Final Precursor Analysis

Accident Sequence Precursor Program -- Office of Nuclear Regulatory Research

Kewaunee Nuclear Power Plant	Both Emergency Diesel Generators Inoperable for 28 Hours	
Event Date 2/26/2003	LER 305/03-002-00	ΔCDP = 3×10^{-6}

August 23, 2005

Event Summary

On February 26, 2003, at 0107 hours, a manual reactor shutdown was initiated, according to Technical Specifications (TS), due to both emergency diesel generators (EDG) being unavailable. At 0239, on February 25, EDG 'A' was removed from service to perform scheduled periodic maintenance. A test run on EDG 'B' was satisfactorily completed at 0159 prior to taking EDG 'A' out of service. TS require that EDG 'B' must be tested daily while EDG 'A' is out of service.

During the daily required test on EDG 'B' (at 0017 on February 26), the diesel failed to start. Troubleshooting revealed a failed relay in the diesel start circuit. The faulty relay was replaced and EDG 'B' was satisfactorily retested and returned to service at 0624, on February 26. The plant shutdown was terminated at 10-percent reactor power. EDG 'A' maintenance was completed and the diesel was returned to service at 0010, on February 27. The total time that both EDGs were out of service was approximately 28 hours.

Further information about the event can be found in References 1 and 2.

Analysis Results

- **Importance**[1]

  This event was modeled as a conditional assessment with both EDGs unavailable for 28 hours. The importance for this condition is $3x10^{-6}$ (mean value). The acceptance threshold for the Accident Sequence Precursor Program is an importance $\geq 1x10^{-6}$. Therefore, this condition is a precursor.

	5%	Mean	95%
Importance	$2x10^{-7}$	$3x10^{-6}$	$1x10^{-5}$

[1] For a conditional assessment, the parameter of interest is the measure of importance. This value is obtained subtracting the baseline core damage probability (CDP) from the conditional core damage probability (CCDP).

- **Dominant Sequences**

  The dominant core damage sequences for this assessment are Loss of Offsite Power (LOOP), Station Blackout (SBO), Sequence 18-03 (32% of the total importance), SBO Sequence 18-06 (31% of the total importance), and SBO Sequence 18-45 (24% of the total importance). The LOOP and SBO event trees with the dominant sequences highlighted are shown in Figure 1 and Figure 2.

  The events and important component failures in LOOP/SBO Sequence 18-03 are:

  - LOOP occurs,
  - Reactor shutdown succeeds,
  - Emergency power fails,
  - Auxiliary feedwater succeeds,
  - Power operated relief valves (PORV) close,
  - Rapid secondary depressurization succeeds,
  - Reactor coolant pump (RCP) seal stage 1 integrity succeeds,
  - Reactor coolant pump (RCP) seal stage 2 integrity succeeds,
  - Operators fail to recover offsite power in 8 hours, and
  - Operators fail to recover an EDG in 8 hours.

  The events and important component failures in LOOP/SBO Sequence 18-06 are:

  - LOOP occurs,
  - Reactor shutdown succeeds,
  - Emergency power fails,
  - Auxiliary feedwater succeeds,
  - Power operated relief valves (PORV) close,
  - Rapid secondary depressurization succeeds,
  - Reactor coolant pump (RCP) seal stage 1 integrity succeeds,
  - Reactor coolant pump (RCP) seal stage 2 integrity fails,
  - Operators fail to recover offsite power in 4 hours, and
  - Operators fail to recover an EDG in 4 hours.

  The events and important component failures in LOOP/SBO Sequence 18-45 are:

  - LOOP occurs,
  - Reactor shutdown succeeds,
  - Emergency power fails,
  - Auxiliary feedwater fails,
  - Operators fail to recover offsite power in 1 hour, and
  - Operators fail to recover an EDG in 1 hour.

- **Results Tables**

  - The importance values for the dominant sequences are shown in Table 1.
  - The event tree sequence logic for the dominant sequences are 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 total result.

Modeling Assumptions

- **Analysis Type**

This event was modeled as a conditional assessment of both EDGs unavailable for approximately 28 hours. The Kewaunee Revision 3.11 Standardized Plant Analysis Risk (SPAR) model, December 31, 2004 was used.

