TECHNICAL DATA

APPENDIX F

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TECHNICAL DATA

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Item F-1
Re-Entry and Suspension of Hibernia J-34

46° 43' 33.84" N
48° 50' 13.00" W

Submitted by:

R.M. Harvey, P.Eng.
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E.P. Lannon, B.Sc. (Geology)

Canada Oil and Gas Lands Administration
St. John's, Newfoundland
July 15, 1982

INTRODUCTION

This report describes operations undertaken by Mobil Oil Canada Limited and Neddrill to suspend the Mobil et al Hibernia J-34 well following loss of the *Ocean Ranger*. It was prepared by the engineering staff of the St. John's office of the Canada Oil and Gas Lands Administration (COGLA) who witnessed the operation. Their primary duties during the suspension were as follows:

- document condition of the *Ocean Ranger* BOP stack prior to re-entry;
- witness re-connection to the BOP stack and removal of the drill string;
- note location of the hang-off point with respect to the sheared end of the pipe to confirm that the string was hung-off on the proper rams;
- inspect sheared end to ensure proper operation of the shear rams;
- witness measurement of the drill pipe removed from the well to ensure that the drill bit had been pulled back into the casing before the pipe was sheared;
- witness setting of mechanical/cement plugs before removal of the BOP stack;
- ensure that the *Ocean Ranger* wreckage was not disturbed during the suspension operation.

Units used throughout are English, as this was the system used during the re-entry and suspension program.

BACKGROUND

On February 15, 1982 at approximately 0300 hrs. the semisubmersible drilling unit *Ocean Ranger* sank during a storm on the Grand Banks with the loss of all hands. The unit, owned and operated by the Ocean Drilling and Exploration Company Limited (ODECO) and its subsidiary, ODECO of Canada Limited, was under contract to Mobil Oil Canada to drill the Mobil et al Hibernia J-34 well approximately 3 miles WSW of the P-15 discovery well. Drilling had commenced on November 27, 1982 and had progressed to 12169 ft. by 1600 hrs. on February 14, 1982 (all depths relative to the *Ocean Ranger* rotary table (RT) elevation). Total depth for the J-34 well was projected to be 14,000 ft.

During the evening of February 14, 1982 the *Ranger* reported that, due to deteriorating weather conditions and mechanical difficulties, it was forced to disconnect the marine riser and the lower marine riser package (LMRP) from the BOP stack, using the shear rams to cut the drill string. The drill bit was reported to have been lifted off bottom and pulled up into 9⅝ inch diameter casing which had been run to a depth of 12014 ft. Prior to shearing, the drill string was reported to have been hung-off on the middle pipe rams, located 6.5 ft. below the shear rams.

After having cut the drill pipe, enabling removal of the LMRP from the BOP stack, the shear rams were left in a closed position, thereby preventing escape of well fluids should hydrostatically underbalanced formations be exposed in the open hole, although lithology indicated the 155 ft. of open hole to be devoid of oil or gas bearing zones.

Subsequent to the sinking of the *Ocean Ranger* the BOP stack was examined from the vessel *Balder Cabot* using a remote controlled vehicle (RCV) equipped with a video camera. This inspection showed the only visible damage to be a bent guidepost. These guideposts are used to guide the LMRP onto the BOP stack during re-connection operations. In addition, the BOP stack was found to be free from debris, with the exception of one piece of drill pipe resting against it.

On June 1, 1982 COGLA approved the proposal prepared by Mobil for re-entry and suspension of the J-34 well. This was done with the concurrence of the *Ocean Ranger* Royal Commission.

ARRIVAL ON-SITE AND ANCHOR DEPLOYMENT

The drillship, *Neddrill 2*, was contracted by Mobil to carry out the suspension operation. It left St. John's on June 4, 1982 at 0300 hrs., arriving on location 1955 hrs. the same day. Several days prior the *Balder Cabot* had placed a sonic beacon belonging to *Neddrill 2* on the BOP stack using a 1 atmosphere Mantis submersible. The *Cabot* had also at this time set out an anchor pattern for the drillship.

Upon arrival at the wellsite the *Neddrill 2* deployed four anchors. COGLA representative, E.P. Lannon, sailed onboard the vessel from St. John's and witnessed deployment of the anchors. He was relieved by R.M. Harvey at 1730 on June 5, 1982.

In order to improve their holding capacity the anchors were permitted to settle into the seafloor for several hours. A tension of 100 tons was then applied to each. Anchor No. 6 would not hold and had to be run out an additional 1000 ft. on the same heading. The anchors' cables were then slacked off and the vessel held on location using the dynamic positioning system. The anchoring system would be used only to prevent the vessel being pushed over the wreck by wind or wave forces should the electrical system fail, thereby endangering the marine riser or the diving bell if these were lowered at the time.

RE-CONNECTION

At 0020 hrs. on June 6, 1982 the diving bell left the surface with two Can Dive divers in saturation. The first of the divers' tasks was to set sonic beacons for the dynamic positioning (DP) system. This was accomplished by 0230 hrs. At approximately 0300 hrs. the DP system lost the signal from the beacons, apparently due to the divers' bubbles. The vessel switched to its taut wire backup while this problem was rectified. The *Ocean Ranger* beacon was removed from the BOP stack at this time and brought to the surface.

At 0420 hrs. guidelines 2 and 4 were run down and attached to the top of the BOP guideposts. The bent No. 3 guidepost was then cut off and the lower marine riser package jig run down to bottom. The purpose of this jig was to measure the distance from the stack centre to the centre of the control pod receptacle and choke and kill connections to ensure that the LMRP constructed for the project would fit the stack.

At 1200 hrs. the jig was located over the stack and connection attempted. It was discovered, however, that a second guidepost was also bent (No. 4) and the jig would not seat properly. The jig was pulled back up and, as the divers were experiencing some difficulties with their communications gear, they were forced to return to the surface as well so that maintenance could be performed on the bell.

Several attempts were made during the afternoon and evening of June 6 to modify the jig and land it without the aid of divers. These attempts were not successful.

At 0545 hrs., June 7, the divers were sent down to cut post No. 4. This was completed by 0630 hrs. and the jig landed. The feeler gauges were set on the pod receptacle and the choke and kill connections. Examination of the jig's position on the stack showed it to be slightly off centre and tilted, indicating that the two remaining guideposts were also slightly bent and would, therefore, have to be removed.

By 1050 hrs. the jig was recovered. Measurement of the feeler gauges indicated no significant differences between the connection positions on the original LMRP and the new unit.

At 1115 the divers began attaching tags to the hydraulic hoses on the BOP stack to identify the function of each line. This was necessary as modifications may have been made to routing of the hoses from the pods to the various pieces of equipment which may not have been shown on diagrams of the BOP system.

The following lines were tagged both "open" and "close":

- annular preventer
- shear rams
- upper pipe rams
- middle pipe rams
- lower pipe rams
- outer kill
- inner kill
- upper outer choke
- upper inner choke

The lower H4 connector had three lines: primary latch and primary/secondary unlatch.

At 1600 hrs. on June 7 the new LMRP was picked up and positioned in the moonpool as assembly of the marine riser commenced. This assembly was complete at midnight at which time an attempt was made to latch the connector. This effort succeeded at 0030 hrs. on June 8 when additional weight was applied to the LMRP. By 0630 hrs. all of the hydraulic lines were disconnected, function tested and reconnected, confirming proper hose routing.

OPENING OF SHEAR RAMS AND RE-CONNECTION TO DRILL STRING

Following connection of the LMRP to the BOP stack the choke and kill lines were pressure tested successfully to 4500 psi (both lines held this pressure). The choke line was then pressurized to about 550 psi and the valves opened. The pressure dropped indicating that there was no pressure under the shear rams. The kill line was then pressurized up to 500 psi and opened. The pressure dropped to 100 psi. This pressure is attributable to thermal stresses and is not considered significant.

By 0840 on June 8 the well was being circulated through the upper choke, down through the drill string, up the annulus and out the kill line. The pressure on the pumps was 1300 psi, the flow rate was about 50 gallons per minute. Brine at a weight of 9.2 pounds per gallon was pumped down. The returning mud had a weight of 9.1 to 9.2 pounds per gallon.

At 1335 on June 8 the shear rams were opened and the milling tool run to grind off the top of the sheared pipe. Three joints of drill collar and 5 joints of drill pipe were used.

By 1500 hrs. the mill had been turning for about one half hour without progress. It was decided to pull it out of the hole to examine it. When it was brought out it was found to have a piece of drill pipe wedged in its throat together with the top of a hang-off tool.

The crew of the *Ocean Ranger* thus had pulled up, inserted the hang-off tool in the drill string and had run this tool back down to the BOP stack, landing it on the closed middle pipe rams. Before the top of the hang-off tool could be uncoupled, however, the shear rams were closed, cutting the drill string.

Therefore, when the clockwise rotating mill engaged the top of the sheared pipe it had unscrewed the left-handed thread of the hang-off tool, disengaging it from the bottom half of the tool. Further rotation only damaged the threads of the tool. When the mill was removed the top of the sheared pipe was recovered.

A number of attempts were made during the evening of June 8 to re-connect the hang-off tool. These attempts were unsuccessful. At 0630 hrs. on June 9, the drill crew succeeded in re-connecting to the bottom portion of the hang-off tool, using another undamaged hang-off tool top. Tension was then applied, reaching 320,000 pounds (compared with a total string weight of 350,000 pounds) before the connection parted. Examination of the threads of the hang-off tool indicated that it had been only partially engaged.

At 0700 hrs. another attempt was made. Four equally spaced grooves were ground at right angles to the threads of the original hang-off tool. This was then sent down and screwed into the bottom part of the tool. Mobil was concerned that this connection would part a second time and therefore decided to strip the pipe through closed pipe rams, that is, keep one set of rams closed at all times while the pipe was being pulled from the hole. Thus, if the connection parted, the large diameter cylindrical bottom of the hang-off tool would be stopped by the pipe ram, probably causing the string to break just below it. With the hang-off tool then removed from the drill string, retrieval of the drill pipe from the hole would be greatly simplified.

At 1900 hrs. on June 9 tension was applied to the drill string. Rams No. 3 and 4 were both closed. A tension of 370,000 pounds was necessary before the string started to move. At 0100, June 10, the hang-off tool was recovered and removed from the drill string. The combined length of the hang-off tool and sheared pipe was 77¼ in., which is the distance between the middle pipe ram and the shear ram.

After removal of the hang-off tool, the drill string was run down to bottom to determine the depth the *Ocean Ranger* had reached. When this was accomplished, the pipe was removed from the hole, laid down and measured. The measurements are as follows:

NEDDRILL		
5 stands drill pipe	502	
1 single DP		
down on kelly	22	
	524	ft.
ODECO		
115 stands DP	10,664.63	
1 double DP	62.72	
1 pup	21.73	
6 heavyweight DP	182.22	
16 6¾" drill collars	496.18	

1 jar	16.22	
2 6¾" DC	62.33	
1 8½" stabilizer	3.95	
1 6¾" monel DC	29.80	
1 8½" stabilizer	4.08	
1 turbine	57.52	
1 bit	2.00	
	11,603.38	ft.
Total string length	12,127.38	
Difference in elevation *Neddrill/OR*	51.	
Drill string stretch Approx.	4.	
	12,182.	ft.
Ocean Ranger RT to middle pipe rams	328.	
Hang-off tool	8.	
Ocean Ranger drill string	11,603.	
	11,940.	ft.

The casing shoe is located at 12014 ft. Therefore the string was pulled approximately 75 ft. into the casing.

This, together with the presence of the hang-off tool indicates that the well was closed-in in an orderly and proper manner. In addition, examination of the top of the sheared pipe indicates that the shear rams functioned properly in cutting the pipe.

SETTING OF MECHANICAL/CEMENT PLUGS

The first of two bridge plugs was set by Schlumberger wireline at 11826 ft. at 0100 hrs., Friday, June 11/82. This plug was tested to 2500 psi for 5 minutes. At 1000 hrs. a bail or container of cement was sent down on wireline to provide a 15 ft. cement plug on top of the mechanical plug.

At this point R.M. Harvey was relieved by D.C. Strong.

The second plug was set at 1497 ft. at 1200 hrs. and also tested to 2500 psi. A cement slurry was then pumped down through the drill pipe to form a 150 ft. cement plug above the bridge plug. The drill pipe was then pulled up to 1200 ft., reverse circulated to clear any cement from the drill string and then pulled from the hole.

At 1845 hrs. the BOP stack was unlatched and retrieval operations commenced. At 2230 hrs. the BOP stack was out of the water and the tabs on posts, guidelines and the beacon holder were being cut off to facilitate the securing of the stack.

At 0100 hrs., June 12, 1982, installation of the support beams commenced. The skid frame was then assembled around the BOP stack, enabling the marine riser to be disconnected. The stack was then skidded into the T-slot between the two *Neddrill* BOP stacks for the trip back to St. John's.

At 0700 hrs. the corrosion cap was run down to the wellhead on drillpipe. The cap was landed at 0730 hrs. and the drillpipe disconnected.

At 0800 hrs. anchor handling commenced. The vessels *Boltentor* and *Nordertor* first retrieved anchors 6 and 7 which lay on either side of the *Ocean Ranger* wreckage, keeping tension on the anchor lines by pulling ahead as the lines were being reeled in on the windlasses. There was no visible indication that the *Ocean Ranger* wreckage was disturbed during this operation. The anchors on the starboard side were then retrieved. Examination of cables 6 and 7 showed some individual strand breakage.

By 1430 all the anchors were retrieved, the hydrophones retracted and the tautline pulled in. The vessel then departed for St. John's. On the way back to port, the stands of *Ocean Ranger* drill pipe were picked up, broken out and laid down.

The vessel arrived in St. John's at 0800 hrs., June 13, 1982. Mobil Oil was requested to store the sheared pipe and hang-off tool securely pending a decision from the *Ocean Ranger* Royal Commission regarding its disposition.

At no time did the *Ocean Ranger* wreckage appear to have been disturbed during this operation.

Robert M. Harvey
Derek C. Strong
Edward P. Lannon

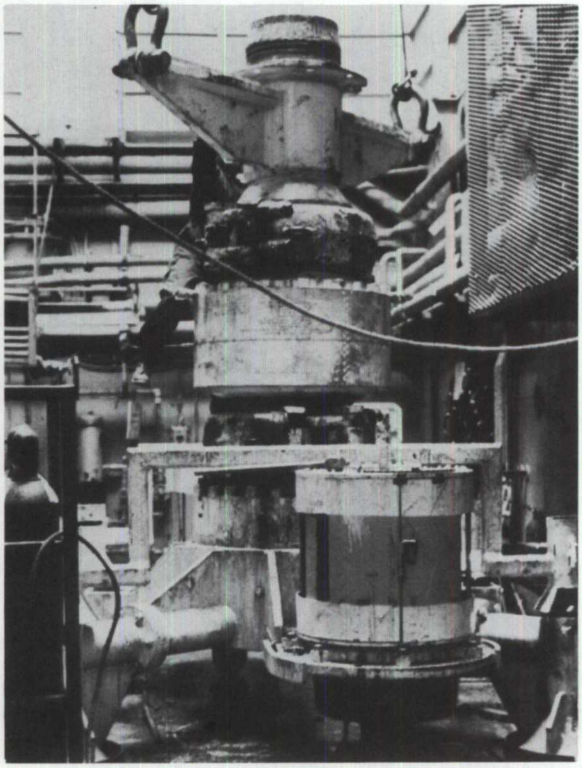


FIGURE 1 *Ocean Ranger* Lower Marine Riser Package

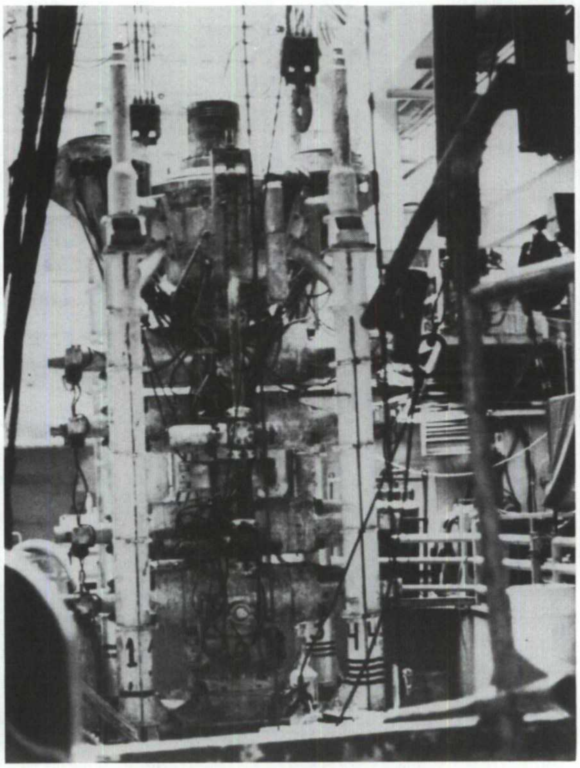


FIGURE 2 *Ocean Ranger* Blowout Preventer Stack (June, 1981)

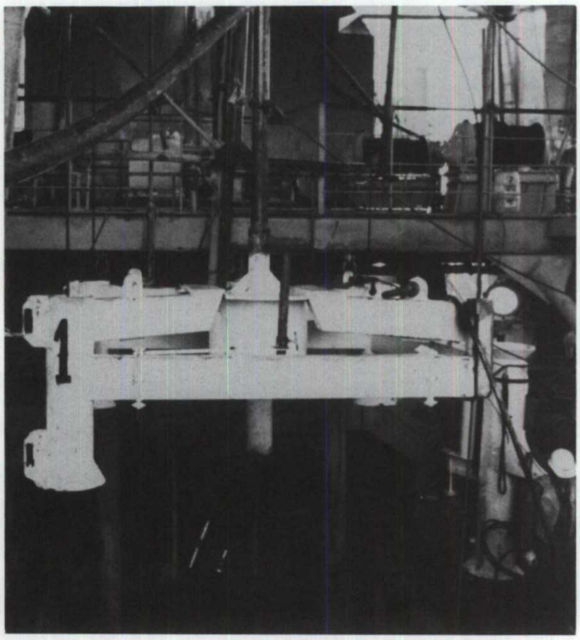


FIGURE 3 Lower Marine Riser Measurement Jig

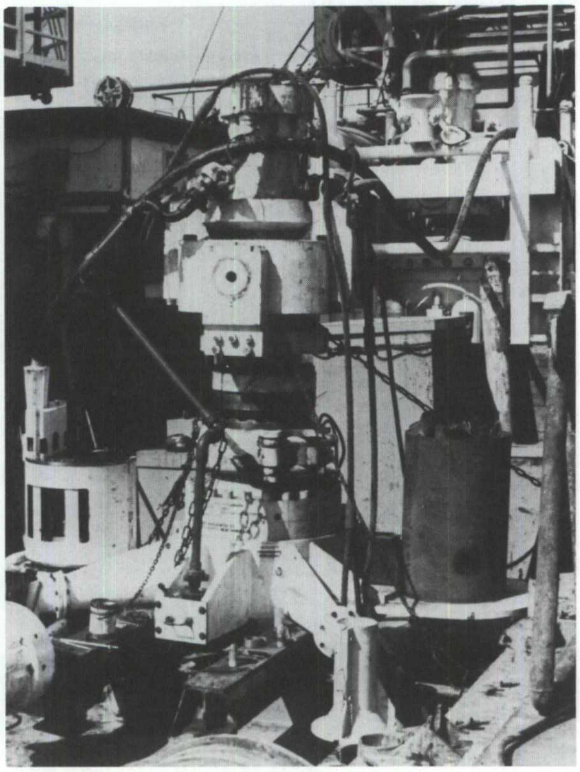


FIGURE 4 LMRP assembly by Mobil for re-entry to Hibernia J-34. Note: Only one control pod has been installed.

FIGURE 5 Drill fluid being pumped from the J-34 well.

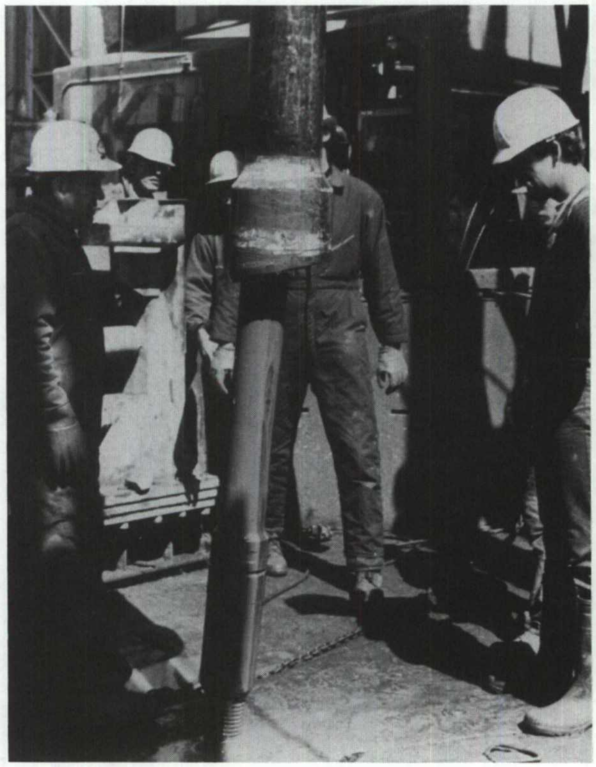


FIGURE 6 Mill pulled from hole with sheared pipe wedged in its throat. Note top of hang-off tool.

FIGURE 7 Mill used to grind down the sheared end of the drill pipe.

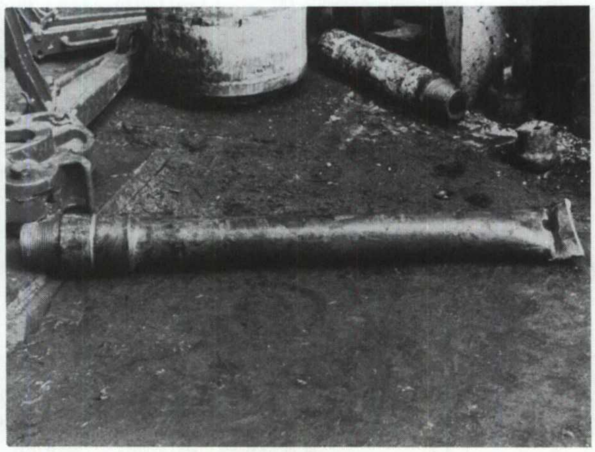


FIGURE 8 Sheared pipe removed from mill.

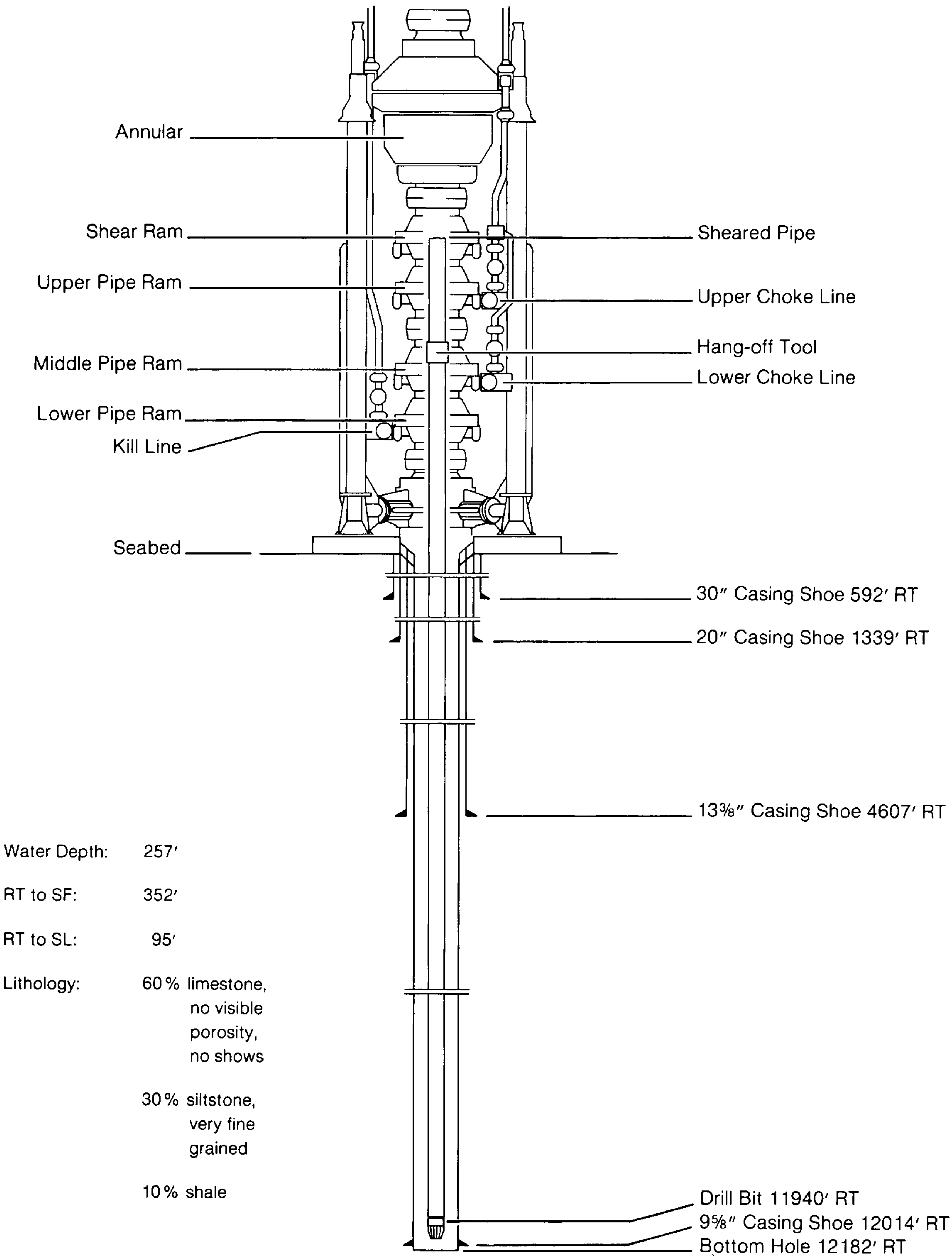


FIGURE 9 Hibernia J-34 well diagram

FIGURE 10 *Ocean Ranger* hang-off tool. The large diameter steel bottom section is designed to rest on the pipe rams of the BOP stack.

