Final ASP Program Analysis – Reject

<table>
<tr><th colspan="4">Accident Sequence Precursor Program – Office of Nuclear Regulatory Research</th></tr>
<tr><td colspan="1">Calvert Cliffs, Unit 2</td><td colspan="3">Automatic Reactor Trip due to Loss of Offsite Power to Safety-Related Buses</td></tr>
<tr><td>Event Date: 4/7/2015</td><td colspan="2">LER: 318-2015-002
IRs: 50-318-15-02, 50-318-2015-04, and 50-318-2015-09</td><td>CCDP = 1×10^{-6}</td></tr>
<tr><td colspan="4">Plant Type: Combustion Engineering (Generation II) Two-Loop Pressurized-Water Reactor (PWR) with Dry Ambient Pressure Containment</td></tr>
<tr><td colspan="4">Plant Operating Mode (Reactor Power Level): Mode 1 (100% Reactor Power)</td></tr>
<tr><td>Analyst:
Gary Wang</td><td>Reviewers:
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9/21/2016</td></tr>
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EVENT DETAILS

Event Description. On April 7, 2015, at 12:39 p.m., Calvert Cliffs Nuclear Power Plant Unit 1 and Unit 2 reactors automatically tripped due to the failure of a transmission line in Southern Maryland.[1] The failure of the transmission line caused a grid disturbance, when both 500kV offsite power sources for the site decreased approximately 11-percent in voltage from 525kV to 465kV. This decrease in voltage was detected by the transient under-voltage relay, which actuated for the 4.16kV essential safety features (ESF) buses 21 and 24 for Unit 2, resulting in both ESF bus feeder breakers to trip open and the automatic start of both Unit 2 emergency diesel generators (EDGs).

The grid disturbance also caused the loss of supply power to both 120V alternating current (AC) power supplies 2Y09 and 2Y10 for Unit 2. This resulted in loss of power to the turbine control system, which caused the turbine valves to close resulting in a loss of load condition and subsequent Unit 2 reactor trip. The plant response to the Unit 2 reactor trip was complicated by EDG 2B failing to provide power to the 4.16kV ESF bus 24. This resulted in a loss of the salt water (SW) pumps 22 and 23, which were aligned to the 4.16kV ESF bus 24. It was also determined that the Unit 2 ESF train sequencer for train A did not perform its safety function to sequence electrical loads on its associated 4.16kV ESF bus 21. The combination of the loss of the 4.16kV ESF bus 24 and the failure of the ESF train A sequencer resulted in a complete loss of SW cooling for 12 minutes until operators manually started the SW pump 21.

In addition, the steam generator feedwater pumps (SGFPs) tripped due to loss of power to the digital ovation system, which caused all of the feed regulating valves to drive shut and a subsequent initiation of the auxiliary feedwater actuation system. The nonsafety-related electrical buses were less impacted by the electrical transient and all of the reactor coolant pumps continued to operate. However, 4 of the 6 Unit 2 circulating water pumps tripped on under-voltage, but sufficient circulating water flow remained available to maintain condenser vacuum and the normal heat sink for reactor decay heat removal.

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1 The impacts of this event for Unit 1 are described in a separate analysis (ML16167A305). This report focuses solely on the effects of the event on Unit 2.

Normal offsite power was restored to 4.16kV ESF bus 24 at 12:59 p.m. EDG 2B was restored at 5:30 p.m. on April 8, 2015 and EDG shutdown sequencer 2A was restored at 4:33 a.m. on April 9, 2015. Additional information is provided in licensee event report (LER) 318-2015-002 (Ref. 1) and special inspection report (IR) 50-318-2015-09 (Ref. 2).

Cause. The root cause of the dual-unit trip event was determined to be an offsite grid disturbance resulting in an under-voltage condition (transient under-voltage relays actuated) on the 4.16kV ESF buses.

The root cause of the failure of EDG 2B to load was due to a failure of the input transistors on an integrated circuit chip in the speed switch. The root cause of the failure of the ESF train A shutdown sequencer was due to a failure of an electrical component in the step 1 portion of the shutdown sequencer.

MODELING

SDP Results/Basis for ASP Analysis. The ASP Program performs independent analyses for initiating events. ASP analyses of initiating events account for all failures/degraded conditions and unavailabilities (e.g., equipment out for test/maintenance) that occurred during the event, regardless of licensee performance.[2]

The NRC conducted a special inspection to review the April 7th dual-unit reactor trip at Calvert Cliffs Nuclear Power Plant. No findings were identified during the inspection; see IR 50-318-2015-09 and IR 50-318-2015-02 (Ref. 3) for additional information. LER 318-2015-002 was closed in IR 50-318-2015-04 (Ref. 4).

An independent ASP analysis is required because this was an initiating event [reactor trip with loss of main feedwater (MFW)] with a loss of offsite power (LOOP) to both ESF buses and the failure of additional equipment (e.g., EDG 2B, ESF train A sequencer).

Analysis Type. An initiating event analysis using the Calvert Cliffs Unit 2 SPAR Model posted for test/limited use, dated July 27, 2016.

SPAR Model Modifications. The following Calvert Cliffs Unit 2 SPAR model modifications were made as part this analysis:

Base Model Changes[3]

- The OTC (*once-through cooling*) fault tree contains unnecessary auxiliary feedwater (AFW) system logic intended to parse the pressurizer power-operated relief valve (PORV) success criteria.[4] The SPAR model success criteria already uses the limiting criteria of 2 of 2 PORVs; therefore, the applicable logic has been deleted. Specifically, transfers gates AFW-FCNTRL (*AFW flow control available*) and LPF-OPER (*operator fails to establish LPF in the short and long term*), as well as gate OTC-4 (*operator fails long term AFW flow*) and

[2] ASP analyses also account for any degraded condition(s) that were identified after the initiating event occurred if the failure/degradation exposure period(s) overlapped the initiating event date.

[3] Most of these base model changes are incorporated already into the test/limited used Calvert Cliffs Unit 2 SPAR model.

[4] The licensee PORV success criteria for OTC is 1 of 2 PORVs given successful AFW flow for a certain period of time.

basic event AFW-SYS-FC-AP2311 [*global failure of decay heat removal when not in EOP-8 (PSA)*] have been eliminated. The modified OTC fault tree is shown in Figure C-1 (Appendix C).

- Basic event HE-LOCHS (*house event – total loss of condenser heat sink initiator*) was added to the MFW fault tree [inserted under gate MFW-2 (*feedwater is unavailable given SLOCA, SGTR, or LOCHS*)] to account for the loss of MFW given a loss of condenser heat sink initiating event. In addition, the LOCHS-ATWS flag set was modified by setting basic event RPS-XHE-XL-ERROR to TRUE. These two changes were made to get the correct conditional core damage probability (CCDP) for a loss of condenser heat sink initiating event at Calvert Cliffs Unit 2, which is the plant-specific ASP threshold for this analysis. The modified MFW fault tree is shown in Figure C-2 (Appendix C).

Analysis-Specific Changes

- The MFW fault tree was modified to allow credit for potential recovery of MFW. New basic event MFW-XHE-RECOVER (*operators fail to recover MFW*) was added under gate MFW-1 (*feedwater is unavailable given SLOCA*) and set to IGNORE. The modified MFW fault tree is shown in Figure C-2 (Appendix C).
- The ACP-BUS-21 (*Calvert Cliffs 2 PWR G 4kV bus 21 fails*) and ACP-BUS-24 (*Calvert Cliffs 2 PWR G 4kV bus 24 fails*) fault trees were modified to include the loss of offsite power to both of these ESF buses due to decreased grid voltage. For the ACP-BUS-21 fault tree, a new AND gate named ACP-BUS21-9 (*degraded voltage leads to a LOOP to both ESF buses*) was inserted under gate ACP-BUS21-3 (*loss of offsite power to 4kV bus 21*). Basic event HE-LOOP-2A (*loss of offsite power DIV-2A flag*) and basic event OEP-XHE-XL-NR01H (*operator fails to recover offsite power in 1 hour*) were inserted under this gate.[5] Similarly for the ACP-BUS-24 fault tree, a new AND gate named ACP-BUS24-9 was inserted under gate ACP-BUS24-3 (*loss of offsite power to 4kV bus 24*). Basic events HE-LOOP-2B (*loss of offsite power DIV-2B flag*) and OEP-XHE-XL-NR01H were inserted under this gate. Due to Unit 1 electrical dependencies of certain shared components/systems (e.g., motor-driven AFW pumps), similar fault tree modifications were made on fault trees ACP-BUS-11 (*Calvert Cliffs 1 PWR G 4kV bus 11 fails*) and ACP-BUS-14 (*Calvert Cliffs 1 PWR G 4kV bus 14 fails*). These modified fault trees are shown in Figure C-3, Figure C-4, Figure C-5, and Figure C-6 (Appendix C).
- The ESF train A sequencer failed to automatically start associated train A equipment (e.g., instrument air compressor 21 and SW pump 21). To credit the potential for operators to manually start train A equipment, the EPS-DGN2A fault tree was modified. Specifically, a new AND gate named EPS-DGN2A-2 (*sequencer A fails and operators fail to manually start equipment*) was inserted under the top gate with a new OR gate named EPS-DGN2A-3 (*sequencer A fails*) inserted under gate EPS-DGN2A-2. Basic events EPS-SEQ-FO-DG2A (*DG 2A sequencer module fails to operate as required*) and EPS-SEQ-CF-DGALL (*CCF of EDG sequencers*) were moved under this gate.[6] In addition, new basic event named EPS-XHE-SEQA (*operators fail to start train A equipment manually*) was inserted under gate

[5] The one hour offsite power recovery event was selected because the limiting scenario for Calvert Cliffs Unit 2 (and most PWRs) is 1 hour given a loss of steam generator (SG) cooling and failure of once-through cooling. The human failure event (HFE) is evaluated using event-specific information; see Key Modeling Assumptions for additional information.

[6] The description of basic event EPS-SEQ-CF-DGALL had an incorrect description, which was modified for this analysis to prevent confusion.

EPS-DGN2A-2 and set to IGNORE. The revised EPS-DGN2A fault tree is shown in Figure C-7 (Appendix C).

