Pressurized Water Reactor
B&W Technology
Crosstraining Course Manual

Chapter 2.3

Reactor Coolant Pumps and Motors

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2.3 REACTOR COOLANT PUMPS AND MOTORS

Learning Objectives:

1. Explain how the plant operator can determine a seal failure using the seal pressure indicators.

2. Explain the purposes of the protection provided by the following reactor coolant pump start interlocks:

    a. low oil pressure.
    b. minimum seal injection water and component cooling water flow.
    c. cold water interlock.
    d. core lift interlock.

2.3.1 Introduction

The Reactor Coolant Pumps (RCPs) (Figure 2.3-1) provide the motive power to circulate reactor coolant through the reactor core for heat removal. The RCPs circulate the reactor coolant through the reactor vessel to the steam generators and return it to the reactor vessel. Four RCPs — two in parallel between each steam generator and the reactor vessel — provide this function. The RCPs are bottom-vertical-suction, horizontal-discharge, single-stage centrifugal units. Each pump shaft is sealed by a three-stage mechanical seal package. The units are driven by constant speed, vertical, squirrel-cage induction motors. The motor is connected to the pump by means of a removable shaft coupling. A motor stand, approximately 16 ft. high, is used as a transition between the pump and motor assemblies. The motor stand, in conjunction with the removable shaft coupling, allows a pump seal package to be replaced without removing the motor. The pump, motor stand, and motor together give the unit an overall height of approximately 32 ft.

2.3.2 Pump Description

The reactor coolant pumps are Bingham units (Figure 2.3-2). Design parameters are given in Table 2.3-2. The RCPs are designed to pump borated water at 2500 psig and 650°F. The design lifetime of the pumps is 40 years, except for normal wearing parts. The pumps consists of two major sections: (1) the hydraulic section containing the pump casing, impeller, and diffuser and (2) the shaft seal section containing the three mechanical seals and connections for seal leakoff and seal injection.

2.3.2.1 Hydraulic Section

The pump casing, which is welded to the reactor coolant piping, includes a bottom suction inlet passage, which delivers the coolant to the pump impeller. The impeller, in turn, discharges the coolant into the multivane diffuser, which discharges the coolant equally around the periphery of the casing. The pump internals can be removed for inspection or maintenance without removing the casing from the piping. A water-lubricated, self-aligning bearing is located in the lower end of the stuffing box. The source of lubricating water comes from the shaft seal section.

The impeller is the rotating part of the pump hydraulic section and is designed for operating hydraulic forces. Coolant is forced into the central portion of the impeller by the positive pressure on the pump suction. The rotation of the impeller adds energy to the coolant in the form of velocity head. The coolant is thrown out of the impeller into the diffuser by centrifugal force. The diffuser is a stationary part of the pump. The vanes of the diffuser are shaped to provide the coolant with progressively expanding space. This gradually reduces the velocity of the water; thus, velocity energy is changed to pressure head in the pump discharge. The pump casing, stuffing box, and shaft seal package make up the reactor coolant pressure boundaries for the pump assembly.

2.3.2.2 Reactor Coolant Pump Seal Injection

The seal injection system is shown in detail in Figure 3-2. As shown in this figure, the injection system may be supplied from any normal makeup pump. Valves V-380A and V-381B are normally both open. If seal injection the reactor coolant pump seals is lost, the seals could be damaged and, in turn, cause a LOCA.

The amount of seal injection to the reactor coolant pumps is governed by a flow control valve in each supply line. The individual seal injection control valves maintain the seal injection flow to their respective RCPs. The control scheme consists of comparing seal injection flow from the flow transmitter upstream of the individual seal injection control valve with a setpoint supplied by the operator. Operator-controlled isolation valves are installed in each seal injection line. Seal injection filters are provided to ensure a clean supply of seal water to the reactor coolant pumps.

An ESFAS signal realigns the seal injection flow path by closing V-380A, which aligns the B-High Pressure Injection pump to supply seal injection. Additional information on the RCP seal injection is in Chapter 3.0, Makeup and Purification System.

2.3.2.3 Reactor Coolant Pump Seal Return

The seal return system consists of individual seal return isolation valves, a reactor building isolation valve, and the seal return coolers cooled by component cooling water (Figure 3-1). The individual seal return isolation valves will automatically close if the following conditions exist:

a. The combination of an idle RCP and a low seal injection flow signal.

b. If a RCP is running and both seal injection flow and component cooling water flow are lost to the RCP.

These interlocks prevent the flow of hot reactor coolant across the pump seal faces.

The seal return piping penetrates the reactor building and then connects to the seal return coolers. An isolation valve (V-283B) located in this line is closed by an ESFAS signal and provides redundant isolation for the individual seal return valves. Additional information on the RCP seal return is in Chapter 3.0, Makeup and Purification System.

2.3.2.4 Shaft Seal Section

The reactor coolant pump shaft is sealed by means of a mechanical seal system containing a combination of rubbing face mechanical seals in series. During normal plant operations, water for cooling and lubricating the seal is provided by the makeup and purification system. Water is injected below the first mechanical seal at a sufficient pressure to ensure flow into the pump. Most of the injected flow passes into the pump casing with a small amount passing up through the seals. The water flowing out of the seal package is directed to both the makeup and purification system and the reactor coolant drain tank.

The shaft seal section is shown in detail in Figure 2.3-3. Water for cooling and lubricating the seals is injected below the bottom seal at approximately 9.5 gpm per pump. Part of the seal flow, about 8.0 gpm, passes into the pump casing through the radial bearing. The remaining flow, approximately 1.5 gpm, passes through the seal package where its pressure drop is divided equally across the three seals. This pressure breakdown is accomplished by a combination of staging coils (pressure breakdown devices) and the clearances of the seals. The flow rates through the two parallel flowpaths are such that almost the entire 1.5 gpm passes through the staging coils and into the seal return line. Only approximately 0.01 gpm passes across the seal faces and into the seal leakage chamber. The stationary seal faces consist of rings that are constructed of carbon material, whereas the rotating seal face rings are constructed of a titanium carbide material. Should one or two seals fail, the remaining seal(s) will take the full system pressure, but seal leakage will increase. A seal leakage chamber is mounted above the top seal to collect the upper seal’s leakage flow. Seal leakage flow is routed to a seal leakage monitoring device, which contains a switch that will trigger an alarm if the seal leakage exceeds a predetermined quantity. Maximum allowable total seal outflow (seal return plus leakage) is 2.1 gpm. The seal return flow is returned to the makeup and purification system makeup tank, and the seal leakage flow is routed to the reactor coolant drain tank for reprocessing.

