Reliability Study Update

Emergency Diesel Generator

1997–2005

This report presents a performance evaluation of the emergency diesel generators (EDGs) at U.S. commercial power plants. The evaluation is based on the operating experience from fiscal year 1997 through 2005. This is the latest update to NUREG/CR-5500 Volume 5, updating data, availability and reliability estimates, trends, and figures. The data for the initial EDG study were obtained from LERs and Special Reports for plants reporting under Regulatory Guide 1.108 for 1987 through 1993. Plants have not been reporting these Special Reports to NRC since RG 1.108 was canceled. Therefore, the EDG results used in this update were obtained from the Equipment Performance and Information Exchange (EPIX) database using the Reliability and Availability Database System (RADS) software for 1997 through 2005. In addition, the maintenance out-of-service estimates are obtained from the reactor oversight program (ROP) and the failure to recover estimates are from NUREG/CR-5500 Volume 5.

This report calculates two basic models for the EDGs. The first model, start mission, models the period when the EDG has achieved rated speed and/or voltage (FTS) and includes the load and run model (FTLR). The load and run demand includes the loading of the EDG and closing of the output circuit breaker, as well as the first hour of operation. The EDG run mission (FTR) is for seven hours which makes a total of 8-hours of operation.

1   LATEST VALUES AND TRENDS

1.1 Industry-Wide Unavailability and Unreliability

The industry-wide unavailability and unreliability of the EDGs have been estimated from operating experience. A failure to start (FTS) unavailability and an 8-hour mission unreliability were evaluated, see Table 1. The estimates are based on failures that occurred during unplanned demands, cyclic, and quarterly surveillance tests.

Table 1. Industry-wide values.

	Model	Lower (5%)	Mean	Upper (95%)
No Recovery	Failure-to-Start (Unavailability)	8.47E-03	1.47E-02	2.24E-02
	8-hour Mission (Unreliability)	8.92E-03	2.17E-02	3.88E-02
With Recovery	Failure-to-Start (Unavailability)	8.68E-03	1.27E-02	1.73E-02
	8-hour Mission (Unreliability)	8.42E-03	1.61E-02	2.58E-02

1.2 Fail to Start Model Results

An extremely statistically significant[1] decreasing trend is shown for the industry estimates of EDG Unavailability (FTS), without Recovery, on a per fiscal year basis. A statistically significant trend is shown for the Unavailability with Recovery case. Figure 1 shows the trend in the FTS model, Unavailability without Recovery. Table 2 shows the data points for Figure 1. Figure 3 shows the trend in the FTS model, Unavailability with Recovery. Table 3 shows the data points for Figure 3.
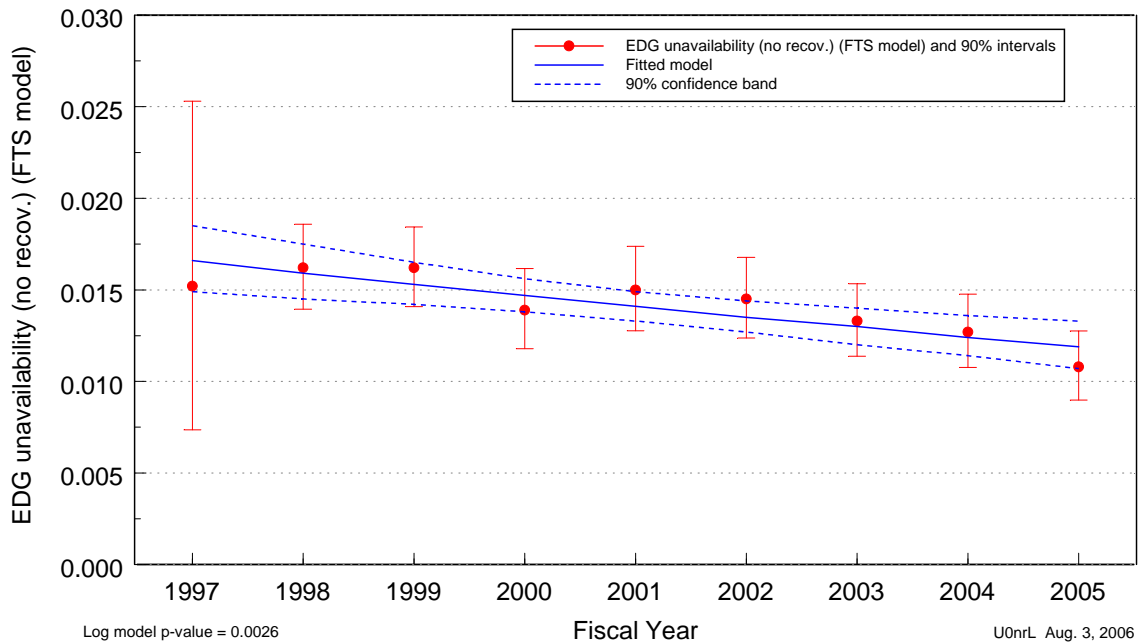

