Component Performance Study

Turbine-Driven Pumps

1998–2006

1 INTRODUCTION

This report presents a performance evaluation of turbine-driven pumps (TDPs) at U.S. commercial nuclear power plants. This report does not estimate values for use in probabilistic risk assessments (PRAs), but does evaluate component performance over time. Reference 1 (NUREG/CR-6928) reports TDP unreliability estimates using Equipment Performance and Information Exchange (EPIX) data from 1998–2002 and maintenance unavailability (UA) performance data using MSPI Basis Document data from 2002–2004 for use in PRAs.

The trend evaluations in this study are based on the operating experience failure reports from fiscal year (FY) 1998 through FY 2006 as reported in EPIX. The TDP failure modes considered are for standby systems: failure-to-start (FTS), failure-to-run ≤ 1 hour (FTR≤1H), failure-to-run > 1 hour (FTR>1H), and for normally running systems: FTS and failure-to-run (FTR). TDP train maintenance unavailability data for trending are from the same time period, as reported in the Reactor Oversight Program (ROP) and EPIX. In addition to the presentation of the component failure mode data and the UA data, an 8-hour unreliability is calculated and trended.

Previously, the study relied on operating experience obtained from licensee event reports, Nuclear Plant Reliability Data System (NPRDS), and EPIX.

The EPIX database (which includes as a subset the Mitigating Systems Performance Index (MSPI) designated devices) has matured to the point where component availability and reliability can be estimated with a higher degree of assurance of accuracy. In addition, the population of data is much larger than the population used in the previous study. The objective of the effort for the updated component performance studies is to obtain annual performance trends of failure rates and probabilities. 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.

2 SUMMARY OF FINDINGS

The results of this 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 TDP results.

[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).

- Standby systems, industry-wide TDP FTR>1H trend. (see Figure 3)
- Frequency (events per reactor year) of FTR>1H events, standby TDPs. (see Figure 14)

The two trends are actually the same increase in FTR>1H events. There were five FTR>1H events in the standby TDPs. Four of the five events occurred during FY 2004 to FY 2006. The trend may change rapidly with zero events in the next year. In addition, the run hours associated with FTR>1H for the standby systems decreased during these same years.

Statistically significant decreasing trends were identified in the TDP results for the following:

- Pooled AFW, HPCI, and RCIC TDP UA trend. (see Figure 6)
- Frequency (events per reactor year) of start demands, standby TDPs. (see Figure 9)
- Standby TDP run hours per reactor critical year of run ≤ 1H hours. (see Figure 10)

3 FAILURE PROBABILITIES AND FAILURE RATES

3.1 Overview

The industry-wide failure probabilities and failure rates of TDPs have been calculated from the operating experience for FTS, FTR≤1H, FTR>1H, and FTR. The TDP data set obtained from EPIX includes TDPs in the systems listed in Table 1. Table 2 shows industry-wide failure probability and failure rate results for the TDP from Reference 1.

The TDPs are assumed to operate both when the reactor is critical and during shutdown periods with sufficient steam pressure. The number of TDPs in operation is assumed to be constant throughout the study period. All demand types are considered—testing, non-testing, and, as applicable, emergency safeguard feature (ESF) demands.

Table 1. TDP systems.

System	Description	Standby	Normally Running
AFW	Auxiliary feedwater	67	
HPCI	High pressure coolant injection	24	
MFW	Main feedwater		54
RCIC	Reactor core isolation cooling	30	
	Total	121	54

Table 2. Industry-wide distributions of p (failure probability) and λ (hourly rate) for TDPs.

Operation	Failure Mode	5%	Median	Mean	95%	Distribution		
						Type	α	β
Standby	FTS	7.0E-06	2.5E-03	7.0E-03	3.0E-02	Beta	0.40	5.71E+01
	FTR≤1H	7.0E-05	1.5E-03	2.5E-03	8.0E-03	Gamma	0.80	3.20E+02
	FTR>1H	3.0E-07	3.0E-05	7.0E-05	2.5E-04	Gamma	0.50	7.14E+03
Running/ Alternating	FTS	1.5E-03	1.5E-02	2.0E-02	6.0E-02	Beta	1.20	6.00E+01
	FTR	1.5E-06	5.0E-06	6.0E-06	1.2E-05	Gamma	3.00	5.00E+05

3.2 TDP Failure Probability and Failure Rate Trends

The trends are shown for industry standby (Stby) and for industry normally running (NR) results.

Trends in the standby TDP failure probabilities and failure rates are shown in Figure 1 to Figure 3. The data for the trend plots are contained in Table 7 to Table 9. The standby systems from Table 1 are trended together for each failure mode. Trends in the failure probabilities and failure rates for normally operating TDPs are shown in Figure 4 and Figure 5. The data for the trend plots are contained in Table 10 and Table 11.

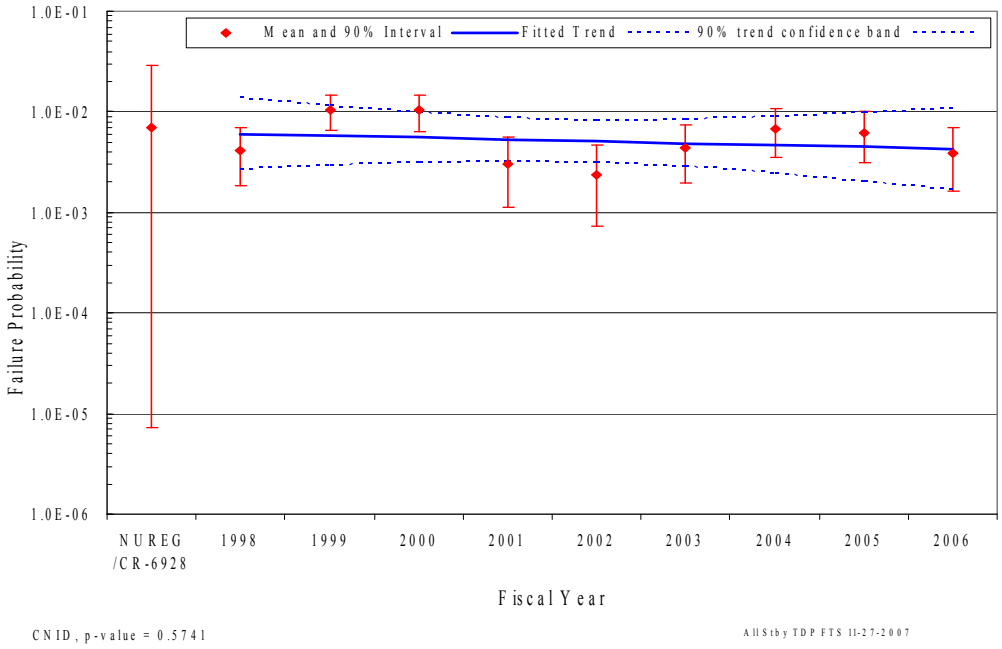

Figure 1. Standby systems, industry-wide TDP FTS trend.

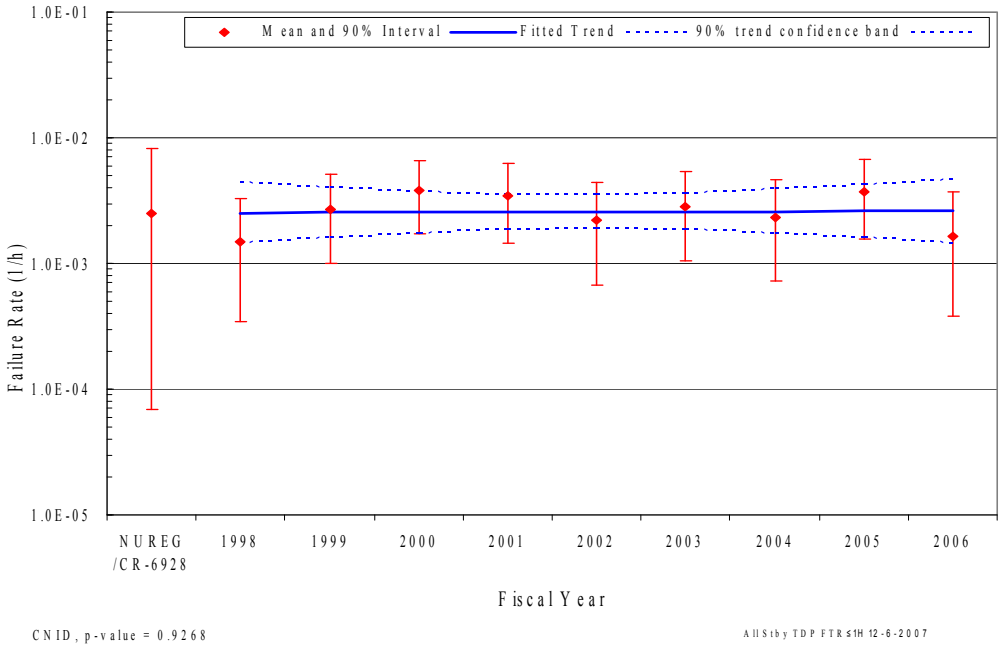

Figure 2. Standby systems, industry-wide TDP FTR≤1H trend.