An integral heat exchanger is mounted on the motor support stand. The purpose of this heat exchanger is to cool the recirculated seal injection water during normal operations. The cooled injection water in turn cools the seal package and the lower radial bearing as it travels down the shaft to the pump casing. A recirculation flow of 40 gpm is maintained through the heat exchanger by the shaft-mounted recirculation impeller. The recirculated seal injection water is cooled by the component cooling water (CCW) system. Operation of the seal section under abnormal conditions is described below:

a. Loss of Component Cooling Water

In the event CCW flow is lost to the heat exchanger, seal temperatures are still maintained within limits by the 9.5-gpm seal injection flow. Operating time is unlimited as long as seal injection flow is maintained.

b. Loss of Seal Injection Water

A loss of seal injection flow to the RCP will still allow unlimited operation as long as CCW flow is maintained to the heat exchanger. In this mode, flow along the RCP shaft reverses and approximately 1.5 gpm flows up along the shaft and is mixed with flow from the recirculation impeller (38.5 gpm). The combined flow passes through the heat exchanger. Out of the heat exchanger the flow divides, with 1.5 gpm passing up through the seals and 38.5 gpm passing down the shaft to mix with the flow coming up the shaft.

c. Loss of Seal Injection and Component Cooling Water

Should both component cooling and seal injection water flows be interrupted while RCS temperature is above 200°F, the pump(s) must be shut down immediately.

d. Seal Failure

As previously stated the plant operator can, using the seal pressure indicators, determine the location of a seal failure. During normal pump running conditions, the total pressure drop from the seal injection inlet (2210 psig) to the seal return outlet (20 psig) is divided equally between the three seal sections. A failure of any one of the seals will cause the remaining two seals to share the same differential pressure. Reactor coolant pump operation may continue under this condition. A failure of any two seal sections would require the remaining seal to withstand the full differential pressure. Reactor coolant pump shutdown would be required, followed by a plant shutdown, cooldown and depressurization for seal replacement.

Table 2.3-1 lists the expected pressure for various seal failure conditions.

Table 2.3-1 - Seal Failure Indication
Seal Failure

	Seal #1	Seal #2	Seal #3
P3*	1115	1115	20
P2*	2210	1115	1115
P1*	2210	2210	2210

*Refer to Figure 2.3-3 for location of pressure detectors.
P1 is always 2210 psig.

2.3.3 RCP Motor

The RCP is driven by a vertical, solid-shaft, squirrel-cage induction motor (Figure 2.3-4). The motor is rated at 10,000 hp continuous duty. This power requirement occurs during plant heatup while cold reactor coolant is being pumped. The power required by the pump at normal operating temperatures is about 9000 hp. The RCP motor design parameters are listed in Table 2.3-2.

The motors are totally enclosed with dual air-to-water heat exchangers, which provide closed-circuit cooling airflow through the motor. The motors are equipped with anti-rotation devices to prevent reverse rotation of the pump; this reduces the starting current required to approximately 3000 amps. Each motor contains a flywheel that provides continued (coastdown) flow following a loss of RCP power. This allows reactor power to be reduced before flow through the core is reduced, ensuring that localized boiling conditions, departure from nucleate boiling, are not reached. Because the flywheel has such a large mass and rotates at a speed of 1200 rpm during normal operation, a loss of flywheel integrity could result in high-energy missiles and excessive vibration of the RCP assembly. The safety consequences of a loss of flywheel integrity could be significant because of possible damage to the reactor coolant system, the primary containment, or engineered safety features equipment. The quality of the flywheels is closely controlled, and their operating environment is not severe; therefore, the use of proper materials, design, and in-service inspections ensures a sufficiently small probability of flywheel failure.

The motor bearings include an upper guide and thrust (Kingsbury type) bearing and a lower guide bearing. The thrust bearing can accept the upward thrust generated by RCS pressure when the pump is idle or running. It also accepts thrust in the downward direction generated by the weight of the rotating elements and the pumping action when running. Both sets of bearings are oil lubricated and are cooled by heat exchangers supplied with component cooling water. The lower guide bearing sits in an oil bath that has an integral oil cooler. During normal operation, oil is supplied to the thrust bearing by means of hydrodynamic action caused by shaft rotation. During startup and shutdown of the RCP, sufficient oil pressure cannot be supplied to the thrust bearing; therefore, a high- pressure oil lift system is used to supply sufficient pressure to the bearing. A high-pressure oil lift pump must be started before the RCP is energized. If it fails to establish oil pressure, the other lift pump is started. Thrust-bearing oil pressure is monitored and interlocked with the pump motor controller. As motor speed increases the lift motor is shut off automatically. During pump shutdown, the oil lift pumps are started prior to stopping the pump. After the RCP motor speed reaches zero, the oil lift pump(s) may be stopped.

2.3.4 RCP Start Interlocks

Figure 2.3-5 shows a simplified logic diagram associated with the starting of the reactor coolant pumps. The diagram shown is for reactor coolant pump A1. There are three protections afforded by the start interlock circuit: pump protection, cold water interlock and core lift interlock.

2.3.4.1 Pump Protection

To ensure that vital RCP auxiliaries are functioning properly before the pump is started, the following conditions must be met:

a. Oil pressure, as measured in the upper radial and thrust bearings, must be greater than setpoint for at least 2 min. This ensures sufficient oil film on the shoes of the thrust bearing to minimize starting torque.

b. Both oil reservoirs, upper and lower, must have a minimum level to ensure sufficient oil for motor operations.

c. Both component cooling water and seal injection water must be available for cooling the seal water heat exchanger, motor-bearing oil coolers, and seal packages.

2.3.4.2 Cold Water Interlock

A cold water accident is not possible in this reactor because the reactor coolant piping does not contain check or isolation valves. Also, single-loop operation is not permitted. However, starting an idle pump will cause an increase in coolant flowrate and a decrease in average core temperature. With a negative moderator temperature coefficient, a power rise will occur as a result of a positive reactivity addition. For the case of one or more idle pumps, the interlock prevents the starting of an idle pump if the reactor power is above 22%. This ensures that a high-pressure trip setpoint will not be reached before equilibrium conditions following the restart are attained.

