Final Precursor Analysis

Accident Sequence Precursor Program – Office of Nuclear Regulatory Research

Farley, Unit 2	Standby Service Water Pump Unavailable for 23 Days	
Event Date: 8/2/2009	**LER:** 364/09-001-01 **IR:** 50-364/10-07	**ΔCDP =** 9×10^{-6}

EVENT SUMMARY

Event Description. On August 02, 2009, while swapping Service Water (SW) pumps in preparation to swap Train B to Train A, plant personnel heard sounds that resulted in a decision to secure SW Pump 2E shortly after being started. As soon as SW Pump 2E was secured, the sound stopped. Investigation discovered that the seismic support assembly for SW Pump 2E was no longer capturing the pump column. Inspection of the underwater seismic support assembly indicated the lower two of the four wall plate bolts were degraded and missing the nuts.

On August 15, 2009, the SW Pump 2E was started for post-maintenance testing following repairs that had been made to its seismic support ring. After approximately 10 minutes of operation, an abnormal noise was observed coming from the pump, and motor running amps were noted to be abnormally high. The pump was secured following approximately 1 hour of operation, and was found to be in a seized condition.

Following removal of the SW Pump 2E, the failed pump was transported to a vendor facility for a detailed root cause analysis of the failure mechanism. The pump seal rings were found to be broken, pump shaft coatings at the bearing journal locations were found to be corroded and delaminated, and the associated bearings were damaged. SW Pump 2E was restored on August 19, 2009 after repairs were complete.

Additional information is provided in References 1 and 2.

Cause. The root cause of the degradation of the SW pump seismic support rings was determined to be the failure of the licensee to appropriately monitor of the seismic supports to identify degradation.

The causes which contributed to the SW Pump 2E shaft seizure included vendor design and manufacturing issues such as material selection and interference fit parameters associated with the pump wear rings, inadequate commercial grade dedication associated with the process of coating the pump shafts at the bearing journal locations (as several shaft bearings and associated journal coatings were found to be degraded and damaged), and failure to meet the design specification for minimum rotor critical speed.

Condition Duration. SW Pump 2E was secured from normal operation on July 27. The pump was run on August 2nd, but secured after 10 minutes of operation due to a degraded seismic support assembly. After repairs were complete, the shaft of SW Pump 2E seized after approximately one hour of operation during post-maintenance testing on August 15th. Due to

failure mechanisms and the very short run times of SW Pump 2E, this analysis assumes that the pump was unavailable from July 27th to August 19th (when the pump repairs were complete). Therefore, the SW Pump 2E was unavailable for 23 days.

Additional Event Details. No relevant equipment was reported to be out-of-service due to test or maintenance in Reference 1. In addition, a search of licensee event reports (LERs) for Joseph M. Farley Nuclear Plant reveals no other safety-related equipment to be unavailable during the period of this analysis.

ANALYSIS RESULTS

Importance. The importance (i.e., ΔCDP) value for this event is 8.6×10^{-6}. The ASP Program acceptance threshold is a ΔCDP of 1×10^{-6}.

Dominant Sequence. The dominant accident sequence, Transient (TRANS) Sequence 02-02-10 (CCDP = 4.7×10^{-6}) contributes 54% of the total internal events ΔCDP. Additional sequences that contribute greater than 1% of the total internal events ΔCDP are provided in Appendix A.

The dominant sequence is shown graphically in Figure B-1, Figure B-2, and Figure B-3 in Appendix B. The events and important component failures in TRANS Sequence 02-02-10 are:

- Loss of condenser heat sink occurs,
- Reactor scram succeeds,
- AFW succeeds,
- Power-operated relief valves (PORVs) successfully close (if opened),
- RCPs seal cooling fails,
- RCPs are successfully tripped,
- Rapid secondary depressurization succeeds,
- RCP Seal 1 integrity is maintained,
- RCP Seal 2 fails (binding/popping),
- High-pressure injection fails,
- Secondary side cooldown fails, and
- Low-pressure injection fails.

