

Component Performance Study

Motor-Driven Pumps

1998–2006

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 2006 as reported in EPIX. The MDP failure modes considered are for standby systems: failure-to-start (FTS), failure-to-run ≤ 1 hour ($FTR \leq 1H$), 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 significant¹ 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 (events 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:

- Normally running systems, industry-wide MDP FTS trend. (see Figure 4)
- Normally running systems, industry-wide MDP FTR trend. (see Figure 5)
- Pooled AFW, HPCI, and RCIC 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 (events per reactor year) of FTS events, normally running MDPs. (see Figure 17)

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, $FTR \leq 1H$, $FTR > 1H$, 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.

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 1. MDP systems.

System	Description	Standby	Normally Running
AFW	Auxiliary feedwater	112	
CCW	Component cooling water		247
CDS	Condensate system		137
CRD	Control rod drive		42
CSR	Containment spray recirculation	143	
CVC	Chemical and volume control		45
EPS	Emergency power supply	5	
ESW	Emergency service water	95	
HPCS	High pressure core spray	9	
HPSI	High pressure injection	155	
LPCI	Low pressure coolant injection	126	
LPCS	Low pressure core spray	67	
LPI	Low pressure injection	142	
MFW	Main feedwater		50
NSW	Normal service water		312
Total		854	833

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.

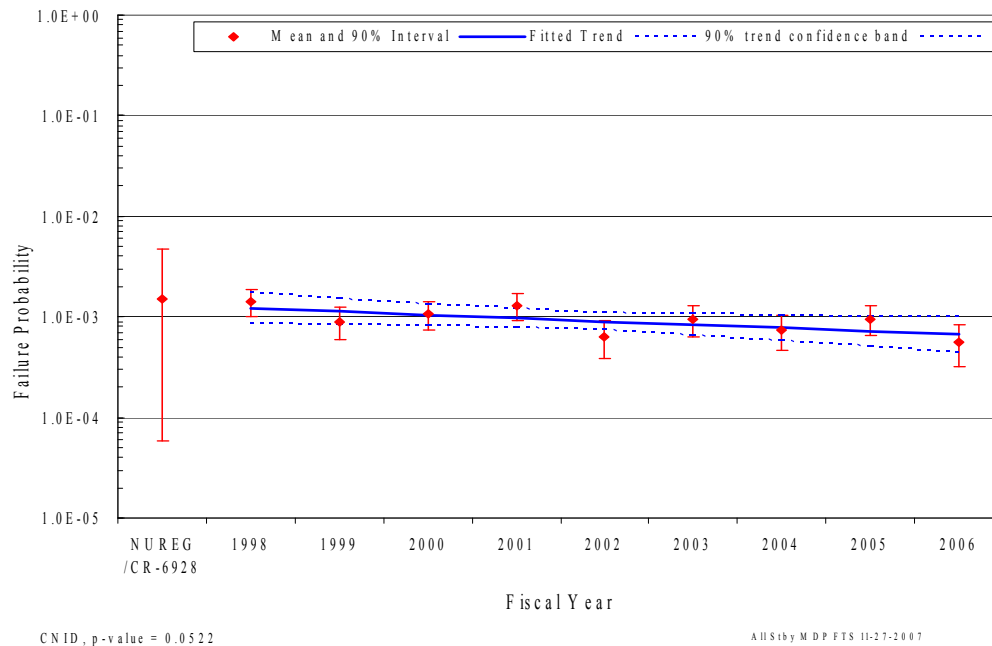


Figure 1. Standby systems, industry-wide MDP FTS trend.