2.3.4.3 Core Lift Interlock

If any three RCPs are running, the fourth RCP cannot be started until cold-leg temperature is greater than 500°F. The purpose of the core lift interlock is to prevent the lifting of the fuel assemblies. At temperatures of less than 400°F the fuel assemblies may have a tendency to “float” off the lower grid. As the individual assemblies move up and down, because of the relative motion between the assemblies, wear and vibration problems could over a long period of time cause damage to the fuel assemblies. Setting the temperature limit at 500°F ensures that actual cold-leg temperature, allowing for uncertainties, is hot enough to preclude this from happening.

2.3.5 Pump Operating Characteristics

Core flow is dependent on several parameters, of which the number and configuration of running reactor coolant pumps are the most important in determining total core flow. As shown in Figure 2.3-6, the flow is divided equally among the loops with all four pumps running. Any deviation from this will be accounted for by the integrated control system. With less than the full complement of running pumps, flow will be divided as shown on the table at the bottom of the figure. It should be noted that reverse flow will occur in any idle pump.

Figure 2.3-7 shows a typical reactor coolant pump head capacity curve. Nominal flow of 104,000 gpm occurs at the maximum point on the pump efficiency curve. This operating point is determined by parameters such as pump impeller design, system flow resistance, and operating speed.

2.3.6 Reactor Coolant Pump Instrumentation

Each reactor coolant pump is fully instrumented both in the pump section and in the motor section (Figure 2.3-8). Temperatures are monitored on pump and motor bearings, shaft seal inlets, and motor windings. Seal inlet pressures provide the operator with indication of shaft seal performance. Level switches in the motor section provide pump interlock signals for starting of the reactor coolant pump.

2.3.6.1 Motor Instrumentation

Located on top of the motor shaft is a speed indicator, which provides a speed signal through two transmitters to the start/stop circuits of the oil lift pumps for automatic operation. Two temperature elements provide indication of upper radial bearing and thrust bearing temperatures. The high-pressure oil lift pump has three pressure switches on its discharge, which with the level switch on the oil sump provide part of the start interlock circuit for the RCP. Motor-winding temperatures are indicated by attached temperature elements. A level switch located on the motor cooler is designed to alert the operator if any leakage occurs in the cooler. The lower motor bearing temperature element provides temperature alarm and indication in the control room, and, as with the upper motor bearing, a level switch in the oil sump provides a signal for the motor start circuit.

2.3.6.2. Pump Instrumentation

Each section of the shaft seal package has a pressure transmitter on the inlet. These pressure transmitters can be used by the operator to provide indication of proper seal operation and to assess any seal problems that may occur during operation. Several temperature elements, located in the pump section, provide indication of shaft seal inlet and outlet temperature, lower-bearing temperature, and component cooling water outlet temperature. Seal leakage is returned to the reactor coolant drain tank through a leakage detector, which contains a level switch. If leakage should become excessive, level would increase and alert the operator to a possible seal problem.

2.3.7 PRA Insights

From a risk standpoint, the reactor coolant pump seal package is a major contributor. A failure of the seal package may lead to a small-break loss-of-coolant accident, which is one of the significant accident sequences listed in the Arkansas Nuclear One-Unit 1 PRA.

Seals fail for many reasons; however, the seal failure probability is increased if CCW is lost. According to NUREG/CR-4948, "Technical Findings Related to Generic Issue 23: Reactor Coolant Pump Seal Failure," the Midland Plant's frequency of RCP seal loss-of-coolant core damage sequences initiated by losses of CCW is 5.7×10^{-5}/ reactor year.

2.3.8 Summary

The plant utilizes Bingham RCPs driven by three-phase induction motors. There are four reactor coolant pumps, one located on each of two cold-leg returns from each steam generator to the reactor vessel.

Each RCP consists of two major assemblies: (1) the hydraulic section, which contains the pump suction and discharge nozzles and the impeller, which provides the motive force for the coolant in the RCS, and (2) the shaft seal section, which contains a shaft seal package consisting of three rubbing face mechanical seals and an attached heat exchanger. The heat exchanger provides cooling for the seal injection water. After entering the pump, the cooled seal injection water is directed to the mechanical seals for lubrication, and the majority of flow is directed down the shaft into the pump casing. Seal return is routed to the makeup and purification system, and seal leakage is collected in the reactor coolant drain tank. The motor section, the drive unit, is cooled by a closed-circuit cooling system. The bearings in the motor are oil lubricated. An oil lift system provides sufficient oil pressure to lubricate these bearings until the motor can supply its own oil pressure. Other major components include the motor flywheel for extending pump coastdown on a pump trip and the anti-rotation device to prevent reverse pump rotation.

Start interlocks prevent the energizing of the RCP motor unless certain conditions are satisfied. These interlocks provide the following: pump and motor protection, cold water accident protection, and core lift problem protection.

TABLE 2.3-2
REACTOR COOLANT PUMP DESIGN DATA

Item	Data
Number of pumps	4
Design pressure, psig	2500
Hydrotest pressure (cold), psig	3125
Design temperature, °F	650
Operating speed (nominal), rpm	1194
Pumped fluid temperature, °F	70 to 596
Developed head, ft	376
Capacity, gpm	104,200 to 108,500
Hydraulic efficiency, %	86 to 87.5
Seal water injection (minimum), gpm	9.5 per pump
Seal water return (normal), gpm	1.0 per pump

Motor Design

Item	Data
Motor rating, hp (continuous)	10,000
Type	Vertical, solid-shaft, squirrel-cage induction
Motor housing	Totally enclosed, water-cooled
Synchronous speed, rpm	1200
Design lifetime, yr	40
Rated voltage	13,800
Thrust bearings	Kingsbury type (up and down)
Radial guide bearings	Tilting pad
Lubricating system	water cooled
Anti-reverse-rotation device	Prevents reverse rotation; withstands torque of both reverse flow and phase reversal.
Oil reservoir levels	Local indicators, alarm contacts pump start interlock circuit
Oil pressure switches	One on the discharge of each of the two oil lift system pumps, three on discharge manifold for pump interlock circuit