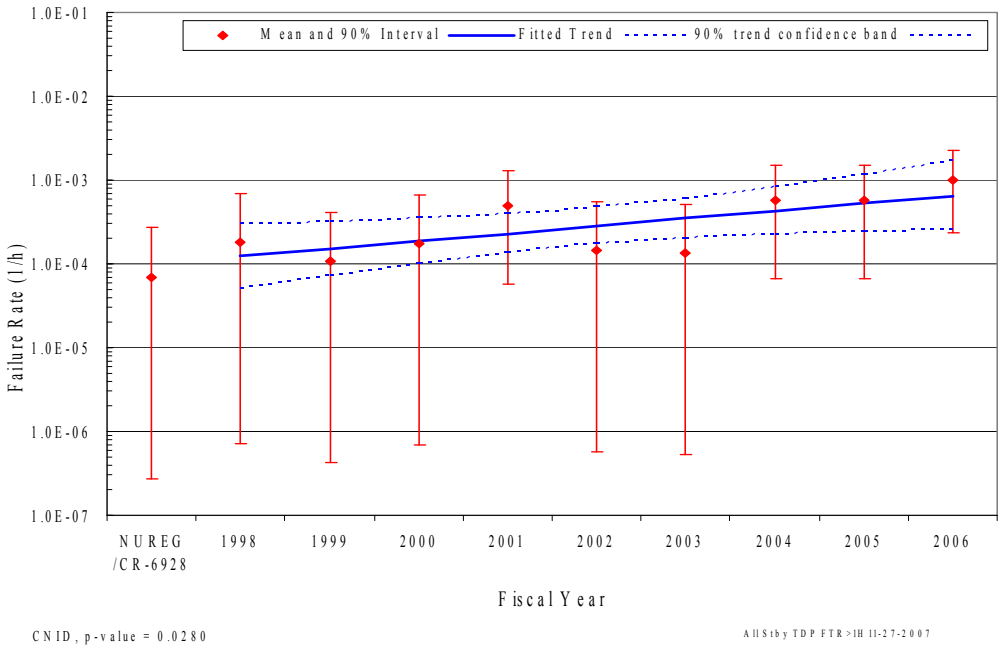

Figure 3. Standby systems, industry-wide TDP FTR>1H trend.

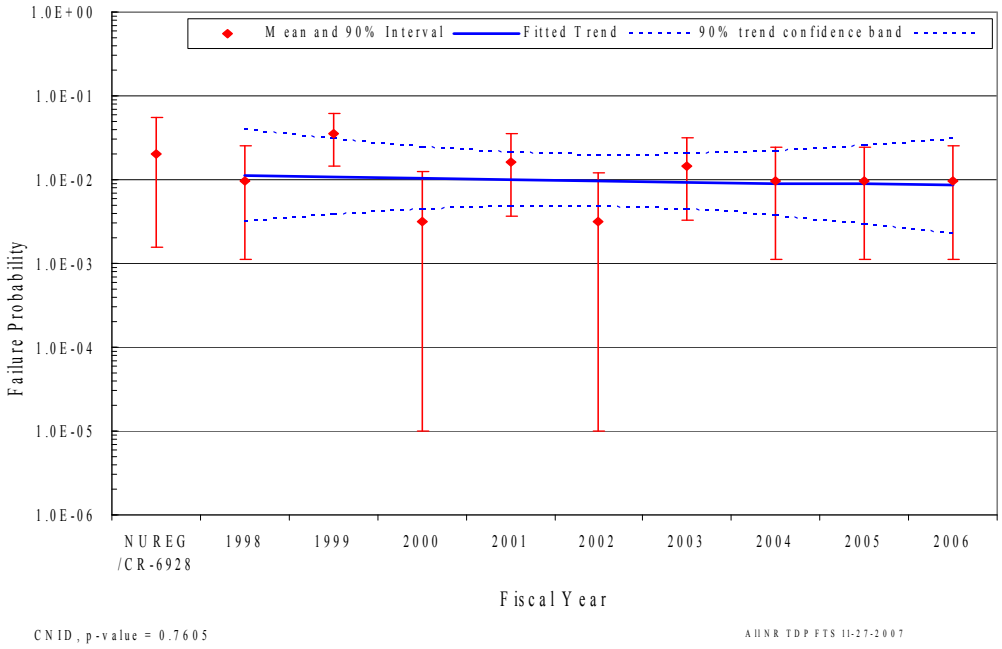

Figure 4. Normally running systems (MFW), industry-wide TDP FTS trend.

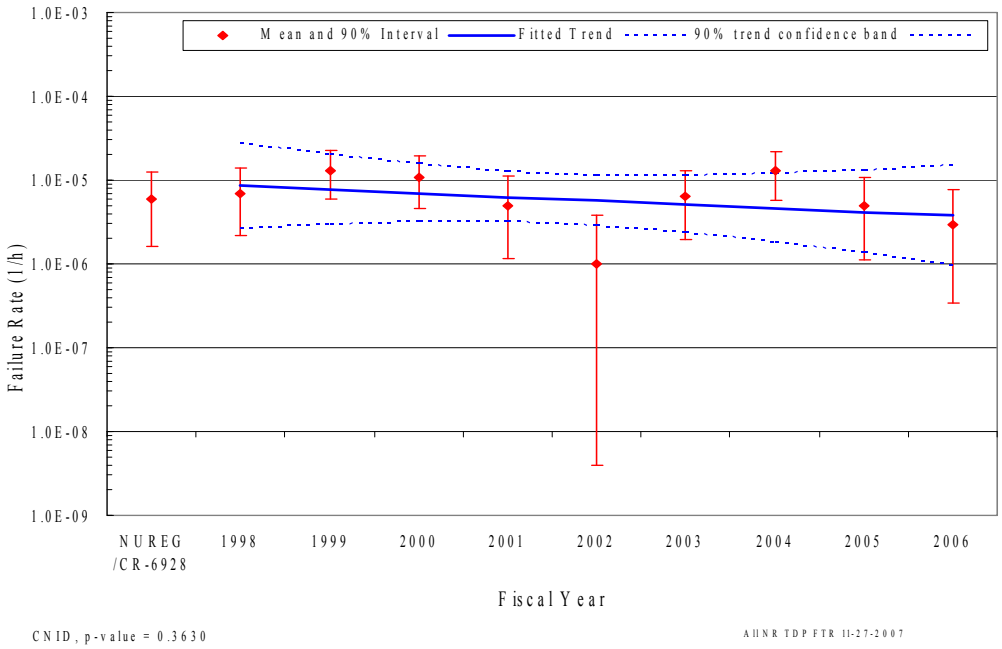

Figure 5. Normally running systems (MFW), industry-wide TDP FTR trend.

In the plots, the means of the posterior distributions from the Bayesian update process were trended across the years. The posterior distributions were also used for the vertical bounds for each year. The 5th and 95th percentiles of these distributions give an indication of the relative variation from year to year in the data. When there are no failures, the interval tends to be larger than the interval for years when there are one or more failures. The larger interval reflects the uncertainty that comes from having little information in that year's data. Such uncertainty intervals are determined by the prior distribution. In each plot, a relatively "flat" constrained noninformative prior distribution (CNID) is used, which has large bounds.

The horizontal curves plotted around the regression lines in the graphs form 90 percent simultaneous confidence bands for the fitted lines. The bounds are larger than ordinary confidence intervals for the trended values because they form a band that has a 90% probability of containing the entire line. In the lower left hand corner of the trend figures, the regression p-values are reported. They come from a statistical test on whether the slope of the regression line might be zero. Low p-values indicate that the slopes are not likely to be zero, and that trends exist.

Further information on the trending methods is provided in Section 2 of the Overview and Reference document. A final feature of the trend graphs is that the baseline industry values from Table 2 are shown for comparison.

4 UNAVAILABILITY

4.1 Overview

The industry-wide test or maintenance unavailability (UA) of TDP trains has been calculated from the operating experience. UA data are for TDP trains, which can include more than just the TDP. However, in most cases the TDP contributes the majority of the UA reported. Table 3 shows overall results for the TDP from Reference 1 based on UA data from MSPI Basis Documents, covering 2002 to 2004. In the calculations, planned and unplanned unavailable hours for a train are combined.

Table 3. Industry-wide distributions of unavailability for TDPs.

Description	Mean	Distribution	α	β
Turbine-Driven Pump Test or Maintenance (AFW)	5.00E-03	Beta	2.00	398.00
Turbine-Driven Pump Test or Maintenance (HPCI)	1.20E-02	Beta	3.00	247.00
Turbine-Driven Pump Test or Maintenance (RCIC)	1.00E-02	Beta	5.00	495.00

4.2 TDP Unavailability Trends

For the 1998-2006 period, the following are overall maintenance unavailability data. Note that these data do not supersede the data in Table 3 for use in risk assessments.

The trend in standby TDP train unavailability is shown in Figure 6. The data for this figure is in Table 12. The TDPs in systems AFW, HPCI, and RCIC are pooled and trended (these are the systems with maintenance unavailability data currently analyzed). The trend chart shows the results of using data for each year's component unavailability data over time. The yearly (1998–2006) unavailability and reactor critical hour data were obtained from the ROP (1998 to 2001) and EPIX (2002 to 2006) data for the TDP component. The total downtimes during operation for each plant and year were summed, and divided by the corresponding number of TDP-reactor critical hours. Unavailability data for shutdown periods are not reported.

