NEDO-24083
78NED282
CLASS I
NOVEMBER 1978

LICENSING TOPICAL REPORT

RECIRCULATION PUMP SHAFT SEAL LEAKAGE ANALYSIS

GENERAL ELECTRIC

A

NEDO-24083
78NED282
Class I
November 1978

LICENSING TOPICAL REPORT

RECIRCULATION PUMP SHAFT SEAL LEAKAGE ANALYSIS

Approved: [signature]
F. J. Mollerus, Manager
Heat Exchangers and Pump Design

NUCLEAR ENERGY PROJECTS DIVISION • GENERAL ELECTRIC COMPANY
SAN JOSE, CALIFORNIA 95125

GENERAL ELECTRIC

DISCLAIMER OF RESPONSIBILITY

This document was prepared by or for the General Electric Company. Neither the General Electric Company nor any of the contributors to this document:

A. *Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this document, or that the use of any information disclosed in this document may not infringe privately owned rights; or*

B. *Assumes any responsibility for liability or damage of any kind which may result from the use of any information disclosed in this document.*

TABLE OF CONTENTS

		Page
1.	SUMMARY AND CONCLUSIONS	1-1
2.	PUMP GENERAL DESCRIPTION	2-1
3.	RECIRCULATION PUMP SEAL MONITORING SYSTEMS	3-1
3.1	Summary	3-1
3.2	Configuration	3-1
3.3	Seal Cooling Monitoring System	3-1
3.4	Seal Performance Monitoring System	3-1
3.5	Cavity Pressure Monitoring	3-2
3.6	Seal Purge Flow Rate Monitoring	3-2
3.7	Sensor Interpretation of Seal Performance	3-3
3.8	Drywell Equipment Sump Monitoring System	3-3
3.9	Drywell Atmosphere Monitoring	3-4
3.10	Seal Leakage Operator Actions	3-4
3.11	Recirculation Pump Seal Cooling Functional Independence	3-5
4.	ANALYSIS	4-1
4.1	Method and Theory	4-1
4.2	Hydraulic Model	4-2
4.3	Assumptions	4-2
4.4	Summary of Results	4-3
5.	CONCLUSIONS	5-1

LIST OF ILLUSTRATIONS

Figure	Title	Page
2-1	Sealing System and Leakage Path (Configuration 1)	2-3
2-2	Sealing System and Leakage Path (Configuration 2)	2-4
3-1	Recirculation Pump Seal Cooling System	3-8
4-1	RELAP-4 Seal Model (Configuration 1)	4-5
4-2	RELAP-4 Seal Model (Configuration 2)	4-6
4-3	Simplified Seal Geometry	4-7

LIST OF TABLES

Table	Title	Page
3-1	Typical Operating Conditions and Alarm Setpoints	3-7
3-2	Seal Performance Monitoring	3-7
4-1	Recirculation Pump Leakage in Event of a Gross Seal Failure	4-4

1.0 SUMMARY AND CONCLUSIONS

The purpose of this report is to show that total loss of cooling water to the primary reactor coolant recirculation pump seals will not result in unacceptable degradation of the seals. Two systems provide cooling water to the recirculation pump seals:

(1) Reactor Building Closed Cooling Water (RBCCW) System, and

(2) Seal Purge System.

If either cooling system fails to operate, the other system will provide adequate cooling to the recirculation pump seals to prevent damage. Each system has alarms and annunciators to identify degraded cooling conditions so appropriate action can be taken to correct any system malfunctions. In the unlikely event that both seal cooling systems failed to operate and the reactor operator ignored all alarms and annunciators and took no corrective action, the recirculation pump would continue to run, thus degrading the seals.

This report will show that:

(1) the two recirculation pump seal cooling systems are functionally independent and it is highly unlikely that both systems would be inoperable at the same time;

(2) the recirculation pump seal cooling systems have in-depth instrumentation to identify any seal cooling system failure in sufficient time to allow an operator to take appropriate action prior to any serious seal degradation; and

(3) recirculation pump seal leakage through severely degraded seals is not a safety concern.

It is concluded that failure of one of the recirculation pump seal cooling systems will not result in any immediate operational problem. Through appropriate operator attention and action, malfunctions of the recirculation pump seal cooling systems will be diagnosed and any required corrective action

will be taken prior to any recirculation pump seal damage. Even if both seal cooling systems fail to operate and no corrective action is taken, the leakage past the degraded recirculation pump seals is sufficiently small so no safety concerns exist.

2.0 PUMP GENERAL DESCRIPTION

The design of the recirculation pump incorporates mechanical shaft seal assemblies to control leakage around the rotating shaft of the recirculation pump. The shaft seal design incorporates a series of seals, bushings and bearings (Figures 2-1 and 2-2). Each pump has two seals built into a cartridge assembly which can be replaced without removing the motor from the pump. Each seal can adequately limit leakage in the event that the other seal should fail.

Even though General Electric uses two different recirculation pump configurations, the seal designs are essentially the same. Both designs use hydrostatically balanced mechanical shaft seals. In addition, the seal chambers are cooled to improve the performance and longevity of the nonmetallic parts.

Each recirculation pump utilizes two functionally independent seal cooling systems:

(1) the RBCCW System, and

(2) the Seal Purge System.

Incorporated within the recirculation pump is a heat exchanger through which reactor water flows from the pump cavity to the lower seal cavity (Figure 3-1). To cool this water, RBCCW is circulated through the heat exchanger, thereby removing heat. The reactor water then is used to maintain the recirculation pump seals at the correct operating temperature.

