Final Precursor Analysis

Accident Sequence Precursor Program -- Office of Nuclear Regulatory Research

Waterford Steam Electric Station, Unit 3	Failure of Emergency Diesel Generator Fuel Oil Line	
Event Date: 9/29/2003	**LER:** 382/03-002	**ΔCDP**[1] **=** 2×10^{-6}

Event Summary

September 29, 2003 at about 1020 hours with the plant in Mode 1 (approximately 90% power and coasting down for Refuel 12), Emergency Diesel Generator (EDG) 'A' was started to perform the monthly surveillance run in accordance with station operating procedures.

At approximately 1309 hours with EDG 'A' running loaded, the left/right bank cross connect fuel oil tubing failed rendering the engine inoperable.

Although, EDG 'A' testing surveillances were successfully completed prior to September 29, 2003, there is firm evidence that after the last successful surveillance on September 2, 2003 EDG 'A' may not have been able to complete a mission run time of 24 hours.

The following summarizes the event and its prior contributors:

- January 21 - Work request submitted describing a one dpm fuel oil leak at a compression fitting for EDG 'A'.
- May 15 - Maintenance including removal of entire piece of fuel oil tubing and compression fittings, shop fabrication of fuel oil tubing using new tubing and Swagelock fittings (replacing Imperial fittings), and installation of the new tubing, was performed.
- May 16 - System engineer raised concern over possible cleanliness issues for internals of the newly installed tubing, causing its removal, inspection, and reinstallation on day shift.
- May 16 - Post maintenance testing on EDG 'A' was satisfactorily performed with no fuel oil leakage.
- June 9 - EDG 'A' started and loaded to perform monthly surveillance run.

[1]Since this condition did not involve an actual initiating event, the parameter of interest is the measure of the incremental increase between the conditional probability for the period in which the condition existed and the nominal probability for the same period but with the condition nonexistent and plant equipment available. This incremental increase or importance" is determined by subtracting the CDP from the CCDP. The value shown is for internal events only.

- July 8 - EDG 'A' started and loaded to perform monthly surveillance run.
- August 4 - EDG 'A' started and loaded to perform monthly surveillance run.
- September 2 - EDG 'A' started and loaded to perform monthly surveillance run.
- September 29 1020 - EDG 'A' started and loaded to perform monthly surveillance run.
- September 29 1309 - EDG 'A' fuel oil tubing failed two hours and 48 minutes into its run, causing local diesel operator to trip the engine.
- Total run time on EDG 'A' since fuel oil tubing replacement was 27 hours and 49 minutes.

Analysis Results

- **Incremental Core Damage Probability (ΔCDP)**

  The point estimate of the ΔCDP from internal events (LOOP) for this event is 1.9E-6. The acceptance threshold for the Accident Sequence Precursor Program is a ΔCDP of 1.0 x 10^{-6}. This event is a precursor. This event was modeled as a conditional assessment of loss of offsite power (LOOP).

  The individual month contribution to the total internal events ΔCDP is given below:

Month ➜	**June**	**July**	**August**	**September**
ΔCDP	1.7E-7	1.3E-7	5.5E-7	1.1E-6
Fraction of total ΔCDP	9%	7%	28%	56%

The uncertainty distributions for individual months are given below:

ΔCDP-June		
5%	**Mean**	**95%**
8.7E-10	1.4E-7	6.4E-7

ΔCDP-July		
5%	**Mean**	**95%**
9.6E-10	1.3E-7	5.5E-7

ΔCDP-August		
5%	**Mean**	**95%**
3.8E-9	5.0E-7	2.1E-6

ΔCDP-September		
5%	**Mean**	**95%**
1.2E-8	1.0E-6	4.3E-6

Tables 5 and 6 show the base case and the current case results by month. Table 7 shows the total internal events ΔCDP and CDP results. It should be noted that the total conditional core damage probability (CCDP) in a given month is the summation of the base case CDP and the current case ΔCDP for that month.

- **Dominant Sequences**

The dominant internal events sequences for this analysis are: Loss of Offsite Power (LOOP), Station Blackout (SBO) Sequence 15-21 (76% of the total ΔCDP), LOOP Sequence 13 (8%) and LOOP Sequence 14 (8%).

The events and important component failures in LOOP/SBO Sequence 15-21 are:

- LOOP occurs,
- Reactor trip succeeds,
- Emergency power fails,
- Emergency feedwater succeeds,
- Safety relief valves (SRVs) reclose,
- Operator fails to isolate RCP seal controlled bleedoff,
- Operator fails to maintain RCS subcooling > 50°F,
- RCP seals integrity maintained,
- Failure to recover offsite power in four hours,
- Failure to recover emergency diesel generators in four hours.

Modeling Assumptions

The initiating event frequency was adjusted for the seasonal variation [5], which also resulted in adjustment of non-recovery probabilities. It should be noted that switchgear related and grid-related LOOPs tend to occur in the summer months (May-September). In Louisiana, extreme weather-related LOOPs are also weighted heavily toward the summer months, especially August and September, due to the hurricane season [6, 7]. Thus, LOOP frequency and non-recovery probabilities were calculated.

EDG recovery was also credited, due to the relatively simple nature of EDG-A repair[8].

A more detailed explanation of the model is contained in the Appendices.

There were no other significant events at the Waterford plant in the period of interest, except for a several day period in May when EDG-B was down for maintenance. The truck mounted TEDs (temporary emergency diesels) were on standby at the plant during that period. Since EDG-A had almost 24 hours of running time left before the cross-connect tubing failure, and the TEDs were available as a recovery action, this resulted in a negligible risk increase and was not analyzed.

Unique Design Features

Lack of feed and bleed capability. Waterford 3 does not have a reactor coolant system power operated relief valve (PORV). Thus, the unit does not have the feed and bleed capability as the charging pump head is insufficient to lift the safety valves.

Emergency power. The unit has two 4.4MW emergency diesel generators, and two main 4.16 kV emergency buses, 3A3-S and 3B3-S. In addition, a third bus, 3AB3-S is manually connected to either emergency bus (but not to both at the same time), to provide power to “third” (installed spare) components in the following systems: HPI, CCW, chilled water and associated valves. Any changes in alignment or loading of this bus are accomplished by a “dead bus transfer.”

The EDGs are cooled by a closed loop jacket water cooling system. The ultimate heat sink is the CCW system. While the EDGs are idle, the jacket water cooling system and the engine lube system are maintained in warm condition, by usage of electric resistance heating, in order to minimize EDG startup wear and tear.

In addition to the EDGs, there are two TED (temporary emergency diesel generators), which may be available at the plant. These are truck mounted and are shuttled between Waterford and another plant in case of need (e.g., hurricane precaution). They are not credited either in the IPE analysis or in the SPAR model.

Normal power. In case of normal unit shutdown or startup, switchover of offsite power from auxiliary transformers to startup transformers (or vice versa) is accomplished manually as a live overlapping synchronous transfer. In case of loss of the main generator, the transfer is automatic, via dead bus transfer.

A 1990 grid stability study by the utility concluded that loss of Waterford 3 generating capacity under maximum reactive power conditions will not cause grid instability.

In the UFSAR electrical systems description, a statement is made to the effect that in case of LOOP, the reactor can be run down in power and sufficient steam bypassed to the condenser to enable continued feeding of house loads from the main generator without resorting to emergency power. However, no such credit is given in the Chapter 15 UFSAR LOOP analysis.

Ultimate heat sink. CCW is the ultimate heat sink for most risk significant systems at Waterford. This system has three pumps, A, B, and AB (see discussion above on emergency power). CCW rejects heat to two dry cooling towers and, in case of need, to the ACW (auxiliary cooling water system). ACW has two loops and its ultimate heat sink are two wet cooling towers.

– **Modeling Assumptions Summary**

Key modeling assumptions. The key modeling assumptions are listed below and discussed in detail in the following sections. These assumptions are important contributors to the overall risk.

- **Degradation of the fuel cross-connect tubing is proportional to the EDG runtime.** Reference 2, page 24, states that “Entergy determined that improper alignment of the tubing in the compression fitting and potential over tightening of the compression fitting resulted in the uneven and excessive scoring. With these conditions established, the vibrational stresses subjected to the flawed tubing connection experienced during operation or the diesel generator resulted in fatigue failure of the tubing on September 29, 2003.”

- **LOOP Durations, Condition Durations and Mission Times considered in this analysis are based on Reference 2, page 27, and are shown in table below.**

Period	Assign to month	Condition duration (d)	EDG-A test runtime at start of period (hr:min)	Time remaining on EDG-A = minimum LOOP duration in current case, (hr)	Mission time in current case = 24 hr - previous column (hr)
May 17 - June 9	not analyzed	NA	4:54	22.92	NA
June 9 - July 8	June	29	4:46	18.15	5.85
July 8 - August 4	July	27	5:23	12.77	11.23
August 4 - September 2	August	29	4:36	8.17	15.83
September 2 - September 29	September	27	5:22	2.8	21.2

- **On-load test is equal to LOOP operation in terms of wear and tear on the diesel and its cross-connect piping.** The vibration during on-load test is expected to be similar to the vibration during an actual LOOP start and run demand.

- **EDG-B was not subject to the same failure mechanism in the cross-connect fuel tubing. This failure in EDG-A tubing was an independent failure and was not common-cause failure related.** Reference 2, page 23, states that "Entergy determined the Train B emergency diesel generator was not susceptible to the same failure mechanism since the fuel lines were the original lines having never been replaced by Entergy." Since the failure was associated with improper alignment of the tubing following a maintenance activity to repair a small fuel oil leak, no increased common cause coupling is assessed.

Other assumptions. Other assumptions that have a negligible impact on the results due to relatively low importance include the following:

- **EDG A degradation during the month of May including the EDG B maintenance event is not risk significant.** Reference 1 states that during May 25, 2003 though May 31, 2003, EDG B was not available due to planned maintenance. During this time, the Temporary Emergency Diesels (TEDs) were available as a backup to the out of service EDG ‘B; and would have been started in the event of an emergency with failure of offsite power and EDG-A in accordance with plant procedures. Therefore, due to the presence of TEDs and almost 24 hours remaining on EDG-A cross-connect fuel tubing before vibration induced failure, the risk associated with the degraded EDG A during May is estimated to be small and was not explicitly analyzed.

- Inter-test periods were picked to be the months of June, July, August and September, for simplicity, and for the purposes of calculating LOOP frequencies and non-recovery probabilities. This results in a negligible error as the tests did not occur on the first of the month but shortly thereafter. Correct number of hours between tests was used in the calculation of ΔCDP and CDP.

- The approximate nature of modeling of the AB emergency bus and the AB train of HPI, CCW and CWS in the Waterford SPAR model was taken into account via a sensitivity analysis. In the default case, some cutsets would need to be modified to account for this (e.g., cutsets #2 or #3 in sequence 15-21, see Tables 3A through 3D).

- Consequential LOOP was not modeled as the Unit did not shut down for a few days after the event.

- **Fault Tree Modifications**

  Auxiliary Component Cooling Water System loop A fails (EPS-ACW-A). This system (including both loop A and loop B) and its associated wet cooling towers is the additional heat sink to the Component Cooling Water (CCW) system (which uses dry cooling towers as its primary heat sink). Due to the fact that the emergency diesel generators (EDGs) jacket cooling water system is cooled by CCW, which also depends on emergency power, the SPAR model logic loop was cut in such a way that ACW loop A failures show up in minimal cutsets of condition assessment when EDG A is set in the failed condition (EDG A FTR basic event set to TRUE). In order to correct this, a house event was added to the fault tree EPS-ACW-A, which is set to FALSE in the base case and TRUE in the current case of condition assessment. This house event, EPS-ACW-A-SWITCH, fails loop A of ACW when set to TRUE. The modified detail of this fault tree is shown in Figure 3.

  Component Cooling Water System loop A fails (EPS-CCW-A). Similarly to the discussion above, event EPS-CCW-A-SWITCH was added to this fault tree, in order to correct errors in minimal cutsets originating from cutting of the logic loop due to EDG-CCW dependencies. The event is set to FALSE in the base case and TRUE in the current case of condition assessment. The TRUE setting fails EPS-CCW-A fault trees, such that no CCW loop A failures show up in minimal cutsets when EDG A is in the failed condition. The modified detail of this fault tree is shown in Figure 4.

It should be noted that Waterford 3 CCW system consists of three loops, A, B, and AB. Loop AB does not have an EDG-backed emergency bus. Its supporting emergency bus AB can be manually connected to either emergency bus A or B (backed by EDGs), and thus, the above change was not implemented on loop AB of CCW.

Essential Chilled Water pump A and AB failures (EPS-CWS-A). The Essential Chilled Water system (CWS) is used for switchgear room cooling. Like CCW, it contains three loops, A, B and AB, with similar electrical dependencies as above. It depends on CCW for cooling. The modeling of this dependency in SPAR is such that cooling of loop A of CWS can be accomplished via either loop A or AB of CCW. Thus, setting the above EPS-CCW-A-SWITCH to TRUE, will not directly fail loop A of CWS, and, as a result, erroneous CWS-A failure events will show up in minimal cutsets of the condition assessment. For this reason, fault tree EPS-CWS-A was changed, by adding the house event EPS-CWS-A-SWITCH, similarly to the changes above. This event fails only loop A of CWS when set to TRUE, loop AB can still operate per discussion above. The modified fault tree is shown in Figure 5.

- **Basic Event Probability Changes**

  Table 4 provides all the basic events whose probabilities were modified to reflect the best estimate of the conditions during the event. The Table contains the current case probability values of the modified events for the month of September (Appendices contain discussions of all the significant months in the period in question). In addition, the Table contains other significant events that show up in the minimal cutsets of the condition. The basis for changes to the basic event probabilities are provided below.

  Emergency diesel generator 'A' (EDG-A) fails to run (EPS-DGN-FR-DG3A). This event was set to 'TRUE' in the current case model to reflect the failure of the cross-connect fuel tubing.

  Emergency diesel generator 'B' (EDG-B) fails to run (EPS-DGN-FR-DG3B). The mission time of this event was adjusted in the current case to equal the fraction of the 24 hour base case mission time in which EDG-A was failed. Thus, the mission time equals 5.85 hours in June, 11.23 hours in July, 15.83 hours in August and 21.2 hours in September.

Common cause failure to run of emergency diesel generators (EPS-DGN-CCF-RUN). The SAPHIRE-calculated probability of this event was manuallydjusted to reflect the diminished run time in the current case, as explained above, and due to incorrect CCF probability generation in this case by SAPHIRE (see note under "SPAR Model Corrections." While EDG-A experienced an independent or random failure in the current case condition assessment, EDG-B still continued to be subject to the common cause failure mechanisms during its run time. EDG run time CCF contributes about 1% to the total ΔCDP.

Operators fail to recover emergency diesel generators in 1 hour, 4 hours (EPS-XHE-XL-NR01H, EPS-XHE-XL-NR04H). These events were changed from the base case (where generic diesel generator recovery was considered) to reflect the probability of repair of EDG-A cross-connect tubing, thus substantially decreasing the EDG non-recovery probability. EDG-B repair was not credited, as the generic non-recovery probability is high (0.5-0.8). EDG-A recovery considers the time available for repair, which has a substantially bigger margin in the case of the 4 hour recovery.

Operators fail to recover offsite power in 1 hour, 2 hours, 4 hours (OEP-XHE-XL-NR01H, OEP-XHE-XL-NR02H, OEP-XHE-XL-NR04H). These events were changed from the base case to reflect the probability of recovery of offsite power for those LOOP events which last longer than the run time remaining on the cross-connect fuel tubing of EDG-A for that particular month (i.e., for LOOPs longer than 18.15 hours in June, 12.77 hours in July, 8.17 hours in August and 2.8 hours in September). These events were also changed in the base case from the original LOOP model (see discussion below under SPAR model corrections).

It should be noted that the non-recovery probabilities in 1, 2 and 4 hours refer to the times after the onset of EDG-A failure in cross-connect tubing and are calculated based on the LOOPs with duration longer than the remaining run time on such. In September, for example, these non-recovery probabilities are calculated based on LOOPs with duration longer than 2.8 hours and for times of 3.8, 4.8 and 6.8 hours after LOOP initiation (and 1, 2 and 4 hours after cross-connect tubing fails).

Frequency of initiating event LOOP (IE-LOOP). Frequency of this initiating event was adjusted in the current case to reflect the frequency of those LOOPs with duration longer than the remaining run time on EDG-A cross-connect fuel tubing. Thus, this frequency contains LOOPs longer than 18.15 hours in June, 12.77 hours in July, 8.17 hours in August and 2.8 hours in September). Note that the base case LOOP frequency was also changed from the original SPAR model and specialized to the 4 months in question (see discussion below under SPAR model corrections). For convenience and ease of modeling, LOOP frequencies in both the current and the base case models are in units of **per month**.

New events EPS-ACW-A-SWITCH, EPS-CCW-A-SWITCH, EPS-CWS-A-SWITCH. As explained above in the fault tree section, these events were added to correct some minimal cutset errors due to logic loop modeling of CCW, ACW and CWS systems. In the current case they are set to TRUE.

Non-LOOP initiators. These events were set to FALSE in the current case for convenience, as the condition failures impact only LOOP modeling.

Generic template and basic compound events constituents for failure to start and failure to run early (ZT-XYZ-FS, ZT-XYZ-FS-NS, ZT-XYZ-FS-NR, ZT-XYZ-FR-E). These events were all set to FALSE or 0. ‘XYZ’ could be ‘CHL’, ‘DGN’, ‘FAN’, ‘MDP’, ‘TDP’, for, respectively, chillers, diesel generators, fans, motor driven pumps and turbine driven pumps. In other words, ‘ZT’ events easily set failure probabilities or rates for many components in these generic categories. FTS and FR-E probabilities were set to 0 in the current case, because, in our employment of the simplified LOOP SPAR models, the current case is the continuation of the base case LOOPs with duration longer than the specified time period (i.e., the run time left on EDG-A cross-connect tubing, 5.85 hours in June, 11.23 hours in July, 15.83 hours in August and 21.2 hours in September).

