Emergency Power System Unreliability

1998–2008

1 INTRODUCTION

This report presents an unreliability evaluation of the emergency power system (EPS) at 104 U.S. commercial nuclear power plants listed in Table 1. For each plant the corresponding Standardized Plant Analysis Risk (SPAR) model (version model indicated in Table 1) was used in the yearly calculations. Demand, run hours, and failure data from fiscal year (FY) 1998 through FY 2008 for selected components in the EPS were obtained from the Equipment Performance and Information Exchange (EPIX) database. Train unavailability data (outages from test or maintenance) were obtained from the Reactor Oversight Process (ROP) Safety System Unavailability (SSU) database (FY 1998–FY 2001) and the Mitigating Systems Performance Index (MSPI) database (FY 2002–FY 2008). Common-cause failure (CCF) data used in the models are from the 2005 update to the CCF database.

Table 1. Plant EPS Class listing.

Class	Plant	Version
Class 2	Brunswick 1	3.31
Class 2	Brunswick 2	3.31
Class 2	Callaway	3.31
Class 2	Clinton 1	3.31
Class 2	Columbia 2	3.31
Class 2	Comanche Peak 1	3.31
Class 2	Comanche Peak 2	3.31
Class 2	Cook 1	3.32
Class 2	Cook 2	3.32
Class 2	Cooper	3.31
Class 2	Crystal River 3	3.32
Class 2	Davis-Besse	3.31
Class 2	Duane Arnold	3.31
Class 2	Fort Calhoun	3.31
Class 2	Ginna	3.31
Class 2	Grand Gulf	3.31
Class 2	Harris	3.31
Class 2	Kewaunee	3.31
Class 2	McGuire 1	3.31
Class 2	McGuire 2	3.31
Class 2	Monticello	3.31
Class 2	Nine Mile Pt. 1	3.21
Class 2	Nine Mile Pt. 2	3.21
Class 2	Oconee 1	3.31
Class 2	Oconee 2	3.31
Class 2	Oconee 3	3.31
Class 2	Oyster Creek	3.31
Class 2	Palisades	3.31
Class 2	Perry	3.31
Class 2	Pilgrim	3.31
Class 2	Robinson 2	3.31
Class 2	Seabrook	3.21
Class 2	Summer	3.32
Class 2	Vermont Yankee	3.31
Class 2	Waterford 3	3.31

Class	Plant	Version
Class 2	Wolf Creek	3.31
Class 3	Arkansas 1	3.31
Class 3	Arkansas 2	3.31
Class 3	Beaver Valley 1	3.31
Class 3	Beaver Valley 2	3.31
Class 3	Braidwood 1	3.31
Class 3	Braidwood 2	3.31
Class 3	Byron 1	3.31
Class 3	Byron 2	3.31
Class 3	Calvert Cliffs 1	3.21
Class 3	Calvert Cliffs 2	3.21
Class 3	Catawba 1	3.32
Class 3	Catawba 2	3.32
Class 3	Diablo Canyon 1	3.31
Class 3	Diablo Canyon 2	3.31
Class 3	Farley 1	3.31
Class 3	Farley 2	3.31
Class 3	Hatch 1	3.31
Class 3	Hatch 2	3.31
Class 3	Hope Creek	3.21
Class 3	Indian Point 2	3.31
Class 3	Indian Point 3	3.31
Class 3	La Salle 1	3.31
Class 3	La Salle 2	3.31
Class 3	Millstone 2	3.21
Class 3	Millstone 3	3.21
Class 3	Palo Verde 1	3.31
Class 3	Palo Verde 2	3.31
Class 3	Palo Verde 3	3.31
Class 3	Peach Bottom 2	3.31
Class 3	Peach Bottom 3	3.31
Class 3	River Bend	3.31
Class 3	Salem 1	3.22
Class 3	Salem 2	3.22
Class 3	San Onofre 2	3.21

Class	Plant	Version
Class 3	San Onofre 3	3.21
Class 3	Sequoyah 1	3.31
Class 3	Sequoyah 2	3.31
Class 3	South Texas 1	3.21
Class 3	South Texas 2	3.21
Class 3	St. Lucie 1	3.31
Class 3	St. Lucie 2	3.32
Class 3	Surry 1	3.31
Class 3	Surry 2	3.31
Class 3	Susquehanna 1	3.31
Class 3	Susquehanna 2	3.31
Class 3	Three Mile Isl 1	3.31
Class 3	Turkey Point 3	3.31
Class 3	Turkey Point 4	3.31
Class 3	Vogtle 1	3.31
Class 3	Vogtle 2	3.31
Class 3	Watts Bar 1	3.21
Class 4	Browns Ferry 1	3.21
Class 4	Browns Ferry 2	3.21
Class 4	Browns Ferry 3	3.21
Class 4	Dresden 2	3.31
Class 4	Dresden 3	3.31
Class 4	Fermi 2	3.31
Class 4	FitzPatrick	3.31
Class 4	Limerick 1	3.21
Class 4	Limerick 2	3.21
Class 4	North Anna 1	3.31
Class 4	North Anna 2	3.31
Class 4	Point Beach 1	3.31
Class 4	Point Beach 2	3.31
Class 4	Prairie Island 1	3.31
Class 4	Prairie Island 2	3.31
Class 4	Quad Cities 1	3.31
Class 4	Quad Cities 2	3.31

This report does not attempt to estimate basic event values for use in a probabilistic risk assessment (PRA). Suggested values for such use are presented in the report, *Industry-Average*

Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants, NUREG/CR-6928 (Reference 1). Baseline EPS unreliability results using basic event values from that report are summarized in Section 3. Trend results for EPS (using system-specific data) are presented in Section 4. Similar to previous system study updates, Section 5 contains importance information (using the baseline results from Section 3), and Section 7 describes the EPS.