Modeling Assumptions Summary

Key modeling assumptions. The key modeling assumptions are listed below. These assumptions are important contributors to risk.

- **EDG 'B' failed to start and was recoverable within approximately 4 hours.** The EDG 'B' failure was diagnosed and the diesel was restored to service in approximately 6 hours. However, based on judgement of the Senior Resident Inspector (SRI) at the site, recovery of EDG 'B' may have been possible in approximately 4 hours. Therefore, recovery of EDG 'B' was credited, using the SPAR-H Human Reliability Analysis Method (Ref. 4), for all EDG recovery events greater than or equal to 4 hours. For all EDG recovery events less than 4 hours, recovery was not credited in this analysis. Further details on the recovery of EDG 'B' are provided in the following sections.

- **EDG 'A' was out of service for maintenance and could not be recovered prior to core uncovery.** EDG 'A' was out of service for maintenance and was restored to service 24 hours after EDG 'B' failed to start during daily testing. Restoration of EDG 'A' was not possible prior to core uncovery during a postulated SBO event.

- **Basic Event Probability Changes**

Table 4 provides all the basic events that were modified to reflect the condition being analyzed. The basis for these changes is provided below.

- **EDG 'A' is unavailable due to testing and maintenance (EPS-DGN-TM-1A).** This probability was set to TRUE. EDG 'A' was out of service for maintenance for approximately 46 hours.

- **EDG 'B' fails to start (EPS-DGN-FS-1B).** This probability was set to TRUE. EDG 1B failed to start during daily testing required per TS.

- **AFW TDP '1C' unavailable due to testing and maintenance (AFW-TDP-TM-1C).** This probability is set to FALSE. Maintenance of the TDP is not allowed during EDG maintenance. Normally the SPAR model rules would prohibit this event from appearing in a cutset, but setting EPS-DGN-TM-1A to TRUE circumvents the proper execution of this rule.

- **Operator fails to recover an EDG in 1 hour (EPS-XHE-XL-NR01H).** This probability was set to True. See Key Modeling Assumptions for further details.

- **Operator fails to recover an EDG in 2 hours (EPS-XHE-XL-NR02H).** This probability was set to True. See Key Modeling Assumptions for further details.

- **Operator fails to recover an EDG in 3 hours (EPS-XHE-XL-NR03H).** This probability was set to True. See Key Modeling Assumptions for further details.

- **Operator fails to recover an EDG in 4 hours (EPS-XHE-XL-NR04H).** This probability was set to 0.2 using the SPAR-H method. In both the Diagnosis and Action parts of the SPAR-H analysis, the Stress performance shaping factor (PSF) was set to Extreme and the Complexity PSF was set to Moderately Complex. In the Action part of the SPAR-H analysis, the Available Time PSF was set to Barely Adequate. All other PSFs were set to Nominal. See Attachment A for further details.

- **Operator fails to recover an EDG in 6 hours (EPS-XHE-XL-NR06H).** This probability was set to 0.1 using the SPAR-H method. The Stress PSF was set to Extreme and the Complexity PSF was set to Moderately Complex. All other PSFs were set to Nominal. See Attachment A for further details.

- **Operator fails to recover an EDG in 8 hours (EPS-XHE-XL-NR08H).** This probability was set to 0.1 using the SPAR-H method. The Stress PSF was set to Extreme and the Complexity PSF was set to Moderately Complex. All other PSFs were set to Nominal. See Attachment A for further details.

- **Sensitivity Analysis**

  Sensitivity analyses were performed to determine the effects of modeling uncertainties on results based on best estimate assumptions. Changes to PSFs used in the analysis do not significantly change the results.

References

1. LER 305/03-002-00, “Shutdown Initiated- Diesel Generator Failed to Start Test- Unusual Event- Caused by Start Relay Failure,” dated April 28, 2003.

2. NRC Special Inspection Report 50-305/03-08, dated January 26, 2004.

3. Idaho National Engineering and Environmental Laboratory, “Simplified Plant Analysis Risk (SPAR) Model for Kewaunee Nuclear Power Plant,” Revision 3.11, December 31, 2004.

