Final Precursor Analysis

Accident Sequence Precursor Program – Office of Nuclear Regulatory Research

River Bend Station	Loss of Normal Service Water, Circulating Water, and Feedwater Due to Electrical Fault	
Event Date: 05/24/2012	**LER:** 458/12-003 **IR:** 50-458/12-09, 50-458/12-10	**CCDP =** 2×10^{-4}
Plant Type: Boiling Water Reactor (BWR); General Electric-6 with a Mark III Containment		
Plant Operating Mode (Reactor Power Level): Mode 1 (33% Reactor Power)		

EXECUTIVE SUMMARY

Due to an electrical feeder cable fault to nonsafety-related 4.16 kV Bus NNS-SWG2A that occurred on May 21, 2012, the licensee was powering all circulating water (CW) pumps, feedwater (FW) pumps, and normal service water (NSW) pumps from a single source (Bus NNS-SWG2B) while repairs were being performed. This electrical alignment left the plant susceptible to a loss of all three systems (CW, FW, and NSW) given a single failure causing the unavailability of nonsafety-related 4.16 kV Bus NNS-SWG2B. On May 24th, a fault on FW Pump B motor termination box was not isolated by the associated motor feeder breaker (due to failed lockout relay) causing the loss of Bus NNS-SWG2B leading to loss of CW, FW, and NSW, and a subsequent reactor trip. The loss of feedwater and circulating water pumps caused the unavailability of the normal source of reactor inventory control and decay heat removal via the main condenser, respectively.

Given the loss of FW, reactor core isolation cooling (RCIC) or high-pressure core spray (HPCS) must supply makeup to the reactor or operators must depressurize the reactor coolant system (RCS) to allow low-pressure injection systems to provide inventory control. The safety relief valves (SRVs) provide RCS pressure control if the main condenser is unavailable. However, given the loss of NSW, at least 2 of the 4 standby service water pumps must successfully start and run to provide the capability to transfer heat to the ultimate heat sink. With no standby service water to transfer heat to the ultimate heat sink, suppression pool cooling (required for RCIC, HPCS, and successful pressure control via the SRVs), shutdown cooling [via the residual heat removal (RHR) system], and containment heat removal are rendered unavailable.

According to the risk analysis modeling assumptions used in this ASP analysis, the most likely core damage sequences [accounting for approximately 96% of the conditional core damage probability (CCDP)] are the loss of power to all NSW, FW, and CW pumps and subsequent reactor trip (which occurred during the event) combined with postulated failures/unavailabilities of standby service water components causing system failure. If the standby service water system had failed (leading to the loss of the ultimate heat sink) without recovery of power to NSW pumps (not possible during the event; and therefore, not credited), core damage could have occurred.

EVENT DETAILS

Event Description. On May 24th, the reactor plant was operating at 33 percent power with one FW pump (Pump C) and two CW pumps (Pumps B and D) in service. At approximately 1:48 p.m., operators started the FW Pump B and a subsequent fault occurred in the FW pump motor termination box. The fault was not isolated by the motor feeder breaker due to a failed lockout relay. As a result, the supply breaker for the nonsafety-related 4.16 kV Supply Bus NNS-SWG2B tripped to clear the fault. This resulted in the loss of power to all running FW, CW, and NSW pumps.[1]

The operators initiated a manual reactor scram due to the trip of all running FW and CW pumps, and immediately began implementing procedures EOP-1, "Reactor Pressure Vessel Control," and EOP-3, "Secondary Containment and Radioactive Release Control." The operators initiated the RCIC system per procedure EOP-1 for reactor level control. Soon after the manual scram, the control room received a report of smoke from the circuitry board for FW Pump B. At 1:58 p.m., the fire brigade reported that the smoke was dissipating and there was physical damage to the connection box, but no visible fire was identified. At 2:05 p.m., the operators closed the main steam isolation valves.

