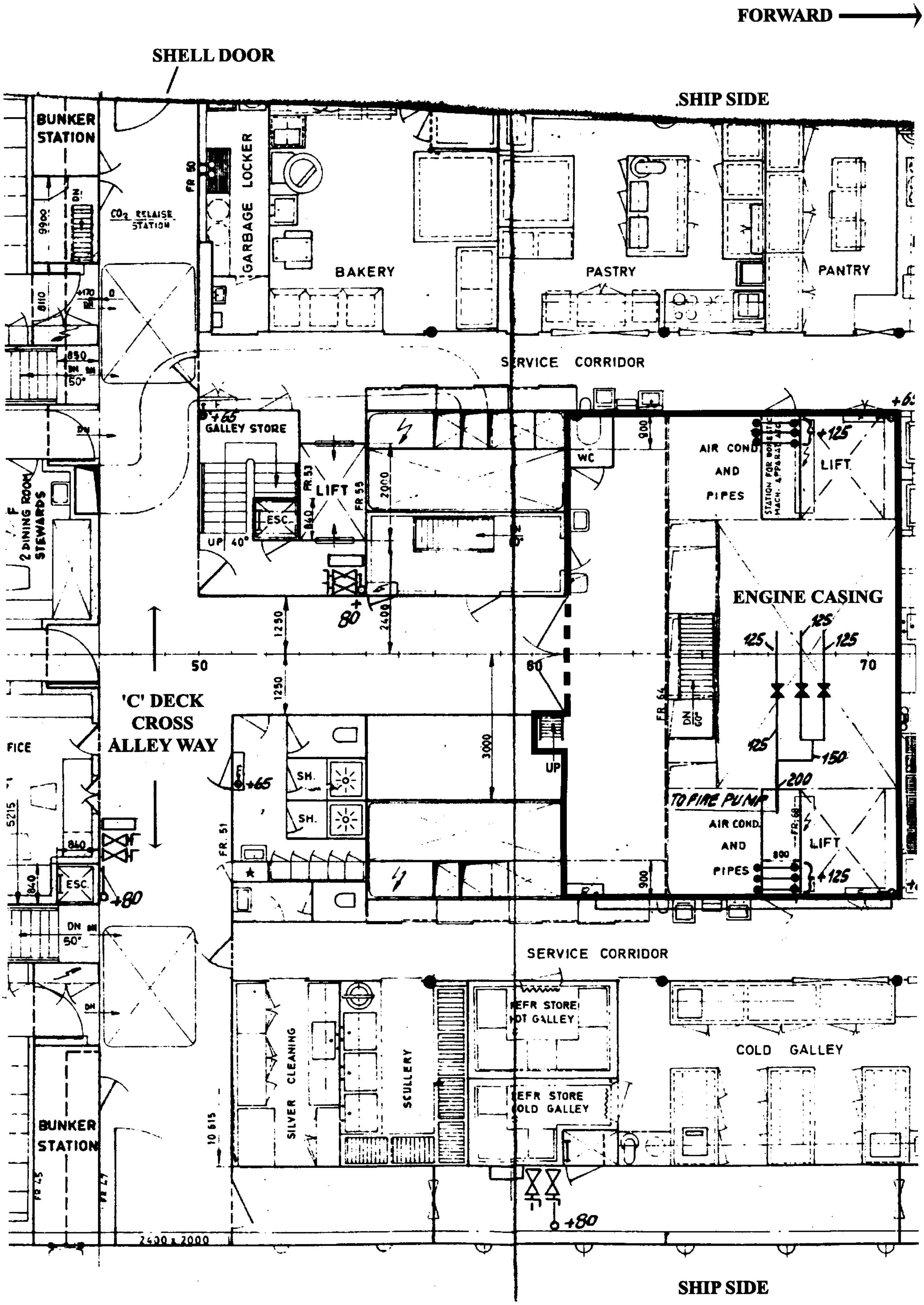



Figure 2c - 'C' deck cross alley way

easing gear crank handles by hand to lift the valve he noted that the valve spindle did not move. His initial impression was that the safety valves were open.

He checked the starboard economiser safety valves and assessed that they were open and passing steam.

The second engineer joined him. They slacked back the port economiser safety valve easing gear and tried to lift open the valves, again by hand, using the easing gear crank handle. Since the valve spring loads were not very great, they expected the valve spindles to move. They didn't, and they concluded the valves were jammed closed.

The temporary boiler was put back in service.

### 1.3.3 The emergency response

When the fire alarm sounded, the assessment party was called out and the master immediately went to the bridge. At 1400, a broadcast was made for the ship's medical team to go to C deck cross-alleyway. The main engine revolutions were reduced.

The doctor and nurse responded straightaway to the call, and found Mr Pickard lying face down on the deck. His boiler suit was hot and wet, and it was obvious he had been severely scalded. He was placed in the recovery position after first clearing his airways and removing his boiler suit. He was then transferred by stretcher to the medical centre for further medical care.

The doctor informed the bridge about what he had found and requested an immediate medical evacuation. The Naples harbour authority and the ship's agents were contacted with a request to arrange a helicopter evacuation, but when they attempted to do so were informed that none was available. A fast launch was, therefore, requested. The ship meanwhile had altered course towards Naples and was returning at full speed.

By 1452, a coastguard cutter and a pilot boat were alongside. The pilot boarded *Island Princess*, but because the doctor had become increasingly concerned with Mr Pickard's condition, he was kept in the medical centre. The ship continued towards Naples, but as the patient's condition deteriorated, the doctor recommended that he be transferred ashore. He was placed on a stretcher, taken down to the shell door opening, and transferred to the waiting coastguard cutter.

The cutter cleared *Island Princess* at 1517. Mr Pickard remained under the constant care of the doctor and nurse throughout the transfer to the hospital.

When the cutter arrived at the berth, it was met by an Italian medical team, which arranged for the doctor, nurse and patient to be transported to the emergency resuscitation ward at Loreto A Mare hospital, Naples.

Mr Pickard was pronounced dead at 1555.

Meanwhile back on board, Mr Clayton was, after walking to the medical centre, beginning to have difficulty breathing. It also became apparent he had extensive burns to his face, back and legs. His clothing was immediately removed and cool towels were applied to the burned areas.

*Island Princess* stopped off her berth at 1547. Mr Clayton was taken to the boat deck by wheelchair. At 1550, he was transferred to a ship's launch accompanied by his manager, and transferred ashore to a waiting ambulance which took him to the Cardavare Vi burns hospital in Naples.

Mr Clayton was later transferred by air ambulance to a Wakefield hospital in England where he died 13 days after the accident.

Following the accident, Princess Cruises provided stress counselling on board the ship to crew members and contractors.

## 1.4 *ISLAND PRINCESS'*S STEAM GENERATION PLANT

*Island Princess*'s steam generation system was typical of a motor vessel **(Figure 3)**. Two waste heat boilers (economisers) heated by main engine exhaust gas, worked in combination with two auxiliary oil-fired boilers. When the main engines were shut down, steam was provided by the oil-fired boilers.

Steam was supplied to the galley, laundry, air conditioning system and machinery space installations, including three sea water evaporators. The evaporator produced fresh water for the steam plants and drinking water.

To meet demand at sea, control of steam output was achieved by automatic burner control on the oil-fired boilers. Control used to be achieved by varying the admission of exhaust gases to the economiser by means of a by-pass damper, but because of leakage and unacceptable noise levels, it had not been used since the 1970s.

The economisers and oil-fired boilers were situated inside the boiler space in the upper parts of the engine room casing **(Figures 2a and 2b)**. The oil-fired boilers were installed port and starboard on Aloha deck, and the economisers port and starboard, directly above the boilers, on Promenade deck.

Details of the oil-fired boilers and economisers are described in **Annex I** and **(Figures 4 and 5)**.

### 1.4.1 Economisers

The economisers were Aalborg AQ7 type, which are of a flat-ended all welded vertical shell and tube type construction. They were designed to heat the water within the shell space by heat transfer through smoke tubes supported by top and bottom tube plates.

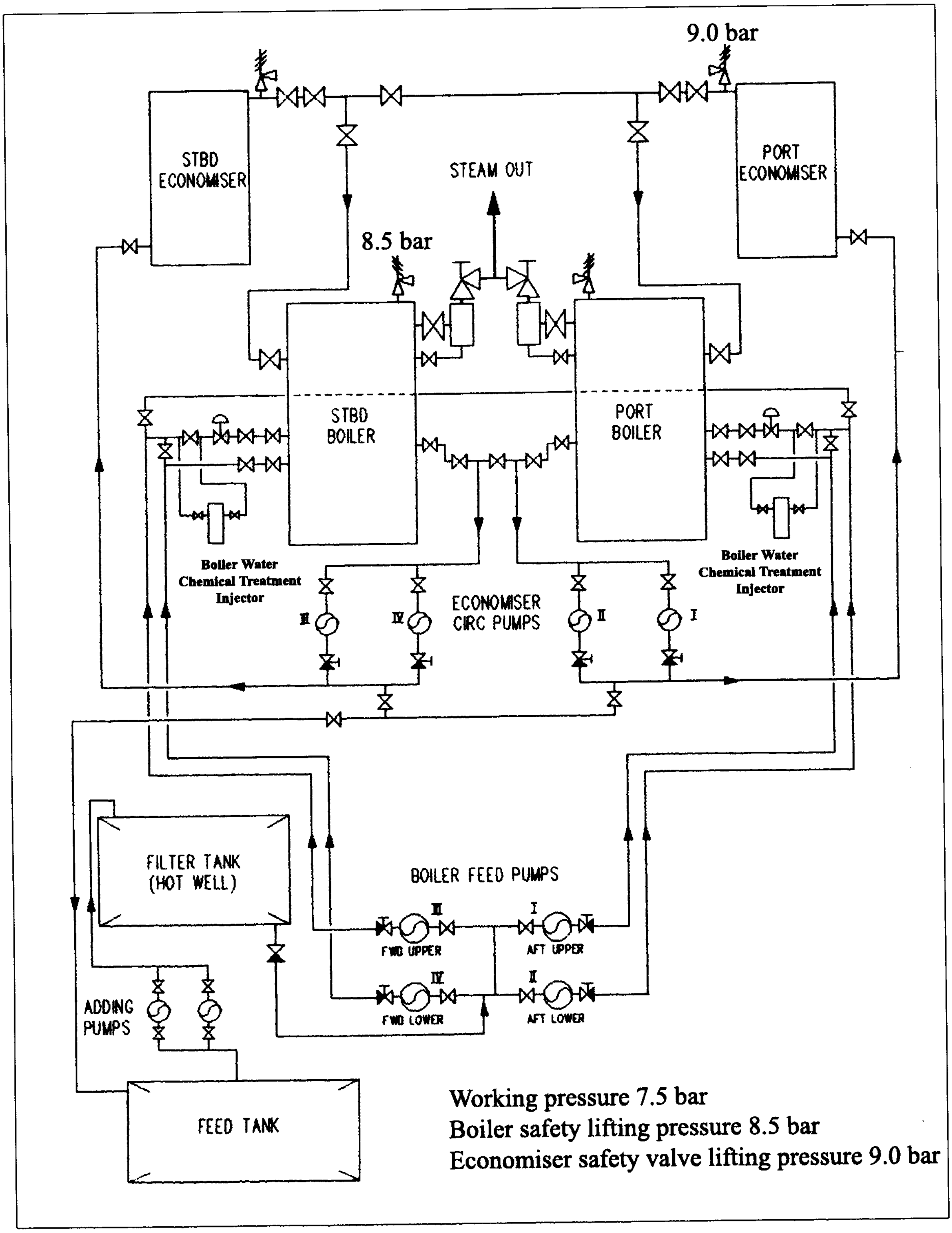
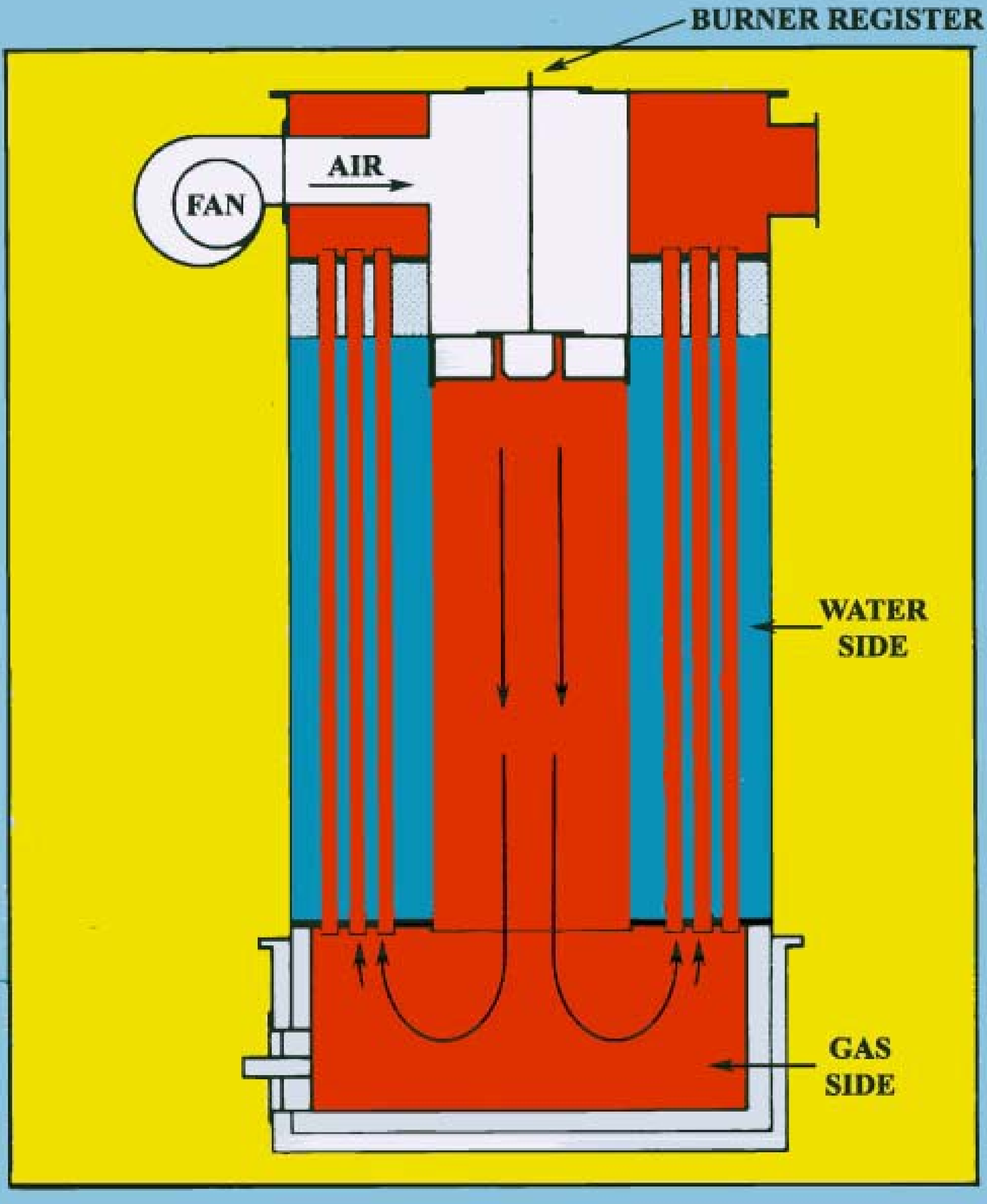


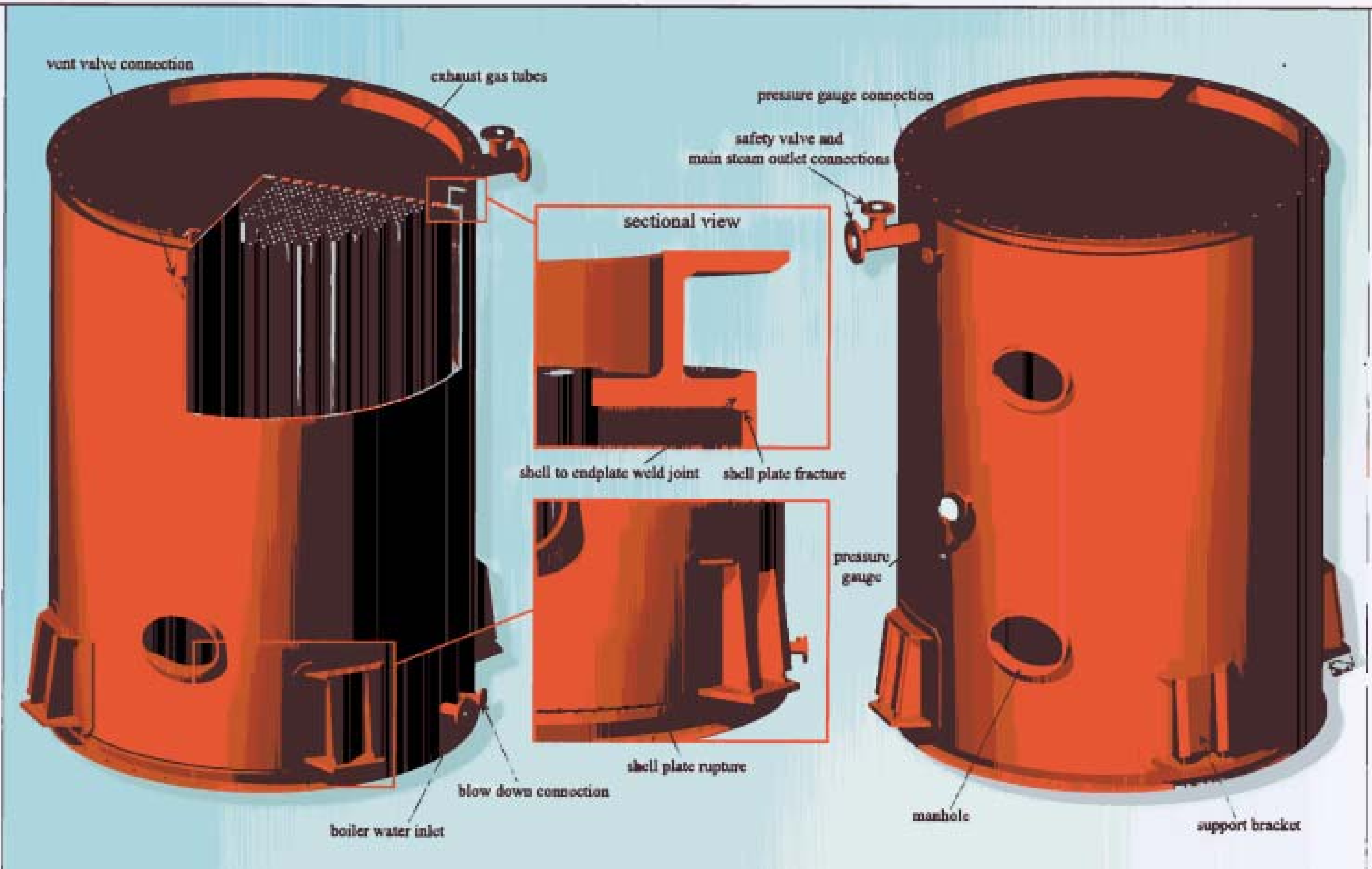

Figure 3 - Boiler feed and economiser circulation system

Figure 4




## Down-Fired Oil-Fired Boiler

Type O.F.19.