SAPHIRE 8 Report. The SAPHIRE 8 Condition Assessment Report (Appendix A) provides the following:

- Modified basic events and initiating event frequencies, including base and change case probabilities/frequencies.
- Dominant sequences (including ΔCDP).
- Sequence logic for all dominant sequences.
- Fault tree definitions.
- Sequence cutsets.
- Definitions and probabilities for key basic events.

MODELING ASSUMPTIONS

Analysis Type. The Revision 8.51 of the Farley 1 & 2 SPAR model created in July 2010 was used for this event analysis. This event was modeled as unavailability of the standby SW pump for 23 days.

Analysis Rules. The ASP Program uses Significance Determination Process (SDP) results for degraded conditions when available. The SDP analyzed the performance deficiency involving the installation of seismic support rings on SW Pump 2E. The analysis determined the inspection finding to be GREEN (i.e., very low safety significance) in SDP Phase 1 because the plant still had two pumps for both trains; therefore, satisfying Technical Specifications. However, the ASP Program analyzes events where multiple degraded conditions are present during the same period. This event involved multiple degraded conditions on the same piece of equipment (i.e., the degraded seismic support rings and pump shaft coating on SW Pump 2E). Note that that the condition duration of degraded seismic support rings was enveloped by the condition duration of degraded pump shaft coating). Therefore, since this event involved multiple deficiencies, this analysis focuses on the unavailability of SW Pump 2E for 23 days.

Modeling Assumptions. The following modeling assumptions were determined to be vital to this event analysis:

- The standby service water pump (SW Pump 2E) was unavailable for 23 days. The repairs to SW Pump 2E required a pump replacement; therefore, no credit for pump recovery was credited in this analysis.

- This analysis also considers the increase in the initiating event frequency of a total loss of service water due to the failure of SW Pump 2E.

Base SPAR Model Modification. The service water system is normally aligned to supply cooling water to 1 out 2 component cooling water (CCW) heat exchangers. The in-service CCW train is rotated equally between the two CCW heat exchangers. Therefore, to ensure this aspect of operation is captured, the SWS-ROTATED change case needs to be applied to the base SPAR model. This change case is already located in the list of change cases for the Farley, Revision 8.51 SPAR model. However, an analyst must check the change case and resolve the base model to properly apply the change set.

Basic Event Probability Changes. The following initiating event frequencies and basic event probabilities were modified for this event analysis:

- In the SPAR model, SW Pump 2E is normally running and SW Pump 2C is in standby; therefore, SW Pump 2C basic events are used to represent the standby pump (SW Pump 2E) for this analysis. The basic event SWS-MDP-FR-P1C was set to TRUE to represent the failure of the standby SW Pump 2E to run.

- To ensure that the common-cause failure probabilities for the SW pumps are correctly calculated, the basic event SWS-MDP-FS-P1C was set to 1.0 (independent failure).

- An increase of approximately 25 percent in the total loss of service water initiating event frequency was estimated using the total loss of service water system initiating event fault

tree (IEFT-LOSWS).[1] This increase is based on the unavailability of the standby service water pump during the condition duration.

This increase was calculated by solving the IEFT-LOSWS fault tree using the base model (i.e., not using a workspace module) to determine the base initiating event failure probability (5.9×10^{-4}). A separate calculation using the same fault tree is then made with the standby pump unavailable (i.e., basic event SWS-MDP-FS-P1C set to TRUE). This calculation yields an initiating event failure probability of 7.3×10^{-4}. The ratio of initiating event probabilities is calculated to be 1.24 (i.e., an approximate increase of 25%).

Please note that the calculation method used within SAPHIRE 8 for conditional common-cause failure (CCF) calculations has not been fully discussed for the common-cause failure rate terms. The current CCF events with the initiating event fault tress are prefixed (i.e., the CCF terms do not automatically respond to changes in the independent event failure basic events). The effects of the current calculation method are not fully understood at this time and will need to be addressed as the support system initiating event modeling is developed further.

Based on this estimated increase, the basic event IE-LOSWS was set to 5×10^{-4} per year (i.e., a 25 percent increase of the base initiating event frequency of 4×10^{-4} per year).