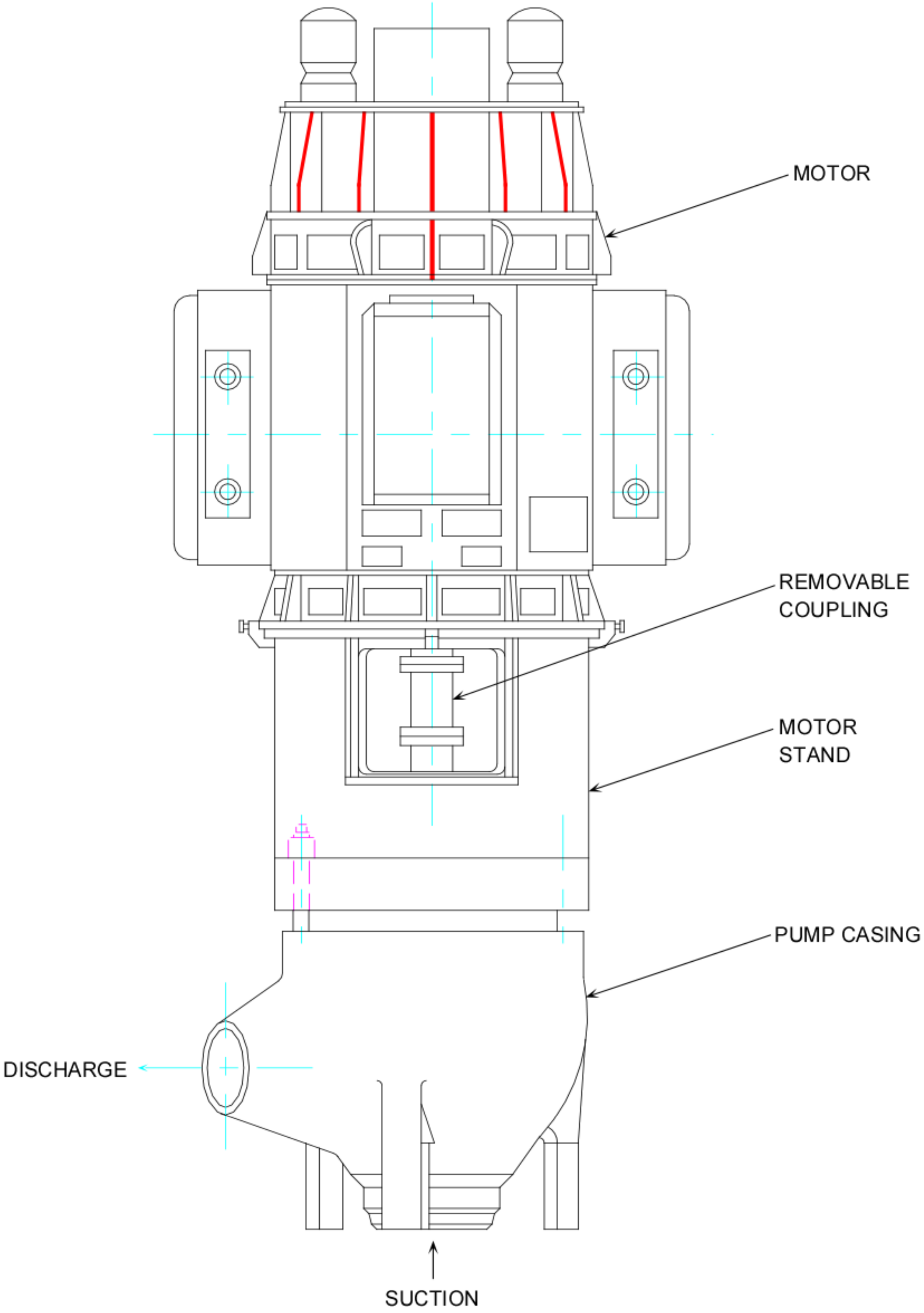

Figure 2.3-1 Reactor Coolant Pump and Motor Assembly

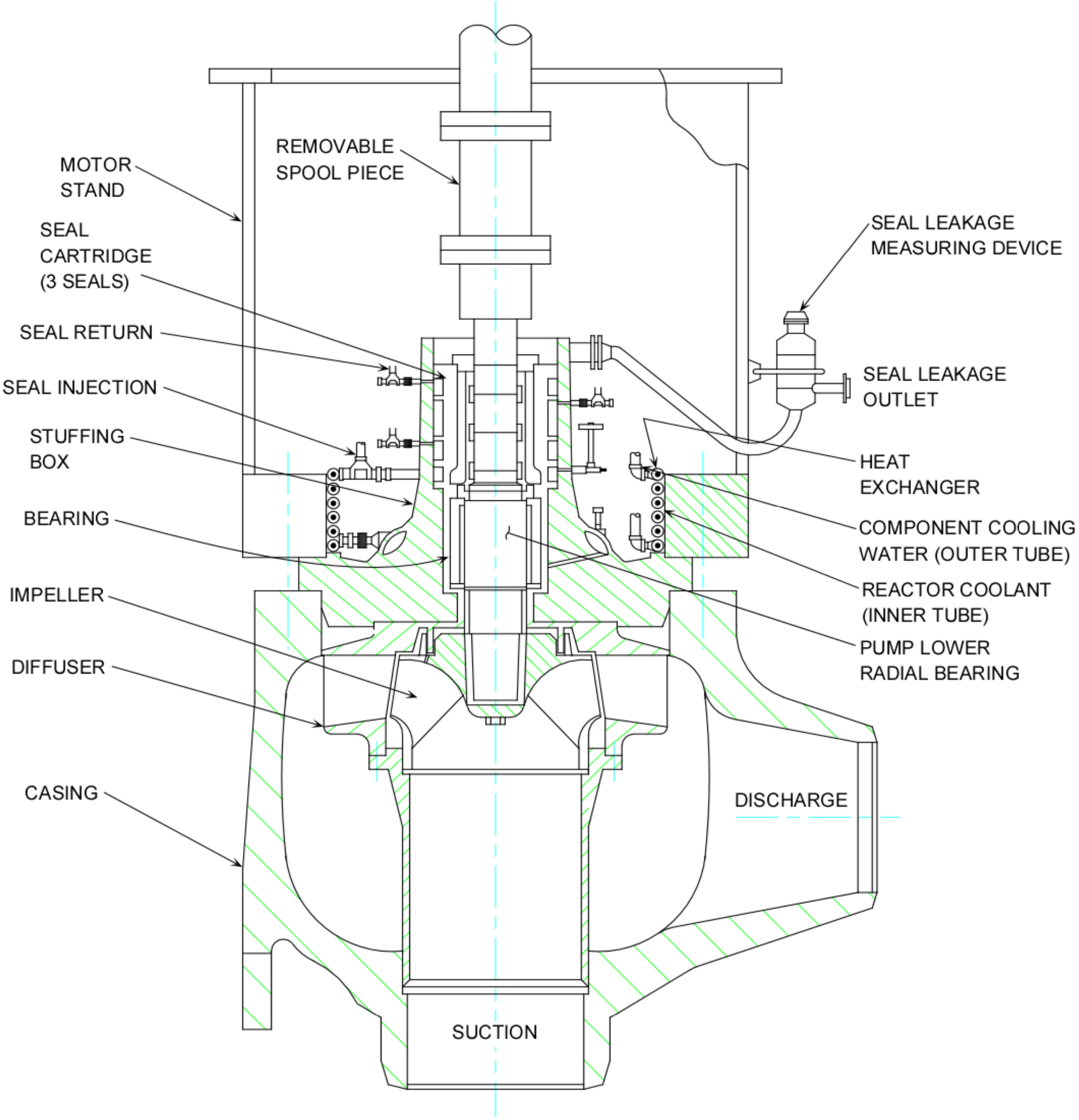

