Final Precursor Analysis

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

Fitzpatrick	Automatic Reactor Trip and Loss of Offsite Power Due to the August 14, 2003, Transmission Grid Blackout	
Event Date 8/14/2003	LER: 333/03-001	CCDP[1] = 4×10^{-6}

December 17, 2004

Event Summary

At 1611 hours on August 14, 2003, Fitzpatrick experienced grid instability and a subsequent 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. On August 29, EDG A was determined to be inoperable due to out of tolerance no-load frequency, traceable to recovery from the August 14 event (Ref. 1). EDG A provided reliable emergency power throughout the LOOP event, and the equipment outage occurred after the event itself. Therefore, the inoperability of EDG A will be addressed in a separate analysis.

Recovery opportunities. Offsite power was recovered over a period of time, commencing at 1900 hours on August 14, 2003, with restoration of the 115 kV transmission system with an imposed load limit and ending at 2400 hours on August 14, 2003, with restoration of 115 kV transmission system to full capacity. Offsite power was restored to the first emergency bus at 2307 hours and to the second emergency bus at 2328 hours (Ref. 1).

Analysis Results

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

  The CCDP for this event is 4×10^{-6}. 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	**4×10^{-6}**	3×10^{-7}	1×10^{-5}

- **Dominant Sequences**

[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 dominant core damage sequence for this assessment is LOOP/station blackout sequence (SBO) 47-08 (48.6% 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 47-08 are:

- LOOP occurs,
- reactor shutdown succeeds,
- emergency power is unavailable,
- safety relief valves successfully reclose,
- reactor core isolation cooling provides sufficient flow to the reactor vessel,
- operator fails to strip dc loads, and
- ac power is not recovered in 2 hours.

- **Results Tables**

  - The CCDP value for the dominant sequence is shown in Table 1.
  - The event tree sequence logic for the dominant sequence is presented in Table 2a.
  - Table 2b defines the nomenclature used in Table 2a.
  - The most important cut sets for the dominant sequence 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 Fitzpatrick SPAR model (Ref. 3) was used for this assessment. The specific model version used as a starting point for this analysis is dated December 10, 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 to the plant's switchyard is assumed to be stable and useable when reported as such to plant operators by load dispatchers. This occurred at 1900 hours, about 3 hours following LOOP, in this event. This time is reasonable as the best estimate recovery time because it reflects the emergency operations policy for system restoration as documented in the North American Electric Reliability Council (NERC) Operating Manual (Ref. 4).

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. 5). 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 was not available in the switchyard until 3 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 was not available in the switchyard until 3 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 was not available in the switchyard until

[2] Sensitivity analysis has shown that the difference between 30 and 60 minutes restoration time has minimal effect on the results.

3 hours after the LOOP. Therefore, there was no opportunity to recover offsite power in 2 hours and OEP-XHE-XL-NR02H was set to TRUE.

- ***Probability of failure to recover offsite power in 4 hours (OEP-XHE-XL-NR04H).*** During the event, offsite power was not available in the switchyard until 3 hours after the LOOP. Therefore, the operators had approximately 1 hour to recover offsite power to the vital safety buses, which is double the required time to perform the action. Using the SPAR human error model to determine the value (see Attachment C), OEP-XHE-XL-NR04H was set to 1.0×10^{-2}.

- ***Probability of failure to recover offsite power in 10 hours (OEP-XHE-XL-NR10H).*** During the event, offsite power was not available in the switchyard until 3 hours after the LOOP. Therefore, the operators had approximately 6 hours to recover offsite power to the vital safety buses, which is double the required time to perform the action. Using the SPAR human error model to determine the value (see Attachment C), OEP-XHE-XL-NR10H was set to 1.0×10^{-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 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 hours.

References

1. Licensee Event Report 333/03-001, Revision 0, *Automatic Reactor Shutdown Due to Grid Instability Associated With the August 14th, 2003 Transmission Grid Blackout and Related Plant MODE Change with the A EDG Subsystem Inoperable*, event date August 14, 2003 (ADAMS Accession No. ML0329601250).

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

3. R. F. Buell and J. A. Schroeder, *Standardized Plant Analysis Risk Model for Fitzpatrick (ASP BWR C)*, Revision 3, December 2004.

4. NERC Operating Manual.

5. 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	47-08	1.7×10^{-6}	48.6%
Total (all sequences)[2]		**3.5×10^{-6}**	

1. Values are point estimates. (File name: GEM 333-03-001 12-13-2004.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	47-08	/RPS, EPS, /SRV, /RCI, STRIP-LOAD, AC-2HR

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

EPS	EMERGENCY POWER IS UNAVAILABLE
AC-02H	OPERATOR FAILS TO RECOVER AC POWER IN 2 HOURS
RCI	RCIC FAILS TO PROVIDE SUFFICIENT FLOW TO REACTOR
RPS	REACTOR SHUTDOWN FAILS
SRV	SRVS FAIL TO CLOSE
STRIP-LOAD	FITZPATRICK 125 DC LOAD STRIPPING FAILS

Table 3. Conditional cut sets for dominant sequences.

