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FACIL:50-305 Kewaunee Nuclear Power Plant, Wisconsin Public Servic 05000305
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SUBJECT: LER 95-006-00:on 950420,recent changes in pump operating practice resulted in inadequate thrust bearing lubrication & failed B SI pump.Reviewed procedures.W/951101 ltr.

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TITLE: 50.73/50.9 Licensee Event Report (LER), Incident Rpt, etc.

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November 1, 1995

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U. S. Nuclear Regulatory Commission
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Ladies/Gentlemen:

Docket 50-305
Operating License DPR-43
Kewaunee Nuclear Power Plant
Reportable Occurrence 95-006-00

In accordance with the requirements of 10 CFR 50.73, "Licensee Event Report System," the attached Licensee Event Report (LER) for reportable occurrence 95-006-00 is being submitted.

Sincerely,

M. L. Marchi
Manager - Nuclear Business Group

DLR/jmf

Attach.

cc - INPO Records Center
US NRC Senior Resident Inspector
US NRC, Region III

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NRC FORM 366 (5-92) | U.S. NUCLEAR REGULATORY COMMISSION

APPROVED BY OMB NO. 3150-0104
EXPIRES 5/31/95

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LICENSEE EVENT REPORT (LER)

(See reverse for required number of digits/characters for each block)

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TITLE (4) Recent Changes in Pump Operating Practice Resulted in Inadequate Thrust Bearing Lubrication and Failure of the B SI Pump

EVENT DATE (5)			LER NUMBER (6)			REPORT NUMBER (7)			OTHER FACILITIES INVOLVED (8)	
MONTH	DAY	YEAR	YEAR	SEQUENTIAL NUMBER	REVISION NUMBER	MONTH	DAY	YEAR	FACILITY NAME	DOCKET NUMBER
									N/A	05000
04	20	95	95	-- 006 --	00	11	01	95	FACILITY NAME	DOCKET NUMBER 05000

OPERATING MODE (9)	N	THIS REPORT IS SUBMITTED PURSUANT TO THE REQUIREMENTS OF 10 CFR §: (Check one or more) (11)			
POWER LEVEL (10)	0	20.402(b)	20.405(c)	50.73(a)(2)(iv)	73.71(b)
		20.405(a)(1)(i)	50.36(c)(1)	50.73(a)(2)(v)	73.71(c)
		20.405(a)(1)(ii)	50.36(c)(2)	50.73(a)(2)(vii)	X OTHER
		20.405(a)(1)(iii)	50.73(a)(2)(i)	50.73(a)(2)(viii)(A)	(Specify in Abstract below and in Text, NRC Form 366A)
		20.405(a)(1)(iv)	50.73(a)(2)(ii)	50.73(a)(2)(viii)(B)	
		20.405(a)(1)(v)	50.73(a)(2)(iii)	50.73(a)(2)(x)	Voluntary

LICENSEE CONTACT FOR THIS LER (12)

NAME	TELEPHONE NUMBER (Include Area Code)
Dennis L. Rozell	(414) 388-2560

COMPLETE ONE LINE FOR EACH COMPONENT FAILURE DESCRIBED IN THIS REPORT (13)

CAUSE	SYSTEM	COMPONENT	MANUFACTURER	REPORTABLE TO NPRDS	CAUSE	SYSTEM	COMPONENT	MANUFACTURER	REPORTABLE TO NPRDS
E	BQ	P	B260	Y					

SUPPLEMENTAL REPORT EXPECTED (14)		EXPECTED SUBMISSION DATE (15)	MONTH	DAY	YEAR
YES (If yes, complete EXPECTED SUBMISSION DATE)	X NO				

ABSTRACT (Limit to 1400 spaces, i.e., approximately 15 single-spaced typewritten lines) (16)

On April 20, 1995, with the plant in refueling shutdown, SI Pump B was damaged during the performance of the Safety Injection (SI) flow test. Internal damage was caused by the failure of the thrust bearing and resulted in metal fragments from pump impeller to casing contact being dispersed into the SI system. The bearing failure was due to an increase in pump starts with short run times during the previous fuel cycle which resulted in inadequate bearing lubrication.

This event is being reported because it has been determined that this event contains information of potential generic interest.

Extensive efforts were taken to flush the SI system of all metal fragments. Long term corrective actions include: requiring a minimum run time for the SI pumps, reviewing procedures to determine if additional reference values for normal pump/motor operation should be included, and changing maintenance practices to include pre-lubrication of pump bearings prior to a planned pump start and monthly lubrication of pump bearings. To help prevent a similar event, this event will be included in training for the technical and operations staff.