Figure 2.3-2 Reactor Coolant Pump Cross Section

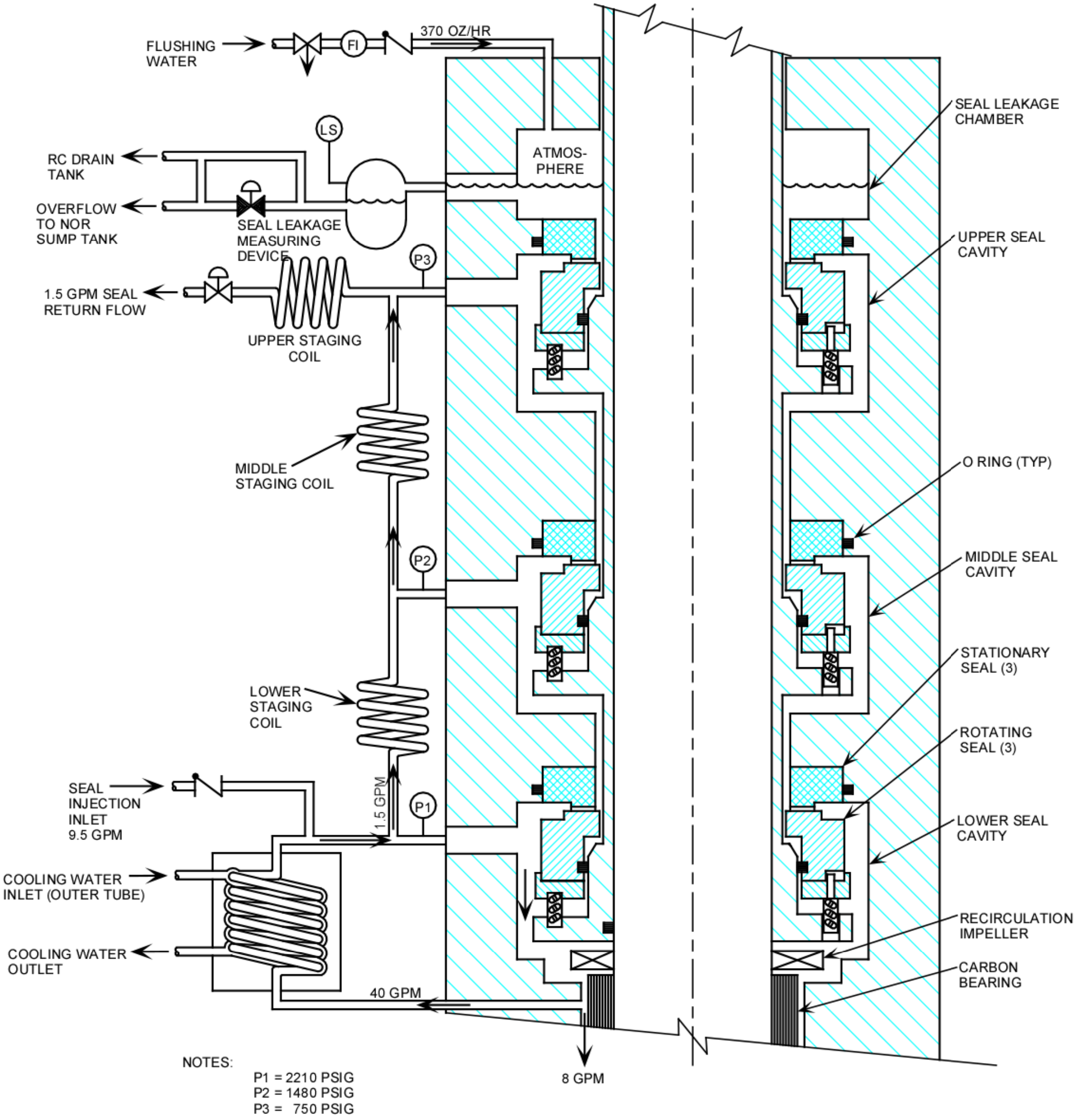