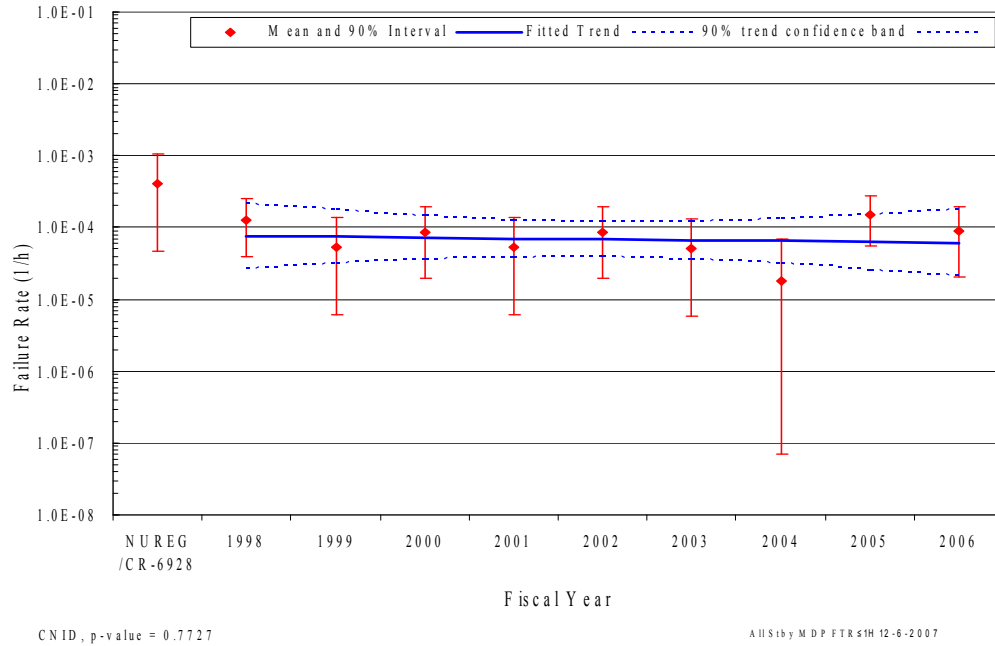


Figure 2. Standby systems, industry-wide MDP FTR $\leq$ 1H trend.

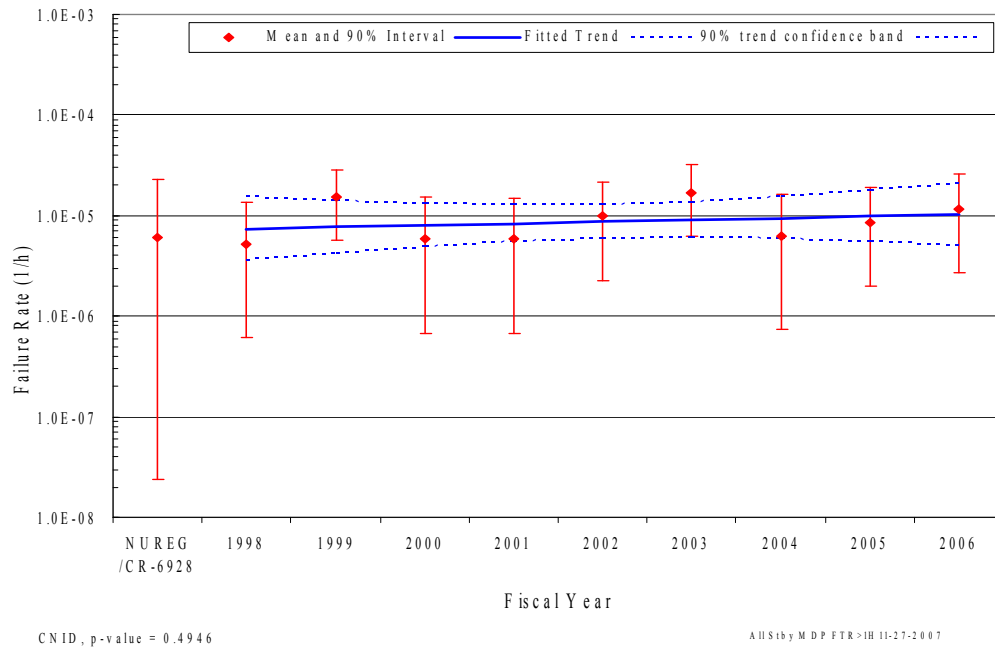


Figure 3. Standby systems, industry-wide MDP FTR $>$ 1H trend.