- The CVC [*chemical and volume control system (CVCS) unavailable*] fault tree was modified to account for the loss of offsite power to both 4.16kV ESF buses. A new OR gate CVC-2 (*LOOP occurs*) was inserted under existing gate CVC-1 (*CVCS unavailable during a LOOP*). House event HE-LOOP was moved under gate CVC-2. In addition, a new AND gate CVC-3 (*LOOP to both ESF buses only*) was inserted under gate CVC-2. Basic events HE-LOOP-2A and HE-LOOP-2B were inserted under gate CVC-3. The revised CVC fault tree is shown in Figure C-8 (Appendix C).
- Following the reactor trip, the Unit 2 instrument air compressors did not start causing header pressure to decrease to 65 psig (air supplied from the backup banks maintained this pressure). Instrument air compressor 22 was initially unavailable due to a lack of electrical power (bus 24 was deenergized until offsite power was restored approximately 20 minutes after the reactor trip). After EDG 2A started and reenergized bus 21, instrument air compressor 21 failed to load due to low lube oil pressure.[7] Operators subsequently entered loss of instrument air procedures at approximately 1:25 p.m. The operators successfully reset the instrument air compressors even though procedures provided insufficient guidance for resetting the instrument air compressor following a low lube oil pressure trip condition. Approximately 20 minutes after the event initiated, operators restarted instrument air compressor 21. In addition, the Unit 1 plant air compressor was available via cross-connect to supply the Unit 2 instrument air header pressure. To model this recovery, the Unit 2 instrument air fault tree (IAS-UNIT2) was modified. New basic event IAS-XHE-UNIT2 (*operators fail to recovery instrument air*) was inserted under gate IAS-U2-2 (*instrument air compressors are unavailable*) and set to IGNORE. The revised IAS-UNIT2 fault tree is shown in Figure C-9 (Appendix C).

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

- The probability of IE-LOMFW (loss of main feedwater) was set to 1.0; all other initiating event probabilities were set to zero.[8]
  - Even though MFW was not restored during the event (due to AFW successfully providing makeup to the SGs), MFW recovery may have been possible during the event if needed (i.e., if postulated failures of AFW had occurred). There were procedural deficiencies with starting the SGFPs with lack of ovation displays and some water intrusion into the pump lube oil system; however, these issues did not cause a loss of function of these pumps. Therefore, the probability for basic event MFW-XHE-RECOVER was set to a screening value of 0.1.[9]
- The degraded grid voltage experienced during the event caused 4 of the 6 circulating water pumps to trip. The Calvert Cliffs Unit 2 SPAR model main circulating water system (MCW)

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[7] The low lube oil pressure also affected instrument air compressor 22 after offsite power was restored to bus 24.

[8] The loss of offsite power and loss of condenser heat sink event trees were not used because the nonsafety-related buses remained energized and the condenser heat sink was maintained through the duration of the event, respectively.

[9] NUREG-1792, "Good Practices for Implementing Human Reliability Analysis," provides that 0.1 is an appropriate screening (i.e., typically conservative) value for most post-initiator HFEs. Note that the use of lower failure probability for recovery has a negligible effect on the results.

fault tree does not explicitly model the circulating water pumps.[10] Sufficient circulating water flow remained available to maintain condenser vacuum and the normal heat sink throughout the event. Therefore, it was determined that no modeling changes were needed to account for partial loss of circulating water that occurred during this event.

- Basic event EPS-DGN-FS-2B (*diesel generator 2B fails to start)* was set to TRUE to account for the failure of EDG 2B to load to 4.16kV ESF Bus 24.[11]
- Basic event EPS-SEQ-FO-DG2A was set to TRUE because the ESF train A sequencer failed to automatically start associated equipment (e.g., SW pump 21).
    - The probability for basic event EPS-XHE-SEQA was set to screening value of 0.1; additional credit has a negligible effect on the analysis results.
- Basic event IAS-MDC-CF-U2IACFR (*common-cause failure of Unit 2 instrument air compressors 21 and 22 to run*) was set to TRUE to account for the unavailability of the both Unit 2 instrument air compressors due to the low lube oil pressure interlock.
    - Normal instrument air pressure was restored when instrument air compressor 21 was started within 20 minutes of the event initiation. Therefore, the probability for basic event IAS-XHE-UNIT2 was set to screening value of 0.1.
- House events HE-LOOP-2A and HE-LOOP-2B were set to TRUE because of the loss of offsite power (due to decreased voltage) to both 4.16kV ESF buses. House events HE-LOOP-1A and HE-LOOP-1B were also set to TRUE because of dependencies between Unit 1 and Unit 2 electrical systems.
    - *Offsite Power Recovery.* This event involved the functional loss of offsite power to both 4.16kV ESF buses due to decreased grid voltage. This decreased voltage only last for a short period of time and operators successfully restored offsite power to ESF bus 24 approximately 20 minutes after event initiation. Therefore, offsite power recovery to both ESF buses is credited in this analysis and is evaluated using the SPAR-H Human Reliability Analysis Method (Reference 6 and Reference 7).

      The most limiting scenario for a Combustion Engineering PWR is a sequence involving the postulated failure of all SG cooling (e.g., AFW, MFW, and low-pressure feedwater via the condensate pumps) and once-through cooling. During this postulated scenario, if SG cooling and/or once-through cooling is lost due to the loss of offsite power to the ESF bus(es) and subsequent failure of the associated EDG(s), operators would have approximately 1 hour to recover offsite power to avoid core damage.

      Table 1 and Table 2 provide the key qualitative information for this recovery and the performance shaping factor (PSFs) adjustments required for the quantification of offsite power recovery within 1 hour (i.e., basic event OEP-XHE-XL-NR01H) using SPAR-H. Therefore, the human error probability (HEP) for offsite power recovery to an ESF bus within 1 hour (represented by basic event OEP-XHE-XL-NR01H) is calculated using the following SPAR-H formula:

      OEP-XHE-XL-NR01H = (Product of Diagnosis PSFs × Nominal Diagnosis HEP) + (Product of Action PSFs × Nominal Action HEP)

[10] The MCW fault tree is composed only of electrical power and salt water system dependencies.

[11] Using the SAPHIRE event and condition (ECA) workspace automatically recalculates the associated common-cause failure (CCF) parameters associated with this piece of equipment. Appendix A presents the results of these calculations.

$$= \quad (0.04 \times 0.01) + (1 \times 0.001) = 1\times10^{-3}$$

Therefore, the probability for basic event OEP-XHE-XL-NR01H was set to 1×10^{-3}.

Table 1. Key Qualitative Information for Offsite Power Recovery within 1 Hour.

Definition	For this recovery to be successful, operators must align a 13kV source of offsite power to an ESF bus within 1 hour.
Description and Event Context	Given the loss of offsite power to one or both ESF buses and the subsequent unavailabilities of all SG cooling and once-through cooling, operators would have approximately 1 hour to re-energize an ESF bus prior to core uncovery.
Operator Action Success Criteria	If the 13kV power is available (as it was during this event) operators must verify that the applicable EDG output breaker is open and close the appropriate 4kV feeder breaker to restore power to the associated 4.16kV ESF bus.
Nominal Cues	Loss of voltage on one or both 4.16kV ESF buses.
Procedural Guidance	▪ EOP-0, "Post-Trip Immediate Actions" ▪ AOP-7I, "Loss of 4kV, 480V or 208/120V Instrument Bus Power" ▪ OI-27C, "4.16kV System"
Diagnosis/Action	This recovery action contains diagnosis and action activities.

Table 2. SPAR-H Evaluation for Offsite Power Recovery within 1 Hour.

PSF	Multiplier Diagnosis / Action	Notes
Time Available	0.01 / 1	For recovery of offsite power within 1 hour, more than 30 minutes would be available to perform the actions required to re-energize a safety bus prior to core uncovery. Therefore, the diagnosis PSF for available time is assigned as *Expansive Time* (i.e., ×0.01; time available is >2 times nominal and >30 minutes). Sufficient time exists to perform the action component of the offsite power recovery; therefore, the action PSF for available time is set to *Nominal*. See Reference 7 for guidance on apportioning time between the diagnosis and action components of an HFE.
Stress	2 / 1	The PSF for diagnosis stress is assigned a value of *High Stress* (i.e., ×2) due to the (postulated) loss of all safety-related 4.16kV AC power and core damage would occur if operators fail to restore power to an ESF safety bus. The PSF for action stress was not determined to be a performance driver for this HFE; and therefore, was assigned a value of *Nominal* (i.e., ×1).

PSF	Multiplier Diagnosis / Action	Notes
Complexity	2 / 1	The PSF for diagnosis complexity is assigned a value of *Moderately Complex* (i.e., ×2) because operators would have to deal with multiple equipment unavailabilities and the concurrent actions/multiple procedures during a LOOP to both ESF buses and subsequent (postulated) EDG- and/or AC-related failures that result in a loss of all safety-related 4.16kV AC power. The PSF for action complexity was not determined to be a performance driver for this HFE; and therefore, was assigned a value of *Nominal* (i.e., ×1).
Procedures Experience/Training, Ergonomics/HMI, Fitness for Duty, Work Processes	1 / 1	No event information is available to warrant a change in these PSFs (diagnosis or action) from *Nominal* for this HFE.

- All other safety systems responded as designed.

ANALYSIS RESULTS

CCDP. The CCDP for this analysis is 1.46×10^{-6}. The ASP Program acceptance threshold is a CCDP of 1×10^{-6} or the CCDP equivalent of an uncomplicated reactor trip with a non-recoverable loss of feedwater and condenser heat sink, whichever is greater. The CCDP for a loss of condenser heat sink for Calvert Cliffs Unit 2 is 1.84×10^{-6}. Therefore, this event is not a precursor and is screened out of the ASP Program.

Dominant Sequence. The dominant accident sequence is LOMFW sequence 15-09 (CCDP = 7.7×10^{-7}), which contributes approximately 53% of the total internal events CCDP. The cut sets and sequences that contribute to the top 95% and/or at least 1% of the total internal events CCDP are provided in Appendix A.

The dominant sequence is shown graphically in Figure B-1 in Appendix B. The events and important component failures in LOMFW sequence 15-09 are:

- A loss of MFW initiating event occurs,
- Reactor trip fails,
- Reactor coolant system pressure is successfully mitigated,
- SG cooling succeeds (e.g., AFW or MFW) succeeds,
- Emergency boration is successful,
- A pressurizer relief valve fails to close, and
- High-pressure injection fails.

REFERENCES

1. Constellation Energy, "LER 318/15-002 – Calvert Cliffs Unit 1 and Unit 2 Automatic Reactor Trips Due to Transmission System Disturbance," dated June 5, 2015 (ML15160A321).

2. U.S. Nuclear Regulatory Commission, "Calvert Cliffs Nuclear Power Plant Unit 1 and 2 – NRC Special Inspection Report 05000317/2015009 and 05000318/2015009," dated May 27, 2015 (ML15147A354).

3. U.S. Nuclear Regulatory Commission, "Calvert Cliffs Nuclear Power Plant – NRC Integrated Inspection Report 05000317/2015002 and 05000318/2015002, dated July 27, 2015 (ML15306A51).

4. U.S. Nuclear Regulatory Commission, "Calvert Cliffs Nuclear Power Plant – NRC Integrated Inspection Report 05000317/2015004 and 05000318/2015004, dated February 9, 2016 (ML16041A289).

5. U.S. Nuclear Regulatory Commission, NUREG-1792 "Good Practices for Implementing Human Reliability Analysis," dated April 2005 (ML051160213).

