Final Precursor Analysis

Accident Sequence Precursor Program -- Office of Nuclear Regulatory Research

D.C. Cook Nuclear Plant Unit 2	Reactor Trip from RCP Bus Undervoltage Signal Complicated by Diesel Generator Output Breaker Failure	
Event Date 11/08/2005	LER 316/05-001	Mean CCDP[1] = 8×10^{-6}

March 9, 2007

Event Summary

At 0355 hours on November 8, 2005, perturbations were experienced in the Unit 2 main generator and plant bus electrical parameters, and operators observed reactor coolant pump (RCP) motor current oscillations and indications of low voltage on all four 600-volt AC safety buses. Control room operators contacted the transmission distribution center to determine if the perturbations were the result of a grid disturbance. No grid disturbances were reported.

At 0358 hours, an RCP bus undervoltage reactor trip signal was received and the Unit 2 reactor and main turbine tripped. At the time of the trip, reactive loading spiked greater than 600 mega volt amps, indicating that the main generator was motoring at that time. Arcing was observed by a security officer in the vicinity of the Unit 2 Main Generator Exciter at the approximate time the unit tripped.

Following the reactor trip, the RCP buses automatically transferred to the reserve feed supply, as designed. However, the low voltage conditions on the safety buses had resulted in the automatic start of emergency diesel generators (EDGs) and actuation of load shed for the A and B 4kV safety buses. Because the 2CD EDG output breakers were in lockout status due to maintenance, the load shed function was blocked and did not occur for that train. On the other hand, the C and D 4kV safety buses remained energized from the reserve feed supply via the RCP buses.

When the loads were shed from the A and B 4kV safety buses, the Unit 2 west (W) centrifugal charging pump (CCP), which had been in service, lost power and because no charging pumps were running, letdown flow from the reactor coolant system (RCS) automatically isolated. The operating Unit 2 West (W) essential service water (ESW) pump lost power and the cross-tied Unit 1 East (E) ESW pump automatically started due to low pressure on the associated ESW header. The T21A, A, 4kV safety bus was re-energized automatically following the start of the 2AB EDG; however, the breaker from the diesel generator to the T21B, B, 4kV safety bus (i.e., T21B4 breaker) failed to close, and the B bus remained de-energized.

At approximately 0406 hours, operators started the Unit 2 E CCP and restored normal RCS makeup and letdown flow from the RCS. At 0510 hours, the 2AB EDG output breaker providing

[1] The event best-estimate conditional core damage probability is based on the initiating event assessment taking into account the potential occurrence of a loss of offsite power in consequence of the reactor/generator trip as per the industry operational experience (e.g., due to induced grid degradation or during a switching transient following the main generator trip) as well as the unavailable equipment during the trip (i.e., 2CD EDG out of service for planned maintenance, and T21B4 output breaker of 2AB EDG in failure).

power to the A 4kV bus (T21A11) unexpectedly opened. The breaker re-closed without manual action after 23 seconds. When the breaker opened, a load sequence signal on the T21A bus was initiated and all loads re-sequenced onto the bus.

The 2CD EDG was restored to operable status at 0606 hours. Power was restored to bus T21B from reserve feed at approximately 1100 hours. The 2AB EDG was restored to operable status on November 10, 2005, at 0222 hours."

The above event description from the LER [1] points to the following, among others, when the reactor tripped on the RCP bus undervoltage:

- 2CD EDG was out of service for preventive maintenance, and
- One of the two output breakers of 2AB EDG, i.e., T21B4 breaker to the T21B safety bus, failed to close upon demand.

Note that only the "automatic" closure function of the T21B4 breaker was unavailable, because operators could manually close the breaker if they wanted. The inspection report [2] indicates that operators did not attempt to manually close the breaker, choosing instead to quarantine it to investigate the failure to close.[2]

It is also notable that the T21B4 breaker was already in a degraded state approximately 12 days before the reactor trip according to the root cause investigation [1]. The event assessment, therefore, requires identification of the plant configurations beginning from the time when the functional degradation of the circuit breaker occurred.

Condition Duration. The automatic closure function of the T21B4 breaker was unavailable for 13 days, 6 hours, and 12 minutes (i.e., approximately 320 hours) from 2110 hours, October 27, 2005 through 0222 hours, November 10, 2005. During this period, 2CD EDG was inoperable for a total time of 16 hours and 22 minutes due to the aforementioned three separate instances. Note that the actions required by Technical Specifications for the EDG system inoperability were not properly completed, because the degradation of T21B4 breaker was not known to the operators until the breaker was demanded to close upon the low voltage conditions on the safety buses following the reactor trip.

The equipment status which needs to be taken into account in the event assessment (especially, condition assessment) includes [1-3]:

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[2] Of the two output breakers of 2AB EDG (i.e., T21A11 for T21A bus and T21B4 for T21B bus), the T21A11 breaker performs relatively far more important functions because it provides AC power to many safety-critical components (e.g., safety injection pump 2S, motor-driven auxiliary feedwater pump 2W, containment spray pump 2W, residual heat removal pump 2W, essential service water pump 2W, component cooling pump 2W, centrifugal charging pump 2W, etc.) through the T21A bus. The most important function carried out by the T21A11 breaker that actually degraded appears to be the provision of power to the exhaust fan, exhaust fan damper and panel cooling fan in the 2AB EDG room. This function has impact on the long-term cooling of the diesel generator, and as such, potential failure of the diesel generator upon loss of this function during the mission time has been taken into account in the event assessment.

- <u>2AB EDG</u>: At 2010 hours, October 27, 2005, 2AB EDG was electively taken out of service to support installation and testing of a modification in the control room EDG panel as related to the addition of supplemental diesel generators (SDGs), as will be discussed later. At 2311 hours of the same day, the work was completed and 2AB EDG became available.

- <u>T21B4 breaker</u>: The automatic closure function of T21B4 breaker was disabled during the installation and testing services conducted in connection with the addition of SDGs. The services lasted about 3 hours, and it is conservatively assumed that the automatic closure function failed at 2010 hours, October 27, 2005. The circuit breaker was declared operable following trouble shooting and repair on November 10, 2005 at 0222 hours.

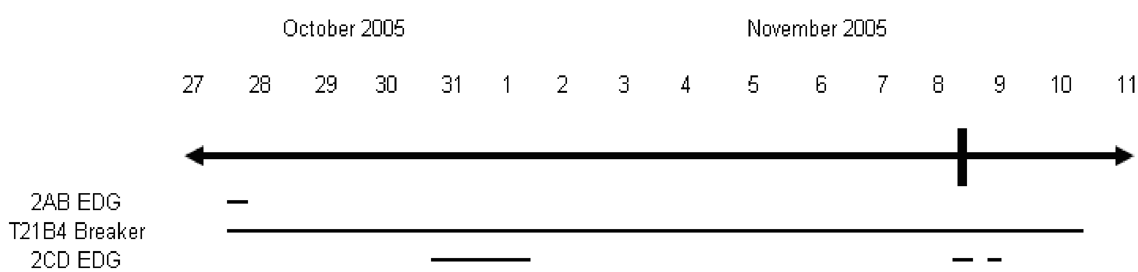
- <u>2CD EDG</u>: While the automatic function of the T21B4 output breaker for 2AB EDG was disabled, there were three instances where 2CD EDG was also out of service:

  - Electively taken inoperable to support installation of the SDGs for approximately twelve and a half hours (i.e., from 2258 hours, October 31, 2005 through 1125 hours, November 1, 2005)

  - Taken out of service for planned maintenance for about 3 hours (i.e., from 0305 hours, November 8, 2005 through 0606 hours, November 8, 2005)

  - Declared inoperable for testing for about 1 hour (i.e., from 2052 hours, November 8, 2005 through 2146 hours, November 8, 2005)

The plant configurations of interest are depicted below along a time line. The vertical line represents the time when the reactor trip took place, i.e., 0358 hours, November 8, 2005.



From the diagram above, the following three different plant configurations can be identified.

1) <u>Double outage of 2AB EDG and T21B4 breaker for 3 hours</u>: 2AB EDG out of service to support the control-room panel modification with T21B4 breaker in failure.

2) Double outage of 2CD EDG and T21B4 breaker for 16.5 hours: 2CD EDG out of service to support the modification, planned maintenance, and testing withT21B4 breaker in failure.

3) Single outage of T21B4 breaker for 299 hours: T21B4 breaker in failure.

Figure 1 shows a simplified diagram of the electrical power distribution system at D.C. Cook Unit 2 [2]. More details of the event can be found in References [1-3].

Cause. The reactor trip and the breaker failures occurred due to the following reasons:

a) Reactor Trip: The root cause of the reactor trip induced by RCP bus undervoltage conditions was that the preventive maintenance program failed to provide adequate preventive maintenance on the main generator exciter brushes; specifically, periodic thermography, brush holder inspections, and brush holder replacements were not performed.

b) Breaker Failures: Both output breakers of the 2AB EDG experienced malfunctions during the event. The causes of these malfunctions are:

- The T21B4 breaker failed to close automatically upon demand following a load shed, because an improperly crimped lug on a conductor to a test switch in the breaker's closing circuit was disturbed during installation and testing services for a modification in the control room EDG panel.

