PDR



ORNL #62B-13819C/62X-30
SAI #1-147-08-492-00

# FAILURE MODES AND EFFECTS ANALYSIS
# FOR THE
# OCONEE 1 NUCLEAR POWER STATION
# MAKEUP AND PURIFICATION SYSTEM

Prepared for the
Instrumentation and Controls Division
Union Carbide Corporation, Nuclear Division

by
Science Applications, Inc.
Systems Analysis Division

October 28, 1983

ORNL #62B-13819C/62X-30
SAI #1-147-08-492-00

# FAILURE MODES AND EFFECTS ANALYSIS
# FOR THE
# OCONEE 1 NUCLEAR POWER STATION
# MAKEUP AND PURIFICATION SYSTEM

Prepared for the
Instrumentation and Controls Division
Union Carbide Corporation, Nuclear Division
P.O. Box X
Oak Ridge, TN 37830

by

Science Applications, Inc.
Systems Analysis Division
Jackson Plaza Tower
800 Oak Ridge Turnpike
Oak Ridge, TN 37830

October 28, 1983

TABLE OF CONTENTS

**TABLE OF CONTENTS** (Continued)

## LIST OF TABLES



## LIST OF FIGURES

# 1.0 INTRODUCTION

The implications of failures of safety systems on nuclear power plant safety have been studied extensively. Currently, the safety implications of control system failures in nuclear power plants are being investigated by the Oak Ridge National Laboratory. A major task in this effort is the preparation of Failure Modes and Effects Analyses (FMEA) of plant systems to aid in the analysis of control system malfunctions and identification of possible consequences to safety. Specifically, the studies are directed at identifying failures contributing to reactor coolant overcooling, reactor coolant undercooling or degradation of the ability of safety systems to respond on demand.

Although the objectives of the broad study are generic, specific nuclear power plant systems' designs are required for the preparation of a detailed FMEA. For this reason, the FMEA is being performed on the systems of the Oconee Nuclear Power Station. This report documents the results of the FMEA of the Makeup and Purification (MU&P) system.

To achieve the program objectives, the FMEA of the MU&P system included detailed consideration of the equipment associated with reactor coolant letdown, the HPI pumps, makeup, chemical addition and processing, RC pump seal return and seal injection. In addition, the analysis included consideration of failures of interfacing support systems including control instrumentation, cooling water, instrument air and AC electric power distribution systems.

The major results of the study are summarized in Section 2, Summary of Results. The design of the MU&P system and interfacing support systems are described in Section 3, System Description. The FMEA methodology and the analysis results are described in detail in Section 4, Failure Modes and Effects Analysis. For convenience, the lengthy tables of results have been placed at the end of each section.

## 2.0 SUMMARY OF RESULTS

A detailed FMEA of the MU&P system has been performed to evaluate the extent to which MU&P component failures or interfacing support system failure contribute to reactor coolant overcooling, undercooling or degradation of safety functions.

Due to the complexity of the MU&P system, the FMEA was performed in two steps. A component level FMEA was performed first to evaluate the effects of component failures on its subsystem and subsystem interfaces. The results of the component level FMEA are presented in Appendices A through F.

The major subsystem effects, including pressure boundary failures, flow blockage failures, flow increase failures and loss of chemical addition or coolant purification capability, then were considered as postulated functional failures to evaluate system and plant level effects. The relationship of component failures to functional failures and the detailed system level FMEA results, including the effects of interfacing support system failures are discussed in Section 4.2.

The detailed FMEA results have been reviewed to identify those functional failures and effects which are judged to have a significant impact on safety. For the specified effects of significance, the key contributing component failures for the initiating functional failures then were identified. The effects of MU&P component failures and functional failures of support systems judged to be significant are listed in Table 1.

Pressure boundary failures in the high pressure letdown piping are significant due to the simultaneous initiation of an isolatable small LOCA and draining of the LST possibly leading to failure of HPI pump A and/or B. Pressure boundary failures in other subsystems would contribute to HPI pump failure but not initiate an RC leak or small LOCA. In addition to pressure boundary cracks such as LD Cooler tube failure, pressure boundary failures could occur following maintenance on redundant components such as the LD coolers. If, following maintenance, LD cooler C1A remained isolated with a drain path open, the plant could be started-up and operated using the cooler, C1B. The failure condition could remain undetected until cooler C1A isolation valves were opened creating the LOCA.

This functional failure potentially contributes to either overcooling and undercooling conditions. A LOCA with inadequate emergency injection would result in undercooling. An isolatable LOCA also is a pressurized thermal shock (PTS) transient of interest since the RCS would initially be reduced in temperature during depressurization and subsequently repressurize following isolation of the leak path.

Flow blockage and flow increase failures, possibly caused by control instrumentation failures, could result in draining the LST or directly blocking flow to the HPI pumps. Either condition could result in failing the operating HPI pump. Low LST level is alarmed and the operator can be expected to provide an alternate supply of water to the HPI pump with reasonably high probability. Closure of the isolation valve in the LST outlet line, however, would result in a rapid pump failure due to cavitation. In addition, the high indicated LST level and low indicated makeup and seal injection flowrates may induce the operator to start a second HPI pump possibly resulting in its failure.

The postulated failure of interfacing cooling water systems, although unlikely, was found to have potentially significant effects. Failure of the CC system results in termination of cooling water flow to the RC pump seals and LD cooler, automatic isolation of letdown flow on high letdown temperature and a resulting slow decrease in LST level. If the operator allowed the LST to drain resulting in failure of the operating HPI pump, RC pump seal failure could occur following the loss of seal injection flow. The small LOCA (pump seal failure) and degraded emergency HPI due to common cause is considered significant.

Although the LPSW system performs a safety function in its emergency mode of operation, it also must function during normal plant operation to support control system functions. For this reason, failure of this interfacing support system was included for completeness. Failure of the LPSW, in addition to causing loss of CC function discussed above, results in loss of cooling water to the HPI pump motor bearing and most other emergency systems. The significance of this event is increased since the LPSW system failure affects both Unit 1 and Unit 2 systems.

The failure of most AC electric power buses serving the MU&P were found to have small effect. However, due to the possible manual transfer of 208 VAC buses XS1 and XS2 to a single power source, one of several bus failures could effectively block emergency HPI if required. Although this event is not a control system failure, it may be significant and is identified for future reference.

In conclusion, a FMEA has been performed on the Oconee Unit 1 MU&P system to evalute the effect of MU&P component failures. In general, most component failures have small effects due to the redundancy of key MU&P components and the availability of effective remedial actions. As discussed above, however, several failures were found to have significant effects including the degradation of the emergency HPI function and/or the initiation of RC leaks or small LOCA's.

TABLE 1. SUMMARY OF SIGNIFICANT EFFECTS OF MU&P COMPONENT AND SUPPORT SYSTEM FAILURES

| Functional Failure | Failure Causes | Effect | Significance |
|---|---|---|---|
| 1. Pressure Boundary Failures in High Pressure Letdown Piping | o Letdown Cooler tube failure or<br><br>o Placing the spare letdown cooler in operation if its drain valves had been left open and isolation valves left closed due to improper prior maintenance. | o Isolatable RC Leak or Small LOCA and<br><br>Rapid draining of LST and possible consequential failure of operating HPI pump(s). An attempt to restore flow by starting the spare HPI pump could result in its failure. Pump damage can be prevented by the operator providing an alternate source of borated water to the HPI pumps. | Initiation of an isolatable RC leak or small LOCA and degradation or the required safety function, Emergency HPI, due to a common cause. |
| 2. Flow Blockage Failures in Low Pressure Letdown Piping Upstream of LST | o Closure of purification demineralizer or makeup filter isolation valves due to valve operator, control instrumentation or maintenance failure, or<br><br>o Transfer of 3-Way valve diverting flow from LST to bleed holdup tank due to valve operator or control instrumentation failure. | o Draining of LST and possible consequential failure of operating HPI pump(s). An attempt to restore flow by starting the spare HPI pump could result in its failure. Pump damage can be prevented by the operator removing the blockage or providing an alternate supply of borated water to the HPI pumps. | Degradation of the emergency HPI safety function. |
| 3. Flow Blockage Failures in Low Pressure HPI Pump Suction Piping | o Closure of HPI pump suction valve due to valve operator or control instrumentation failure. | o Cavitation and rapid failure of operating HPI pump(s). An attempt to restore flow by starting the spare HPI pump could result in its failure. Pump damage can be prevented by tripping the HPI pump(s) or rapidly providing an alternate source of borated water. | Degradation of the emergency HPI safety function. |
| 4. Pressure Boundary Failure in the Low Pressure Letdown Piping | o Placing a spare purification demineralizer or makeup filter in operation if its drain valves had been left open and isolation valves left closed due to improper prior maintenance, or<br><br>o A letdown relief valve opening and failing open following a flow blockage (assumes blockage is removed; otherwise see Item 2). | o Draining of LST and possible consequential failure of the operating HPI pump(s). An attempt to restore flow by starting the spare HPI pump could result in its failure. Pump damage can be prevented by providing an alternate source of borated water to the HPI pumps. | Degradation of the emergency HPI safety function. |

TABLE 1. SUMMARY OF SIGNIFICANT EFFECTS OF MU&P COMPONENT AND SUPPORT SYSTEM FAILURES (Continued)

| Functional Failure | Failure Causes | Effect | Significance |
|---|---|---|---|
| 5. Flow Increase Failure in the Makeup Piping | o Opening of makeup control valve due to valve operator or control instrumentation failure, or<br>o Opening of HPI discharge valve due to valve operator or control instrumentation failure. | o Draining of LST and possible consequential failure of the operating HPI pumps. An attempt to increase flow by starting spare HPI pump could result in its failure. Pump damage can be prevented by throttling the Makeup flow or providing an alternate source of borated water to the HPI pumps. | Degradation of the emergency HPI safety function. |
| 6. Component Cooling Water System Failures | o CC containment isolation valve closes due to valve operator or control instrumentation failure, or<br>o Trip of one CC pump and failure of spare to start. | o Loss of CC system can result in termination of cooling water flow to RC pump seals and isolation of letdown. Unless an alternate supply of borated water is provided to the operating HPI pump, seal injection flow could be lost and consequential failure of RC pump seals could occur. | Initiation of an RC leak or small LOCA and degradation of the required safety function, Emergency HPI, due to a common cause. |
| 7. Low Pressure Service Water System Failures | o Common cause failure of LPSW system (e.g., all pump suction strainers blocked). | o Loss of LPSW to the operating HPI pump(s) could result in failure of the pump. Loss of the LPSW system would affect the operability of almost all plant safety systems and the CC system (see above). | Initiation of an RC leak or small LOCA (due to loss of CC and seal injection) and degradation of many safety functions. |

## 3.0 SYSTEM DESCRIPTION

### 3.1 MAKEUP AND PURIFICATION SYSTEM OVERVIEW

The Makeup and Purification (MU&P) System consists of the piping and process equipment required to remove, process and replace reactor coolant at the flowrates required to maintain constant Reactor Coolant System (RCS) coolant volume. The major functions performed by the MU&P System are:

1. Letdown Control: Controlled removal of reactor coolant from the RCS and reduction of coolant temperature and pressure at a preset flowrate.
2. Purification: Removal of impurities from the reactor coolant using boric acid saturated ion exchange resins.
3. Coolant Processing and Chemical Addition: Recovery of concentrated boric acid and demineralized water from letdown reactor coolant; supply of demineralized (boric acid free) water and concentrated boric acid to adjust reactor coolant boric acid concentrations; and supply of lithium hydroxide to control reactor coolent pH.
4. Reactor Coolant Pump (RC Pump) Seal Return: Collection, filtering and cooling of coolant flowing past the RC Pump shaft face seals.
5. RC Pump Seal Injection: Injection and filtering of processed letdown coolant to the RC pumps' shaft seals at a constant flowrate.
6. RC Makeup: Injection of process letdown coolant to the RCS at a flowrate controlled to maintain constant reactor coolant volume.

In addition to the normal functions performed by the MU&P System, portions of the system are used to provide emergency injection of coolant following design basis plant accidents.

The major equipment and process flows within the MU&P system are illustrated in Figures 1 and 2. For the purposes to this study, the overall system has

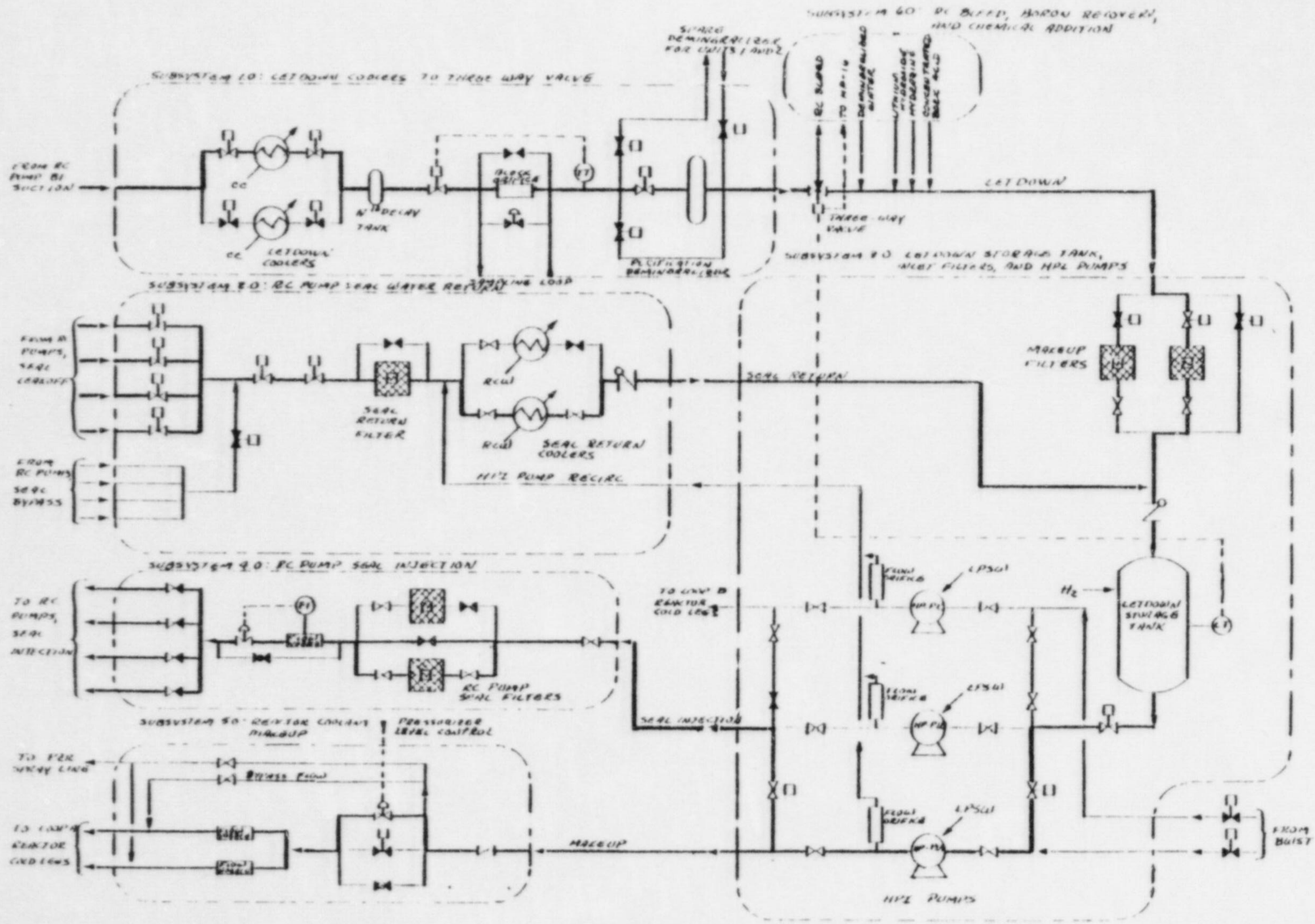


Figure 1. Makeup and Purification System Flow Sheet, Subsystems 1.0 - 5.0.

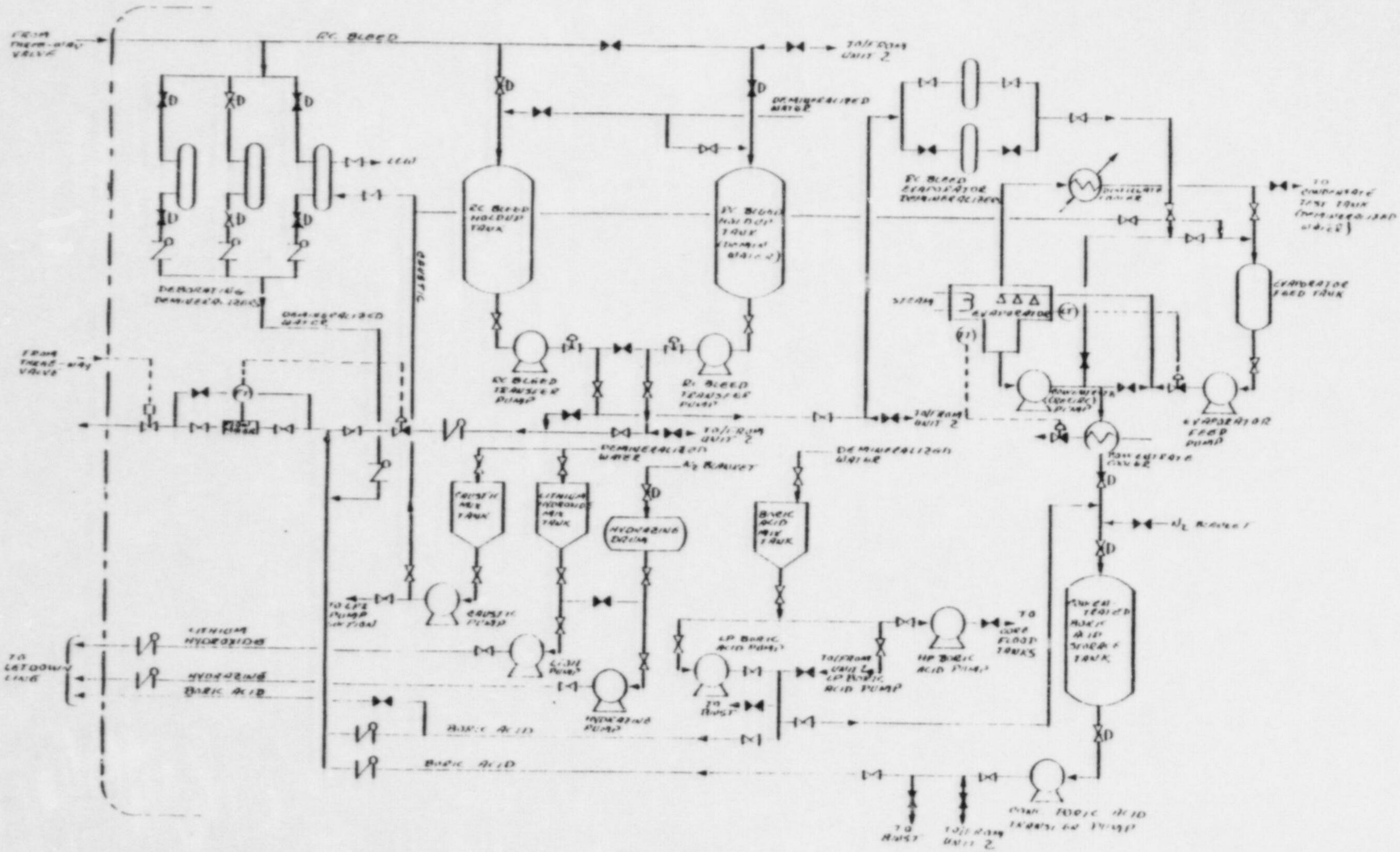


Figure 2. Makeup and Purification System Flow Sheet, Subsystem 6.0.

been divided into six subsystems, which are indicated in Figures 1 and 2 and described in the following sections.

### 3.2 SUBSYSTEM DESCRIPTIONS

The MU&P System was divided into six subsystems as shown in Figures 1 and 2. This section presents a brief functional description of each subsystem including any assumptions which were required to define the various operating modes of the system. Descriptions are based on material in the Oconee FSAR (Reference 1); specific FSAR reference drawings for the subsystems are as follows:

| | |
|---|---|
| Subsystem 1.0 | Letdown Subsystem: Letdown Coolers to Three-Way Valve<br>Figure 9-2A*, Figure 9.3-2 (Sheet 4); |
| Subsystem 2.0 | RC Pump Seal Return Subsystem<br>Figure 9.3-2 (Sheets 1 and 4); |
| Subsystem 3.0 | HPI Pump Subsystem: Letdown Storage Tank, Inlet Filters, and HPI Pumps<br>Figure 9.3-2 (Sheet 4); |
| Subsystem 4.0 | RC Pump Seal Injection Subsystem<br>Figure 9.3-2 (Sheets 1 and 4); |
| Subsystem 5.0 | RC Makeup Subsystem<br>Figure 9.3-2 (Sheets 1 and 4); |
| Subsystem 6.0 | Chemical Processing Subsystem: RC Bleed, Boron Recovery, and Chemical Addition<br>Figure 9.3-1 (Sheet 1), Figures 9.3-2 (Sheet 1), Figure 9.3-5 (Sheets 1, 3 and 4) |

Subsystems 1 through 5 of the MU&P System are shown in Figure 1. The Chemical Processing Subsystem is shown in Figure 2.

#### 3.2.1 Letdown Subsystem

The main functions of this subsystem are to cool and depressurize the letdown flow from the RCS and to remove impurities. This subsystem interfaces with

*Reference 2

the HPI Pump and Chemical Processing Subsystems at the 3-Way Valve. Letdown cooler HP-C1A or HP-C1B reduces the temperature of the letdown flow to a temperature suitable for purification in the letdown demineralizers and subsequent injection into the RCS. Heat in the letdown cooler is rejected to the Component Cooling System. The letdown flow rate is limited by a fixed block orifice which reduces the letdown pressure from RCS operating pressure to a pressure slightly above atmospheric. HP-7, a normally closed, remotely operated control valve in parallel with the block orifice can be opened to increase the flow rate if required. In addition, normally closed HP-42, in parallel with HP-7, may be manually positioned for flow control. Upon leaving the letdown coolers, a one-to-two gallon per minute sample flow is continuously bypassed around the block orifice through a radiation monitor loop and a boron meter loop. Reactor coolant is monitored for gamma activity and boron content before being returned to the letdown stream upstream of the purification demineralizer. The letdown flow normally passes through purification demineralizer HP-X1 to remove reactor coolant impurities other than boron and then to the 3-way valve HP-14.

### 3.2.2 RC Pump Seal Return Subsystem

The RC pump seal return subsystem consists of the return piping and instrumentation from the RC pump seals, seal return coolers, and a single filter installed upstream of the coolers. The system provides for the return and seal water cooling in the circulation loop of seal water through the reactor coolant pumps. This subsystem also is used to remove heat added by the operating HPI pump or pumps.

A set of four return lines, one from the face seals on each RC pump, normally collects the seal return flow into a common return header. Another set of four return lines, normally closed, collects the flow bypassing the face seals when required on each RC pump. These lines are utilized when the leakage rate past the face seals on any operating pump is less than one gpm (normal flow is approximately three gpm per pump).

The reactor coolant pump seal return header is an outflow line which penetrates the Reactor Building. The header has an electric motor-operated isolation valve inside the Reactor Building and a pneumatic valve outside which are automatically closed by an engineered safeguards (ES) signal. The seal return filter and coolers are outside the Reactor Building.

The seal return filter is installed in the seal return line upstream of the seal return coolers to remove particulate matter. A bypass is installed to permit servicing during operation.

The seal return coolers are sized to remove the heat added by the operating HPI pumps and the heat picked up in passage through the reactor coolant pump seals. Heat from these coolers is rejected to the Recirculated Cooling Water (RCW) System. Two coolers are provided in parallel and one is normally in operation. The flow from the seal return coolers discharges directly to the inlet header of the Letdown Storage Tank (LST).

### 3.2.3 HPI Pump Subsystem

This subsystem consists of two makeup filters, the LST, three HPI pumps, pump discharge manifold, and other associated piping. The system collects the seal return and letdown flows from the RCS for the normal operation of the HPI pumps and discharges it to the RC pump seal and makeup subsystems.

The LST serves as a receiver for letdown, seal return, chemical addition, and system makeup. The tank also accommodates temporary changes in system coolant volume. All flows except seal return pass through one of the makeup filters before entering the LST. One filter is normally in operation and one is spare. The LST is continuously charged with hydrogen for RCS oxygen control.

During normal operation of the RCS, one high pressure injection (HPI) pump continuously supplies high pressure water from the LST to the seals of each of the reactor coolant pumps and to a makeup line connection to the Loop A RCS cold legs. Three HPI pumps are provided, each capable of supplying the required reactor coolant pump seal and makeup flow. One is normally in operation while another is in standby status to be used as needed. The third pump is used only for emergency injection.

### 3.2.4 RC Pump Seal Injection Subsystem

This subsystem distributes seal injection water to the four RC pumps. It consists of the seal injection header from the HPI pump discharge manifold, two RC pump seal filters, four individual injection lines (one to each RC pump), and associated piping and instrumentation.

Seal injection flow is filtered prior to entering the individual seal injection lines. One filter is normally in operation and one is spare. In addition, a bypass around both filters is available to permit maintenance during operation.

A flow control valve in the seal injection header to the pump seals automatically maintains the desired total injection flow to the seals. Manually pre-set throttle valves in each pump seal injection line provide a capability to balance the seal injection flow rates. A portion of the water supplied to the seals enters the RCS (~5 gpm per RC pump). The remainder returns to the letdown storage tank after passing through the seal return subsystem (~3 gpm per RC pump).

The four individual injection lines penetrate the Reactor Building. These lines each contain a stop-check valve inside and outside the Reactor Building for Reactor Building isolation.

### 3.2.5 RC Makeup Subsystem

The RC makeup subsystem is designed to control makeup requirements during normal operation, design reactor coolant system transients, and Reactor Coolant System cooldown. The subsystem consists of a makeup header off the HPI pump discharge manifold, a flow control loop, two main reactor inlets to the Loop A cold legs, and additional paths, bypassing the makeup flow control valve, feeding a small amount of flow to the reactor cold leg inlet nozzles and the pressurizer spray line.

Normal makeup flow is delivered to the two reactor cold legs of Loop A. During normal operation, makeup flow is diverted around the emergency HPI flow path through a flow control valve. The pneumatically operated control valve throttles the makeup flow to the two reactor cold legs to maintain constant pressurizer level. The flow bypassing the makeup control valve is assumed to provide a minimum flow to minimize temperature changes in the reactor cold leg inlet nozzles and the pressurizer spray line.

### 3.2.6 Chemical Processing Subsystem

This subsystem serves three functions:

1. Intermittent letdown of reactor coolant to a holdup tank and replacement with demineralized water or continuous operation of a deborating demineralizer;
2. Recovery of boric acid and demineralized water from letdown reactor coolant for reuse in the plant;
3. Chemical addition including the addition of boric acid to reactor coolant for reactivity control, lithium hydroxide for pH control, hydrazine for oxygen control during shutdown. The subsystem also provides caustic for resin regeneration in the demineralizers and chemistry control in the boron recovery operation.

Major components in this subsysytem have been shown in Figure 2.

#### RC Bleed Holdup

RC Bleed Holdup is used for the collection and storage of reactor coolant. The coolant is received from the letdown line both as a result of reactor coolant expansion during startup and for boric acid concentration reduction during startup and normal operation. It is either conveyed to the coolant bleed holdup tank for storage or passed through a deborating demineralizer for boric acid removal and returned as unborated makeup to the makeup line. It was assumed that one deborating demineralizer is in operation, one is regenerated and available in stand-by, and a third is being regenerated at any time. A spray nozzle in the coolant bleed tanks on the inlet line allows some of the gases to be released. Recirculating the tank allows further stripping action to occur. Demineralized water can also be returned to the makeup line from the demineralized water holdup tank. Coolant from the bleed holdup tank is pumped to boron recovery for processing.

The coolant bleed holdup tank and the concentrated boric acid storage tank are vented to the gaseous waste vent header to provide for filling and emptying without overpressurization or causing a vacuum to exist. In addition, each tank is equipped with a relief valve and a vacuum breaker. Pressurized nitrogen can be supplied to each tank to allow purging.

Instruments and controls for operation of this system are located in the control room. Instruments and controls for the coolant bleed holdup tanks and pumps, demineralized water holdup tank and pump, and the concentrated boric acid storage tank and pump are duplicated on local auxiliary control boards.

Boron Recovery

Boron recovery is operated on a batch basis and is sized to process all of the reactor coolant bled from the RCS operating on an 8-hour per day basis. The system receives coolant from the bleed holdup tank through the coolant bleed evaporator demineralizers (one in operation; one available in stand-by) into the feed tank which is sized to hold sufficient feed for about five hours of evaporator operation. The coolant is then pumped into the evaporator by the evaporator feed pump which maintains a level in the evaporator while the recirculating pump recirculates the coolant until the temperature is stabilized. The distillate is returned to the feed tank until the distillate is of the desired quality for pumping to the condensate test tanks. The evaporator concentrate is sampled and normally pumped to the concentrated boric acid storage tanks at approximately 8700 ppm boron. The evaporator concentrate can be allowed to increase to 26000 ppm boron and pumped to the drumming station for ultimate disposal as solid waste.

## Chemical Addition

The chemical addition portion of this system delivers the necessary chemicals to other systems as required. Boric acid is provided to the spent fuel pool, borated water storage tank, letdown storage tank, and core flooding tanks as makeup for leakage or to change the concentration of boric acid in the associated systems. Sodium hydroxide (caustic) is added to the waste evaporator feed tank during evaporator operation and to the deborating demineralizer during demineralizer resin regeneration.

A boric acid mix tank and a concentrated boric acid storage tank are provided as sources of concentrated boric acid solution. These tanks provide redundant supplies of boric acid solution to increase the reactor coolant system boron concentration to that required for cold shutdown. Tank heaters and electrically heat traced transfer lines maintain the fluid temperature above that required to assure solubility of the boric acid. Three boric acid pumps are provided to transfer the concentrated boric acid solution from the boric acid tank to the borated water storage tank (BWST), makeup filters, spent fuel storage pool, or the core flooding tanks. One high pressure pump supplies boric acid to the core flooding tanks. The two low pressure pumps supply boric acid to other tanks, systems, and locations.

The caustic mix tank is used to prepare solution which neutralizes the feed to the waste evaporator. It also supplies sodium hydroxide to the deborating demineralizer for regeneration. The caustic pump transfers sodium hydroxide from the caustic mix tank to the intended destination.

Lithium hydroxide is mixed and added to the RCS from the lithium hydroxide tank. The lithium hydroxide pump transfers lithium hydroxide from the LiOH tank to the letdown line upstream of the makeup filters.

A 55-gallon drum supplies hydrazine to the Reactor Coolant System; the hydrazine is used to scavenge dissolved oxygen, primarily following a reactor shutdown. The hydrazine pump transfers to the letdown line upstream of the makeup filters.

### 3.3 MU&P SUPPORTING SYSTEMS

The operation of the MU&P equipment requires that plant systems providing support functions operate properly. The major support functions required by the MU&P system are Control Instrumentation, Cooling Water, Instrument Air and Electric Power.

Although the detailed analysis of support system failures are beyond the scope of the present analysis, degraded operating states of the support systems must be understood to adequately specify MU&P system interface failure modes. A brief description of the systems providing support functions is given below.

#### 3.3.1 <u>Control Instrumentation</u>

The control instrumentation function is provided by a number of separately identified instrumentation "systems." These include the Non-Nuclear Instrumentation (NNI), Engineered Safeguards Protective System (ESPS), and a variety of miscellaneous control circuits and local control panels.

The principal instrumentation system controlling the Makeup and Purification system is the NNI. This system, described in References 1, 4 and 5, provides parameter measurement and control room display and manual and automatic control signals. The major automatic control circuits are the makeup control which regulates the makeup valve position to maintain constant pressurizer level, the seal injection control which regulates the seal injection valve position to maintain constant flowrate and the 3-way valve control which transfers the letdown flow to the LST upon low LST level, control rod insertion limit or demineralized water/boric acid makeup "batch complete" limit.

The Engineered Safeguards Protection System (ESPS) is designed to initiate emergency functions upon detection of plant accident conditions. Among these actions are the isolation of letdown and seal return flow, opening the flowpath from the BWST to the HPI pumps, initiating operation of the three HPI pumps and initiating unthrottled injection to the RCS through four flowpaths.