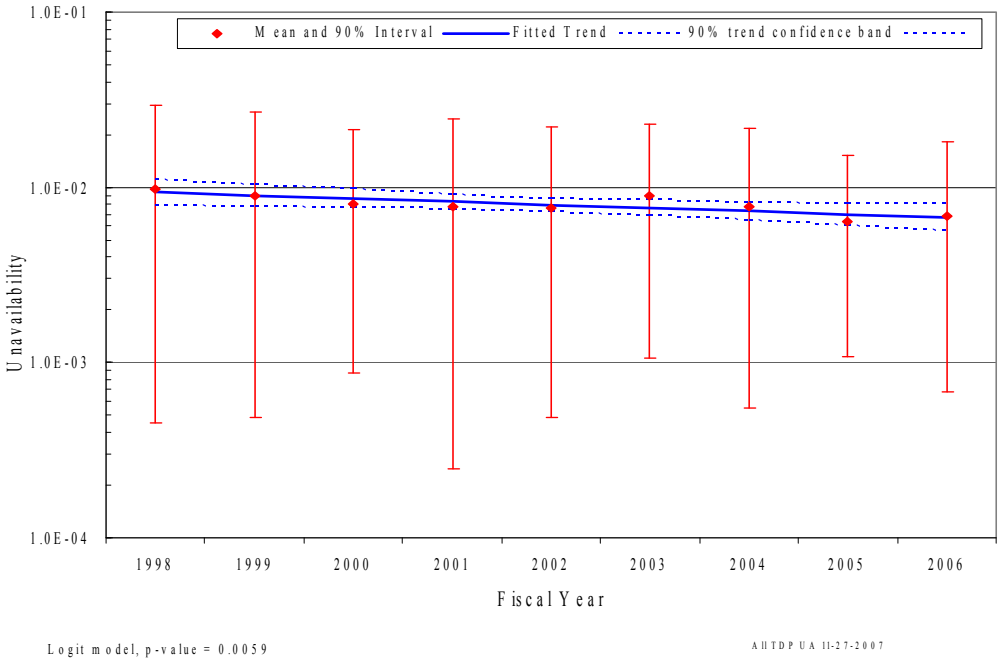

Figure 6. Pooled AFW, HPCI, and RCIC TDP UA trend.

The mean and variance for each year is the sample mean and variance calculated from the plant-level unavailabilities for that year. The vertical bar spans the calculated 5th to 95th percentiles of the beta distribution with matching means.

For the trend graphs, a least squares fit is sought for the model $logit(P)=a+bt$, where P is the unavailability, t is a year, and the logit of P is defined as the logarithm of $[P/(1-P)]$. Section 3 in the Overview and Reference document provides further information. In the lower left hand corner of the trend figures, the p-value is reported.

5 TDP UNRELIABILITY TRENDS

Trends in total component unreliability are shown in Figure 7 and Figure 8. Plot data for these figures are in Table 13 and Table 14, respectively. Total unreliability is defined as the result of an OR gate with the FTS, FTR≤1H, FTR >1H (or FTR), and UA as basic event inputs. The FTR>1H is calculated for 7 hours and the FTR is calculated for 8 hours to provide the results for an 8-hour mission. Since the normally running systems TDP components do not have UA data or the FTR≤1H data, there is no UA or FTR≤1H input to the OR gate for that calculation. The trending method is described in more detail in Section 4 of the Overview and Reference document. In the lower left hand corner of the trend figures, the regression method is reported.

The standby systems from Table 2 are trended together.

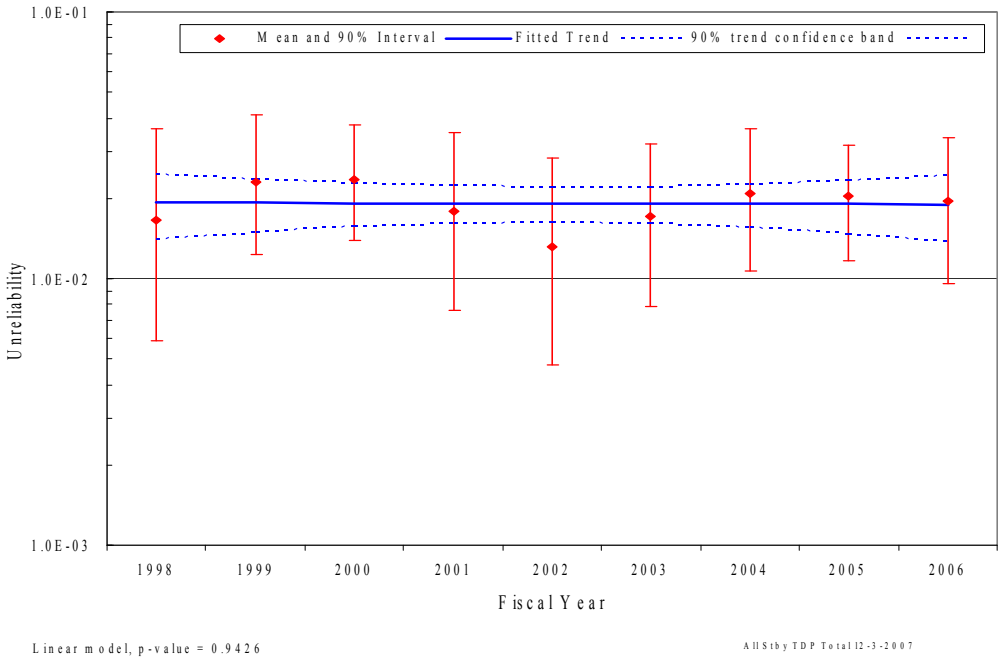

Figure 7. Standby systems, industry-wide TDP unreliability trend (8-hour mission).

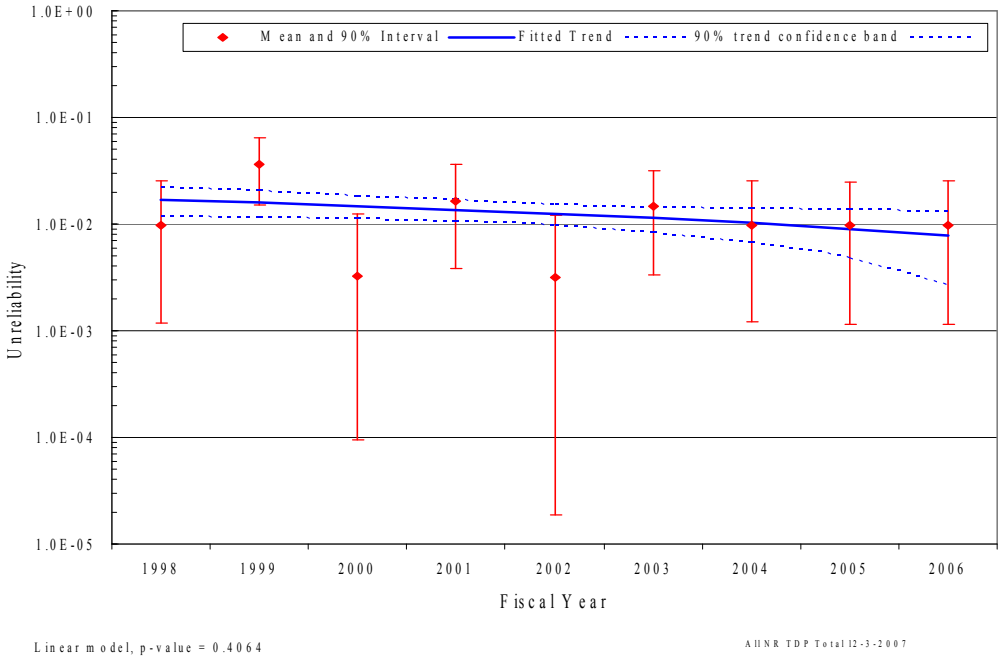

Figure 8. Normally running systems (MFW), industry-wide TDP unreliability trend (8-hour mission).

6 ENGINEERING TRENDS

This section presents frequency trends for TDP failures and demands. The data are normalized by reactor year for plants that have the equipment being trended. The rate methods described in Section 2 of the Overview and Reference document are used.

6.1 Standby TDP Engineering Trends

Figure 9 shows the trend for standby TDP demands. Figure 10 shows the trend for TDP load and run demands. Figure 11 shows the trend for the TDP run hours. Table 15, Table 16, and Table 17 provide the plot data respectively.

Figure 12 shows the trend for TDP FTS events. Figure 13 shows the trend TDP FTR≤1H events, and Figure 14 shows the trend for the TDP FTR>1H events. Table 18, Table 20, and Table 21 provide the plot data respectively. The standby systems from Table 2 are trended together for each figure.

Table 4 summarizes the failures by system, year, for the FTS failure mode. Table 5 summarizes the failures by system, year, for the FTR≤1H failure mode. Table 6 summarizes the failures by system, year, for the FTR>1H and FTR failure mode.