Figure 2.3-3 Shaft Seal Arrangement

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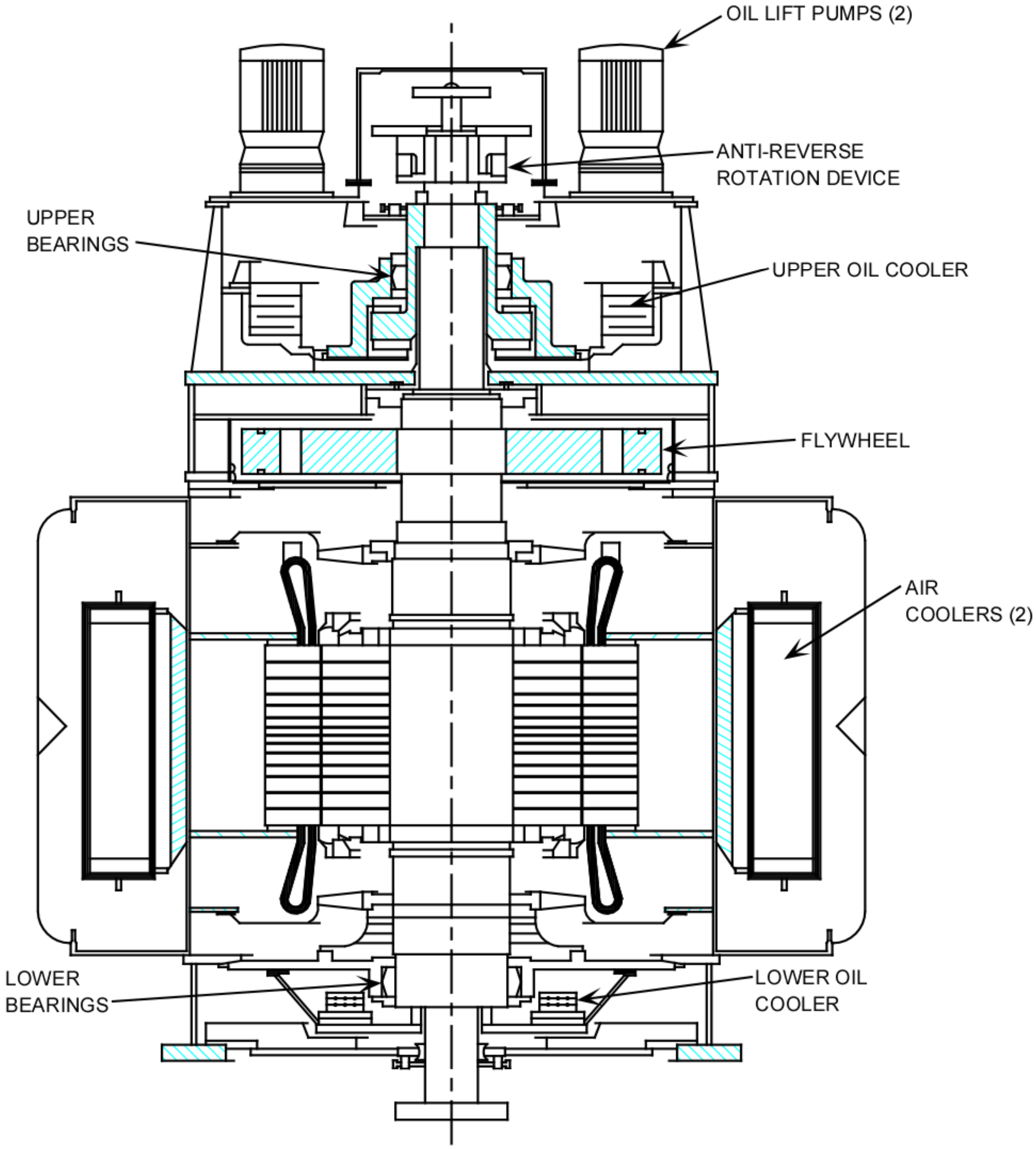