# Port economiser

Figure 5

The steam/water passed through the main outlet from the economiser to the boiler. Each economiser was designed to operate full with 10 tonnes of water. In 1989, Lloyd's Register of Shipping approved the economiser scantlings for an increase in design pressure from 8.5 to 9.0bar to accommodate a new oil-fired boiler installation.

The same type of economiser was fitted on the sister ship, *Pacific Princess*.

The exhaust gases from the two sets of engines on either side passed through the port and starboard economisers respectively. The gases entered the inlet header on the underside of the economisers, passed through the heat exchange tubes to the outlet header and into the exhaust stack.

The inlet header acted as an expansion joint to allow for thermal movement of the installation.

Each economiser had two safety valves, one air vent valve, a pressure gauge, blowdown valve, inlet and outlet valves, and three manholes. The economisers were supported by four brackets welded on to the shell-plate at the lower tube plate level. The brackets were bolted on two longitudinal "I" beams which were part of the ship's structure. Lateral movement of the economiser was contained by horizontal tie rods.

### 1.4.2 Oil-fired boilers

The two boilers were Spanner, down-fired double pass shell-type boilers, manufactured by Senior Green Ltd. The approved design pressure was 8.5bar. They were rated to produce 4000kg of steam per hour at an operating pressure of 7.5bar. They replaced the original oil-fired boilers in 1989.

The boiler safety valves were set at a lifting pressure of 8.5bar. The high pressure steam trip was set at 7.8bar.

Electrically-driven pumps circulated boiler water between the boilers and economisers.

### 1.4.3 Economiser safety valves (Figures 6a and 6b)

The safety valves were made by NAF NordAmatur A/S, Linköping, Sweden, a leading manufacturer of globe valves and safety valves. The company is referred to as NordAmatur in the rest of the report. A detailed specification of the type of safety valve fitted to the economisers is described in **Annex I**.

The safety valves were NAF 546348 duplex (double) simple, spring-loaded safety valves, set in a single carbon steel valve body having a common inlet. The valve body was mounted on the economiser in the fore and aft direction. For the purpose of the report, individual safety valves are referred to as the aft or forward valves as appropriate. Each valve is designed with a capacity to be sufficient to prevent overpressure. Two valves are fitted as a safety precaution, should one fail to operate as designed.

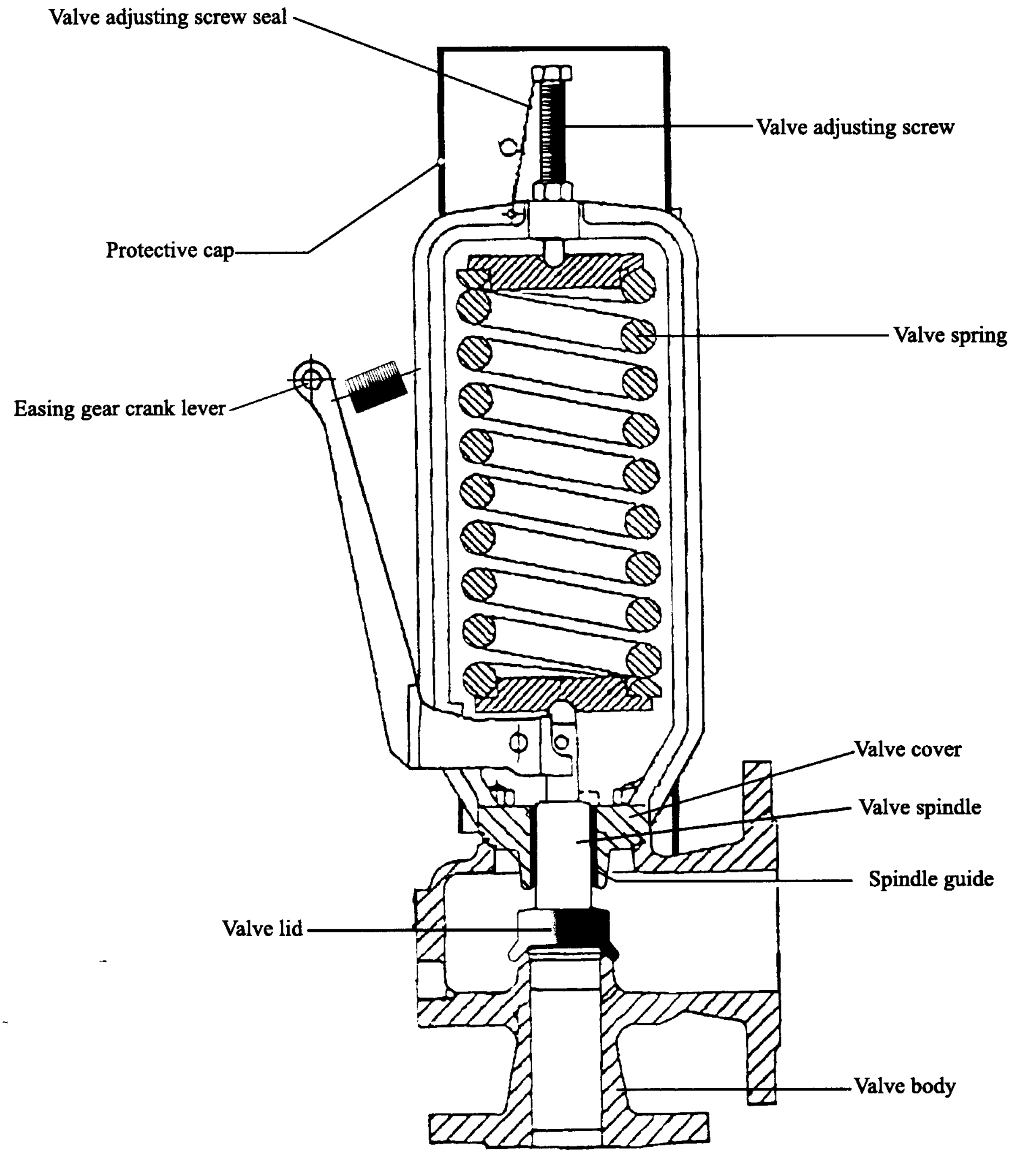



Figure 6a - Spring Loaded Safety Valve

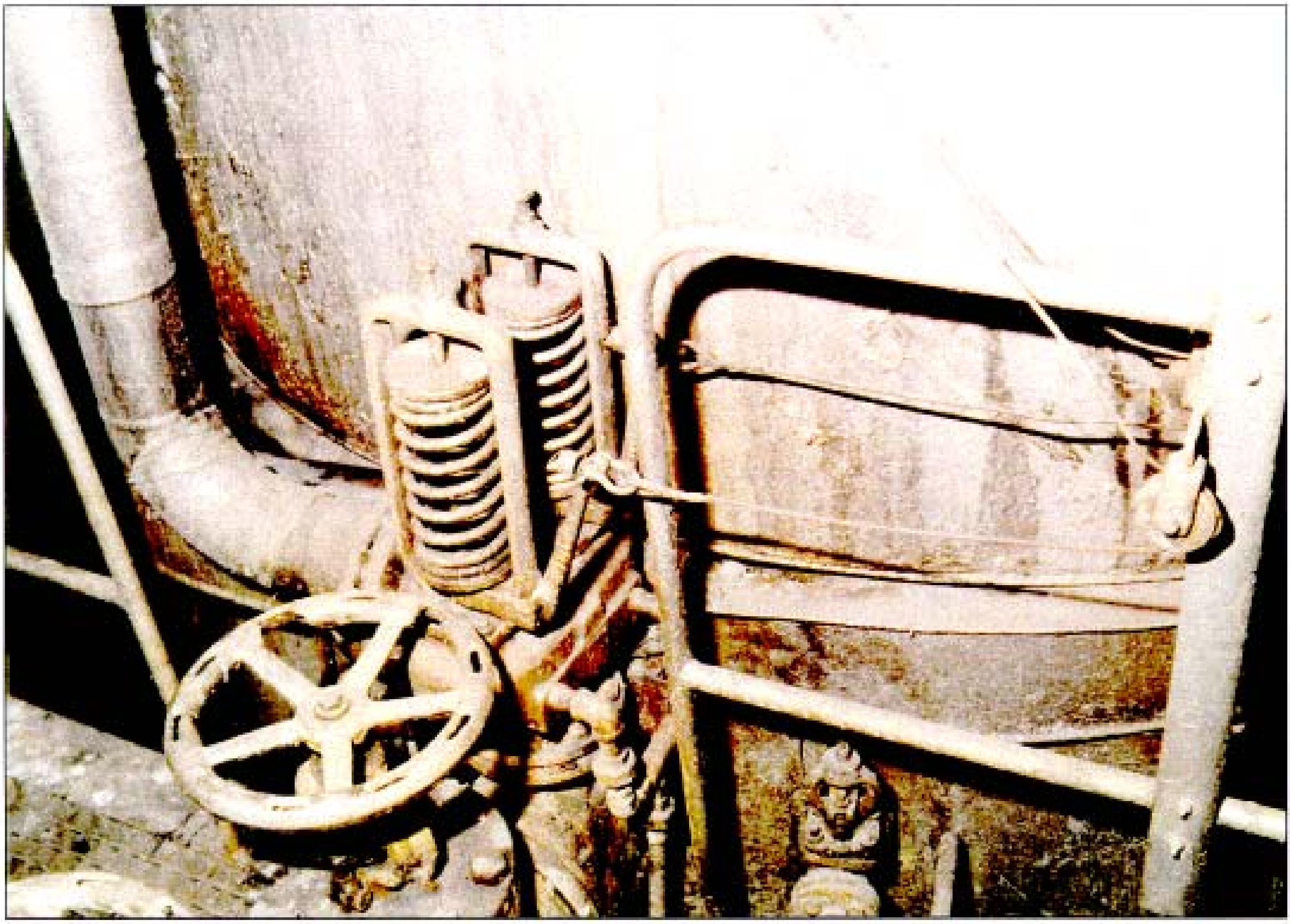


Figure 6b - Starboard economiser safety valve


Figure 6c - Sealing arrangement for the NordAmatur safety valve
(photo taken at the factory)

The valves were designed and first manufactured in the late 1960s and approved by LRS in 1972.

The opening pressure was set using the spring adjusting screw in the bonnet.

The spring adjusting screw had a facility to enable the valve to be sealed to provide evidence of unauthorised adjustment of the valve setting with the adjusting screw **(Figure 6c)**. The springs were encased in a metal shield.

According to the manufacturer the valves were suitable for steam, air and other gases, and water/steam mixture. None of these commodities would corrode the valve materials.

The stainless steel valve spindle is guided by a 2.0mm thick, composite lined guide bush press fitted to the housing of the valve cover **(Figures 6a and Figure 7)**. The guide bush is a Glacier DU bearing. DU is a trademark for The Glacier Bearing Company.

The composite is 0.2mm thick and consists of sintered bronze, PTFE and lead, and is backed on to soft metal. It is designed to operate without lubricants at between 200°C and +280°C. It resists most solvents and many industrial liquids and gases, including oil and water. For the purpose of safety valve use, the guide bush should not be bored, broached or burnished.

To ensure correct running clearance between the spindle and bush, Glacier and NordAmatur specify machining tolerances for the valve spindle and bush housing diameters. The surface finish of the valve spindle is also specified.

The safety valves are set to a nominal lifting pressure of 9.0bar.

The safety valve was fitted with an identification plate stating NAF number, set pressure, working range of springs and makers serial number.

The safety valves on the oil-fired boilers and economisers were fitted with easing gear designed to open the safety valves with or without pressure on the boiler, and maintain them in the open position. They could be used to release pressure in an emergency, and to test the safety valve for freedom of movement. Each of the four handwheels, situated on the boiler flat level of Fiesta deck, remotely operated the safety valve easing gear bell-crank on each oil-fired boiler and economiser. The bell-cranks were connected to the handwheels operating cables running on pulley wheel guides. Each handwheel had an indicator to show that the safety valves were selected "open" or "closed" **(Figure 8)**, but were not marked to identify the corresponding safety valve.

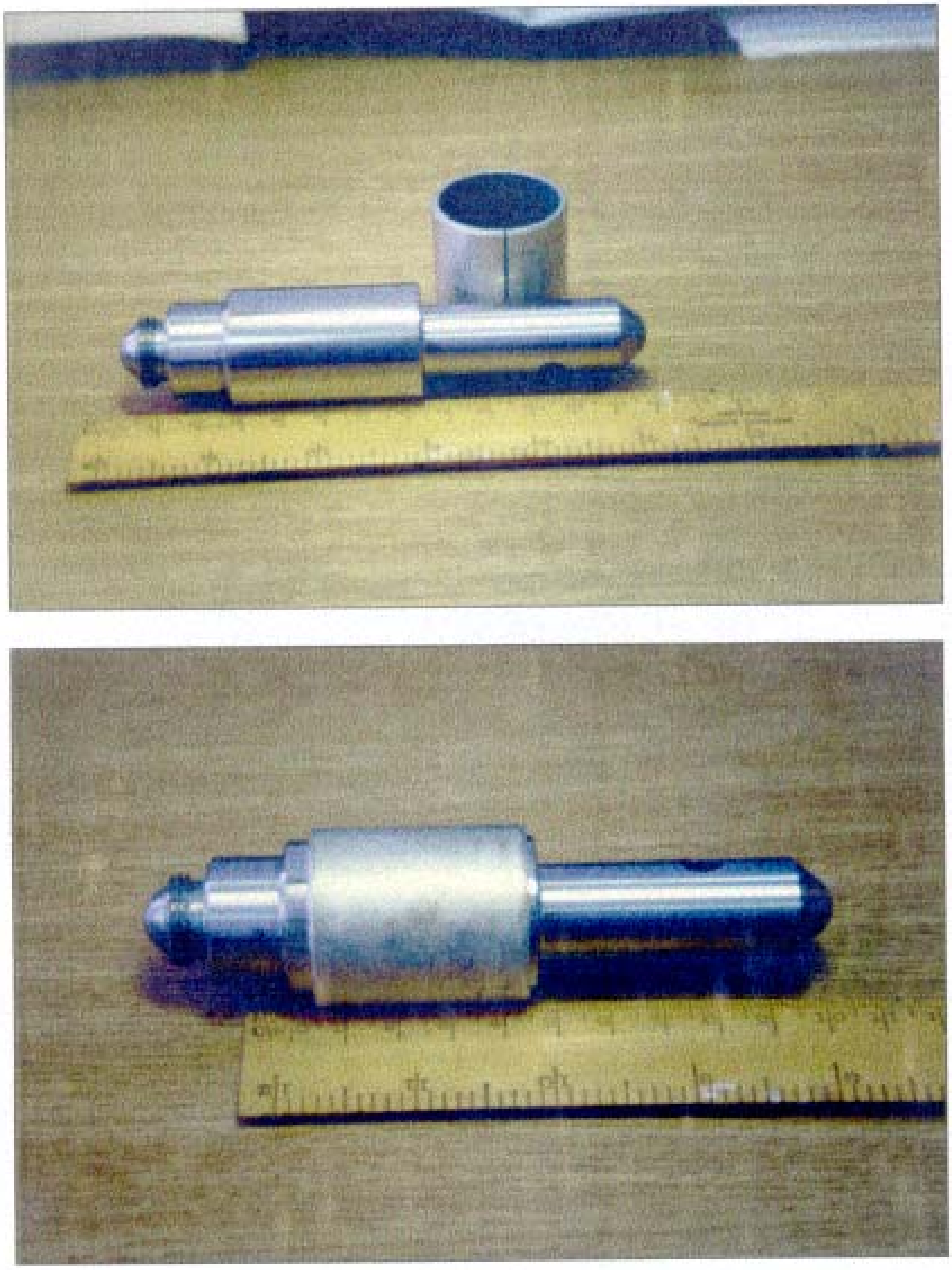


Figure 7 - Spindle guide and spindle

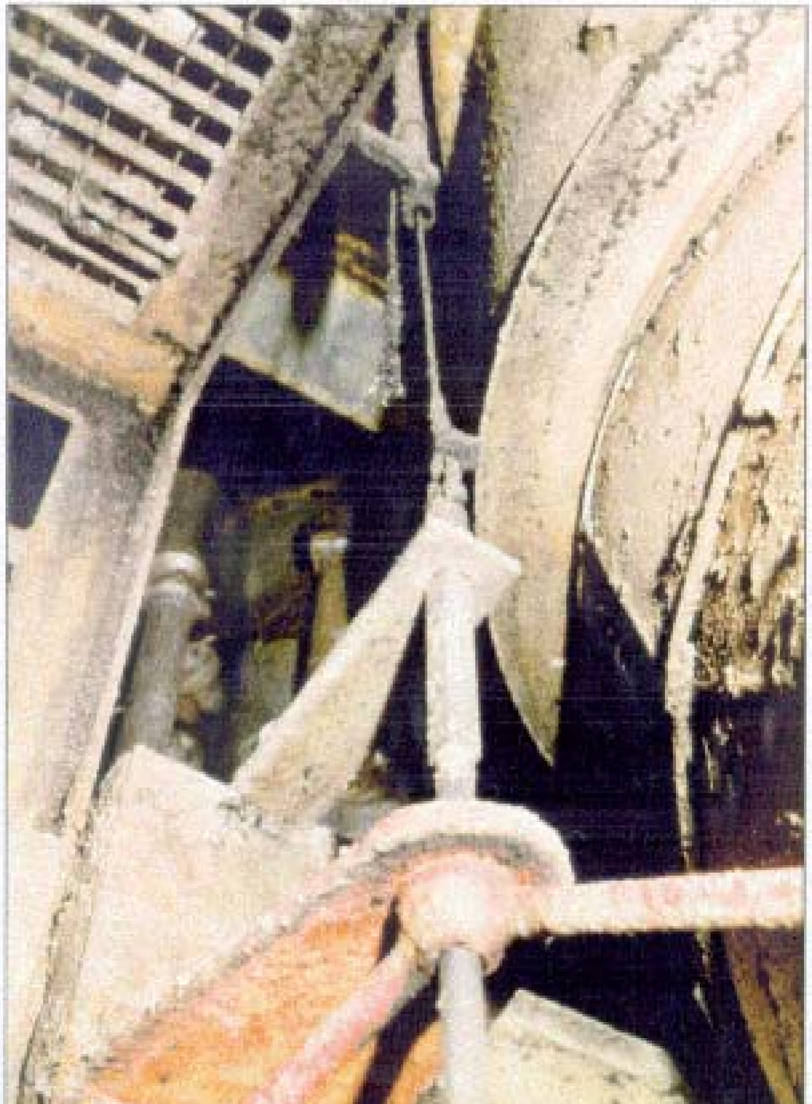


Figure 8 - Starboard economiser casing gear and handwheel in the open position

## 1.5 POST-ACCIDENT EXAMINATION OF THE ECONOMISER AND SAFETY VALVES

### 1.5.1 On-site examination

The port and starboard economiser safety valves were examined in position on the economisers. The safety valve drains were clear.

Port economiser safety valves

The indicators on the safety valve easing gear handwheels indicated fully open. The handwheels could be turned easily.

The operating cable had been broken accidentally after the accident, when the shell-plate lagging was removed to find the location of the rupture. All cable pulleys in the system were free to move.

Because the accident occurred in Italian territorial waters, it was investigated by the Public Prosecutor of the District Court of Naples and, under judicial supervision, the port economiser safety valves were removed to a local workshop ashore for testing and examination.