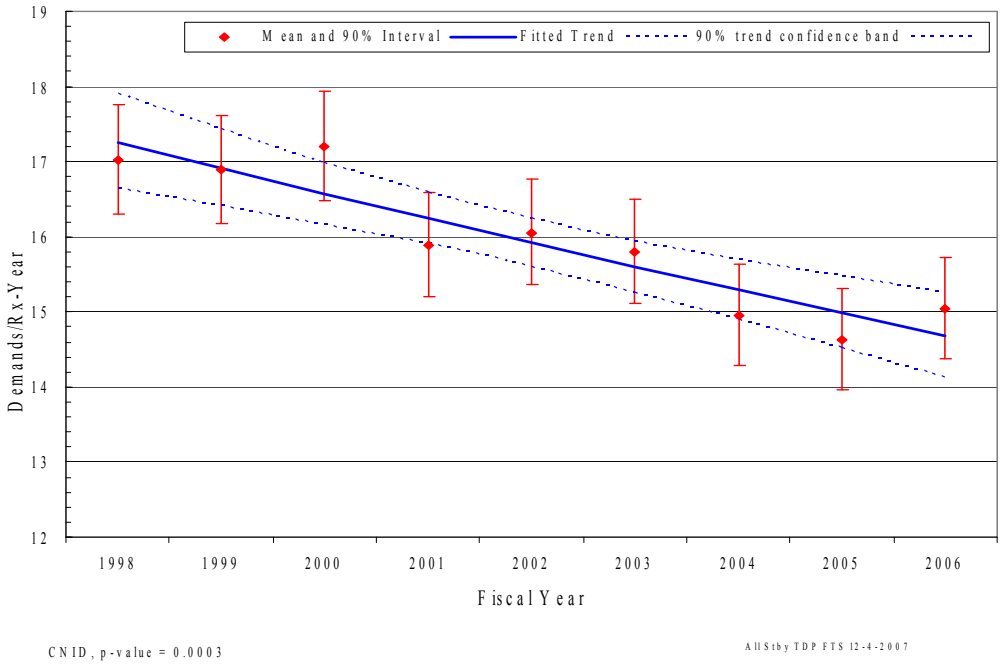

Figure 9. Frequency (events per reactor year) of start demands, standby TDPs.

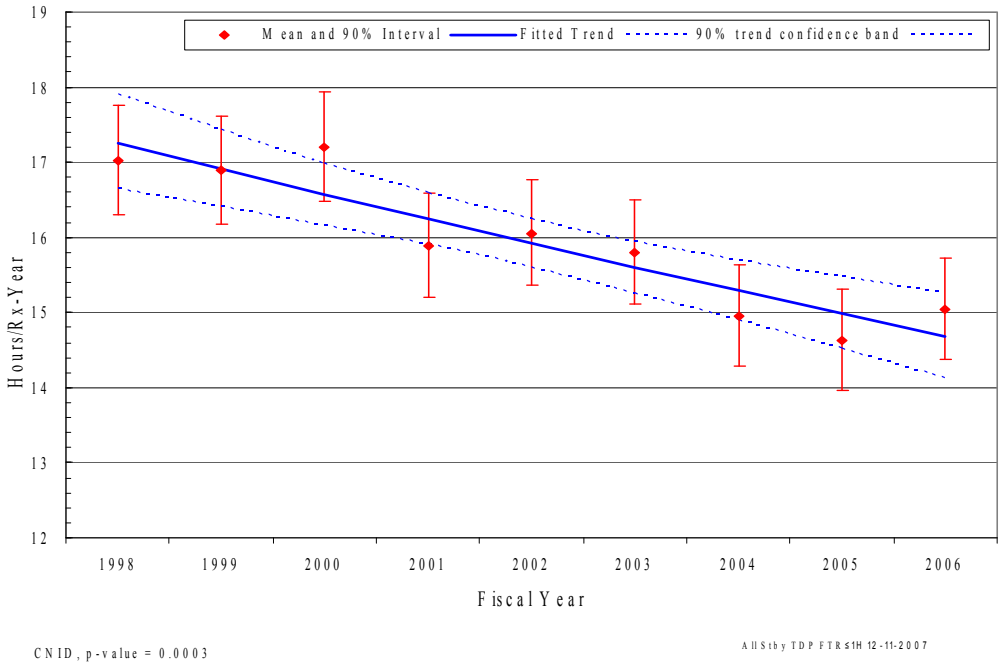

Figure 10. Standby TDP run hours per reactor critical year of run ≤ 1H hours.

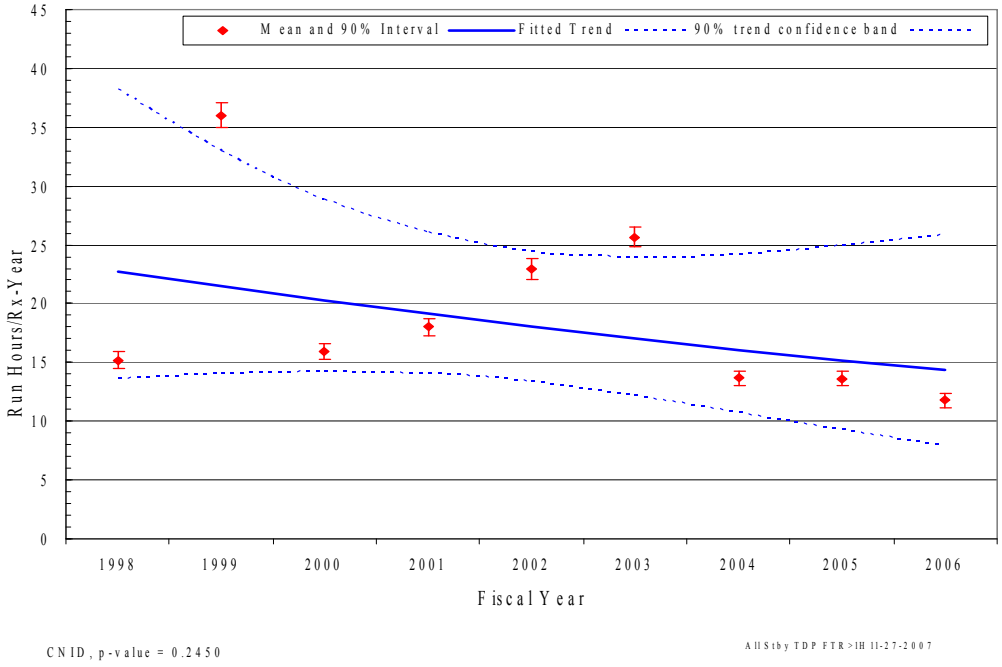

Figure 11. Standby TDP run hours per reactor critical year.

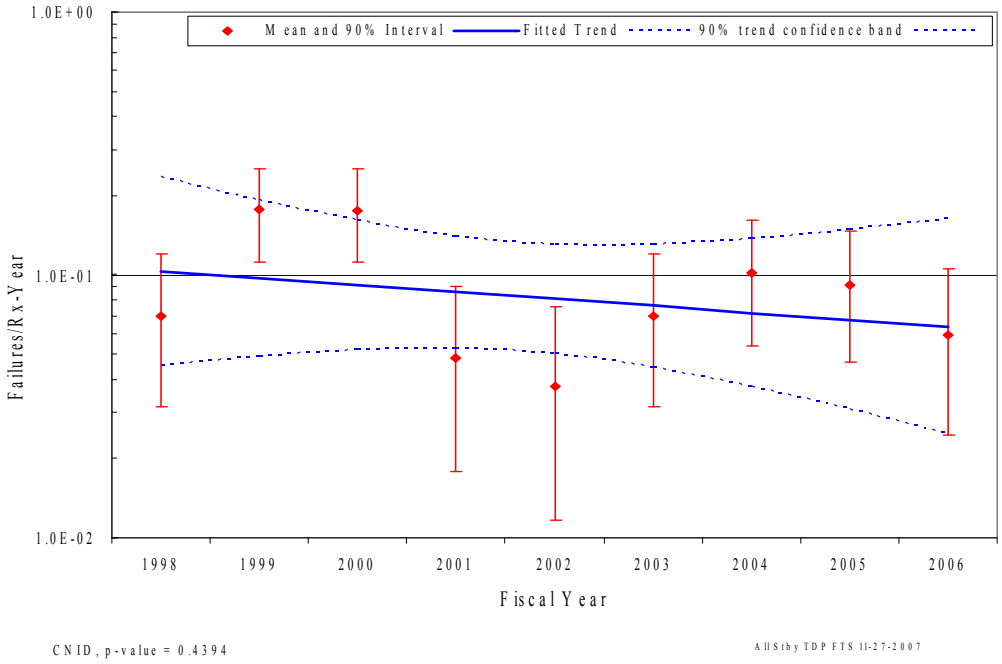

Figure 12. Frequency (events per reactor year) of FTS events, standby TDPs.

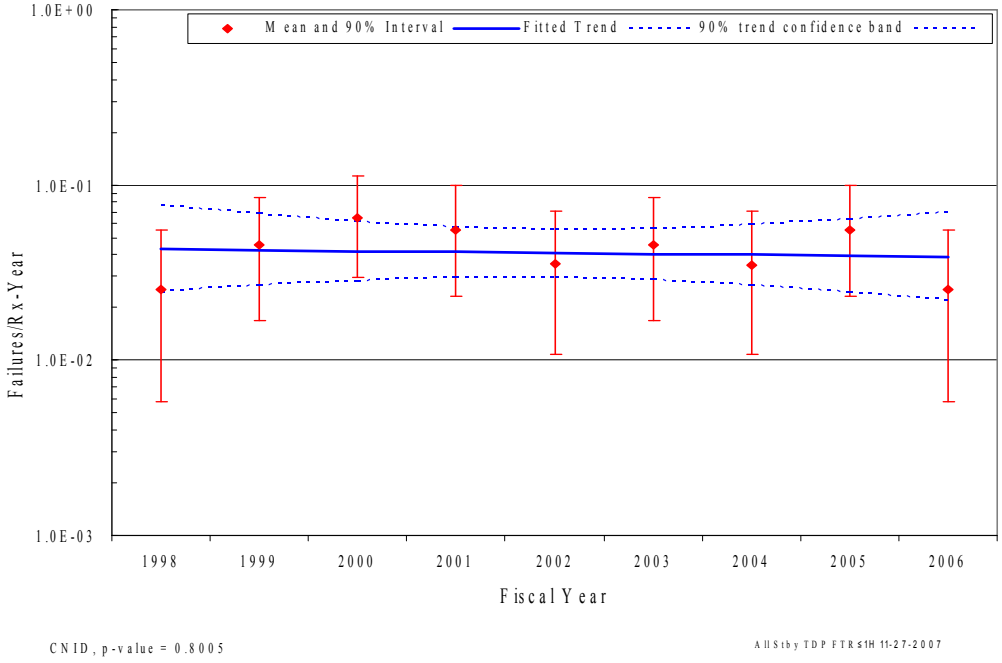

Figure 13. Frequency (events per reactor year) of FTR≤1H events, standby TDPs.