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

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

Appendix A: SAPHIRE 8 Worksheet

Summary of Conditional Event Changes

Event	Description	Cond. Value	Nominal Value
EPS-DGN-FS-2B	DIESEL GENERATOR 2B FAILS TO START	TRUE	5.00E-3
EPS-SEQ-FO-DG2A	DG 2A SEQUENCER MODULE FAILS TO OPERATE AS REQUIRED	TRUE	3.00E-3
EPS-XHE-SEQA	OPERATORS FAIL TO START TRAIN A EQUIPMENT MANUALLY	0.1	IGNORE
HE-LOOP-1A	LOSS OF OFFSITE POWER DIV-1A FLAG	TRUE	FALSE
HE-LOOP-1B	LOSS OF OFFSITE POWER DIV-1B FLAG	TRUE	FALSE
HE-LOOP-2A	LOSS OF OFFSITE POWER DIV-2A FLAG	TRUE	FALSE
HE-LOOP-2B	LOSS OF OFFSITE POWER DIV-2B FLAG	TRUE	FALSE
IAS-MDC-CF-U2IACFR	CCF OF UNIT 2 INSTR. AIR COMPRESSORS 21 & 22 TO RUN	TRUE	1.21E-5
IAS-XHE-UNIT2	OPERATORS FAIL TO RESTORE INSTRUMENT AIR (UNIT 2)	0.1	IGNORE
IE-LOMFW[a]	LOSS OF MAIN FEEDWATER	1.00E+0	1.86E-2
MFW-XHE-RECOVER	OPERATORS FAILS TO RECOVER MFW	0.1	IGNORE
OEP-XHE-XL-NR01H	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR	1.00E-3	5.46E-1

a. All other initiating event probabilities were set to zero.

Automatic RASP CCF Parameter Changes

Event	Description	Cond. Value	Nominal Value
EPS-DGN-CF-ALL5FS	CCF OF ALL FIVE DIESEL GENERATORS TO START	5.99E-4	1.73E-6
EPS-DGN-CF-2AB0CFS	CCF OF DIESEL GENERATOR 2A, 2B AND SBO TO START	4.33E-3	1.25E-5
EPS-DGN-CF-2ABFS	COMMON CAUSE FAILURE OF UNIT 2 DIESEL GENERATORS TO START	1.38E-2	3.99E-5
EPS-DGN-CF-1B2ABFS	CCF OF FAIRBANKS MORRIS DIESEL GENERATORS 1B, 2A, & 2B TO START	4.33E-3	1.25E-5
EPS-SEQ-CF-DGALL	CCF OF ALL SEQUENCER MODULES	3.33E-3	5.87E-6
EPS-DGN-FR-2B	DIESEL GENERATOR 2B FAILS TO RUN	1.00E+0	2.84E-2
EPS-DGN-TM-2B	DIESEL GENERATOR 2B UNAVAILABLE DUE TO T & M	TRUE	1.43E-2
EPS-DGN-CF-2AB0CFR	CCF OF DIESEL GENERATOR 2A, 2B AND SBO TO RUN	1.61E-4	7.31E-5
EPS-DGN-CF-2ABFR	COMMON CAUSE FAILURE OF UNIT 2 DIESEL GENERATORS TO RUN	2.25E-4	2.25E-4
EPS-DGN-CF-ALL5FR	CCF OF ALL FIVE DIESEL GENERATORS TO RUN	2.08E-5	1.05E-5
EPS-DGN-CF-1B2ABFR	CCF OF FAIRBANKS MORRIS DIESEL GENERATORS 1B, 2A & 2B TO RUN	1.61E-4	7.31E-5
DGS-OOS	DGs in T&M	TRUE	5.62E-2

Dominant Sequence Results

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

Event Tree	Sequence	CCDP	% Contribution	Description
LOMFW	15-09	7.70E-7	52.7%	RPS, /RCSPRESS, /SGC-A, /BORATION, PORV-A, HPI
LOMFW	02-9-4	3.31E-7	22.7%	/RPS, /SGC, /PORV, LOSC, RCPT, HPI
LOMFW	14	1.42E-7	9.7%	/RPS, SGC, OTC
LOMFW	15-10	7.43E-8	5.1%	RPS, /RCSPRESS, /SGC-A, BORATION
LOMFW	15-12	7.29E-8	5.0%	RPS, RCSPRESS

Event Tree	Sequence	CCDP	% Contribution	Description
LOMFW	02-8-4	6.36E-8	4.4%	/RPS, /SGC, /PORV, LOSC, /RCPT, CBO, RSUB, RCPSI04, HPI
Total		**1.46E-6**	**100.0%**	

Referenced Fault Trees

Fault Tree	Description
BORATION	EMERGENCY BORATION
CBO	CONTROLLED BLEEDOFF ISOLATED
HPI	HIGH PRESSURE INJECTION
LOSC	RCP SEAL INTEGRITY MAINTAINED
OTC	ONCE THROUGH COOLING
PORV-A	PORVs AND SRVs ARE CLOSED
RCPSI04	RCP SEALS FROM LOSS OF ALL COOLING
RCPT	REACTOR COOLANT PUMPS TRIPPED
RCSPRESS	RCS PRESSURE LIMITED
RPS	REACTOR TRIP
RSUB	REACTOR COOLANT SUBCOOLING MAINTAINED
SGC	STEAM GENERATOR COOLING (AFW or MFW)

Cut Set Report – LOMFW 15-09

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

#	CCDP	Total %	Cut Set
Total	7.70E-7	100	Displaying 12 Cut Sets. (12 Original)
1	1.00E-7	12.99	IE-LOMFW,PPR-SRV-OO-2RV200LIQ,RPS-RTB-FC-FTO
2	1.00E-7	12.99	IE-LOMFW,PPR-SRV-OO-2RV201LIQ,RPS-RTB-FC-FTO
3	1.00E-7	12.99	IE-LOMFW,PPR-SRV-OO-2ERV404LIQ,RPS-RTB-FC-FTO
4	1.00E-7	12.99	IE-LOMFW,PPR-SRV-OO-2ERV402LIQ,RPS-RTB-FC-FTO
5	7.50E-8	9.74	IE-LOMFW,PPR-SRV-OO-2RV200LIQ,RPS-VCF-FO-MECH
6	7.50E-8	9.74	IE-LOMFW,PPR-SRV-OO-2RV201LIQ,RPS-VCF-FO-MECH
7	7.50E-8	9.74	IE-LOMFW,PPR-SRV-OO-2ERV404LIQ,RPS-VCF-FO-MECH
8	7.50E-8	9.74	IE-LOMFW,PPR-SRV-OO-2ERV402LIQ,RPS-VCF-FO-MECH
9	1.75E-8	2.27	IE-LOMFW,PPR-SRV-OO-2RV200LIQ,RPS-VCF-FO-ELEC,RPS-XHE-XM-SCRAM
10	1.75E-8	2.27	IE-LOMFW,PPR-SRV-OO-2RV201LIQ,RPS-VCF-FO-ELEC,RPS-XHE-XM-SCRAM
11	1.75E-8	2.27	IE-LOMFW,PPR-SRV-OO-2ERV404LIQ,RPS-VCF-FO-ELEC, RPS-XHE-XM-SCRAM
12	1.75E-8	2.27	IE-LOMFW,PPR-SRV-OO-2ERV402LIQ,RPS-VCF-FO-ELEC, RPS-XHE-XM-SCRAM

Cut Set Report - LOMFW 2-9-4

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

#	CCDP	Total %	Cut Set
	3.31E-7	100	Displaying 947 Cut Sets. (947 Original)
1	8.25E-8	24.91	IE-LOMFW,CCW-CFG-AP-HX21OP,CCW-XHE-XM-KBI,RCP-XHE-XM-TRIP, SWS-VCF-TM-21
2	8.25E-8	24.91	IE-LOMFW,CCW-CFG-AP-HX22OP,CCW-XHE-XM-KBI,RCP-XHE-XM-TRIP, SWS-VCF-TM-22
3	3.52E-8	10.64	IE-LOMFW,CCW-CFG-AP-HX22OP,CCW-HTX-TM-21,RCP-XHE-XM-TRIP, SWS-VCF-TM-22

#	CCDP	Total %	Cut Set
4	3.52E-8	10.64	IE-LOMFW,CCW-CFG-AP-HX21OP,CCW-HTX-TM-22,RCP-XHE-XM-TRIP, SWS-VCF-TM-21
5	7.34E-9	2.22	IE-LOMFW,CCW-P23-FACA,EPS-FLAG-NODGOOS,HVC-CHL-CF-SWG2122FR, HVC-XHE-XM-P727,HVC-XHE-XM-RC1,RCP-XHE-XM-TRIP1
6	7.34E-9	2.22	IE-LOMFW,CCW-P23-FACB,EPS-FLAG-NODGOOS,HVC-CHL-CF-SWG2122FR, HVC-XHE-XM-P727,HVC-XHE-XM-RC1,RCP-XHE-XM-TRIP1
7	5.19E-9	1.57	IE-LOMFW,CCW-P23-FACA,EPS-FLAG-NODGOOS,HVC-CHL-CF-SWG2122FR, HVC-SYS-FC-TEMPFANS,HVC-XHE-XM-P727,RCP-XHE-XM-TRIP1
8	5.19E-9	1.57	IE-LOMFW,CCW-P23-FACB,EPS-FLAG-NODGOOS,HVC-CHL-CF-SWG2122FR, HVC-SYS-FC-TEMPFANS,HVC-XHE-XM-P727,RCP-XHE-XM-TRIP1
9	4.49E-9	1.36	IE-LOMFW,CCW-P23-FACB,EPS-FLAG-NODGOOS,HVC-CHL-FR-SWG21, HVC-CHL-FR-SWG22,HVC-XHE-XM-P727,HVC-XHE-XM-RC1,RCP-XHE-XM-TRIP1
10	4.49E-9	1.36	IE-LOMFW,CCW-P23-FACA,EPS-FLAG-NODGOOS,HVC-CHL-FR-SWG21, HVC-CHL-FR-SWG22,HVC-XHE-XM-P727,HVC-XHE-XM-RC1,RCP-XHE-XM-TRIP1
11	4.13E-9	1.25	IE-LOMFW,CCW-CFG-AP-HX22OP,CCW-XHE-XR-HTX21,RCP-XHE-XM-TRIP, SWS-VCF-TM-22
12	4.13E-9	1.25	IE-LOMFW,CCW-CFG-AP-HX21OP,CCW-XHE-XR-HTX22,RCP-XHE-XM-TRIP, SWS-VCF-TM-21