REFERENCES

1. Southern Company, "LER 364/09-001-01– Service Water Pump Seismic Supports Degraded," dated March 1, 2010.

2. U.S. Nuclear Regulatory Commission, "Joseph M. Farley Nuclear Plant - Special Inspection Report 05000364/2010007," dated June 2, 2010.

[1] INL performed independent calculations on the increase in total loss of service water initiating event frequency due to loss of the standby pump. The calculations yielded similar results and INL agreed with this estimate.

Appendix A
SAPHIRE 8 Condition Assessment Report

SAPHIRE Version 8.0.7.10
SPAR Model of Farley, Units 1 & 2 Revision 8.51 (July 2010)

Condition Assessment Summary

Condition Duration	23 days
CCDP	2.036E-5
CDP	1.180E-5
Δ CDP	**8.557E-6**

Summary of Conditional Event Changes

Event	Description	Cond. Value	Nominal Value
IE-LOSWS	TOTAL LOSS OF SERVICE WATER	5.000E-4	4.000E-4
SWS-MDP-FR-P1C	SWS PUMP P001C FAILS TO RUN	TRUE	1.200E-4
SWS-MDP-FS-P1C	SWS PUMP P001C FAILS TO START	1.000E+0	2.000E-3
SWS-MDP-CF-START	SWS PUMPS FAIL FROM COMMON CAUSE TO START	0.000E+0	4.692E-7
SWS-MDP-CF-RUN	SWS PUMPS FAIL FROM COMMON CAUSE TO RUN	4.653E-4	5.583E-8

Event Tree Dominant Results

Only items contributing at least 1.0% to the total CCDP are displayed.

Event Tree	CCDP	CDP	Δ CDP	Description
TRANS	5.358E-6	9.255E-8	5.266E-6	GENERAL TRANSIENT
LOSWS	6.930E-6	5.544E-6	1.386E-6	TOTAL LOSS OF SERVICE WATER
LOMFW	6.697E-7	1.153E-8	6.582E-7	LOSS OF MAIN FEEDWATER TRANSIENT
LOCHS	5.377E-7	9.226E-9	5.285E-7	LOSS OF CONDENSER HEAT SINK TRANSIENT
LOOP	4.651E-7	1.229E-7	3.422E-7	LOSS OF OFFSITE POWER
SGTR	2.344E-7	1.116E-7	1.227E-7	STEAM GENERATOR TUBE RUPTURE
Total	**2.009E-5**	**1.157E-5**	**8.524E-6**	

Dominant Sequence Results

Only items contributing at least 1.0% to the total CCDP are displayed.

Event Tree	Sequence	CCDP	CDP	Δ CDP	Description
TRANS	02-02-10	4.713E-6	1.952E-8	4.693E-6	/RPS, /AFW, /PORV, LOSC, /RCPT, /RSD, /BP1, BP2, /FW, HPI, /SSC1, LPI
LOSWS	04-02-10	6.301E-6	5.041E-6	1.260E-6	IEFT-LOSWS, /RPS, /AFW-S, /PORV, LOSC-S, REC-SWS, /RCPT, /RSD, /BP1, BP2, /FW, HPI, /SSC1, LPI
LOMFW	02-02-10	5.891E-7	2.437E-9	5.867E-7	/RPS, /AFW, /PORV, LOSC, /RCPT, /RSD, /BP1, BP2, /FW, HPI, /SSC1, LPI
LOCHS	02-02-10	4.713E-7	1.949E-9	4.693E-7	/RPS, /AFW, /PORV, LOSC, /RCPT, /RSD, /BP1, BP2, /FW, HPI, /SSC1, LPI
TRANS	02-03-10	2.356E-7	9.729E-10	2.346E-7	/RPS, /AFW, /PORV, LOSC, /RCPT, /RSD, BP1, /BP2, /FW, HPI, /SSC1, LPI
LOOP	02-02-10	1.653E-7	2.099E-8	1.444E-7	/RPS, /EPS, /AFW-L, /PORV-L, LOSC-L, /RSD, /BP1, BP2, /OPR-02H, /FW, HPI, /SSC1, LPI
SGTR	14	1.180E-7	6.241E-10	1.173E-7	/RPS, /AFW, HPI, /SGI, /SSC1, RHR-LPI

