Final ASP Analysis – Precursor

Accident Sequence Precursor Program – Office of Nuclear Regulatory Research			
Davis-Besse Nuclear Power Station	Field Flash Selector Switch Failure Results in Emergency Diesel Generator Unavailability		
Event Date: 5/27/2021	**LER:** None **IR:** 05000346/2021050	**CCDP =** 9×10^{-6}	
Plant Type:	Babcock & Wilcox Raised-Loop Pressurized-Water Reactor (PWR) with Large, Dry Containment		
Plant Operating Mode (Reactor Power Level):	Mode 1 (100% Reactor Power)		
Analyst: Christopher Hunter	**Reviewer:** Mehdi Reisi Fard	**Completion Date:** 6/15/2022	

1 EXECUTIVE SUMMARY

On May 27, 2021, the division ‘1’ emergency diesel generator (EDG) failed to reach required voltage and frequency during surveillance testing. Troubleshooting efforts by the licensee found that manual switch contacts in the field flash circuit path had fouling present that prohibited the current flow necessary to flash the generator field during the EDG starting sequence.

The safety-related EDGs use current from the station’s 125-volt (V) direct current (DC) system to supply the generator field during the starting sequence. Once the current supplied by the generator is adequate to maintain the EDG field, a separate contact opens and stops the current flow from the 125V DC system. The licensee’s investigation found that the field flash selector switch (FFSS) contacts were visible without disassembling the switch and the contacts appeared fouled.

The licensee modified the EDG field flash circuit when it implemented a modification in 2006. Originally, the field flash circuit had a single circuit path that was used to flash the field for the monthly slow-start surveillance test, the semiannual fast-start surveillance test, and automatic starts from standby conditions. A series of modifications made multiple EDG changes, which included installing new voltage regulators in the EDGs and modifying the field flash circuits to have two parallel paths in the circuit. The desired path is selected using the FFSS. The first path, which is selected for the monthly surveillance tests, flashes the generator field when EDG speed reaches 800 rpm. The second path, which is selected for automatic starts from standby conditions and for the semiannual fast-start surveillance test, flashes the generator field when EDG speed reaches 400 rpm.

The mean core damage probability (ΔCDP) for this event is 9×10^{-6} and, therefore, this event is a precursor. The dominant hazards for this accident sequence precursor (ASP) analysis are internal fires, internal events, and high winds, which contribute approximately 58 percent, 41 percent, and 1 percent of the total ΔCDP, respectively. The risk contribution from seismic events, internal floods, and tornados is minimal for this analysis. Note the internal fire modeling in the Davis-Besse SPAR model is largely based on the results of the individual plant examinations of external events (IPEEE) that was completed in 1994 and the SPAR model results have not been compared with the licensee’s current probabilistic risk assessment for internal fires. Therefore, the risk from internal fire scenarios could be over- or under-estimated. This is a key uncertainty associated with this analysis.

An apparent violation and an unresolved issue related to the failure of the division ‘1’ EDG FFSS was initially identified by NRC inspectors. However, subsequent evaluation and discussion with the licensee determined that there was no licensee performance deficiency associated with this event and, therefore, an independent ASP analysis was performed.

2 EVENT DETAILS

2.1 Event Description

On May 27, 2021, the division ‘1’ EDG failed to reach required voltage and frequency during surveillance testing. Troubleshooting efforts by the licensee found that manual switch contacts in the field flash circuit path had fouling present that prohibited the current flow necessary to flash the generator field during the EDG starting sequence.

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Additional information is provided in inspection report (IR) 05000346/2021050, “Davis-Besse Nuclear Power Station – Special Inspection Reactive Report 05000346/2021050 and Apparent Violation,” (ML21321A365). Note that there was no licensee event report (LER) issued for this condition.

2.2 Cause

Fouling of the FFSS contacts resulted in the failure of the division ‘1’ EDG failure to start during the semiannual fast-start surveillance test performed on May 27, 2021.