Cut Set Report – LOMFW 14

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

#	CCDP	Total %	Cut Set
	1.42E-7	100	Displaying 6546 Cut Sets. (6546 Original)
1	2.40E-8	16.94	IE-LOMFW,AFW-XHE-XM-HXNORM,AFW-XHE-XM-UQ,HPI-XHE-XM-OTC,MFW-XHE-RECOVER
2	9.43E-9	6.65	IE-LOMFW,ACP-BAC-LP-MCC214R,AFW-SYS-FC-MAKEUP
3	4.25E-9	3.00	IE-LOMFW,AFW-XHE-XM-HXNORM,AFW-XHE-XM-UQ,MFW-XHE-RECOVER,PPR-SRV-CC-2ERV404
4	4.25E-9	3.00	IE-LOMFW,AFW-XHE-XM-HXNORM,AFW-XHE-XM-UQ,MFW-XHE-RECOVER,PPR-SRV-CC-2ERV402
5	3.96E-9	2.80	IE-LOMFW,AFW-XHE-XM-HXNORM,AFW-XHE-XM-UQ,HPI-XHE-XM-OTC,SWS-VCF-TM-22
6	2.70E-9	1.91	IE-LOMFW,AFW-XHE-XM-HX,AFW-XHE-XM-UQ,CVC-23-RUNNING,DCP-BDC-LP-11
7	2.70E-9	1.91	IE-LOMFW,AFW-XHE-XM-HX,AFW-XHE-XM-UQ,CVC-22-RUNNING,DCP-BDC-LP-11
8	2.00E-9	1.41	IE-LOMFW,AFW-XHE-XM-F33,AFW-XHE-XM-F3WS,HPI-XHE-XM-OTC,MFW-XHE-RECOVER
9	1.54E-9	1.08	IE-LOMFW,AFW-XHE-XM-HX,AFW-XHE-XM-UQ,DCP-VCF-FC-1D05,HPI-XHE-XM-OTC
10	1.54E-9	1.08	IE-LOMFW,AFW-XHE-XM-HX,AFW-XHE-XM-UQ,DCP-VCF-FC-1D07,HPI-XHE-XM-OTC
11	1.46E-9	1.03	IE-LOMFW,AFW-VCF-RP-5BCMNPIPE2,HPI-XHE-XM-OTC,SWS-VCF-TM-22
12	1.43E-9	1.01	IE-LOMFW,AFW-XHE-XM-HX,AFW-XHE-XM-UQ,DCP-VCF-FC-MMXCB21A,HPI-XHE-XM-OTC
13	1.43E-9	1.01	IE-LOMFW,AFW-XHE-XM-HX,AFW-XHE-XM-UQ,DCP-VCF-FC-MMXAB11A,HPI-XHE-XM-OTC

Cut Set Report - LOMFW 15-10

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

#	CCDP	Total %	Cut Set
	7.43E-8	100	Displaying 294 Cut Sets. (294 Original)
1	3.20E-8	43.09	IE-LOMFW,CVC-XHE-XM-BOR,RPS-RTB-FC-FTO
2	2.40E-8	32.32	IE-LOMFW,CVC-XHE-XM-BOR,RPS-VCF-FO-MECH
3	5.60E-9	7.54	IE-LOMFW,CVC-XHE-XM-BOR,RPS-VCF-FO-ELEC,RPS-XHE-XM-SCRAM

#	CCDP	Total %	Cut Set
4	8.77E-10	1.18	IE-LOMFW,IAS-VCF-TM-2PAXCONN,IAS-XHE-UNIT2,RPS-RTB-FC-FTO
5	7.92E-10	1.07	IE-LOMFW,RCS-PHN-RPS0KI1432-1,RPS-RTB-FC-FTO,SWS-VCF-TM-22

Cut Set Report - LOMFW 15-12

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

#	CCDP	Total %	Cut Set
	7.29E-8	100	Displaying 103 Cut Sets. (103 Original)
1	2.24E-8	30.72	IE-LOMFW,RCS-PHN-MODPOOR,RPS-RTB-FC-FTO
2	1.68E-8	23.04	IE-LOMFW,RCS-PHN-MODPOOR,RPS-VCF-FO-MECH
3	5.66E-9	7.77	IE-LOMFW,PPR-SRV-CC-2ERV404,RPS-RTB-FC-FTO
4	5.66E-9	7.77	IE-LOMFW,PPR-SRV-CC-2ERV402,RPS-RTB-FC-FTO
5	4.25E-9	5.83	IE-LOMFW,PPR-SRV-CC-2ERV404,RPS-VCF-FO-MECH
6	4.25E-9	5.83	IE-LOMFW,PPR-SRV-CC-2ERV402,RPS-VCF-FO-MECH
7	3.92E-9	5.38	IE-LOMFW,RCS-PHN-MODPOOR,RPS-VCF-FO-ELEC,RPS-XHE-XM-SCRAM
8	1.17E-9	1.61	IE-LOMFW,PPR-SRV-CC-2RV200,RPS-RTB-FC-FTO
9	1.17E-9	1.61	IE-LOMFW,PPR-SRV-CC-2RV201,RPS-RTB-FC-FTO
10	9.91E-10	1.36	IE-LOMFW,PPR-SRV-CC-2ERV404,RPS-VCF-FO-ELEC,RPS-XHE-XM-SCRAM
11	9.91E-10	1.36	IE-LOMFW,PPR-SRV-CC-2ERV402,RPS-VCF-FO-ELEC,RPS-XHE-XM-SCRAM
12	8.78E-10	1.20	IE-LOMFW,PPR-SRV-CC-2RV200,RPS-VCF-FO-MECH
13	8.78E-10	1.20	IE-LOMFW,PPR-SRV-CC-2RV201,RPS-VCF-FO-MECH

Cut Set Report - LOMFW 2-8-4

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

#	CCDP	Total %	Cut Set
	6.37E-8	100	Displaying 179 Cut Sets. (179 Original)
1	2.10E-8	32.92	IE-LOMFW,CCW-CFG-AP-HX21OP,CCW-XHE-XM-KBI,RCS-MDP-LK-SEALS04,SWS-VCF-TM-21
2	2.10E-8	32.92	IE-LOMFW,CCW-CFG-AP-HX22OP,CCW-XHE-XM-KBI,RCS-MDP-LK-SEALS04,SWS-VCF-TM-22
3	8.95E-9	14.06	IE-LOMFW,CCW-CFG-AP-HX22OP,CCW-HTX-TM-21,RCS-MDP-LK-SEALS04, SWS-VCF-TM-22
4	8.95E-9	14.06	IE-LOMFW,CCW-CFG-AP-HX21OP,CCW-HTX-TM-22,RCS-MDP-LK-SEALS04, SWS-VCF-TM-21
5	1.05E-9	1.65	IE-LOMFW,CCW-CFG-AP-HX22OP,CCW-XHE-XR-HTX21, RCS-MDP-LK-SEALS04,SWS-VCF-TM-22
6	1.05E-9	1.65	IE-LOMFW,CCW-CFG-AP-HX21OP,CCW-XHE-XR-HTX22, RCS-MDP-LK-SEALS04,SWS-VCF-TM-21

Referenced Events

Event	Description	Probability
ACP-BAC-LP-MCC214R	BUS FAIL TO OPERATE	3.33E-5
AFW-MDP-TM-23	AFW TDP-23 UNAVAILABLE DUE TO T & M	3.63E-3
AFW-PMP-CF-UNIT1&2	ALL AFW PUMPS IN BOTH UNITS ARE LOST DUE TO COMMON CAUSE	4.13E-6
AFW-SYS-FC-MAKEUP	DEMIN MAKEUP WATER TO CST 12 VALVES FAIL (PSA)	2.83E-4
AFW-TDP-FR-21	AFW TDP-21 FAILS TO RUN	3.95E-2
AFW-TDP-FR-22	AFW TDP-22 FAILS TO RUN	3.95E-2
AFW-VCF-RP-5BCMNPIPE2	2PIPECOMMON AFW - COMMON DISCH HDR EARLY PIPE BREAK (PSA)	4.42E-6

Event	Description	Probability
ACP-BAC-LP-MCC214R	BUS FAIL TO OPERATE	3.33E-5
AFW-SYS-FC-MAKEUP	DEMIN MAKEUP WATER TO CST 12 VALVES FAIL (PSA)	2.83E-4
AFW-VCF-RP-5BCMNPIPE2	2PIPECOMMON AFW - COMMON DISCH HDR EARLY PIPE BREAK (PSA)	4.42E-6
AFW-XHE-XM-F33	OPERATIONS ALIGNS LONG TERM AFW ON PUMP CAVITATION WITH INDICATION AVAILABLE	1.00E-3
AFW-XHE-XM-F3WS	OPERATIONS FAILS TO ALIGN LONG TERM AFW WITH ALL INDICATION AVAILABLE	1.00E-3
AFW-XHE-XM-HX	OP FAILS TO CONTROL AFW FLOW - SPAR	1.20E-1
AFW-XHE-XM-HXNORM	OP FAILS TO CONTROL AFW FLOW - SPAR	1.00E-3
AFW-XHE-XM-UQ	OPS ERRONEOUSLY UNDERFILLS S/G DURING LOSS OF FLOW CONTROL	1.20E-2
CCW-CFG-AP-HX21OP	CCW HTX-22 IN STANDBY CCW HTX-21 IN OPERATION	5.00E-1
CCW-CFG-AP-HX22OP	CCW HTX-21 IN STANDBY CCW HTX-22 IN OPERATION	5.00E-1
CCW-HTX-TM-21	CCW HEAT EXCHANGER 21 IN T & M	8.54E-3
CCW-HTX-TM-22	CCW HTX-22 UNAVAILABLE DUE TO T & M	8.54E-3
CCW-P23-FACA	CCW PUMP 23 ELECTRICALLY ALIGNED TO FACILITY A	5.00E-1
CCW-P23-FACB	CCW PUMP 23 ELECTRICALLY ALIGNED TO FACILITY B	5.00E-1
CCW-XHE-XM-KBI	OPS FAILS TO PLACE STANDBY CCW HX IN SERVICE W/IN 10 MINUTES OF HX FAILURE PRIOR TO TRIP	2.00E-2
CCW-XHE-XR-HTX21	OPERATOR FAILS TO RESTORE CCW HTX-21 AFTER T & M	1.00E-3
CCW-XHE-XR-HTX22	OPERATOR FAILS TO RESTORE CCW HTX-22 AFTER T & M	1.00E-3
CVC-22-RUNNING	CVC 122 RUNNING	3.33E-1
CVC-23-RUNNING	CVC 23 RUNNING	3.33E-1
CVC-XHE-XM-BOR	OPS FAILS TO EMERGENCY BORATE W/IN 5 MINS FOLLOWING ATWS WHERE ALL CEAS FAIL TO DROP	2.00E-2
DCP-BDC-LP-11	BUS FAILS TO OPERATE	5.64E-6
DCP-VCF-FC-1D05	1OPAMP11 125VDC - DC BUS 11 LOAD SHARING CIRCUIT FAILS DURING OPERATION (PSA)	5.33E-5
DCP-VCF-FC-1D07	2OPAMP21 125VDC - DC BUS 21 LOAD SHARING CIRCUIT FAILS DURING OPERATION (PSA)	5.33E-5
DCP-VCF-FC-MMXAB11A	BATTERY 11 WITH ASSOCIATED CABLES, FUSE & DISC SWITCH/LINK FAILS TO OPERATE (PSA)	4.98E-5
DCP-VCF-FC-MMXCB21A	BATTERY 21 WITH ASSOCIATED CABLES, FUSE & DISC SWITCH/LINK FAILS TO OPERATE (PSA)	4.98E-5
EPS-FLAG-NODGOOS	NO DGS OOS	9.44E-1
HPI-XHE-XM-OTC	OPERATOR FAILS TO INITIATE FEED AND BLEED COOLING	2.00E-2
HVC-CHL-CF-SWG2122FR	CCF OF SWGR RM HVAC A/C UNITS 21 & 22 FAIL TO RUN	8.64E-4
HVC-CHL-FR-SWG21	SWGR RM HVAC A/C UNIT 21 FAILS DURING OPERATION	2.30E-2
HVC-CHL-FR-SWG22	SWGR RM HVAC A/C UNIT 22 FAILS DURING OPERATION	2.30E-2
HVC-SYS-FC-TEMPFANS	SWGR TEMP FANS FAIL TO OPERATE AS REQUIRED (PSA)	2.12E-3
HVC-XHE-XM-P727	FAILURE TO MANUALLY ALIGN FROM RECIRC MODE TO ONCE-THROUGH MODE.	3.00E-1
HVC-XHE-XM-RC1	OPS FAILS TO INSTALL PORTABLE FANS TO VENTILATE BOTH SWGR ROOMS WITHIN 9 HOURS	3.00E-3
IAS-VCF-TM-2PAXCONN	IA/PA UNIT 2 X-CONNECT LINE OUT-OF-SERVICE (PSA)	5.48E-3
IAS-XHE-UNIT2	OPERATORS FAIL TO RECOVERY INSTRUMENT AIR	1.00E-1
IE-LOMFW	LOSS OF MAIN FEEDWATER	1.00E+0
MFW-XHE-RECOVER	OPERATORS FAIL TO RECOVER MFW	1.00E-1