Although the operation of the emergency HPI mode in response to an accident is not considered, the impact on normal MU&P system operation following a spurious ES signal is considered as an interface failure.

In addition to the major instrumentation systems affecting the MU&P system, a large number of individual control circuits are provided to control individual components. In general, these circuits are considered as individual interfaces to MU&P system components.

### 3.3.2 Cooling Water

Cooling water is provided to the MU&P system by the Component Cooling (CC) system, the Low Pressure Service Water (LPSW) system and the Recirculating Cooling Water (RCW) system. The CC system provides cooling water to the letdown (LD) coolers, the LPSW provides cooling water to the HPI pumps' motor bearings and the RCW provides cooling water to the seal return coolers. The CC, LPSW and RCW systems are described in Reference 1.

### 3.3.3 Instrument Air

Plant instrument air is required to position MU&P system pneumatic valves. Instrument air is provided by three compressors and associated distribution piping and equipment. Very little information describing the instrument air system was available. The assumed system configuration was based on RCW and electric power interface information obtained from References 1 and 3.

### 3.3.4 Electric Power

MU&P system pump and valve motors' are provided electric power by the plant electric power distribution system. Electric power is distributed from Standby Buses #1 and #2 through transformers to 4160 VAC switchgear groups TC, TD and TE. The power source of each of the switch gear groups is automatically transferred between Bus #1 or Bus #2 based on power availability. The 4160 VAC switchgear groups supply power to the three HPI pumps' motors and 600 VAC buses through transformers. The power sources of many of the 600 VAC buses also are automatically transferred. 600 VAC buses supply 208 VAC buses through transformers. MU&P system motor operated valves and small pump motors are powered by the 208 VAC buses. The power distribution system is defined by the plant one-line electric power distribution drawings, Reference 3.

## 4.0 FAILURE MODES AND EFFECTS ANALYSIS

### 4.1 TECHNICAL APPROACH

The analysis results documented in this report have been developed using failure modes and effects analysis (FMEA) techniques. A FMEA identifies failure modes for components of concern and traces their effects on other components, subsystems, and systems. Emphasis is placed on identifying significant effects associated with specific component failures. The advantage of the analysis technique is that while it is simple to apply, it provides for an orderly examination of potentially important failure modes throughout a system.

In a FMEA, the impact or effect of a potential fault is documented in tables which identify the failed component being considered. Support systems associated with the component (for example, electric power for a motor-operated valve) also must be considered. Potential component fault modes due to internal failures or unavailability of support systems, the impact of the fault on system operation, and potential remedial action if the fault occurs are listed in the FMEA tables. Analysis of the completed tables permits identification of failures which have significant impact on system operation.

Because of the multiplicity of functions provided by the MU&P system, an initial FMEA was performed on a subsystem level. MU&P subsystems are described in Section 3.0. Interfaces between each subsystem, including inlet and outlet links to other subsystems, support systems, and other reactor plant systems, were carefully defined during the analysis to permit integration of the subsystem analyses into a single analysis package for the entire system. Faults due to component failures were traced through the linked subsystems to identify the impact of such failures on the entire system. The impact of support system unavailabilities was traced in a similar way, except faults in all subsystems due to the unavailability were concurrently traced for impact. Certain faults were grouped to facilitate analysis. As an example of this, a failed closed state was defined for normally open manual valves. This failure state included faults due to internal damage, due to plugging and due to inadvertant closure. Similarly, filter plugging was considered in the same category as plugged lines.

The FMEAs for each subsystem are detailed in Appendices A through F. These appendices describe each component considered in the subsystem analyses, along with appropriate fault documentation, as described above. The subsystem FMEAs were formatted to permit computerized data basing at some future date, if desired, for the inventory of components, the failure modes, the interfaces involved, the effects, and the remedial actions available. The impact of the subsystem faults at the subsystem boundaries is summarized in Section 4.3. The integration of the subsystem analysis results into a system-level failure analysis is documented in the following section.

## 4.2 SYSTEM LEVEL FMEA RESULTS

As discussed in Section 4.1, Technical Approach, the high complexity of the MU&P functions required that postulated failure modes and their effects be considered in two levels of detail. In the first step, the effect of individual MU&P subsystem component failures on subsystem functions and subsystem interfaces was analyzed. The MU&P subsystems defined for this analysis have been described in Section 3.2. The results of the subsystem level results are described in Section 4.3.

The second step of the analysis involved the integration of the subsystem failure effects to determine system and plant level failure modes and effects. In addition to considering failure effects resulting from component failure occurring within MU&P subsystems, the systems level analysis considered interfacing support systems failures. The support systems, described in Section 3.3, typically interface with multiple MU&P subsystems. As such the effects of functional support systems' failures are considered at the system level.

The system and plant level effects were analyzed based on a set of eight functional failures that represent both component failures within the MU&P subsystems and interfacing support system failures. The set of functional failures considered is discussed in Section 4.2.1. The system and plant level effects of each of the functional failures are described in Section 4.2.2. System and plant level effects considered to be of potential significance to reactor colant overcooling or undercooling or degradation of safety functions have been summarized in Section 2, Summary of Results.

4.2.1 Functional Failures

The systems level FMEA considered two categories of failure: functional failures originating within the MU&P system and functional failures of interfacing support systems.

The use of "functional failures" in a FMEA is not typical of the general methodology. However, in performing the analysis it was recognized the effect of many individual component failures would produce identical system level effects, and the analysis could be made more tractible by grouping these. Thus, the particular failure modes of sets of components were grouped into functional failure mode (e.g., any of several series valves failing closed could result in the functional failure, blocked flow). This procedure will produce acceptable results provided that any component failure mode of significance is covered by one of the functional failure modes. Furthermore, the traceability of the constituent component failures must be maintained.

The functional failures of interfacing support systems were treated in a more general fashion. The functional failures were selected based on their potential direct effects on the MU&P system. Other failure modes of support systems, not effecting the MU&P system would be normally considered in FMEA's of the specific support systems, but was not identified in this study.

4.2.1.1 Functional Failures Occurring Within the MU&P

Four functional failure modes were selected for the MU&P system level analysis: Pressure Boundary Failure, Flow Blockage, Flow Increase and Loss of Chemical Addition or Purification Capability. Although several component failures would produce one of these functional failures, the system level effects differ depending on the location of the particular failure. Thus, the four general functional failures were considered for each MU&P subsystem and, in some cases, more than one location within a subsystem.

The development of the functional failure modes was based on the identified component failures from the detailed component level system analyses. Table 2 lists the functional failure modes and significant precipitating component failures for each subsystem. The major function failures and their precipitating component failures are discussed below.

Pressure boundary failures include any release of the letdown reactor coolant from the MU&P system. Primary attention has been given to pressure boundary failures which can occur due to system operation or misoperation. These include valve stem seal failures in high pressure portions of the system, opened and subsequently failed open relief valves, unisolated vent or drain paths, and cracks in potentially high vibration or high thermal stress areas.

Although some postulated pressure boundary failures would be unlikely as an isolated event, consideration was given to undetected mispositioned valves. For instance, the possibility of a technician entering the containment and opening redundant drain isolation valves is very small. However, during cooler maintenance, both drain valves could be opened and the drain path isolated from the rest of the system as part of a normal maintenance procedure. If the valves were not restored to their original positions and plant operation subsequently resumed, placing the affected cooler in operation would result in significant leakage of reactor coolant.

Flow blockage functional failures involve a significant reduction or complete termination of the process flowrate. As with other functional failures, the location of the failure was found to affect the system response and, for this reason, flow blockages were considered for each subsystem.

The principal flow blockage found was spurious closure of the MU&P in-line valves. These closures could occur due to failures within the valve operator, a failed control signal (interface failure), a maintenance failure or, in some cases, loss of instrument air pressure (interface failure). Other flow blockage or loss of flow failures included plugged filters and tripped pumps.

Flow increase functional failures typically were found to result from a control valve or its bypass valve failing open. Other failures resulting in a greater potential for increased flow, such as starting a second pump, would be limited in their effect by the control system.

Failure of chemical addition or coolant purification capability typically was found to result from a flow blockage or the opening of a flowpath bypassing operating demineralizers or filters. These particular failure modes, however, were considered in the assessment of impact on makeup flow chemistry or purity rather than flowrate.

#### 4.2.1.2 Support System Functional Failures

The MU&P system interfaces directly with seven major support systems: two control instrumentation systems, three cooling water systems, the instrument air system, and the A.C. electric power distribution system. The impacts of failures of these support functions has been assessed to identify specific effects on the MU&P system and, to the extent known, the impact on other plant systems.

Although detailed FMEA's of the support systems have not been attempted as part of this study, the support system configurations were reviewed and some potential support systems failure modes identified. In general, the failure modes which were identified were only those that specifically effected MU&P functions.

The two control instrumentation systems considered were the Engineered Safeguards Protection System (ESPS) and the Non-Nuclear Instrumentation (NNI). The MU&P system does not require the ESPS for any of its normal operating modes. However, spurious actuation of the ESPS has a significant impact on the MU&P system and was included as a failure mode for this reason. The normal control instrumentation for the MU&P is the NNI system. Other control circuits which may or may not be formally part of the NNI have been included to the extent they were known. The failure modes considered include "high" and "low" failures of each MU&P control circuit and combinations of these failures based on specific failures of the NNI power supplies.

Failures of the three major cooling water systems, Component Cooling (CC), Low Pressure Service Water (LPSW) and Recirculating Cooling Water (RCW) were considered based on their potential impacts on the MU&P. In general, loss of cooling water to the specific serviced MU&P component and loss of the complete cooling water system were assumed. Component isolation typically could occur due to valve closures. System failures were considered as a bounding failure. In addition to direct MU&P impacts, cooling water failures were traced through other MU&P support systems requiring cooling water (e.g., Instrument Air).

Complete loss of instrument air to all MU&P components was the only failure mode of this support system considered. Although loss of instrument air to a specific subset of these components may be possible, insufficient information was available to specify those failure modes.

Failures of single buses supplying AC power to MU&P components were considered. In general, buses were assumed to be deenergized due to a bus fault or loss of single supply bus. Failures of multiple supplies with provisions for automatic transfer was not considered. Multiple bus failures were considered based on the possibility of a single common supply bus failure (i.e., if two buses could be manually transferred to a single bus, the failure mode was considered). The buses considered under AC power failures ranged from the 4160 VAC switchgear groups TC, TD and TE to the 208 VAC buses. Failure of 120 VAC instrument buses are considered as part of instrumentation failures. MU&P components directly requiring DC power could not be found.

4.2.2 System and Plant Level Effects

The functional failures described above have been evaluated to assess their impact on overall MU&P system function and consequential effects on the plant. The results of the systems level FMEA are discussed below and described in

Tables 3 through 10. One table for each of the following MU&P and support system functional failure types (as described in Section 4.2.1) is included:

1. Pressure Boundary Failures
2. Flow Blockages
3. Flow Increases
4. Loss of Chemical Addition, Coolant Purification Capability
5. Control Instrumentation Malfunctions
6. Cooling Water Failures
7. Instrument Air Failures
8. AC Electric Power Failures

The significant failure modes and effects have been summarized in Section 2, Summary of Results.

4.2.2.1 <u>Pressure Boundary Failures</u>

The effects and required remedial actions for each of the MU&P Pressure Boundary (P.B.) failures discussed in Section 4.2.1 are listed in Table 3. The significant effects are discussed below for the potential locations of MU&P P.B. failures. The effect of hydrogen gas release is discussed separately.

<u>P.B. Failures in the High Pressure Letdown Piping (Letdown Subsystem)</u>

P.B. failures in the high pressure letdown piping, as discussed in Section 4.2.1, can result from LD cooler tube failures, unisolated vent or drain paths or valve stem seal failures. The effect of small leaks (>10 gpm) are expected to be limited to plant shutdown and repair. Larger leaks such as a tube failure or an unisolated drain path would result in decreasing RCS pressure and pressurizer level and significant decrease in the LST level. If the RCS pressure decrease did not result in automatic initiation of the HPI mode, the operator must provide an alternate supply of borated water to the operating HPI pump prior to draining the LST to prevent pump damage. These P.B. failures can be isolated by operator action.

The principal significance of these P.B. failures is considered to be the loss of reactor coolant from the RCS and simultaneously creating the potential for consequential failure of the operating HPI pump due to the single cause. Isolatable small LOCA's have been considered to be of significance to pressurized thermal shock (PTS) sequences.

P.B. Failures in the Low Pressure Letdown or Pump Seal Return Piping (Letdown, HPI Pump and RC Pump Seal Return Subsystems)

The principal effect of a P.B. failure in the low pressure letdown piping is the reduction of the LST level and potential for consequential failure of the operating HPI pump. As above, this condition requires that an alternate supply of borated water be supplied to the HPI pump prior to draining the LST. In the low pressure letdown piping, however, the maximum rate of LST inventory decrease would be limited to the letdown or seal return flowrate. Furthermore, once the leak is isolated (resulting in a probable isolation of letdown), the rate of LST inventory decrease would be limited further to the seal injection and makeup valve bypass flowrates.

P.B. Failures in the Makeup and Seal Injection Piping (Makeup and Seal Injection Subsystems)

Potential P.B. failure locations in the high pressure makeup and seal injection piping were found to be fewer than in the letdown piping. An unisolated drain line following seal injection filter maintenance could result in: diversion of makeup and seal injection flow to the high activity waste tank; decreasing LST and possibly pressurizer levels; and possible HPI pump runout. In addition, an attempt to terminate the leak by improperly closing a low pressure drain valve (e.g., HP-375) could result in piping rupture.

A P.B. failure of this type can be isolated. However, the LST inventory will continue to be transferred to the RCS until the setpoint pressurizer level is restored. The continued LST inventory loss would require that an alternate supply of borated water be supplied to the HPI pump to prevent consequential pump failure. Until the leak is isolated, the emergency HPI function is degraded.

Valve stem seal failures, in general, are expected to be small. This leakage will result in a very slow decrease in the LST level.

Also of potential concern is the possibility of a vibration induced piping crack in the high pressure HPI pump discharge piping. The effects of this failure would be similar to the unisolated drain path P.B. failure discussed above. However, depending on the locations of the crack and accessible isolation valves, one or two HPI pumps may be unavailable for emergency service until the crack is repaired. Additional effects of the high pressure water jet through the crack are possible but unevaluated.

Although a piping crack of this type could be induced by the normal operation of the MU&P system, the postulated failure is considered beyond the scope of "control system failures."

Release of Hydrogen Gas

In addition fo the direct effects of releasing or diverting the process fluid, the hydrogen gas dissolved in the fluid can be released creating the potential for fires or explosions. For most of the P.B. failures discussed, including unisolated drain lines or safety valve lifts, the process fluid and dissolved gas would be diverted to waste tanks where the released gas could be contained. Postulated piping cracks, however, release the fluid directly to the equipment rooms. Depending on the room ventilation in the areas involved, the release of hydrogen gas may represent an additional, though unevaluated, hazard.

4.2.2.2 Flow Blockage Failures

Table 4 lists the effects of system level flow blockage failures and possible remedial actions. The principal initiating cause of flow blockage failures identified was the closure of in-line valves in the major MU&P subsystems.

The significance of flow blockage failures varied with the potential for draining the LST or blocking the flow to the operating HPI pump.

Flow blockage failures in the Makeup, Seal Injection, Seal Return and the high pressure piping in the letdown subsystem were found to have relatively minor effects. Makeup blockages result in the gradual increase in LST level and decrease in pressurizer level due to the 62 gpm letdown and seal return flowrate and 32 gpm seal injection flowrate. Blockage of seal injection, seal return or letdown in the high pressure piping results in gradual increase in pressurizer level and decrease in LST level due to the net flowrate into the RCS of 20 gpm or less. The effects of flow blockage failures in other MU&P subsystems are discussed below.

Flow Blockage in the Low Pressure Letdown Piping (Letdown, HPI Pump, Subsystem)

Flow blockage failures in the low pressure letdown piping results in pressurization of the piping and diversion of the letdown flow to waste tanks through the letdown relief valve. A similar effect also occurs if the 3-way valve transfers the letdown flow to the Bleed Holdup tank.

Following these flow blockage failures, the LST level will decrease at a rate limited by the existing letdown flowrate. Manual closure of the containment isolation valves (in the high pressure letdown piping) results in throttling of the makeup flow to the RCS and limiting the rate of LST level decrease to the seal injection and makeup valve bypass flowrates.

As discussed above, the operator must remove the flow blockage or provide an alternate source of borated water to the HPI pump prior to draining the LST to prevent HPI pump failure.

Flow Blockage in the HPI Pump Suction Piping (HPI Pump Subsystem)

A flow blockage in the pump suction piping such as closure of valve HP-23 will result in immediate HPI pump cavitation. Unless the operator removes the flow blockage, trips the operating HPI pump(s) or opens a flow path from the BWST rapidly, failure of the operating pump(s) is expected to occur.

Information available to the operator to diagnose this flow blockage is limited and may be confusing. Decreasing pressurizer level, low seal injection flow alarms and an increasing LST level also would be produced by an HPI pump trip. If the operator attempted to restore flow by starting the backup HPI pump, the backup pump may fail also.

4.2.2.3 Flow Increase Failures

The effects and required remedial actions of identified MU&P flow increase failures are listed in Table 5. One flow increase failure was found to have significant results. Other flow increase failures were controlled by automatic control instrumentation or resulted in a gradual increase in LST level.

An increase in the makeup flowrate, potentially resulting from the makeup control valve or the HPI discharge valve opening, would result in a decreasing LST level. The rate of LST level decrease could be comparable to the rates resulting from P.B. or flow blockage failures. As with other failures resulting in decreasing LST level, the operator must throttle makeup flow, increase letdown flow or provide an alternate source of water to the HPI pump prior to draining the LST to prevent failure of the operating HPI pump.

4.2.2.4 Loss of Chemical Addition or Coolant Purification Capability

The analysis of the effects of P.B. failures, flow blockages and flow increases addressed the physical transport of the process fluid through the MU&P system and the effects of flow perturbations. However, one of the major functions of the MU&P is the removal of impurities from the letdown coolant and modification of the fluid chemistry. Effects and required remedial actions for failures of coolant purification and chemical addition capability are listed in Table 6 and discussed below.

The analysis of loss of chemical addition or purification capability did not identify any failures of significance which would occur in near term plant operation. The major effect of failures of this type is expected to be exceeding reactor coolant chemistry specifications. While this may result in a required plant shutdown, no consequential failures of safety significance could be identified even if the reactor were operated over periods of days or weeks.

Failure of boric acid addition or failure to terminate demineralized water addition are unlikely due to system redundancy. In addition, even if these failures were to occur, additional control rod insertion failures and/or improper plant cooldown would have to be postulated to result in effects of significance.

Bypassing the makeup or seal injection filters may result in increased HPI pump or RC pump seal wear - if significant quantities of particulates built up or were injected into the MU&P. However, flowpaths from potential sources of particulates which bypass the makeup filters could not be identified.

#### 4.2.2.5 Support Systems Failures

In addition to considering the effects of MU&P system failures, the analysis considered the consequential MU&P failure modes and effects resulting from required support system failures. As discussed in Section 4.2.1, the support systems considered were the ESPS and NNI control instrumentation systems, the CC, LPSW and RCW cooling water systems, the instrument air system and the electric power distribution system.

The support systems were reviewed to identify potential failure modes which effect, specifically, MU&P functions. As such the postulated support system failure modes were considered adequate to address consequential MU&P failure modes. However, detailed specification of support system failure modes or their plant level effects would require detailed FMEA's of the specific support systems which was not attempted in this study.

The MU&P and selected plant level effects of support system interface failure are discussed below.

Control Instrumentation Malfunctions

The effects and required remedial actions of automatic control instrumentation malfunctions are listed in Table 7. The failure modes considered include spurious one or two channel ESPS actuation, failure of each NNI control circuit affecting the MU&P and combinations of control circuit failures resulting from specified NNI instrument power supply failures. Failures of manual control circuits of individual MU&P isolation valves have not been listed separately in Table 7. Typically, failures of these circuits can result in the opening of normally closed valves or closing of normally open valves. These failure modes have been considered under flow blockage and flow increase failures listed in Tables 4 and 5.

No effects of significance affecting the MU&P were identified beyond those previously discussed in Tables 4 and 5.

Cooling Water Failures

Three cooling water systems provide cooling water to MU&P components. The CC system provides cooling water to the LD coolers, the LPSW system provides cooling water to the HPI pumps' motor bearing coolers and the RCW provides cooling water to the seal return coolers.

The effects and required remedial actions for cooling water systems failures are listed in Table 8. Two failure modes were postulated for each cooling water system: loss of cooling water to the serviced MU&P component and complete cooling water system failure.

The MU&P response to loss of CC to the operating LD cooler would be automatic closure of the containment isolation valve on high letdown temperature. As previously discussed, this results in throttled makeup flow and a slow decrease in the LST level. The operator would be required to provide an alternate source of borated water for the HPI pumps prior to draining the LST to prevent pump damage. Complete failure of the CC system would result in loss of cooling to the RC labyrinth seals in addition to the LD cooler. If an alternate supply of cooling water was not provided to the operating HPI pump and pump failure occurred, the RC pump seals could be damaged due to the concurrent failure of seal injection and cooling water. Although this sequence is improbable, RC pump seal failures could occur with a degraded HPI capability.

The effect of loss of LPSW to the operating HPI pump motor bearings would result in bearing overheating and eventual damage. Although the details of the cooling water distribution piping to the HPI pumps were not available, it was assumed that cooling water to an individual pump could be isolated following HPI pump motor maintenance and improperly remain in an isolated state. Indication of cooling water isolation is unknown.

Complete failure of the LPSW is considered to be an extremely unlikely event. However, if the LPSW system failed (due to common mode plugging of the LPSW pumps' suction strainers, for instance), cooling water would be lost to several operating and standby systems including the HPI pump motors and the CC systems of Oconee Units 1 and 2. The overall effects of this event have not been evaluated in detail.

The loss of RCW to the operating seal return cooler would result in the gradual increase in the LST fluid temperature. Whether this temperature could rise to the point where the HPI pump NPSH became inadequate has not been evaluated. The rate of increase in temperature is expected to be slow.

As with the LPSW system, complete failure of the RCW is expected to be extremely unlikely. If this event occurred, however, loss of cooling water to the instrument air system and main feedwater and steam system components would occur. Loss of instrument air, causing closure of the letdown, makeup and seal return isolation valves would result in a more rapid rise in the temperature of the water pumped through the HPI pump recirculation path. Other plant level effects include loss of main feedwater.

Instrument Air Failure

The effect of a loss of instrument air and required remedial actions are listed in Table 9. As described above, loss of instrument air would result in closure of the letdown and seal return isolation valves and the makeup control valve and the seal injection control valve will open. The seal injection flowrate is not expected to increase significantly. Assuming the total seal injection flowrate doubles, the net injection rate would be approximately 40 gpm. The LST level would be decreasing gradually governed by this rate. Although the operator must monitor the LST level, and restore letdown or provide an alternate source of borated water to the LST, this effect is not considered to be of major significance. Other plant level effects include probable reactor trip resulting initially in high SG levels and subsequently trip of the main feedwater pumps.

AC Electric Power Failures

Table 10 lists the effects and required remedial actions for AC electric power failures. As discussed in Section 4.2.1, failure of each bus supplying MU&P components was assumed resulting in the components and other buses supplied from the failed bus being deenergized. Automatic transfer devices were assumed to operate properly thus limiting the number of deenergized buses to those which are assumed failed, supplied from a single deenergized bus with or without the possibility of manual transfer. In cases where a bus could be supplied from either of two buses with manual transfer capability, the bus was assumed potentially deenergized if either of the supply buses was assumed failed.

Most effects of bus failures were not considered significant. The effects on the MU&P system fell into two basic categories: operating pumps, including the operating HPI pump, stopping and electric motor operated valves deenergized and incapable of changing position on demand. Deenergizing the operating HPI pump or other pump motors was not found to be significant due to the availability of energized backup pumps and lack of consequential pump damage.

Since motor operated valves do not change position following electric power failure, there were no immediate effects following assumed bus failures. However, a possible configuration was identified with significant possible effects. Although beyond the scope of control system failures, this failure mode is identified for completeness.

The BWST isolation valve HP-24 and HPI discharge valve HP-26 are powered from 208 VAC Bus XS1; 208 VAC Bus XS2 powers the corresponding valves in the other train, HP-25 and HP-27. It was found that 208 VAC buses XS1 and XS2 can be manually transferred to the same 600 VAC supply bus.

In this configuration, a single failure of 4160 VAC buses TC or TD or 600 VAC buses XS1, XS2, X8 or X9 could prevent the four identified HPI valves from moving to their emergency positions on demand. Since the HPI function is defeated, this configuration may be a violation of the single failure criterion.

In addition, should an ES signal occur (for any reason), HPI pump C would fail due to the blocked suction path and the LST level would be decreasing due to continued RC pump seal injection and makeup control valve bypass flow. The operator must provide an alternate supply of borated water to the HPI pumps prior to draining the LST (or trip the pumps) to prevent failing the remaining two HPI pumps.

## 4.3 SUBSYSTEM LEVEL RESULTS

Detailed FMEAs of the subsystems described in Section 3.2 were completed and are presented in Appendices A-F. The results of these analyses are summarized in this section. Included are tables for each subsystem which provide a list of the failure effects at the subsystem boundaries along with the failures which can lead to those effects.

Brief discussions of the major effects for each subsystem also are included in this section. Effects such as incorrect process signals and P.B. failures have been discussed previously in Section 4.2. Even though process signals that do not directly control could still potentially induce operator response leading to additional effects, given an incorrect signal, such responses were considered secondary and were generally not discussed further. Effects on isolation capability were also not discussed further since isolation was not considered normal operation and could generally be effected with available backup when required. Reactor coolant leaks are discussed with system level results and are likewise not discussed further here.

4.3.1 Letdown Subsystem

The major effects at the subsystem interface resulting from the various subsystem failures include: reduced, increased, and terminated letdown flow to three-way valve HP-14; reactor coolant leaks; bypassing of letdown flow around the purification demineralizers; and failure to reduce the temperature of letdown flow from the subsystem. These effects can be precipitated by such failures as internal component failures, spurious control signals, or a loss of cooling water to the operating cooler. The detailed Letdown system FMEA results are presented in Appendix A.

Reduced letdown flow can result from valves developing stem seal leaks. Reduction in letdown flow can also result from the spurious opening of relief valves downstream of the block orifice. A radiation monitor loop and a boron meter loop bypass the block orifice. If a drain valve in either loop is left open after maintenance, a significant leak could occur when the use of the loops is initiated. A leak in one of these loops would reduce the letdown flow from the subsystem. Another possible failure is the opening of the normally closed control valve HP-9 due to operator error or a spurious control signal which would result in letdown flow diverted to the Unit 2 LST.

Increased letdown flow can result from normally closed manual or control valves such as HP-42 or HP-7 being opened or failing open. Increased letdown flow can also occur if a spurious control signal opens HP-7, HP-9, or HP-11. If such a signal is received by HP-9 or HP-11, the increased letdown flow may result from the addition of Unit 2 letdown flow.

Termination of letdown flow can result from internal component failures and spurious control signals. Normally open manual or control valves can fail closed obstructing letdown flow, resin beads in purification demineralizer HP-X1 can agglomerate and plug resulting in flow blockage, or a main pipe or orifice can plug obstructing flow. Spurious control signal ordering closure to HP-1, HP-3, HP-5, HP-6, or HP-8, can also terminate letdown flow.

Reactor coolant leaks can occur due to pipe cracks, a tube rupture in letdown cooler HP-C1A or HP-C1B or an unisolated vent or drain path.

Subsystem failures resulting in bypassing of the purification demineralizers may result in failure to remove RC impurities. If the normally closed valve HP-13 is opened due to operator error or spurious control signal, the letdown flow would bypass the purification demineralizer.

A loss of cooling water to the operating cooler would result in an increase in temperature of the letdown flow out of the subsystem. High cooler discharge temperature initiates isolation of the letdown flow upstream of the demineralizer. If the temperature interlock failed to close the letdown isolation valve HP-5 upon loss of cooling water to the operating cooler, the purification demineralizer HP-X1 could experience excessive heating causing resin beads to decompose or melt and subsequently block letdown flow.

#### 4.3.2 RCP Seal Return Subsystem

Single failures within the seal return subsystem can result in the following effects at the subsystem interfaces: blockage of flow from the RC pump seals; loss of, or reduced flow to the letdown storage tank (LST); and, temperature effects on discharge flow to the LST (high and low). Other effects of subsystem failures include reactor coolant leaks to the RCW or the auxiliary building; incorrect process indicators (flow, pressure, temperature signals); and, lack of system isolation when demanded. The results of the RCP Seal Return Subsystem FMEA are presented in Appendix B.

Different degrees of flow blockage from the RC pump seals can result from subsystem failures. Blockage from a single pump can result from valve failures or blockages on one of the return lines from the individual pumps. Seal blockage from all four RC pump can result from any blockage in the common seal return header upstream of the LST. Potential failures in this category include: filter plugging; cooler tube blockage; and failed closed reactor building (RB) isolation valves and inline valves such as filter isolation valves, cooler isolation valves, and check valves. In addition to internal faults or inadvertent closure of a valve, loss of instrument air can result in the closure of the pneumatic RB isolation valve; a spurious signal from the I&C system can close the other RB isolation valve; and a spurious ES signal can close them both. If detected, blockages associated with the filter or coolers can be bypassed with local action.

Failures which result in reduced flow to the LST include loss of HPI pump recirculation flow (input from the HPI Pump subsystem); and component faults within the subsystem, such as cooler tube rupture, leaks, or the inline flow blockages. Failures which result in complete loss of seal return and HPI pump recirculation flow to the LST are limited to closure failures (blockages, inadvertent closure, etc.) of inline isolation and check valves downstream of the HPI pump recirculation line inlet (just upstream of the seal return coolers).

Temperature variations in the seal return flow to the LST can result from faults internal and external to the subsystem. High discharge temperature can result from internal cooler damage, vapor lock in the cooler, or loss of RCW. Loss of flow from the HPI pump recirculation line (Subsystem 3.0) to the system and through the cooler results in reduced flow and somewhat lower seal return discharge temperature to the LST.

### 4.3.3 HPI Pumps Subsystem

Failures in this subsystem primarily affect output flow to RC makeup system and RC pump seal injection. Inlet flow can also be blocked from the seal return subsystem if the check valve to the LST plugs or fails closed.

Component faults within the subsystem can also result in reduced $H_2$ concentration in the reactor coolant makeup. The results of the HPI Pump Subsystem FMEA are presented in Appendix C.

Effects on discharge flow from the subsystem to RC makeup and seal injection include immediate loss of flow, reduced flow, and eventual loss of available makeup. Failures that result in loss of available makeup in the LST can lead to cavitation of the HPI pumps (if the LST empties while feeding the HPI pumps) and consequential pump damage or failure. These failures include blockages upstream of the LST (inline valves failed or inadvertently closed, makeup filter plugged as well as loss of instrument air or a spurious I&C signal closing the makeup filter inlet valve), and loss of inlet flow to the subsystem from letdown, seal return, or RC Bleed. If detected, most of the blockages can be bypassed from the control room. However, many blockages that restrict flow into the LST cannot be bypassed during steady state operation.

Failures which result in immediate loss of RC makeup and seal injection include: valve failures on the suction or discharge of the operating HPI pump; and pump failures (both due to internal damage, loss of low pressure service water, and loss of power supply). The precipitating valve failures can occur due to internal faults or due to a spurious I&C signal to certain motor-operated valves on the pump manifold. Flow can be lost to only the RC makeup header or only to seal injection as a result of similar valve failures on the HPI pump discharge manifold (internal faults, inadvertent closure, spurious I&C signals). In most cases the system can be realigned with alternate valving and/or an alternate HPI pump to restore flow. However, there is potential for loss of NPSH and damage in bringing the alternate pump onstream if sequencing and alignment are not correct.

Some reduction in subsystem discharge flow can result from a failed check valve (loss of backflow prevention) on the discharge of a nonoperating HPI pump. This failure mode would allow recirculation back through the nonoperating pump and the operating pump suction, resulting in reduction of actual discharge flow.

