Component Performance Study

Motor-Driven Pumps

1998–2007

1 INTRODUCTION

This report presents a performance evaluation of the centrifugal motor-driven pumps (MDPs) 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 MDP 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 2007 as reported in EPIX. The MDP 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). MDP 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, the following statistically significant increasing trends were identified in the MDP 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).

- Frequency (demands per reactor year) of start demands, normally running MDPs. (see Figure 15)
- Normally running MDP run hours per reactor critical year. (see Figure 16)

These trends are not adverse trends; they only indicate an increase in demands and run hours for normally running pumps. Run hours have increased since plant capacity factors have increased over time. The demand occurrence rate per MDP run hour has remained essentially constant over the trending period. Statistically significant decreasing trends were identified in the MDP results for the following:

- Standby systems, industry-wide MDP FTR>1H trend. (see Figure 3)
- Normally running systems, industry-wide MDP FTS trend. (see Figure 4)
- Normally running systems, industry-wide MDP FTR trend. (see Figure 5)
- Pooled AFW, HPI, and HCS MDP UA trend. (see Figure 6)
- Standby systems, industry-wide MDP unreliability trend (8-hour mission). (see Figure 7)
- Normally running systems (MFW), industry-wide MDP unreliability trend (8-hour mission). (see Figure 8)
- Frequency (failures per reactor year) of FTR>1H events, standby MDPs. (see Figure 14)
- Frequency (failures per reactor year) of FTS events, normally running MDPs. (see Figure 17)
- Frequency (failures per reactor year) of FTR events, normally running MDPs. (see Figure 18)

3 FAILURE PROBABILITIES AND FAILURE RATES

3.1 Overview

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

Table 1. MDP systems.

System	Description	Standby	Normally Running
AFW	Auxiliary feedwater	115	
CCW	Component cooling water		264
CDS	Condensate system		140
CRD	Control rod drive		42
CSR	Containment spray recirculation	152	
CVC	Chemical and volume control		120
EPS	Emergency power supply	16	
HPCS	High pressure core spray	9	
HPSI	High pressure injection	174	
LPCI	Low pressure coolant injection	147	
LPCS	Low pressure core spray	68	
LPSI	Low pressure injection	165	
MFW	Main feedwater		56
MSS	Main steam	21	
SLC	Standby liquid control	65	
SWN	Normal service water		262
SWS	Emergency service water (Standby)	187	
	Total	1119	884

The MDPs are assumed to operate both when the reactor is critical and during shutdown periods. The number of MDPs 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 2. Industry-wide distributions of p (failure probability) and λ (hourly rate) for MDPs.

Operation	Failure Mode	5%	Median	Mean	95%	Distribution		
						Type	α	β
Standby	FTS	6.0E-05	1.0E-03	1.5E-03	5.0E-03	Beta	0.90	6.00E+02
	FTR≤1H	5.0E-05	3.0E-04	4.0E-04	1.0E-03	Gamma	1.50	3.75E+03
	FTR>1H	2.5E-08	2.5E-06	6.0E-06	2.5E-05	Gamma	0.50	8.33E+04
Running/ Alternating	FTS	8.0E-05	1.2E-03	2.0E-03	6.0E-03	Beta	0.90	4.50E+02
	FTR	6.0E-07	4.0E-06	5.0E-06	1.2E-05	Gamma	1.50	3.00E+05

3.2 MDP 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 MDP 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 MDPs are shown in Figure 4 and Figure 5. The data for the trend plots are contained in Table 10 and Table 11.

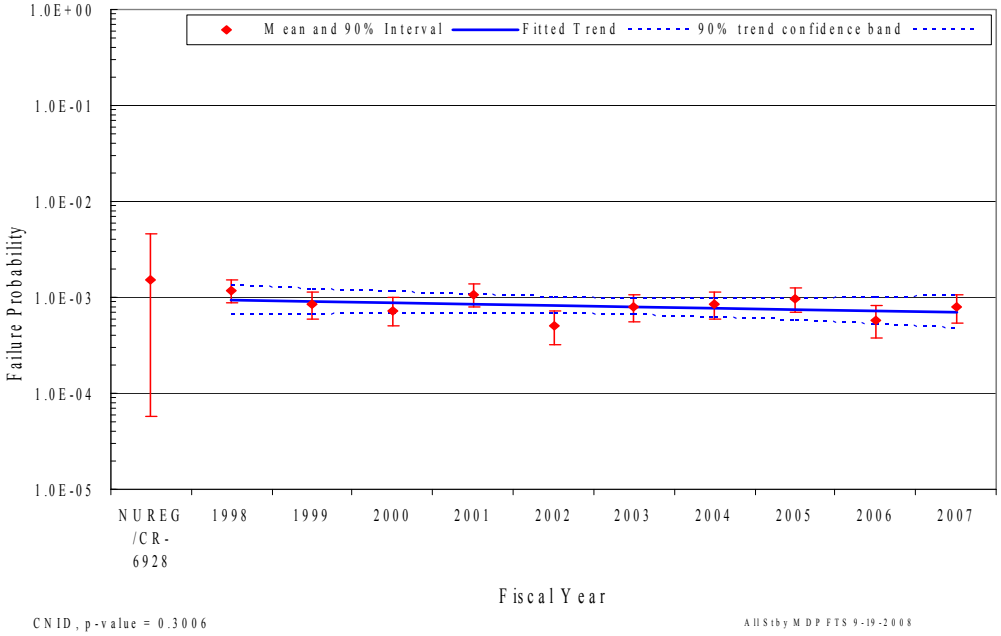

Figure 1. Standby systems, industry-wide MDP FTS trend.

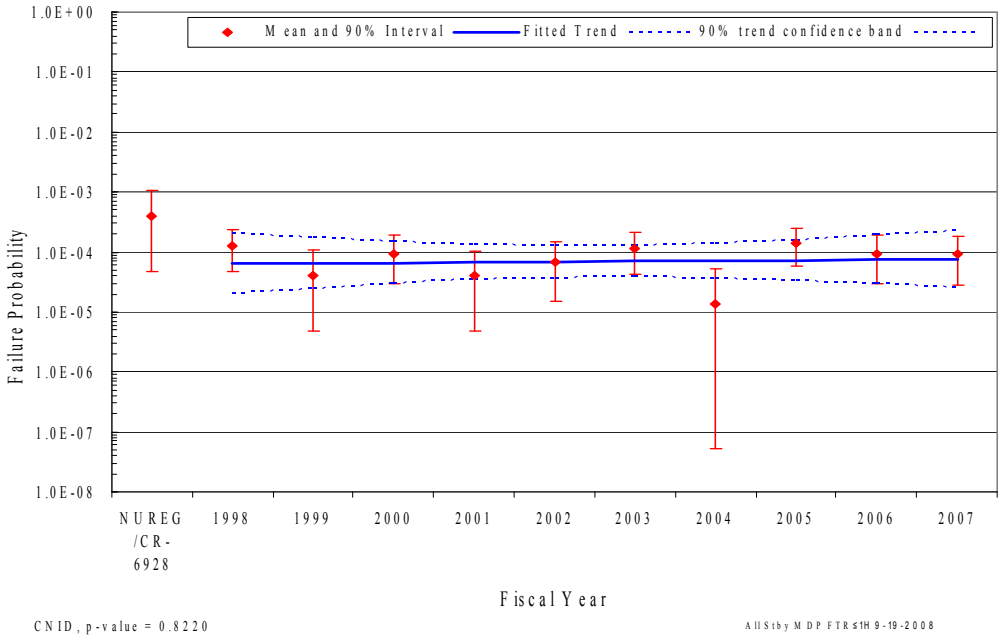

Figure 2. Standby systems, industry-wide MDP FTR≤1H trend.

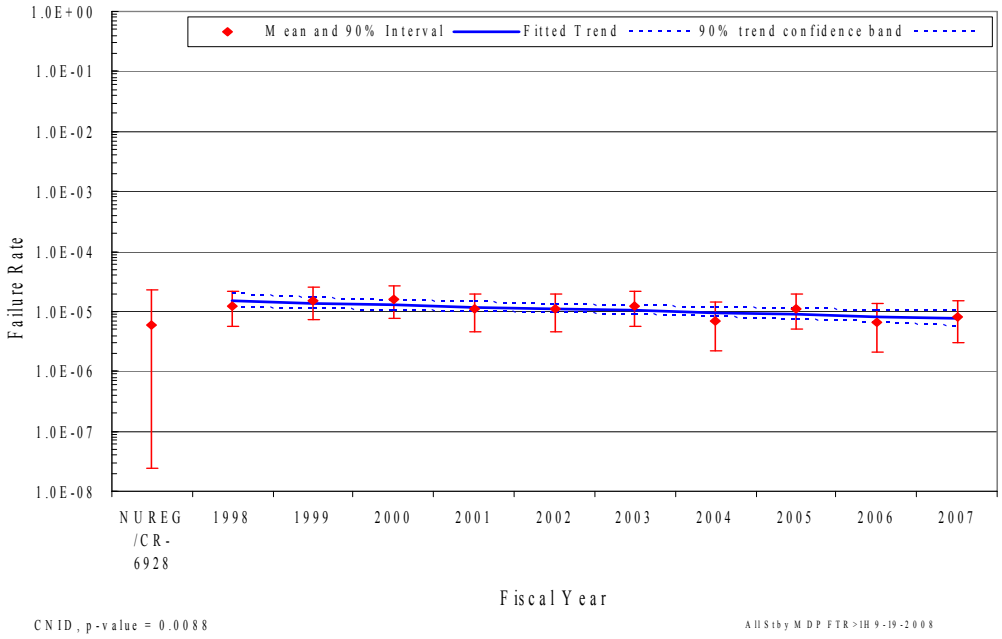

Figure 3. Standby systems, industry-wide MDP FTR>1H trend.

