New Brunswick Power
Point Lepreau Generating Station

Information Report

Events Leading To Foreign Material Being Left in the Primary Heat Transport System

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(2)

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1.0 SUMMARY

On October 6 1995, following an extensive maintenance outage which had included boiler primary side cleaning, a Primary Heat Transport (PHT) system pump run was started in preparation for ultrasonic feeder flow measurements. Wooden debris in the system resulted in failure of the shaft seals of PHT Pump 1.

The subsequent investigation and assessment of this event provided an understanding of both the pump shaft failure mechanism and the origin of the debris in the PHT system. The pump shaft failed as a result of friction-generated heat resulting from contact between the rotating shaft and the stationary seal housing. This contact was initiated by mechanical and hydraulic imbalance in the pump impeller caused by wooden debris lodged in the impeller. The origin of the wooden debris was a temporary plywood cover which was inadvertently left in a boiler following maintenance. This cover moved from the boiler to the pump impeller when the PHT pumps were started. The cover was not accounted for and verified as being removed prior to boiler closure, although a visual inspection was conducted. A detailed institutional process for component accounting and verification of removal of materials did not exist at the time of this event.

Details of the methods used to establish alternative heat sinks, provide debris recovery facilities, and to assess the fitness-for-duty of the heat transport system and fuel channels prior to reactor startup are discussed in detail elsewhere (References #1, 14, 15, 16). This report will concentrate on the events leading up to and following the events which ultimately resulted in failure of the PHT pump shaft.

2.0 DESCRIPTION

2.1 PLANT CONDITIONS PRIOR TO THE EVENT

The reactor was shut down in the Guaranteed Shutdown State (GSS) with the PHT system pressurized to 6 Mpa, in preparation for startup.

New seals had been installed for Pump P1 and P4, on September 1, 1995. Each HT Pump subsequently ran for 10 - 15 minutes. Shaft runout & vibration data for both pumps was normal. B01 was opened for primary side cleaning from September 18 to 24, 1995.
B01 was closed on September 25, 1995.

HT Pumps P1, P2, P3 and P4 were bumped for 10 - 15 seconds on October 3, 1995. This was done in order to demonstrate the integrity of the pump seals and support venting and filling of the PHT system. Subsequent review of shaft runout and vibration data indicated that this was the most likely time at which the wooden nozzle cover broke free and entered the pump suction.
On October 6 1995, all pumps were bumped and subsequently run in preparation for HTS warm-up. This was possibly the time that a part of the wooden cover became lodged in the impeller.

2.2 SEQUENCE OF EVENTS

The probable pump failure sequence on October 6 is outlined below:

16:36 to 16:51h.	P1 was started. Wood in the suction line caused initial radial runout of 300 to 500 microns at the shaft coupling (Alarm setpoint = 400 microns; normal=100 microns). Runout varied erratically; decreased to 50 microns and then increased to 500 microns. Pump motor vibrations remained well below alarm limits.
16:51h.	Coupling radial runout off scale > 500 microns Metal-to-metal contact in the dry region of the seal.
16:55h.	Coupling runout ranged from 300 to 500 microns Friction continued to increase shaft temperature.
16:57h.	High metal temperature caused gland seal cooling water outlet temperature to increase rapidly from 40 to > 120 degrees C.
16:59h.	Pressure in all stages increased rapidly to 6 MPa. Sparks , steam and water were observed to be coming from the seal area.
17:01h.	Shaft temperature > 800 degrees C. resulting in ductile overload. Shaft failed (approximately 10 seconds prior to pump shutdown). Pump delta P decreased rapidly. Pump motor shut down.

3.0 ANALYSIS OF CORRECTIVE ACTIONS

3.1 OPERATOR ACTIONS

On October 6 1995, during operation of the four main PHT pumps for cold ultrasonic flow measurements, Main Control Room (MCR) indication was received that PHT P1 shaft run-out was abnormal. At this time a mechanic, who was already in the reactor building, was requested to check and report on pump operation in the field. Field observation of pump operation was reported to appear normal. While this information was being communicated to the Control Room Operator (CRO), alarms were received in the MCR indicating a heat transport pump seal failure. The mechanic in the field then informed the CRO that water was coming from the seal. He also reported that sparks and steam were coming from the area of the seal housing. Shutdown Cooling Pump (SDC) P2 was placed in service. The main heat transport pumps were shut down. The Primary Heat Transport (PHT) system was depressurized.

A review of the actions taken by operating personnel in response to the information they had available during the failure sequence of PHT P1, concluded that operating personnel response was consistent with current procedural requirements.

3.2 PUMP SHAFT FAILURE MECHANISM

Imbalance forces, likely caused by mechanical and hydraulic forces in the impeller, resulted in sufficient flexing of the shaft to allow the seal sleeve to contact the dry seal flange. It was also noted that there was evidence of pump journal contact with its bearing but no sign of contact between the impeller and the wear ring. The resultant welding of the seal sleeve and seal flange, due to frictional heat, would have occurred rapidly following contact. The resultant galling effect generated immense heat which in turn transferred through the seal sleeve into the pump shaft. The heat generated was enough to elevate the shaft temperature to the point that material properties were reduced to the plastic regime. At this point, the shaft sheared easily without creating undue stress on the pump motor.

Figure 1 illustrates the general location of the shaft failure. Figure 2 shows a more detailed view of the shaft fracture location and the heat affected zones. Figure 3 shows the shaft fracture location looking down on the Auxiliary Seal Flange. Figure 4 shows an end view of the segment of the pump shaft at the fracture location.

Shaft Fracture
The pump shaft fracture occurred 398 mm from the motor coupling end of the shaft, which is approximately in the middle of the breakdown bushing (pressure cell) portion of the seal flange assembly, just above the tertiary seal (refer to Figure 2). The fracture was perpendicular to the axis of the shaft and the fracture surfaces were relatively coarse and jagged, typical of torsional overload. The fracture surfaces were moderately damaged from post failure rubbing. A significant amount of deformation was evident near the fracture indicating ductile torsional overload. The total angular twist, or plastic deformation, of the material was estimated to be 120° to 160°, based on the rotation of axial scratches on the surface of the shaft at the fracture location. Fractographic analysis using the scanning electron microscope (SEM) confirmed the fracture to be ductile overload.