Deviations in RCS chemistry quality can occur as a result of two internal subsystem faults as well as loss of inlet flows from the Chemical Addition System. Internally the $H_2$ supply valve to the LST tank can fail closed, cutting off the $H_2$ supply; and the vent valve on the LST can fail closed, allowing potential accumulation of non-$H_2$ noncondensible gases in the LST and reduction of $H_2$ mass transfer to the reactor coolant.

Incorrect level indication in the LST due to transmitter failure, connection leaks, or loss of power to the transmitter, could lead an operator to take faulty remedial action. This could result in overfilling the LST, which could reduce or stop $H_2$ addition, or allowing the LST level to drop, which could result in loss of NPSH to the HPI pumps and ultimate loss of subsystem discharge flow to makeup and seal injection as discussed above.

#### 4.3.4 RC Pump Seal Injection

The major effect of single failures within the seal injection subsystem is loss of or reduced seal flow to the RC pumps. Other effects include increased seal injection flow to a single pump and incorrect process signals (pressure and flow) transmitted to the I&C system and the control room. The results of the RC Pump Seal Injection Subsystem FMEA are presented in Appendix D.

Subsystem failures can result in loss of seal injection flow to all four RC pumps, loss of flow to only a single pump, increased flow to a single pump, and reduced flow to all four pumps. Loss of seal flow to all four pumps can result from blockages in the inlet header (inline valves failed or inadvertantly closed, filters plugged, or orifice plugged) or loss of inlet flow to the system from the HPI pumps. Inline blockage from failure of the header flow control valve failing closed can result from an I&C signal failure, in addition to an internal fault. If detected, blockages associated with the filter path or the control valve can be bypassed, but no bypass exists in the event of failure of the inlet block valve. Reduced flow to all four pumps can result from partial failures of inline components, system leaks, and I&C-fault-induced failures of the header flow control valve.

Component faults in one of the four individual injection lines can result in loss of seal injection to a single RC pump. Each line has a throttle valve, and a flow measuring nozzle, and check valves that could potentially fail closed or plug. If one of the throttle valves fails open, increased flow to a single RC pump can result.

### 4.3.5 Reactor Coolant Makeup Subsystem

Single failures in the RC makeup subsystem can impact normal makeup flow to the cold legs, cooling flow to the cold leg inlet nozzles and pressurizer spray lines, and inlet flow rate from the letdown storage tank in Subsystem 3.0. The results of the RC Makeup Subsystem FMEA are presented in Appendix E.

Failure effects on the normal makeup flow to the cold leg include: loss of flow, reduction in flow, increased flow, and flow imbalance between the two cold leg inlets. Loss of input flow from the HPI pumps (Subsystem 3.0) and failure of the block valve on the inlet header (plugging, damage, inadvertant closure, etc.) will result in total loss of makeup flow. In addition, single downstream blockages in the main flow path can stop normal makeup flow, but some flow will continue to the RCS via the minimum flow bypass loop to the cold leg inlet nozzles and the pressurizer spray line. These blockages could potentially result from failures associated with the flow control valve, block valves, and inline check valve. Failures in the instrument air system or I&C system, in addition to internal damage, could fault the flow control valve. However, both a remote operated and local bypass around the flow control valve are available to resume flow.

Increased flow through the normal makeup path can result from either the flow control valve or the normally closed motor operated ES valve failing open. In addition to internal faults, the control valve can fail open due to an instrument air system fault and a control signal fault, and the ES valve can open on a spurious ES or I&C signal.

Failures which result in flow imbalance between the two reactor cold legs are limited to component faults within the subsystem. These include blockages associated with the check valve or flow orifice on one of the cold leg inlets.

Failure effects on the bypass flow paths to the cold leg inlet nozzles and the pressurizer spray line include loss of flow and excess flow to one of the inlet nozzles. Loss of flow to both nozzles and the spray line can result from failure of the inlet block valve to the minimum flow bypass loop and the inlet block valve to the subsystem. Loss of flow to one nozzle can result from failure of either the throttle valve or the block valve on either cooling flow line. Loss of flow to the pressurizer spray line which branches off one of the cooling flow lines can likewise result from line blockages upstream of the spray line inlet. Excess flow to one nozzle and possibly the spray line can result from the throttle valve on one of the lines failing open. Likewise, a temporary reduction in flow in these lines can result from open-valve-failures in the normal makeup flow path, diverting flow away from the minimum flow bypass loop. Instrument air system and I&C system faults, in addition to internal faults, could produce this effect through inadvertant opening of the flow control valve or the ES valve.

Excess flow rate through the subsystem via failed open valves could also potentially result in drop in the letdown storage tank level and possible loss of NPSH to the HPI pumps (Subsystem 3.0) and increased level in the pressurizer.

4.3.6 Chemical Processing Subsystem

The major effects of failures in this subsystem is loss of demineralized water return to the LST, loss of RC bleed holdup and transfer capability, loss of chemical addition capabilities including boric acid addition, loss of boron recovery capability, and loss of deboration capability. These effects are summarized in Table 11 and discussed below. The results of the Chemical Processing Subsystem FMEA are presented in Appendix F.

Failures which result in loss of demineralized water return to the reactor coolant system include electric power supply failure to the transfer pump, transfer pump failure, and failures in any one of several manual isolation or control valves. Failures in control valves HP-15 and HP-16, either from control signal failures or internal valve failures, can also result in loss of return flow. Since this system is operated on demand only, failure to supply the holdup tank with demineralized water or allowing the tank to remain empty can result in no demineralized water available when required. However, the valve configuration would allow makeup from the bleed holdup tank (although it would not have been through the boron recovery cycle) or makeup from the Unit 2 demineralized water or bleed holdup tanks.

Loss of bleed holdup and transfer capability can result from valve failures, plugs in lines due to loss of trace heating, and unavailability of the holdup tank. However, valve configuration would allow bleed flow to the demineralized water holdup tank or the Unit 2 bleed or demineralized water holdup tanks. Electric power supply failure or transfer pump failure can result in loss of flow to boron recovery which also leads unavailability of the holdup tank for subsequent bleed and makeup cycles.

Addition of hydrazine and lithium hydroxide to the reactor coolant is also a per-demand-operation. Failure to supply either chemical can result from manual isolation, control, or check valve failures; or allowing either tank to remain empty. Valve configuration would allow pumping either chemical to its destination through the other chemical pump; however, if both chemicals are required simultaneously, failure of either pump results in unavailability of that chemical.

Failure to provide caustic to the LPI pumps, RC bleed evaporator, and deborating demineralizers can result from isolation valve failures, electric power supply and pump failures, or allowing the mix tank to remain empty. No remedial action within the subsystem is available to compensate for loss of caustic either within the subsystem or at the interfaces.

Loss of concentrated boric acid to the makeup filters and the BWST can result from allowing the concentrated boric acid storage tank to empty, various manual isolation or control valve failures, electric power supply or transfer pump failures, or plugs in lines due to trace heating failures. Two sources of concentrated boric acid are available: a boric acid mix tank and the concentrate from boron recovery. In the event of failure of one source, the other would be available to supply boric acid requirements. The valve configuration would also allow boric acid addition from the Unit 2 concentrated boric acid storage tank.

Failures in the boron recovery operation result in no concentrate flow to the concentrated boric acid storage tank. Component failures include various pumps and manual valves, either of two control valves, the evaporator, feed storage tank, and trace heating. Support system failures such as steam supply and electric power can also result in boron recovery failure. Recirculation paths can be established so that concentrated boric acid is returned either to the evaporator or the evaporator feed tank rather than the storage tank.

Failure of the deboration capability in the on-line deborating demineralizer results from various manual isolation and control valve failures, failure of caustic flow for regenerating the resin, and plugs in lines due to trace heating failures. These failures result in the requirement that a second demineralizer is available. Flow can also be diverted to the bleed holdup tank with makeup provided from the demineralized water holdup tank.

## TABLE 2. FUNCTIONAL FAILURES AND POTENTIAL PRECIPITATING COMPONENT FAILURES

| Functional Failure | Precipitating Component Failure | Comments |
|---|---|---|
| 1. Pressure Boundary Failures | | |
| 1.1 Letdown Subsystem | | |
| 1.1.1 In Containment Pressure Boundary (P.B.) Failure | Through wall piping crack, valve stem seal failure, unisolated vent or drain path, LD cooler tube failure. | Through wall piping cracks are included for completeness but are not considered a "control system failure." Valve stem seal failures and unisolated vent or drain path are possible though unlikely. |
| 1.1.2 Out-of-Containment High Pressure P.B. Failure Upstream of Block Orifice | Through wall piping crack, valve stem seal failure, unisolated vent or drain path. | Through wall piping cracks are included for completeness but are not considered a "control system failure." Valve stem seal failures and unisolated vent or drain path are possible though unlikely. |
| 1.1.3 Out-of-Containment Low Pressure P.B. Failure Upstream of 3-Way Valve | Opened and/or failed open relief valve, unisolated vent or drain path, diversion of Unit 1 letdown to Unit 2. | Relief valves will open following a letdown flow blockage. Diversion of Unit 1 flow to Unit 2 possible due to a mispositioned demineralizer isolation valve. Valve stem seal leakage and cracks in low pressure piping not considered. |

TABLE 2. FUNCTIONAL FAILURES AND POTENTIAL PRECIPITATING COMPONENT FAILURES (Continued)

| Functional Failure | Precipitating Component Failure | Comments |
|---|---|---|
| 1.2 P.B. Failure in the HPI Pump Subsystem | Opened and/or failed open relief valve, unisolated vent or drain path, vibration induced piping cracks. | Relief valves will open following a letdown flow blockage. Vibration induced piping cracks included since they could result from normal operation. In the pump suction piping such cracks are not expected to result in significant leakage. |
| 1.3 P.B. Failure in the Seal Return Subsystem | Opened and/or failed open relief valve, Seal Return Cooler tube failure, unisolated vent or drain path. | Relief valves may or may not open following a seal return flow blockage. In addition, reactor coolant expected to be diverted to containment through R.C. pumps' vapor vents. |
| 1.4 P.B. Failure in the Makeup Subsystem | Vibration induced piping cracks, unisolated vent or drain path, valve stem seal failure. | Significant through-wall piping cracks are unlikely but are included due to expected pump induced vibration. |
| 1.5 P.B. Failure in the Seal Injection Subsystem | Vibration induced piping cracks, unisolated vent or drain path, valve stem seal failure. | Significant through-wall piping cracks are unlikely but are included due to expected pump induced vibration. |
| 1.6 P.B. Failure in the Chemical Processing Subsystem | Unisolated vent or drain paths. | |

TABLE 2. FUNCTIONAL FAILURES AND POTENTIAL PRECIPITATING COMPONENT FAILURES (Continued)

| Functional Failure | Precipitating Component Failure | Comments |
|---|---|---|
| 2. Flow Blockages | | |
| 2.1 Letdown Subsystem Blockage | Spurious isolation valve closure due to valve operator, signal or maintenance failure, loss of instrument air, plugged purification demineralizer. | Plugged demineralizer considered unlikely unless condition existed prior to placing the demineralizer in use. |
| 2.2 HPI Pump Subsystem Blockage | Spurious isolation valve closure due to valve operator, signal or maintenance failure, plugged makeup filter(s), spurious operation of 3-way valve, HPI pump trip. | HPI pump trip not formally a "blockage" but does result in loss of flow. |
| 2.3 Seal Return Subsystem Blockage | Spurious isolation valve closure due to valve operator, signal or maintenance failure, plugged seal return filter. | Filter plugging would be gradual and not expected to significantly reduce flowrate. |
| 2.4 Makeup Subsystem Blockage | Spurious control valve closure due to valve operator signal or instrument air failure, spurious closure of manual isolation valve due to maintenance failure. | |

TABLE 2. FUNCTIONAL FAILURES AND POTENTIAL PRECIPITATING COMPONENT FAILURES (Continued)

| Functional Failure | Precipitating Component Failure | Comments |
|---|---|---|
| 2.5 Seal Injection Subsystem Blockage | Spurious control valve closure due to valve operator or signal failure, spurious closure of manual isolation valve due to maintenance failure. | |
| 2.6 Chemical Processing Subsystem Blockage | Spurious isolation valve closure due to operator, signal or maintenance failure, transfer pump trip. | Transfer pump trip not formally a blockage but does result in loss of flow. |
| 3. Flow Increases | | |
| 3.1 Letdown Subsystem Flow Increases | Spurious opening of LD control valve due to valve operator or signal failure. | |
| 3.2 HPI Pump Subsystem Flow Increases | Spurious transfer of 3-way valve, spurious opening of BWST isolation valve(s), spurious addition from chemical processing subsystem. | Start of second HPI pump also will result in an increase in pump recirculation flowrate. |
| 3.3 Seal Return Subsystem Flow Increases | RC pump seal failure, opening seal bypass flowpath. | RC pump failure not formally within MU&P system. |

TABLE 2. FUNCTIONAL FAILURES AND POTENTIAL PRECIPITATING COMPONENT FAILURES (Continued)

| Functional Failure | Precipitating Component Failure | Comments |
|---|---|---|
| 3.4 Makeup Subsystem Flow Increases | Spurious opening of MU control valve or HPI injection valves due to valve operator or signal failure. | |
| 3.5 Seal Injection Subsystem Flow Increases | Spurious opening of seal injection control valve due to valve operator or signal failure, loss of instrument air. | |
| 3.6 Chemical Processing Subsystem Flow Increases | | |
| 3.6.1 Flow to Subsystem Increases | Spurious transfer of 3-way valve, increased letdown flowrate during bleed operations. | Internal Chemical Processing Subsystem flow increases not listed in Table 2. |
| 3.6.2 Flow to HPI Pump Subsystem Increases | Spurious opening of control valve due to valve operator or signal failure or spurious start of transfer pump during feed and bleed operations. | |

**TABLE 2. FUNCTIONAL FAILURES AND POTENTIAL PRECIPITATING COMPONENT FAILURES** (Continued)

| Functional Failure | Precipitating Component Failure | Comments |
|---|---|---|
| 4. Loss of Chemical Addition, Coolant Purification Capability | | |
| 4.1 Failure of Chemical Addition from Chemical Processing Subsystem | Spurious closure of control or isolation valve, failure of transfer pump(s), depletion of inventory. | |
| 4.2 Failure of Hydrogen Supply | Spurious closure of pressure regulator, inventory depletion. | |
| 4.3 Bypass of Filters or Demineralizers | Spurious opening of bypass valve due to valve operator, signal or maintenance failure. | |

TABLE 3. PRESSURE BOUNDARY FAILURES IN THE MAKEUP AND PURIFICATION SYSTEM

| Failure/Location | Effect | Remedial Actions |
|---|---|---|
| 1. Letdown Subsystem | | |
| 1.1 In-Containment Pressure Boundary (P.B.) Failure | RCS leak or small LOCA - decreasing LST and pressurizer levels, decreasing RCS pressure, and high contaminent radiation alarms alert the situation. If the LST is drained prior to ES, actuation of the HPI mode, the operating HPI pump(s) may fail. | Emergency procedures for RCS leaks or small LOCA's must be followed depending on wnether the leak rate exceeds the capacity of the MU&P system. The operator must initiate an alternate supply of borated water to the LST or directly to the HPI pumps. Letdown flowpath may be isolated and the isolated and the HPI mode of operation may be initiated automatically if the RCS pressure decreases to 1500 psi. |

TABLE 3. PRESSURE BOUNDARY FAILURES IN THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure/Location | Effect | Remedial Actions |
|---|---|---|
| 1.2 LD Cooler Tube Failure | RCS leak or small LOCA - decreasing LST and pressurizer levels and high CC surge tank and radiation alarms alert operator to the situation. Until isolated, reactor coolant will pressurize the CC system resulting in the in-containment CC relief valves opening and discharging to the containment sump. If the LST is drained prior to ES actuation of the HPI mode, the operating HPI pump(s) may fail. | Emergency procedures for RCS leaks or small LOCA's must be followed depending on whether the leak rate exceeds the capacity of the MU&P System. Automatic isolation of the LD coolers from the RCS will not not occur. The operator must isolate the LD cooler(s) from the RCS based on high CC surge tank level and pressure. The situation may be confused by high containment sump levels and possible radiation alarms resulting from the CC relief valve discharge. The operator must initiate an alternate supply of borated water to the LST or directly to the HPI pumps. |

TABLE 3. PRESSURE BOUNDARY FAILURES IN THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure/Location | Effect | Remedial Actions |
|---|---|---|
| 1.3 Out-of-Containment High Pressure P.B. Failure Upstream of Block Orifice | RC leak or small LOCA outside containment. Decreasing LST and possibly pressurizer levels, possibly decreasing RCS pressure, high level radiation alarms and high auxiliary building sump levels alert operator to the situation. Leakage will continue until the letdown flow path is isolated by the operator or automatically isolated by the ESPS if RC pressure decreases to 1500 psi. Effect of significant reactor coolant discharge unknown (see High Energy Line Break Analysis). If the LST is drained prior to ES actuation of the HPI mode, the operating HPI pump(s) may fail. | Leak path must be isolated by closing containment isolation valves. Procedures for a letdown line failure or leakage outside containment must be followed (if they exist). Procedures covering subsequent shutdown of the plant without letdown must be followed, unless the leak path can be isolated from the letdown path. The operator must initiate an alternate supply of borated water to the LST or directly to the HPI pumps. |

TABLE 3. PRESSURE BOUNDARY FAILURES IN THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure/Location | Effect | Remedial Actions |
| --- | --- | --- |
| 1.4 Out-of-Containment Low Pressure P.B. Failure Downstream of Block Orifice and Upstream of 3-Way Valve | RC leak outside containment. Leak flowrate will be limited to a small increase above existing flowrate. Local radiation alarms, high sump or waste holdup tank levels and decreasing LST level alert operator to the situation. Manual isolation of letdown is required. If the LST is allowed to be drained, the operating HPI pump(s) may fail. | Procedures for a letdown line failure or leakage outside containment must be followed (if they exist). Operator must isolate the leak and open an alternate flowpath from the BWST or bleed holdup/boric acid tanks to the HPI pumps. Procedures covering subsequent shutdown of the plant without letdown must be followed. |

TABLE 3. **PRESSURE BOUNDARY FAILURES IN THE MAKEUP AND PURIFICATION SYSTEM** (Continued)

| Failure/Location | Effect | Remedial Actions |
|---|---|---|
| 2. HPI Pump Subsystem | | |
| 2.1 P.B. Failure Between 3-Way Valve and LST | RC leak outside containment. Leak flowrate will be limited to a small increase above existing flowrate. Local radiation alarms, high sump or waste holdup tank levels and decreasing LST level alert operator to the situation. Manual isolation of letdown may be required. If the LST is allowed to be drained, the operating HPI pump(s) may fail. In addition, failures in locations downstream of check valve HP-7 could result in the release of $H_2$ which create the potential for fires or explosions. | Procedures for a letdown line failure or leakage outside containment must be followed (if they exist). Operator must isolate the break and open an alternate flowpath from the BWST to the HPI pumps if makeup to the LST is terminated. Procedures covering subsequent shutdown of the plant without letdown must be followed. |

TABLE 3. PRESSURE BOUNDARY FAILURES IN THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure/Location | Effect | Remedial Actions |
| --- | --- | --- |
| 2.2 P.B. Failure Between the LST and HPI Pumps | RC leak outside containment. Local radiation alarms, high sump, waste holdup and/or bleed holdup tank levels, decreasing seal injection and makeup flowrates and possibly decreasing LST level alert operator to the situation. Larger leak rates may result in HPI pump cavitation and reduction in pump flowrate. This will result in the makeup control valve, HP-12, and seal injection control valve HP-31, opening to compensate, exacerbating the cavitation. This condition could lead to HPI pump damage unless the pump is manually tripped. If the HPI pump is tripped, RC pumps can continue to operate with CC water. In addition, leak paths in these locations may result in the release of $H_2$ which create the potential for fires or explosions. | Operator should trip the operating HPI pump if low or erratic flow persists, isolate the leak and provide an operable path for boric acid addition and RC pump seal injection. The letdown path to the Bleed Holdup tanks then must be initiated to control pressurizer level. |

**TABLE 3. PRESSURE BOUNDARY FAILURES IN THE MAKEUP AND PURIFICATION SYSTEM** (Continued)

| Failure/Location | Effect | Remedial Actions |
|---|---|---|
| 3. RC Pump Seal Return Subsystem | | |
| 3.1 P.B. Failure Between RC Pumps and HPI Pump Subsystem | Small RC leak outside or inside containment. Local radiation alarms, high sump, waste tank or quench tank level and a decreasing LST level alerts operator to the situation. | Isolate and repair the leak. If the leak must be isolated, the flow past RC pumps' seals will be diverted to the containment sump or quench tank. |
| 3.2 Seal Return Cooler Tube Failure | Small leak to RCW System. Increasing RCW surge tank level, high RCW radiation alarms and decreasing LST tank level alert the operator to the situation. | Isolate the affected cooler and divert seal return flow through spare cooler. |

TABLE 3. PRESSURE BOUNDARY FAILURES IN THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure/Location | Effect | Remedial Actions |
|---|---|---|
| 4. Makeup Subsystem - P.B. Failure Between HPI Pumps and RCS Pressure Boundry Check Valves | RC leak or high energy line failure outside or inside containment. Local radiation alarms, high sump levels, possible low seal injection flowrate alarms and decreasing LST and Pressurizer levels alert operator to situation. Significant P.B. failures will result in opening the makeup control valve and increasing the rate of decrease of the LST level. If the LST is allowed to be drained, failure of the operating HPI pump(s) may occur. Unless tripped automatically by motor protection devices (if they exist) or by the operator, pump damage could occur. Effect of makeup fluid discharge unknown (see High Energy Line Break Analysis). In addition, breaks in these locations may result in the release of $H_2$ creating the potential for fires or explosions. | Procedures for an RC leak or a high energy line break must be followed. Operator should trip the operating HPI pump, if required, isolate the break and provide an operable path for boric acid addition and RC pump seal injection. Depending on the failure location, RC Pump seal injection may or may not be possible. |

TABLE 3. PRESSURE BOUNDARY FAILURES IN THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure/Location | Effect | Remedial Actions |
|---|---|---|
| 5. Seal Injection Subsystem - P.B. Failure Between Makeup Subsystem and RC Pumps | RC leak or high energy line failure outside or inside containment. Low seal injection flowrate alarms, local radiation alarms, high sump or waste tank levels, and decreasing LST level alert operator to situation. Significant piping failures will result in opening the makeup control valve and increasing the rate of decrease of the LST level. If the LST is allowed to be drained, failure of the operating HPI pump(s) may occur. Unless tripped automatically by motor protection devices (if they exist) or by the operator, pump damage could occur. Effect of makeup fluid discharge unknown (see High Energy Line Break Analysis). In addition, breaks in these locations may result in the release of $H_2$ creating the potential for fires or explosions. | Emergency procedures for a high energy line break must be followed. Operator should trip the operating HPI pump, if required, isolate the break and provide an operable path for boric acid addition and RC pump seal injection. Depending on the failure location, RC Pump seal injection may or may not be possible. |

TABLE 3. PRESSURE BOUNDARY FAILURES IN THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure/Location | Effect | Remedial Actions |
|---|---|---|
| 6. Coolant Processing and Storage Subsystem - P.B. Failure in the Coolant Processing and Storage Subsystem | Radiation alarms and high sump level alert the operator to the situation. Flooding may be a problem due to size of Bleed Holdup Tanks (~100,000 gal.). Normal letdown/makeup will be automatically initiated if a low LD Tank level results. | Operators must isolate the failure and take appropriate measures to control flooding. The BWST can supply RCS boric acid requirements if required. |

TABLE 4. FLOW BLOCKAGES IN THE MAKEUP AND PURIFICATION SYSTEM

| Failure/Location | Effect | Remedial Actions |
|---|---|---|
| 1. Letdown Subsystem | | |
| 1.1 Flow Blockage in High Pressure Letdown Path to Isolation Valve Downstream of Block Orifice - Letdown-Makeup Operation or Operatior With Deborating Demineralizers | Reduced letdown from RCS results in makeup flow throttled due to increasing pressurizer level. Seal injection results in a continued net injection of 20 gpm and gradually decreasing LST level. | Operator can establish an alternate letdown flowpath or clear the flow blockage. Minimum HPI pump flow recirculation must be maintained. Continued operation may require makeup to LST or throttling seal injection flow. |
| 1.2 Flow Blockage in Low Pressure Letdown Path to Connection With 3-Way Valve - Letdown-Makeup Operation or Operation With Deborating Demineralizers | Increased line pressure lifts letdown line relief valve. Leak rate less than preexisting letdown flowrate. Decreasing LST level and increasing waste holdup tank level alert operator to the situation. Unless a source of water is provided to the LST or HPI pump is provided, LST will be drained possibly resulting in damage to the operating HPI pump. If relief valve falls to close after blockage is cleared, see Table 1, Pressure Boundary Failures. | Provide an alternate source of makeup water to the LST or HPI pumps. Close the letdown containment isolation valve(s) to isolate the relief valve and remove the flow blockage. |

TABLE 4. FLOW BLOCKAGES IN THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure/Location | Effect | Remedial Actions |
| --- | --- | --- |
| 1.3 Flow Blockage in High Pressure Letdown Path to Isolation Valve Downstream of Block Orifice - Letdown to Bleed Holdup Tank Operation | Increasing level in pressurizer results in throttling makeup flow. Demineralized water or boric acid flow to LD tank will continue resulting in an alarmed high LD tank level. | Operator can establish an alternate letdown flowpath or clear the flow blockage. Minimum HPI pump flow recirculation must be maintained. Continued operation requires throttling makeup to LD tank to avoid filling tank. |
| 1.4 Flow Blockage in Low Pressure Letdown Path to Connection With 3-Way Valve - Letdown to Bleed Holdup Tank Operation | Letdown flow diverted to waste holdup tank. No change in LST level until letdown-makeup operation resumed - see Item 1.2. | Remove flow blockage. After letdown-makeup operation resumed, see Item 1.2. |
| 2. 3-Way Valve | | |
| 2.1 3-Way Valve Switches from Letdown to LST to Chemical Processing Subsystem | Flow to LST stops while makeup to RCS continues at previous flowrates. Low LST level is alarmed and the level signal may automatically transfer valve to original position. Unless an alternate source of makeup water to LST is provided, the LST will be drained possibly resulting in damage to the operating HPI pumps. | Operator manually can transfer the 3-Way Valve to direct flow to the LST, open the bypass line from the letdown line to the makeup filters or provide makeup to the LST from the Chemical Processing Subsystem. If LST level cannot be maintained, the operator must throttle makeup flow to the RCS or trip the HPI pumps. |

**TABLE 4. FLOW BLOCKAGES IN THE MAKEUP AND PURIFICATION SYSTEM** (Continued)

| Failure/Location | Effect | Remedial Actions |
|---|---|---|
| 2.2 3-Way Valve Switches from Letdown to Chemical Processing Subsystem to LST | LST level will increase and be alarmed on high level. | Return 3-Way Valve to original position or isolate makeup flow from Chemical Processing Subsystem to LST. |
| 2.3 3-Way Valve Fails to Switch Letdown to LST on Demand | Following a low LST level demand, failure to transfer will result in continued decreasing in LST level. Unless an alternate source of makeup water to the LST is provided, the LST will be drained possibly resulting in demage to the operating HPI pumps. Following a "batch complete" or "control rod insertion limit" demand, makeup to the LST will be isolated resulting in a low LST level (see above). | Operator manually can open the bypass line from the letdown line to the makeup filters or provide makeup to the LST from the Chemical Processing Subsystem. If LST level cannot be maintained, the operator must throttle makeup flow to the RCS or trip the HPI pumps. |

TABLE 4. FLOW BLOCKAGES IN THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure/Location | Effect | Remedial Actions |
|---|---|---|
| 3. HPI Subsystem | | |
| 3.1 Flow Blockage in Piping From 3-Way Valve to LST - Letdown-Makeup Operation or Operation With Deborating Demineralizers | Increased line pressure lifts letdown line relief valve. Leak rate less than preexisting letdown flowrate. Decreasing LST level and increasing waste holdup tank level alert operator to the situation. Unless a source of water is provided to the LST or HPI pump is provided, LST will be drained possibly resulting in damage to the operating HPI pump. If relief valve fails to close after blockage is cleared, see Table 3, Pressure Boundary Failures. | Provide an alternate source of makeup water to the LST or HPI pumps. Close the letdown containment isolation valve(s) to isolate the relief valve and remove the flow blockage. |
| 3.2 Flow Blockage in Piping from 3-Way Valve to LST - Letdown to Bleed Holdup Tank Operation | Flow to LST stops while makeup to RCS continues at previous flowrates. Unless an alternate source of makeup water to LST is provided, the LST will be drained possibly resulting in damage to the operating HPI pumps. | Operator can establish an alternate letdown flowpath to the LST or clear the flow blockage. Continued operation may require throttling seal injection flowrate. |

TABLE 4. FLOW BLOCKAGES IN THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure/Location | Effect | Remedial Actions |
| --- | --- | --- |
| 3.3 Flow Blockage in Piping From LST to HPI Pump Inlets | Low indicated makeup flowrate and low seal injection flowrate alarms alert operator to the situation. Unless the operator trips the operating HPI pump(s) or establishes a flowpath from the BWST rapidly, the operating HPI pump(s) will fail. In addition, the blockage will result in pressurization of the letdown piping and lifting the letdown and LST relief valves. If the relief valves fail to close following removal of the blockage, see Table 3, Pressure Boundary Failures. | Operator must open path from the BWST or trip the operating HPI pump(s). To terminate flow leakage through the relief valves, the flow blockage must be removed or a letdown flowpath to the Bleed Holdup tanks established. If the operating HPI pump(s) fail, the operator must establish a flowpath through the remaining operable HPI pump(s) for RC pump seal injection and boration of the RCS. |
| 3.4 Operating HPI Pump(s) Stop | Low indicated makeup flowrates, and low seal injection flowrates alert operator to the situation. Continued letdown flow and RC pump seal return flow result in an increasing LST level and a decreasing pressurizer level. | Operator may isolate letdown flow and start an alternate HPI pump after assessing the reason for the stoppage. Letdown flow may then be restored. |

TABLE 4. FLOW BLOCKAGES IN THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure/Location | Effect | Remedial Actions |
|---|---|---|
| 4. Flow Blockage in Seal Return Subsystem | RC pumps' seal return flow alarms alert operator to the situation. Leakage past the RC pumps' seals will be released to the containment sump or quench tank through the pumps' vapor vents. | Bypass or remove the blockage. If the blockage isolated the HPI recirculation path, increase letdown (and makeup) flow, if required. Monitor LST level and initiate makeup of demineralized water/boric acid if required. |
| 5. Flow Blockage in Makeup Subsystem | Operator alerted to the situation by decreasing pressurizer level and increasing LST level. Continued operation would slowly drain the pressurizer possibly resulting in a reactor trip. With the pressurizer at an initially low level, the pressurizer may be drained during the subsequent transient. | Remove or bypass the flow blockage using one or more of the four HPI lines to the RCS to restore pressurizer level. If required, reduce letdown flow or boric acid/demineralized water flows to prevent filling the LST. |

**TABLE 4. FLOW BLOCKAGES IN THE MAKEUP AND PURIFICATION SYSTEM** (Continued)

| Failure/Location | Effect | Remedial Actions |
|---|---|---|
| 6. Flow Blockage in RC Pumps Seal Injection Subsystem | Seal injection flow to one or more RC pumps will cease. Operator alerted to the situation by seal injection low flow alarms. Reactor coolant will pass through the labyrinth seal (thermal barrier) where it will be cooled by the CC water supplied to the pump. The lower temperature reactor coolant flows through the RC Pumps' seals and back to the LST. | Restore seal injection. Observe RC pump procedures for operation without seal injection. |
| 7. Coolant Processing and Storage Subsystem | | |
| 7.1 Flow Blockage in Letdown Path Through Deborating Demineralizers | Decreasing LST level will result in the automatic transfer of the 3-Way Valve to the LST. However, until letdown flow path is restored, the letdown piping will be pressurized resulting in the letdown relief valve lifting and diverting letdown flow to the waste holdup tank. | Clear or bypass flow blockage and restore deborating demineralizer operation. |