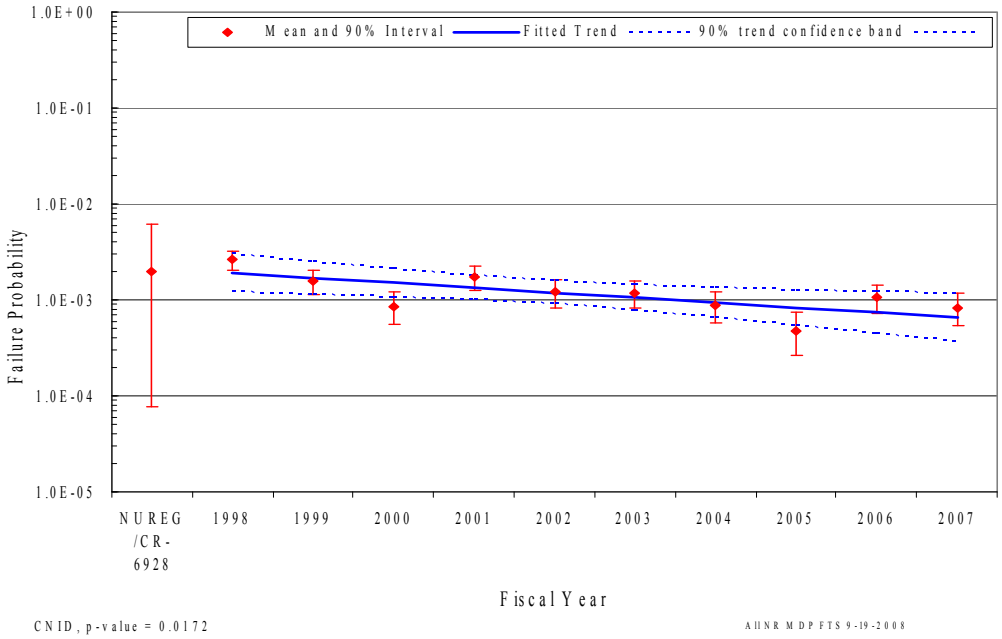

Figure 4. Normally running systems, industry-wide MDP FTS trend.

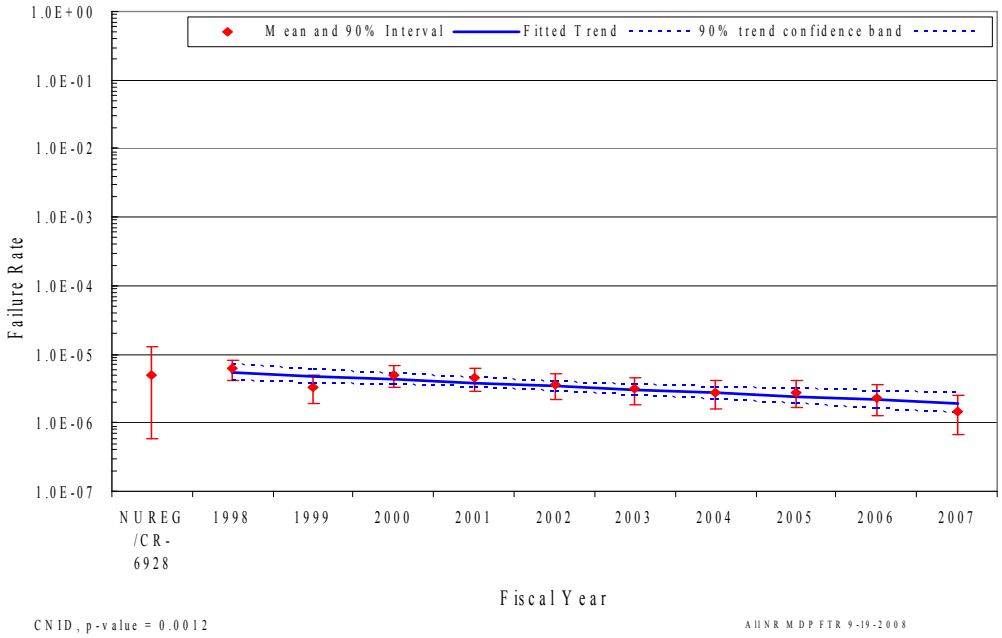

Figure 5. Normally running systems, industry-wide MDP FTR trend.

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 MDP trains has been calculated from the operating experience. UA data are for MDP trains, which can include more than just the MDP. However, in most cases the MDP contributes the majority of the UA reported. Table 3 shows overall results for the MDP 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 MDPs.

Description	Mean	Distribution	α	β
Motor-Driven Pump Test or Maintenance (AFW)	4.00E-03	Beta	2.50	622.50
Motor-Driven Pump Test or Maintenance (CCW)	6.00E-03	Beta	1.20	198.80
Motor-Driven Pump Test or Maintenance (ESW)	1.20E-02	Beta	1.00	82.33
Motor-Driven Pump Test or Maintenance (HPCS)	1.20E-02	Beta	1.50	123.50
Motor-Driven Pump Test or Maintenance (HPSI)	4.00E-03	Beta	2.50	622.50
Motor-Driven Pump Test or Maintenance (NSW)	1.50E-02	Beta	6.00	394.00
Motor-Driven Pump Test or Maintenance (Other)	8.00E-03	Beta	1.00	124.00
Motor-Driven Pump Test or Maintenance (RHR BWR)	8.00E-03	Beta	6.00	744.00
Motor-Driven Pump Test or Maintenance (RHR PWR)	6.00E-03	Beta	3.00	497.00
Motor-Driven Pump Test or Maintenance (RHRSW)	6.00E-03	Beta	1.20	198.80

4.2 MDP Unavailability Trends

For the 1998-2007 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 MDP train unavailability is shown in Figure 6. The data for this figure is in Table 12. The MDPs 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 (1998–2007) unavailability and

reactor critical hour data were obtained from the ROP (1998 to 2001) and EPIX (2002 to 2007) data for the MDP component. The total downtimes during operation for each plant and year were summed, and divided by the corresponding number of MDP-reactor critical hours. Unavailability data for shutdown periods are not reported.

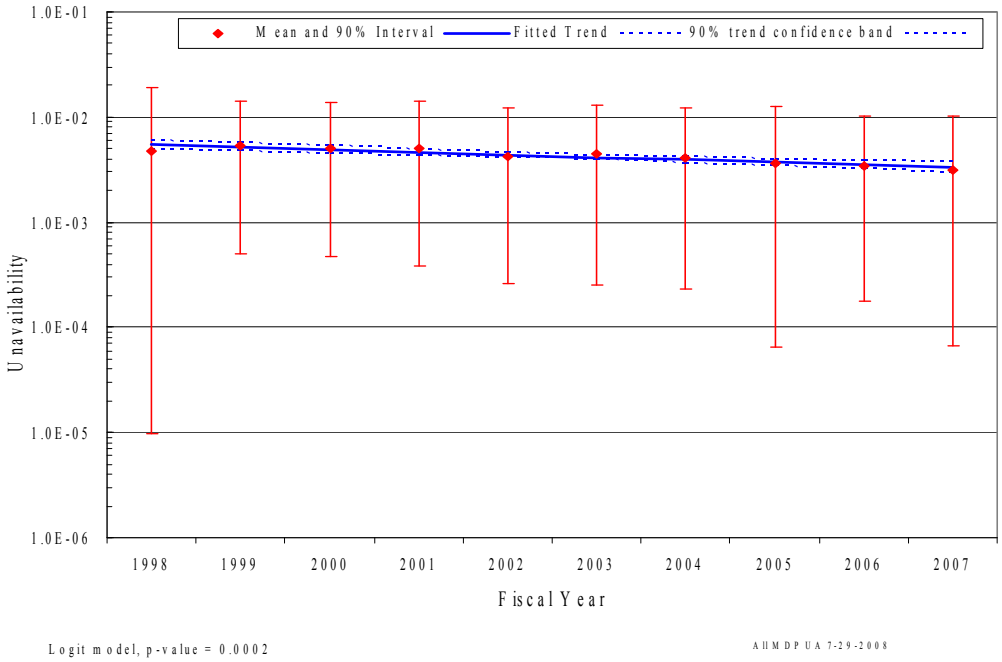

Figure 6. Pooled AFW, HPI, and HCS MDP UA trend.

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 MDP 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 MDP 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.