On 16 December, nine days after the accident, the Italian Authorities tested the valves. They were subjected to a hydraulic pressure to 12bar, 3bar above their lifting pressure. The valves did not lift, but the aft valve leaked oil at 0.5bar **(Figure 9)**. The test was witnessed by an MAIB inspector, Princess Cruises and other interested parties.

Sludge and scale deposits were not seen inside the valve chest, although close examination of its interior and the valve seat was hindered by poor lighting and the restricted view. Signs of red rust deposits were, however, seen where one spindle entered its guide.

In March 1998 the Italian authorities made further tests to establish the force needed to open the valves. These tests were also witnessed by an MAIB inspector, Princess Cruises and other interested parties.

- An incremental jacking load up to a maximum force of 9800 newtons was applied to each valve spindle. Each spindle did not move. The load was equivalent to 87bar pressure acting on the valve, 9.6 times working pressure of the economiser.

- One spindle was subjected to an incremental jacking load up to a maximum of 16286 newtons, but did not move. This load was equivalent to 144bar or, 16 times the working pressure of the economiser.

All the tests were carried out in the cold condition.

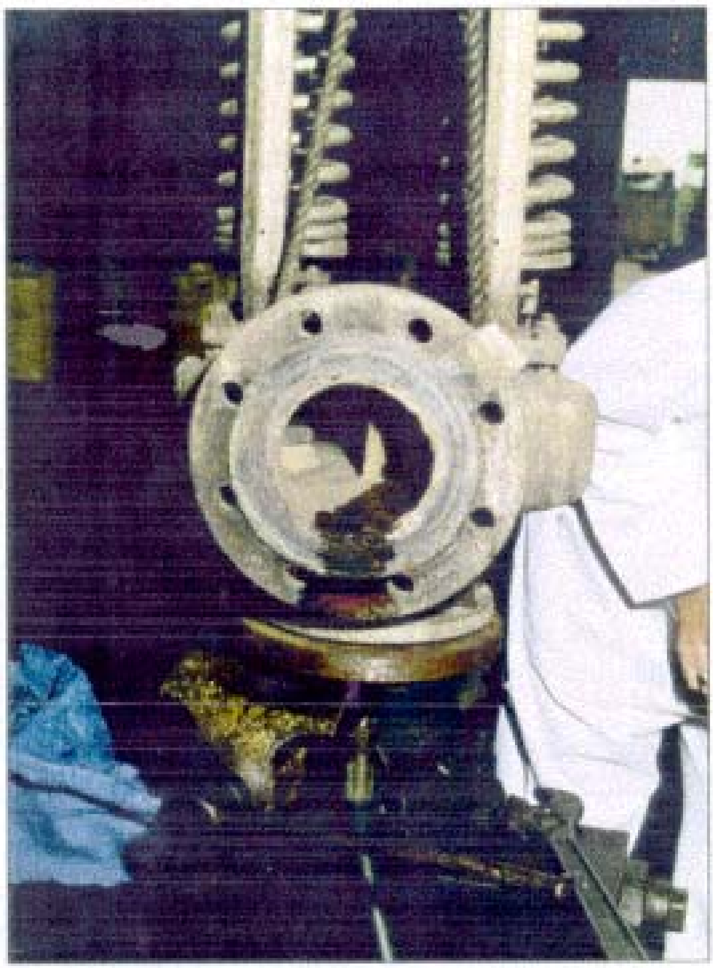


Figure 9 - Port economiser safety valve leaking under hydraulic pressure of 0.5 bar

Starboard economiser safety valves

On the ship the easing gear handwheel for the starboard economiser safety valves was found in the open position, with the operating cable tight, and secured to the wheel and valve easing gear cranks. The engineers reported that the safety valve easing gear held the aft valve open but the forward valve was shut. When the forward easing gear wire was pulled by hand the bulldog grip slipped.

When they disconnected the easing gear wire from the valves, the aft valve closed. The easing gear wire was then re-secured to the forward valve and the handwheel operated. The valve opened smoothly.

The valves were hydraulically tested in the ship's workshop, and found to lift at 9.0 bar. It was not possible to lift the safety valves by manually pulling the easing gear levers.

The safety valves were dismantled and inspected. Compared with the forward valve spindle, the aft valve spindle was a looser fit in its guide. Both spindles could be pushed through the guides without difficulty.

The engineers reported no chemical accumulation on the inside of the valve chest, with the exception of a very small amount on the valve lids and seats. Brown deposits observed on the spindles and guides were hardly enough to get a decent sample. There was pitting corrosion on the spindle surfaces.

At a post-accident survey of the safety valve components an LRS surveyor advised fitting new spindles. New ones were made but, because of the damage to the starboard economiser, the safety valves were not recommissioned.

The valve chest and safety valve components are shown in **Figure 10**.

Port economiser

The port economiser shell-plate lagging was removed before examination.

The shell-plate was ruptured circumferentially about 35mm from its lower edge. It occurred along the shell-to-endplate weld toe, and through an arc subscribing the forward support bracket and the port support bracket **(Figure 5)**. The shell had sprung outwards at the rupture, leaving an air gap of up to 20mm. Magnetic particle inspection showed a crack extending 16mm into the support bracket doubling plate welds.

Visual examination of the rupture surfaces indicated a mainly bright metal colour interspersed with brown stains, ductile necking and areas having a crystalline type failure appearance.

The shell-plate had barrelled outwards to approximately 37mm.

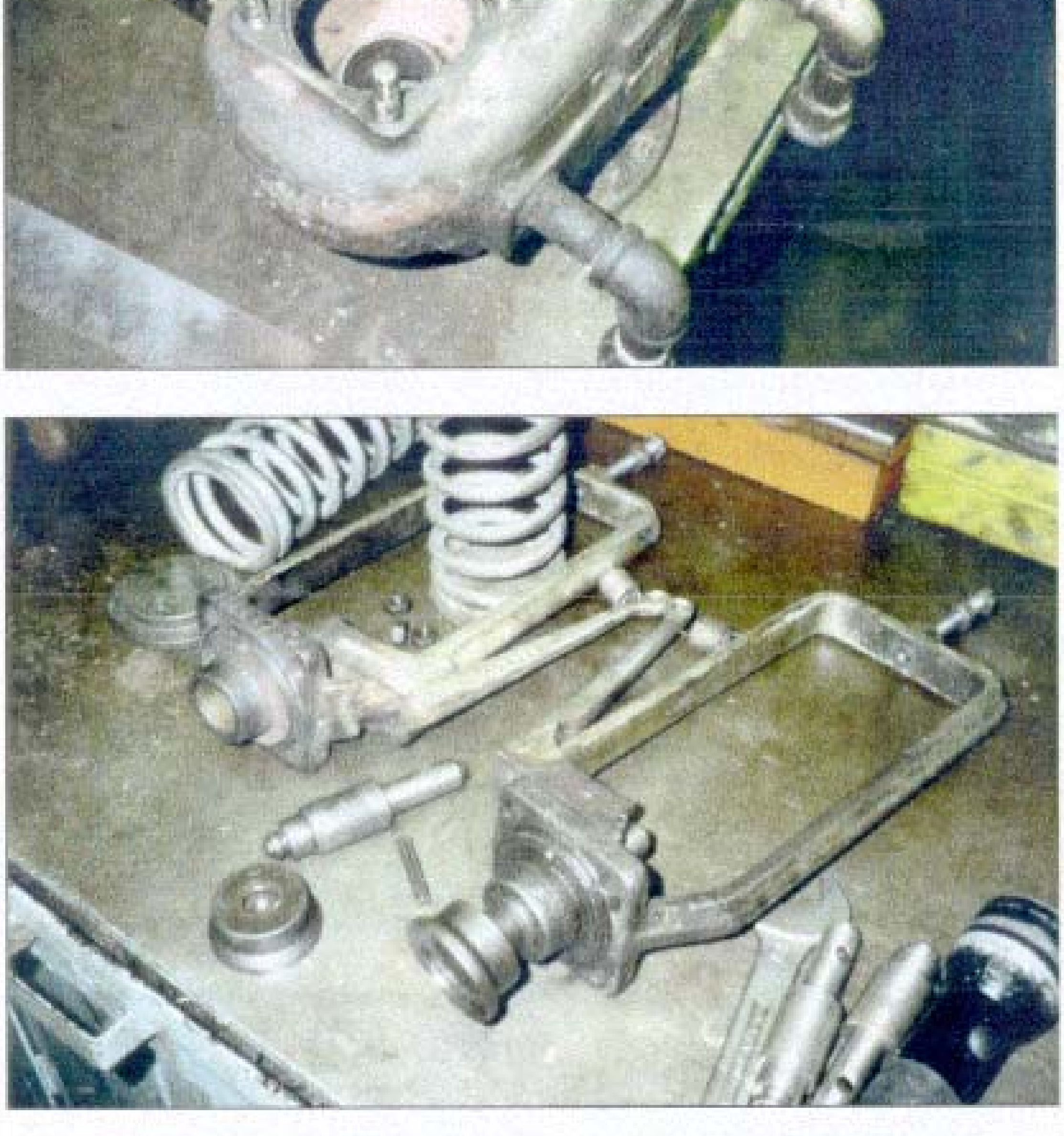


Figure 10 - Starboard safety valves

Ultrasonic testing identified continuous waterside cracking along the circumferences of top and bottom shell-to-endplate weld toes. Maximum crack depth was 8mm, 66% shell-plate thickness. A weld repair on the top seam completed in 1995 was cracked up to 25% shell-plate thickness.

The setting of the economiser valves was found to be:

- vent and drain valves shut;
- pressure gauge valve open;
- outlet valve shut;
- feed water inlet valve shut;
- water circulating pump shut.

Tests confirmed the pressure gauge to be in working order.

Starboard economiser

The starboard economiser shell-plate lagging was removed to reveal the shell-plate had also barrelled outwards.

Ultrasonic tests of the top and bottom shell-to-endplate weld toes indicated similar cracking to that found on the port economiser: continuous waterside cracking along the top and bottom shell-to-endplate weld toes. The maximum crack depth was 4mm, 33% of shell-plate thickness.

*Pacific Princess*

Post-accident ultrasonic tests on the port shell-type Aalborg economiser of the sister ship, *Pacific Princess,* indicated continuous waterside circumferential cracking along the top and bottom shell-to-endplate weld toes to a depth of 6mm, 50% shell-plate thickness. Its shell was also barrelled.

### 1.5.2 The Test House (Cambridge) Ltd laboratory-based analysis of the port economiser's plate fracture, waterside deposit samples and safety valves

The Test House (Cambridge) Ltd was contracted by the MAIB to analyse the samples. The company is a wholly owned subsidiary of The Welding Institute (TWI). It is accredited for mechanical, metallurgical, corrosion and non-destructive testing.

The company's professional experience extends over 25 years in the manufacture, condition monitoring and failure analysis of water-tube boilers for main propulsion plant, and auxiliary shell water-tube fired and waste heat recovery type boilers.

The Test House employed a specialist boiler water chemist from Royal and SunAlliance Laboratories to analyse the boiler water test samples.

Summary of The Test House report of plate fracture and waterside deposit samples

To complete the failure analysis, the laboratory was provided with samples removed from *Island Princess*. These were as follows:

- Boiler shell-plate sample removed from the region of the port economiser rupture **(Figure 11)**;
- Section of shell to bottom tube plate weld removed from the port economiser **(Figure 12)**;
- Waterside deposit sample removed 17 December 1997 from the port boiler, lower tube plate aft inboard mud hole **(Figure 13)**;
- Waterside deposit sample removed 17 December 1997 from the port economiser lower inboard manhole tube plate;
- Waterside deposit taken 3 January 1998 from the starboard economiser bottom tube plate.

Summary of Analysis

1. The shell-plate fracture face sample exhibited three clearly identifiable zones comprising an inner sub-critical fatigue crack growth front, a central tensile overload region, and an outer shear area **(Figures 14 and 15)**.

2. Depth of the fatigue crack, which had originated from waterside corrosion grooving at the bottom tube plate joining weld toe, had propagated to a depth which ranged from 2.5mm at one sample end, to 7mm at the other.

3. The deposit and corrosion products present in the region of sub-critical fatigue crack growth, were consistent with a feed water hardness and extraneous non-ferrous corrosion product origin.

4. Final critical fracture, or plastic collapse of the uncracked ligament of shell-plate, had occurred in a single catastrophic ductile event, involving tensile and shear components **(Figure 15)**.

5. Metallographic examination of the shell-plate fracture face sample, identified additional evidence of under-deposit corrosion and associated incipient secondary corrosion fatigue cracks.

6. Appearance of the under-deposit corrosion front, and presence of free elemental copper in the deposit, were both consistent with either low or high pH type gouging corrosion **(Figure 16)**.

7. Microstructural features apparent at the fracture edge were consistent with a fatigue crack originating at the bottom tube plate weld toe. Beyond the fatigue-cracked region, evidence of a single event overload or plastic collapse was apparent **(Figure 15)**.

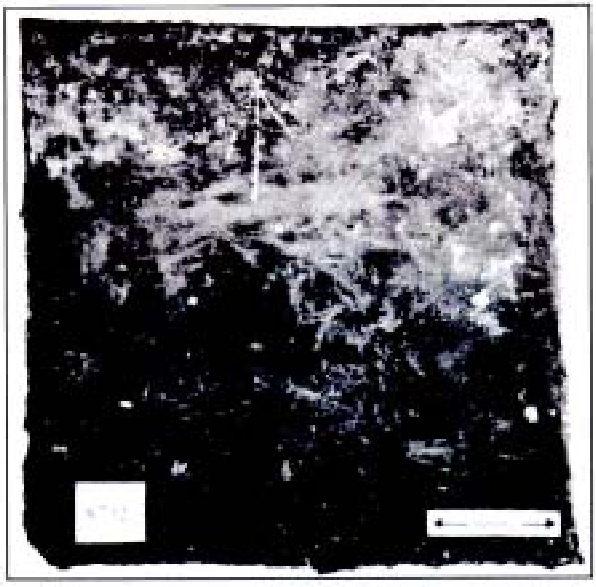


Figure 11 - Boiler shell plate sample removed from port economiser

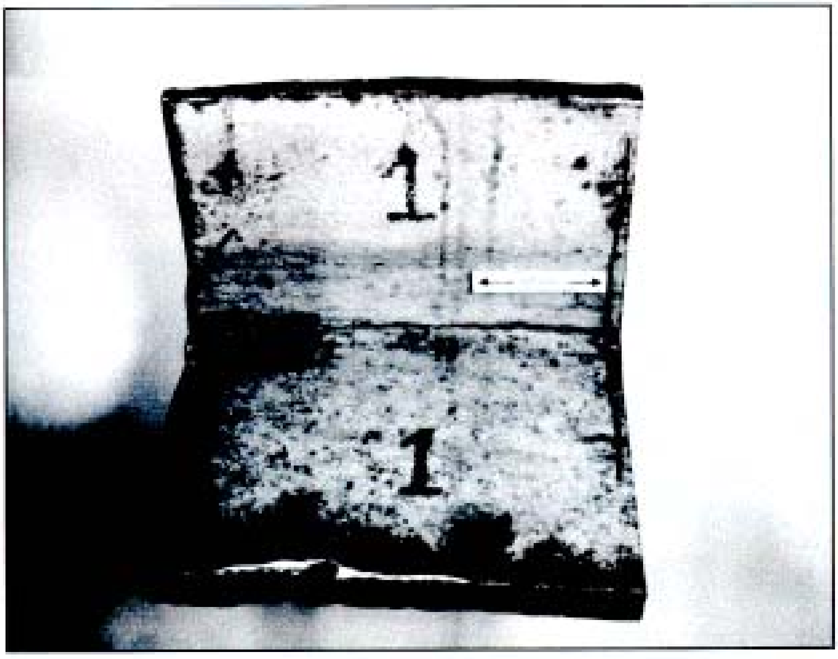



Figure 12 - Section of shell to bottom tube plate weld removed from the port economiser

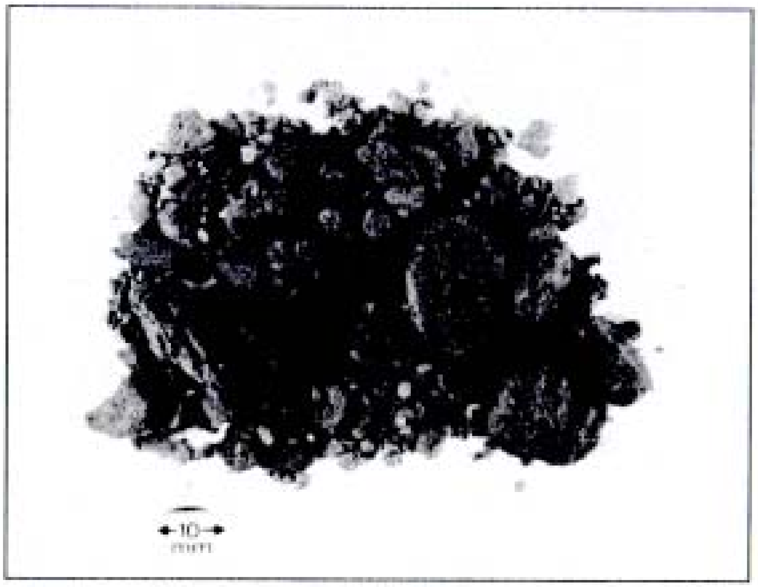


Figure 13 - Waterside deposit from port boiler, lower tube plate aft inboard mud hole

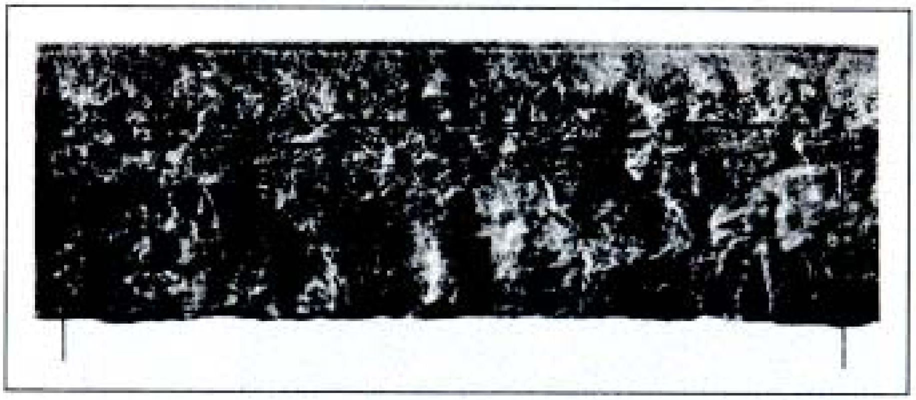


Figure 14 - Field of fracture face close to opposite end of shell plate sample.
Arrows define extent of sub-critical crack front.