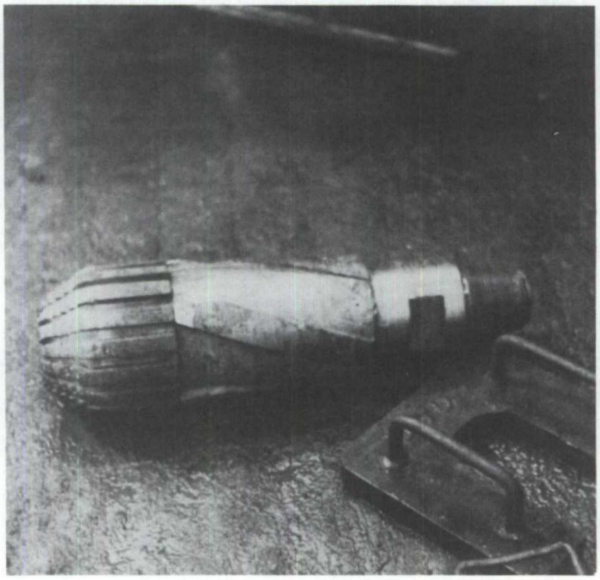


FIGURE 11 *Ocean Ranger* Drill Bit

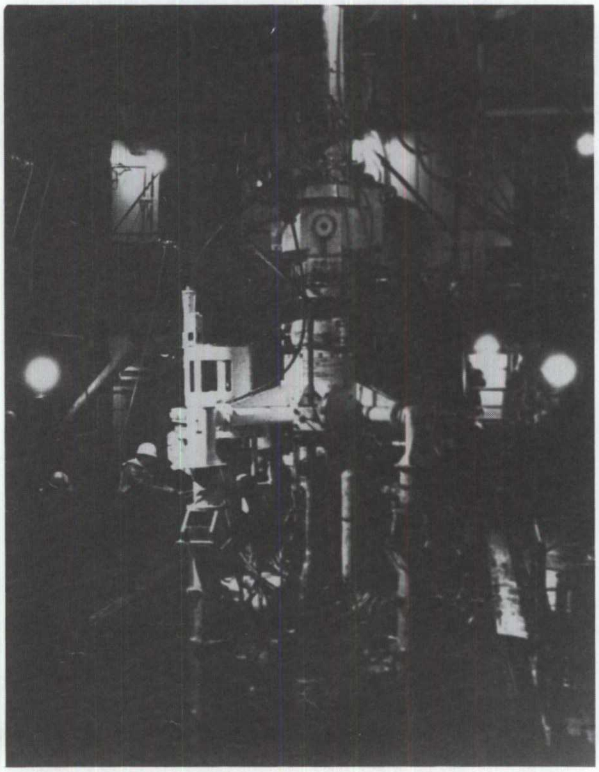


FIGURE 12 *Ocean Ranger* BOP stack in the *Neddrill* 2 moonpool.

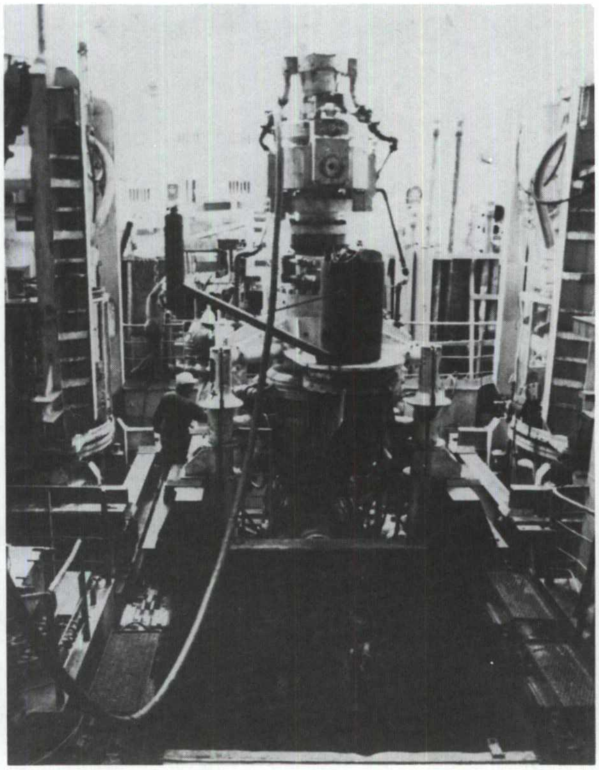


FIGURE 13 BOP stack pulled back.

Item F-2
Items Recovered During the Royal Commission's Dive Survey

1. 1 section of platform leg including porthole with glass broken out and deadlight cover attached.
2. 1 porthole with glass intact and deadlight cover attached.
3. 1 porthole with glass broken out and deadlight cover attached.
4. 2 horizontal instrument panel sections (less switches) from extreme left and right of ballast control panel.
5. Switches and lights for above panels.
6. 2 horizontal instrument panel sections from centre of control panel complete with switches.
7. 6 banks of solenoid-operated pneumatic valves; 18 manual control rods in place in solenoids.
8. 8 packages of books and documents retrieved from ballast control room.

Item F-3
Engineering Reports, A to I

Prepared by:

Aviation Safety Engineering Facility,
Aviation Safety Bureau
Transport Canada

REPORT A **Portholes Examination**

REPORT B **Porthole Glass Pressure Tests**

REPORT C **Analysis of Solenoid Control Valves**

REPORT D **Ballast Control Mimic Panel Analysis**

REPORT E **Ballast Control Panel Light Bulb Analysis**

REPORT F **Ballast Control Panel Tests**

REPORT G **Ballast Control Electrical System & Overall Analysis**

REPORT H **Pump Switch Failure Demonstration**

REPORT I **Microswitch Failure Analysis**

[Editors note: Editorial changes have been made to these reports, with the author's approval, to assist in publication.]

REPORT "A"
ENGINEERING REPORT
EP 266/82
PORTHOLES EXAMINATION
8 September 1983

INTRODUCTION

1.1 On 15 February 1982 the mobile offshore drilling rig *Ocean Ranger* capsized and sank during a severe storm 180 miles off the coast of Newfoundland. All 84 men aboard were lost. The Royal Commission investigating the *Ocean Ranger* Marine Disaster requested the Aviation Safety Engineering (ASE) Facility, of the Aviation Safety Bureau, Transport Canada to assist in the investigation by conducting certain tests and analyses on three portholes forwarded to the ASE Facility under a covering letter dated 3 August 1982.

1.2 Specifically, it was requested that ASE try to determine:

a) the type of glass used in the portholes;
b) the uniform pressure required to burst the glass in the one good porthole received;
c) the direction of forces which caused the glass to burst in the other two portholes;
d) how the glass was removed in one of the portholes received;
e) whether the deadlights were open or closed when the glass burst;
f) the torque required to loosen the deadlight bolts;
g) other observations as pertinent to the porthole damage.

1.3 Further communications with the Royal Commission on 14 December 1982 more specifically identified the portholes received. The Ballast Control Room section of drawing number P-0403 was referred to, and a reference point B4, as indicated on the drawing, located the inboard aft porthole which was identified as porthole number 1. The portholes were subsequently numbered anticlockwise 1-4 when viewing the drawing. The portholes received were further identified as follows:

No. 1, inboard aft porthole, broken, containing fragments of glass. This porthole was removed to allow entry into the ballast control room during the diving survey;

No. 2, porthole not broken (to be used in burst test);

No. 4, porthole, one of two set in a "spectacle" insert plate. Broken, containing no glass fragments.

It was reported that the three portholes received had been recovered during the diving survey following the disaster.

EXAMINATION

2.1 The three portholes received are shown in Photo 1 numbered 1, 2 and 4. The deadlight bolts on portholes 1 and 4 were only "hand-tight" and were easily removed (no torque reading). The deadlight bolts on porthole No. 2 were "frozen" on their threads, likely due to salt-water immersion. When these bolts were "unfrozen", they were also determined to be hand-tight and subsequently moved freely. The force required to loosen the frozen bolts was not directly related to the actual clamping force on the deadlight. Photo 2 shows the three portholes with deadlights open.

2.2 An initial examination of each porthole as received was conducted. Pertinent measurements were taken and a brief description of each was compiled.

PORTHOLE NO. 1, PHOTOS 3 AND 4

The porthole glass was broken, leaving glass fragments in a continuous pattern around the porthole circumference. The glass fragments were held in place by the locking ring. The glass thickness was measured at different locations around the circumference and was found to average 14.95 mm (0.59 inches). The inside diameter of the glass locking ring was measured across three diameters at 120° to each other and found to be 459 mm (18.09 inches) in each direction, indicating no out-of-round. The outside diameter of the locking ring was similarly measured and found to be 476 mm (18.74 inches) in each direction. This measurement was also assumed to be approximately equal to the diameter of the porthole glass (after accounting for clearance to allow for glass expansion).

The inside surface of the deadlight was examined using an optical microscope. The inside surface displayed a golden-brown coloured tinge with a well distributed random pattern of corrosion pitting. The corrosion pitting was considered to be severe in comparison with the two other porthole deadlights. The comparative severity of the corrosive attack was post recovery in nature. Concentrated over one area on the inside surface, there was a fine distribution of reflective particles. The particles were lying on the surface, not embedded, and a sampling was taken for closer examination.

Energy dispersive x-ray analysis indicated the particles to be predominantly salt crystals, the origin of which is considered to be evaporated sea water. One of the particles collected, however, was analysed as glass. There did not appear to be any predominance of minute scratches on the inside surface of the deadlight, such as might be caused by broken glass impacting the surface.

PORTHOLE NO. 2, PHOTOS 5 AND 6

The glass in porthole No. 2 was intact. No visible damage marks were observed. The glass thickness at various locations was measured and found to average 14.7 mm (0.58 inches). A straight edge placed on the glass surface showed it to be relatively flat but with a slight concave nature on the inboard side measuring 0.20 mm (0.008 inches) at the centre of the glass. The inside diameter of the locking ring was measured across three diameters at 120° to each other and found to be 460 mm (18.11 inches) in each direction, indicating no out-of-round. The outside diameter of the locking ring was similarly measured and found to be 476 mm (18.74 inches) in each direction. Optical examination of the inside surface of the deadlight revealed minor corrosion pitting caused by salt-water exposure.

PORTHOLE NO. 4, PHOTOS 7 AND 8

There was no glass in porthole No. 4. The rubber glass seal was in place in the seal groove of the glass support flange. The seal was broken at one location adjacent to the deadlight hinge, Photo 9, but none of the seal was missing. On the outboard edges of the glass support flange and porthole, numerous impact marks and gouges were observed, Photo 10. These marks were bright in colour and appeared to be randomly located around the full circumference of the porthole. The marks appeared to be the result of concentrated and repeated impacts. Testing showed that the orientation and severity of the impact marks could only have been made by blows from outside the porthole. They were bright in colour (indicating them to be recent in nature) and it was determined, most likely, that they occurred during removal of the porthole from the rig structure. The glass locking ring was still in place and the width of the groove which held the glass was measured. The groove width measured from the top of the seal was 14.5 mm (0.59 inches) and without the seal the groove measured 16 mm (0.63 inches). The inside diameter of the locking ring as measured across three diameters at 120° to each other, was 459 mm (18.07 inches) and the outside diameter was 476 mm (18.74 inches) in each direction indicating no out-of-round. As with the deadlight of porthole No. 2, the inside surface of the porthole No. 4 deadlight showed minor amounts of corrosion pitting caused by salt-water exposure. There did not appear to be any predominance of scratches on the inside surface of the deadlight such as may have been caused by broken glass impacting the surface.

2.3 Detailed examination of porthole No. 1 revealed that the glass remnants were sloped towards the inboard side of the porthole. Using a level and a dial indicator, it was possible to measure the slope of the glass on the outboard surface. The calculated slope angle of the glass surface was 2.3 degrees. The direction of slope on the glass indicates an inward force on the glass caused failure. The locking ring was removed from the porthole and the glass was removed, Photo 11. The rubber glass seal was found intact and in place in its groove. One distinctive characteristic of the glass fragments was the pattern of cracking, Photo 12. In all cases, the outboard surface of the glass had formed what could be described as a "shear lip". This cracking pattern is typical of a bending overload failure with the direction of force acting from the outboard to the inboard side of the glass.

2.4 Detailed examination of porthole No. 4 revealed a protruding "lip" of metal on the locking ring, Photo 13. This material lip was continuous around the circumference of the ring on the side adjacent to the glass. The ring was removed for closer examination. Photo 14 shows a polished and chemically etched cross section of the locking ring from porthole No. 4 illustrating the protruding lip. Examination of the material structure in the vicinity of the lip revealed a pattern of material flow indicating shear deformation of the ring at that point. A cross section of the ring was taken 180° opposite the section shown in Photo 14 for comparison. The magnitude of the shear deformation did not appear to differ by a measurable amount. This pattern of shear deformation and the continuous protruding lip around the full circumference of the ring, is an indication that glass failure occurred in an inboard direction as a result of high impact loading evenly distributed over the glass surface. A similar examination of the ring cross section from porthole No. 1 was done. There was no protruding lip found and no strong indication of shear deformation on the ring surface adjacent to the glass.

2.5 Metallurgical examination of the material microstructure of the locking rings revealed a narrow band of deformation slip lines (characterized by a crosshatch pattern) just below the ring surface which mates with the glass, Photo 15 and 16. The slip line pattern extended further below the surface in the ring from porthole No. 4 and was much more prevalent in the area of the protruding lip, Photo 17. Slip lines are formed as a result of deformation in the material and are characterized by a crosshatch pattern.

2.6 Energy dispersive x-ray analysis indicated the material of the porthole glass locking ring to be a copper-bronze casting alloy containing lead, tin and zinc as alloying elements. Brinell Hardness tests on the ring cross sections gave values of 40-45 Brinell Hardness Number (BHN, 500 kgm load) for both rings.

2.7 The granular pattern of failure of the glass from porthole No. 1 and the lack of any distinctive sharp splinters is typical of tempered glass failures. Examination of the glass did not reveal any laminations and it was concluded that the porthole glass used was tempered or "toughened" glass.

DISCUSSION

3.1 The metallurgical analysis of the locking rings indicates that the loads on the glass of porthole No. 4 were of higher magnitude and more of an impact nature than the loads on the glass of porthole No. 1. It is considered most probable that the glass in porthole No. 4 burst due to a dynamic surface ocean wave impact. On the other hand, the lack of any significant material deformation in the locking ring from porthole No. 1 suggests more of a static loading condition. Static pressure loads would be applied as a result of sinking to the sea floor if a pressure differential exists across the glass. This would require the deadlight to be closed and sealed, trapping an air pocket on the inboard side of the glass. The static pressure loads alone would not have been sufficient to burst the porthole glass. However, a concentrated blow by a sharp object might easily shatter tempered glass, particularly if it is already sustaining a pressure load. It is, therefore, considered likely that the glass received a blow from some object while it was submerged.

3.2 If glass particles had been observed imbedded on the inside surface of the deadlight from porthole No. 4, or if distinctive scratches were observed on this surface, a positive conclusion might have been drawn that the deadlight was closed when the glass burst under the dynamic loading conditions of the wave impact. Although not necessarily conclusive evidence, the lack of such witness marks does suggest that the porthole No. 4 deadlight was open at the time. Due to the more static loading conditions under which the glass burst in Porthole No. 1, similar witness marks would not be expected on the inner surface of this deadlight, even though it was concluded that this deadlight was closed at the time.

CONCLUSIONS

4.1 The type of glass used in the portholes was tempered or "toughened" glass.

4.2 The uniform pressure required to burst the glass in porthole No. 2 will be determined under separate testing, refer to ASE Report "B", (EP 90/83).

4.3 The glass in portholes No. 1 and No. 4 burst as a result of forces applied in an inboard direction. No more definitive direction of force in relation to the glass surface could be determined.

4.4 There were repeated impact marks on the outboard glass supporting flange of porthole No. 4, which contained no glass.

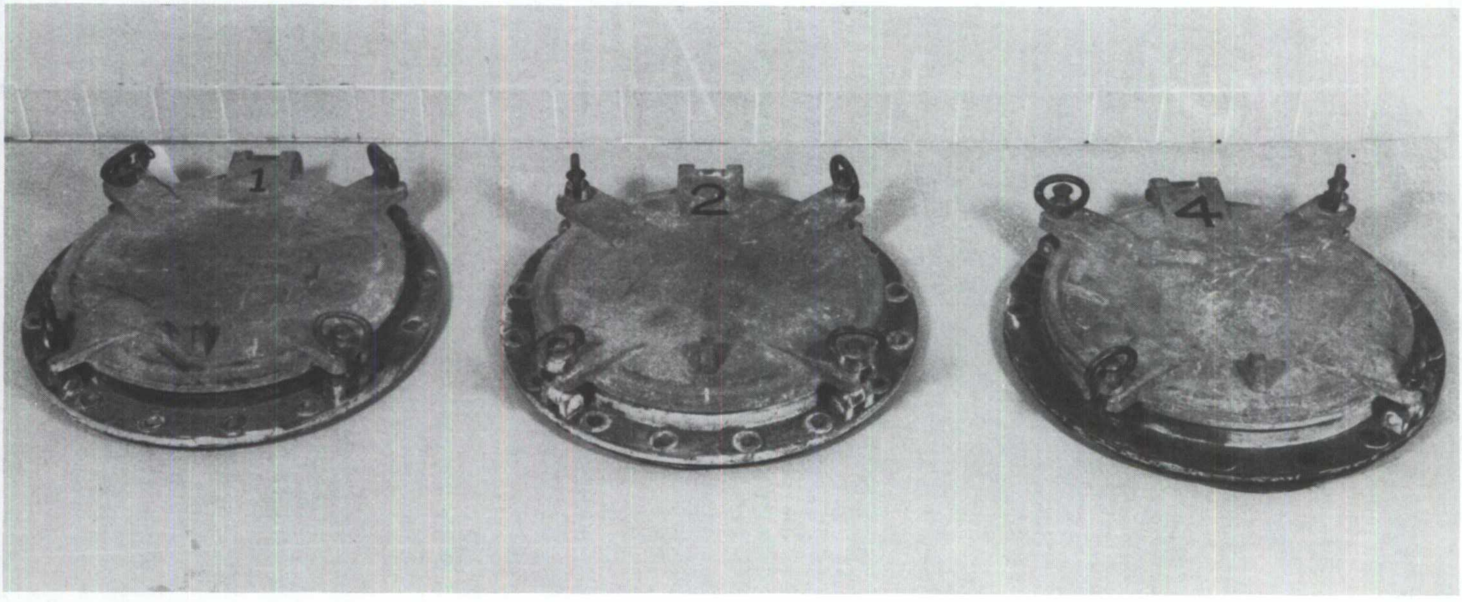
4.5 There was not sufficient evidence available on the porthole to enable conclusive determination of how the glass was removed.

4.6 Analysis indicates that the glass in porthole No. 1 probably failed under uniform pressure loads resulting from sinking to the sea floor, but assisted by a blow to the glass while submerged. It is also concluded that the deadlight was probably closed at the time of glass failure.

4.7 The glass in porthole No. 4 failed due to loads of an impact nature, likely resulting from surface waves. It was also determined that the deadlight was probably open at the time of failure.

4.8 The deadlight bolts on portholes 1, 2 and 4 were hand tight, and no significant break away torque values were recorded.

PHOTO 1 Portholes as received with deadlights closed. Identified by the numbers 1, 2 and 4.



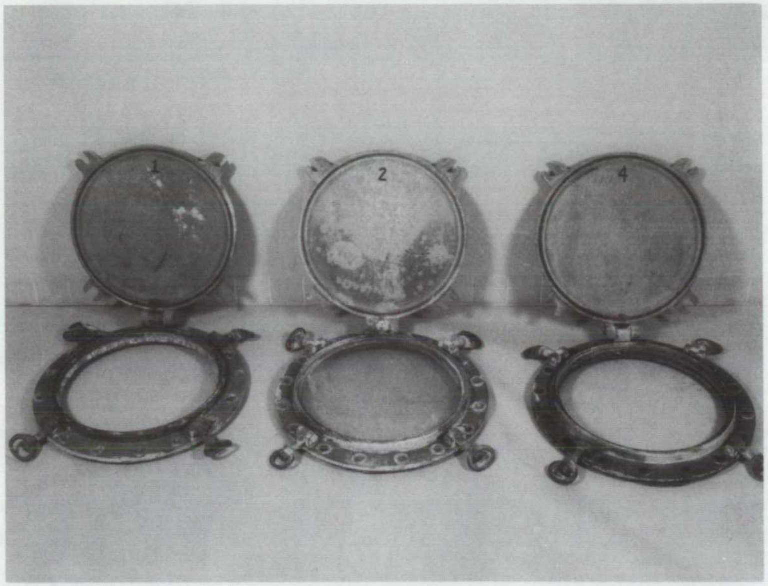


PHOTO 2 Portholes with deadlights open show the glass condition in each case.

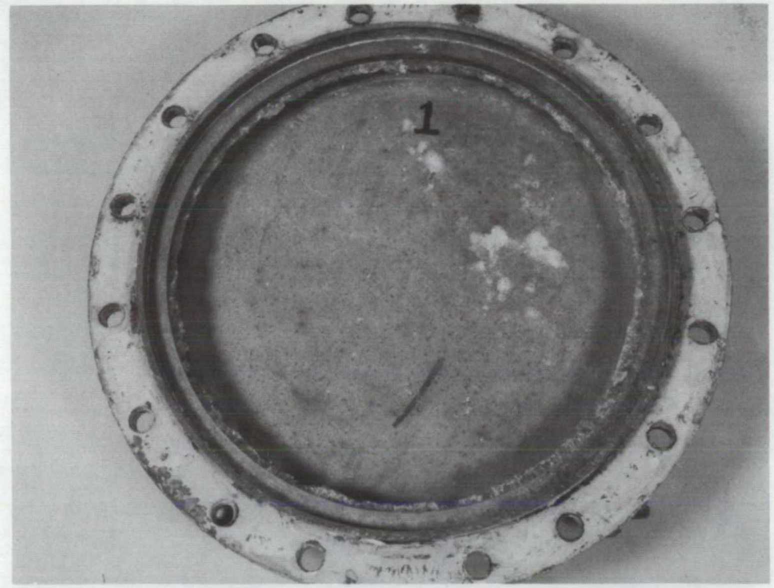


PHOTO 3 Porthole No. 1 with deadlight closed, view looking inboard.

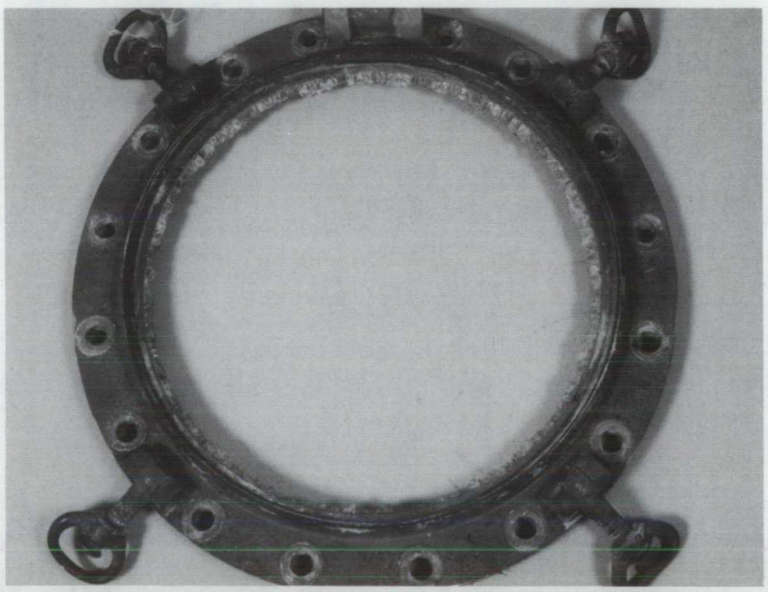


PHOTO 4 Porthole No. 1 with deadlight open, view looking outboard. Note glass fragments in continuous pattern around circumference.

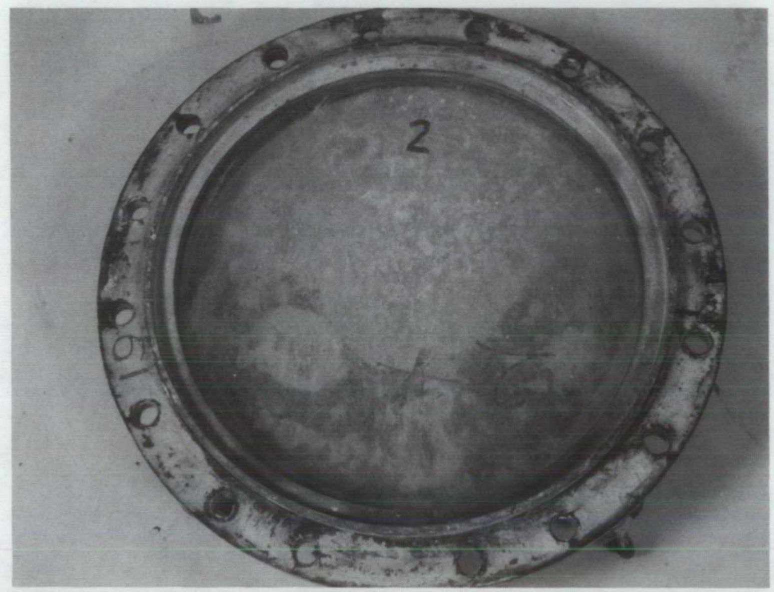


PHOTO 5 Porthole No. 2 with deadlight closed, view looking inboard.

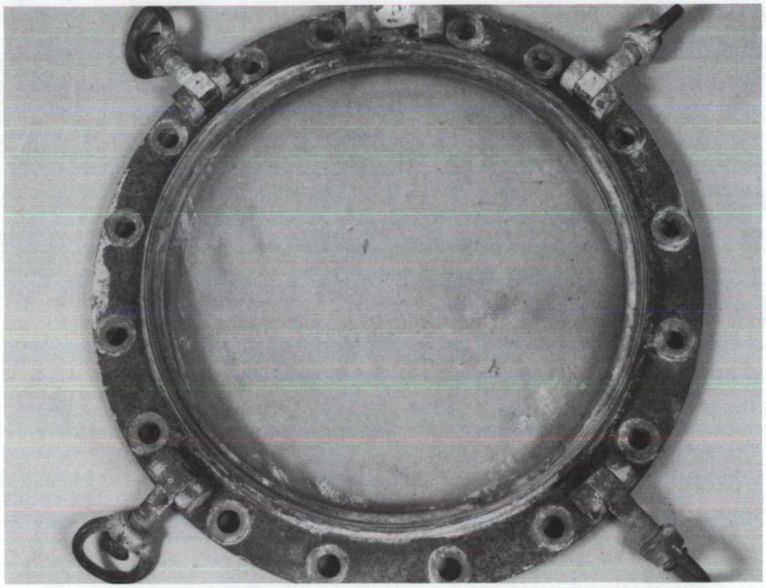


PHOTO 6 Porthole No. 2 with deadlight open, view looking outboard. Note glass intact.

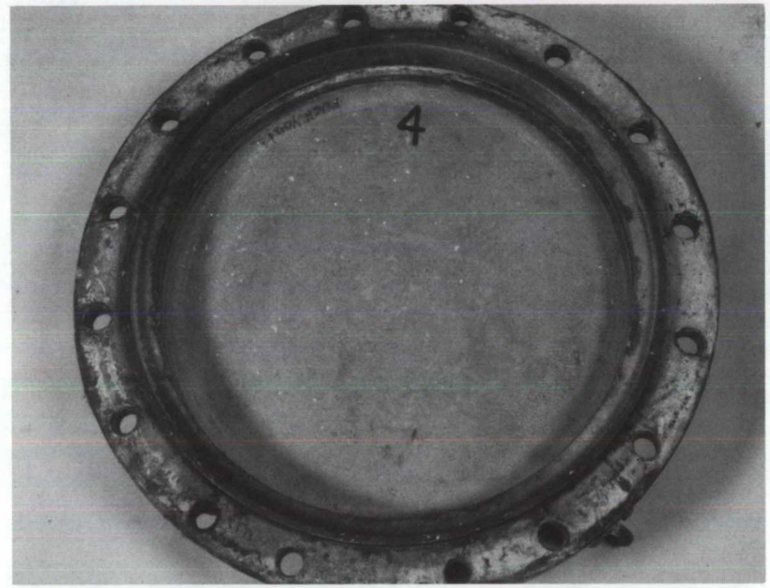


PHOTO 7 Porthole No. 4 with deadlight closed, view looking inboard.

