Appendix G
Ex-Vessel Downstream Effects Evaluation

G.1 Introduction

This appendix documents the ex-vessel downstream effects evaluation for the U.S. EPR ECCS/SIS to verify that this system and its components function as designed under post-LOCA conditions. This evaluation verifies that inadequate core or containment cooling will not occur because of debris blockage at flow restrictions, plugging or excessive wear of close-tolerance subcomponents in pumps, valves, and other components in the ECCS flow path. This evaluation uses the guidance of NRC Generic Letter GL 2004-02 for ex-vessel downstream evaluation.

G.1.1 Safety Injection Function

Each SIS train delivers borated water to the RCS by one of three systems that share common piping and valves:

- MHSI.
- LHSI.
- Accumulator injection systems.

The MHSI and LHSI systems share an isolable suction line from the IRWST, and a three-way valve connects the IRWST to either the MHSI or LHSI pump suctions. The injection pumps draw water from the IRWST for their emergency function. The discharge lines for the MHSI, LHSI, and accumulator injection systems branch together to a single injection nozzle on the associated RCS cold leg. The MHSI and the accumulators inject directly into the cold legs. The LHSI pumps inject through the LHSI heat exchangers to the cold legs. In the long-term cooling following a LOCA, the LHSI discharge can be switched to the RCS hot legs to prevent boron precipitation and mitigate steaming from the break.

G.2 Assumptions and Design Information

G.2.1 Accident Scenarios

SIS actuation provides protection for different postulated transients, accidents, and operating events. This evaluatation addresses accident scenarios with the potential for debris transportation to the IRWST that could get to the SIS sump strainers and potentially affect ECCS operation. These accidents are the following:

- Small break LOCA (SBLOCA)
- Large break LOCA (LBLOCA)

This evaluation addresses ECCS operation during long-term decay heat removal from the RCS and mitigation of boric acid precipitation.

G.2.1.1 *SBLOCA*

The most limiting SBLOCA is a break with a cross-sectional area of up to approximately 0.5 ft^2 in the cold leg between the SIS injection location and the RPV, with coincident loss of offsite power (LOOP). This event may not immediately challenge the SIS if the CVCS compensates for the reactor coolant loss. The loss of primary coolant eventually results in a decrease in primary system pressure and pressurizer level. The SIS actuates on low pressurizer pressure and automatically starts the MHSI and LHSI pumps. During partial cooldown, the RCS pressure decreases sufficiently to allow MHSI injection into the cold legs. The LHSI pumps actuate and re-circulate, through their specific tangential minimum flow line, into the IRWST, where they take suction.

In contrast to a LBLOCA, the stages of the SBLOCA (such as partial cooldown, controlled state and safe shutdown state) prior to long-term decay heat removal occur over a longer period of time. The duration of each stage depends on the break size and the performance of the ECCS.

For this evaluation, the SBLOCA is bounded by the LBLOCA, recirculation, and post-LOCA, long-term cooling. The ECCS flows and debris generated during a SBLOCA will be smaller than during a LBLOCA. The SBLOCA is bounded by the conditions of the LB LOCA regarding the evaluation of downstream components.

G.2.1.2 *LBLOCA*

For the LBLOCA, the break is assumed to open instantaneously and results in high loss of reactor coolant inventory, and high temperature and pressure inside the containment. This LBLOCA, also called the double-ended break, evolves in three phases:

- The blowdown until accumulator injection.
- Refill of the RPV lower plenum by the SIS.
- Re-flooding of the core by the accumulators first, and then by the MHSI and LHSI pumps until a complete quenching of the core.

To reach the safe shutdown state, the LHSI cold leg injection is switched to LHSI hot leg injection (required for cold leg breaks) to prevent boron precipitation inside the core and excessive boron dilution inside the IRWST. The break flow is compensated by the ECCS/SIS. The SIS aids in containment heat removal.

The MHSI pumps maintain cold leg injection.

G.2.2 Mission Time

“Mission time” is defined as the amount of time that a given component is required to fulfill its safety function in a post-LOCA accident condition. Defining a mission time for this evaluation establishes a duration for which wear or debris-induced failure of a component will not have an adverse impact on ECCS operation. For this evaluation, the mission time for ECCS components following a LBLOCA is 30 days of continuous operation.