Thermo-Mechanical Damage
Discolouration of the shaft adjacent to the fracture location indicated elevated temperature. There was a distinct heat affected zone approximately 25 mm on both sides of the fracture. The shaft was fused to the seal sleeve at the location of the fracture. The melting point of the type 410 stainless steel shaft and sleeve is about 1500°C. The sealing sleeve fractured at the same location as the shaft. There was extensive mechanical damage on the outside surface of the sleeve, 25 mm on both sides of the fracture location. The mechanical damage was oriented in the circumferential direction and is typical of severe metal-to-metal wear. Minor galling was also evident on the outside surface of the sleeve at the location of the stationary part of the secondary seal. The inside of the sleeve displayed a distinct heat affected zone approximately 25 mm on both sides of the fracture. There was no evidence of rotation of the sleeve on the shaft. There were no material or manufacturing defects detected.

Bushing Damage
The inside diameter of the breakdown bushing displayed extensive mechanical damage, similar to the corresponding surface of the sleeve. Metal had flashed out the ends of the bushing leaving a

lip. The inside diameter of the bushing increased by up to 5 mm as a result of the wear with the sleeve. Discolouration of the undamaged surfaces indicated the part had overheated. The fillet weld connecting the bushing to the flange had failed, most likely during disassembly based on the clean fracture surface. There was no evidence of rotation of the bushing on the flange. It was reported that the bushing separated easily from the sleeve during disassembly. This indicates that the sleeve was not welded to the bushing and the shaft had not seized. There was also evidence of wear between the outside of the sleeve and the inside of the seal flange assembly and auxiliary seal flange. The damage at those locations was significant but less severe. The mechanical and heat damage was more severe at the breakdown bushing because of the greater thickness of the seal flange and subsequent contact surface area.

Hardness Testing Results

Hardness testing indicated the shaft was heated to temperatures in excess of 800°C through the full thickness of the shaft. The highest hardness values (>60 HRC) were obtained at the fracture surface and decreased on both sides of the fracture. Overheating of the shaft was confirmed by evidence of microstructural changes. Metallography revealed hard martensitic microstructures indicating the shaft was transformed to austenite then quenched. The austenitic transformation temperature is about 750°C for 410 stainless steel. Based on the flow lines evident in the microstructure, the ductile fracture occurred at the elevated temperature. Quenching of the steel occurred after fracture.

Condition of Other Seal Stages

Damage below the seal flange assembly was minimal. The carbon seal ring of the tertiary seal displayed extensive scoring, but was still intact. All other seal components were in good condition. The rapid increase in seal pressure differential was not caused by failure or damage of the seal components. The loss of seal was most likely caused by dimensional changes associated with the extensive overheating at the top of the seal assembly.

Condition of Other Components

Components below the seal assembly were in relatively good condition. The impeller displayed some scuff marks and scratches. Wood fibers were evident on the surface of the impeller. During disassembly of the pump, pieces of wood were discovered in the eye of the impeller. The pump journal and bearing had evidence of rubbing over the lower one third of the assembly but no serious damage.

3.3 MODIFIED WOODEN COVER

The debris found in the impeller of PHT Pump 1 (P1), and within other areas of the PHT system, was determined to be from a modified wooden cover used in the cold leg nozzle during maintenance of Boiler B01. A sketch of the modified cover (the cover involved in this incident) is shown in Figure 5. The purpose of this cover was to provide temporary closure of the cold leg nozzle of the boilers. It had been used sequentially in all of the boilers during the performance of maintenance activities.

Design and construction of the wooden covers did not take into consideration the possibility of one inadvertently being left in the system as a source of loose parts. As such, no assessment was performed of these materials, or their associated potential impact on the heat transport system, and no exact record of the composition or amount of material used was maintained.

3.4 EVENTS LEADING TO THE WOODEN COVER BEING INADVERTENTLY LEFT IN THE COLD LEG NOZZLE OF BOILER #1 (Event Precursor)

The following events and conditions resulted in the plywood cover being left in the outlet nozzle in the coldleg side of boiler #1:

Events on September 24, 1995 - 08:00 hours - 19:00 hours
On shift #2 on September 24, 1995 a Mechanical Maintenance (MM) crew prepared boiler #1 for box-up. Both the hotleg and coldleg sides of boiler #1 were cleaned and vacuumed. Two aluminium covers from the nozzles in the hotleg side of boiler #1 were removed. The MM crew left two inflatable bungs, which were inside the two nozzles of the hotleg side of the boiler, were left in place. They also left in place, a modified wooden cover which was installed in the coldleg nozzle of boiler #1.
The Boiler Coordinator (BC) conducted the final visual inspection of boiler #1. His assessment was that the boiler was clean. Boiler #1 was left ready for box-up by the incoming MM crew at the end of #2 shift.

Events on September 24, 1995 - 19:00 hours - 24:00 hours
At about 19:45 h shift turnover between the outgoing and incoming Senior Mechanical Maintainer (SMM) was underway. The outgoing SMM informed the incoming SMM that, among other activities, boiler #1 was clean and ready for box-up when the operating shift requested.

The incoming SMM met with his crew and told them that boiler #1 was clean, the tape had been removed, the tape residue had been removed and the covers had been removed. He told them that they would need to remove the two inflatable bungs in the hotleg side. The MMs interpreted the SMM's words as meaning, that it would be necessary to enter the hotleg side of the boiler in order to remove the inflatable bungs. However, it would not be necessary to enter the coldleg side of the boiler as they had just been informed that "all covers had been removed".

Events on September 25, 1995 - 00:01 hours - 04:00 hours
At about 00:01 - 00:30 h the MM crew arrived at boiler #1 and prepared for one of the crew members to enter the hotleg side of the boiler. The MM who entered saw the air lines running to the two inflatable bungs in the nozzles. He used a vacuum to perform one last cleaning, then exited. At about 01:00 h the SMM was informed that the boiler was ready for a final inspection.

The SMM arrived at boiler #1 at about 01:20 h to perform the final boiler inspection. He saw the air lines running to the two inflatable bungs and observed the hotleg area to be clean. His assessment was that the hotleg side of boiler #1 was "clean as a whistle" and he made this comment to one of the MMs. The SMM told the three MMs that the hotleg side was ready and to start to box it up.

The SMM put his portable light into the coldleg side and laid it down on the surface of the bowl. It remained in this position throughout his inspection. He entered the manway up to his hips. As he did in the hotleg side, the SMM looked around for any foreign objects, tape or tape residue. He observed the coldleg side of the boiler to be clean.

