Final Precursor Analysis

Accident Sequence Precursor Program --- Office of Nuclear Regulatory Research

Nine Mile Point 1	Automatic Reactor Trip and Loss of Offsite Power Due to the August 14, 2003, Transmission Grid Blackout	
Event Date 8/14/2003	LER: 220/03-002	CCDP[1] = 2×10^{-5}

December 17, 2004

Event Summary

At 1611 hours on August 14, 2003, Nine Mile Point 1 experienced grid instability and a subsequent turbine trip followed by reactor trip while operating at 100% power. Loss of offsite power (LOOP) occurred at 1613 hours. Plant emergency diesel generators (EDGs) started and supplied power to safety-related plant loads until offsite power was restored. Attachment A is a timeline of significant events. (Refs. 1 and 2).

Cause. The reactor trip and LOOP were caused by grid instability associated with the regional transmission system blackout that occurred on August 14, 2003.

Other conditions, failures, and unavailable equipment. No other significant conditions, failures, or unavailable equipment occurred during the event.

Recovery opportunities. Offsite power was available and within normal voltage and frequency limits at approximately 1756 hours. Offsite power was restored to the first emergency bus at 2339 hours and to the second emergency bus at 0018 hours on August 15.

Analysis Results

- **Conditional Core Damage Probability (CCDP)**

  The CCDP for this event is 2×10^{-5}. The acceptance threshold for the Accident Sequence Precursor Program is a CCDP of 1×10^{-6}. This event is a precursor.

	Mean	5%	95%
Best estimate	**2×10^{-5}**	1×10^{-6}	5×10^{-5}

[1] For the initiating event assessment, the parameter of interest is the measure of the CCDP. This is the value obtained when calculating the probability of core damage for an initiating event with subsequent failure of one or more components following the initiating event. The reported value is the estimated mean CCDP.

- **Dominant Sequences**

The dominant core damage sequence for this assessment is LOOP/station blackout sequences 22-16 (68.8% of the total CCDP). The LOOP and station blackout event trees are shown in Figures 1 and 2.

The events and important component failures in LOOP Sequence 22-16 are:

– loss of offsite power occurs,
– reactor shutdown succeeds,
– emergency power is unavailable,
– safety relief valves successfully reclose,
– isolation condenser fails,
– manual reactor depressurization succeeds,
– firewater injection fails, and
– ac power is not recovered in 30 minutes.

- **Results Tables**

– The CCDP values for the dominant sequences are shown in Table 1.
– The event tree sequence logic for the dominant sequences is presented in Table 2a.
– Table 2b defines the nomenclature used in Table 2a.
– The most important cut sets for the dominant sequences are listed in Table 3.
– Table 4 presents names, definitions, and probabilities of (1) basic events whose probabilities were changed to update the referenced SPAR model, (2) basic events whose probabilities were changed to model this event, and (3) basic events that are important to the CCDP result.

Modeling Assumptions

- **Assessment Summary**

This event was modeled as a loss of offsite power initiating event. Rev. 3.10 (SAPHIRE 7) of the Nine Mile Point 1 SPAR model (Ref. 3) was used for this assessment. The specific model version used as a starting point for this analysis is dated December 31, 2004.

Since this event involves a LOOP of significant duration (potentially longer than the battery depletion time), probabilities of nonrecovery of offsite power at different times following the LOOP are important factors in the estimation of the CCDP.

Best estimate: Offsite power was available and within normal voltage and frequency limits at approximately 1756 hours. Failure to recover offsite power to plant safety-related loads (if needed because EDGs fail to supply the loads), given recovery of power to the switchyard, could result from (1) operators failing to restore proper breaker line-ups, (2) breakers failing to close on demand, or (3) a combination of operator and breaker failures. The dominant contributor to failure to recover offsite power to plant safety-related loads in this situation is operators failing to restore proper breaker line-ups. This analysis assumed that at least 30 minutes are necessary to restore power to an emergency bus given that

offsite power is available in the switchyard[2]. The time available for operators to restore proper breaker line-ups to prevent core damage is dependent on specific accident sequences and is modeled as such using the SPAR human reliability model (Ref. 4). Assumptions described below, combined with the assumption of offsite power restoration described above, form the bases for the LOOP nonrecovery probabilities.