Generic template and basic compound events constituents for failure to run late, or run continuously (ZT-XYZ-FR-L, ZT-XYZ-FR-NR). ‘XYZ’ stands for the same generic components as listed above. These events had the mission time changed from 23 hours or 24 hours to the mission time of the current case calculation, i.e., 24 hours minus the run time remaining on the EDG-A cross-connect fuel tubing (i.e., the mission time was 5.85 hours in June, 11.23 hours in July, 15.83 hours in August and 21.2 hours in September), i.e., the same mission time as that used for EDG-B.

The CCF probabilities of the individual components for failure to start and failure to run are automatically adjusted by SAPHIRE to the correct values when the ZT events are modified in the above manner.

- **Other Items of Interest**

  Loop AB of HPI, CCW and CWS depends only on the ‘A’ emergency diesel generator in the present SPAR model, even though manual switching of bus ‘AB’ to EDG-B power is possible. This results in tolerable errors in ΔCDP modeling of current condition.

sensitivity analyses were performed to determine the effects of model uncertainties on results based on best estimate assumptions. The following table provides the results of the sensitivity analyses.

Modification	New ΔCDP	CDP
EDG-B replaces EDG-A in the model for the month of September	7.8E-7[1]	4.6E-6[1]
Hurricanes removed from LOOP frequency	5.0E-7	8.1E-6
2 extreme hurricanes in historical data passed over site	7.6E-6	2.1E-5
no EDG-A recovery in 1 hr	3.4E-6	1.3E-5

1. These are the values for September only (which contributes 56% to the total ΔCDP and 35% to the total CDP in the default case). This particular analysis requires additional changes to fault trees.

- EDG-A and EDG-B were made to switch places in the model to investigate the effect of simplifications in the SPAR treatment of emergency bus AB (this bus is always connected to EDG-A in the model, instead of being able to be switched to EDG-B). This analysis was only run for the month of September. The change in ΔCDP was relatively small, from 1.1E-6 to 7.8E-7, with the same base case CDP for September of 4.6E-6.
- Hurricanes removed from LOOP frequency calculation due to precautionary shutdown and existence of TEDs: the ΔCDP is 5.0E-7 (compared to the default case of 1.9E-6) and the base case CDP is 8.1E-6 compared to the default case of 1.3E-5. September contribution is about 53% in this case.
- If 2 hurricanes in the historical data base are allowed in the extreme weather LOOP frequency, the ΔCDP rises to 7.6E-6 and the CDP to 2.1E-5.
- If no EDG-A recovery is allowed in the case of the “1hr” requirement, the ΔCDP rises to 3.4E-6 and the sequences 15-27 and 15-30 become dominant, in addition to 15-21.

In conclusion, the significant effect is observed when extreme weather is taken out of the model, which will result in a significant decrease in the ΔCDP, when 2 hurricanes are counted in the extreme weather in the historic data base (a significant increase in ΔCDP) and when 1 hr EDG-A repair is disallowed (significant increase in ΔCDP).

- **SPAR Model Corrections**

Modeling of EDG dependence on CCW for jacket water cooling was added by INEEL.

The base case model was adjusted somewhat from the original Waterford model. In addition to the fault tree modifications specified above, the LOOP frequencies and associated 1, 2 and 4 hour non-recovery probabilities were modified based on seasonal and monthly variations[5],[6],[7] (see the Appendices for detailed developments of frequencies and non-recovery probabilities).

Two errors were found in connection with LOOP sequence 15-30. A global sequence recovery rule specifies that 1 hr run time should be used for the turbine-driven EFW pump. The event “EPS” is misspelled in the rule. Additionally, the substitute 1 hr run-time failure probability basic event EFW-TDP-FR-TD1HR has erroneous compound event logic, such that its probability equals that of the 24 hr event, EFW-TDP-FR-AB. The event ZT-TDP-FR-L should be deleted from the logic of the 1hr event, as it models run failures after 1 hr of TDP running time. The net result of these EFW TDP modeling errors is minor in the default case.

It should be noted that SAPHIRE gives erroneous results when ZT-XYZ-FR-E events have the mission time set to 0. Instead, the probability of the basic event has to be set to 0 or FALSE.

SAPHIRE calculation of CCF probability is in error (double counting of independent failures) if independent failures change the group failure criterion to one remaining component (as is the case with the diesel generators in this analysis). Thus, the CCF to run probability for the emergency diesel generators was manually set to the correct value to override the SAPHIRE generated CCF probability.

GEM LHS method of uncertainty analysis gives erroneous results by orders of magnitude in this analysis (see Appendix D), whereas the Monte Carlo method gives correct results (within the scaling factor error inherent in the 7.22 version of GEM).

References

1. Licensee Event Report 382/03-002, “Failure of Emergency Diesel Generator A Fuel Oil Line, Unit 3,” event date September 29, 2003.
2. Waterford Steam Electric Station, Unit 3 - NRC Integrated Inspection Report 2003-007, EA 03-230, dated February 2, 2004, Section 4OA3, Event Followup 71153.
3. Enforcement Action EA-03-230.
4. SPAR LOOP model description, Chapter 8 of SPAR Model Report, Rev. 3, Standardized Plant Analysis Risk Model, Level 1, Change 3.11, created December 2004.
5. Draft NUREG/CR-INEEL/EXT-04-02326, “Evaluation of Loss of Offsite Power Events at Nuclear Power Plants: 1986 - 2003" (Draft), October 2004.
6. “Hurricane Occurrences, 1900-2003” on http://www.nhc.noaa.gov/paststate.html.
7. NUMARC 87-00, “Guidelines and Technical Bases for NUMARC Initiatives Addressing Station Blackout at Light Water Reactors,” November 1987
8. NUREG-1032, “Evaluation of Station Blackout Accidents at Nuclear Power Plants,” June 1988.
9. Waterford 3, Rev. 3, Standardized Plant Analysis Risk Model, Level 1, Change 3.11, created December 2004.
10. Entergy Operations, Inc., “Final Safety Analysis Report, Revision 13, Waterford Steam Electric Station, Unit 3 (Waterford 3), Docket Number 50-382,” submitted May 20, 2004.
11. Entergy Operations, Inc., “Waterford 3 Probabilistic Risk Assessment: Individual Plant Examination for the Waterford 3 Nuclear Power Plant,” August, 1992.
12. Dr. Marc Levitan, “Comparative Analysis of Hurricane Vulnerability of New Orleans and Baton Rouge”, LSU Hurricane Center, April 2003.

Table 1. Incremental Core Damage Probabilities of Dominating Sequences.

Event Tree Name	Sequence Number	ΔCDP[1]	% Contribution
LOOP/SBO	15-21	1.4E-6	76
LOOP	13	1.6E-7	8
LOOP	14	1.6E-7	8
Total (all sequences)[2]		**1.9E-6**	**100**

1. Values are point estimates of internal events analysis. Due to the modeling method employed, the ΔCDP shown here, i.e., the incremental CDP due to the condition modeled, is the "CCDP" calculated by the GEM run. The actual total CCDP for the period in question is then ΔCDP (or "CCDP" in the GEM output) + base case CDP of 1.32E-5, i.e., CCDP = 1.51E-5.
2. Total ΔCDP includes all sequences (including those not shown in this table).

Table 2a. Event Tree Sequence Logic for Dominating Sequences.

Event Tree Name	Sequence Number	Logic ("/" Denotes Success; See Table 2b for Top Event Names)
LOOP/SBO	15-21	/RPS EPS /EFW-B /SRV-B CBO RSUB /RCPSI04 OPR-04H DGR-04H
LOOP	13	/RPS /EPS /EFW-L SRV-L HPI-L
LOOP	14	/RPS /EPS EFW-L

Table 2b. Definitions of Top Events Listed in Table 2a.

Top Event	Definition
CBO	Failure to isolate controlled bleedoff of RCP seals
DGR-04H	Failure to recover emergency diesel generators in four hours
EFW-B	Emergency feedwater unavailable in SBO
EFW-L	Emergency feedwater unavailable in LOOP
EPS	Emergency power system unavailable
HPI-L	High pressure injection unavailable in LOOP
OPR-04H	Offsite power not recovered in four hours
RCPSI04	RCP seals integrity not maintained
RPS	Reactor fails to trip
RSUB	Failure to maintain RCS subcooling > 50°F
SRV-B	SRVs fail to reseat after challenges in SBO
SRV-L	SRVs fail to reseat after challenges in LOOP

Table 3a. Conditional Cut Sets for the Dominant Sequences for the Month of June.

ΔCDP	Percent Contribution	Minimum Cut Sets (of basic events)
Event Tree: LOOP/SBO, Sequence 15-21		
4.6E-8	35.1	IE-LOOP|>T[1] EPS-DGN-TM-DG3B EPS-XHE-XL-NR04H OEP-XHE-XL-NR04H
4.1E-8	31.2	IE-LOOP|>T[1] CCW-MDP-TM-B EPS-XHE-XL-NR04H OEP-XHE-XL-NR04H
2.4E-8	18.2	IE-LOOP|>T[1] EPS-DGN-FR-DG3B EPS-XHE-XL-NR04H OEP-XHE-XL-NR04H
1.0E-8	7.8	IE-LOOP|>T[1] EPS-FAN-TM-3BSB EPS-XHE-XL-NR04H OEP-XHE-XL-NR04H
1.3E-7	**100**	**Total (all cutsets)[2]**

ΔCDP	Percent Contribution	Minimum Cut Sets (of basic events)
Event Tree: LOOP, Sequence 13		
3.9E-9	23.7	IE-LOOP|>T[1] PPR-SRV-OO-1 PPR-SRV-CO-L CWS-CHL-TM-B
3.9E-9	23.7	IE-LOOP|>T[1] PPR-SRV-OO-2 PPR-SRV-CO-L CWS-CHL-TM-B
1.6E-9	9.9	IE-LOOP|>T[1] PPR-SRV-OO-2 PPR-SRV-CO-L CWS-MDP-TM-B
1.6E-9	9.9	IE-LOOP|>T[1] PPR-SRV-OO-2 PPR-SRV-CO-L HPI-MDP-TM-B
1.6E-9	9.9	IE-LOOP|>T[1] PPR-SRV-OO-1 PPR-SRV-CO-L CWS-MDP-TM-B
1.6E-9	9.9	IE-LOOP|>T[1] PPR-SRV-OO-1 PPR-SRV-CO-L HPI-MDP-TM-B
1.6E-8	**100**	**Total (all cutsets)[2]**

<table>
<tr><th>ΔCDP</th><th>Percent Contribution</th><th>Minimum Cut Sets (of basic events)</th></tr>
<tr><td colspan="3">Event Tree: LOOP, Sequence 14</td></tr>
<tr><td>2.6E-9</td><td>17.2</td><td>IE-LOOP|>T[1] EFW-MOV-CC-FTSST
EFW-XHE-XL-FTSST EFW-MDP-TM-B</td></tr>
<tr><td>1.9E-9</td><td>12.7</td><td>IE-LOOP|>T[1] EFW-CKV-CF-SG</td></tr>
<tr><td>9.5E-10</td><td>6.7</td><td>IE-LOOP|>T[1] EFW-MDP-TM-B EFW-TDP-FR-AB</td></tr>
<tr><td>9.5E-10</td><td>6.7</td><td>IE-LOOP|>T[1] CCW-CTD-TM-A EHV-FAN-TM-25B
HVC-XHE-XM-ALTCL</td></tr>
<tr><td>8.1E-10</td><td>5.5</td><td>IE-LOOP|>T[1] CWS-CHL-TM-B CCW-XHE-XM-AB
HVC-XHE-XM-ALTCL</td></tr>
<tr><td>6.8E-10</td><td>4.6</td><td>IE-LOOP|>T[1] EFW-TNK-FC-CSP</td></tr>
<tr><td>6.5E-10</td><td>4.4</td><td>IE-LOOP|>T[1] CCW-MDP-TM-AB CWS-CHL-TM-B
HVC-XHE-XM-ALTCL</td></tr>
<tr><td>1.5E-8</td><td>100</td><td>Total (all cutsets)[2]</td></tr>
</table>

Table 3b. Conditional Cut Sets for the Dominant Sequences for the Month of July

<table>
<tr><th>ΔCDP</th><th>Percent Contribution</th><th>Minimum Cut Sets (of basic events)</th></tr>
<tr><td colspan="3">Event Tree: LOOP/SBO, Sequence 15-21</td></tr>
<tr><td>3.0E-8</td><td>29.8</td><td>IE-LOOP|>T[1] EPS-DGN-TM-DG3B EPS-XHE-XL-NR04H
OEP-XHE-XL-NR04H</td></tr>
<tr><td>3.0E-8</td><td>29.7</td><td>IE-LOOP|>T[1] EPS-DGN-FR-DG3B EPS-XHE-XL-NR04H
OEP-XHE-XL-NR04H</td></tr>
<tr><td>2.6E-8</td><td>26.5</td><td>IE-LOOP|>T[1] CCW-MDP-TM-B EPS-XHE-XL-NR04H
OEP-XHE-XL-NR04H</td></tr>
<tr><td>6.6E-9</td><td>6.6</td><td>IE-LOOP|>T[1] EPS-FAN-TM-3BSB EPS-XHE-XL-NR04H
OEP-XHE-XL-NR04H</td></tr>
<tr><td>2.4E-8</td><td>2.4</td><td>IE-LOOP|>T[1] EPS-XHE-XR-FN3BSB EPS-XHE-XL-NR04H
OEP-XHE-XL-NR04H</td></tr>
<tr><td>1.3E-8</td><td>1.3</td><td>IE-LOOP|>T[1] EPS-XHE-XL-NR04H OEP-XHE-XL-NR04H
EPS-DGN-CF-RUN</td></tr>
</table>

ΔCDP	Percent Contribution	Minimum Cut Sets (of basic events)
Event Tree: LOOP/SBO, Sequence 15-21		
1.0E-7	**100**	**Total (all cutsets)[2]**

ΔCDP	Percent Contribution	Minimum Cut Sets (of basic events)
Event Tree: LOOP, Sequence 13		
2.7E-9	23.6	IE-LOOP|>T[1] PPR-SRV-OO-2 PPR-SRV-CO-L CWS-CHL-TM-B
2.7E-9	23.6	IE-LOOP|>T[1] PPR-SRV-OO-1 PPR-SRV-CO-L CWS-CHL-TM-B
1.2E-9	9.8	IE-LOOP|>T[1] PPR-SRV-OO-2 PPR-SRV-CO-L HPI-MDP-TM-B
1.2E-9	9.8	IE-LOOP|>T[1] PPR-SRV-OO-2 PPR-SRV-CO-L CWS-MDP-TM-B
1.2E-9	9.8	IE-LOOP|>T[1] PPR-SRV-OO-1 PPR-SRV-CO-L CWS-MDP-TM-B
1.2E-9	9.8	IE-LOOP|>T[1] PPR-SRV-OO-1 PPR-SRV-CO-L HPI-MDP-TM-B
1.2E-8	**100**	**Total (all cutsets)[2]**

ΔCDP	Percent Contribution	Minimum Cut Sets (of basic events)
Event Tree: LOOP, Sequence 14		
1.8E-9	16.0	IE-LOOP|>T[1] EFW-MOV-CC-FTSST EFW-XHE-XL-FTSST EFW-MDP-TM-B
1.3E-9	12.0	IE-LOOP|>T[1] EFW-MDP-TM-B EFW-TDP-FR-AB
1.3E-9	11.8	IE-LOOP|>T[1] EFW-CKV-CF-SG
7.0E-10	6.2	IE-LOOP|>T[1] CCW-CTD-TM-A EHV-FAN-TM-25B HVC-XHE-XM-ALTCL
5.8E-10	5.1	IE-LOOP|>T[1] CWS-CHL-TM-B CCW-XHE-XM-AB HVC-XHE-XM-ALTCL
1.1E-8	**100**	**Total (all cutsets)[2]**

Table 3c. Conditional Cut Sets for the Dominant Sequences for the Month of August.