The EPS was grouped into three classes based on design considerations and configurations. Class 2 EPS includes configurations that effectively result in a success criterion of one of two EDGs (or other emergency power sources). Class 3 EPS includes configurations that effectively result in a success criterion of one of three EDGs (or other emergency power sources). EPS designs effectively resulting in a success criterion of one of four or more are included in Class 4. Table 1 summarizes the plants and their classes.

The EPS model is evaluated using the loss of offsite power (LOOP) flag set in the SPAR model. The LOOP flag set assumes all ac power is unavailable and that the EPS system is required to perform to mitigate the effects of the LOOP initiating event. All models include failures due to unavailability while in test or maintenance. Human error has not been included in the SPAR model logic. An overview of the trending methods, glossary of terms, and abbreviations can be found in the Overview and Reference document on the Reactor Operational Experience Results and Databases web page.

Two modes of the models for the EPS system are calculated. The EPS start-only model is the SPAR EPS model modified by setting all fail-to-run basic events to zero (False), setting unit cross-tie events to False, setting all recovery events to False, and setting all cooling basic events to False. The 8-hour mission model includes all basic events in the EPS SPAR model.

2 SUMMARY OF FINDINGS

The results of this EPS system unreliability study are summarized in this section. Of particular interest is the existence of any statistically significant[1] increasing trends. In this update, two statistically significant increasing trends were identified in the EPS unreliability trend results:

- Trend of EPS system unreliability (start-only model), as a function of fiscal year. (see Figure 3)

- Trend of EPS system unreliability (8-hour model), as a function of fiscal year. (see Figure 4)

The increasing trend in the EPS unreliability (Figure 3 and Figure 4) is statistically significant and is primarily due to the increasing trend in the greater than 1 hour failure to run events.

This update identified no statistically significant decreasing trends in the EPS results.

The industry-wide EPS start-only and 8-hour basic event group importances were evaluated and are shown in Figure 5. In both cases, the leading contributors to EPS system unreliability are the 1E

[1] Statistically significant is defined in terms of the 'p-value.' A p-value is a probability indicating whether to accept or reject the null hypothesis that there is no trend in the data. P-values of less than or equal to 0.05 indicate that we are 95% confident that there is a trend in the data (reject the null hypothesis of no trend.) By convention, we use the "Michelin Guide" scale: p-value < 0.05 (statistically significant), p-value < 0.01 (highly statistically significant); p-value < 0.001 (extremely statistically significant).

Generator group of basic events, generator auxiliary equipment, and special events. Cooling and the cross-tie to another unit were also important for the 8-hour mission model only.

3 INDUSTRY-WIDE UNRELIABILITY

The EPS fault trees from the SPAR models were evaluated for each of the 104 operating U.S. commercial nuclear power plants.

The industry-wide unreliability of the EPS has been estimated for two modes of operation. A start-only model and an 8-hour mission model were evaluated, see Table 2. The uncertainty distributions for the EPS classes include both plant design variability (within a class) and parameter uncertainty while using industry-wide component failure data (FY 1998–FY 2002)[2]. Table 2 shows the percentiles and mean of the aggregated sample data (Latin hypercube, 1000 samples for each model) collected from the uncertainty calculations of the EPS fault trees in the SPAR models. In Figure 1 and Figure 2, the 5th and 95th percentiles and mean point estimates are shown each class and for the industry.

Table 2. Industry-wide unreliability values.

Model	EPS Grouping	Lower (5%)	Median	Mean	Upper (95%)
Start-Only	Industry	4.98E-07	6.77E-05	3.11E-04	1.36E-03
	Class 2	1.41E-05	4.36E-04	6.79E-04	2.11E-03
	Class 3	1.77E-06	3.40E-05	1.42E-04	6.43E-04
	Class 4	1.92E-09	6.57E-06	3.60E-05	1.63E-04
8-hour Mission	Industry	1.12E-05	3.99E-04	1.05E-03	4.01E-03
	Class 2	7.72E-05	1.59E-03	2.12E-03	5.94E-03
	Class 3	3.04E-05	2.47E-04	5.75E-04	2.15E-03
	Class 4	9.96E-07	4.36E-05	2.07E-04	1.03E-03

[2] By using industry-wide component failure data, individual plant performance is not included in the distribution of results.

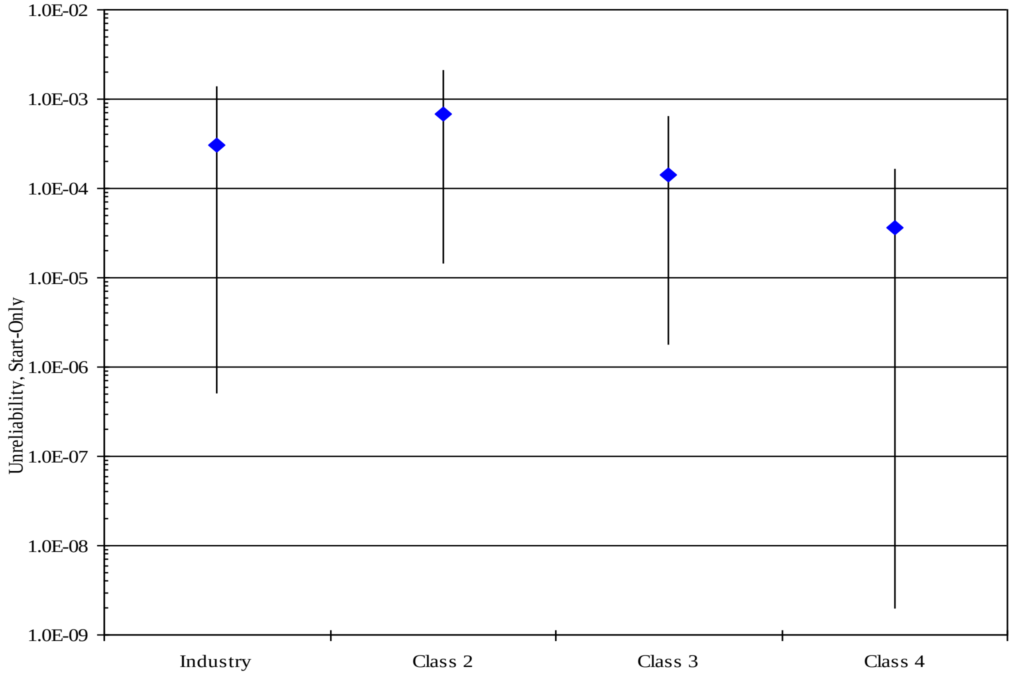

Figure 1. EPS start-only mission unreliability for Class 2, 3, and 4 and industry-wide groupings.