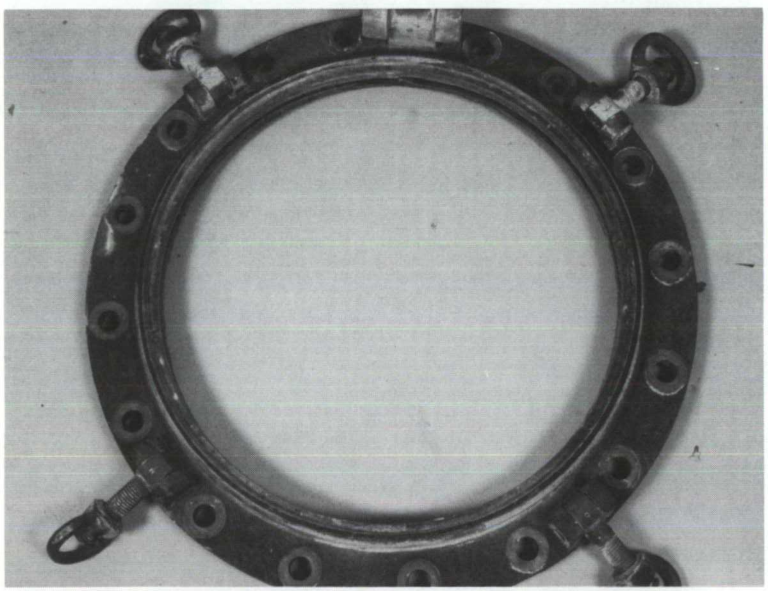


PHOTO 8 Porthole No. 4 with deadlight open, view looking outboard. Note glass completely removed, no fragments.

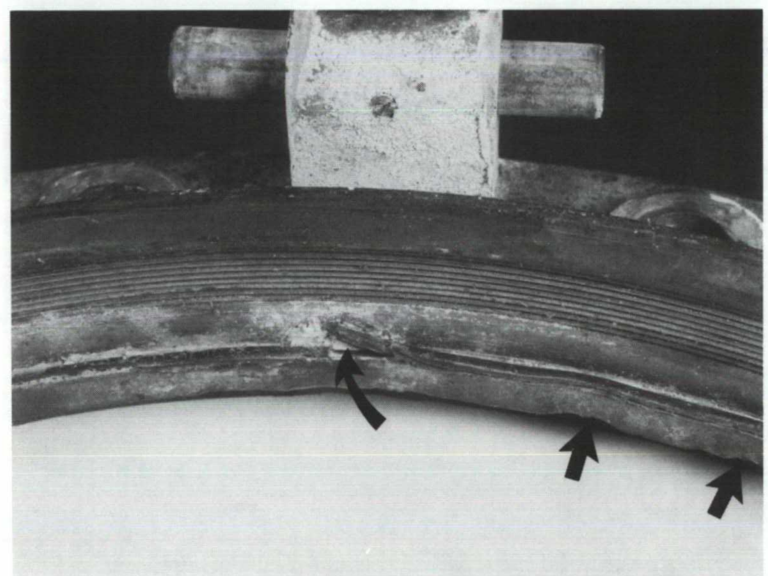


PHOTO 9 Porthole No. 4 showing broken seal (arrows) adjacent to the deadlight hinge. Also note profile of impact marks on outer edge of porthole (arrows) compare with photo 10.

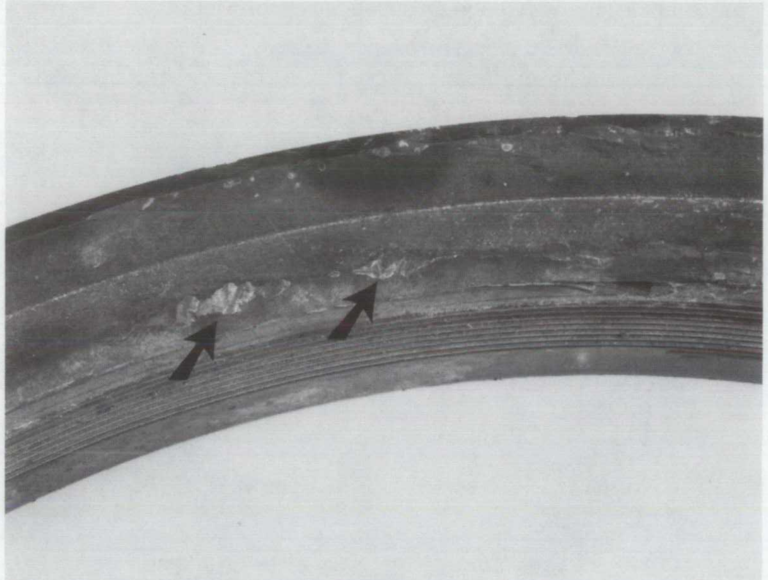


PHOTO 10 Porthole No. 4 showing impact marks and gouges (arrows) on the outboard edges of the porthole.

PHOTO 11 Porthole No. 1 glass fragments after removal of the locking ring.

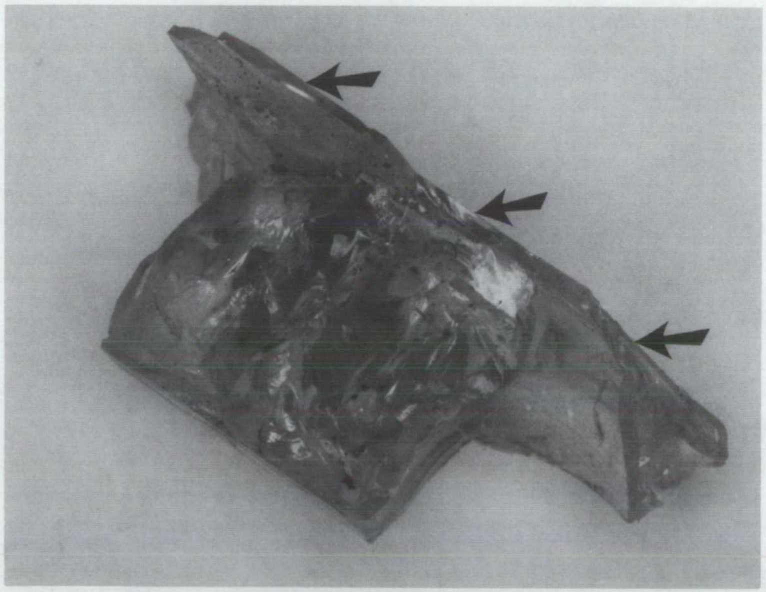


PHOTO 12 Glass fragment from porthole No. 1 displays a distinctive *shear lip* on the outboard side of the glass (arrows).

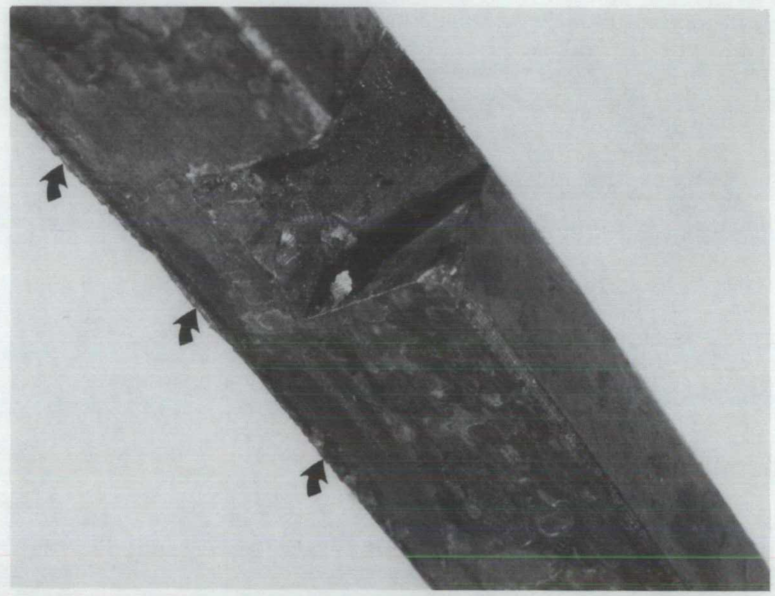


PHOTO 13 Glass locking ring from porthole No. 4 shows protruding lip of material along the inside edge (arrows).

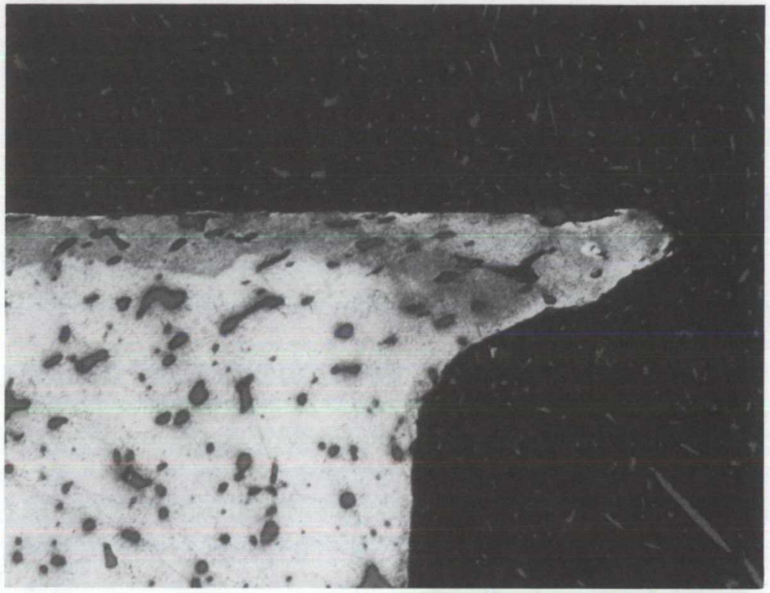


PHOTO 14 Cross section of locking ring shows protruding lip of material. Note the pattern of flow near the base of the lip indicating smearing deformation of the material.

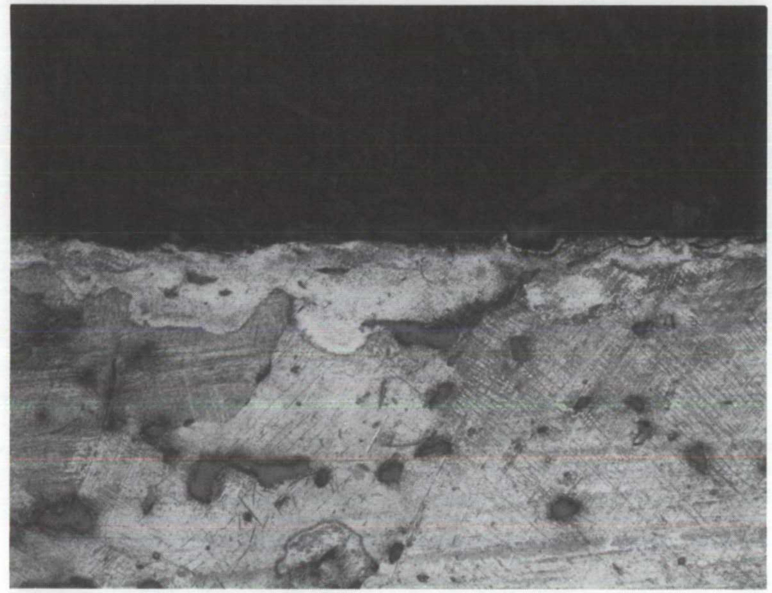


PHOTO 15 Deformation slip lines (crosshatch pattern) adjacent to the glass mating surface of porthole No. 4 locking ring.

PHOTO 16 Deformation slip lines as in photo 15.

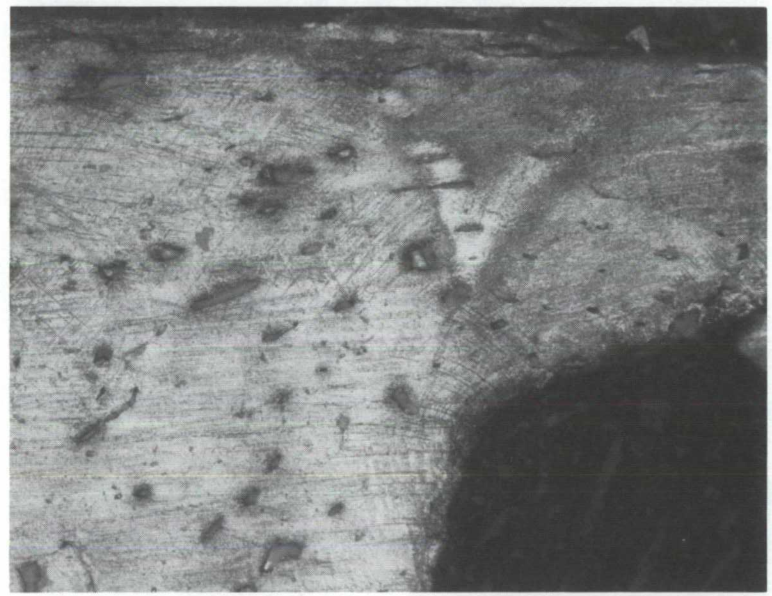


PHOTO 17 Porthole No. 4 locking ring cross section showing high concentration of deformation slip lines around the base of the protruding lip.

REPORT "B"
ENGINEERING REPORT
EP 90/83
PORTHOLE GLASS PRESSURE TESTS
8 September 1983

INTRODUCTION

1.1 The Royal Commission investigating the *Ocean Ranger* Marine Disaster requested the Aviation Safety Engineering (ASE) facility, of the Aviation Safety Bureau, Transport Canada to assist in the investigation by conducting certain tests and analyses on typical porthole glass and the No. 2 porthole retrieved from the rig's ballast control room. It was requested that ASE determine the pressure at which glass would fracture for comparison with standards and to provide burst pressure data for wave force analysis.

TEST DESCRIPTION

2.1 A test fixture depicted in Photos 1 and 2 was constructed. It consists of a heavy steel plate on a stand to which a porthole is bolted, and an air supply line complete with a small air tank intended to provide enough air to blow out the glass when it breaks in a manner similar to the water of a wave driving the fractured glass through the porthole. A gate valve, pressure gauge and pressure transducer controlled and monitored the test pressure.

2.2 A high speed film camera and two video cameras were used to film every test. The high speed camera was run at 2000 frames per second to record the fracture event and the distribution and speed of the glass fragments. One video camera monitored the pressure gauge while the other covered the test area, giving an overall view of the fixture and glass distribution.

2.3 The tests were controlled by a minicomputer which timed the start of the video cameras, valve opening, high speed camera start and the air exhaust at the end of the high speed film run. It also monitored and stored the output of the pressure transducer throughout the test. At the end of the test the data stored was printed out in graphical form. Figures 1 through 5 are direct computer printouts of these tests.

2.4 The porthole glass used in the rig's ballast control room was 1.5 centimeters thick and 48 centimeters in diameter. The No. 2 porthole glass retrieved from the *Ocean Ranger* was marked "Tempered Glass". The glass was presumed to be manufactured to Japanese Industrial Standard (JIS) F2410, of which a copy is attached.

2.5 Porthole glass from two different suppliers was obtained. It was considered that the glass was manufactured under a similar standard as JIS-F2410. Six sheets of glass from a Canadian manufacturer and three sheets of glass from a Japanese manufacturer were purchased. All nine sheets of glass had approximately the same dimensions and were all marked "Toughened" or "Tempered Glass".

2.6 Tempering or toughening of glass is traditionally a heat treatment process which heats the finished cut sheet of glass slowly to approximately 600 degrees Centigrade and then rapidly cools it with air. This process causes the surface part of the glass to be "frozen" in compression, greatly strengthening the glass sheet. However when the glass does fracture the internal stress will "explosively" drive thousands of fractures through the glass, creating the characteristic small, generally rectangular fragments of "toughened" glass.

2.7 All glass sheets, including the porthole No. 2 glass, were checked for evidence of tempering. The glass was placed between two sheets of optical polarizing plastic which would show the bifringe patterns characteristic of residual stress gradients in the glass. The bifringe patterns of three types of glass tested were markedly different as is evident from Photos 3, 4 and 5. This indicates that the cooling method used in the heat treatment processes were different. The *Ocean Ranger* glass was evidently cooled by a concentrated blast of air on both sides of the glass from a slightly off central location, while the Canadian and Japanese glass showed very little bifringe pattern and in a much more distributed way. These glass sheets were cooled with a more distributed air supply affecting more even cooling and less internal stress gradient. All glass tested fractured into the characteristic rectangular fragments, suggesting proper temper had been achieved.

2.8 Microscopic examination of the rig's No. 2 porthole glass revealed extensive pitting on both sides of the glass, with a density of approximately one pit per ten square centimeters and an average pit size of half a millimeter. Pitting typically reduces the fracture strength of glass, especially tempered glass. In order to determine the effects of pitting, a new sheet of both Japanese and Canadian glass was intentionally pitted in a manner similar to the *Ocean Ranger* glass. Their rupture strength was greatly reduced, as is evident from Table 1.

2.9 A total of twelve tests were performed on the ten sheets of glass tested. The results of the six most significant tests are listed in Table 1. One of these tests was a static pressure test to determine the extent of glass deformation (bulging) as a function of pressure. The deformation was measured directly with a lever arm over the glass and a displacement indicator. It was determined that at a pressure of 96 psi (6.8 kg/cm^2) the glass bulged 7.5 millimeters; causing angular rotation of the glass at the edge of the locking ring of approximately eight degress creating a total force of 120 tons or one ton per centimeter of locking ring.

2.10 The other five tests listed in Table 1 were semi-dynamic, i.e. the air pressure was allowed to rise as fast as the equipment allowed. The time required to reach rupture pressure was largely a function of glass strength and leakage around the glass, and could not be controlled without interfering with the typical glass mounting. All results of these tests are shown in Table 1 and graphs 1 to 5.

2.11 After testing the rigs's No. 2 porthole to bursting, the porthole locking ring was subjected to a metallurgical analysis, the results of which are attached.

CONCLUSIONS

3.1 The Canadian glass when new and undamaged failed just above the Japanese Industrial Standard F2410 proof pressure of 7 kg/cm^2 (99 psi). All other glass failed below this standard.

3.2 Surface pitting greatly reduced the rupture strength of the glass.

3.3 The *Ocean Ranger* porthole No. 2 glass was tempered in a different manner than all other glass tested.

3.4 Elastic deformation of the glass prior to rupture was found to be 7.5 millimeter bulge at 7 kg/cm^2.

3.5 The *Ocean Ranger* No. 2 porthole glass failed at a pressure of 4.8 kg/cm^2 (68 psi) causing deformation to the locking ring very similar to that found on the No. 4 porthole locking ring.

Department of Transport
Aviation Safety Engineering Laboratory
International Request for Technical Analysis

REQUIREMENTS

The No. 2 porthole from the *Ocean Ranger* Oil Rig was pressure tested as documented in ASE Report "B", (EP 90/83). Following testing, the glass retaining ring was removed. It is requested of the Materials Analysis Section (ASE/MAT) that the retaining ring be analysed metallurgically for evidence of material deformation and comparison made with previous metallurgical analyses made of the retaining rings from portholes No. 1 and 4, refer to ASE Report "A", (EP 266/82).

2 August, 1983 M. Vermij

FINDINGS

1. Close examination of the glass retaining ring from porthole No. 2 was carried out in-situ prior to pressure testing. There was no indication of any material lip observed on the ring. The No. 2 porthole is shown mounted on the test rig in Photo 6 following the pressure test to glass failure. The glass retaining ring was removed, brushed clean and examined optically. A continuous "lip" of material was observed around the full circumference of the ring on the side adjacent to the glass, see Photos 7 and 8. This material lip was very similar in nature to the protruding material lip observed on the glass retaining ring from porthole No. 4, see Photo 9.

2. The No. 2 porthole glass retaining ring was sectioned in the transverse direction and mounted for metallurgical examination. Photo 10 shows the ring in cross section and illustrates the protruding lip of material, which is generally similar in nature to the cross sectional view of the material lip in the ring for porthole No. 4, Photo 11. The effect of the material deformation is revealed by the pattern of material flow in the vicinity of the lip, also generally similar in the two rings being compared.

3. Energy dispersive x-ray analysis indicated the material of the No. 2 porthole glass retaining ring to be a copper-bronze casting alloy containing lead, tin and zinc as alloying elements. Brinell Hardness testing on the ring cross sections gave values within the range of 40-45 Brinell Hardness Number (BHN, 500 kgm load, 10 mm ball) which has previously been measured for the rings from portholes 1 and 4. Material and hardness values compared favourably for all three rings tested (Portholes 1, 2 and 4).

4. The chemical etching of the ring cross section from porthole No. 2 revealed only slight deformation slip lines formed as a result of material deformation. The degree of this deformation pattern was much less than observed in the cross section from porthole No. 4 and more similar in degree to the deformation patterns observed in the ring cross section from porthole No. 1.

5. From results of the No. 2 porthole pressure test it was shown that the test was conducted at a pressure rate of approximately 27 psi/sec, with glass rupture occurring at about 2.5 seconds. Under these conditions the test is considered to be essentially dynamic in nature, although not with the same dynamic impact loading believed to have been experienced by the glass of porthole No. 4, which was concluded to have failed under wave impact conditions. The similarities of the deformation lip on the retaining rings from portholes No. 2 and No. 4 and lack of deformation lip on the ring from porthole No. 1 (which failed under more static pressure conditions) is considered to indicate that the deformation lip on the glass retaining ring is caused by dynamic loading.

6. The relative differences in the degree of deformation slip line patterns of the retaining rings from portholes No. 1, No. 2 and No. 4 would appear to be a function of the nature of loading on the porthole glass. The porthole No. 4 retaining ring shows the greatest degree of slip line patterns and is also the one considered to have experienced the greatest degree of impact loading.

31 August, 1983 J.W. Hutchinson

TEST NUMBER	TEST RESULT REFERENCE	GLASS ORIGIN	CONDITION	PRESSURE TO FAILURE		TIME TO FAILURE
				kg/cm2	PSI	(SEC)
1		Japan (new)	clean	6.8	96	Static
2	6	Canada (new)	clean	7.4	105	5.7
3	11	Japan (new)	clean	6.8	96	7.0
4	7	Ocean Ranger	pitted	4.8	68	2.9
5	8	Canada (new)	pitted	5.6	79	3.4
6	10	Japan (new)	pitted	3.6	51	6.6

PRESSURE TEST RESULTS

TABLE 1

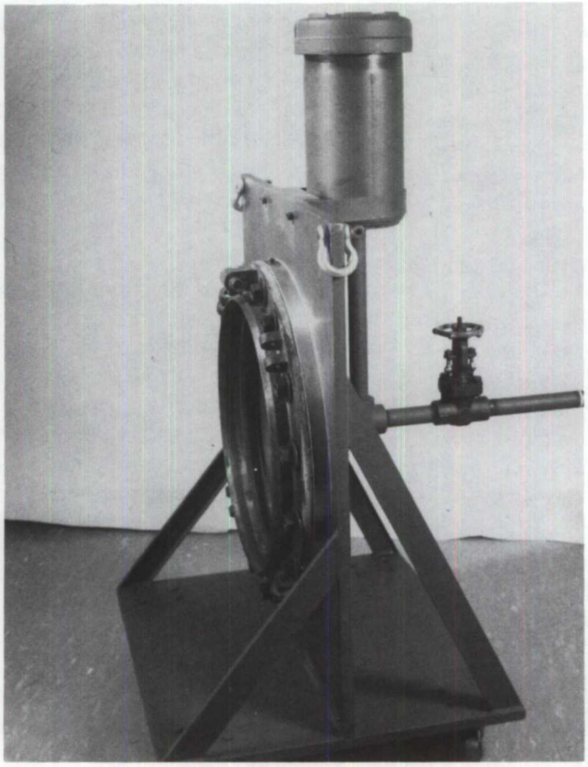


PHOTO 1 Side view of porthole glass test fixture.

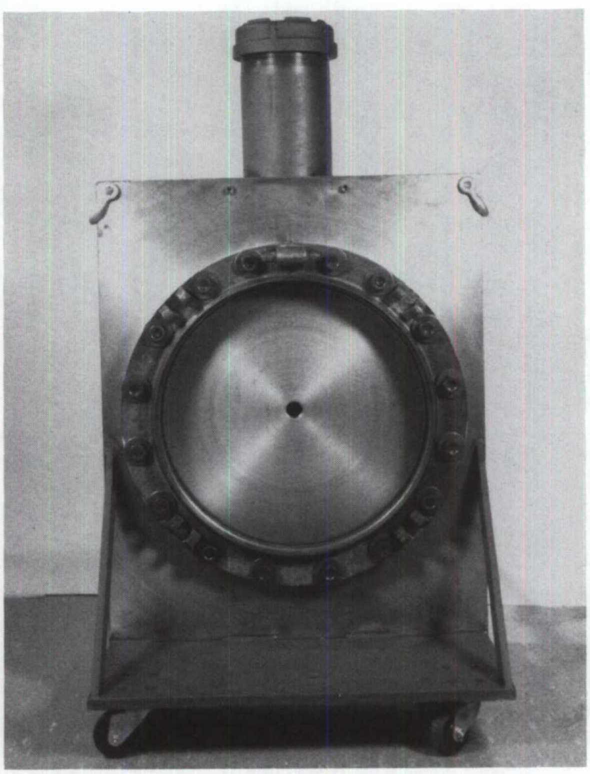


PHOTO 2 Frontal view of porthole glass test fixture.

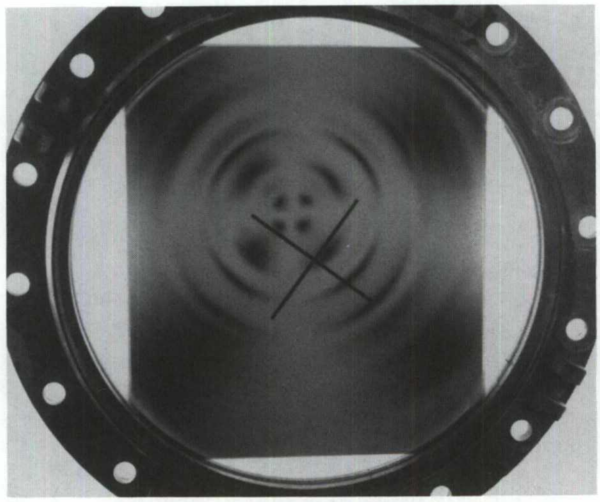


PHOTO 3 Bifringe pattern of *Ocean Ranger* #2 porthole glass, showing strong stress gradients.

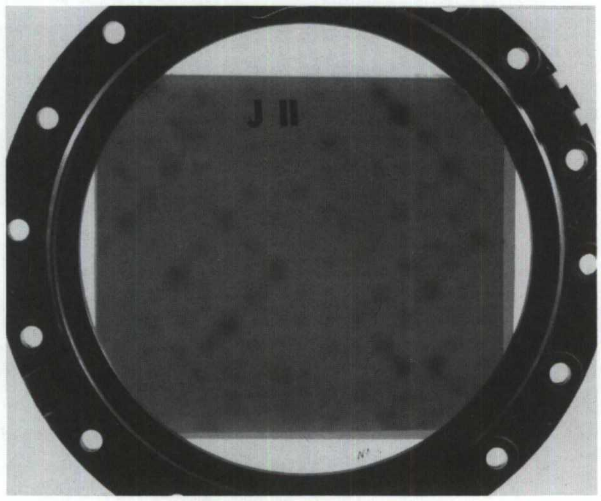


PHOTO 4 Bifringe pattern of Japanese glass (new) showing little stress gradients.

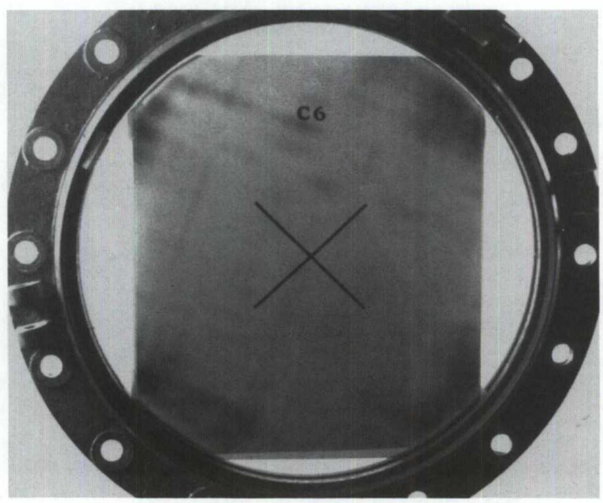


PHOTO 5 Bifringe pattern of Canadian glass (new) showing weak stress gradient patterns.