G.2.3 Components of Interest

Table G.2-1 lists the SIS/RHRS/IRWST components in the downstream effects evaluation. These components are in the ECCS flow path during SBLOCA and LBLOCA operations.

Table G.2-1 Components in the ECCS Flow Path during a LB LOCA

Components	Description
PUMPS	
LHSI Pump (30JND10/20/30/40 AP001)	**Type**: Centrifugal **Arrangement**: Horizontal **Flow Rate**: ~441.6 lbm/s (maximum)
MHSI Pump (30JNG10/20/30/40 AP001)	**Type**: Centrifugal **Arrangement**: Horizontal **Flow Rate**: ~152.6 lbm/s (maximum)
HEAT EXCHANGERS	
LHSI Heat Exchanger (30JNG10/20/30/40 AC001)	**Type**: Shell and Tube, U-Tube, Horizontally Mounted **Number of Shell in Series**: 1 **Number of Tube Passes**: 2 **Tube Material**; Austenitic Steel **Flow rate**: ~392.4 lbm/s (during LB LOCA LHSI Injection)
VALVES AND ORIFICES	
Motor Operated Valves:	
30JNG10/20/30/40 AA102	**Function**: LHSI Heat Exchanger Control Valve **Size**: 8 inches **Type**: Globe Valve
30JNG10/20/30/40 AA104	**Function**: LHSI Throttle Control Valve **Size**: 8 inches **Type**: Globe Valve
30JNG10/20/30/40 AA060	**Function**: LHSI Discharge Valve **Size**: 8 inches **Type**: Globe Valve
30JNG10/20/30/40 AA061	**Function**: LHSI Discharge Valve **Size**: 4 inches **Type**: Globe Valve
30JNA10/20/30/40 AA002	**Function**: Hot Leg (RCPB) Isolation Valve **Size**: 10 inches **Type**: Globe Valve

Components	Description
30JNG10/20/30/40 AA001	**Function**: LHSI Pump Suction from IRWST Isolation Valve **Size**: 14 inches **Type**: Gate Valve
30JNG12/22/32/42 AA001	**Function**: LHSI Hot Leg Injection Isolation Valve **Size**: 8 inches **Type**: Globe Valve
30JNK10/20/30/40 AA001	**Function**: IRWST 3-Way Isolation Valve **Size**: Inlet – 16 inches; MHSI Outlet – 10 inches; LHSI Outlet – 14 inches **Type**: 3-Way Globe Valve
30JND10/20/30/40 AA002	**Function**: MHSI Pump Discharge Valve **Size**: 6 inches **Type**: Globe Valve
30JND10/20/30/40 AA004	**Function**: MHSI Small Miniflow Line Isolation Valve **Size**: 2 inches **Type**: Globe Valve
30JNG10/20/30/40 AA004	**Function**: LHSI Tangential Miniflow Line Check Valve **Size**: 4 inches **Type**: Lift Check with Electric Motor
30JNA10/20/30/40 AA001	**Function**: Hot Leg (RCPB) Isolation Valve **Size**: 10 inches **Type**: Gate Valve
Manual Valves:	
30JND10/20/30/40 AA001	**Function**: MHSI Suction Isolation Valve **Size**: 10 inches **Type**: Globe Valve
30JND10/20/30/40 AA003	**Function**: MHSI 2nd RCPB Isolation Valve **Size**: 6 inches **Type**: Globe/Check Valve
30JNG10/20/30/40 AA006	**Function**: LHSI 2nd RCPB Isolation Valve **Size**: Inlet – 8 inches ; Outlet – 10 inches **Type**: Globe/Check Valve

Components	Description
Check valves:	
30JND10/20/30/40 AA007	**Function**: MHSI Check Valve **Size**: 6 inches **Type**: Swing Check Valve
30JNG12/22/32/42 AA002	**Function**: LHSI Hot Leg Injection Check Valve **Size**: 8 inches **Type**: Swing Check Valve
30JNG10/20/30/40 AA009	**Function**: LHSI Check Valve **Size**: 8 inches **Type**: Swing Check Valve
30JNG10/20/30/40 AA011	**Function**: LHSI Check Valve **Size**: 8 inches **Type**: Swing Check Valve
30JNG13/23/33/43 AA005	**Function**: Cold Leg Check Valve **Size**: 12 inches **Type**: Swing Check Valve
30JNK10/20/30/40 AA010	**Function**: MHSI Check Valve **Size**: 4 inches **Type**: Swing Check Valve
Orifices:	
30JND10/20/30/40 BP003	**Function**: MHSI Discharge Orifice **Size**: 6 inches
30JND10/20/30/40 BP002	**Function**: MHSI Miniflow Orifice **Size**: 2 inches
30JNG12/22/32/42 BP001	**Function**: LHSI Tangential Miniflow Orifice **Size**: 4 inches
30JNG10/20/30/40 BP061	**Function**: LHSI Outside Containment Bypass Line Orifice **Size**: 4 inches