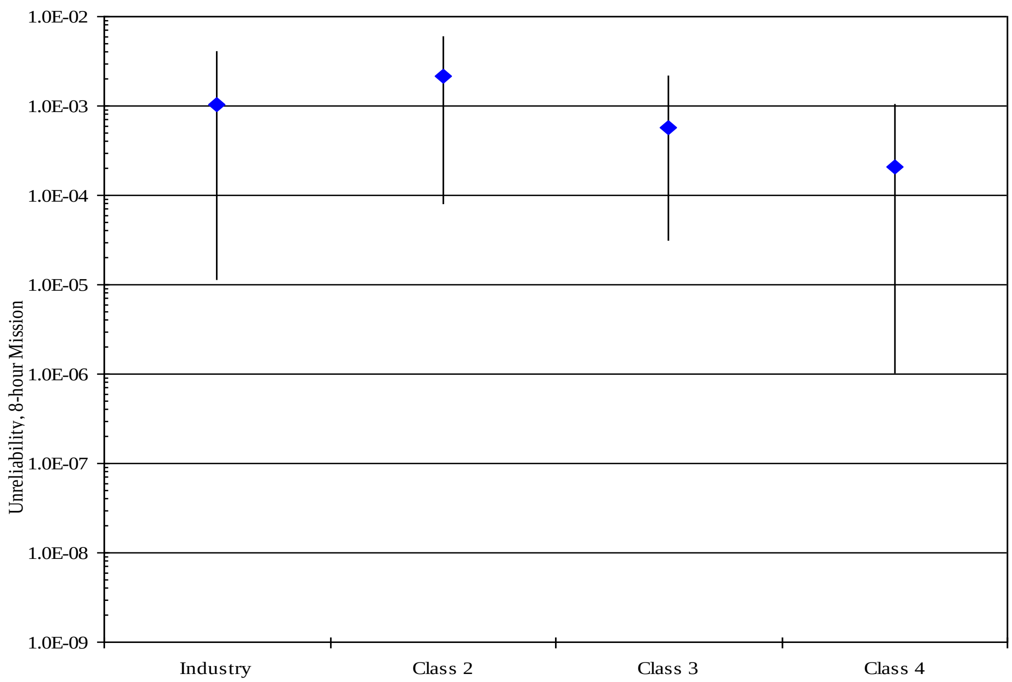

Figure 2. EPS 8-hour mission unreliability for Class 2, 3, and 4 and industry-wide groupings.

4 INDUSTRY-WIDE TRENDS

The yearly (FY 1998–FY 2008) failure and demand or run time data were obtained from EPIX for the EPS system. EPS train maintenance unavailability data for trending are from the same time period, as reported in the ROP and EPIX. The component basic event uncertainty was calculated for the EPS system components using the trending methods described in Section 1 and 2 of the Overview and Reference document. These data were loaded into the EPS system fault tree in each SPAR model with an EPS system (see Table 1).

The trend charts show the results of varying component reliability data over time and updating generic, relatively-flat prior distributions using data for each year. In addition, for comparison, this update (current SPAR/EPIX) is shown. Section 4 of the Overview and Reference link on the System Studies main web page provides more detailed discussion of the trending methods. In the lower left hand corner of the trend figures, the regression method is reported.

The components that were varied in the EPS model are:

- EPS diesel generator start, run, and test and maintenance.

Figure 3 shows the trend in the EPS start-only model unreliability. Table 4 shows the data points for Figure 3. No statistically significant trends within the industry-wide estimates of EPS system unreliability (FTS) on a per fiscal year basis were identified.

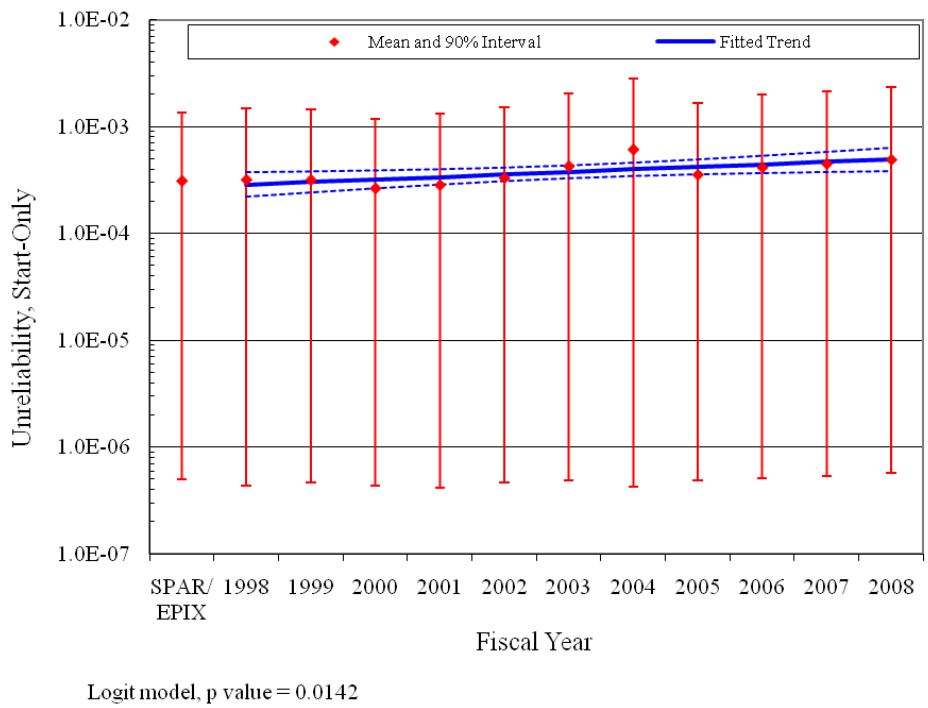

Figure 3. Trend of EPS system unreliability (start-only model), as a function of fiscal year.