- **Important Assumptions**

Important assumptions regarding power recovery modeling include the following:

– No opportunity for the recovery of offsite power to safety-related loads is considered for any time prior to power being available in the switchyard.
– At least 30 minutes are required to restore power to emergency loads after power is available in the switchyard.
– SPAR models do not credit offsite power recovery following battery depletion.

The GEM program used to determine the CCDP for this analysis will calculate probabilities of recovering offsite power at various time points of importance to the analysis based on historical data for grid-related LOOPs. In this analysis, this feature was overridden; offsite power recovery probabilities were based on (1) known information about when power was restored to the switchyard and (2) use of the SPAR human error model to estimate probabilities of failing to realign power to emergency buses for times after power was restored to the switchyard.

Attachment B is a general description of analysis of loss of offsite power events in the Accident Sequence Precursor Program. It includes a description of the approach to estimating offsite power recovery probabilities.

- **Basic Event Probability Changes**

Table 4 includes basic events whose probabilities were changed to reflect the event being analyzed. The bases for these changes are as follows:

– ***Probability of failure to recover offsite power in 30 minutes (OEP-XHE-XL-NR30M).*** During the event, offsite power of sufficient quality was not available in the switchyard until approximately 1.5 hours after the LOOP. Therefore, there was no opportunity to recover offsite power in 30 minutes and OEP-XHE-XL-NR30M was set to TRUE.

– ***Probability of failure to recover offsite power in 1 hour (OEP-XHE-XL-NR01H).*** During the event, offsite power of sufficient quality was not available in the switchyard until approximately 1.5 hours after the LOOP. Therefore, there was no opportunity to recover offsite power in 1 hour and OEP-XHE-XL-NR01H was set to TRUE.

– ***Probability of failure to recover offsite power in 2 hours (OEP-XHE-XL-NR02H).*** During the event, offsite power of sufficient quality was not available in the switchyard until approximately 1.5 hours after the LOOP. Therefore, the operators

[2] Sensitivity analysis has shown that the difference between 15 and 60 minutes restoration time has minimal effect on the results.

had approximately 30 minutes to recover offsite power to the vital safety buses. Using the SPAR human error model to determine the value (see Attachment C), OEP-XHE-XL-NR02H was set to $1.0{\times}10^{-1}$.

– ***Probability of failure to recover offsite power in 4 hours (OEP-XHE-XL-NR04H).*** During the event, offsite power of sufficient quality was not available in the switchyard until approximately 1.5 hours after the LOOP. Therefore, the operators had approximately 2.5 hours to recover offsite power to the vital safety buses. Using the SPAR human error model to determine the value (see Attachment C), OEP-XHE-XL-NR08H was set to $1.0{\times}10^{-2}$.

– ***Probability of failure to recover offsite power in 8 hours (OEP-XHE-XL-NR08H).*** During the event, offsite power of sufficient quality was not available in the switchyard until approximately 1.5 hours after the LOOP. Therefore, the operators had approximately 6.5 hours to recover offsite power to the vital safety buses. Using the SPAR human error model to determine the value (see Attachment C), OEP-XHE-XL-NR08H was set to $1.0{\times}10^{-3}$.

– ***Probability of failure to recover offsite power in 10 hours (OEP-XHE-XL-NR10H).*** During the event, offsite power of sufficient quality was not available in the switchyard until approximately 1.5 hours after the LOOP. Therefore, the operators had approximately 8.5 hours to recover offsite power to the vital safety buses. Using the SPAR human error model to determine the value (see Attachment C), OEP-XHE-XL-NR08H was set to $1.0{\times}10^{-3}$.

– ***Probability of diesel generators failing to run (ZT-DGN-FR-L).*** The default diesel generator mission times were changed to reflect the actual time to recover power to the first safety bus (7.5 hours). Since the overall fail-to-run is made up of two separate factors, the mission times for the factors were set to the following: ZT-DGN-FR-E = 1 hour (base case value) and ZT-DGN-FR-L = 6.5 hours.

References

1. Licensee Event Report 220/03-002, Revision 1, *Reactor Scram Due to Grid Disturbance*, event date August 14, 2003 (ADAMS Accession No. ML040290600).