- Breaker T21AI I cycled open unexpectedly for 23 seconds. The cause of this unexpected occurrence was due to failure of the AB EDG Trip Control Auxiliary Time Delay Relay. Evaluation of the relay indicates that this failure was caused by chlorine-induced corrosion of the relay coil as a result of contamination introduced during the manufacturing process.

Recovery opportunities. During the event, circuit breaker T21B4 failed to automatically close after the AB EDG started and came up to speed and voltage. However, operators did not attempt to manually close the breaker, choosing instead to quarantine it to investigate the failure to close [2], as mentioned before. The inspection report [2] also indicates that the circuit breaker was in a state that could be manually closed by operators if needed. This recovery potential is explicitly taken into account in the event assessment.

Other concurrent or windowed events. No other significant operating events existed at D.C. Cook 2 according to the LER Search Database, while the automatic closure function of the T21B4 breaker was disabled.

Analysis Results

- **Importance**

Two different types of analyses were performed to evaluate the impact of the 2AB EDG output breaker T21B4 malfunction and the associated EDG unavailability on plant risk: a) initiating event assessment and b) condition assessment. The initiating event assessment projects a conditional core damage probability (CCDP) of 8.8×10^{-6} (point estimate) for the event. The uncertainty distribution for the CCDP is given below.

	CCDP		
	5%	**Mean**	**95%**
D.C. Cook 2	2.6E-6	8.0E-6	1.9E-5

Condition assessment also has been carried out for three different plant outage configurations discussed above, namely: 1) 2AB EDG and T21B4 breaker for 3 hours, 2) 2CD EDG and breaker T21B4 for 16.5 hours, and 3) breaker T21B4 for 299 hours. The condition assessment for each of these configurations yields an importance (i.e., ΔCDP) of 2.6×10^{-8}, 2.2×10^{-7}, and 7.0×10^{-9}, respectively, to result in a total importance of 2.5×10^{-7}, which is consistent with Reference 2.

As the initiating event assessment yields a higher importance than the condition assessment, the discussion below is focused on the former.

- **Dominant Sequences**

The dominant core damage sequence for this event is Transient Sequence 2-18-03 resulting from the RCP bus undervoltage followed by a consequential loss of offsite power. This sequence represents a station blackout (SBO) condition where core damage occurs due to loss of all instrumentation and control as a result of operator failure to recover offsite power or a diesel generator prior to battery depletion, i.e., within 4 hours following the consequential loss of offsite power. The events and important component failures for Sequence 2-18-03 shown in Figures 2 through 4 include:

- Transient due to RCP bus undervoltage,
- Consequential loss of offsite power,
- Successful operation of the reactor protection system,
- Failure of the emergency power system,
- Successful operation of the auxiliary feedwater system,
- Successful reclosure of power operated relief valve (PORVs) and/or safety relief valves (SRV) after opening,
- Successful rapid depressurization of the secondary side,
- Integrity of the RCP seal first stage maintained,
- Integrity of the RCP seal second stage maintained,

- Operator failure to recover offsite power in 4 hours, and
- Operator failure to recover emergency diesel in 4 hours.

- **Results Tables**

  - The conditional probabilities 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.
  - Definitions and probabilities for modified or dominant basic events are provided in Table 4.

Modeling Assumptions

- **Analysis Type**

The Revision-3-Plus (Change 3.31) of the D.C. Cook 1 and 2 Standardized Plant Analysis Risk (SPAR) model [5] created in December 2005 was used for this assessment. The SPAR Revision-3-Plus models T21A and T21B buses collectively, and the T21B4 circuit breaker is not included in the model. Therefore, the SPAR model has been modified to enable the event assessment, and these modeling updates are discussed in the sequel.

Using the modified SPAR model as a new base model for this event analysis, both initiating event assessment and condition assessment were performed. The initiating event assessment was made with a new event tree developed for a special type of transient caused by RCP bus undervoltage (named IE-RCP-UV) in order to take into account a consequential LOOP. When the reactor tripped at D.C. Cook Unit 2, 2CD EDG was out of service and the automatic closure function of the T21B4 breaker was disabled. Hence, these equipment unavailability was accounted for in the initiating event assessment. On the other hand, the condition assessment was performed for each of the three plant configurations mentioned earlier.

- **Unique Design Features**

Emergency power system. The emergency power system of D.C. Cook 2 is quite unique in that, for instance: 1) 2AB EDG provides power to 4kV T21A and T21B safety buses when these buses are de-energized by a loss of offsite power; however, 2) the continuous operation of this diesel requires room cooling provided by several components (e.g., room supply fan, exhaust fan, etc.) fed by 600V motor control centers that are powered by 2AB EDG through the 4kV T21A and T21B buses. Therefore, there exist “circular functional dependencies” among components of the emergency power system.

- **Modeling Assumptions Summary**

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

- **Consequential LOOP given a reactor trip [4].** The operating experience of nuclear power plants indicates that a loss of offsite power may occur subsequent to a reactor trip which is unrelated to a LOOP. In such events called consequential LOOPs, the LOOP would not have occurred if the reactor trip had not occurred. The data analysis recently performed as part of reevaluation of station blackout risk at nuclear power plants indicates that: (1) there were 2797 reactor trips not initiated by a LOOP over the period 1986-2004; and (2) of these, nine resulted in consequential LOOPs. Therefore, the mean value of the conditional probability of a consequential LOOP given a reactor trip can be computed using the updated Jeffreys noninformative distribution as follows:

$$(9 + 0.5) / (2797 + 1) = 3.4\times10^{-3}$$

This probability of a consequential LOOP occurring following a reactor trip is used in the event assessment under the assumption that the industry data which the value is based on (i.e., nine consequential LOOPs out of 2797 LOOP-unrelated reactor trips) is also applicable to D.C. Cook 2. Note that there is an increasing trend in the likelihood of a consequential LOOP according to the industry operating experience [4]. Neglecting the potential occurrence of a consequential LOOP, especially in the cases where the emergency power system is degraded as in this event, will result in underestimation of the event importance.[3]

- **Actual equipment unavailability.** The plant Technical Specifications (TS) requires that 2AB EDG be declared inoperable even if only one of the output breakers failed or degraded as in this event. However, the event assessment was performed by taking into account the actual status of equipment; namely, even though T21B4 breaker failed, it was assumed that 2AB EDG was functional.

- **Manual closure of T21B4 breaker.** The T21B4 output breaker was in a state that could be manually closed by the operators, as mentioned earlier. The nonrecovery probability of 2×10^{-3} obtained through SPAR-H analysis [6] as described in Appendix A is used for the best estimate event assessment, and sensitivity analyses with respect to this breaker recovery were conducted.

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[3] In the accident sequences of the present SPAR models (i.e., Revision 3 Plus, Change 3.31), the potential occurrence of consequential LOOPs is not taken into account, although the unconsideration of these events is compensated to some extent by the inclusion of consequential LOOPs in estimating the frequency of LOOP initiating event. In other words, the LOOP initiating event frequency of 3.59×10^{-2} used in the SPAR models include consequential LOOPs. However, this frequency is set to zero in the initiating event assessment for a non-LOOP transient as in this event, and as a result, consequential LOOPs will not be taken into account in such an initiating event assessment unless the sequence modeling is appropriately modified to include them.

- **Room cooling for 2AB EDG.** The long-term operation of 2AB EDG requires power to both T21A and T21B buses, because although the supply fan for the diesel generator room is powered by T21A bus (i.e., through a 600V motor control center fed by 4kV T21A bus), the room exhaust fan, room exhaust fan damper, and panel cooling fan are powered by T21B bus [7]. Therefore, even if only the T21B bus is de-energized as a result of the T21B4 breaker failure with the T21A bus still energized, it is assumed that 2AB EDG will fail within a few hours of diesel operation because of an increase of the room temperature to a point where the sensitive protective and control circuits will cause the EDG to trip. Note that a diesel generator is required to operate for a mission time of 24 hours in the SPAR model.

- **EDG non-recovery probability.** EDG 2CD was out of service for preventive maintenance when the reactor tripped, and was restored to an operable condition 2 hours 11 minutes later. The default EDG non-recovery probabilities (EPS-XHE-XL-NR...) in station blackout sequences are based on 2 failed EDGs and an operator selecting the quickest to repair EDG. Since EDG 2CD's actual restoration time is similar to the median of the default curve (2 hr. vs 4 hr.), the default curve was used.