Figure 4 shows the trend in the 8-hour mission unreliability. No statistically significant trend within the industry-wide estimates of EPS system unreliability (8-hour mission) on a per fiscal year basis was identified. Table 5 shows the data points for Figure 4.

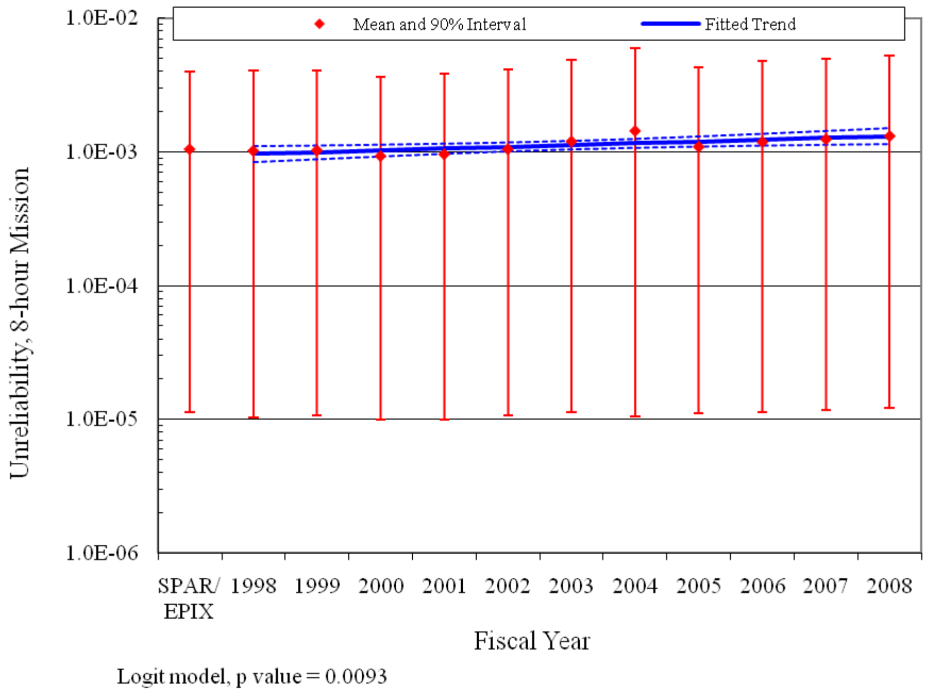

Figure 4. Trend of EPS system unreliability (8-hour model), as a function of fiscal year.

5 BASIC EVENT GROUP IMPORTANCES

The EPS basic event group Fussell-Vesely importances were calculated for the FTS and 8-hour model for each plant using the industry-wide data (1998–2002). These basic event group importances were then averaged across all plants to represent an industry-wide basic event group importance. The industry-wide EPS start-only and 8-hour basic event group importances are shown in Figure 5. In both cases, the leading contributors to EPS system unreliability are the 1E Generator group of basic events, generator auxiliary equipment, and special events. Cooling and the cross-tie to another unit were also important for the 8-hour mission model only. For more discussion on the EPS diesel generators, see the emergency diesel generator component reliability study at NRC Reactor Operational Experience Results and Databases. Table 3 shows the SPAR model EPS importance groups and their descriptions.

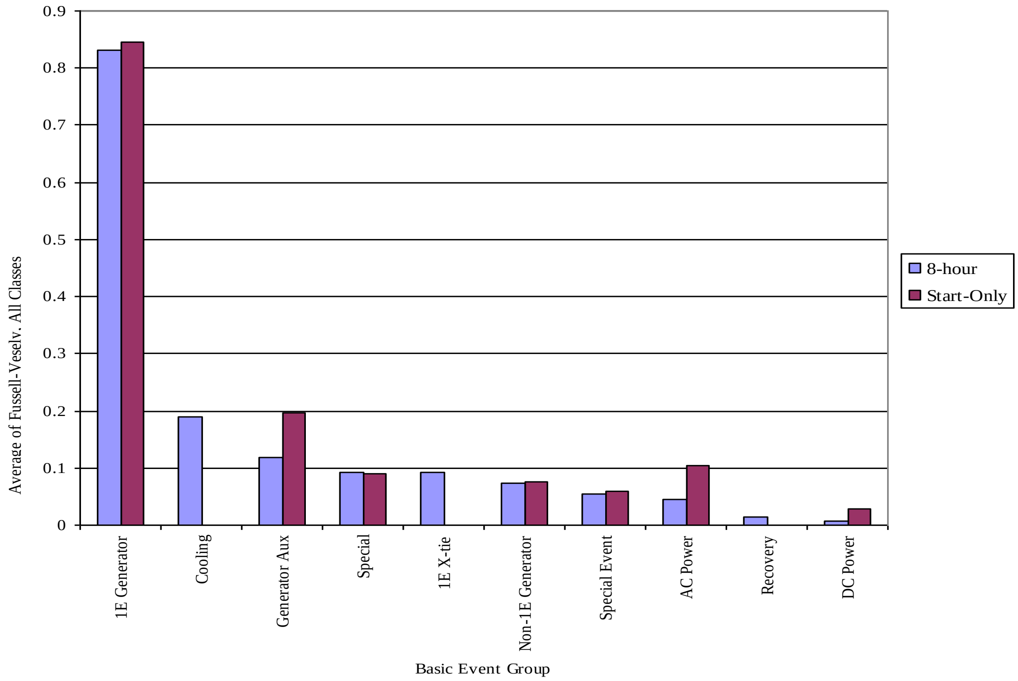

Figure 5. EPS industry-wide basic event group importances.