Description of Event

On April 20, 1995, with the plant in refueling shutdown and the reactor vessel head removed, Surveillance Procedure (SP) 33-191, "Safety Injection Flow Test" was performed to test the operability of the SI system [BQ].

During the performance of the SP, each Safety Injection pump[P] is individually operated and flow through all SI flow paths to the reactor coolant system (RCS) cold legs (CL) and the reactor vessel (RV) [RPV] is verified (see attached diagram).

At 2113, A SI pump was started. The pump was shut off because a deflector disc, part of the seal assembly, was rubbing on the inboard side of the outboard bearing housing. The deflector disc had moved due to a loose set screw. Movement of the deflector did not impact pump operability.

At 2203, B SI Pump was started to perform the train B portion of SP 33-191. During this standard procedure sequence, the B SI Pump ran continuously while valves were manipulated to obtain the desired flow paths. At 2330, B SI pump was aligned for Train A RV injection and the bearing temperatures were stabilizing when RV injection flow, indicated on flow indieator [FI]FI-924, dropped from approximately 230 gpm to 30 gpm. Approximately 10 minutes prior to the indieated loss of flow, a puff of smoke was seen issuing from the thrust bearing housing breather. The test personnel immediately monitored the thrust bearing temperature which climbed to 179°F and then dropped to a range of 160°F to 170°F. Bearing temperature's remained within the operating limits and test termination criteria.

Initially the operating crew believed the loss of flow was caused by a failure in FI-924. I&C staff vented FI-924 which resulted in no change in the indieated flow rate. Train B RV Injection flow was opened to establish flow through both RV flow paths. Indicated flow, using FI-924, increased to 200 gpm and then dropped to approximately 50 gpm. Operations stopped the pump. I&C calibrated FI-924. The instrument loop was found within the procedural acceptance criteria.

On April 21, 1995 at 0139, B SI Pump was started still aligned for train A RV Injection. To verify flow through the pump, the SI flow test line was opened to align pressure indicator [PI] PI-929. Opening the test line permits measuring the RV Injection piping static pressure downstream of SI-9B [ISV], "Safety Injection to the Reactor Vessel Isolation Valve", and upstream of SI-14A(B)[ISV], "Reactor Vessel Injection Line Isolation Valve", which are locked in throttled positions to balance SI flow. The pressure at this point in the RV injection piping was equal to pump discharge pressure. The pump was stopped. At this time, the loss of flow was believed to be due to a valve failure between the pump discharge and the test line process connection.

At 0600, B SI Pump was again started in an attempt to identify the portion of the injection piping which may have been blocked. Various valve configurations and pressure gauges were used to try and locate the blockage. The results of the testing were inconclusive.

It was decided to inspect SI-9B because it was easy to disassemble, the valve had experienced a galled seat and plug in the past, and it provided access to the SI piping. The valve internals were found in operable condition with the wedge attached to the stem. Boroscopic inspection of the piping upstream and downstream of the valve body revealed no evidence of the passage of any foreign objects. Plans were also made to perform radiography (RT) on SI-14A and B.

At approximately 1300, check valve SI-6B [ISV], immediately downstream of B SI Pump, was opened to inspect the valve internals and conduct boroscopic inspection of the piping downstream of the check valve. The boroscopic examination revealed a suspected foreign object near SI-7B [ISV], "Safety Injection Pump 1B Discharge Valve." Removal of the bonnet from SI-7B and visual inspection found no foreign objects.

LICENSEE EVENT REPORT (LER)
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Radiography of the SI-14 valves and their downstream orifices revealed clear indication of foreign objects in SI-14B and less definite indication of foreign objects in SI-14A.

During the night shift on April 22, 1995, the SI-14 valves were cut out of the piping and the presence of debris was confirmed. Numerous metallic fragments had collected within the area of each valves' plugs and immediately upstream of the valve seats. Radiography of the downstream flow orifices showed no presence of foreign objects. RT of the orifice in the B SI Pump mini-flow recirculation line to the RWST revealed the presence of a foreign object upstream of the first plate in the multistage orifice.

Efforts commenced to identify the source of the loose parts. B SI Pump was disassembled for inspection. The results of the disassembly revealed significant damage to the pump thrust bearing. Both sides of the bearing showed loss of babbitt material. The outboard thrust bearing was significantly discolored due to heat. The thrust bearing shaft collar contact surfaces were deeply grooved. The outboard face of the shaft collar was discolored due to heat. The lube oil in the pump showed fine metal shavings resulting from the loss of babbitt material. The journal bearings were in good condition. Opening the inner casing to expose the pump shaft and impellers revealed the pump internals were damaged. Inspection of the B SI Pump shaft driven lube oil pump revealed a foreign object in the suction chamber.