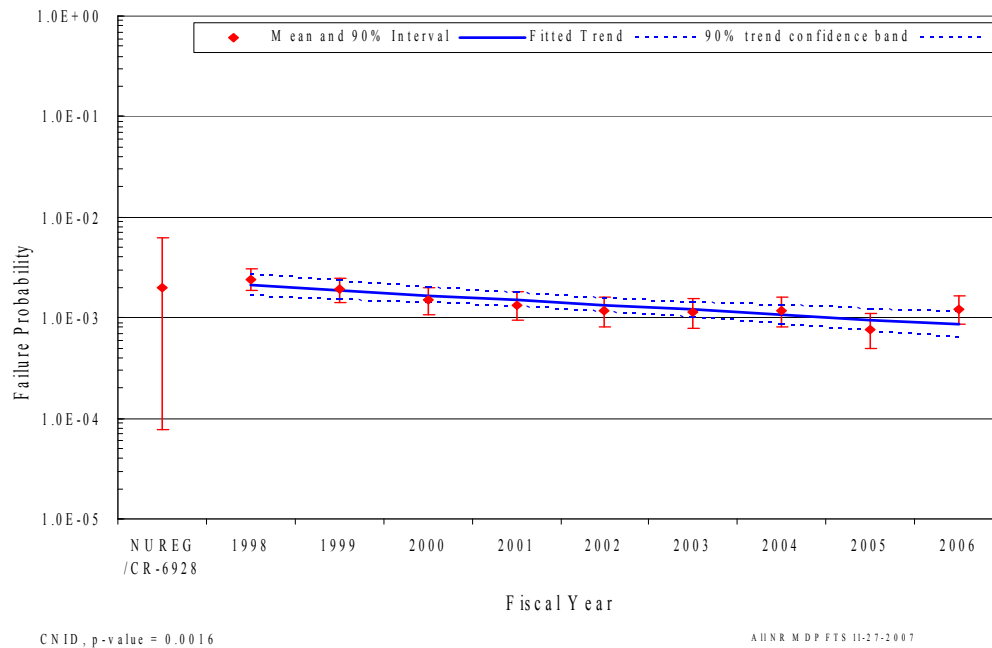


Figure 4. Normally running systems, industry-wide MDP FTS trend.

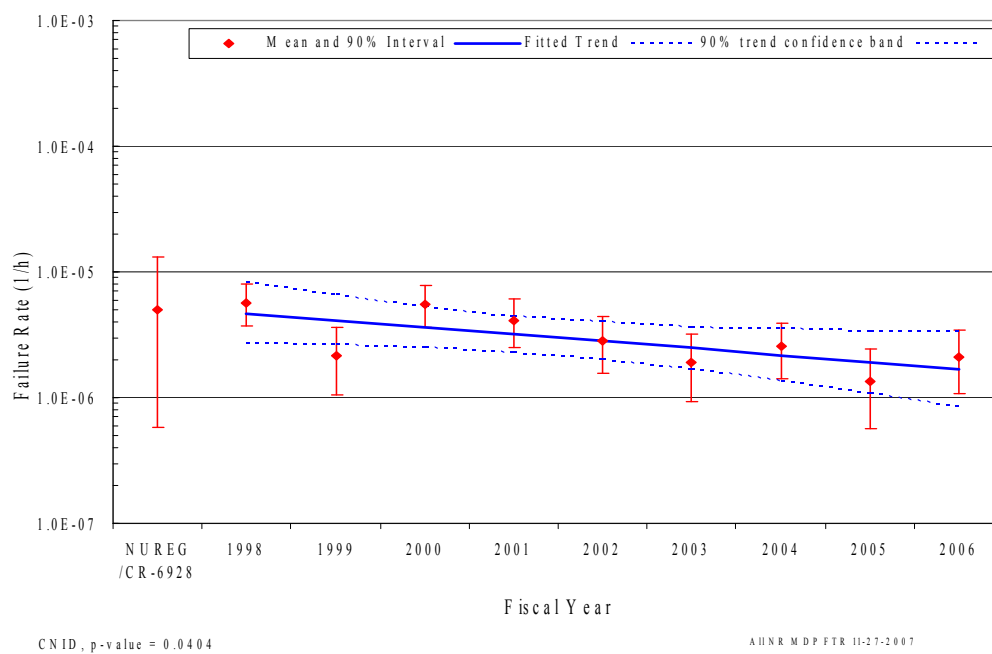


Figure 5. Normally running systems, industry-wide MDP FTR trend.

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 1998-2006 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 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 (1998–2006) unavailability and reactor critical hour data were obtained from the ROP (1998 to 2001) and EPIX (2002 to 2006) 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.