- **Treatment of common cause failures.** One of the two EDGs at D.C. Cook Unit 2 was out of service for preventive maintenance when the reactor tripped, and therefore, the CCF potential in the remaining EDGs (i.e., EDG AB in Unit 2 and the two EDGs in Unit 1) should be evaluated as part of the event assessment. Various views exist among PRA professionals as to how to model the conditional CCF potential, especially when a component in the common cause component group is out for preventive maintenance. In this event assessment, the analysis: (1) set the test/maintenance basic event to 1.0; and (2) set the remaining basic events (i.e., failure to start and failure to run for the specific EDG) to FALSE. This method removes from the cutsets disallowed maintenance combinations and remove random failures of the equipment that is supposedly out for test or maintenance. In addition, the CCF probabilities associated with the component under test or maintenance (i.e., including preventive maintenance) remain nominal.

- **Event Tree Modifications**

Transient event tree for RCP bus undervoltage. A new event tree (Figure 2) was developed for a special type of transient caused by RCP bus undervoltage (named IE-RCP-UV) in order to take into account a consequential loss of offsite power, i.e., a LOOP in consequence of a reactor trip caused by RCP bus undervoltage). This event tree can be regarded as a special case of the general transients event tree included in the original SPAR model.[4] If a LOOP occurs subsequent to the reactor trip (e.g., during

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[4] The general transients initiating event in the original SPAR model for D.C. Cook includes plant transients resulting from RCP bus undervoltage as part of the events modeled. The frequency of the IE-RCP-UV initiating event was set to a value of 1×10^{-13} per year in the SPAR model modified for event assessment so that the event assessment can be properly performed without double

a switching transient in the switchyard), the IE-RCP-UV initiating event transfers to the loss of offsite power (i.e., LOOP) event tree; otherwise, it transfers to the general transient (i.e., TRANS) event tree.

- **Fault Tree Modifications**

Fault tree for consequential LOOP . A new fault tree for consequential LOOP given a reactor trip, called CONSQ-LOOP, was developed with a basic event, BE-CONSQ-LOOP (Figure 5). The mean value of the conditional probability of a consequential LOOP given a reactor trip, i.e., 3.4×10^{-3} as discussed above, is used as the probability for this basic event.

Specific modeling of AC power dependency. In the original SPAR model for D.C. Cook 1 and 2, the 4kV T11A and T11B safety buses of the emergency power system are collectively modeled. As a result, top event ACP-T11AB, "4160 VAC BUS T11A/B FAILS," is used to model the power dependency of many safety components on either T11A or T11B bus. To analyze the risk impact of the event including de-energization of the T11B bus,[5] the ACP-T11AB top event was broken into ACP-T11A ("4160 VAC BUS T11A FAILS") and ACP-T11B ("4160 VAC BUS T11B FAILS") top events, which were then used to enhance the power dependency modeling. A large number of fault trees that have been modified or developed to change the power dependency, or take into account the consequential LOOP are described in Appendix B.

- **Offsite Power Recovery Data Modifications**

The offsite power recovery failure probabilities included in the SPAR model are based on the frequency-weighted average of the recovery failure probabilities for all types of LOOP events, i.e., plant-centered (PC), switchyard-centered (SC), grid-related (GR), and weather-related (WR). The frequencies used for the weighting process are the initiating event frequencies for each type of LOOP. In the best estimate event assessment, the LOOP does not occur as an initiating event, but following the reactor trip. Of the nine consequential LOOP events mentioned earlier, two events were plant-centered, six events were switchyard-centered, and one event was grid-related with no consequential LOOP for weather-related reasons. Based on these specific data for consequential LOOPs, the parameters used for calculating the offsite power nonrecovery probabilities as well as the LOOP initiating event frequency were modified as follows:

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counting of any risk contributions. In the initiating event assessment, this value (i.e., 1×10^{-13}) is changed to 1 by the GEM code. The condition assessment is conducted by setting the frequency of the IE-RCP-UV initiating event to a value of 0 to avoid double counting of the risk contributions from transient scenarios caused by the RCP bus undervoltage.

[5] The D.C. Cook SPAR model represents Unit 1. It is assumed here that this model is also applicable to Unit 2. In the event assessment, the component IDs corresponding to Unit 1 were used; for example, T11B bus and T11B4 breaker of Unit 1 were used in lieu of T21B bus and T21B4 breaker of Unit 2.

Parameter	Original	Modified
ZV-LOOP-PC-LAMBDA	2.07E-03	2.22E-01
ZV-LOOP-SC-LAMBDA	1.04E-02	6.67E-01
ZV-LOOP-GR-LAMBDA	1.86E-02	1.11E-01
ZV-LOOP-WR-LAMBDA	4.83E-03	0.00E+00
LOOP Frequency	3.59E-02	1.00E+00

For instance, the modified value of 2.22×10^{-1} for ZV-LOOP-PC-LAMBDA was obtained by dividing 2 by 9 because there were two plant-centered consequential LOOPs out of the nine events. This value is used as a weighting factor for the time-dependent recovery curve for plant-centered LOOP. The modification of these parameters results in increased potential to recover from a consequential offsite power as compared to a LOOP initiating event, partly because: (a) the weather-related parameter (i.e., ZV-LOOP-WR-LAMBDA) is set to zero as a result of no occurrence of a consequential LOOP due to weather conditions according to the aforementioned industry database; and (b) the LOOP occurring due to weather conditions has the largest nonrecovery probabilities as compared to the LOOPs caused by other reasons (i.e., plant-centered, switchyard-centered, and grid-related).

- **Other Items of Interest**

  - The original SPAR model [5] gives a total internal-events core damage frequency (CDF) of 4.25×10^{-5} per year. On the other hand, the modified base model to perform the event assessment (i.e., with the enhanced modeling of the electric power distribution system and the correction of high pressure injection modeling, as discussed later) yields a total CDF of 4.37×10^{-5}.

  - The emergency power system at D.C. Cook 2 consists of two diesel generators, i.e., 2AB EDG and 2CD EDG. The functional degradation in T21B4 circuit breaker was caused during the modification work to add supplemental diesel generators (SDGs) at D.C. Cook. The SDGs are credited in neither the SPAR model [5], nor the licensee's risk assessment of the event [3]. Therefore, the SDGs are not given credit in this event assessment.

- **Sensitivity Analyses**

  Sensitivity analyses were performed to determine the effects of model uncertainties on results based on best estimate assumptions. The following table summarizes the results of the sensitivity analyses in terms of conditional core damage probabilities.

Sensitivity Case	Importance
Case A: Assume no potential loss of offsite power as a consequence of the reactor/generator trip in the midst of the unavailability of 2CD EDG and the degradation of T21B4 output breaker	1.6E-6
Case B: Assume a complete recovery of the operator from the automatic closure functional failure of theT21B4 breaker	8.7E-6
Case C: Take no credit for the manual closure of the T21B4 breaker	1.5E-4
Case D: No consideration of the diesel generator room cooling for long-term operation of 2AB EDG	8.7E-6

- In Case A, the potential loss of offsite power as a consequence of the reactor/generator trip is not considered. In other words, the industry experience of nine consequential LOOPs over 19 years is not accounted for. The result indicates that the event importance is reduced by a factor of 5.7 as compared to the event best estimate. This event importance, 1.6×10^{-6}, is identical to the CCDP for the situation where a reactor trip occurs due to a plant transient (e.g., caused by an RCP bus undervoltage condition as in this event) without known equipment unavailability, i.e., with all systems or components available for operation when needed. Note that the unavailability of 2CD EDG and the degradation of T21B4 output breaker do not have any impact on the CCDP, because the emergency power system, including the diesel generator and the output breaker, is not challenged during the plant transient as a result of the continuous availability of the preferred power source, i.e., offsite electrical power. The event would be a precursor (i.e., CCDP>1×10^{-6} and CCDP greater than that for IE-LOMFW) even if consequential LOOP is not considered.

- In Case B, it is assumed that even if T21B4 circuit breaker automatically fails to close upon demand, it does not matter because operators will be able to "manually" close it with a success probability of 1. The result of this sensitivity case shows that the optimistic assumption as to the manual recovery of the failed breaker has a very small impact on the event importance, because: (1) a considerably low value obtained from SPAR-H analysis (i.e., 0.002, see Appendix A) is used as the base recovery failure probability for the breaker; and as a result, (2) even if this value is decreased to a value of 0 (i.e., perfect manual recovery), the relatively minor change in the manual breaker non-recovery probability has insignificant impact on the result.

- Case C shows that the event importance considerably increases over the base estimate (i.e., by a factor of about 17) if no credit is taken for the operator recovery of the failed T21B4 breaker. This large increase in the risk impact is due to the fact that: a) the room cooling function for 2AB EDG has been included in the SPAR model for the event assessment; b) some equipment which support this room cooling function (e.g., room supply fan, room exhaust fan damper, panel cooling fan, etc.) receive motive power from a 600V motor control center fed by the 4kV T21B safety bus; and as a result, c) the long-term operability of 2AB EDG will be lost due to a loss of room cooling as a consequence of the T21B4 breaker failure.