Sulzer Bingham, the manufacturer of the pump, was contacted to provide a technical representative to support the root cause analysis and repair of the B SI Pump.

Because of the debris found downstream of SI-14B, it was decided to perform more radiographic inspections at the low points in the piping. Four locations were identified. The radiographs were taken and three of the locations were clean. Debris was discovered in the fourth location downstream of SI-9B.

A decision was made to do a full reactor vessel core off-load, remove all vessel internals, and to flush the SI system. As reactor vessel core components were removed, they were inspected and/or vacuumed to remove any debris.

On April 24, 1995, with the Technical Representative on site, a detailed inspection of the B SI Pump was performed.

As a further precaution, since both Residual Heat Removal pumps were operable and the SI Pumps were not required to be operable to support plant conditions, the decision was made to inspect the A SI Pump. The A SI Pump thrust bearing was inspected. The shoes from both sides of the thrust bearing were removed. The shoes on the inboard side of the shaft collar, which resist motion of the shaft towards the motor, were in good condition. The thrust bearing shoes on the outboard side of the shaft collar, which resist motion of the shaft away from the motor, showed evidence of wear. All six shoes on the outboard side showed evidence of babbitt material loss from the surface. In discussion with the Technical Representative, the bearing shoes were within tolerance but this loss of babbitt material is not expected for normal wear. The thrust bearing assembly had previously been replaced in 1993.

A review of the operation of the lube oil system [LL] was performed. The lube oil pump [P] is shaft driven. There is no oil pumped to the thrust bearing until the pump shaft is turning during the start and there is no oil pumped to the bearings during the final pump coast down. Therefore, the only lubrication to the thrust bearing at pump start is residual oil from its previous run. The duty cycle was discussed with the Technical Representative. This pump is not designed to frequently start and stop but to run continuously. The frequent start/stop design for this type of pump would include an electrically driven lube oil pump in parallel with the shaft driven pump.

A parallel investigation of past operations and maintenance history for the SI pumps revealed the pumps had been operated much more frequently during the last operating cycle due to the need to fill the B SI Accumulator [TK]. The increase in running frequency was from approximately 7 starts per year to one start every four days (using alternate pumps). Maintenance records indicate the B SI pump thrust bearing to be the original bearing. The age of the bearing, coupled with the lack of lubrication during initial pump starting, and the significant increase in the starting frequency during the last operating cycle, was determined to be the most probable cause of the thrust bearing failure.

A system flush was performed on April 27 and 28 after the full reactor vessel core off-load and removal of the vessel lower internals. The bottom of the vessel was inspected and vacuumed prior to the system piping flush. This initial cleanup was performed to estimate the amount of material that may have entered the RCS from the SI Pump. A small piece of debris was found and removed.

After the flush was complete, filters which had been installed specifically for the flushing were inspected. At SI-10A [ISV], "Loop A Cold Leg Injection Line Isolation Valve," one very small piece and a few fines were collected. At SI-10B [ISV], "Loop B Cold Leg Injection Line Isolation Valve," just a few fines were found. At SI-14A, two small pieces, and at SI-14B, six medium to large metal shards, were collected. The reactor vessel was then vacuumed again and the RCS loop piping was inspected and vacuumed. Three post system flush radiographs were taken on the B train RV injection line. No debris was identified.

Cleanup of the RCS and reactor vessel was completed on April 29, 1995. Replacement of the fuel and reactor vessel internals was completed on May 4, 1995.

Upon completion of core reload, vessel assembly, repair of the SI Pumps, and re-installation of all piping and valves associated with inspection and flushing activities, both SI Pumps were tested to verify pump operability. The tests verified acceptable pump operation, and satisfied the pump vendor's concerns and requirements. Two special test procedures were used to test the B SI Pump. One test was performed to verify proper operation of the pump and the other test collected pump performance data to ensure the rebuilt pump was capable of performing its intended function.

Safety Injection Pump A was verified to be operable by performing SP 33-191 after the thrust bearing was replaced.

On May 5, 1995, more radiographs were taken at valves SI-10A(B) and SI-14A(B), after the SI pump full flow SP had been performed. The radiographs verified that the throttle valves were free of debris. With the retest of the SI pumps completed and the final throttle valve radiographs clean, efforts to flush the SI system free of debris were considered successful.