Event Tree	Sequence	CCDP	CDP	Δ CDP	Description
TRANS	02-02-11	9.433E-8	4.724E-10	9.386E-8	/RPS, /AFW, /PORV, LOSC, /RCPT, /RSD, /BP1, BP2, /FW, HPI, SSC1
LOOP	02-05	1.429E-7	5.483E-8	8.809E-8	/RPS, /EPS, /AFW-L, /PORV-L, LOSC-L, /RSD, /BP1, BP2, OPR-02H, HPI-L
Total		**2.036E-5**	**1.180E-5**	**8.557E-6**	

Referenced Fault Trees

Fault Tree	Description
BP1	RCP SEAL STAGE 1 INTEGRITY (BINDING/POPPING)
BP2	RCP SEAL STAGE 2 INTEGRITY
HPI	HIGH PRESSURE INJECTION
HPI-L	HIGH PRESSURE INJECTION
IEFT-LOSWS	TOTAL LOSS OF SERVICE WATER IE FAULT TREE
LOSC	LOSS OF SEAL COOLING
LOSC-L	FARLEY RCPSL USING LOOP-FTF FAULT TREE FLAGS
LOSC-S	RCP SEALS SURVIVE LOSS OF COOLING
LPI	LOW PRESSURE INJECTION
OPR-02H	OFFSITE POWER RECOVERY IN 2 HRS
REC-SWS	SWS RECOVERED
RHR-LPI	RHR OR LPI SYSTEM - SGTR
SSC1	FARLEY SECONDARY SIDE COOLDOWN FAULT TREE

Cutset Report - TRANS 02-02-10

Only items contributing at least 1% to the total are displayed.

#	Prob/Freq	Total%	Cutset
	7.479E-5	100	Displaying 191 of 191 Cutsets.
1	7.444E-5	99.54	IE-TRANS,RCS-MDP-LK-BP2,SWS-MDP-CF-RUN

Cutset Report - LOSWS 04-02-10

Only items contributing at least 1% to the total are displayed.

#	Prob/Freq	Total%	Cutset
	1.000E-4	100	Displaying 1 of 1 Cutsets.
1	1.000E-4	100	IE-LOSWS,RCS-MDP-LK-BP2

Cutset Report - LOMFW 02-02-10

Only items contributing at least 1% to the total are displayed.

#	Prob/Freq	Total%	Cutset
	9.349E-6	100	Displaying 83 of 83 Cutsets.
1	9.305E-6	99.54	IE-LOMFW,RCS-MDP-LK-BP2,SWS-MDP-CF-RUN

Cutset Report - LOCHS 02-02-10

Only items contributing at least 1% to the total are displayed.

#	Prob/Freq	Total%	Cutset
	7.479E-6	100	Displaying 75 of 75 Cutsets.
1	7.444E-6	99.54	IE-LOCHS,RCS-MDP-LK-BP2,SWS-MDP-CF-RUN

Cutset Report - TRANS 02-03-10

Only items contributing at least 1% to the total are displayed.

#	Prob/Freq	Total%	Cutset
	3.739E-6	100	Displaying 47 of 47 Cutsets.
1	3.722E-6	99.54	IE-TRANS,RCS-MDP-LK-BP1,/RCS-MDP-LK-BP2,SWS-MDP-CF-RUN

Cutset Report - LOOP 02-02-10

Only items contributing at least 1% to the total are displayed.

#	Prob/Freq	Total%	Cutset
	2.624E-6	100	Displaying 1045 of 1045 Cutsets.
1	2.278E-6	86.82	IE-LOOP,/OEP-XHE-XL-NR02H,RCS-MDP-LK-BP2,SWS-MDP-CF-RUN
2	1.543E-7	5.88	IE-LOOP,CCW-MDP-CF-ABCSTRT,/OEP-XHE-XL-NR02H,RCS-MDP-LK-BP2

Cutset Report - SGTR 14

Only items contributing at least 1% to the total are displayed.