Table 3. EPS model basic event importance group descriptions.

Group	Description
1E Generator	All basic events associated with the primary emergency power supplies. Includes diesel, gas turbine, and hydro powered equipment. The start, run, common-cause, and test and maintenance are included in this group of basic events.
1E X-tie	Cross-tie or swing 1E qualified generating equipment available to the EPS in the model.
AC Power	Buses and circuit breakers in the EPS model.
Cooling	Cooling support components: service water or component cooling pumps, valves, and heat exchangers.
DC Power	Buses, circuit breakers, battery chargers, and batteries in the EPS model.
Generator Aux	This group includes the emergency power auxiliary components that are explicitly modeled in the EPS system. Includes the fuel oil, starting air, room cooling, and electrical dedicated to the generators.
Non 1E Generator	All basic events associated with the secondary emergency power supplies. Includes diesel, gas turbine, and hydro powered equipment. The start, run, common-cause, and test and maintenance are included in the group of basic events.
Recovery	This group contains the events that allow operator recovery from expected automatic actions.
SBO Generator	These are all the various types of alternate power supplies: Diesel generators, combustion-turbines, and hydro-turbines.
Special Event	These are various special events that are added to the model to model plant-specific conditions that affect the EPS.

The basic event group importances were also averaged across plants of the same EPS class to represent class basic event group importances. The class EPS start-only and 8-hour basic event group importances are shown in Figure 6, Figure 7, and Figure 8. In both cases, for all classes, the leading contributor to EPS system unreliability is the 1E Generator group of basic events.

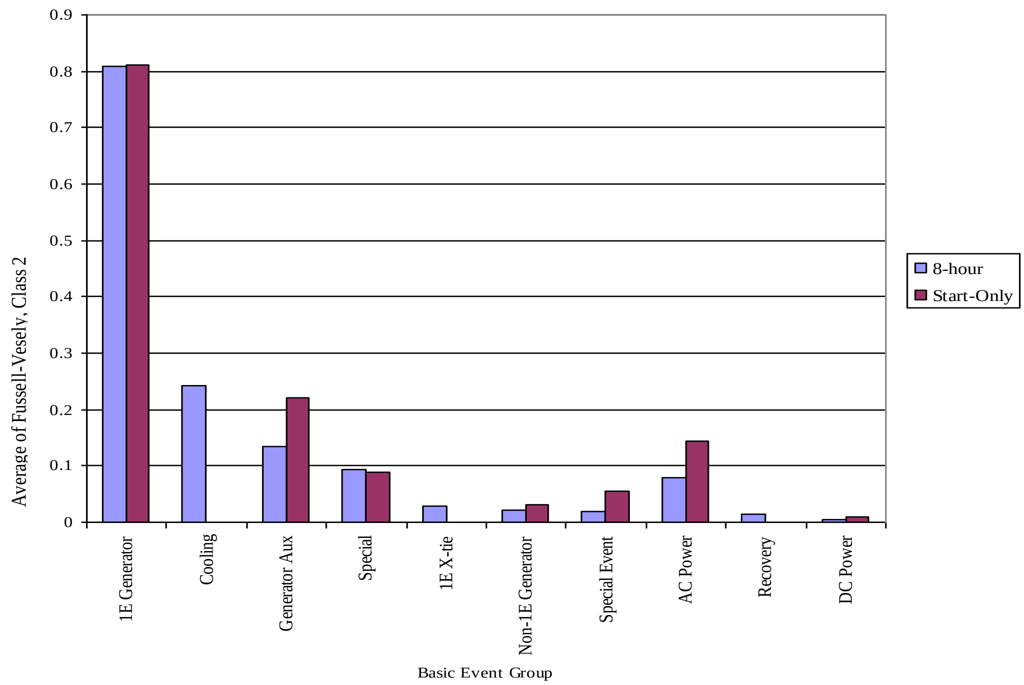

Figure 6. EPS Class 2 basic event group importances.

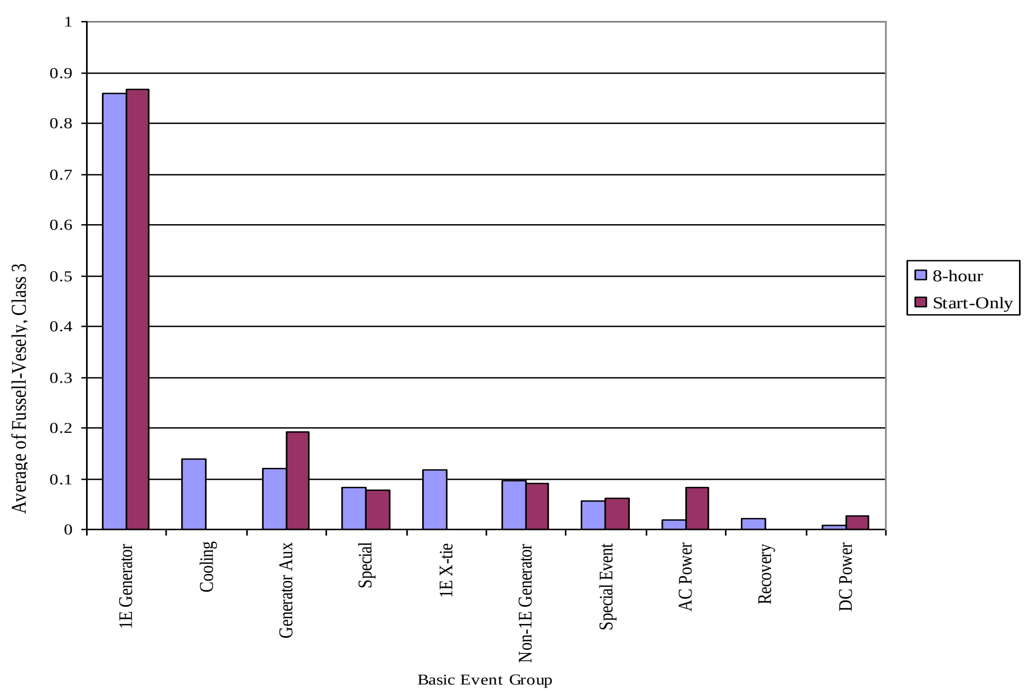

Figure 7. EPS Class 3 basic event group importances.