Cause of Event

Four potential failure mechanisms were identified which could have caused the observed damage to the B SI pump internals:

1. Failure of the locking rings,

2. A loose part entering the pump,

3. A total loss of flow through, or deadheading of, the pump, or

4. A thrust bearing failure.

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Locking ring failure:

The damaged impeller shaft was inspected. All impellers were attached to the shaft and the retaining rings were intact, therefore, this was eliminated as a cause.

Loose part entering the pump:

A loose part entering the SI pump has been eliminated as the cause of the pump failure. Casing damage characteristic of loose parts in the flow path did not exist in the first five stages of the pump. There were no mechanical marks on any accessible flow surfaces.

Loss of flow through, or deadheading of, the pump:

The loss of flow through or deadheading of the pump has also been eliminated as a cause. Any loss of flow through the pump would result in scoring in tight clearance areas of the pump internals/impellers and resulting shaft heat up. There was no evidence of any scoring indicative of loss of flow through the pump in these critical areas. Also, prior to the indicated decrease in flow, the pump operated for 87 minutes with flow indication to the reactor vessel of approximately 200 gpm. The flow element and instrument loop were demonstrated operable by I&C using standard calibration procedures.

For the pump to be deadheaded, the recirculation path would have to have been blocked. Subsequent review of the procedures and valve lineups confirm all valves in the recirculation flow path were open. All motor operated valves (MOVs) had been tested per the MOVATS program and were in service.

Thrust bearing failure:

The fourth failure mechanism, failure of the thrust bearing, has been determined to be the cause of the event. The evidence supporting this conclusion is as follows:

1. The outboard thrust bearing rings and shoes are scored and darkened from heat.

2. The surface of each of the six outboard shoes is deeply scored.

3. There is no babbitt material left on any of the outboard shoe faces.

4. The surface of the shaft collar, in contact with the outboard thrust bearing shoes, shows deep scoring and discoloration.

5. The inboard thrust bearing shoes show the same loss of babbitt material and scoring, with a much lesser degrce of darkening due to heat.

6. The inboard shaft collar surface shows the same degree of damage as the inboard thrust bearing shoes.

7. The lower thrust bearing housing was full of metal shavings typical of the babbitt material.

8. The Lube Oil reservoir contained significant amounts of metal shavings.

9. Failure of the thrust bearing would allow the shaft to move axially, well beyond the normal limit.

10. Though the pump is hydraulically balanced, changes in flow through the pump would result in axial shaft loads imparted on the thrust bearing.

11. At pump startup, the initial thrust caused by the beginning rotation of the impellers is against the outboard thrust bearing.

Failure of the thrust bearing will result in the uneven distribution of damage as observed in the pump internals. With the manufacturing tolerances between impeller thickness, volute width, and other elements, excess axial motion will result in the closest component contacting the casing or other stationary pump internal component. In this case it was the seventh stage impeller. Failure of the outboard thrust bearing, allowed the shaft to move outward. The seventh stage impeller contacted the casing at 3600 rpm. The casing and impeller material is type 304 stainless steel; any contact would result in immediate galling and the generation of significant heat. This is evident by the heat or "weld" deposited material on the outboard face of the seventh stage impeller. Heat transmitted through the impeller to the shaft would cause differential expansion of the material further increasing the contact in this area. Qualitative measurements have estimated that approximately one quarter inch of material has been removed from certain areas of the outboard face of the seventh stage casing volute. The unequal distribution of wear seen in the subsequent high stage impellers is also characteristic of this type of failure. The decreasing amount of damage to the outboard surfaces of the impellers of stages 8,9,10 and 11, and the minimal damage to the outboard surfaces of three of the five lower stage impellers, supports this conclusion.

Interviews with the Nuclear Auxiliary Operator and two Plant Maintenance personnel in the area of the pump at the time of the event support this conclusion. During the performance of SP-33-191, a puff of smoke was seen coming from the breather on the thrust bearing housing and local thrust bearing temperature increased to 179°F. Bearing temperatures were then seen to decrease and stabilize between 160°F and 170°F. Lube oil pressure, temperature and lube oil flow were noted to be normal at this time.

Approximately 10 minutes later, the loss of flow occurred.

Three failure mechanisms for thrust bearing failure were investigated. They are:

1. An unusual axial load on the pump,

2. Loss of lubrication during operation, or

3. Wear associated with pump oporation.

The following discussion focuses on the root cause of the thrust bearing failure.

As previously discussed, no loose parts passed through the pump. Therefore, impact loads caused by a loose part lodging between a stationary and rotating element did not exist. The SP that was being performed when the pump failed is a routine procedure, performed every outage. The flow paths, sequence of testing, and acceptance criteria were unchanged from past practice. There is no evidence of any cavitation in the impellers. There were no unusual flow lineups or changes which would have caused pump run out. As previously documented, the pump was not deadheaded during the test. Therefore, there were no unusual axial loads on the bearing.