2. NRC Region 1 Grid Special Report, October 15, 2003 (ADAMS Accession No. ML0324102160).

3. R. E. Gregg and J. A. Schroeder, *Standardized Plant Analysis Risk Model for Nine Mile Point 1 (ASP BWR A)*, Revision 3.10, December 2004.

4. D. Gertman, et al., *SPAR-H Method*, INEEL/EXT-02-10307, Draft for Comment, November 2002 (ADAMS Accession No. ML0315400840).

Table 1. Conditional probabilities associated with the highest probability sequences.

Event tree name	Sequence no.	Conditional core damage probability (CCDP)[1]	Percentage contribution
LOOP	22-16	1.1×10^{-5}	68.8%
Total (all sequences)[2]		**1.6×10^{-5}**	

1. Values are point estimates. (File name: GEM 220-03-002 03-21-2005.wpd)
2. Total CCDP includes all sequences (including those not shown in this table).

Table 2a. Event tree sequence logic for the dominant sequences.

Event tree name	Sequence no.	Logic (“/” denotes success; see Table 2b for top event names)
LOOP	22-16	/RPS, EPS, /SRV, ISO, /DEP, VA2, AC-30MIN

Table 2b. Definitions of fault trees listed in Table 2a.

AC-30MIN	RECOVERY OF AC POWER WITHIN 30 MINUTES FAILS
DEP	MANUAL REACTOR DEPRESSURIZATION FAILS
EPS	EMERGENCY POWER IS UNAVAILABLE
ISO	ISOLATION CONDENSER FAILS
RPS	REACTOR SHUTDOWN FAILS
SRV	SRVs FAIL TO CLOSE
VA2	FIREWATER INJECTION FAILS

Table 3. Conditional cut sets for dominant sequences.

CCDP[1]	Percent contribution	Minimal cut sets[2]	
Event Tree: LOOP, Sequence 22-16			
1.0×10^{-6}	9.2	EPS-XHE-XL-NR30M FWS-EDP-TM-02	EPS-DGN-CF-RUN
6.3×10^{-7}	5.6	EPS-XHE-XL-NR30M FWS-EDP-FR-02	EPS-DGN-CF-RUN
5.2×10^{-7}	4.6	EPS-XHE-XL-NR30M FWS-EDP-FS-02	EPS-DGN-CF-RUN
3.8×10^{-7}	3.4	EPS-XHE-XL-NR30M FWS-EDP-TM-02	EPS-DGN-CF-START
1.1×10^{-5}	**Total (all cut sets)[3]**		

1. Values are point estimates.
2. See Table 4 for definitions and probabilities for the basic events.
3. Totals include all cut sets (including those not shown in this table).

Table 4. Definitions and probabilities for modified or dominant basic events.

Event name	Description	Probability/ frequency	Modified
EPS-DGN-CF-RUN	DIESEL GENERATORS FAIL BY COMMON CAUSE TO RUN	2.3×10^{-4}	No
EPS-DGN-CF-START	DIESEL GENERATORS FAIL BY COMMON CAUSE TO START	8.4×10^{-5}	No
EPS-XHE-XL-NR30M	OPERATOR FAILS TO RECOVER AN EDG IN 30 MINUTES	9.2×10^{-1}	No
FWS-EDP-FR-02	FIRE WATER ENGINE DRIVEN PUMP 02 FAILS TO RUN	3.0×10^{-3}	No
FWS-EDP-FS-02	FIRE WATER ENGINE DRIVEN PUMP 02 FAILS TO START	2.5×10^{-3}	No
FWS-EDP-TM-02	FIRE WATER ENGINE DRIVEN PUMP 02 IS UNAVAILABLE DUE TO T&M	5.0×10^{-3}	No
IE-LOOP	LOSS OF OFFSITE POWER INITIATING EVENT	1.0	Yes[1]
OEP-XHE-XL-NR30M	OFFSITE POWER NOT RECOVERED IN 30 MINUTES	TRUE	Yes[2]
OEP-XHE-XL-NR01H	OFFSITE POWER NOT RECOVERED IN 1 HOUR	TRUE	Yes[2]
OEP-XHE-XL-NR02H	OFFSITE POWER NOT RECOVERED IN 2 HOURS	1.0×10^{-1}	Yes[2]
OEP-XHE-XL-NR04H	OFFSITE POWER NOT RECOVERED IN 4 HOURS	1.0×10^{-2}	Yes[2]
OEP-XHE-XL-NR08H	OFFSITE POWER NOT RECOVERED IN 8 HOURS	1.0×10^{-3}	Yes[2]
OEP-XHE-XL-NR10H	OFFSITE POWER NOT RECOVERED IN 10 HOURS	1.0×10^{-3}	Yes[2]
OPR-XHE-XM-SHED	OPERATOR FAILS TO SHED DC LOADS	1.0×10^{-2}	Yes[3]
ZT-DGN-FR-L	DIESEL GENERATOR FAILS TO RUN (LATE)	5.2×10^{-3}	Yes[4]