ΔCDP	Percent Contribution	Minimum Cut Sets (of basic events)
		Event Tree: LOOP/SBO, Sequence 15-21
1.6E-7	37.1	IE-LOOP|>T[1] EPS-DGN-FR-DG3B EPS-XHE-XL-NR04H OEP-XHE-XL-NR04H
1.1E-7	26.5	IE-LOOP|>T[1] EPS-DGN-TM-DG3B EPS-XHE-XL-NR04H OEP-XHE-XL-NR04H
9.9E-8	23.6	IE-LOOP|>T[1] CCW-MDP-TM-B EPS-XHE-XL-NR04H OEP-XHE-XL-NR04H
2.5E-8	5.9	IE-LOOP|>T[1] EPS-FAN-TM-3BSB EPS-XHE-XL-NR04H OEP-XHE-XL-NR04H
4.2E-7	**100**	**Total (all cutsets)[2]**

ΔCDP	Percent Contribution	Minimum Cut Sets (of basic events)
		Event Tree: LOOP, Sequence 13
9.5E-9	23.6	IE-LOOP|>T[1] PPR-SRV-OO-1 PPR-SRV-CO-L CWS-CHL-TM-B
9.5E-9	23.6	IE-LOOP|>T[1] PPR-SRV-OO-2 PPR-SRV-CO-L CWS-CHL-TM-B
4.1E-9	9.8	IE-LOOP|>T[1] PPR-SRV-OO-1 PPR-SRV-CO-L CWS-MDP-TM-B
4.1E-9	9.8	IE-LOOP|>T[1] PPR-SRV-OO-1 PPR-SRV-CO-L HPI-MDP-TM-B
4.1E-9	9.8	IE-LOOP|>T[1] PPR-SRV-OO-2 PPR-SRV-CO-L CWS-MDP-TM-B
4.1E-9	9.8	IE-LOOP|>T[1] PPR-SRV-OO-2 PPR-SRV-CO-L HPI-MDP-TM-B
4.2E-8	**100**	**Total (all cutsets)[2]**

ΔCDP	Percent Contribution	Minimum Cut Sets (of basic events)
Event Tree: LOOP, Sequence 14		
6.8E-9	16.0	IE-LOOP|>T[1] EFW-MDP-TM-B EFW-TDP-FR-AB
6.5E-9	15.1	IE-LOOP|>T[1] EFW-MOV-CC-FTSST EFW-XHE-XL-FTSST EFW-MDP-TM-B
4.8E-9	11.1	IE-LOOP|>T[1] EFW-CKV-CF-SG
2.5E-9	5.9	IE-LOOP|>T[1] CCW-CTD-TM-A EHV-FAN-TM-25B HVC-XHE-XM-ALTCL
2.1E-9	4.8	IE-LOOP|>T[1] CWS-CHL-TM-B CCW-XHE-XM-AB HVC-XHE-XM-ALTCL
1.7E-9	4.0	IE-LOOP|>T[1] EFW-TNK-FC-CSP
4.3E-8	**100**	**Total (all cutsets)[2]**

Table 3d. Conditional Cut Sets for the Dominant Sequences for the Month of September

ΔCDP	Percent Contribution	Minimum Cut Sets (of basic events)
Event Tree: LOOP/SBO, Sequence 15-21		
3.5E-7	43.9	IE-LOOP|>T[1] EPS-DGN-FR-DG3B EPS-XHE-XL-NR04H OEP-XHE-XL-NR04H
1.9E-7	23.5	IE-LOOP|>T[1] EPS-DGN-TM-DG3B EPS-XHE-XL-NR04H OEP-XHE-XL-NR04H
1.7E-7	20.9	IE-LOOP|>T[1] CCW-MDP-TM-B EPS-XHE-XL-NR04H OEP-XHE-XL-NR04H
4.2E-8	5.2	IE-LOOP|>T[1] EPS-FAN-TM-3BSB EPS-XHE-XL-NR04H OEP-XHE-XL-NR04H
8.0E-7	**100**	**Total (all cutsets)[2]**

ΔCDP	Percent Contribution	Minimum Cut Sets (of basic events)
Event Tree: LOOP, Sequence 13		
2.0E-8	23.5	IE-LOOP|>T[1] PPR-SRV-OO-1 PPR-SRV-CO-L CWS-CHL-TM-B
2.0E-8	23.5	IE-LOOP|>T[1] PPR-SRV-OO-2 PPR-SRV-CO-L CWS-CHL-TM-B
8.3E-9	9.8	IE-LOOP|>T[1] PPR-SRV-OO-1 PPR-SRV-CO-L CWS-MDP-TM-B
8.3E-9	9.8	IE-LOOP|>T[1] PPR-SRV-OO-1 PPR-SRV-CO-L HPI-MDP-TM-B
8.3E-9	9.8	IE-LOOP|>T[1] PPR-SRV-OO-2 PPR-SRV-CO-L HPI-MDP-TM-B
8.3E-9	9.8	IE-LOOP|>T[1] PPR-SRV-OO-2 PPR-SRV-CO-L CWS-MDP-TM-B
8.5E-8	**100**	**Total (all cutsets)[2]**

ΔCDP	Percent Contribution	Minimum Cut Sets (of basic events)
Event Tree: LOOP, Sequence 14		
1.9E-8	20.1	IE-LOOP|>T[1] EFW-MDP-TM-B EFW-TDP-FR-AB
1.3E-8	14.2	IE-LOOP|>T[1] EFW-MOV-CC-FTSST EFW-XHE-XL-FTSST EFW-MDP-TM-B
9.8E-9	10.5	IE-LOOP|>T[1] EFW-CKV-CF-SG
5.1E-9	5.5	IE-LOOP|>T[1] CCW-CTD-TM-A EHV-FAN-TM-25B HVC-XHE-XM-ALTCL
9.2E-8	**100**	**Total (all cutsets)[2]**

1. LOOP duration greater than the run time remaining on the EDG A for the particular month.
2. Total Importance includes all cutsets (including those not shown in this table).

Table 4. Definitions and Probabilities for Modified and Dominant Basic Events.[1]

Event Name	Description	Probability/ Frequency (Per Hour)	Modified
CCW-CTD-TM-A	LOOP A CCW DRY COOLING TOWER T&M	6.5E-002	No
CCW-MDP-TM-AB	CCW MDP AB UNAVAILABLE DUE TO T&M	7.1E-003	No
CCW-MDP-TM-B	CCW MDPB UNAVAILABLE DUE TO T&M	7.1E-003	No
CCW-XHE-XM-AB	OP FAILS TO ALIGN CCW MDP AB	1.0E-002	No
CWS-CHL-TM-AB	ESS. CHILLED WATER CHILLER AB T&M	1.1E-002	No
CWS-CHL-TM-B	ESS. CHILLED WATER CHILLER B UNAVAIL. T&M	1.1E-002	No
CWS-MDP-TM-AB	ESS. CHILLED WATER PUMP AB UNAVAIL. T&M	4.4E-003	No
CWS-MDP-TM-B	ESS. CHILLED WATER PUMP B UNAVAIL. T&M	4.4E-003	No
CWS-XHE-XR-B	OPERATOR FAILS TO RESTORE ESS. CHILLED WATER	1.0E-003	No
CWS-XHE-XR-CHLRB	OPERATOR FAILS TO RESTORE ESS. CHLRB POST T&M	1.0E-003	No
EFW-CKV-CC-207AB	FAILURE OF EFW TDP DISCHARGE CHECK VALVE 207A	1.0E-004	No
EFW-CKV-CF-PMPDIS	CCF OF EFW PUMP DISCHARGE CHECK VALVES	6.8E-007	No
EFW-CKV-CF-SG	CCF OF STEAM GENERATOR CHECK VALVES 2191A&B	2.8E-006	No
EFW-MDP-FR-B	EFW MDP B FAILS TO RUN	1.1E-004	Yes [2]
EFW-MDP-TM-B	EFW MDP B UNAVAILABLE DUE TO T&M	4.4E-003	No
EFW-MOV-CC-FTSST	TDP STEAM SUPPLY MOVS FAIL TO OPERATE	1.0E-003	No
EFW-PMP-CF-RUN	CCF OF EFW PUMPS TO RUN	6.6E-007	Yes [3]
EFW-TDP-FR-AB	EFW TDPA/B FAILS TO RUN	1.1E-003	Yes [2]
EFW-TDP-TM-AB	EFW TDP A/B UNAVAILABLE DUE TO TEST AND MAINT	4.4E-003	No
EFW-TNK-FC-CSP	EFW CONDENSATE STORAGE POOL FAILURES	1.0E-006	No
EFW-XHE-XA-DEP	OP FAILS TO RECOVER FROM LOSP BEFORE CSP DEPL	2.9E-002	No

Event Name	Description	Probability/ Frequency (Per Hour)	Modified
EFW-XHE-XL-FTSST	OP. FAILS TO RECOVER FAILURE OF STEAM SUPPLY	7.5E-001	No
EFW-XHE-XL-MDFRB	OPERATOR FAILS TO RECOVER EFW MDP B	7.5E-001	No
EFW-XHE-XM-MKUP	OP. FAILS TO ALIGN BACKUP WTR SOURCE LONG TERM	2.0E-005	No
EHV-FAN-TM-25B	TEST & MAINT. OF FAN AH-25(3BSB)	1.8E-003	No
EPS-ACW-A-SWITCH	FAILS ACW A WHEN TRUE	TRUE	Yes
EPS-CCW-A-SWITCH	FAILS LOOP A WHEN SET TO TRUE	TRUE	Yes
EPS-CWS-A-SWITCH	FAILS CWS-A WHEN TRUE	TRUE	Yes
EPS-DGN-CF-RUN	COMMON CAUSE FAILURE OF EDGS	4.7E-004	Yes [4]
EPS-DGN-FR-DG3A	DIESEL GENERATOR 3A-S FAILS TO RUN	TRUE	Yes
EPS-DGN-FR-DG3B	DIESEL GENERATOR 3B-S FAILS TO RUN	1.7E-002	Yes [2]
EPS-DGN-TM-DG3B	DG 3B-S UNAVAILABLE DUE TO T&M	8.0E-003	No
EPS-FAN-TM-3BSB	DG-3B ROOM FAN 3B-SB UNAVAILABLE DUE TO T&M	1.8E-003	No
EPS-XHE-XL-NR01H	OPERATOR FAILS TO RECOVER EDG IN 1HR	0.1	Yes [5]
EPS-XHE-XL-NR04H	OPERATOR FAILS TO RECOVER EDG IN 4HR	8.0E-003	Yes [5]
EPS-XHE-XR-FN3BSB	OP. FAILS TO RESTORE DG-3B FAN 3B-SB POST T&M	1.0E-003	No
HPI-MDP-TM-B	HPI MDP B UNAVAILABLE DUE TO TEST AND MAINTEN	4.4E-003	No
HPI-XHE-XR-B	OPERATOR FAILS TO RESTORE HPI MDP B AFTER T&M	1.0E-003	No
HVC-XHE-XM-ALTCL	OPERATOR FAILS TO ALIGN ALT COOLING METHOD	1.0E-002	No
IE-HPI-HLDIS-V	HPI HOT LEG DISCHARGE ISLOCA	FALSE	Yes [6]
IE-HPIA-DIS-V	HPI TRAIN A COLD LEG DISCHARGE ISLOCA	FALSE	Yes [6]
IE-HPIB-DIS-V	HPI TRAIN B COLD LEG DSCHG ISLOCA	FALSE	Yes [6]
IE-LDCAB	LOSS OF DC BUS 3AB-S	FALSE	Yes [6]

Event Name	Description	Probability/ Frequency (Per Hour)	Modified
IE-LLOCA	LARGE LOCA	FALSE	Yes [6]
IE-LOCCW	LOSS OF COMPONENT COOLING WATER	FALSE	Yes [6]
IE-LOOP	LOSS OF OFFSITE POWER	3.9E-003	Yes [7]
IE-LPI-DIS-V	LPI COLD LEG DISCHARGE ISLOCA	FALSE	Yes [6]
IE-MLOCA	MEDIUM LOCA	FALSE	Yes [6]
IE-SDC-SUC-V	SDC SUCTION ISLOCA	FALSE	Yes [6]
IE-SGTR	SG TUBE RUPTURE	FALSE	Yes [6]
IE-SLOCA	SMALL LOCA	FALSE	Yes [6]
IE-TRANS	TRANSIENT	FALSE	Yes [6]
PPR-SRV-CO-L	SRVS OPEN DURING LOOP	1.6E-001	No
PPR-SRV-OO-1	SRV 1 FAILS TO RESEAT	3.0E-003	No
PPR-SRV-OO-2	SRV 2 FAILS TO RESEAT	3.0E-003	No
OEP-XHE-XL-NR01H	OPERATOR FAILS TO RECOVER OFP	9.0E-001	Yes [8]
OEP-XHE-XL-NR02H	OPERATOR FAILS TO RECOVER OFP	8.3E-001	Yes [8]
OEP-XHE-XL-NR04H	OPERATOR FAILS TO RECOVER OFP	7.4E-001	Yes [8]
ZT-CHL-FR-E	CHILLER UNIT FAILS TO RUN	0.0E+000	Yes
ZT-CHL-FR-L	CHILLER UNIT FAILS TO RUN	8.4E-003	Yes
ZT-CHL-FR-NR	CHILLER UNIT FAILS TO RUN	1.1E-003	Yes
ZT-CHL-FS-NR	CHILLER UNIT FAILS TO START	0.0E+000	Yes
ZT-CHL-FS-NS	CHILLER UNIT FAILS TO START	0.0E+000	Yes
ZT-DGN-FR-E	DIESEL GENERATOR FAILS TO LOAD AND RUN	0.0E+000	Yes
ZT-DGN-FR-L	DIESEL GENERATOR FAILS TO RUN LATE	1.7E-002	Yes
ZT-DGN-FS	DIESEL GENERATOR FAILS TO START	0.0E+000	Yes
ZT-FAN-FR-E	HVAC FAN FAILS TO RUN EARLY	0.0E+000	Yes
ZT-FAN-FR-L	HVAC FAN FAILS TO RUN LATE	3.2E-003	Yes

Event Name	Description	Probability/ Frequency (Per Hour)	Modified
ZT-FAN-FR-NR	HVAC FAN FAILS TO RUN W/O RESTART	1.7E-004	Yes
ZT-FAN-FS	HVAC FAN FAILS TO START	0.0E+000	Yes
ZT-MDP-FR-E	MOTOR DRIVEN PUMP FAILS TO RUN EARLY	0.0E+000	Yes
ZT-MDP-FR-L	MOTOR DRIVEN PUMP FAILS TO R UN LATE	1.1E-004	Yes
ZT-MDP-FR-NR	MOTOR DRIVEN PUMP FAILS TO RUN	8.5E-005	Yes
ZT-MDP-FS-NR	MOTOR DRIVEN PUMP FAILS TO START	0.0E+000	Yes
ZT-MDP-FS-NS	MOTOR DRIVEN PUMP FAILS TO START	0.0E+000	Yes
ZT-TDP-FR-E	TURBINE DRIVEN PUMP FAILS TO RUN EARLY	0.0E+000	Yes
ZT-TDP-FR-L	TURBINE DRIVEN PUMP FAILS TO RUN LATE	1.1E-003	Yes
ZT-TDP-FS-NR	TURBINE DRIVEN PUMP FAILS TO START	0.0E+000	Yes
ZT-TDP-FS-NS	TURBINE DRIVEN PUMP FAILS TO START	0.0E+000	Yes

1 Current case values in this Table are for the month of September. Other months would have somewhat different values for certain basic events based on mission time, LOOP frequency and offsite power non-recovery probabilities. Note that the IE frequencies are in units of /month. See Appendices for a full discussion of the model.

2 These basic event probabilities were not changed directly, but indirectly via the "ZT" events in the bottom of the Table. The ZT events are used in the SPAR model as either templates or constituents of compound events, thus facilitating quick changes based on mission time and other considerations. ZT events associated with failure to start or failure to run early were set to 0 in the model. ZT events associated with failure to run late were changed to reflect the mission time in the particular month of consideration (in September the mission time was set to 21.2 hours).

3 Not changed directly, but as a result of mission time changes for run failures.

4 Set to reflect the mission time for run time failures associated with this CCF event. While the EDG-A failure considered in this analysis was independent of EDG B, the latter diesel generator continued to run and be subject to failure modes stemming from common cause mechanisms, which add a small fraction to the independent run failure probability of EDG-B. EDG-B CCF failures contribute about 1% of the ΔCDP.

5 The EDG recovery probabilities in the SPAR model were changed to reflect considerations of the particular failure event at EDG-A. These are developed in Appendix B. (The 1 hr repair failure probability is taken from the licensee's calculation). No credit is given for repair of EDG-B.

6 These initiating event frequencies were set to FALSE for convenience, as only LOOP calculation will be affected by the condition considered.

7 This is the frequency of LOOP of duration > remaining run time on EDG-A in the particular month. For September, the frequency is 3.9E-3/mo of a LOOP with duration>2.8 hrs.

8 The offsite power non-recovery probabilities were changed from the base case to reflect such for a LOOP of certain duration as per above. It should be noted that the non-recovery times of 1, 2 and 4 hours denote that time period after EDG-A cross-connect

tubing fails. In the month of September, those times are 3.8hrs, 4.8hrs and 6.8hrs (as the EDG-A run time remaining is 2.8 hrs) and the non-recovery probabilities are calculated for those times based on the LOOPs with duration over 2.8 hrs.