- In Case D, the portion of the SPAR model representing the room cooling function for 2AB EDG was disabled to see the impact on the final result by setting the associated house event to boolean TRUE. The re-quantification of the event importance for this case indicates that the result is identical to that of Case B for the following reasons: a) the room cooling function for 2AB EDG is supported by AC power through T21B4 breaker as discussed above; b) 2AB EDG will fail to run if either the room cooling function or the T21B4 breaker is lost; and c) Cases B and D each represents a sensitivity case where the failure of 2AB EDG due to loss of the room cooling function is not accounted for.

- **SPAR Model Correction**

All the event assessments described in this report have been performed after correcting the following two oversights from the original SPAR model for D.C. Cook (Revision-3-Plus, Change 3.31, December 2005) [5].

a) **HPI Modeling.** Success of high pressure injection (HPI) at D.C. Cook requires delivery of water from the refueling water storage tank (RWST) to the reactor vessel by one-out-of-two HPI trains or one-out-of-two charging trains to 1 of 4 cold legs [5]. However, HPI is incorrectly modeled in the original SPAR model such that high pressure injection fails if either charging system or HPI system fails. Therefore, the “OR” gate for “HPI and charging system failures” (i.e., HPI-CHV-SYS-F) was changed to “AND” gate.

b) **AC Power Dependency.** The following components are modeled in the original SPAR model for D.C. Cook (Revision-3-Plus, Change 3.31) as depending on the 4kV T11A/B safety buses. However, a detailed review of the plant drawings performed by an NRC staffer with operational experience indicates that the following components depend on neither T11A nor T11B bus, but in fact on T11D bus:

1) PORV 153 block valve
2) RWST miniflow MOV 262
3) VCT isolation MOV A 451
4) CCW loop A heat exchanger HE-15W ESW outlet MOV 733
5) CVC charging system discharge MOV 255 to boron injection tank
6) CVC charging system discharge MOV 250 to cold legs
7) CVC charging system suction MOV 910
8) RHR to HPI parallel cross-connect MOV 361

Therefore, the electric power dependency was accordingly corrected (see Appendix B).

References

1. LER 316/05-001, Revision 00, “Reactor Trip from RCP Bus Undervoltage Signal Complicated by Diesel Generator Output Breaker Failure,” Event Date: November 8, 2005.

2. NRC Special Inspection Report, “D.C. Cook Nuclear Power Plant, Unit 2 - NRC Special Inspection Report 05000316/2005013,” December 22, 2005.

3. American Electric Power Service Corporation, “Risk Assessment for Breaker 2-T21B4 Failure on 11-08-05,” D.C. Cook Nuclear Plant Calculation/Report, Calculation No. PRA-SDP-001, Revision 0, December 9, 2005.

4. S.A. Eide, et al., “Reevaluation of Station Blackout Risk at Nuclear Power Plants, Analysis of Loss of Offsite Power Events: 1986-2004,” NUREG/CR-6890, Vol. 1, December 2005.

5. Idaho National Engineering and Environmental Laboratory, “Standardized Plant Analysis Risk Model for D.C. Cook 1 & 2,” Revision 3 Plus (Change 3.31), December 2005.

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

7. Indiana and Michigan Power Company, “D.C. Cook – Updated Final Safety Analysis Report,” Revision 18, December 7, 2002.

8. Nuclear Regulatory Commission, “Risk Assessment of Operating Events Handbook: SDP Phase 3, ASP, MD 8.3,” Revision 0, 2005.

Table 1. Conditional core damage probabilities of dominating sequences.

Event tree name	Sequence no.	Importance[1]	Contribution
RCP-BUS-UV	2-18-03	3.1E-6	35.2
RCP-BUS-UV	2-17	1.9E-6	21.6
RCP-BUS-UV	1-02-02-06	1.0E-6	11.4
Total (all sequences)[2]		**8.8E-6**	**100**

1. Values are point estimates.
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)	
RCP-BUS-UV	2-18-03	CONSQ-LOOP EPS /PORV-B /BP1 OPR-04H	/RPS /AFW-B /RSD /BP2 DGR-04H
RCP-BUS-UV	2-17	CONSQ-LOOP /EPS FAB-L	/RPS AFW-L
RCP-BUS-UV	1-02-02-06	/CONSQ-LOOP /AFW LOSC /RSD BP2	/RPS /PORV /RCPT /BP1 HPI

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

Top Event	**Definition**
AFW	AUXILIARY FEEDWATER
AFW-B	Developed Event
AFW-L	Developed Event
BP1	RCP SEAL STAGE 1 INTEGRITY
BP2	RCP SEAL STAGE 2 INTEGRITY
CONSQ-LOOP	CONSEQUENTIAL LOOP GIVEN A REACTOR TRIP
DGR-04H	DIESEL GENERATOR RECOVERY (IN 4 HR)
EPS	EMERGENCY POWER
FAB-L	FEED AND BLEED Developed Event
HPI	HIGH PRESSURE INJECTION
LOSC	RCP SEAL COOLING MAINTAINED
MFW	MAIN FEEDWATER
OP-LPI	OPERATOR DEPRESS. FOR LPI (PORVs, etc.)
OPR-04H	OFFSITE POWER RECOVERY (IN 4 HR)
PORV	PORVs ARE CLOSED
PORV-B	Developed Event
RCPT	REACTOR COOLANT PUMPS TRIPPED
RPS	REACTOR SHUTDOWN
RSD	RAPID SECONDARY DEPRESS

Table 3. Conditional cut sets for the dominant sequences.

Importance	Percent Contribution	Minimum Cut Sets (of basic events)
Event Tree: RCP-BUS-UV Sequence: 2-18-03		
2.2E-006	70.01	EPS-XHE-XL-NR04H OEP-XHE-XL-NR04H /RCS-MDP-LK-BP2 EPS-DGN-FR-1AB EPS-DGN-TM-1CD BE-CONSQ-LOOP
5.3E-007	16.92	EPS-XHE-XL-NR04H OEP-XHE-XL-NR04H /RCS-MDP-LK-BP2 EPS-DGN-FS-1AB EPS-DGN-TM-1CD BE-CONSQ-LOOP
2.1E-007	6.77	EPS-XHE-XL-NR04H OEP-XHE-XL-NR04H /RCS-MDP-LK-BP2 EPS-DGN-TM-1CD BE-CONSQ-LOOP EPS-XHE-XM-BKR
3.1E-006	**100**	**Total (all cutsets)[1]**

Importance	Percent Contribution	Minimum Cut Sets (of basic events)
Event Tree: RCP-BUS-UV Sequence: 2-17		
1.0E-006	52.44	AFW-XHE-XM-XTIEUNIT EPS-DGN-TM-1CD ACP-BK-T11A11 BE-CONSQ-LOOP
4.2E-007	21.50	AFW-TRAINB-OUTAGE EPS-DGN-TM-1CD ACP-BK-T11A11 BE-CONSQ-LOOP
4.2E-007	21.50	AFW-TRAINA-OUTAGE EPS-DGN-TM-1CD ACP-BK-T11A11 BE-CONSQ-LOOP
2.0E-006	**100**	**Total (all cutsets)[1]**

Importance	Percent Contribution	Minimum Cut Sets (of basic events)
Event Tree: RCP-BUS-UV Sequence: 1-02-02-06		
4.5E-007	44.70	ESW-STR-CF-STR RCS-MDP-LK-BP2
1.0E-007	10.43	CVC-XHE-XM-CVCSXTIE CCW-MOV-CF-410420 RCS-MDP-LK-BP2
1.0E-007	10.43	CVC-XHE-XM-CVCSXTIE RCS-MDP-LK-BP2 ESW-MOV-CF-733737
1.0E-006	**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	Modified
ACP-BK-T11A11			
AFW-TRAINA-OUTAGE	OPPOSITE UNIT-OUTAGE AFW TRAIN A MAINTENANCE	4.1E-002	No
AFW-TRAINB-OUTAGE	OPPOSITE UNIT-OUTAGE AFW TRAIN B MAINTENANCE	4.1E-002	No
AFW-XHE-XM-XTIEUNIT	OPERATOR FAILS TO XTIE OPPOSITE UNIT AFW SYST	1.0E-001	No
BE-CONSQ-LOOP	CONSEQUENTIAL LOOP FOLLOWING A REACTOR TRIP	3.4E-003	No
CCW-MOV-CF-410420	CCF OF CCW HEAT EXCHANGERS MOVS 410 & 420 TO	2.6E-005	No
CVC-XHE-XM-CVCSXTIE	OPERATOR FAILS TO ALIGN CVCS XTIE TO ALTERNATE SOURCE	2.0E-002	No
EPS-DGN-FR-1AB	DIESEL GENERATOR 1AB FAILS TO RUN	2.1E-002	No
EPS-DGN-FS-1AB	DIESEL GENERATOR 1AB FAILS TO START	5.0E-003	No
EPS-DGN-TM-1CD	DIESEL GENERATOR 1CD UNAVAILABLE DUE TO TEST	1.0E+000	Yes
EPS-XHE-XL-NR04H	OPERATOR FAILS TO RECOVER EMERGENCY DIESEL IN 4 HOURS	4.8E-001	No
EPS-XHE-XM-BKR	FAILURE TO MANUALLY CLOSE T11B4 BREAKER	2.0E-003	No
ESW-MOV-CF-733737	CCF OF ESW HEAT EXCHANGERS MOVS ESW 733 & 737	2.6E-005	No
OEP-XHE-XL-NR04H	OPERATOR FAILS TO RECOVER OFFSITE POWER IN 4	8.0E-002	Yes
RCS-MDP-LK-BP2	RCP SEAL STAGE 2 INTEGRITY (BINDING/POPPING O	2.0E-001	No