1. Initiating event assessment– all other initiating event frequencies set zero.
2. Evaluated per the SPAR-H method (Ref. 4). See report and Attachment C for further details.
3. Change made based on Licensee comment. See Attachment D for further details.
4. Changed mission times to correspond to the time offsite power was restored to the first vital bus. See report and Basic Event Probability Changes for further details.

Attachment A
Event Timeline

Table A.1 Timeline of significant events.

Date	Time	Event
8/14/03	1611	Turbine trip and reactor trip due to grid instability
	1612	Offsite power is lost to emergency buses; emergency diesel generators automatically start and load to power the emergency buses
	1707	Offsite power is reconnected to normal buses
	2339	First emergency bus (10600) is switched to offsite power source
8/15/03	0018	Second emergency bus (10500) is switched to offsite power source

Attachment B
LOOP Analysis Procedure

This procedure is not intended to stand alone; instead it is intended to augment *ASP Guideline A: Detailed Analysis*[3]. LOOP event analyses are a type of initiating event assessment as described in ASP Guideline A. Specific analysis steps that are unique to ASP analysis of LOOP events are included here.

1. Determine significant facts associated with the event.

1.1 Determine when the LOOP occurred.
1.2 Determine when stable offsite power was first available in the switchyard.
1.3 Determine when offsite power was first restored to an emergency bus.
1.4 Determine when offsite power was fully restored (all emergency buses powered from offsite, EDGs secured).
1.5 Identify any other significant conditions, failures, or unavailabilities that coincided with the LOOP.

2. Model power recovery factors associated with the best estimate case and any defined sensitivity cases.

2.1 For the best estimate case, the LOOP duration is the time between the occurrence of the LOOP and the time when stable power was available in the switchyard plus the assumed time required to restore power from the switchyard to emergency buses. Attachment C documents the probabilistic analysis of power recovery factors for the best estimate case analysis.
2.2 If EDGs successfully start and supply emergency loads, plant operators do not typically rush to restore offsite power to emergency buses, preferring to wait until grid stability is more certain. Therefore, a typical upper bound sensitivity case considers the LOOP duration as the time between the occurrence of the LOOP and the time when offsite power was first restored to an emergency bus. Attachment C documents the probabilistic analysis of power recovery factors for the sensitivity case analysis.

3. Model event-specific mission durations for critical equipment for the best estimate case and any defined sensitivity cases. (For most equipment, SPAR model failure probabilities are not functions of defined mission durations and are therefore not affected by this analysis step. Notable exceptions include EDGs and, for PWRs, turbine-driven auxiliary feedwater pumps.)

3.1 For the best estimate case, mission durations are set equal to the assumed LOOP duration as defined in Step 2.1 above.
3.2 For a typical upper bound sensitivity case, mission durations are set equal to the time between the occurrence of the LOOP and the time when offsite power was fully restored to all emergency buses. (Note these mission durations are longer than the assumed LOOP duration defined in Step 2.2 above; they are intended to represent the longest possible mission duration for any critical equipment item.)

[3] ASP Guideline A: Detailed Analysis, U.S. Nuclear Regulatory Commission.