The purpose of the seal purge system is to prevent "dirt" from entering the seal cavity. This is done by injecting clean water from the CRD system into the seal cavity and maintaining the cavity at a pressure sufficient to prevent "dirty" water from entering the cavity. Although the seal purge system is designed to purge the recirculation pump seal cavity, it also efficiently provides a cooling function.

Cooling water from the lower seal cavity passes into the upper seal cavity through the seal staging orifice at the rate of approximately 1 gpm. There are two paths for this cooling water to exit the pump: (1) through the seal staging line at approximately 1 gpm, and (2) across the second seal face at approximately 50 oz/hr. Both of these cooling water paths are piped to the drywell equipment sump. In the event of seal failure, some fluid may bypass the pump case and flash to steam in the drywell.

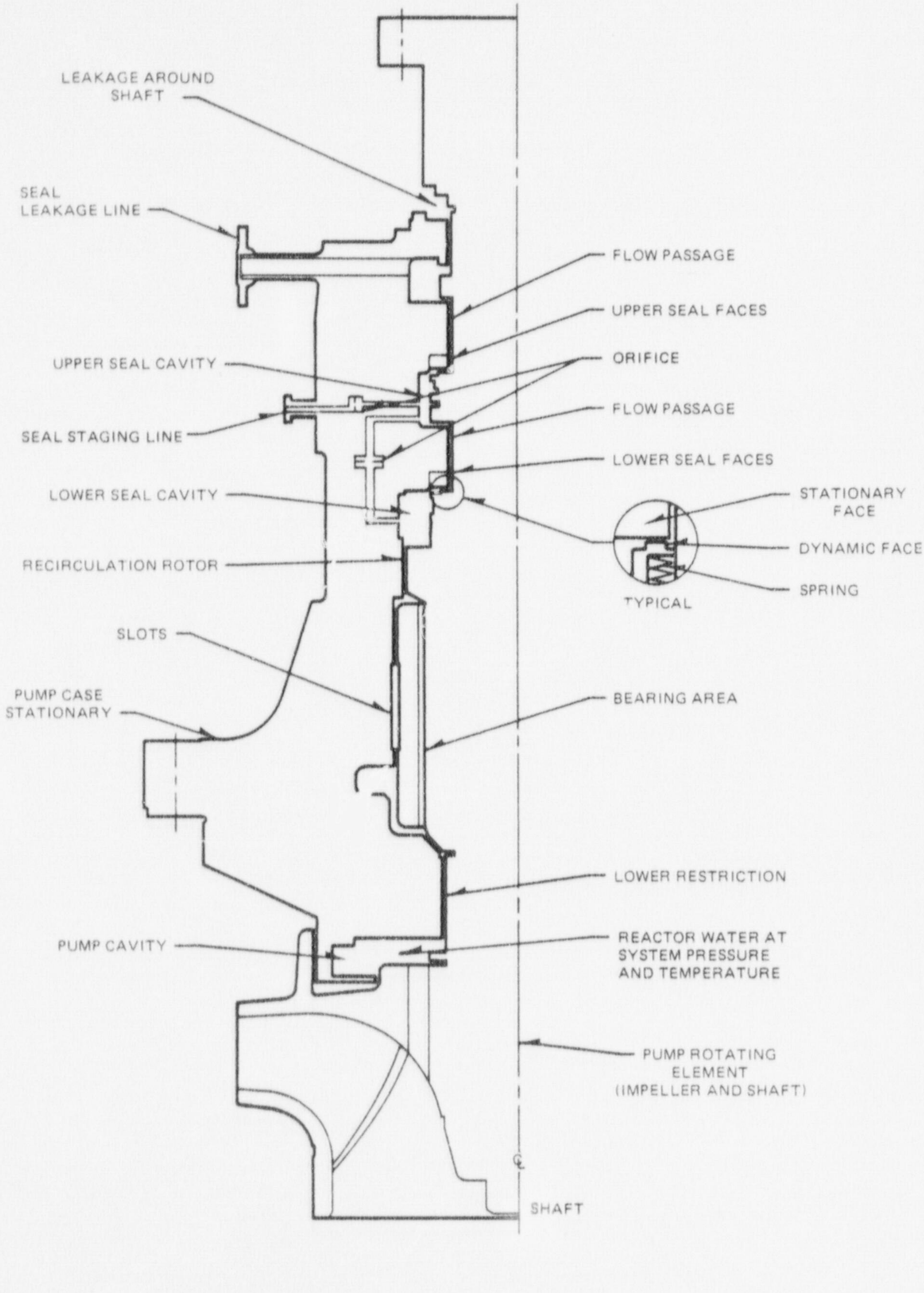


Figure 2-1. Sealing System and Leakage Path (Configuration No. 1)