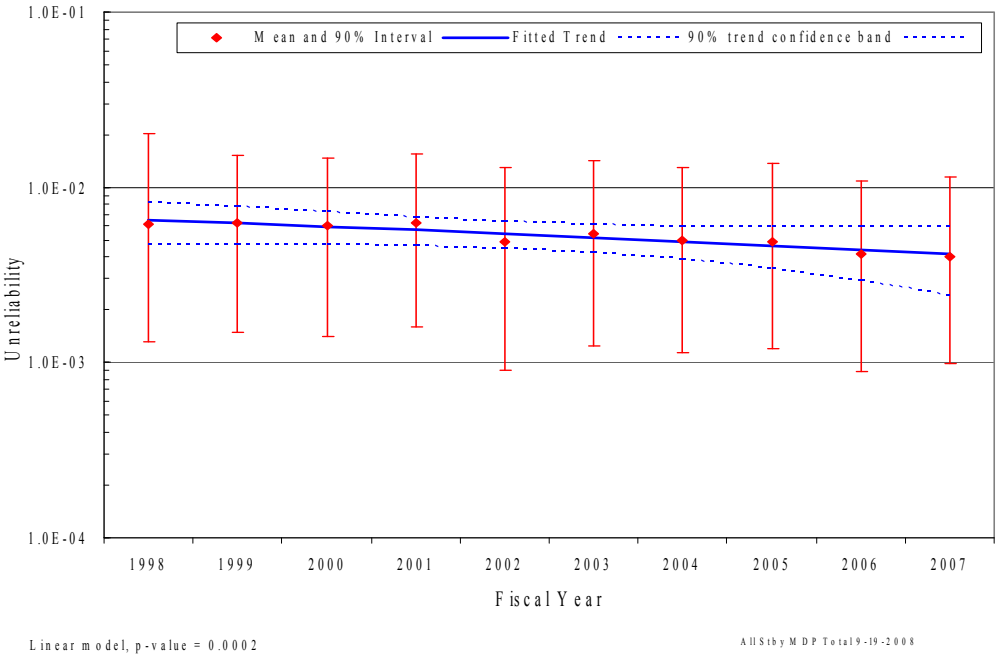

Figure 7. Standby systems, industry-wide MDP unreliability trend (8-hour mission).

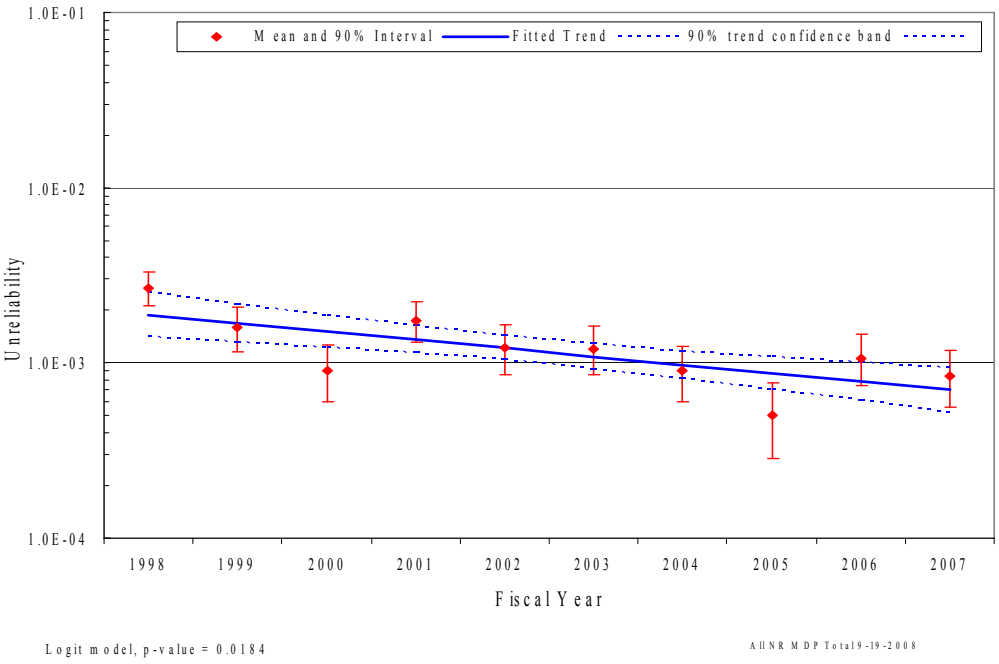

Figure 8. Normally running systems (MFW), industry-wide MDP unreliability trend (8-hour mission).

6 ENGINEERING TRENDS

This section presents frequency trends for MDP 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 MDP Engineering Trends

Figure 9 shows the trend for standby MDP start demands. Figure 10 shows the trend MDP run ≤1 hour demands. Figure 11 shows the trend for the MDP run hours. Table 15, Table 16, and Table 17 provide the plot data, respectively.

Figure 12 shows the trend for MDP FTS events. Figure 13 shows the trend MDP FTR≤1H events, and Figure 14 shows the trend for the MDP FTR 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 and year for the FTS failure mode. Table 5 summarizes the failures by system and year for the FTR≤1H failure mode. Table 6 summarizes the failures by system and year for the FTR>1H failure mode.

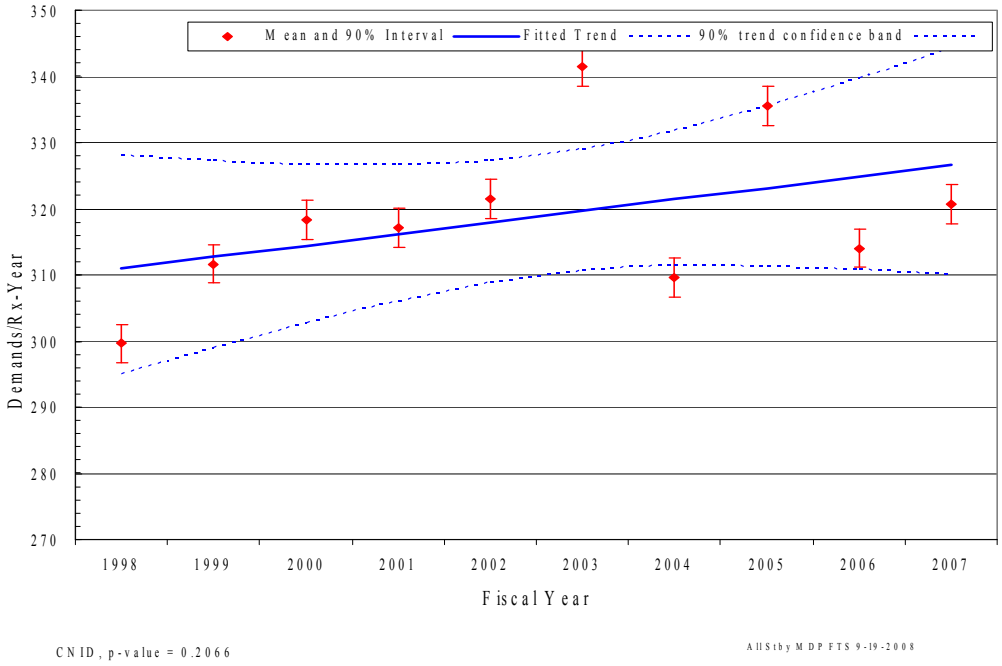

Figure 9. Frequency (demands per reactor year) of start demands, standby MDPs.

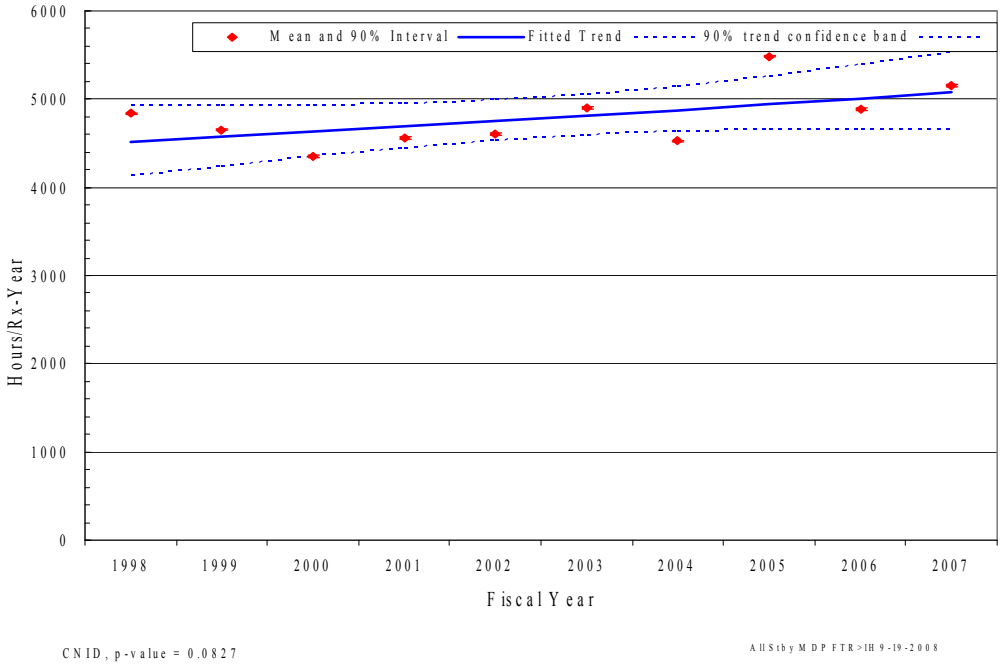

Figure 10. Standby MDP run hours per reactor critical year of run ≤ 1H hours.