Attachment C
Power Recovery Modeling

- **Background**

The time required to restore offsite power to plant emergency equipment is a significant factor in modeling the CCDP given a LOOP. SPAR LOOP/SBO models include various sequence-specific ac power recovery factors that are based on the time available to recover power to prevent core damage. For a sequence involving failure of all of the cooling sources, only about 30 minutes would be available to recover power to help avoid core damage. On the other hand, sequences involving successful early inventory control and decay heat removal, but failure of long-term decay heat removal, would accommodate several hours to recover ac power prior to core damage.

In this analysis, offsite power recovery probabilities are based on (1) known information about when power was restored to the switchyard and (2) estimated probabilities of failing to realign power to emergency buses for times after offsite power was restored to the switchyard. Power restoration times were reported by the licensee in the LER and in response to the questionnaire that was conducted by the NRC Regional Office. The time used is the time at which the grid operator informed the plant that power was available to the switchyard (with a load limit). Although the load limit was adequate to energize plant equipment and, if necessary, prevent the occurrence of an SBO sequence, plant operators did not immediately load safety buses onto the grid. This ASP analysis does not consider the possibility that grid power would have been unreliable if that power were immediately used.

Failure to recover offsite power to plant safety-related loads (if needed because EDGs fail to supply the loads), given recovery of power to the switchyard, could result from (1) operators failing to restore proper breaker line-ups, (2) breakers failing to close on demand, or (3) a combination of operator and breaker failures. The dominant contributor to failure to recover offsite power to plant safety-related loads in this situation is operators failing to restore proper breaker line-ups. The SPAR human error model (ref.) was used to estimate nonrecovery probabilities as a function of time following restoration of offsite power to the switchyard. The best estimate analysis assumes that at least 30 minutes are necessary to restore offsite power to emergency buses given offsite power is available in the switchyard.

- **Human Error Modeling**

The SPAR human error model generally considers the following three factors:

- Probability of failure to diagnose the need for action
- Probability of failure to successfully perform the desired action
- Dependency on other operator actions involved in the specific sequence of interest

This analysis assumes no probability of failure to diagnose the need to recover ac power and no dependency between operator performance of the power recovery task and any other task the operators may need to perform. Thus, each estimated ac power nonrecovery probability is based solely on the probability of failure to successfully perform the desired action.

The probability of failure to perform an action is the product of a nominal failure probability (1.0×10^{-3}) and the following eight performance shaping factors (PSFs):

– Available time
– Stress
– Complexity
– Experience/training
– Procedures
– Ergonomics
– Fitness for duty
– Work processes

For each ac power nonrecovery probability, the PSF for available time is assigned a value of 10 if the time available to perform the action is approximately equal to the time required to perform the action, 1.0 if the time available is between 2 and 5 times the time required, and 0.1 if the time available is greater than 5 times the time required. If the time available is inadequate (i.e., less than the time to restoration of power to the switchyard plus 15 minutes for the best estimate), the ac power nonrecovery probability is 1.0 (TRUE).

The PSF for stress is assigned a value of 5 (corresponding to extreme stress) for all ac power nonrecovery probabilities. Factors considered in assigning this PSF include the sudden onset of the LOOP initiating event, the duration of the event, the existence of compounding equipment failures (ac power recovery is needed only if one or more emergency buses are not powered by EDGs), and the existence of a direct threat to the plant.

For all of the ac power nonrecovery probabilities, the PSF for complexity is assigned a value of 2 (corresponding to moderately complex) based on the need for multiple breaker alignments and verifications.

For all of the ac power nonrecovery probabilities, the PSFs for experience/training, procedures, ergonomics, fitness for duty, and work processes are assumed to be nominal (i.e., are assigned values of 1.0).

- **Results**

Table C.1 presents the calculated values for the ac power nonrecovery probabilities used in the best estimate analysis.

Table C.1 AC Power Nonrecovery Probabilities

Nonrecovery Factor	Nominal Value	PSF		Nonrecovery Probability
		Time Available	Product of All Others	
OEP-XHE-XL-NR30M	1.0×10^{-3}	Inadequate	--	TRUE
OEP-XHE-XL-NR01H	1.0×10^{-3}	Inadequate	--	TRUE
OEP-XHE-XL-NR02H	1.0×10^{-3}	10	10	1.0×10^{-1}
OEP-XHE-XL-NR04H	1.0×10^{-3}	1	10	1.0×10^{-2}
OEP-XHE-XL-NR08H	1.0×10^{-3}	0.1	10	1.0×10^{-3}

Nonrecovery Factor	Nominal Value	PSF		Nonrecovery Probability
		Time Available	Product of All Others	
OEP-XHE-XL-NR10H	1.0×10^{-3}	0.1	10	1.0×10^{-3}

Attachment D
Response to Comments

Comments were provided by the licensee (Ref. 1).