Event	Description	Probability
PPR-SRV-CC-2ERV402	2ERV-402 FAILS TO OPEN ON DEMAND	3.54E-3
PPR-SRV-CC-2ERV404	2ERV-404 FAILS TO OPEN ON DEMAND	3.54E-3
PPR-SRV-CC-2RV200	FAILURE OF SRV 2RV-200 TO OPEN	7.32E-4
PPR-SRV-CC-2RV201	FAILURE OF SRV 2RV-201 TO OPEN	7.32E-4
PPR-SRV-OO-2ERV402LIQ	2ERV 402 FAILS TO RECLOSE AFTER PASSING LIQUID	6.25E-2
PPR-SRV-OO-2ERV404LIQ	2ERV 2 FAILS TO RECLOSE AFTER PASSING LIQUID	6.25E-2
PPR-SRV-OO-2RV200LIQ	SRV 2RV-200 FAILS TO RECLOSE AFTER PASSING LIQUID	6.25E-2
PPR-SRV-OO-2RV201LIQ	SRV RV-201 FAILS TO RECLOSE AFTER PASSING LIQUID	6.25E-2
RCP-XHE-XM-TRIP	OPERATIONS FAILS TO TRIP THE RCPS WHEN THE CCW PUMPS WERE NOT AVAIL FOR RECOVERY - ASA - U2 TRIP NEOP8	5.00E-4
RCP-XHE-XM-TRIP1	OPERATIONS FAILS TO TRIP THE RCPS WHEN THE CCW PUMPS WERE NOT STARTED IN TIME	2.00E-2
RCS-MDP-LK-SEALS04	RCP SEALS FAIL W/O COOLING AND INJECTION	1.27E-4
RCS-PHN-MODPOOR	MODERATOR TEMP COEFFICIENT NOT ENOUGH NEGATIVE	1.40E-2
RCS-PHN-RPS0KI1432-1	FRACTION OF THE CYCLE OPERATIONS CANNOT MITIGATE AN ATWS WHEN THE TBVS DO NOT QUICK OPEN (PSA)	3.00E-2
RPS-RTB-FC-FTO	TRIP CIRCUIT BREAKERS FAIL TO OPEN	1.60E-6
RPS-VCF-FO-ELEC	ELECTRICAL (UV & ST) RPS FAILURE TO OPEN TRIP CIRCUIT BREAKERS	1.40E-5
RPS-VCF-FO-MECH	CONTROL ROD ASSEMBLIES FAIL TO INSERT	1.20E-6
RPS-XHE-XM-SCRAM	OPS FAILS TO MANUALLY TRIP THE RX WITHIN 5 MINUTES FOLLOWING THE FAILURE OF RPS AND DSS	2.00E-2
SWS-VCF-TM-21	SW HDR 21 IS UNAVAILABLE WHEN UNIT 1 IS AT-POWER (PSA)	1.65E-2
SWS-VCF-TM-22	SW HDR 22 IS UNAVAILABLE WHEN UNIT 2 IS AT-POWER (PSA)	1.65E-2