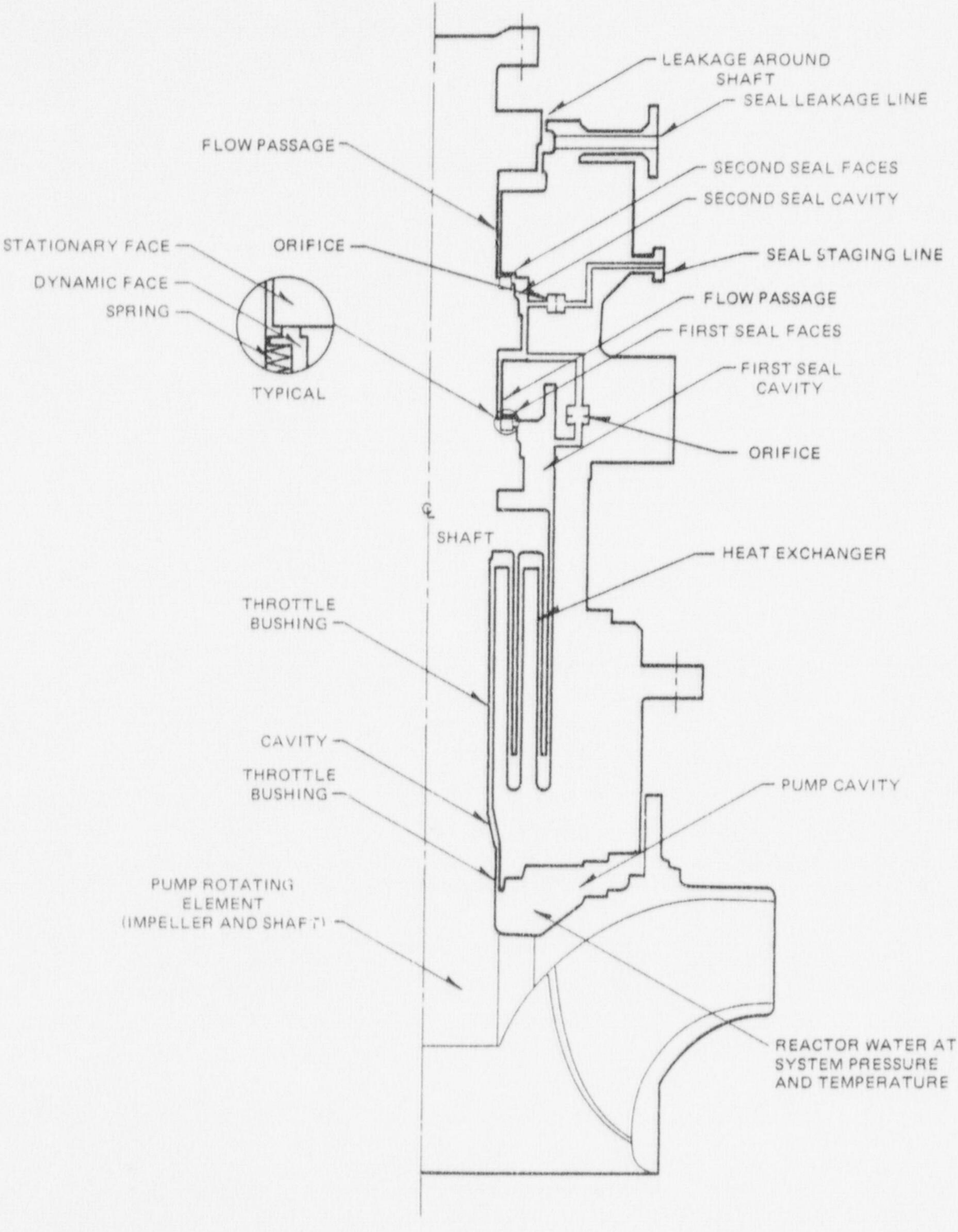


Figure 2-2. Sealing System and Leakage Path (Configuration No. 2)

3.0 RECIRCULATION PUMP SEAL MONITORING SYSTEMS

3.1 SUMMARY

Both recirculation pumps have two seal monitoring systems, each serving a different function. One system monitors the seal cooling water temperatures and alarms if temperature limits are exceeded. The other system monitors the performance or condition of the seals. This system will show seal deterioration trends and also will alarm when normal seal leakage rates are exceeded.

3.2 CONFIGURATION

Each recirculation pump has its own seal monitoring systems. A diagram, showing the configuration of the systems, is given in Figure 3-1. The following paragraphs describe the operation and alarm setpoints of these systems.

3.3 SEAL COOLING MONITORING SYSTEM

Two pairs of temperature elements (TE1 and TE2) monitor each seal cavity of the pump. For each pair of thermocouples, one serves as a spare (wired out to junction box), while the other is connected to pen recorder TR1. The recorder will trigger an alarm to annunciate high temperature when the seal cavity temperature exceeds 180°F. Seal deterioration will occur if the temperature exceeds 250°F. To achieve this condition would require the loss of both CRD seal injection water and RBCCW.

3.4 SEAL PERFORMANCE MONITORING SYSTEM

Seal condition or performance is monitored by two types of sensors.

One type of sensor monitors the pressure level within the seal cavities, presenting the plant operator with a visual display of the sensed pressure in each of the cavities. The second type of sensor monitors the rate of seal staging flow from the upper seal cavities.

3.5 CAVITY PRESSURE MONITORING

The pressure levels within Seal Cavity Nos. 1 and 2 are measured with identical instruments arranged similarly. Only one circuit - Seal Cavity No. 1 pressure monitoring - will be discussed. The pressure within Seal Cavity No. 1 is measured using pressure transmitter PT1. The transmitter is a pressure to electrical signal converter that produces an output signal varying from 10 to 50 mA, whose magnitude is proportional to the sensed pressure within its dynamic range. This output signal is then applied to pressure indicator PI1 located on the control room main recirculation panel for plant operator read out.

3.6 SEAL PURGE FLOW RATE MONITORING

Although each seal is designed to seal against full reactor pressure during normal operation, each seal operates against approximately one half of the reactor operating pressure. Pressure-reducing orifices, installed between the seal cavities and on the outlet of the upper seal, restrict the flow of seal leakage or purge water past the seals, thereby distributing the reactor pressure between the two seals.

Seal purge flow from the second restricting orifice (4b) is drained and routed to the drywell equipment sump for disposal. This drain flow is monitored by a flow switch which will activate an annunciator to signal "pump seal staging flow" indicating abnormal flow past Seal No. 1. Depending on the size and make of the pump, this switch can be adjusted from 0.75 to 1.25 gpm. Normal flow will range from 0.6 to 1.0 gpm.