Although subsequent investigation determined that the cover was in place, the SMM did not see the modified plywood cover in the coldleg nozzle.

Confident that the coldleg side of boiler #1 was clean, the SMM told the MMs that the coldleg area was clean and instructed them to proceed with box-up at approximately 01:30 h.

The MMs moved the necessary tools and equipment around to the manway on the coldleg side of boiler #1. Having been informed that the coldleg area was clean and ready for box up by the SMM, they did not look into the coldleg side. The MM crew proceeded to box-up the coldleg side.

Events on September 25, 1995 - 04:00 hours - 08:00 hours
At about 04:15 h the MM crew left the boiler cabinet and took their dinner break. Some time after dinner they informed the SMM that boiler #1 box-up was complete. The SMM turned over the shift to the incoming SMM. He provided the incoming SMM with an overview of the status of work underway. This overview included the information that boiler #1 was now boxed-up.

3.5 HUMAN FACTORS ASSESSMENT

There are a number of factors which individually, or in sum, may have contributed to the SMM's inability to see the plywood cover. These are:

1. The SMM had been told by the outgoing SMM that boiler #1 had been cleaned and was ready for box-up when Operations requested this. Upon his arrival at boiler #1 the SMM asked one MM how the boiler looked. The reply was that it was clean and ready for box-up. On the basis of these verbal clues it is unlikely that the SMM expected to see a cover in the coldleg nozzle.

2. The SMM was not aware that a specially modified plywood cover had been fabricated for the coldleg nozzle of the boilers. He was not aware that this cover lay slightly recessed inside the nozzle. On this basis, when he looked into the coldleg side, and had he been checking for a cover at all, he would reasonably have been looking for an aluminum cover of the familiar inverted "top hat" design. As he did not see this type of cover he may have concluded that no cover was in place.

3. The light, lying on the bowl of the coldleg side would have thrown light in an arc of less than 180 degrees. The field of light may have been further reduced depending upon the actual position of the light as it lay on the rounded surface of the boiler bowl. It is unknown if the outlet nozzle fell into the illuminated area. The respirator which the SMM wore may also have impaired his vision. These factors, combined with the fact that the cover, over time and with use, had taken on a dark color, not unlike the color of the boiler plate, may have made the cover difficult to see.

4. There are three factors which may have unconsciously affected the time and attention which the SMM allocated to the final inspection of boiler #1. These are:

(a) The final inspection of boiler #1 fell to the SMM when at the last moment the BC was unavailable. The SMM is authorized by the work plan to conduct this inspection. However, this was a late additional task added to the SMM's already busy schedule.

(b) The final clean-up and box-up of boilers #1 and #3 were critical path activities.

(c) The box-up of boiler #1, while important to the SMM, was not in his view the only critical work underway on this particular shift. The repair of the boiler tube in boiler #3 warranted, in his opinion, priority attention.

3.6 ACCOUNTING OF MATERIALS USED IN BOILERS

During the 1995 outage the majority of work performed within the four boilers was conducted by contractors in accordance with their approved procedures. Point Lepreau maintenance staff's role was largely limited to:

- the physical opening of the boilers,
- decontamination of the boilers,
- the installation and removal of inflatable bungs and covers,
- the final cleaning of the boilers,
- the final visual inspection of the boilers for cleanliness, and,
- the physical closing of the boilers.

A Mechanical Maintenance Procedure for opening and closing a boiler exists. The procedure calls for the boiler bowl to be vacuumed clean. It requires the plywood cover or debris screen to be removed from the coldleg side of the boiler. The procedure also requires an independent visual check to ensure that all tools and equipment have been removed. Mechanical Maintenance staff are also acutely aware of the need to ensure that a high level of cleanliness is maintained in a boiler. On this basis, Mechanical Maintainers take personal responsibility to make sure that they remove from the boiler any tools or materials which they may take into the boiler.
The associated work plan made a number of specific references to the need to ensure boiler cleanliness. It also calls for a final inspection of the boilers to verify that the boiler is empty and clean. This inspection was conducted prior to boxing-up boiler #1. However, the modified plywood cover in the coldleg outlet nozzle was not detected.

4.0 CONSEQUENCES

4.1 SAFETY SIGNIFICANCE

At the time of the pump failure the reactor was in the Guaranteed Shutdown State (GSS) and had been shutdown for six months for an extensive maintenance outage. Channel decay powers ranged from 0.5 kW to about 2.8 kW. With a total core decay heat of about 550 kW, the majority of heat input to the PHT system was from the main pumps themselves. This heat source was eliminated when the pumps were tripped.

The major significance of the event was that a wooden boiler nozzle cover was destroyed by the pump impeller and resulting debris came to rest in the header, feeders and fuel channels, causing in some cases a significant reduction in coolant flows in the channels. Given the extremely low decay heat, no actual net flow was required to cool the channel, there being sufficient cooling provided by heat rejection to the end shields, moderator system, and from the end fittings to the vault air. The reductions in coolant flow did not result in overheating of any fuel, hence there was no public safety significance of the incident at the existing decay power levels.

The breach of the pressure boundary at the PHT pump seal constituted a minor radiation hazard to the workers involved in the investigation at the scene. While this event did not result in any immediate significant radiological hazard, recommissioning activities resulted in a total dose of 942 mSv being assignment to this event. It is estimated that another 20 mSv of committed tritium dose will be assigned in the following year.

Neither the pump shaft failure nor the breach of the pressure boundary impaired the ability to transfer effectively to the shutdown cooling mode of operation.

The introduction of debris to feeders, fuel channels and potentially other Heat Transport and Auxiliaries pipework had significant potential safety impact on at-power operation. An extensive program was developed to address this issue. A major program was initiated immediately after the event to locate and retrieve debris. Extensive flow verification was undertaken to verify debris removal prior to returning the unit to service.

4.2 ECONOMIC SIGNIFICANCE

The event resulted in severe damage to the PHT P#1. The rotating assembly had to be replaced. The major economic consequences were related to the loss of production due to extension of the 1995 outage, while the cost of time and material for cleanup and recovery activities represented about half of the value of the lost energy.

5.0 ROOT CAUSE ASSESSMENT

The root cause of this event was a failure to remove the temporary cover installed in the coldleg nozzle of boiler #1. The cover was not accounted for and verified as removed from the boiler following maintenance, although a visual inspection was conducted. A detailed institutional process for verification did not exist at the time of the event.