At 3:01 p.m., the licensee began restoring power to the nonsafety-related Train B Buses by connecting them to the associated Train A Buses. With the exception of the bus providing power to the CW and NSW pumps, the Train A Busses were available and could provide power to the Train B Buses. The Train A Bus (NNS-SWG2A) providing power to the CW and NSW pumps remained unavailable due to a cable failure that occurred on May 21st.[2]

During the cooldown, the operators used the RCIC system for level control and the SRVs for pressure control. At 3:34 p.m., reactor coolant level reached a Level 8 condition, and the RCIC system automatically stopped running. The SRVs were subsequently closed, and RCIC was restarted after reactor vessel water level was reduced below Level 8. The licensee continued to cooldown the plant using the RCIC system and the SRVs until the RHR system could be placed in service. The licensee reached Cold Shutdown conditions at 2:00 am on May 25. Additional information is provided in References 1–3.

MODELING ASSUMPTIONS

Analysis Type. The River Bend SPAR model, created in April 2012, was used for this event analysis. This event was modeled as a loss of NSW initiating event.

Analysis Rules. The ASP program uses Significance Determination Process results for degraded conditions when available. However, the ASP Program performs independent analyses for initiating events.

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1 On May 22nd, the licensee closed a tie breaker to power nonsafety-related 4160 V Bus NNS-SWG2A from the opposite train switchgear. This resulted in all CW pumps and NSW water pumps receiving power through nonsafety-related 4160 V Bus NNS-SWG2B. This power alignment was made due to a Bus NNS-SWG2A feeder cable failure experienced on May 21st that resulted in the trip of two of the four CW pumps and a subsequent reactor scram due to low condenser vacuum.

2 With both buses (NNS-SWG2A and NNS-SWG2B) that supply power to the CW pumps unavailable, recovery of the condenser heat sink was not possible for this event.

Key Modeling Assumptions. The following modeling assumptions were determined to be significant to the modeling of this event analysis:

- This analysis models the May 24, 2012 reactor trip at River Bend as a loss of NSW event and subsequent manual reactor trip.
- The normal service water pumps were not recoverable due to both nonsafety-related 4.16 kV supply buses (NNS-SWG2A and NNS-SWG2B) being damaged.

Fault Tree Modification. Added Basic Event IEFT-LONSW-NONVITAL (*Loss of Non-Vital Bus Supplying Power to NSW and SWC Pumps*) in the IEFT-LONSW Fault Tree to account for the non-recoverable loss of NSW due to the NSW and service water cooling (SWC) pumps losing power. See Figure B-1 for the modified IEFT-LONSW Fault Tree.

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

- The probability of IE-LONSW *(Loss of Normal Service Water Initiating Event)* was set to 1.0; all other initiating event probabilities were set to zero.
- The basic event IEFT-LONSW-NONVITAL was set to TRUE to account for the loss of electrical power to all NSW and SWC pumps.[3]
- Basic Event RCI-RESTART (*Restart of RCIC is Required*) was set to TRUE because operators needed to manually restart RCIC after reactor coolant level reached a Level 8 and RCIC automatically stopped, as designed.

ANALYSIS RESULTS

Conditional Core Damage Probabilities. The point estimate CCDP for this event is 1.8×10^{-4}.

The Accident Sequence Precursor Program acceptance threshold is a CCDP of 1×10^{-6} or the CCDP equivalent of a reactor trip with a non-recoverable loss of secondary plant systems (e.g., feed water and condensate), whichever is greater. This CCDP equivalent for River Bend is 3×10^{-6}.

Dominant Sequence. The dominant accident sequence is LONSW Sequence 10 (CCDP = 1.1×10^{-4}), which contribute approximately 63% of the total internal events CCDP. Additional sequences that contribute greater than 1% of the total internal events CCDP are provided in Appendix A.

The dominant sequences are shown graphically in Figure B-2 in Appendix B. The events and important component failures in LONSW Sequence 10 are:

- Non-recoverable loss of NSW occurs,
- Reactor scram succeeds,
- Steam relief valves succeed (reclose if opened),
- HPCS succeeds,
- Suppression pool cooling fails,
- Manual reactor depressurization succeeds,

3 Although not modeled because the effect on the analysis results would be negligible, recovery of power to SWC pumps was possible by aligning power for the pumps via the Train A buses.

- Shutdown cooling mode of RHR fails, and
- Containment heat removal fails (i.e., containment coolers).