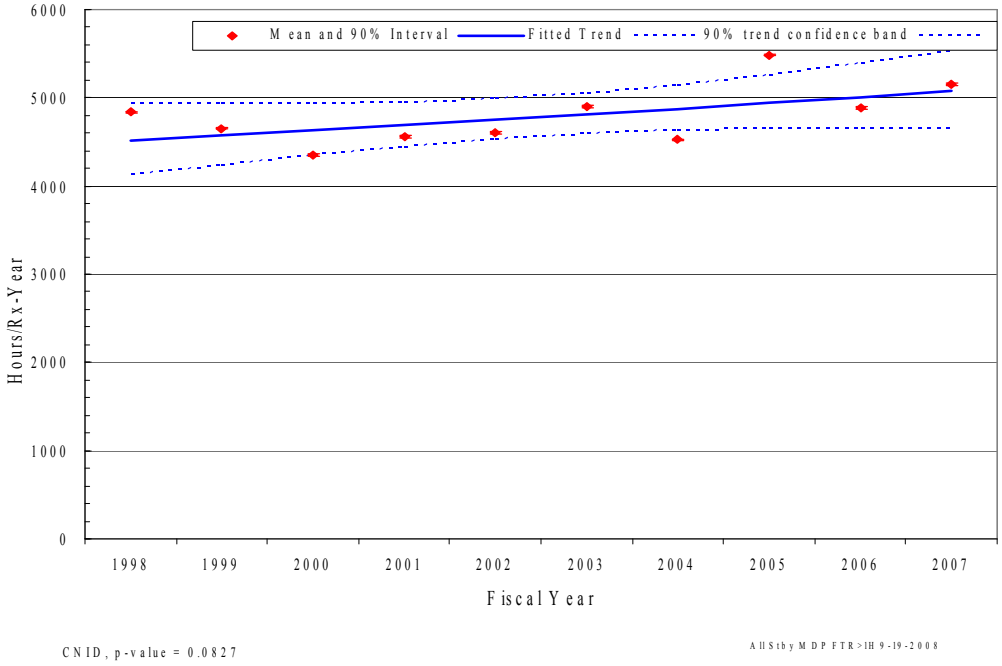

Figure 11. Standby MDP run hours per reactor critical year.

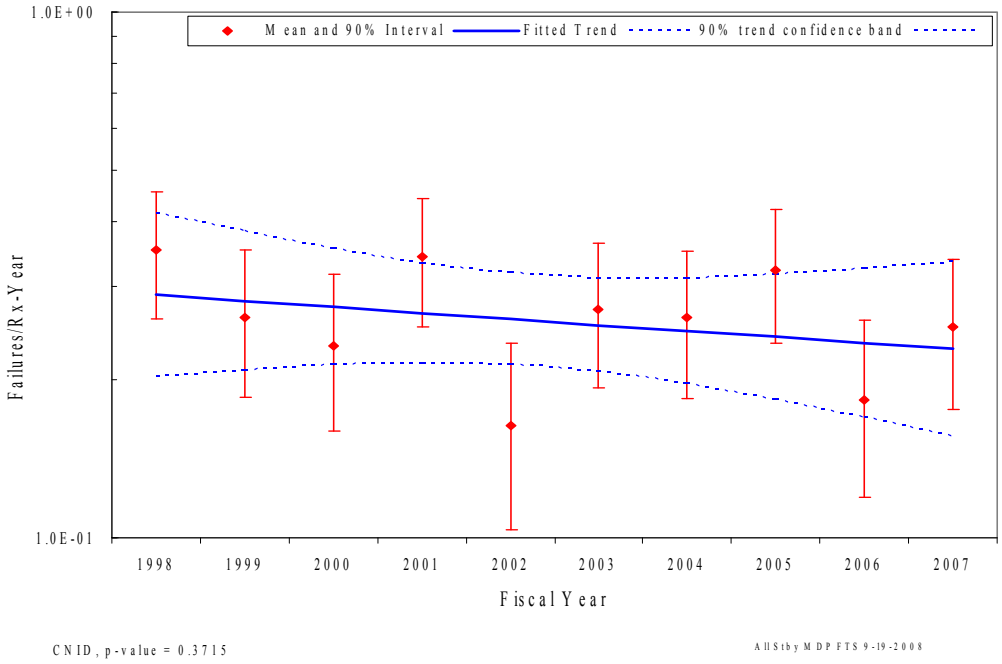

Figure 12. Frequency (failures per reactor year) of FTS events, standby MDPs.

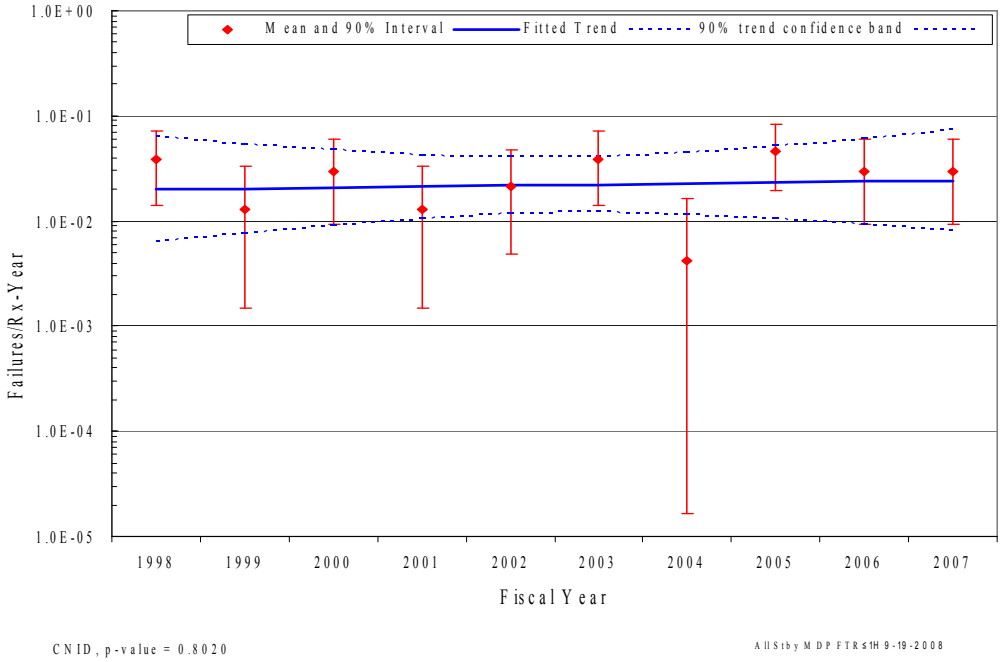

Figure 13. Frequency (failures per reactor year) of FTR≤1H events, standby MDPs.

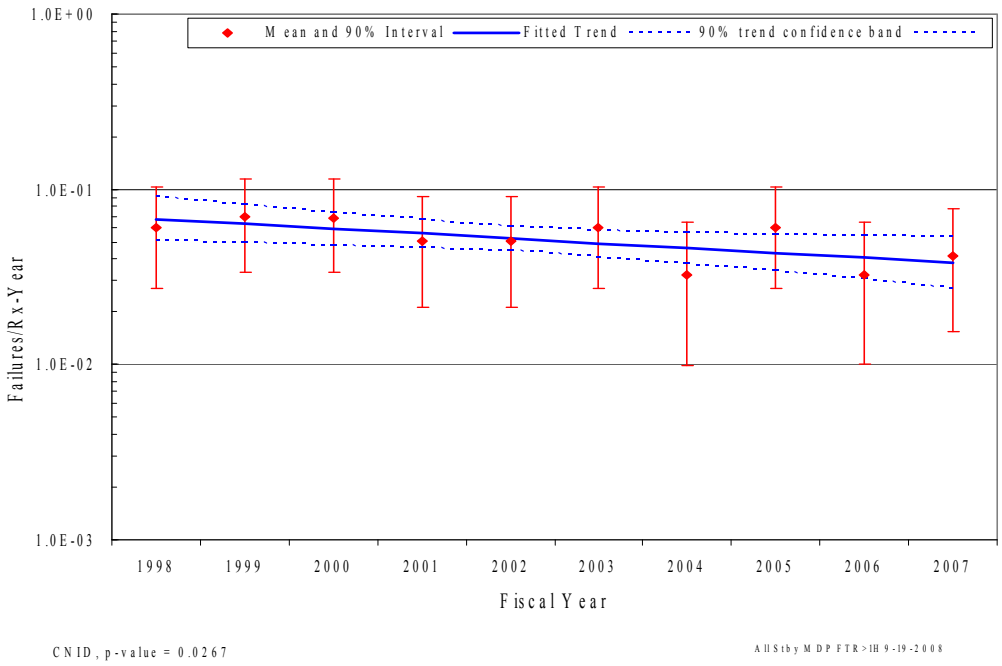

Figure 14. Frequency (failures per reactor year) of FTR>1H events, standby MDPs.

6.2 Normally Running MDP Engineering Trends

Figure 15 shows the trend for normally running MDP demands and Figure 16 shows the trend for the MDP run hours. Table 21 and Table 22 provide the plot data, respectively.

Figure 17 shows the trend for MDP FTS events and Figure 18 shows the trend for the MDP FTR events. Table 23 and Table 24 provide the plot data respectively. The normally running systems from Table 2 are trended for each figure.