Leakage past the outer seal is collected by a second drain system. A bushing in the pump case around the shaft has been provided to limit leakage in the event of a gross failure of both seals. A flow switch in this drain line will activate an annunciator to signal abnormal outer seal leakage flow. Again, depending on the size and make of the pump, this switch can be adjusted from 0.05 to 0.5 gpm. Normal flow will range from near zero to 0.008 gpm. If there is a gross failure of the upper seal, flow in this line will be about 1.4 gpm.

3.7 SENSOR INTERPRETATION OF SEAL PERFORMANCE

By sensing seal cavity pressures and seal staging and drain flows, the condition of each seal can be determined. In Table 3-2, typical pressures and flow rates are given for all possible combinations of upper and lower seal conditions. As evident from the table, each combination has a unique set of pressures and flow rates, allowing the operator to determine the relative condition of the seals.

1. Failure of No. 1 Seal Only - No. 2 seal pressure would approach No. 1 seal pressure. Leakage through the second seal pressure staging orifice (4b) will go to ∿ 1.1 gpm and FS2 will alarm.

2. Failure of No. 2 Seal Only - No. 2 seal pressure would drop dependent upon magnitude of failure. Leakage through FS1 will exceed setpoint and alarm.

3. Failure of Both Seals - Pressure in both seal cavities would drop depending on magnitude of failure. (Lower seal cavity pressure may not drop significantly unless failure was large.) Both FS1 and FS2 would alarm.

3.8 DRYWELL EQUIPMENT SUMP MONITORING SYSTEM

Within the drywell, there are two equipment sumps to handle leakage water from various sources.

The recirculation pump seal staging line and the seal leakage line drain into the drywell equipment sump. This sump can handle up to 100 gpm with two pumps running and has a storage capacity of 500 gal.

The other sump handles the leakage from the drywell floor drains. A postulated complete loss of recirculation pump seal faces would result in water/steam escaping past the outer restriction bushing into the drywell volume. The resulting condensate would be collected by the floor drains. The sump also has a 500-gal. reservoir and a pumping capacity of 100 gpm.

Besides the flow switch annunciators, leakage to the drywell equipment sump is monitored and recorded in the control room. The recorded leakage rate is inspected at the minimum of every 24 hours as required by Technical Specifications. The plant licensing limit for total drywell leakage is 30 gpm of which up to 5 gpm may be attributed to unidentified leakage. An increase in unidentified leakage as measured by the floor drain sump pump could be an indication of failure to both seals. In any case, the operator is required to take specific action if either of these limits are exceeded.

3.9 DRYWELL ATMOSPHERE MONITORING

In addition to the seal leakage flow switches and drywell sump monitoring, the atmosphere of the drywell is monitored. Gross seal leakage failure may lead to changes in:

(1) drywell pressure;

(2) drywell temperature;

(3) drywell humidity; and

(4) activity of the drywell atmosphere.

These parameters are monitored and recorded in the control room.

3.10 SEAL LEAKAGE OPERATOR ACTIONS

By relying on the seal leakage monitoring systems as described previously in this section, plant operators are warned of impending seal failures and can take appropriate action before gross seal leakage can occur. Upon indications of seal degradation, operating plant personnel attention will be directed toward ensuring that other limits such as plant technical specifications are not exceeded. The plant licensing limit for total drywell leakage is 30 gpm, of which, up to 5 gpm may be attributed to unidentified leakage. If violation of this limit is not imminent and, since no threat to plant personnel or public safety exists, reactor power operation is continued while the drywell sump

flows, drywell pressure and drywell atmosphere are closely monitored. If violation of limits is anticipated, procedures for an orderly shutdown and pump isolation will be implemented. If limits are exceeded, plant shutdown within specified technical specifications is required. During this period, the reactor water level is maintained from the following sources:

System	Approximate Makeup Flow Available
Condenser and Feedwater	Up to 5300 gpm
Control Rod Drive (CRD)	Up to 100 gpm
Reactor Core Isolation Coolant (RCIC)	600-800 gpm
High Pressure Core Spray (HPCS)	1800-2800 gpm*

3.11 RECIRCULATION PUMP SEAL COOLING FUNCTIONAL INDEPENDENCE

Seal cooling for the reactor coolant recirculation pumps is provided by the Reactor Building Closed Cooling Water (RBCCW) system. The seal purge system, which is part of the control rod drive (CRD) hydraulic system, also provides cooling to the recirculation pump seals even through the primary purpose is recirculation pump seal purge. If the RBCCW system failed to provide cooling for any reason, the seal purge system would adequately cool the recirculation pump seals for as long as required. These two systems are functionally independent and failure of one system will not lead to failure of the other system such that recirculation pump seal failure will result due to loss of cooling water.

The functional independence of the two systems is manifest from the fact that, although the two systems do provide a common function (seal cooling), the designs are based on diverse requirements. Each of the two systems has a completely independent piping system: the pumps, the piping and even the water sources are completely independent. The CRD hydraulic system (the seal purge) uses the condensate storage system as its source of water, while the RBCCW system is a closed system which draws makeup from the demineralized

*At reactor pressure of 1040 psia.

water system. Also, the power, control and instrumentation required for the two systems are independent. Based on the Nuclear Island GESSAR design, power for each system is taken from different electric power busses. For the Nuclear Island GESSAR design, the RBCCW system is connected to emergency diesel power for all conditions except LOCA. As a result of the functional diversity of the two systems the controls and instrumentation are also independent. Diverse and independent instrumentation is used to monitor the recirculation pump seal condition and each systems status.