Figure 1. Trend of EDGs unavailability (FTS model, no recovery), as a function of fiscal year.

The leading contributor to EDG system short-term unavailability without recovery is maintenance out of service. Figure 2 shows the distribution of segment failure contributions for the unavailability (FTS model) without recovery model.

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[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).
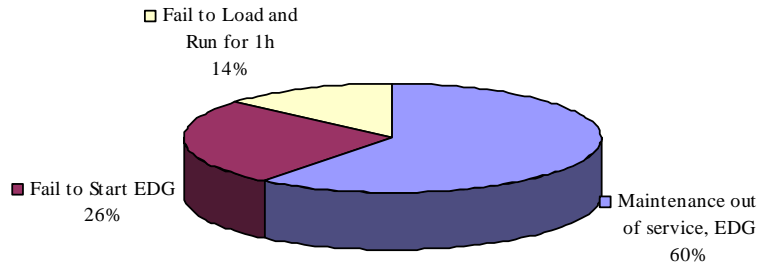
Figure 2. Segment failure distribution, FTS without recovery model.
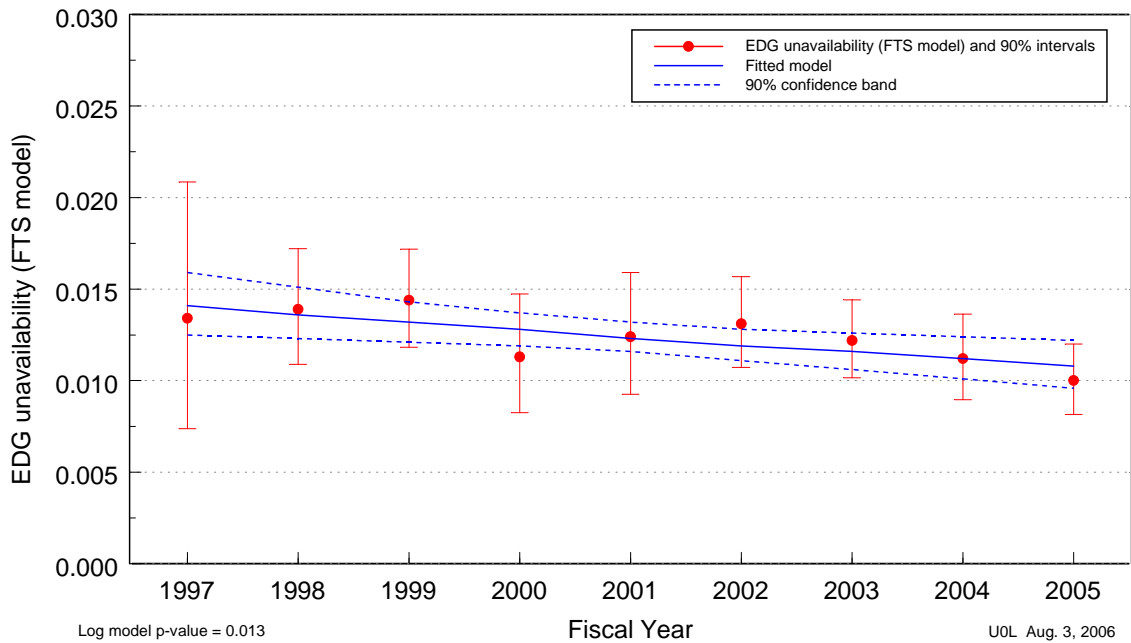

Figure 3. Trend of EDGs unavailability (FTS model, with recovery), as a function of fiscal year.