1. Comment from Licensee - EDG recovery

“No basis for the assumption that Emergency Diesel Generators (EDGs) cannot be recovered is provided in the PPA. The NMP1 PRA model includes credit for EDG recovery based on NUREG-1032. It is recommended that the PPA consider crediting EDG recovery.”

Response: Credit for EDG recovery is given in the final analysis.

2. Comment from Licensee - DC load shedding

“The model used for the PPA includes a basic event for DC Load Shedding under Station Blackout (SBO) conditions. Basic event ‘OEP-XHE-XM-LSHED’ models operators beginning to shed DC loads within 15 minutes. The value of 2E-2 and associated logic is similar to the O15 Top Event used in the NMP 1 PRA. In the model used for the PPA, failure of the load shed action leads to a 2 hour Alternating Current (AC) power recovery requirement. However, given failure of this action, the NMPI model asks, conditionally, if operators begin load shedding within 30 minutes. This is treated with top event O30 which has a value of 0.5. The combined time-depended DC Load shedding criteria allows a 8 hour AC power recovery if O15 is successful, 4 hours for AC recovery if O15 is failed and 030 is successful, and 2 hours if both O15 and O30 fail.
Please consider the following options to more closely match the NMPI model as the DC Load Shedding basic event shows up in the most dominant cutsets reported in the PPA analysis:

1) Multiply the OEP-XHE-XM-LSHED basic event by the O30 conditional value (0.5) to allow the PPA Event tree node ‘DCL’ to represent the conditions that lead to a 2 hour AC power recovery requirement.

2) Add an additional event tree node for the 30 minute conditional action so that the 2, 4, and 8 hour recovery windows are applied, as appropriate.”

Response: This proposed approach to modeling load shedding appears sound. Based on discussions with INEEL SPAR modeling personnel, changing the SPAR model in this regard would have a minimal impact on the base model results. Thus, there is no need to change the base model. However, as pointed out, the results of this precursor analysis are sensitive to the probability of not successfully shedding DC loads. If the logic leading to sequences 22-02 and 22-03 were changed to credit the factor of 0.5 following failure to shed DC loads in 15 minutes, two new sequences between 22-01 and 22-02 would be created, one resulting in OK where AC power is recovered in 4 hours and the other resulting in CD where AC power is not recovered in 4 hours. Furthermore, the SPAR human error model would credit a factor of 0.1 between failing to shed DC loads in 15 minutes versus 30 minutes. Therefore applying the additional factor of 0.5 to DC load shedding across the board (i.e., setting the probability of OPR-XHE-XM-LSHED to 0.01 instead of 0.02) makes the precursor analysis more consistent with the NMP 1 PRA, and is conservative with respect to SPAR modeling guidelines. This change was made, but had a negligible effect on the quantitative result.

3. Comment from Licensee - Offsite power recovery

"In the PPA analysis, the values for failing to recover AC power were increased significantly. This appears to be due to the time window available between when load dispatchers declared the grid stable and the expiration of the various time windows. Even if it were assumed that operators would have waited for the load dispatchers before trying to recover offsite power given EDG failures, it is highly doubtful that they would also wait for the load dispatchers before staging their actions. In this regard, the reductions are overly conservative. Operator focus regarding offsite power recovery would have been keen throughout the event. If EDGs had failed, operators would have aggressively staged offsite power recovery actions, per procedures, and would not have been significantly slowed by interactions with the load dispatchers.

It should be noted that Electrical Design Data has shown that offsite power voltage and frequency were within normal limits at 1 hr and 45 minutes following event initiation. This is consistent with the PPA assumptions wherein the 30 minute and 60 minute offsite power basic events are set to failed. However, the 2, 4, 8, and 10 hour values should not be penalized to the degree specified in the PPA."