#	Prob/Freq	Total%	Cutset
	1.872E-6	100	Displaying 54 of 54 Cutsets.
1	1.861E-6	99.42	IE-SGTR,SWS-MDP-CF-RUN

Cutset Report - TRANS 02-02-11

Only items contributing at least 1% to the total are displayed.

#	Prob/Freq	Total%	Cutset
	1.497E-6	100	Displaying 88 of 88 Cutsets.
1	1.489E-6	99.45	IE-TRANS,OPR-XHE-XM-DEPRCS2,RCS-MDP-LK-BP2,SWS-MDP-CF-RUN

Cutset Report - LOOP 02-05

Only items contributing at least 1% to the total are displayed.

#	Prob/Freq	Total%	Cutset
	2.268E-6	100	Displaying 1393 of 1393 Cutsets.
1	1.063E-6	46.86	IE-LOOP,OEP-XHE-XL-NR02H,RCS-MDP-LK-BP2,SWS-MDP-CF-RUN
2	7.198E-8	3.17	IE-LOOP,CCW-MDP-CF-ABCSTRT,OEP-XHE-XL-NR02H,RCS-MDP-LK-BP2
3	6.348E-8	2.8	IE-LOOP,EPS-DGN-TM-DG12A,HPI-MDP-TM-P002C,OEP-VCF-LP-SITEAV,OEP-XHE-XL-NR02H,RCS-MDP-LK-BP2
4	5.482E-8	2.42	IE-LOOP,EPS-DGN-TM-DG1B,OEP-XHE-XL-NR02H,RCS-MDP-LK-BP2,SWS-MDP-FS-P1A
5	5.482E-8	2.42	IE-LOOP,EPS-DGN-TM-DG1B,OEP-XHE-XL-NR02H,RCS-MDP-LK-BP2,SWS-MDP-FS-P1B
6	4.616E-8	2.04	IE-LOOP,EPS-DGN-TM-DG12A,HPI-MDP-TM-P002C,OEP-VCF-LP-SNGLAV,OEP-XHE-XL-NR02H,RCS-MDP-LK-BP2
7	3.227E-8	1.42	IE-LOOP,EPS-DGN-FR-DG12A,HPI-MDP-TM-P002C,OEP-VCF-LP-SITEAV,OEP-XHE-XL-NR02H,OEP-XHE-XX-NR02H1,RCS-MDP-LK-BP2
8	3.174E-8	1.4	IE-LOOP,EPS-DGN-TM-DG12A,OEP-VCF-LP-SITEAV,OEP-XHE-XL-NR02H,RCS-MDP-LK-BP2,SWS-MDP-FS-P1E
9	3.174E-8	1.4	IE-LOOP,EPS-DGN-TM-DG12A,OEP-VCF-LP-SITEAV,OEP-XHE-XL-NR02H,RCS-MDP-LK-BP2,SWS-MDP-FS-P1D
10	3.063E-8	1.35	IE-LOOP,EPS-DG1-2A-UNIT2,HPI-MDP-TM-P002C,OEP-VCF-LP-SITEAV,OEP-XHE-XL-NR02H,RCS-MDP-LK-BP2
11	2.787E-8	1.23	IE-LOOP,EPS-DGN-FR-DG1B,OEP-XHE-XL-NR02H,OEP-XHE-XX-NR02H1,RCS-MDP-LK-BP2,SWS-MDP-FS-P1B
12	2.787E-8	1.23	IE-LOOP,EPS-DGN-FR-DG1B,OEP-XHE-XL-NR02H,OEP-XHE-XX-NR02H1,RCS-MDP-LK-BP2,SWS-MDP-FS-