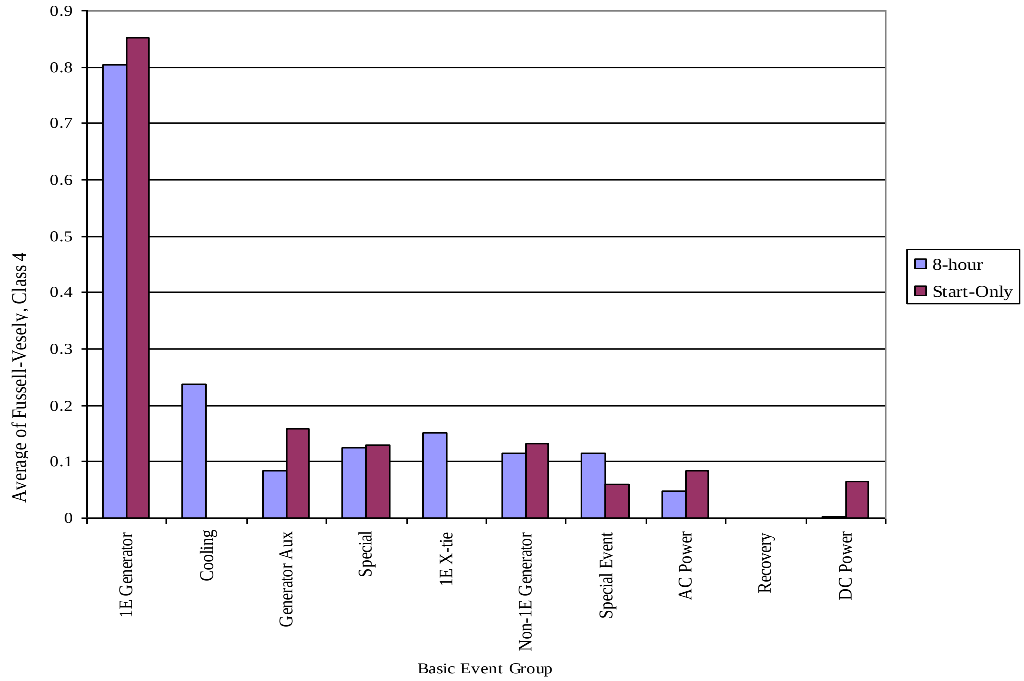

Figure 8. EPS Class 4 basic event group importances.

6 DATA TABLES

Table 4. Plot data for EPS start-only trend, Figure 3.

FY/Source	Regression Curve Data Points			Plot Trend Error Bar Points		
	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
SPAR/ EPIX				4.98E-07	1.36E-03	3.11E-04
1998	2.87E-04	2.21E-04	3.72E-04	4.33E-07	1.48E-03	3.18E-04
1999	3.03E-04	2.42E-04	3.79E-04	4.67E-07	1.44E-03	3.17E-04
2000	3.19E-04	2.64E-04	3.87E-04	4.35E-07	1.17E-03	2.64E-04
2001	3.37E-04	2.86E-04	3.98E-04	4.17E-07	1.31E-03	2.84E-04
2002	3.56E-04	3.08E-04	4.12E-04	4.69E-07	1.52E-03	3.31E-04
2003	3.76E-04	3.27E-04	4.32E-04	4.93E-07	2.04E-03	4.26E-04
2004	3.97E-04	3.43E-04	4.59E-04	4.23E-07	2.79E-03	6.11E-04
2005	4.19E-04	3.56E-04	4.94E-04	4.92E-07	1.64E-03	3.55E-04
2006	4.42E-04	3.65E-04	5.36E-04	5.08E-07	1.97E-03	4.16E-04
2007	4.67E-04	3.73E-04	5.84E-04	5.39E-07	2.13E-03	4.49E-04
2008	4.93E-04	3.80E-04	6.39E-04	5.68E-07	2.33E-03	4.90E-04

Table 5. Plot data for EPS 8-hour trend, Figure 4.

FY/Source	Regression Curve Data Points			Plot Trend Error Bar Points		
	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
SPAR/ EPIX				1.12E-05	4.01E-03	1.05E-03
1998	9.67E-04	8.46E-04	1.11E-03	1.02E-05	4.07E-03	1.02E-03
1999	9.97E-04	8.88E-04	1.12E-03	1.06E-05	4.03E-03	1.03E-03
2000	1.03E-03	9.31E-04	1.13E-03	9.98E-06	3.64E-03	9.33E-04
2001	1.06E-03	9.73E-04	1.15E-03	9.89E-06	3.81E-03	9.62E-04
2002	1.09E-03	1.01E-03	1.18E-03	1.07E-05	4.15E-03	1.05E-03
2003	1.13E-03	1.05E-03	1.21E-03	1.12E-05	4.85E-03	1.20E-03
2004	1.16E-03	1.08E-03	1.25E-03	1.06E-05	5.98E-03	1.44E-03
2005	1.20E-03	1.10E-03	1.30E-03	1.10E-05	4.31E-03	1.10E-03
2006	1.23E-03	1.12E-03	1.36E-03	1.14E-05	4.77E-03	1.19E-03
2007	1.27E-03	1.13E-03	1.43E-03	1.18E-05	5.00E-03	1.25E-03
2008	1.31E-03	1.15E-03	1.50E-03	1.23E-05	5.28E-03	1.32E-03

7 EPS SYSTEM DESCRIPTION

The EPS is designed to provide backup, onsite ac power to vital buses given a LOOP until offsite power can be restored to the plant. EPS designs vary widely among the 104 U.S. commercial nuclear power plants. A summary of those designs is presented in Table 6. Typical EPS designs include two, three, or four EDGs, with only one of the EDGs required for success. However, as indicated in Table 6, there are many variations of these typical designs, including shared EDGs and/or the ability to cross-tie to other EDGs (at multi-plant sites), and availability of alternate ac sources such as gas turbine generators (GTGs) or hydro turbine generators (HTGs). In addition, several of the plants require two EDGs for long-term success, rather than one.