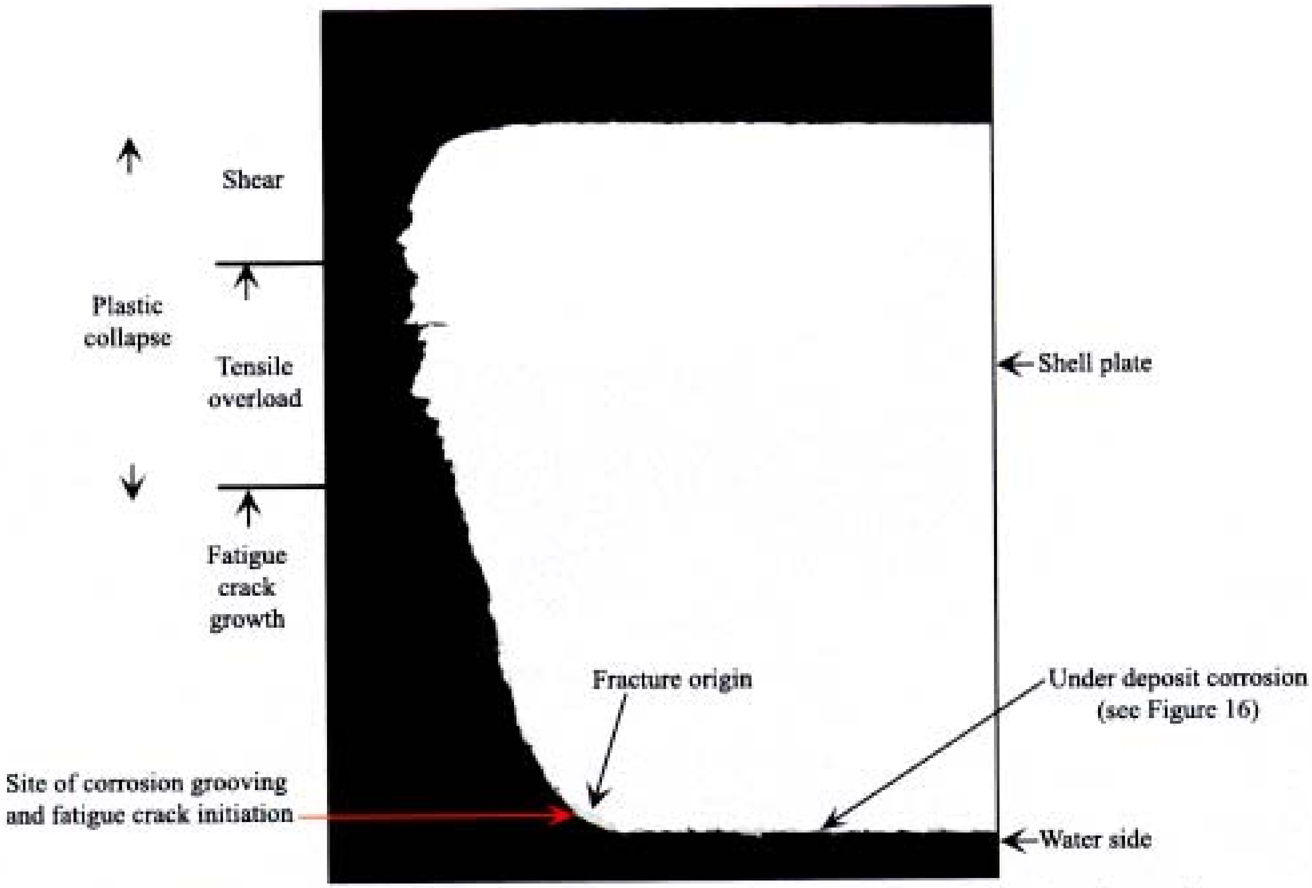



Figure 15 - Photomacrograph x8, as polished. Fracture face edge showing scale coated fracture origin, arrowed.

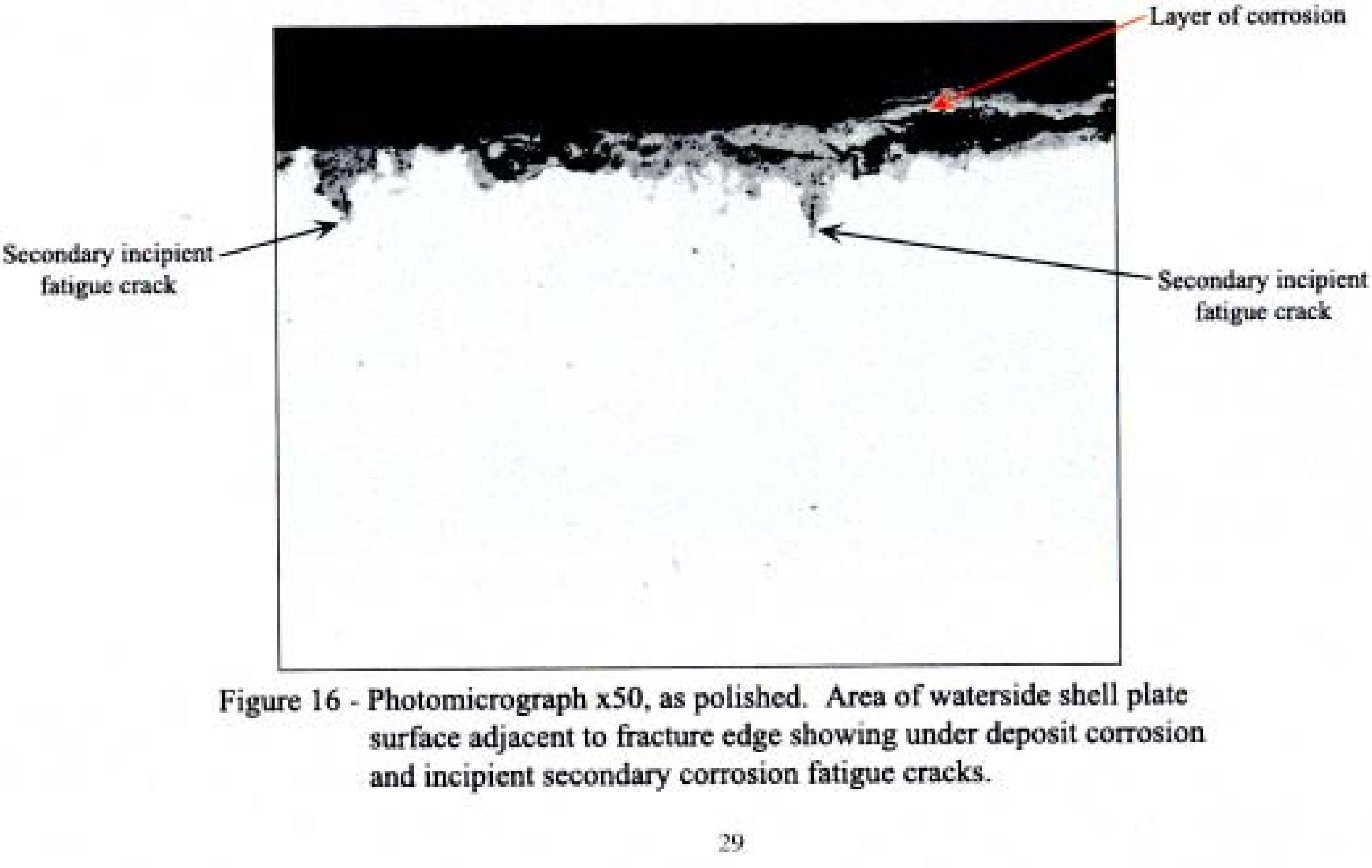



Figure 16 - Photomicrograph x50, as polished. Area of waterside shell plate surface adjacent to fracture edge showing under deposit corrosion and incipient secondary corrosion fatigue cracks.

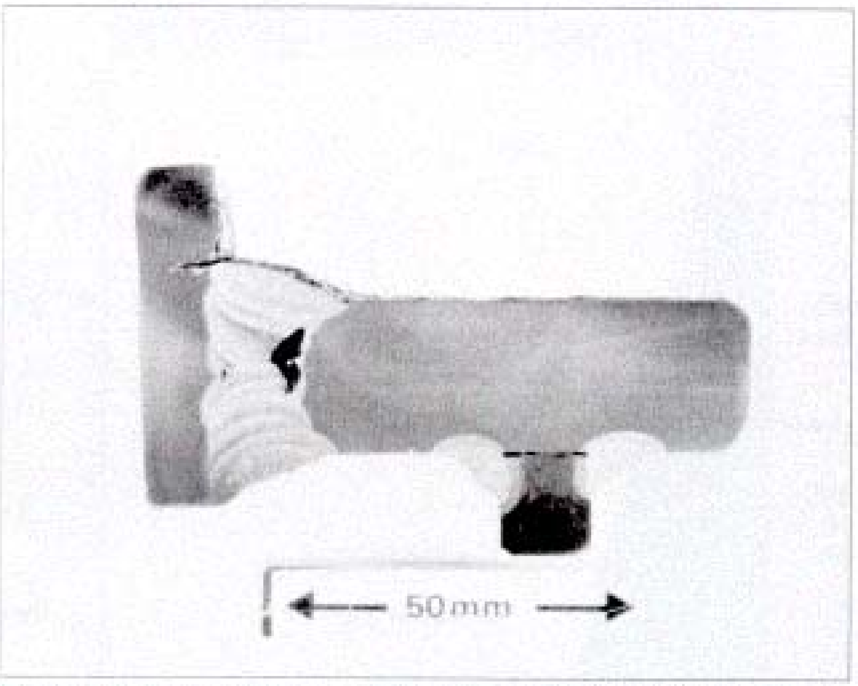



Figure 17 - Shell to bottom tube plate weld showing fatigue crack and apparent welding defects

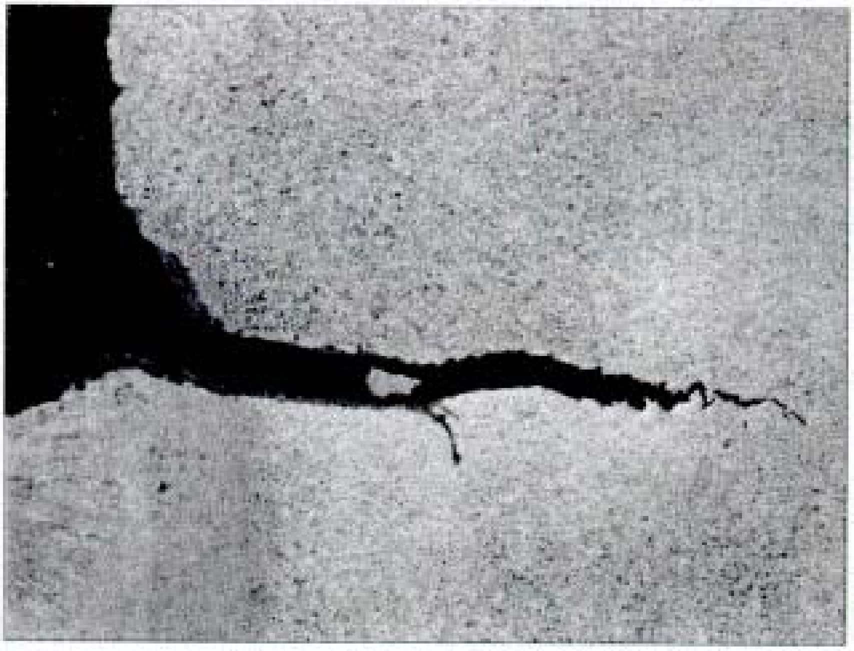


Figure 18 - Scale coated fatigue crack with overload tear extension

8. The shell-plate parent material microstructure appeared free from anomalies and consistent with a boiler type plate supplied in the hot rolled or normalised condition.

9. Tensile test data and chemical analysis of the shell-plate steel were both free from anomalies. For the purpose of establishing a comparative type, a plate of similar properties and analysis is specified in BS1501 as a steel 161-430.

10. Vickers hardness surveys identified irregular high hardness values under the fatigue crack. In the absence of a heat affected zone (HAZ) in this area, the increase was attributed to strain hardening, and probably resulted from outward bending of the shell.

11. Deposit samples appeared to have originated from water hardness constituents. Based on the apparent magnesium/calcium ratios, likely origins of the feed water hardness were thought to be potable water in the case of the port fired boiler sample, and sea or brackish water contamination in the case of the port and starboard economisers. The latter contamination probably preceded the installation of the oil-fired boilers in 1989.

12. Presence of copper, zinc and aluminium in the deposits were thought to represent water transported corrosion products from some ancillary non-ferrous item or items, such as the evaporator or condenser.

13. The shell-to-bottom tube plate weld sample exhibited features and evidence similar to that of the shell-plate fracture face sample. Fatigue crack initiation in this sample was located in corrosion grooving at the shell-plate weld toe. The fatigue crack had propagated to a depth of 6.3mm. Beyond the fatigue crack there was evidence of ductile tearing to an additional depth of 1.3mm **(Figures 17 and 18)**.

14. A significant volume of pre-existing welding defects was apparent in the tube plate to shell-plate joining weld. The defects present were clearly associated with original boiler construction, and had not grown in service or during the shell rupture incident.

15. Deposits and corrosion damage at the waterside of the shell-to-bottom tube plate sample were consistent with other evidence, which included under deposit gouging corrosion and secondary incipient corrosion fatigue cracking **(Figure 15)**.

<u>Conclusions and discussion of the analysis</u>

Sudden rupture of the economiser shell-plate had resulted from plastic collapse of plate material ahead of a pre-existing fatigue or corrosion fatigue crack. Estimation of the pressure necessary to cause such a collapse was outside the scope of this investigation.

It would appear that at some time preceding the rupture, the boiler shell had suffered waterside corrosion grooving at the bottom tube plate to shell weld toe. A fatigue crack had subsequently initiated at the groove site and propagated up to 7mm into the shell-plate. Although final catastrophic collapse of the shell might then have been associated with overpressurisation of the boiler, fatigue crack failure would have eventually occurred under normal boiler operation.

Had the boiler shell not experienced extensive earlier weakening by fatigue cracking, the bursting pressure would have been higher. Had this occurred the scale of the rupture-related damage would have been far more severe.

Failure of shell boilers at tube plate or endplate attachment sites by the proposed mechanism is not an uncommon occurrence, particularly in fired boilers. Guidance on periodic inspection and critical defect assessment at such crack sensitive joints is given in Safety Assessment Federation (SAFed) document "Guidelines for the Examination of Boiler Shell-to-Endplate and Furnace-to-Endplate Welded Joints" (ISBN 1 901212 05 x). Interestingly, the SAFed document also gives positive critical assessment criteria for buried original manufacturing defects of the type identified in the shell-to-endplate attachment weld.

Evidence suggested that before the failure incident, the boiler systems had suffered contamination by both hard potable water, and sea or brackish water. Such incidents had apparently overwhelmed the chemical control system resulting in scale deposit formation and associated grooving and under-deposit corrosion. Presence of pitting corrosion would also suggest that economisers had been fed with oxygenated water, which may have resulted from low feed temperature, loss of hydrazine reserve, or both.

Earlier documentary evidence of economiser shell-plate cracking at locations of endplate attachments on board both *Island Princess* and *Pacific Princess* might have resulted from a similar failure mechanism to the one identified in this failure analysis.

### 1.5.3 Summary of The Test House report of the port safety valve examination

Valve body **(Figure 19)**

From the maker's plate details, the valve had originally been designed for a range of lift pressures between 6.4 and 8.6bar. The valve body had an attached repairers plate under the name of Henze Services Inc, but it was unclear as to what repairs or refurbishment work had been completed.

The valve body was of cast carbon-manganese steel type, with chromium rich stainless steel type weld overlays at each of the seat faces. At some time in the valve's history its mounting flange had been redrilled on different hole centres.

Weld overlaying at the seats had been satisfactorily completed and was judged to be of a suitable hardness for the service duty. Both seat faces were in reasonable condition, with no evidence of cross face erosion damage **(Figure 20)**.

Internal surfaces of the valve body had suffered earlier pitting corrosion and were of a red hue **(Figure 21)**.

Both seats exhibited accumulated boiler water deposits consistent with significant steam/water passing having occurred. Analysis of the deposits was consistent with a sludge from a phosphate conditioned boiler water. It indicated a high proportion of

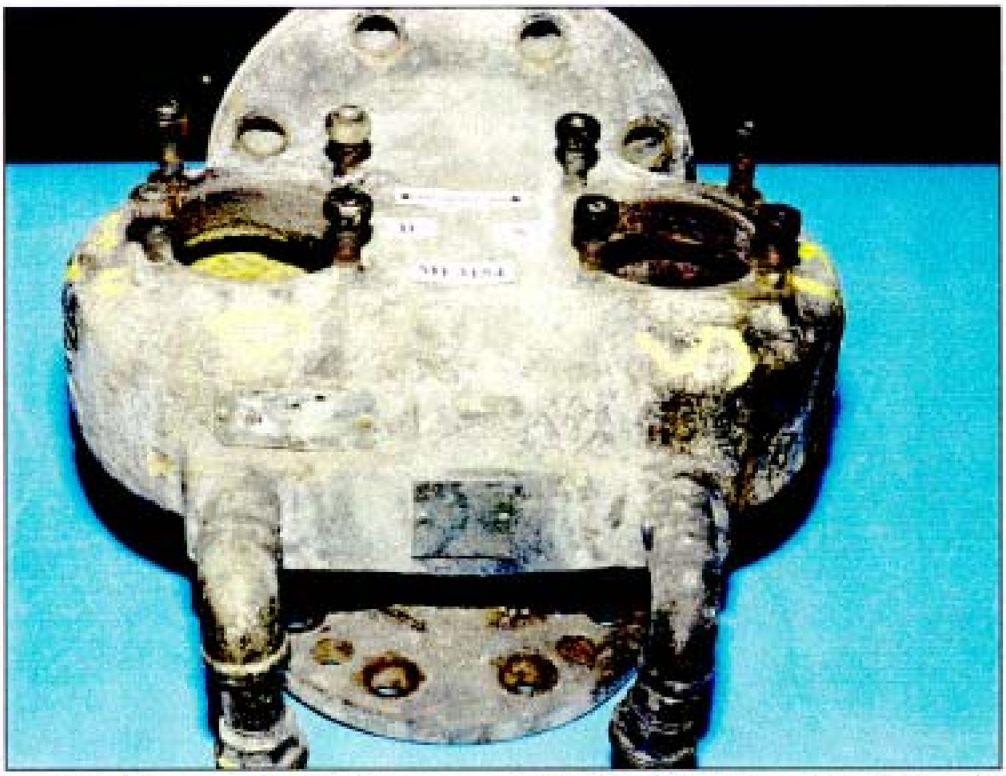


Figure 19 - Valve body showing repairers plate top left, makers plate bottom right and redrilled boiler mounting flange

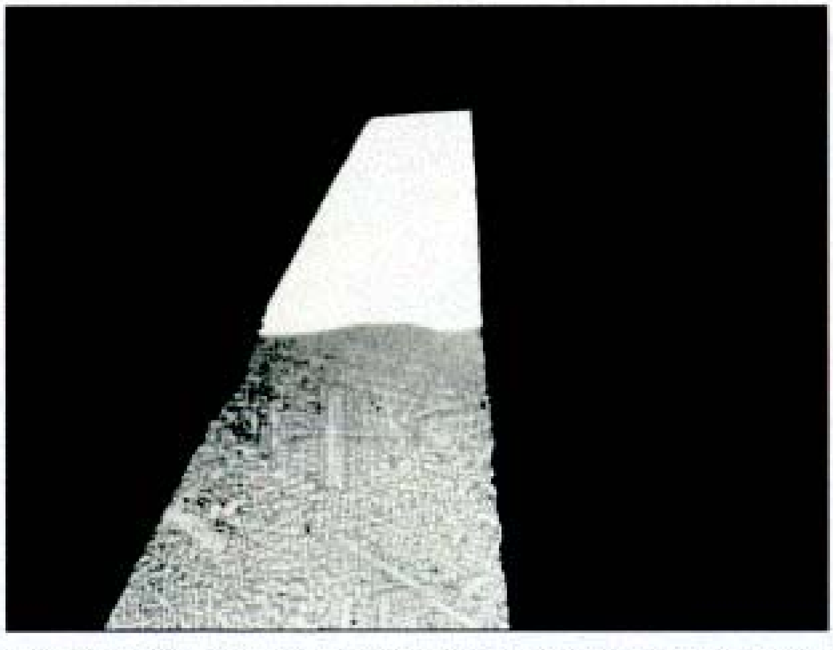


Figure 20 - Macrograph x10, etched Nital. Section through forward side valve seat, showing weld overlay and seat face.