Figure 2.3-4 Reactor Coolant Pump Motor Cross Section

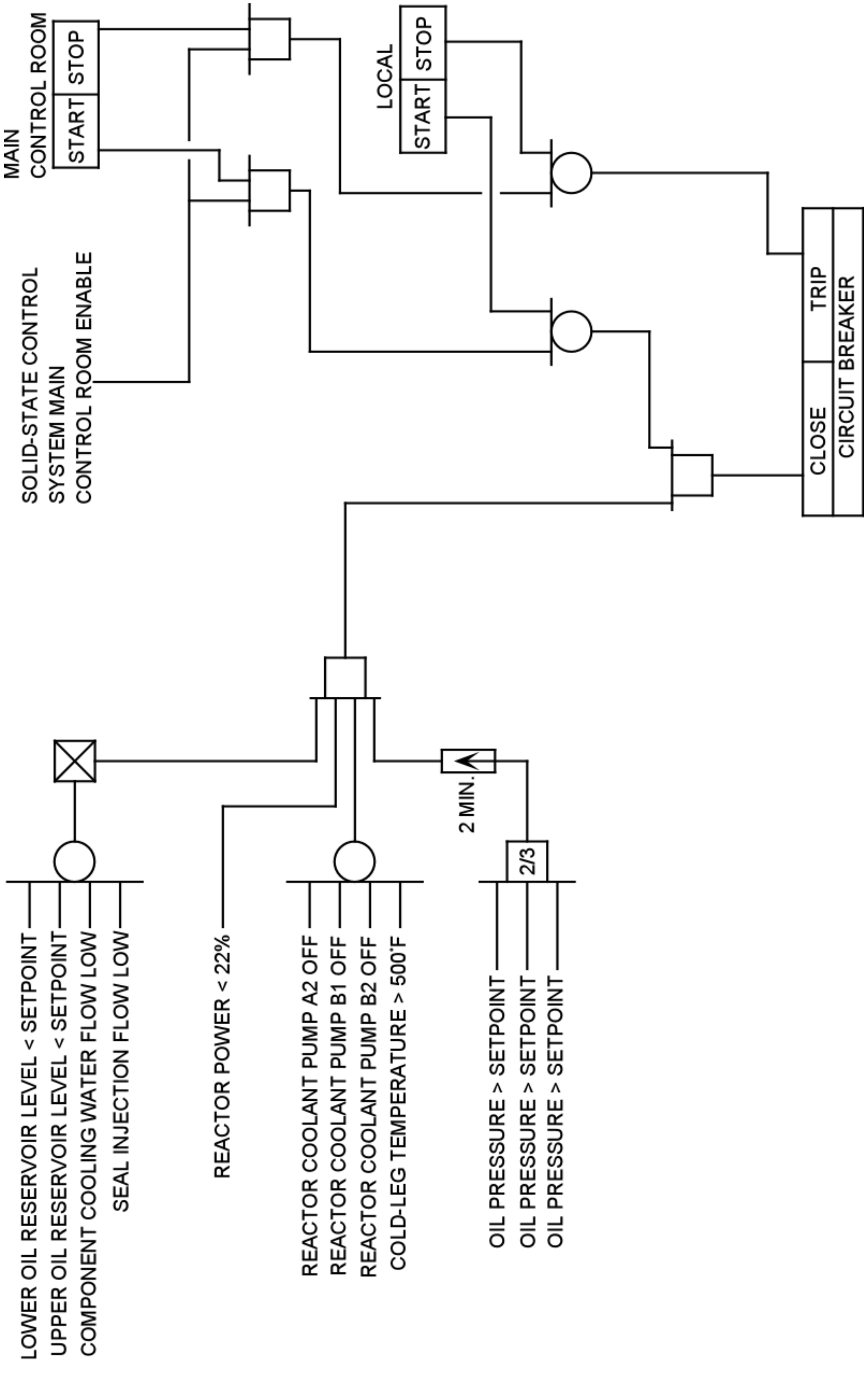
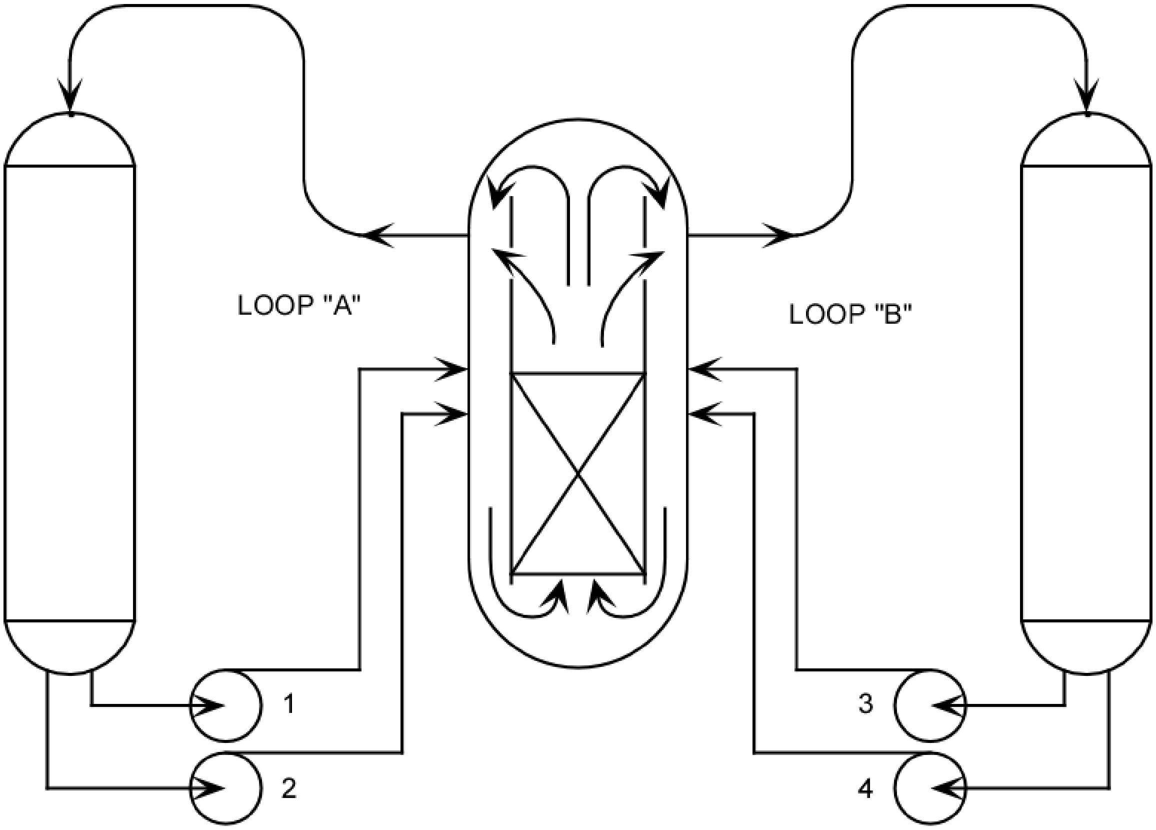


Figure 2.3-5 Reactor Coolant Pump Start Logic



PUMPS RUNNING	FLOW PER PUMP, %				CORE FLOW, %
	1	2	3	4	
1,2,3,4	25	25	25	25	100
1,2,3	26	26	32	-10	74
1,2	27	27	-4	-4	46
1,3	32	-9	32	-9	46
1	33	-6	-2	-2	23