During the disassembly of the pump's lube oil system, a triangular picce of what appeared to be ceramic material was found in the lube oil pump's suction chamber. This foreign object was firmly adhered to the suction chamber surface opposite the entrances to the screw impellers. It required a tool and significant force to pry the object from the chamber surface. This piece was too large to pass through the screws and discharge tubing. While it is small enough to have passed through the lube oil pump suction tubing, there is a metal filter element at the suction inlet in the reservoir, which would have prevented the foreign object from entering the suction tubing. As previously noted, operations and maintenance personnel stationed at the pump during the performance of the SP, reported normal lube oil pressure, temperature and flow. Therefore, from the location of the object out of the pump suction flow path, its firm attachment to the chamber surface, and the observations reported by personnel, it has been concluded that this foreign object did not contribute to the event.

The design of the SI Pump's lube oil system reveals the following facts. The lube oil pump is a shaft driven pump. During pump starting and stopping, lubricating oil is not available at full pressure and flow until the pump is up to speed. Therefore, the thrust bearing is dependent upon the oil trapped in the reservoir of the housing and the oil film remaining from the previous pump operation. The lube oil system is cooled with a Service Water (SW) [BI]heat exchanger[HX]. Duration of pump run time has an effect on lubricating oil temperature and viscosity. As with any piece of rotating machinery, equipment operating time has an impact on the lubrication system and rotating elements. Operation for short time periods does not allow the equipment to fully warm-up and reach steady state operating conditions.

In discussions with plant personnel, and in researching both SI Pump's maintenance and testing records, the following observations and recent changes in pump operating practice were found to be relevant:

- The thrust bearing assembly in B SI Pump is the original bearing assembly. Inspection of the thrust bearing on March 29, 1990 reported satisfactory bearing condition.

- The thrust bearing assembly in A SI Pump was replaced in 1993. When inspected in the 1995 outage, the shoes in the outboard thrust bearing showed loss of babbitt material. This loss of material was not normal as stated by the Technical Representative, but was within acceptable limits.

- Due to leakage from the B SI Accumulator during the 1994-1995 operating cycle, both SI Pumps were operated at a much greater frequency than was past operating practice. During the past year, the SI Pumps have been started approximately every four days on an alternate basis.

- The run time of the pumps when filling the accumulators is typically four to five times shorter than the run times associated with the routine SPs. The average run time is approximately 17 minutes during SP 33-98, greater than 60 minutes for SP 33-191 (full flow test), and about 22 minutes for other miscellaneous surveillance tests. The pump run time during the accumulator filling operation is between 1 and 7 minutes.

A discussion with the Prairie Island SI System Engineer pointed out the following differences between the two plants' operating and maintenance practices:

1. Prairie Island (PI) uses 150 SSU oil in their SI lube oil system.

2. PI personnel hand lubricates the bearings once per month as recommended in the technical manual and hand lubricates the bearings prior to every start of the pump for any normal operating or testing activity.

A review of the Vendor Technical Manual states the recommended oil viscosity is 150 SSU at 100°F. A review of past maintenance records from 1972 onwards shows we have used a lubricating oil viscosity of 335 SSU at 100°F. Review of the capability of the lube oil pump to deliver adequate flow at pressure using the higher viscosity oil shows that the lube oil pump performance is actually improved by the higher viscosity oil. The operating experience where pump run times are typical of the SP run times combined with the observation of acceptable thrust bearing condition after 19 years of operation, support the conclusion that the viscosity discrepancy did not contribute to the event.

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The decision not to follow the recommended monthly lubrication of the bearings is documented in an internal memo dated June 30, 1994, which is contained in the pump technical manual. This decision was based on the observed bearing assembly wear prior to 1993 and did not consider the change in pump operation caused by the B SI Accumulator leakage.

The observed changes in KNPP pump operation, the differences between maintenance practices, and the pump lubrication design support the conclusion that the thrust bearing failure in B SI Pump is due to the frequent and short duration operation of the pump to fill the B SI Accumulator. The condition of the newer A SI Pump thrust bearing with less starts along with discussions with the Technical Representative and Field Services Engineer at Sulzer Bingham Pumps also supports this conclusion.

The age of the thrust bearing assembly in the B SI Pump may have been a minor contributing factor. Any contribution is believed to be negligible since inspection of the bearing in 1990, after 17 years of routine operation, showed acceptable condition.