Table 5a. Base Case CDF (/mo)

	June	July	August	September
All CDF	2.9E-6	2.5E-6	3.9E-6	5.1E-6
All LOOP sequences	2.1E-6	1.8E-6	3.2E-6	4.4E-6
LOOP, seq. 13	5.0E-9	4.8E-9	5.8E-9	6.7E-9
LOOP, seq. 14	6.7E-8	6.4E-8	7.7E-8	8.9E-8
LOOP, seq. 15-21	1.9E-6	1.6E-6	2.9E-6	4.1E-6
LOOP, seq. 15-30	1.0E-7	9.4E-8	1.3E-7	1.6E-7

Table 5b. Base Case CDP

	June	July	August	September
All CDP	2.7E-6	2.2E-6	3.7E-6	4.6E-6
All LOOP sequences	2.0E-6	1.6E-6	3.0E-6	3.9E-6
LOOP, seq. 13	4.7E-9	4.2E-9	5.4E-9	5.9E-9
LOOP, seq. 14	6.4E-8	5.6E-8	7.3E-8	7.8E-8
LOOP, seq. 15-21	1.8E-6	1.4E-6	2.8E-6	3.7E-6
LOOP, seq. 15-30	9.5E-8	8.3E-8	1.2E-7	1.4E-7

Table 6. Current Case ΔCDP

	June	July	August	September
All ΔCDP	1.7E-7	1.3E-7	5.5E-7	1.1E-6
All LOOP sequences	1.7E-7	1.3E-7	5.5E-7	1.1E-6
LOOP, seq. 13	1.6E-8	1.2E-8	4.2E-8	8.5E-8
LOOP, seq. 14	1.5E-8	1.1E-8	4.3E-8	9.2E-8
LOOP, seq. 15-21	1.3E-7	1.0E-7	4.2E-7	8.0E-7

Table 7. ΔCDP and CDP Results June-September

	ΔCDP	**CDP**
All	1.9E-6	1.3E-5
LOOP	1.9E-6 (100%)	1.1E-5 (100%)
LOOP, 13	1.6E-7 (8%)	2.0E-8 (0%)
LOOP, 14	1.6E-7 (8%)	2.7E-7 (2%)
LOOP, 15-21	1.4E-6 (76%)	9.7E-6 (88%)
LOOP, 15-30	9.0E-8 (5%)	3.6E-7 (3%)

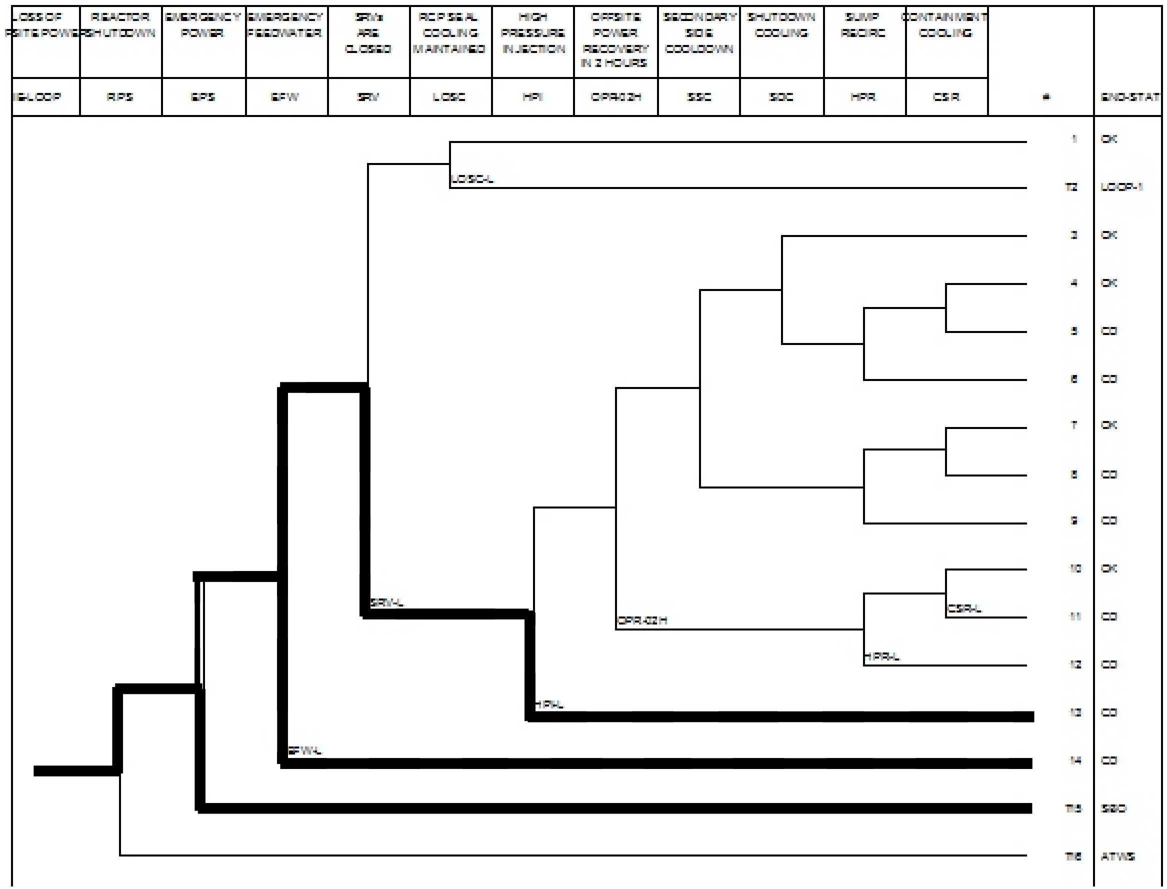

Figure 1: LOOP Event Tree with Dominant Sequences Highlighted (Most Dominant - Full, Less Dominant - Dashed)

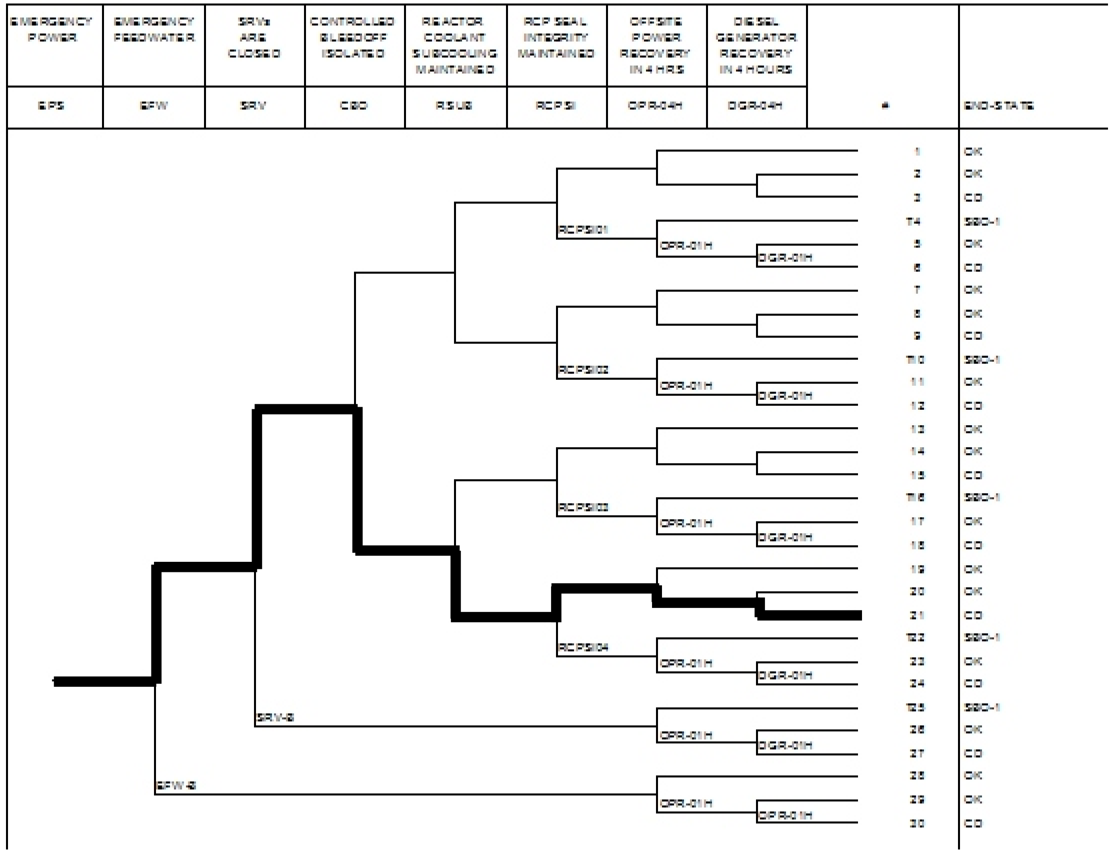

Figure 2. SBO Event Tree with Dominant Sequence Highlighted

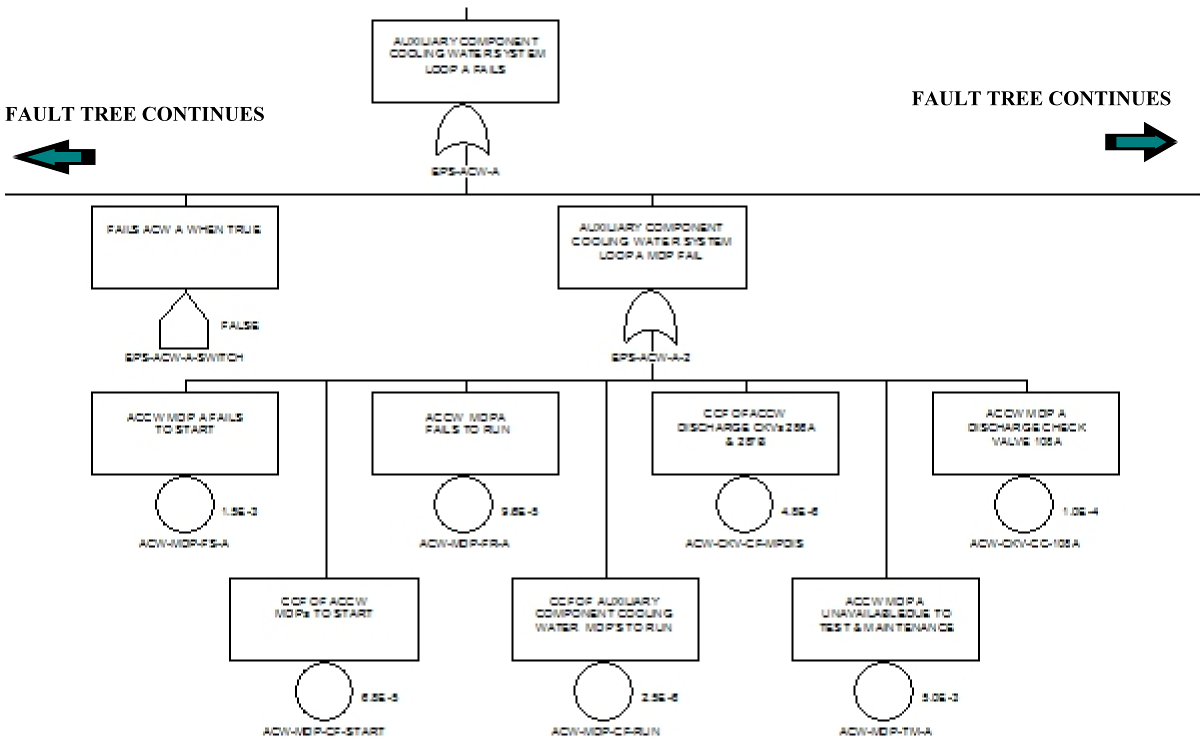

Figure 3. Modified Detail of Fault Tree EPS-ACW-A Showing the Added House Event

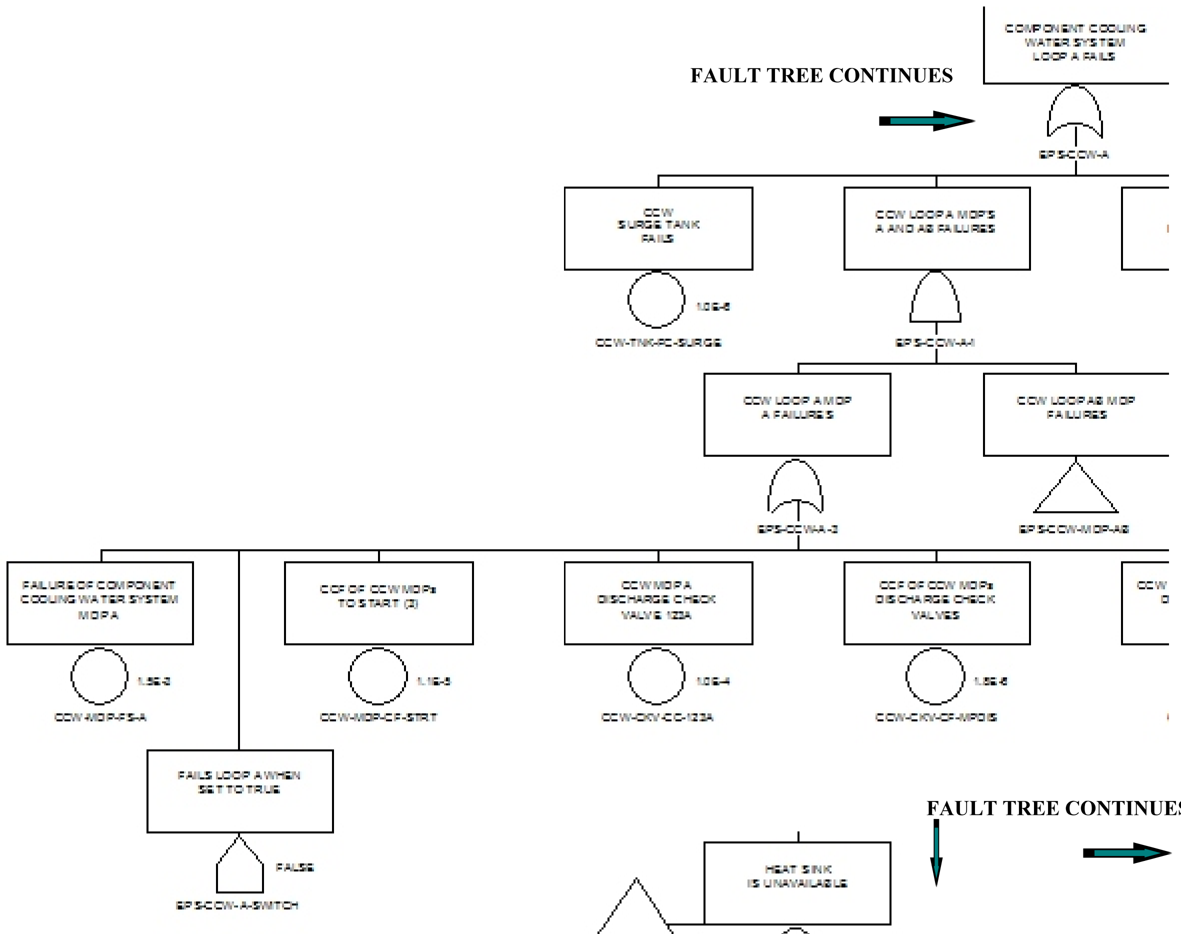

Figure 4. Modified Detail of Fault Tree EPS-CCW-A Showing the Added House Event

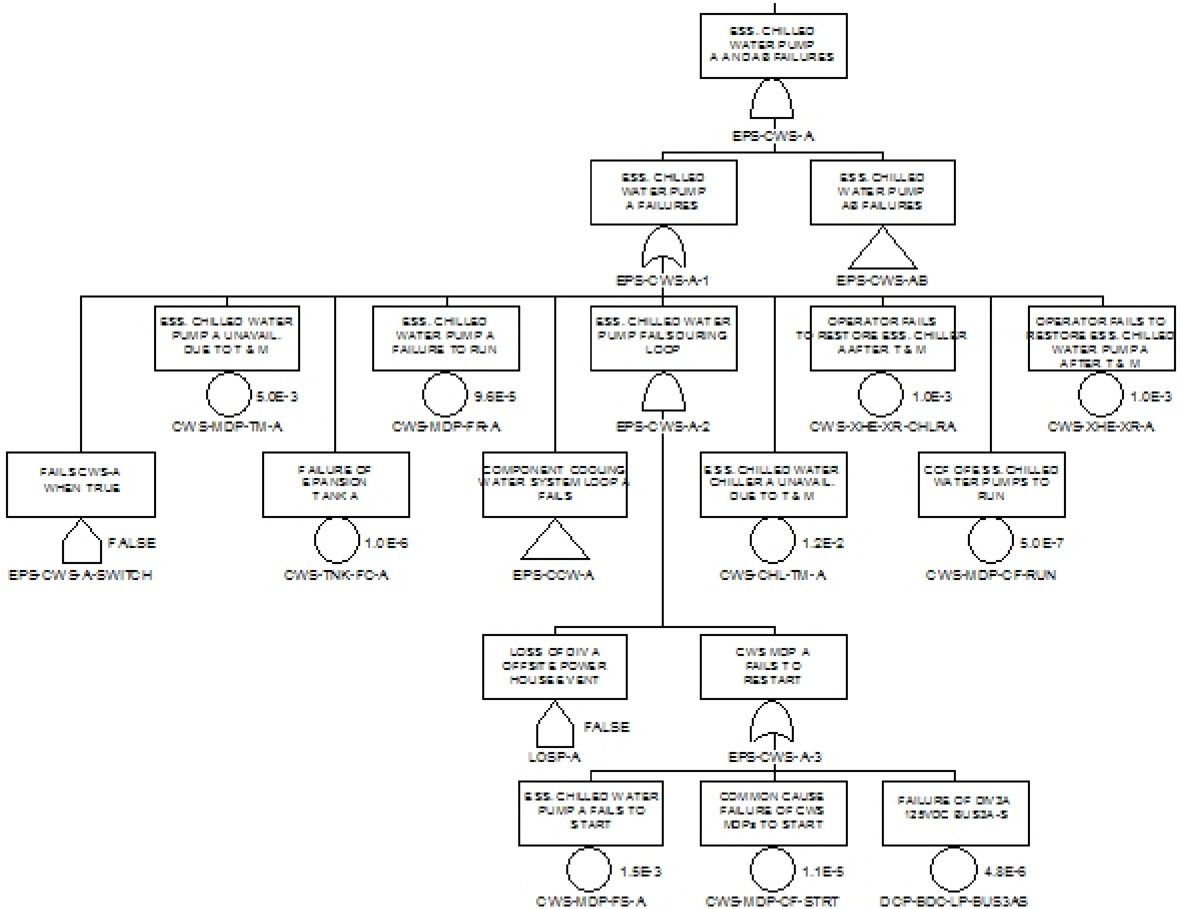

Figure 5. Modified Fault Tree EPS-CWS-A Showing the Added House Event EPS-CWS-A-SWITCH

Appendix A

LOOP Frequency and Non-Recovery Probability Development

APPENDIX A. LOOP Frequency and Non-Recovery Probability Development

1. Approach

This appendix develops site specific LOOP frequencies and non-recovery probabilities. The objective is to determine the appropriate LOOP frequency and non-recovery probabilities for each month that EDG A cross-connected fuel tubing was degraded. This includes the months of June, July, August and September. Since there are seasonal variations associated with the loss of offsite power, this appendix develops site specific LOOP data for each month.

Previous LOOP analysis have divided LOOP events into categories. The primary reference used in this appendix (Reference 5) uses five categories:

Plant Centered
Switchyard Centered
Grid Related
Severe Weather Related
Extreme Weather Related

Each of these categories is evaluated for site specific and seasonal variations.

2. Development of LOOP Frequencies

2.1 Plant Centered

Reference 5 defines a plant-centered event as a LOOP event in which the design and operational characteristics of the nuclear power plant unit itself play the major role in the cause and duration of the loss of offsite power. The value used for this frequency is 2.38E-03 as shown in Table 3-1 of Reference 5. This value is not adjusted for seasonal variation consistent with the data shown in Table 6-2 of Reference 5.