Therefore, it is highly unlikely that any event will lead to failure of both cooling water systems to operate or to the creation of a condition whereby the system and/or seal condition instrumentation will fail to function.

Table 3-1

TYPICAL OPERATING CONDITIONS AND ALARM SETPOINTS

	Normal Operating		
	With Seal Purge Injection and RBCCW	With RBCCW Only	Alarm
TE2	127°F	153°F	180°F
TE1	115°F	150°F	180°F
FS1	0.0065 gpm	0.0065 gpm	0.1 gpm
FS2	0.7 gpm	0.7 gpm	0.9 gpm
PT2	1020 psig	1020 psig	----
PT1	510 psig	510 psig	----

Notes:

(1) Temperatures are based on injection water temperature of 110°F and cooling water temperature of 105°F.

Table 3-2

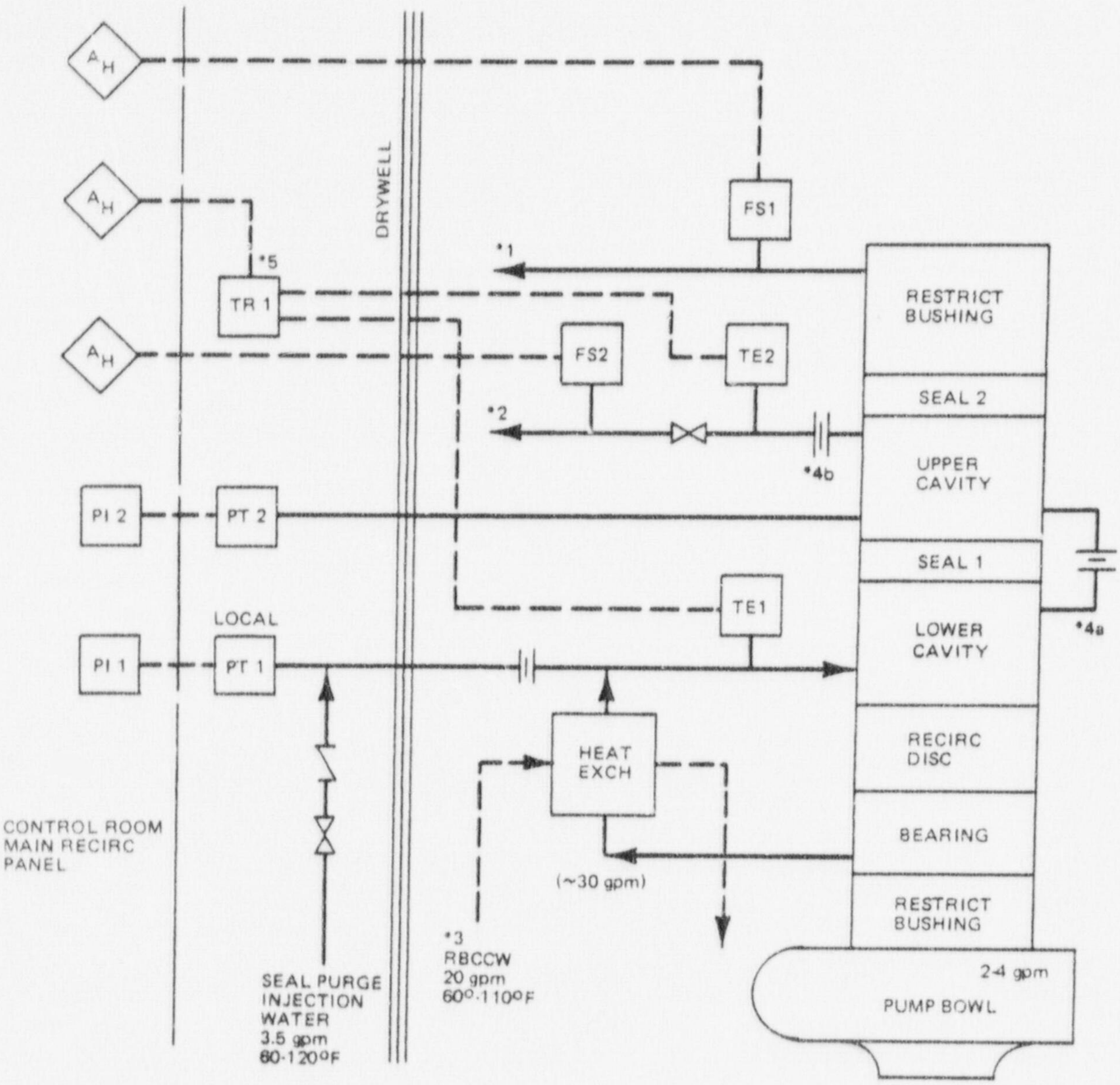
SEAL PERFORMANCE MONITORING

Seal Condition		PT1 (psi)	PT2 (psi)	FS1 (gpm)	FS2 (gpm)
Seal 1	Seal 2				
N	N	1020	510	0.006	1
D	N	1020	>560	0.006	>1*
N	D	1020	<460	1.4*	1
D	D	<970	<460	>1.4*	>1*

N = normal

D = degradation

* = condition annunciated



*NOTES:
1. SEAL LEAKAGE TO DRYWELL EQUIPMENT SUMP, 0.0065 gpm
2. SEAL STAGING TO DRYWELL EQUIPMENT SUMP, 1 gpm
3. REACTOR BUILDING CLOSED COOLING WATER
4. SEAL PRESSURE STAGING ORIFICES (INTERNAL)
5. CONTROL ROOM AUXILIARY PANEL

Figure 3-1. Recirculation Pump Seal Cooling System

4.0 ANALYSIS

4.1 METHOD AND THEORY

In order to evaluate the fluid loss during a total seal failure, the RELAP-4 Computer Program was used. The RELAP-4 Computer Program was developed by the Aerojet Nuclear Company for the Energy Research and Development Administration and is intended for transient thermal-hydraulic analysis.