REFERENCES

1. River Bend Station, "LER 458/12-003– Reactor Scram Following a Loss of Main Reactor Feedwater Pump Due to Electrical Fault," dated July 23, 2012 (ML12209A097).

2. U.S. Nuclear Regulatory Commission, “River Bend Station - NRC Augmented Inspection Team Report 05000458/2012009,” dated August 7, 2012 (ML12221A233).

3. U.S. Nuclear Regulatory Commission, “River Bend Station – NRC Augmented Inspection Team Follow-Up Inspection Report 05000458/2012010,” dated November 23, 2012 (ML12328A178).

4. Idaho National Laboratory, NUREG/CR-6883, “The SPAR-H Human Reliability Analysis Method,” August 2005 (ML051950061).

5. Idaho National Laboratory, “INL/EXT-10-18533, SPAR-H Step-by-Step Guidance,” May 2011 (ML112060305).

Appendix A: Analysis Results

Summary of Conditional Event Changes

Event	Description	Cond. Value	Nominal Value
IEFT-LONSW-NONVITAL	LOSS OF NON-VITAL BUS SUPPLYING POWER TO NSW AND SWC PUMPS	TRUE	NOT MODELED
IE-LONSW[a]	LOSS OF NORMAL SERVICE WATER	1.00E+0	1.00E+0
RCI-RESTART	RESTART OF RCIC IS REQUIRED	TRUE	1.50E-1

a. All other initiating probabilities are set to zero.

Dominant Sequence Results

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

Event Tree	Sequence	CCDP	% Contribution	Description
LONSW	10	1.14E-04	62.58%	IEFT-LONSW, /RPS, /SRV, /HCS, SPC, /DEP, SDC, CHR, SWSR
LONSW	34	6.19E-05	33.98%	IEFT-LONSW, /RPS, /SRV, HCS, /RCI, SPC, /DEP, LPI, /VA, SDC1, CHR, SWSR2
LONSW	63	3.66E-06	2.01%	IEFT-LONSW, /RPS, /SRV, HCS, RCI, DEP
LONSW	31	2.60E-06	1.43%	IEFT-LONSW, /RPS, /SRV, HCS, /RCI, SPC, /DEP, LPI, /VA, SDC1, CHR, /SWSR2, PCSR, /CVS01, LI00
	Total	**1.82E-04**	**100%**	

Referenced Fault Trees

Fault Tree	Description
CHR	CONTAINMENT HEAT REMOVAL (FAN COOLERS)
DEP	MANUAL REACTOR DEPRESS
HCS	HIGH-PRESSURE COOLANT SPRAY
IEFT-LONSW	LOSS OF NORMAL SERVICE WATER (IE FAULT TREE)
LPI	LOW-PRESSURE INJECTION (LPCS OR LPCI)
RCI	REACTOR CORE ISOLATION COOLING
SDC	SHUTDOWN COOLING
SDC1	RIVER BEND SHUTDOWN COOLING FAULT TREE
SRV	SAFETY RELIEF VALVES (RECLOSE IF OPENED)
SPC	SUPPRESSION POOL COOLING
SPC1	RIVER BEND SUPPRESSION POOL COOLING FAULT TREE
SWSR	SERVICE WATER SYSTEM RECOVERY
VA	ALTERNATE LOW-PRESSURE INJECTION

Cut Set Report - LONSW 10

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

#	CCDP	Total%	Cut Set
	1.14E-4	100	Displaying 2082 of 2082 Cut Sets.
1	1.32E-5	11.7	IE-LONSW,SSW-MDP-TM-P2B,SSW-XHE-XR-3302
2	1.32E-5	11.7	IE-LONSW,SSW-MDP-TM-P2D,SSW-XHE-XR-3302
3	1.28E-5	11.2	IE-LONSW,SSW-MDP-TM-P2B,SSW-MOV-CC-F055A
4	1.28E-5	11.2	IE-LONSW,SSW-MDP-TM-P2D,SSW-MOV-CC-F055A
5	6.62E-6	5.83	IE-LONSW,RHR-XHE-XM-ERROR,SSW-MDP-TM-P2D
6	6.62E-6	5.83	IE-LONSW,RHR-XHE-XM-ERROR,SSW-MDP-TM-P2B