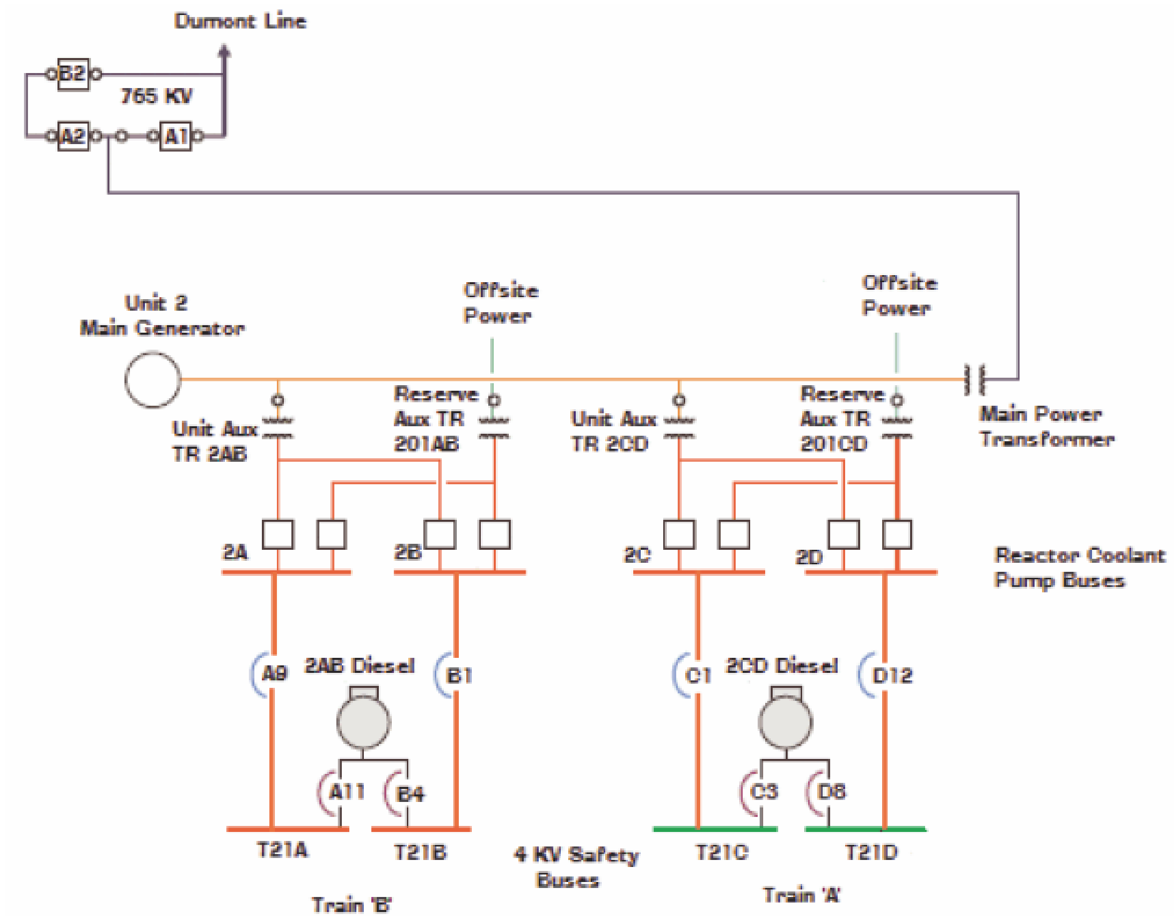

Figure 1. Electric Power Diagram at D.C. Cook 2. [2]

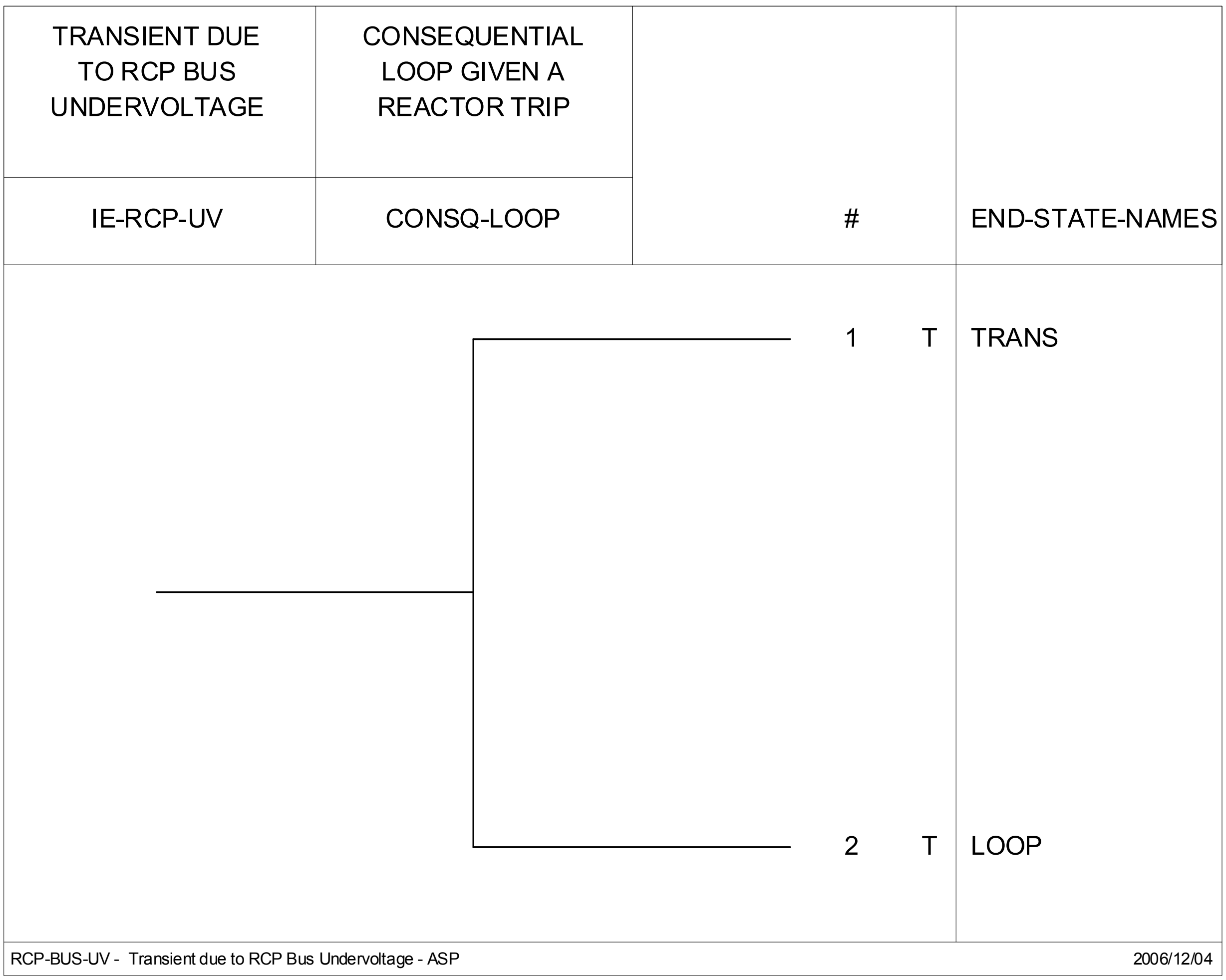

Figure 2. Event tree for transient due to RCP bus undervoltage.