The RELAP-4 program analysis is based on a model of the actual system to be analyzed. The model defines fluid volumes, junctions and initial conditions. The fluid volumes are control volumes used to represent system piping and plenums. The fluid volumes are connected by junctions which are used to transfer fluid into and out of fluid volumes. A junction that connects two adjacent fluid volumes is also a control volume which represents one-half of the fluid in each adjacent fluid volume.

The fluid dynamics portion of RELAP-4 solves the fluid mass, energy and flow equations for the model defined. Two forms of the flow equation were used for this application: (1) compressible single-stream flow with momentum flux, and (2) compressible two-stream flow with one-dimensional momentum mixing. The second form is only used when two streams can combine and exchange momentum on a one-dimensional basis.

The solution of the fluid flow equations is done by a fully implicit mathematical technique; however, the hydraulics portion is explicit and requires smaller time steps for solution. The program calculates optimal time steps and compares them with the user input time steps. If user input time steps are too large for accurate answers, the program will use its own time steps.

The RELAP-4 program calculates energy loss terms due to wall friction and flow area expansions and contractions. Contraction coefficients for junctions must be input by the user.

4.2 HYDRAULIC MODEL

Figures 4-1 and 4-2 illustrate the model used for this application of RELAP-4. The models simulate fluid volumes, interconnecting junctions and initial conditions. The model for pump configuration No. 1 (Figure 4-1) contains the pump casing, parallel flow circuit in the bearing area, recirculation rotor, seal cavities, passages underneath seal faces, and the leakage line and last passage between shaft and seal housing.

The model for pump configuration No. 2 contains similar components; namely, the pump casing, throttle bushings, seal cavities, and passages underneath seal faces (backup rings). The leakage lines and final restriction were not modeled to simplify the analysis. Also, the actual pump design includes a multiple pass heat exchanger between Volumes 2 and 3. This passage also was not modeled.

In both analyses, the seal staging flow was not modeled. However, its leakage was calculated by using relationship between pressure differential (ΔP), flow area (A), loss coefficient (K), and density (ρ), or:

$$\Delta P = \frac{K}{A^2} \frac{W^2}{2g\rho}$$

4.3 ASSUMPTIONS

The general configuration of the mechanical seals (Figure 4-3) for the BWR configuration pumps consists of stationary parts and rotating or dynamic parts, with actual sealing of fluid being achieved at the interface of the seal faces. These faces are lapped and spring loaded to maintain contact at all times. The rotating faces are tungsten carbide, the stationary faces are processed carbon and the gaskets between the stationary parts are elastomeric O-rings. Typical gross failure of the mechanical seals would consist of warpage, hairline cracks (heat checks) and grooving of the seal faces due to excessive thermal gradients and dirt.

In order to develop a computer model, the complex failure mode of the seals was simplified by assuming the seal faces are separated by 0.010 inch. The 0.010-in. gap will account for any new flow areas created by cracks, warpage or grooves in the seal faces. Due to the nature of the seal cavity, even if the seal faces were fractured, the seals would remain captured in the seal cavity. Since the fractured seals would remain in the seal cavity and are spring loaded to maintain contact between faces, the 0.010-in. gap assumption is more than adequate for modeling gross seal failure.

4.4 SUMMARY OF RESULTS

Utilizing RELAP-4, the calculated leakage rates in the event of recirculation pump seal failure are 7.68 lb/sec and 7.17 lb/sec for recirculation pump configurations 1 and 2, respectively (Table 4-1). Water will enter the first throttle bushing as a single-phase fluid and will exit the last seal as an expanding two-phase fluid at approximately 20% quality. Downstream of the last seal, there are two possible paths for the leakage. A portion of it will leak around the pump shaft into the drywell, while the largest fraction will be piped to the drywell equipment sump. It is estimated that only 33% of the leakage will escape to the drywell volume and approximately 67% will go to the equipment sump.

Table 4-1 also reports the volumetric water makeup requirements which would be required to replace the corresponding leakage through the failed seals. The volume at 420° represents the quantity of water requfred through the feedwater system to compensate for loss of fluid through the failed seals. The volume at 70°F would be the makeup required from ambient water sources.

Table 4-1

RECIRCULATION PUMP LEAKAGE IN EVENT OF A GROSS SEAL FAILURE

	Total Leakage (lb/sec)	Exit Quality (%)	Equivalent Makeup Requirement	
			gpm @ 420°F	gpm @ 70°F
Configuration No. 1	7.68	17.8	65.27	55.41
Configuration No. 2	7.17	21	60.91	51.72