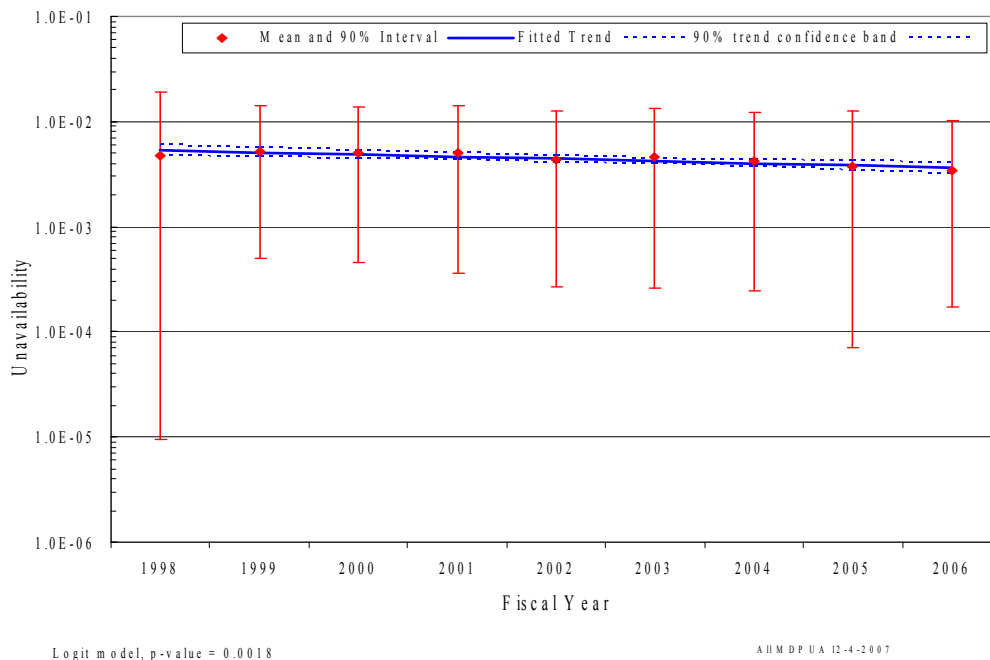


Figure 6. Pooled AFW, HPCI, and RCIC MDP UA trend.

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 $\text{logit}(P)=a+bt$, 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, $\text{FTR} \leq 1\text{H}$, $\text{FTR} > 1\text{H}$ (or FTR), and UA as basic event inputs. The $\text{FTR} > 1\text{H}$ 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 $\text{FTR} \leq 1\text{H}$ data, there is no UA or $\text{FTR} \leq 1\text{H}$ 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.