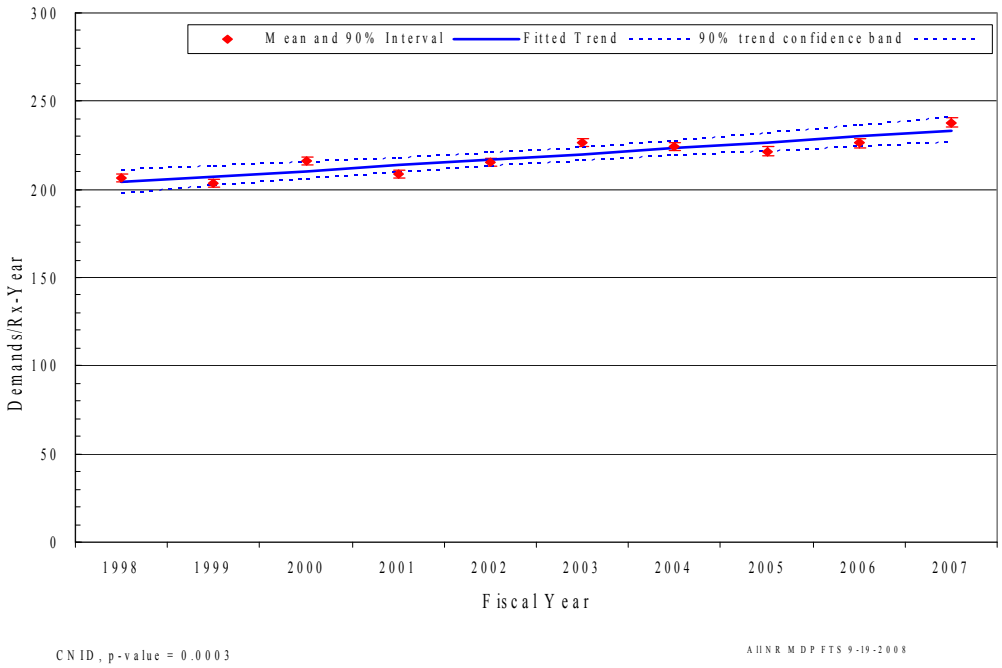

Figure 15. Frequency (demands per reactor year) of start demands, normally running MDPs.

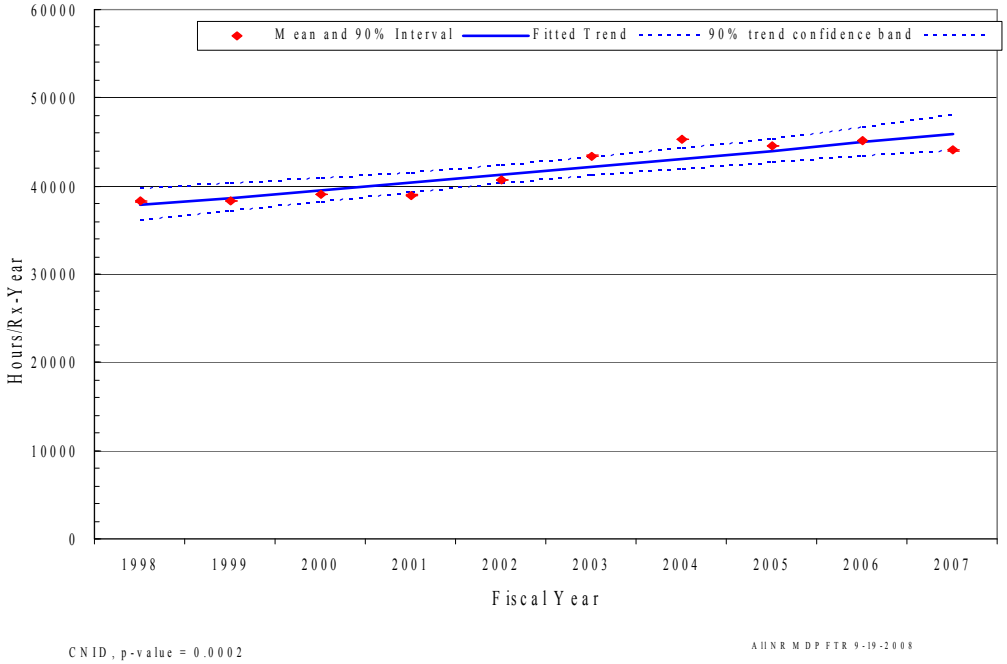

Figure 16. Normally running MDP run hours per reactor critical year.

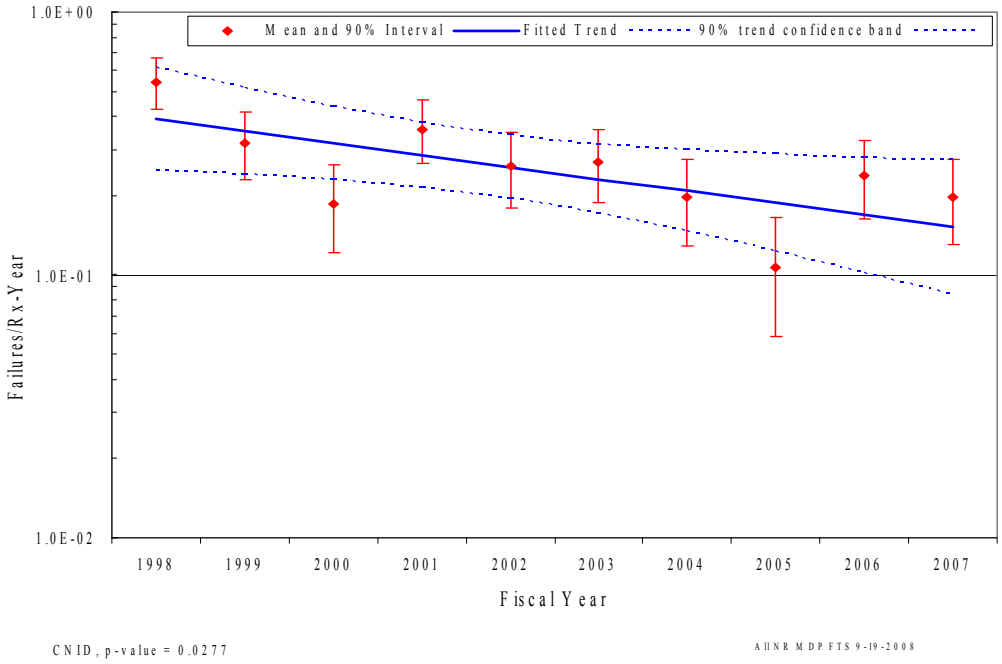

Figure 17. Frequency (failures per reactor year) of FTS events, normally running MDPs.

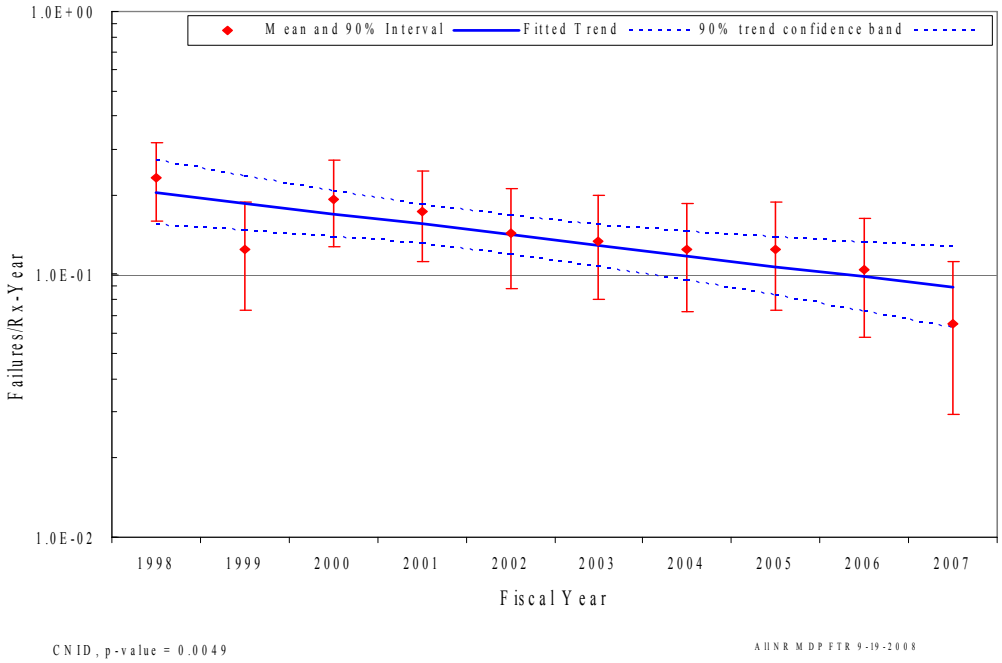

Figure 18. Frequency (failures per reactor year) of FTR events, normally running MDPs.