6.0 IMMEDIATE RECOMMISSIONING ACTIONS

6.1 ASSESSMENT OF MISSING COVER MATERIALS

A modified wooden cold leg cover, weighing 5 to 6 kg, was determined to be the cause of the PHT Pump shaft failure, and the source of the heat transport system debris.
To assess the approximate quantity of materials associated with the missing cover, three of the remaining original cold leg nozzle covers were disassembled.

The average number of screws for the missing cover was calculated at 75, with a total range of 50 to 98. Each cover half was assembled as a component with an average of 65 ± 3 screws of various sizes used to hold it together. If a large quantity of one screw length was used, fewer screws of other lengths were needed. Hence the subtotal range of 48-88 screws of all sizes was calculated by estimating twice the minimum cover half number (24) and maximum number (44). The total range was calculated by adding 10 additional screws for mounting the 5 angle tabs retrieved.

6.2 DEBRIS FLOWPATHS

An assessment of potential debris pathways was carried out. In order to obtain a full appreciation of potential debris distribution within the heat transport and auxiliary systems pipework, a systematic review was conducted of associated flowsheets, and operating conditions surrounding the Pump 1 (P1) failure. Using Boiler B01 as a starting point, the review considered all pathways up to effective debris barriers (i.e., filters, heat exchanger tubesheets, fuel string, see Figure 6). The possibility of debris reaching the fuel channels, and the associated effects on fuel and fuel channel assemblies was considered. It was essential that the investigation be extensive and thorough in order to confirm that all avenues were explored. These activities then formed the basis for the operations associated with debris retrieval and accounting. The impact that debris may have on the operation of relief valves, and possible effect on the freedom of movement for other pieces of key equipment, was also considered.

6.3 DEBRIS INSPECTION AND RETRIEVAL

Based on the debris flowpath assessment, the majority of inspection activities were associated with Reactor Inlet Headers RIH2 and RIH6, and their respective feeders. To inspect and retrieve debris from these areas, specialized tools were designed and developed. The methods used included robotic and manual techniques which were successful in inspecting and retrieving debris from these locations. Part of these activities required the removal and re-installation of the south end cap from RIH2, and RIH6. An extensive program was initiated to recover the maximum practical amount of debris using mechanical retrieval techniques and feeder backflushing. Tests conducted by AECL at Sheridan Park demonstrated that feeder backflushing was highly effective in removing wood debris and screws located in the feeder, end fitting liner tube, or at the end plate of the first fuel bundle in the channel. The recovery program was successful in removing the majority of wooden pieces large enough to cause significant feeder blockage. A significant amount of shredded wood debris was also recovered, as were a significant number of screws and larger metal components such as handles and hinges.

6.4 DEBRIS ACCOUNTING METHODOLOGY

To accurately report the amount of wood and metal retrieved, and to document the location where the material was found, the debris recovered from the Primary Heat Transport System (PHT) was recorded, dried, weighed, photographed, catalogued and stored. Unique identification numbers were assigned for traceability.

6.5 POTENTIAL CONSEQUENCES AND DISPOSITION OF REMAINING DEBRIS

As it was not possible to recover all the material from the cover, extensive effort was placed in understanding the behaviour of these materials in the system, and on their potential effect on plant operation and safety. Based on this information, the run up plan was modified to both assist in the "clean up" and to verify that conditions were safe to raise power.

Based on the original estimate of the mass of the cover and the mass of debris retrieved, it was estimated that less than 1 kg of wood remained in the system. Based on the extensive search in potentially affected piping, clean up of the affected headers, and backflushing of the feeders, it was concluded that the remaining wood was in small splinters and chips and was located either in the fuel bundles or the inlet liner area of the fuel channels in core pass 2-3. A significantly smaller amount was likely similarly located in pass 6-7. Very fine fragments that could pass through the fuel string were likely homogeneously dispersed throughout the system.

The feeder backflushing technique was shown in the laboratory to be effective in removing the debris from the front of the first bundle endplate. This was confirmed in reactor by revisiting Channel R16 with the CIGAR camera. In the initial CIGAR camera inspection of Channel R16 a significant amount of debris was located in front of the bundle endplate. After feeder backflushing, reinspection showed that the debris had been effectively removed. To confirm the effectiveness of feeder backflushing, backflushing flowrates were measured to verify that minimum criteria were achieved or exceeded. The endplates of the first bundle in several channels were inspected using a CIGAR inspection camera delivered into the end fitting by the fueling machine, to provide final validation of the effectiveness of the feeder backflush process. In addition, cold ultrasonic flow measurements were performed on all 380 channels as a prerequisite to proceeding from the Guaranteed Shutdown State (GSS). During performance of these measurements on 14 December 1995, an anomaly was identified in Channel L16, indicating a reduction in expected channel flow of approximately 22%. Subsequent investigation revealed the partial obstruction was due to wooden debris, which also contained one metal screw, at the feeder elbow nearest the end fitting. The debris was removed by disassembling the adjacent Grayloc fitting. Subsequent flow checks confirmed flows to be normal.

Wood Behavior - Breakdown Under Temperature and Radiation Conditions
Autoclave experiments showed that wood degrades to small particles and oil-like residues at temperatures similar to those experienced at Heat Transport System Operating temperatures. Degradation products are then dispersed by the turbulent flow of the PHT system. The particulates quickly degrade to soluble chemical compounds which are subsequently removed by the purification system .

Experiments performed in the Gamma Cell at Whiteshell Laboratories, with an applied gamma dose rate of 0.5 MRad/h (5 kGy/h) for a period of 80 hours (equivalent to approximately 0.1% of full power), would quickly break down the particles and disperse the residue.

During the start-up, the PHTS was warmed up and the GSS permitry was surrendered. The reactor was taken critical and power was raised to 2% FP to aid in the decomposition of the wood. After about four hours at 2% FP (and after about thirty six hours with the PHTS hot), reactor power was reduced, and the PHTS was cooled down. Three fuel channels (R16, A12, and L22) were then defueled. All bundles from these channels were inspected for wood related products, and the flow in 15 channels was remeasured using the ultrasonic flow technique.

Based on the chemistry data observed during the soak period combined with the bundle inspection results, it was evident that the thermal soak significantly reduced the wood residue. However, it appeared that the decomposition process was not fully complete. An additional 12 hour thermal soak at low power (< 2%) was then performed. At the end of this period the fuel from channel E20 was removed and the first six bundles were inspected. Given the findings of this inspection, it was evident that the potential for sub-channel blockages, caused by wood splinters, had been eliminated, and that any remaining fragments would not impede heat transfer from the bundles.