2.2 Switchyard Centered

Reference 5 defines switchyard-centered loss of offsite power event as that which the equipment or human-induced failures of equipment in the switchyard play the major role in the loss of offsite power,

Table 6-2 shows a seasonal variation for this category with 5 events occurring in the summer and zero events occurring in the non-summer period between 1997 to 2003. It also shows that there are 271 reactor critical hours applicable to the summer period.

Using a Bayes updated distribution with a Jeffreys nonimformative prior the frequency of switchyard-centered LOOP = 5.5 event/271 rcys = 2.03E-2 /rcry.

2.3 Grid Related

Reference 5 defines grid-related loss of offsite power events as that which the initial failure occurs in the interconnected transmission grid that is outside the direct control of plant personnel. Table 6-2 of Reference 5 shows a seasonal variation for this category with 10 events occurring in the summer and zero events occurring in the non-summer period between 1997 to 2003. It also shows that there are 271 reactor critical hours applicable to the summer period.

Using a Bayes updated distribution with a Jeffreys nonimformative prior the frequency of switchyard-centered LOOP = 10.5 event/271 rcys = 3.87E-2 /rcry.

2.4 Severe Weather Related (SW)

Reference 5 defines severe weather events as weather with forceful and non-localized effects. Examples of severe weather include thunderstorms, snow, and ice storms. LOOP events involving hurricanes, strong winds greater than 125 miles per hour, and F2+ tornadoes are included in the extreme weather category. Note that although the NUMARC document included tornadoes in Extreme Severe Weather (a category similar to Extreme Weather), the current NUREG does not. F2 tornadoes have winds between 113 and 157 which would meet the extreme weather condition.

In this analysis, severe weather is composed of 3 components: high winds (>75mph) resulting from thunderstorms and similar events; high winds (>75mph) resulting from weak or weakening hurricanes which do not meet the 125mph criterion; and F1 tornadoes.

A review of operating experience from 1948 to 2003 found one hurricane with maximum “gusts” at 108 mph (Betsy on 9/10/1965) in the NOAA historical database for New Orleans International Airport (about 21 miles form Waterford). There were other hurricanes which may have influenced the site. Figure A.1 shows tracks of hurricanes in the 1950-2003 period. Previous periods in NOAA data bases were not used to maximize the accuracy of data. It can be seen that, based on track data and hurricane strengths there are 6 potential hurricanes which may have affected the site: Elena ‘85, Bob ‘79, Betsy ‘65, Camille ‘69, Florence ‘88 and Flossy ‘56. However, on closer inspection, none of them save Betsy affected the site.

Of the 6, Bob may have passed very close to or over the site (the site is adjacent to intersection of Bob and Interstate 110, on the Mississippi river in the figure. Note that the figure does not show Lake Pontchartrain.). However, it was a weak hurricane, with maximum winds of only around 75 mph, according to NOAA information. Due to its fast forward motion (reflected in its relative deep penetration inland) and the fact that the site was on the left side of the hurricane, the wind speeds at the site may have been substantially reduced (maximum wind speeds include both the rotational and the forward component).

Similarly, Camille and Elena were fast moving hurricanes that had the site on the left side. Furthermore, they were both approximately 100+ miles away (from the center to the site) at the nearest point, and the winds diminish approximately 10% for each 30 miles of intervening ground [Reference 12]. Reports on Camille (Category 5), published on NOAA sites, state that only the two Louisiana parishes northeast of New Orleans suffered heavy damage. Florence and Flossy were weak Category 1 hurricanes which were too far away.

Thus, only Betsy is left with sufficient wind speeds at the site. This is corroborated by Section 2.3 of the FSAR, which lists several instances of hurricanes affecting Louisiana since 1963, but only Betsy having sufficient wind speeds.

Using a Bayes updated distribution with a Jeffreys nonimformative prior: Frequency (SW hurricanes)= 1.5 events/53 yrs = 2.8E-2 per yr. Using the factor of 1.2E-2 (Reference 9, page A-21) for conditional LOOP probability from high winds results in a LOOP frequency of 3.4E-4/yr. This frequency is apportioned to the June-September period the same way as the extreme hurricane frequency.

The data for thunderstorm winds>75 mph is based on the actual data for the St. Charles parish where the site is located (see http://www4.ncdc.noaa.gov-cgi/win/wwcgi.dl?wwEvent~Storms). The data were recorded very close to the site. There were five events in the 55 year period 1950-2004. The five events were recorded at 29°59'N and 90°30'W, 29°59'N and 90°17'W, 29°59'N and 90°15'W, 30°00'N and 90°15'W, 30°00'N and 90°15'W. The site is located at 29°59'42"N and 90°28'16"W. While the thunderstorm frequency shows peaking in the months of interest (FSAR and NOAA sites), the actual events had a distribution such that only one occurred in the June-September period. There is discrepancy among various sources concerning thunderstorms, tornadoes and hurricanes, thus we will use the actual site data when possible, and in this case will not specialize the frequency to months of interest, i.e., uniform monthly distribution over 12 months will be assumed. (The other sources such as NOAA for example, may average data over a wider area, whereas local conditions may be different). This uniform monthly distribution assumption does not significantly affect the results.

Thus, the high wind frequency is 5.5 events/55 years = 0.1/yr. The resulting LOOP frequency is then 0.1/yr * 1.2E-2 = 1.2E-3/yr or 1.E-4/mo.

The F1 tornado frequency is similarly derived from the actual events (see http://www4.ncdc.noaa.gov-cgi/win/wwcgi.dl?wwEvent~Storms). There were 5 events in St. Charles parish and 4 events in St. John the Baptist parish (the site is close to the border between the two), in the 55 years of observation (1950 to 2004). The areas of the two parishes are 284 mi^2 and 219 mi^2. Thus, the F1 tornado density frequency is (9+0.5)/(284+219)/54 = 3.43E-4/mi^2/yr. Using a conversion factor of 12.5 for multiple rights of way and 1.2E-2 for high wind LOOP initiation, results in a LOOP frequency of 5.15E-5/yr or 4.29E-6/mo from this source. The tornado frequency will be assumed uniform across the year, which is corroborated by the data. NOAA sites specify a dip in the tornado incidence at the site in the months of interest.

Therefore the LOOP frequency due to high winds is 3.4E-4 + 1.2E-3 + 5.2E-5 = 1.7E-3/yr, of which the hurricane contribution will have a non-uniform monthly distribution. Note that Reference 5 estimates the SW LOOP frequency for the industry as 2.98E-03 /rcy and that Reference 8, Table 3-3, estimates the frequency at 2.2E-02. The Reference 5 value includes two snow related events that are not applicable to Waterford. If these events are removed, the frequency becomes 1.66E-3 /rcy.

Note that the calculated frequency of high winds at the site is somewhat higher than that quoted in the FSAR, which reports a return period of 25 years for 70 mph winds and 50 years for 90 mph winds at the site.

2.5 Extreme Weather Related (EW)

Reference 5 defines extreme weather as events that have the potential to cause significant damage to the electrical transmission system and long offsite power restoration times such as hurricanes with strong winds greater than 125 miles and tornadoes. Note that NUMARC 87-00 only included the occurrence of great hurricanes where wind speeds are greater than or equal to 125 mph in a similar category (Extreme Severe Weather) and included tornadoes in the Severe Weather category. Therefore, the extreme weather LOOP frequency contains two components: hurricanes and F2+ tornadoes.

Two extreme weather events impacting three units are identified for the industry in Reference 5 which covers the period from 1986 to 2003 resulting in a extreme weather frequency of 2.3E-03/rcry. These events include Hurricane Andrew that impacted both Turkey Point units and a tornado event that affected David Besse. No extreme weather events were identified for Waterford. A review of the NOAA database using a longer duration of 1900 to 2003, found no hurricanes with winds greater than 124 mph.

The data on hurricanes is not clear. The Betsy event was included in the severe weather, however it is possible that the winds at the site may have exceeded 125 mph. The site was on the right site of the hurricane, thus maximizing the observed winds and it was closer to Betsy by about 20 miles than the New Orleans airport where the wind speeds were measured. Conflicting data on this event has been gathered from various sources. NOAA data seem to indicate wind gusts of 108 mph at the airport on September 10, 1965. The FSAR specifies sustained winds of 85 mph and gusts of 112 mph at the airport on September 9, 1965. Furthermore, the FSAR states that “extreme winds” of 125 mph were estimated on top of the Federal Building in New Orleans. Thus it is possible that the winds at the site may have been in the extreme category.

However, discounting Betsy as a extreme weather event (sensitivity analysis was performed instead) would indicate 0 events in the data base from 1900 to 2003. Thus the LOOP frequency from extreme hurricanes is 0.5/103 = 4.85E-3/yr, with monthly distribution as developed for the project.

The F2+ tornado frequency was again developed based on the actual events using the above data source for thunderstorms and tornadoes. There were 2 events in St. Charles parish and 3 in St. John the Baptist. Using the parish areas as above, this results in the F2+ tornado density frequency of (5 +0.5)/(219+284)/55 = 1.99E-4/mi^2/yr. Using the conversion factor of 12.5 for multiple rights of way, the LOOP frequency due to F2+ tornadoes is 1.99E-4 * 12.5 = 2.49E-3/yr, which will be uniformly apportioned over the 12 months (LOOP frequency of 2.07E-4/mo). Note that the calculated tornado density frequency is substantially higher than the Reference 8 data of 3.2E-5/mi^2/yr. Data elsewhere on NOAA sites suggest a F2+ frequency of 8.0E-5/mi^2/yr.

Therefore the LOOP frequency due to EW (hurricanes and tornados) = 4.85E-3 + 2.49E-3 per yr = 7.74E-3 / rcy.

Table A.1. Development of Components of LOOP Without Month Specialization

LOOP Category	INEEL SPAR 3.11 (based on NUREG/CR-INEEL/EXT-04-02326 (Reference 5)	Seasonal LOOP frequency based on draft NUREG, and this project, summer months, May-Sep (/yr)	Frequency in this model for the 4 months of interest (/mo)
Plant Centered	2.38E-03	No Change	2.0E-04
Switchyard related	8.74E-03	2.0E-02	1.7E-03
Grid related	1.67E-02	3.9E-02	3.2E-03
Severe weather caused	2.98E-03	1.6E-03	1.85E-04 AVG[5] See Table A.4a for individual months
Extreme weather caused	2.32E-03	7.3E-03	1.35E-03AVG[5] See Table A.4b for individual months
TOTAL LOOP	**3.1E-02**	**7.0E-02**	**6.7E-03**

3. Allocation of LOOP Frequencies to Months of Interest

This section develops LOOP frequencies for the four months of interest: June, July August and September. As a result, the LOOP (and other initiator) frequencies used in the project are in the units of per month.

Tables A.3 and A.4 show the incidence of major hurricanes (Cat 3-5) over a ~100 year period in the area of interest (Gulf coast and the US). For the Waterford site, the average of Louisiana and Mississippi incidences is used, as the site is approximately equidistant from the LO-TX and the MS-AL borders. Table A.4 also shows the calculated conditional probability of major hurricanes in the months of interest (June-September). It is assumed that the major hurricanes produce LOOP with a probability of 1, in the “extreme weather” category. The monthly frequencies of extreme weather induced LOOPs is shown based on the extreme weather frequency at the Waterford site of 4.8E-3/yr, developed above. Tornadoes are also included in the extreme weather category. Tornadoes in the Gulf are a year-round phenomenon, with a uniform distribution assumed, though in reality the probability density peaks early and late in the year, with a dip across most of the period of interest here.

In the case of “severe weather,” there are two components, weak hurricanes (Cat 1-2) and other forceful storms with non-localized effects. Examples of severe weather include thunderstorms, snow, and ice storms. The weak hurricanes are assumed to follow the same monthly distribution of frequency as the major ones.

Table A.5 shows the total monthly LOOP frequency for the period of interest, based on the components shown in Tables A.1 and A.4. These are our base case LOOP frequencies.

4. Development of Current Case LOOP Frequencies and Non-Recovery Probabilities

Table A.6 shows the non-recovery parameters which will be used in development of current case LOOP frequencies and all non-recovery probabilities. The parameters of interest are α and β, such that the non-recovery probability for the i-th LOOP component is given by the expression:

$$P_{NR}^{i} = \exp\{-(t/\beta_i)^{**}\alpha_i\},$$

where i is the i-th LOOP category, and t is the recovery time of interest

Based on this information, monthly current case LOOP frequencies and non-recovery probabilities are developed in Tables A.7-A.10. It should be noted that the recovery times of interest are not 1, 2 and 4 hours in the SPAR model (and our base case) but those times after the onset of EDG-A failure due to cross-connect tube failure. For example, for the September current case, the recovery times of interest are 3.8 hrs, 4.8 hrs and 6.8 hrs (i.e., 1, 2 and 4 hours, respectively, after the 2.8 hr time marking the beginning of the current case LOOP or the failure of cross-connect tubing).

Likewise, the base case non-recovery probabilities (for the 1, 2 and 4 hour time periods) are developed in Tables A.11.

The base case and the current case data are summarized in Tables A.12 and A.13.

Table A.2. LOOP Durations, Condition Durations and Mission Times Considered (27hr 49 min of run time remaining on EDG-A cross-connect fuel tubing after modification on May 16, 2003)

Period	Assign to month	Condition duration (d)	EDG-A test runtime at start of period (hr:min)	Time remaining on EDG-A = minimum LOOP duration in current case, (hr)	Mission time in current case = 24 hr - previous column (hr)
May 17 - June 9	not analyzed	NA	4:54	22.92	NA
June 9 - July 8	June	29	4:46	18.15	5.85
July 8 - August 4	July	27	5:23	12.77	11.23
August 4 - September 2	August	29	4:36	8.17	15.83
September 2 - September 29	September	27	5:22	2.8	21.2

Table A.3. Hurricane Occurrences 1900-2003 in the US and the Gulf Coast (major hurricanes, Categories 3-5).

Region	June	July	August	September	October	All Months
US	2	3	15	36	8	64
Florida, NW	0	1	0	5	1	7
Florida, SW	0	0	1	5	3	9
Alabama	0	1	0	4	0	5
Mississippi	0	1	1	4	0	6
Louisiana	2	0	4	5	1	12
Texas, N	1	1	3	2	0	7
Texas, Central	0	0	1	1	0	2

Region	June	July	August	September	October	All Months
Texas, S	0	0	3	3	0	6

Table A.4. Hurricane Occurrences, Probabilities and Frequencies for the Waterford Site (Major, Cat. 3-5), Based on Period 1900-2003

Region	June	July	August	September	October	All Months
Louisiana	2	0	4	5	1	12
Mississippi	0	1	1	4	0	6
LO+MS	2	1	5	9	1	18
Site conditional probability, $(LO+MS)_{month}$ / $(LO+MS)_{total}$	11.1	5.6	27.8	50	NA	100
Severe weather frequency on site, (/mo), last column in /yr	3.8E-05	1.9E-05	9.4E-05	1.7E-04	NA	1.35E-03/yr
Extreme weather frequency on site, (/mo), last column in /yr	5.4E-04	2.7E-4	1.4E-3	2.4E-3	NA	4.85E-3/yr

Table A.4a. LOOP Frequencies, /mo, Severe Weather

Category	June	July	August	September
LOOP, thunderstorms	1.0E-4	1.0E-4	1.0E-4	1.0E-4
LOOP, F1	4.3E-6	4.3E-6	4.3E-6	4.3E-6
LOOP, weak hurricanes	3.8E-5	1.9E-5	9.4E-5	1.7E-4
Total SW LOOP	1.4E-4	1.2E-4	2.0E-4	2.7E-4

Table A.4b. LOOP Frequencies, /mo, Extreme Weather

Category	June	July	August	September
LOOP, F2+	2.1E-4	2.1E-4	2.1E-4	2.1E-4
LOOP, extreme hurricanes	5.4E-4	2.7E-4	1.4E-3	2.4E-3
Total EW LOOP	7.5E-4	4.8E-4	1.6E-3	2.6E-3

Table A.5. LOOP Frequency for the Project, June - September

	June	July	August	September
LOOP Frequency (/mo)	6.0E-3	5.7E-3	6.9E-3	8.0E-3

Table A.6. Non-Recovery Probability Parameters for Various LOOP Types[1]

Type LOOP	Type Frequency λ_i (/mo)	α	β
Plant Centered	2.0E-4	0.610	0.333
Switchyard	1.7E-3	0.678	0.981
Grid	3.2E-3	0.819	2.431
Severe weather	month dependent	0.422	1.872
Extreme weather	month dependent	1.400	85.63

1. Parameters used for calculating non recovery probabilities, per SPAR LOOP model, using the expression $P_{NR}^{i} = \exp\{-(t/\beta_i)^{**}\alpha_i\}$, where i is the i-th LOOP category, and t is the recovery time of interest.