3 MODELING

3.1 SDP Results/Basis for ASP Analysis

The ASP Program uses SDP results for degraded conditions when available (and applicable). In response to this event, the NRC performed a special inspection per Management Directive 8.3, “NRC Incident Investigation Program” (ML18073A200). The special inspection, as documented in IR 05000346/2021050, identified an apparent violation and an unresolved issue related to the failure of the division ‘1’ EDG FFSS. Subsequent evaluation and discussion with the licensee determined that there was no licensee performance deficiency associated with this event. Therefore, an independent ASP analysis was performed because there was no performance deficiency identified and its potential risk significance. A search of additional Davis-Besse LERs did not reveal any “windowed” events.

3.2 Analysis Type

An initiating event analysis was performed using a test and limited use of the version 8.58 standardized plant analysis risk (SPAR) model for Davis-Besse Nuclear Power Plant created in June 2022. This SPAR model includes the following hazards:

- Internal events,
- Internal floods,
- Internal fires,
- Seismic, and
- High winds (including tornados).

3.3 SPAR Model Modifications

The following SPAR model modifications were made to support this analysis:

- *Crediting FLEX Strategies*. The probability of basic event FLX-XHE-XE-ELAP (*operators fail to declare ELAP when beneficial*) was set to its nominal value of 10^{-2} to activate the credit for FLEX mitigation strategies for postulated station blackout (SBO) scenarios for which an extended loss of AC power (ELAP) is declared.

- *FLEX Reliability Parameters*. The base SPAR models currently use the reliability parameters of permanently installed equipment as placeholders for FLEX equipment because FLEX-specific reliability parameters were not available when the FLEX logic was incorporated into the SPAR models. The FLEX reliability parameters used in this analysis were updated based on the generic values provided in PWROG-18043-NP, “FLEX Equipment Data Collection and Analysis,” (ML22123A259).

- *Offsite Power Recovery and EDG Repair Credit during ELAP Scenarios*. The base SPAR model provides credit for offsite power recovery and EDG repair for SBO/ELAP scenarios. However, potential EDG repair credit is not applicable early in ELAP scenarios because the Davis-Besse FLEX final integrated plan only allows a 10-minute period for an auxiliary operator to troubleshoot the failed EDGs prior the ELAP declaration prior to having to report back to the main control room (MCR) for his/her FLEX implementation task. Therefore, credit for early EDG repair credit (i.e., 2 hours or less) was removed from all ELAP sequences by setting the applicable EDG repair basic events to TRUE. In addition, the available time for offsite power recovery and EDG repair time is overly optimistic for some ELAP scenarios. The times were reset using the following considerations:
  - For sequences where the deep load shed, FLEX DGs, the emergency feedwater (EFW) or turbine-driven auxiliary feedwater (TDAFW) pumps supply makeup to the steam generators are successful, the offsite power recovery and EDG repair time available remains set to 24 hours.
  - For sequences where the deep load shed and SG feed from either the EFW or TDAFW pumps are successful, but the FLEX DGs fail, the offsite power recovery

and EDG repair time available is set to the extended battery depletion time of 14.6 hours.

– For sequences where deep load shed fails, the offsite power recovery and EDG repair time available is set to the nominal battery depletion time of 2 hours.

- *72-Hour AC Power Recovery Requirement*. The base SPAR model requires AC power recovery within 72 hours for a safe/stable end state for ELAP scenarios with successful FLEX implementation. If AC power is not recovered in these scenarios, the SPAR models assume core damage. The American Society of Mechanical Engineers/American Nuclear Society probabilistic risk assessment standard definition for safe/stable end state does not require AC power recovery. Because of the large uncertainty in modeling assumptions related to availability and reliability of components and strategies for mission times that are well beyond 24 hours and the unclear basis for requiring AC power recovery within 72 hours, the 72-hour AC power requirement was eliminated in this analysis. As part of this change, the failure to run events for FLEX diesel generators and pumps have a 72-hour mission time in the base SPAR model. These mission times were reset to be consistent with the 24-hour mission time used in the SPAR model.