Effects of Operation with Residual Screws in the PHTS

Based on the estimate of the number of screws in the cover, and on the number retrieved, it is estimated that up to 22 screws may remain in the system. These screws are expected to either be held up in the dead space of the liner tube or in the channels associated with core pass 2-3. Screws that are held up in the liner tube holes could eventually enter the fuel channel. The evaluation of the debris removed from each feeder indicated that there were no more than three loose screws recovered from any one channel.

A review of the safety issues with respect to operating with loose screws in the fuel channel, indicated the following potential concerns:

- fretting damage on pressure tubes,
- scratching of pressure tubes during fuelling,
- fretting and subsequent failure of fuel elements,
- adverse impact on fuelling machine operation,
- subchannel heat transfer effects.

A fuel channel fitness for service assessment was performed to demonstrate that the integrity of a pressure tube is not compromised by the presence of debris prior to the next scheduled fuel channel inspection in April 1997. As well, an enhanced fuel channel in-service inspection (ISI) plan was developed.

6.6 CONSIDERATION OF EVENT IMPACT ON SIMILAR EQUIPMENT

Assessment of the Need to Inspect Other PHT Pumps

A review of the operating parameters of the other 3 pumps showed that no unusual operating characteristics (i.e., imbalance, runout) were evident during their test runs. The failure of P1 shaft was not the result of a manufacturer flaw or a generic design weakness under normal operation. All other covers used during the outage were accounted for, hence there were no sources to create this incident in other pumps. Furthermore, no anomalies were reported with the performance of other pumps. Thus, inspection of other PHT pumps was not considered to be necessary.

Assessment of the Requirement to Modify the Seal Design
A possible seal design change to increase the clearance between the seal sleeve and the stationary seal flange, as well as other parts, stator holders, etc., was evaluated by the manufacturer. Based on past performance of the seal assemblies, and the potential for additional D_2O leakage into the reactor building as a result of seal failure, the implementation of such changes was not considered to be necessary.

Assessment of the Need to Modify Procedures
A revision of the Primary Heat Transport Operating Manual was initiated which includes improved procedures for startup, bumping and running of the PHT pumps. The revised operating manual was issued prior to startup. The new procedures identify additional monitoring requirements and PHT pump shutdown criteria in response to vibration alarms related to shaft runout. The new requirements include:
- Field monitoring of the performance of pumps on startup.
- Not restarting pumps which experience runout or vibration alarms during bumping until the cause of the alarm has been assessed and dispositioned.
- Immediate shutdown of a running pump upon receipt of high or erratic runout indication.
- Lowering of runout alarm limits (from 400 microns to 300 microns), so they are closer to normal operating levels.

6.7 STARTUP ACTIVITIES TO ASSURE SAFE RETURN TO POWER

In addition to the strategy employed to eliminate remaining wood debris via thermal decomposition and low power irradiation, a number of other activities were implemented that were designed to demonstrate the adequacy of channel flows. Cold ultrasonic flow measurements were performed for all 380 channels prior to removal of guaranteed shutdown conditions in order to obtain an accurate assessment of channel flows. A comprehensive program of channel flow verification using heat balance was also performed at 8, 30, 50, 75 and 77 percent power levels. Channel flows were compared with NUCIRC computer code predictions, historical data, and symmetric channels, using pre-assigned acceptance criteria. Flow verifications were scheduled to be performed on a monthly basis for the first four months after startup. Following this period flow verifications will revert to the standard quarterly frequency.

Also, prior to run-up, key safety related valves which could have potentially been affected by debris were tested. A program to flush safety related transmitters was also undertaken. A temporary log N trip setpoint was installed in Shutdown Systems SDS1 and SDS2 to provide additional protection during the thermal and low power decomposition of wood operations. This trip was removed following completion of this phase of the run-up.

Fuel performance monitoring will be continue to be conducted via the standard techniques using the Gaseous Fission Product monitoring and Delayed Neutron monitoring systems. The former provides on-line indication of fuel failures, while the latter is used to locate defects. It is normal practice at PLGS to refuel defects expeditiously.

7.0 LONG TERM CORRECTIVE ACTIONS

As of December 28, 1995, planned recovery, inspection, and testing operations were complete and the station was operating normally at 100% FP. As a result of the hot soak and subsequent reactor operations, any remaining wood debris had been eliminated. Residual metal debris is estimated at about 22 metal screws. A metal tab, which may have been installed on the temporary cover, was not located and was presumed to have been lost external to the system during transfer of the cover between boilers. Channel flow measurements confirmed that HT system flows were normal indicating that, in all likelihood, the tab is not in the HT system. The metal screws or fragments are anticipated to be trapped in the end fitting liner tube or in the fuel channel.

The activities conducted to assure PHT cleanliness, and the program of comprehensive monitoring during the run-up of the reactor, have provided a high degree of assurance that safe operation for the Point Lepreau station has not been compromised in any way as a result of this incident.

Selected fuel removed from all of the 95 Reactor Inlet Header 2 (RIH2) channels during normal fueling operations will be inspected following discharge to the spent fuel bay. If fuel damage is detected which indicates the presence of metal debris in a channel, consideration will be given to future inspection of such channels as part of the scheduled inspection program. Fuel channel inspections are planned for 1997, at which time volumetric assessment and hydrogen pickup measurements will be performed.

8.0 References

1) NB Power Detailed Event Report 33100-95.10.06 "Heat Transport Pump Failure" dated 95-11-20.

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3) Debris Flowpaths by D. Loughead.

4) Failure Investigation of PHT Pump 1, Preliminary Results by J. Slade dated October 24, 1995.

5) AECL Report "Degradation of Wood Products Under CANDU-6 Out-of-Core Primary Heat Transport Condition" by E.J. Moskal dated 1995 October 31.

6) AECL Report, E.J. Moskal to C. MacNeil, dated 1995 November 7.

7) AECL Memorandum Elliot to MacNeil "Decomposition of the Wood in the PHTS at PT. Lepreau" dated 1995 November 17.

8) RPC to C. MacNeil Report dated 1995 November 20.

9) AECL Report 87-31100-220-047 "Assessment of Postulated Flaws in Pt. Lepreau NGS Due to Potential Debris" prepared by H. Wong dated November 1995.