#	CCDP	Total%	Cut Set
7	5.74E-6	5.05	IE-LONSW,RHR-MDP-TM-PC002B,SSW-XHE-XR-3302
8	5.53E-6	4.87	IE-LONSW,RHR-MDP-TM-PC002B,SSW-MOV-CC-F055A
9	1.36E-6	1.2	IE-LONSW,SSW-MDP-FS-P2B,SSW-XHE-XR-3302
10	1.36E-6	1.2	IE-LONSW,SSW-MDP-FS-P2D,SSW-XHE-XR-3302
11	1.31E-6	1.16	IE-LONSW,SSW-MDP-FS-P2B,SSW-MOV-CC-F055A
12	1.31E-6	1.16	IE-LONSW,SSW-MDP-FS-P2D,SSW-MOV-CC-F055A
13	1.25E-6	1.1	IE-LONSW,CHR-ACX-TM-FANA,RHR-XHE-XM-ERROR
14	1.25E-6	1.1	IE-LONSW,CHR-ACX-TM-FANB,RHR-XHE-XM-ERROR

Cut Set Report - LONSW 34

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

#	CCDP	Total%	Cut Set
	6.19E-5	100	Displaying 891 of 891 Cut Sets.
1	3.05E-5	49.3	IE-LONSW,SSW-MOV-CF-DISCH
2	1.27E-5	20.4	IE-LONSW,SSW-MDP-CF-START
3	7.01E-6	11.3	IE-LONSW,SSW-MDP-CF-RUN
4	6.29E-6	10.2	IE-LONSW,NSW-XHE-XL-NOREC2,SSW-MOV-CF-F055AB
5	1.00E-6	1.62	IE-LONSW,SSW-XHE-XR-3302,SSW-XHE-XR-3303
6	9.63E-7	1.56	IE-LONSW,SSW-MOV-CC-F055B,SSW-XHE-XR-3302

Cut Set Report - LONSW 63

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

#	CCDP	Total%	Cut Set
	3.66E-6	100	Displaying 413 of 413 Cut Sets.
1	1.11E-6	30.5	IE-LONSW,ADS-XHE-XM-MDEPR,HCS-MDP-TM-HPCS,RCI-TDP-FR-TRAIN
2	9.36E-7	25.6	IE-LONSW,ADS-XHE-XM-MDEPR,CDS-XVM-OC-F001
3	5.64E-7	15.4	IE-LONSW,ADS-XHE-XM-MDEPR,HCS-MDP-TM-HPCS,RCI-TDP-FS-RSTRT,RCI-XHE-XL-RSTRT
4	1.83E-7	5.01	IE-LONSW,ADS-XHE-XM-MDEPR,HCS-MDP-TM-HPCS,RCI-TDP-FS-TRAIN
5	1.52E-7	4.16	IE-LONSW,ADS-XHE-XM-MDEPR,HCS-MOV-CC-F004,RCI-TDP-FR-TRAIN
6	1.50E-7	4.09	IE-LONSW,ADS-XHE-XM-MDEPR,HCS-MDP-FS-HPCS,RCI-TDP-FR-TRAIN
7	7.70E-8	2.11	IE-LONSW,ADS-XHE-XM-MDEPR,HCS-MOV-CC-F004,RCI-TDP-FS-RSTRT,RCI-XHE-XL-RSTRT
8	7.58E-8	2.07	IE-LONSW,ADS-XHE-XM-MDEPR,HCS-MDP-FS-HPCS,RCI-TDP-FS-RSTRT,RCI-XHE-XL-RSTRT
9	5.73E-8	1.57	IE-LONSW,ADS-XHE-XM-MDEPR,HCS-MDP-FR-HPCS,RCI-TDP-FR-TRAIN
10	3.92E-8	1.07	IE-LONSW,ADS-XHE-XM-MDEPR,HCS-MOV-CC-F004,RCI-TDP-TM-TRAIN
11	3.85E-8	1.05	IE-LONSW,ADS-XHE-XM-MDEPR,HCS-MDP-FS-HPCS,RCI-TDP-TM-TRAIN