Appendix B: Key Event Tree

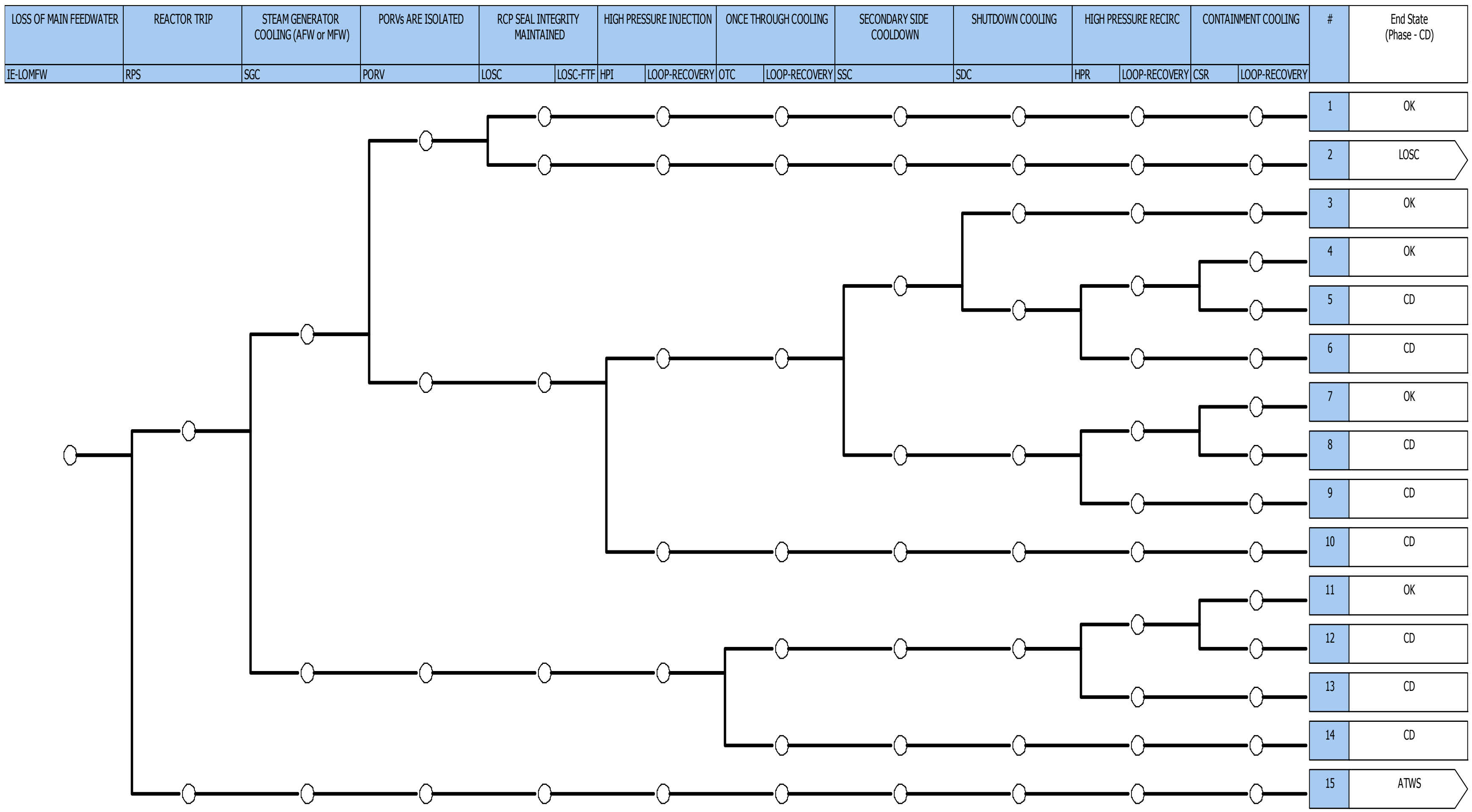

Figure B-1. Loss of MFW Event Tree

Appendix C: SPAR Model Modifications

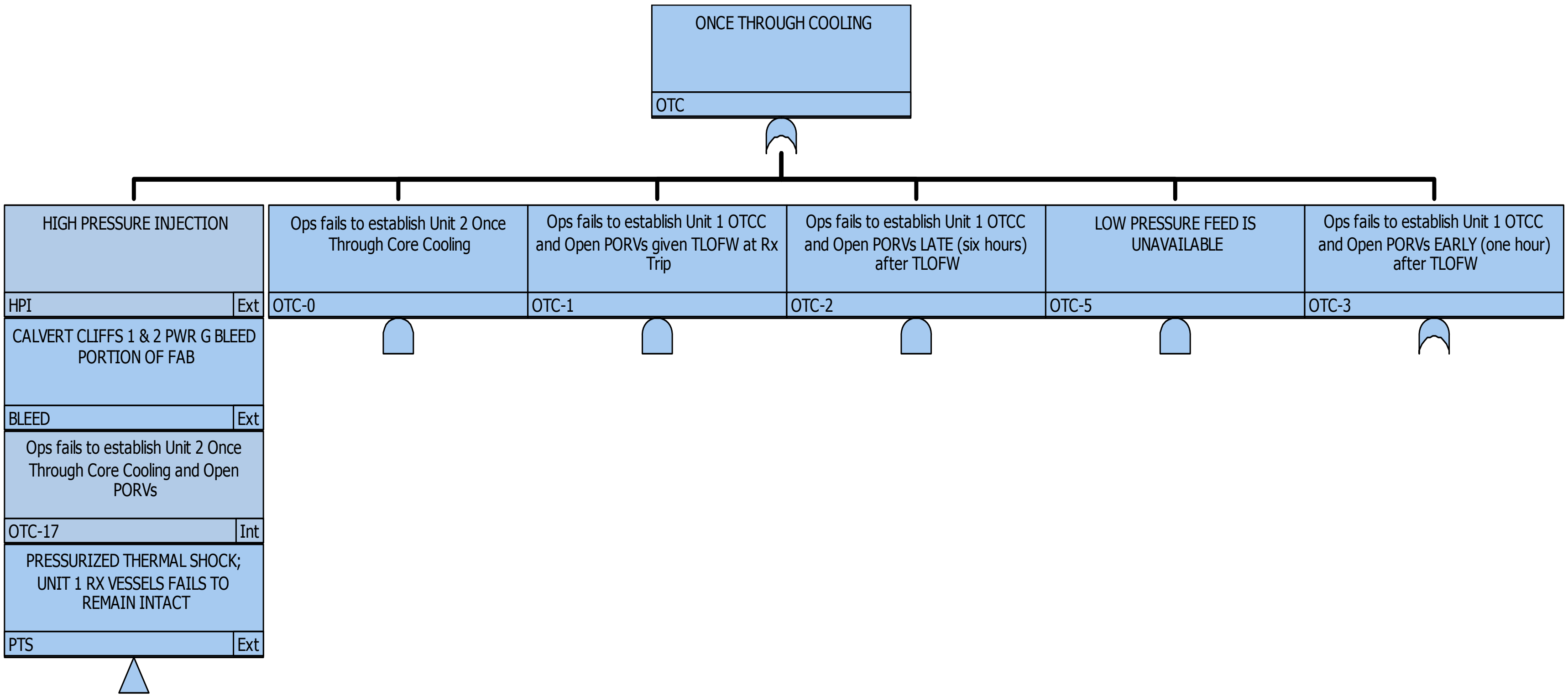

Figure C-1. Modified OTC Fault Tree

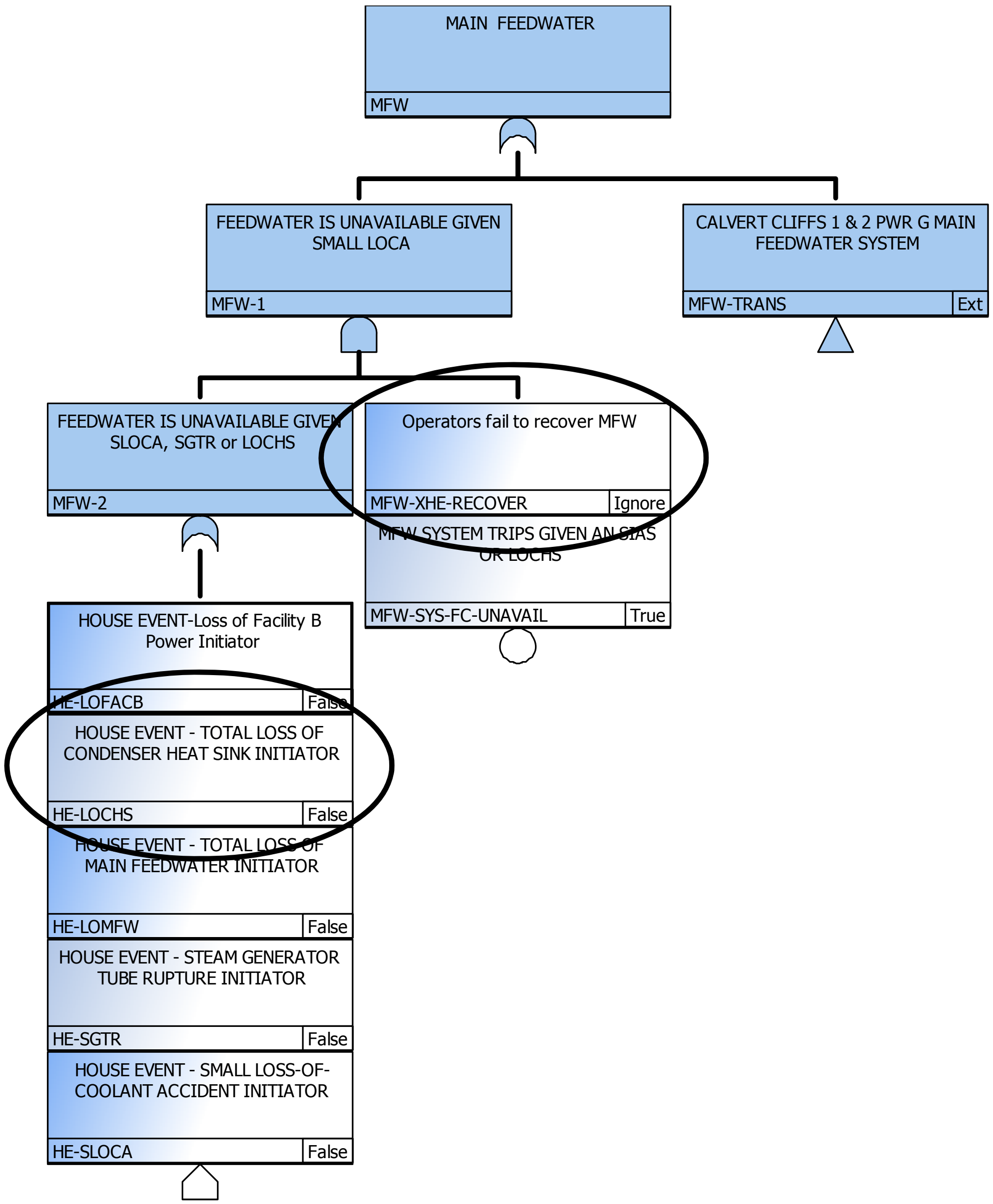

Figure C-2. Modified MFW Fault Tree