4. Idaho National Engineering and Environmental Laboratory, “The SPAR-H Human Reliability Analysis Method INEEL/EXT-02-01307,” May 2004.

Table 1. Importance values of dominating sequences.

Event tree name	Sequence no.	Importance[1] (CCDP-CDP)	Contribution
SBO	18-03	1.1E-006	32.2
SBO	18-06	9.5E-007	30.6
SBO	18-45	7.3E-007	23.5
Total (all sequences)[(2)]		**3.2E-006**	**100**

1. Values are point estimates. (File name: GEM 335-03-002.wpd)
2. Total Importance includes all sequences (including those not shown in this table).

Table 2a. Event tree sequence logic for dominating sequences.

Event tree name	Sequence no.	Logic ("/" denotes success; see Table 2b for top event names)
SBO	18-03	/RPS EPS /AFW-B /PORV-B /RSD /BP1 /BP2 OPR-08H DGR-08H
SBO	18-06	/RPS EPS /AFW-B /PORV-B /RSD /BP1 BP2 OPR-04H DGR-04H
SBO	18-45	/RPS EPS AFW-B OPR-01H DGR-01H

Table 2b. Definitions of top events listed in Table 2a.

Top Event	Definition
AFW-B	Auxiliary feedwater (AFW) fails during SBO
BP1	RCP seal stage 2 integrity fails
BP2	RCP seal stage 2 integrity fails
DGR-01H	Operator fails to recover an EDG in 1 hour
DGR-04H	Operator fails to recover an EDG in 4 hour
DGR-08H	Operator fails to recover an EDG in 8 hours
EPS	Emergency power system fails
OPR-01H	Operator fails to recover offsite power in 1 hour
OPR-04H	Operator fails to recover offsite power in 4 hour
OPR-08H	Operator fails to recover offsite power in 8 hours
PORV-B	PORVs fail to close during SBO
RPS	Reactor protection system fails
RSD	Rapid secondary depressurization fails

Table 3. Conditional cut sets for the dominant sequence. (See Table 4 for definitions and probabilities for the basic events.)

Importance	Percent Contribution	Minimum Cut Sets (of basic events)		
Event Tree: LOOP/SBO, Sequence 18-03				
1.1E-006	100.0	EPS-XHE-XL-NR08H	OEP-XHE-XL-NR-08H	
1.1E-006	**100**	**Total (all cutsets)[1]**		
Importance	**Percent Contribution**	**Minimum Cut Sets (of basic events)**		
Event Tree: LOOP/SBO, Sequence 18-06				
9.5E-007	100.0	EPS-XHE-XL-NR04H	OEP-XHE-XL-NR-04H	RCS-MDP-LK-BP2
9.5E-007	**100**	**Total (all cutsets)[1]**		
Importance	**Percent Contribution**	**Minimum Cut Sets (of basic events)**		
Event Tree: LOOP/SBO, Sequence 18-45				
3.4E-007	46.1	AFW-TDP-FS-1C	OEP-XHE-XL-NR01H	
2.3E-007	31.8	AFW-TDP-FR-1C	OEP-XHE-XL-NR01H	
7.3E-007	**100**	**Total (all cutsets)[1]**		

1. Total Importance includes all cutsets (including those not shown in this table).

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

Event Name	Description	Probability/ Frequency (per hour)	Modified
AFW-TDP-FR-1C	AFW turbine-driven pump 1C fails to run	4.1×10^{-3}	No
AFW-TDP-FS-1C	AFW turbine-driven pump 1C fails to start	6.0×10^{-3}	No
AFW-TDP-TM-1C	AFW turbing-driven pump 1C unavailable due to test and maintenance	False	Yes[1]
EPS-DGN-FS-1B	Diesel generator 1B fails to start	True	Yes[1]
EPS-DGN-TM-1A	Diesel generator 1A is unavailable due to test and maintenance	True	Yes[1]
EPS-XHE-XL-NR01H	Operator fails to recover an EDG in 1 hour	True	Yes[2]
EPS-XHE-XL-NR02H	Operator fails to recover an EDG in 2 hours	True	Yes[2]
EPS-XHE-XL-NR03H	Operator fails to recover an EDG in 3 hours	True	Yes[2]
EPS-XHE-XL-NR04H	Operator fails to recover an EDG in 4 hours	2.0×10^{-1}	Yes[2]
EPS-XHE-XL-NR06H	Operator fails to recover an EDG in 6 hours	1.1×10^{-1}	Yes[2]
EPS-XHE-XL-NR08H	Operator fails to recover an EDG in 8 hours	1.1×10^{-1}	Yes[2]
OEP-XHE-XL-NR01H	Operator fails to recover offsite power in 1 hour	5.3×10^{-1}	No
OEP-XHE-XL-NR04H	Operator fails to recover offsite power in 4 hours	2.2×10^{-1}	No
OEP-XHE-XL-NR08H	Operator fails to recover offsite power in 8 hours	1.2×10^{-1}	No
RCS-MDP-LK-BP2	RCP seal stage 2 integrity (binding/popping o-rings)	2.0×10^{-1}	No