**TABLE 4. FLOW BLOCKAGES IN THE MAKEUP AND PURIFICATION SYSTEM** (Continued)

| Failure/Location | Effect | Remedial Actions |
|---|---|---|
| 7.2 Flow Blockage in Letdown Path From 3-Way Valve to Bleed Holdup Tank | Letdown line pressure will increase resulting in the letdown relief valve opening and diverting letdown flow to the waste holdup tank. | Operator manually can transfer 3-Way Valve to the LST or close the letdown containment isolation valve. |
| 7.3 Flow Blockage in Makeup Path to LST | Decreasing LST level will result in the automatic transfer of the 3-Way Valve to the LST. | Clear or bypass flow blockage and restore letdown flowpath to Bleed Holdup tanks. |

## TABLE 5. FLOW INCREASES IN THE MAKEUP AND PURIFICATION SYSTEM

| Failure/Location | Effect | Remedial Actions |
|---|---|---|
| 1. Letdown Subsystem | | |
| 1.1 Flow Increase in Letdown Path to 3-Way Valve-Normal Letdown-Makeup Operation or Deborating Demineralizer Operation | Makeup valve to RCS opens in response to decreasing pressurizer level. LST level may increase. Single LD cooler operation could result in increased letdown fluid temperatures. If sufficiently high, letdown will be automatically isolated (see Table 4, Item 1.1). | Attempt to reduce flowrate or manually isolate. |
| 1.2 Flow Increase in Letdown Path to 3-Way Valve-Letdown to Bleed Holdup Tank | Makeup valve to RCS opens in response to decreasing pressurizer level. LST level decreases. 3-way valve will automatically transfer letdown to LST if LST level is sufficiently low. Single LD cooler operation could result in increased letdown fluid temperatures. If sufficiently high, letdown will be automatically isolated. | Attempt to reduce letdown flowrate. If required, transfer 3-way valve position to LST. |

TABLE 5. FLOW INCREASES IN THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure/Location | Effect | Remedial Actions |
|---|---|---|
| 2. 3-Way Valve | | |
| 2.1 3-Way Valve Switches from Letdown to LST to Chemical Processing Subsystem | Flow to LST stops while makeup to RCS continues at previous flowrates. Low LST level is alarmed and the level signal may automatically transfer valve to original position. Unless an alternate source of makeup water to LST is provided, the LST will be drained possibly resulting in damage to the operating HPI pumps. | Operator manually can transfer the 3-Way Valve to direct flow to the LST, open the by-pass line from the letdown line to the makeup filters or provide makeup to the LST from the Chemical Processing Subsystem. If LST level cannot be maintained, the operator must throttle makeup flow to the RCS or trip the HPI pumps. |
| 2.2 3-Way Valve Switches from Letdown to Chemical Processing Subsystem to LST | LST level will increase and be alarmed on high level. | Return 3-Way Valve to original position or isolate makeup flow from Chemical Processing Subsystem to LST. |
| 3. HPI Pump Subsystem | | |
| 3.1 Flow Increase in Flowpath to LST from Chemical Processing Subsystem | LST level increases. Excessive addition of demineralized water will result in control rod insertion and automatic termination of demineralized water flow to LST. | Reduce or isolate flow from boric acid or bleed holdup tanks. Transfer letdown flow to LST if required. |
| 3.2 Flow Increase in Flowpath to HPI Pumps from BWST | LST level will increase. | Isolate BWST from HPI pump subsystem. |

**TABLE 5. FLOW INCREASES IN THE MAKEUP AND PURIFICATION SYSTEM** (Continued)

| | Failure/Location | Effect | Remedial Actions |
|---|---|---|---|
| 4. | Flow Increase in Seal Return Subsystem | Makeup flow to RCS automatically increased in response to decreased pressurizer level. | Observe operating procedures for increased seal return flow which may be indicative of a damaged RC pump seal. |
| 5. | Flow Increase in Makeup Subsystem | Operator alerted to the situation by increased pressurizer level and and decreased LST level. Unless the LST level decrease can be terminated by throttling makeup flow, increasing letdown flow or providing an alternate source of borated water to the HPI pump(s), the LST will be drained possibly resulting in HPI pump failure. | Attempt to throttle makeup flowrate. Increase letdown flowrate if required to prevent filling pressurizer or draining LST. |
| 6. | Flow Increase in RC Pump Seal Injection Subsystem | Increasing pressurizer level will result in automatic throttling of makeup flow to RCS to compensate for increased seal injection. | Attempt to throttle RC pump seal injection flow. |

TABLE 5. FLOW INCREASES IN THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure/Location | Effect | Remedial Actions |
|---|---|---|
| 7.0 Coolant Processing and Storage Subsystem | | |
| 7.1 Flow Increase in Flowpath to Bleed Holdup Tanks from Letdown Subsystem | Makeup valve to RCS opens in response to decreasing pressurizer level. LST level decreases. 3-way valve will automatically transfer letdown to LST if LST level is sufficiently low. Single LD cooler operation could result in increased letdown fluid temperatures. If sufficiently high, letdown will be automatically isolated. | Attempt to reduce letdown flowrate. If required, transfer 3-way valve position to LST. |
| 7.2 Flow Increase in Flowpath to HPI Subsystem from Chemical Processing Subsystem | LST level increases. Excessive addition of demineralized water will result in control rod insertion and automatic termination of demineralized water flow to LST. | Reduce or isolate flow from boric acid or bleed holdup tanks. Transfer letdown flow to LST if required. |

## TABLE 6. LOSS OF CHEMICAL ADDITION, COOLANT PURIFICATION CAPABILITY IN THE MAKEUP AND PURIFICATION SYSTEM

| Failure | Effect | Remedial Actions |
|---|---|---|
| 1. Boric Acid Makeup From Concentrated Boric Acid Tanks to LST Fails | None during normal operation. | If required for plant shutdown, concentrated boric acid may be added to the LST from the boric acid mix tank or lower concentration boric acid may be injected from the BWST to the RCS. |
| 2. Demineralized Water Makeup to LST Fails | Failure to reduce the boric acid concentration of the reactor coolant will result in a slow decrease in core power due to decreasing core reactivity. | Restore demineralized water makeup to LST. |
| 3. Lithium Hydroxide Addition to LST Fails | Slow decrease in pH of reactor coolant. If pH exceeds specifications, plant shutdown will be required. | Monitor pH of reactor coolant. Restore lithium hydroxide addition to LST or shutdown plant if required. |
| 4. Hydrazine Addition to LST Fails | None during plant power operation. Hydrazine is required in the RCS only during plant shutdown for oxygen concentration reduction (Note: hydrazine is used during power operation for feedwater oxygen control. If feedwater oxygen concentration exceeds specifications, plant shutdown is required.). | Restore hydrazine addition capability. |

**TABLE 6. LOSS OF CHEMICAL ADDITION, COOLANT PURIFICATION CAPABILITY IN THE MAKEUP AND PURIFICATION SYSTEM** (Continued)

| | Failure | Effect | Remedial Actions |
|---|---|---|---|
| 5. | Hydrogen Supply to LST Isolated | Slow reduction in hydrogen concentration and increase in oxygen concentration in reactor coolant. If oxygen concentration exceeds specification, plant shutdown is required. | Monitor oxygen concentration in reactor coolant. Restore hydrogen addition to LST or shutdown plant if required. |
| 6. | Purification Demineralizers Bypassed or Depleted | Slow increase in reactor coolant impurities. If dissolved impurity concentration of reactor coolant exceeds specifications, plant shutdown may be required. | Monitor reactor coolant chemistry. Restore purification demineralizer operation or shutdown plant if required. |
| 7. | Seal Injection Filters Bypassed | Filter unavailable for removal of particulates prior to injection through RC pump seals. Unless bypassed, purification demineralizers and/or letdown filters can remove coolant particulates. | Restore seal injection filters to operation. |

## TABLE 7. EFFECTS OF CONTROL INSTRUMENTATION MALFUNCTIONS ON THE MAKEUP AND PURIFICATION SYSTEM

| Failure | Effect | Remedial Actions |
|---|---|---|
| 1. Spurious ES Signals (1 or 2 Output Channels) | Letdown and seal return lines isolated, 2 or 3 HPI pump injection mode initiated. RC pumps continue to operate with seal leakage flow directed through the pumps' vapor vents. | After confirming no emergency condition exists, the operator may bypass the ES system, restore letdown and seal return flow, and return to pressurizer level controlled, single HPI pump makeup operation. |
| 2. Spurious NNI Automatic Control Signals (Circuit Failures) | | |
| 2.1 High Letdown Fluid Temperature Circuit Isolates Letdown Valve HP-5 | Letdown flow isolated. Makeup flow will be throttled automatically based on increasing pressurizer level. Pressurizer level will continue to rise slowly and the LST level decrease due to the net 20 gpm seal injection input (See Table 4, Item 1.1, 1.2). | Operator alerted to the situation by high letdown temperature alarm. The operator can manually restore letdown flow and repair temperature circuit. |

**TABLE 7. EFFECTS OF CONTROL INSTRUMENTATION MALFUNCTIONS ON THE MAKEUP AND PURIFICATION SYSTEM** (Continued)

| Failure | | Effect | Remedial Actions |
|---|---|---|---|
| 2.2 | Low LST Level, "CRD Dilution Permit" or the "Batch Complete" Circuits Transfers 3-Way Valve From the Chemical Processing Subsystem to the LST | MU&P system operation transfers from "Bleed and Feed" to normal letdown-makeup operation.* | The operator is alerted to the situation by a spurious low level alarm if the LST level transmitter failed low. |
| 2.3 | Pressurizer Level Control Circuit Opens Makeup Control Valve (HP-120) | Flow increase - Makeup subsystem. See Table 5, Item 5. | See Table 5, Item 5. |
| 2.4 | Pressurizer Level Control Closes Makeup Control Valve (HP-120) | Flow blockage - Makeup subsystem. See Table 4, Item 5. | See Table 4, Item 5. |
| 2.5 | RC Seal Injection Flow Control Circuit Closes Control Valve HP-31 | Seal injection flow ceases and low flow is alarmed. RC pump continue to operate with reactor coolant cooled in the labyrinth seal, passing through the shaft seals and returning through the seal return subsystem. | Operator slowly restores seal injection flow by manually opening HP-31 or its bypass valve HP-140. |

*Assumes the signal from the 3-Way Valve Operator (HP-14) to the Chemical Processing Isolation Valve (HP-16) closes the isolation valve. If isolation valve remains open, see Table 5, Item 7.2.

TABLE 7. EFFECTS OF CONTROL INSTRUMENTATION MALFUNCTIONS ON THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure | Effect | Remedial Actions |
|---|---|---|
| 2.6 RC Seal Injection Flow Control Circuit Opens Control Valve HP-31 | Small increase in flowrate expected. The long term effects on the RC pumps and whether the increased flow is sufficient to trip the high seal $\Delta$P alarms is not known. | Operator manually can throttle HP-31. |
| 3. Spurious NNI Automatic Control Signals (NNI Power Failures) | | |
| 3.1 Failure of Panelboard KI Power to ICS/NNI | The makeup control (HP-120) and letdown control valves' controls transfer to manual with their power supply automatically transferring to Panelboard KU. The valves will remain in position. The seal injection control valve (HP-31) automatic control will continue to function with its power supply automatically transferring to Panelboard KU. A spurious low LST signal will result in 3-way valve (HP-14) transferring letdown flow to the LST. Numerous other plant controls, alarms and indicators deenergized. | Emergency procedure for loss of KI bus, EP/O/A/1800/3, must be followed. These actions should include taking manual control valve (HP-120) and the turbine bypass valves and verifying other automatic actions. |

TABLE 7. EFFECTS OF CONTROL INSTRUMENTATION MALFUNCTIONS ON THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure | Effect | Remedial Actions |
|---|---|---|
| 3.2 Failure of Hand Power to ICS/NNI (Branch HX) | E/P transducers for the letdown (HP-7), makeup (HP-120) and RC pump seal (HP-31) flow control valves freezing in position. Power to these transducers may be transferred to Panelboard KU (whether this transfer is automatic, as with loss of KI, or manual is unknown). The 3-Way Valve (HP-14) will be switched to transfer letdown flow to the LST. Numerous other plant controls, alarms are deenergized. | Operator must follow applicable procedures for loss of Hand Power. These actions should includue transferring (or verifying the transfer) the power for the makeup, seal injection and turbine bypass valves to KU, tripping the main feedwater pump and verifying the automatic initiation and control of emergency feedwater. |
| 3.3 Failure of Auto Power to ICS/NNI (Branch H) | Automatic transfer of the makeup flow control to manual will occur. The valve (HP-120) will remain in position. Numerous other plant controls, alarms and indicators are deenergized. | Operator must follow applicable procedures for loss of autopower. These actions should include taking manual control of makeup flow, tripping the main feedwater pumps and verifying the automatic initiation and control of emergency feedwater and turbine bypass valves. |

TABLE 7. EFFECTS OF CONTROL INSTRUMENTATION MALFUNCTIONS ON THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure | Effect | Remedial Actions |
|---|---|---|
| 3.4 Failure of Hand Power Branch H1X to ICS/NNI | Automatic control of makeup valve HP-120 operable. If manual control of valve at ICS Hand Station selected, valve will open or close to midposition. Numerous other (non-letdown/makeup) plant controls, alarms and indicators are deenergized. | Operator must follow applicable procedures for loss of H1X power. These actions should include transferring turbine bypass valve controls to KU and manually controlling them, tripping the main feedwater pumps and verifying the automatic initiation and control of emergency feedwater. |
| 3.5 Failure of Hand Power Branch H2X to ICS/NNI | E/P transducers for the letdown (HP-7), Makeup (HP-120) and RC pump seal (HP-31) flow control valves are deenergized resulting in those valves freezing in position. Power to these transducers to Panelboard KU (whether this transfer is automatic as with loss of KI, or manual is unknown). The 3-Way Valve (HP-14) will be switched to transfer letdown flow to the LST. Other makeup/letdown alarms and indicators will also be deenergized. | Operator must follow applicable procedures for loss of H2X Power. These actions should include transferring (or verifying the transfer) the power for the makeup and seal injection to KU. Operator should be cautioned to verify operability of indicators he uses. |

TABLE 7. EFFECTS OF CONTROL INSTRUMENTATION MALFUNCTIONS ON THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure | Effect | Remedial Actions |
|---|---|---|
| 3.6 Failure of Auto Power Branch H1 to ICS/NNI | Automatic transfer of the makeup flow control to manual will occur. The valve (HP-120) will remain in position. Numerous other plant controls, alarms and indicators are deenergized. | Operator must follow applicable procedures for loss of H1. These actions should include taking manual control of makeup flow, tripping the main feedwater pumps and verifying the automatic initiation and control of emergency feedwater and turbine bypass valves. |
| 3.7 Failure of Auto Power Branch H2 to ICS/NNI | Numerous RC pump and LST alarms spuriously annunciate and indicators deenergized. Although no automatic controls are affected, if the operator trips the RC pumps, they cannot be restarted due to the spurious low seal injection flow interlock. | Operator should be cautioned to verify operability of alarms and indicators used for plant control/recovery. |

TABLE 7. EFFECTS OF CONTROL INSTRUMENTATION MALFUNCTIONS ON THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure | Effect | Remedial Actions |
| --- | --- | --- |
| 3.8 Power for Selected Pressurizer Level Transmitter Fails (Branch HEX, HEY or KU) | Indicated high pressurizer level will result in makeup control valve HP-120 closing. Pressurizer level will decrease and LST level will increase. In addition, if HEX or HEY failed power is selected for the SG startup level transmitter, low indicated SG startup level will result in overfilling the affected SG resulting in an automatic trip of the main feedwater pumps. If KU failed power is selected, the power computer will be lost. | Operator is alerted to the situation by high indicated and alarmed LST level. The operator should be cautioned to verify the operability of pressurizer level indications and alarms. Once the power failure is identified the operator may select one of the two operable pressurizer level transmitters for indication and control. |

TABLE 8. EFFECTS OF COOLING WATER FAILURES ON THE MAKEUP AND PURIFICATION SYSTEM

| Failure | Effect | Remedial Actions |
|---|---|---|
| 1. Component Cooling (CC) System Failures | | |
| 1.1 Loss of CC Water to Operating LD Cooler | Increase in letdown fluid temperature resulting in automatic letdown isolation. See Table 4, Letdown Subsystem. | Restore CC flow to operating or standby LD cooler and place in operation. See also Table 4, Letdown Subsystem. |
| 1.2 Loss of CC (Unit 1) | In addition to letdown flow isolation, cooling water will be lost to RC Pump labyrinth seals and CRDM cooling jackets. RC Pump can continue to operate without CC, however, only if the seal injection flowrate can be maintained. Loss of CRDM cooling may result in reactor trip. | Restore a flowpath from the BWST or the Chemical Processing subsystem to the HPI pumps. Restore CC flow to LD cooler and other required components. |
| 2. Low Pressure Service Water (LPSW) System Failures | | |
| 2.1 Loss of LPSW to Operating HPI Pump Motor Bearings | Motor bearing will overheat eventually requiring HPI pump trip. Long term operation would damage bearings. | Restore LPSW to operating pump or trip operating HPI pump and start backup HPI pump. |

TABLE 8. EFFECTS OF COOLING WATER FAILURES ON THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure | Effect | Remedial Actions |
|---|---|---|
| 2.2 Loss of LPSW | In addition to loss of motor bearing cooling for the three HPI pumps, cooling water to Unit 1 and 2 CC coolers (see item 1), the RC pump motor bearing coolers, emergency feedwater pump and turbine coolers, LPI coolers, RB cooling units, etc., will be lost. | Depending on the mode of failure, the backup LPSW pump may be started, the HPSW system may be used or the cause of failure (e.g., blocked LPSW suction strainers, loss of AC power) may be removed. |
| 3. Recirculating Cooling Water (RCW) System Failures | | |
| 3.1 Loss of RCW to Operating Seal Return Cooler | Gradual increase in seal return temperature due to heat addition from RC pump seals and HPI pump. It is not known whether or how quickly the temperature could rise to the point where the HPI pump NPSH is inadequate. | Restore RCW to operating cooler or place standby cooler in operation. If seal return coolers' cooling water still unavailable, increased letdown and isolate HPI pump recirculation loop if required. |

TABLE 8. EFFECTS OF COOLING WATER FAILURES ON THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure | Effect | Remedial Actions |
| --- | --- | --- |
| 3.2 Loss of RCW | In addition to the above, cooling water to the main feedwater and condensate pumps (drivers) resulting in a loss of main feedwater, loss of spent fuel pool cooling, loss of cooling to air compressors plus loss of cooling to other miscellaneous functions. Reactor and turbine trip expected. Loss of air compressor cooling water result in loss of air compressors A, B, and C (existance of backup compressors unknown), and assumed isolation of letdown, seal return and makeup flows (see Table 6). Loss of main feedwater will result in automatic start of emergency feedwater with pneumatic control valves automatically supplied from a backup $N_2$ tank. | Follow emergency procedures for loss of instrument air. Restore cooling water and air supply to pneumatic valves and restore letdown makeup operation. If air supply cannot be restored, manually restore makeup to RCS from BWST or makeup tank, provide makeup to LST from letdown or Bleed Holdup/Boric Acid tanks, if required, restore letdown to LST or Bleed Holdup tank, and restore seal return to the LST. |

TABLE 9. EFFECTS OF INSTRUMENT AIR FAILURES ON THE MAKEUP AND PURIFICATION SYSTEM

| Failure | Effect | Remedial Actions |
|---|---|---|
| Loss of Instrument Air | Pneumatic valves in the letdown line, seal return line, RCS makeup line and the makeup line from the coolant storage subsystem close; the seal injection control valve opens and pneumatic valves in other systems move to their failure position. Seal injection flow is passed through the RC pump labyrinth seals to the RCS and through the #1 and #2 shaft seals and the RC pumps' vapor vents to the containment. Main feedwater will trip on high SG level (assuming reactor trip following loss of instrument air pressure) and emergency feedwater will be initiated and controlled using backup $N_2$ tanks for pneumatic control valves. | Operator must follow emergency procedure for loss of instrument air. Manually restore instrument air and/or manually restore letdown, seal return and makeup flows. |

TABLE 10. EFFECTS OF AC ELECTRIC POWER FAILURES ON THE MAKEUP AND PURIFICATION SYSTEM

| Failure | Effect | Remedial Actions |
|---|---|---|
| 1. 4160 VAC Bus 1TC Deenergized | o Operating HPI pump P1A stops, terminating seal injection and makeup to RCS.<br><br>o LPSW pump A stops, reducing cooling water flow to Unit 1 and 2 serviced components by 50% including the component coolers. A gradual increase in letdown temperature is expected which may result in automatic isolation of letdown.<br><br>o RCW pump D, if in operation, stops, reducing the cooling water flow to Unit 1, 2 and 3 serviced components by 33%. Overall effects of the RCW reduction are not known; the specific impact on the seal return temperature is expected to be minor. | Start standby HPI pump P1B, standby LPSW pump B and the standby RCW pump. If required open the letdown isolation valve which may close on high letdown temperature. Restore bus 1TC to service. |

TABLE 10. EFFECTS OF AC ELECTRIC POWER FAILURES ON THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure | Effect | Remedial Actions |
|---|---|---|
| 1. 4160 VAC Bus 1TC Deenergized (cont'd) | o One or both HPI discharge valves (HP-26, 27) and one or both BWST isolation valves to the HPI pumps (HP-24, 25) may be deenergized and not able to open if powered via bus TC.<br><br>o The discharge valve from both letdown coolers A and B (HP-3, 4) may be deenergized and not able to close if powered via bus TC.<br><br>o Air compressor motor B is deenergized and stops if energized via buses XF, X1 and TC. The air supply to serviced components is assumed to be provided by compressors B and C. | Verify that either 208 VAC Bus XS1 or XS2 is energized via 1TD. Manually transfer one of these buses if required. |
| 2. 4160 VAC Bus 1TD Deenergized | o Standby HPI pump P1B and standby LPSW pump B (if connected to bus 1TD) deenergized and unavailable if required. | Restore bus 1TD to service. |

TABLE 10. EFFECTS OF AC ELECTRIC POWER FAILURES ON THE MAKEUP AND PURIFICATION SYSTEM
(Continued)

| Failure | Effect | Remedial Actions |
| --- | --- | --- |
| 2. 4160 VAC Bus 1TD Deenergized (cont'd) | o One or both HPI discharge valves (HP-26, 27) and one or both BWST isolation valves to the HPI pumps (HP-24, 25) may be deenergized and not able to open if powered via bus TD. | Verify that either 208 VAC Bus XS1 or XS2 is energized via 1TC. Transfer one of these buses if required. |
| | o The discharge valve from both letdown coolers A and B (HP-3, 4) may be deenergized and not able to close if powered via bus TD. | |
| | o Air compressor motor A is deenergized and stops if energized via buses XD, X2 and TD. The air supply to serviced components is assumed to be provided by compressors A and C. | |
| 3. 4160 VAC Bus 1TE Deenergized | o Standby HPI pump P1C deenergized and unavailable if required. If RCW pump A is in service, it will stop, reducing cooling water flow to Unit 1, 2 and 3 serviced components by 33%. | Start standby RCW pump if RCW pump A was in service. Restore bus 1TE to service. |

TABLE 10. EFFECTS OF AC ELECTRIC POWER FAILURES ON THE MAKEUP AND PURIFICATION SYSTEM
(Continued)

| Failure | Effect | Remedial Actions |
|---|---|---|
| 3. 4160 VAC Bus 1TE Deenergized (cont'd) | o Compressor Motors A and/ or B may be deenergized and stop if powered via backup buses X3 and TE. The ability of compressor C, assumed to be powered from a Unit 2 or 3 bus, to maintain air pressure is unknown (see Table 9, Failure of Instrument Air). | Transfer compressor motors to be energized via 4160 VAC buses 1TC and 1TD. |
| 4. 600 VAC, 208 VAC Buses XL Deenergized | The distillate pump, low pressure boric acid pump A, boric acid mix tank agitator and heater deenergized. Effect of this failure on plant power operation expected to be small. | Restore power to the XL buses. Concentrated boric acid requirements can be supplied via boric acid pump B. |
| 5. 600 VAC, 208 VAC Buses XN Deenergized | The low pressure boric acid pump B and the lithium hydroxide pump and tank agitator deenergized. Effect of this failure on plant power operation expected to be small. | Restore power to the XN buses. Concentrated boric acid requirements can be supplied via boric acid pump A. Lithium hydroxide can be added using the hydrazine pump. |

TABLE 10. EFFECTS OF AC ELECTRIC POWER FAILURES ON THE MAKEUP AND PURIFICATION SYSTEM (Continued)

| Failure | Effect | Remedial Actions |
|---|---|---|
| 6. 600 VAC Buses XS1, XS2, X8 or X9 Deenergized | o One or both HPI discharge valves (HP-26, 27) and one or both BWST isolation valves to the HPI pumps (HP-24, 25) may be deenergized and not able to open if energized via XS1, XS2, X8 or X9.<br>o The discharge valve from both letdown coolers A and B (HP-3, 4) may be deenergized and not able to close if energized via XS1, XS2, X8 or X9. | Verify that either 208 VAC bus XS1 or XS2 is energized. Manually transfer one of these buses to an energized 600 VAC bus if required. Restore power to deenergized bus. |
| 7. 208 VAC Bus XS1 | BWST isolation valve to the HPI pumps (HP-24) and the HPI pumps A and B HPI discharge valve (HP-26) deenergized and not able to open if required. | Restore Bus XS1 to service. |
| 8. 208 VAC Bus XS2 | BWST isolation valve to the HPI pumps (HP-25) and the HPI pump C HPI discharge valve (HP-27) deenergized and not able to open if required. | Restore Bus XS2 to service. |

TABLE 10. EFFECTS OF AC ELECTRIC POWER FAILURES ON THE MAKEUP AND PURIFICATION SYSTEM
(Continued)

| Failure | Effect | Remedial Actions |
|---|---|---|
| 8. 208 VAC Bus XS2 (cont'd) | o The discharge valve from both letdown coolers A and B (HP-3, 4) deenergized and not able to close if required. | |

**TABLE 11. FMEA SUMMARY FOR SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM**

| Effects at Subsystem Interface | Precipitating Faults/Failure Modes |
|---|---|
| Chemical Addition: | |
| 1. No $N_2H_4$ Available to Makeup Filters | a. $N_2$ blanket system fails isolation |
| | b. Manual control, isolation valves fail closed |
| | c. Check valves fail to prevent backflow |
| | d. Hydrazine drum empties and not replaced. Leaks from the tank will eventually lead to the same effect |
| 2. Alternate Flow Path Through Lithium Hydroxide Pump Required | a. Electric power supply to hydrazine pump fails |
| | b. Hydrazine pump fails |
| | c. Manual isolation valves fail closed |
| 3. No LiOH Available to Makeup Filters | a. Demineralized water supply to mix tank fails |
| | b. Lithium hydroxide tank empties and not refilled. Leaks from the tank will eventually lead to same effect |
| | c. Manual isolation valves fail closed |
| 4. Decreased LiOH Available to Makeup Filters | a. Sampling, waste lines downstream of tank fail open |
| 5. Incorrect LiOH Concentration Available to Makeup Filters | a. Manual isolation valve DW-121 fails open and dilutes LiOH in tank; fails closed and results in concentrated LiOH in tank. |
| 6. Alternate Flow Path Through Hydrazine Pump Required | a. Electric power supply to lithium hydroxide pump fails |
| | b. Lithium hydroxide pump fails |
| | c. Manual isolation valves fail closed |

**TABLE 11. FMEA SUMMARY FOR SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM**
(Continued)

| Effects at Subsystem Interface | Precipitating Faults/Failure Modes |
|---|---|
| 7. No Caustic Available to LPI Pumps, RC Bleed Evaporator Feed Tank, Deborating Demineralizers | a. Demineralized water supply to mix tank fails |
| | b. Manual isolation valves fail closed |
| | c. Causic mix tank empties and not refilled. Leaks from the tank will eventually lead to same effect |
| | d. Electric power supply to caustic pump fails |
| | e. Caustic pump fails |
| 8. Decreased Caustic Available to LPI Pumps, RC Bleed Evaporator Feed Tank, Deborating Demineralizers | a. Sampling, waste lines downstream of tank fail open |
| 9. Incorrect Caustic Concentration Available to LPI Pumps, RC Bleed Evaporator Feed Tank, Deborating Demineralizers | a. Manual isolation valve DW-120 fails open and dilutes caustic in tank; fails closed and results in concentrated caustic in tank |
| Boric Acid Addition: | |
| 1. No Boric Acid Available to Makeup Filters, BWST Filters, BWST | a. Flows from boron recovery and boric acid mix tank fail and concentrated boric acid storage tank empties and not refilled. Leaks from tank will eventually lead to same effect. |
| | b. Manual isolation valves and manual control valve CS-62 fail closed |
| | c. Electric power supply to concentrated boric acid transfer pump fails |
| | d. Concentrated boric acid transfer pump fails |

TABLE 11. FMEA SUMMARY FOR SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM (Continued)

| Effects at Subsystem Interface | Precipitating Faults/Failure Modes |
|---|---|
| 1. No Boric Acid Available to Makeup Filters, BWST Filters, BWST (cont'd) | e. Electric power supply to trace heating or trace heating fails leading to plugged lines |
| 2. No Boric Acid Flow Available to Core Flood Tank | a. Electric power supply to HP boric acid pump fails |
| | b. HP boric acid pump fails |
| | c. Manual isolation valves fail closed |
| 3. Decreased Boric Acid Flow Available to Makeup Filters, BWST | a. Drain, sample lines downstream of storage tank fail open |
| 4. Boron Recovery or Adequate Concentrated Boric Acid Storage Tank Inventory Required as Boric Acid Source (Internal Subsystem Effect Only) | a. Demineralized water supply to boric acid mix tank fails |
| | b. Manual isolation valves fail closed |
| | c. Manual isolation valve DW-118 fails open and dilutes boric acid in mix tank; fails closed and results in concentrated boric acid in mix tank |
| | d. Electric power supply to mix tank heater or mix tank heater fails leading to plugged lines |
| | e. Mix tank empties and not refilled. Leaks from tank will eventually lead to same effect |
| 5. Incorrect Process Parameters to I&C System and Control Room | a. Electric power supplies to transmitters fail |
| - Boric Acid Mix Tank Level, Temperature | b. Transmitter signal connection leaks |
| - LP Boric Acid Pump Discharge Pressure | c. Transmitters fail |
| - Concentrated Boric Acid Storage Tank Level | |

**TABLE 11. FMEA SUMMARY FOR SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM**
(Continued)

| Effects at Subsystem Interface | Precipitating Faults/Failure Modes |
|---|---|
| RC Bleed Holdup Tanks and Transfer Pumps: | |
| 1. No Demineralized Water to Makeup Filters | a. Manual isolation and control valves fail closed |
| | b. Demineralized water supply to demineralized water holdup tank fails |
| | c. $N_2$ blanket to demineralized water holdup tank fails resulting in tank unavailability |
| | d. Demineralized water holdup tank empties and not refilled. Leaks from tank will eventually lead to same effect |
| | e. Electric power supply to bleed transfer pump fails |
| | f. RC bleed transfer pump fails |
| | g. Check valves fail to prevent backflow |
| | h. Control valves HP-15 or HP-16 fail closed (control signal, instrument air supply, electric power supply, valve failure) |
| | i. Control valves HP-15 or HP-16 fail open allowing backflow from letdown line |
| | j. Electric power supply to trace heating or trace heating fails leading to plugged lines |
| | k. Flow orifices plug |
| 2. Decreased Demineralized Water to Makeup Filters | a. Waste, drain, or sample lines downsteam of holdup tank fail open |
| 3. Increased Demineralized Water to Makeup Filters | a. Control valves HP-15 and HP-16 fail open (control signal fails to close valve or spurious signal to open valve) |

TABLE 11. FMEA SUMMARY FOR SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM (Continued)

| Effects at Subsystem Interface | Precipitating Faults/Failure Modes |
|---|---|
| 4. Alternate Flow Path Through Unit 2 Bleed Holdup Tank Required | a. RC bleed flow from letdown fails |
| | b. Manual isolation and control valves fail closed |
| | c. $N_2$ blanket to bleed holdup tank fails resulting in tank unavailability |
| | d. RC bleed holdup tank empties and not refilled. Leaks from tank will eventually lead to same effect |
| | e. Electric power supply to trace heating or trace heating fails leading to plugged lines |
| | f. Waste, drain, sample lines downstream of holdup tank fail open |
| | g. Electric power supply to bleed transfer pump fails |
| | h. RC bleed transfer pump fails |
| | i. Flow orifice plugs |
| | j. Check valves fail to prevent backflow |
| 5. Incorrect Process Parameters to I&C System and Control Room | a. Electric power supply to transmitters fail |
| - RC Bleed Holdup Tank Level | b. Transmitter connection leaks |
| - RC Bleed Flow | c. Transmitter fails |
| - Demineralized Water Holdup Tank Level | |
| - Demineralized Water Flow | |