Table A.7a. Non-Recovery Probabilities and LOOP Fractions for June

LOOP type	LOOP freq. (/mo)	Non-recovery probability, 18.15 hr	Non-recovery probability, 19.15 hr	Non-recovery probability, 20.15 hr	Non-recovery probability, 22.15 hr
Plant centered	2.0E-4	1.1E-5	7.2E-6	5.0E-6	2.4E-6
Switchyard	0.002	7.2E-4	5.5E-4	4.3E-4	2.5E-4
Grid related	3.2E-3	5.6E-3	4.4E-3	3.5E-3	2.2E-3
Severe weather	1.4E-4	7.4E-2	6.9E-2	6.5E-2	5.9E-2
Extreme weather	7.5E-4	8.9E-1	8.8E-1	8.8 E-1	8.6 E-1

Table A.7b. LOOP Frequencies for June

Total LOOP frequency (/mo)	LOOP frequency of duration > 18.15 hr (/mo)
6.0E-3	7.1E-4

Table A.7c. LOOP Non-Recovery Probabilities for Current Case LOOPs in June[1]

	19.15 hr	20.15 hr	22.15 hr
$\Sigma\lambda_i P(LOOP_i \mid T>T^*)$	7.0E-4	6.9E-4	6.7E-4
Non-recovery probability of LOOPs with duration>18.15 hr, $\Sigma\lambda_i P(LOOP_i \mid T>T^*)/\lambda_{LOOP \mid T>18.15\ hr}$	9.8E-1	9.7E-1	9.5E-1

1. T* is the recovery time of interest, T is the LOOP duration time, i is the i-th LOOP category and λ is the LOOP frequency (/mo)

Table A.8a. Non-Recovery Probabilities and LOOP Fractions for July

LOOP type	LOOP freq. (/mo)	Non-recovery probability, 12.77 hr	Non-recovery probability, 13.77 hr	Non-recovery probability, 14.77 hr	Non-recovery probability, 16.77 hr
Plant centered	2.0E-4	9.6E-5	6.2E-5	4.1E-5	1.8E-5
Switchyard	1.7E-3	3.4E-3	2.5E-3	1.9E-3	1.1E-3
Grid related	3.2E-3	2.0E-2	1.6E-2	1.2E-2	7.7E-3
Severe weather	1.2E-4	1.1E-1	9.8E-2	9.2E-2	8.0E-2
Extreme weather	4.8E-4	9.3E-1	9.3E-2	9.2E-1	9.0E-1

Table A.8b. LOOP frequencies for July

Total LOOP frequency (/mo)	LOOP frequency of duration > 12.77 hr (/mo)
5.7E-3	5.4E-4

Table A.8c. LOOP Non-Recovery Probabilities for Current Case LOOPs in July

	13.77 hr	14.77 hr	16.77 hr
$\Sigma\lambda_i P(LOOP_i \mid T>T^*)$	5.21E-4	5.05E-4	4.79E-4
Non-recovery probability of LOOPs with duration>12.77 hr, $\Sigma\lambda_i P(LOOP_i \mid T>T^*)/\lambda_{LOOP \mid T>12.77\ hr}$	9.6E-1	9.3E-1	8.9E-1

Table A.9a. Non-Recovery Probabilities and LOOP Fractions for August

LOOP type	LOOP freq. (/mo)	Non-recovery probability, 8.17 hr	Non-recovery probability, 9.17 hr	Non-recovery probability, 10.17hr	Non-recovery probability, 12.17 hr
Plant centered	2.0E-4	8.7E-4	5.2E-4	3.2E-4	1.3E-4
Switchyard	1.7E-3	1.5E-2	1.1E-2	7.6E-3	4.0E-3
Grid related	3.2E-3	6.7E-2	5.1E-2	4.0E-2	2.4E-2
Severe weather	2.0E-4	1.6E-1	1.4E-1	1.3E-1	1.1E-1
Extreme weather	1.6E-3	9.6E-1	9.6E-1	9.5E-1	9.4E-1

Table A.9b. LOOP Frequencies for August

Total LOOP frequency (/mo)	LOOP frequency of duration > 8.17 hr (/mo)
6.9E-3	1.8E-3

Table A.9c. LOOP Non-Recovery Probabilities for Current Case LOOPs in August

	9.17 hr	10.17 hr	12.17 hr
$\Sigma\lambda_i P(LOOP_i \mid T>T^*)$	1.73E-3	1.68E-3	1.60E-3
Non-recovery probability of LOOPs with duration>8.17 hr, $\Sigma\lambda_i P(LOOP_i \mid T>T^*)/\lambda_{LOOP \mid T>8.17\ hr}$	9.6E-1	9.3E-1	8.9E-1

Table A.10a. Non-Recovery Probabilities and LOOP Fractions for September

LOOP type	LOOP freq. (/mo)	Non-recovery probability, 2.8 hr	Non-recovery probability, 3.8 hr	Non-recovery probability, 4.8 hr	Non-recovery probability, 6.8 hr
Plant centered	2.0E-4	2.6E-2	1.2E-2	6.1E-3	1.8E-3
Switchyard	1.7E-3	1.3E-1	8.2E-2	5.3E-2	2.4E-2
Grid related	3.2E-3	3.3E-1	2.4E-1	1.7E-1	9.8E-2
Severe weather	2.7E-4	3.1E-1	2.6E-1	2.3E-1	1.8E-1
Extreme weather	2.6E-3	9.9E-1	9.9E-1	9.8E-1	9.7E-1

Table A.10b. LOOP Frequencies for September

Total LOOP frequency (/mo)	LOOP frequency of duration > 2.8 hr (/mo)
8.0E-3	3.9E-3

Table A.10c. LOOP Non-Recovery Probabilities for Current Case LOOPs in September

	3.8 hr	4.8 hr	6.8 hr
$\Sigma\lambda_i P(LOOP_i \mid T>T^*)$	3.5E-3	3.3E-3	2.9E-3
Non-recovery probability of LOOPs with duration>2.8 hr, $\Sigma\lambda_i P(LOOP_i \mid T>T^*)/\lambda_{LOOP \mid T>2.8\ hr}$	9.0E-1	8.3E-1	7.4E-1

Table A.11a. Base Case Non-Recovery Probabilities for Individual LOOP Categories at 1, 2 and 4 hrs

LOOP type	Non-recovery probability, 1 hr	Non-recovery probability, 2 hr	Non-recovery probability, 4 hr
Plant centered	.141	.0505	.0105
Switchyard	.363	.198	.0748
Grid related	.617	.426	.222
Severe weather	.464	.358	.252
Extreme weather	.998	.995	.986

Table A.11b. Σ Non-EW LOOP Frequencies * Non-Recovery Probabilities (Column A.4 of Table A.4 * Table AI.11a Rows 2-5)

	1 hr recovery	2 hr recovery	4 hr recovery
$\Sigma\lambda_i P(LOOP_i \mid T>T^*)$	2.63E-3	1.72E-3	8.43E-4

Table A.11c. Extreme Weather LOOP Frequencies * Non-Recovery Probabilities (Table A.3 * Table A.11a row 6)

	June	July	August	September
$\lambda ewP(LOOPew \mid T>T^*)$ for $T^* = 1$ hr	8.28E-4	5.48E-4	1.68E-3	2.72E-3
$\lambda ewP(LOOPew \mid T>T^*)$ for $T^* = 2$ hr	8.09E-4	5.32E-4	1.65E-3	2.68E-3
$\lambda ewP(LOOPew \mid T>T^*)$ for $T^* = 4$ hr	7.86E-4	5.15E-4	1.62E-3	2.63E-3

Table A.11d. Total, for Extreme Weather + Non-Extreme Weather, Σ LOOP frequencies * Non-Recovery Probabilities (Tables A.11b + A.11c)

	June	July	August	September
$\Sigma\lambda_i P(LOOP_i \mid T>T^*)$ for $T^* = 1$ hr	3.46E-3	3.18E-3	4.31E-3	5.35E-3
$\Sigma\lambda_i P(LOOP_i \mid T>T^*)$ for $T^* = 2$ hr	2.53E-3	2.25E-3	3.37E-3	4.40E-3
$\Sigma\lambda_i P(LOOP_i \mid T>T^*)$ for $T^* = 4$ hr	1.63E-3	1.36E-3	2.46E-3	3.47E-3

Table A.11e. Total Base Case Non-Recovery Probabilities (Table A.11d. / Table A.5)

	June	July	August	September
Probability of offsite power non-recovery in 1 hr	.575	.555	.625	.670
Probability of offsite power non-recovery in 2 hr	.420	.393	.488	.551
Probability of offsite power non-recovery in 4 hr	.271	.237	.357	.435

Table A.12. Base Case Data Input, Summary

	June	July	August	September
LOOP frequency (/mo)	6.02E-3	5.73E-3	6.90E-3	7.98E-3
Non-recovery probability, 1 hr	.575	.555	.625	.670
Non-recovery probability, 2 hr	.420	.393	.488	.551
Non-recovery probability, 4 hr	.271	.237	.357	.435

Table A.13. Current Case Data Input, Summary

	June	July	August	September
LOOP frequency (/mo)	7.08E-4	5.41E-4	1.80E-3	3.93E-3
Non-recovery probability, 1 hr	.983	.963	.962	.897
Non-recovery probability, 2 hr	.970	.933	.933	.830
Non-recovery probability, 4 hr	.946	.885	.888	.743

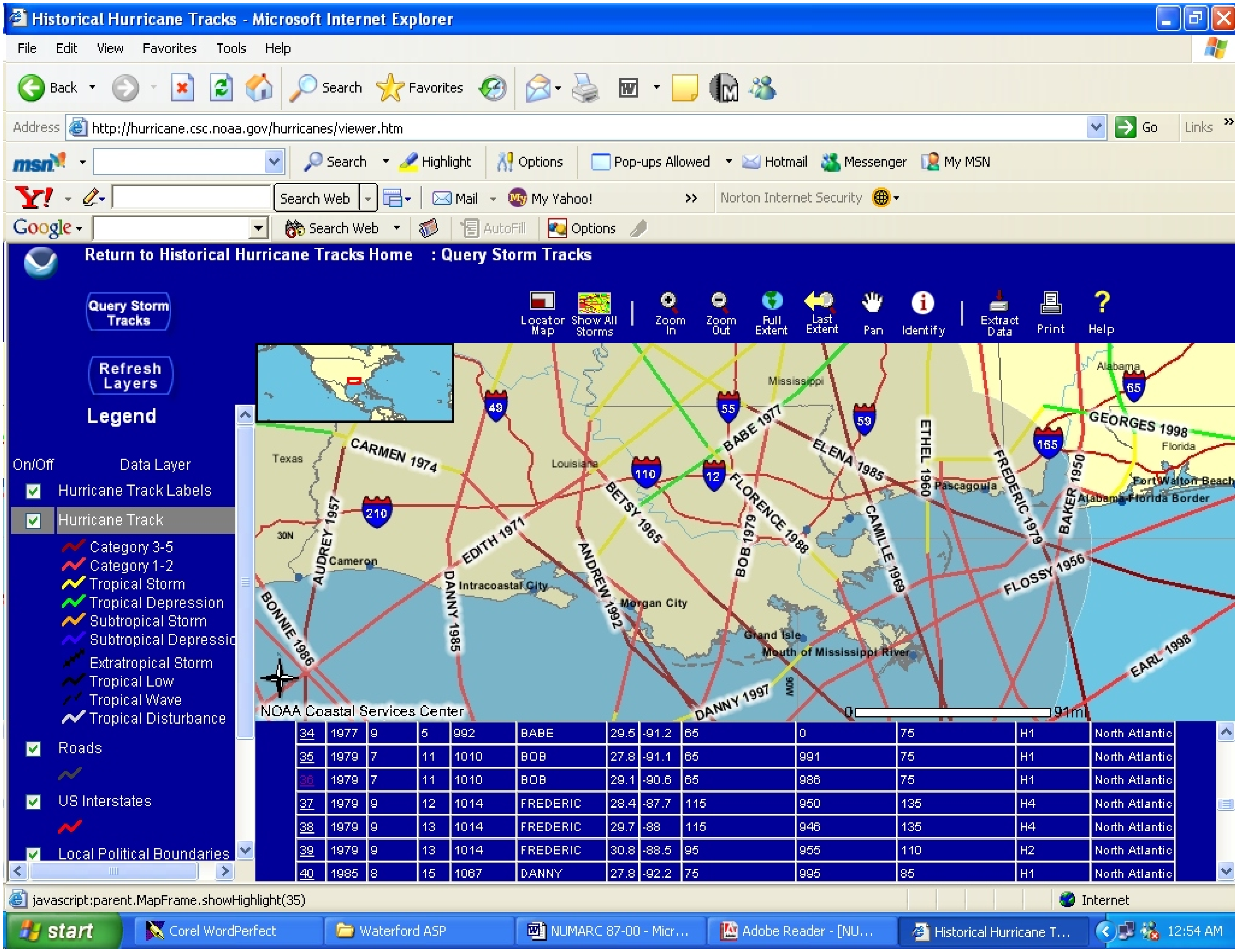

Figure A.1 Closeup, 1950-2003 Hurricanes (Lake Pontchartrain not shown)

Appendix B

Emergency Diesel Generator Repair Modeling

Appendix B. Emergency Diesel Generator Repair Modeling

The HEP analysis was performed for two actions:

- The timely stop of fuel leak before the environment in the EDG room degrades to a point that it becomes impossible to enter
- The timely repair of the cross-connect tubing to return the EDG to availability

The failure probability of recovery of the EDG during the sequences was estimated using the standard SPAR Model Human Error Worksheet. The worksheets used to determine the value are included below.

B.1 Important Recovery Considerations

An auxiliary operator will be sent to each EDG room/control panel immediately upon LOOP. It was assumed that it would take the operator 10 to 15 minutes to arrive following a LOOP. There will be continuous manning of this station (EDG control panel) throughout the event. Typically, some 5 times an hour there will be an actual walkdown of the diesel. So, even allowing for complacency which will set in after the EDG has run for some time, and even if the control panel is in a separate room, we consider that the event -- burst cross-over fuel tubing, will be discovered within 10-15 minutes. Another maximum of 8-10 minutes might pass before the fuel booster pump (which in Waterford's case is DC power driven) is secured. It could easily be shut off by pressing the reset button on the control panel, but apparently the operator in the event was unaware of this option, so it was shut off at its breaker panel. In the actual event, this took approximately 4 minutes. The booster pump is rated at 12.5 gpm maximum flow rate (regardless of the pressure), thus the quantity of fuel oil spilled was limited. The diesel generator was also immediately shut down. Failure to do so in this situation would have resulted in permanent damage to the diesel on about the same time scales as considered available here for shutting off the fuel transfer pump.

While the EDG is in operation prior to securing the fuel booster pump, the ventilation system will be operating, thus effectively mitigating environmental effects of fuel vapors filling the room. The capacity of the sump system in the EDG room is sized to accommodate an entire day tank worth of fuel, i.e., more than 2 hrs of full flow from the fuel leak, such that there will not be a significant quantity of fuel oil on the floor to hamper any repair operation. Except for the hot exhaust manifold consideration below, the environment will be maintained acceptable for personnel to enter and work in.

The fuel spray may come in contact with the exhaust manifold, either directly or indirectly, by soaking through the insulation wrapped around it and associated piping. This manifold is hot enough such that it can ignite the fuel, or, more likely, produce thick smoke, complicating or preventing visibility and/or breathing. Such events would lead to actuation of the Cardox system for fire suppression. Actuation of the Cardox system would render the environment uninhabitable for personnel for a long time. Furthermore, the EDG room ventilation system would stop sweeping smoke from the room as soon as its associated EDG stops.

This smoke scenario is unlikely because, in our estimate, it would take at least 1/2 hour to soak through the manifold insulation, assuming the fuel is actually spraying in the right direction and there is no shielding around the manifold. Thus, it seems this worst case could be averted with a high probability. The assumption will thus be made that no ignition or smoke production will take place, i.e., repair of cross-over tubing can proceed given the timely shutoff of the fuel transfer pump.

The repair itself is relatively simple. Assuming a blackout with a skeleton crew, it is estimated that it will take 1 to 2 hours to replace the cross-over fuel tubing. The EDG room and its ingress/egress passages will have emergency lighting. It is not known whether emergency lighting exists in the maintenance shop, however, there is confidence that some form of lighting will be made available or improvised, if necessary. While the power and compressed air tools would be inoperable, the repair is simple and can be accomplished with manual tools (e.g., hacksaw) and even using such things as flex tubing as the design pressure of the fuel system is 50 psi.

B.2 HEP PSFs

The HEP can be split in two parts -- timely stop of fuel leak (before the environment becomes impossible) and timely repair of the cross-connect tubing. The total non-recovery HEP will then be the sum of the two parts. There is no diagnosis in this case, as the auxiliary operator will be able to see the leak upon diesel walkdown.

The SPAR-H worksheets for the two actions are shown in Tables B.1 and B.2. It should be noted that the SPAR-H model was not designed for repair actions such as those included in this analysis, but its use appears reasonable for the 4 hr repair, as there will be time to repeat the repair if it doesn't fix the problem. However, in the 1 hr repair case the ergonomics PSF of "nominal" (value of 1) would be too optimistic, whereas the ergonomics PSF of "poor" (value of 10) would be too pessimistic, and there are questions whether the SPAR-H model can be used here at all. Since the licensee has stated that the repair probability would be 0.1 for this action, and the NRC has accepted this, the value of 0.1 will be used for the 1 hr repair failure probability (i.e., including both the timely stop of the fuel leak and the repair of it). It should also be noted that the available time will be greater than 1 hr in the current case because the EDG-A failure will occur some time after the reactor trip, thus the core decay power will be lower.

Thus, using the SPAR-H model, where the base case action HEP is 1.E-3, the total HEP is 8.E-3 for the 4 hr repair, and the HEP of 0.1 will be used for the 1 hr repair, as per discussion above. These are the probabilities for non-recovery of the specific EDG-A failure mode. Recovery of EDG-B is conservatively not credited, as the generic non-recovery probabilities are high and are for repair of two diesel generators, EDG-B failure to start and associated repair are taken out of the current case model, and the repair resources are assumed to be concentrated on the diesel that is easier to fix.

The above HEP values can be compared to the generic EDG non-recovery probabilities of 0.841 for the 1 hr recovery and 0.5 for the 4 hr recovery, in the INEEL Waterford SPAR model. It should be noted that the simple failure-to-start recoveries are already included in the failure to start probabilities of emergency diesel generators.

SPAR Model Human Error Worksheet

Plant: Waterford 3 **Event Name**: Failure to stop the fuel oil line leak

Task Error Description: Failure to stop the fuel oil line leak

Does this task contain a significant amount of diagnosis activity ? YES ___ NO ✓

If Yes, Use Table 1 below to evaluate the PSFs for the Diagnosis portion of the task before going to Table 2. If No, go directly to Table 2.

Table B.1. Diagnosis Worksheet.