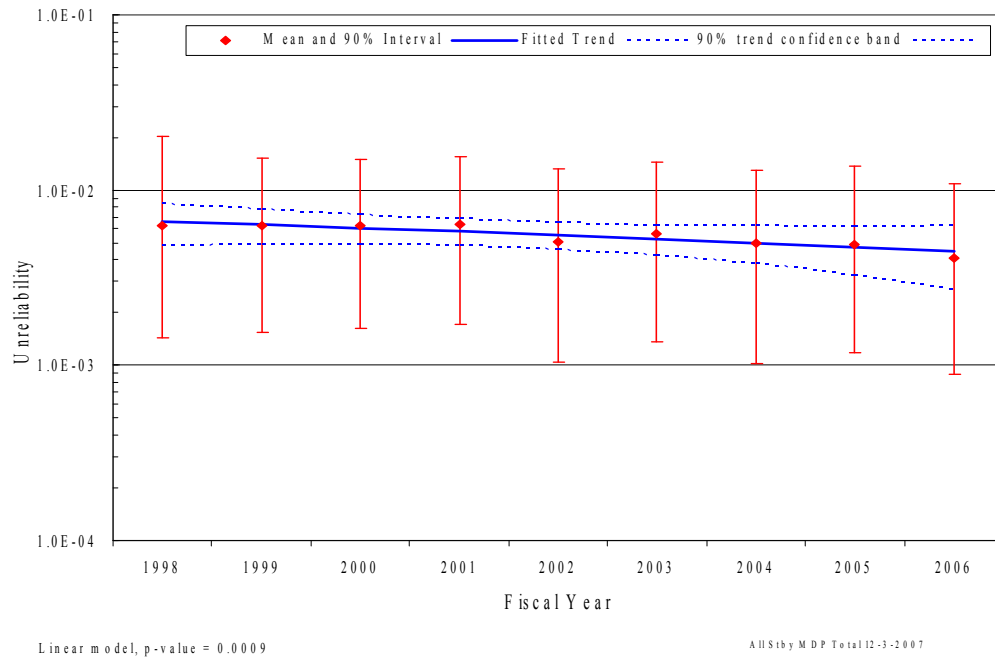


Figure 7. Standby systems, industry-wide MDP unreliability trend (8-hour mission).

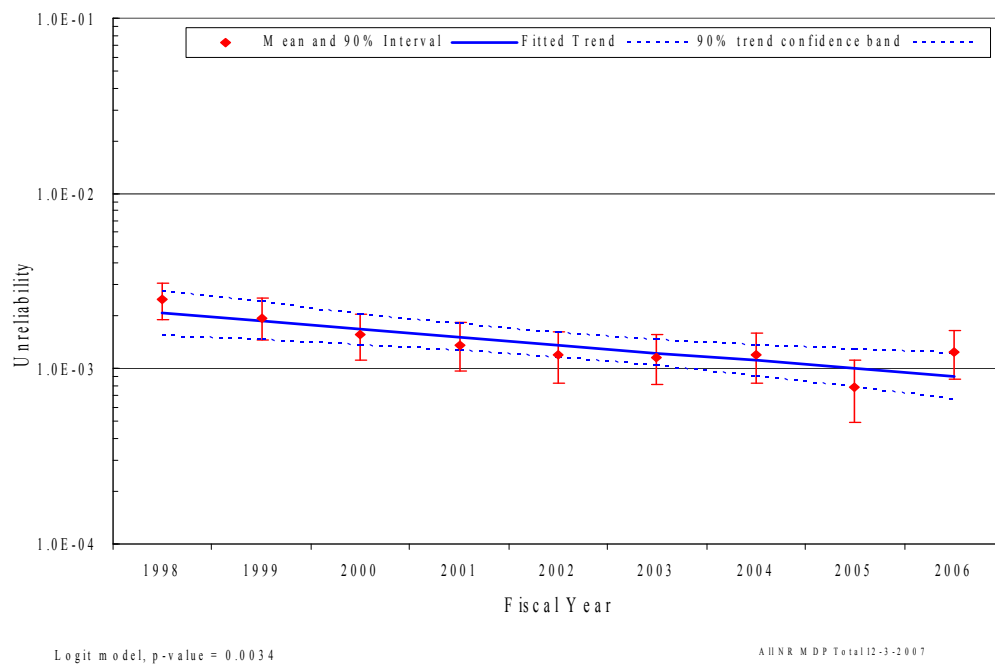


Figure 8. Normally running systems (MFW), industry-wide MDP unreliability trend (8-hour mission).

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 demands. Figure 10 shows the trend MDP load and run 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 $\leq$ 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, year, for the FTS failure mode. Table 5 summarizes the failures by system, year, for the FTR $\leq$ 1H failure mode. Table 6 summarizes the failures by system, year, for the FTR $>$ 1H failure mode.