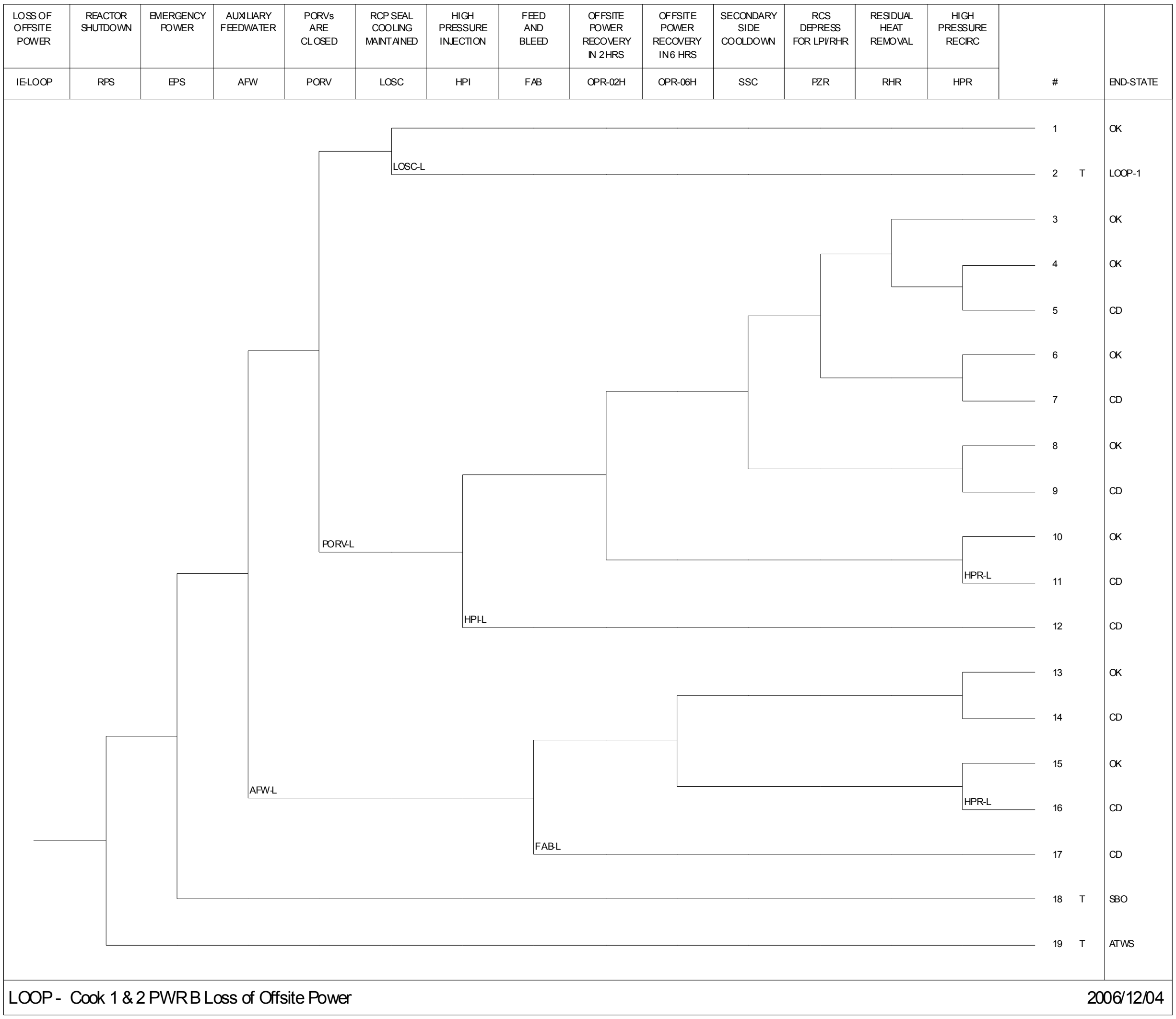

Figure 3. Event tree for loss of offsite power.

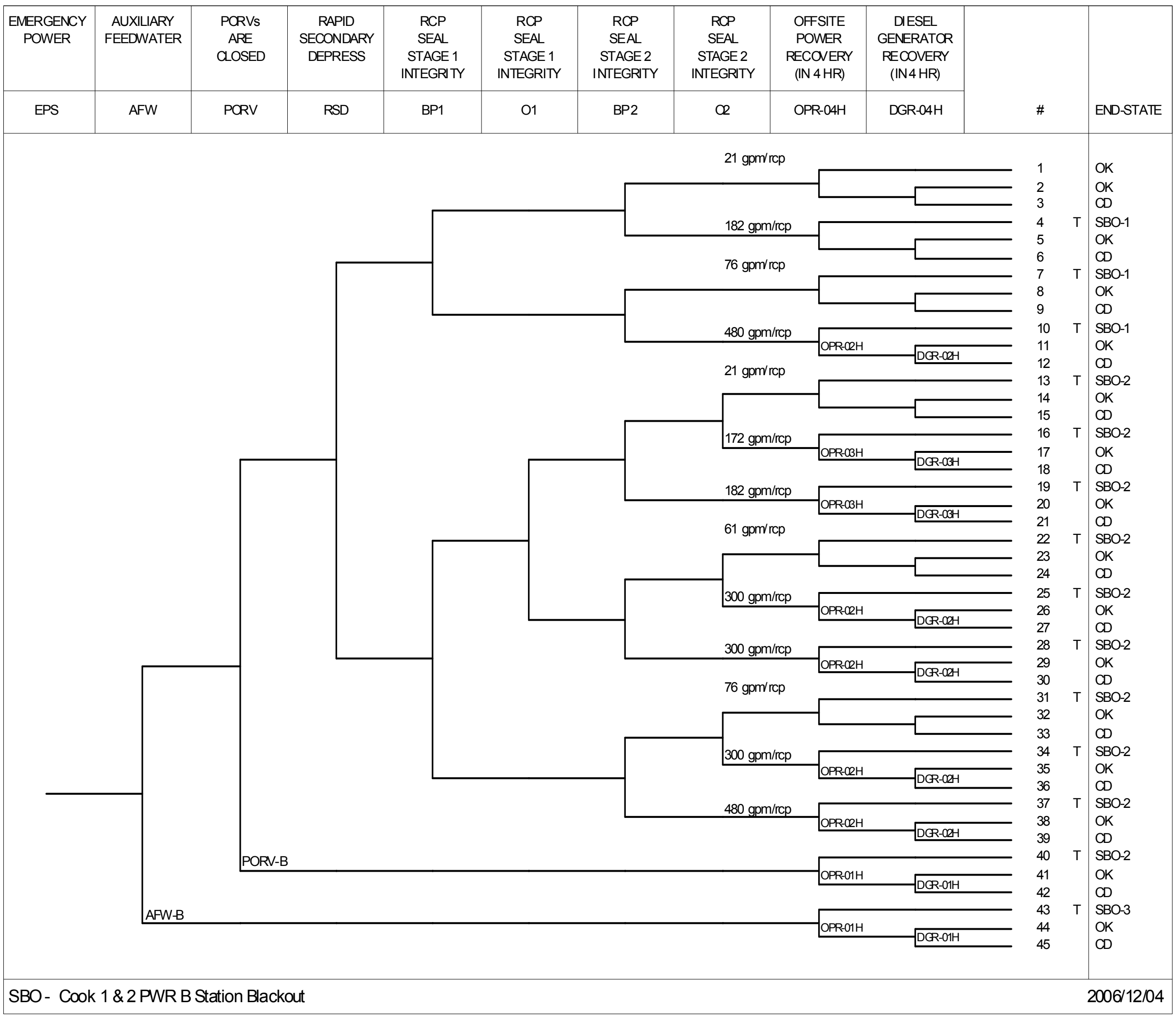

Figure 4. Event tree for station blackout.