Cut Set Report - LONSW 31

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

#	CCDP	Total%	Cut Set
	2.60E-6	100	Displaying 60 of 60 Cut Sets.
1	2.31E-6	89	IE-LONSW,CVENT,SSW-MOV-CF-F055AB
2	1.20E-7	4.63	IE-LONSW,CVENT,SSW-MOV-CC-F055A,SSW-XHE-XR-3303
3	1.16E-7	4.46	IE-LONSW,CVENT,SSW-MOV-CC-F055A,SSW-MOV-CC-F055B

Referenced Events

Event	Description	Probability
ADS-XHE-XM-MDEPR	OPERATOR FAILS TO DEPRESSURIZE THE REACTOR	4.00E-3
CDS-XVM-OC-F001	CST SUPPLY TO RCIC/HPCS ISOLATION VALVE F001 FAILS CLOSED	2.34E-4
CHR-ACX-TM-FANA	CHR FAN COOLER A OUT FOR TEST OR MAINTENANCE	2.50E-3
CHR-ACX-TM-FANB	CHR FAN COOLER B OUT FOR TEST OR MAINTENANCE	2.50E-3
CVENT	CONTAINMENT VENTING CAUSES LOSS OF OPERATING INJECTION SOURCE	1.25E-1
HCS-MDP-FR-HPCS	HPCS PUMP FAILS TO RUN	3.62E-4
HCS-MDP-FS-HPCS	HPCS PUMP FAILS TO START	9.47E-4
HCS-MDP-TM-HPCS	HPCS IS UNAVAILABLE BECAUSE OF MAINTENANCE	7.05E-3
HCS-MOV-CC-F004	HPCS INJECTION VALVE F004 FAILS TO OPEN	9.63E-4
IE-LONSW	LOSS OF NORMAL SERVICE WATER	1.00E+0
NSW-XHE-XL-NOREC2	OPERATOR FAILS TO RECOVER NORMAL SERVICE WATER	3.40E-1
RCI-TDP-FR-TRAIN	RCIC PUMP FAILS TO RUN GIVEN THAT IT STARTED	3.95E-2
RCI-TDP-FS-RSTRT	RCIC FAILS TO RESTART GIVEN START AND SHORT-TERM RUN	8.00E-2
RCI-TDP-FS-TRAIN	RCIC PUMP FAILS TO START	6.49E-3
RCI-TDP-TM-TRAIN	RCIC PUMP TRAIN IS UNAVAILABLE BECAUSE OF MAINTENANCE	1.02E-2
RCI-XHE-XL-RSTRT	OPERATOR FAILS TO RECOVER RCIC FAILURE TO RESTART	2.50E-1
RHR-MDP-TM-PC002B	RHR TRAIN PC002B IS UNAVAILABLE DUE TO T & M	5.74E-3
RHR-XHE-XM-ERROR	OPERATOR FAILS TO START/CONTROL RHR	5.00E-4
SSW-MDP-CF-RUN	SSW PUMPS FAIL FROM COMMON CAUSE TO RUN	7.01E-6
SSW-MDP-CF-START	SSW PUMPS FAIL FROM COMMON CAUSE TO START	1.26E-5
SSW-MDP-FS-P2B	SSW PUMP P2B FAILS TO START	1.36E-3
SSW-MDP-FS-P2D	SSW PUMP P2D FAILS TO START	1.36E-3
SSW-MDP-TM-P2B	SSW PUMP P2B IS UNAVAILABLE DUE TO T & M	1.32E-2
SSW-MDP-TM-P2D	SSW PUMP P2D IS UNAVAILABLE DUE TO T & M	1.32E-2
SSW-MOV-CC-F055A	SSW BASIN OUTLET ISOLATION VLV F055A FAILS TO OPEN	9.63E-4
SSW-MOV-CC-F055B	SSW BASIN OUTLET ISOLATION VLV F055B FAILS TO OPEN	9.63E-4
SSW-MOV-CF-DISCH	SSW PUMP DISCHARGE VALVES F040A/B/C/D FAIL TO OPEN	3.05E-5
SSW-MOV-CF-F055AB	SSW BASIN DISCHARGE VALVES F055A/B FAIL TO OPEN	1.85E-5
SSW-XHE-XR-3302	OPERATOR FAILS TO RESTORE SSW TRAIN A DISCHARGE VALVE SWP-3302 FOLLOWING T&M	1.00E-3
SSW-XHE-XR-3303	OPERATOR FAILS TO RESTORE SSW TRAIN B DISCHARGE VALVE SWP-3303 FOLLOWING T&M	1.00E-3