10) "Fitness for Service Guidelines for Zirconium Alloy Pressure Tubes in Operating CANDU Reactors" COG Report 91-66, May 1991.

11) P.J. Reid to R.A. Gibb "Fuel Element Power Limits with Organic Deposits and Reduced Sheath-to-Coolant Heat Transfer" TU-08634, 1995 November 28.

12) R. F. Dam and G.D. Harvel to P.D. Thompson "Flow Blockage Analysis of Wood and Screw Debris in HTS of PLGS for Support of Reactor Startup" dated November 29, 1995.

13) Loughead D. "Point Lepreau Generating Station Operating Manual - Primary Heat Transport System" OM 33100 Rev. 5/9 dated November 1995.

14) NBP Information Report IR-78200-10 Rev. 0 "PHT Recommissioning Project - Recovered Debris Classification and Characterization."

15) A.J.Benton et all, "Assessment and Recommissioning of the Primary Heat Transport System", Point Lepreau Generating Station Information Report, IR 33100 - 12, Rev 1, March 19, 1996.

16) S.H. Groom, "Consequences Of Foreign Materials Left in the Primary Heat Transport System", Point Lepreau Generating Station Information Report, IR 33100 - 13, Rev 1, April 1996.

9.0 ACKNOWLEDGMENTS

This program was accomplished with assistance from Atomic Energy of Canada Limited (AECL), Babcock & Wilcox (B&W), Ontario Hydro, NB Research and Productivity Council (RPC) and other outside contractor expertise over an 11 week period in the fall of 1995. In addition, an independent overview team of three outside advisors with broad industry experience was appointed by senior NB Power management to review the event and provide independent advice and assessment. A dedicated team of station staff was assigned to implement recovery operations. The efforts of a great many dedicated people went into the completion of the work necessary to place the plant into a safe state for continued operation, and into assembling the material for this report. I want to take this opportunity to acknowledge these efforts, and to thank the many individuals who participated in the successful completion of these tasks.

10.0 ATTACHMENTS

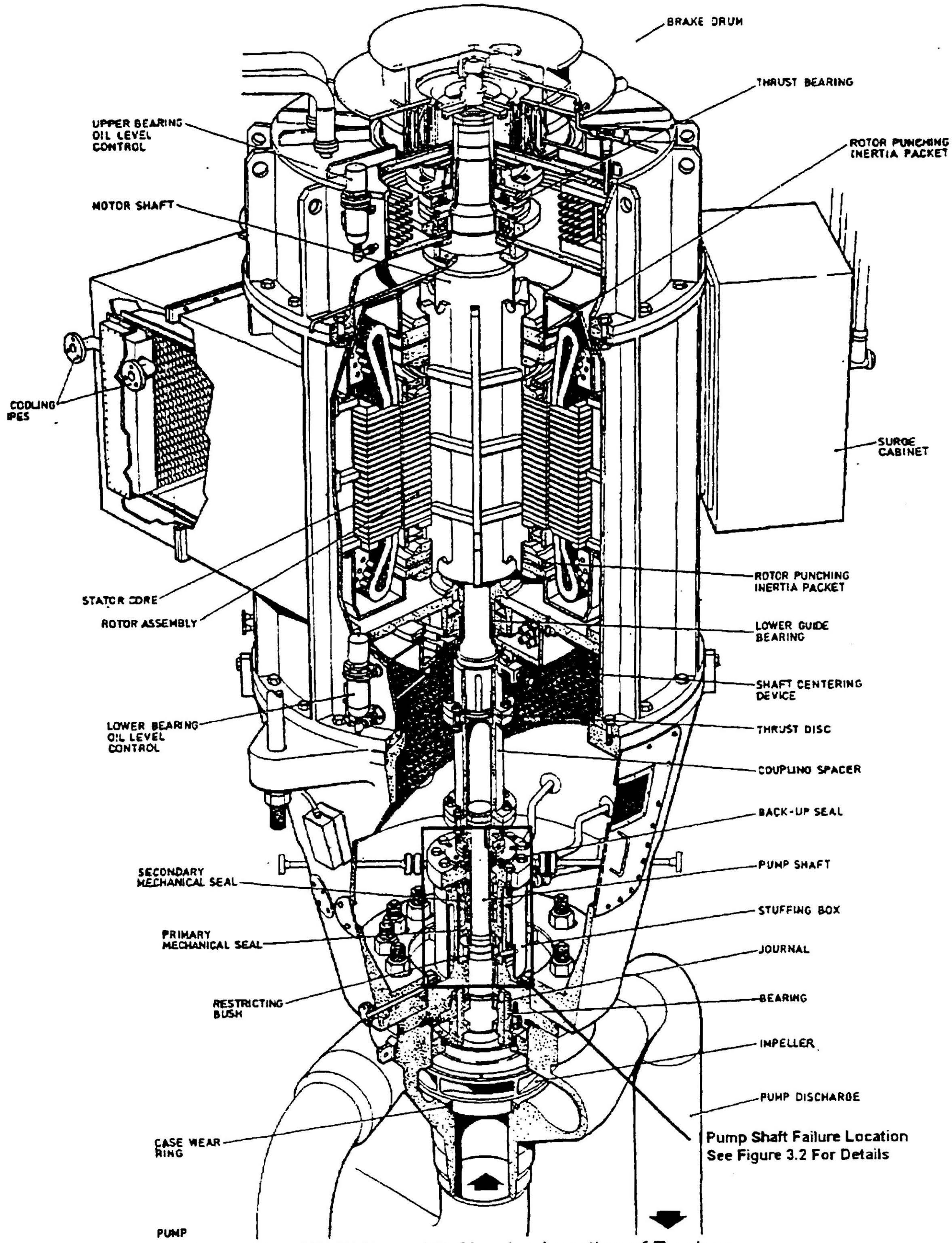
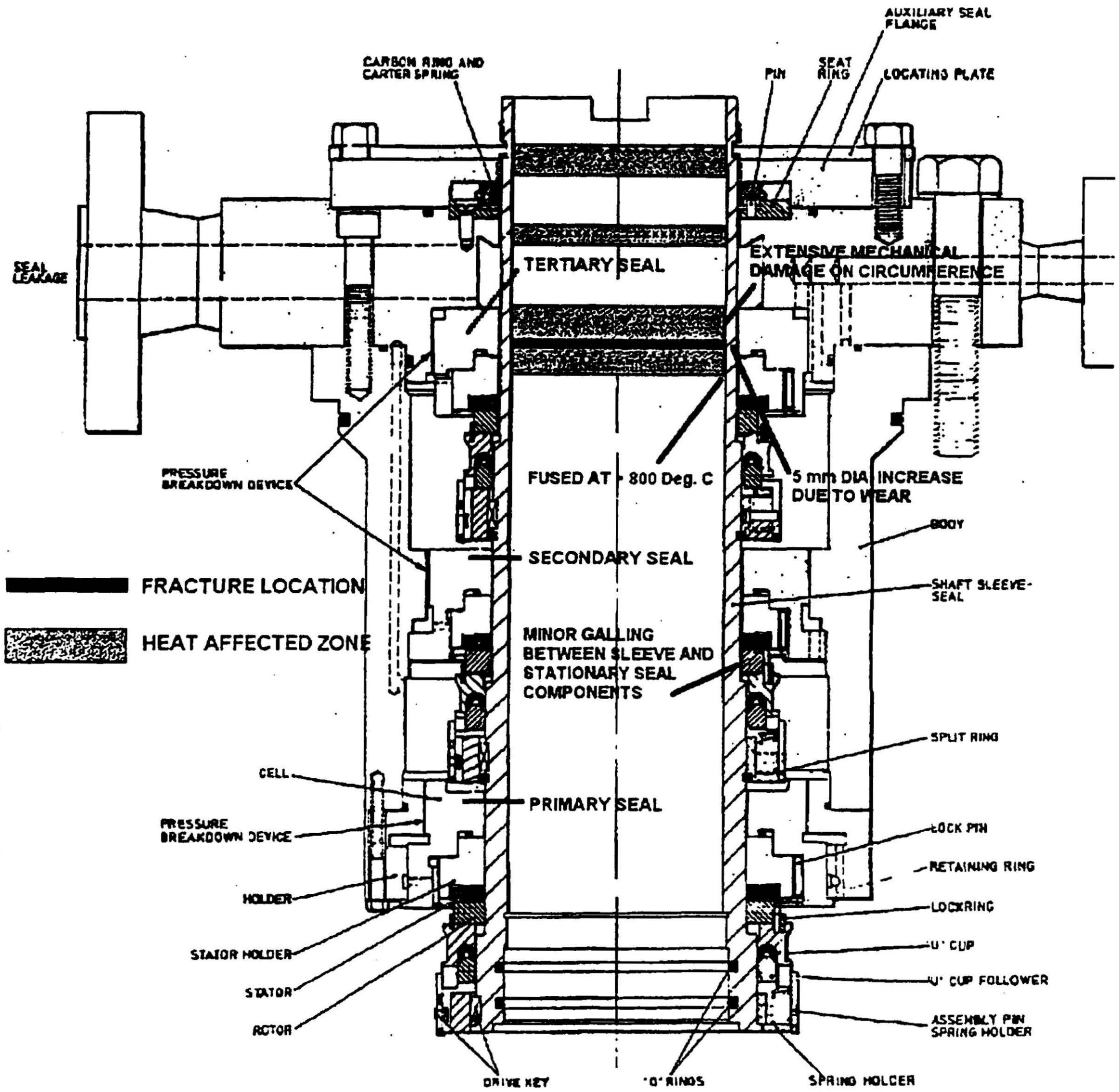