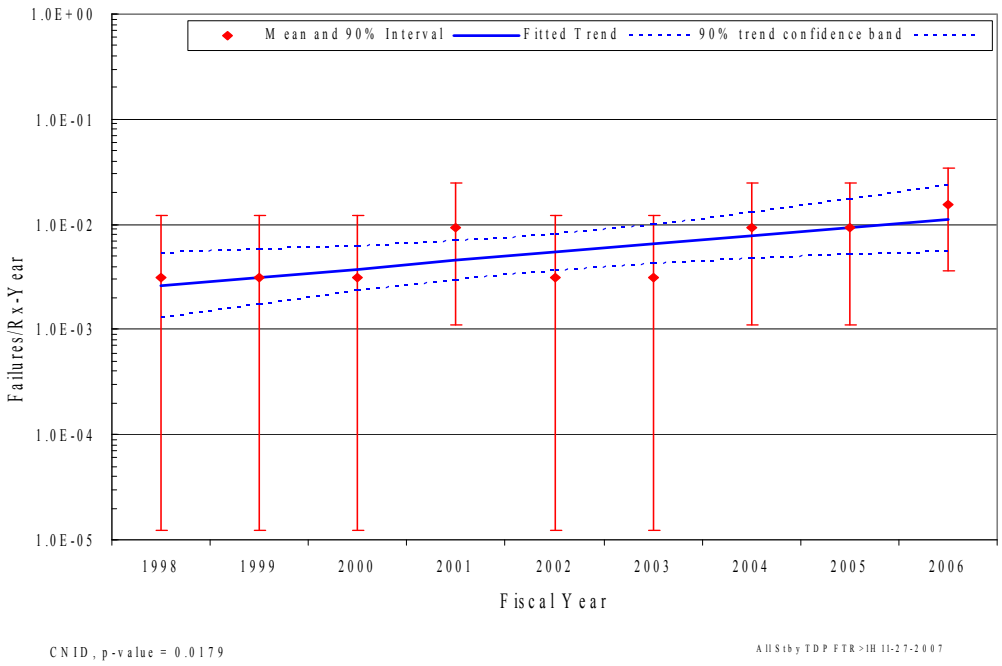

Figure 14. Frequency (events per reactor year) of FTR>1H events, standby TDPs.

6.2 Normally Running TDP Engineering Trends

Figure 15 shows the trend for TDP start demands and Figure 16 shows the trend for the TDP run hours. Table 21 and Table 22 provide the plot data respectively.

Figure 17 shows the trend for TDP FTS events and Figure 18 shows the trend for the TDP FTR events. Table 23 and Table 24 provide the plot data, respectively. The normally running system (MFW) from Table 2 is trended for each figure.

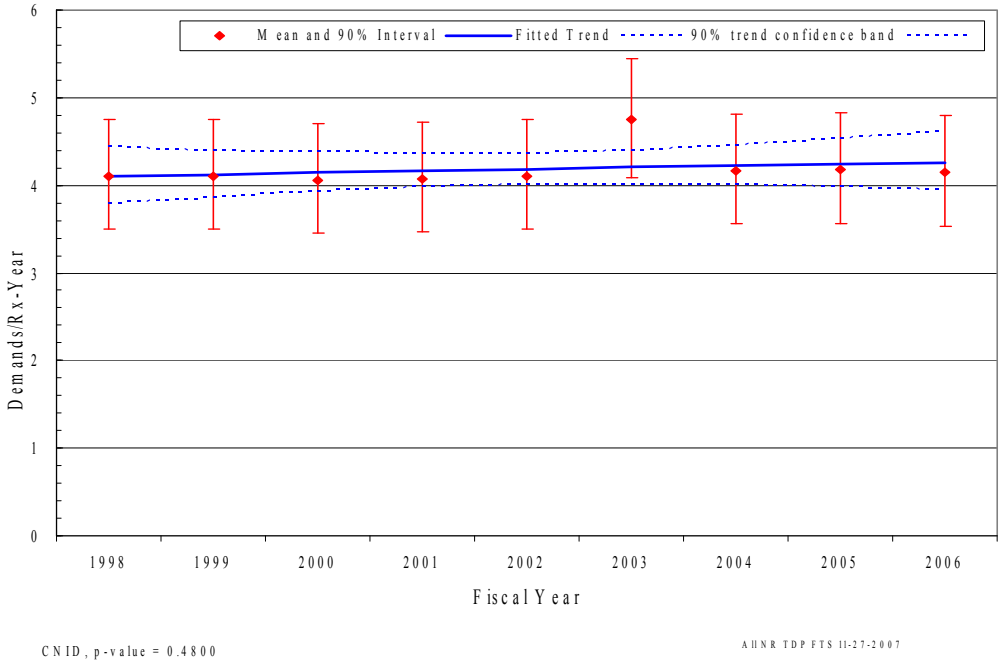

Figure 15. Frequency (events per reactor year) of start demands, normally running TDPs.

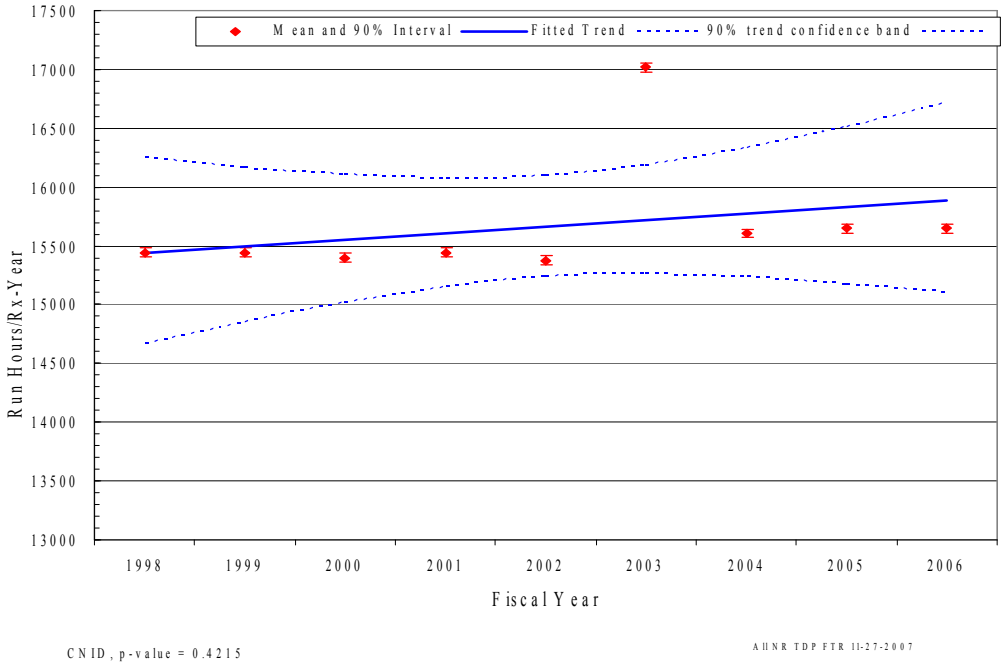

Figure 16. Normally running TDP run hours per reactor critical year.

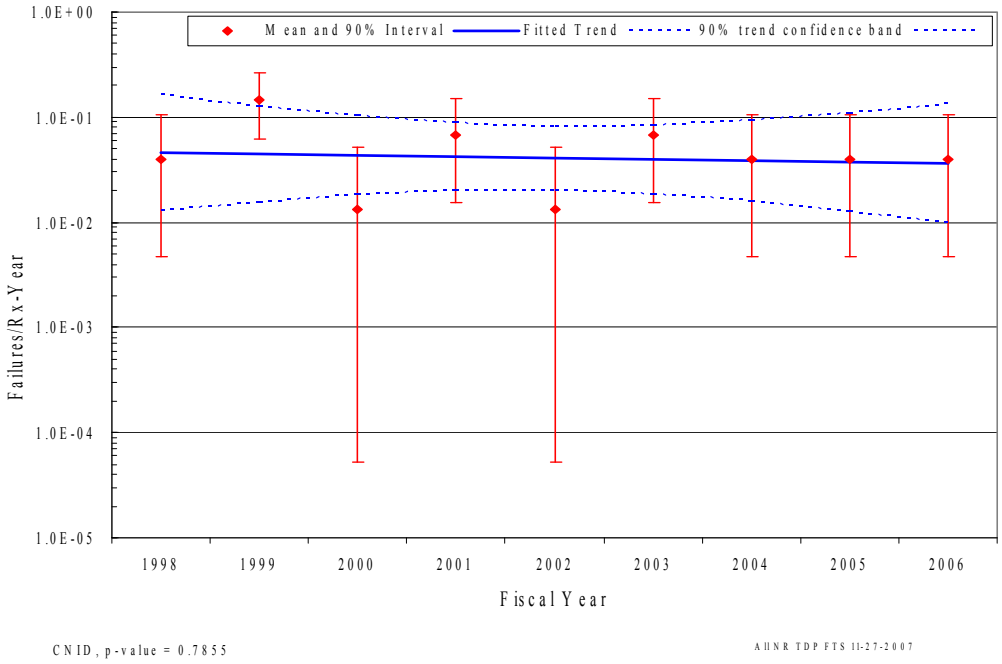

Figure 17. Frequency (events per reactor year) of FTS events, normally running TDPs.