Appendix B: Modified Fault Tree and Key Event Trees

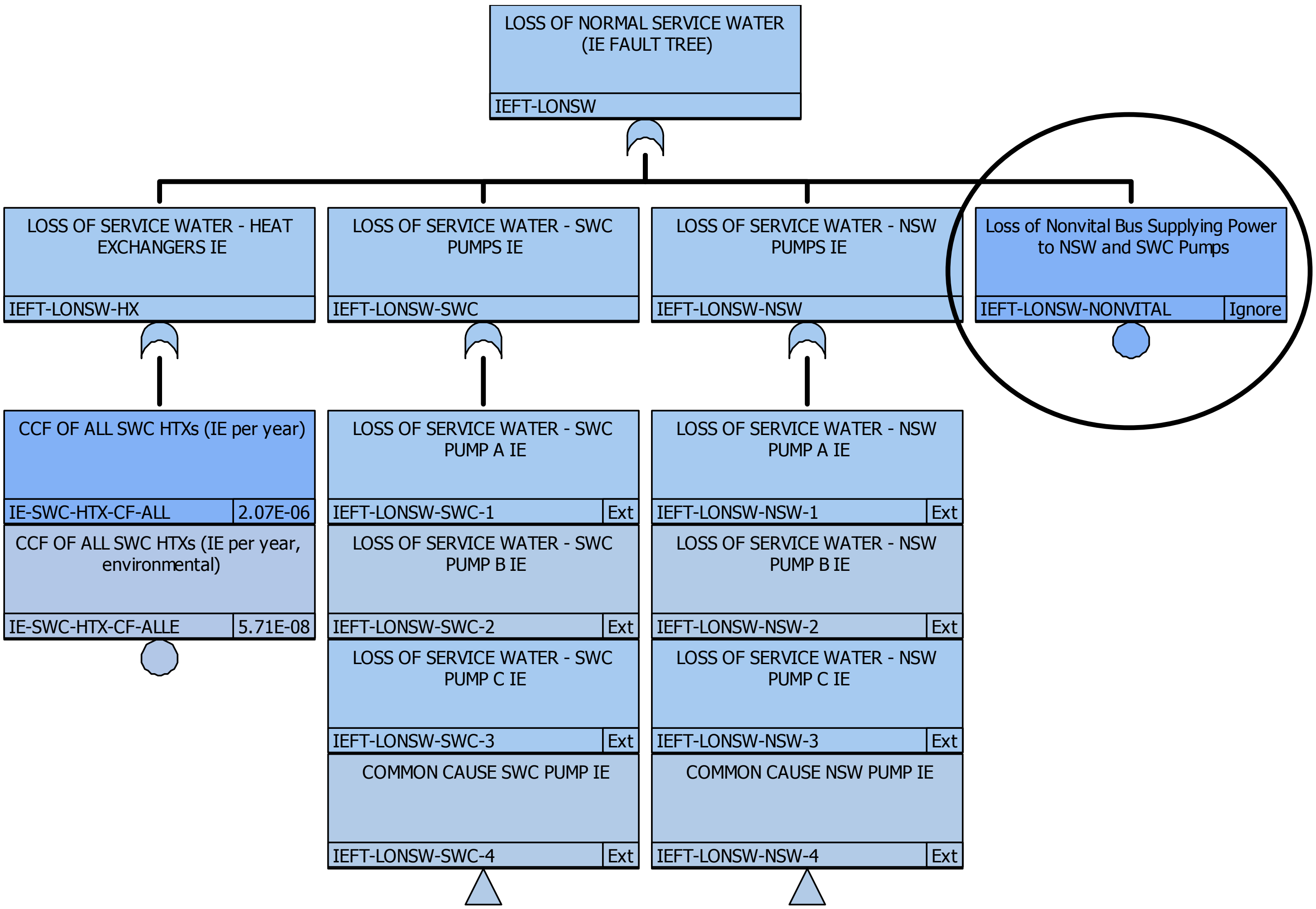

Figure B-1. Modified IE-LONSW Fault Tree.