TABLE 11. FMEA SUMMARY FOR SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM
(Continued)

| Effects at Subsystem Interface | Precipitating Faults/Failure Modes |
|---|---|
| **Boron Recovery:** | |
| 1. Alternate Flow Path Through Second Evaporator Demineralizer Required (Internal Subsystem Effect Only) | a. Manual isolation valves fail closed<br>b. Demineralizer resin fill fails<br>c. Demineralizer tank or tank vents leak |
| 2. RC Bleed Evaporator Feed Tank Required to be Full at Beginning of Boron Recovery Cycle (Internal Subsystem Effect Only) | a. Electric power supply to trace heating or trace heating fails leading to plugged lines<br>b. RC bleed flow from holdup tank fails<br>c. Evaporator distillate, distillate cooler flows fail<br>d. Manual isolation valves fail |
| 3. No Temperature Control of Distillate Returned to Evaporator Feed Tank, Condensate Test Tank (Demineralized Water) | a. Cooling water supply to distillate cooler fails<br>b. Loss or degraded heat transfer capability in distillate cooler |
| 4. No or Decreased Distillate Flow to Condensate Test Tanks (Demineralized Water) | a. Cooler tubes blocked or tube rupture leading to decreased flow or coolant release to distillate<br>b. Distillate cooler leaks<br>c. Evaporator distillate flow fails; see effects 5 and 6 |
| 5. Boron Recovery Stops; Concentrated Boric Acid Storage Tanks Required to be Full (Internal Subsystem Effect Only) | a. Evaporator concentrate flow returned to feed tank or evaporator<br>b. Evaporator feed tank empties and not refilled. Leaks from tank, including vent and relief valves failed open, will eventually lead to same effect<br>c. Manual isolation valves fail closed |

TABLE 11. FMEA SUMMARY FOR SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM (Continued)

| Effects at Subsystem Interface | Precipitating Faults/Failure Modes |
|---|---|
| 5. Boron Recovery Stops; Concentrated Boric Acid Storage Tanks Required to be Full (Internal Subsystem Effect Only) (cont'd) | d. Electric power supply to evaporator feed pump or concentrate pump fails |
| | e. Evaporator feed pump or concentrate pump fails |
| | f. Control valves CT-24 or CT-40 fail to operate (instrument air, control signal, valve failure) |
| | g. Waste, drain, sample lines downstream of feed tank or evaporator fail open |
| | h. Steam supply to evaporator fails |
| | i. Loss of heat transfer capability in evaporator |
| | j. Evaporator empties and not refilled. Leaks from evaporator will eventually lead to same effect |
| | k. Electric power supply to trace heating, or evaporator heating fails leading to plugged lines |
| 6. Boron Recovery Rate Decreases; Concentrated Boric Acid Storage Tank Required to be Full (Internal Subsystem Effect Only) | a. Electric power supply to trace heating, trace heating, or evaporator heating fails leading to plugged lines |
| | b. Evaporator tubes blocked or tube rupture leading to decreased flow or steam release to vapor space |
| | c. Concentrate cooler leaks |
| 7. No Temperature Control of Concentrate Returned to Boric Acid Storage Tanks (Internal Subsystem Effect Only) | a. Cooling water supply to concentrate cooler fails |
| | b. Loss or degraded heat transfer capability in concentrate cooler |
| | c. Temperature transmitter control signal to cooling water control valve fails |

TABLE 11. FMEA SUMMARY FOR SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM
(Continued)

| Effects at Subsystem Interface | Precipitating Faults/Failure Modes |
|---|---|
| <u>Deborating Demineralizer</u>: | |
| 1. No RC Return to Makeup Filters | a. RC bleed flow from 3-way valve fails |
| | b. Manual isolation valves fail closed |
| | c. Control valve HP-16 fails closed (instrument air, control signal, valve failure) |
| | d. Check valve fails to prevent backflow |
| 2. Deboration Stops; Alternate Flow Path Through Second Demineralizer Required | a. Resin in demineralizer saturates or was not regenerated as required due to failure to provide caustic. |
| 3. No RC Return to Makeup Filters; Alternate Flow Path Through Second Demineralizer Required | a. Manual isolation, control valves fail closed |
| | b. Tank empties. Leaks from tank; including vent and relief valves failed open, will eventually lead to same effect. |
| | c. Electric power supply to trace heating, trace heating fails leading to plugged lines |
| 4. Decreased Return Flow to Makeup Filters; Alternate Flow Path Through Second Demineralizer Required | a. Waste, drain, sample lines fail open |
| | b. Demineralizer tank leaks |

## 5.0 REFERENCES


1. Oconee Nuclear Station, Final Safety Analysis Report, 1982.

2. Oconee Nuclear Station, Final Safety Analysis Report, Revision 18.

3. Plant Electrical Distribution System Drawings 0701, 0702, 0703, 0704, and 0705.

4. Oconee 1 ICS - Instruction Book, Bailey Meter Co., March 1977.

5. Letter from R. L. Gill (Duke Power) to R. C. Kryter (ORNL), October 19, 1982.

**APPENDIX A**

FAILURE MODES AND EFFECTS ANALYSIS
SUBSYSTEM 1.0: LETDOWN SUBSYSTEM

Reference Drawings: FSAR Figure 9.3-2
FSAR Figure 9-2A

## SUBSYSTEM 1.0: LETDOWN COOLERS TO 3-WAY VALVE HP-14 (HP-V10)

| Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|
| 1.1 Letdown Coolers: | | | | | |
| 1.1.1 Miscellaneous Normally Closed, Manual Valves Such as HP-329 (Including Double Isolation Valves Such as HP-32 and HP-359) | 1. Opened or fails open due to internal fault | Vent or Drain | Reduced letdown flow rate; RC leak | Some letdown flow is diverted to sumps; hence, reduced letdown flow to 3-way valve HP-14 (HP-V10) and RC leak | Though detection is difficult, close or repair when found |
| 1.1.2 Valve HP-1 (NO) (HP-V1A) | 1. Fails closed due to internal fault | -- | Letdown flow to Ltdn Cooler HP-C1A obstructed | Letdown flow to 3-way valve HP-14 (HP-V10) is terminated | Open HP-V1B and use Ltdn Cooler HP-C1B |
| | 2. Spuriously closed | Control Signal | Letdown flow to Ltdn Cooler HP-C1A obstructed | Letdown flow to 3-way valve HP-14 (HP-V10) is terminated | Open HP-V1A |
| | 3. Fails to close when required due to internal fault | -- | Unobstructed letdown flow to Ltdn Cooler HP-C1A. Ltdn Cooler HP-C1A cannot be isolated if valve HP-1 (HP-V1A) is open | If HP-C1A has experienced a loss of cooling water, then letdown fluid temperature will increase; letdown flow to 3-way valve HP-14 (HP-V10) will continue until series isolation valve HP-3 (HP-V2A) or HP-5 (HP-V3) is closed to protect HP-X1. If HP-C1A has experienced a tube rupture, then an RC leak to CCW system will occur | Close series isolation valve<br>None |
| | 4. Fails to close when required due to unavailability of electric power | Electric Power | Unobstructed letdown flow to Ltdn Cooler HP-C1A. Ltdn Cooler HP-C1A cannot be isolated if valve HP-1 (HP-V1A) is open | If HP-C1A has experienced a loss of cooling water, then letdown fluid temperature will increase; letdown flow to 3-way valve HP-14 (HP-V10) will continue until series isolation valve HP-3 (HP-V2A) (powered from separate bus or manually closed) or HP-5 (HP-V3) is closed to protect HP-X1. If HP-C1A has experienced a tube rupture, then an RC leak to CCW system will occur | Close series isolation valve<br>Restore electric power |

Reference Drawings: FSAR Figure 9.3-2
FSAR Figure 9-2A

# SUBSYSTEM 1.0: LETDOWN SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 1.1.3 | Valve HP-2 (NC) (HP-V1B) | 1. Fails open due to internal fault | -- | Unobstructed letdown flow to Ltdn Cooler HP-C1B | Unless component cooling water provided to Ltdn Cooler HP-C1B, letdown temperature will increase possibly resulting in letdown isolation, i.e., termination of letdown flow to 3-way valve HP-14 (HP-V10) | Close HP-4 (HP-V2B) |
| | | 2. Spuriously opened | Control Signal | Unobstructed letdown flow to Ltdn Cooler HP-C1B | Unless component cooling water provided to Ltdn Cooler HP-C1B, letdown temperature will increase possibly resulting in letdown isolation, i.e., termination of letdown flow to 3-way valve HP-14 (HP-V10) | Close HP-2 (HP-V1B), close HP-4 (HP-V2B) |
| | | 3. Fails to open when required due to internal fault | -- | Use of Ltdn Cooler HP-C1B prevented | May result in increased letdown temperature or continued letdown isolation | None (isolate and repair) |
| | | 4. Fails to open when required due to unavailability of electric power | Electric Power | Use of Ltdn Cooler HP-C1B prevented | May result in increased letdown temperature or continued letdown isolation | Restore electric power |
| 1.1.4 | Operating Letdown Cooler HP-C1A (or HP-C1B) | 1. Loss of cooling water flow | Component Cooling Water System | Increased letdown temperature. High temperature sensed on TT-3 resulting in automatic closure of isolation valve HP-5 (HP-V3) and indicated in control room | Increased letdown fluid temperature possibly resulting in automatic letdown flow isolation, i.e., termination of letdown flow to 3-way valve HP-14 (HP-V10) | Isolate HP-C1A and utilize HP-C1B if cooling water available to HP-C1B. Restore letdown flow if it has been isolated |
| | | 2. Reduction in heat transfer capability due to fouling | -- | Increased letdown temperature. High temperature sensed on TT-3 and indicated in control room | Increased letdown fluid temperature | Isolate HP-C1A, utilize HP-C1B |

Reference Drawings: FSAR Figure 9.3-2
FSAR Figure 9-2A

# SUBSYSTEM 1.0: LETDOWN SUBSYSTEM (Continued)

| | Component | Potential Failure Mode | | Immediate Effects | | |
|---|---|---|---|---|---|---|
| | | Mode | Interface Involved | Within Subsystem | At Subsystem Interface | Remedial Action Within Subsystem |
| 1.1.4 | Operating Letdown Cooler HP-C1A (or HP-C1B) (cont'd) | 3. Tube rupture | Component Cooling Water System | Reduced letdown flow rate due to flow diversion | Reduced letdown flow to 3-way valve HP-14 (HP-V10). Loss of reactor coolant to CCW system. Decreasing Ltdn tank level, RCS pressure. Safety injection signal will not isolate letdown cooler. Increased CCW surge tank level, discharge of reactor coolant through CCW relief valves to RB | Close HP-1 (HP-V1A) and HP-3 (HP-V2A), and open path through HP-C1B |
| 1.1.5 | Standby Letdown Cooler HP-C1B (or HP-C1A) | 1. Tube rupture | Component Cooling Water System | Reduced letdown flow rate due to flow diversion | Reduced letdown flow to 3-way valve HP-14 (HP-V10). Loss of reactor coolant to CCW system. Decreasing Ltdn tank level, RCS pressure. Safety injection signal will isolate letdown cooler. Increased CCW surge tank level, discharge of reactor coolant through CCW relief valves to RB | Close or verify closure of HP-4 (HP-V2B); letdown flow through HP-C1A is possible once leak is isolated |
| 1.1.6 | Valve HP-3 (NO) (HP-V2A) | 1. Fails closed due to internal fault | -- | Letdown flow through HP-C1A is obstructed | Letdown flow to 3-way valve HP-14 (HP-V10) is terminated | Close HP-1 (HP-V1A), open HP-2 (HP-V1B) to divert letdown flow through HP-C1B |
| | | 2. Spuriously closed | Control Signal | Letdown flow through HP-C1A is obstructed | Letdown flow to 3-way valve HP-14 (HP-V10) is terminated | Open HP-3 (HP-V2A) |
| | | 3. Fails to close when required due to internal fault | -- | Prevents isolation of HP-C1A | If HP-C1A has experienced a tube rupture, HP-1 (HP-V1A) has been closed, and HP-C1B is to be used, then an RC leak to the CCW system will occur. | None |
| | | | | | If HP-C1A has experienced a loss of cooling water and HP-1 (HP-V1A) can not be closed, then letdown fluid temperature will increase and HP-5 (HP-V3) will close terminating letdown flow to HP-14 (HP-V10) | Automatic closure of HP-5 (HP-V3); HP-C1A cannot be isolated until HP-3 (HP-V2A) is repaired |

## SUBSYSTEM 1.0: LETDOWN SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 1.1.6 | Valve HP-3 (NO) (HP-V2A) (cont'd) | 4. Fails to close when required due to unavailability of power on bus 1EXS21 | Electric Power | Prevents isolation of HP-C1A | If HP-C1A has experienced a tube rupture, HP-1 (HP-V1A) has been closed, and HP-C1B is to be used, then an RC leak to the CCW system will occur. If HP-C1A has experienced a loss of cooling water and HP-1 (HP-V1A) cannot be closed, then letdown fluid temperature will will increase and HP-5 (HP-V3) will close terminating letdown flow to HP-14 (HP-V10) | None<br>Automatic closure of HP-5 (HP-V3); HP-C1A cannot be isolated until power is restored on bus 1EXS21 |
| | | 5. Fails to close when required due to failure of ES signal | Engineered Safeguards Protective System (ESPS) | Prevents isolation of HP-C1A | If HP-C1A has experienced a tube rupture, HP-1 (HP-V1A) has been closed, and HP-C1B is to be used, then an RC leak to the CCW system will occur. If HP-C1A has experienced a loss of cooling water and HP-1 (HP-V1A) cannot be closed, then letdown fluid temperature will increase and HP-5 (HP-V3) will close terminating letdown flow to HP-14 (HP-V10) | None<br>Automatic closure of HP-5 (HP-V3); HP-C1A cannot be isolated until ES signal is restored |
| 1.1.7 | Valve HP-4 (NO) (HP-V2B) | 1. Fails closed due to internal fault | -- | None | None | Close HP-2 (HP-V1B) to divert letdown flow through HP-C1A |
| | | 2. Spuriously closed | Control Signal | None | None | Open HP-4 (HP-V2B) |
| | | 3. Fails to close when required due to internal fault | -- | Prevents isolation of HP-C1B | If HP-C1B has experienced a tube rupture, then an RC leak to the CCW system will occur | None; HP-C1B cannot be isolated until HP-4 (HP-V2B) is repaired |
| | | 4. Fails to close when required due to unavailability of power on bus 1EXS21 | Electric Power | Prevents isolation of HP-C1B | If HP-C1B has experienced a tube rupture, then an RC leak to the CCW system will occur | None; HP-C1B cannot be isolated until power is restored on bus 1EXS21 |

Reference Drawings: FSAR Figure 9.3-2
FSAR Figure 9-2A

# SUBSYSTEM 1.0: LETDOWN SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 1.1.7 | Valve HP-4 (NO) (HP-V2B) (cont'd) | 5. Fails to close when required due to failure of ES signal | Engineered Safeguards Protective System (ESPS) | Prevents isolation of HP-C1B | If HP-C1B has experienced a tube rupture, then an RC leak to the CCW system will occur | None; HP-C1B cannot be isolated until ES signal is restored |
| 1.2 | Block Orifice: | | | | | |
| 1.2.1 | Miscellaneous Normally Closed Manual Valves Such as HP-36 or HP-332 | 1. Opened or fails open due to internal fault | Vent or Drain | Reduced letdown flow rate | Reduced letdown flow to 3-way valve HP-14 (HP-V10) | Though detection is difficult, close or repair when found |
| 1.2.2 | Valve HP-5 (NO) (HP-V3) | 1. Fails closed due to internal fault | -- | Letdown flow terminated | Letdown flow to 3-way valve HP-14 (HP-V10) is terminated | Close HP-3 (HP-V2A), HP-4 (HP-V2B), and HP-6 (HP-V4) and repair |
| | | 2. Spuriously closed | Control Signal | Letdown flow terminated | Letdown flow to 3-way valve HP-14 (HP-V10) is terminated | Open HP-5 (HP-V3) |
| | | 3. Fails to close when required due to internal fault | -- | High temperature letdown flow to purification demineralizer is unobstructed. Increased letdown fluid temperature may result in melting the resin beads in HP-X1 and thus blocking flow | High temperature letdown flow possibly causing flow blockage if resin beads in HP-X1 melt | Close HP-6 (HP-V4). If purification resins damaged, use standby demineralizer |
| | | 4. Spuriously closed due to unavailability of instrument air (assumed) | Instrument Air | Letdown flow terminated | Letdown flow to 3-way valve HP-14 (HP-V10) is terminated | Restore instrument air, open HP-5 (HP-V3) |
| | | 5. Fails to close when required due to unavailability of letdown temperature interlock | Plant Instrumentation | High temperature letdown flow to purification demineralizer is unobstructed. Increased letdown fluid temperature may result in melting the resin beads in HP-X1 and thus blocking flow | High temperature letdown flow possibly causing flow blockage if resin beads in HP-X1 melt | Close HP-6 (HP-V4) and restore temperature interlock. If purification resins damaged, use standby demineralizer |

Reference Drawings: FSAR Figure 9.3-2
FSAR Figure 9-2A

# SUBSYSTEM 1.0: LETDOWN SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 1.2.2 | Valve HP-5 (NO) (HP-V3) (cont'd) | 6. Fails to close when required due to unavailability of ES signal | Engineered Safeguards Protective System (ESPS) | Failure of one of two redundant containment isolation valves. High temperature letdown flow to purification demineralizer is unobstructed. Increased letdown fluid temperature may result in melting the resin beads in HP-X1 and thus blocking flow | None, if HP-6 (HP-V4) successfully closes. Otherwise, high temperature letdown flow possibly causing flow blockage if resin beads in HP-X1 melt | Close HP-6 (HP-V4) and restore ES signal. If purification resins damaged, use standby demineralizer |
| 1.2.3 | Valve HP-6 (NO) (HP-V4) | 1. Fails closed due to internal fault | -- | Letdown flow to purification demineralizer is obstructed unless HP-42 or HP-7 (HP-V5) is open | Letdown flow to 3-way valve HP-14 (HP-V10) is terminated unless HP-42 or HP-7 (HP-V5) is open | Utilize HP-7 (HP-V5) for letdown throttling |
| | | 2. Spuriously closed | Control Signal | Letdown flow to purification demineralizer is obstructed unless HP-42 or HP-7 (HP-V5) is open | Letdown flow to 3-way valve HP-14 (HP-V10) is terminated unless HP-42 or HP-7 (HP-V5) is open | Open HP-6 (HP-V4) or HP-7 (HP-V5) |
| | | 3. Fails to close when required due to internal fault | -- | Letdown flow to block orifice is unobstructed | If HP-5 (HP-V3) has failed to close and the letdown flow has not been cooled, then temperature of letdown flow to HP-14 (HP-V10) will continue to increase and resin beads in HP-X1 may melt causing flow blockage | Close HP-8 (HP-V7) to protect purification demineralizer HP-X1 |
| | | 4. Fails to close when required due to unavailability of instrument air (assumed) | Instrument Air | Letdown flow to block orifice is unobstructed | If HP-5 (HP-V3) has failed to close and the letdown flow has not been cooled, then temperature of letdown flow to HP-14 (HP-V10) will continue to increase and resin beads in HP-X1 may melt causing flow blockage | Close HP-8 (HP-V7) to protect purification demineralizer HP-X1; restore instrument air |
| 1.2.4 | Block Orifice | 1. Fails plugged | -- | Letdown flow to purification demineralizer is obstructed if HP-42 and HP-7 (HP-V5) are closed | Letdown flow to 3-way valve HP-14 (HP-V10) is terminated if HP-42 and HP-7 (HP-V5) are closed | Utilize HP-7 (HP-V5) for letdown flow throttling |
| 1.2.5 | Flow Transmitter FT-29 | 1. Internal fault results in incorrect signal | Plant Instrumentation | None | Incorrect information sent to plant operators | Isolate and repair |
| | | 2. Fails due to loss of power | Electric Power | None | Incorrect information sent to plant operators | Restore electric power |

Reference Drawings: FSAR Figure 9.3-2
FSAR Figure 9-2A

## SUBSYSTEM 1.0: LETDOWN SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 1.2.6 | Valve HP-39 (NO) | 1. Fails closed due to internal fault | -- | Letdown flow to purification demineralizer is obstructed if HP-42 and HP-7 (HP-V5) are closed | Letdown flow to 3-way valve HP-14 (HP-V10) is terminated if HP-42 and HP-7 (HP-V5) are closed | Open HP-7 (HP-V5) |
| 1.2.7 | Valve HP-42 (NC) | 1. Fails open due to internal fault | -- | Unobstructed letdown flow through orifice bypass to purification demineralizer | Increased letdown flow to 3-way valve HP-14 (HP-V10) | Isolate block orifice to reduce letdown flow |
| 1.2.8 | Valve HP-40 (NO) | 1. Fails closed due to internal fault | -- | Letdown flow to HP-7 (HP-V5) is obstructed | None, if HP-7 (HP-V5) (NC) is closed. Otherwise, reduced letdown flow to 3-way valve HP-14 (HP-V10) | Open HP-42, if required |
| 1.2.9 | Valve HP-7 (NC) (HP-V5) | 1. Fails open due to internal fault | -- | Block orifice bypassed, increased letdown flow | Increased letdown flow to 3-way valve HP-14 (HP-V10), and potentially increased letdown temperatures | Close HP-40 and/or HP-41 and repair |
| | | 2. Spuriously opened | Control Signal | Block orifice bypassed, increased letdown flow | Increased letdown flow to 3-way valve HP-14 (HP-V10) | Close HP-7 (HP-V5) |
| | | 3. Fails to open when required due to internal fault | -- | Additional letdown flow not provided | Additional letdown flow not provided | Open HP-42 if required, close HP-40 and HP-41 and repair |
| | | 4. Fails to open when required due to unavailability of instrument air (assumed) | Instrument Air | Additional letdown flow not provided | Additional letdown flow not provided | Utilize HP-42, if required; restore instrument air |
| 1.2.10 | Valve HP-41 (NO) | 1. Fails closed due to internal fault | -- | Obstructs letdown flow to purification demineralizer if HP-7 (HP-V5) is open | Reduced letdown flow to 3-way valve HP-14 (HP-V10) if HP-7 (HP-V5) is open | Utilize HP-42 if required |
| 1.2.11 | Radiation Monitor Loop | 1. Normally closed manual drain valve opened, fails open, or not closed after maintenance, or relief valve spuriously opens | High Activity Waste Tank, Miscellaneous Waste Tank | Diversion of letdown flow when radiation monitoring loop used | Reduced letdown flow to 3-way valve HP-14 (HP-V10); flow diverted to Miscellaneous Waste Tank or High Activity Waste Tank | Isolate Loop; close valve or repair when found; sampling available at other points in subsystem |
| | | 2. Loop becomes plugged | -- | Reduced letdown flow; radiation monitoring prevented | Reduced letdown flow to 3-way valve HP-14 (HP-V10) | Unplug when found; sampling available at other points in subsystem |

# SUBSYSTEM 1.0: LETDOWN SUBSYSTEM (Continued)

| Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|
| 1.2.12 Boron Meter Loop | 1. Normally closed manual drain valve opened, fails open, or not closed after maintenance, or relief valve spuriously opens | High Activity DR Tank, Miscellaneous Waste Tank | Diversion of letdown flow when boron meter loop used | Reduced letdown flow to 3-way valve HP-14 (HP-V10); flow diverted to High Activity DR Tank or Miscellaneous Waste Tank | Isolate Loop; close valve or repair when found; sampling available at other points in subsystem |
| | 2. Loop becomes plugged | -- | Reduced letdown flow; boron content measurement prevented | Reduced letdown flow to 3-way valve HP-14 (HP-V10) | Unplug when found; sampling available at other points in subsystem |
| 1.3 Purification Demineralizer: | | | | | |
| 1.3.1 Flow Nozzle | 1. Fail plugged | -- | Letdown flow to purification demineralizer is obstructed | Letdown flow to 3-way valve HP-14 (HP-V10) is reduced or terminated | |
| 1.3.2 Flow Transmitters FT-6, FT-6P, and FT-6A | 1. Internal fault results in incorrect signal | Plant Instrumentation | None | None | Utilize FT-29 to determine letdown flow (requires HP-7 (HP-V5) and HP-42 be shut), repair transmitters; restore electric power |
| | 2. Control power failure results in incorrect signal | Electric Power | None | None | |
| 1.3.3 Pressure Gauge PG-73 | 1. Internal fault results in incorrect measurement | Plant Instrumentation | None | None | Repair when detected |

Reference Drawings: FSAR Figure 9.3-2
FSAR Figure 9-2A

## SUBSYSTEM 1.0: LETDOWN SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 1.3.4 | Temperature Transmitter TT-3 | 1. Internal fault results in incorrect signal | Plant Instrumentation | If a spuriously high temperature signal is transmitted, HP-5 (HP-V3) is automatically closed, obstructing letdown flow to purification demineralizer | Letdown flow to 3-way valve HP-14 (HP-V10) is terminated | Open HP-5 (HP-V3) after assessing failure; repair transmitter |
| | | | | If a spuriously low temperature signal is transmitted, HP-5 (HP-V3) would not be automatically closed if required. Excessive letdown temperatures would result in purification demineralizer heating, or resin bead melting and flow blockage | High temperature letdown flow possibly causing flow blockage if resin beads in HP-X1 melt | Close HP-6 (HP-V4); repair transmitter |
| | | 2. Control power failure results in incorrect signal | Electric Power | If a spuriously high temperature signal is transmitted, HP-5 (HP-V3) is automatically closed, obstructing letdown flow to purification demineralizer | Letdown flow to 3-way valve HP-14 (HP-V10) is terminated | Open HP-5 (HP-V3) after assessing failure; restore electric power |
| | | | | If a spuriously low temperature signal is transmitted, HP-5 (HP-V3) would not be automatically closed if required. Excessive letdown temperatures would result in purification demineralizer heating, or resin bead melting and flow blockage | High temperature letdown flow possibly causing flow blockage if resin beads in HP-X1 melt | Close HP-6 (HP-V4); restore electric power |
| 1.3.5 | Miscellaneous Relief Valves Like RV-52 (HP-43) and Normally Closed, Manual Valves Like HP-44 | 1. Relief valve spuriously opens | Liquid Waste Drain | RC leak | Reduced letdown flow to 3-way valve HP-14 (HP-V10); RC leak | Isolate |
| | | 2. NC manual valve fails open due to internal fault | Sampling System | RC leak | Reduced letdown flow to 3-way valve HP-14 (HP-V10) if sample flow exists; RC leak | None (isolate and repair) |
| 1.3.6 | Valve HP-195 (NO) | 1. Fails closed due to internal fault | -- | Letdown flow to purification demineralizer is obstructed | Letdown flow to 3-way valve HP-14 (HP-V10) is terminated | None (isolate and repair) |

## SUBSYSTEM 1.0: LETDOWN SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 1.3.7 | Valve HP-196 (NC) | 1. Fails open due to internal fault | Outlet of Letdown Filter HP-F1A | Reduced letdown flow to purification demineralizer | Reduced letdown flow to 3-way valve HP-14 (HP-V10). (Letdown flow bypasses HP-X1 and HP-14 (HP-V10)) | Close HP-57 |
| 1.3.8 | Valve HP-197 (NC) | 1. Fails open due to internal fault | Inlet of Letdown Filter HP-F1A | Reduced letdown flow to purification demineralizer | Reduced letdown flow to 3-way valve HP-14 (HP-V10). (Letdown flow bypasses HP-X1 and HP-14 (HP-V10)) | Close HP-57 |
| 1.3.9 | Valve HP-13 (NC) (HP-V6) | 1. Fails open due to internal fault | -- | Letdown flow bypasses the purification demineralizer; letdown flow chemistry altered | Letdown flow chemistry altered | None |
| | | 2. Spuriously opened | Control Signal | Letdown flow bypasses the purification demineralizer; letdown flow chemistry altered | Letdown flow chemistry altered | Close HP-13 (HP-V6) |
| | | 3. Fails to open when required due to internal fault | -- | Purification demineralizer HP-X1 bypass unavailable if required | Letdown flow to 3-way valve HP-14 (HP-V10) is terminated if HP-X1 is plugged | Open HP-9 (1HP-V8) and HP-11 (1HP-V9) and use HP-X2 if available |
| | | 4. Potential failure to open due to unavailability of instrument air (assumed) | Instrument Air | Purification demineralizer HP-X1 bypass unavailable if required | Letdown flow to 3-way valve HP-14 (HP-V10) is terminated if HP-X1 is plugged | Restore instrument air; open HP-9 (1HP-V8) and HP-11 (1HP-V9) and use HP-X2 if available |
| 1.3.10 | Valve HP-8 (NO) (HP-V7) | 1. Fails closed due to internal fault | -- | Letdown flow through purification demineralizer HP-X1 is obstructed | Letdown flow to 3-way valve HP-14 (HP-V10) is terminated | Open HP-9 (1HP-V8) and HP-11 (1HP-V9) and utilize purification demineralizer HP-X2 if not being used by Unit 2 |
| | | 2. Spuriously closed | Control Signal | Letdown flow through purification demineralizer HP-X1 is obstructed | Letdown flow to 3-way valve HP-14 (HP-V10) is terminated | Open HP-9 (1HP-V8) and HP-11 (1HP-V9) and utilize purification demineralizer HP-X2 if not being used by Unit 2 |

## SUBSYSTEM 1.0: LETDOWN SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 1.3.10 | Valve HP-8 (NO) (HP-V7) (cont'd) | 3. Fails to close when required due to internal fault | -- | Purification demineralizer HP-X1 isolation is unavailable | Continued letdown flow to 3-way valve HP-14 (HP-V10) | Close HP-47 |
| | | 4. Fails to close when required due to unavailability of instrument air (assumed) | Instrument Air | Purification demineralizer HP-X1 isolation is unavailable | Continued letdown flow to 3-way valve HP-14 (HP-V10) | Close HP-47; restore instrument air |
| 1.3.11 | Purification Demineralizer HP-X1 | 1. Fail plugged | -- | Letdown flow is blocked in purification demineralizer HP-X1 | Letdown flow to 3-way valve HP-14 (HP-V10) is terminated | Isolate HP-X1 using HP-8 (HP-V7) and use HP-X2 if available or bypass by opening HP-13 (HP-V6) (reduced chemistry control) |
| 1.3.12 | Stop Check Valve HP-47 | 1. Fails plugged | -- | Letdown flow through purification demineralizer HP-X1 is obstructed | Letdown flow to valve HP-14 (HP-V10) is terminated | Isolate HP-X1 using HP-8 (HP-V7) and use HP-X2 if available or bypass by opening HP-13 (HP-V6) (reduced chemistry control) |
| 1.3.13 | Valve HP-9 (NC) (1HP-V8) | 1. Fails open due to internal fault | -- | If purification demineralizer HP-X2 is being used by Unit 2, then the letdown flows of the two units may be mixed depending on the pressure difference between the two letdown flows | Increased or reduced letdown flow to 3-way valve HP-14 (HP-V10) | Remedial action dependent on Unit 2 operating requirements |
| | | 2. Spuriously opened | Control Signal | If purification demineralizer HP-X2 is being used by unit 2, then the letdown flows of the two units may be mixed depending on the pressure difference between the two letdown flows | Increased or reduced letdown flow to 3-way valve HP-14 (HP-V10) | Close HP-9 (1HP-V8) |