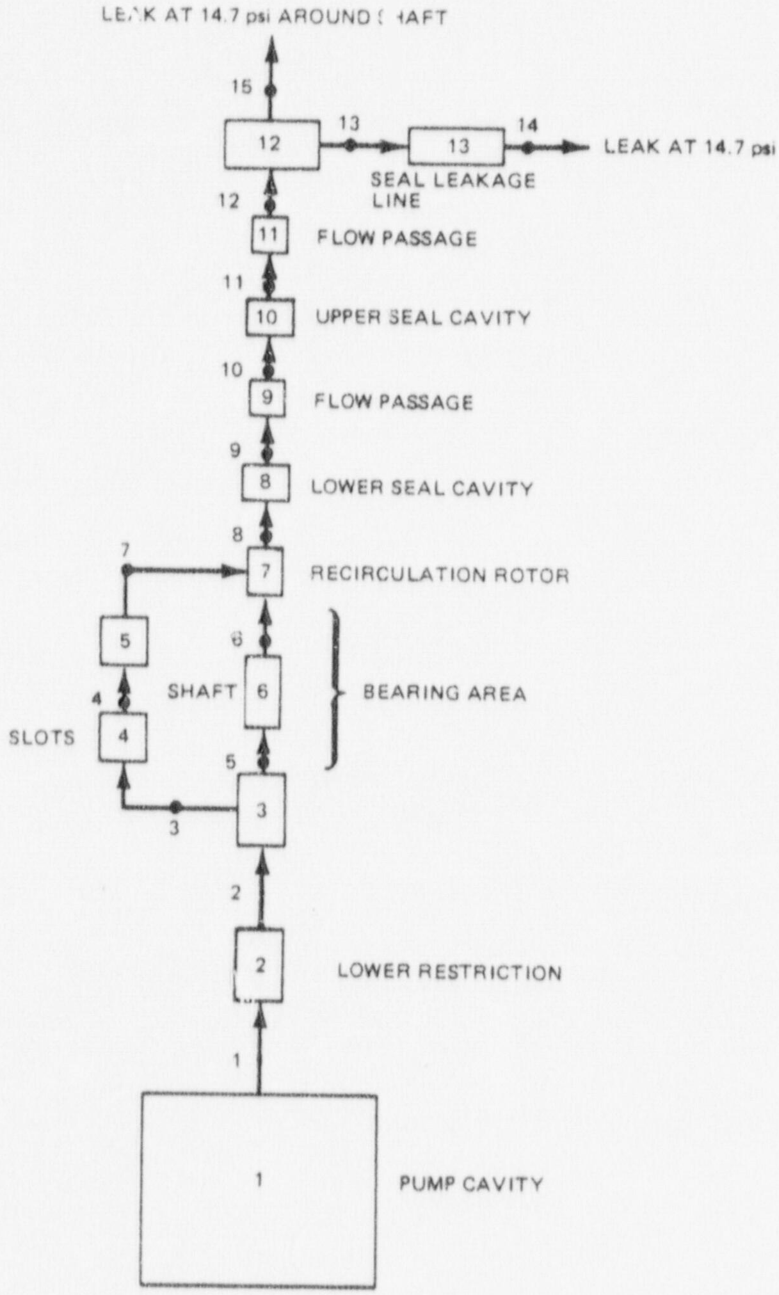


Figure 4-1. RELAP-4 Seal Model (Configuration 1)