Figure 2.3-6 Reactor Coolant Flow Versus Number of Pumps Operating

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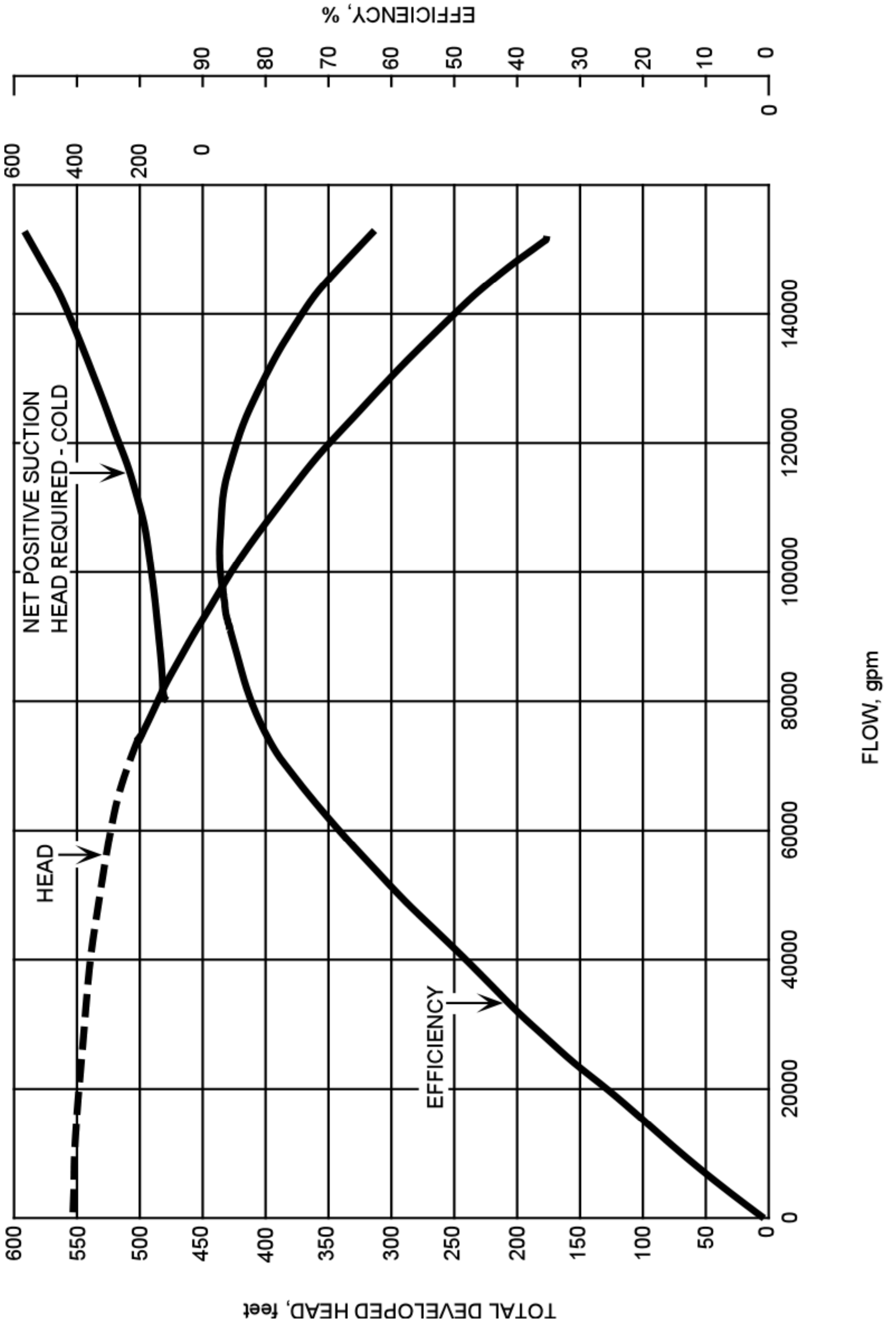

* TO OBTAIN PRESSURE IN PSI MULTIPLY BY .433

Figure 2.3-7 Reactor Coolant Pump Head Capacity Curve

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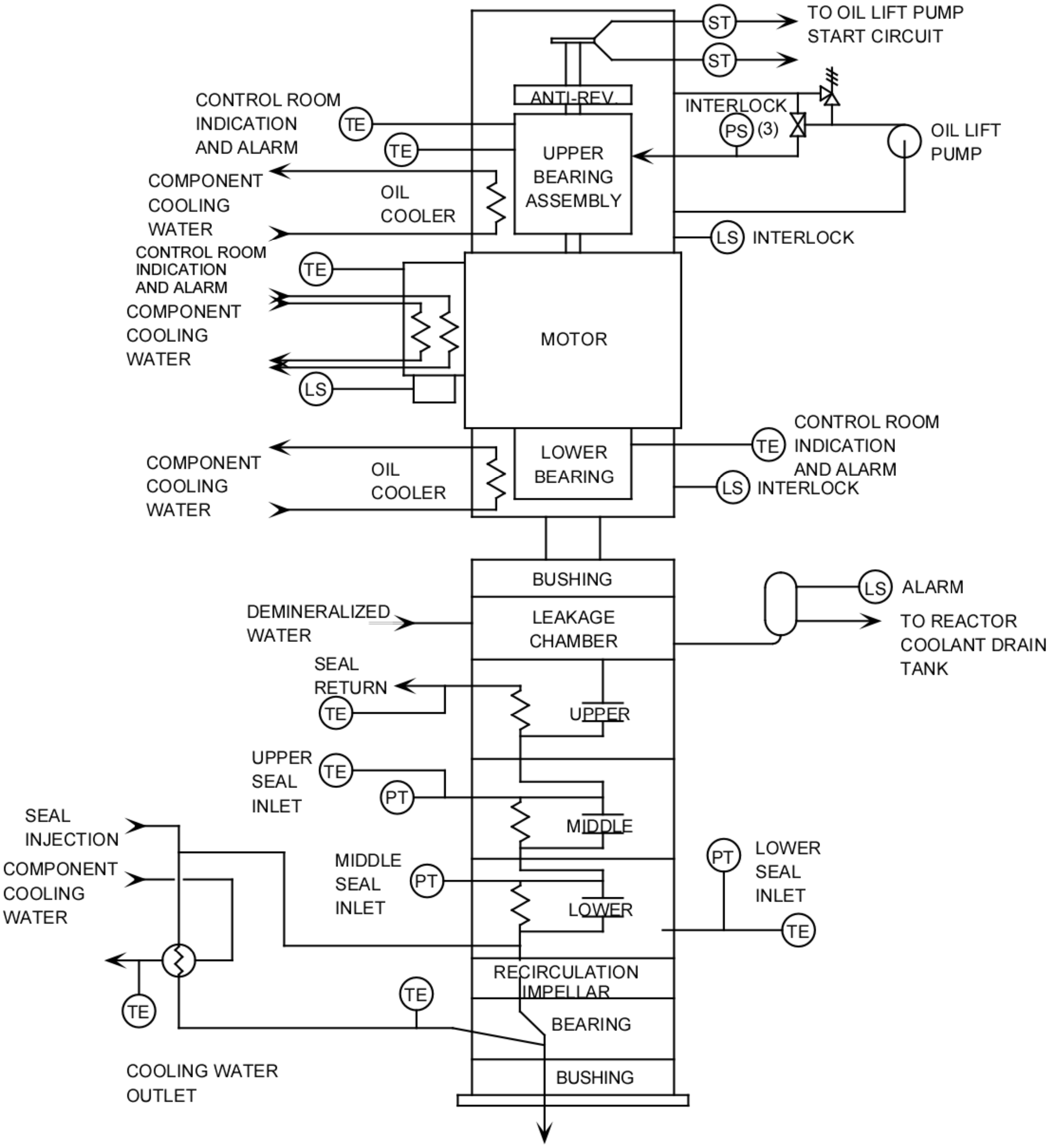

Figure 2.3-8 Reactor Coolant Pump Instrumentation