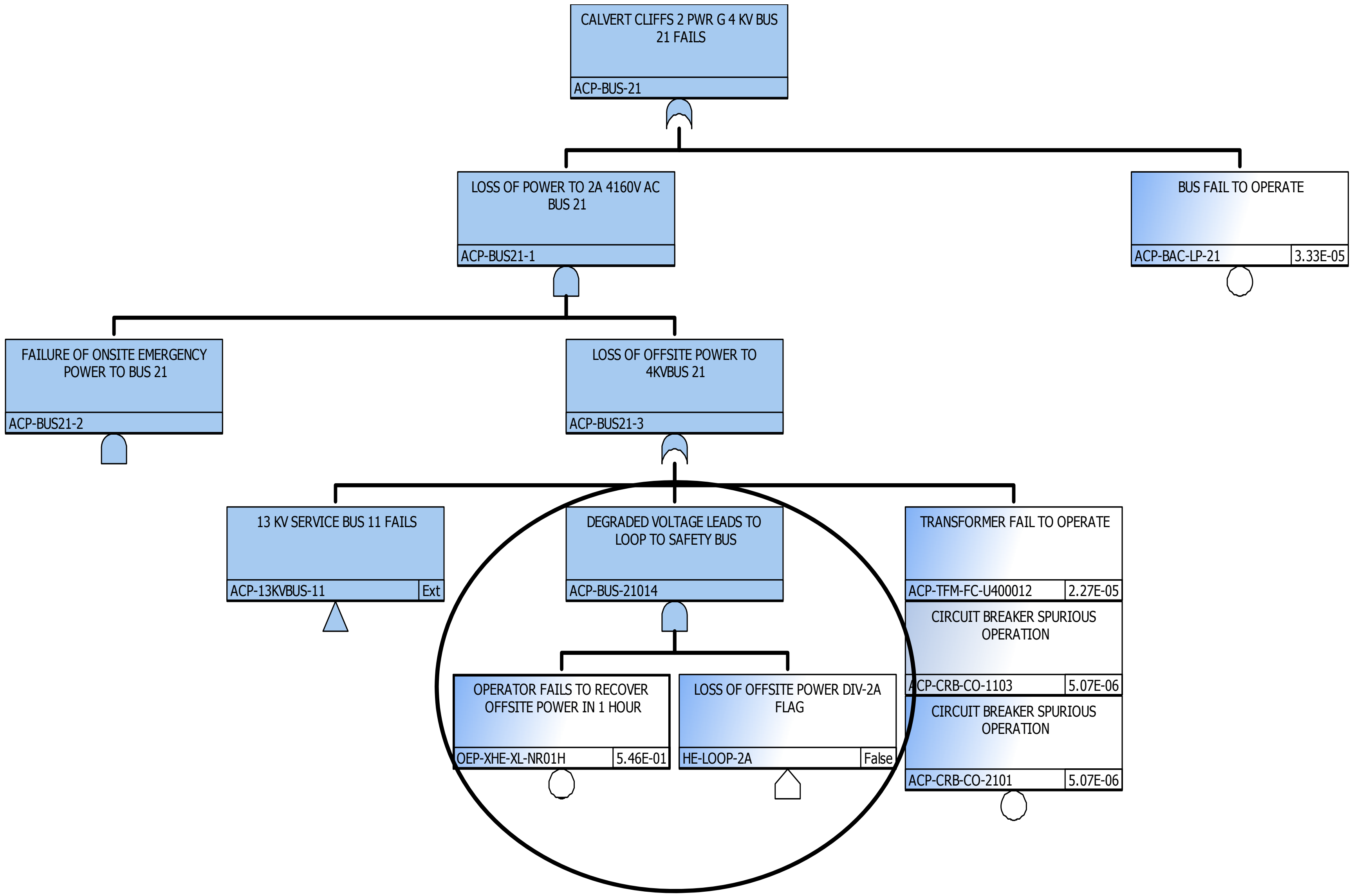

Figure C-3. Modified ACP-BUS-21 Fault Tree

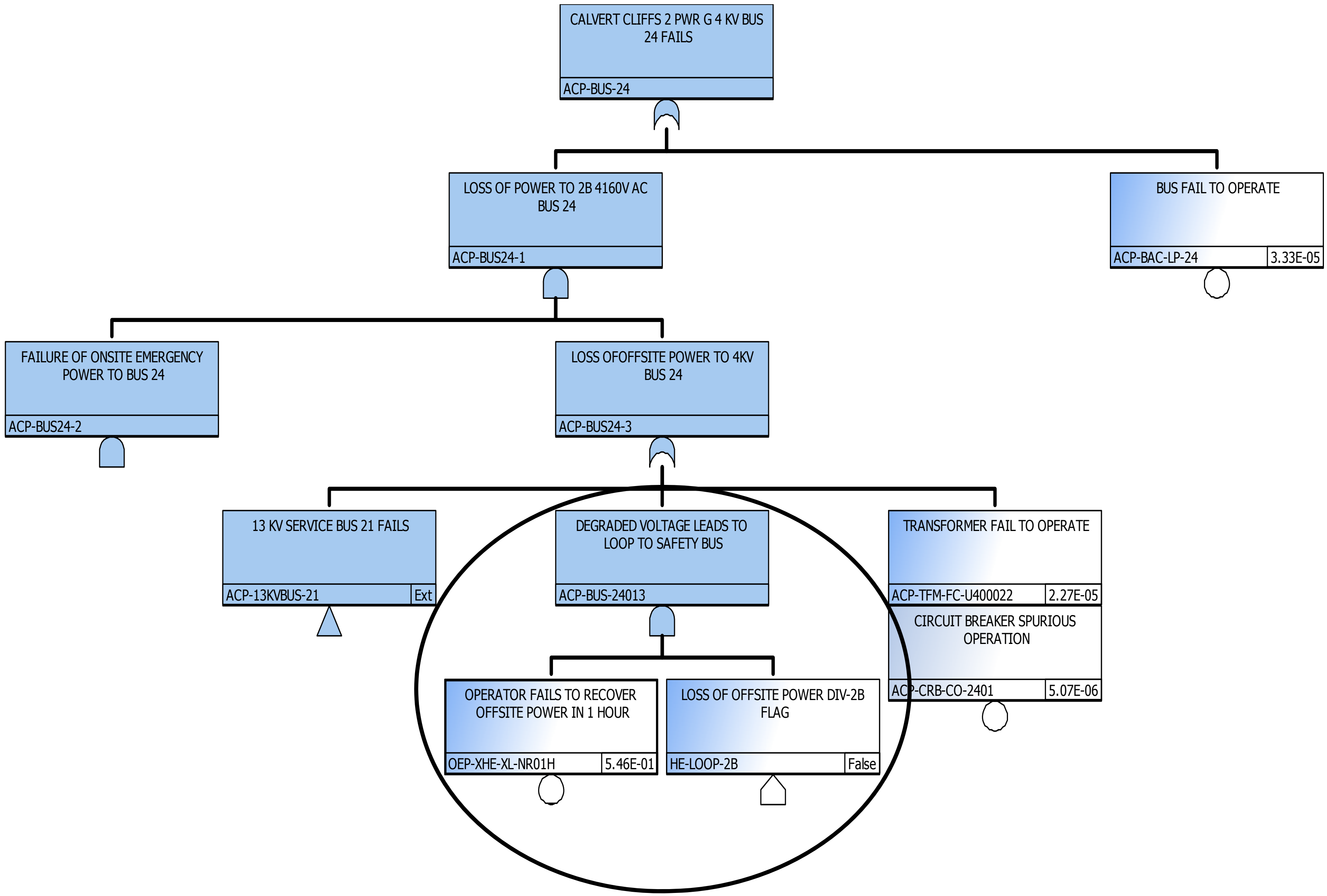

Figure C-4. Modified ACP-BUS-24 Fault Tree

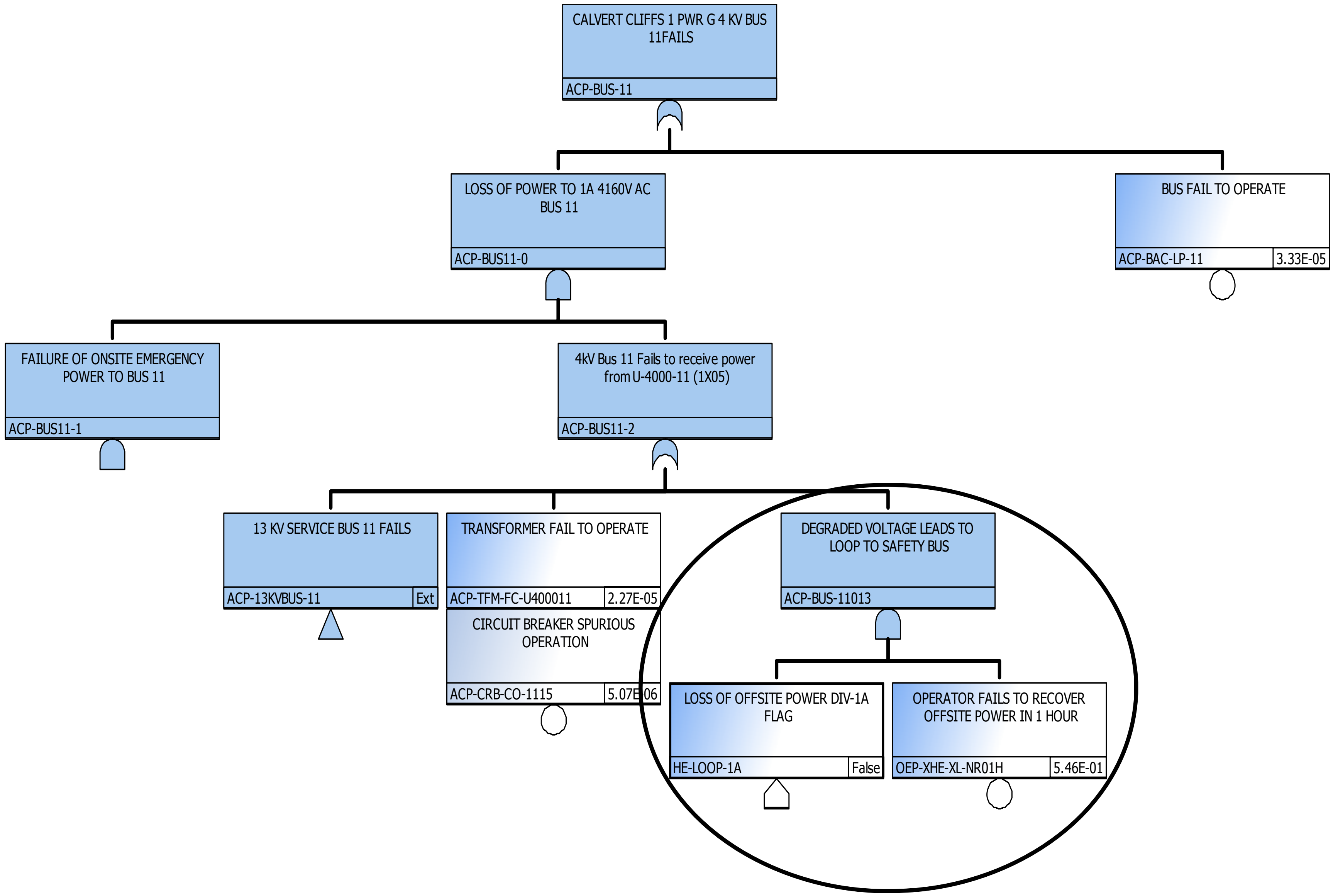

Figure C-5. Modified ACP-BUS-11 Fault Tree

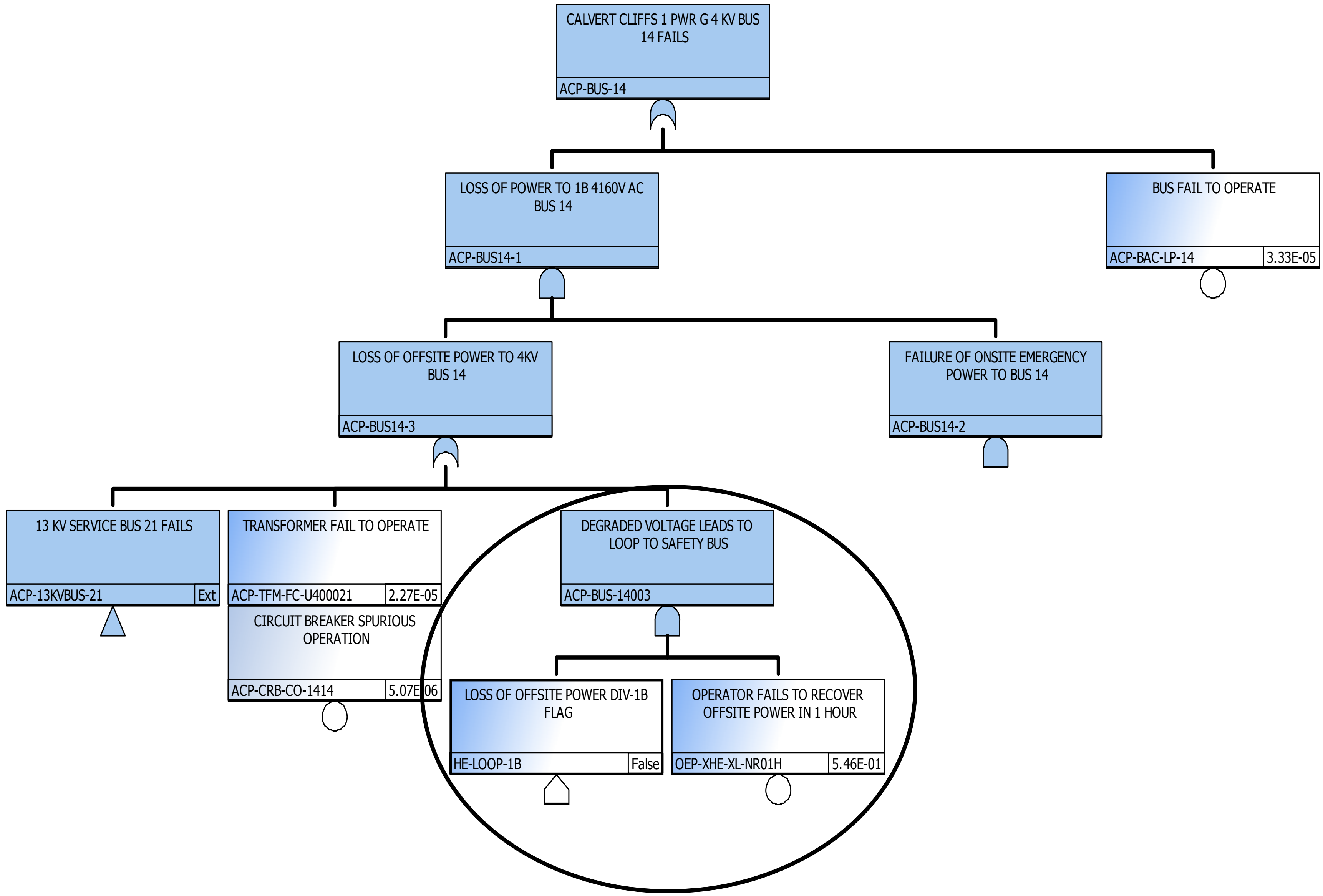