- *Division '1' EDG Recovery Credit for Dominant Fire Scenario.* To model credit for recovery of the division '1' EDG in the dominant fire scenario, fire in the MCR results in evacuation, the EPS-DGN11-HARDWARE fault tree was modified. A new AND gate EPS-DGN11-HARDWARE5 was inserted under the top gate. Then all the applicable failure mode basic events [including the common-cause failure (CCF) events in the EPS-DGN11 fault tree] for the division '1' EDG were moved under a new OR gate EPS-DGN11-HARDWARE511. In addition, a new complement house event HE-FIRE-CRE (*MCR fire*) and recovery event EPS-XHE-DGN11-FFSS (operators fail to recover FFSS) were inserted under new OR gate EPS-DGN11-HARDWARE511. The house event HE-FIRE-CRE was also added to the FRI-FF01-CRE-LOOP and FRI-FF01-CRE-SBO flag sets. The EDG CCF basic event were removed from the EDG-DGN11 fault tree. The modified EPS-DGN11-HARDWARE and EPS-DGN11 fault trees are shown in Figures B-1 and B-2 in Appendix B.

3.4 Exposure Time

The last successful test of the division '1' EDG with the FFSS selected to the fast-start setting (i.e., 400 rpm) was on November 12, 2020. The division '1' EDG was tested successfully on monthly basis since that date; however, these tests were performed at slow-start setting of 800 rpm. At the conclusion of the monthly tests, the FFSS was placed in the fast-start setting of 400 rpm. The division '1' EDG failed to start during semiannual fast-start surveillance test on May 27, 2021. The EDG was repaired and returned to service on May 28th. The exact time of when the FFSS contact had fouled to point to lead to the failure in the fast-start setting is unknown. For these types of scenarios, Volume 1 (internal events) of the Risk Assessment of Operational Events (or RASP) Handbook (ML17348A149) recommends the exposure time (*T*) be calculated by dividing time interval from the failure and the last successful operation (*t*) by 2 and adding the repair time. The total time (*t*) between semi-annual tests was 197 days and the repair time was 1 day. Therefore, the exposure time was calculated as:

$$T = \frac{t}{2} + repair\ time = \frac{196\ days}{2} + 1\ day = 99\ days$$

This exposure time of the degraded division '1' EDG FFSS is a key uncertainty for this analysis, which is discussed further in Section 4.4.

3.5 Analysis Assumptions

The following modeling assumptions were determined to be significant to the modeling of this initiating event assessment:

- Basic event EPS-DGN-FS-DG11 was set to TRUE because the division '1' EDG failed to start in the fast-start setting due to its degraded FFSS.
  - *Recovery of the Division '1' EDG*. According to Davis-Besse FLEX final integrated plan, an auxiliary operator is sent to troubleshoot the failed EDGs during a SBO for a 10-minute period prior to reporting to the MCR for his/her FLEX implementation task. This time period is pretty limited given a postulated SBO has the two failed EDGs along with the failed SBO diesel generator. However, if TDAFW pump or EFW pumps is successful and there is no loss-of-coolant accident from either the reactor coolant pump seals or a stuck power-operated relief valve, additional time will be available after extended loss of AC power (ELAP) is declared and DC loads are successfully shed. Additional personnel will also be reporting to plant that can be sent to troubleshoot the failed EDGs (including the SBO diesel generator). The time available to recover the division '1' EDG will approximately 14.6 hours after DC loads are successfully shed on the division '1' DC train. The division '2' DC battery will be depleted in approximately 2 hours and will be rendered unrecoverable at that time. Given the extended time available to restore the division '1' EDG during the applicable scenarios, credit for recovery of this EDG was provided in the best estimate case. However, the plant procedures do not explicitly direct operators to shift the FFSS to slow-start position. In addition, operators would need to restore DC powered EDG support system(s) (e.g., DC lube oil pump) that were deenergized during the load shed activities that is not procedurally directed. Given these negative considerations, recovery credit for the division '1' EDG was limited to a probability of 0.5. This credit was provided in two different ways. For applicable ELAP scenarios where extended time was available after successful deep load shed is performed on the division '1' battery, the applicable EDG repair basic events (e.g., EPS-XHE-XL-NR24H) were set to a probability of 0.5. For the dominant fire scenario (fire in the MCR results in evacuation), the probability of basic event EPS-XHE-DGN-FFSS was set to 0.5. The crediting of the EDG recovery is a key uncertainty that is discussed further in Section 4.4.