Table 4. Summary of MDP 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	FY 07	Total	Percent of Failures
AFW	115	5.7%	3	6	3	5	0	4	0	3	3	6	38	6.5%
CCW	264	13.2%	12	9	2	9	6	6	3	0	9	6	71	12.2%
CDS	140	7.0%	2	3	2	1	2	1	2	0	1	1	16	2.7%
CRD	42	2.1%	2	2	2	4	2	0	0	0	0	1	15	2.6%
CSR	152	7.6%	2	2	1	5	0	7	2	3	1	0	29	5.0%
CVC	120	6.0%	23	12	3	13	6	12	4	2	6	5	95	16.3%
EPS	16	0.8%	0	0	0	0	1	0	0	1	2	0	5	0.9%
HPCS	9	0.4%	0	0	0	0	0	1	1	1	1	0	4	0.7%
HPSI	174	8.7%	13	3	4	8	6	2	8	5	1	3	59	10.1%
LPCI	147	7.3%	3	3	7	4	0	2	1	2	2	2	29	5.0%
LPCS	68	3.4%	2	0	0	0	2	1	0	1	0	1	9	1.5%
LPI	165	8.2%	4	3	2	2	3	4	4	5	1	3	39	6.7%
MFW	56	2.8%	2	1	3	2	0	1	1	1	1	0	15	2.6%
MSS	21	1.0%	0	0	0	0	0	1	0	2	0	0	3	0.5%
SLC	65	3.2%	1	2	0	3	0	0	1	3	0	1	12	2.1%
SWN	262	13.1%	12	4	6	6	9	6	9	7	6	6	73	12.5%
SWS	187	9.3%	7	7	6	7	4	5	9	6	7	9	72	12.3%
Total	2003	100.0%	88	57	41	69	41	53	45	42	41	44	584	100.0%

Table 5. Summary of MDP 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	FY 07	Total	Percent of Failures
AFW	115	5.7%	0	1	1	0	1	1	0	1	0	1	6	14.0%
CCW	264	13.2%	0	0	0	0	1	0	0	1	0	0	2	4.7%
CDS	140	7.0%	0	0	0	0	0	0	0	0	0	1	1	2.3%
CRD	42	2.1%	0	0	0	0	0	0	0	0	0	0	0	0.0%
CSR	152	7.6%	1	0	0	0	0	0	0	2	1	0	4	9.3%
CVC	120	6.0%	0	0	0	0	0	0	2	3	2	0	7	16.3%
EPS	16	0.8%	0	0	0	0	0	0	0	0	0	0	0	0.0%
HPCS	9	0.4%	0	0	0	0	0	0	0	0	0	0	0	0.0%
HPSI	174	8.7%	0	0	0	1	0	0	0	0	0	2	3	7.0%
LPCI	147	7.3%	0	0	0	0	0	0	0	1	0	0	1	2.3%
LPCS	68	3.4%	0	0	0	0	0	0	0	0	0	0	0	0.0%
LPI	165	8.2%	0	0	1	0	1	0	0	0	1	0	3	7.0%
MFW	56	2.8%	0	0	0	0	1	0	0	0	0	0	1	2.3%
MSS	21	1.0%	0	0	0	0	0	0	0	0	0	0	0	0.0%
SLC	65	3.2%	0	0	0	0	0	0	0	0	0	0	0	0.0%
SWN	262	13.1%	0	0	0	0	1	1	2	1	0	1	6	14.0%
SWS	187	9.3%	3	0	1	0	0	3	0	1	1	0	9	20.9%
Total	2003	100.0%	4	1	3	1	5	5	4	10	5	5	43	100.0%

Table 6. Summary of MDP 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	FY 07	Total	Percent of Failures
AFW	115	5.7%	1	0	0	1	0	0	0	1	0	0	3	1.8%
CCW	264	13.2%	4	1	7	1	1	2	1	1	2	1	21	12.8%
CDS	140	7.0%	6	3	1	1	2	1	0	1	2	0	17	10.4%
CRD	42	2.1%	2	1	4	1	1	1	0	0	0	0	10	6.1%
CSR	152	7.6%	1	1	0	0	0	0	1	0	0	0	3	1.8%
CVC	120	6.0%	5	3	2	4	5	4	4	4	2	2	35	21.3%
EPS	16	0.8%	0	2	0	1	0	0	0	0	0	0	2	1.2%
HPCS	9	0.4%	0	0	0	0	0	0	0	0	0	0	0	0.0%
HPSI	174	8.7%	0	3	0	0	0	1	0	1	1	0	6	3.7%
LPCI	147	7.3%	0	0	0	0	0	1	0	0	0	1	2	1.2%
LPCS	68	3.4%	0	0	0	0	0	0	1	0	0	0	1	0.6%
LPI	165	8.2%	0	0	1	0	1	2	0	0	0	0	4	2.4%
MFW	56	2.8%	3	0	1	2	0	0	1	0	1	1	9	5.5%
MSS	21	1.0%	0	0	0	0	0	0	0	2	0	0	2	1.2%
SLC	65	3.2%	0	0	0	0	0	0	0	0	0	0	0	0.0%
SWN	262	13.1%	3	4	4	8	5	5	6	6	3	2	41	25.0%
SWS	187	9.3%	4	1	6	3	4	2	1	2	2	3	8	4.9%
Total	2003	100.0%	29	19	26	22	19	19	15	18	13	10	164	100.0%

7 MDP ASSEMBLY DESCRIPTION

The MDP consists of the pump, motor-driver, and circuit breaker sub-components. All of the pumps are centrifugal, but can be different configurations. The drivers are medium or large ac motors. For most PWRs, the MDP assembly includes a speed increaser, which is treated as a sub-component.

8 DATA TABLES

Table 7. Plot data for standby MDP 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						5.83E-05	4.66E-03	1.50E-03
1998	35	29664.5	9.28E-04	6.46E-04	1.33E-03	8.68E-04	1.51E-03	1.17E-03
1999	26	30851.4	9.00E-04	6.62E-04	1.22E-03	5.92E-04	1.13E-03	8.43E-04
2000	23	31600.6	8.72E-04	6.74E-04	1.13E-03	5.01E-04	9.93E-04	7.30E-04
2001	34	31399.8	8.46E-04	6.79E-04	1.05E-03	7.94E-04	1.39E-03	1.08E-03
2002	16	31833.3	8.20E-04	6.70E-04	1.00E-03	3.22E-04	7.30E-04	5.09E-04
2003	27	33811.4	7.95E-04	6.47E-04	9.76E-04	5.66E-04	1.06E-03	7.99E-04
2004	26	30733.1	7.70E-04	6.11E-04	9.72E-04	5.94E-04	1.13E-03	8.46E-04
2005	32	33222.4	7.47E-04	5.67E-04	9.83E-04	7.01E-04	1.25E-03	9.61E-04
2006	18	31090.9	7.24E-04	5.22E-04	1.00E-03	3.80E-04	8.23E-04	5.84E-04
2007	25	31867.1	7.02E-04	4.77E-04	1.03E-03	5.48E-04	1.06E-03	7.85E-04

Table 8. Plot data for standby MDP 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						4.69E-05	1.04E-03	4.00E-04
1998	4	29768.3	6.33E-05	2.03E-05	1.98E-04	4.65E-05	2.37E-04	1.26E-04
1999	1	30925.0	6.46E-05	2.45E-05	1.70E-04	4.77E-06	1.06E-04	4.07E-05
2000	3	31594.8	6.58E-05	2.92E-05	1.48E-04	2.88E-05	1.87E-04	9.32E-05
2001	1	31492.8	6.71E-05	3.37E-05	1.34E-04	4.70E-06	1.04E-04	4.00E-05
2002	2	31831.4	6.84E-05	3.71E-05	1.26E-04	1.52E-05	1.46E-04	6.61E-05
2003	4	33756.0	6.98E-05	3.82E-05	1.28E-04	4.19E-05	2.13E-04	1.13E-04
2004	0	31014.5	7.12E-05	3.66E-05	1.38E-04	5.32E-08	5.19E-05	1.35E-05
2005	5	32805.7	7.26E-05	3.33E-05	1.58E-04	5.90E-05	2.54E-04	1.42E-04
2006	3	31117.5	7.40E-05	2.93E-05	1.87E-04	2.92E-05	1.90E-04	9.44E-05
2007	3	31919.7	7.55E-05	2.53E-05	2.26E-04	2.86E-05	1.86E-04	9.24E-05

Table 9. Plot data for standby MDP 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						2.36E-08	2.30E-05	6.00E-06
1998	6	478584.2	1.47E-05	1.13E-05	1.91E-05	5.62E-06	2.13E-05	1.24E-05
1999	7	460819.4	1.37E-05	1.10E-05	1.71E-05	7.17E-06	2.47E-05	1.48E-05
2000	7	432011.4	1.27E-05	1.06E-05	1.54E-05	7.61E-06	2.62E-05	1.57E-05
2001	5	451196.0	1.19E-05	1.01E-05	1.39E-05	4.61E-06	1.98E-05	1.11E-05
2002	5	455565.9	1.10E-05	9.48E-06	1.28E-05	4.57E-06	1.96E-05	1.10E-05
2003	6	484845.1	1.03E-05	8.76E-06	1.20E-05	5.56E-06	2.11E-05	1.23E-05
2004	3	449142.1	9.54E-06	7.96E-06	1.14E-05	2.19E-06	1.42E-05	7.08E-06
2005	6	542949.2	8.88E-06	7.16E-06	1.10E-05	5.01E-06	1.90E-05	1.11E-05
2006	3	483772.7	8.26E-06	6.40E-06	1.07E-05	2.05E-06	1.33E-05	6.62E-06
2007	4	511792.8	7.68E-06	5.70E-06	1.04E-05	2.98E-06	1.52E-05	8.08E-06

Table 10. Plot data for normally running MDP 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						7.77E-05	6.22E-03	2.00E-03
1998	53	20004.7	1.90E-03	1.20E-03	3.01E-03	2.06E-03	3.23E-03	2.62E-03
1999	31	19734.7	1.69E-03	1.15E-03	2.49E-03	1.13E-03	2.04E-03	1.56E-03
2000	18	21016.6	1.50E-03	1.08E-03	2.08E-03	5.61E-04	1.22E-03	8.63E-04
2001	35	20227.2	1.33E-03	1.00E-03	1.78E-03	1.27E-03	2.22E-03	1.72E-03
2002	25	20883.4	1.19E-03	8.99E-04	1.57E-03	8.35E-04	1.61E-03	1.20E-03
2003	26	21969.7	1.05E-03	7.80E-04	1.43E-03	8.32E-04	1.58E-03	1.18E-03
2004	19	21814.9	9.37E-04	6.59E-04	1.33E-03	5.78E-04	1.23E-03	8.77E-04
2005	10	21491.8	8.33E-04	5.47E-04	1.27E-03	2.64E-04	7.45E-04	4.79E-04
2006	23	21953.4	7.41E-04	4.50E-04	1.22E-03	7.21E-04	1.43E-03	1.05E-03
2007	19	23083.9	6.59E-04	3.68E-04	1.18E-03	5.46E-04	1.16E-03	8.30E-04