CCDP[1]	Percent contribution	Minimal cut sets[2]	
Event Tree: LOOP, Sequence 47-02			
5.5×10^{-7}	33.1	EPS-XHE-XL-NR02H EPS-XHE-XR-FIREDAMP	DCP-XHE-XM-STRIP
3.6×10^{-7}	21.7	EPS-XHE-XL-NR02H EPS-DGN-CF-RUN	DCP-XHE-XM-STRIP
2.2×10^{-7}	13.1	EPS-XHE-XL-NR02H ESW-MOV-CF-102AB	DCP-XHE-XM-STRIP
1.7×10^{-6}	**Total (all cut sets)[3]**		

1. Values are point estimates.
2. See Table 4 for definitions and probabilities for the basic events.
3. Totals includes 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
DCP-XHE-XM-STRIP	OPERATOR FAILS TO STRIP DC LOADS TO EXTEND BATTERY LIFE	3.0×10^{-2}	No
EPS-DGN-CF-RUN	COMMON CAUSE FAILURE OF DIESEL GENERATORS TO RUN	1.7×10^{-5}	No
EPS-XHE-XL-NR02H	OPERATOR FAILS TO RECOVER EDG IN 2 HOURS	7.1×10^{-1}	No
EPS-XHE-XR-FIREDAMP	FAILURE TO RESTORE FIRE DAMPERS AFTER TEST AND MAINTENANCE	2.6×10^{-5}	No
ESW-MOV-CF-102AB	ESW LOAD ISOLATION VALVES FAIL FROM COMMON CAUSE	1.0×10^{-5}	No
IE-LOOP	LOSS OF OFFSITE POWER INITIATING EVENT	1.0	Yes[1]
OEP-XHE-XL-NR30M	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 30 MINUTES	TRUE	Yes[2]
OEP-XHE-XL-NR01H	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 1 HOUR	TRUE	Yes[2]
OEP-XHE-XL-NR02H	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 2 HOURS	TRUE	Yes[2]
OEP-XHE-XL-NR04H	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 4 HOURS	1.0×10^{-2}	Yes[2]
OEP-XHE-XL-NR10H	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 10 HOURS	1.0×10^{-3}	Yes[2]
PPR-SRV-OO-1VLV	ONE SRV FAILS TO CLOSE	2.0×10^{-3}	Yes[3]
ZT-DGN-FR-L	EDG FAILS TO RUN (LONG TERM)	4.8×10^{-3}	Yes[4]

1. Initiating event assessment– all other initiating event frequencies set to zero.
2. Evaluated per SPAR-H method (Ref. 5). See Attachment C for further details.
3. Updated value per detailed review of LERs.
4. Changed mission time to correspond to the time that 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.

Time[1]	Event
1611	Reactor trips due to grid instability
1613	Offsite power is lost to emergency buses; emergency diesel generators automatically start and load to power the emergency buses
1900	Offsite power is restored to the switchyard with a 5 MW load limit
2000	Load limit is raised from 5 MW to 10 MW
2307	First emergency bus (10600) is switched to offsite power source
2328	Second emergency bus (10500) is switched to offsite power source
2345	Emergency diesel generators are shut down
2400	All load restrictions are removed

1. All times are on August 14, 2003.

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.)

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[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 4 times the time required, and 0.1 if the time available is greater than or equal to 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 30 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}	Inadequate	--	TRUE
OEP-XHE-XL-NR04H	1.0×10^{-3}	1	10	1.0×10^{-2}
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. D-1).

1. Comment from Licensee - Reactor coolant boil-off time

"The ASP analysis did not include the three-hour reactor coolant boil-off time, which would take place in a site blackout sequence after battery depletion with initially successful HPCI/RCIC. Crediting this time in the analysis would increase the maximum offsite power recovery time to 7 hours and reduce the CCDP. The NRC analysis permitted a maximum recovery time of only 4 hours, i.e. 3 hours (when the 115kV system was first adequately energized), plus one hour to realign the safety buses, 10500 and 10600."