SPAR modeling of the EPS incorporates the plant-to-plant design and operational differences indicated in Table 6. Table 6 shows the generating equipment used in the SPAR EPS model. In some cases, two models use the same equipment. These are repeated for each entry to show how the SPAR models calculate. All ac emergency power sources that either are automatically started and aligned to essential buses given a LOOP or can be manually started and aligned within approximately 30 minutes are included in the SPAR EPS fault trees. Additional emergency power sources such as GTGs or HTGs that require more than 30 minutes to start and align to essential buses are included in other parts of the SBO event tree, typically as additional credit for recovery of ac power. Included in the SPAR EPS fault trees are dependencies such as room cooling, service water cooling, and DC power.

Table 6. EPS configurations at U.S. commercial nuclear power plants.

Class	Plant	Total	1E Generator	1E X-tie	Non-1E Generator
Class 2	Beaver Valley 1	2	2		
Class 2	Brunswick 1	4	2	2	
Class 2	Brunswick 2	4	2	2	
Class 2	Callaway	2	2		
Class 2	Clinton 1	2	2		
Class 2	Columbia 2	2	2		
Class 2	Comanche Peak 1	2	2		
Class 2	Comanche Peak 2	2	2		
Class 2	Cook 1	2	2		
Class 2	Cook 2	2	2		
Class 2	Cooper	2	2		
Class 2	Crystal River 3	2	2		
Class 2	Davis-Besse	2	2		
Class 2	Duane Arnold	2	2		
Class 2	Fort Calhoun	2	2		
Class 2	Ginna	2	2		
Class 2	Grand Gulf	2	2		
Class 2	Harris	2	2		
Class 2	Kewaunee	2	2		
Class 2	McGuire 1	2	2		
Class 2	McGuire 2	2	2		
Class 2	Monticello	2	2		
Class 2	Nine Mile Pt. 1	2	2		
Class 2	Nine Mile Pt. 2	2	2		
Class 2	Oconee 1	2	1	1	
Class 2	Oconee 2	2	1	1	
Class 2	Oconee 3	2	1	1	
Class 2	Oyster Creek	2	2		
Class 2	Palisades	2	2		
Class 2	Perry	2	2		
Class 2	Pilgrim	2	2		
Class 2	River Bend	3	3 (C EDG is different)		1
Class 2	Robinson 2	3	2		1
Class 2	Seabrook	2	2		
Class 2	Summer	2	2		
Class 2	Vermont Yankee	2	2		
Class 2	Waterford 3	2	2		
Class 2	Wolf Creek	2	2		
Class 3	Arkansas 1	3	2		1
Class 3	Arkansas 2	3	2		1
Class 3	Beaver Valley 2	4	2	2	
Class 3	Braidwood 1	4	4		
Class 3	Braidwood 2	4	4		
Class 3	Byron 1	4	2	2	
Class 3	Byron 2	4	2	2	
Class 3	Calvert Cliffs 1	5	2	2	1

Table 6. EPS configurations at U.S. commercial nuclear power plants.

Class	Plant	Total	1E Generator	1E X-tie	Non-1E Generator
Class 3	Calvert Cliffs 2	5	2	2	1
Class 3	Catawba 1	4	2	2	
Class 3	Catawba 2	4	2	2	
Class 3	Diablo Canyon 1	3	3		
Class 3	Diablo Canyon 2	3	3		
Class 3	Farley 1	5	3	2	
Class 3	Farley 2	5	3	2	
Class 3	Hatch 1	5	3	2	
Class 3	Hatch 2	5	3	2	
Class 3	Hope Creek	4	4		
Class 3	Indian Point 2	3	3		
Class 3	Indian Point 3	3	3		
Class 3	La Salle 1	4	2	2	
Class 3	La Salle 2	4	2	2	
Class 3	Millstone 2	3	2		1
Class 3	Millstone 3	3	2		1
Class 3	Palo Verde 1	8	2	4 (not effective in model)	2 (need both)
Class 3	Palo Verde 2	8	2	4 (not effective in model)	2 (need both)
Class 3	Palo Verde 3	8	2	4 (not effective in model)	2 (need both)
Class 3	Peach Bottom 2	4	4 (2 of 4)		
Class 3	Peach Bottom 3	4	4 (2 of 4)		
Class 3	Salem 1	4	3		1
Class 3	Salem 2	4	3		1
Class 3	San Onofre 2	4	2	2	
Class 3	San Onofre 3	4	2	2	
Class 3	Sequoyah 1	4	2	2	
Class 3	Sequoyah 2	4	2	2	
Class 3	South Texas 1	3	3		
Class 3	South Texas 2	3	3		
Class 3	St. Lucie 1	4	2	2	
Class 3	St. Lucie 2	4	2	2	
Class 3	Surry 1	4	3		1
Class 3	Surry 2	4	3		1
Class 3	Susquehanna 1	5	5 (2 of the EDGs cannot support all loads)		
Class 3	Susquehanna 2	5	5 (2 of the EDGs cannot support all loads)		
Class 3	Three Mile Isl 1	3	2		1
Class 3	Turkey Point 3	4	2	2	
Class 3	Turkey Point 4	4	2	2	
Class 3	Vogtle 1	3	2	1	
Class 3	Vogtle 2	3	2	1	
Class 3	Watts Bar 1	4	2	2	
Class 4	Browns Ferry 1	8	4	4	
Class 4	Browns Ferry 2	6	4	2	
Class 4	Browns Ferry 3	8	4	4	
Class 4	Dresden 2	5	2	1	2
Class 4	Dresden 3	5	2	1	2
Class 4	Fermi 2	9	4		5
Class 4	FitzPatrick	4	4		
Class 4	Limerick 1	6	4	2	

Table 6. EPS configurations at U.S. commercial nuclear power plants.