1. Set to True to reflect plant conditions. See Basic Event Probability Changes for further details.
2. Evaluated per SPAR-H method (Ref. 4). See Key Modeling Assumptions and/or Attachment A for further details.

Attachment A
AC Power Revovery Modeling

Background and Modeling Details of AC Power Recovery
The time required to restore AC power to plant emergency equipment is a significant factor in modeling the importance given a postulated loss of offsite power (LOOP) and/or station blackout (SBO). Standardized Plant Analysis Risk (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 1 hour 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 industry average recovery values for all four LOOP types (plant centered, grid-related, severe weather, and extreme weather). The SPAR-H Human Reliability Analysis Method (Ref. 4) was used to estimate non-recovery probabilities of a single emergency diesel generator (EDG).

Diagnosis and Dependency
The SPAR Human Reliability Analysis Method considers the following three factors:

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

This analysis determined that the probability of failure to successfully perform action needed to recover a failed EDG is negligible for the 6 and 8 hour cases because the probability of failing the diagnosis is an order of magnitude higher. Dependency is normally considered when multiple operator actions are present in the same cutset. However, dependency between offsite power and EDG recovery tasks is considered low and does not change the best estimate EDG non-recovery probabilities.

Performance Shaping Factors
The probability of failure to properly diagnose a condition or failure is the product of a nominal failure probability (1.0×10^{-2}) and the following eight performance shaping factors (PSFs):

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

Available Time
The PSF for Available Time is nominal for diagnosis because it is much less than the 4, 6, or 8 hours that are the key recovery times. However, the Available Time PSF for action is judged to be barely adequate for the 4 hour case, based on the SRI's assessment that the repairs would take

approximately 4 hours. Since the repair was completed within 6 hours, with no appreciable hurry on the licensee's part, the PSF is nominal for the 4 and 6 hour recovery times.

Stress

The PSF for Stress is assigned a value of 5 (corresponding to Extreme Stress) for non-recovery probabilities greater than or equal to 4 hours, EPS-XHE-XL-NR04H, EPS-XHE-XL-NR06H, and EPS-XHE-XL-NR08H. Factors considered in assigning this PSF level are the "disruptive" stress of a postulated SBO and the eminent core damage if AC power (either an EDG or offsite power) is not restored to a safety bus prior to core uncovery.

Complexity

The PSF for Complexity is assigned a value of 2 (corresponding to Moderately Complex) for the three EDG non-recovery probabilities. A postulated SBO would "involve concurrent actions" such as communications and coordination of multiple crews outside the control room: EDG repair crew, offsite power repair crew, and utility switchyard operators.

All Other PSFs

For all of the AC power non-recovery probabilities, the PSFs for time, experience/training, procedures, ergonomics, fitness for duty, and work processes are set to be nominal (i.e., are assigned values of 1.0). Details of the condition, plant response, and historical crew performance did not warrant a change from nominal for these PSFs.

Table A.1. EDG non-recovery probabilities.