Response: The SPAR model does not credit recovery of offsite power in a station blackout following depletion of station batteries. Breakers in the switchyard and in the plant would have to be closed, and that may not be possible or feasible without any ac or dc power available. The SPAR model would be revised only if (1) a procedure exists to recover offside power following battery depletion, (2) the procedure has been demonstrated to work, and (3) operators are trained on the procedure. Furthermore, thermal-hydraulic models do not show a three hour boil-off time in this scenario; the time would be closer to one hour.

2. Comment from Licensee - Firewater backup for EDG jacket cooling

"The crosstie between the firewater system and EDG jacket coolers can be credited in accident sequence cutsets which involve failures of components in the ESW system with successful closure of 46MOV-102A/B. As an example, for the dominant core damage sequence LOOP/SBO sequence 47-02, fire water cross-tie recovery can be credited for cutsets of CCDP 6.5E-7 and below."

Response: The firewater backup is included for EDG cooling. For sequence 47-02, each cut set in the GEM report with CCDP below 6.5E-7 contains the event FWS-XHE-ERROR. FWS-XHE-ERROR is defined as "operator fails to start/control firewater injection/cooling," which is used for alternate injection and for EDG jacket cooling. The probability of FWS-XHE-ERROR is 6.0E-2.

References:

1. Entergy Nuclear Operations, Inc. Comments on Preliminary Accident Sequence Precursor Analysis of August 14, 2003 Operational Event, Letter from Michael R. Kansler to U.S. Nuclear Regulatory Commission, May 17, 2004 (ML041460505).

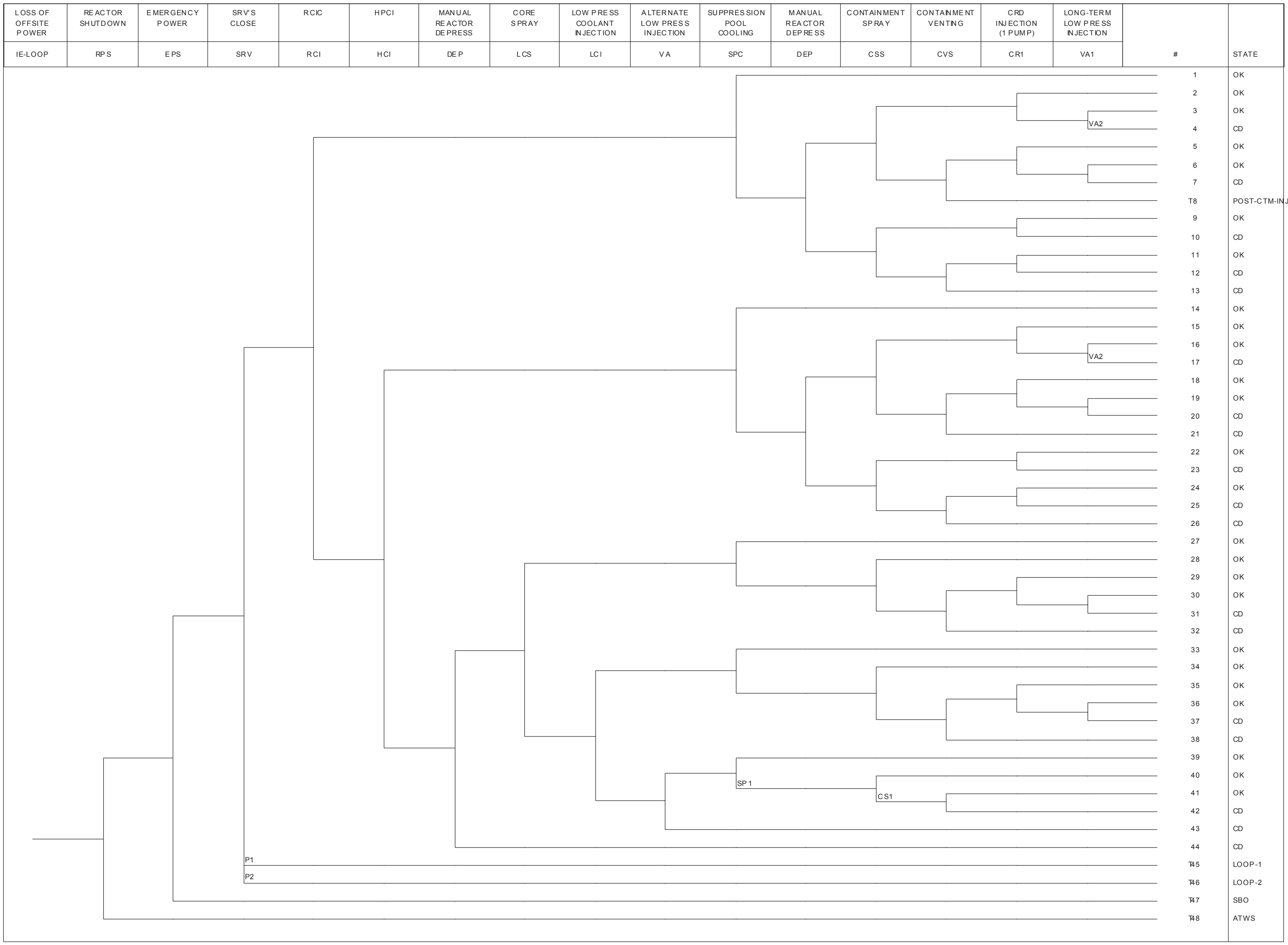

Figure 1: Fitzpatrick LOOP event tree.