The process that resulted in the decision to continue to use the Safety Injection Pumps to fill the Accumulator is a major contributor to this event. Early in the last cycle, Plant Operations raised concerns about the increase in starting frequency on the Safety Injection Pumps due to the accumulator leakage. It was questioned if consideration should be given to reviewing the preventive maintenance procedures to see if any of the longer term procedures should be pulled forward. Plant Operations also initiated actions to establish an alternate means of filling the Accumulator. The final assessment was that none of this was necessary as there was adequate margin in the design of the pumps.

Upon review of the sequence of events, it has been concluded that the continued operation of the B SI Pump while attempting to determine the source of the flow problem, contributed to the distribution of debris throughout the SI system piping. The operator aligned the pump to inject through the CL lines to cool the pump, as the symptoms indicated a loss of flow through the pump. The local observation of the high thrust bearing temperature was reported to the control room within the same time frame that the loss of flow through the RV injection lines was noted. As reported, the bearing temperature remained below the upper limit for pump operation as stated in the procedure.

Another contributing factor was the content of the SP being used. As the current procedure is written, indicated pump amps are recorded at various procedure steps, but the procedure does not contain any information regarding normal pump amps for any given flow lineup, any acceptance criteria regarding pump amps, or termination criteria associated with pump amps. The increase in pump amps as compared to previous tests was not discovered until after the event during the review of the impact of the failure on the SI pump motor. Based on the guidance in the procedure regarding bearing temperature limits and no information about pump motor amps, the continued pump operation to verify flow instrument operability and valve operability was reasonable.

Analysis of Event

This event is being reported as a voluntary LER because the event contains information of generic interest.

Since the event occurred when the SI system was not required to be operable and the failure of B SI Pump, if it had been called upon to operate during plant operation, was not likely and would not have rendered both trains of SI out of service, this event is not reportable. The A SI Pump was in operable condition. The B SI Pump was repaired and tested prior to returning the pump to service. Both pumps were inspected, repaired, tested and found to be operable prior to operability being required by the plant Technical Specifications.

The implications of the failure are focused in three areas:

1. Did the failure of B SI Pump occur during an earlier pump start and result in loose parts in the SI system during power operation?

2. Was a failure of A SI Pump imminent? and

3. What would have been the consequences of the failure of B SI Pump when the SI system was required to mitigate the consequences of an accident?

Failure of the B SI Pump during an earlier pump start:

Safety injection system surveillance procedure results from the previous operating cycle were reviewed and compared to the data from the most recent performance of SP 33-191 in which the pump failed. The surveillance procedures record the control room indication of pump amps as one of the pump performance parameters. The review of the recorded pump amp values indicates that the damage occurred during the performance of SP 33-191 on April 20, 1995. Indicated pump current during the April 20 test was 8 to 10 amps higher than previously recorded values in all but one flow lineup. Previous SP results show a one to two amp variation during the performance of the SP. The maximum SP pump amps were compared to the motor nameplate rating and service factor. At no time during the SP did the pump amps exceed the motor rating. This supports the conclusion that the failure occurred on April 20, 1995 and not before.

Failure of A SI Pump Thrust Bearing:

The thrust bearing in A SI Pump was replaced in 1993. After the failure in B SI Pump, the A SI Pump thrust bearing was inspected. The results of the inspection revealed the onset of the loss of babbitt material from the surface of the shoes. Although this loss is not normal for the thrust bearing assembly, the remaining material was sufficient to support continued operation of the pump (the failure of the thrust bearing was not imminent). The leakage from B SI Accumulator was repaired during the 1995 outage and the start frequency of the SI pumps was returned to normal for the next operating cycle. Therefore, there is no reason to suspect the A SI Pump thrust bearing would have failed prior to the next scheduled inspection.

Failure of B SI Pump during SI System Operation:

The failure of the B SI Pump thrust bearing resulted in the blockage of flow through SI-14A and B. These valves throttle SI flow through the RV injection piping to balance flow through the redundant headers and prevent pump run out. These valves were positioned during the original plant startup testing of the SI system. The valve stems are locked in the throttle position. The position of the valve plug is approximately 1/8 inch off the valve seat as determined from radiography and plug-to-seat gap measurements during cleaning. These valves are located inside containment and would be inaccessible after most design basis events where SI is required to mitigate the consequences of an accident.

If the failure had occurred during plant operation, with injection into the reactor vessel head, flow blockage could have occurred. However, the SI RV injection lines are not part of the required SI lineup for KNPP. The SI lineup for KNPP is through the CL injection lines. Although both of the RV injection throttling valves plugged during the event, the loss of RV injection flow has no effect on safe plant operation.