Figure 1 General Assembly of PHT Pump P1 Showing Location of Fracture



Location of Damage Observed on PHT Pump P01 Shaft

Figure 2 Details of Damage Observed on PHT Pump P1 Shaft

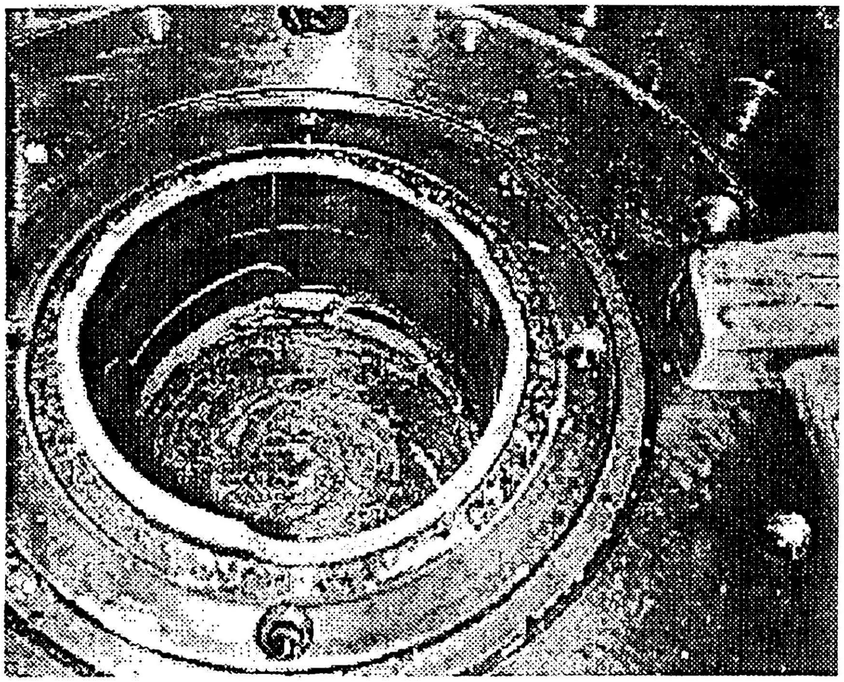


Figure 3 View of Pump Shaft Fracture looking down on Auxiliary Seal Flange

(Note : Pump Shaft dropped below normal operating position in seal housing)