PSFs	PSF Levels	Multiplier for Diagnosis	If non-nominal PSF levels are selected, please note specific reasons in this column
1. Available Time	Inadequate	1.0[a]	
	Barely adequate < 20 m	10	
	Nominal ≈ 30 m	1	
	Extra > 60 m	0.1	
	Expansive > 24 h	0.01	
2. Stress	Extreme	5	
	High	2	
	Nominal	1	
3. Complexity	Highly	5	
	Moderately	2	
	Nominal	1	
4. Experience/ Training	Low	10	
	Nominal	1	
	High	0.5	
5. Procedures	Not available	50	
	Available, but poor	5	
	Nominal	1	
	Diagnostic/symptom oriented	0.5	
6. Ergonomics	Missing/Misleading	50	
	Poor	10	
	Nominal	1	
	Good	0.5	

PSFs	PSF Levels	Multiplier for Diagnosis	If non-nominal PSF levels are selected, please note specific reasons in this column
7. Fitness for Duty	Unfit	1.0[a]	
	Degraded Fitness	5	
	Nominal	1	
8. Work Processes	Poor	2	
	Nominal	1	
	Good	0.8	

a. Task failure probability is 1.0 regardless of other PSFs.

Table B.2. Action Worksheet.

– Table B.2a. Action stop leak
– Table B.2b. Action repair leak

Table B.2a. Action Stop Leak Worksheet.

PSFs	PSF Levels	Multiplier for Action	If non-nominal PSF levels are selected, please note specific reasons in this column
1. Available Time	Inadequate	1.0[a]	Timing of shutting the pump at the breakers leaves some time before condition in EDG room untenable.
	Time available ≈ time required	10	
	Nominal	1 ✓	
	Available > 5x time required	0.1	
	Available > 50x time required	0.01	
2. Stress	Extreme	5	LOOP with EDG failure is a high stress situation for the aux operator in EDG room, but insulated from stress in control room.
	High	2 ✓	
	Nominal	1	
3. Complexity	Highly	5	
	Moderately	2	
	Nominal	1 ✓	
4. Experience/ Training	Low	3 ✓	The operator was not aware of pushing the reset button to stop the fuel leak.
	Nominal	1	
	High	0.5	
5. Procedures	Not available	50	
	Available, but poor	5	
	Nominal	1 ✓	

6. Ergonomics	Missing/Misleading	50	
	Poor	10	
	Nominal	1 ✓	
	Good	0.5	
7. Fitness for Duty	Unfit	1.0[a]	
	Degraded Fitness	5	
	Nominal	1 ✓	
8. Work Processes	Poor	2	
	Nominal	1 ✓	
	Good	0.8	

a. Task failure probability is 1.0 regardless of other PSFs.

Table B.2b. Action Repair Leak Worksheet.

PSFs	PSF Levels	Multiplier for Action	If non-nominal PSF levels are selected, please note specific reasons in this column
1. Available Time	Inadequate	1.0[a]	Some time would be required to set up the work to repair the leaking line. Worst case would be in an SBO condition where shop tools and lighting would be compromised. The task is relatively simple even assuming a skeleton night shift crew and little supervision available.
	Time available ≈ time required	10 ✓	
	Nominal	1✓	
	Available > 5x time required	0.1	PSF of 1 for the 4 hr repair, PSF of 10 for the 1 hr repair (actual available times longer).
	Available > 50x time required	0.01	
2. Stress	Extreme	5	Mechanic doing the repair somewhat insulated from stress of the control room.
	High	2 ✓	
	Nominal	1	
3. Complexity	Highly	5	
	Moderately	2	
	Nominal	1 ✓	
4. Experience/ Training	Low	3	
	Nominal	1 ✓	
	High	0.5	
5. Procedures	Not available	50	due to simplicity of repair
	Available, but poor	5	
	Nominal	1 ✓	

6. Ergonomics	Missing/Misleading Poor Nominal Good	50 10 ✓ 1 ✓ 0.5	Nominal: simple repair with manual tools, and lighting can be improvised. This can be used for the 4 hr repair, and would probably be too optimistic for the 1 hr repair. Poor: the workers will be hobbled by the blackout conditions and effects of the oil spill in the EDG room. This can be used for the 1 hr case, but is probably too conservative in the light of the ease of repair.
7. Fitness for Duty	Unfit Degraded Fitness Nominal	1.0[a] 5 1 ✓	
8. Work Processes	Poor Nominal Good	2 1 ✓ 0.8	due to simplicity and training involved

a. Task failure probability is 1.0 regardless of other PSFs.

Table B.3. Task Failure Probability Without Formal Dependence Worksheet.

Task Portion	Nom. Prob.	Time	Stress	Compl.	Exper./ Train.	Proced.	Ergon.	Fitness	Work Process	Prob.
Diag.	1.0E-2									
Action stop leak	1.0E-3	x 1.0	x 2.0	x 1.0	x3.0	x 1.0	x 1.0	x 1.0	x 1.0	6.E-3
Action repair leak, 1 hr	1.0E-3	x 10	x 2.0	x 1.0	x 1.0	x 1.0	x 1.0	x 1.0	x 0.8	2.E-2
Action repair leak, 4 hr	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 0.8	2.E-3
Total, stop leak + repair leak, 1hr	Note: action stop leak and action repair leak, 1 hr combined (added)									2.6E-2 to 0.21; 0.1 will be used
Total, stop leak + repair leak, 4hr	Note: action stop leak and action repair leak, 4 hr combined (added)									8.0E-3

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.

Table B.4. Dependency Condition Worksheet.

Condition Number	Crew (same or different)	Location (same or different)	Time (close in time or not close in time)	Cues (additional or not additional)	Dependency	Number of Human Action Failures Rule
1	s	s	c	–	complete	If this error is the 3rd **error in the sequence**, then the dependency is at least **moderate**. If this error is the 4th **error in the sequence**, then the dependency is at least **high**. This rule may be ignored only if there is compelling evidence for less dependence with the previous tasks.
2	s	s	nc	na	high	
3	s	s	nc	a	moderate	
4	s	d	c	–	high	
5	s	d	nc	na	moderate	
6	**s**	**d**	**nc**	**a**	**low**	
7	**d**	**s**	**c**	**–**	**moderate**	
8	**d**	**s**	**nc**	**na**	**low**	
9	**d**	**s**	**nc**	**a**	**low**	
10	**d**	**d**	**c**	**–**	**moderate**	
11	**d**	**d**	**nc**	**na**	**low**	
12	**d**	**d**	**nc**	**a**	**low**	
13 ✓					**zero**	

Appendix C

Hurricane and Tornado Background Data

Appendix C. Hurricane and Tornado Background Data[2]

The site is at 29°59'42"N and 90°28'16"W, close to the southwestern corner of Lake Pontchartrain, and 20 miles west of New Orleans, according to the NRC site. The historical hurricane data is inconclusive regarding the possibility that winds>124 mph (power lines design winds) may have been experienced at the site.

There are several considerations:

- uncertainty in hurricane tracks and recorded wind speeds from years past; discretized nature of the existing windspeed vs. location data makes it hard to ascertain the actual site conditions;

- right side of a hurricane will experience higher windspeeds than the left side due to the generally counterclockwise nature of the hurricane swirling winds in the Northern hemisphere;

- wind gusts (generally, 3-5 seconds in duration) are typically 20-25% and up to 50% higher wind speeds than the hurricane sustained 1 minute winds; wind gusts are dependent on local topology and will increase in relative speed to the sustained winds, as the hurricane makes landfall, due to increased turbulence;

- eyewall wind profiles are such that the wind speeds at elevation of power lines (about 100 feet off the ground) are about 10% higher than the surface wind speeds;

- hurricane eye diameters range from 5 miles to 120 miles (most are 20-40 miles in diameter); the maximum winds are experienced at the eyewall;

- almost all hurricanes spawn tornadoes upon landfall. For example, hurricane Beulah spawned 115 tornadoes in SE Texas in September 1967. Hurricane Andrew spawned 62 tornadoes in 1992. It seems that the more intense hurricanes tend to produce more tornadoes. The tornado mix tends to be somewhat skewed toward the weaker tornadoes, when compared to mid-latitude tornadoes, though some F4 tornadoes (but no F5s) have also been spawned by hurricanes. Such tornadoes can occur far from the storm center.

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[2] Based on hurricane data at http://hurricane.csc.noaa.gov/hurricanes/, www.aoml.noaa.gov/hrd/Landsea/deadly/index.html, http://weather.unisys.com/hurricane/atlantic/index.html, www.nhc.noaa.gov/pastall.shtml and tornado data at www.spc.noaa.gov, www.nssl.noaa.gov/hazard/, www.ncdc.noaa.gov/oa/climate/severeweather/tornadoes.html and www.tornadoproject.com.

- hurricane landfalls experience decade-related patterns of affected geographic areas. Also, often there are distinct trends at the beginning of a decade and at the end of a decade. Other patterns suggest overall lessening/strengthening of hurricane activity in certain decades. The trend in the recent decades has been somewhat away from the Gulf coast, i.e., the Gulf Coast (especially western Gulf Coast) conditional landfall probability has recently been smaller than it was early in the century and in the 60s and the 70s; and the current period is somewhat less active in overall landfalling frequency than some of the periods in the past.

- there seems to be a tendency of hurricane tracks to cluster away from the Waterford site. However, some hurricanes (or remnants thereof) did pass very close to the site. Figure C.1 shows tracks of Cat 4-5 hurricanes in the site vicinity from 1900-2003;

- the penetration of high winds inland is dependent on forward hurricane speeds. It seems that the Waterford site is in the envelope of high sustained winds (>124 mph) for intense hurricanes moving at forward speeds greater than 9 mph. Thus, an intense hurricane (Cat 4 or 5) moving forward at those speeds in a certain direction and landfalling in a certain area might produce such high sustained surface winds at the Waterford site.

Taking all these considerations together, it seems possible but uncertain whether the Waterford site has experienced sufficiently high hurricane-related winds and other effects to cause a LOOP, since 1900. As an example, when hurricane Betsy passed over Louisiana, moving in a northwesterly direction, wind gusts of 108 mph were clocked at the New Orleans international airport on September 10, 1965. Just a few hours earlier, upon crossing the Louisiana coastline, Betsy was at its most intense (eye diameter of 80 miles and windspeeds of 150 mph). At its closest, the airport was about 20-30 miles NE of the hurricane eye. The site is about 10-20 miles west of the airport and was thus closer to the hurricane eye. The eye may have passed very close to the Waterford site, with maximum surface sustained winds of around 120mph, according to interpolation of some tracking records. Thus, keeping in mind that wind gusts are localized phenomena, it is possible that higher speed gusts may have been experienced at the site than at the airport (and still higher at the power lines elevation).

The Cat 4 New Orleans hurricane of 1915 apparently passed very close to or over the site, but at that point it was a Cat 3 hurricane (or lower), and it is unknown what the relevant local wind speeds might have been.

Another concern is the fact that any nuclear power plant in the path of a hurricane will be shut down as a precaution, and modeling hurricane-induced LOOPS at full power would be conservative. Hence, such considerations should be relegated to the shutdown model. In addition, the Waterford site will have the truck mounted TEDs at the site for the duration of the emergency, thus further diminishing the risk importance of hurricane-induced LOOPs.

Due to the uncertainties noted above, as our default case, we will use the NUREG-1032 frequency of 0 instances of >124 mph wind speeds at the site in the 103 years since 1900 (i.e., assume the statistics of 0.5 such LOOPs in the 103 years). In a sensitivity analysis, we will assume 2 such instances in that time period. In another sensitivity analysis, we will take out the hurricane LOOPs from consideration altogether, due to the precautionary shutdown and the presence of the TEDs.

As for the tornados, Figure C.2 shows the tornado probability distribution at the site. A dip in the months of interest is noted. Looking at the 1950-1995 data for the surrounding counties, though, a relatively flat distribution is noted:

St. Charles parish, 6 tornados, none in the months of interest.
Orleans parish, 12 tornados, 5 in the months of interest (but 2 of those 5 were F0).
Jefferson parish, 28 total, 11 in the period of interest
La Fourche parish, 9 total, 3 in the mos of interest.
St. John the Baptist, 11 total, 4 in the mos of interest
St. James and Ascension, no tornados.

Thus, approximately 1/3 of the tornados were in the 4 months of interest.

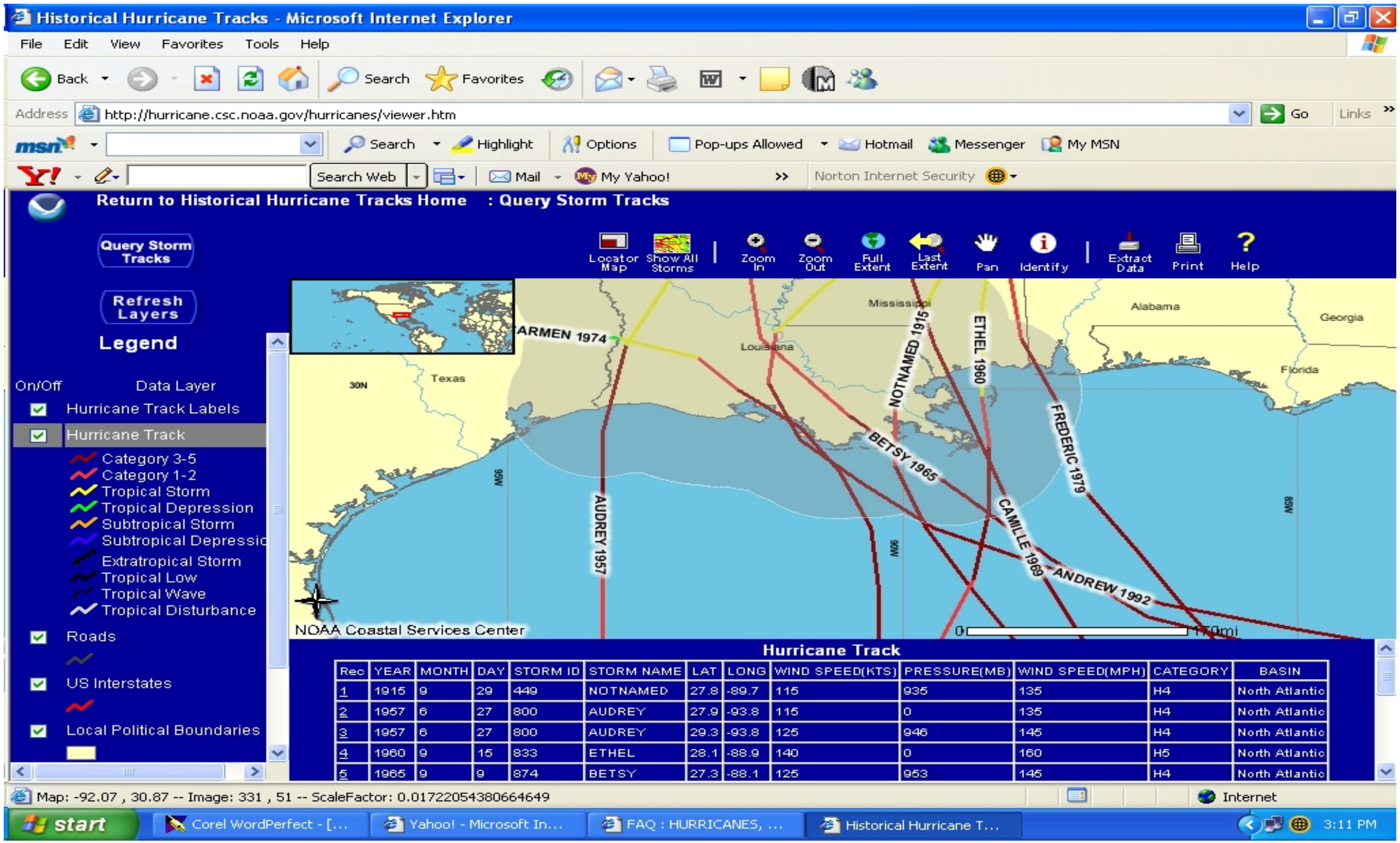

Figure C.1 Category 4 - 5 Hurricanes, 1900-2003 (Lake Pontchartrain not shown)

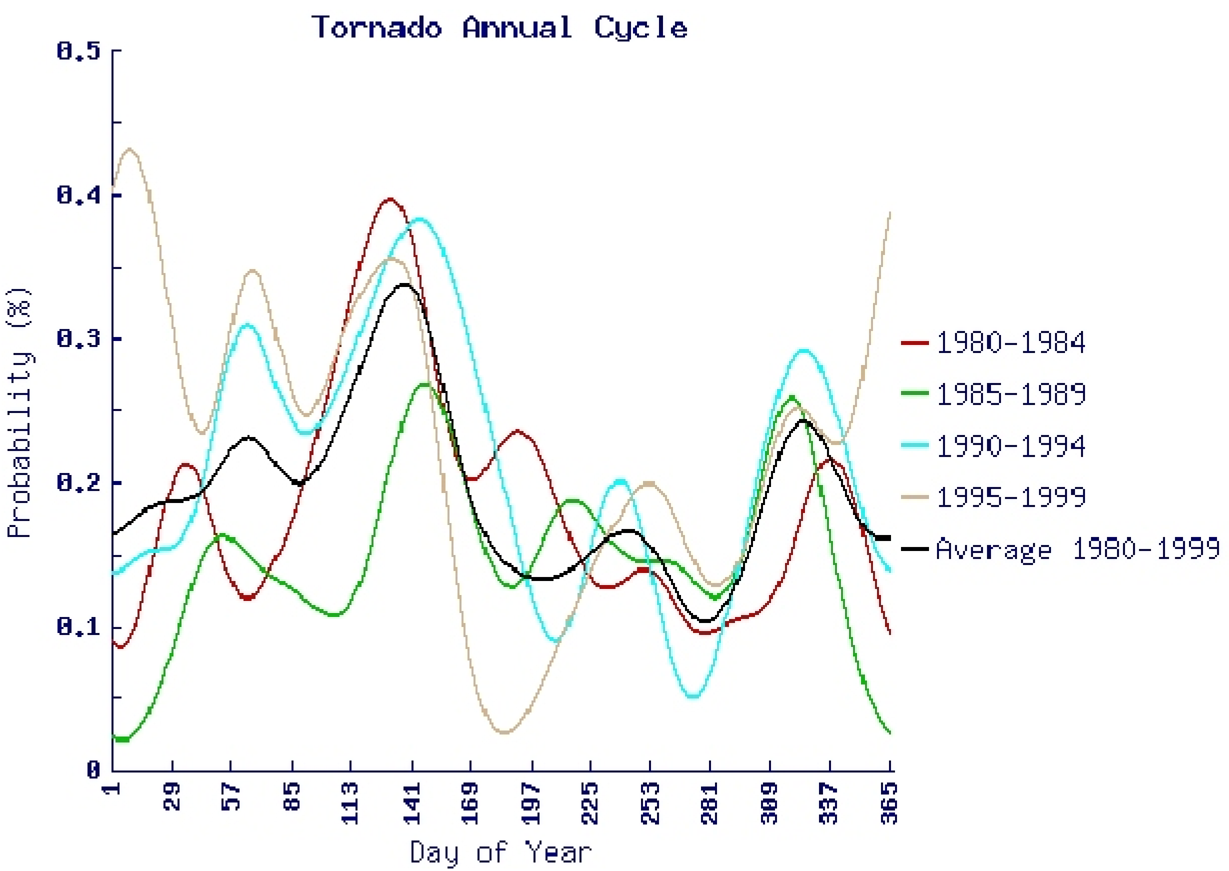

Figure C.2 Tornados at Waterford

Appendix D

Uncertainty Analysis

Appendix D. Uncertainty Analysis

Special considerations have to be given to the uncertainty analysis, because the change sets used for the current case point estimate utilize manual changes to some basic events. These manual changes replace the point estimates of these events, which means that such events are left without an uncertainty distribution. This is because the changed events are typically compound events composed of several underlying events. In order to remedy this situation, these events were changed differently in the current case for the uncertainty analysis.