Non-recovery Factor	Nominal Value	Performance Shaping Factors			Non-recovery Probability
		Stress	Complexity	Time	
EPS-XHE-XL-NR04H	Diagnosis:$1x10^{-2}$ Action: $1x10^{-3}$	5 5	2 2	1 10	$1x10^{-1}$ $1x10^{-1}$ Total: $2x10^{-1}$
EPS-XHE-XL-NR06H	Diagnosis:$1x10^{-2}$ Action: $1x10^{-3}$	5 5	2 2	1 1	$1x10^{-1}$ $1x10^{-2}$ Total: $1.1x10^{-1}$
EPS-XHE-XL-NR08H	Diagnosis:$1x10^{-2}$ Action: $1x10^{-3}$	5 5	2 2	1 1	$1x10^{-1}$ $1x10^{-2}$ Total: $1.1x10^{-1}$

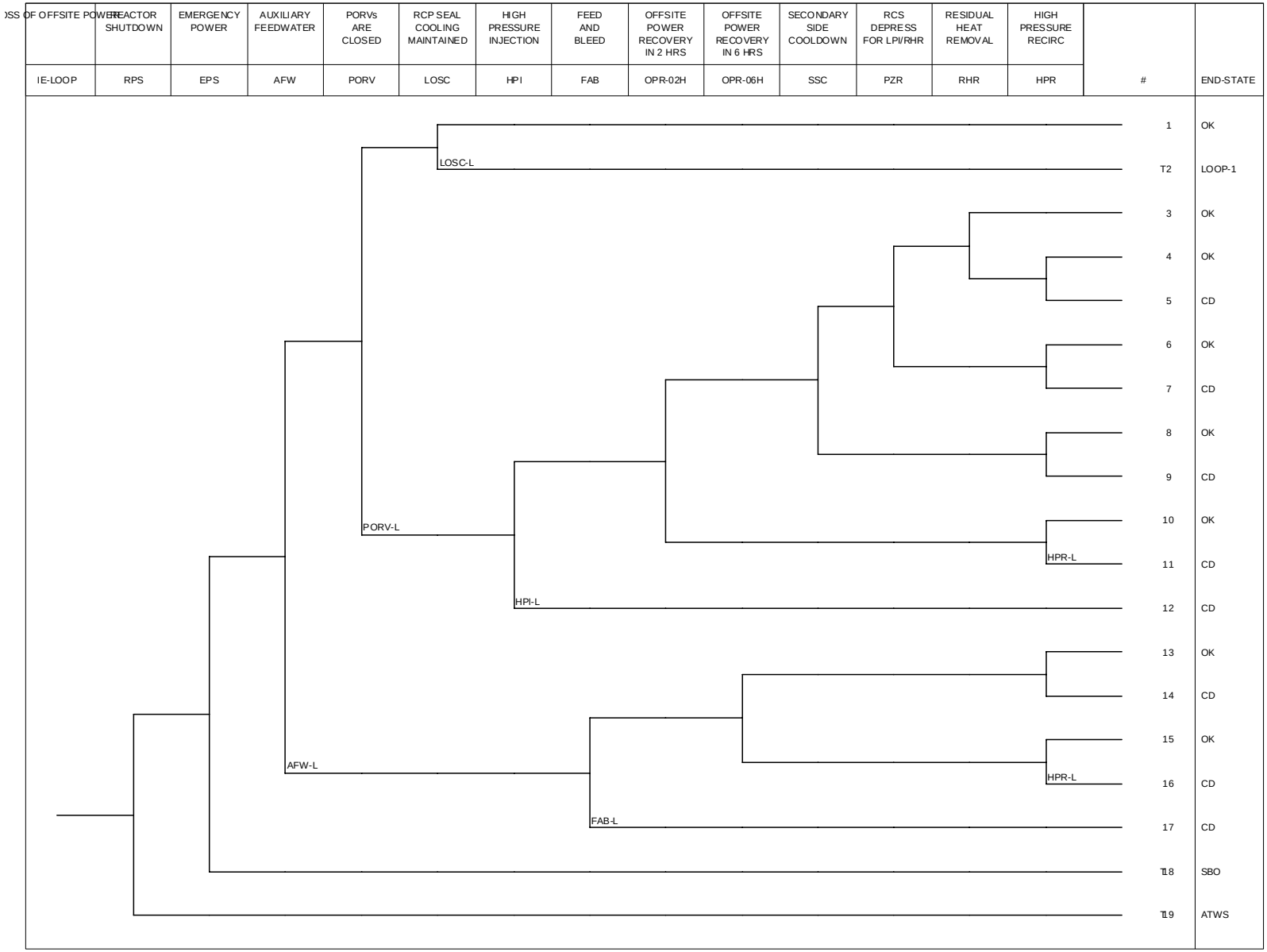

Figure 1: Kewaunee LOOP event tree.