Figure C-6. Modified ACP-BUS-14 Fault Tree

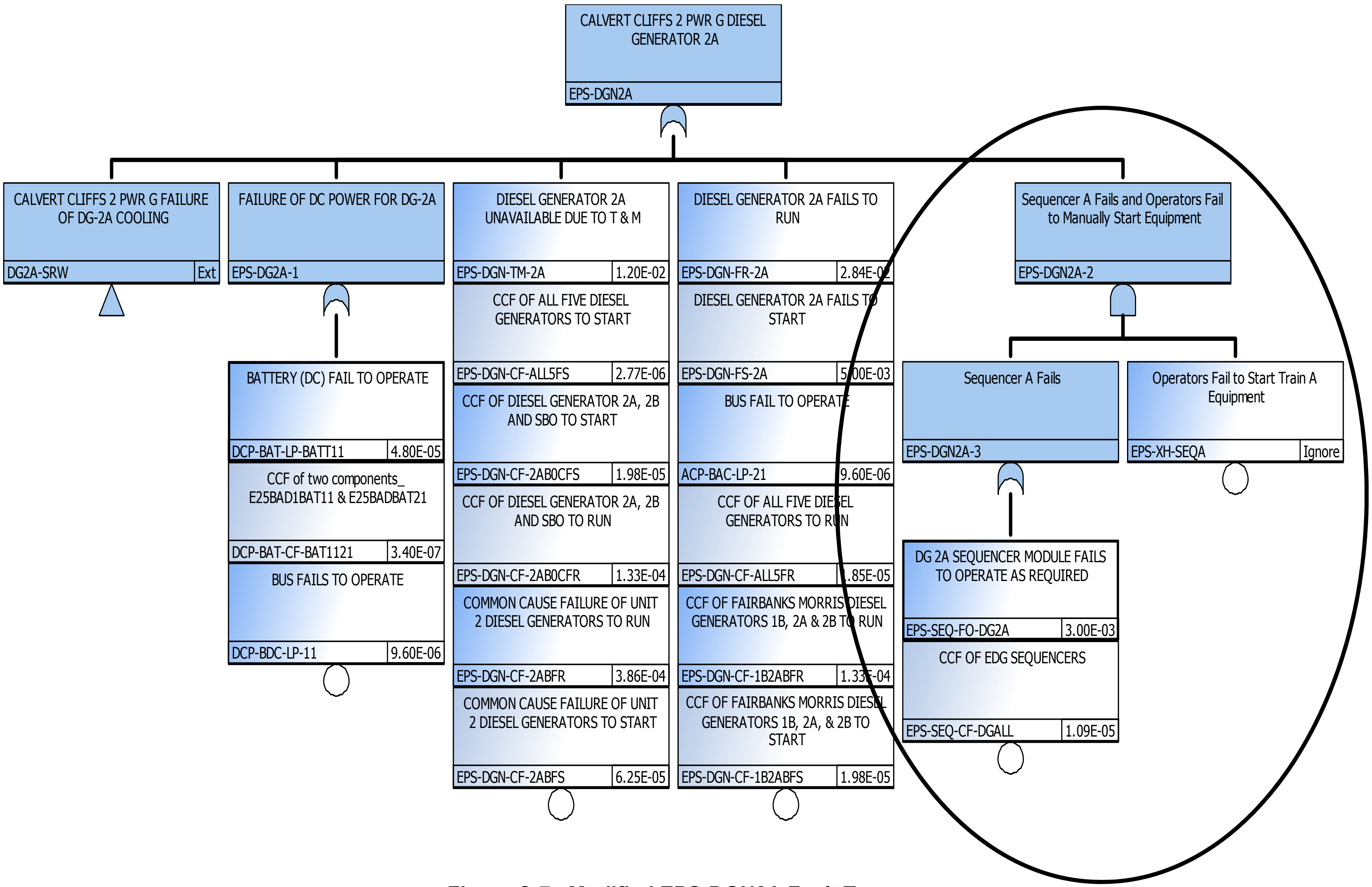

Figure C-7. Modified EPS-DGN2A Fault Tree

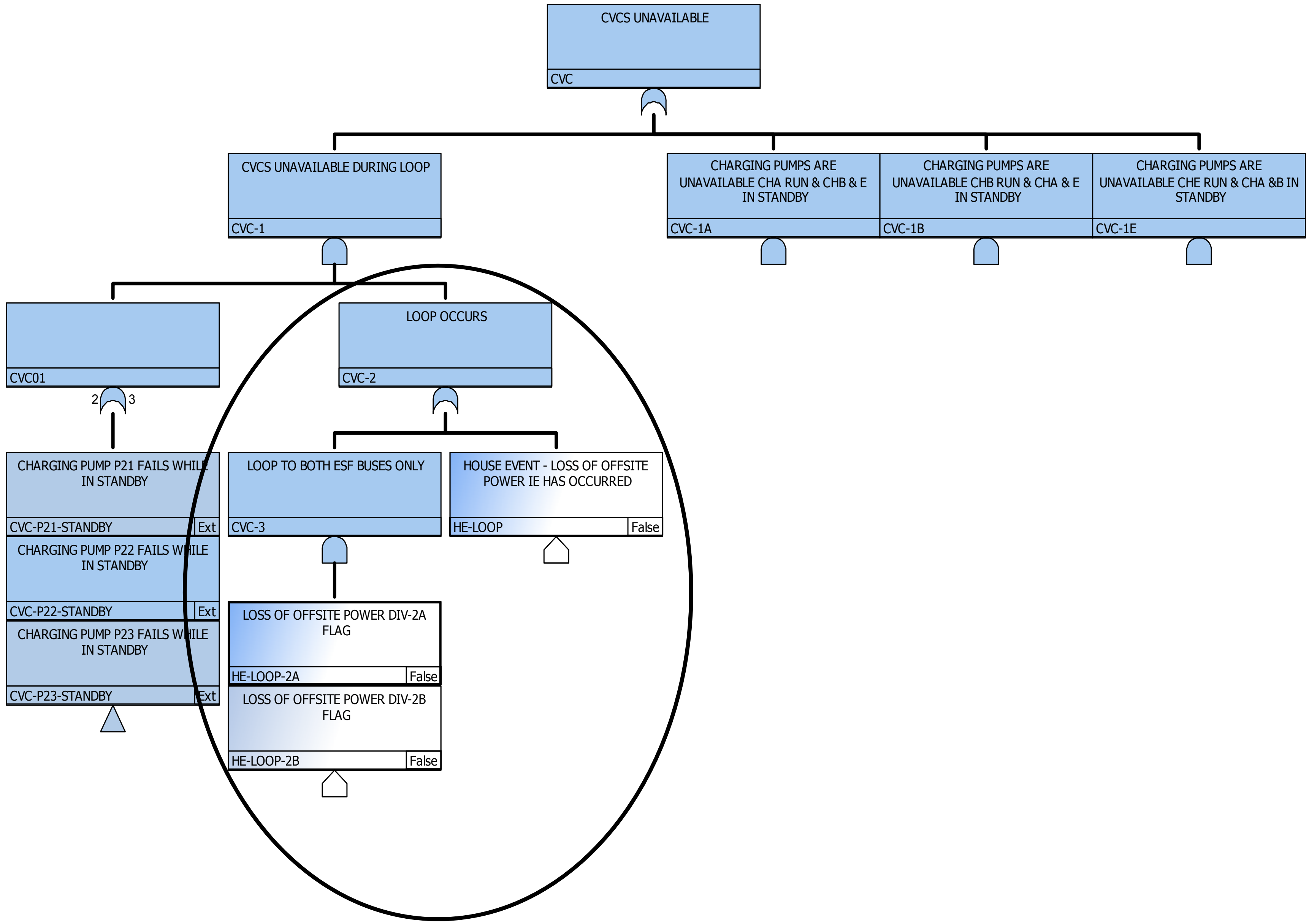

Figure C-8. Modified CVC Fault Tree

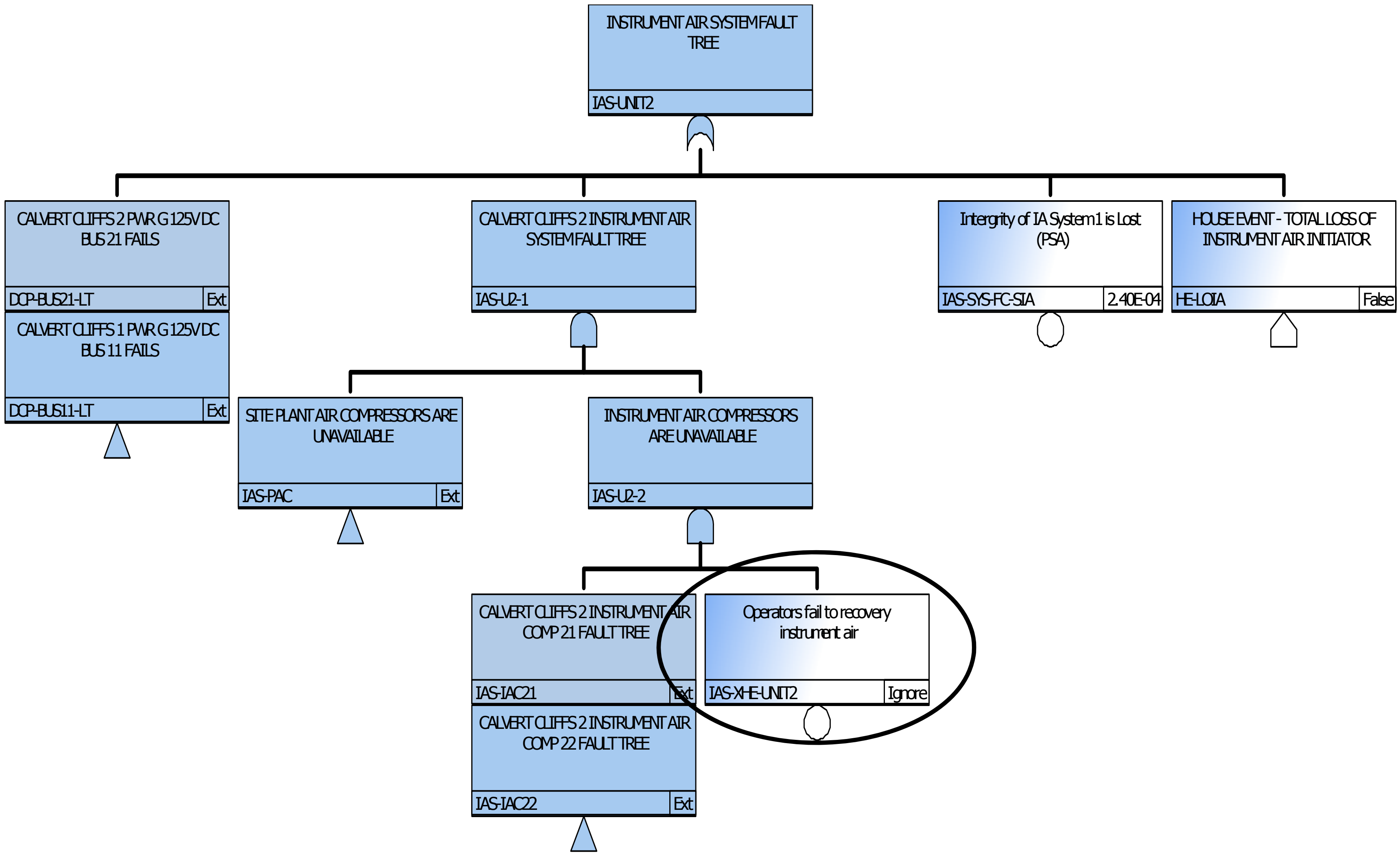

Figure C-9. Modified IAS-UNIT2 Fault Tree