Table 11. Plot data for normally running MDP 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						5.86E-07	1.30E-05	5.00E-06
1998	23	3709606.0	5.40E-06	4.10E-06	7.11E-06	4.18E-06	8.30E-06	6.09E-06
1999	12	3717111.0	4.82E-06	3.83E-06	6.07E-06	1.89E-06	4.87E-06	3.24E-06
2000	19	3799840.0	4.30E-06	3.55E-06	5.23E-06	3.26E-06	6.91E-06	4.94E-06
2001	17	3779727.0	3.84E-06	3.24E-06	4.55E-06	2.86E-06	6.34E-06	4.46E-06
2002	14	3946085.0	3.43E-06	2.91E-06	4.04E-06	2.16E-06	5.20E-06	3.54E-06
2003	13	4212100.0	3.06E-06	2.57E-06	3.66E-06	1.85E-06	4.60E-06	3.10E-06
2004	12	4404455.0	2.73E-06	2.22E-06	3.36E-06	1.61E-06	4.14E-06	2.75E-06
2005	12	4323265.0	2.44E-06	1.91E-06	3.12E-06	1.63E-06	4.21E-06	2.80E-06
2006	10	4375593.0	2.18E-06	1.63E-06	2.92E-06	1.28E-06	3.61E-06	2.32E-06
2007	6	4272389.0	1.95E-06	1.38E-06	2.74E-06	6.67E-07	2.53E-06	1.47E-06

Table 12. Plot data for all standby MDP 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	7674.5	1713844.0	5.45E-03	4.91E-03	6.05E-03	9.65E-06	1.89E-02	4.72E-03
1999	12906.2	2452646.0	5.16E-03	4.72E-03	5.64E-03	5.07E-04	1.43E-02	5.28E-03
2000	13106.3	2527489.0	4.88E-03	4.53E-03	5.26E-03	4.70E-04	1.39E-02	5.10E-03
2001	12594.7	2486451.0	4.62E-03	4.34E-03	4.93E-03	3.88E-04	1.44E-02	5.10E-03
2002	11211.2	2621261.0	4.38E-03	4.13E-03	4.64E-03	2.64E-04	1.23E-02	4.23E-03
2003	11454.8	2595146.0	4.14E-03	3.91E-03	4.39E-03	2.55E-04	1.31E-02	4.46E-03
2004	10828.8	2650608.0	3.92E-03	3.68E-03	4.18E-03	2.28E-04	1.21E-02	4.11E-03
2005	9594.8	2627175.0	3.71E-03	3.45E-03	4.00E-03	6.58E-05	1.25E-02	3.68E-03
2006	9155.2	2664121.0	3.52E-03	3.22E-03	3.84E-03	1.79E-04	1.02E-02	3.41E-03
2007	8187.3	2651618.0	3.33E-03	3.00E-03	3.70E-03	6.60E-05	1.04E-02	3.12E-03

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

FY	Regression Curve Data Points			Plot Trend Error Bar Points		
	Mean	Lower (5%)	Mean	Lower (5%)	Mean	Mean
1998	6.47E-03	4.72E-03	8.22E-03	1.31E-03	2.02E-02	6.11E-03
1999	6.21E-03	4.73E-03	7.70E-03	1.48E-03	1.53E-02	6.27E-03
2000	5.96E-03	4.71E-03	7.20E-03	1.40E-03	1.48E-02	6.03E-03
2001	5.70E-03	4.64E-03	6.76E-03	1.59E-03	1.56E-02	6.30E-03
2002	5.44E-03	4.48E-03	6.39E-03	9.03E-04	1.29E-02	4.88E-03
2003	5.18E-03	4.23E-03	6.14E-03	1.25E-03	1.41E-02	5.45E-03
2004	4.92E-03	3.86E-03	5.98E-03	1.14E-03	1.30E-02	5.01E-03
2005	4.67E-03	3.42E-03	5.91E-03	1.21E-03	1.37E-02	4.86E-03
2006	4.41E-03	2.92E-03	5.89E-03	8.92E-04	1.09E-02	4.13E-03
2007	4.15E-03	2.40E-03	5.90E-03	9.86E-04	1.14E-02	4.05E-03

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

FY	Regression Curve Data Points			Plot Trend Error Bar Points		
	Mean	Lower (5%)	Mean	Lower (5%)	Mean	Mean
1998	1.89E-03	1.40E-03	2.53E-03	2.11E-03	3.28E-03	2.67E-03
1999	1.69E-03	1.32E-03	2.17E-03	1.16E-03	2.07E-03	1.59E-03
2000	1.51E-03	1.23E-03	1.87E-03	6.01E-04	1.26E-03	9.03E-04
2001	1.36E-03	1.13E-03	1.62E-03	1.31E-03	2.26E-03	1.76E-03
2002	1.22E-03	1.03E-03	1.43E-03	8.65E-04	1.64E-03	1.23E-03
2003	1.09E-03	9.27E-04	1.28E-03	8.57E-04	1.61E-03	1.21E-03
2004	9.76E-04	8.16E-04	1.17E-03	6.00E-04	1.25E-03	8.99E-04
2005	8.74E-04	7.08E-04	1.08E-03	2.86E-04	7.67E-04	5.02E-04
2006	7.83E-04	6.10E-04	1.01E-03	7.38E-04	1.45E-03	1.07E-03
2007	7.02E-04	5.22E-04	9.42E-04	5.58E-04	1.17E-03	8.42E-04

Table 15. Plot data for standby MDP 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	29665	99.0	3.11E+02	2.95E+02	3.28E+02	2.97E+02	3.03E+02	3.00E+02
1999	30851	99.0	3.13E+02	2.99E+02	3.27E+02	3.09E+02	3.15E+02	3.12E+02
2000	31601	99.3	3.14E+02	3.03E+02	3.27E+02	3.15E+02	3.21E+02	3.18E+02
2001	31400	99.0	3.16E+02	3.06E+02	3.27E+02	3.14E+02	3.20E+02	3.17E+02
2002	31833	99.0	3.18E+02	3.09E+02	3.27E+02	3.19E+02	3.25E+02	3.22E+02
2003	33811	99.0	3.20E+02	3.11E+02	3.29E+02	3.38E+02	3.45E+02	3.42E+02
2004	30733	99.3	3.21E+02	3.11E+02	3.32E+02	3.07E+02	3.12E+02	3.10E+02
2005	33222	99.0	3.23E+02	3.11E+02	3.35E+02	3.33E+02	3.39E+02	3.36E+02
2006	31091	99.0	3.25E+02	3.11E+02	3.40E+02	3.11E+02	3.17E+02	3.14E+02
2007	31867	99.4	3.27E+02	3.10E+02	3.44E+02	3.18E+02	3.24E+02	3.21E+02

Table 16. Plot data for standby MDP 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	29768	99.0	3.12E+02	2.97E+02	3.27E+02	2.98E+02	3.04E+02	3.01E+02
1999	30925	99.0	3.13E+02	3.01E+02	3.26E+02	3.09E+02	3.15E+02	3.12E+02
2000	31595	99.3	3.15E+02	3.04E+02	3.26E+02	3.15E+02	3.21E+02	3.18E+02
2001	31493	99.0	3.17E+02	3.07E+02	3.26E+02	3.15E+02	3.21E+02	3.18E+02
2002	31831	99.0	3.18E+02	3.10E+02	3.27E+02	3.19E+02	3.24E+02	3.22E+02
2003	33756	99.0	3.20E+02	3.12E+02	3.28E+02	3.38E+02	3.44E+02	3.41E+02
2004	31015	99.3	3.21E+02	3.12E+02	3.31E+02	3.10E+02	3.15E+02	3.12E+02
2005	32806	99.0	3.23E+02	3.12E+02	3.34E+02	3.28E+02	3.34E+02	3.31E+02
2006	31118	99.0	3.25E+02	3.12E+02	3.38E+02	3.11E+02	3.17E+02	3.14E+02
2007	31920	99.4	3.26E+02	3.11E+02	3.42E+02	3.18E+02	3.24E+02	3.21E+02

Table 17. Plot data for standby MDP 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	478584	99.0	4.51E+03	4.13E+03	4.93E+03	4.82E+03	4.85E+03	4.83E+03
1999	460819	99.0	4.57E+03	4.24E+03	4.93E+03	4.64E+03	4.67E+03	4.65E+03
2000	432011	99.3	4.63E+03	4.34E+03	4.93E+03	4.34E+03	4.36E+03	4.35E+03
2001	451196	99.0	4.69E+03	4.44E+03	4.95E+03	4.55E+03	4.57E+03	4.56E+03
2002	455566	99.0	4.75E+03	4.53E+03	4.99E+03	4.59E+03	4.61E+03	4.60E+03
2003	484845	99.0	4.82E+03	4.59E+03	5.05E+03	4.89E+03	4.91E+03	4.90E+03
2004	449142	99.3	4.88E+03	4.63E+03	5.14E+03	4.51E+03	4.54E+03	4.52E+03
2005	542949	99.0	4.94E+03	4.65E+03	5.25E+03	5.47E+03	5.50E+03	5.48E+03
2006	483773	99.0	5.01E+03	4.66E+03	5.39E+03	4.88E+03	4.90E+03	4.89E+03
2007	511793	99.4	5.07E+03	4.65E+03	5.53E+03	5.14E+03	5.16E+03	5.15E+03