# SUBSYSTEM 1.0: LETDOWN SUBSYSTEM (Continued)

| Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|
| 1.3.13 Valve HP-9 (NC) (1HP-V8) (cont'd) | 3. Fails to open when required due to internal fault | -- | Prevents use of spare purification demineralizer HP-X2 by unit 1 | Potential reduction in chemistry control | Continue to use HP-X1 if available or open HP-13 (HP-V6) and bypass HP-X1 |
| | 4. Potential failure to open due to unavailability of instrument air (assumed) | Instrument Air | Prevents use of spare purification demineralizer HP-X2 by unit 1 | Potential reduction in chemistry control | Continue to use HP-X1 if available or open HP-13 (HP-V6) and bypass HP-X1; restore instrument air |
| 1.3.14 Valve HP-11 (NC) (1HP-V9) | 1. Fails open due to internal fault | -- | If purification demineralizer HP-X2 is being used by unit 2, then the letdown flow of unit 2 will leak into the letdown flow of unit 1 if unit 2 letdown pressure is greater than unit 1 letdown pressure | Increased letdown flow to 3-way valve HP-14 (HP-V10) | Close HP-10 (2HP-V8) and HP-12 (2HP-V9) depending on Unit 2 operating requirements |
| | 2. Spuriously opened | Control Signal | If purification demineralizer HP-X2 is being used by unit 2, then the letdown flow of unit 2 will leak into the letdown flow of unit 1 if unit 2 letdown pressure is greater than unit 1 letdown pressure | Increased letdown flow to 3-way valve HP-14 (HP-V10) | Close HP-11 (1HP-V9) |
| | 3. Fails to open when required due to internal fault | -- | Prevents use of spare purification demineralizer HP-X2 by unit 1 | Potential reduction in chemistry control | Continue to use HP-X1 if available or open HP-13 (HP-V6) and bypass HP-X1 |
| | 4. Potential failure to open due to unavailability of instrument air (assumed) | Instrument Air | Prevents use of spare purification demineralizer HP-X2 by unit 1 | Potential reduction in chemistry control | Continue to use HP-X1 if available or open HP-13 (HP-V6) and bypass HP-X1; restore instrument air |

# APPENDIX B

## FAILURE MODES AND EFFECTS ANALYSIS
## SUBSYSTEM 2.0: RC PUMP SEAL RETURN SUBSYSTEM

Reference Drawings: FSAR Figure 9.3-2 (Sheets 1 and 4)

# SUBSYSTEM 2.0: RCP SEAL WATER RETURN

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 2.1 | Seal Leak-off Line(s) (4 Total, 1/RCP): | | | | | |
| 2.1.1 | Pressure Transmitter(s) 1PT-19, 1PT-20, 1PT-21, 1PT-22 | 1. Instrument connection leak | -- | Small loss of reactor coolant | Incorrect pressure signal to I&C system and control room | If accessible, repair component |
| | | 2. Transmitter failure due to internal faults | -- | No effect | Incorrect pressure signal to I&C system and control room | If accessible, repair component |
| | | 3. Incorrect output due to loss of power | I&C System, Electric Power Supply | No effect | Incorrect pressure signal to I&C system and control room | Restore power supply |
| 2.1.2 | Motor Operated Isolation Valve(s) HP-228 (1HP-V43A), HP-232 (1HP-V43B), HP-226 (1HP-V43C), HP-230 (1HP-V43D) | 1. Closes on spurious signal | I&C System | Flow stopped in single leak-off line | Seal leak-off flow from a single RC pump blocked, control room alarm | Attempt to open failed valve or open seal bypass valve (HP-275) |
| | | 2. Inadvertantly closed | -- | Flow stopped in single leak-off line | Seal leak-off flow from a single RC pump blocked, control room alarm | Reopen valve |
| | | 3. Fails closed due to internal fault | -- | Flow stopped in single leak-off line | Seal leak-off flow from a single RC pump blocked, control room alarm | Open seal bypass valve (HP-275) |
| | | 4. Valve fails to close when required due to control signal failure | I&C System | Flow not isolated | Subsystem not isolated from RCS | Close local valves on affected line |
| | | 5. Valve fails to close on demand | Electric Power Supply | Flow not isolated | Subsystem not isolated from RCS | Restore power, close local valves on affected line |
| | | 6. Valve fails to close on demand due to internal fault | -- | Flow not isolated | Subsystem not isolated from RCS | Close local valves on affected line |
| 2.1.3 | Manual Isolation Valves (2/line) HP-205, HP-207, HP-212, HP-214, HP-219, HP-221, HP-259, HP-261 | 1. Valve failed closed (plugging, damaged, etc.) | -- | Flow stopped in single leak-off line | Seal leak-off flow from a single RC pump blocked, control room alarm | Open bypass valve around failed valve (local action) |
| 2.1.4 | Flow Transmitter(s) 1FT-19, 1FT-20, 1FT-21, 1FT-22, 1FT-113, 1FT-114, 1FT-115, 1FT-116 | 1. Instrument connection leak | -- | Small loss of reactor coolant | Incorrect flow signal to I&C system and control room | If accessible, isolate leaking transmitter(s), flow bypass available (local action just outside of secondary shielding) |

## SUBSYSTEM 2.0: RC PUMP SEAL RETURN SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 2.1.4 | Flow Transmitter(s) 1FT-19, 1FT-20, 1FT-21, 1FT-22, 1FT-113, 1FT-114, 1FT-115, 1FT-116 (cont'd) | 2. Incorrect output due to loss of power | Electric Power Supply, I&C System | No effect | Incorrect flow signal to I&C system and control room | Restore power supply |
| | | 3. Transmitter failure due to internal fault | -- | No effect | Incorrect flow signal to I&C system and control room | If accessible, utilize bypass, isolate component and repair (local action just outside of secondary shielding) |
| 2.2 | Seal Bypass Line(s) (Normally Closed, Open When #1 Seal-Leakoff Rate is Too Low) (4 Total, 1/RCP): | | | | | |
| 2.2.1 | Pressure Transmitter(s) 1PT-19, 1PT-20, 1PT-21, 1PT-22 | 1. Instrument connection leak | -- | Small loss of reactor coolant | Incorrect pressure signal transmitted to I&C and control room | If accessible, repair component |
| | | 2. Incorrect output due to loss of power | Electric Power Supply, I&C System | No effect | Incorrect pressure signal transmitted to I&C and control room | Restore power supply |
| | | 3. Transmitter failure due to internal fault | -- | No effect | Incorrect pressure signal transmitted to I&C and control room | If accessible, repair component |
| 2.2.2 | Check Valve(s) HP-263, HP-266, HP-269, HP-272 | 1. Valve failed closed (plugged, damaged, etc.) | -- | Flow in a single bypass line stopped | Seal bypass flow path blocked from a single RC pump | If accessible, repair component |
| | | 2. Valve fails to prevent backflow | -- | No effect during steady state | No effect during steady state | Repair component at shutdown |
| 2.2.3 | Manual Isolation Valves (2/line) HP-264, HP-265, HP-267, HP-268, HP-270, HP-271, HP-273, HP-274 | 1. Valve fails closed (plugged, damaged, etc.) | -- | Flow in a single bypass line stopped | Seal bypass flow path blocked from a single RC pump | If accessible, repair component |
| 2.2.4 | Flow Transmitter(s) 1FT-109, 1FT-110, 1FT-111, 1FT-112 | 1. Instrument connection leak | -- | Small loss of reactor coolant | Incorrect flow signal transmitted to I&C and control room | If accessible, repair component |
| | | 2. Transmitter failure due to internal fault | -- | No effect | Incorrect flow signal transmitted to I&C and control room | If accessible, repair component |
| | | 3. Incorrect output due to loss of power | Electric Power Supply, I&C System | No effect | Incorrect flow signal transmitted to I&C and control room | Restore power supply |

## SUBSYSTEM 2.0: RC PUMP SEAL RETURN SUBSYSTEM (Continued)

| Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|
| **2.3 Seal Bypass Return Header:** | | | | | |
| 2.3.1 Motor Operated Isolation Valve HP-275 (HP-V48) | 1. Valve fails to open when required due to control signal failure or closes on spurious signal | I&C System | Seal return bypass flow blocked | Seal return bypass flow path unavailable to all RC pumps | None |
| | 2. Valve fails to open on demand or closes on spurious signal | Electric Power Supply | Seal return bypass flow blocked | Seal return bypass flow path unavailable to all RC pumps | Restore power |
| | 3. Valve fails to open on demand due to internal fault | -- | Seal return bypass flow blocked | Seal return bypass flow path unavailable to all RC pumps | Repair component if accessible |
| | 4. Valve fails open or fails to close when required | I&C System, Electric Power Supply, Internal | No effect | No effect | Repair component if accessible |
| 2.3.2 Motor Operated Isolation Valve to Stand Pipe Fill and Makeup HP-276 (HP-V49) | 1. Valve fails open due to internal fault | -- | Stand pipe fill lines open to seal return flow | Potential loss of vent on RCP vent seal | None |
| | 2. Valve opens on spurious signal | I&C System | Stand pipe fill lines open to seal return flow | Potential loss of vent on RCP vent seal | None |
| **2.4 Seal Water Cooler Inlet Header:** | | | | | |
| 2.4.1 Motor Operated Isolation Valve HP-20 (HP-V12) | 1. Valve fails closed due to internal fault | -- | Seal return flow stopped | Seal return flow from all RC pumps stopped | Repair component |
| | 2. Valve closes on spurious signal | I&C System, ES | Seal return flow stopped | Seal return flow from all RC pumps stopped | None |
| | 3. Valve inadvertantly closed | -- | Seal return flow stopped | Seal return flow form all RC pumps stopped | Reopen valve |
| | 4. Valve fails to close on demand | Electric Power Supply | Reactor building isolation degraded | Seal return flow continues to letdown storage tank | Restore power |
| | 5. Valve fails to close when required | ES | Reactor building isolation degraded | No effect provided, redundant valve closes | None |
| | 6. Valve fails to close when required | I&C System | Reactor building isolation degraded, seal return flow not isolated from coolers | Seal return flow continues to letdown storage tank | Utilize valve HP-21 |
| | 7. Valve fails to close on demand due to internal fault | -- | Reactor building isolation degraded, seal return flow not isolated from coolers | Seal return flow continues to letdown storage tank | Utilize valve HP-21 |
| 2.4.2 Pneumatic Operated Isolation Valve HP-21 (HP-V13) | 1. Valve fails closed (assuming valve is air-to-open) | Instrument Air | Seal return flow stopped | Seal return flow from all RC pumps stopped | Attempt to open valve locally |
| | 2. Valve closes on spurious signal | I&C System | Seal return flow stopped | Seal return flow from all RC pumps stopped | Attempt to open valve locally |
| | 3. Valve closes on spurious signal | ES | Seal return flow stopped | Seal return flow from all RC pumps stopped | Attempt to open valve locally |

## SUBSYSTEM 2.0: RC PUMP SEAL RETURN SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 2.4.2 | Pneumatic Operated Isolation Valve HP-21 (HP-V13) (cont'd) | 4. Valve fails closed due to internal fault | -- | Seal return flow stopped | Seal return flow from all RC pumps stopped | Repair component |
| | | 5. Valve fails to close on demand due to internal fault | -- | Reactor building isolation degraded, seal return flow not isolated from seal return coolers | Seal return flow continues to letdown storage tank | Utilize valve HP-20 |
| | | 6. Valve fails to close when required | ES | Reactor building isolation degraded | No effect provided redundant valve closes | None |
| | | 7. Valve fails to close when required | I&C System | Reactor building isolation degraded, seal return flow not isolated from coolers | Seal return flow continues to letdown storage tank | Utilize valve HP-20 |
| 2.4.3 | Seal Return Filter Throttle Valve HP-277 (HP-V50) | 1. Valve failed closed (plugged, damaged, etc.) | -- | Seal return flow reduced or stopped | Seal return flow from all RC pumps reduced or stopped | Repair component |
| 2.4.4 | Seal Return Filter Isolation Valve(s) HP-278, HP-279 | 1. Valve failed closed (plugged, damaged, etc.) | -- | Seal return flow reduced or stopped | Seal return flow from all RC pumps reduced or stopped | Open bypass valve (HP-280) around filter (local action) |
| 2.4.5 | Seal Return Filter | 1. Filter plugged | -- | Seal return flow reduced or stopped | Seal return flow from all RC pumps reduced or stopped high P transmitted on 1PT-114 | Open bypass valve (HP-280) around filter (local action) |
| 2.5 | Seal Return Cooler(s): | | | | | |
| 2.5.1 | Manual Isolation Valve(s) HP-72, HP-74, HP-75, HP-77 | 1. Valve fails closed (plugging, damaged, stuck closed, etc.) | -- | Seal return flow reduced or stopped | Seal water flow from all RC pumps reduced or stopped | Valve in spare cooler (local action) |
| 2.5.2 | Operating RC Seal Return Cooler HP-C1B (or Spare HP-C1A) | 1. Heat exchanger tubes blocked | -- | Seal return flow reduced or stopped | Seal water flow from all RC pumps reduced or stopped | Valve in spare cooler (local action) and repair blocked cooler |
| | | 2. Tube failure | RCW System | Loss of reactor coolant to RCW system | Reactor coolant leakage to RCW system, reduced seal water return to letdown storage tank | Valve in spare cooler (local action) or isolate seal return header from control room if required and take appropriate precautions for stopping seal return |

# SUBSYSTEM 2.0: RC PUMP SEAL RETURN SUBSYSTEM (Continued)

| Component | | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 2.5.2 | Operating RC Seal Return Cooler HP-C1B (or Spare HP-C1A) (cont'd) | 3. Loss of RCW | RCW System | Loss of seal return cooling (high cooler discharge temperature) | High temperature discharge to letdown storage tank, high temperature reading on TT-45 or TT-46 | Valve in spare cooler if RCW is available to it (local action) |
| | | 4. Loss of heat transfer capability due to internal damage | -- | Loss of seal return cooling (high cooler discharge temperature) | High temperature discharge to letdown storage tank, high temperature reading on TT-45 or TT-46 | Isolate affected cooler and valve in spare (local action) |
| | | 5. Vapor lock in cooler | -- | Reduction in seal return cooling capacity (high cooler discharge temperature) | High temperature discharge to letdown storage tank, high temperature reading on TT-45 or TT-46 | Isolate affected cooler and valve in spare (local action) |
| 2.5.3 | Cooler Discharge Header Check Valve HP-189 | 1. Valve fails closed (plugging, damaged, etc.) | -- | Seal return flow reduced or stopped | Seal return flow to letdown storage tank reduced or stopped, seal return flow from all RC pumps reduced or stopped | Repair component |
| | | 2. Valve fails to prevent backflow | Seal Water Coolers, Letdown Storage Tank, Makeup Filter(s) Discharge | No effect during steady state since pressures at outlet interfaces are lower than cooler discharge line pressure | No effect during steady state since pressures at outlet interfaces are lower than cooler discharge line pressure | No immediate action necessary, repair component |
| 2.6 | System Inlet Flows: | | | | | |
| 2.6.1 | Seal Injection Flow | 1. Loss of flow | Seal Injection (Subsystem 4.0), RC Pumps | Seal return flow from RCS hotter than normal seal return | Slightly hotter discharge flow to letdown storage tank | None |
| 2.6.2 | HPI Pump Recirculation | 1. Loss of flow | HPI Pumps (Subsystem 3.0) | Reduced flow through seal return coolers | Reduced flow and somewhat cooler discharge than normal to letdown storage tank | None |
| 2.7 | System Piping: | | | | | |
| 2.7.1 | Vents, Drains, Piping, Instrument Connections, etc. | 1. System leaks | -- | Loss of reactor coolant | Loss of reactor coolant, slightly reduced flow to letdown storage tank | Isolate leaks and repair as needed |

# APPENDIX C

FAILURE MODES AND EFFECTS ANALYSIS

SUBSYSTEM 3.0: HPI PUMP SUBSYSTEM

Reference Drawings: FSAR Figure 9.3-2 (Sheet 1)

# SUBSYSTEM 3.0: LETDOWN STORAGE TANK (LST), INLET FILTERS, AND HPI PUMPS

| Component | | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 3.1 | Letdown (Makeup) Filters (2): | | | | | |
| 3.1.1 | Pneumatic Operated Inlet Valve(s) HP-17 (HP-V29A), HP-18 (HP-V29B) | 1. Valve fails closed (assumed valve is air-to-open) | Instrument Air | Loss of flow to LST from letdown, chemical addition, and system makeup | Reduction and eventual loss of available makeup in LST | Utilize spare filter, open valve locally, bypass to LST, or switch to BWST if LST level is unacceptably low |
| | | 2. Valve fails closed due to internal fault | -- | Loss of flow to LST from letdown, chemical addition, and system makeup | Reduction and eventual loss of available makeup in LST | Utilize spare filter, bypass to LST, or switch to BWST if LST level is unacceptably low |
| | | 3. Valve closes on spurious signal | I&C System | Loss of flow to LST from letdown, chemical addition, and system makeup | Reduction and eventual loss of available makeup in LST | Utilize spare filter, open valve locally, bypass to LST or switch to BWST if LST level is unacceptably low |
| | | 4. Valve inadvertantly closed | -- | Loss of flow to LST from letdown, chemical addition, and system makeup | Reduction and eventual loss of available makeup in LST | Reopen valve |
| | | 5. Valve fails to close when required | I&C, Electric Power Supply, Internal | Cannot isolate filter for maintenance | No effect | Repair component |
| 3.1.2 | Makeup Filter P Transmitter 1PT-15 | 1. Transmitter failure due to internal fault | -- | Potential for undetected filter plugging | Incorrect pressure drop signal to I&C and control room | Monitor pressure drop with local gage |
| | | 2. Incorrect output due to loss of power | Electric Power Supply, I&C | Potential for undetected filter plugging | Incorrect pressure drop signal to I&C and control room | Monitor pressure drop with local gage |
| | | 3. Instrument connection leak | -- | Small loss of reactor coolant and small reduction in flow to LST | Incorrect pressure drop signal to I&C and control room | Repair leak |
| 3.1.3 | Filter(s) HP-F1A, HP-F1B | 1. Filter plugged | -- | Letdown, chemical addition, and system makeup flow reduced or stopped | Reduced inventory in LST and high pressure drop signal to I&C from 1PT-15 | Utilize spare filter or bypass filters via HP-19 |

Reference Drawings: FSAR Figure 9.3-2 (Sheet 1)

## SUBSYSTEM 3.0: HPI PUMP SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 3.1.4 | Manual Filter Discharge Block Valve(s) HP-57, HP-58 | 1. Valve failed closed (plugging, damaged, etc.) | -- | Loss of flow to LST from letdown, chemical addition, and system makeup | Reduction and eventual loss of available makeup in LST | Utilize spare filter path or bypass filters via HP-19 |
| 3.2 | Letdown Storage Tank: | | | | | |
| 3.2.1 | Inlet Check Valve HP-78 | 1. Valve failed closed | Subsystem 2.0 | Loss of all flow to LST, potential loss of NPSH to HPI pumps if LST level is too low | Reduction and eventual loss of available makeup in LST, flow blocked from seal return (Subsystem 2.0) | Monitor LST level, switch to BWST if LST level is unacceptably low |
| | | 2. Valve fails to prevent backflow | Subsystem 2.0 (Seal Return) | None during steady state | None since check valve HP-18 in Subsystem 2.0 is a backup | Repair component |
| 3.2.2 | Tank Vent Globe Valve HP-80 | 1. Valve failed closed (plugged, damaged, etc.) | Chemical Addition (Subsystem 6.0) | Loss of normal LST vent path, buildup of noncondensible gases in LST, potential reduction in $H_2$ mass transfer rate into reactor coolant | Potential reduction of $H_2$ concentration in reactor coolant and reduction in $O_2$ scavenging capability | Monitor LST pressure and level and repair component |
| 3.2.3 | Manual $H_2/N_2$ Supply/Isolation Valve H-111 | 1. Valve failed closed (plugged, damaged, etc.) | $H_2$ Bulk Storage, $N_2$ Blanketing System | Loss of $H_2$ addition to LST | Reduction in $H_2$ concentration in reactor coolant and reduction in $O_2$ scavenging capability | Repair component |
| 3.2.4 | Level Transmitters 1LT-33P1, 1LT-33P2 | 1. Transmitter failure due to internal fault | -- | If selected transmitter indicates low flow from 3-way valve automatically transfers letdown flow to LST and operator may increase LST level with bleed holdup. Potential for LST tank overfilling, $H_2$ addition blockage, and lower $H_2$ concentration in RCS. If transmitter indicates high, operator may decrease letdown flow and potentially reduce NPSH on HPI pumps | Loss of or incorrect LST level indication, incorrect signal to 3-way valve interlock circuit and potential for reduced $H_2$ concentration in RCS. Operator response may also result in decreased letdown flow | Monitor with redundant transmitter |

## SUBSYSTEM 3.0: HPI PUMP SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 3.2.4 | Level Transmitters 1LT-33P1, 1LT-33P2 (cont'd) | 2. Incorrect output due to loss of power to transmitter | Electric Power Supply, I&C System | If selected transmitter indicates low flow from 3-way valve automatically transfers letdown flow to LST and operator may increase LST level with bleed holdup. Potential for LST tank overfilling, $H_2$ addition blockage, and lower $H_2$ concentration in RCS. If transmitter indicates high, operator may decrease letdown flow and potentially reduce NPSH on HPI pumps | Loss of or incorrect LST level indication, incorrect signal to 3-way valve interlock circuit and potential for reduced $H_2$ concentration in RCS. Operator response may also result in decreased letdown flow | Restore power supply or monitor with redundant transmitter if on a different power source |
| | | 3. Instrument connection leak | -- | Small loss of LST inventory. Both transmitters affected. If selected transmitter indicates low flow from 3-way valve automatically transfers letdown flow to LST and operator may increase LST level with bleed holdup. Potential for LST tank overfilling, $H_2$ addition blockage, and lower $H_2$ concentration in RCS. If transmitter indicates high, operator may decrease letdown flow and potentially reduce NPSH on HPI pumps | Loss of or incorrect LST level indication, incorrect signal to 3-way valve interlock circuit and potential for reduced $H_2$ concentration in RCS. Operator response may also result in decreased letdown flow | Repair component |
| 3.2.5 | Pressure Transmitter 1PT-10 | 1. Incorrect output due to loss of power | Electric Power Supply, I&C System | No effect | Loss of or incorrect LST pressure indication | Restore power supply |
| | | 2. Transmitter failure | -- | No effect | Loss of or incorrect LST pressure indication | Repair component |
| | | 3. Instrument connection leak | -- | Small loss of LST inventory | Loss of or incorrect LST pressure indication | Repair component |
| 3.3 | HPI Pump Suction Headers: | | | | | |
| 3.3.1 | Motor Operated Isolation Valve HP-23 (HP-V21) | 1. Valve fails closed | -- | Flow to HPI pumps stopped, loss of NPSH to HPI pump resulting possible in pump damage | Immediate loss of flow to RC makeup and RC pump seals | Align supply from BWST via motor operated valves and align alternate HPI pump if required |

Reference Drawings: FSAR Figure 9.3-2 (Sheet 1)

## SUBSYSTEM 3.0: HPI PUMP SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 3.3.1 | Motor Operated Isolation Valve HP-23 (HP-V21) (cont'd) | 2. Valve closes on spurious signal | I&C System | Flow to HPI pumps stopped, loss of NPSH to HPI pump resulting possible in pump damage | Immediate loss of flow to RC makeup and RC pump seals | Manually open valve or align supply from BWST via motor operated valves and align alternate HPI pump if required |
| | | 3. Valve inadvertantly closed | -- | Flow to HPI pumps stopped, loss of NPSH to HPI pump resulting possible in pump damage | Immediate loss of flow to RC makeup and RC pump seals | Reopen valve, align alternate HPI pump if required |
| | | 4. Valve fails to close when required | I&C System, Electric Power Supply, Internal Fault | LST discharge not isolated | No effect | Utilize local valves for isolation |
| 3.3.2 | Check Valve HP-97 | 1. Valve fails closed | -- | Flow to HPI pump stopped, loss of NPSH to HPI pump resulting in possible pump damage | Immediate loss of flow to RC makeup and RC pump seals | Align supply from BWST via motor operated valves and align alternate HPI pump if required |
| | | 2. Valve fails to prevent backflow | -- | No effect during steady state operation | No effect during steady state operation | Monitor pressure and level in LST. Isolate LST if BWST flow is aligned |
| 3.3.3 | Motor Operated Isolation Valve HP-98 (HP-V28A) | 1. Valve fails closed | -- | Flow to HPI pump 1A stopped, if in use pump 1A may be damaged | If HP-P1A in use, loss of flow to RC makeup and seal injection. If HP-P1B in use, no effect | Trip HPI pump 1A and use pump 1B |
| | | 2. Valve inadvertantly closed | -- | Flow to HPI pump 1A stopped, if in use pump 1A may be damaged | If HP-P1A in use, loss of flow to RC makeup and seal injection. If HP-P1B in use, no effect | Trip HPI pump 1A and use pump 1B |
| | | 3. Valve closes on spurious signal | I&C System | Flow to HPI pump 1A stopped, if in use pump 1A may be damaged | If HP-P1A in use, loss of flow to RC makeup and seal injection. If HP-P1B in use, no effect | Trip HPI pump 1A and use pump 1B |
| | | 4. Valve fails to close on demand | -- | Cannot remotely isolate pump HP-P1A for maintenance | No effect | Isolate pump HP-P1A with manual valves. If desired, utilize one of 2 remaining HPI pumps |

Reference Drawings: FSAR Figure 9.3-2 (Sheet 1)

# SUBSYSTEM 3.0: HPI PUMP SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 3.3.3 | Motor Operated Isolation Valve HP-98 (HP-V28A) (cont'd) | 5. Valve fails to close when required | I&C System | Cannot remotely isolate pump HP-P1A for maintenance | No effect | Isolate pump HP-P1A with manual valves. If desired, utilize one of 2 remaining HPI pumps |
| | | 6. Valve fails to close when required | Electric Power Supply | Cannot remotely isolate pump HP-P1A for maintenance | No effect | Isolate pump HP-P1A with manual valves. If desired, utilize one of 2 remaining HPI pumps |
| 3.3.4 | Manual Isolation Valves HP-99 (HP-V28B), HP-100 (HP-V28C), HP-111 (HP-V26C) | 1. Valve fails closed (plugging, damaged, etc.) | -- | Suction to standby pump HP-P1C blocked. If pump is started, pump may be damaged | If pump HP-P1C in use, loss of flow to RC makeup and seal injection. If other pump in use, no effect | Utilize alternate HPI pump |
| 3.3.5 | Manual Isolation Valve HP-107 (HP-V26B) | 1. Valve fails closed (plugging, damaged, etc.) | -- | Suction to standby pump HP-P1B blocked. If pump is started, pump may be damaged | If pump HP-P1B in use, loss of flow to RC makeup and seal injection. If other pump in use, no effect | Utilize alternate HPI pump |
| 3.3.6 | Manual Isolation Valve HP-103 (HP-V26A) | 1. Valve fails closed (plugging, damaged, etc.) | -- | Flow to operating pump HP-P1A blocked. Unless pump is tripped, pump damage could occur | If pump HP-P1A in use, loss of flow to RC makeup and seal injection. If other pump in use, no effect | Trip HPI pump 1A and utilize pump 1B |
| 3.4 | HPI Pumps and Discharge Manifold: | | | | | |
| 3.4.1 | Operating HPI Pump HP-P1A | 1. Mechanical failure to operate | -- | No discharge flow from failed pump | No flow to RC makeup or RC pump seals | Utilize alternate HPI pump |
| | | 2. Pump fails due to loss of power | Electric Power Supply | No discharge flow from failed pump | No flow to RC makeup or RC pump seals | Restore power or utilize an alternate HPI pump on another power source |
| 3.4.2 | Spare HPI Pumps HP-P1B, HP-P1C | 1. Pump fails to start due to signal failure | I&C System | No discharge flow from pump demanded | If pump is demanded because of failure with operating pump, no flow to RC makeup or RC pump seals. If pumps are just being switched, no effect | Utilize alternate HPI pump, repair circuit |

Reference Drawings: FSAR Figure 9.3-2 (Sheet 1)

# SUBSYSTEM 3.0: HPI PUMP SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 3.4.2 | Spare HPI Pumps HP-P1B, HP-P1C (cont'd) | 2. Pump fails to start due to internal fault | -- | No discharge flow from pump demanded | If pump is demanded because of failure with operating pump, no flow to RC makeup or RC pump seals. If pumps are just being switched, no effect | Utilize alternate HPI pump, repair pump |
| 3.4.3 | Discharge Check Valve(s) HP-105, HP-108 | 1. Valve in operating pump discharge fails closed (plugging, damaged, etc.) | -- | No discharge flow through failed valve | No flow from operating HPI pump to RC makeup or RC pump seals | Utilize alternate HPI pump |
| | | 2. Valve in standby pump discharge fails to prevent backflow | -- | Backflow through a nonoperating spare pump to suction of operating pump (potential HPI pump damage) | Reduced flow to seal injection and/or makeup | Isolate failed check valve (local action). Monitor critical flows |
| 3.4.4 | Recirculation Line(s) Associated With Pumps: HP-P1A, HP-P1B, HP-P1C | 1. Line blockage due to plugged block valve or orifice | Seal Return Cooler Inlet (Subsystem 2.0) | Potential damage to HPI pump via pump deadheading if pump discharge to makeup and seal injection is not enough for pump operation | Potential loss of RC makeup and seal injection | Utilize alternate HPI pump (other action available from outside the subsystem) |
| 3.4.5 | Discharge Block Valve(s) HP-106 (HP-V34A), HP-110 (HP-V34B), HP-114 (HP-V34C) | 1. Valve in operating pump discharge fails closed (plugged, damaged, etc.) | RCP Seals, Reactor Inlet Line Loops A, B and Crossovers A and B | No discharge flow through failed valve | No discharge flow from operating HPI pump to RC pumps seals or RC makeup | Utilize alternate HPI pump |
| 3.4.6 | Motor Operated Isolation Valve HP-115 (HP-V35A) | 1. Valve closes on spurious signal | I&C System | If pump HP-P1A operating, flow to seal injection is stopped. If pump HP-P1B is operating, flow to normal RC makeup is stopped | If pump HP-P1A operating, flow to seal injection is stopped. If pump HP-P1B is operating, flow to normal RC makeup is stopped | If operating pump is HP-P1A, start pump HP-P1B. If operating pump is HP-P1B, start HP-P1A or (for unthrottled makeup) open valve HP-118 to reactor inlet LOOP B |

# SUBSYSTEM 3.0: HPI PUMP SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 3.4.6 | Motor Operated Isolation Valve HP-115 (HP-V35A) (cont'd) | 2. Valve fails closed due to internal fault | -- | If pump HP-P1A operating, flow to seal injection is stopped. If pump HP-P1B is operating, flow to normal RC makeup is stopped | If pump HP-P1A operating, flow to seal injection is stopped. If pump HP-P1B is operating, flow to normal RC makeup is stopped | If operating pump is HP-P1A, start pump HP-P1B. If operating pump is HP-P1B, start HP-P1A or (for unthrottled makeup) open valve HP-118 to reactor inlet LOOP B |
| | | 3. Valve inadvertantly closed | -- | If pump HP-P1A operating, flow to seal injection is stopped. If pump HP-P1B is operating, flow to normal RC makeup is stopped | If pump HP-P1A operating, flow to seal injection is stopped. If pump HP-P1B is operating, flow to normal RC makeup is stopped | Reopen valve |
| | | 4. Valve fails to close when required | I&C System, Electric Power Supply, or Internal Fault | Intended isolation not effected | No effect on steady state operation | Utilize local isolation valves |
| 3.4.7 | Isolation Valve HP-118 (HP-V35B) | 1. Valve fails open (damaged, etc.) | -- | Loss of separation between HPI injection paths A and B | No effect during normal operation since injection path B is normally closed | Utilize HP-117 for isolation |
| 3.4.8 | Isolation Valve HP-117 (HP-V35C) | 1. Valve fails closed (plugging, damaged, etc.) | -- | Loss of ability to use HP-P1B as spare for safety injection to cold leg B | Loss of ability to use HP-P1B as spare for safety injection to cold leg B | Repair component |
| 3.5 | System Inlet Flows: | | | | | |
| 3.5.1 | Reactor Coolant Letdown Inlet Flow | 1. Loss of flow | Subsystem 1.0 | Reduction and eventual loss of available makeup in LST, loss of letdown flow to subsystem | Loss of letdown flow to subsystem | Monitor LST level and utilize supply from BWST, bleed holdup tank, or boric acid tank |
| 3.5.2 | RC Bleed Makeup Feed Inlet Flow | 1. Loss of flow | Subsystem 6.0 | If in letdown/bleed and feed operating mode, reduction in LST level | Loss of batch inputs to LST from RC bleed makeup | Restore letdown flow to LST |
| 3.5.3 | RCP Seal Return Inlet Flow | 1. Loss of flow | Subsystem 2.0 | Partial loss of flow to LST, loss of HPI pump recirculation | Potential long-term loss of LST level and requirement to switch to BWST suction | Monitor LST level, utilize RC bleed makeup or BWST if required |