The leading contributor to EDG system short-term unavailability with recovery is maintenance out of service. Figure 4 shows the distribution of segment failure contributions for the unavailability (FTS model) with recovery model.
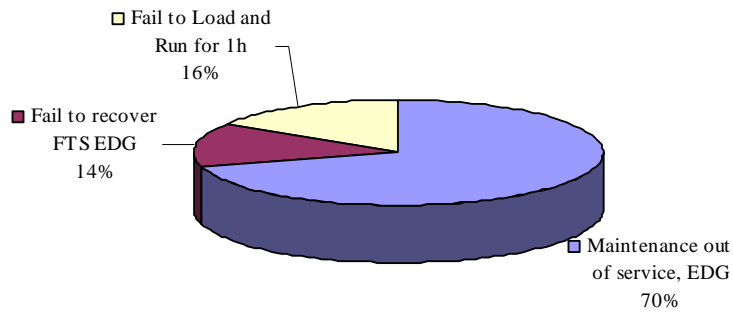

Fail to Load and
Run for 1h
16%

Fail to recover
FTS EDG
14%

Maintenance out
of service, EDG
70%

Figure 4. Segment failure distribution, FTS with recovery model.

1.3 Fail to Operate for 8-Hour Model

No statistically significant trend within the industry estimates of EDGs Unreliability (8-hour mission), with or without Recovery, on a per fiscal year basis was identified. Figure 5 displays the trend by fiscal year of the EDGs unreliability calculated from the 1997–2005 experience without recovery. Table 4 shows the data points for Figure 5. Figure 7 shows the trend in the 8-hour mission model unreliability with recovery. Table 5 shows the data points for Figure 7.

Figure 5. Trend of EDGs unreliability (8-hour model, no recovery), as a function of fiscal year.

The leading contributor to EDG system short-term unreliability without recovery is maintenance out of service. Figure 6 shows the distribution of segment failure contributions for the unreliability without recovery model.

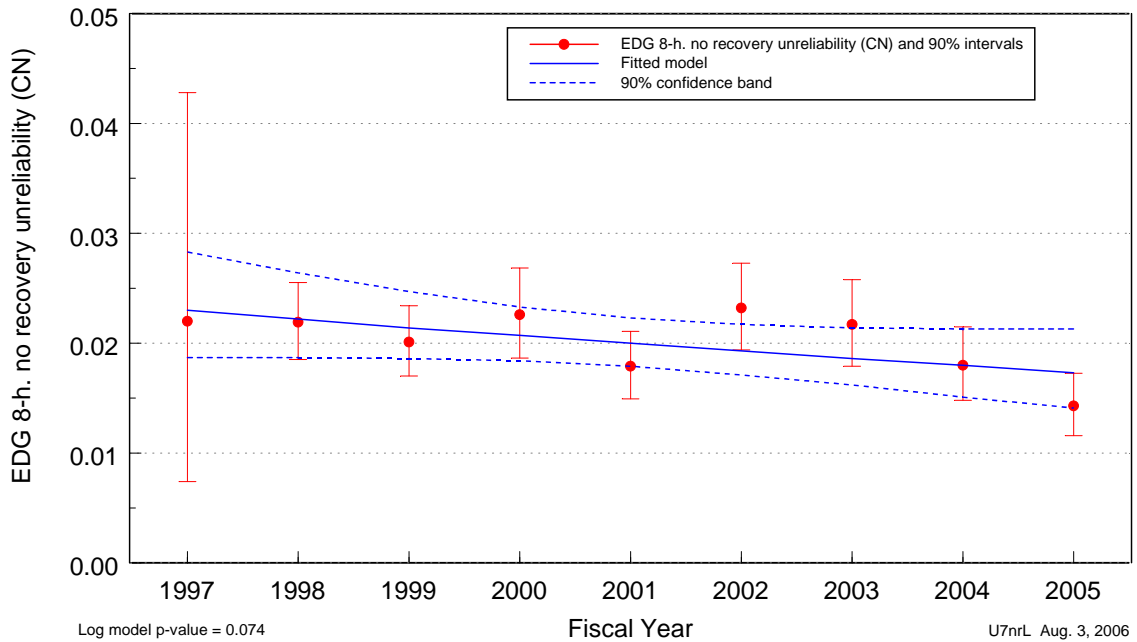**Figure 6. Segment failure distribution, FTS without recovery model.**

Figure 7. Trend of EDGs unreliability (8-hour model, with recovery), as a function of fiscal year.