UDC 629.12.011.83: 666.181

JAPANESE INDUSTRIAL STANDARD　　JIS

Tempered Glasses for Ships' Side Scuttles

F 2410-1955

1. Scope

1.1 This standard covers the tempered glass for ships' side scuttles (hereinafter referred to as the "tempered glass").

2. Class

2.1 Tempered glass shall be classified into the following two classes:

(1) Transparent tempered glass

(2) Ground tempered glass

3. Dimensions and Dimensional Tolerance

3.1 Dimensions of tempered glass shall be in accordance with Table 1.

Table 1

Unit: mm

Nominal diameter	Dimensions of glass	
	Diameter	Thickness
200	212	10 12
250	262	
300	312	10 12
350	362	15
400	412	

3.2 Dimensional tolerances of tempered glass shall be in accordance with Table 2.

Table 2

Unit: mm

Diameter	Tolerance
212	± 1.0
262	
312	
362	
412	

Thickness	Tolerance
10	± 1.0
12	
15	

4. Quality

4.1 In addition to the quality of tempered glass specified in Table 3, its characteristic shall fulfil the following requirements, namely, the clearance test, impact test and pressure test specified in 5.3, 5.4 and 5.5 respectively.

Table 3

Kinds of defect	Specifications for quality
Bubbles, stones, knots, striates and reams	In accordance with the specification for the standard product of 32"×24" or less size given in Table 4 of JIS R 3202-Polished Plate Glass.
Spots, cloudings, and scratches	No remarkable interference for practical purpose.
Grizzles	Not to have
Edge chippings	Within 3 mm towards inside from the circumference
Overall appearance	No permissible defects shall be concentrated
Ground surface of tempered glass	No part left on the ground surface through which clearly seen a perspective image.

5. Method of Test

5.1 **Measuring Method of Dimensions** The thickness of the tempered glass shall be measured by a micrometer with an accuracy up to 1/100 mm, and the thickness shall be determined by counting fractions over 1/2 as one and disregarding the rest.

5.2 **Appearance** The visual inspection of the tempered glass shall be performed by naked eyes at a distance of approximately 50 cm from the front face of the sample.

5.3 **Clearance Test**

(1) **Supporting Method of Sample** The sample shall be set on the surface plate, as shown in Fig. 1, so as to make a concentric circle with the inside circle of the surface plate. Further, a weight of approximately 5 kg shall be loaded on the central part of the sample.

(2) **Surface Plate** The surface plate having a hole of 12 mm less than the diameter of the sample shall be used as shown in Table 4.

Table 4

Unit: mm

Diameter of sample (A)	Diameter of inside circle (B)
212	200
262	250
312	300
362	350
412	400

(3) **Measuring Method** The clearance between the circumference of the sample and its surface plate shall be measured by a clearance gauge choosing any point which equally divides the circumference into three parts.

(4) **Condition of Acceptance** When the mean value of the measurement at the three points falls within 0.5 mm, the products shall be accepted.

5.4 **Impact Test**

(1) **Supporting Method of Sample** The sample shall be so supported on the frame of hardwood shown in Fig. 2 that the sample will make a horizontal at the time of impact. In case of testing the opaque tempered glass, the ground surface shall be laid downwards.

(2) **Falling Body** A good finished steel ball of 225±5 g in weight and 38 mm in diameter shall be used.

(3) **Condition of Impulse** The steel ball at rest shall be dropped on the central part of the sample without giving any force. In this case the height shall be in accordance with Table 5 and impulse acted on the glass surface is limited just for once, and the testing shall be performed at a normal temperature.

Table 5 [1]

Thickness of sample (mm)	Falling height of steel ball (m)
10	2.5
12	
15	3.0

Note [1] The above table provides only for the transparent tempered glass. For the ground tempered glass, these shall be determined by the agreement between the purchaser and the manufacturer.

(4) **Condition o. Acceptance** Being free from cracks and fractures, the glasses shall be accepted.

5.5 Pressure Test

(1) **Supporting Method of Sample** Samples shall be exactly fitted to a water pressure testing device as shown in Fig. 3.

(2) **Condition of Water Pressure** The samples shall be tested by applying the pressure, according to each diameter and thickness of glass, specified in Table 6.

Table 6 [1]

Unit: kg/cm²

Thickness of sample (mm) \ Diameter of sample (mm)	212	262	312	362	412
10	9	6	5	4	3
12	12	9	7	6	5
15	—	14	11	9	7

Note [1] The above table provides only for the transparent tempered glass. For the ground tempered glass, these shall be determined by the agreement between the purchaser and the manufacturer.

(3) **Condition of Acceptance** The samples to withstand the pressure specified in Table 6 shall be accepted.

6. Inspection

6.1 The appearance and dimensions should be, as a rule, inspected on each product.

6.2 Sampling method to be used in 5.3~5.5 shall be conducted by rational sampling method upon egreement of the parties concerned.

6.3 Being inspected for appearance, dimensions and characteristics of the sample, it shall be determined to accept or not.

7. Marking

7.1 Every plate of tempered glass shall be plainly and indelibly marked with the indicatin of tempered glass, manufacturer's name or mark.

8. Designation

8.1 The tempered glass shall be designated in order of the class and dimensions.

Example: Class of transparent tempered glass, dimensions of 212 mm in diameter and 10 mm in thickness shall be expressed by Transparent D 212×10.

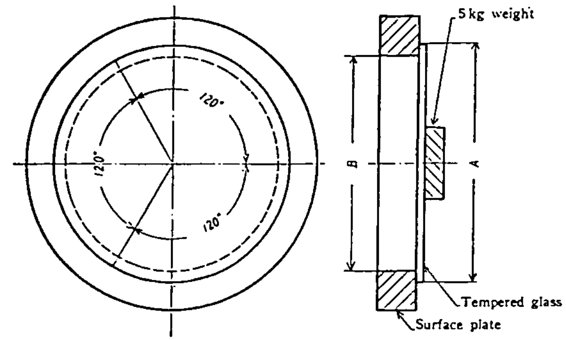


Fig. 1

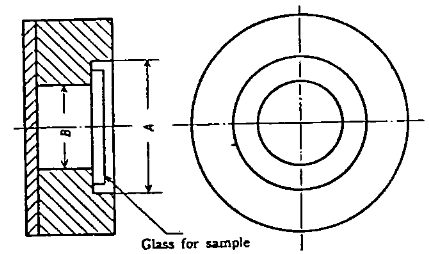


Fig. 2

Unit: mm

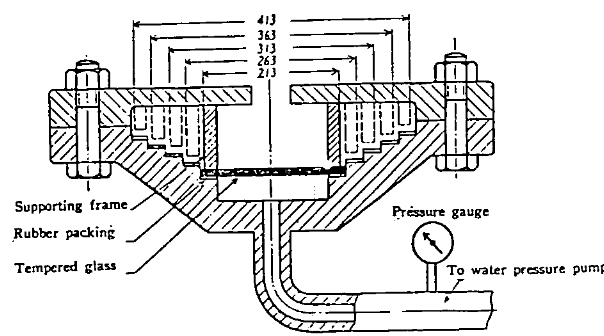


Fig. 3

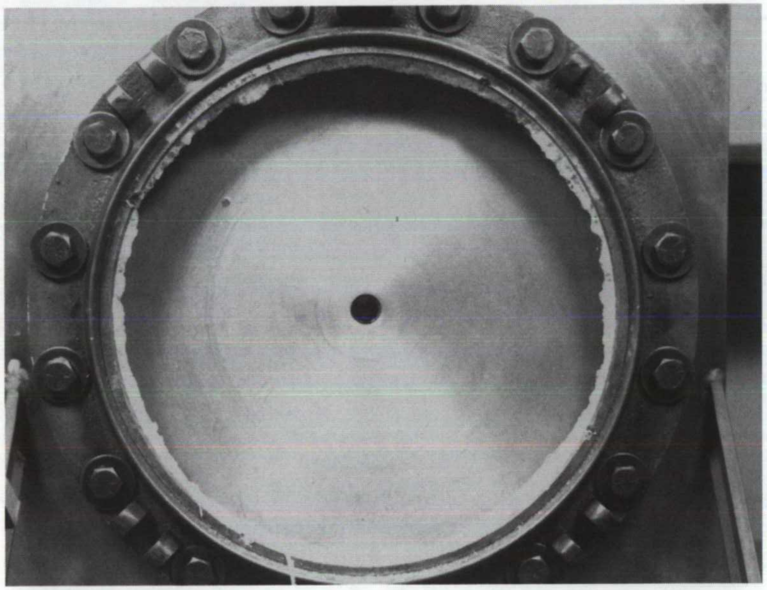


PHOTO 6 Porthole No. 2 following testing mounted on the test rig. Glass retaining ring in place.

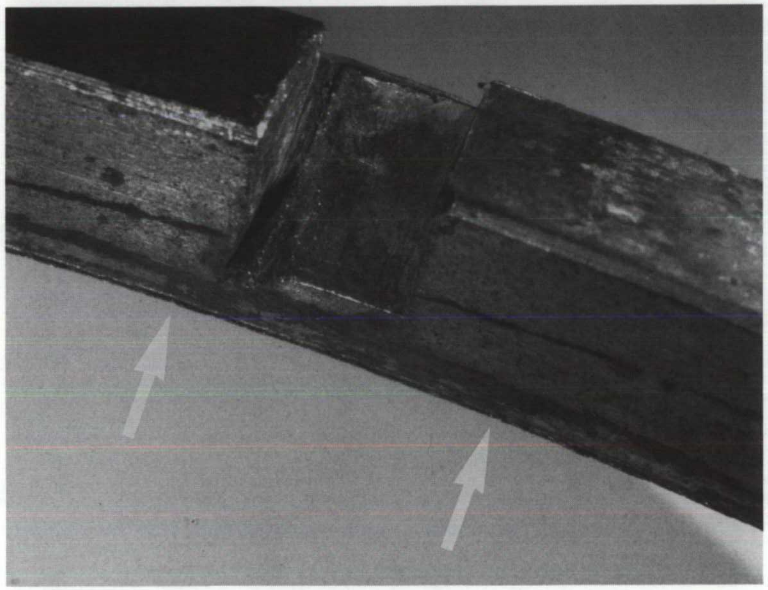


PHOTO 7 Glass retaining ring removed from porthole No. 2 shows protruding lip of deformed material (arrows).

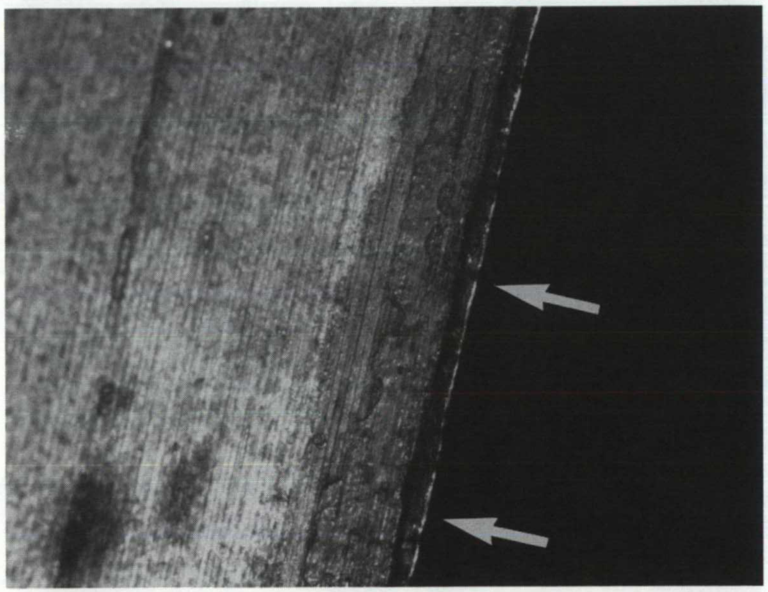


PHOTO 8 Close-up view of the material lip (arrows).

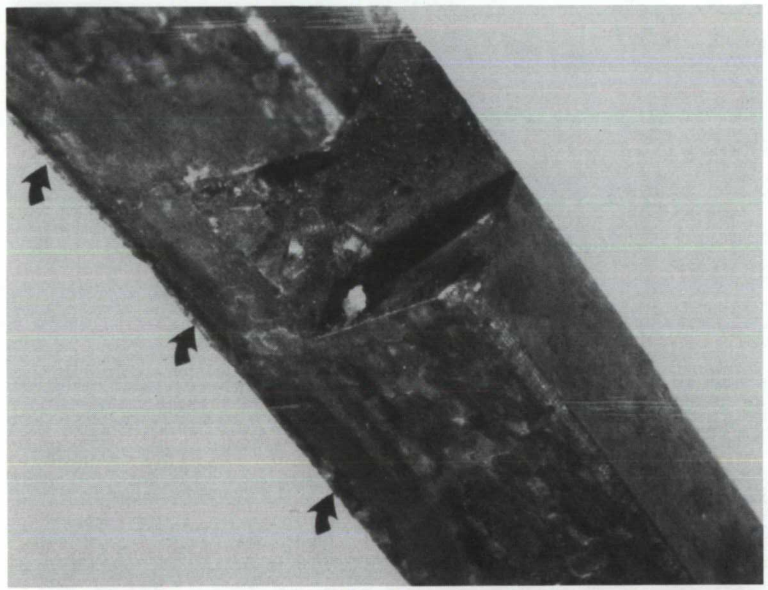


PHOTO 9 Glass retaining ring from porthole No. 4 shows similar protruding material lip (arrows).

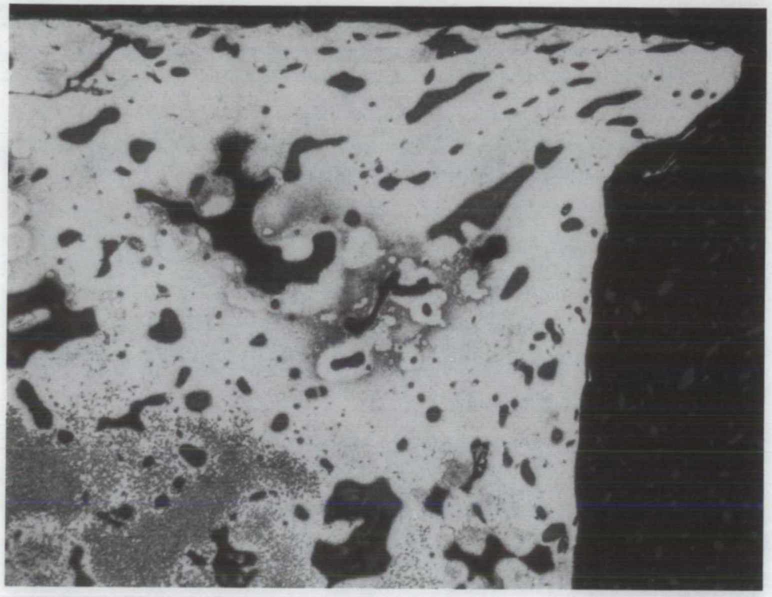


PHOTO 10 Cross section of retaining ring from porthole No. 2 shows distinct protruding lip. Note the pattern of flow at the lip indicating smearing deformation of the material.

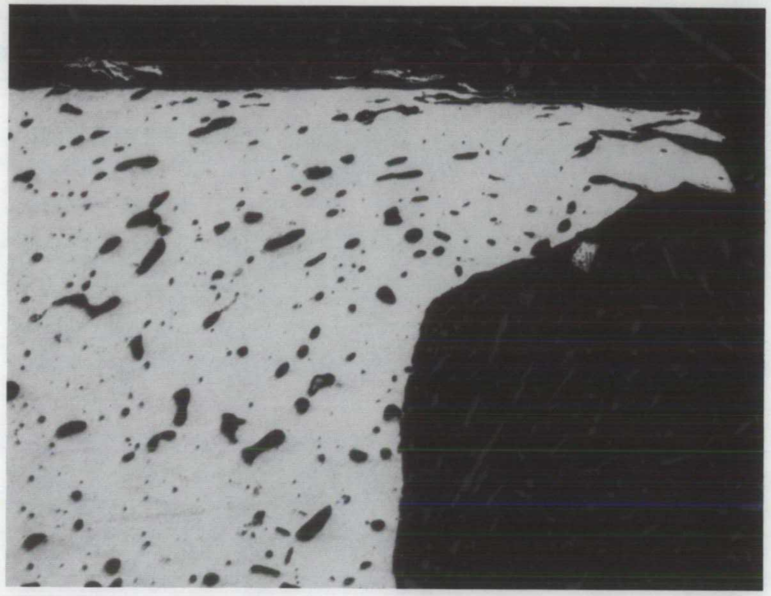
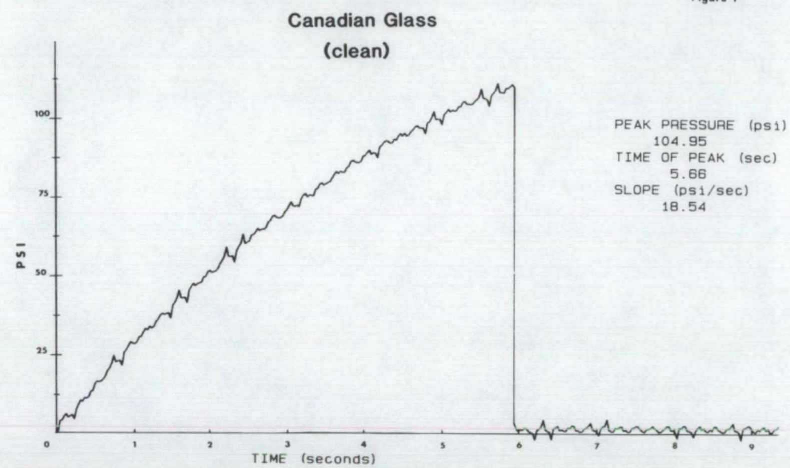


PHOTO 11 Cross section of retaining ring from porthole No. 4 shows similar protruding lip.

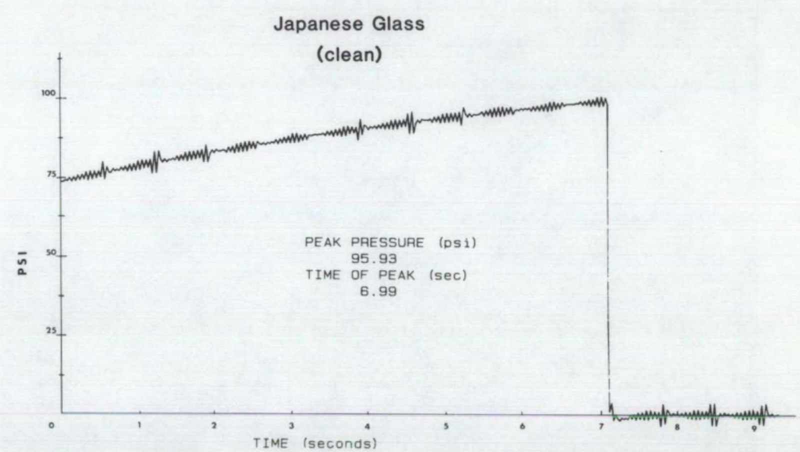
OCEAN RANGER PRESSURE PROFILE 6

Figure 1



OCEAN RANGER PRESSURE PROFILE 11

Figure 2



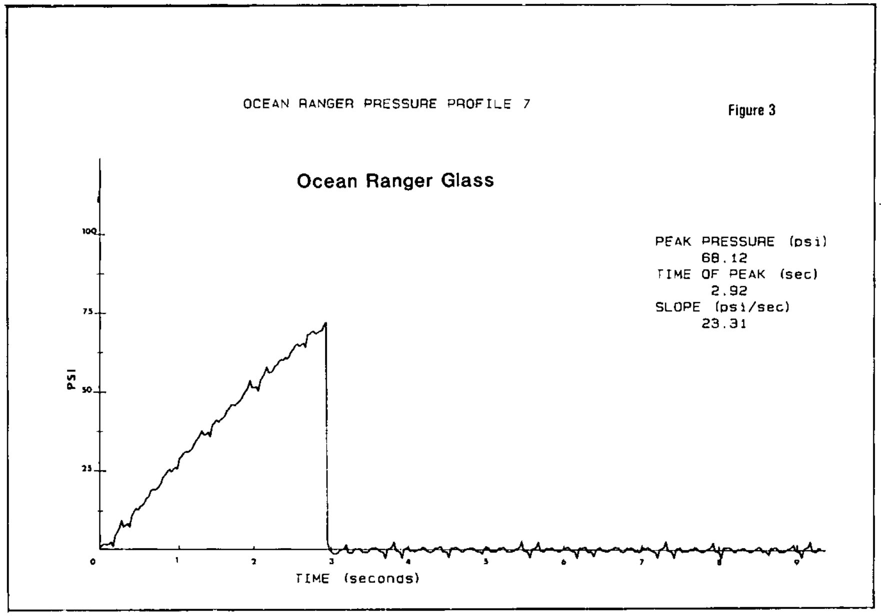


Figure 3

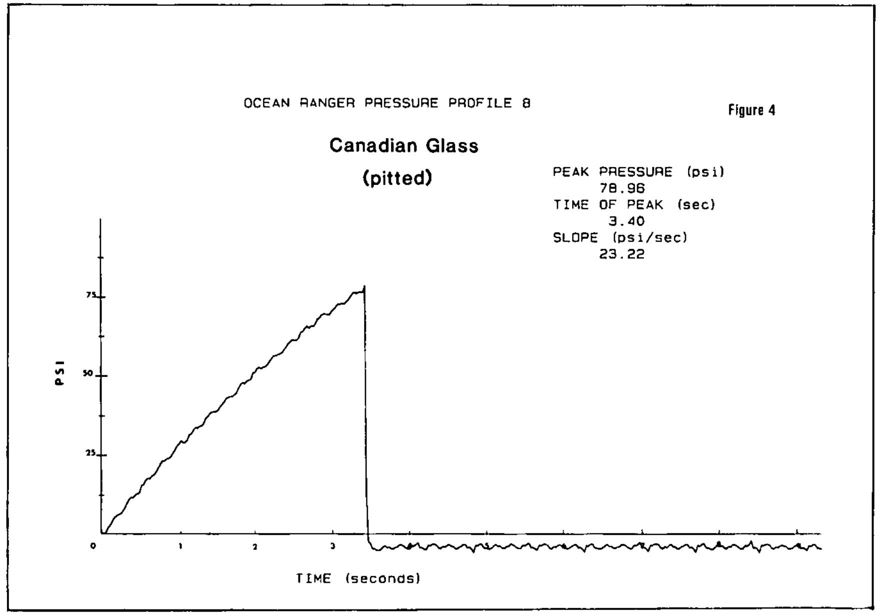


Figure 4

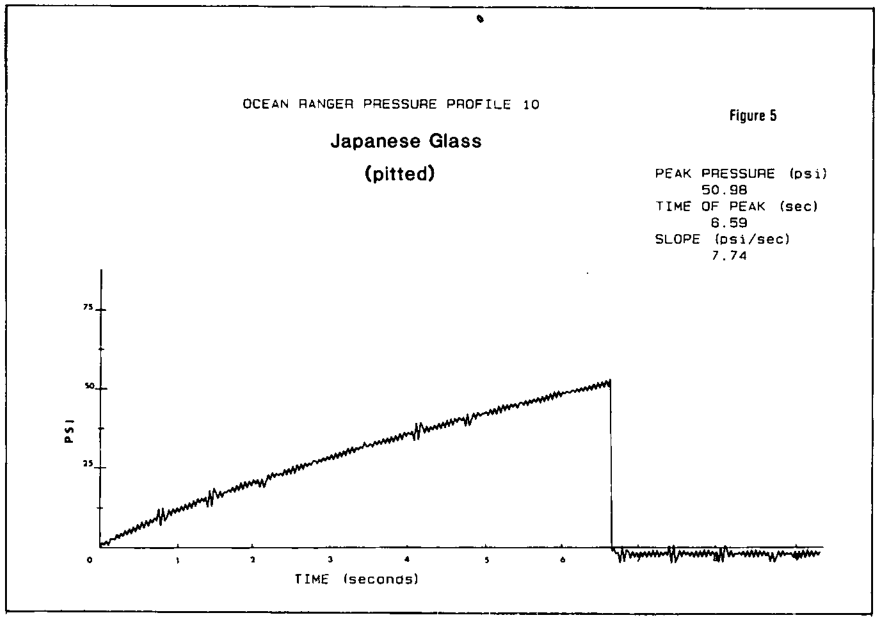


Figure 5

REPORT "C"
ENGINEERING REPORT EP 265/82
ANALYSIS OF SOLENOID CONTROL VALVES
8 September 1983

INTRODUCTION

1.1 The Royal Commission investigating the *Ocean Ranger* Marine Disaster requested the Aviation Safety Engineering (ASE) Facility, of the Aviation Safety Bureau, Transport Canada to assist in the investigation by conducting certain tests and analyses on four banks of 11 solenoid control valves and two banks of 10 solenoid control valves which were removed, during underwater salvage efforts, from the *Ocean Ranger's* ballast control room. These 64 solenoid control valves were forwarded to the ASE Facility under covering letters dated 29 July 1982 and 3 August 1982.

1.2 It was specifically requested that ASE try to determine:

a) evidence of manual operation of the control valves;
b) whether rubber plugs not found on the valves had been pushed inside the valve solenoid housing;
c) which valves were in the activated and which were in the non-activated position;
d) material transfer evidence and/or indentations on the valve solenoid plungers indicative of manual operation;
e) the nature of any debris found inside the valves;
f) the possible effect of salt-water immersion on the solenoid valves;
g) the extent of air leakage from the valves when submitted to the normal operating air pressure of 90 psi;
h) whether the valves functioned normally when electrically activated;
i) other relevant observations.

EXAMINATION AND ANALYSIS

2.1 The 64 solenoid control valves received were identified as SMC model VS4130, 4-way solenoid valve of spool type, port size 3/8" with standard size piping, manufactured by SMC, Shoketsu Kinzoku Kogyo Co., Ltd. This type of valve has a single spring return mechanism and is normally operated with 90 psi air, and a 115 volts AC supply. The six solenoid control valve banks, as received, were located underneath the ballast control room mimic panel and are shown in Photos 1-3. A layout of the relative positions of all 64 valves in the 6 banks is shown in Figure 1. When activated, the solenoid valves control the opening and closing of the tank butterfly valves; thereby governing the relative distribution of air and water in the various tanks within the pontoons and hence, the relative flotation characteristics of the mobile drilling rig.

2.2 Thirty-two solenoid valves were used for the port side pontoons, and thirty-two for the starboard pontoons. Two different designation systems were found to identify the valves, as is evidence from Photo 4:

a) a brass plate with lettering P1, P2, . . . P32 for the port side S1, S2, . . . S32 for the starboard side;
b) a red plastic label 'Dymo' tape with white lettering SOV-1 to SOV-32 for valves P1 to P32 inclusive SOV-33 to SOV-64 for valves S1 to S32 inclusive.

Table 1 lists which butterfly valve each solenoid valve controlled, as per the Royal Commission *Ocean Ranger* Exhibit 74A drawing 061.

2.3 The capability for manual activation of the solenoid control valves is provided for emergencies in the form of a brass plug and actuator rod. Photo 5 illustrates a broken and an intact actuator rod, both inserted into a brass plug. An actuator rod received in a bent condition is shown on Photo 6. The threaded section of a non-broken actuator rod was measured as 1.9 inch and its shank as 2.3 inches. The diameter was measured as 0.21 inch.