4 ANALYSIS RESULTS

4.1 Results

The mean ΔCDP for this analysis is calculated to be 9.4×10^{-6}. The ASP Program threshold is 1×10^{-6} for degraded conditions; therefore, this event is a precursor. The parameter uncertainty results for this analysis provided below:

Table 1. Parameter Uncertainty Results

5%	Median	Pt. Estimate	Mean	95%
1.3×10^{-6}	5.7×10^{-6}	8.5×10^{-6}	9.4×10^{-6}	3.0×10^{-5}

4.2 Dominant Hazards[1]

The dominant hazards for this analysis are internal fires (ΔCDP = 4.9×10^{-6}) and internal events (ΔCDP = 3.5×10^{-6}), which contribute approximately 58 percent and 41 percent of the total ΔCDP, respectively. High winds contribute approximately 1 percent (ΔCDP = 9.9×10^{-8}), while internal flooding, tornados, and seismic hazards are minimal contributors to the total ΔCDP for this analysis.

4.3 Dominant Sequences

The dominant accident sequence is FRI-FF01-CRE (*fire in the MCR results in evacuation*) sequence 2-5 (ΔCDP = 4.0×10^{-6}), which contributes approximately 47 percent of the total ΔCDP. The sequences that contribute at least 5.0 percent to the total CCDP are provided in the following table. The event tree with the dominant sequence is shown graphically in Figures A-1 and A-2 of Appendix A.

Table 2. Dominant Sequences

Sequence	ΔCDP	%	Description
FRI-FF01-CRE 2-5	4.0×10^{-6}	46.7%	Fire in the MCR that requires evacuation of operators. Operators are directed to the use the auxiliary shutdown panel with division ‘1’ equipment, the failure of the division ‘1’ EDG is assumed to result in core damage.
LOOPWR 16-03-03	7.8×10^{-7}	9.1%	Weather-related LOOP initiating event occurs; emergency power system failure results in SBO; AFW is successful; operators declare ELAP; the FLEX diesel generators successfully charge the division ‘1’ safety-related battery; the EFW pump successfully supplies the SGs; RCS makeup fails; and operators fails to recover AC power results in core damage.
FRI-FF01-CRS 2-16-03-03	4.3×10^{-7}	5.0%	Fire in the MCR results in a LOOP; emergency power system failure results in SBO; AFW is successful; operators declare ELAP; the FLEX diesel generators successfully charge the division ‘1’ safety-related battery; the EFW pump successfully supplies the SGs; RCS makeup fails; and operators fails to recover AC power results in core damage.

4.4 Key Uncertainties

A review of the analysis assumptions and results reveal the following key uncertainties:

- *Internal Fire Modeling*. The internal fire modeling in the Davis-Besse SPAR model is largely based on the results of the IPEEE that was completed in 1994. The SPAR model results have not been compared with the licensee’s current probabilistic risk assessment

[1] The ΔCDPs presented in Sections 4.2 and 4.3 are point estimates.

for internal fires. Performing a detailed comparison between the two models for the identification of SPAR model changes would be a significant level of effort and is beyond the scope of the ASP Program. Given that the overall risk impact due to internal fires is similar, this issue was not pursued any further.

- *Exposure Time*. Fouling of the FFSS contacts resulted in the failure of the division ‘1’ EDG failure to start sometime between the last successful semiannual fast-start surveillance test performed November 12, 2020, and failure on May 27, 2021 (196 days). There is no additional information available to reduce the uncertainty of when the fouling on the FFSS contacts reach the level that would have resulted in the failure division ‘1’ EDG to start during this period. A sensitivity analysis was performed to determine the risk of the maximum exposure time of 197 days, which includes the 1 day of repair time. The mean ΔCDP for this 197-day exposure time is 2.2×10^{-5}. In addition, a sensitivity evaluation was performed to determine the minimum exposure time required for the ΔCDP to exceed the precursor threshold of 1×10^{-6}. It was determined that an exposure time of least 8 days (approximate) is needed to exceed the precursor threshold.