The leading contributor to EDG system short-term unreliability with recovery is maintenance out of service. Figure 8 shows the distribution of segment failure contributions for the unreliability with recovery model.
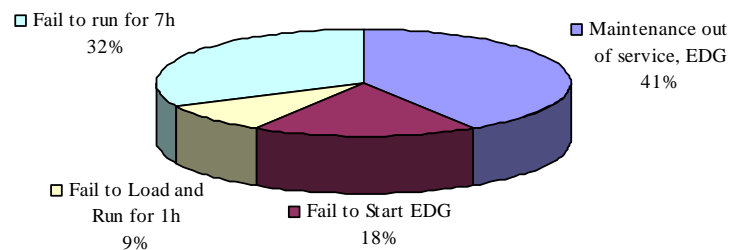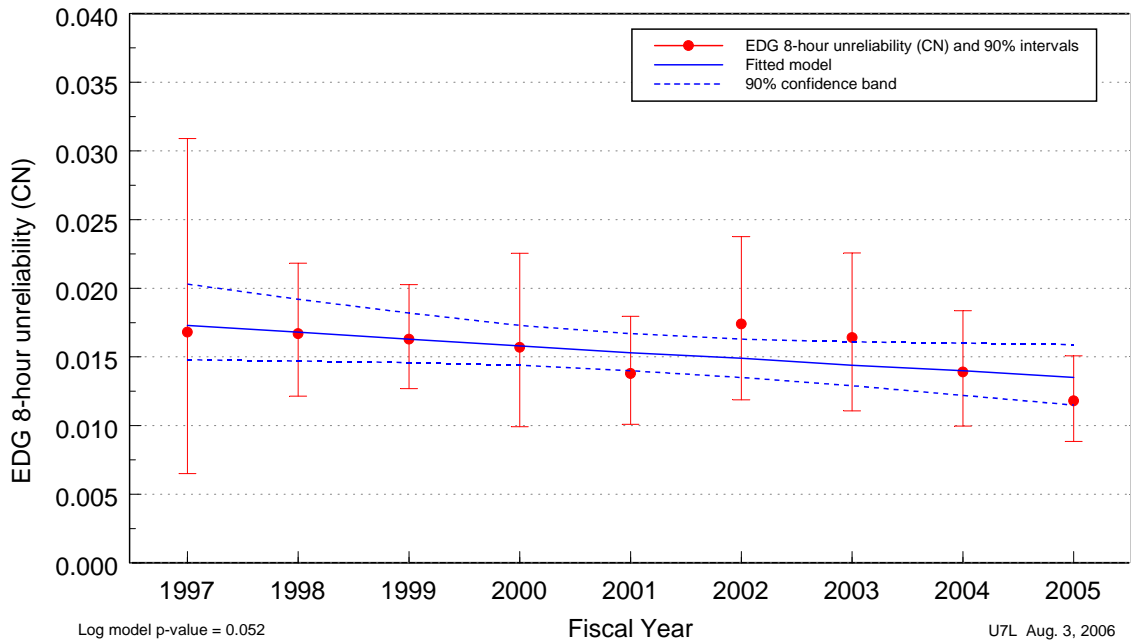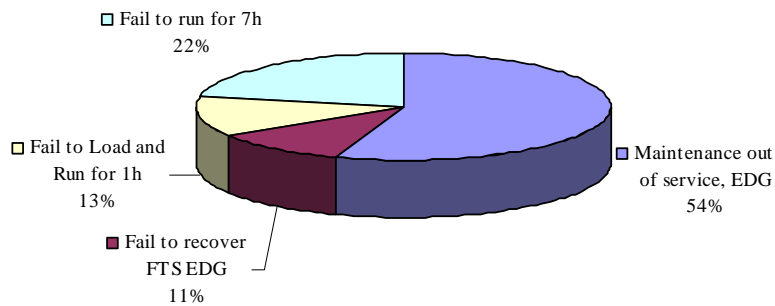

Figure 8. Segment failure distribution, FTS without recovery model.

2 DATA TABLES

2.1 Data Tables for Unreliability and Unavailability Trends

Table 2. Plot data table for EDGs unavailability, FTS model, no recovery, Figure 1.