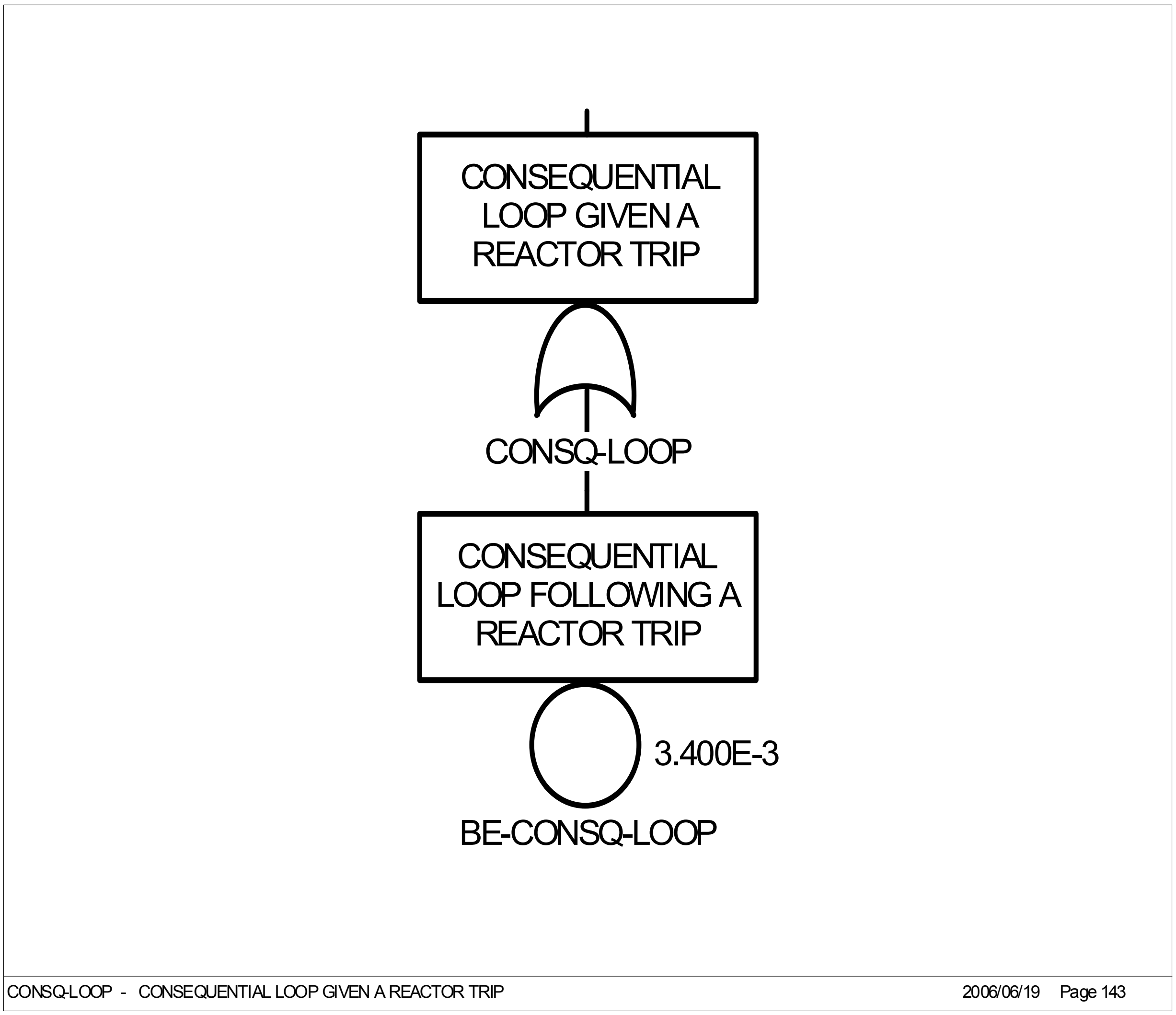

Figure 5. Fault tree for consequential LOOP given a reactor trip.

Appendix A

Human Performance Modeling

HRA Worksheets for At-Power
SPAR HUMAN ERROR WORKSHEET

Plant: D.C. COOK 2 Initiating Event: ________________ Basic Event: EPS-XHE-XM-BKR Event Coder: IK
Basic Event Context: Automatic closure function of T11B4 breaker fails during LOOP
Basic Event Description: Operator fails to manually close T11B4 breaker

Does this task contain a significant amount of diagnosis activity? YES ☐ (start with Part I - Diagnosis) NO ✓ (skip Part I - Diagnosis; start with Part II - Action) Why? The failure of the automatic closure function of T11B4 output breaker for 1AB EDG is annunciated by an alarm in the control room.

PART I. EVALUATE EACH PSF FOR DIAGNOSIS

A. Evaluate PSFs for the Diagnosis Portion of the Task, if any.

PSFs	**PSF Levels**	**Multiplier for Diagnosis**	**Please note specific reasons for PSF level selection in this column.**
Available Time	Inadequate time	P(failure) = 1.0 ☐	
	Barely adequate time (≈2/3 x nominal)	10 ☐	
	Nominal time	1 ☐	
	Extra time (between 1 and 2 x nominal and > than 30 min)	0.1 ☐	
	Expansive time (> 2 x nominal and > 30 min)	0.01 ☐	
	Insufficient information	1 ☐	
Stress/ Stressors	Extreme	5 ☐	
	High	2 ☐	
	Nominal	1 ☐	
	Insufficient information	1 ☐	
Complexity	Highly complex	5 ☐	
	Moderately complex	2 ☐	
	Nominal	1 ☐	
	Obvious diagnosis	0.1 ☐	
	Insufficient information	1 ☐	
Experience/ Training	Low	10 ☐	
	Nominal	1 ☐	
	High	0.5 ☐	
	Insufficient information	1 ☐	
Procedures	Not available	50 ☐	
	Incomplete	20 ☐	
	Available, but poor	5 ☐	
	Nominal	1 ☐	
	Diagnostic/symptom oriented	0.5 ☐	
	Insufficient information	1 ☐	
Ergonomics/ HMI	Missing/Misleading	50 ☐	
	Poor	10 ☐	
	Nominal	1 ☐	
	Good	0.5 ☐	
	Insufficient information	1 ☐	

PSFs	PSF Levels	Multiplier for Diagnosis	Please note specific reasons for PSF level selection in this column.
Fitness for Duty	Unfit	P(failure) = 1.0 ☐	
	Degraded Fitness	5 ☐	
	Nominal	1 ☐	
	Insufficient information	1 ☐	
Work Processes	Poor	2 ☐	
	Nominal	1 ☐	
	Good	0.8 ☐	
	Insufficient information	1 ☐	

Plant: D.C. COOK 2 Initiating Event: _________________ Basic Event: EPS-XHE-XM-BKR Event Coder: IK
Basic Event Context: Automatic closure function of T11B4 breaker fails during LOOP
Basic Event Description: Operator fails to manually close T11B4 breaker

B. Calculate the Diagnosis Failure Probability.

(1) If all PSF ratings are nominal, then the Diagnosis Failure Probability = 1.0E-2
(2) Otherwise, the Diagnosis Failure Probability is: 1.0E-2 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Diagnosis: 1.0E-2 x ___ x ___ x ___ x ___ x ___ x ___ x ___ x ___ = [ ]

C. Calculate the Adjustment Factor IF Negative Multiple (≥ 3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-2 for Diagnosis. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

$$HEP = \frac{NHEP \cdot PSF_{composite}}{NHEP \cdot (PSF_{composite} - 1) + 1}$$

Diagnosis HEP with Adjustment Factor = [ ]

D. Record Final Diagnosis HEP.

If no adjustment factor was applied, record the value from Part B as your final diagnosis HEP. If an adjustment factor was applied, record the value from Part C.

Final Diagnosis HEP = [ ]

Plant: D.C. COOK 2 Initiating Event: ________________ Basic Event: EPS-XHE-XM-BKR Event Coder: IK
Basic Event Context: Automatic closure function of T11B4 breaker fails during LOOP
Basic Event Description: Operator fails to manually close T11B4 breaker

PART II. EVALUATE EACH PSF FOR ACTION

A. Evaluate PSFs for the Action Portion of the Task, if any.

PSFs	PSF Levels	Multiplier for Diagnosis		Please note specific reasons for PSF level selection in this column.
Available Time	Inadequate time	P(failure) = 1.0	☐	Conservatively assumed that extra time is not available so that the resulting HEP does not become too low following the RASP recommendation (see page B.8-7 which states the lowest HEP of 5E-4).
	Time available is ≈ the time required	10	☐	
	Nominal time	1	✓	
	Time available $\geq$ 5x the time required	0.1	☐	
	Time available is $\geq$ 50x the time required	0.01	☐	
	Insufficient information	1	☐	
Stress/ Stressors	Extreme	5	☐	The LOOP events are assumed to generate high stress.
	High	2	✓	
	Nominal	1	☐	
	Insufficient information	1	☐	
Complexity	Highly complex	5	☐	
	Moderately complex	2	☐	
	Nominal	1	✓	
	Insufficient information	1	☐	
Experience/ Training	Low	3	☐	
	Nominal	1	✓	
	High	0.5	☐	
	Insufficient information	1	☐	
Procedures	Not available	50	☐	
	Incomplete	20	☐	
	Available, but poor	5	☐	
	Nominal	1	✓	
	Insufficient information	1	☐	
Ergonomics/ HMI	Missing/Misleading	50	☐	
	Poor	10	☐	
	Nominal	1	✓	
	Good	0.5	☐	
	Insufficient information	1	☐	
Fitness for Duty	Unfit	P(failure) = 1.0	☐	
	Degraded Fitness	5	☐	
	Nominal	1	✓	
	Insufficient information	1	☐	
Work Processes	Poor	5	☐	
	Nominal	1	✓	
	Good	0.5	☐	
	Insufficient information	1	☐	

Plant: D.C. COOK 2 Initiating Event: ________________ Basic Event: EPS-XHE-XM-BKR Event Coder: IK
Basic Event Context: Automatic closure function of T11B4 breaker fails during LOOP
Basic Event Description: Operator fails to manually close T11B4 breaker

B. Calculate the Action Failure Probability.

(1) If all PSF ratings are nominal, then the Action Failure Probability = 1.0E-3
(2) Otherwise, the Action Failure Probability is: 1.0E-3 x Time x Stress or Stressors x Complexity x Experience or Training x Procedures x Ergonomics or HMI x Fitness for Duty x Processes

Action: 1.0E-3 x 1.0 x 2.0 x 1.0 x 1.0 x 1.0 x 1.0 x 1.0 x 1.0 = **2.0E-3**

C. Calculate the Adjustment Factor IF Negative Multiple (≥ 3) PSFs are Present.

When 3 or more negative PSF influences are present, in lieu of the equation above, you must compute a composite PSF score used in conjunction with the adjustment factor. Negative PSFs are present anytime a multiplier greater than 1 is selected. The Nominal HEP (NHEP) is 1.0E-3 for Action. The composite PSF score is computed by multiplying all the assigned PSF values. Then the adjustment factor below is applied to compute the HEP:

Action HEP with Adjustment Factor = ________

$$HEP = \frac{NHEP \cdot PSF_{composite}}{NHEP \cdot (PSF_{composite} - 1) + 1}$$

D. Record Final Action HEP.

If no adjustment factor was applied, record the value from Part B as your final action HEP. If an adjustment factor was applied, record the value from Part C.