#	Prob/Freq	Total%	Cutset
			P1A
13	2.645E-8	1.17	IE-LOOP,EPS-DGN-FS-DG12A,HPI-MDP-TM-P002C,OEP-VCF-LP-SITEAV,OEP-XHE-XL-NR02H,RCS-MDP-LK-BP2
14	2.381E-8	1.05	IE-LOOP,EPS-DGN-TM-DG12A,HPI-MDP-FS-P002C,OEP-VCF-LP-SITEAV,OEP-XHE-XL-NR02H,RCS-MDP-LK-BP2
15	2.347E-8	1.03	IE-LOOP,EPS-DGN-FR-DG12A,HPI-MDP-TM-P002C,OEP-VCF-LP-SNGLAV,OEP-XHE-XL-NR02H,OEP-XHE-XX-NR02H1,RCS-MDP-LK-BP2
16	2.308E-8	1.02	IE-LOOP,EPS-DGN-TM-DG12A,OEP-VCF-LP-SNGLAV,OEP-XHE-XL-NR02H,RCS-MDP-LK-BP2,SWS-MDP-FS-P1E
17	2.308E-8	1.02	IE-LOOP,EPS-DGN-TM-DG12A,OEP-VCF-LP-SNGLAV,OEP-XHE-XL-NR02H,RCS-MDP-LK-BP2,SWS-MDP-FS-P1D
18	2.284E-8	1.01	IE-LOOP,EPS-DGN-FS-DG1B,OEP-XHE-XL-NR02H,RCS-MDP-LK-BP2,SWS-MDP-FS-P1A
19	2.284E-8	1.01	IE-LOOP,EPS-DGN-FS-DG1B,OEP-XHE-XL-NR02H,RCS-MDP-LK-BP2,SWS-MDP-FS-P1B

Referenced Events

Event	Description	Probability
CCW-MDP-CF-ABCSTRT	CCF OF CCW MDP'S TO START	3.151E-5
EPS-DG1-2A-UNIT2	DIESEL GENERATOR 1/2A REQUIRED FOR UNIT 2 CONLOCA	5.790E-3
EPS-DGN-FR-DG12A	DIESEL GENERATOR 1-2A FAILS TO RUN	2.411E-2
EPS-DGN-FR-DG1B	DIESEL GENERATOR 1B FAILS TO RUN	2.411E-2
EPS-DGN-FS-DG12A	DIESEL GENERATOR 1-2A FAILS TO START	5.000E-3
EPS-DGN-FS-DG1B	DIESEL GENERATOR 1B FAILS TO START	5.000E-3
EPS-DGN-TM-DG12A	DG 1-2A UNAVAILABLE DUE TO TEST AND MAINTENANCE	1.200E-2
EPS-DGN-TM-DG1B	DG 1B UNAVAILABLE DUE TO TEST AND MAINTENANCE	1.200E-2
HPI-MDP-FS-P002C	CHARGING PUMP P002C FAILS TO START	1.500E-3
HPI-MDP-TM-P002C	PUMP P002C IS IN TEST OR MAINTENANCE	4.000E-3
IE-LOCHS	LOSS OF CONDENSOR HEAT SINK	8.000E-2
IE-LOMFW	LOSS OF MAIN FEEDWATER	1.000E-1
IE-LOOP	LOSS OF OFFSITE POWER	3.590E-2
IE-LOSWS	TOTAL LOSS OF SERVICE WATER	5.000E-4
IE-SGTR	STEAM GENERATOR TUBE RUPTURE	4.000E-3
IE-TRANS	TRANSIENT	8.000E-1
OEP-VCF-LP-SITEAV	SITE LOOP (WEIGHTED AVERAGE)	5.790E-1
OEP-VCF-LP-SNGLAV	SINGLE UNIT LOOP (WEIGHTED-AVERAGE)	4.210E-1
OEP-XHE-XL-NR02H	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS	3.181E-1
OEP-XHE-XX-NR02H1	CONVOLUTION FACTOR FOR 1FTR-OPR (2HR AVAIL)	2.530E-1
OPR-XHE-XM-DEPRCS2	OPERATOR FAILS TO DEPRESSURIZE RCS/SECONDARY SIDE (RAPID)	2.000E-2
RCS-MDP-LK-BP1	RCP SEAL STAGE 1 INTEGRITY (BINDING/POPPING OPEN) FAILS	1.250E-2
RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING OPEN) FAILS	2.000E-1
SWS-MDP-CF-RUN	SWS PUMPS FAIL FROM COMMON CAUSE TO RUN	4.653E-4
SWS-MDP-FS-P1A	SWS PUMP P001A FAILS TO START	2.000E-3
SWS-MDP-FS-P1B	SWS PUMP P001B FAILS TO START	2.000E-3
SWS-MDP-FS-P1D	SWS PUMP P001D FAILS TO START	2.000E-3
SWS-MDP-FS-P1E	SWS PUMP P001E FAILS TO START	2.000E-3