FY	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1997	7.33E-03	1.52E-02	2.53E-02	1.49E-02	1.66E-02	1.85E-02
1998	1.40E-02	1.62E-02	1.86E-02	1.45E-02	1.59E-02	1.75E-02
1999	1.40E-02	1.62E-02	1.84E-02	1.42E-02	1.53E-02	1.65E-02
2000	1.18E-02	1.39E-02	1.62E-02	1.38E-02	1.47E-02	1.56E-02
2001	1.27E-02	1.50E-02	1.73E-02	1.33E-02	1.41E-02	1.49E-02
2002	1.24E-02	1.45E-02	1.68E-02	1.27E-02	1.35E-02	1.44E-02
2003	1.13E-02	1.33E-02	1.53E-02	1.20E-02	1.30E-02	1.40E-02
2004	1.07E-02	1.27E-02	1.47E-02	1.14E-02	1.24E-02	1.36E-02
2005	8.95E-03	1.08E-02	1.27E-02	1.07E-02	1.19E-02	1.33E-02

Table 3. Plot data table for EDGs unavailability, FTS model, with recovery, Figure 3.

FY	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1997	7.34E-03	1.34E-02	2.08E-02	1.25E-02	1.41E-02	1.59E-02
1998	1.09E-02	1.39E-02	1.72E-02	1.23E-02	1.36E-02	1.51E-02
1999	1.18E-02	1.44E-02	1.72E-02	1.21E-02	1.32E-02	1.43E-02
2000	8.27E-03	1.13E-02	1.48E-02	1.19E-02	1.28E-02	1.37E-02
2001	9.22E-03	1.24E-02	1.59E-02	1.16E-02	1.23E-02	1.32E-02
2002	1.07E-02	1.31E-02	1.57E-02	1.11E-02	1.19E-02	1.28E-02
2003	1.01E-02	1.22E-02	1.44E-02	1.06E-02	1.16E-02	1.26E-02
2004	8.96E-03	1.12E-02	1.36E-02	1.01E-02	1.12E-02	1.24E-02
2005	8.18E-03	1.00E-02	1.20E-02	9.59E-03	1.08E-02	1.22E-02

Table 4. Plot data table for EDGs unreliability, 8-hour mission, no recovery, Figure 5.

FY	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1997	7.39E-03	2.20E-02	4.28E-02	1.87E-02	2.30E-02	2.83E-02
1998	1.85E-02	2.19E-02	2.55E-02	1.87E-02	2.22E-02	2.64E-02
1999	1.70E-02	2.01E-02	2.34E-02	1.86E-02	2.14E-02	2.47E-02
2000	1.86E-02	2.26E-02	2.68E-02	1.84E-02	2.07E-02	2.33E-02
2001	1.49E-02	1.79E-02	2.10E-02	1.79E-02	2.00E-02	2.23E-02
2002	1.93E-02	2.32E-02	2.72E-02	1.71E-02	1.93E-02	2.17E-02
2003	1.80E-02	2.17E-02	2.58E-02	1.62E-02	1.86E-02	2.14E-02
2004	1.48E-02	1.80E-02	2.14E-02	1.51E-02	1.80E-02	2.13E-02
2005	1.16E-02	1.43E-02	1.73E-02	1.41E-02	1.73E-02	2.13E-02

Table 5. Plot data table for EDGs unreliability, 8-hour mission, with recovery, Figure 7.

FY	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1997	6.49E-03	1.68E-02	3.09E-02	1.48E-02	1.73E-02	2.03E-02
1998	1.22E-02	1.67E-02	2.19E-02	1.47E-02	1.68E-02	1.92E-02
1999	1.27E-02	1.63E-02	2.03E-02	1.46E-02	1.63E-02	1.82E-02
2000	9.87E-03	1.57E-02	2.25E-02	1.44E-02	1.58E-02	1.73E-02
2001	1.01E-02	1.38E-02	1.80E-02	1.40E-02	1.53E-02	1.67E-02
2002	1.19E-02	1.74E-02	2.38E-02	1.35E-02	1.49E-02	1.63E-02
2003	1.11E-02	1.64E-02	2.26E-02	1.29E-02	1.44E-02	1.61E-02
2004	9.92E-03	1.39E-02	1.83E-02	1.22E-02	1.40E-02	1.60E-02
2005	8.87E-03	1.18E-02	1.51E-02	1.15E-02	1.35E-02	1.59E-02