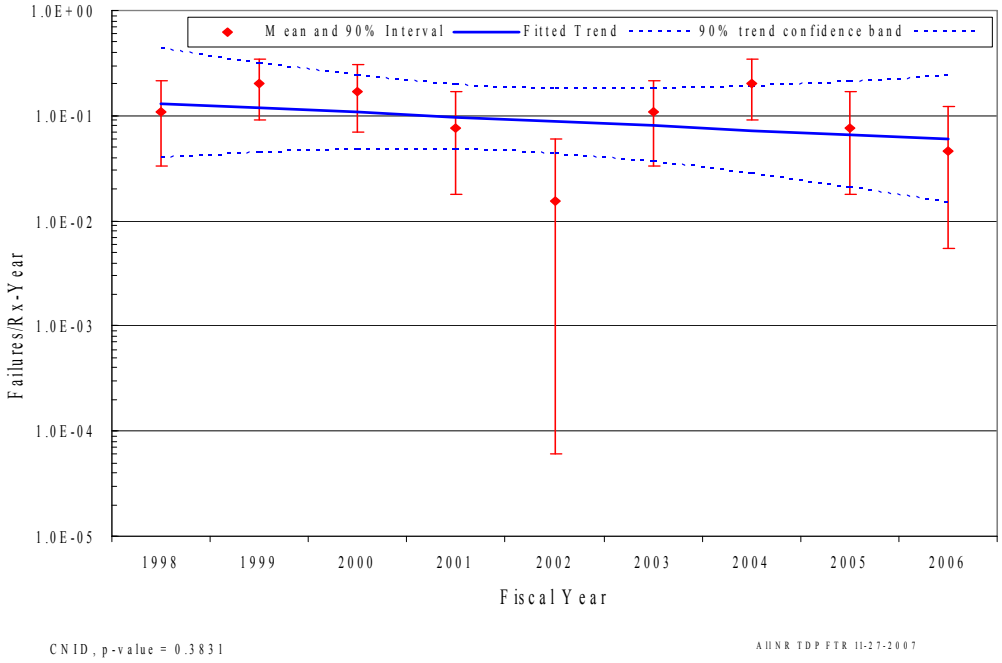

Figure 18. Frequency (events per reactor year) of FTR events, normally running TDPs.

Table 4. Summary of TDP failure counts for the FTS failure mode over time by system.

System Code	TDP Count	TDP Percent	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	Total	Percent of Failures
AFW	67	38.3%	4	8	7	3	2	3	6	4	4	41	47.7%
HPCI	24	13.7%	1	4	4	1	1	0	0	1	0	12	14.0%
MFW	54	30.9%	1	5	0	2	0	2	1	1	1	13	15.1%
RCIC	30	17.1%	1	4	5	0	0	3	3	3	1	20	23.3%
Total	175	100.0%	7	21	16	6	3	8	10	9	6	86	100.0%

Table 5. Summary of TDP failure counts for the FTR≤1H failure mode over time by system.

System Code	TDP Count	TDP Percent	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	Total	Percent of Failures
AFW	67	38.3%	1	3	2	4	2	3	2	2	2	21	61.8%
HPCI	24	13.7%	0	0	2	0	0	1	0	0	0	3	8.8%
RCIC	30	17.1%	1	1	2	1	1	0	1	3	0	10	29.4%
Total	121	69.1%	2	4	6	5	3	4	3	5	2	34	100.0%

Table 6. Summary of TDP failure counts for the FTR>1H and FTR failure mode over time by system.

System Code	TDP Count	TDP Percent	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	Total	Percent of Failures
AFW	67	38.3%	0	0	0	1	0	0	1	0	2	4	12.1%
HPCI	24	13.7%	0	0	0	0	0	0	0	1	0	1	3.0%
MFW	54	30.9%	3	6	5	2	0	3	6	2	1	28	84.8%
RCIC	30	17.1%	0	0	0	0	0	0	0	0	0	0	0.0%
Total	175	100.0%	3	6	5	3	0	3	7	3	3	33	100.0%

7 TDP ASSEMBLY DESCRIPTION

The TDP is generally comprised of a pump, a turbine driver, and a governor. Most plant designs use a single stage “Terry Turbine”, whose piece-parts include a turbine trip and throttle valve, a mechanical overspeed trip mechanism, and a lubrication system. The various types of governors, used for turbine speed control are mostly manufactured by the Woodward Corporation. For the AFW system TDP, the governors are predominantly mechanical/hydraulic; pressure-compensated, and have a pneumatic remote speed-setting capability. For the RCIC and HPCI systems, the TDPs typically have a Woodward type EG-M electric/electronic governor and EG-R hydraulic actuators. Piece-parts of all governors include a turbine stop valve and a governor valve, while the EG-M usually includes a ramp generator/signal converter and other electrical controls.

8 DATA TABLES

Table 7. Plot data for standby TDP FTS industry trend. Figure 1

FY/ Source	Failures	Demands	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
NUREG /CR-6928						7.26E-06	2.91E-02	7.00E-03
1998	6	1497.8	6.04E-03	2.64E-03	1.38E-02	1.85E-03	7.02E-03	4.10E-03
1999	16	1486.5	5.79E-03	2.92E-03	1.14E-02	6.58E-03	1.49E-02	1.05E-02
2000	16	1517.5	5.54E-03	3.15E-03	9.74E-03	6.46E-03	1.46E-02	1.03E-02
2001	4	1398.0	5.31E-03	3.25E-03	8.67E-03	1.12E-03	5.68E-03	3.03E-03
2002	3	1413.3	5.09E-03	3.15E-03	8.22E-03	7.19E-04	4.67E-03	2.33E-03
2003	6	1389.9	4.88E-03	2.85E-03	8.34E-03	1.99E-03	7.53E-03	4.40E-03
2004	9	1319.0	4.67E-03	2.45E-03	8.90E-03	3.58E-03	1.06E-02	6.76E-03
2005	8	1286.6	4.48E-03	2.04E-03	9.78E-03	3.14E-03	9.97E-03	6.19E-03
2006	5	1323.6	4.29E-03	1.68E-03	1.09E-02	1.62E-03	6.94E-03	3.90E-03

Table 8. Plot data for standby TDP FTR≤1H industry trend. Figure 2

FY/ Source	Failures	Hours	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
NUREG /CR-6928						6.84E-05	8.11E-03	2.50E-03
1998	2	1497.8	2.52E-03	1.43E-03	4.44E-03	3.41E-04	3.29E-03	1.49E-03
1999	4	1486.5	2.53E-03	1.58E-03	4.05E-03	9.96E-04	5.07E-03	2.70E-03
2000	6	1517.5	2.54E-03	1.73E-03	3.75E-03	1.73E-03	6.57E-03	3.82E-03
2001	5	1398.0	2.56E-03	1.84E-03	3.55E-03	1.45E-03	6.22E-03	3.48E-03
2002	3	1413.3	2.57E-03	1.88E-03	3.50E-03	6.79E-04	4.41E-03	2.19E-03
2003	4	1389.9	2.58E-03	1.84E-03	3.61E-03	1.06E-03	5.38E-03	2.86E-03
2004	3	1319.0	2.59E-03	1.74E-03	3.86E-03	7.21E-04	4.68E-03	2.33E-03
2005	5	1286.6	2.60E-03	1.60E-03	4.22E-03	1.56E-03	6.69E-03	3.74E-03
2006	2	1323.6	2.61E-03	1.46E-03	4.67E-03	3.80E-04	3.67E-03	1.66E-03

Table 9. Plot data for standby TDP FTR>1H industry trend. Figure 3

FY/ Source	Failures	Run Time (h)	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
NUREG /CR-6928						2.75E-07	2.69E-04	7.00E-05
1998	0	1336.9	1.26E-04	5.14E-05	3.09E-04	7.23E-07	7.06E-04	1.84E-04
1999	0	3170.8	1.55E-04	7.35E-05	3.27E-04	4.32E-07	4.22E-04	1.10E-04
2000	0	1407.1	1.91E-04	1.03E-04	3.54E-04	7.05E-07	6.88E-04	1.79E-04
2001	1	1583.8	2.35E-04	1.38E-04	3.99E-04	5.93E-05	1.32E-03	5.06E-04
2002	0	2019.5	2.89E-04	1.74E-04	4.79E-04	5.78E-07	5.64E-04	1.47E-04
2003	0	2259.3	3.55E-04	2.05E-04	6.16E-04	5.40E-07	5.27E-04	1.37E-04
2004	1	1204.9	4.37E-04	2.28E-04	8.39E-04	6.80E-05	1.51E-03	5.80E-04
2005	1	1200.5	5.38E-04	2.45E-04	1.18E-03	6.81E-05	1.51E-03	5.81E-04
2006	2	1035.0	6.62E-04	2.58E-04	1.70E-03	2.37E-04	2.29E-03	1.03E-03