The normal lineup is through the RCS Cold Leg injection lines, common to both SI pumps. Both SI Pumps deliver flow through a common header which branches into two redundant RCS loop injection flow paths. Each redundant loop injection flow path has a throttling valve, SI-10A(B), a flow limiting orifice downstream of these valves, and a motor operated isolation valve, SI-11A(B). These valves are also located in containment and are inaccessible during most design basis transients where SI is required to mitigate the consequences of the accident. The throttling valves, SI-10A(B), are locked in throttled position similar to SI-14A(B). The flow gap between the plug and seat on SI-10A(B)is larger than on SI-14A(B) therefore, the flow rate through SI-10A(B) is much higher.

During the investigation of the root cause, a discussion was held with the engineers involved in the various aspects of the recovery and licensing personnel regarding the question of whether SI-10A(B) would have plugged with the fragments observed and collected from SI-14A(B). It was concluded that no plugging of SI-10A(B) would have occurred because:

1. A larger gap exists in SI-10A(B) as compared to SI-14A(B),

2. Fragments were found downstream of SI-10 A(B), and

3. The fact that after the pump failure occurred, the B SI Pump injected through the cold leg flow path without plugging SI-10A(B).

If an actual event did occur, both pumps would be injecting through the common cold leg header, prior to the branch lines to the cold legs. This would result in a lower flow rate through each pump. Under these conditions, it is reasonable to expect the flow through the B SI Pump would be lower than that through the A SI Pump. The reduced flow rate through the B SI Pump results in reduced carrying capacity of the observed fragments. The migration of the larger fragments observed to have plugged the SI-14A(B) valves would have been significantly reduced.

It has been concluded that the failure of B SI pump would not have rendered both trains of SI inoperable, had it occurred during plant operation, for the following reasons:

1. The RV injection flow paths where plugging did occur are not part of the SI licensing basis,

2. The post accident flow through individual pumps is less than the test criteria, therefore the migration of fragments would have been significantly reduced, and

3. Blockage of SI-10A(B) would not have occurred since there were no fragments found in SI-10A(B) after the failure, but fragments were recovered downstream of SI-10A(B).

The above discussion assumed the pump would have failed during an actual event. It is highly improbable that the B Sl pump would have failed though. The failure of the B SI Pump occurred after seven different system lineups. Each lineup introduces an axial load on the thrust bearing assembly due to flow rate changes through the pump. During an actual event, once the pump starts, flow remains relatively constant. Any changes in flow occur gradually as RCS system pressure changes. Step changes in flow, typical of opening and closing MOVs to align different flow paths, would not occur. The actual service conditions during an event are less challenging to pump components than the sequence of SP testing.

Corrective Actions

Short Term Corrective Actions:

1. The SI system piping was radiographed, and portions were removed, cleaned, flushed and reinstalled. Radiography of portions of the system piping, and the throttle valves SI-14A(B) and SI-11A(B) and their downstream orifices, after the pump flow tests confirmed the absence of foreign material in the piping.

2. The RCS, reactor vessel, reactor vessel internals and fuel assemblies were cleaned and inspected to the greatest extent possible.

3. The B SI Pump was repaired and tested. The test results were reviewed and found to be acceptable prior to declaring the pump operable.

4. The A SI Pump was inspected with the assistance of the Technical Representative. The bearings were inspected and the thrust bearing shoes in the outboard thrust bearing were replaced. The A SI Pump was tested using the standard SPs. The test results proved the pump to be operable.

Long Term Corrective Actions:

1. Operators will be directed (and procedures revised) to operate the SI pumps for 15 to 20 minutes after starting. This clearly applies to only routine activities and testing. The concern about minimizing pump operating time while on recirculation is still valid (the 30 minute limit remains in effect).

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2. Lubrication of the bearings will be implemented on a monthly basis as is recommended in the technical manual. Prior to routine starts of either SI Pump from the Control Room control switch, the bearings in the pump will be pre-lubricated.

3. Appropriate plant procedures will be reviewed to determine if additional reference values for normal or anticipated normal pump/motor operation should be included. This would provide the operator with reference values to compare current operating parameters with normal operating parameters.

4. This event will be used as a case study on the importance of conservative decision making. The training will be provided to the technical and operating staff.

Additional Information

Safety Injection pumps are Bingham-Willamette Co.(now Sulzer Bingham Co.), Model 4x6x9, Type CP, 11 stage, 3600 RPM pumps.