G.2.4 Post-LOCA Fluid Constituents

Table G.2-2 shows the total amount of debris generated during a LBLOCA.

Table G.2-2 Total Debris Generated during the LB LOCA

Debris Source	Particulate	Small Fines	Large Pieces	Totals
Reflective Metal Insulation (RMI) (ft^2)	0	1471.46	490.49	1961.95
Microtherm (ft^3)	1.00	0	0	1.00
Qualified Epoxy Coatings (lbm)	126.30	0	0	126.30
Qualified IOZ Coatings (lbm)	958.70	0	0	958.70
Unqualified Coatings (lbm)	250.00	0	0	250.00
Latent Debris (lbm)	127.50	22.50	0	150.00
Miscellaneous (ft^2)	0	0	100.00	100.00

The amount of debris that passes through the sump screen depends on the sump screen hole size, ratio of open to close area of the screen, the fluid approach velocity to the screen, and the screen geometry. This evaluation conservatively assumes that the particulates generated during the LBLOCA are less than or equal to the hole size of the sump screen. As a result, the ECCS ingests 100 percent of the microtherm and coating particulates.

Bypass testing of the latent debris yielded bypass percentages of less than 70 percent (see Appendix E, Section E.7.3). This evaluation uses a bounding bypass percentage of 70 percent latent debris (particulate and fiber).

Transport testing shows that the RMI debris generated during a LBLOCA will be stopped by the retention basket (see Appendix E, Section E.7.1). This evaluation assumes no RMI bypass through the sump screen.

G.2.5 ECCS Flow Rate and Flow Velocity

The SIS design allows fluid velocities in excess of debris material terminal settling velocities to exist, and debris settling will not occur.

G.2.6 Summary of Assumptions and Conservatisms

Assumptions and conservatisms used in this evaluation are summarized as follows:

1. One hundred percent of microtherm and coating particulates and 70 percent of latent debris (particulate and fiber) are assumed to pass through the strainers and ingested into the ECCS. RMI debris generated during a LBLOCA will be stopped by the retention basket.

Table G.2-3 lists the amount of debris in the post-LOCA fluid that will be used for confirmatory tests. The concentrations of the debris (in parts per million) are determined based on the assumption that the IRWST contains 400,000 gallons of water.

Table G.2-3 Post-LOCA Fluid Constituents

Debris	Amount	Concentration (ppm)
Microtherm (ft^3)	1.00	19
Qualified Epoxy Coatings (lbm)	126.30	38
Qualified IOZ Coatings (lbm)	958.70	291
Unqualified Coatings (lbm)	250.00	76
Latent Particulates (lbm)	89.25	27
Latent Fiber (lbm)	15.75	5

G.3 ECCS Component Evaluations

This section evaluates the ECCS pumps, heat exchangers, valves, instrument tubes, and piping regarding wear and blockage.

G.3.1 Wear Rate Evaluation

Erosive wear is caused by particles that impinge on a component surface and remove material from the surface because of momentum effects. The wear rate of a material depends on the debris type, debris concentration, material hardness, flow velocity, and valve position.

The component vendor(s) will provide data to support acceptable wear rates based on the provided equipment specifications.

G.3.2 LHSI and MHSI Evaluation

The LHSI and MHSI pumps are horizontally mounted, centrifugal pumps with single mechanical seals. The pumps are sized in safety injection mode to provide nominal flow rates.

Generally, particulates tend to accumulate and potentially affect flow through close clearances (wear rings or sleeve bearings). The LHSI and MHSI pumps will be designed with increased clearances to support successful post-LOCA operations.

To verify that the LHSI and MHSI pumps operate with post-LOCA fluids for at least 30 days, the pump vendor, at a minimum, is required to provide the following during procurement:

1. A list of the opening sizes and internal running clearances for the LHSI and MHSI pumps.

2. Hydraulic performance test results confirming that the LHSI and MHSI pumps can provide the required safety injection flow rates for at least 30 days of ECCS post-LOCA operation.