Table 10. Plot data for normally running TDP FTS industry trend. Figure 4

FY/ Source	Failures	Demands	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
NUREG /CR-6928						1.55E-03	5.62E-02	2.00E-02
1998	1	115.1	1.11E-02	3.11E-03	3.89E-02	1.11E-03	2.50E-02	9.69E-03
1999	5	115.0	1.08E-02	3.74E-03	3.05E-02	1.46E-02	6.14E-02	3.59E-02
2000	0	113.6	1.04E-02	4.35E-03	2.46E-02	1.01E-05	1.23E-02	3.18E-03
2001	2	114.1	1.01E-02	4.79E-03	2.10E-02	3.69E-03	3.55E-02	1.63E-02
2002	0	115.3	9.72E-03	4.84E-03	1.94E-02	9.99E-06	1.22E-02	3.14E-03
2003	2	133.3	9.40E-03	4.42E-03	1.99E-02	3.28E-03	3.16E-02	1.45E-02
2004	1	116.6	9.09E-03	3.71E-03	2.21E-02	1.10E-03	2.48E-02	9.60E-03
2005	1	116.6	8.79E-03	2.97E-03	2.58E-02	1.10E-03	2.48E-02	9.60E-03
2006	1	115.6	8.50E-03	2.30E-03	3.09E-02	1.11E-03	2.49E-02	9.66E-03

Table 11. Plot data for normally running TDP FTR industry trend. Figure 5

FY/ Source	Failures	Run Time (h)	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
NUREG /CR-6928						1.64E-06	1.26E-05	6.00E-06
1998	3	432339.6	8.52E-06	2.63E-06	2.76E-05	2.16E-06	1.40E-05	6.98E-06
1999	6	432339.6	7.69E-06	2.92E-06	2.03E-05	5.87E-06	2.23E-05	1.30E-05
2000	5	432339.6	6.95E-06	3.11E-06	1.55E-05	4.56E-06	1.96E-05	1.10E-05
2001	2	432339.6	6.28E-06	3.11E-06	1.27E-05	1.14E-06	1.10E-05	4.98E-06
2002	0	428499.6	5.67E-06	2.83E-06	1.14E-05	3.95E-09	3.86E-06	1.00E-06
2003	3	482259.6	5.12E-06	2.34E-06	1.12E-05	1.96E-06	1.28E-05	6.34E-06
2004	6	438099.6	4.62E-06	1.80E-06	1.19E-05	5.81E-06	2.20E-05	1.28E-05
2005	2	438099.6	4.17E-06	1.33E-06	1.31E-05	1.13E-06	1.09E-05	4.93E-06
2006	1	438099.6	3.77E-06	9.60E-07	1.48E-05	3.47E-07	7.70E-06	2.96E-06

Table 12. Plot data for all standby TDP unavailability trend. Figure 6

FY	UA Hours	Critical Hours	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	6499.3	687134.0	9.35E-03	7.88E-03	1.11E-02	4.52E-04	2.95E-02	9.73E-03
1999	8466.4	963737.3	8.97E-03	7.78E-03	1.03E-02	4.86E-04	2.67E-02	9.02E-03
2000	8065.0	991023.9	8.61E-03	7.66E-03	9.68E-03	8.70E-04	2.14E-02	8.10E-03
2001	7660.5	997228.2	8.26E-03	7.48E-03	9.13E-03	2.46E-04	2.47E-02	7.77E-03
2002	7687.4	995788.8	7.93E-03	7.23E-03	8.70E-03	4.88E-04	2.21E-02	7.65E-03
2003	8677.7	975812.1	7.61E-03	6.89E-03	8.40E-03	1.05E-03	2.30E-02	8.87E-03
2004	7676.4	1004083.0	7.30E-03	6.49E-03	8.21E-03	5.46E-04	2.19E-02	7.69E-03
2005	6163.2	984691.8	7.01E-03	6.08E-03	8.08E-03	1.09E-03	1.51E-02	6.33E-03
2006	6871.4	1005001.0	6.72E-03	5.67E-03	7.98E-03	6.86E-04	1.82E-02	6.79E-03

Table 13. Plot data for Standby TDP unreliability trend. Figure 7

FY	Regression Curve Data Points			Plot Trend Error Bar Points		
	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	1.92E-02	1.40E-02	2.44E-02	5.84E-03	3.64E-02	1.66E-02
1999	1.92E-02	1.49E-02	2.35E-02	1.23E-02	4.11E-02	2.30E-02
2000	1.92E-02	1.56E-02	2.27E-02	1.39E-02	3.76E-02	2.35E-02
2001	1.91E-02	1.61E-02	2.22E-02	7.59E-03	3.53E-02	1.78E-02
2002	1.91E-02	1.63E-02	2.19E-02	4.74E-03	2.83E-02	1.32E-02
2003	1.91E-02	1.60E-02	2.21E-02	7.88E-03	3.19E-02	1.71E-02
2004	1.90E-02	1.55E-02	2.26E-02	1.06E-02	3.67E-02	2.08E-02
2005	1.90E-02	1.47E-02	2.33E-02	1.17E-02	3.17E-02	2.03E-02
2006	1.90E-02	1.38E-02	2.42E-02	9.58E-03	3.38E-02	1.96E-02

Table 14. Plot data for NR TDP unreliability trend. Figure 8

FY	Regression Curve Data Points			Plot Trend Error Bar Points		
	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	1.70E-02	1.18E-02	2.22E-02	1.17E-03	2.53E-02	9.75E-03
1999	1.59E-02	1.16E-02	2.02E-02	1.52E-02	6.37E-02	3.60E-02
2000	1.47E-02	1.12E-02	1.83E-02	9.41E-05	1.25E-02	3.27E-03
2001	1.36E-02	1.06E-02	1.66E-02	3.78E-03	3.61E-02	1.64E-02
2002	1.25E-02	9.64E-03	1.53E-02	1.89E-05	1.22E-02	3.15E-03
2003	1.13E-02	8.29E-03	1.44E-02	3.38E-03	3.21E-02	1.46E-02
2004	1.02E-02	6.61E-03	1.38E-02	1.22E-03	2.51E-02	9.70E-03
2005	9.04E-03	4.71E-03	1.34E-02	1.15E-03	2.50E-02	9.64E-03
2006	7.90E-03	2.70E-03	1.31E-02	1.14E-03	2.52E-02	9.68E-03

Table 15. Plot data for standby TDP start demands trend. Figure 9

FY	Demands	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	1498	88.0	1.73E+01	1.66E+01	1.79E+01	1.63E+01	1.78E+01	1.70E+01
1999	1486	88.0	1.69E+01	1.64E+01	1.74E+01	1.62E+01	1.76E+01	1.69E+01
2000	1518	88.2	1.66E+01	1.62E+01	1.70E+01	1.65E+01	1.79E+01	1.72E+01
2001	1398	88.0	1.62E+01	1.59E+01	1.66E+01	1.52E+01	1.66E+01	1.59E+01
2002	1413	88.0	1.59E+01	1.56E+01	1.62E+01	1.54E+01	1.68E+01	1.61E+01
2003	1390	88.0	1.56E+01	1.53E+01	1.59E+01	1.51E+01	1.65E+01	1.58E+01
2004	1319	88.2	1.53E+01	1.49E+01	1.57E+01	1.43E+01	1.56E+01	1.49E+01
2005	1287	88.0	1.50E+01	1.45E+01	1.55E+01	1.40E+01	1.53E+01	1.46E+01
2006	1324	88.0	1.47E+01	1.41E+01	1.53E+01	1.44E+01	1.57E+01	1.50E+01

Table 16. Plot data for standby TDP run ≤1-hour run-hours trend. Figure 10

FY	Hours	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	1498	88.0	1.73E+01	1.66E+01	1.79E+01	1.63E+01	1.78E+01	1.70E+01
1999	1486	88.0	1.69E+01	1.64E+01	1.74E+01	1.62E+01	1.76E+01	1.69E+01
2000	1518	88.2	1.66E+01	1.62E+01	1.70E+01	1.65E+01	1.79E+01	1.72E+01
2001	1398	88.0	1.62E+01	1.59E+01	1.66E+01	1.52E+01	1.66E+01	1.59E+01
2002	1413	88.0	1.59E+01	1.56E+01	1.62E+01	1.54E+01	1.68E+01	1.61E+01
2003	1390	88.0	1.56E+01	1.53E+01	1.59E+01	1.51E+01	1.65E+01	1.58E+01
2004	1319	88.2	1.53E+01	1.49E+01	1.57E+01	1.43E+01	1.56E+01	1.49E+01
2005	1287	88.0	1.50E+01	1.45E+01	1.55E+01	1.40E+01	1.53E+01	1.46E+01
2006	1324	88.0	1.47E+01	1.41E+01	1.53E+01	1.44E+01	1.57E+01	1.50E+01