Response: The assumed time to restore power to plant loads following recovery of power to the switchyard has been changed from 1 hour to 0.5 hour. This changes the probabilities of failing to recover power for times greater than or equal to 2 hours.

References:

1. Constellation Energy Nuclear Operations, Inc. Review and Comment: Nine Mile Point Unit 1 Preliminary Accident Sequence Precursor Analysis of the August 14, 2003 Operational Event, Letter from William C. Holston to U.S. Nuclear Regulatory Commission, May 17, 2004 (ML041480357).

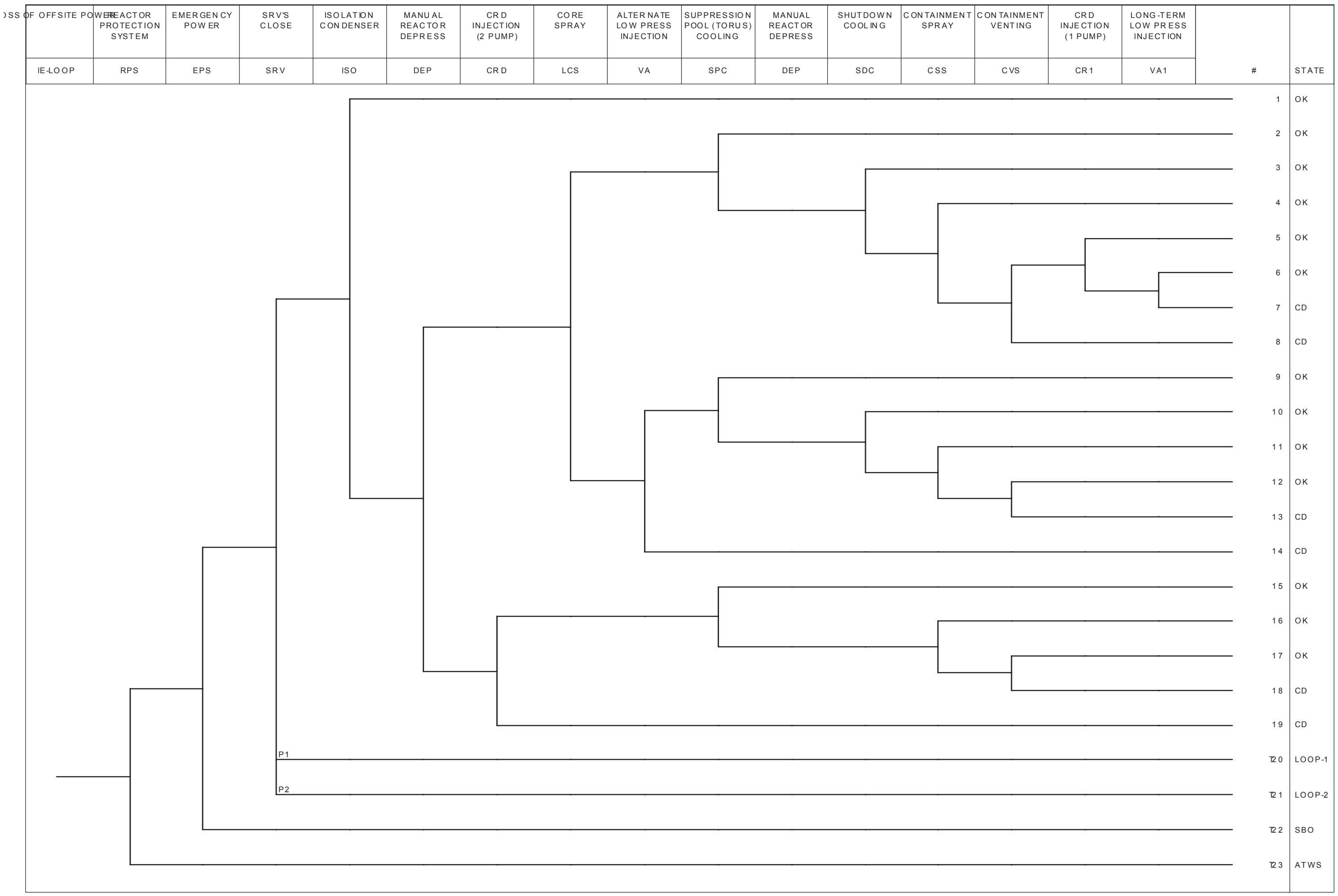

Figure 1: Nine Mile Point 1 LOOP event tree.