The events in question are: LOOP initiating event frequency, CCF probability of EDGs to run and various offsite non-recovery probabilities.

The events current case evaluation was changed such that SAPHIRE calculates the event probabilities from the underlying compound events. Thus, the underlying uncertainty distribution is preserved. As an added bonus, this simplifies calculations of basic event probabilities in the point estimate calculations as well, such that handling of sensitivity analyses is facilitated (e.g., calculation of offsite power non-recovery probabilities is done automatically by SAPHIRE, once the correct LOOP type frequencies are put in).

The three classes of events were calculated (within the base-case and the current case SPAR models) from the simpler constituent events as follows:

1) IE-LOOP = LOOP-BASE * NREC(T*);

where LOOP-BASE – base case LOOP frequency;
LOOP-BASE = $\Sigma\lambda_{LOOP\text{-}BASE,\, i}$; where $\lambda_{LOOP\text{-}BASE,\, i}$ is the frequency of the ith type of LOOP in the base case (events ZV-LOOP-LAMBDA-XY in the SPAR model); utilize library PLUG_ LOOPREC.DLL, procedure FREQ_SUM in SAPHIRE;
NREC(T*) – offsite power non-recovery probability at the month's characteristic time T* (e.g., 2.8 hrs for September, the time of EDG-A failure after LOOP initiation);
NREC(T*) = $\Sigma\lambda_{LOOP\text{-}BASE,\, i}$ * $NREC_i$(T*), where $NREC_i$(T*) is the ith LOOP type non-recovery probability at time T*; utilize library PLUG_ LOOPREC.DLL, procedure NREC_WEIGHTED_AVE in SAPHIRE, with recovery time input as T*;

for in-SAPHIRE calculation of IE-LOOP, library PLUGUTIL.DLL, procedure MULTIPLY was utilized with inputs of LOOP-BASE and NREC(T*).

2) CCF(EDG-FTR) = α_2 * FTR (EDG-3B);

where α_2 is the CCF parameter for failure of 2/2 EDGs;
FTR(EDG-3B) – compound event in the SPAR model for EDG-3B failure to run probability

for in-SAPHIRE calculation of CCF(EDG-FTR), library PLUGUTIL.DLL, procedure MULTIPLY was used. This automatically changes CCF with respect to each month's characteristic running time, as FTR(EDG-3B) is a compound event in its own right, whose constituent building blocks (ZT-events) have the running time information inside them, per the current case change set.

3) NREC(X) = NREC(T*+X) / NREC(T*);

where X is the time of interest in the LOOP/SBO event trees (1hr, 2hr or 4 hr), T* is the month's characteristic time of EDG-A failure after LOOP event (e.g., 2.8 hrs in September), and the NRECs are compound events calculated as per above for NREC(T*);

for in-SAPHIRE calculation of NREC(X), library PLUGUTIL.DLL, procedure DIVIDE was used.

In order to distinguish between base case and current case calculations, duplicate of event tree LOOP was created, with initiating event IE-LOOP-BASE, which is calculated as in the base case SPAR model. The initiating event IE-LOOP is the current case LOOP frequency, calculated as above. Additionally, fault trees OPR-01H, OPR-02H and OPR-04H (offsite power non-recovery in 1, 2 and 4 hrs, respectively) were changed to allow toggling between the base case and the current case, using the event OEP-XHE-XL-FLAG (set to TRUE for current case). The modified fault trees are shown in Figures D.1, D.2 and D.3.

The change set for the uncertainty distribution can also be used for the point estimates. The differences between this change set and the one described in the main report are the following:

1) The change set for the uncertainty distribution does not contain events IE-LOOP, EPS-EDG-CF-RUN, OEP-XHE-XL-NR01H, OEP-XHE-XL-NR02H, OEP-XHE-XL-NR04H. These events have been reset from the point estimate change set, i.e., SAPHIRE automatically calculates the correct value based on the underlying compound events and calculations as specified above;

2) Event IE-LOOP-BASE is set to FALSE (base case LOOP frequency);

3) Event OEP-XHE-XL-FLAG is set to TRUE (enables current case NREC calculation);

4) Events EPS-XHE-XL-NR01H and EPS-XHE-XL-NR02H are given the "O" distribution type (constrained noninformative), i.e., similar to the base case distributions.

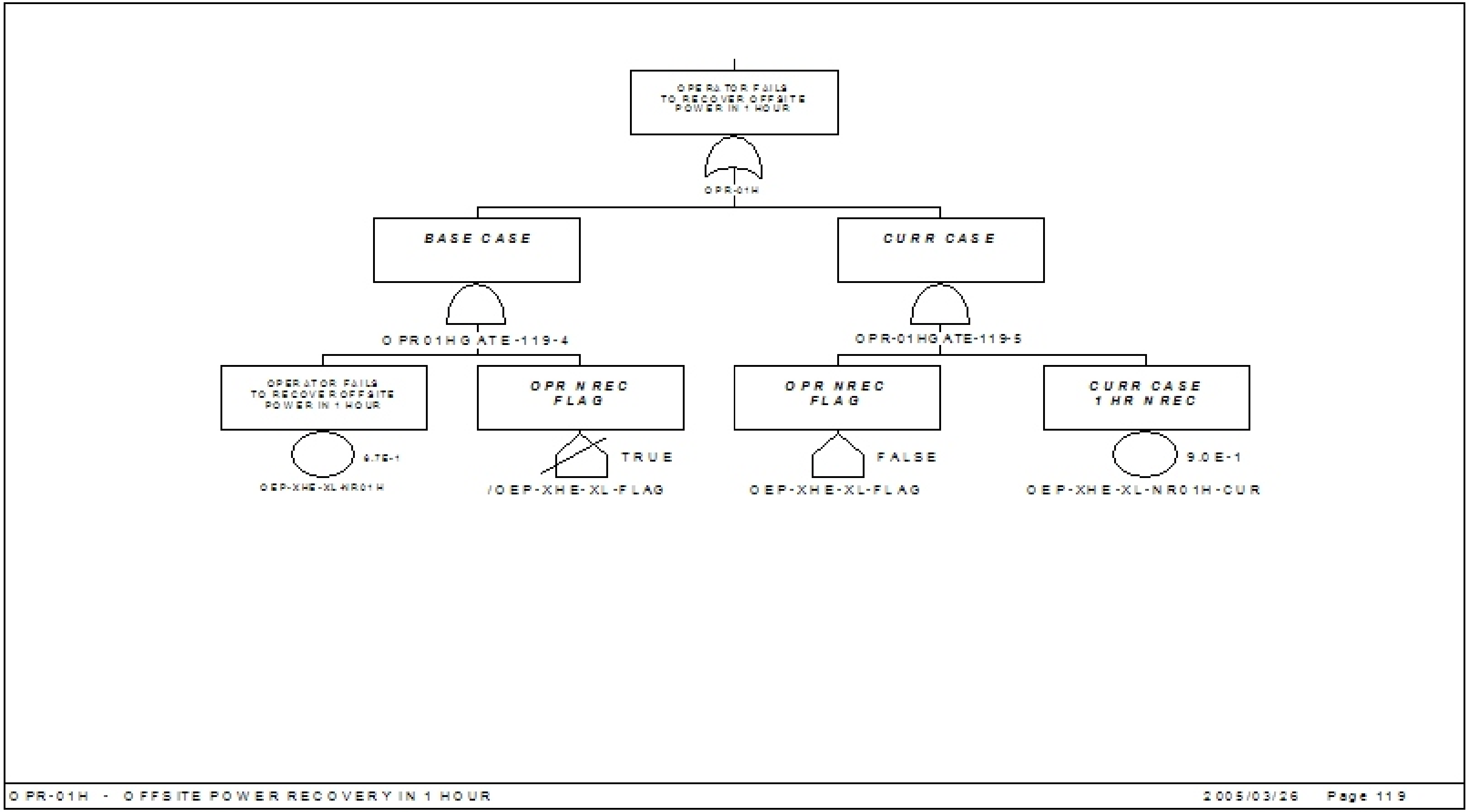

Figure D.1 Modified Fault Tree OPR-01H, Offsite Power Non-Recovery in 1 hr

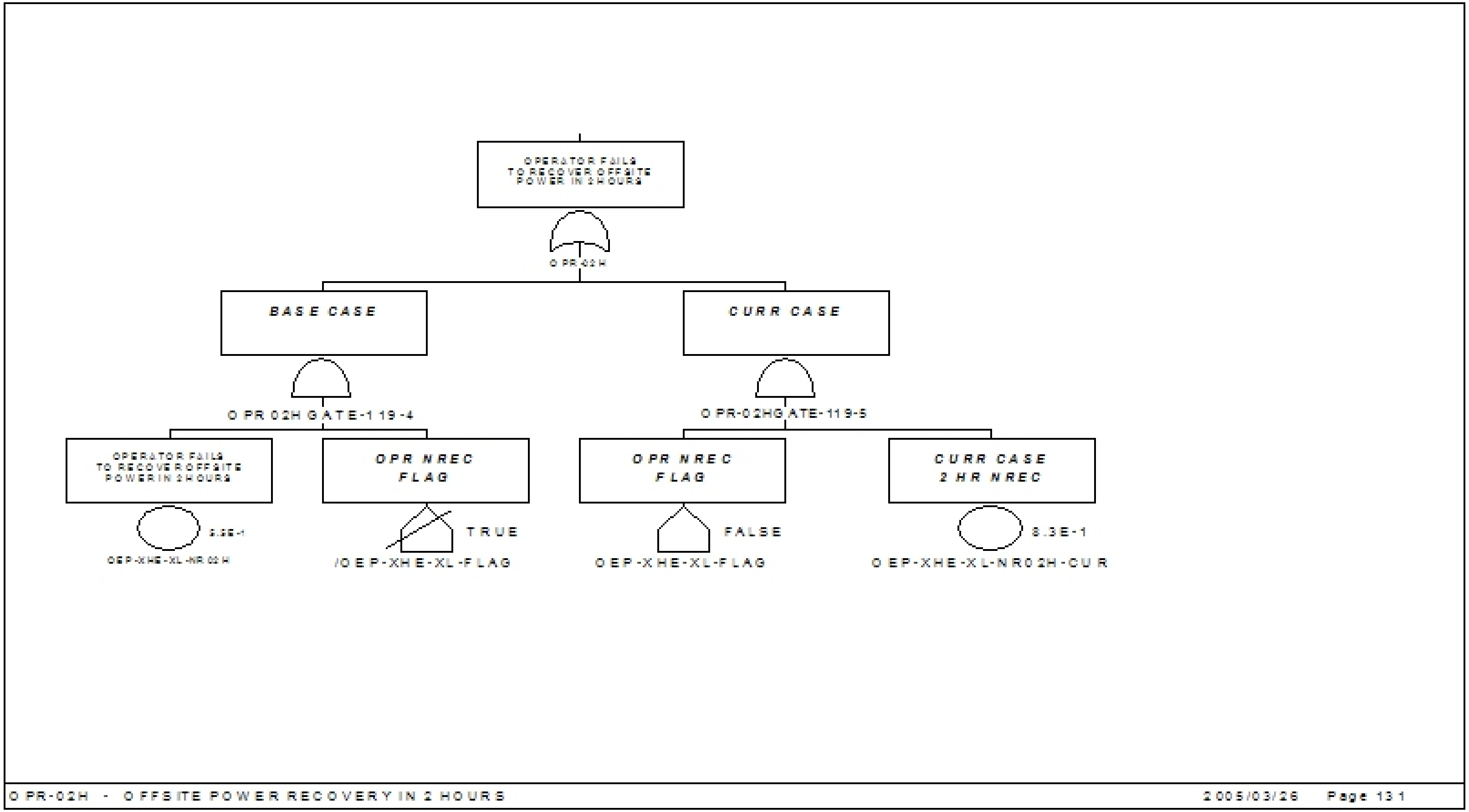

Figure D.2 Modified Fault Tree OPR-02H, Offsite Power Non-Recovery in 2 hr

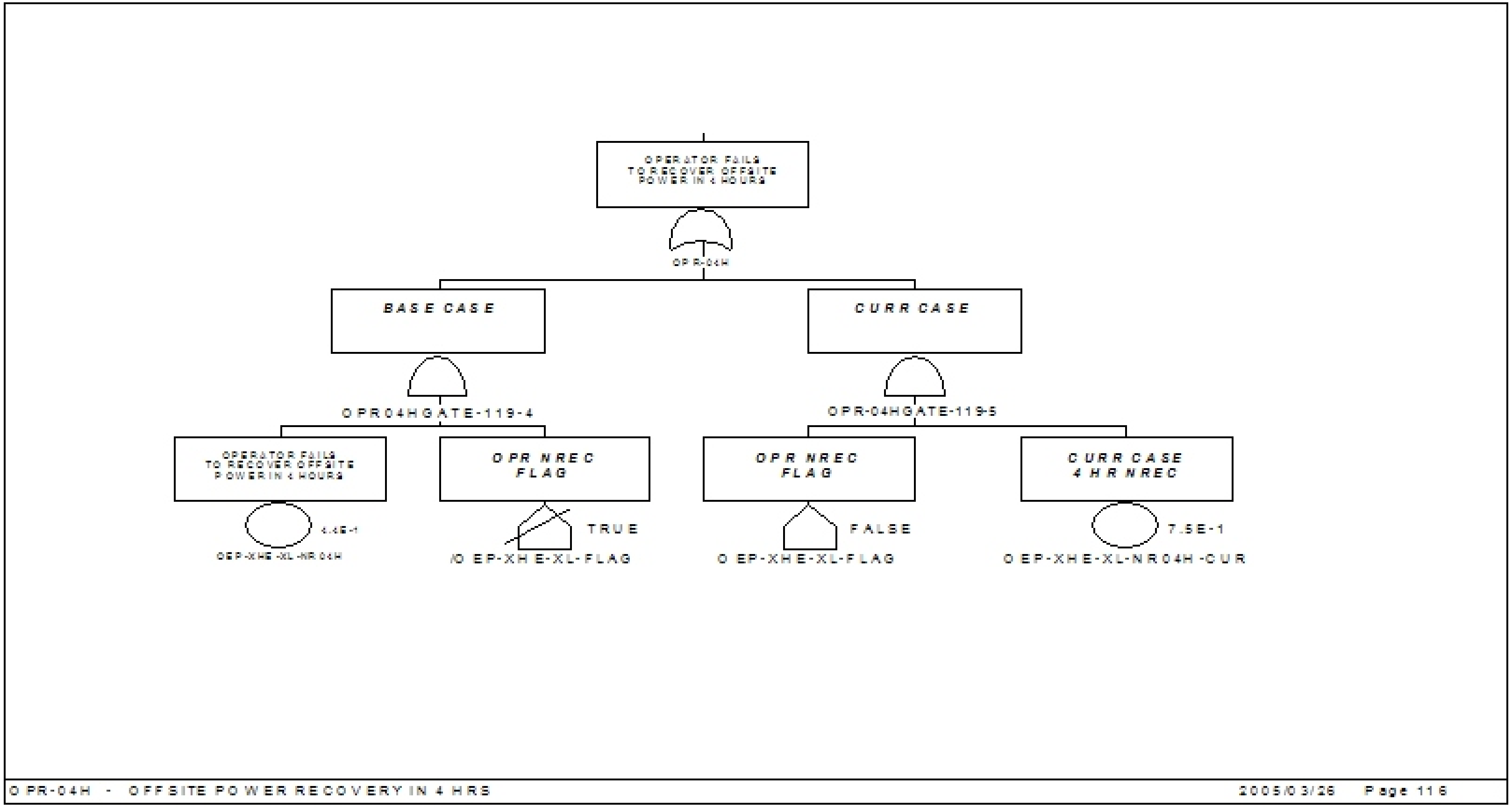

Figure D.3 Modified Fault Tree OPR-04H, Offsite Power Non-Recovery in 4 hr