Figure 21 - Forward side valve seat and associated deposits

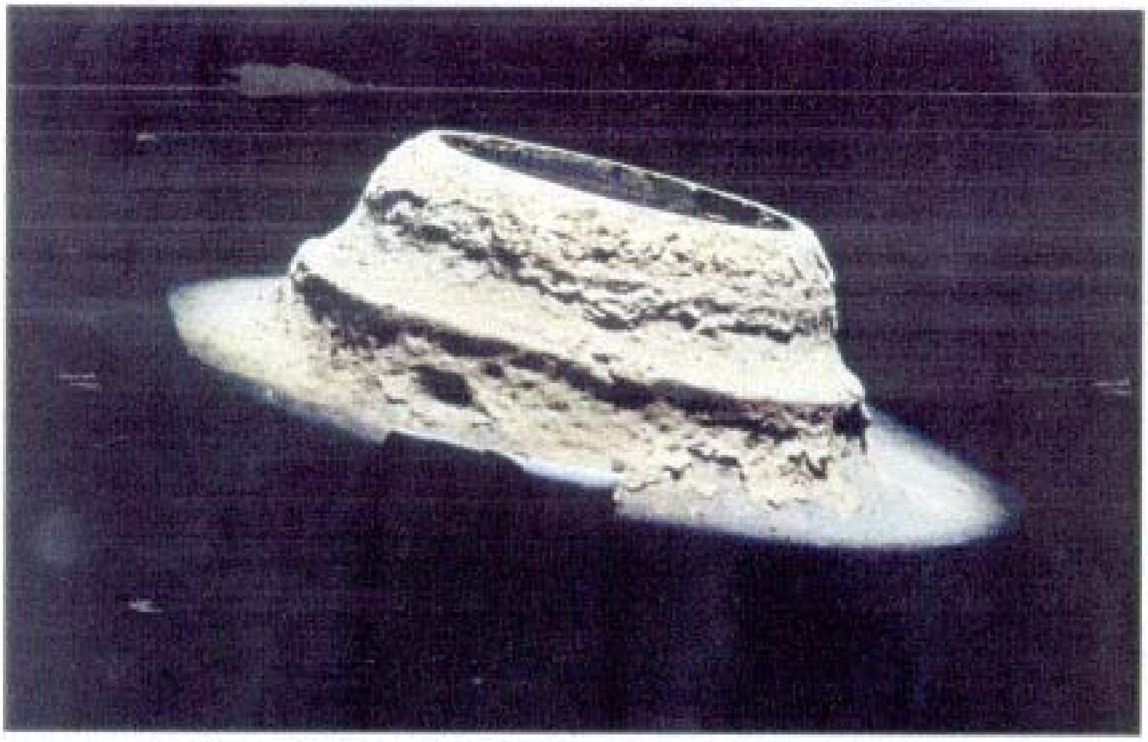


Figure 22 - Forward side valve seat and associated deposits

calcium carbonate in the deposits, which suggested that the boiler phosphate reserve had, recently, been overwhelmed by an ingress of hard, untreated, water. Based on the deposits calcium/magnesium ratio, shore-side potable water appeared the most likely origin of the water hardness constituents **(Figure 22)**.

The accumulation of the deposits on the valve seat is consistent with regular discharge of steam/water emulsion through the valve. The working pressure of the steam plant was controlled automatically at 7.5bar. The lifting pressure of the oil-fired boiler and economiser safety valves were 8.5 and 9.0bar respectively. It is unlikely therefore that the economiser safety valves discharged in response to overpressure. The deposits probably resulted from leakage past the valve seat; a view supported by evidence of leakage during the post-accident jacking tests in Naples.

Valve lid, bonnet and cap assemblies

Both spindles were of similar dimensions, and had probably originated from the same parent steel cast. Dimensions and material type (13% chromium stainless steel) were both in accord with the NordAmatur spindle drawing supplied; suggesting that they were either of original supply or the product of soundly executed reverse engineering. The material type indicated that it matched the materials used for manufacture of spindles up until 1975 **(Annex I)**.

The aft side spindle was bent, and its bottom end cap retaining thread was worn or stripped. Extent of bottom end thread damage was such that the valve lid could no longer be held captive on the spindle end. It was not possible to positively identify the precise location of bending, or its potential contribution to seizure **(Figure 23)**.

Both spindles exhibited top and bottom end mechanical damage in the form of hammer type indentations. Top end marks were of bright appearance and probably represented post-incident damage. This contrasted with bottom end damage, which was of an age at least pre-dating the spindles last re-entry into service. Presence of such damage suggested that spindle seizure had occurred in the past, and that the extent of earlier seizure was severe **(Figures 24 and 25)**.

Supplementary laboratory work supported this view. The analysis found that the region of top end mechanical damage comprised largely background contributions from the stainless steel spindle parent material. This contrasted with the region of damage at the spindle bottom end which appeared to be overlaid with a corrosion product coating. Presence of phosphorus and calcium in the corrosion product was also consistent with in-service deposition in a boiler waterside environment.

This supplementary work also identified presence of an increased chlorine content at the valves steam/waterside. Such evidence would have implications with regard to corrosion of the spindle, and is indicative of earlier system contamination by seawater.

The dimensions of both valve lids were similar to indicate they had probably originated from the same parent steel cast of the correct 13% chromium steel type specified by NordAmatur. There are however differences between the NordAmatur drawings and the seat face diameters to suggest that those supplied were not the

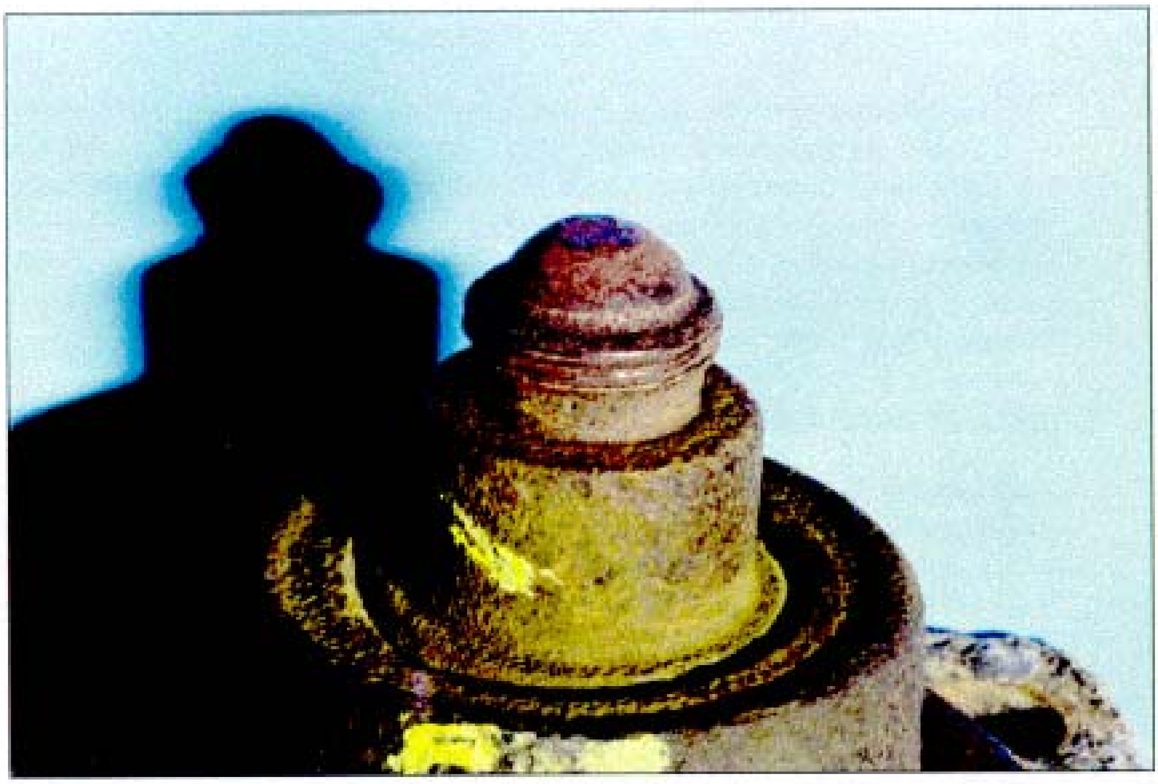


Figure 23 - Aft side valve spindle, showing worn or stripped cap retaining threads

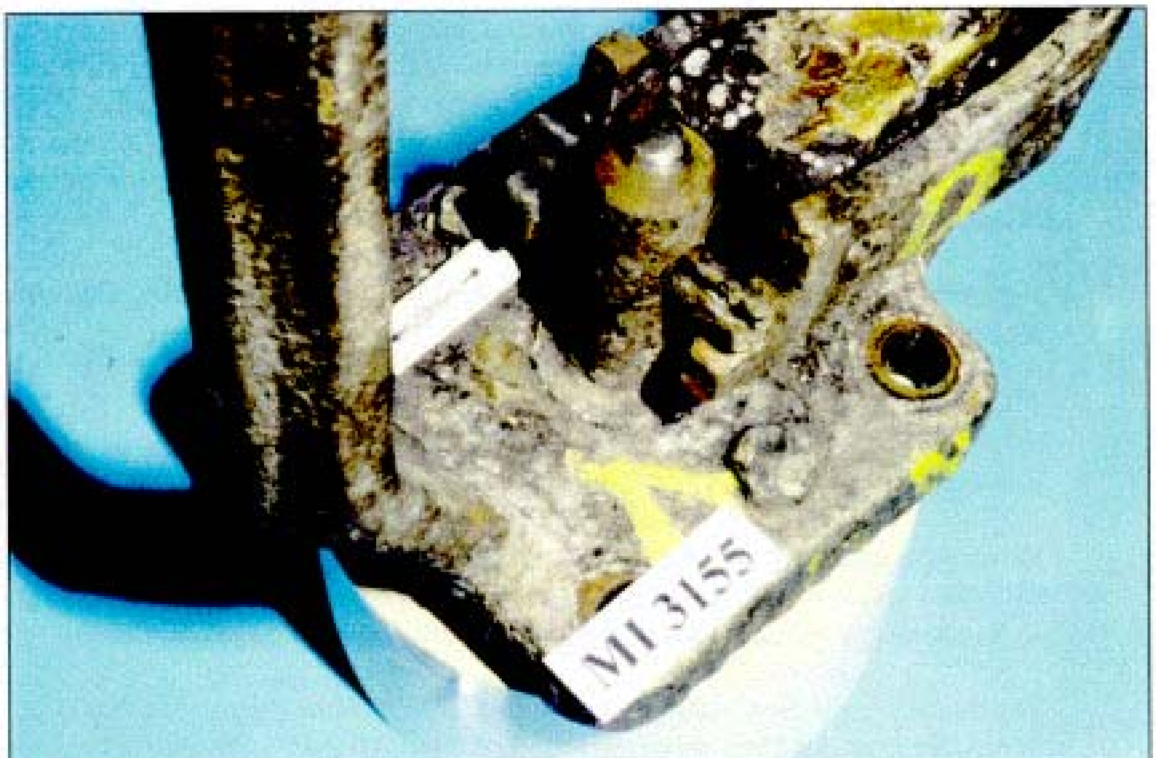



Figure 24 - Aft side valve lid and spindle, showing bright hammer type marks at the spindle top


Figure 25 - Aft side valve lid underside and spindle, showing heavily oxidised hammer type marks at the spindle bottom


Figure 26 - Forward side valve cap, showing raised seating face, steam / water passing marks and associated deposits

originals, or that they had been re-machined. Based on the actual measured raised face diameters, it should still have been possible to effect a seal with the seat.

Though exhibiting clear evidence of steam/water passing marks, the seat faces of both lids were in reasonable condition, with no evidence of cross-face erosion damage **(Figure 26)**.

Sectioning confirmed spindle seizure in both cases to have resulted from severe corrosion of the spindle at the guide bush interface. Though a working clearance was evident at the spindle to guide interface, it was filled with corrosion products, boiler water sludge deposits, and extraneous material which may have entered the clearance space from above the valve lid **(Figures 27, 28, 29, 30, 31 and 32)**.

Corrosion was also apparent on the one guide bush split examined, and at the guide bush interface with the valve lid casting. The latter corrosion had resulted in significant incursions into the forward side valve lid casting **(Figure 33)**.

Both guide bushes were of longitudinally split composite metal type, and included an internal bronze lining. Features of the bushing were consistent with the Glacier Metals type reported to be used by NordAmatur in original supply.

The condition of the inner guide bush linings appeared to vary, and significant damage was apparent in the forward side. Its extent in the section examined was reflected in the remaining coating thickness which ranged from effectively none, to a maximum of 0.20mm.

<u>Valve springs</u> **(Figure 34)**

Valve spring wire diameters accorded with the size specified by NordAmatur for lift pressures of 6.4 to 8.6bar. This suggested they were both of original supply, and had not been changed when NordAmatur specified a larger wire diameter to upgrade the lift pressure to the range 8.6 to 11.5bar.

Service set pressures of 10.6bar and 8.9bar were estimated by indirect means for the forward and aft valve sides respectively. The estimated values served to confirm that the valve had been set close to the correct pressure, and below the post-incident 12bar pressure applied to confirm spindle seizure.

In estimating the lift settings reported, no account was taken of spindle friction or the effect of elevated temperature on spring stiffness and seat throat dimensions.

<u>Conclusions and discussion</u>

The Test House concluded that the safety valve failed to lift because both spindles seized in their respective guides. Seizure was in turn attributed to spindle corrosion damage and accumulated corrosion products, boiler sludge deposits, and other extraneous material at spindle to guide bush interfaces.

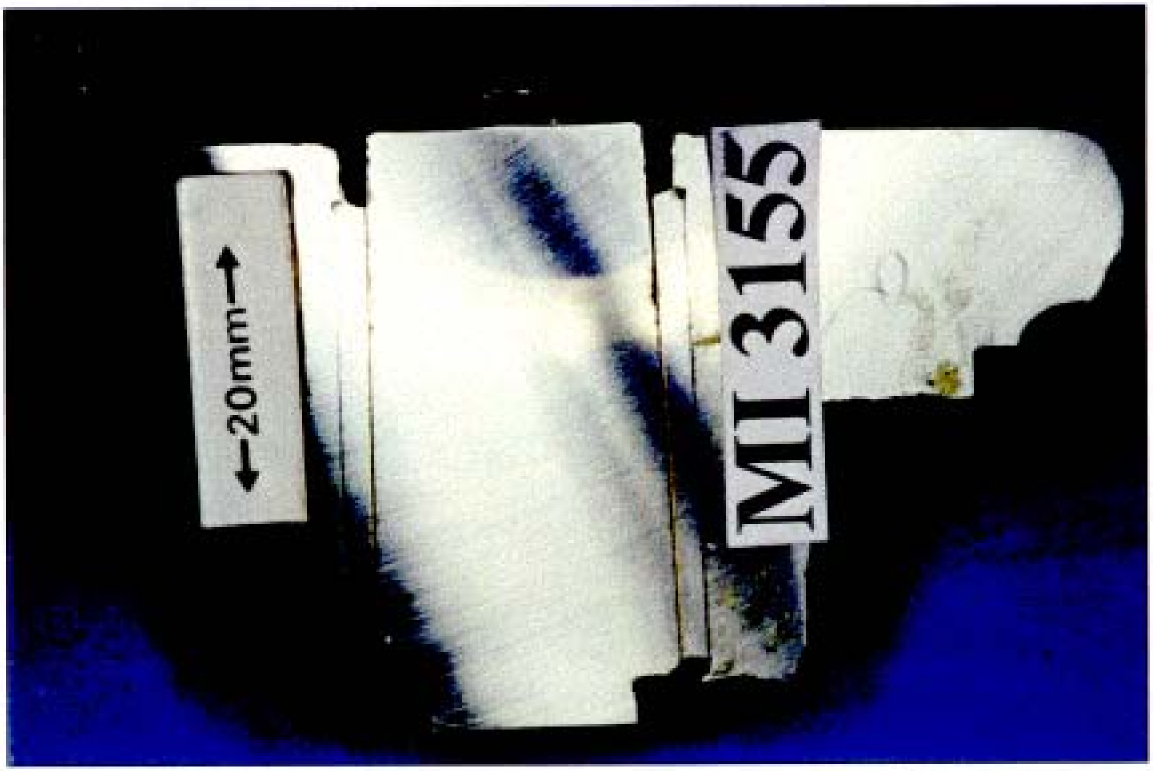



Figure 27 - Aft side spindle to guide interface - off centre longitudinal section

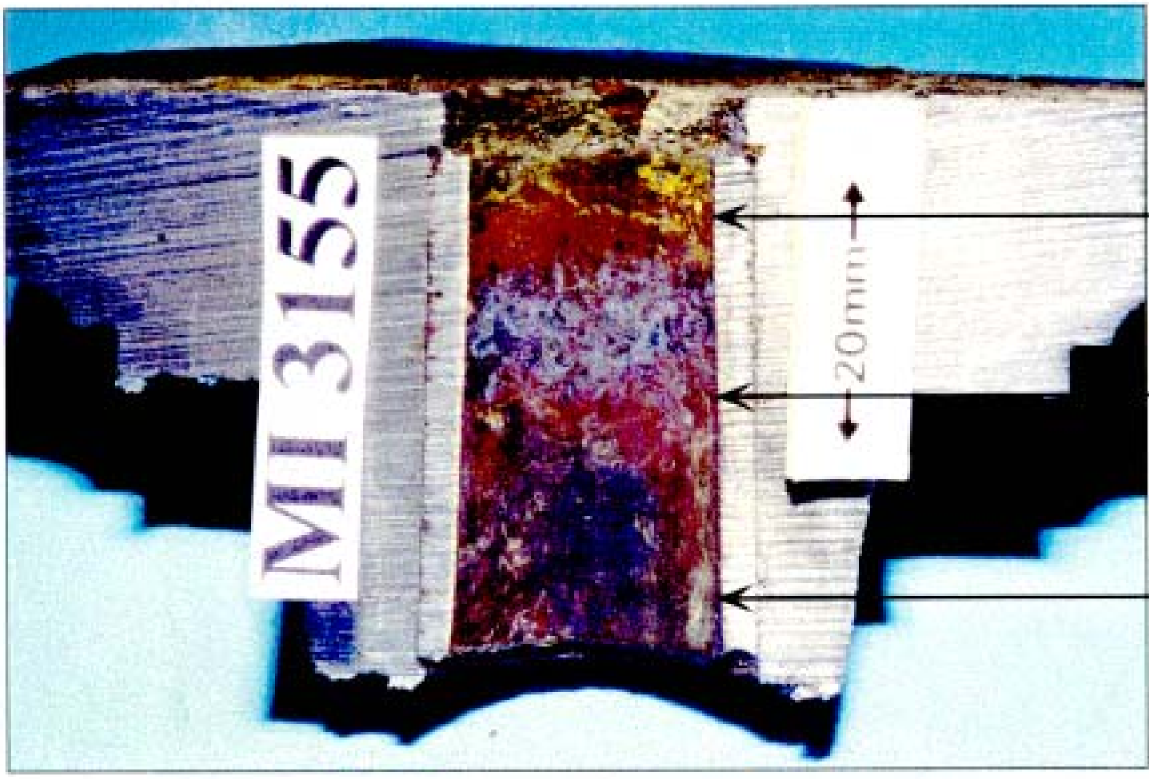



Figure 28 - Aft side spindle guide bush - off centre longitudinal section


Figure 29 - Aft side spindle - off centre longitudinal section
(lower installed location shown to figures right)