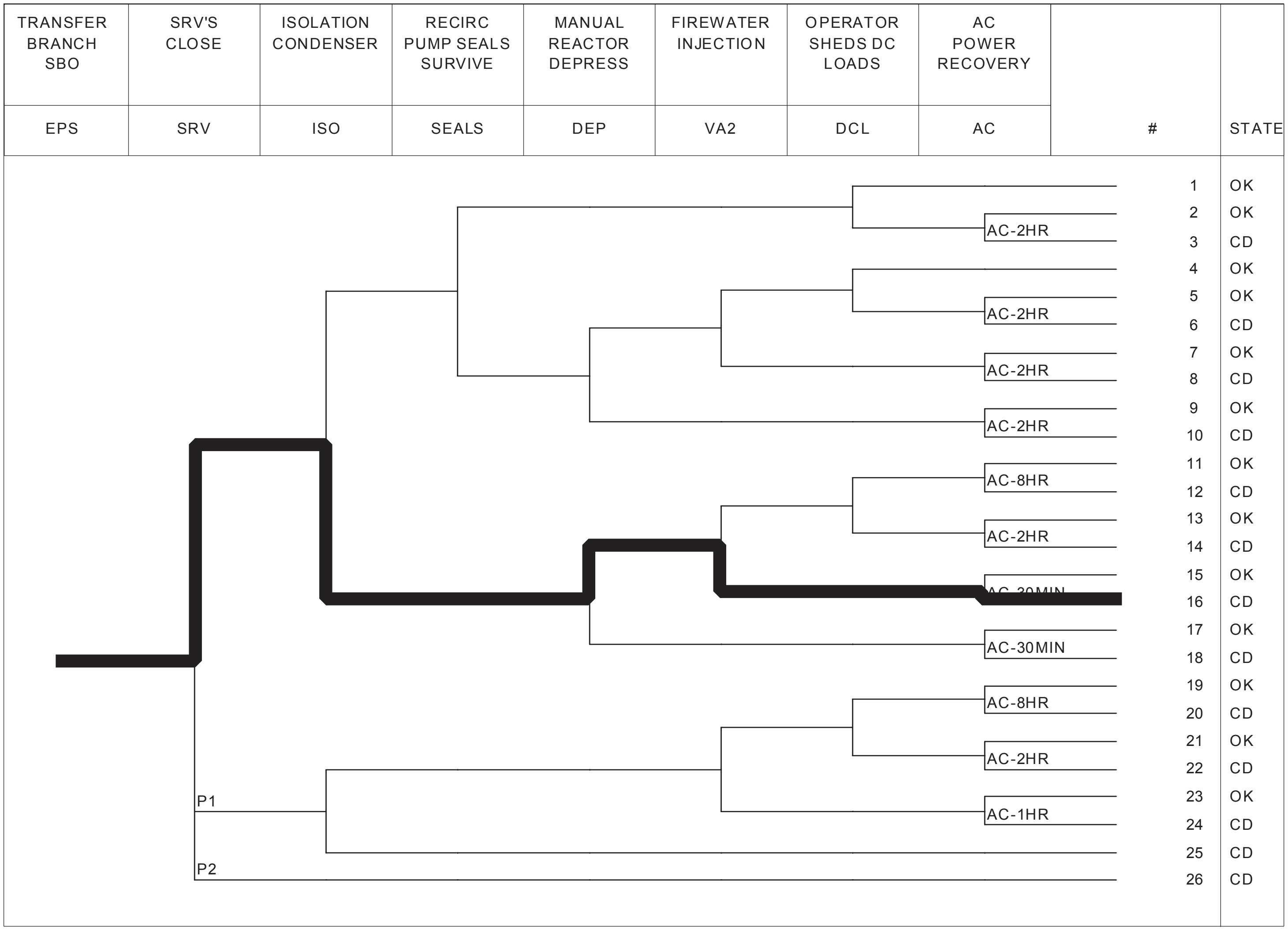

Figure 2: Nine Mile Point 2 SBO event tree with dominant sequence highlighted.