Reference Drawings: FSAR Figure 9.3-2 (Sheet 1)

## SUBSYSTEM 3.0: HPI PUMP SUBSYSTEM (Continued)

| Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|
| 3.6 System Piping: | | | | | |
| 3.6.1 Vents, Drains, Piping, Instrument Connections, etc. | 1. System leaks | -- | Loss of reactor coolant, potential for loss of NPSH to HPI pumps | Loss of reactor coolant, potential for slight reduction in makeup flow or seal injection | Isolate leak, utilize supply from BWST if required |

# APPENDIX D

## FAILURE MODES AND EFFECTS ANALYSIS
## SUBSYSTEM 4.0: RC PUMP SEAL INJECTION SUBSYSTEM

Reference Drawings: FSAR Figure 9.3-2 (Sheets 1 and 4)

# SUBSYSTEM 4.0: RC PUMPS SEAL INJECTION

| Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|
| **4.1 RC Pumps Seal Injection Header:** | | | | | |
| 4.1.1 Seal Injection Header Manual Isolation Valve HP-126 (HP-V27B) | 1. Valve fails closed (plugged, damaged, etc.) | -- | Seal injection flow stopped | Seal injection flow to RC pumps stopped | Repair component |
| 4.1.2 Seal Injection Header Pressure Transmitter 1PT-18 | 1. Incorrect output due to loss of power | I&C System, Electric Power Supply | No effect | Incorrect pressure signal | Repair component |
| | 2. Instrument connection leak | -- | Small loss of reactor coolant | Incorrect pressure signal | Repair component |
| | 3. Transmitter failure due to internal fault | -- | No effect | Incorrect pressure signal | Repair component |
| **4.2 RC Pump Seal Filters:** | | | | | |
| 4.2.1 Operating Filter Manual Isolation Valves HP-29, HP-132, HP-133, HP-134 | 1. Valve fails closed (plugged, damaged, etc.) | -- | Flow through filter stopped | Seal injection flow to RC pumps stopped | Valve in spare filter path, or bypass both main and standby filters (local action) |
| 4.2.2 Operating Seal Filter HP-F-1B (HP-F-1A Standby) | 1. Filter plugged | -- | Flow through filter stopped | Seal injection flow to RC pumps stopped | Valve in spare filter path, or bypass both main and standby filters (local action) |
| 4.2.3 Manual Isolation Valves for Standby Filter or Bypass HP-28, HP-135 | 1. Valve fails to open on demand | -- | No effect during normal operation. Loss of spare or bypass capacity | No effect during normal operation when spare or bypass is not demanded | If one of these backups has failed, utilize the remaining one if required |
| 4.2.4 Standby Filter Manual Isolation Valves HP-129, HP-130, HP-131 | 1. Valve fails closed (plugged, damaged, etc.) | -- | Flow through standby filter prevented | No effect | Valve in filter bypass if required (local action) |
| **4.3 Seal Injection Flow Control:** | | | | | |
| 4.3.1 Flow Orifice | 1. Orifice plugged | -- | Seal injection flow reduced or stopped and control signal to throttle valve incorrect | Seal injection flow to RC pumps stopped | Repair component |

Reference Drawings: FSAR Figure 9.3-2 (Sheets 1 and 4)

## SUBSYSTEM 4.0: RC PUMP SEAL INJECTION SUBSYSTEM (Continued)

| | Component | Potential Failure Mode | | Immediate Effects | | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| | | Mode | Interface Involved | Within Subsystem | At Subsystem Interface | |
| 4.3.2 | Flow Controller/ Transmitter 1PT-75 | 1. Transmitter failure | Electric Power Supply, I&C System, Internal Fault | Incorrect signal to flow control valve, potentially resulting in too much or too little flow. | Negligable effect for high flow since flow is throttled downstream. On low flow, reduced seal injection flow to RC pumps. Incorrect signal to I&C system | Monitor and control flow from individual seal injection lines if required |
| 4.3.3 | Flow Control Valve HP-31 (HP-V42) | 1. Valve fails open (valve assumed air-to-close) | Instrument Air | Full HPI pump discharge flow to individual seal injection lines | Negligable effect on seal injection supply | Manually control seal flow with HP-140 or with individual seal injection line throttle valves (local action) |
| | | 2. Valve fails open | Control Signal from 1FT-75, Electric Power Supply | Full HPI pump discharge flow to individual seal injection lines | Negligable effect on seal injection supply | Manually control seal flow with HP-140 or with individual seal injection line throttle valves (local action) |
| | | 3. Valve fails open due to internal damage | -- | Full HPI pump discharge flow to individual seal injection lines | Negligable effect on seal injection supply | Manually control seal flow with HP-140 or with individual seal injection line throttle valves (local action) |
| | | 4. Valve fails closed | Control Signal from 1FT-75, Electric Power Supply | Seal injection flow reduced or stopped | Seal injection flow to RC pumps stopped | Valve in bypass and manually control seal flow from header (HP-140) or from individual seal injection lines (local action) |
| | | 5. Valve fails closed due to internal damage or plugging, etc. | -- | Seal injection flow reduced or stopped | Seal injection flow to RC pumps stopped | Valve in bypass and manually control seal flow from header (HP-140) or from individual seal injection lines (local action) |

## SUBSYSTEM 4.0: RC PUMP SEAL INJECTION SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 4.3.4 | Manual Isolation Valve(s) HP-138, HP-139 | 1. Valve fails closed (plugged, damaged, etc.) | -- | Seal injection flow stopped | Seal injection flow to RC pumps stopped | Valve in bypass and manually control seal flow from header (HP-140) or from individual seal injection lines (local action) |
| 4.4 | Individual RC Pump Seal Injection Lines (4 Total, 1/RC Pump): | | | | | |
| 4.4.1 | Flow Transmitter(s) 1FT-101, 1FT-102, 1FT-103, 1FT-104 | 1. Incorrect output due to loss of power | I&C System, Electric Power Supply | No effect | Incorrect flow signal to control room | Restore power |
| | | 2. Instrument connection leak | -- | Small loss of reactor coolant | Incorrect flow signal to control room | Repair component if accessible |
| | | 3. Transmitter failure due to internal fault | -- | No effect | Incorrect flow signal to control room | Repair component if accessible |
| 4.4.2 | Manual Throttle Valve(s) HP-64, HP-65, HP-66, HP-67 | 1. Valve fails closed (plugged, damaged, etc.) | -- | Seal injection flow in affected line stopped | Seal injection flow to one RC pump stopped | Repair component if accessible |
| | | 2. Valve fails open | -- | Flow in affected line unthrottled | Seal injection flow to a single RC pump higher than setpoint | Repair component, utilize stop check valves in line on short term basis for flow throttling if required (local action) |
| 4.4.3 | Check Valves (2/line) HP-144, HP-145, HP-146, HP-147, HP-283, HP-284, HP-286, HP-393 | 1. Valve fails closed | -- | Flow in affected seal injection line stopped | Seal injection flow to a single RC pump stopped | Repair component if accessible |
| | | 2. Valve fails to prevent backflow | -- | No effect since there are 2 check valves per line (one inside and one outside RB) | No effect since there are 2 check valves per line | Repair component at shutdown |
| 4.4.4 | Manual Isolation Valves On Line to RC Pump HP-394, HP-285 | 1. Valve fails closed | -- | Flow in affected Seal Injection line stopped | Seal injection flow to a single RC pump stopped | Repair component if accessible |
| 4.5 | System Inlet Flows: | | | | | |
| 4.5.1 | Seal Injection Flow From HPI Pumps | 1. Loss of flow | Subsystem 3.0 | No flow | Loss of Seal Injection to RC pumps | None |

Reference Drawings: FSAR Figure 9.3-2 (Sheets 1 and 4)

## SUBSYSTEM 4.0: RC PUMP SEAL INJECTION SUBSYSTEM (Continued)

| Component | Potential Failure Mode | | Immediate Effects | | Remedial Action Within Subsystem |
|---|---|---|---|---|---|
| | Mode | Interface Involved | Within Subsystem | At Subsystem Interface | |
| 4.6 System Piping: | | | | | |
| 4.6.1 Vents, Drains, Piping, Instrument Connections, etc. | 1. System leaks | -- | Loss of reactor coolant | Loss of reactor coolant, potential for slight reduction in seal injection rate if leak is downstream of flow control valve (HP-31) | Isolate leaks and repair as needed |

# APPENDIX E

## FAILURE MODES AND EFFECTS ANALYSIS
## SUBSYSTEM 5.0: REACTOR COOLANT MAKEUP SUBSYSTEM

Reference Drawings: FSAR Figure 9.3-2 (Sheets 1 and 4)

# SUBSYSTEM 5.0: REACTOR COOLANT (RC) MAKEUP

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 5.1 | Reactor Inlet Line Loop A Header: | | | | | |
| 5.1.1 | Manual Isolation Valve HP-118 (HP-V27A) | 1. Valve fails closed (plugging, damaged, etc.) | -- | Makeup flow stopped | Loss of normal makeup flow | Repair component, if required provide makeup flow via Loop B injection path (open local HP-18 and throttle with remote HP-27) |
| 5.1.2 | Flow Transmitter 1FT-7, 7A and 7B | 1. Transmitter failure due to internal fault | -- | No effect | Incorrect flow signal on one transmitter | Repair component |
| | | 2. Incorrect output due to signal failure | I&C System, Electric Power Supply | No effect | Incorrect flow signal from all 3 transmitters | Restore power supply |
| | | 3. Instrument connection leak | -- | Small loss of reactor coolant | Incorrect flow signals from all 3 transmitters | Repair component |
| 5.1.3 | Motor Operated Valve HP-26 (HP-V24A) | 1. Valve opens on spurious signal | I&C System | Makeup flow is not throttled | Increased makeup flow, increased pressurizer level, drop in LST level, potential loss of HPI pump NPSH | Manually close valve (local action) |
| | | 2. Valve opens on spurious signal | ES | Makeup flow is not throttled | Increased makeup flow, increased pressurizer level, drop in LST level, potential loss of HPI pump NPSH | Manually close valve (local action) |
| | | 3. Valve inadvertantly opened | -- | Makeup flow is not throttled | Increased makeup flow, increased pressurizer level, drop in LST level, potential loss of HPI pump NPSH | Close valve |
| | | 4. Valve fails open due to internal fault | -- | Makeup flow is not throttled | Increased makeup flow, increased pressurizer level, drop in LST level, potential loss of HPI pump NPSH | Isolate with HP-118 (local action) (will stop makeup flow) |
| | | (Modes involving failure to open are part of emergency HPI and not included here) | | | | |
| 5.2 | Minimum Flow Bypass Loops: | | | | | |
| 5.2.1 | Manual Isolation Valve HP-234 | 1. Valve fails closed (plugging, damaged, etc.) | -- | No flow through minimum flow loop | No cooling flow to pressurizer spray line or cold leg inlet nozzles, no effect on makeup capacity | Repair component |

Reference Drawings: FSAR Figure 9.3-2
(Sheets 1 and 4)

## SUBSYSTEM 5.0: REACTOR COOLANT MAKEUP SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 5.2.2 | Flow Transmitters 1FT-117, 1FT-118 | 1. Instrument connection leak | -- | Small loss of coolant | Incorrect flow signal to control room | Repair component |
| | | 2. Incorrect output due to loss of power | Electric Power Supply, I&C System | No effect | Incorrect flow signal to control room | Restore power supply |
| | | 3. Transmitter failure due to internal fault | -- | No effect | Incorrect flow signal to control room | Repair component |
| 5.2.3 | Manual Throttle Valve HP-241 | 1. Valve fails closed (plugging, damaged, etc.) | -- | Minimum flow path blocked to one of two reactor cold leg inlet nozzles | No cooling flow to one cold leg inlet nozzle | Repair component |
| | | 2. Valve fails open | -- | Minimum flow path unthrottled to one of two reactor cold leg inlet nozzles, automatic reduction in flow through normal makeup valve | Excess flow (full HPI pump discharge to minimum flow loop) to one reactor cold leg inlet nozzle, potential drop in LST level | If required valve HP-234 available to block flow into loop (local action), repair component |
| 5.2.4 | Manual Throttle Valve HP-235 | 1. Valve fails closed (plugging, damaged, etc.) | -- | Minimum flow path blocked to pressurizer spray line and one of two reactor cold leg inlet nozzles | No effect on reactor makeup, but no cooling flow to pressurizer spray line or to one cold leg inlet nozzle | Repair component |
| | | 2. Valve fails open | -- | Minimum flow path unthrottled to pressurizer spray line and one of two reactor cold legs, automatic reduction in flow through normal makeup valve | Excess flow to pressurizer spray line and to one reactor cold leg inlet nozzle, potential drop in LST level | Close valve HP-234, or valves HP-340 and HP-356 in reactor building (local action) |
| 5.2.5 | Manual Isolation Valve HP-340 | 1. Valve fails closed (plugging, damage, etc.) | -- | Minimum flow path blocked to pressurizer spray line | No bypass flow to pressurizer spray line | Repair component |
| 5.2.6 | Manual Isolation Valve HP-356 | 1. Valve fails closed (plugging, damage, etc.) | -- | Minimum flow path blocked to one of two reactor cold legs | No bypass cooling flow to one of two reactor cold leg inlet nozzles (no effect on normal makeup) | Repair component |
| 5.3 | Normal Makeup Flow Control Loop: | | | | | |
| 5.3.1 | Flow Transmitter 1FT-10, 10A, 10B | 1. Instrument connection leak | -- | Small loss of coolant | Incorrect flow signal from all transmitters | Monitor flow with FT-7, repair component |
| | | 2. Incorrect output due to loss of power | Electric Power Supply, I&C System | No effect | Incorrect flow signal from all transmitters | Monitor flow with FT-7, restore powere supply |
| | | 3. Transmitter failure | -- | None | Incorrect flow signal from failed transmitter | Monitor flow with FT-7, repair component |

# SUBSYSTEM 5.0: REACTOR COOLANT MAKEUP SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 5.3.2 | Flow Control Valve HP-120 (HP-V23) | 1. Valve fails closed (assuming valve is air-to-open) | Instrument Air | Normal flow to reactor inlets stopped, flow through minimum flow loop continues | Bypass flow continues. Overall significant reduction in makeup flow | If required, manually control with bypass valve HP-26 |
| | | 2. Valve fails closed due to internal fault | -- | Normal flow to reactor inlets stopped, flow through minimum flow loop continues | Bypass flow continues. Overall significant reduction in makeup flow | If required, manually control with bypass valve HP-26 |
| | | 3. Valve closes down due to incorrect control signal | I&C System | Normal flow to reactor inlets reduced, flow through minimum flow loop continues | Bypass flow continues. Overall significant reduction in makeup flow | If required, manually control with bypass valve HP-26 |
| | | 4. Valve fails open due to internal fault | -- | HPI flow not throttled. Excess makeup flow to RCS | Excess makeup flow to RCS, temporary decreased bypass flow to pressurizer spray line, potential drop in LST holdup, potential loss of NPSH to HPI pump | Isolate valve HP-120 and manually control flow with bypass valve HP-26 |
| | | 5. Valve opens up due to incorrect control signal | I&C System | HPI flow not throttled. Excess makeup flow to RCS | Excess makeup flow to RCS, temporary decreased bypass flow to pressurizer spray line, potential drop in LST holdup, potential loss of NPSH to HPI pump | Isolate valve HP-120 and manually control flow with bypass valve HP-26 |
| 5.3.3 | Manual Isolation Valves HP-119, HP-121 | 1. Valve fails closed (plugging, damage, etc.) | -- | Normal makeup flow to RCS stopped, bypass flow through minimum flow loop continues | Bypass flow continues. Overall significant reduction in makeup flow | Isolate valve HP-120 and manually control flow with bypass valve HP-26 |
| 5.3.4 | Check Valve HP-194 | 1. Valve fails closed (plugging, damage, etc.) | -- | Normal makeup flow to RCS stopped, bypass flow through minimum flow loop continues | Bypass flow continues Overall significant reduction in makeup flow | If required, provide makeup flow via Loop B injection path (open local HP-118 and throttle with remote HP-27) |
| | | 2. Valve fails to prevent backflow | -- | No effect during steady state operation | No effect during steady state operation | Repair component at shutdown |
| 5.3.5 | Inlet Line Orifices | 1. Orifice plugged | -- | Normal flow to one of two cold legs stopped or reduced, increased flow to the other cold leg | Flow imbalance between the two reactor cold legs | Repair component |

Reference Drawings: FSAR Figure 9.3-2 (Sheets 1 and 4)

## SUBSYSTEM 5.0: REACTOR COOLANT MAKEUP SUBSYSTEM (Continued)

| | | Potential Failure Mode | | Immediate Effects | | |
|---|---|---|---|---|---|---|
| | Component | Mode | Interface Involved | Within Subsystem | At Subsystem Interface | Remedial Action Within Subsystem |
| 5.3.6 | Inlet Line Check Valves HP-126, HP-127 | 1. Valve failed closed (plugging, damage, etc.) | -- | Normal flow to one of two reactor cold legs stopped or reduced, increased flow to the other cold leg | Flow imbalance between the two reactor cold legs | Repair component |
| 5.4 | Subsystem Input: | | | | | |
| 5.4.1 | Flow From HPI Pumps | 1. Loss of flow | Subsystem 3.0 | Loss of makeup flow and flow to pressurizer spray line | Loss of makeup flow and bypass flow to pressurizer spray line | None |
| | | 2. Reduced flow | Subsystem 3.0 | Reduced makeup flow and reduced flow to pressurizer spray line | Reduced makeup flow and bypass reduced flow to pressurizer spray line | None |
| 5.5 | System Piping: | | | | | |
| 5.5.1 | Vents, Drains, Piping, Instrument Connections, etc. | 1. System leaks | -- | Loss of reactor coolant | Loss of reactor coolant, potential for reduction in reactor coolant makeup rate | Isolate leaks and repair as needed |

**APPENDIX F**

FAILURE MODES AND EFFECTS ANALYSIS
SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM

Reference Drawings: FSAR Figure 9.3-1 (Sheet 1)
FSAR Figure 9.3-2 (Sheet 3)
FSAR Figure 9.3-5 (Sheets 1,3,&4)

# SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM

| Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|
| 6.1 Chemical Addition: | | | | | |
| 6.1.1 Manual Control Valve (N-83) | 1. $N_2$ blanket system fails | $N_2$ Blanket | Possible $N_2H_4$ backflow; no $N_2$ blanket in $N_2H_4$ drum | No $N_2H_4$ available to makeup filters | Close control valve N-83 |
| | 2. Valve fails closed | -- | No $N_2$ blanket in $N_2H_4$ drum; possible explosive mixture | Probably none | |
| 6.1.2 Check Valve (N-84) | 1. Fails to prevent backflow | -- | $N_2H_4$ backflow; possible explosive mixture | No $N_2H_4$ available to makeup filters | Close control valve N-83 |
| 6.1.3 Hydrazine Drum | 1. Drum leaks | -- | Possible explosive mixture; eventual loss of suction pressure to pump | Eventual loss of $N_2H_4$ available to makeup filters | Isolate drum and replace |
| | 2. Drum emptied | -- | No $N_2H_4$ | No $N_2H_4$ available to makeup filters | Isolate drum and replace |
| 6.1.4 Manual Isolation Valves (CA-88, CA-45) | 1. Valves fail closed | -- | No $N_2H_4$ | No $N_2H_4$ available to makeup filters | None |
| 6.1.5 Manual Isolation Valves (CA-52, CA-54) | 1. Valves fail closed | -- | No $N_2H_4$ | None if alternate flow path available | Open CA-46; crossover to pump CA-P3 |
| 6.1.6 Hydrazine Pump (CA-P4) | 1. Electric power supply fails | Electric Power | Pump stops; no $N_2H_4$ | None if alternate flow path available | Open CA-46; crossover to pump CA-P3 |
| | 2. Pump fails | -- | No $N_2H_4$ | None if alternate flow path available | Open CA-46; crossover to pump CA-P3 |
| 6.1.7 Check Valve (CA-56) | 1. Fails to prevent backflow | -- | Possible backflow to drum if pump is not running | No $N_2H_4$ available to makeup filters | Close CA-54 |
| 6.1.8 Manual Isolation Valve (DW-121) | 1. Demineralized water supply fails | Demineralized Water | No demineralized water to tank | No LiOH available to makeup filters | None |
| | 2. Valve fails closed | -- | No demineralized water to tank | No LiOH or incorrect LiOH concentration available to makeup filters | Concentration checked via sampling |
| | 3. Valve fails open | -- | Dilutes LiOH in tank | Incorrect LiOH concentration available to makeup filters | Concentration checked via sampling |
| 6.1.9 LiOH Mix Tank (CA-T3) | 1. Tank leaks | -- | Eventual loss of suction pressure to pump | Eventual loss of LiOH available to makeup filters | None |
| | 2. Tank empties | -- | No LiOH | No LiOH available to makeup filters | None |
| 6.1.10 Sampling, Waste Lines | 1. Lines fail open | -- | Decreased LiOH | Decreased LiOH available to makeup filters | None |

Reference Drawings: FSAR Figure 9.3-1 (Sheet 1)
FSAR Figure 9.3-2 (Sheet 3)
FSAR Figure 9.3-5 (Sheets 1,3,&4)

## SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 6.1.11 | Manual Isolation Valve (CA-44) | 1. Valve fails closed | -- | No LiOH | No LiOH available to makeup filters | None |
| 6.1.12 | Manual Isolation Valve (CA-47, CA-49) | 1. Valves fail closed | -- | No LiOH | None if alternate flow path available | Open CA-46; crossover to pump CA-P4 |
| 6.1.13 | LiOH Pump (CA-P3) | 1. Electric power supply fails | Electric Power | Pump stops; no LiOH | None if alternate flow path available | Open CA-46; crossover to pump CA-P4 |
| | | 2. Pump fails | -- | No LiOH | None if alternate flow path available | Open CA-46; crossover to pump CA-P4 |
| 6.1.14 | Check Valve (CA-51) | 1. Fails to prevent backflow | -- | Possible backflow to tank if pump is not running | No LiOH available to makeup filters | Close CA-49 |
| 6.1.15 | Manual Isolation Valve (DW-120) | 1. Demineralized water supply fails | Demineralized Water | No demineralized water to tank; no caustic or incorrect caustic concentration available to boron recovery | No caustic or incorrect caustic concentration available to LPI pumps | Concentration checked via sampling |
| | | 2. Valve fails closed | -- | No demineralized water to tank; no caustic or incorrect caustic concentration available to boron recovery | No caustic or incorrect caustic concentration available to LPI pumps | Concentration checked via sampling |
| | | 3. Valve fails open | -- | Dilutes caustic in tank; incorrect caustic concentration available to boron recovery | Incorrect caustic concentration available to LPI pumps | Concentration checked via sampling |
| 6.1.16 | Caustic Mix Tank (CA-T1) | 1. Tank leaks | -- | Eventual loss of suction pressure to pump | Eventual loss of caustic available to LPI pumps | None |
| | | 2. Tank empties | -- | No caustic available to boron recovery | No caustic available to LPI pumps | None |
| 6.1.17 | Manual Isolation Valves (CA-34, CA-35, CA-37) | 1. Valves fail closed | -- | No caustic available to boron recovery | No caustic available to LPI pumps | None |
| 6.1.18 | Caustic Pump (CA-P1) | 1. Electric power supply fails | Electric Power | Pump stops; no caustic available to boron recovery | No caustic available to LPI pumps | None |
| | | 2. Pump fails | -- | No caustic available to boron recovery | No caustic available to LPI pumps | None |
| 6.1.19 | Sampling, Waste Lines | 1. Lines fail open | -- | Decreased caustic available to boron recovery | Decreased caustic available to LPI pumps | None |

Reference Drawings: FSAR Figure 9.3-1 (Sheet 1)
FSAR Figure 9.3-2 (Sheet 3)
FSAR Figure 9.3-5 (Sheets 1,3,&4)

## SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM (Continued)

| Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|
| 6.2 Boric Acid Addition: | | | | | |
| 6.2.1 Manual Isolation Valve (DW-118) | 1. Demineralized water supply fails | Demineralized Water | No demineralized water to tank; no boric acid or incorrect boric acid concentration available to concentrated boric acid storage tanks | None if concentrated boric acid available from boron recovery or adequate concentrated boric acid storage tank inventory is available | Concentration checked via sampling |
| | 2. Valve fails closed | -- | No demineralized water to tank; no boric acid or incorrect boric acid concentration available to concentrated boric acid storage tanks | None if concentrated boric acid available from boron recovery or adequate concentrated boric acid storage tank inventory is available | Concentration checked via sampling |
| | 3. Valve fails open | -- | Dilutes boric acid; incorrect boric acid concentration to concentrated boric acid storage tanks | None if concentrated boric acid available from boron recovery or adequate concentrated boric acid storage tank inventory is available | Concentration checked via sampling |
| 6.2.2 Boric Acid Mix Tank (CA-T2) | 1. Electric power supply fails | Electric Power | Heater fails; boric acid may crystallize; small potential for plugging and loss of flow to storage tanks | None if concentrated boric acid available from boron recovery or adequate concentrated boric acid storage tank inventory is available | Replace heater; unplug lines |
| | 2. Heater fails | -- | Boric acid may crystallize; small potential for plugging and loss of flow to storage tanks | None if concentrated boric acid available from boron recovery or adequate concentrated boric acid storage tank inventory is available | Replace heater; unplug lines |
| | 3. Tank leaks | -- | Eventual loss of suction pressure to pumps | None if concentrated boric acid available from boron recovery or adequate concentrated boric acid storage tank inventory is available | None |
| | 4. Tank empties | -- | No boric acid flow to concentrated boric acid storage tanks | None if concentrated boric acid available from boron recovery or adequate concentrated boric acid storage tank inventory is available | None |
| 6.2.3 Level Transmitter | 1. Electric power supply fails | Electric Power | No local level indication | No level indication to I&C system | None |
| | 2. Connection leaks | Process Signal | Incorrect signal to transmitter | No level indication to I&C system | None |
| | 3. Transmitter fails | -- | No local level indication | No level indication to I&C system | None |

Reference Drawings: FSAR Figure 9.3-1 (Sheet 1)
FSAR Figure 9.3-2 (Sheet 3)
FSAR Figure 9.3-5 (Sheets 1,3,&4)

## SUBSYSTEM 6.0: CHEMICAL PROCESSING SUB'ISTEM (Continued)

| | | Potential Failure Mode | | Immediate Effects | | |
|---|---|---|---|---|---|---|
| | Component | Mode | Interface Involved | Within Subsystem | At Subsystem Interface | Remedial Action Within Subsystem |
| 6.2.4 | Temperature Transmitter | 1. Electric power supply fails | Electric Power | No local temperature indication | None | None |
| | | 2. Connection leaks | Process Signal | Incorrect signal to transmitter | None | None |
| | | 3. Transmitter fails | -- | No local temperature indication | None | None |
| 6.2.5 | Manual Isolation Valve (CA-4) | 1. Valve fails closed | -- | No boric acid to storage tanks | None if concentrated boric acid available from boron recovery or adequate concentrated boric acid storage tank inventory is available | None |
| 6.2.6 | Miscellaneous Piping | 1. Electric power supply to trace heating fails | Electric Power | Boric acid may crystallize; small potential for plugging and loss of flow to concentrated boric acid storage tanks | None if concentrated boric acid available from boron recovery or adequate concentrated boric acid storage tank inventory is available | Restore trace heating; unplug lines |
| | | 2. Trace heating fails | -- | Boric acid may crystallize; small potential for plugging and loss of flow to concentrated boric acid storage tanks | None if concentrated boric acid available from boron recovery or adequate concentrated boric acid storage tank inventory is available | Restore trace heating; unplug lines |
| 6.2.7 | Manual Isolation Valve (CA-5) | 1. Valve fails closed | -- | No boric acid to concentrated boric storage tanks; alternate flow path available | None | Alternate flow path through CA-P2B available |
| 6.2.8 | LP Boric Acid Pump (CA-P2A) | 1. Electric power supply fails | Electric Power | Pump stops; no boric acid to concentrated storage tanks; alternate flow path available | None | Alternate flow path through CA-P2B available |
| | | 2. Pump fails | -- | No boric acid to concentrated boric acid storage tanks; alternate flow path available | None | Alternate flow path through CA-P2B available |
| 6.2.9 | Manual Isolation Valve (CA-7) | 1. Valve fails closed | -- | No boric acid to concentrated boric acid storage tanks; alternate flow path available | None | Alternate flow path through CA-P2B available |
| 6.2.10 | Check Valve (CA-15) | 1. Fails to prevent backflow | -- | Possible backflow to mix tank if pump is not running; alternate flow path available | None | Close isolation valve CA-7; alternate flow path through CA-P2B available |

## SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 6.2.11 | Manual Isolation Valves (1CA-16, 1CA-13, 1CA-18, etc.) | 1. Valves fail closed | -- | No boric acid to concentrated boric acid storage tanks | None if concentrated boric acid available from boron recovery or adequate concentrated boric acid storage tank inventory is available | None |
| 6.2.12 | Pressure Transmitter | 1. Electric power supply fails | Electric Power | No local pressure indication | No pressure indication to I&C system | None |
| | | 2. Connection leaks | Process Signal | Incorrect signal to transmitter | No pressure indication to I&C system | None |
| | | 3. Transmitter fails | -- | No local pressure indication | No pressure indication to I&C system | None |
| 6.2.13 | Check Valve (CA-85) | 1. Fails to prevent backflow | -- | Possible backflow if pump is not running | None if concentrated boric acid available from concentrated boric acid transfer pumps | Close 1CA-16, 1CA-18 |
| 6.2.14 | Manual Isolation Valve (CA-25) | 1. Valve fails closed | -- | No boric acid | No boric acid available to core flood tanks | None |
| 6.2.15 | HP Boric Acid Pump (CA-P5) | 1. Electric power supply fails | Electric Power | Pump stops; no boric acid | No boric acid available to core flood tank | None |
| | | 2. Pump fails | -- | No boric acid | No boric acid available to core flood tank | None |
| 6.2.16 | Manual Isolation Valves (1CA-26, 1CA-28) | 1. Valves fail to open, fail closed | -- | No boric acid | No boric acid available to core flood tank | None |
| 6.2.17 | Manual Control Valve (CS-62) | 1. Valve fails closed | -- | No boric acid to concentrated boric acid storage tanks | No boric acid available to makeup filters, BWST | Alternate flow path available |
| 6.2.18 | Concentrated Boric Acid Storage Tank (1WD-T22) | 1. $N_2$ blanket system fails | $N_2$ Blanket | Possible boric acid backflow | None | Close control valve CS-62 |
| | | 2. Electric power supply to trace heating fails | Electric Power | Boric acid crystallizes; potential plugging and loss of flow | No boric acid available to makeup filters, BWST | Alternate flow path available |
| | | 3. Trace heating fails | -- | Boric acid crystallizes; potential plugging and loss of flow | No boric acid available to makeup filters, BWST | Alternate flow path available |
| | | 4. Inlet boric acid flow fails | Boric Acid From Mix Tank/RC Bleed Evaporator Concentrate Cooler | No boric acid | None unless concentrated boric acid storage tanks are empty | Alternate flow path available |

Reference Drawings: FSAR Figure 9.3-1 (Sheet 1)
FSAR Figure 9.3-2 (Sheet 3)
FSAR Figure 9.3-5 (Sheets 1,3,4)

## SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 6.2.18 | Concentrated Boric Acid Storage Tank (1WD-T22) (cont'd) | 5. Tank leaks | -- | Possible flooding; eventual loss of suction pressure to pump | Eventual loss of boric acid available to makeup filters, BWST | Alternate flow path available |
| | | 6. Tank empties | -- | No boric acid | No boric acid available to makeup filters, BWST | Alternate flow path available |
| | | 7. Tank vent, relief valves fail open | -- | Cover gas release to vent header | None | None |
| | | 8. Drain, sample lines fail open | -- | Decreased boric acid | Decreased boric acid available to makeup filters, BWST | Alternate flow path available |
| 6.2.19 | Level Transmitter | 1. Electric power supply | Electric Power | No local level indication | No level indication to I&C system | None |
| | | 2. Connection leaks | Process Signal | Incorrect signal to transmitter | No level indication to I&C system | None |
| | | 3. Transmitter fails | -- | No local level indication | No level indication to I&C system | None |
| 6.2.20 | Manual Isolation, Control Valves (CS-63, CS-64, CS-67) | 1. Valves fail closed | -- | No boric acid | No boric acid available to makeup filters, BWST | Alternate flow path available |
| 6.2.21 | Concentrated Boric Acid Transfer Pump (1WD-P22) | 1. Electric power supply fails | Electric Power | Pump stops; no boric acid | No boric acid available to makeup filters, BWST | Alternate flow path available |
| | | 2. Pump fails | -- | No boric acid | No boric acid available to makeup filters, BWST | Alternate flow path available |
| 6.2.22 | Manual Isolation Valve (CS-68) | 1. Valve fails closed | -- | No boric acid | No boric acid available to makeup filters, BWST | Alternate flow path available |
| 6.2.23 | Manual Isolation Valves (CS-72, CS-79) | 1. Valves fail closed | -- | No boric acid | No boric acid available to available to makeup filters, BWST | Alternate flow path available |
| 6.2.24 | Check Valve (CS-73) | 1. Fails to prevent backflow | -- | Possible backflow if pump is not running | None if concentrated boric acid available from LP boric acid pump | Close CS-72 |
| 6.3 | RC Bleed Holdup Tanks and Transfer Pumps: | | | | | |
| 6.3.1 | Manual Control Valve (CS-41) | 1. RC Bleed flow fails | RC Bleed Flow | RC bleed holdup tank could empty; no impact since rest of subsystem operates only on demand | None if alternate flow path available | Alternate bleed flow available |
| | | 2. Valve fails closed | -- | RC bleed holdup tank could empty; no impact since rest of subsystem operates only on demand | None if alternate flow path available | Bleed flow can be diverted to 2WD-T21A |

Reference Drawings: FSAR Figure 9.3-1 (Sheet 1)
FSAR Figure 9.3-2 (Sheet 3)
FSAR Figure 9.3-5 (Sheets 1,3,44)

## SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 6.3.2 | RC Bleed Holdup Tank (1WD-T21A) | 1. $N_2$ blanket system fails | $N_2$ Blanket | Tank cannot be purged; no impact since rest of subsystem operates only on demand | None if alternate flow path available | None |
| | | 2. Tank leaks | -- | Possible flooding; eventual loss of suction pressure to pump; no impact since rest of subsystem operates only on demand | None if alternate flow path available | Alternate bleed flow available |
| | | 3. Tank empties | -- | No flow; no impact since rest of subsystem operates only on demand | None if alternate flow path available | Alternate bleed flow available |
| | | 4. Tank vent, relief valves fail open | -- | Cover gas release to vent header | None | None |
| 6.3.3 | Level Transmitter | 1. Electric power supply fails | Electric Power | No local level indication | No level indication to I&C system | None |
| | | 2. Connection leak | Process Signal | Incorrect signal to transmitter | No level indication to I&C system | None |
| | | 3. Transmitter failure | -- | No local level indication | No level indication to I&C system | None |
| 6.3.4 | Miscellaneous Piping | 1. Electric power supply to trace heating fails | Electric Power | Boric acid may crystallize; small potential for plugging and loss of flow; no impact since rest of subsystem operates only on demand | None if alternate flow path available | Restore trace heating; unplug lines; alternate bleed flow available |
| | | 2. Trace heating fails | -- | Boric acid may crystallize; small potential for plugging and loss of flow; no impact since rest of subsystem operates only on demand | None if alternate flow path available | Restore trace heating; unplug lines; alternate bleed flow available |
| 6.3.5 | Waste, Drain, Sample Lines | 1. Lines fail open | -- | Decreased flow; no impact since rest of subsystem operates only on demand | None if alternate flow path available | Alternate bleed flow available |
| 6.3.6 | Manual Isolation Valves (CS-42, CS-148, CS-44) | 1. Valves fail closed | -- | No flow to pump; no impact since rest of subsystem operates only on demand | None if alternate flow path available | Alternate bleed flow available |
| 6.3.7 | RC Bleed Transfer Pump (1WD-P21A) | 1. Electric power supply fails | Electric Power | Pump stops; no flow to boron recovery | None if alternate flow path available | Alternate bleed flow available |
| | | 2. Pump fails | -- | No flow to boron recovery | None if alternate flow path available | Alternate bleed flow available |
| 6.3.8 | Check Valve (CS-45) | 1. Fails to prevent backflow | -- | Possible backflow if pump is not running | None if alternate flow path available | Close control valve CS-46 |

## SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM (Continued)

| | | Potential Failure Mode | | Immediate Effects | | |
|---|---|---|---|---|---|---|
| | Component | Mode | Interface Involved | Within Subsystem | At Subsystem Interface | Remedial Action Within Subsystem |
| 6.3.9 | Flow Orifice | 1. Orifice plugs | -- | No flow to boron recovery | None if alternate flow path available | Alternate bleed flow available |
| 6.3.10 | Flow Transmitter | 1. Electric power supply fails | Electric Power | No local flow indication | No flow indication to I&C system | None |
| | | 2. Connection leak | Process Signal | Incorrect signal to transmitter | No flow indication to I&C system | None |
| | | 3. Transmitter failure | -- | No local flow indication | No flow indication to I&C system | None |
| 6.3.11 | Manual Control Valve (CS-46) | 1. Valve fails closed | -- | No flow to boron recovery | None if alternate flow path available | Alternate bleed flow available |
| 6.3.12 | Manual Isolation Valves (CS-80, CS-172, CT-1) | 1. Valves fail closed | -- | No flow to boron recovery | None if alternate flow path available | Alternate bleed flow available |
| 6.3.13 | Manual Isolation Valve (CT-88) | 1. Demineralized water supply fails | Demineralized Water | Demineralized water holdup tank could empty | No demineralized water to makeup filters | Alternate demineralized water flow path available |
| | | 2. Valve fails closed | -- | Demineralized water holdup tank could empty | No demineralized water to makeup filters | Alternate demineralized water flow path available |
| 6.3.14 | RC Demineralized Water Holdup Tank (1WD-T21B) | 1. $N_2$ blanket system fails | $N_2$ Blanket | Tank cannot be purged and is unavailable | No demineralized water to makeup filters | Alternate demineralized water flow path available |
| | | 2. Tank leaks | -- | Possible flooding; eventual loss of suction pressure to pump | Eventual loss of demineralized water to makeup filters | Alternate demineralized water flow path available |
| | | 3. Tank empties | -- | No demineralized water | No demineralized water to makeup filters | Alternate demineralized water flow path available |
| | | 4. Tank vent, relief valves fail open | -- | Cover gas release to vent header | None | None |
| 6.3.15 | Level Transmitter | 1. Electric power supply fails | Electric Power | No local level indication | No level indication to I&C system | None |
| | | 2. Connection leak | Process Signal | Incorrect signal to transmitter | No level indication to I&C system | None |
| | | 3. Transmitter failure | -- | No local level indication | No level indication to I&C system | None |
| 6.3.16 | Waste, Drain, Sample Lines | 1. Lines fail open | -- | Decreased demineralized water | Decreased demineralized water to makeup filters | Alternate demineralized water flow path available |

## SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM (Continued)

| Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|
| 6.3.17 Miscellaneous Piping | 1. Electric power supply to trace heating fails | Electric Power | Boric acid may crystallize; small potential for plugging and loss of flow | No demineralized water to makeup filters | Restore trace heating; unplug lines; alternate demineralized water flow path available |
| | 2. Trace heating fails | -- | Boric acid may crystallize; small potential for plugging and loss of flow | No demineralized water to makeup filters | Restore trace heating; unplug lines; alternate demineralized water flow path available |
| 6.3.18 Manual Isolation Valves (CS-52, CS-149, CS-54) | 1. Valves fail closed | -- | No demineralized water to pump | No demineralized water to makeup filters | Alternate demineralized water flow path available |
| 6.3.19 RC Bleed Transfer Pump (1WD-P21B) | 1. Electric power supply fails | Electric Power | Pump stops; no demineralized water | No demineralized water to makeup filters | Alternate demineralized water flow path available |
| | 2. Pump fails | -- | No demineralized water | No demineralized water to makeup filters | Alternate demineralized water flow path available |
| 6.3.20 Flow Orifice | 1. Orifice plugs | -- | Decreased demineralized water | Decreased demineralized water to makeup filters | Alternate demineralized water flow path available |
| 6.3.21 Manual Control Valve (CS-56) | 1. Valve fails closed | -- | No demineralized water | No demineralized water to makeup filters | Alternate demineralized water flow path available |
| 6.3.22 Flow Transmitter | 1. Electric power supply fails | Electric Power | No local flow indication | No flow indication to I&C system | None |
| | 2. Connection leak | Process Signal | Incorrect signal to transmitter | No flow indication to I&C system | None |
| | 3. Transmitter failure | -- | No local flow indication | No flow indication to I&C system | None |
| 6.3.23 Check Valve (CS-55) | 1. Fails to prevent backflow | -- | Possible backflow if pump is not running | No demineralized water to makeup filters | Close control valve CS-56 |

## SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 6.3.24 | Manual Isolation Valves (CS-83, CS-85, CS-100) | 1. Valves fail closed | -- | No demineralized water | No demineralized water to makeup filters | Alternate demineralized water flow available |
| 6.3.25 | Check Valve (CS-86) | 1. Fails to prevent backflow | -- | Possible backflow if pump is not running | No demineralized water to makeup filters | Close CS-85 |
| 6.3.26 | Control Valve (HP-15) | 1. Control signal fails to open valve | Control Signal From Flow Orifice | Loss of flow to makeup filters | No demineralized water to makeup filters | None |
| | | 2. Control signal fails to close valve | Control Signal From Flow Orifice | Loss of flow control to makeup filters | Increase in demineralized water to makeup filters | Close manual isolation valves; close HP-136 |
| | | 3. Instrument air supply fails | Instrument Air | Loss of flow to makeup filters | No demineralized water to makeup filters | None |
| | | 4. Electric power supply fails | Electric Power | Loss of flow to makeup filters | No demineralized water to makeup filters | None |
| | | 5. Spurious signal to open valve | Control Signal From Flow Orifice | Loss of flow control to makeup filters | Increase in demineralized water to makeup filters | Close manual isolation valves; close HP-136 |
| | | 6. Spurious signal to close valve | Control Signal From Flow Orifice | Loss of flow to makeup filters | No demineralized water to makeup filters | None |
| | | 7. Internal valve failure | -- | Loss of flow to makeup filters | No demineralized water to makeup filters | None |
| 6.3.27 | Manual Isolation Valves (HP-191, HP-192) | 1. Valves fail closed | -- | No flow to flow orifice | No demineralized water to makeup filters | None |
| 6.3.28 | Manual Isolation Valves (HP-52, HP-53) | 1. Valves fail closed | -- | No flow to flow orifice; potential control signal failure | No demineralized water to makeup filters; alternate flow path available | Open HP-54 |
| 6.3.29 | Manual Isolation Valve (HP-54) | 1. Valve fails open | -- | No flow to flow orifice; potential control signal failure | Loss of control of demineralized water to makeup filters | Close HP-136 if HP-15 should be closed |
| 6.3.30 | Flow Orifice | 1. Orifice plugs | -- | No flow; potential control signal failure | No demineralized water to makeup filters; alternate flow path available | Open HP-54 |
| 6.3.31 | Flow Transmitter | 1. Electric power supply fails | Electric Power | Incorrect signal to flow control valve (see 6.3.26) | No flow indication in I&C system | None |
| | | 2. Connection leaks | Process Signal | Incorrect signal to transmitter | No flow indication in I&C system | None |

Reference Drawings: FSAR Figure 9.3-1 (Sheet 1)
FSAR Figure 9.3-2 (Sheet 3)
FSAR Figure 9.3-5 (Sheets 1,3,&4)

## SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 6.3.31 | Flow Transmitter (cont'd) | 3. Transmitter fails | -- | Incorrect signal to flow control valve (see 6.3.26) | No flow indication in I&C system | None |
| 6.3.32 | Control Valve (HP-16) | 1. Control signal fails to open valve | Control Signal From 3-Way Valve | Loss of flow to makeup filters | No demineralized water to makeup filters | None |
| | | 2. Control signal fails to close valve | Control Signal From 3-Way Valve | Loss of flow control to makeup filters | Increase in demineralized water to makeup filters | Close manual isolation valves; close HP-192 |
| | | 3. Instrument air supply fails | Instrument Air | Loss of flow to makeup filters | No demineralized water to makeup filters | None |
| | | 4. Electric power supply fails | Electric Power | Loss of flow to makeup filters | No demineralized water to makeup filters | None |
| | | 5. Spurious signal to open valve | Control Signal From 3-Way Valve | Loss of flow control to makeup filters | Increase in demineralized water to makeup filters | Close manual isolation valves; close HP-192 |
| | | 6. Spurious signal to close valve | Control Signal From 3-Way Valve | Loss of flow to makeup filters | No demineralized water to makeup filters | None |
| | | 7. Internal valve failure | -- | Loss of flow to makeup filters | No demineralized water to makeup filters | None |
| 6.4 | Boron Recovery: | | | | | |
| 6.4.1 | Manual Isolation Valves (CT-3, CT-5) | 1. RC bleed flow fails | RC Bleed Flow From Holdup Tank | No flow to feed tank. Tank has 8-hour capacity; boron recovery will continue until tank is empty | None if feed tank is full | Alternate flow path available |
| | | 2. Valves fail closed | -- | No flow to demineralizer; no effect since second demineralizer available | None if alternate flow path available | Alternate flow path available |
| 6.4.2 | RC Bleed Evaporator Demineralizer | 1. Resin fill fails | Resin Fill | No demineralizing capacity; no effect since second demineralizer available | None if alternate flow path available | Alternate flow path available |
| | | 2. Tank leaks | -- | Decreased flow; no effect since second demineralizer available | None if alternate flow path available | Alternate flow path available |
| | | 3. Tank vent fails open | -- | Decreased flow; no effect since second demineralizer available | None if alternate flow path available | Alternate flow path available |
| 6.4.3 | Manual Isolation Valves (CT-4, CT-6) | 1. Valves fail closed | -- | No flow; no effect since second demineralizer available | None if alternate flow path available | Alternate flow path available |
| 6.4.4 | Manual Isolation Valve (CT-14) | 1. Valve fails closed | -- | No flow to feed tank. Tank has 8-hour capacity; boron recovery will continue until tank is empty | None if feed tank is full | Establish recirculation flow from evaporator |

Reference Drawings: FSAR Figure 9.3-1 (Sheet 1)
FSAR Figure 9.3-2 (Sheet 3)
FSAR Figure 9.3-5 (Sheets 1,3,44)

## SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM (Continued)

| | | Potential Failure Mode | | Immediate Effects | | |
|---|---|---|---|---|---|---|
| | Component | Mode | Interface Involved | Within Subsystem | At Subsystem Interface | Remedial Action Within Subsystem |
| 6.4.5 | Miscellaneous Piping | 1. Electric power supply fails | Electric Power | Boric acid may crystallize; small potential for plugging and loss of flow | None unless concentrated boric acid storage tanks are empty | Restore trace heating; unplug lines |
| | | 2. Trace heating fails | -- | Boric acid may crystallize; small potential for plugging and loss of flow | None unless concentrated boric acid storage tanks are empty | Restore trace heating; unplug lines |
| 6.4.6 | Manual Isolation Valves (CT-16, CT-19, CA-88, CT-49, CT-36) | 1. Evaporator demineralizer flow fails; CT-16 fails closed | Evaporator Demineralizer Flow | No flow to feed tank. Tank has 8-hour capacity; boron recovery will continue until tank is empty | None if feed tank is full | Establish recirculation flow from evaporator |
| | | 2. Caustic flow fails; CA-88 fails closed | Caustic Flow | Chemical imbalance in boron recovery system. | Chemical imbalance in boric acid to makeup filters, BWST | None |
| | | 3. Distillate flow fails; CT-49 fails closed | Distillate Cooler Flow | No flow to feed tank. Tank has 8-hour capacity; boron recovery will continue until tank is empty | None if feed tank is full | Establish recirculation flow from evaporator |
| | | 4. Concentrate flow back to feed tank; CT-36 fails open | Concentrate Flow | Concentrated boric acid returned to feed tank; no boron recovery | None unless concentrated boric acid storage tanks are empty | Close CT-38 to force concentrate flow to concentrate cooler |
| | | 5. Valve CT-19 fails closed | -- | No flow to feed tank. Tank has 8-hour capacity; boron recovery will continue until tank is empty | None if feed tank is full | Establish recirculation flow from evaporator |
| 6.4.7 | Check Valves (CT-18, CT-37, CT-17) | 1. Fail to prevent backflow | -- | Possible backflow to concentrate pump, evaporator demineralizer | None unless concentrated boric acid storage tanks are empty | Close isolation valves CT-16 and CT-19 |
| 6.4.8 | RC Bleed Evaporator Feed Tank (WD-T42) | 1. Tank leaks | -- | Decreased flow; eventual loss of suction pressure to pump. Tank has 8-hour capacity; boron recovery will continue until tank is empty | None if feed tank is full | None |
| | | 2. Tank empties | -- | No flow. Boron recovery stops until tank refilled | None unless concentrated boric acid storage tanks are empty | None |
| | | 3. Tank vent, relief valves fail open | -- | Decreased flow. Tank has 8-hour capacity; boron recovery will continue until tank is empty | None if feed tank is full | None |
| 6.4.9 | Level Transmitter | 1. Electric power supply fails | Electric Power | No local level indication | None | None |
| | | 2. Connection leak | Process Signal | Incorrect signal to transmitter | None | None |
| | | 3. Transmitter failure | -- | No local level indication | None | None |

Reference Drawings: FSAR Figure 9.3-1 (Sheet 1)
FSAR Figure 9.3-2 (Sheet 3)
FSAR Figure 9.3-5 (Sheets 1,3,44)

## SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 6.4.10 | Manual Isolation Valves (CT-22, CT-23) | 1. Valves fail closed | -- | No flow to evaporator feed pump. Recirculation flow path can be established through evaporator but boron recovery stops | None unless concentrated boric acid storage tanks are empty | Establish recirculation flow from evaporator |
| 6.4.11 | RC Bleed Evaporator Feed Pump (WD-P46) | 1. Electric power supply fails | Electric Power | Pump stops; no flow to evaporator. Recirculation flow path can be established through evaporator but boron recovery stops | None unless concentrated boric acid storage tanks are empty | Establish recirculation flow from evaporator |
| | | 2. Pump fails | -- | No flow to evaporator. Recirculation flow path can be established through evaporator but boron recovery stops | None unless concentrated boric acid storage tanks are empty | Establish recirculation flow from evaporoator |
| 6.4.12 | Pressure Transmitter Fails | 1. Electric power supply fails | Electric Power | No local pressure indication | None | None |
| | | 2. Connection leak | Process Signal | Incorrect signal to transmitter | None | None |
| | | 3. Transmitter fails | -- | No local pressure indication | None | None |
| 6.4.13 | Manual Isolation Valve (CT-24) | 1. Valve fails closed | -- | No flow to evaporator. Recirculation flow path can be established through evaporator but boron recovery stops | None unless concentrated boric acid storage tanks are empty | Establish recirculation flow from evaporator |
| 6.4.14 | Control Valve (CT-24) | 1. Control signal fails to open/ valve close | Control Signal From Evaporator Level | Loss of flow control to evaporator. Could flood evaporator or allow dryout. Recirculation flow paths to feed tank or evaporator can be established. Boron recovery stops | None unless concentrated boric acid storage tanks are empty | Establish recirculation flow to feed tank or evaporater |
| | | 2. Instrument air supply fails | Instrument Air | Loss of flow control to evaporator. Could flood evaporator or allow dryout. Recirculation flow paths to feed tank or evaporator can be established. Boron recovery stops | None unless concentrated boric acid storage tanks are empty | Establish recirculation flow to feed tank or evaporator |

## SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 6.4.14 | Control Valve (CT-24) (cont'd) | 3. Spurious signal to open/valve close | Control Signal From Evaporator Level | Loss of flow control to evaporator. Could flood evaporator or allow dryout. Recirculation flow paths to feed tank or evaporator can be established. Boron recovery stops | None unless concentrated boric acid storage tanks are empty | Establish recirculation flow to feed tank or evaporator |
| | | 4. Internal valve failure | -- | Loss of flow control to evaporator. Could flood evaporator or allow dryout. Recirculation flow paths to feed tank or evaporator can be established. Boron recovery stops | None unless concentrated boric acid storage tanks are empty | Establish recirculation flow to feed tank or evaporator |
| 6.4.15 | Check Valve (CT-29) | 1. Fails to prevent backflow | -- | Possible backflow if pump is not running | None unless concentrated boric acid storage tanks are empty | Close control valve CT-28 |
| 6.4.16 | Waste, Drain, Sample Lines | 1. Lines fail open | -- | Decreased flow to evaporator. Recirculation flow path can be established through evaporator but boron recovery stops | None unless concentration boric acid storage tanks are empty | Establish recirculation flow to evaporator if required |
| 6.4.17 | RC Bleed Evaporator (WD-EV1) | 1. $N_2$ blanket system fails | $N_2$ Blanket | Possible explosive mixture forms | None | None |
| | | 2. Steam supply fails | Steam | Evaporator floods. No boron recovery | None unless concentrated boric acid storage tanks are empty | Establish recirculation path to feed tank |
| | | 3. Blocked tubes | -- | Decreased heat transfer; decrease in boron recovery | None unless concentrated boric acid storage tanks are empty | Establish recirculation path to feed tank |
| | | 4. Tube rupture | -- | Steam released to evaporator vapor space; decrease in boron recovery | None unless concentrated boric acid storage tanks are empty | Establish recirculation path to feed tank |
| | | 5. Loss of heat transfer capability | -- | Evaporator floods. No boron recovery | None unless concentrated boric acid storage tanks are empty | Establish recirculation path to feed tank |
| | | 6. Electric power supply fails | Electric Power | Concentrate heater fails; potential plugging and loss of flow | None unless concentrated boric acid storage tanks are empty | Restore heater; unplug lines |

Reference Drawings: FSAR Figure 9.3-1 (Sheet 1)
FSAR Figure 9.3-2 (Sheet 3)
FSAR Figure 9.3-5 (Sheets 1,3,44)

# SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM (Continued)

| | Component | Potential Failure Mode | | Immediate Effects | | |
|---|---|---|---|---|---|---|
| | | Mode | Interface Involved | Within Subsystem | At Subsystem Interface | Remedial Action Within Subsystem |
| 6.4.17 | RC Bleed Evaporator (WD-EV1) (cont'd) | 7. Inlet flow from feed pump fails | -- | No boron recovery | None unless concentrated boric acid storage tanks are empty | Establish recirculation flow path until feed flow restored |
| | | 8. Evaporator leaks | -- | Eventual loss of suction pressure to pump | None unless concentrated boric acid storage tanks are empty | None |
| | | 9. Evaporator empties | -- | Possible damage to evaporator; no boron recovery | None unless concentrated boric acid storage tanks are empty | Shut off steam flow |
| | | 10. Evaporator vent, relief valves fail open | -- | Cover gas release to vent header | None | None |
| 6.4.18 | Evaporator Level Transmitter | 1. Electric power supply fails | Electric Power | Incorrect signal to evaporator feed pump discharge flow control valve (see 6.4.14) | None unless concentrated boric acid storage tanks are empty | None |
| | | 2. Connection leaks | Process Signal | Incorrect signal to evaporator feed pump discharge flow control valve (see 6.4.14) | None unless concentrated boric acid storage tanks are empty | None |
| | | 3. Transmitter fails | -- | Incorrect signal to evaporator feed pump discharge flow control valve (see 6.4.14) | None unless concentrated boric acid storage tanks are empty | None |
| 6.4.19 | Temperature Transmitter | 1. Electric power supply fails | Electric Power | Incorrect signal to transmitter and concentrate cooler discharge flow control (see 6.4.26) | See 6.4.26 | None |
| | | 2. Connection leaks | Process Signal | Incorrect signal to transmitter and concentrate cooler discharge flow control (see 6.4.26) | See 6.4.26 | None |
| | | 3. Transmitter failure | -- | Incorrect signal to transmitter and concentrate cooler discharge flow control (see 6.4.26); no local temperature indication | See 6.4.26 | None |
| 6.4.20 | Distillate Cooler (WD-C9) | 1. Cooling water supply fails | Cooling Water | High temperature distillate returned to feed tank | None | Establish recirculation path to feed tank |
| | | 2. Blocked tube | -- | Decreased heat transfer; high temperature distillate returned to feed tank | None | Establish recirculation path to feed tank |

## SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 6.4.20 | Distillate Cooler (WD-C9) (cont'd) | 3. Tube rupture | -- | Cooling water released to distillate; dilutes feed tank concentration | None | Establish recirculation path to feed tank |
| | | 4. Loss of heat transfer capability | -- | Decreased heat transfer; high temperature distillate returned to feed tank | None | Establish recirculation path to feed tank |
| | | 5. Cooler leaks | -- | Decreased distillate flow | Decreased distillate available to condensate test tanks (demineralized water) | Establish recirculation path to feed tank |
| | | 6. Inlet flow fails | Evaporator Distillate | No distillate flow | No distillate available to condensate test tanks (demineralized water) | None |
| 6.4.21 | Concentrate (Recirc.) Pump (WD-P4) | 1. Electric power supply fails | Electric Power | Pump stops; no concentrate flow | None unless concentrated boric acid storage tanks are empty | None |
| | | 2. Pump fails | -- | No concentrate flow | None unless concentrated boric acid storage tanks are empty | None |
| 6.4.22 | Check Valve (CT-35) | 1. Fails to prevent backflow | -- | Possible backflow if pump is not running | None unless concentrated boric acid storage tanks are empty | Close CT-38, CT-40 |
| 6.4.23 | Pressure Transmitter | 1. Electric power supply fails | Electric Power | No local pressure indication | None | None |
| | | 2. Connection leaks | Process Signal | Incorrect signal to transmitter | None | None |
| | | 3. Transmitter fails | -- | No local pressure indication | None | None |
| 6.4.24 | Manual Isolation Valve (CT-38) | 1. Valve fails open | -- | Concentrate flow recirculated to evaporator. No boron recovery; possible evaporator flooding | None unless concentrated boric acid storage tanks are empty | Open CT-40 to divert flow through concentrate cooler |
| | | 2. Valve fails closed | -- | Possible flooding of concentrate cooler; loss of temperature control in evaporator | None | Flow can be diverted through CT-36 back to feed tank |
| 6.4.25 | Concentrate Cooler (WD-7) | 1. Cooling water supply fails | Cooling Water | High temperature boric acid returned to concentrated boric acid storage tanks | None | Close control valve CT-40 |
| | | 2. Blocked tube | -- | Decreased heat transfer; high temperature boric acid returned to concentrated boric acid storage tanks | None | Close control valve CT-40 |

Reference Drawings: FSAR Figure 9.3-1 (Sheet 1)
FSAR Figure 9.3-2 (Sheet 3)
FSAR Figure 9.3-5 (Sheets 1,3,&4)

## SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM (Continued)

| Component | | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 6.4.25 | Concentrate Cooler (WD-7) (cont'd) | 3. Tube rupture | -- | Cooling water released to concentrate; dilutes boric acid concentration | None | Concentration can be adjusted from boric acid mix tank |
| | | 4. Loss of heat transfer capability | -- | High temperature boric acid returned to concentrated boric acid storage tanks | None | Close control valve CT-40 |
| | | 5. Cooler leaks | -- | Decreased concentrate flow | None unless concentrated boric acid storage tanks are empty | None |
| | | 6. Inlet flow fails | Evaporator Concentrate | No concentrate flow | None unless concentrated boric acid storage tanks are empty | Close control valve CT-40 |
| | | 7. Cooling water control valve fails | Control Signal From Concentrate Cooler Discharge Temperature | No concentrate flow | None unless concentrated boric acid storage tanks are empty | Close control valve CT-40 |
| 6.4.26 | Temperature Transmitter | 1. Electric power supply fails | Electric Power | No signal to cooling water control valve | No signal to cooling water control valve; see 6.4.24 | See 6.4.24 |
| | | 2. Connection leaks | Process Signal | No signal to transmitter | No signal to cooling water control valve; see 6.4.24 | See 6.4.24 |
| | | 3. Transmitter fails | -- | No signal to cooling water control valve | No signal to cooling water control valve; see 6.4.24 | See 6.4.24 |
| 6.4.27 | Control Valve (CT-40) | 1. Instrument air supply fails | Instrument Air | Loss of concentrate flow control | None unless concentrated boric acid storage tanks are empty | Close cooling water control valve; divert concentrate flow back to evaporator through CT-38 or to feed tank through CT-36 |
| | | 2. Control signal fails to open/close valve | Control Signal From Evaporator Temperature Transmitter | Loss of concentrate flow control | None unless concentrated boric acid storage tanks are empty | Close cooling water control valve; divert concentrate flow back to evaporator through CT-38 or to feed tank through CT-36 |

## SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 6.4.27 | Control Valve (CT-40) (cont'd) | 3. Spurious signal to open/close valve | Control Signal From Evaporator Temperature Transmitter | Loss of concentrate flow control | None unless concentrated boric acid storage tanks are empty | Close cooling water control valve; divert concentrate flow back to evaporator through CT-38 or to feed tank through CT-36 |
| | | 4. Internal valve failure | -- | Loss of concentrate flow control | None unless boric acid storage tanks are empty | Close cooling water control valve; divert concentrate flow back to evaporator through CT-38 or to feed tank through CT-36 |
| 6.5 | Deborating Demineralizer: | | | | | |
| 6.5.1 | Manual Control Valve | 1. RC Bleed flow fails | RC Bleed Flow | No flow to deborating demineralizer | No flow to makeup filters | None |
| | | 2. Valve fails closed | -- | No flow to deborating demineralizer | None if alternate flow path available | Alternate flow path available |
| 6.5.2 | Manual Isolation Valve | 1. Valve fails closed | -- | No flow to deborating demineralizer | None if alternate flow path available | Alternate flow path available |
| 6.5.3 | Deborating Demineralizer | 1. Tank leaks | -- | Decreased bleed flow | None if alternate flow path available | Alternate flow path available |
| | | 2. Tank empties | -- | No bleed flow | None if alternate flow path available | Alternate flow path available |
| | | 3. Tank vent, relief valves fail open | -- | Decreased bleed flow | None if alternate flow path available | Alternate flow path available |
| | | 4. Resin saturates | -- | No boron removal from bleed flow | None if alternate flow path available | Alternate flow path available |
| | | 5. Caustic flow fails | Caustic | No demineralizer regeneration | None if alternate flow path available | Alternate flow path available |
| 6.5.4 | Miscellaneous Piping | 1. Electric power supply to trace heating fails | Electric Power | Boric acid may crystallize; small potential for plugging and loss of flow | None if alternate flow path available | Restore trace heating; unplug lines |
| | | 2. Trace heating fails | -- | Boric acid may crystallize; small potential for plugging and loss of flow | None if alternate flow path available | Restore trace heating; unplug lines |
| 6.5.5 | Waste, Drain, Sample Lines | 1. Lines fail open | -- | Decreased bleed flow | None if alternate flow path available | Alternate flow path available |
| 6.5.6 | Manual Isolation Valves | 1. Valves fail closed | -- | No bleed flow | None if alternate flow path available | Alternate flow path available |

Reference Drawings: FSAR Figure 9.3-1 (Sheet 1)
FSAR Figure 9.3-2 (Sheet 3)
FSAR Figure 9.3-5 (Sheets 1,3,4A)

## SUBSYSTEM 6.0: CHEMICAL PROCESSING SUBSYSTEM (Continued)

| | Component | Potential Failure Mode: Mode | Potential Failure Mode: Interface Involved | Immediate Effects: Within Subsystem | Immediate Effects: At Subsystem Interface | Remedial Action Within Subsystem |
|---|---|---|---|---|---|---|
| 6.5.7 | Check Valve (Outlet) | 1. Fails to prevent backflow | -- | Possible backflow to deborating demineralizer | None if alternate flow path available | Close manual isolation valve |
| 6.5.8 | Check Valve (CS-123) | 1. Fails to prevent backflow | -- | Possible backflow to deborating demineralizer | No flow to makeup filters | Close HP.16 |