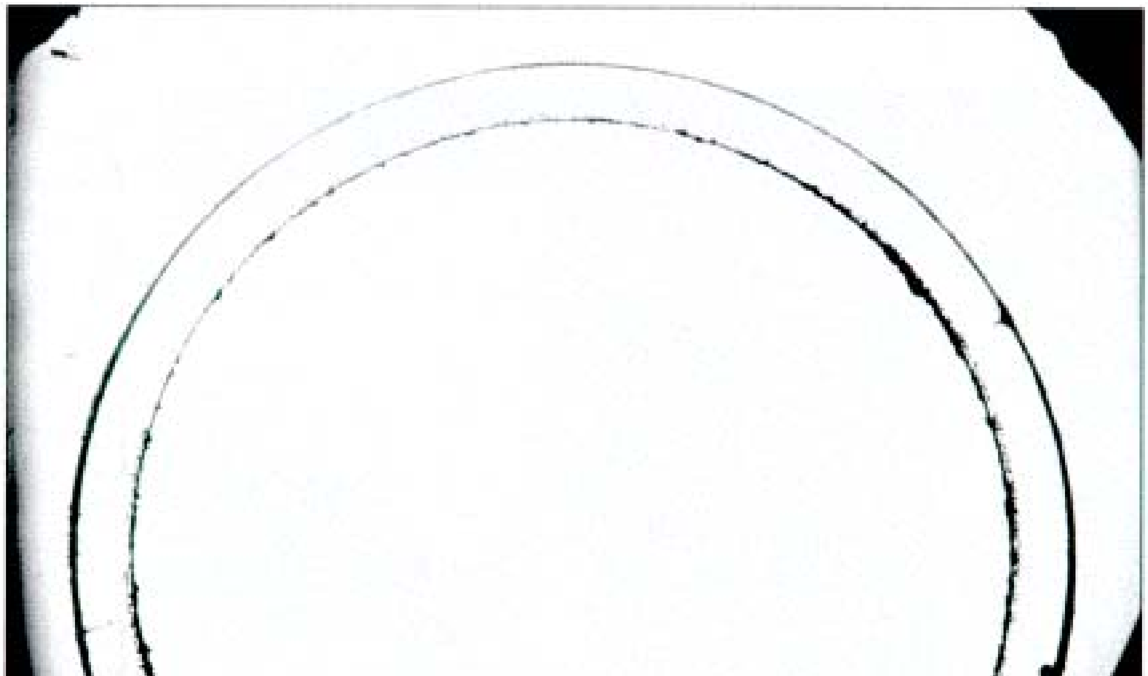


Figure 30 - Forward side spindle to guide bush interface - cross section x3.5

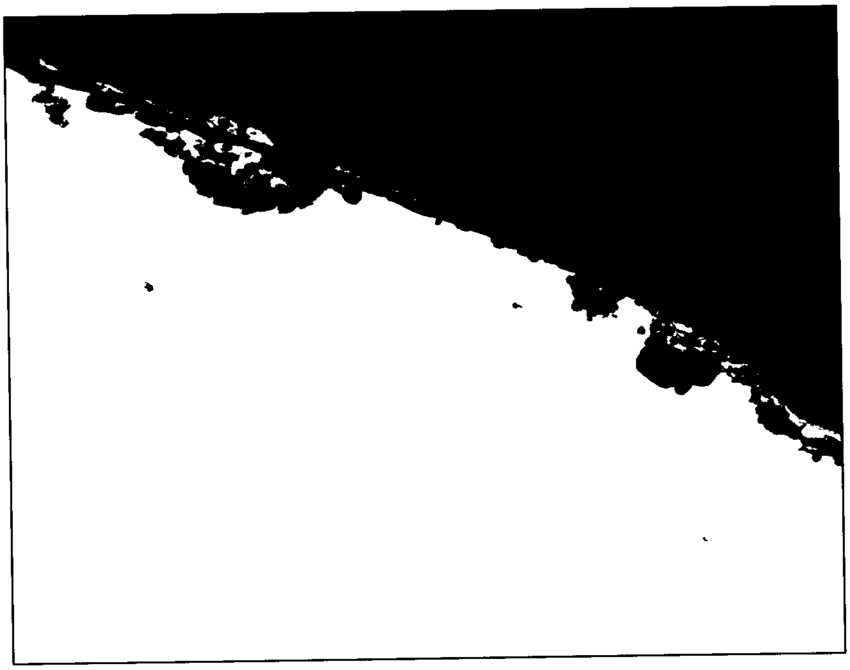


Figure 31 - Micrograph x50, unetched. Forward side spindle cross section

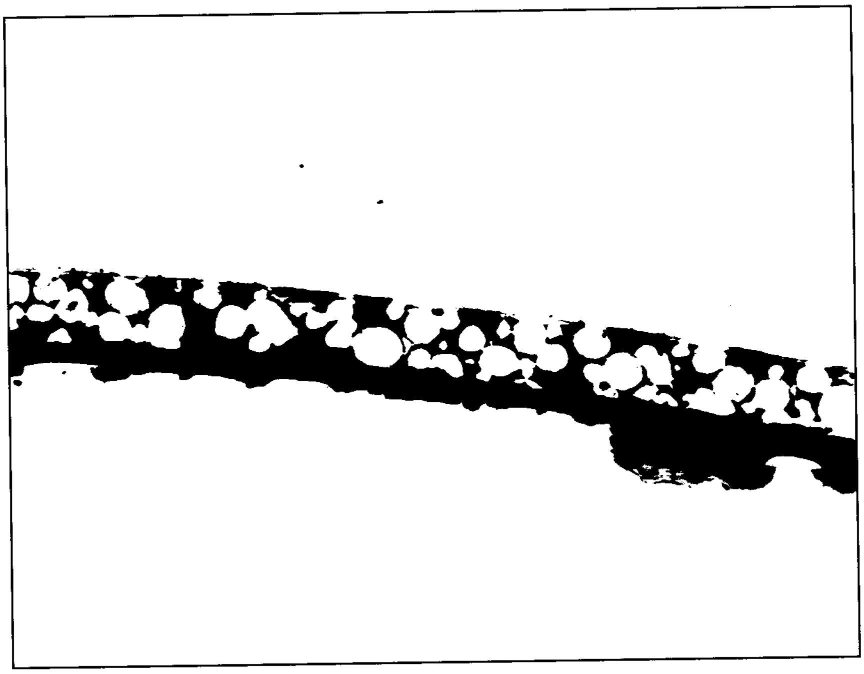


Figure 32 - Micrograph x50, unetched. Forward side spindle and guide cross section

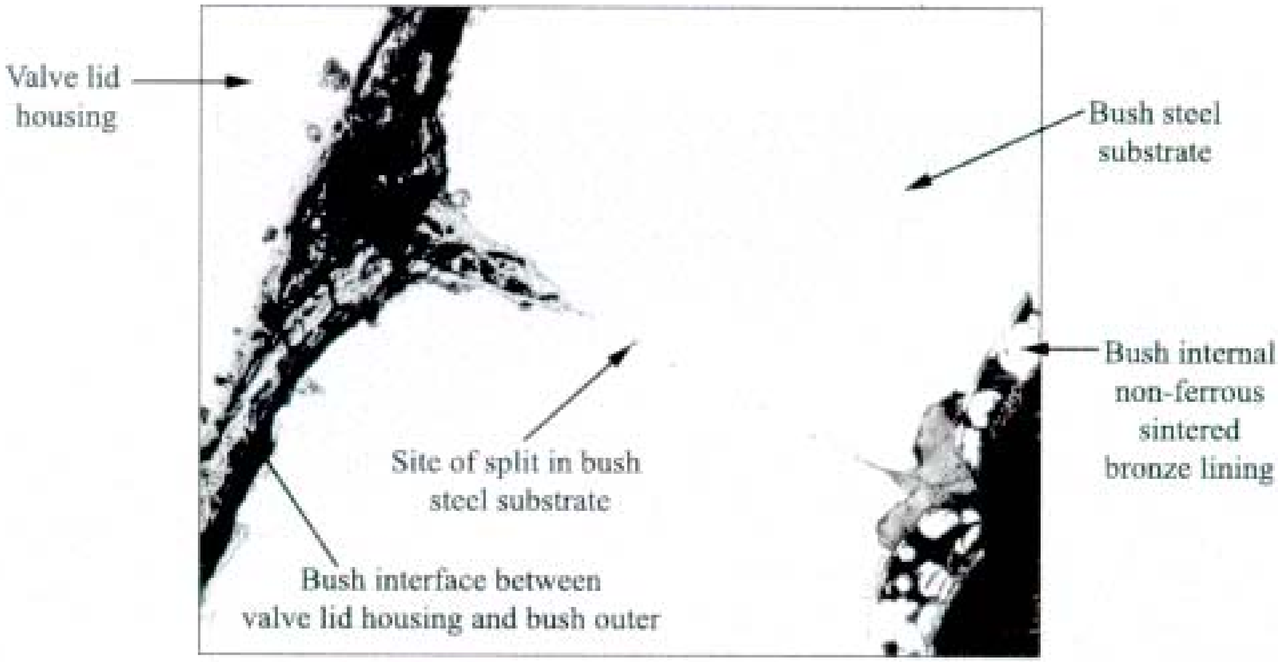



Figure 33 - Micrograph x50, unetched. Forward side spindle guide bush cross section, showing crevice corrosion at the split side.

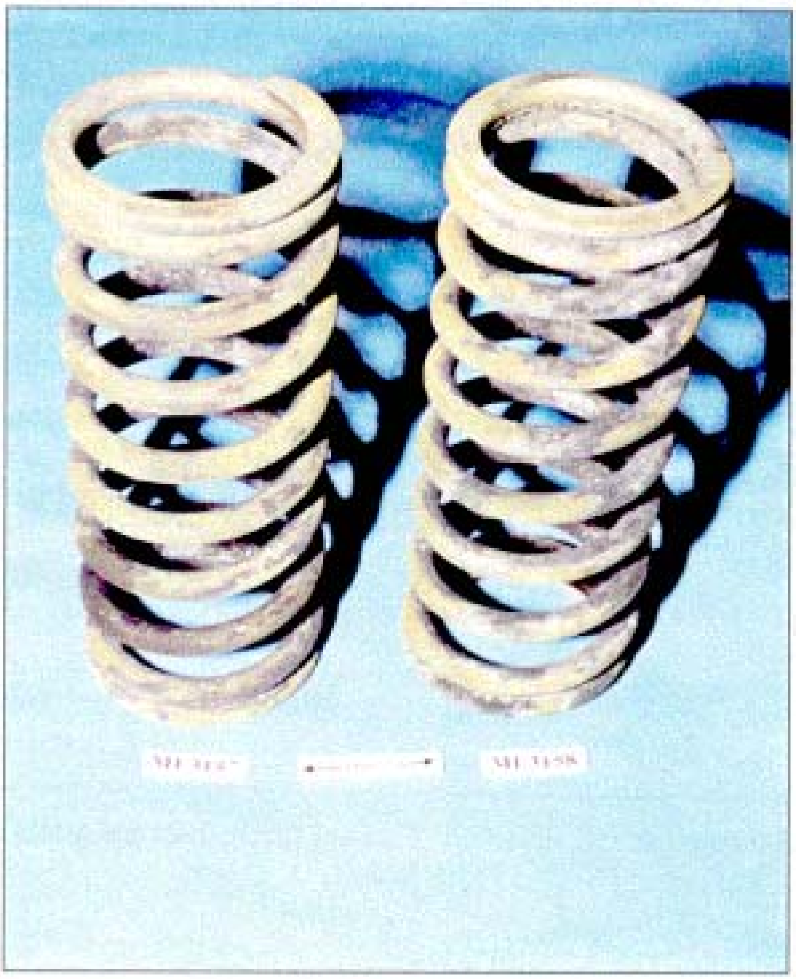


Figure 34 - Valve springs, aft side shown right and forward side shown left

All parts examined were confirmed to be of the correct NordAmatur specified material type, and appeared to be either of original supply or the product of well executed reverse engineering. The aft side spindle was confirmed to be bent while its bottom end cap retaining thread was damaged to a point of functional failure. Evidence of hammer type marks at the bottom of both spindles suggested that each had suffered earlier severe seizure while the forward side guide bush lining was badly damaged, having broken into small pieces.

Valve springs did not appear to have been changed at the time of the boiler system pressure uprating. Despite this, indirect evidence suggested that the valve had still been set to lift at, or close to, the correct pressure of 9bar.

Evidence of boiler water sludge deposits at the valve seats and steam/water passing marks at both valve lid undersides indicate they had been leaking before the incident. The poor internal condition of the valve body, and the severe pitting corrosion of lid undersides, could also have been consistent with earlier discharging of poor quality boiler water into the valve chamber.

In determining why the safety valve had seized, a number of factors appeared significant:

- Apparent leakage of the valve for a period of time preceding the incident.
- Apparent slip of both feed and boiler water chemistry control.
- Corrosion resistance of the spindle steel.

The safety valve's condition preceding the incident was such that leakage of steam/water mixture had occurred through both seats. Due to loss of water chemistry control, the leaked steam/water product had contained a high total dissolved solids (TDS) and insoluble sludge content. Having gained access to the crevice formed at the spindle to guide bush interface, the boiler water contents appear to have left a deposit, and participated in corrosion of the spindle.

Under normal operational conditions of dry clean steam at elevated temperature it would have been expected that a13% chromium steel to have remained passive and corrosion free. In discharges of steam/water mixtures containing high TDS and insoluble sludge and chlorine, the same corrosion resistance could not necessarily be assured. Presence of a crevice effect at the spindle to guide bush interface and the spindles galvanically coupled by contact with a potentially more noble bush lining, may well have further contributed to loss of passivity and consequent corrosion.

## 1.6 ORGANISATIONS, OTHER THAN THE OPERATOR, RESPONSIBLE FOR THE SURVEY OF THE ECONOMISERS

### 1.6.1 The Maritime and Coastguard Agency (MCA) - the flag state administration

The primary purpose of the MCA is to develop, promote and enforce high standards of maritime safety and pollution prevention: to minimise loss of life among seafarers and coastal users; and to minimise pollution from ships to the sea and coastline.

The agency issued an annual passenger ship safety certificate to *Island Princess* which indicated that she satisfied international requirements of the Safety of Life at Sea Convention (SOLAS). It also issued the International Safety Management (ISM) Code certificates stating that the management procedures on board *Island Princess* and the owners' management procedures complied with the requirements of the international convention.

Satisfactory survey of the economisers is a condition that must be satisfied before the passenger safety certificate can be issued.

In 1990 a Memorandum of Understanding (MOU) was agreed between the MCA and classification societies to define the extent of delegation for the survey and certification on UK registered vessels. The MCA audits the societies to ensure compliance.

*Island Princess*'s hull and machinery, including the economisers, were surveyed by LRS as a prerequisite for issuing a passenger ship safety certificate.

### 1.6.2 Lloyd's Register of Shipping

Founded in 1760 and reconstituted in 1834, the constitution of LRS is directed to "*secure for the benefit of the community high technical standards of design, manufacture, construction, maintenance and performance, for the purpose of enhancing the safety of life and property both at sea and on land*". As a non-profit distributing organisation, LRS is financially independent, using income from fees to improve technical services. It operates independently of any government or other body.

LRS is one of six major classification societies whose main function is to carry out surveys of ships under construction and at regular intervals thereafter. Like all classification societies, its surveyors carry out periodic surveys of hull and equipment on ships for compliance with the minimum standards set by international conventions and applicable classification rules.

LRS was responsible for surveying the economisers on *Island Princess* in accordance with the applicable LRS rules and regulations.

## 1.7 OPERATIONAL HISTORY OF THE ECONOMISERS AND OIL-FIRED BOILERS

### 1.7.1 The economisers

In 1974, when *Island Princess* changed to UK registry, it was found that the economisers on *Pacific Princess* and *Island Princess* were fitted with the duplex full lift safety valves, type NAF 546315 65/100mm, with a bore size of 31mm.

In a letter to MCA, dated 30 May 1975, together with the documented specification of the valve, P&O Cruises advised consideration of replacing the safety valve. The type specified was the duplex full lift NAF 546348, 65/100mm, bore size 38mm in accordance with NordAmatur's brochure No FK4672(5)E. This was the type of valve fitted to the economiser at the time of the accident.

In January 1979, *Pacific Princess*'s starboard economiser overpressurised. This resulted in barrelling of the shell-plate and rupture of the bottom shell-to-endplate circumferential weld joint through 15% of its length between two support brackets. Nobody was injured. This economiser was replaced by a water tube type exhaust gas heater. The remaining port shell-type economiser was kept in service.

The *Pacific Princess* accident in1979 was very similar to that of *Island Princess*. The rupture occurred one hour after the ship had left port. Like *Island Princess* the economiser had been shut down for repair in harbour. It too contained water and once the engines were running the exhaust gasses began to heat up the contents. As steam pressure built up, it could not vent to atmosphere because the safety valves had seized in the closed position.

Following that accident, economisers were examined on other Princess Cruises' passenger ships, including *Island Princess*. Barrelling of the shell-plate was found on two out of the four shell-type economisers installed in *Sun Princess*. No barrelling was found in *Island Princess*'s economisers.

P&O Cruises concluded that these incidents were caused by overpressure due to the seizure of the safety valves. Their spindles had seized due to a combination of fine clearances between the spindle and its guide, and scale deposits accumulating from steam and water leakage past the valve lid.

P&O Cruises proposed to fit modified Hopkinson safety valves to *Pacific Princess*, *Island Princess* and *Sun Princess* economisers. They asked for the valves to be set at 5% above the lifting pressure of the oil-fired boilers, and proposed that the valves be opened annually for overhaul, and set in a workshop ashore with an MCA surveyor in attendance. MCA noted this proposal. The valves would be sealed and refitted without further testing. This procedure became the normal practice in the 1980s.

In 1980, the MCA surveyor reported to his headquarters that, although the safety valves on *Sun Princess* had been replaced by Hopkinson safety valves, little could be gained by changing the NordAmatur safety valves on the *Pacific Princess* and *Island Princess* economisers.

During the annual passenger ship safety certificate survey in October 1988, *Island Princess* economiser safety valves were surveyed by an MCA surveyor. He reported to Princess Cruises that the valve spindles had seized in their guides. He advised that they were prone to seizure and leakage after being in service for a relatively short period. He recommended that the port and starboard economiser safety valves should be replaced as soon as new ones were available. There is nothing on record to indicate the MCA followed up its surveyor's concerns.