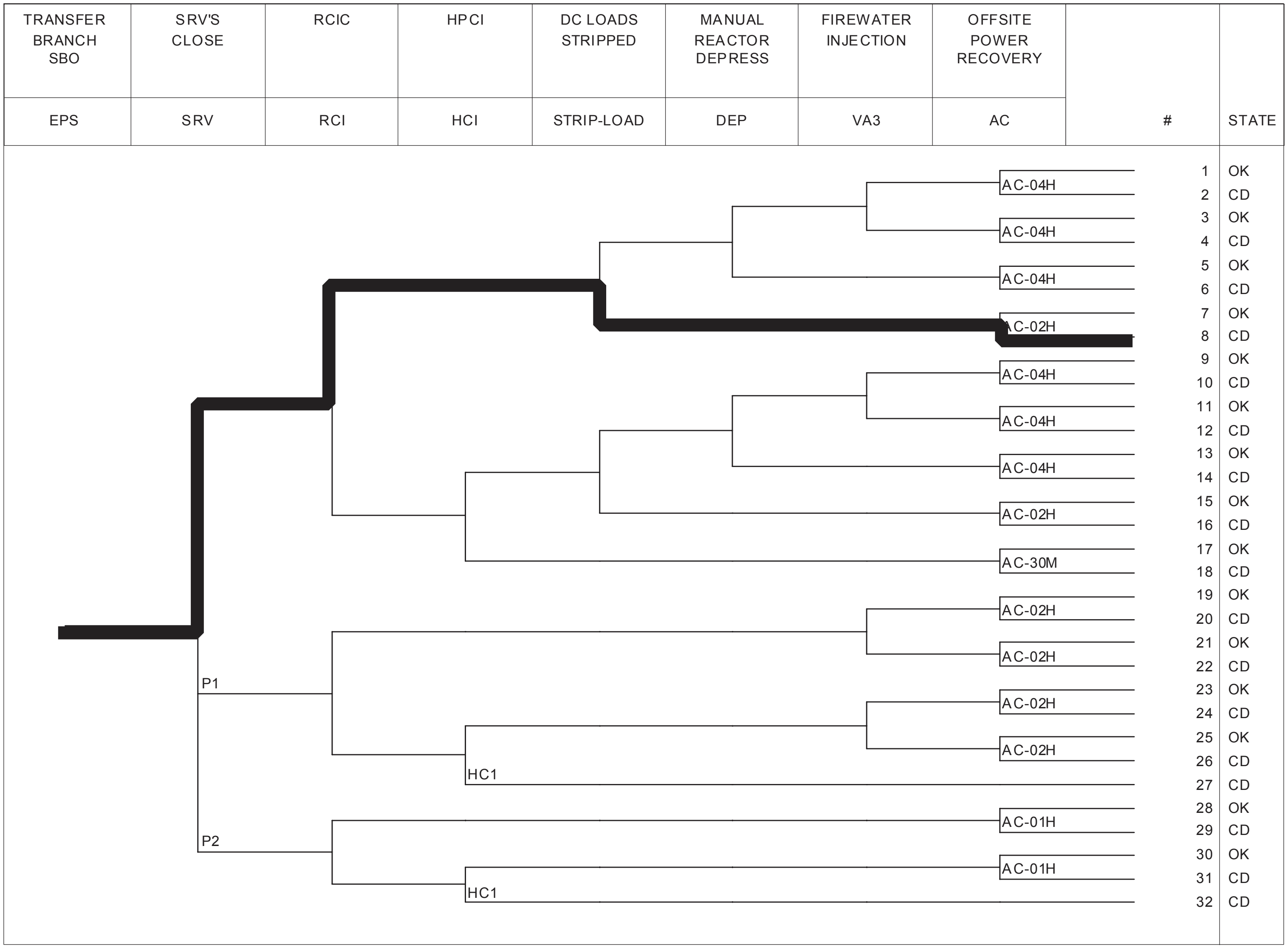

Figure 2: Fitzpatrick SBO event tree with dominant sequence highlighted.