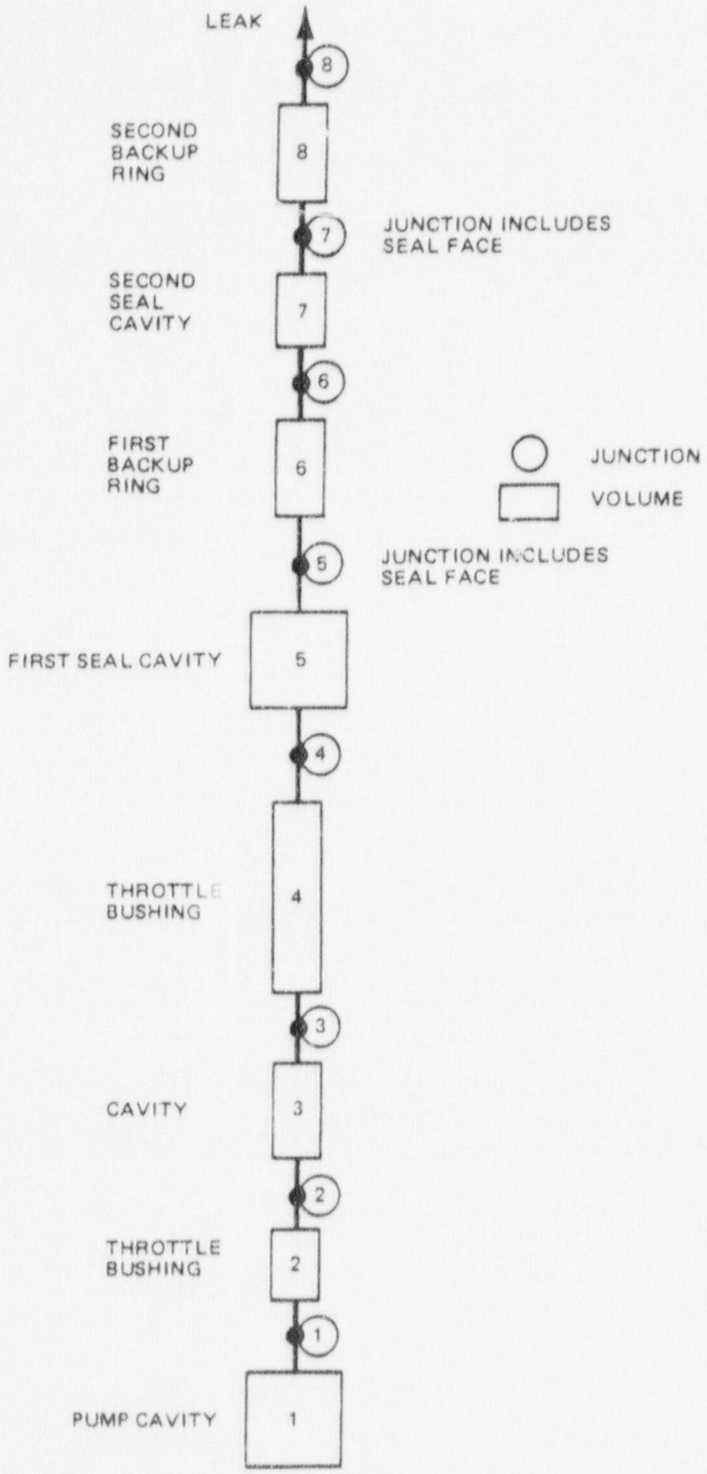
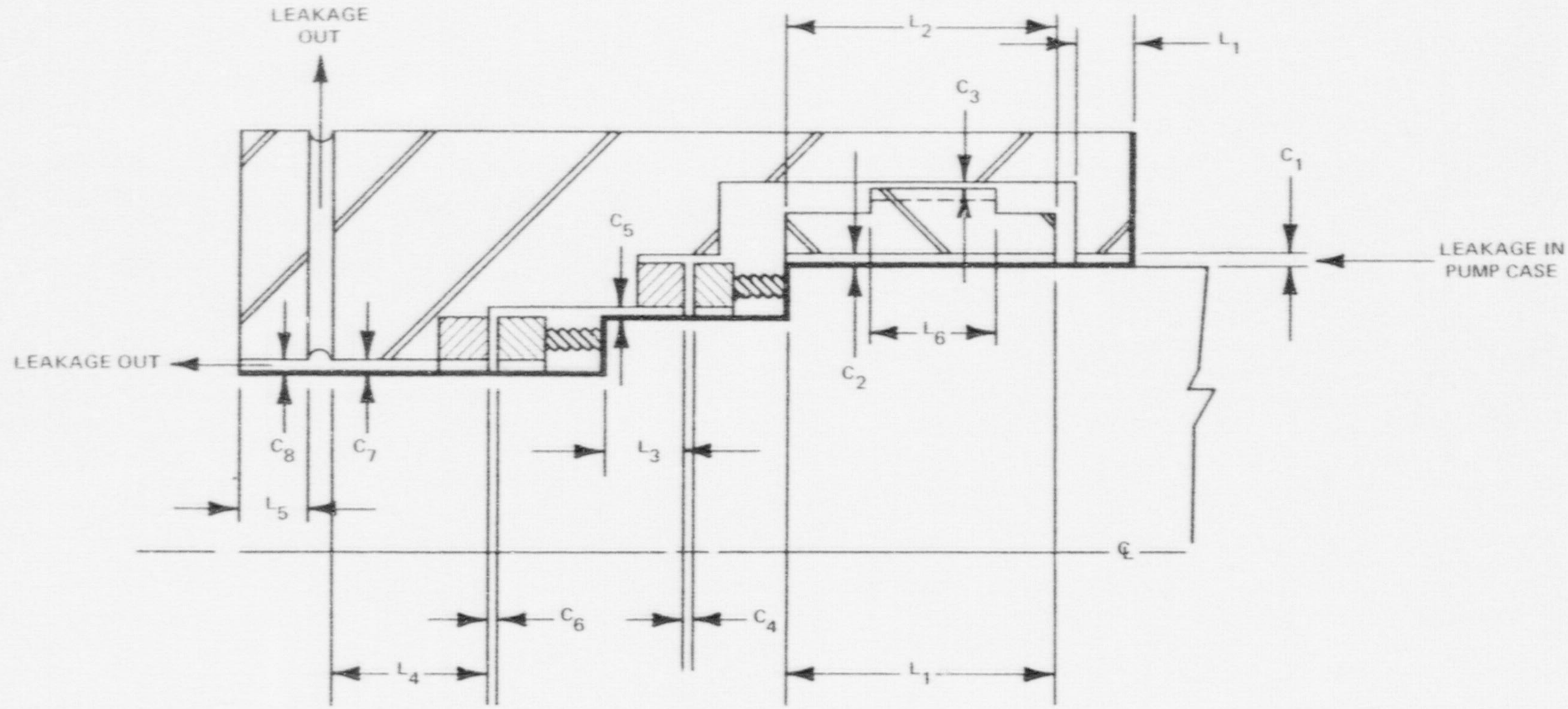


Figure 4-2. RELAP-4 Seal Model (Configuration 2)



NOTE: (1) CLEARANCES C_4 & C_6 ARE NORMALLY ZERO
(2) THIS RESTRICTION WAS NOT CONSIDERED IN THE ANALYSIS

	L_1	L_2	L_3	L_4	L_5	L_6		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8		
CONFIGURATION (1)	6	12.00	4.00	4.00	2.00	6.00		0.025	0.007	THREE 3/8 x 3/8 SLOTS	0.010 (1)	0.250	0.010 (1)	0.250	0.007		
CONFIGURATION (2)	11.00	N/A	2.75	3.38	0.500 (2)	N/A		0.027	N/A	N/A	0.010 (1)	0.060	0.010 (1)	0.060	0.125 (2)		

Figure 4-3. Simplified Seal Geometry

5.0 CONCLUSIONS

In summary, failure of the recirculation pump seal cooling water will not result in a safety problem. Through operator observation, system failures are diagnosed and appropriate action will be taken to correct any problems prior to gross seal failure. Even in the case of extreme seal failure, the fluid loss is well within the normal reactor water fluxtuations and will be compensated for by normal vessel water level controls. Therefore, no potential hazard to the health and safety of the public will result from failure of recirculation pump seal cooling systems.