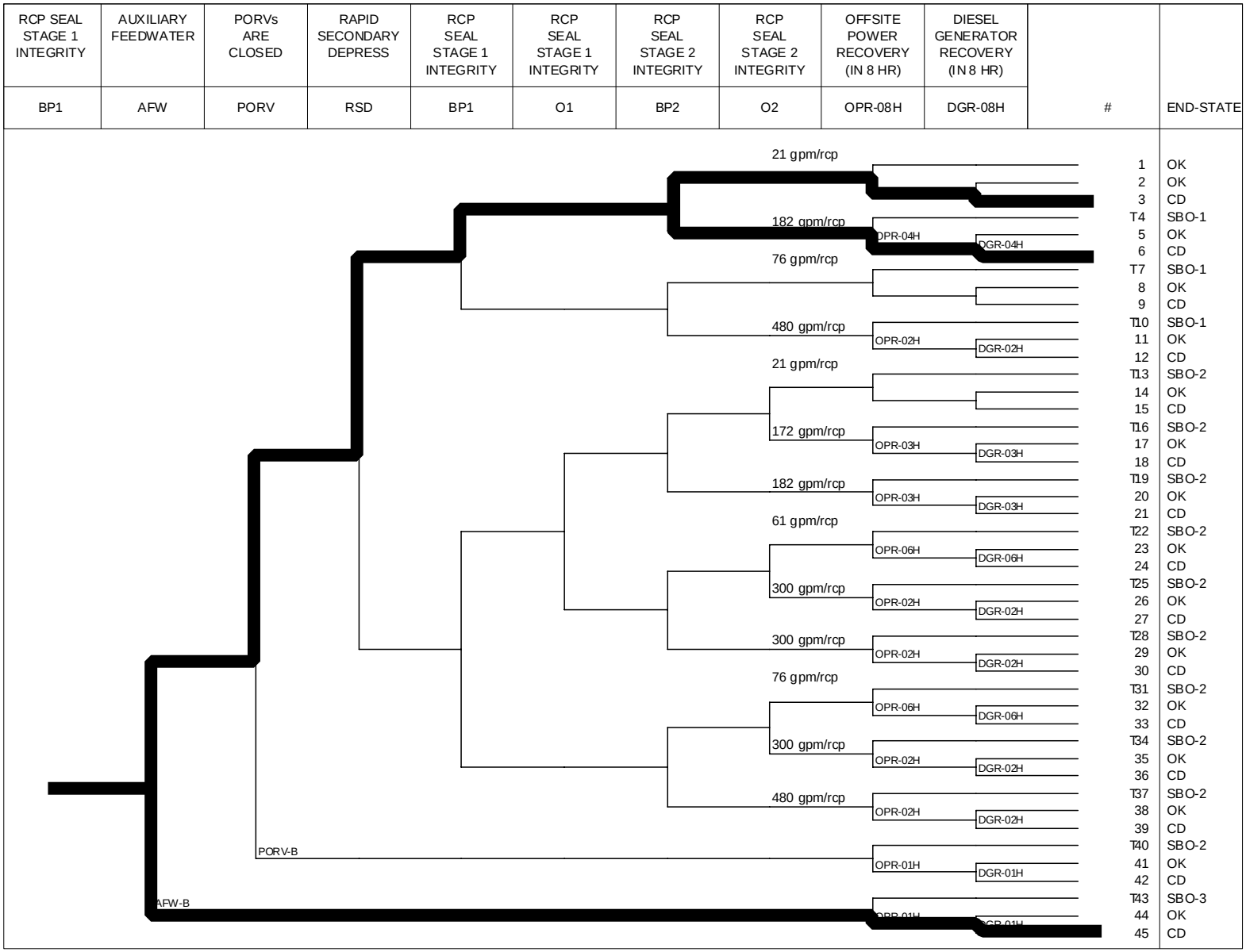

Figure 2: Kewaunee SBO event tree (with dominant sequences highlighted).