Table 18. Plot data for standby MDP 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	35	99.0	2.90E-01	2.02E-01	4.15E-01	2.61E-01	4.54E-01	3.52E-01
1999	26	99.0	2.82E-01	2.08E-01	3.82E-01	1.85E-01	3.52E-01	2.63E-01
2000	23	99.3	2.75E-01	2.13E-01	3.55E-01	1.59E-01	3.16E-01	2.32E-01
2001	34	99.0	2.68E-01	2.15E-01	3.33E-01	2.52E-01	4.43E-01	3.42E-01
2002	16	99.0	2.61E-01	2.13E-01	3.19E-01	1.03E-01	2.35E-01	1.64E-01
2003	27	99.0	2.54E-01	2.07E-01	3.12E-01	1.93E-01	3.63E-01	2.73E-01
2004	26	99.3	2.47E-01	1.96E-01	3.12E-01	1.84E-01	3.51E-01	2.62E-01
2005	32	99.0	2.41E-01	1.83E-01	3.17E-01	2.35E-01	4.20E-01	3.22E-01
2006	18	99.0	2.35E-01	1.69E-01	3.25E-01	1.19E-01	2.59E-01	1.83E-01
2007	25	99.4	2.29E-01	1.56E-01	3.35E-01	1.76E-01	3.39E-01	2.52E-01

Table 19. Plot data for standby MDP 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	4	99.0	1.99E-02	6.28E-03	6.29E-02	1.41E-02	7.19E-02	3.82E-02
1999	1	99.0	2.03E-02	7.64E-03	5.41E-02	1.49E-03	3.32E-02	1.27E-02
2000	3	99.3	2.08E-02	9.12E-03	4.73E-02	9.19E-03	5.96E-02	2.97E-02
2001	1	99.0	2.12E-02	1.06E-02	4.27E-02	1.49E-03	3.32E-02	1.27E-02
2002	2	99.0	2.17E-02	1.17E-02	4.05E-02	4.87E-03	4.70E-02	2.12E-02
2003	4	99.0	2.22E-02	1.20E-02	4.10E-02	1.41E-02	7.19E-02	3.82E-02
2004	0	99.3	2.27E-02	1.15E-02	4.46E-02	1.67E-05	1.63E-02	4.24E-03
2005	5	99.0	2.32E-02	1.05E-02	5.12E-02	1.94E-02	8.36E-02	4.67E-02
2006	3	99.0	2.37E-02	9.26E-03	6.08E-02	9.21E-03	5.98E-02	2.97E-02
2007	3	99.4	2.42E-02	7.98E-03	7.37E-02	9.18E-03	5.96E-02	2.96E-02

Table 20. Plot data for standby MDP 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	6	99.0	6.76E-02	5.05E-02	9.04E-02	2.72E-02	1.03E-01	5.99E-02
1999	7	99.0	6.34E-02	4.96E-02	8.11E-02	3.35E-02	1.15E-01	6.92E-02
2000	7	99.3	5.95E-02	4.84E-02	7.32E-02	3.34E-02	1.15E-01	6.90E-02
2001	5	99.0	5.58E-02	4.67E-02	6.68E-02	2.11E-02	9.07E-02	5.07E-02
2002	5	99.0	5.24E-02	4.43E-02	6.19E-02	2.11E-02	9.07E-02	5.07E-02
2003	6	99.0	4.92E-02	4.13E-02	5.86E-02	2.72E-02	1.03E-01	5.99E-02
2004	3	99.3	4.61E-02	3.77E-02	5.65E-02	9.97E-03	6.47E-02	3.22E-02
2005	6	99.0	4.33E-02	3.41E-02	5.50E-02	2.72E-02	1.03E-01	5.99E-02
2006	3	99.0	4.06E-02	3.06E-02	5.40E-02	9.99E-03	6.49E-02	3.23E-02
2007	4	99.4	3.81E-02	2.73E-02	5.32E-02	1.53E-02	7.78E-02	4.14E-02

Table 21. Plot data for normally running MDP 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	20005	97.0	2.04E+02	1.98E+02	2.11E+02	2.04E+02	2.09E+02	2.06E+02
1999	19735	97.0	2.07E+02	2.02E+02	2.13E+02	2.01E+02	2.06E+02	2.03E+02
2000	21017	97.3	2.10E+02	2.06E+02	2.15E+02	2.14E+02	2.19E+02	2.16E+02
2001	20227	97.0	2.14E+02	2.09E+02	2.18E+02	2.06E+02	2.11E+02	2.09E+02
2002	20883	97.0	2.17E+02	2.13E+02	2.21E+02	2.13E+02	2.18E+02	2.15E+02
2003	21970	97.0	2.20E+02	2.16E+02	2.24E+02	2.24E+02	2.29E+02	2.26E+02
2004	21815	97.3	2.23E+02	2.19E+02	2.28E+02	2.22E+02	2.27E+02	2.24E+02
2005	21492	97.0	2.27E+02	2.22E+02	2.32E+02	2.19E+02	2.24E+02	2.22E+02
2006	21953	97.0	2.30E+02	2.24E+02	2.36E+02	2.24E+02	2.29E+02	2.26E+02
2007	23084	97.0	2.33E+02	2.26E+02	2.41E+02	2.35E+02	2.41E+02	2.38E+02

Table 22. Plot data for normally running MDP 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	3709606	97.0	3.78E+04	3.61E+04	3.96E+04	3.82E+04	3.83E+04	3.82E+04
1999	3717111	97.0	3.86E+04	3.72E+04	4.02E+04	3.83E+04	3.84E+04	3.83E+04
2000	3799840	97.3	3.95E+04	3.82E+04	4.08E+04	3.90E+04	3.91E+04	3.91E+04
2001	3779727	97.0	4.03E+04	3.92E+04	4.15E+04	3.89E+04	3.90E+04	3.90E+04
2002	3946085	97.0	4.12E+04	4.02E+04	4.23E+04	4.07E+04	4.07E+04	4.07E+04
2003	4212100	97.0	4.21E+04	4.11E+04	4.32E+04	4.34E+04	4.35E+04	4.34E+04
2004	4404455	97.3	4.30E+04	4.19E+04	4.42E+04	4.53E+04	4.53E+04	4.53E+04
2005	4323265	97.0	4.40E+04	4.27E+04	4.54E+04	4.45E+04	4.46E+04	4.46E+04
2006	4375593	97.0	4.49E+04	4.33E+04	4.66E+04	4.51E+04	4.51E+04	4.51E+04
2007	4272389	97.0	4.59E+04	4.40E+04	4.80E+04	4.40E+04	4.41E+04	4.40E+04

Table 23. Plot data for normally running MDP 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	53	97.0	3.92E-01	2.49E-01	6.16E-01	4.25E-01	6.68E-01	5.41E-01
1999	31	97.0	3.53E-01	2.41E-01	5.15E-01	2.31E-01	4.17E-01	3.19E-01
2000	18	97.3	3.17E-01	2.31E-01	4.37E-01	1.21E-01	2.63E-01	1.87E-01
2001	35	97.0	2.86E-01	2.16E-01	3.79E-01	2.66E-01	4.64E-01	3.59E-01
2002	25	97.0	2.57E-01	1.95E-01	3.39E-01	1.80E-01	3.47E-01	2.58E-01
2003	26	97.0	2.32E-01	1.71E-01	3.13E-01	1.89E-01	3.59E-01	2.68E-01
2004	19	97.3	2.08E-01	1.46E-01	2.97E-01	1.30E-01	2.75E-01	1.97E-01
2005	10	97.0	1.88E-01	1.23E-01	2.87E-01	5.86E-02	1.65E-01	1.06E-01
2006	23	97.0	1.69E-01	1.02E-01	2.79E-01	1.63E-01	3.24E-01	2.38E-01
2007	19	97.0	1.52E-01	8.46E-02	2.74E-01	1.30E-01	2.76E-01	1.97E-01

Table 24. Plot data for normally running MDP 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	23	97.0	2.05E-01	1.54E-01	2.72E-01	1.61E-01	3.18E-01	2.34E-01
1999	12	97.0	1.87E-01	1.47E-01	2.37E-01	7.27E-02	1.87E-01	1.24E-01
2000	19	97.3	1.70E-01	1.39E-01	2.08E-01	1.27E-01	2.71E-01	1.94E-01
2001	17	97.0	1.55E-01	1.30E-01	1.85E-01	1.12E-01	2.48E-01	1.74E-01
2002	14	97.0	1.41E-01	1.19E-01	1.68E-01	8.81E-02	2.12E-01	1.44E-01
2003	13	97.0	1.29E-01	1.07E-01	1.55E-01	8.04E-02	2.00E-01	1.34E-01
2004	12	97.3	1.18E-01	9.48E-02	1.46E-01	7.25E-02	1.87E-01	1.24E-01
2005	12	97.0	1.07E-01	8.30E-02	1.38E-01	7.27E-02	1.87E-01	1.24E-01
2006	10	97.0	9.77E-02	7.21E-02	1.32E-01	5.77E-02	1.63E-01	1.04E-01
2007	6	97.0	8.91E-02	6.25E-02	1.27E-01	2.93E-02	1.11E-01	6.47E-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.