Class	Plant	Total	1E Generator	1E X-tie	Non-1E Generator
Class 4	Limerick 2	6	4	2	
Class 4	North Anna 1	5	2	2	1
Class 4	North Anna 2	5	2	2	1
Class 4	Point Beach 1	5	4		1
Class 4	Point Beach 2	5	4		1
Class 4	Prairie Island 1	4	2	2	
Class 4	Prairie Island 2	4	2	2	
Class 4	Quad Cities 1	5	1	2	2
Class 4	Quad Cities 2	5	1	2	2

The typical EPS consists of two or more emergency power sources, usually diesel generators, connected to two or more vital or safety buses. These vital buses power equipment needed for safe shutdown during most transients that are postulated at nuclear power plants.

Figure 9 shows the simplest EPS configuration. Variations are: more buses, usually with their own emergency power sources, swing power sources that can power vital buses at either of two units, and alternate emergency power sources typically referred to as station blackout generators.

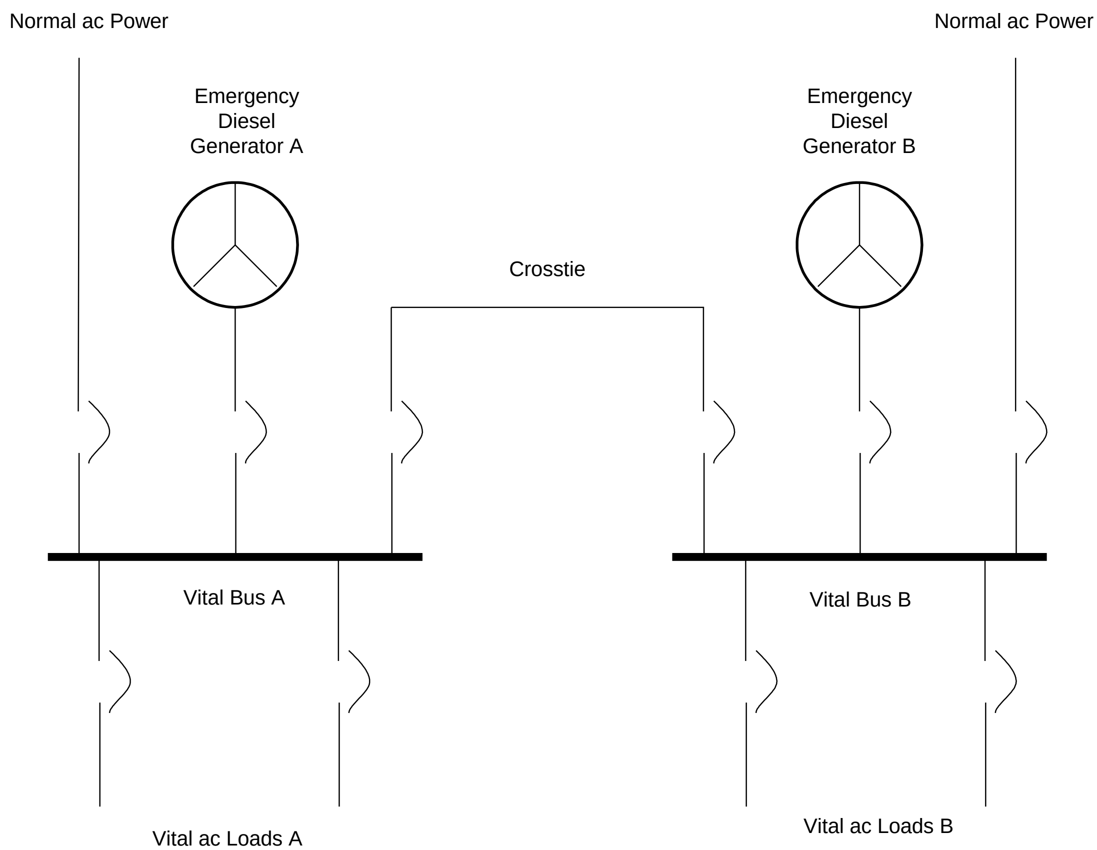

Figure 9. Simplified EPS system schematic.

The SPAR models of the EPS include many more components than those shown in Figure 9. Most of these components are related to the support needed for the emergency power source success. Some of these are explicitly modeled in SPAR if there is a common-mode failure of multiple generators. Generally, these include:

- Cooling—Cooling is required to remove heat from the lubricating oil and the engine itself. Cooling is provided by service water either directly or through a closed loop cooling system such as component cooling water. Some emergency power sources have dedicated cooling systems that are independent of the service water systems.

- Room Cooling—Room cooling is usually required for extended performance of the EPS. The room cooling is provided by air conditioning heat exchangers that may be cooled by a chilled water source.

- Fuel Oil—Fuel oil is usually provided from a common fuel oil tank to separate 'day tanks' for each emergency power source. Pumps, valves, and instrumentation are required to maintain day tank levels and to supply fuel oil to the engine itself.

- Sequencer—The sequencer strips loads from the dead bus prior to attempting to load the bus with the emergency power source. Then the sequencer sequences loads back onto the bus once it has been re-energized.

- DC Power—DC power is provided by the vital batteries. DC power provides the energy to operate breakers and powers the control circuitry for the EPS.

8 REFERENCE

1. S.A. Eide, et al, *Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants*, U.S. Nuclear Regulatory Commission, NUREG/CR-6928, February 2007.