Appendix B
Key Event Trees

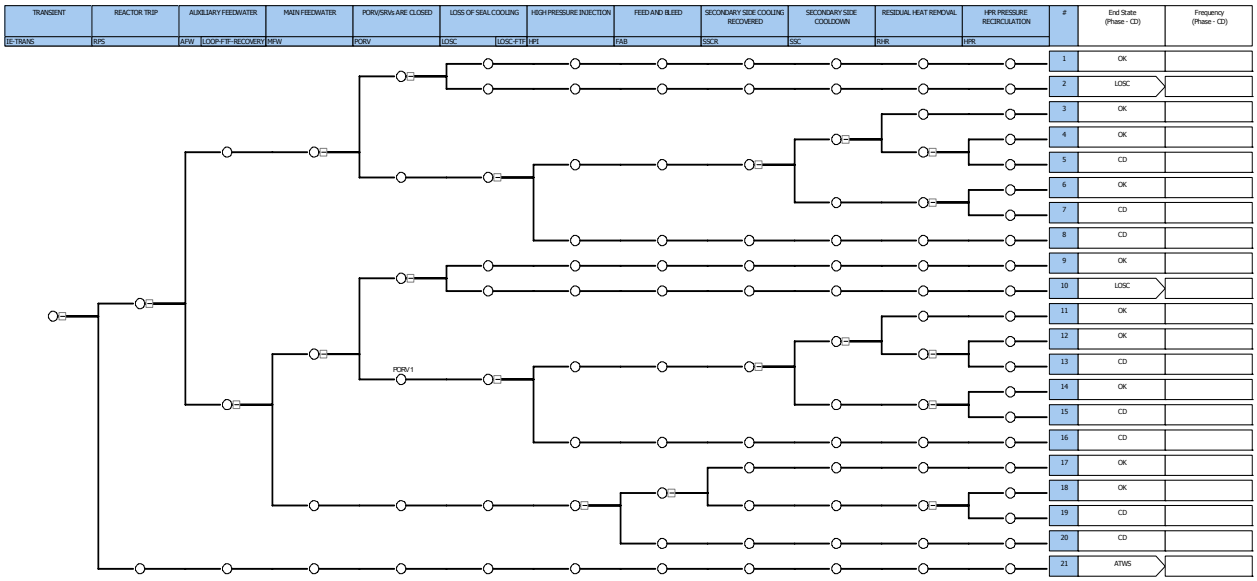

Figure B-1. Farley Transient Event Tree.