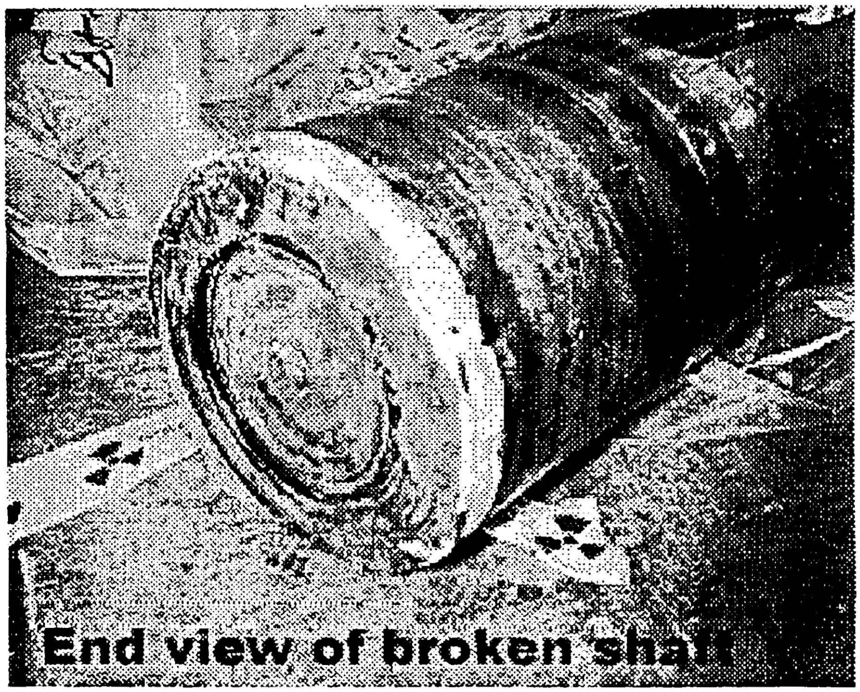


Figure 4 End View of Fracture Shaft Removed from Pump P1

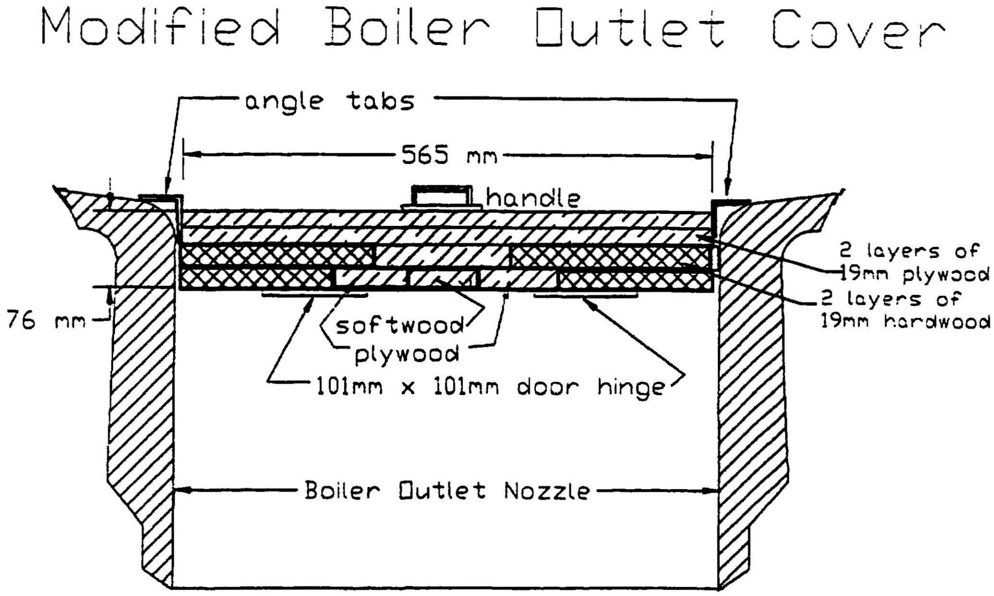


Figure 5 Modified Cover

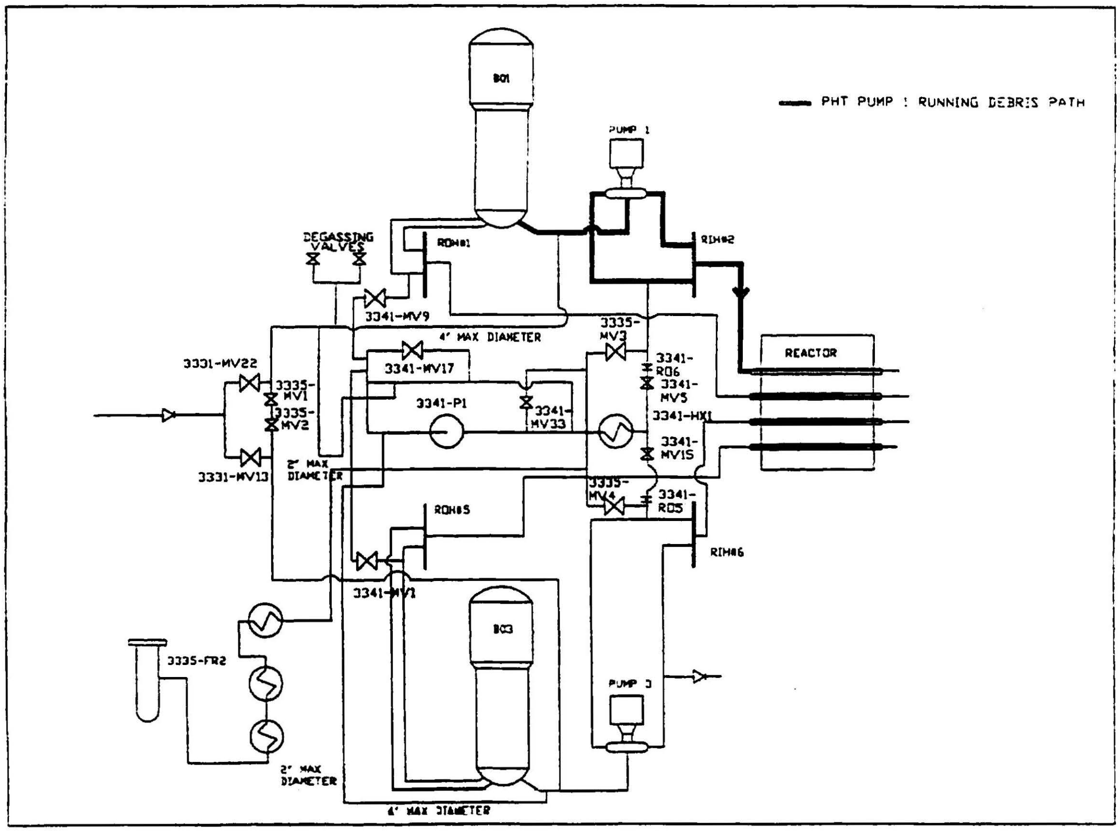


Figure 6 PHT Pump P1 Suction and Discharge