2.4 The 64 valves were received in three different conditions:

a) with a brass plug with or without actuator rod remains;
b) with rubber plugs;
c) without plugs.

Eighteen valves were received with a brass plug, of which 14 had actuator rods inserted into the brass plug. All of these 14 actuator rods were fractured. Four non-broken actuator rods were also received; hence, the total number of brass rods received matched the number of brass plugs. The individual valve conditions are as listed in Table 2 with Photo 4 showing the three types. The rubber plugs found on 22 valves had a molded, crosswise slit in them to prevent any pressure differential buildup behind the plug. In service operation, the micro command switch on the mimic ballast control panel energizes a relay, which in turn allows electrical current to operate the associated solenoid control valve using 115 volts AC. In an emergency, the solenoid valves can be activated manually, through the use of actuating rods inserted into a brass plug.

2.5 Photos 7 and 8 show the various valve components. Photo 8 is a cross section of the internal valve mechanism. The components, numerically identified on Photos 7 and 8, are listed below:

1. solenoid housing and gasket;
2. solenoid core;
3. solenoid;
4. plastic keeper;

Solenoid Valves	Butterfly Valves
1, 2, 3, 4	Ballast water tanks
5, 6	Drill water tanks
7, 8, 9, 10, 11	Ballast water tanks
12, 13	Drill water tanks
14, 15, 16	Ballast water tanks
17, 18, 19	Drill water pump to tanks
20	Ballast water manifold
21, 22, 23	Emergency bilge suction
24, 25, 26	Ballast water pumps to manifold
27	Ballast water manifold
28, 29	Drill water service
30	Overboard
31	Sea water tank
32	Sea chest

TABLE 1

SOLENOID CONTROL VALVES AND CORRESPONDING BUTTERFLY VALVES PORT AND STARBOARD

5. spool fitting inside the sleeve;
6. sleeve with its six "O" rings;
7. spool return spring;
8. main valve body with its five chambers for the air flow;
9. back plate and gasket.

The solenoid core is normally pulled electrically to actuate the valve. In an emergency, it can be pushed manually by insertion of the brass actuator rod against the spool, which then moves within the sleeve, allowing the air flow to travel within the valve chambers.

2.6 A copy of drawing NMA 298-2, shown as Figure 2, illustrates the air system. The typical assembly of a solenoid bank is comprised of an intake and exhaust manifold, a sub-plate for each valve and the 10 or 11 valves as shown on Photo 9. Each manifold has three isolated air ducts in which the air flows through the individual valves. The air ducts constitute the air supply in the middle, and two exhausts, one on each side. The 90 psi air travels through the manifold ducts, sub-plate ports and valve chambers. The ports and chambers are identified on Photo 10 as E1 and E2, S, and C1 and C2; for exhausts 1 and 2, supply and cylinders 1 and 2 respectively. When in a non-activated position, this air escapes through the exhaust; and when in an activated position, the air is directed to the butterfly valves' piston.

2.7 The activated and non-activated sleeve-spool positions are shown on Photos 11 and 12 to illustrate the air flow direction. In the non-activated position, the air flows from "S" to "C1". Since the two cylinder 1 exhausts are normally sealed on both sides as shown on Photo 13, the air is trapped inside the valve. When the spool is pushed during activation, the air travels from "S" to "C2" and then to the opened cylinder 2 control line leading to the tank butterfly valve. The air previously trapped inside the valve in the non-activated position is bled to the manifold exhaust line through "E1", as "C1" and "E1" now interconnect. When the spool returns to the non-activated position, "C2" and "E2" interconnect and the air bleeds to the manifold exhaust line through "E2", and the butterfly valve returns to its closed position.

2.8 To verify the state of the solenoid valves, micrometer measurements of the positions of the solenoid cores were taken on all valves. These measurements are listed in Table 3 for the valves with brass plugs, and in Table 4 for the valves without brass plugs. (The measurements are identified numerically from 1 to 4, as shown on Photos 14 and 15). It can be observed that only measurement #3 can be made when no actuator rod is present, but all four measurements can be made with the actuator rod present. Measurement #3 gives the solenoid core depth with reference to the exterior surface of the valve solenoid housing. The average value measured was 0.72 inch for the valves with brass plugs, and 0.52 inch for the valves without. One valve (P-13) which was received with a brass plug had a 0.65 reading for measurement #3, more than halfway between those with and without brass plugs.

with brass plugs				with rubber plugs		without plugs	
with actuator rod		without actuator rod					
Starboard	Port	Starboard	Port	Starboard	Port	Starboard	Port
S1 S3 S6 S7 S8 S9 S10 S14 S15 S16	P2 P11 P12 P16	S2	P13 P14 P15	S4 S18 S19 S20 S23 S25 S27 S28	P3 P8 P9 P10 P17 P18 P22 P23 P24 P25 P26 P27 P29 P32	S5 S11 S12 S13 S17 S21 S22 S24 S26 S29 S30 S31 S32	P1 P4 P5 P6 P7 P19 P20 P21 P28 P30 P31

TABLE 2

THE THREE GROUPS OF SOLENOID CONTROL VALVES AS RECEIVED

2.9 The fourteen actuator rods found in the valves had been fractured. The fracture surface of these broken rods was analysed using scanning electron microscopy. All fourteen fracture surfaces were consistent with ductile bending overload failures characterized by a rough, irregular surface, as shown on Photo 16. In each case, the fracture originated in a thread root, Photo 17 and was accompanied by one-way bending deformation adjacent to the fracture.

2.10 Each one of the sixty-four solenoid core faces was examined for actuator rod imprints. All of the faces from the valves where brass plugs were found had a visible and distinctive circular mark. A typical mark, as observed, is shown in Photo 18, which is a scanning electron micrograph using backscattered electron imaging to differentiate the different elements. The circular brass marking diameter was about 0.16 inch. No deformation of the core surface was observed. Four valves (P10, S11, S12 and S13), received without brass plugs, exhibited a deep circular imprint on their solenoid core faces. When individually examined with the scanning electron microscope using backscattered electron imaging, these imprints did not show the typical brass marking observed for the valves found with brass plugs in place, and the imprint diameter was on average 0.11 inch. Some deformation of the core surface was also observed. A typical imprint is shown on Photo 19.

2.11 In their as received condition, none of the 64 solenoid valves could be operated manually because the mechanism was sticking, probably as a result of the lubricant emulsification. Debris was also found in various areas of the valve interior. Once cleaned, the average force required to manually activate the valve by pushing directly on the solenoid core was found to be three pounds for the thirteen valves tested, a force easily overcome by inserting the brass actuator rods. The maximum displacement of the solenoid core and valve spool was measured as 0.20 inch. In the cleaned condition, the solenoid core returned to its non-activated position when the acutator rod was unscrewed.

2.12 Debris was found inside most of the valves. Representative samples were selected and forwarded to the Division of Chemistry at the National Research Council of Canada. The results of the analysis showed that there was no evidence that the fibrous material and the metallic particles found were present inside the valves prior to the valve immersion in sea water. The fibrous material was consistent with fibres originating from marine sponge. The metallic particles found were rust (Fe_2O_3) and alumina (Al_2O_3) which typically result from salt-water corrosion of the iron and aluminum valve components.

2.13 Sixty-three of the sixty-four valves were electrically tested and found to function properly. (The sixty-fourth valve was made available to the Royal Commission for their testing in St. John's, Nfld.). The minimum voltage required to electrically activate the valve was measured as 76 volts on average. The solenoid core was pulled into the activated position immediately upon application of the proper voltage, and similarly released when the voltage was removed.

2.14 A solenoid control valve was tested for leakage under the operational air pressure of 90 psi. The air supply was first admitted through the manifold air supply duct, with the sub-plate cylinder 2 exhaust for all the valve sub-plates blocked off. The air supply was then admitted through the sub-plate cylinder 2 exhaust of the valve. In both cases, a minimal amount of leakage was observed at any of the manifold exhausts, and no significant drop in pressure was noted. The valve was then tested for activation, with a 115 volts AC voltage supply and an internal pressure of 74 psi. The pressure drop was about 2 psi as measured at the sub-plate cylinder 2 exhaust.

Valve	Displacement (inches)			
	#1	#2	#3*	#4
S1	0.665	0.555	0.715	1.190
S2	Rod missing	0.580	0.725	N.A.
S3	0.640	0.510	0.720	1.160
S6	0.650	0.510	0.730	1.135
S7	0.710	0.590	0.730	1.230
S8	0.655	0.560	0.722	1.195
S9	0.730	0.535	0.720	1.185
S10	0.690	0.595	0.715	1.240
S14	0.760	0.620	0.725	1.275
S15	0.645	0.480	0.725	1.115
S16	0.700	0.545	0.725	1.185
P2	0.670	0.550	0.725	1.205
P11	0.690	0.555	0.725	1.205
P12	0.635	0.560	0.730	1.205
P13	Rod missing	0.600	0.655	N.A.
P14	Rod missing	0.550	0.715	N.A.
P15	Rod missing	0.580	0.720	N.A.
P16	0.650	0.630	0.720	1.270

TABLE 3
MICROMETER MEASUREMENTS FOR VALVES WITH BRASS PLUGS
(Refer to Photos 14 and 15 for location of measurements 1 through 4)

*NOTE: Measurement #3 average 0.723 inch. Valve P13 was not included in this average calculation, since its measurement #3 was not in line with the others.

DISCUSSION

3.1 The 64 solenoid control valves were received in either an activated or non-activated position. The state of activation or non-activation was determined from micrometer depth measurements of the solenoid core position. All 18 valves which were received with a brass plug were found to be in the activated position. (This includes valve P13 for which measurement #3 was more than halfway between those valves with brass plugs and those without. It is considered that enough air pressure would have been available to the associated control butterfly valve to open it.) The remaining valves with rubber plugs or no plugs were in a non-activated position. It was established that the rubber plugs found on 22 of the valves played no role in the valve activation. The long period of immersion under sea water resulted in the emulsification of the valves lubricant, thereby causing sticking of the mechanism which could consequently be later determined as activated or non-activated.

3.2 From both optical and scanning electron microscopy analysis, it was determined that all 14 broken actuator rods failed from bending overload. No evidence of torsional overload was found.

3.3 Direct evidence of material transfer from the brass actuator rods onto the solenoid core surface was found for all 18 valves received with brass plugs. No such material transfer evidence was found on any other solenoid core. The deep circular imprints observed on four solenoid cores from valves other than those received with brass plugs was made with a device of a harder material than the iron solenoid core, thereby causing some deformation of the core surface. These deep circular imprints were found to be of a smaller diameter than those made by the brass actuator rods. The force required to activate a valve manually was very small, and only a few seconds (5 to 10) would be required to fully activate the valve manually, once the actuating rod was in place.

3.4 Analysis of the debris materials found inside the valves revealed that they were a direct result of the valves having been submerged at the bottom of the sea for a long period of time, and were not present prior to the accident.

3.5 Testing of the valves demonstrated that they were all serviceable prior to the accident.

3.6 Pressure testing of the valves showed that minimum leakage was present under applied operational pressure.

Valves Port	Measurement #3 (inches)	Valves Starboard	Measurement #3 (inches)
P1	0.522		
P3	0.527		
P4	0.524		
P5	0.525		
P6	0.516	S4	0.522
P7	0.525	S5	0.599
P8	0.523	S11	0.531
P9	0.525	S12	0.526
P10	0.529	S13	0.526
P17	0.524	S17	0.536
P18	0.528	S18	0.519
P19	0.536	S19	0.531
P20	0.529	S20	0.540
P21	0.524	S21	0.519
P22	–	S22	0.525
P23	0.533	S23	0.522
P24	0.527	S24	0.520
P25	0.525	S25	0.527
P26	0.515	S26	0.519
P27	0.522	S27	0.525
P28	0.514	S28	0.528
P29	0.529	S29	0.528
P30	0.522	S30	0.521
P31	0.498	S31	0.525
P32	0.533	S32	0.526
Average	0.524 inch	Average	0.529 inch

TABLE 4
MICROMETER MEASUREMENTS FOR VALVES WITHOUT BRASS PLUGS

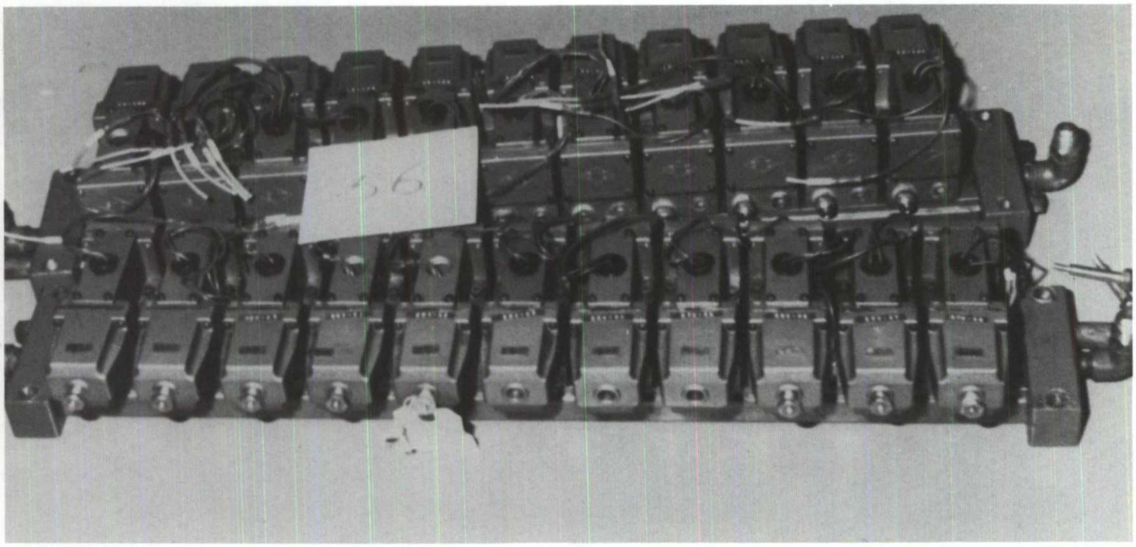
(Refer to Photo 14 for location of measurement #3).

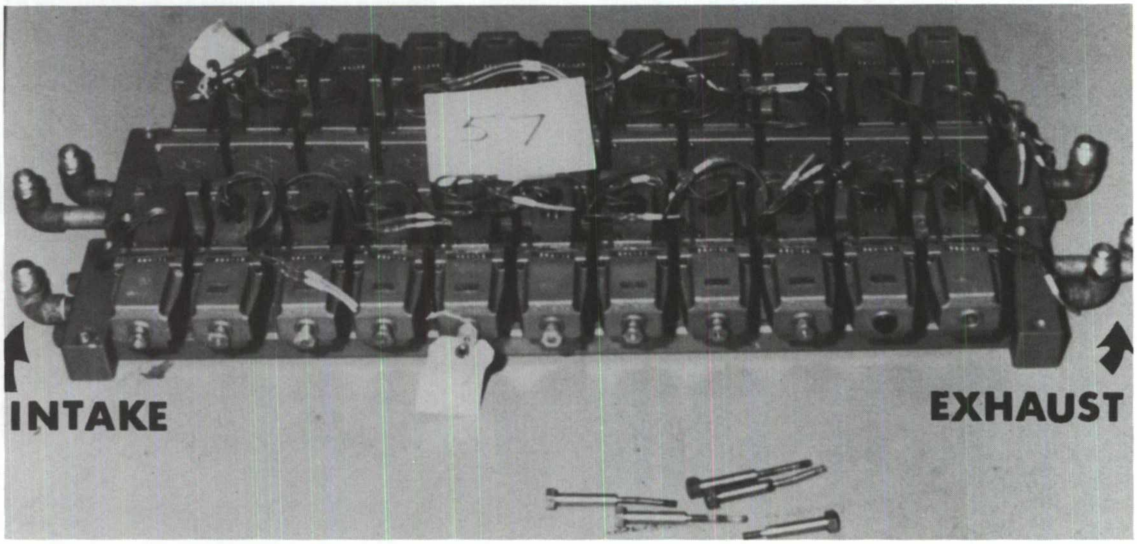
Average value of all measurements: 0.526 inch

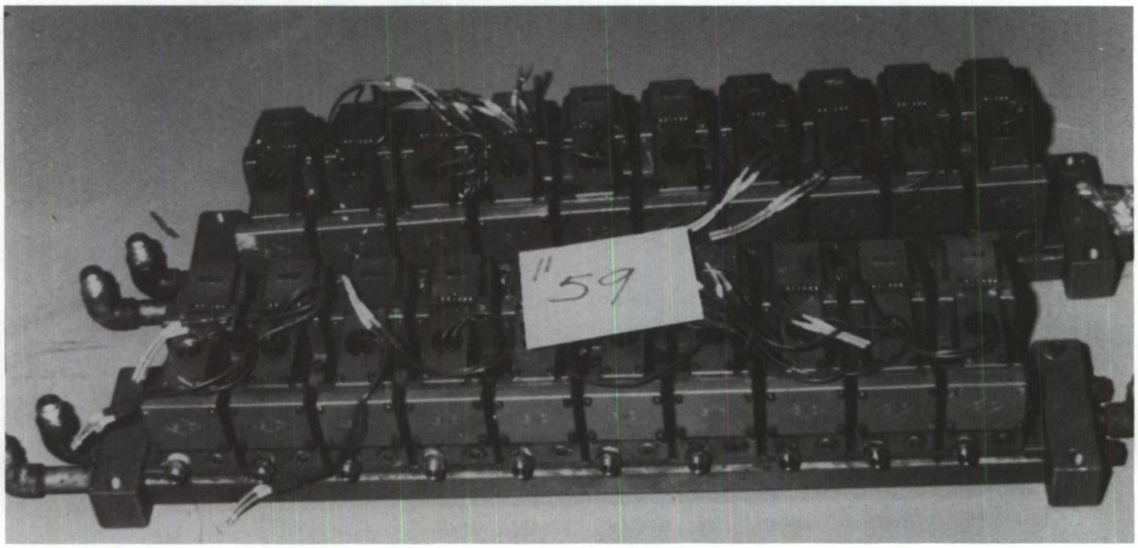
CONCLUSIONS

4.1 In response to the Royal Commission's specific questions (refer to Paragraph 1.2, questions (a) through (i) respectively):

a) there was positive evidence that all those valves found with brass plugs inserted had been manually operated;
b) the rubber plugs found on 22 of the valves were slit crosswise to prevent pressure differential buildup and could not have been pushed inside the valve solenoid housing, nor were any so found;
c) only those solenoid control valves received with brass plugs were found in the activated position. They were concluded to be the only valves manually activated at the time of the accident;
d) all of the valves received with brass plugs exhibited some material transfer from the rods onto the solenoid core faces. None of the valves received without brass plugs exhibited such material deposits. Manipulation of the brass plugs and actuator rods from one valve to the other would have resulted in some of the valves received without brass plugs exhibiting some similar brass markings, since these would not wash away from the solenoid core surface during immersion on the sea floor. Hence, it may be concluded that none of the valves received without brass plugs had been manually operated during the accident sequence. The imprints found on P10, S11, S12 and S13 solenoid core faces were most likely the result of testing prior to the accident with a non-brass rod, and therefore are not considered to be related to the accident;
e) the debris materials found inside the valves were a direct result of the valves submersion in sea water for a long period of time. No evidence was found that any of this debris was present prior to the accident and caused a valve malfunction;
f) the inserted actuator rods held each valve mechanism into an activated position during the accident. Once submerged, the salt-water emulsified the valves' lubricant, causing the valve mechanism to stick. This prevented the manually activated valves from returning to a non-activated position once their brass actuator rod was removed. Since none of the valves received without brass plugs were found in an activated position, it can be concluded that they were either not activated at the time of the accident, or that their mechanism returned to a non-activated position as soon as their electrical power supply was removed;
g) no leakage of any significance was found during testing of the valves using the normal operating air pressure;
h) testing of the valves indicated that they were serviceable prior to the accident;
i) the broken actuator rods all failed through bending overload, and were considered most likely to have all been broken when the solenoid valve banks were being retrieved from the wreckage, and not prior to or during the accident.







PHOTOS 1-3 The six solenoid valve banks as received. The manifold intake and exhaust ends are indicated in the centre photograph.

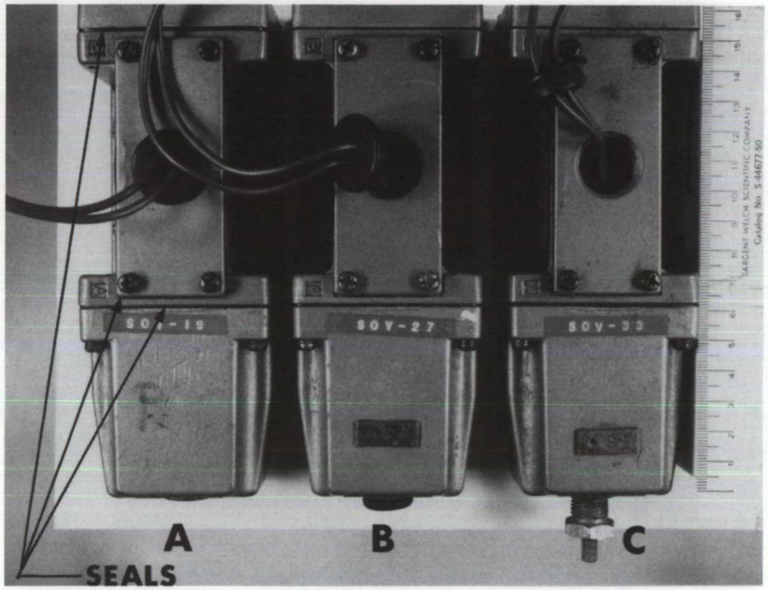


PHOTO 4 Samples of solenoid valves: without rubber plug or brass plug, *A*, with a rubber plug, *B*, with a brass plug and actuator rod remnant, *C*. Note brass plate lettering and plastic label tapes.

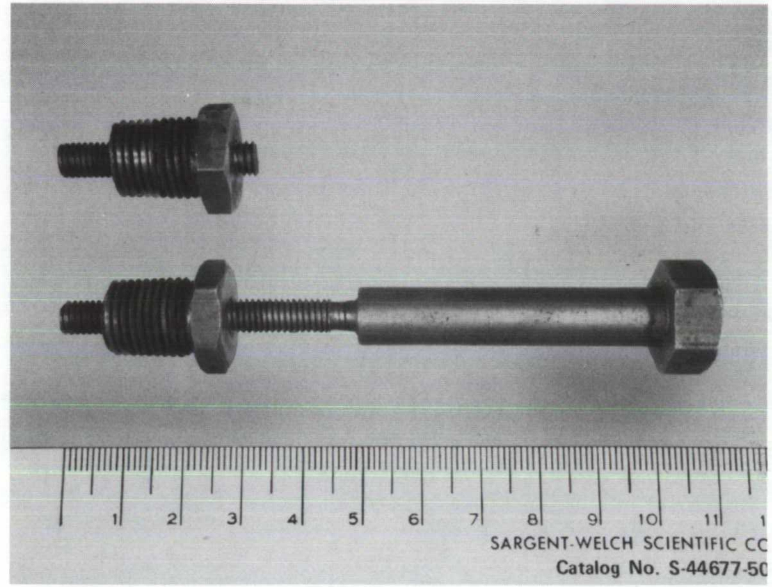


PHOTO 5 A broken and intact actuator rod, inserted into a brass plug.

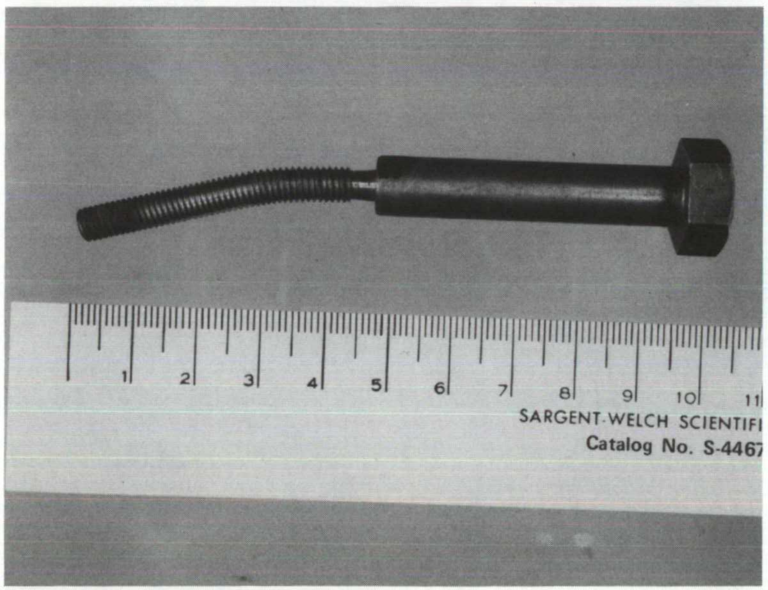


PHOTO 6 A bent actuator rod, as received.

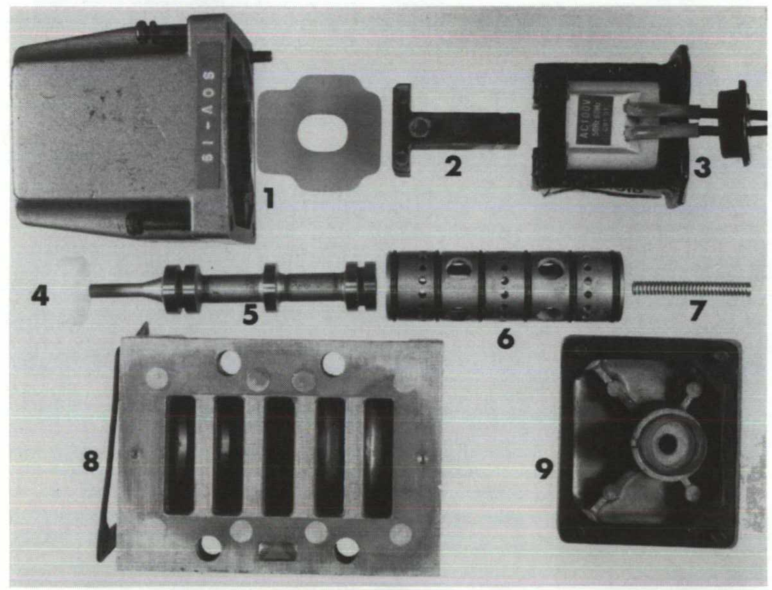


PHOTO 7 The various solenoid valve components: 1) front cover and gasket 2) solenoid core 3) solenoid 4) plastic keeper 5) spool 6) sleeve 7) spring 8) main valve body 9) back plate and gasket.

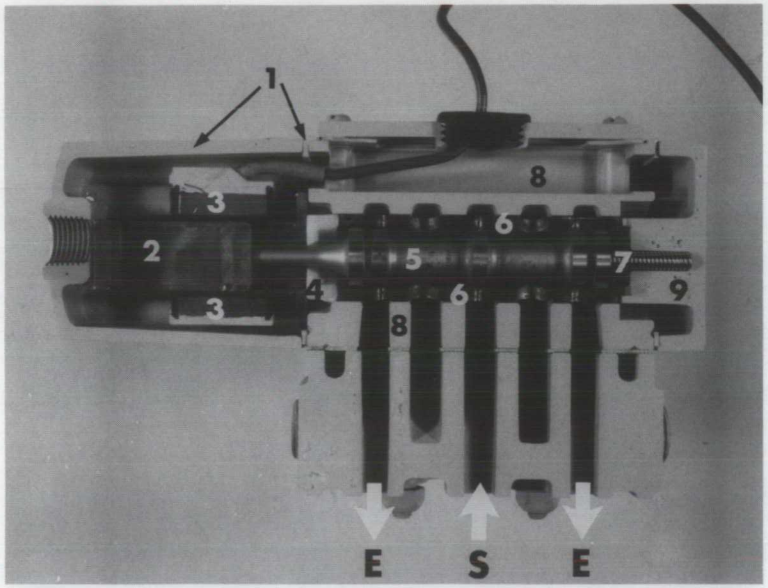


PHOTO 8 Cross-section of a valve, illustrating the internal mechanism. The same numerical identification as in photo 7 is used. The air supply and two exhausts are respectively arrowed as *S* and *E*.