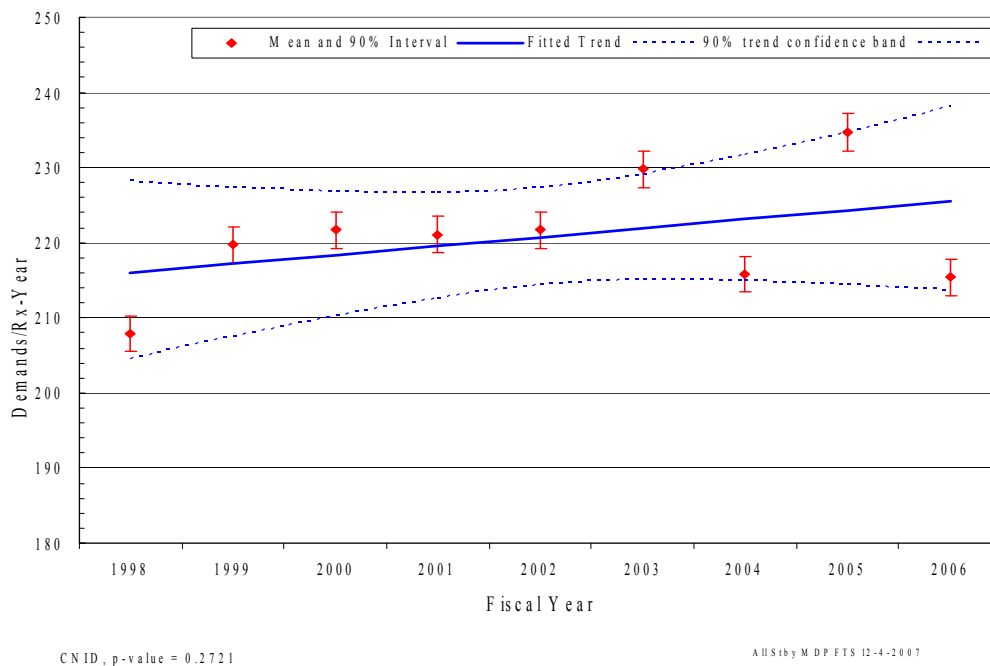


Figure 9. Frequency (events per reactor year) of start demands, standby MDPs.

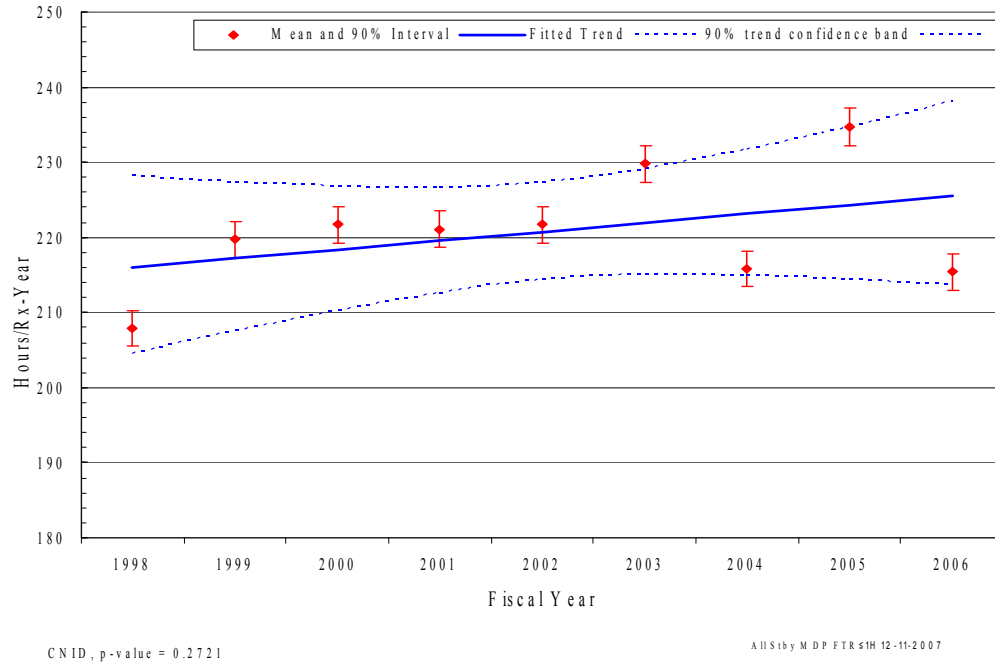


Figure 10. Standby MDP run hours per reactor critical year of run $\leq 1H$ hours.