In 1994 external cracks appeared along the shell-to-top-endplate circumferential weld joint of *Pacific Princess*'s port economiser and were found to penetrate full shell thickness. They were veed out and welded to LRS and the MCA requirements.

Non-destructive testing (NDT) identified an almost identical crack in 1995 in *Island Princess*. Her port economiser leaked steam through a 700mm external crack along the top circumferential weld joint. With the agreement of the MCA and LRS, a similar repair was carried out.

The repairs were tested ultrasonically and considered to be permanent. However, LRS required them to be inspected annually using NDT. Following established procedure, the extent of the NDT was left to the LRS surveyor who confined the examination to the weld repair area.

### 1.7.2 Port oil-fired boiler

During 1996, the port boiler on board *Island Princess* leaked water through cracks in the lower tube plate and tubes. The technical department concluded that the cracks had been caused by overheating in the areas of sludge deposits by the lower tube plate and where the tubes entered the plate. As a temporary measure the cracks were veed out and welded.

At the time of the accident on 7 December 1997, the tubes and lower tube plate were being replaced by the four TEI workmen.

Princess Cruises reported that on *Island Princess* sludge build-up on the lower tube plate was a persistent problem in both boilers. They found that, because of the position of the blowdown valve, it was not possible to remove the sludge completely. An extra blowdown valve has now been fitted to the starboard and port oil-fired boilers.

### 1.7.3 Starboard oil-fired boiler

When the ship arrived in dry-dock, only the starboard boiler supplied steam; the port boiler was being repaired. On 5 December 1997 and two days before the accident, the starboard boiler's furnace overheated, bulged and ruptured. There were no injuries. The boiler water level had fallen below the level of the oil fire trip level. Excessive sludge in the low level float chamber prevented the control air signal from operating the trip.

### 1.7.4 Boiler feed water treatment

Until 1995 the feed water treatment company, Nalfleet, supplied the boiler feed water chemical treatment system for *Island Princess*. In 1995, Drew Ameroid took over and supplied Princess Cruises' entire fleet. In 1997 the contractor was changed to Unitor.

Over the three-year period preceding the economiser rupture in 1997, several boiler water treatment problems were experienced on board *Island Princess*. These were:

| | | |
|---|---|---|
| 1995 | - | changeover to individual product programme |
| | - | high conductivity levels |
| | - | periods of low hydrazine residuals noted |
| 1996 | - | make-up quality concerns, use of shore water |
| | - | low phosphate levels |
| | - | high conductivity |
| | - | sea water contamination |
| | - | dosing problems |
| 1997 | - | make-up quality concerns |
| | - | low phosphate |
| | - | low feed water temperatures noted |
| | - | low hydrazine residuals. |

## 1.8 RECOGNITION OF CRACKING ON CIRCUMFERENTIAL WELDED JOINTS OF BOILERS

### 1.8.1 Guidelines for the examination of boiler shell-to-endplate and furnace-to-endplate weld joints

Since the early 1970s, boiler inspection organisations have been aware that most cracks emanate from the toe of the internal fillet weld at the junctions of the endplate-to-shell and endplate-to-furnace tube. Pressurised hot water shell boilers, including exhaust gas economisers as well as fired steam boilers, suffer from cracking. Such cracks develop because of high fluctuating stress levels at these junctions.

Since 1990, LRS has been present at meetings with the Health and Safety Executive (HSE), and shore-side boiler insurance agencies such as British Engine (now Royal and SunAlliance) and Eagle Star. These meetings had identified circumferential cracking in boilers to be a serious problem.

Since 1993, inspection organisations ashore have noted a marked increase in the number of shell boilers exhibiting circumferential weld joint cracking. Records show that over 10% of boilers tested in 1995 exhibited cracks at the furnace-endplate welds, and 2.5% of boilers had cracks at the shell-to-endplate welds: a three-fold increase since 1992/93. Some of the increase might have been attributable to inspection organisations taking greater care when testing of boilers. However, increasing age of the boiler plant, changes in operational practices, and demand for higher output from smaller boilers, contributed to this increase.

As a result of these findings the Associated Offices of Technical Committee (AOTC), which represented the insurance agencies, produced guidelines for the examination and repair of boiler shell-to-endplate and furnace-to-endplate weld joints, and placed them in the public domain.

In 1997, a revised version of these guidelines was published by the Safety Assessment Association, SAFed, in consultation with HSE and the insurance agencies.[1]

## 1.9 OTHER FATAL ACCIDENTS DUE TO RUPTURE OF SHELL-TYPE ECONOMISERS

In 1987, an MCA surveyor investigated a rupture of an all welded shell-type Aalborg economiser on a Cayman Island oil tankership, *Garth*, classed with DNV. Corrosion fatigue cracking of the circumferential joint was a contributing factor in the accident. Evidence indicated that the economiser might have exploded below the working pressure of 10.5bar.

A massive amount of damage occurred to the engine room casing and surrounding accommodation. Three people were killed and eight were injured.

As a result of this incident and a number of other shell-type oil-fired boiler explosions, the MCA published Merchant Shipping Notice No 1405 in 1990 titled "*Auxiliary boilers on board United Kingdom ships*". The notice emphasised the need for good quality feed water and the use of crack detection procedures where cracks were suspected. Owners were to advise the MCA or the classification society of any cracking found, and of proposed repairs. The notice did not state the extent of testing, or what type of repair ought to be considered.

The Salvage Association has advised the MAIB of an explosion of an AQ7 economiser, classed by American Bureau of Shipping (ABS). The explosion killed 2 people and injured 12 others in 1993. A steam leak had occurred on the inlet flange of the economiser safety valve. The type of safety valve was not reported. To repair the leak the economiser was emptied and isolated. The violent explosion which followed resulted in extensive damage to the engine room, the engine room casing, and the steel bulkheads. The entire living quarters on the poop and boat decks were affected.

The cause of the explosion was two-fold: the economiser was not completely drained because the blowdown valve might have been blocked by large pieces of boiler water scale. The safety valves had seized in the closed position. Separation of the safety valve spindle from its guide was possible only by using a large hammer. ABS, the classification society of the vessel, reported that the boiler and safety valves had been surveyed within the prescribed period.

## 1.10 THE CONTRACTORS ON *ISLAND PRINCESS*

The contractors were craftsmen assigned to general maintenance and repair of machinery and refurbishment of parts of the ship, including hotel and service spaces.

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1 SAFed Guidelines, Shell Boilers ISBN1 90121205x

Among those on board were 12 contractors from TEI, manufacturers of economisers and package boilers. The company installed and maintained oil-fired boilers and economisers ashore and on board ships. Mr Pickard and Mr Clayton worked for TEI.

Mr Pickard had worked for TEI and its preceding companies since 1981 as a coded welder of boilers in major power stations and ships.

Mr Clayton had worked for the company since 1976 as a fitter on ship and shore-side boiler plants.

## 1.11 MANNING AND QUALIFICATIONS OF ENGINEER OFFICERS

Engine room manning, and the qualifications of engineer officers on board *Island Princess*, exceeded international safe manning agreements and requirements of the STCW Convention.

The staff of engineer officers comprised the chief engineer, first engineer, second engineer, four third engineers and three fourth engineer officers.

The chief engineer, a member of the shipboard management team, was in charge of safe operational management and maintenance of the propulsion and auxiliary systems, and engineering service systems of the ship. He held a Combined Class 1 Certificate of Competency (ie for both steam and motor vessels).

The first engineer was in charge of all engineering maintenance and services outside machinery spaces, except for refrigeration and air conditioning. He was the deputy safety officer, with particular responsibility to both engine room and deck technical safety standards. He was the chief engineer's deputy.

The second engineer was in charge of machinery space maintenance, and the supply and organisation of spare parts. Both first and second engineers held Class 1 Combined Certificates of Competency.

The daywork third engineer officer held a Class 1 Motor Certificate of Competency, and was assigned to assist the second engineer officer.

Three engineering sea watches were each manned by one rating and two officers; a third and fourth engineer.

## 1.12 INTERNATIONAL SAFETY MANAGEMENT (ISM) CODE

At the time of the accident, Princess Cruises served as the sales, marketing and technical agent for the operation of eight passenger ships.

Prior to 1993/94 operational control of the company had been conducted from its headquarters in Southampton. It was then moved to Los Angeles, and several senior operational management changes were made, with the appointment of a new Vice-

President Technical, and a new senior Vice President Operational Management. Coincident with this period of change were several retirements and replacements of senior technical superintendents.

Since these changes, Princess Cruises have implemented the International Safety Management (ISM) Code. It provides an international standard for safe management and operation of ships and for pollution prevention. It addresses the need for commitment to safety management to come from the highest level of an organisation, and for the implementation of a safety management system (SMS).

The SMS is described in Princess Cruises' fleet regulations. These define and document the tasks and activities related to safety and environmental protection, both ashore and on board. The company's policy is to protect safety, health and the environment.

The fleet regulations, prior to being issued and implemented, were put out for review to all ships. Sea staff were asked to send in information for possible inclusion. Since the regulations came into force ships' staffs were, and still are, encouraged to send in suggestions.

The ISM Code became mandatory on passenger ships, tankers of all types, and bulk carriers in July 1998. It has two certificates: a document of compliance certificate (DOC) issued to the company and copied to each ship, and a safety management certificate (SMC), relevant to each ship. P&O/Princess Cruises elected to comply with the ISM Code in advance of its mandatory compliance date.

The DOC and the SMC are quality assurance certificates to indicate that a company has complied with the code, and that a safety management system exists.

The objectives of a company safety management system are defined in section 1.2.2 of the ISM Code to:

*1.* *provide for safe practices in ship operation and safe working environment;*

*2.* *establish safeguards against all identified risks; and*

*3.* *continuously improve safety management skills of personnel ashore and on board ships, including preparing for emergencies related both to safety and environmental protection.*

The DOC was issued to Princess Cruises in July 1995 after an MCA audit team interviewed senior management at its Los Angeles headquarters. The DOC was endorsed in September 1997 after another visit by the team.

Following an MCA audit of *Island Princess* in July 1996, an SMC was issued to the ship.

Management personnel reporting lines and roles

The fleet regulations indicated evidence of defined levels of authority and lines of communication between, and among, shore and shipboard personnel. For example the chief engineer officer:

*is directly responsible to the captain, with functional responsibility to the vice president technical, Princess Cruises, or the technical manager of P&O Cruises UK. His primary responsibilities must always be for a safe operation of all machinery, safe working practices within his department, and safety of the ship. He is to maintain and operate the main, auxiliary and domestic machinery of the ship to the highest possible standards, and must never fall below the requirements of the Flag State Administration, Classification Society and Company's standards of passenger safety and customer service. He is responsible for the safety, discipline, administration, training and welfare of the engineer officer and ratings.*

The highest position of authority at Princess Cruises was that of chairman, who acted solely in a supervisory capacity. He was not involved in day-to-day management.

The president reported directly to the chairman. The vice president of maritime affairs had, in his capacity as the "designated person" under the ISM Code, the right of direct access to the president at any time. If necessary, the "designated person" could bypass the president and approach the chairman.

The president's primary task was to run Princess Cruises through an executive committee of senior vice presidents. The aim was to ensure that the company's core business of running passenger cruise ships was being achieved. He visited each ship at least once a year and his last visit to *Island Princess* was in August 1997.

Chaired by the president, certain senior vice presidents and other nominated officials sat on the Safety, Health, Environmental and Welfare Committee (SHEW). This committee met formally two or three times a year. It reviewed the company safety management system, which included non-compliance with that system. If the master of a ship was unable to comply with a particular regulation, he could contact the office for authority to proceed without compliance. The request was usually handled by the "designated person". The three aims of this procedure were:

- to ensure that the company was aware as soon as possible of problems faced by its ships in complying with fleet regulations;
- to reduce the temptation for crew members to decide unilaterally to ignore any particular regulation;
- to share with their masters and chief engineers the responsibility for non-compliance and ensure that appropriate corrective action was taken.

The senior vice president fleet services, reported directly to the president. He was specifically responsible for:

- day-to-day operational efficiency of all Princess Cruises' ships;
- ensuring that safety, health and environmental pollution were given prime consideration;
- maintenance and guidance and instructions to the masters, officers and crew of each ship; and
- ensuring that ships were manned safely.

He fulfilled these responsibilities through a team of vice presidents. Once a week they, and the director of fleet safety and training, met with him to discuss operational and safety issues.

He routinely read the following:

- a summarised ship management report on operational and technical matters following every cruise;
- a full management report of a ship every month, which was first marked up by the "designated person" to draw to his attention matters considered important;
- copies of all incident reports;
- copies of the audit reports;
- a weekly technical report setting out all problems and issues of a technical nature on board any Princess ship, written by the vice president, technical affairs.

No reports or references to problems with *Island Princess* had been made.

A risk management committee was chaired by the "designated person" and met every two months. Princess Cruises reported that the committee did not discuss hazards of overpressure of economisers or the likelihood of safety valve seizure.

The technical manager of the Princess Cruise fleet was the vice president, technical services, and he was assisted by superintendents. The superintendent assigned to *Island Princess* was on board the ship at the time of the incident. A second superintendent was on board to help with supervising the dry-dock refit.

The chief engineer reported to the superintendent assigned to his ship. If ship's staff suggested any changes to fleet regulations, the superintendent would discuss this with them and report to head office. The ship's staff could also send in their recommendations directly to the "designated person" on a formalised non-conformance form. In the superintendent's absence, or when there was a major technical issue, the chief reported directly to the vice president technical services, in Los Angeles.

Masters usually kept the senior vice president, fleet services, fully informed of every reportable incident described in the fleet regulations and annual letters of instruction. The latter encompassed anything concerning the safety of ships or people on board.

Masters had direct access by telephone to the senior vice president, fleet services. They communicated at least once during every cruise. Chief engineers could also telephone him, but normally communication was routed through the master, so that he was fully aware of the issue the chief engineer wished to raise.

There were no existing or current SMC non-conformance notes for *Island Princess* on 7 December 1997. Before then, Princess had issued seven minor non-conformance notes, against which corrective action was taken. None of these referred to boilers or economisers.

Procedures and instructions

The ISM Code requires that management procedures ensure that conditions, activities and tasks, are planned, organised, executed and checked, in accordance with legislative and company requirements.

In support of this requirement *Island Princess* had, for example, an "equipment history report", which indicated details of progress of the planned maintenance and inspection regime. The report recorded dates of inspection of equipment, inspection findings, work undertaken and parts replaced. The following are three such reports:

- *The port economiser was last surveyed internally and externally in June 1997;*
- *The port economiser safety valves were surveyed and set at 9.1bar and tested in June 1997;*
- *On 19 July 1997 a new air register was fitted to the port oil-fired boiler due to excessive carbon build-up on the main flame tube due to damaged and jammed vanes on the old register.*

It was not recorded in the "equipment history report" to show that in August 1997 the port economiser safety valve leaked, that the valve cover and lid were removed, or that the seized valve spindle and guide were freed.

Instead the work was recorded in the 2nd engineer's workbook and reported to the chief engineer.

A "work procedures index report" details inspection requirements and survey intervals. For example, the report indicated a monthly test list of boiler safety devices as follows:

1. *test operation of emergency trip on boiler control panel;*
2. *test low level fuel pressure trip by opening the contacts on low FO pressure switch in FO control cabinet;*
3. *test high pressure steam trip set for 7.8bar;*
4. *test high water level in drum alarm by shutting the steam supply valve to the aft float chamber;*
5. *test low water level in drum alarm and trip by isolating each;*
6. *test forced draught fan failure;*
7. *test flame failure trip by removing the flame scanner from its holder.*

These tests were recorded to have been undertaken on the starboard oil-fired boiler by a senior engineer watchkeeper on 15 November 1997. Twenty days later, within the test period, the low water level trip failed to operate because of excessive sludge build-up in the control mechanism. Consequently, the boiler was damaged.

Princess Cruises reported that the problems experienced with the starboard boiler were attributable to excessively hard water bunkered in Naples which in turn resulted in excessive sludge.

The "work procedures index report" details procedures to clean the boilers, which include removal of sludge and scale from the waterside. The cleaning was completed every three months and was on schedule.

The boilers were blown-down regularly.

Fleet regulations available on board stated that:

*"Accidents have frequently occurred through failure to observe the obvious precautions. As serious injury or death may result, officers must endeavour to foresee the potential risks, particularly those which others do not readily appreciate, and ensure that precautions are taken. Officers must always be alert to notice possible new sources of danger on board and where fresh precautions can profitably be taken these are to be reported to the management."* (Fleet Regulations SAF 1.1 Precautions against accidents 010194).

From the captain's standard format for navigation from Captain's Standing Orders:

*"All officers are encouraged to air their views or advise me on any subject, especially navigation. If you consider my subsequent actions questionable, it is your duty to say so at once. It is my responsibility to either accept or reject your advice."*

A fleet regulation relating to technical standing orders advises that:

*If in any doubt or unsure of anything at all pertaining to the running of the Technical Department generally,* ***PERSONNEL MUST NOT HESITATE TO ASK****.*

The captain's standing orders encourage officers to question the decisions of the captain. The technical standing order expresses clearly the need for officers to ask questions about the running of the technical department. However, the technical department does not have an equivalent standing order which explicitly encourages officers to question the decisions of the chief engineer on matters of operation of the plant.

<u>Internal audit</u>

In addition to the MCA audit of a vessel of the ISM Code of Safety Management Certificate two other audits take place. The first audit is a group audit, conducted by the Director of Safety Audit, based in London. The most recent audit of this kind was conducted on *Island Princess* in September 1995.

The other type of audit is the internal company audit, conducted by Princess Cruises, organised by the "designated person". The last such audit before the accident, had been conducted in *Island Princess* between 25 April and 7 May 1997. It was reported that the starboard oil-fired boiler was not to be used. Corrective action was the responsibility of the Vice President, Technical Services. The boiler was back in service on 8 July 1997. These audit procedures have been in place for some years and the President reads the summaries of the reports.

During August 1997 the President and Senior Vice President, Fleet Services had visited the ship, but not as part of an internal audit. It was a senior management visit and included an inspection of the engine room. No-one drew their attention to any particular defect, issue or problem.

Application of the ISM Code to safety valves and economisers

As discussed in previous paragraphs, shipboard operation and administration were guided by fleet regulations introduced in 1994. The regulations were partly based on fleet letters.

As a result of the economiser and safety valve failures on *Sun Princess* and *Pacific Princess* in 1979, one such letter referred to Princess Cruise instruction to engineers on how to isolate the economiser. These instructions were:

- *engine or engines associated with the economiser should be shut down;*
- *economiser should be isolated and drained;*
- *air cock should be opened to prove that pressure is off the economiser;*
- *manhole doors/doors to be removed;*
- *engines may then be restarted and repairs carried out to the economiser.*

*All engine room staff should be made aware that circulation of economisers should be maintained at all times when boilers are operating and that when exhaust gases are to be passed through the economiser it should be either:*

- *filled with feed water and circulating; or*
- *empty with manhole doors removed.*

Attached to a second fleet letter were the manufacturer's operation and maintenance instructions. These instructions referred to:

- *start up, cleaning and shutting down procedures;*
- *the removal of air pockets, and the opening of vent valves at regular intervals when the economiser had been out of service for some time;*
- *testing of safety valves at regular intervals;* and
- *blowing-down every four hours.*

The requirement to blow down every four hours is considered excessive. Compared with the oil-fired boilers, the economisers operate full of water so steam separation does not take place. Precipitation of sludge and hardness salts (if present) in economisers is less of a problem. Furthermore, blowdown and water treatment via the oil-fired boiler will achieve the same result in respect of the economiser.