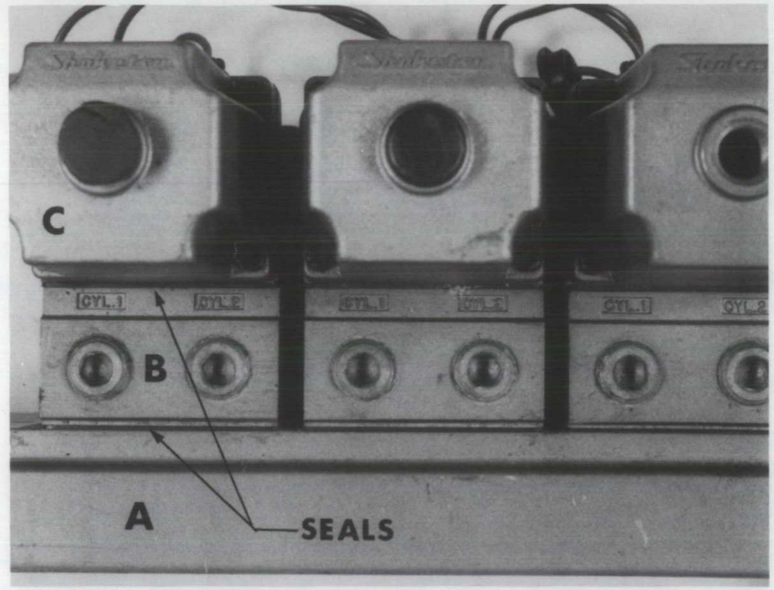


PHOTO 9 Typical assembly of a solenoid valve bank: manifold *A*, sub-plate *B* and valve *C*. Note the rubber plugs on two of the valves.

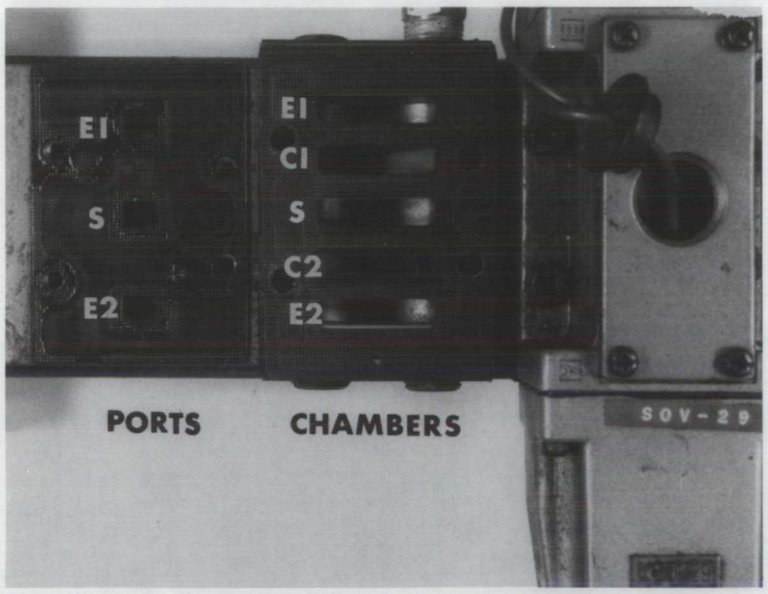


PHOTO 10 The manifold ports and the valve and sub-plate chambers are identified on this photograph.

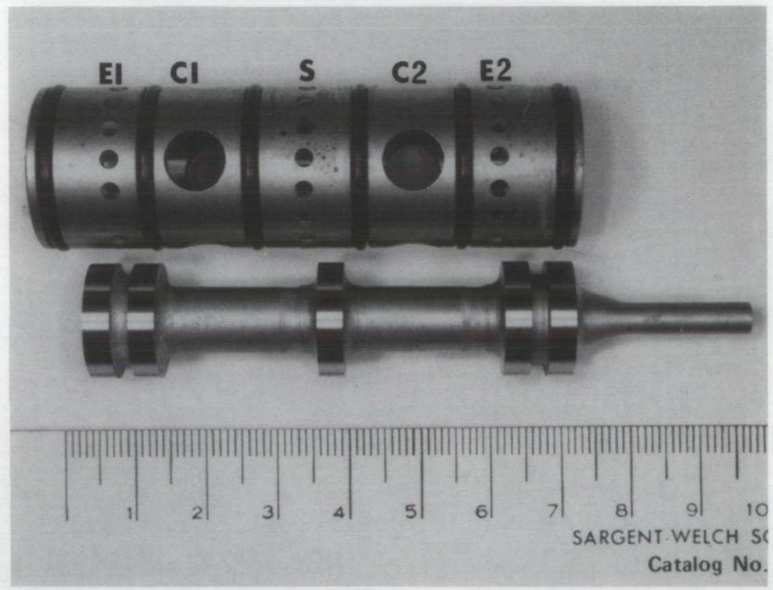


PHOTO 11 The sleeve and spool are shown separated but aligned, in the non-activated valve position. The relationship between the sleeve and the valve chambers is indicated by E1, C1, S, C2, and E2.

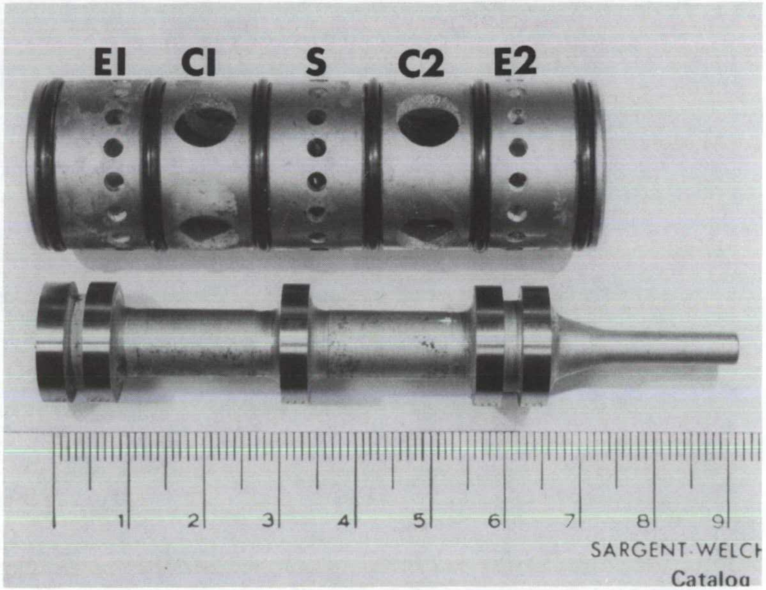


PHOTO 12 The sleeve and spool are shown separated but aligned, in the activated valve position. The relationship between the sleeve and the valve chambers is indicated by E1, C1, S, C2 and E2.

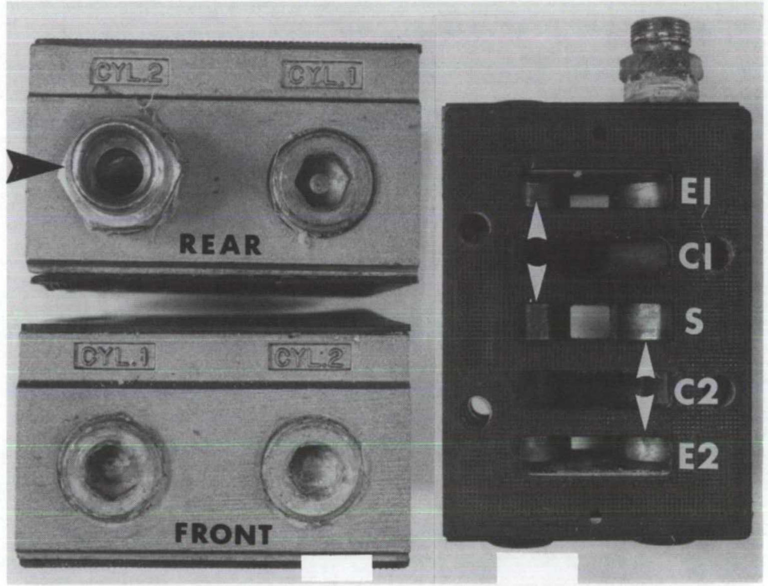
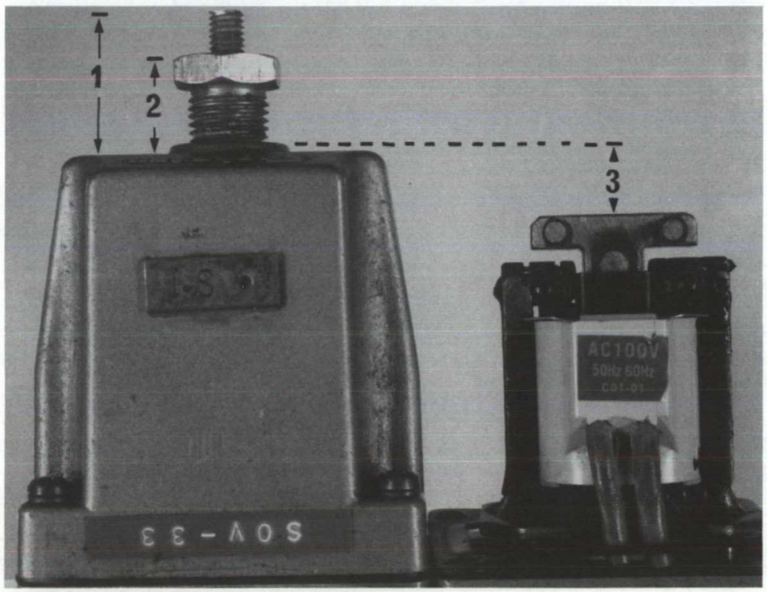
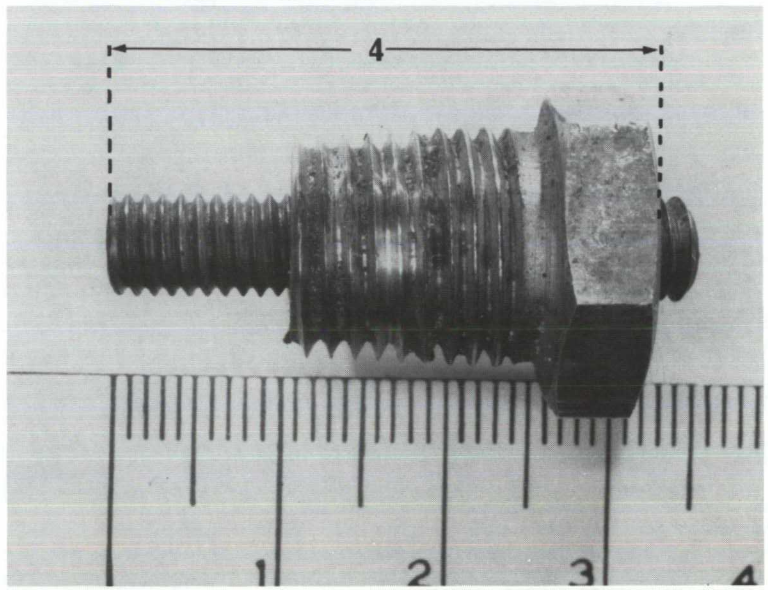


PHOTO 13 The sub-plate front and rear view are shown on the left. The arrow points to the only opened exhausts. The sub-plate top view with the air flow direction from *C1* and *C2* is shown on the right.





PHOTOS 14-15 The four micrometer measurements compiled in tables 3 and 4 are shown here with the reference numbers used in those tables.

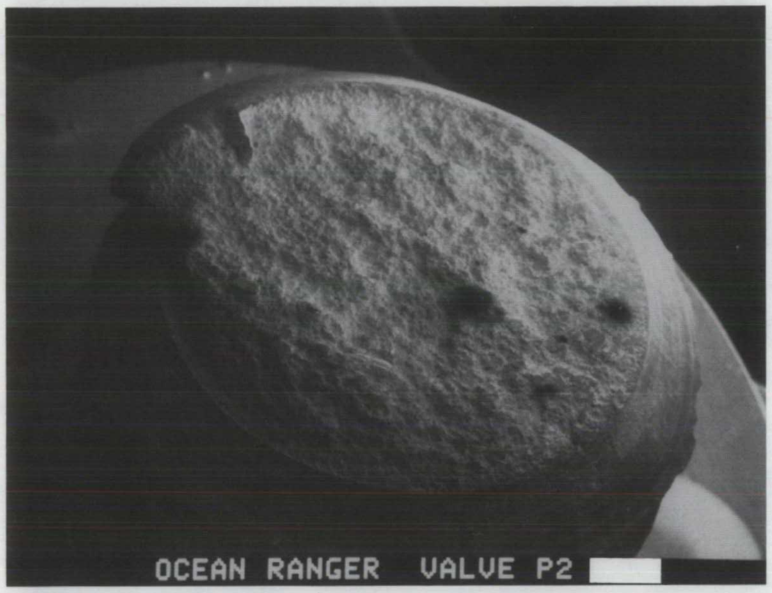


PHOTO 16 SEM photograph showing a typical fracture surface observed in all of the 14 broken actuator rods.

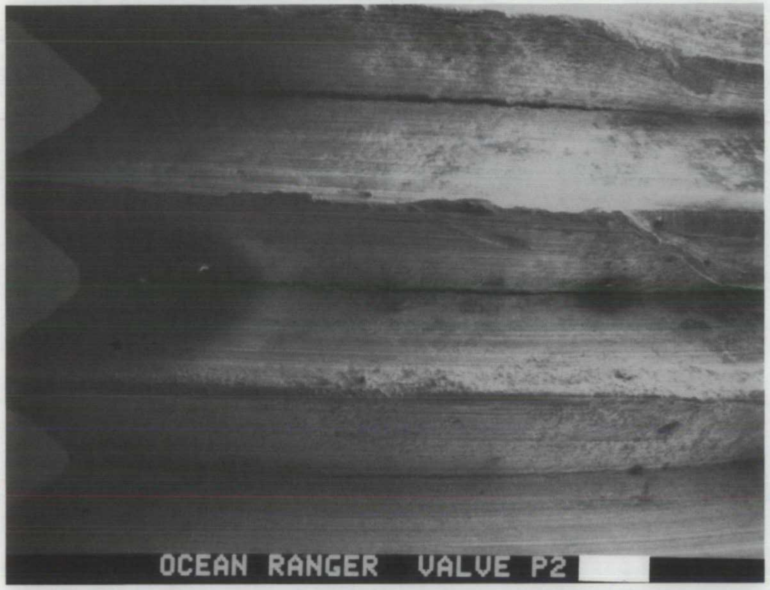


PHOTO 17 SEM photograph showing cracks observed in the thread roots of a failed actuator rod. This was typical for all 14 broken actuator rods examined.

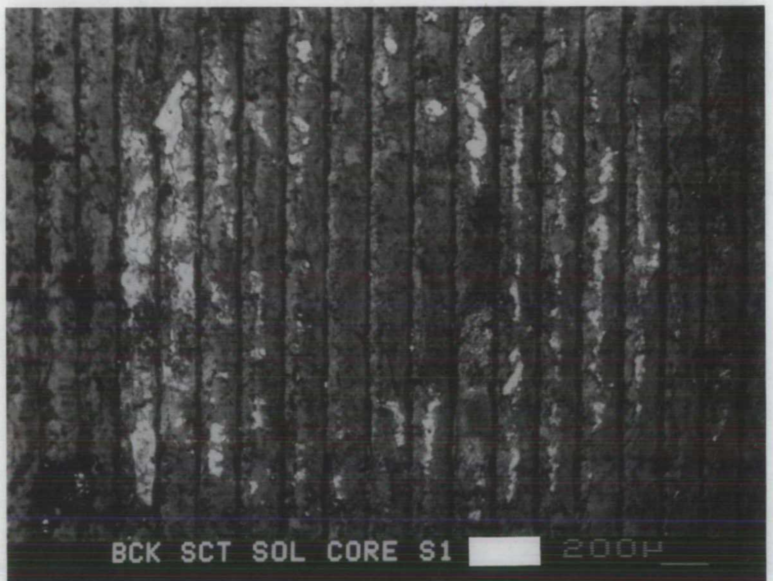


PHOTO 18 Scanning electron micrograph showing a typical brass marking observed on the solenoid core face of valve S1.

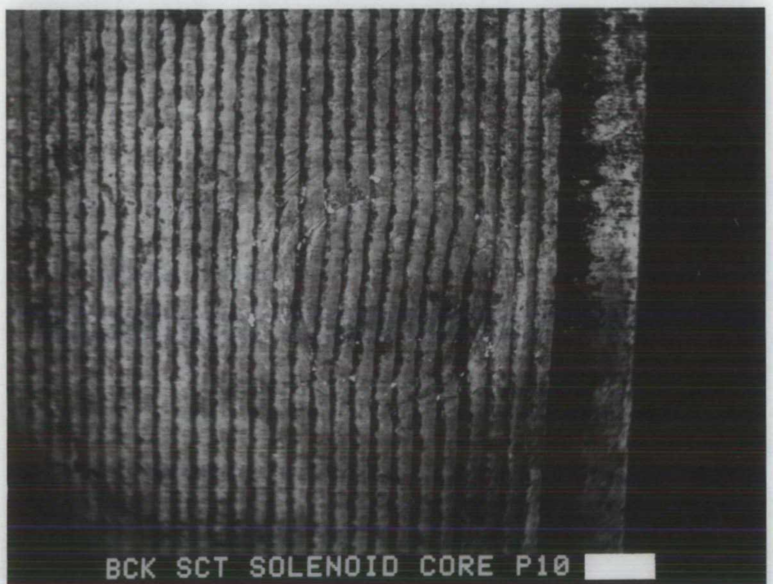


PHOTO 19 Scanning electron micrograph showing a typical imprint as observed on the solenoid core faces of valve P10, S11, S12 and S13.

ARRANGEMENT OF THE 64 SOLENOID VALVES UNDER THE BALLAST CONTROL CONSOLE INDICATING THE CONDITION AS FOUND

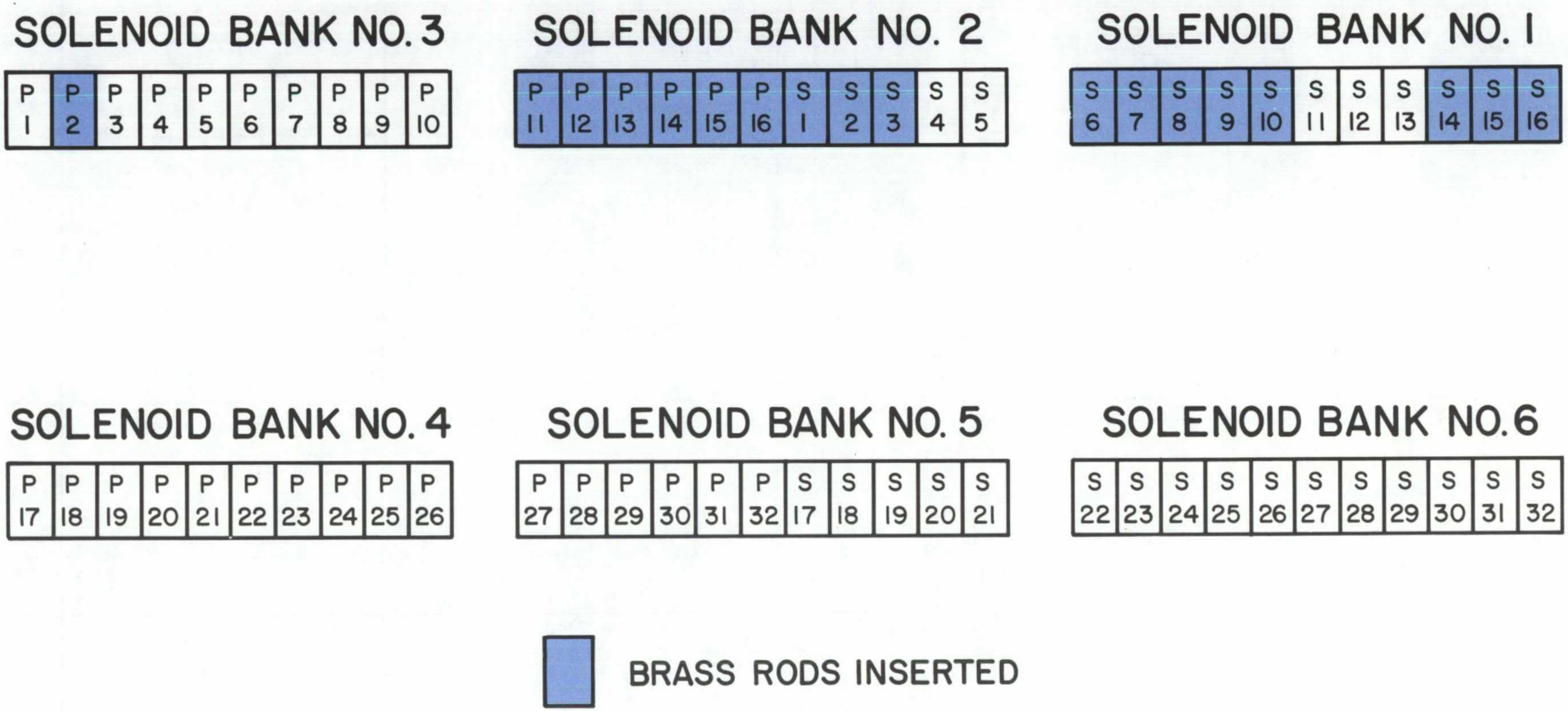


FIGURE 1

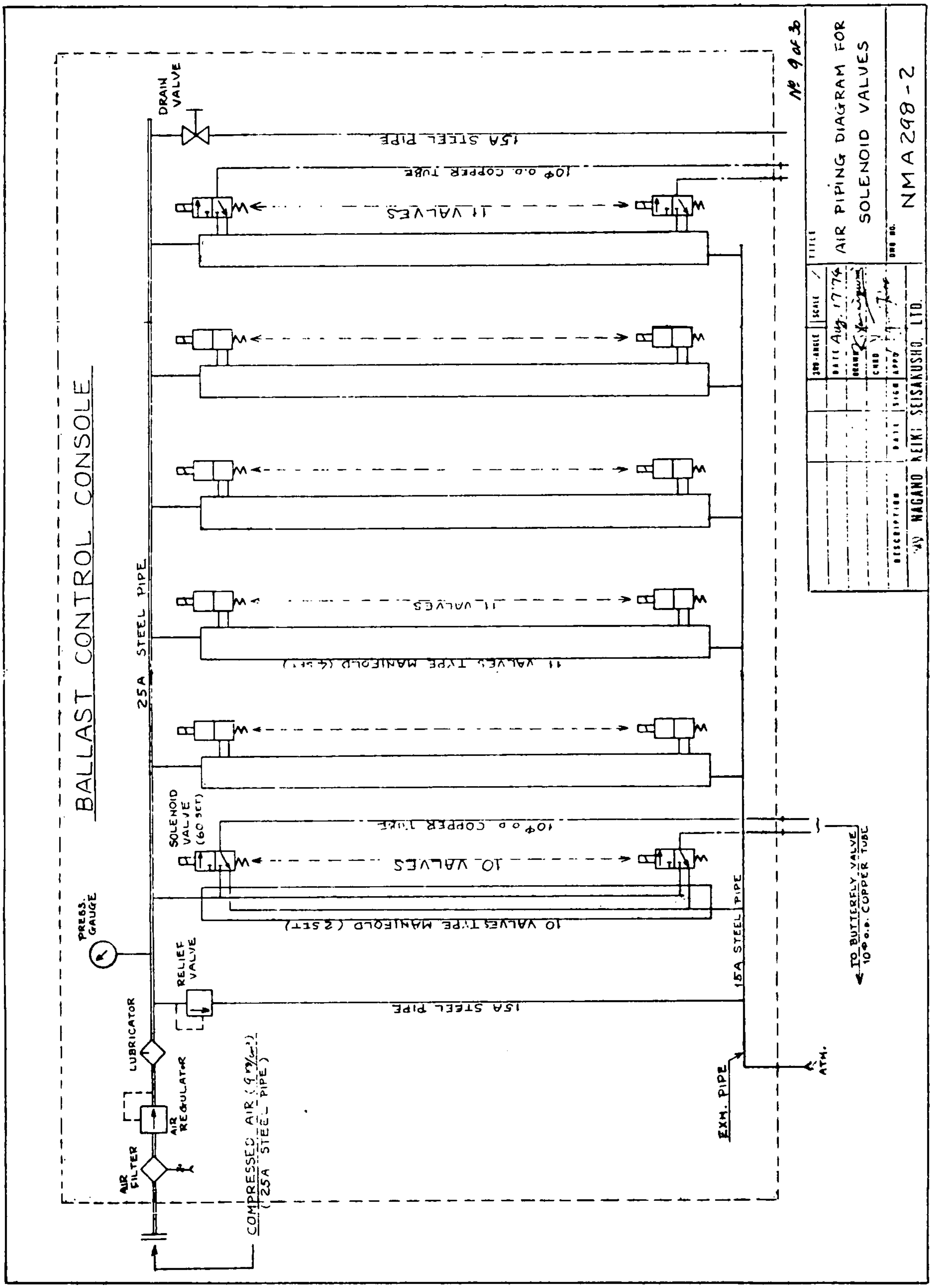

BALLAST CONTROL CONSOLE
AIR PIPING DIAGRAM FOR SOLENOID VALVES
NMA298-2
NAGANO KEIKI SEISAKUSHO, LTD.
DRAIN VALVE
15A STEEL PIPE
10φ o.d. COPPER TUBE
11 VALVES
25A STEEL PIPE
11 VALVES TYPE MANIFOLD
SOLENOID VALVE (60 SET)
10 VALVES
10 VALVE TYPE MANIFOLD (2 SET)
PRESS. GAUGE
RELIEF VALVE
15A STEEL PIPE
LUBRICATOR
AIR REGULATOR
AIR FILTER
COMPRESSED AIR
(25A STEEL PIPE)
EXH. PIPE
ATM.
TO BUTTERFLY VALVE
10φ o.d. COPPER TUBE

FIGURE 2

REPORT "D"
ENGINEERING REPORT EP 331/83
BALLAST CONTROL MIMIC PANEL ANALYSIS
8 September 1983

INTRODUCTION

1.1 The Royal Commission investigating the *Ocean Ranger* Marine Disaster requested the Aviation Safety Engineering (ASE) Facility, of the Aviation Safety Bureau, Transport Canada to assist in the investigation by conducting certain tests and analyses on the ballast control mimic panels recovered from the sunken rig.

1.2 The four panels received are shown in Photos 1 to 4. These photos were taken on the diving vessel shortly after being retrieved from the *Ocean Ranger* ballast control room in July 1982. At that time the panels were hosed down with fresh water and then sprayed with WD-40 to remove as much water as possible in order to try and prevent further corrosion of the switches. On receipt of the four panels by ASE, from the Royal Commission, the following was specifically requested:

1) photograph and identify all control and pump switches and manual valve indicators prior to any testing;
2) examine all switches and indicators for any evidence of burning or charring;
3) examine all switches and indicators for any evidence of arcing across light bulb contacts;
4) record the number of light bulbs in each switch and indicator and determine whether they are operative or not;
5) examine in detail for any evidence of arcing on the contacts of the microswitches contained in the following switch assemblies: port/starboard switches 1 to 16 inclusive, 20, 27, 30 and 32.