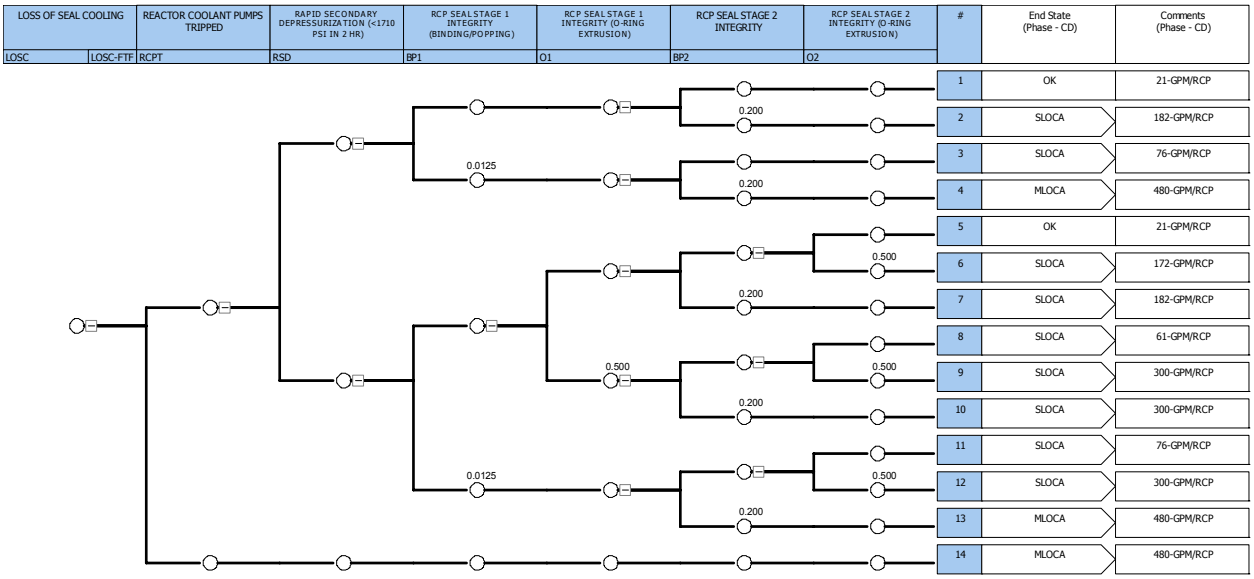

Figure B-2. Farley Loss of RCP Seal Cooling Event Tree.

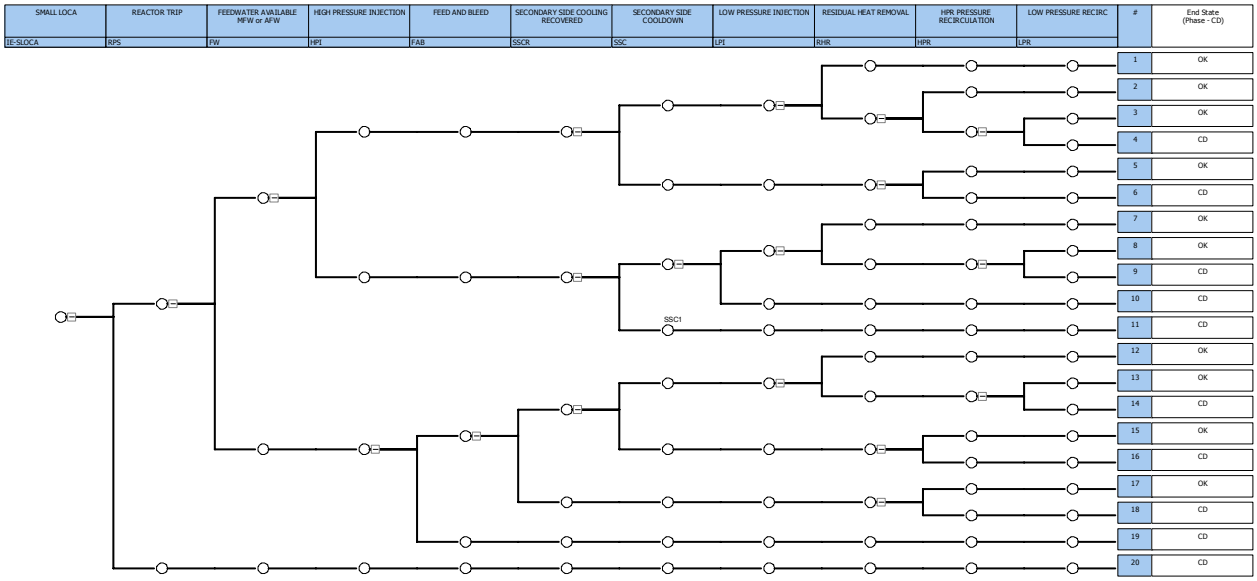

Figure B-3. Farley Small Loss-of-Coolant Accident Event Tree.