NRC FORM 366A (5-92)

U.S. NUCLEAR REGULATORY COMMISSION

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ESTIMATED BURDEN PER RESPONSE TO COMPLY WITH THIS INFORMATION COLLECTION REQUEST: 50.0 HRS. FORWARD COMMENTS REGARDING BURDEN ESTIMATE TO THE INFORMATION AND RECORDS MANAGEMENT BRANCH (MNBB 7714), U.S. NUCLEAR REGULATORY COMMISSION, WASHINGTON, DC 20555-0001, AND TO THE PAPERWORK REDUCTION PROJECT (3150-0104), OFFICE OF MANAGEMENT AND BUDGET, WASHINGTON, DC 20503.

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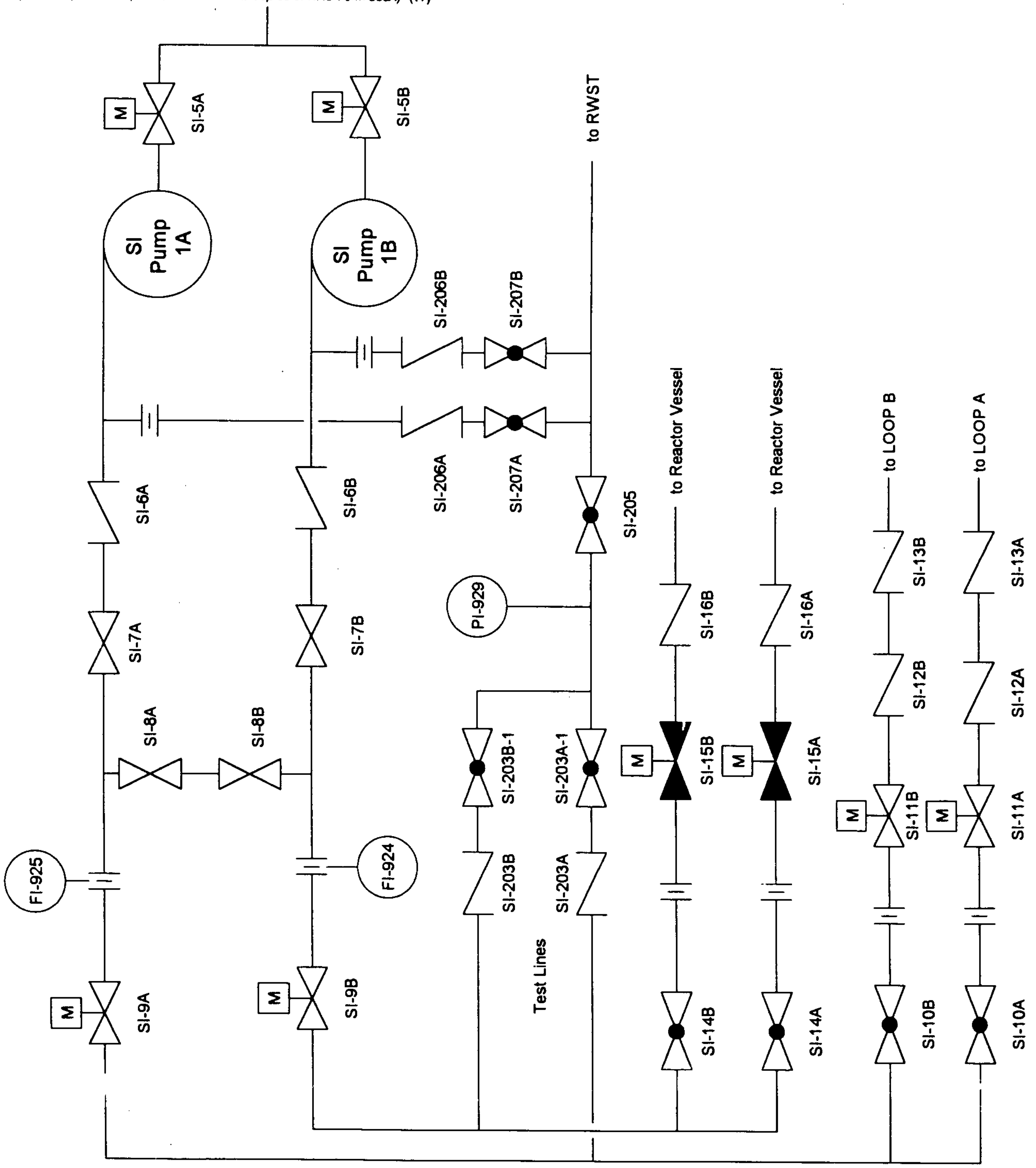

Attachment 1 - Simplified Safety Injection System Diagram