EXAMINATION

2.1 The four panels recovered and forwarded to the ASE facility were the port and starboard tank valve mimic panels and the port and starboard pump room mimic panels as shown in Photos 1 to 4 and described in drawings NMA298-1-1 and 2 attached as Figures 3 and 4.

2.2 The tank mimic panels contained normally 16 pairs of micro command switches numbered 1 to 16 each. It was noted that switches P-2 and P-8 were missing. The pump room panels contained 16 pairs of micro command switches, 10 pairs of indicators and 6 pairs of pump switches which were identified by pump function. Indicator S-35 and the lampholder of switch P-17 were found missing. Also 10 of the 12 red pump stop buttons and 4 of the 12 green pump run buttons were missing, however their light bulbs were still in situ. This is all evidenced in Photos 1 to 4.

2.3 The panels had routing diagrams engraved on them relating each switch and indicator function to the ballast control system in a schematic way, see drawings NMA298-1-1 and 2, Figures 3 and 4.

2.4 The panels appeared to be relatively clean and undamaged. Little or no corrosion was found on the exterior of the switches, its terminals and wiring. The panels themselves were made of stainless steel and were not affected by corrosion. However, the paint which highlighted the engraved lines of the mimic piping diagram was peeled loose in several places as is evident in Photos 2 and 4. Only one switch (P-19) was found to be damaged by sparking and burning around its terminals. This switch is shown in Photo 5. No evidence of soot or blackening (typically the result of burning or sparking) could be found anywhere on the panels except that found on switch pair P-19.

2.5 The wiring for all switches and indicators on the panels was of the same type. It appeared to be 18 gauge with PVC insulation. The insulation was grey in color and much heavier and stiffer than is considered normal for this type of application.

2.6 Each switch pair had 10 soldered connections on 8 terminals and the indicators 5 connections on 4 terminals. The pump switch pair had screwed on lug terminals counting 12 connections on 8 terminals. This gives a total 740 soldered connections on 96 terminals. All terminal connections were exposed as is evident from Photos 5 to 9 which show the back (or underside) of the panels.

2.7 The switches removed from the panels were identified as follows: 62 pairs of micro command switches part number MCN-22-M10, 19 pairs of indicator lights part number MCN-23 both manufactured by IZUMI Denki of Japan; 12 pump switches "red" part number LS-4031E-11R, and 12 pump switches "green" part number LS-1031E-11G both manufactured by Tokyo Denki of Japan. The micro command switches and indicators were designed to accommodate two light bulbs each. However, they were all wired for only one light bulb each. After removal from the panel all switches were photographed in profile on 35 millimeter slides. These slides will be submitted to the Commission with this report.

2.8 The micro command switch construction is depicted in Figure 1. The switch pair as part of the butterfly valve control system is shown in Figure 2 in schematic form. It is indicated by the two areas enclosed by dash lines. From this schematic it is evident that the light bulbs and microswitches of the switch pair are in separate circuits and only relate to each other through the butterfly valve limit switches and the relay contacts.

2.9 Microscopic examination of all light bulb contacts did not reveal any evidence of arcing or burning. Some minor corrosion was found on most contacts; however, this could be attributed to the panels' six month submersion in salt-water. Except for switch pair P-19 none of the valve switches showed any evidence of damage.

2.10 Detailed microscopic examination of the 76 Burgess V4T6 microswitches removed from the micro command switch pairs P1 to 16, 20, 27, 30 and 32 (switches P-2 and P-8 were missing) and S1 to 16, 20, 27, 30 and 32 did not reveal any evidence of arcing on their contacts. Photo 10 shows one of these microswitches with part of its casing removed to reveal its mechanism. All these microswitches were photographed, revealing their mechanism, on 35 mm slides. These slides will be submitted to the Commission with this report.

2.11 The Manual Valve Indicators port/starboard 33 to 41 (S-35 was found missing) were examined for any evidence of damage, such as charring, burning or arcing. No such damage was found on any of the 19 Indicators examined. The light bulb contacts revealed slight corrosion similar to the corrosion found on the switches.

2.12 The pump switches were of a much different design than the micro command switches, as is evident from Photos 11 and 12. A pump switch pair consisted of a momentary push button "run" switch, with a green indicator light which when depressed engaged a self-holding relay which switched "ON" the pump, a self-latching push button "stop" switch, with a red indicator light which when depressed released the relay and stopped the pump. The "stop" button had to be pressed again for the red light to go off and to allow the green run button to be effective. The 18 volt light bulb in the push button of these switches was powered directly from the 115 volt control circuit through a small transformer built into the switch just below the push button, as is evident in Photo 13. The actual switch mechanism was located at the bottom of the switch body, see Photo 13. No arcing or burning damage was found in any of the 24 pump switches in the panels.

2.13 The four panels normally contain one light bulb in each of the 152 switches and 40 indicators. Two switches and one indicator pair plus two light holders were found missing, making the total number of light bulbs examined 184. Of these 184 bulbs 80 were found to have fractured filaments. The analysis of these light bulbs is covered in ASE Report "E", (EP 332/83). All 80 blown light bulbs have been photographed on 35 mm slides and will be submitted to the Commission with this report.

2.14 Switch pair P-19 was the only component found damaged on the panels (except for the light bulbs). Only the "green" switch was damaged, as is evident in Photos 5 and 14. The "red" switch did not show any damage at all. The microswitch housing showed heat damage near the common terminal of the microswitch and a light bulb terminal which was burned off.

DISCUSSION

3.1 The burning of the "green" switch P-19 most likely occurred as a result of sea water ingestion causing a conductive pass between ground and the 115 volt circuit via the metal structural parts of the micro command switch, the metal panel and the 115 volt terminal. It is considered very likely that this switch is the very site where the 115 volts AC "leaked" into the 24 volt AC lamp circuit, causing 68 lights to burnout.

3.2 As is evident from Photo 13 the 18 volt secondary terminals and 115 volt primary terminals in the pump switches are very close together. When the panels were flooded, sea water most likely entered the pump switches at the transformer terminals and shorted the primary to the secondary contacts, leaking the 115 volts into the 18 volt light bulb and blowing the filament with an over-voltage. This occurred only at those pump lights which were lit.

CONCLUSIONS

4.1 All required photographs were made and will be submitted to the Commission with this report.

4.2 No evidence of burning, charring or arcing was found on any of the panels' components, except for the P-19 "green" switch.

4.3 All switches and indicators were wired for only one light bulb. None of them were found with light bulbs missing, except P-17. However, the lamp housings were also missing in this switch pair.

4.4 Eighty of the 184 light bulbs examined had blown filaments.

4.5 A detailed analysis of the light bulb failures is covered in ASE Report "E", (EP 332/83).

4.6 The lower part of the microswitch housing on switch "green" P-19 showed evidence of arcing damage and burning; probably as the result of sea water-assisted shorting between the 115 volt terminals and ground via metal structure in the switch body.

4.7 The shorting of switch "green" P-19 was most likely the site of leakage of the 115 volts into the 24 volt lamp circuit, causing the 68 light bulbs to blow.

4.8 No evidence of any arcing in any of the microswitches examined could be found.

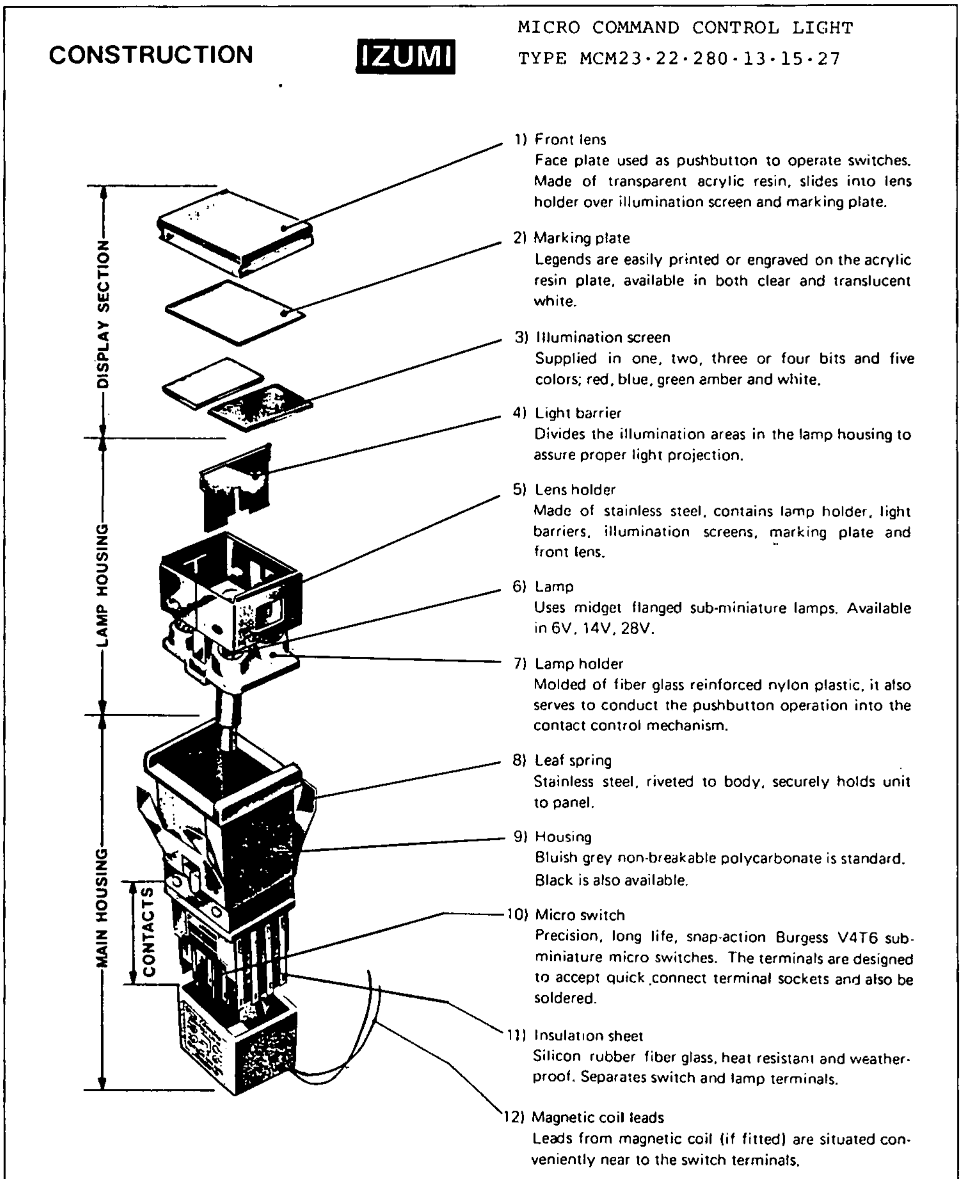


FIGURE 1

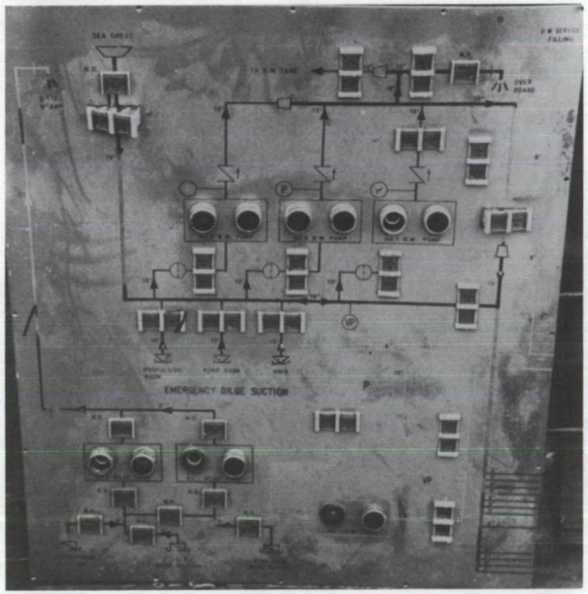


PHOTO 1 Pump room valve mimic panel (port side).

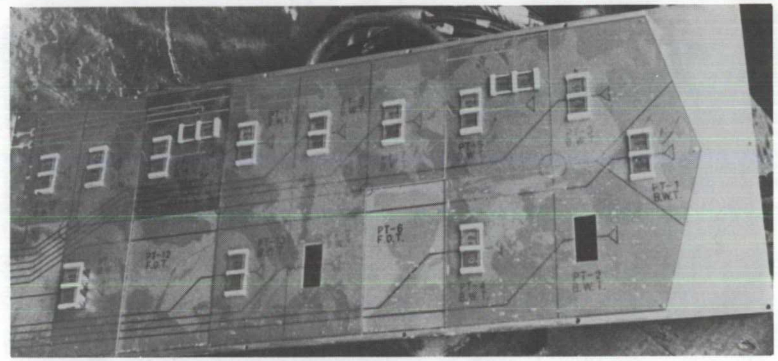


PHOTO 2 Tank valve mimic panel (port side).

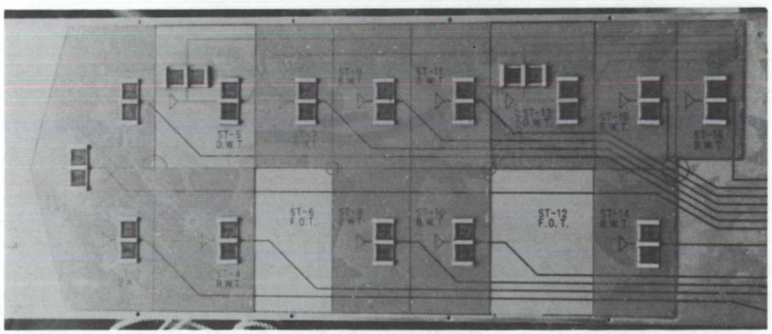


PHOTO 3 Tank valve mimic panel (starboard).

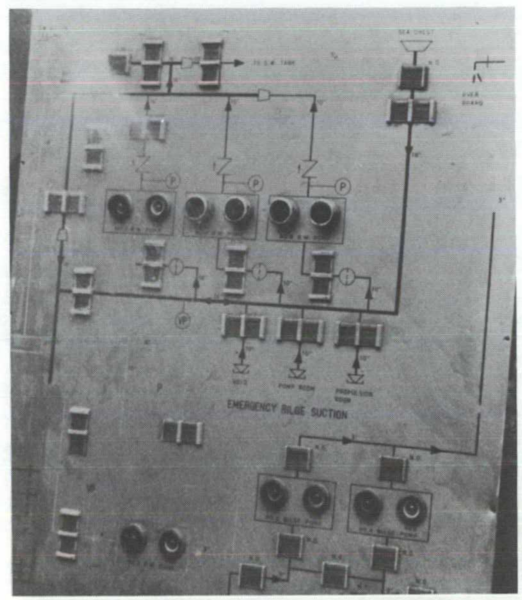


PHOTO 4 Pump room valve mimic panel (starboard).

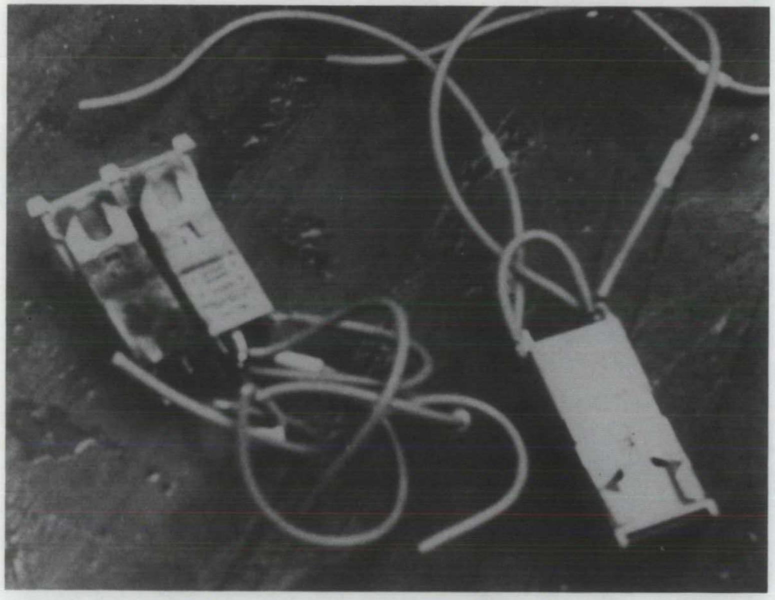


PHOTO 5 Switch P-19 showing sparking damage.

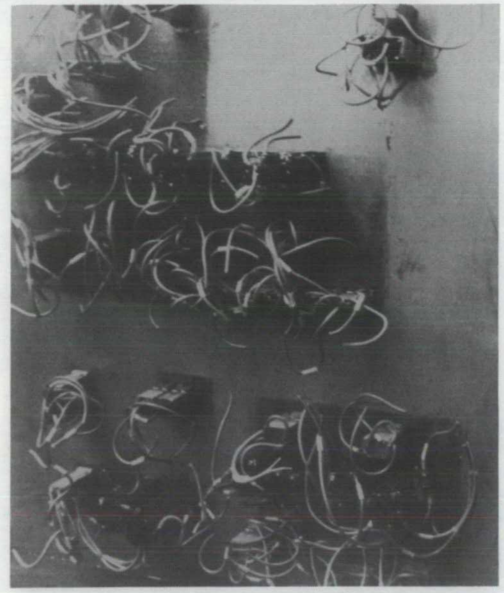


PHOTO 6 Bottom view of pump room valve mimic panel (port side).

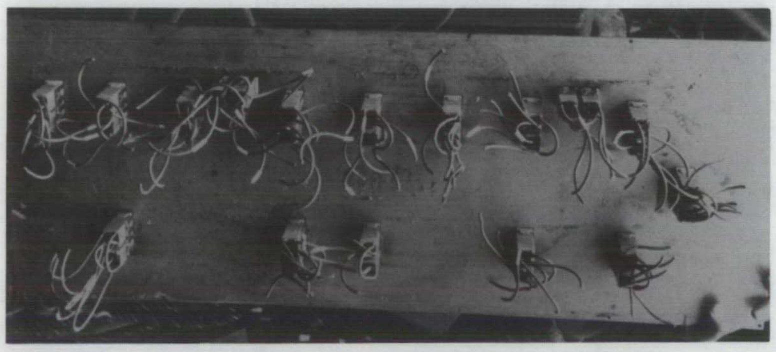


PHOTO 7 Bottom view of tank valve mimic panel (port side).

PHOTO 8 Bottom view of tank valve mimic panel (starboard).

PHOTO 9 Bottom view of pump room valve mimic panel (starboard).

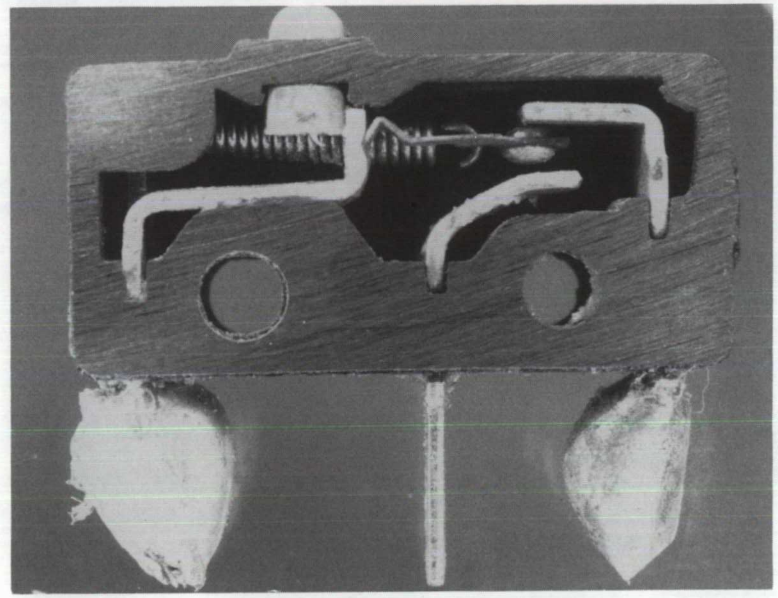


PHOTO 10 Micro switch *Burgess V4T6* revealing interior mechanism and contacts.

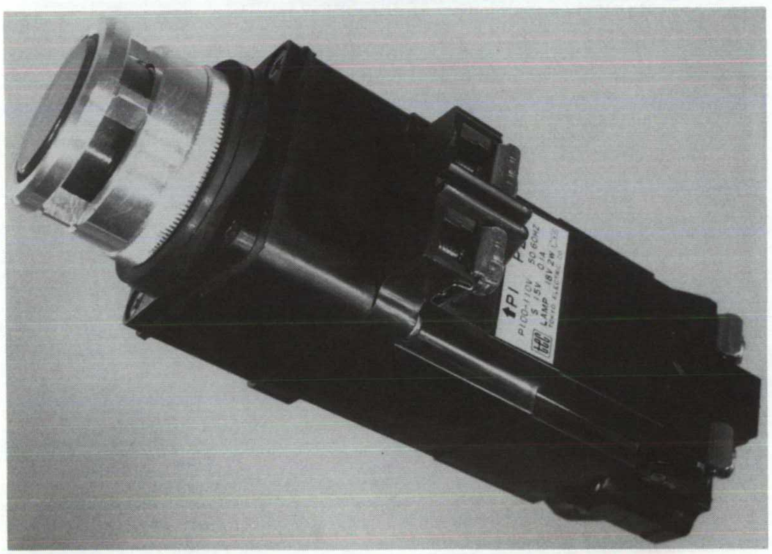


PHOTO 11 Pump switch *red.*

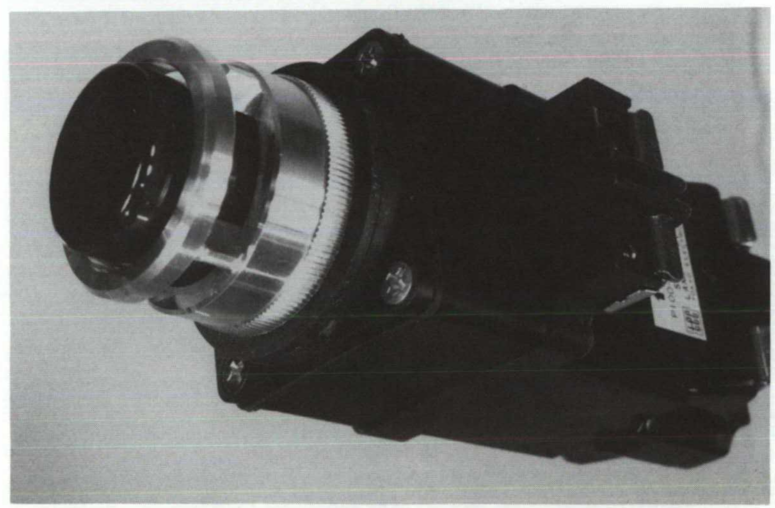


PHOTO 12 Pump switch *green.*

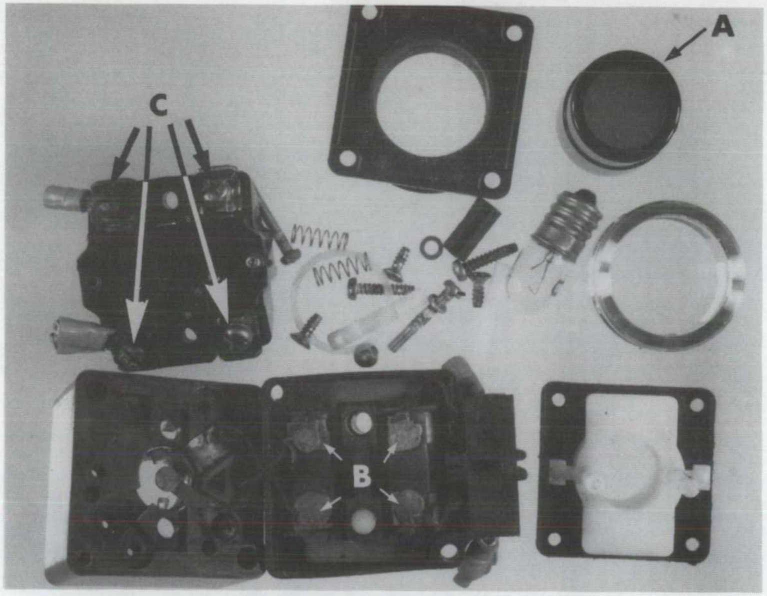


PHOTO 13 Pump switch components showing *A* push button, *B* transformer and *C* switch contacts.

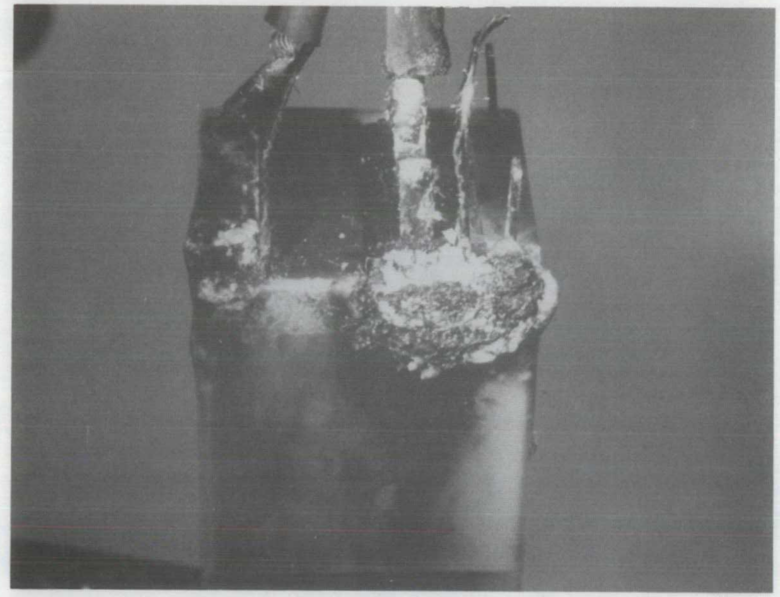


PHOTO 14 Detail of burned area on switch P-19.