3. A list of materials of the wetted pump surfaces (such as wear rings, pump internals, bearing, and casing) and the hardness of each material (for example, Brinell hardness number).

4. Mechanical performance (pump vibration, rotor dynamics, and bearing load) test results and/or relevant analysis to confirm that there will be no adverse changes in system vibration response or rotor dynamics performance during ECCS operation for at least 30 days. Also, provide relevant test results and/or relevant analysis to confirm that any increases in internal bypass flow caused by impeller or casing

wear will not decrease the performance of the pumps or cause accelerated internal wear.

5. Mechanical seal assembly performance test and/or analysis to confirm that ECCS operation with post-LOCA fluids will not impair seal performance, cause seal failure or significantly degrade seal leakage. The pump vendor should also provide an analysis to confirm that the cyclone separator, if applicable, is not susceptible to clogging or impairment by fiber or other particulates and that there is no adverse impact on pump performance or reliability. If the cyclone separators will be impaired in 30 days of operation with post-LOCA fluids, test results and/or analysis should be provided to show that the absence of cyclone separators yields acceptable seal performance.

G.3.3 LHSI Heat Exchanger Evaluation

The LHSI heat exchangers are evaluated for susceptibility to tube plugging. The vendor will verify that plugging by post-LOCA debris constituents will not occur or adversely affect the performance of the heat exchanger. Tube leakage or failure because of abrasive wear will be considered and an analysis or report will be provided to support acceptable performance.

G.3.4 Evaluation of Valves

The ECCS valves, pipes, and orifices are evaluated for susceptibility to blockage. An analysis will be performed to verify adequate performance during operation with post-LOCA fluid.

G.3.5 Confirmatory Items

The design, procurement, installation, and layout of components consider the reliability of the SIS, RHRS, and ECCS. Based on the ex-vessel downstream effects evaluation, the following ECCS components need verification to confirm post-LOCA operation (with debris constituents listed in Table G.2-3) for a minimum of 30 days:

1. The LHSI and MHSI pump vendors, at a minimum, will provide the following:

   - A list of the opening sizes and internal running clearances for the LHSI and MHSI pumps.
   - Hydraulic performance test results confirming that the LHSI and MHSI pumps can provide the required safety injection flow rates for at least 30 days of ECCS post-LOCA operation.
   - A list of the wetted pump surfaces materials (such as wear rings, pump internals, bearing, and casing) and the hardness of each material (for example, Brinell hardness number).
   - Mechanical performance (pump vibration, rotor dynamics, and bearing load) test results and/or relevant analysis to confirm that there will be no adverse changes in system vibration response or rotor dynamics performance during ECCS operation for at least 30 days. Relevant test results and/or relevant analysis will be provided confirming that any increases in internal bypass flow caused by impeller or casing wear will not decrease the performance of the pumps or cause accelerated internal wear for a minimum of 30 days of post-LOCA operation.
   - Mechanical seal assembly performance test and/or analysis to confirm that ECCS operation with post-LOCA fluids will not impair seal performance, cause seal failure, or significantly degrade seal leakage. Also, the pump vendor should provide analysis to confirm that the cyclone separator, if applicable, is not susceptible to clog or impairment by fiber or other particulates and that there will be no adverse impact on pump performance or reliability. If the cyclone separators will be impaired during operation with post-LOCA fluids, test results and/or analysis should be provided to show that the absence of cyclone separators yields acceptable seal performance during post-LOCA operation.

2. The LHSI heat exchanger vendor will verify that plugging or any abrasive wear by post-LOCA debris constituents will not occur or adversely affect heat exchanger performance below specification. Tube leakage or failure because of abrasive wear will be considered and analysis/reports will be provided to support acceptable performance.

3. An analysis of plugging and wear of valves and orifices will be performed to confirm that the overall system resistance/pressure drop across the ECCS is consistent with the safety analysis results for 30 days of post-LOCA operation.

G.4 Conclusions

Vendor testing and/or analyses of the components identified in Section G.3.5 should show that the system as procured will meet the design requirements assumed in the design bases analyses. Meeting these requirements provides assurance that system components are not blocked by debris or degraded to such an extent that they cannot perform their safety function.