Princess Cruises did not blowdown the economisers regularly.

The instructions also advised that when an economiser was shut down, it was safe to pass the full volume of exhaust gas through them if all the following points were satisfied:

- *the gas temperature does not exceed 400°C;*
- *the economiser is emptied completely;*
- *manhole covers and mud doors are removed and mud is drained off.*

The only reference to economisers in the fleet regulations was the procedure to be followed when dumping water from economisers in an emergency.

The procedure was stated as follows:

- *inform bridge that the safety valve will be lifted;*
- *stop affected economiser's circulating pump;*
- *shut the economiser inlet;*
- *open economiser blowdown line to overboard, check that it is clear (pipe gets hot);*
- *jack open safety valves using easing gear;*
- *close economiser outlet valve;*
- *close economiser circulating pump suction and discharge valves;*
- *log the status of all the valves changed from normal in the main log/hand book;*
- *when pressure inside economiser is at atmospheric pressure, open blowdown to boiler feed water tank and close overboard;*
- *blowdown valves and safety valves must remain open whilst the economiser is empty and there is exhaust gas passing through.*

None of the instructions above were followed in preparation for the sea trials of *Island Princess* on 7 December 1997. Instead, water was left in the economisers with the intention of venting through jacked-open safety valves.

At section 10 of the ISM Code, maintenance of the ship and equipment requires that defects of safety equipment and technical systems, and possible causes, if known, should be reported to management. The safety management system should have procedures to identify equipment and technical systems, failure of which would create a hazardous situation. The safety management system should provide specific measures aimed at promoting the reliability of such equipment or system.

Princess Cruises reported that during preparation of the regulations in 1994 ships were asked to submit any special procedures or operating instructions to the company. The ships did not submit any of the 1979 fleet letters relating to the economiser and safety valve incidents. It may never be known why senior officers from *Island Princess* and *Pacific Princess* did not do this. The *Sun Princess* was sold by 1994.

During his first visit to the vessel after the accident, the inspector asked what instructions were on board to advise how the economiser should be shut down in anticipation of the propulsion plant operation. The engineers referred him to the fleet regulations concerning emergency dumping of water from the economisers. They made no reference to the fleet letters.

Princess Cruises have stated that at the time of the accident this correspondence was held on relevant engineering circular files, and that there was no restriction to prevent engineering officers having access to it.

Princess Cruises today take the view that it is not possible to frame regulations to cover every single operation required in the engine room. They contend that the operation of economisers and auxiliary boilers, mountings and other safety features are covered in the syllabus for certificates of competency in both written and oral examinations.

This was not the total view taken by Princess Cruises in 1979. At that time, they made sure that engineers were aware of the correct procedures to prevent economiser overpressure.

However, the accident in 1997 happened on board *Island Princess* despite the owners' awareness of the problem, nearly 20 years earlier.

Unlike in 1979, the safety management system in place in 1997 did not encourage the awareness of engineers to follow correct procedures. It did not encourage feedback to management of information on crucial defects with the safety valves. Management were not well placed to assess the risk of possible seizure of safety valves and economiser overpressure.

<u>Reporting of incidents</u>

If a life-threatening incident occurred on board, fleet regulations required that a preliminary enquiry should take place. The investigating vice president was required to report direct to the senior vice president, fleet services, who then passed a copy of the report to the president. A decision was then taken to investigate further disciplinary issues and possible changes to fleet regulations. Until this accident, no problems or issues with economisers had been brought to the attention of the president.

Following the accident on 7 December 1997, the technical department wanted to amend the fleet regulations for the emergency dumping of the economiser. A system of consultation was used, to ensure that new orders were properly controlled and considered.

Following company procedures, a draft of the revised regulation was submitted to the "designated person". He then amended the wording to the required format, before returning it to the vice president, technical services with an authorisation form for his signature. The "designated person" then endorsed the final draft as a new regulation before it was issued to the fleet.

The new regulation reads:

- *When an uptake economiser is to be used dry, the economiser has to be drained and it is to be ascertained that it is properly drained before any diesel engines associated with the dry economiser are started;*
- *check the instruction book for any special restrictions regarding the dry operation of the economiser;*
- *the economiser circulating pump is to be stopped and the economiser isolated and drained;*
- *the economiser drain valves and air vent valves are to be opened;*
- *when the economiser is empty one manhole cover is to be knocked in. In those cases where a manhole cover is not fitted the safety valve is to be removed completely;*
- *when it has been ascertained that the economiser is empty the diesel engines can be operated.*

<u>Information on board relating to maintenance of economiser safety valves</u>

With reference to the economiser safety valves NordAmatur's general instruction for the installation, maintenance and adjustment of safety valves and relief valves, (bulletin Fi 46.01AE), dated December 1968 was held on board. There was also a drawing of the NAF 546348 safety valve, number 322 32/39. The drawing showed a cross-section and a side view of the valve identifying its main components. Neither document listed spare part requirements.

The instructions provided information on correct installation which were directed mainly to shipbuilders and boiler installers. One section discussed the setting of the blow-down ring, a device not fitted to the NAF 546348 safety valve. The sections on maintenance and set pressure adjustment of safety valves were of principal interest to engineers.

Because the spring range permits a limited adjustment of set pressure, the instructions stated that NordAmatur should be requested to advise on the possible need for spring replacement.

With regard to maintenance, the instructions advised that to obtain tightness between valve lid and seat, the two must be ground separately using lapping tools. The instructions warned against grinding the valve lid and seat together.

The instructions advised that separate instructions were issued for dismantling each type of valves.

Inspector's visit to the safety valve manufacturer's works

A detailed review of the premises and quality control system of NordAmatur (the safety valve manufacturer) indicated that:

- safety valve instructions for repair and maintenance and for ordering of spare parts were issued to the customer;
- safety valve components were readily available to the customer;
- safety valve service facilities were monitored by the Swedish inspection authorities and classification societies;
- new and renovated safety valves were set at lifting pressure and officially sealed before they left the factory;
- randomly selected safety valve spindles, springs, and spindle guides, were found to be within manufacturer's tolerances.

The inspector was shown a document entitled NAF Spring-Loaded Safety Valves; maintenance and installation instructions and spare parts list (Fi46.721(2) v AGB. The instructions were dated November 1992 replacing instructions dated April 1971. The instructions advised installation, maintenance, and overhaul of the type of safety valves fitted to *Island Princess* economisers.

The section on maintenance stated that:

- *the safety valves should be inspected at regular intervals to check that they operate satisfactorily;*
- *if the valve fails to operate despite repeated attempts, contact NordAmatur;*
- *if major changes to the set pressure were required, a different spring was necessary. In such cases NordAmatur should be consulted;*
- *if the seating surfaces are damaged, lap the lid against a flat cast iron ring*
- *lap the valve seat using a suitable lapping mandrill;*
- *never lap the seating surfaces of the lid and seat against one another.*

The instruction contained an illustrated spare parts list and stated that every NordAmatur safety valve is fitted with an identification plate with the following particulars:

- *NordAmatur (NAF) number;*
- *DN/PN numbers;*
- *set pressure;*
- *spring range; and*
- *serial number.*

However, the identification plates of the economiser safety valves on *Island Princess* were found to be covered in paint and impossible to read.

When placing orders for spare parts on the basis of the illustrated list, the information found on the identification plate had to be stated. When ordering springs, the set pressure had to be specified. The design pressure of the economiser had been increased from 8.5 to 9.0bar in 1989 with LRS classification approval. The lifting pressure setting of the safety valves had been raised from 8.5 to 9.0bar.

The springs found on the port economiser safety valves matched those indicated on the identification plate: a spring range of 6.4 to 8.6bar. With a new set pressure of 9.0bar, the spring was out of range. NordAmatur springs with a specified range of 8.0 to 11.6bar were available to cover the new set pressure.

Reporting of deficiencies

LRS rules, the SOLAS Convention and the ISM Code require that defects affecting the safety of the ship are reported.

Since *Island Princess* changed to United Kingdom registry, LRS had surveyed all hull and machinery items for classification purposes.

For the purpose of issuing a passenger safety certificate in April 1980 the MCA granted approval for LRS to conduct 50% hull and machinery work. The MCA continued to survey boilers and mountings. As reported in section 1.7, Princess Cruises and the MCA had agreed the latter would survey the economiser safety valves annually because of previous seizures. The machinery and hull items delegated to LRS were surveyed every two years. Since then, the survey frequency has been changed to every 2½ years.

In September 1996, the MCA formally delegated 100% hull and machinery survey items to LRS for MCA's purpose of issuing passenger ship safety certificates. This included responsibility for surveying boilers and economisers. In March 1997, LRS conducted a survey on *Island Princess* under the terms of this delegation. The economisers and safety valves were last surveyed by LRS in June 1997.

There seems to be no record showing when, and why, Princess Cruises stopped overhauling and testing the economiser safety valves annually in a workshop ashore with an MCA surveyor in attendance **(section 1.7.1)**. Present MCA and Princess Cruises management report that they were unaware of such an arrangement.

The 1971 LRS rules applied to *Island Princess*.

These rules required that the economiser safety valves be set under steam to a pressure not greater than 3% above the design pressure of the economiser. In June 1997, the pressure on the economiser safety valves was set within range, at 9.1bar.

The protective cap and seal arrangement on the safety valve satisfied paragraph J606 of the LRS 1971 classification rules. The rules state in part that:

*the valves, spindles springs and compression screws are to be so encased and locked or sealed, that safety valves and pilot valves, after setting to the working pressure, cannot be tampered with or overloaded in service.*

The safety valve spring-load adjusting screw had provision for a tamper-proof lead type seal, and a metal cover to protect the valve spring and spindle. However, these were missing on *Island Princess*'s economiser safety valves when examined immediately after the accident.

Where the safety valves are set at sea it is the responsibility of the chief engineer to fit the seal and protective cap. Princess Cruises considered that although the LRS Rules require seals and a cover to be fitted, they need not be enforced. It is in the company's interest that they are enforced. Once the safety valves are set, the seals act as a guard against unauthorised adjustment of the spring.

Paint found on the springs indicated that the covers had not been fitted for some time. The port economiser safety valves had seized because of deposit from the boiler water and corrosion. The safety valves had hard deposits on the outside of the valve body. This was possibly due to past steam and water leakage, and gas leakage associated with boiler spaces. The covers are a mandatory and necessary requirement to avoid possible damage to the valves from external environmental deposits. These deposits can contribute to valve spindle seizure.

Resolution 11, chapter 1 of SOLAS requires that:

*Whenever a defect is discovered which affects the safety of the ship, the master or owner should report at the earliest opportunity to the administration, or the nominated surveyor or recognised organisation responsible for issuing the relevant certificate, who shall cause investigation to be initiated to determine whether a survey is required.*

The LRS Classification regulations part 1, chapter 2, section 1, rule 1.1.5 stated that:

*Any damage, defect, breakdown or grounding, which could invalidate the condition for which a Class has been assigned, is to be reported to LR.*

In June 1997, the port economiser safety valves were dismantled and cleaned by ship's engineers, surveyed by the LRS, and reassembled by the engineers. When at sea with economisers steaming, the chief engineer had set and tested the valves to lift at 9.1bar using a calibrated pressure gauge. In accordance with classification society and the MCA requirements, he reported the date of adjustment, pressure setting, his name and rank to LRS.

In August 1997, the engineers discovered that the aft safety valve of the port economiser was leaking steam. They shut the economiser down and drained it, lifted the valve cover from its body and detached the easing gear. There was no spring compression on the aft valve as the engineers started to slacken back the nuts on the valve cover. The valve cover was removed to the engine room workshop. The valve spindle had seized in its guide sleeve with the valve open. To remove the spindle it had to be tapped out. Once the spindle and guide bore were cleaned, the spindle was found to be pitted and a fairly loose fit in the guide.

The valve cover was reassembled. When replacing the cover on to the valve body, the cover studs were used to recompress the valve lid on to its seat before reconnecting. They satisfied themselves that the forward and aft port economiser safety valves were free to lift, by opening and shutting the valves using the easing gear; they did not pressure test the valves.

This work was recorded in the second engineer's workbook and reported to the chief engineer. The work and reason for it was not reported to the classification society, the MCA or Princess Cruises shore management. Princess Cruises have stated that this work was routine maintenance and not subjected to mandatory reporting.

The fact that the valve was defective should have been reported to the Classification Society at the earliest opportunity. The lifting pressure should have been checked and the pressure reported.

Section 10 of the ISM Code provides for assurance that safety systems and equipment are maintained in conformity with relevant rules and regulations. A boiler safety valve is considered to be safety equipment. Any non-conformity should be reported, with its possible causes, if known. Appropriate corrective action should be taken, and records of these activities maintained.

## 1.13 EMERGENCY RESPONSE PROCEDURES

*Island Princess*'s medical staff comprised a doctor and two nurses.

Medicines and equipment on board the ship complied with statutory regulations and directives. A Neil Robertson stretcher forms part of this equipment, and was used to carry Mr Pickard.

In the event of a serious medical emergency a procedure existed in *Island Princess* whereby the medical team could be mustered by means of a coded message. This message could only be initiated by one of the medical staff or a duty officer on the bridge.

If, for example, one of the medical team considered that a serious situation existed, he or she would telephone the bridge and request the coded signal be broadcast. The bridge officer would make a tannoy announcement throughout the ship, give the code and state the location of the incident or the patient.

In this particular case, the announcement was repeated twice from the bridge. The same information was then announced through the pager system and repeated twice.

Two designated people from the accommodation department were required to go to the medical centre to collect the equipment and take it to the scene of the emergency. If they found it had already been taken by the medical team they were to go to the scene to assist.

These procedures were followed in response to the emergency in the boiler space.

Action taken by Mr Hippolyte and the daywork third engineer

These two men responded immediately once they realised that a very serious incident had occurred in the boiler space. They entered the space under dangerous, and possibly, life threatening circumstances. Their attempts to rescue Mr John Pickard were courageous, determined and successful.

Mr Hippolyte and the daywork third engineer should be commended for their actions.

Use of Neil Robertson Stretcher

Mr Pickard was moved to the medical centre from 'C' deck cross-alleyway using a Neil Robertson stretcher **(Figure 35)**. The stretcher requires four people to carry it, two on each side. Although awkward to carry through narrow alleyways it did not, from a medical viewpoint, affect the patient's care. Other stretchers, such as the Para-Guard stretcher have shoulder harnesses front and rear which facilitate movement, especially through narrow spaces, winding alleyways and stairs.

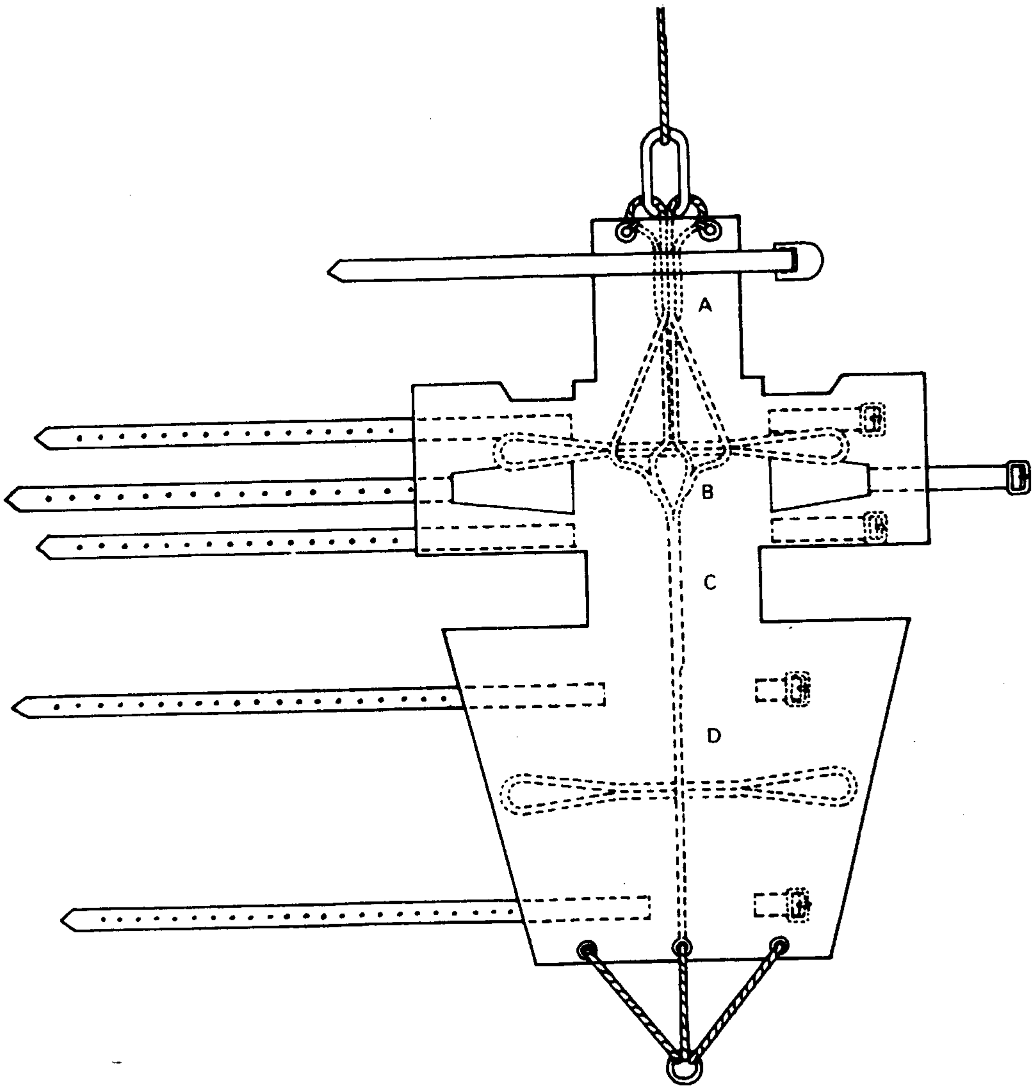
The medical team considered the Neil Robertson stretcher was appropriate in this case. However, they could envisage a situation in which a Para-Guard stretcher would prove even more effective.

This incident raises some doubt about the suitability of a Neil Robertson stretcher for use on board ships, especially in confined spaces. Some paramedic ambulance services ashore use more modern stretchers which may be better suited for ship's use.

Stress Counselling

The provision of a stress counsellor by Princess Cruises, and two British and International Sailors' Society clergymen, was successful. It is generally recognised that major accidents can harm the psychological health of those involved, and can be just as damaging as a physical injury.

The company's rapid provision of stress counselling showed, in a practical way, its acknowledgement and concern for victims of the incident. Stress counselling is worthy of wider consideration by the marine industry in future disasters.




The stretcher is made of stout canvas, stiffened by wooden slats. The portion 'A' takes the head and neck, which are steadied by a canvas strap passing over the forehead. Thus, the head of an unconscious patient can be steadied.

Figure 35 - Neil Robertson Stretcher