- *Recovery of the Division ‘1’ EDG*. Credit for recovery of the actual failure of the division ‘1’ EDG or the postulated failure of the division ‘2’ EDG was provided in the best estimate case. However, the amount of credit is considered a key uncertainty of this analysis. A sensitivity calculation was performed assuming no recovery of the division ‘1’ EDG was possible, which resulted in a ΔCDP of 1.4×10^{-5}.

Appendix A: Key Event Trees

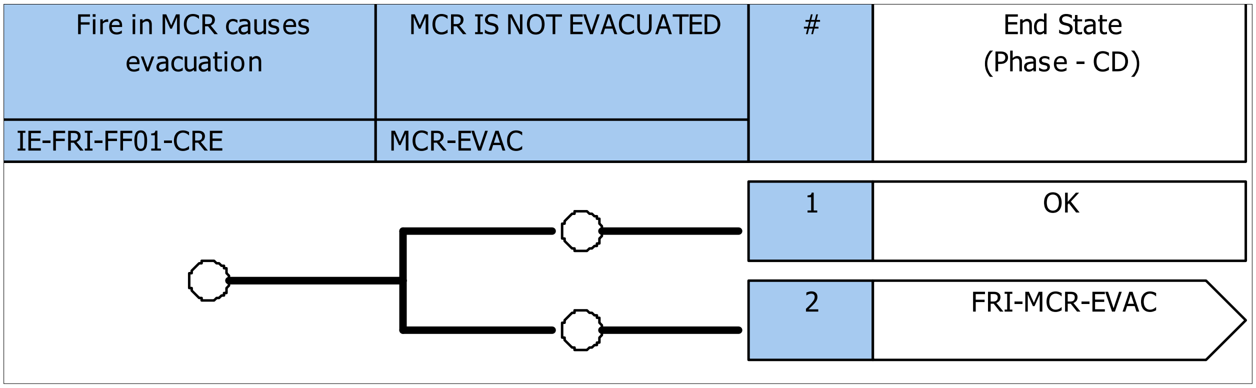

Figure A-1. Davis-Besse FRI-FF01-CRE Event Tree

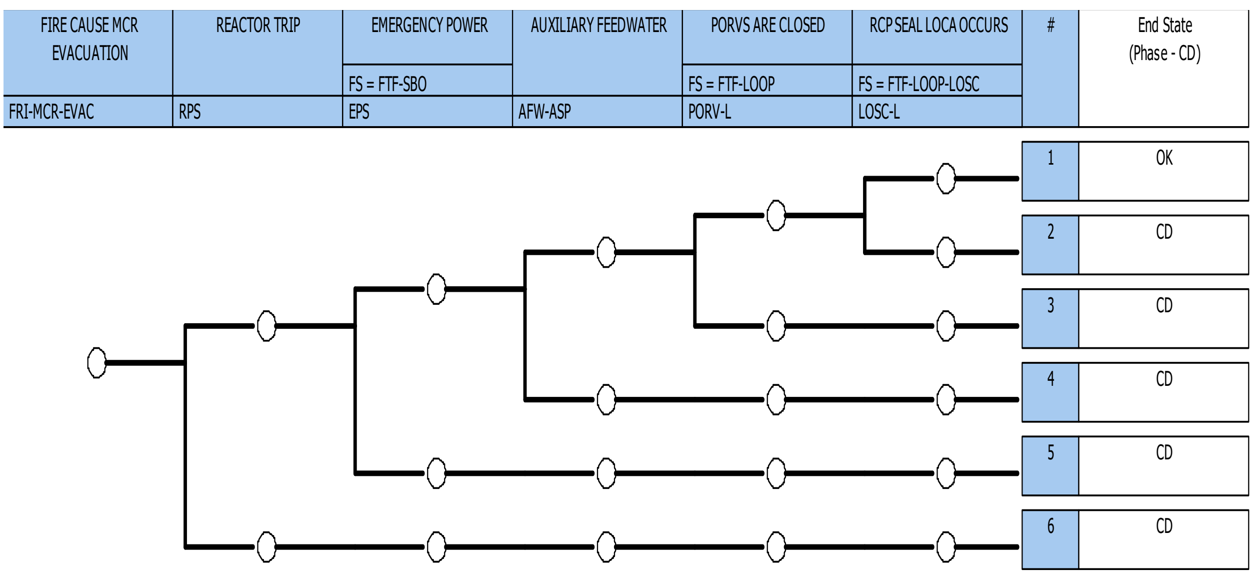