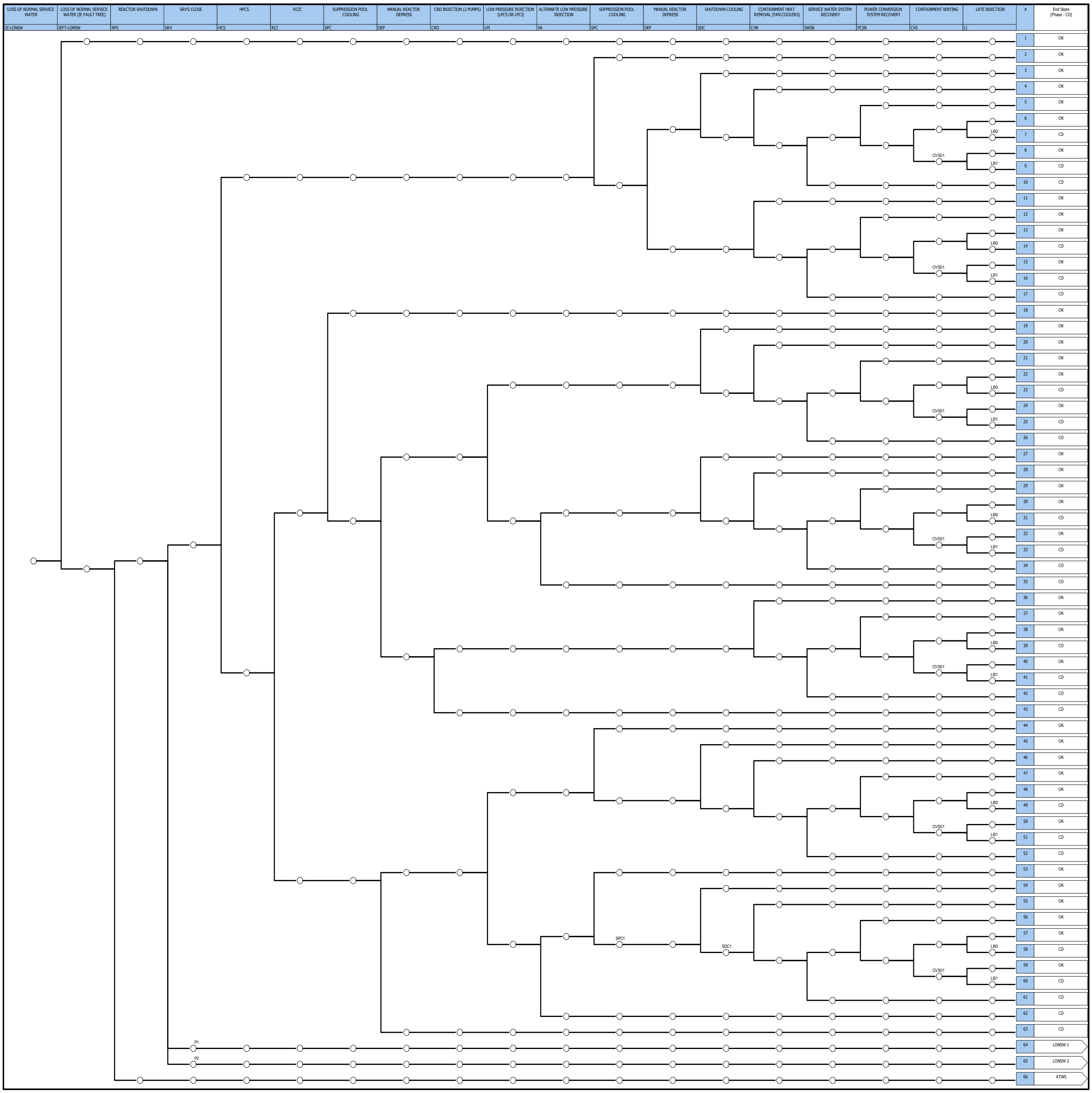

Figure B-2. Loss of NSW event tree.