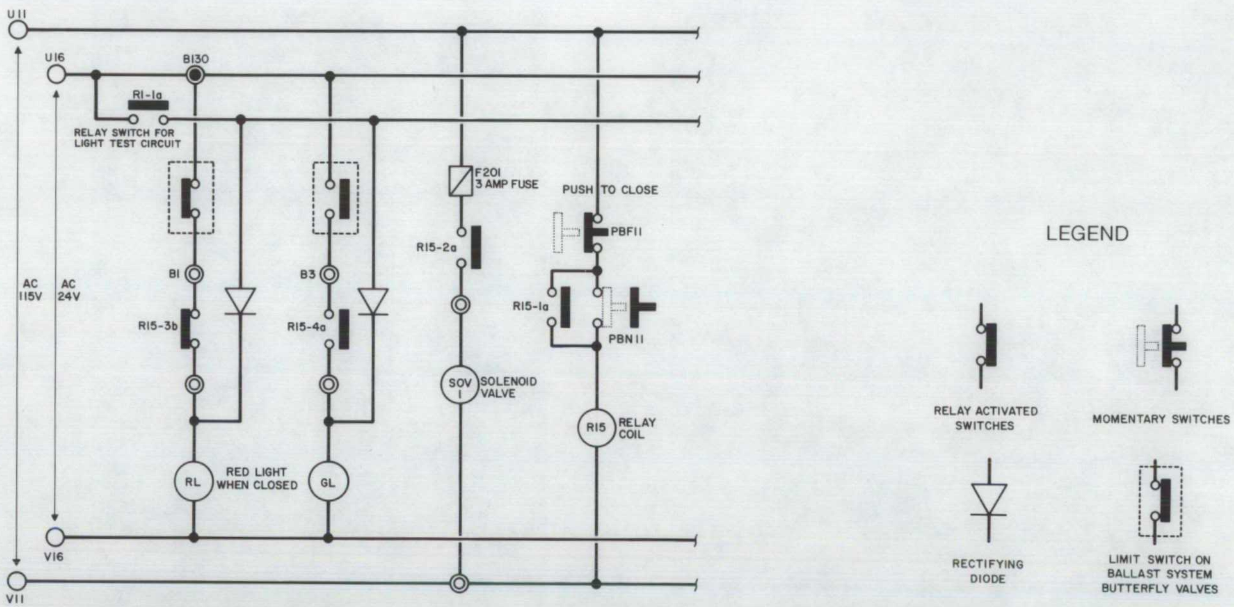


FIGURE 2

OCEAN RANGER MIMIC PANEL
(PORT SECTION)

PT	PORT TANK TANK	O	OPEN	N.O.	NORMALLY OPEN
B.W.	BALLAST WATER	C	CLOSED	N.C.	NORMALLY CLOSED
D.W.	DRILL WATER	S	STOP	P	PRESSURE TRANSMITTER
F.O.	FUEL OIL	R	RUN	VP	VACUUM PRESSURE TRANSMITTER
S.W.	SALT WATER				

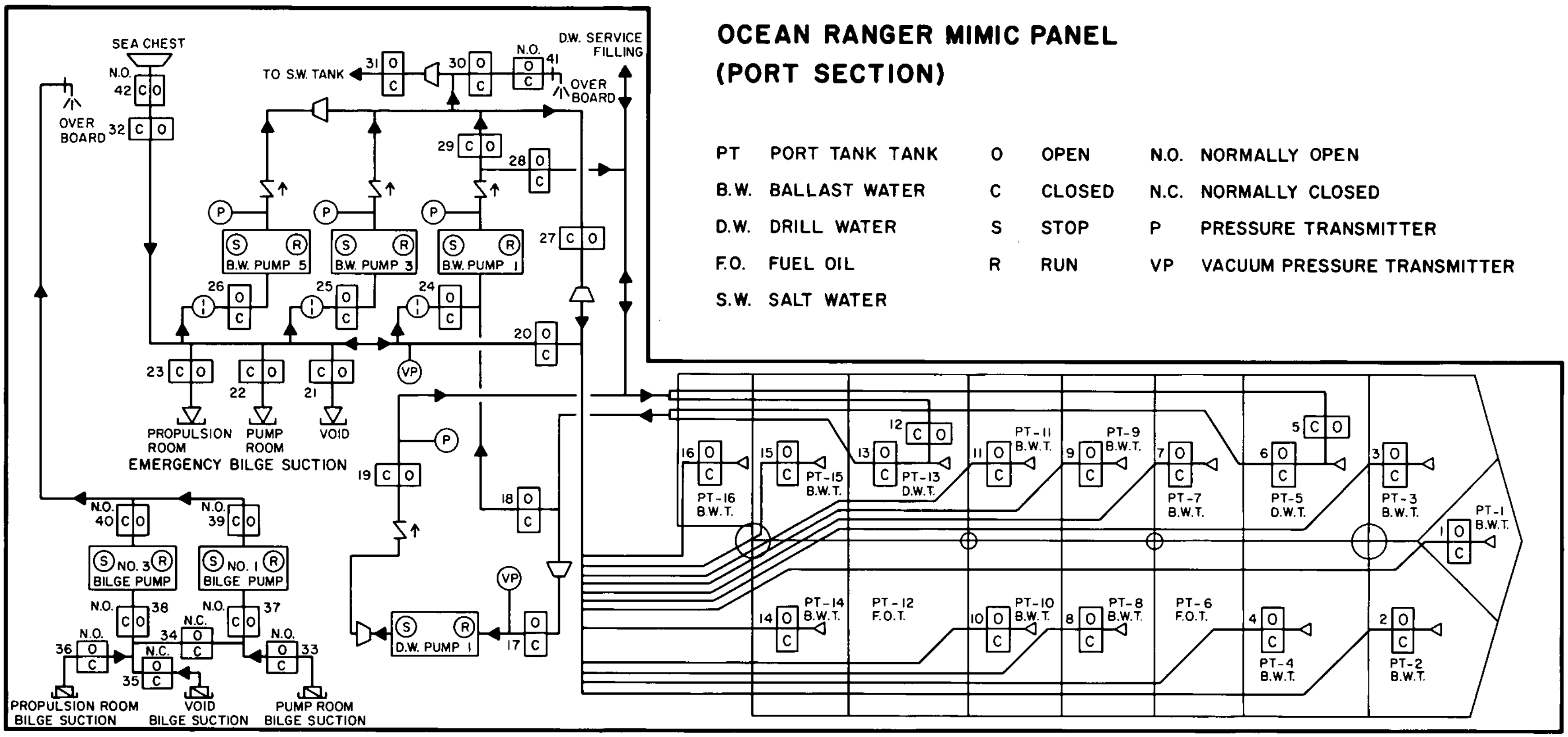


FIGURE 3

OCEAN RANGER MIMIC PANEL
(STARBOARD SECTION)

ST	STARBOARD TANK	O	OPEN	N.O.	NORMALLY OPEN
B.W.	BALLAST WATER	C	CLOSED	N.C.	NORMALLY CLOSED
D.W.	DRILL WATER	S	STOP	P	PRESSURE TRANSMITTER
F.O.	FUEL OIL	R	RUN	VP	VACUUM PRESSURE TRANSMITTER
S.W.	SALT WATER				

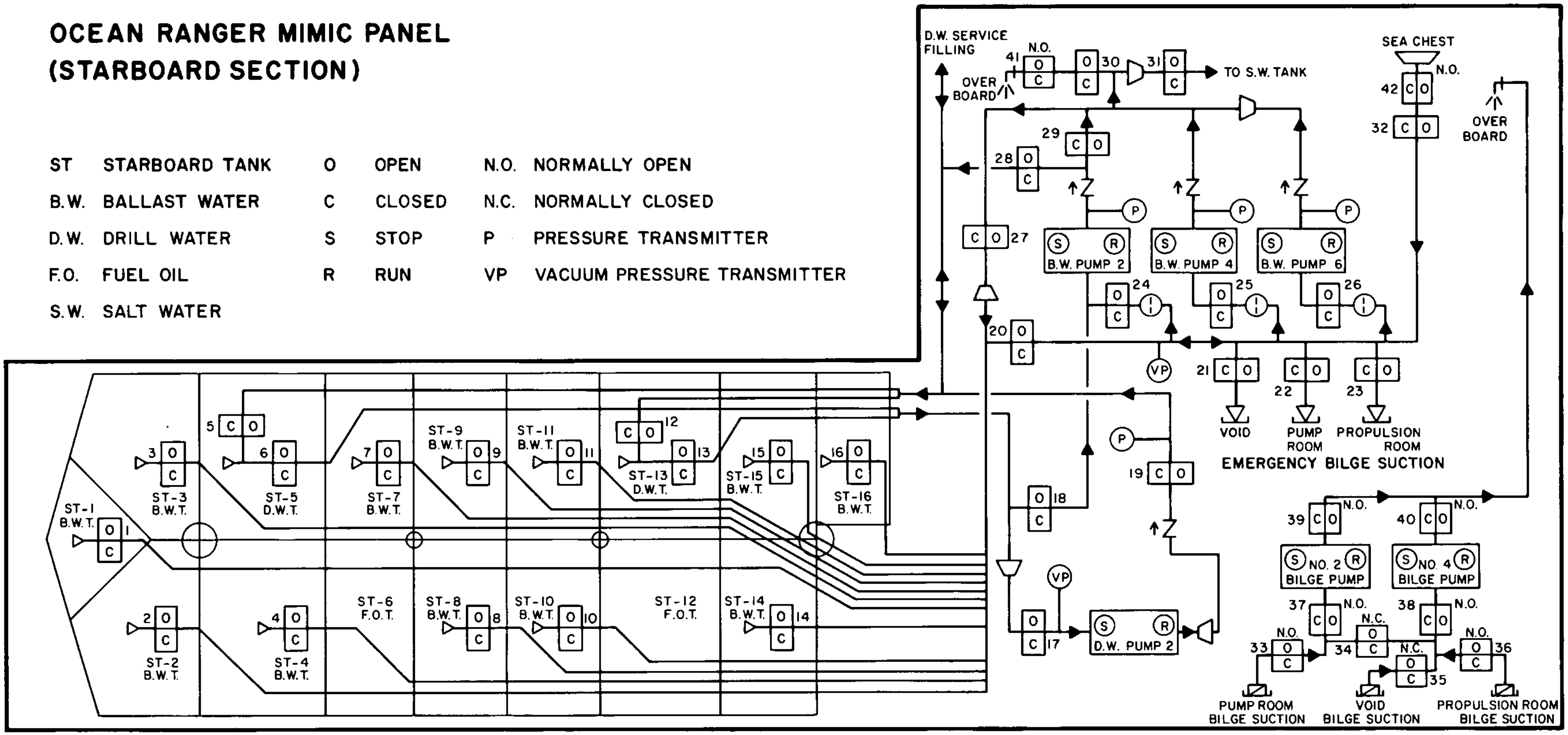


FIGURE 4

REPORT "E"
ENGINEERING REPORT EP 332/83
BALLAST CONTROL PANEL LIGHT BULB ANALYSIS
8 September 1983

INTRODUCTION

1.1 The Royal Commission investigating the *Ocean Ranger* Marine Disaster requested the Aviation Safety Engineering (ASE) Facility, of the Aviation Safety Bureau, Transport Canada to assist in the investigation by conducting certain tests and analyses on the light bulbs which were removed from the *Ocean Ranger* control panel to determine which bulbs remained functional and which bulbs had experienced damage.

EXAMINATION

2.1 For purposes of analysis, the light bulbs from the control panel were divided into four groups: the port side valve light bulbs labelled P1 through P42, the starboard side valve light bulbs S1 through S42, the port pump lights and the starboard pump lights. The port and starboard valve lights numbered 1 to 42 are housed in switch or indicator assemblies that have a capacity of four bulbs each. Most of the assemblies contained only two bulbs each, one to illuminate the red translucent function plate "closed" and one to illuminate the green translucent plate "open". In the assemblies that contained more than two bulbs only two were wired into the circuit. Therefore the extra bulbs were not examined as part of the system. The port and starboard pump lights indicated which pumps were running by illuminating a green bulb while a red button indicated a stopped pump. The switch assemblies were wired for 24 volts to power the light bulbs and a 115 volt circuit ran alongside the 24 volt circuit to power the valve solenoids. The valve lights numbered 33 to 42 were manual valve indicator lights without switches, and were wired for 24 volts only.

2.2 The bulbs found on the panel were manufactured by various companies (Stanley and Chicago Miniature were most common) and were typically type 387. All of the bulbs found were considered acceptable for use in this application.

2.3 Examination of the bulbs included an optical microscopic evaluation of all filaments. This examination revealed that

TABLE 1

Valve Lights – Port and Starboard

SWITCH	COMMENTS
P3 Open	Fracture – Hot.
P3 Closed	Filament fused to glass in three locations, broken in three places.
P4 Open	Broken hot in one location and fused to glass.
P4 Closed	Broken hot and fused to glass.
P5 Closed	Broken hot and fused to glass in two places.
P6 Open	Broken hot and fused to glass.
P7 Open	Support posts and filament through glass.
P11 Closed	Filament fused to glass.
P12 Closed	Broken hot and fused to glass.
P13 Closed	Broken hot several fragments. Burnout due to combination of age and excessive voltage.
P14 Closed	Broken hot and fused to glass.
P15 Open	Brittle fracture.
P16 Closed	Broken hot and slight fusing.
P19 Closed	Broken hot filament.
P20 Open	Broken from each contact post. Failure probably hot.
P20 Closed	Broken near contact post. Failure probably hot.
P25 Open	(Data not included)
P25 Closed	Filament broken hot. Evidence of melt spots on filament and one brittle fracture.
P27 Closed	Broken hot.
P28 Closed	Filament through glass and support post through glass. Possible burnout.
P28 Open	Filament broken loose inside brittle failures.
P29 Open	Filament broken brittle and fusing.
P31 Open	Filament broken hot.
P33 Open	Broken hot near support post.
P34 Closed	Broken hot.
P35 Open	Broken hot, portions fused to glass envelope.
P35 Closed	Broken hot, pieces fused to glass.
P36 Closed	Broken hot between support posts.
P37 Open	Broken hot.
P38 Open	Several fragments of filament hot.

several of the light bulbs contained fractured filaments, Photo 1 and/or stretched filaments, Photo 2 and/or filaments fused to the glass envelope, Photo 3. All of the bulbs with any type of damage were subsequently examined in the Scanning Electron Microscope (SEM). In most cases of fractured filaments, the filament was broken near its contact post, which is an inherently weak spot in light bulb filaments. SEM analysis of the fracture surfaces revealed that most of the failures exhibited a smooth fracture surface, characteristic of a hot filament at the time of failure, except for eight of the fractures which appeared brittle. Photos 4, 5 and 6 show "hot" fractures or smooth fracture surfaces typical of those found in the *Ocean Ranger*. Table 1 contains a list of all of the bulbs examined that exhibited damage.

DISCUSSION

3.1 The "hot" fractures observed in nearly all of the broken filaments can typically occur as a result of three different mechanisms:

a) severe impact while incandescent;
b) burnout due to old age;
c) burnout due to over-voltage.

The fact that 43 percent of the bulbs failed and that no substantial impact would be expected to have occurred during the rig's sinking suggests that the bulbs were burned out due to over-voltage. Laboratory tests of General Electric type 327 bulbs (similar to the bulbs found in the *Ocean Ranger*) were carried out to determine the effects of high voltage. These tests revealed that the filaments fractured typically near one or both of the contact posts and the filament often fused to the glass envelope. The fracture surfaces were typically smooth and similar to those found in the *Ocean Ranger* control panel. The majority of the bulbs examined from the *Ocean Ranger* did not show signs of excessive age (severe notched appearance) which ruled out burning due to old age. High voltages in tests also caused areas of local filament stretch and as voltage levels were increased, the failures became more explosive, with filaments coming to rest fused to the glass envelope.

3.2 A simulation of the starboard side control panel shown in Photo 7 containing new General Electric type 327 bulbs was flooded with sea water to simulate observed damage to the control panel. The 24 volt circuit fuse blew shortly after and all the lights went out. After some time, lights began to flash

TABLE 1 – (CONT'D)

Valve Lights – Port and Starboard

SWITCH	COMMENTS
P41 Open	Broken hot.
P42 Open	Broken hot and aged.
S2 Closed	Filament fused to glass, water present, severely corroded.
S3 Closed	Filament broken. Support post fused to glass.
S5 Open	Filament broken and fused to glass. Failure looks brittle.
S8 Closed	Filament broken hot. Support touching glass. Evidence of local melting.
S13 Closed	Broken hot.
S14 Open	Possible burnout. Not fracture but stretch.
S14 Closed	Support posts fused. Hot fracture.
S15 Closed	Broken filament hot fused to glass.
S16 Closed	Evidence of local melting, fracture.
S17 Open	Broken hot.
S18 Closed	Broken hot.
S20 Open	Broken filament hot. Posts fused to glass.
S21 Closed	Broken hot.
S22 Closed	Broken hot.
S25 Closed	Broken hot. Fused to glass.
S28 Closed	Broken hot and one brittle fracture. Possible burnout.
S29 Open	Broken hot local melting.
S29 Closed	Broken hot and fused. Local melting.
S30 Closed	Broken hot and fused. Brittle failure found.
S31 Closed	Broken hot and fused.
S32 Open	Broken brittle and fused.
S32 Closed	(Data not included)
S33 Open	Broken hot.
S34 Open	Broken hot.
S34 Closed	Broken hot.
S37 Open	Broken hot.
S37 Closed	Broken hot.
S38 Open	Broken hot.
S39 Open	Broken hot.

on randomly with varying high intensity. Of the bulbs examined in the simulation panel approximately 80% revealed damage characteristic of a burnout due to over-voltage. Photos 8 and 9 show filaments from the simulation panel. Photo 8 shows filament stretch similar to that shown in Photo 2 from the actual panel. Photo 9 shows local enlargement of the filament cross section similar to the over-voltage test results depicted in Photo 10 and similar to Photo 4 of the actual panel. Local enlargement of the filament wire near the fracture was not as apparent in the actual *Ocean Ranger* bulbs, possibly because of the age of the filaments. It is possible that the 24 volt circuit blew and the 115 volt circuit arced with the aid of the water, causing the bulbs to see voltages well in excess of 24 volts in the actual *Ocean Ranger* panel as well as in the simulation panel. The light bulbs listed in Table 1 were probably subjected to voltage surges well in excess of 24 volts.

CONCLUSIONS

4.1 The light bulbs were considered to be standard light bulbs for this type of application on a 24 volt circuit.

4.2 The 76 bulbs listed in Table 1 appear to have suffered heat damage, probably due to voltage surges well in excess of 24 volts.

4.3 Eight of the bulbs in Table 1 contained both brittle fractures and evidence of fusing and melting, and were considered burned out also.

4.4 Twenty-three of the bulbs contained filaments and/or support posts fused to the glass envelope indicative of over-voltage or intense heat.

4.5 Figures 1 and 2 are diagrams of the *Ocean Ranger* panel showing the bulbs that were considered to be damaged due to over-voltage and Figure 3 contains a diagram of the simulation panel (starboard panel only) showing the bulbs that were damaged due to over-voltage.

TABLE 1 (CONT'D)

Pumplights—Starboard

SWITCH	COMMENTS
#2 B.W. STOP	Filament fused to glass.
#4 B.W. STOP	Aged and broken hot.
#6 B.W. RUN	Aged and broken hot.
#2 BILGE STOP	Aged broken hot.
#4 BILGE STOP	Aged broken hot.
#2 DRILL STOP	Broken hot.
S39 Closed	Broken hot.
S41 Open	Broken hot.
S42 Open	Broken hot.

Pumplights – Port

SWITCH	COMMENTS
#1 B.W. STOP	Aged and broken hot.
#3 B.W. STOP	Aged and broken hot.
#5 B.W. STOP	Fused and broken hot.
#1 BILGE STOP	Aged and broken hot.
#3 BILGE STOP	Aged and broken hot.
#1 D.W. STOP	Aged and broken hot.

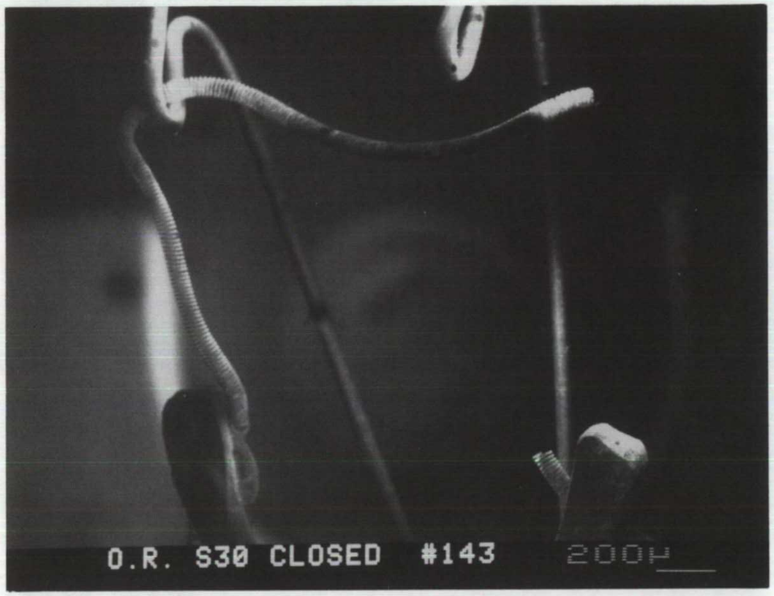


PHOTO 1 Starboard #30 closed. Filament broken near contact post.

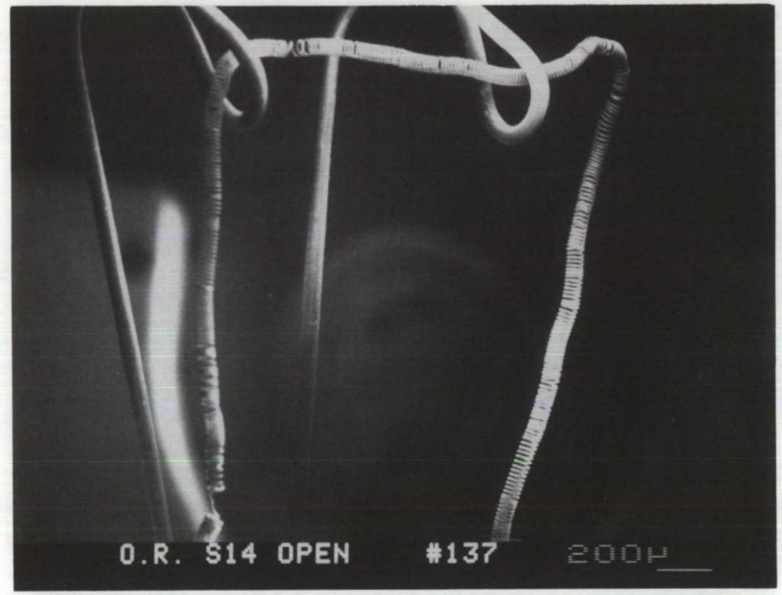


PHOTO 2 Stretched filament damage probably due to high voltage.

PHOTO 3 Filament fused to glass from #2 bilge water starboard *stop* pumplight.

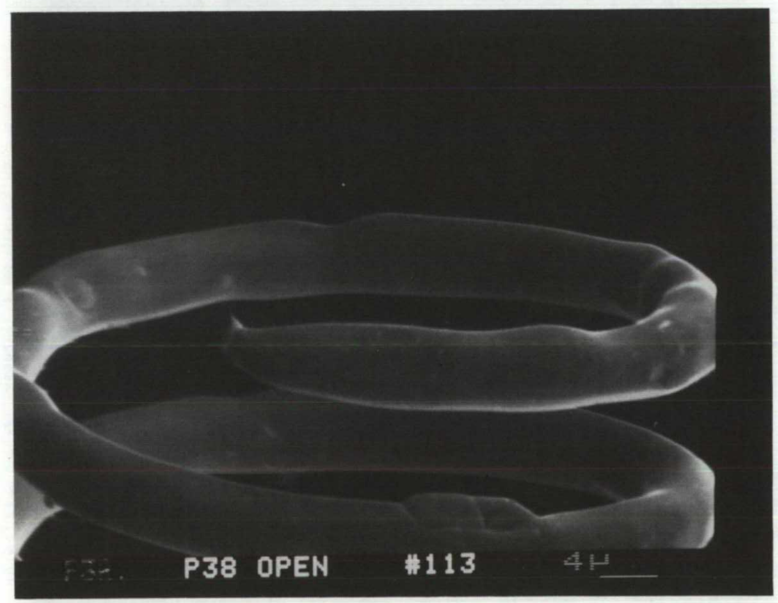


PHOTO 4 Hot fracture of port #38 open bulb.

PHOTO 5 Smooth fracture surface of port ballast water stop bulb.

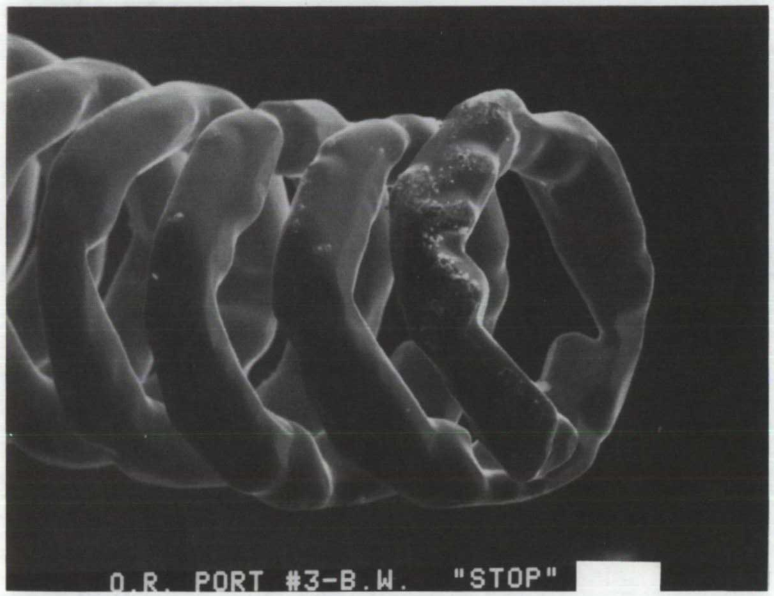


PHOTO 6 Smooth fracture surface of port #3 ballast water stop.

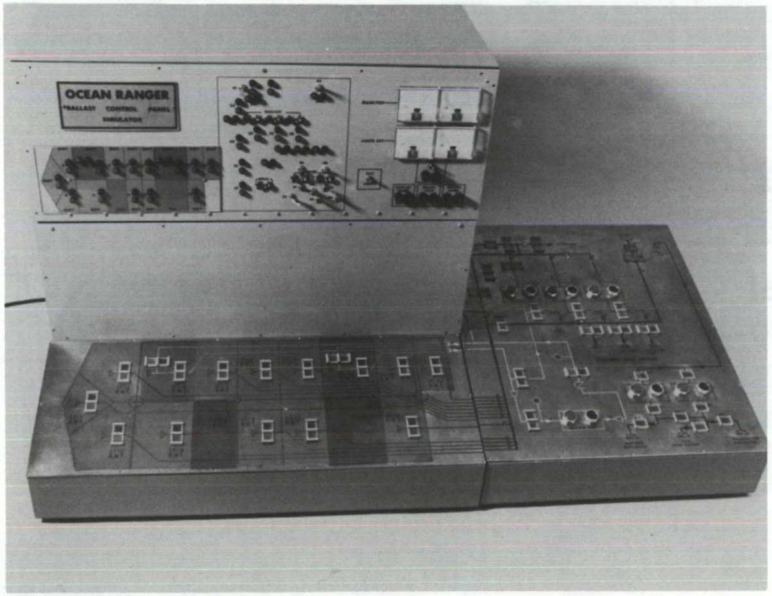


PHOTO 7 Simulation control panel of the *Ocean Ranger*.

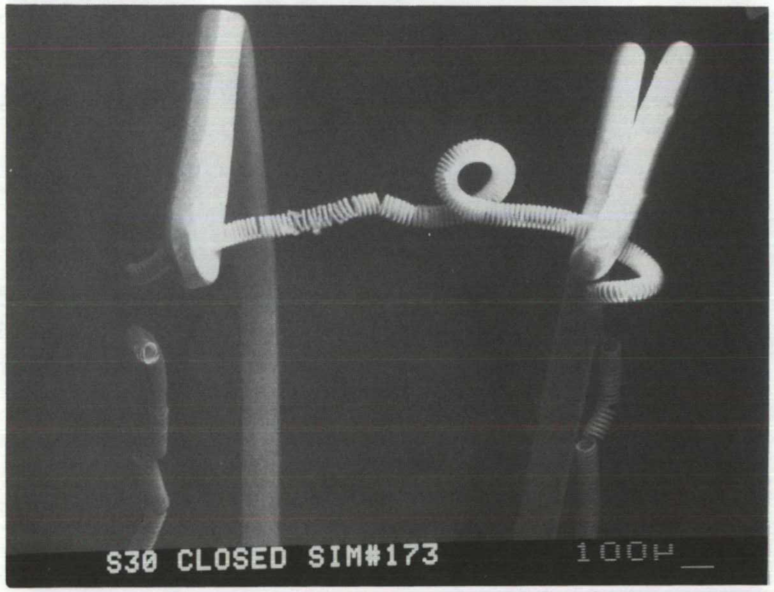


PHOTO 8 Filament from simulation panel flooded with water.