Final Action HEP = **2.0E-3**

Plant: D.C. COOK 2 **Initiating Event:** ________________ **Basic Event:** EPS-XHE-XM-BKR **Event Coder:** IK
Basic Event Context: Automatic closure function of T11B4 breaker fails during LOOP
Basic Event Description: Operator fails to manually close T11B4 breaker

PART III. CALCULATE TASK FAILURE PROBABILITY WITHOUT FORMAL DEPENDENCE ($P_{W/OD}$)

Calculate the Task Failure Probability Without Formal Dependence ($P_{w/od}$) by adding the Diagnosis Failure Probability from Part I and the Action Failure Probability from Part II. In instances where an action is required without a diagnosis and there is no dependency, then this step is omitted.

$P_{w/od}$ = Diagnosis HEP 0 + Action HEP 2.0E-3 = **2.0E-3**

Part IV. DEPENDENCY

For all tasks, except the first task in the sequence, use the table and formulae below to calculate the Task Failure Probability With Formal Dependence ($P_{w/d}$).

If there is a reason why failure on previous tasks should not be considered, such as it is impossible to take the current action unless the previous action has been properly performed, explain here:

Condition Number	Crew (same or different)	Time (close in time or not close in time)	Location (same or different)	Cues (additional or no additional)	Dependency	Number of Human Action Failures Rule ☐ - Not Applicable. Why? ______________
1	s	c	s	na	complete	When considering recovery in a series e.g., 2nd, 3rd, or 4th checker If this error is the **3rd error in the sequence**, then the dependency is at lease **moderate**. If this error is the **4th error in the sequence**, then the dependency is at least **high**.
2				a	complete	
3			d	na	high	
4				a	high	
5		nc	s	na	high	
6				a	moderate	
7			d	na	moderate	
8				a	low	
9	d	c	s	na	moderate	
10				a	moderate	
11			d	na	moderate	
12				a	moderate	
13		nc	s	na	low	
14				a	low	
15			d	na	low	
16				a	low	
17					zero	

Using $P_{w/od}$ = Probability of Task Failure Without Formal Dependence (calculated in Part III):

For Complete Dependence the probability failure is 1.
For High Dependence the probability of failure is $(1+ P_{w/od}/2)$
For Moderate Dependence the probability of failure is $(1+6 \times P_{w/od})/7$
For Low Dependence the probability of failure is $(1+19 \times P_{w/od})/20$
✓ For Zero Dependence the probability of failure is $P_{w/od}$

Calculate $P_{w/d}$ using the appropriate values:

$P_{w/d}$ = (1 + (________ * ________))/ ________ = 2.0E-3

Appendix B

AC Power Dependency Modifications

In the original SPAR model for D.C. Cook 1 and 2, the 4kV T11A and T11B safety buses of the emergency power system are modeled as a unit in the ACP-T11AB fault tree. The top event of this fault tree, i.e., ACP-T11AB representing “4160 VAC BUS T11A/B FAILS,” is included as a transfer event in many other fault trees to model the AC power dependency on the “T11A/B” buses. To enable assessment of the condition involving loss of only T11B and not T11A, the following approach was taken:

1. Identify the fault trees that include the transfer event of ACP-T11A/B from the original SPAR model

2. Identify the components that are modeled as depending on T11A/B in the fault trees identified in Step 1

3. For each component identified in Step 2, determine which bus it actually depends on (i.e., whether T11A, T11B, or other)

4. Modify the SPAR model to reflect the results of Step 3.

Each of these steps is discussed below.

1. <u>Fault Tree Identification</u>

According to the cross reference feature of the SAPHIRE code, the following fault trees include the transfer event of ACP-T11A/B:

HPR-HPI-F, FAB, HPR, LPI-TRAIN-A, PORV, LPR-TRAIN-A, DCP-TDAB, RHR, DCP-DCN, CVC-VCT-ISO, HPR-CS-F, CCW-A, AFW-MDP1W, HPI-MDP1A, RHR-MDP35W, PORV2, EPS, CCW-MDPSPAREB-STANDBY, CVC-MDP1W-STANDBY, HPI-CVCSYS, CCW-MDP10W-STANDBY, CCW-MDPSPAREA-STANDBY, ESW-MDP1W-STANDBY, CTS-PMP-TRNW, PORV1, PZR, PORV-L, PORV-B, MFW-RNDM, PORV-ISO

2. <u>Component Identification</u>

In Table B.1 below, the first column lists the components that are modeled as depending on T11A/B according to the investigation of the above fault trees.

3. <u>Specific AC Power Dependency Investigation</u>

Based on plant documentation (e.g., UFSAR for D.C. Cook and specific electric power distribution drawings, etc.), the actual dependencies are shown in the second column of Table B.1.

4. SPAR Model Modification

Finally, the AC power dependencies for the following fault trees were appropriately modified based on Table B.1:

- ACP-T11AB: 4160 VAC BUS T11A/B FAILS
- HPR-HPI-F: COOK 1 & 2 PWR B NO FLOW FROM THE HPI SYSTEM DURING HPR
- FAB: FEED AND BLEED
- HPR: HIGH PRESSURE RECIRC
- LPI-TRAIN-A: COOK 1 & 2 PWR B FAILURE OF LPI TRAIN A
- PORV: PORVs ARE CLOSED
- LPR-TRAIN-A: COOK 1 & 2 PWR B FAILURE OF LPR TRAIN A
- DCP-TDAB: COOK 1 & 2 PWR B 250 V DC PANEL TDAB UNAVAILABLE
- RHR: RESIDUAL HEAT REMOVAL
- DCP-DCN: COOK 1 & 2 PWR B 250 V DC PANEL 1-DCN UNAVAILABLE
- CVC-VCT-ISO: FAILURE TO ISOLATE VOLUME CONTROL TANK
- HPR-CS-F: COOK 1 & 2 PWR B CHARGING SYSTEM FLOWPATH FAILS DURING HPR
- CCW-A: COOK 1 & 2 PWR B CCW SYSTEM LOOP A FAILS
- AFW-MDP1W: COOK 1 & 2 PWR B AFW MOTOR DRIVEN PUMP 1W FAILURES
- HPI-MDP1A: COOK 1 & 2 PWR B FAILURES OF HPI MDP 1A
- RHR-MDP35W: COOK 1 & 2 PWR B FAILURES OF RHR MDP 35W
- PORV2: PORVs ARE CLOSED
- EPS: EMERGENCY POWER
- CVC-MDP1W-STANDBY: COOK 1 & 2 PWR B FAILURES OF CVC MDP1W
- HPI-CVCSYS: COOK 1 & 2 PWR B CHARGING SYSTEM FAILURE INTO COLD LEGS
- CCW-MDP10W-STANDBY: FAILURES OF CCW LOOP A MDP 10W (WEST)
- ESW-MDP1W-STANDBY: COOK 1 & 2 PWR B ESSENTIAL SERVICE WATER MDP 1W FAILS
- CTS-PMP-TRNW: FAULTS IN CTS PMP 9W TRAIN FAULTS IN CTS PMP 9W TRAIN
- PORV1: COOK 1 & 2 PWR B PORVs/SRVs OPEN DURING TRANSIENT (AFW FAILURE)
- PZR: RCS DEPRESSURIZED FOR LPI/RHR
- PORV-L: COOK 1 & 2 PWR B PORVs/SRVs OPEN DURING LOOP
- PORV-B: COOK 1 & 2 PWR B PORVs/SRVs OPEN DURING STATION BLACKOUT
- MFW-RNDM: FAILURE OF THE MAIN FEEDWATER SYSTEM DURING TRANS - RANDOM
- PORV-ISO: PORV ISOLATION

Table B.1. Table of Corrected / Modified AC Power Dependencies

Components Shown in Original SPAR Model as Depending on "T11A/B"	Actual AC Bus Dependency Implemented in Current ASP Analysis
RHR to HPI parallel cross-connect MOV 361	T11D
PORV 153 block valve	T11D
RWST miniflow MOV 262	T11D
RHR RWST isolation MOV 320 to MDP 35W	T11A
Division 1A DC power path (relevant to DC bus TDAB battery charger)	T11A
AFW TDP 250V DC N train battery charger A	T11A
VCT isolation MOV A 451	T11D
CCW loop A heat exchanger HE-15W ESW outlet MOV 733	T11D
CCW loop A heat exchanger HE-15W ESW outlet MOV 737	T11A
CVC charging system discharge MOV 255 to boron injection tank	T11D
CVC charging system discharge MOV 250 to cold legs	T11D
CVC charging system suction MOV 910	T11D
MFW MDP 1 west	T11A