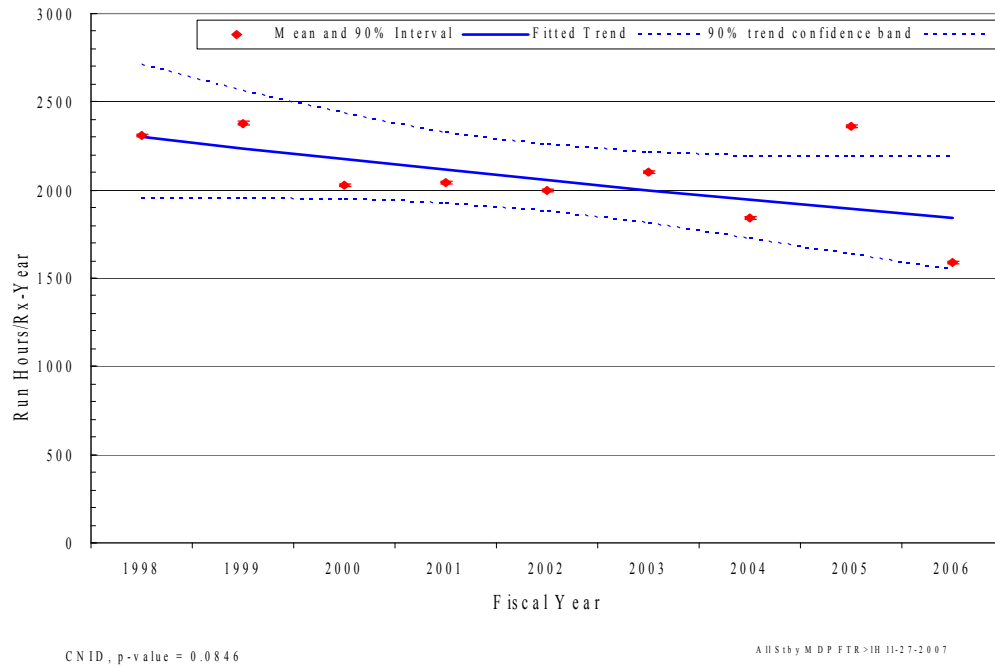


Figure 11. Standby MDP run hours per reactor critical year.

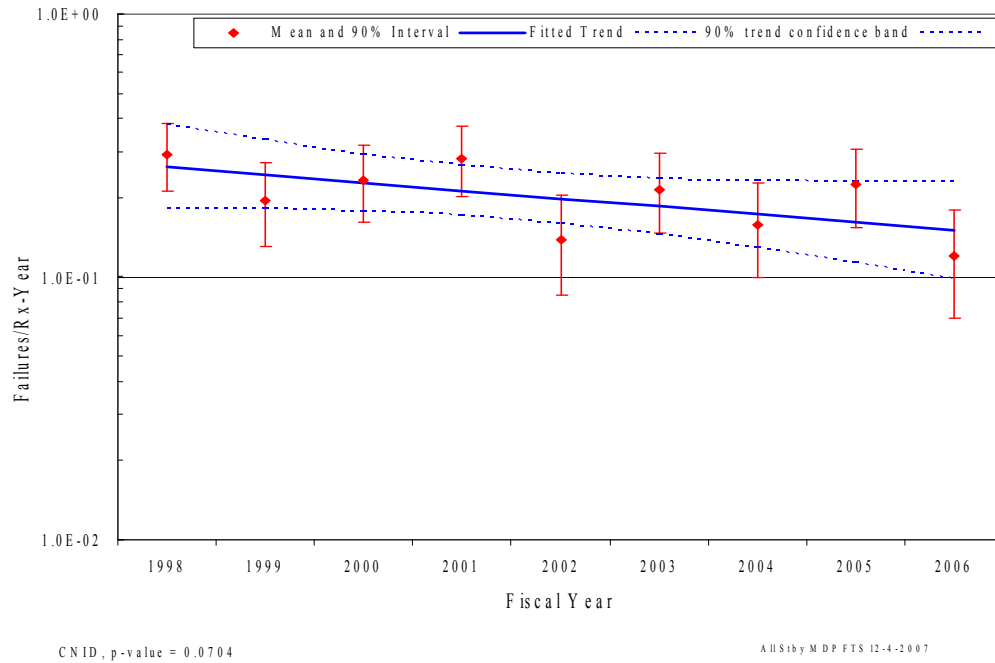


Figure 12. Frequency (events per reactor year) of FTS events, standby MDPs.