Figure A-2. Davis-Besse FRI-MCR-EVAC Event Tree

Appendix B: Modified Fault Trees

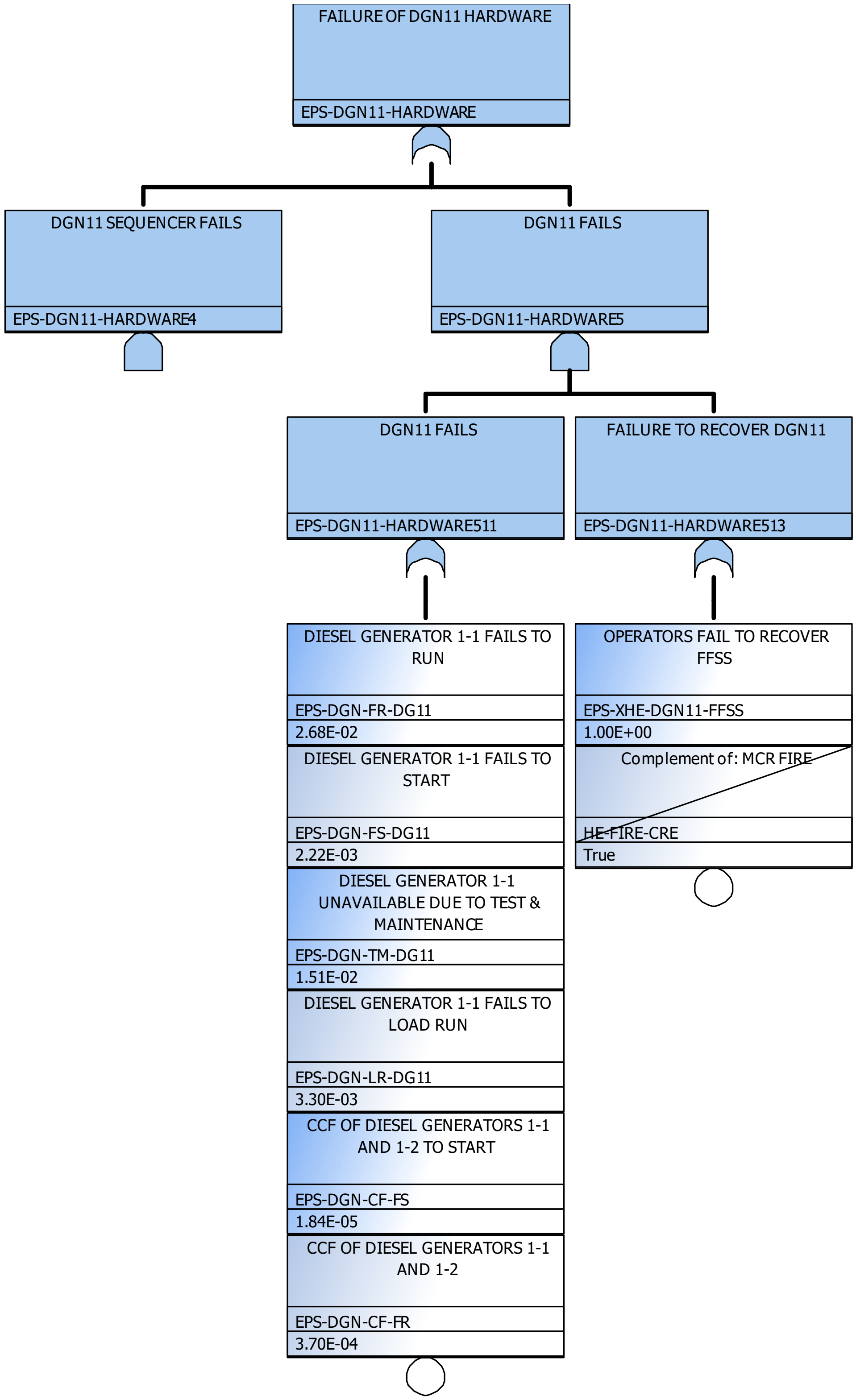

Figure B-1. Modified EPS-DGN11-HARDWARE Fault Tree

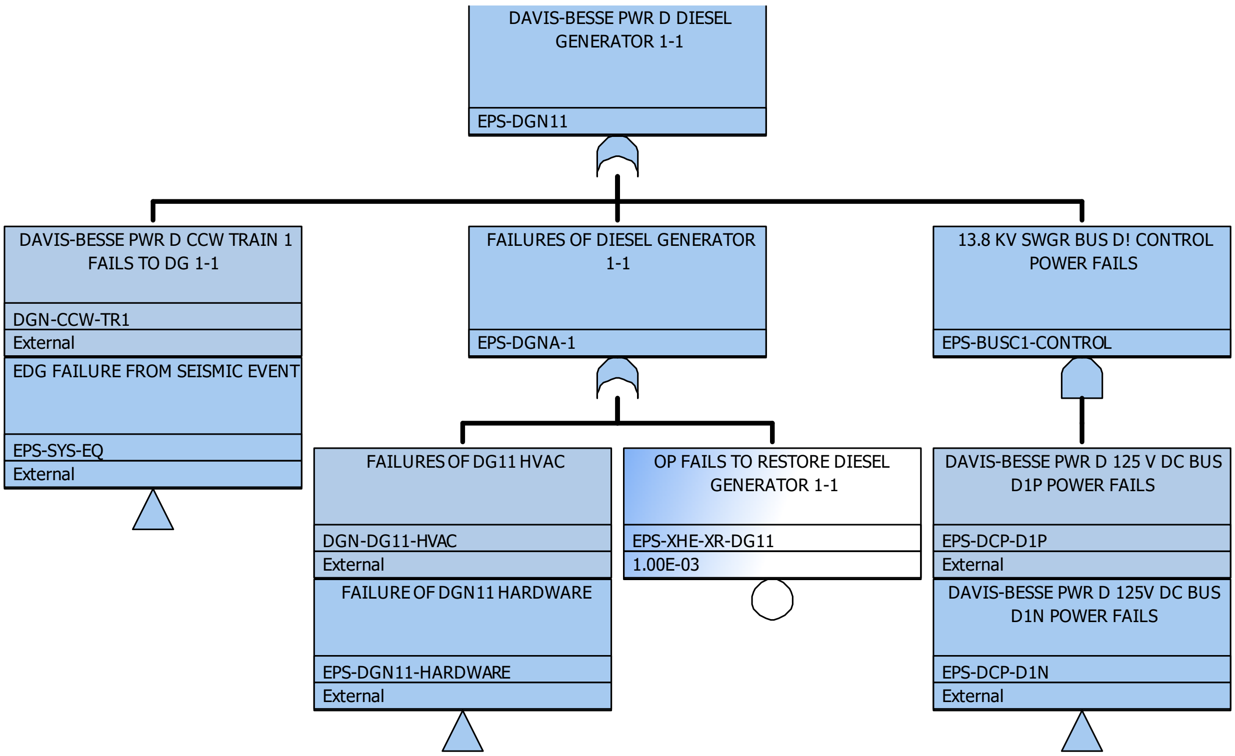

Figure B-2. Modified EPS-DGN11 Fault Tree