Table 17. Plot data for standby TDP run-hours trend. Figure 11

FY	Run Hours	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	1337	88.0	2.28E+01	1.36E+01	3.82E+01	1.45E+01	1.59E+01	1.52E+01
1999	3171	88.0	2.15E+01	1.40E+01	3.29E+01	3.50E+01	3.71E+01	3.60E+01
2000	1407	88.2	2.03E+01	1.43E+01	2.89E+01	1.53E+01	1.67E+01	1.59E+01
2001	1584	88.0	1.91E+01	1.41E+01	2.60E+01	1.73E+01	1.88E+01	1.80E+01
2002	2019	88.0	1.81E+01	1.34E+01	2.44E+01	2.21E+01	2.38E+01	2.29E+01
2003	2259	88.0	1.70E+01	1.21E+01	2.39E+01	2.48E+01	2.66E+01	2.57E+01
2004	1205	88.2	1.61E+01	1.07E+01	2.42E+01	1.30E+01	1.43E+01	1.37E+01
2005	1200	88.0	1.52E+01	9.26E+00	2.49E+01	1.30E+01	1.43E+01	1.36E+01
2006	1035	88.0	1.43E+01	7.93E+00	2.59E+01	1.12E+01	1.24E+01	1.18E+01

Table 18. Plot data for standby TDP FTS events trend. Figure 12

FY	Failures	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	6	88.0	1.03E-01	4.47E-02	2.36E-01	3.15E-02	1.20E-01	6.96E-02
1999	16	88.0	9.68E-02	4.86E-02	1.92E-01	1.12E-01	2.54E-01	1.77E-01
2000	16	88.2	9.11E-02	5.16E-02	1.61E-01	1.11E-01	2.53E-01	1.76E-01
2001	4	88.0	8.58E-02	5.24E-02	1.41E-01	1.78E-02	9.06E-02	4.82E-02
2002	3	88.0	8.09E-02	4.99E-02	1.31E-01	1.16E-02	7.53E-02	3.75E-02
2003	6	88.0	7.62E-02	4.44E-02	1.31E-01	3.15E-02	1.20E-01	6.96E-02
2004	9	88.2	7.18E-02	3.76E-02	1.37E-01	5.40E-02	1.61E-01	1.01E-01
2005	8	88.0	6.76E-02	3.08E-02	1.48E-01	4.64E-02	1.48E-01	9.10E-02
2006	5	88.0	6.37E-02	2.49E-02	1.63E-01	2.45E-02	1.05E-01	5.89E-02

Table 19. Plot data for standby TDP FTR≤1H events trend. Figure 13

FY	Failures	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	2	88.0	4.29E-02	2.44E-02	7.57E-02	5.76E-03	5.56E-02	2.51E-02
1999	4	88.0	4.24E-02	2.65E-02	6.79E-02	1.67E-02	8.50E-02	4.52E-02
2000	6	88.2	4.19E-02	2.84E-02	6.18E-02	2.95E-02	1.12E-01	6.52E-02
2001	5	88.0	4.14E-02	2.97E-02	5.76E-02	2.30E-02	9.89E-02	5.53E-02
2002	3	88.0	4.09E-02	3.00E-02	5.58E-02	1.09E-02	7.07E-02	3.52E-02
2003	4	88.0	4.04E-02	2.89E-02	5.65E-02	1.67E-02	8.50E-02	4.52E-02
2004	3	88.2	3.99E-02	2.68E-02	5.93E-02	1.09E-02	7.05E-02	3.51E-02
2005	5	88.0	3.94E-02	2.43E-02	6.38E-02	2.30E-02	9.89E-02	5.53E-02
2006	2	88.0	3.89E-02	2.18E-02	6.94E-02	5.76E-03	5.56E-02	2.51E-02

Table 20. Plot data for standby TDP FTR>1H events trend. Figure 14

FY	Failures	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	0	88.0	2.62E-03	1.28E-03	5.38E-03	1.23E-05	1.20E-02	3.12E-03
1999	0	88.0	3.15E-03	1.73E-03	5.73E-03	1.23E-05	1.20E-02	3.12E-03
2000	0	88.2	3.77E-03	2.30E-03	6.20E-03	1.23E-05	1.20E-02	3.12E-03
2001	1	88.0	4.53E-03	2.96E-03	6.91E-03	1.10E-03	2.44E-02	9.37E-03
2002	0	88.0	5.43E-03	3.65E-03	8.07E-03	1.23E-05	1.20E-02	3.12E-03
2003	0	88.0	6.51E-03	4.25E-03	9.97E-03	1.23E-05	1.20E-02	3.12E-03
2004	1	88.2	7.80E-03	4.73E-03	1.29E-02	1.10E-03	2.44E-02	9.36E-03
2005	1	88.0	9.36E-03	5.11E-03	1.71E-02	1.10E-03	2.44E-02	9.37E-03
2006	2	88.0	1.12E-02	5.43E-03	2.32E-02	3.58E-03	3.46E-02	1.56E-02

Table 21. Plot data for normally running TDP start demands trend. Figure 15

FY	Demands	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	115	28.0	4.10E+00	3.79E+00	4.44E+00	3.50E+00	4.76E+00	4.11E+00
1999	115	28.0	4.12E+00	3.86E+00	4.40E+00	3.50E+00	4.76E+00	4.11E+00
2000	114	28.1	4.14E+00	3.93E+00	4.37E+00	3.46E+00	4.70E+00	4.06E+00
2001	114	28.0	4.16E+00	3.98E+00	4.36E+00	3.47E+00	4.72E+00	4.07E+00
2002	115	28.0	4.18E+00	4.01E+00	4.36E+00	3.50E+00	4.76E+00	4.11E+00
2003	133	28.0	4.20E+00	4.02E+00	4.40E+00	4.09E+00	5.44E+00	4.75E+00
2004	117	28.1	4.22E+00	4.00E+00	4.46E+00	3.56E+00	4.82E+00	4.17E+00
2005	117	28.0	4.24E+00	3.98E+00	4.53E+00	3.57E+00	4.83E+00	4.18E+00
2006	116	28.0	4.26E+00	3.95E+00	4.61E+00	3.53E+00	4.79E+00	4.14E+00

Table 22. Plot data for normally running TDP run hours trend. Figure 16

FY	Run Hours	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	432369	28.0	1.54E+04	1.47E+04	1.62E+04	1.54E+04	1.55E+04	1.54E+04
1999	432369	28.0	1.55E+04	1.48E+04	1.62E+04	1.54E+04	1.55E+04	1.54E+04
2000	432369	28.1	1.55E+04	1.50E+04	1.61E+04	1.54E+04	1.54E+04	1.54E+04
2001	432370	28.0	1.56E+04	1.51E+04	1.61E+04	1.54E+04	1.55E+04	1.54E+04
2002	430454	28.0	1.57E+04	1.52E+04	1.61E+04	1.53E+04	1.54E+04	1.54E+04
2003	476530	28.0	1.57E+04	1.53E+04	1.62E+04	1.70E+04	1.71E+04	1.70E+04
2004	438129	28.1	1.58E+04	1.52E+04	1.63E+04	1.56E+04	1.56E+04	1.56E+04
2005	438129	28.0	1.58E+04	1.52E+04	1.65E+04	1.56E+04	1.57E+04	1.56E+04
2006	438129	28.0	1.59E+04	1.51E+04	1.67E+04	1.56E+04	1.57E+04	1.56E+04

Table 23. Plot data for normally running TDP FTS events trend. Figure 17

FY	Failures	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	1	28.0	4.59E-02	1.30E-02	1.62E-01	4.71E-03	1.05E-01	4.02E-02
1999	5	28.0	4.45E-02	1.56E-02	1.27E-01	6.13E-02	2.63E-01	1.47E-01
2000	0	28.1	4.32E-02	1.82E-02	1.03E-01	5.25E-05	5.13E-02	1.34E-02
2001	2	28.0	4.19E-02	2.01E-02	8.76E-02	1.53E-02	1.48E-01	6.70E-02
2002	0	28.0	4.07E-02	2.03E-02	8.15E-02	5.27E-05	5.14E-02	1.34E-02
2003	2	28.0	3.95E-02	1.86E-02	8.38E-02	1.53E-02	1.48E-01	6.70E-02
2004	1	28.1	3.84E-02	1.57E-02	9.35E-02	4.70E-03	1.04E-01	4.01E-02
2005	1	28.0	3.72E-02	1.26E-02	1.10E-01	4.71E-03	1.05E-01	4.02E-02
2006	1	28.0	3.61E-02	9.88E-03	1.32E-01	4.71E-03	1.05E-01	4.02E-02

Table 24. Plot data for normally running TDP FTR events trend. Figure 18

FY	Failures	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	3	28.0	1.31E-01	4.00E-02	4.32E-01	3.34E-02	2.17E-01	1.08E-01
1999	6	28.0	1.19E-01	4.45E-02	3.18E-01	9.09E-02	3.45E-01	2.00E-01
2000	5	28.1	1.08E-01	4.78E-02	2.44E-01	7.04E-02	3.03E-01	1.69E-01
2001	2	28.0	9.77E-02	4.79E-02	1.99E-01	1.77E-02	1.71E-01	7.71E-02
2002	0	28.0	8.85E-02	4.37E-02	1.79E-01	6.06E-05	5.92E-02	1.54E-02
2003	3	28.0	8.02E-02	3.62E-02	1.78E-01	3.34E-02	2.17E-01	1.08E-01
2004	6	28.1	7.27E-02	2.79E-02	1.90E-01	9.06E-02	3.44E-01	2.00E-01
2005	2	28.0	6.58E-02	2.06E-02	2.10E-01	1.77E-02	1.71E-01	7.71E-02
2006	1	28.0	5.97E-02	1.49E-02	2.39E-01	5.43E-03	1.21E-01	4.63E-02

9 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.