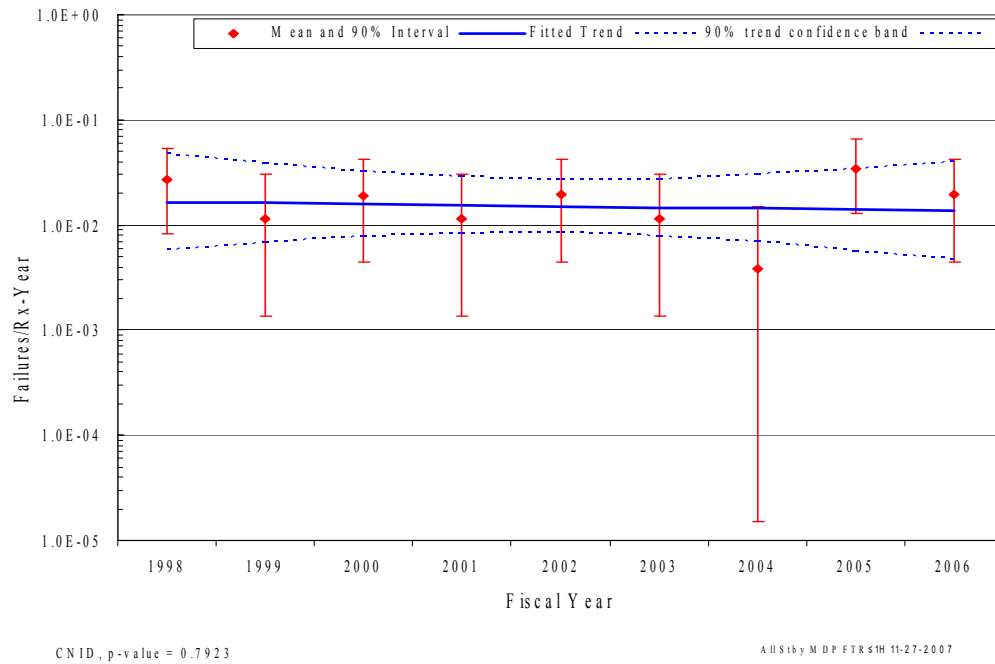


Figure 13. Frequency (events per reactor year) of FTR≤1H events, standby MDPs.

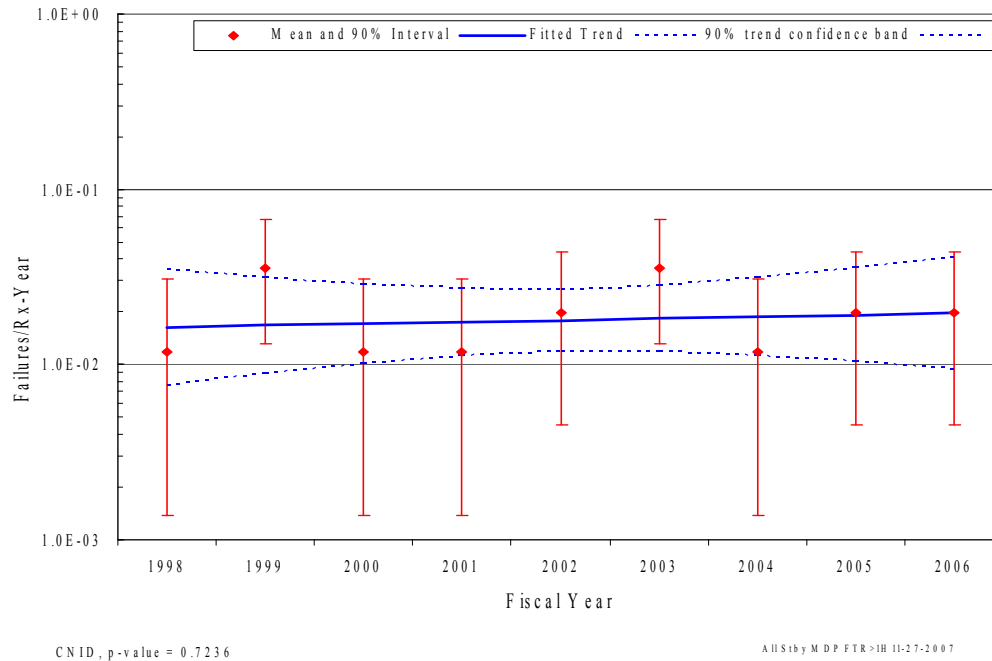


Figure 14. Frequency (events per reactor year) of FTR>1H events, standby MDPs.

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.

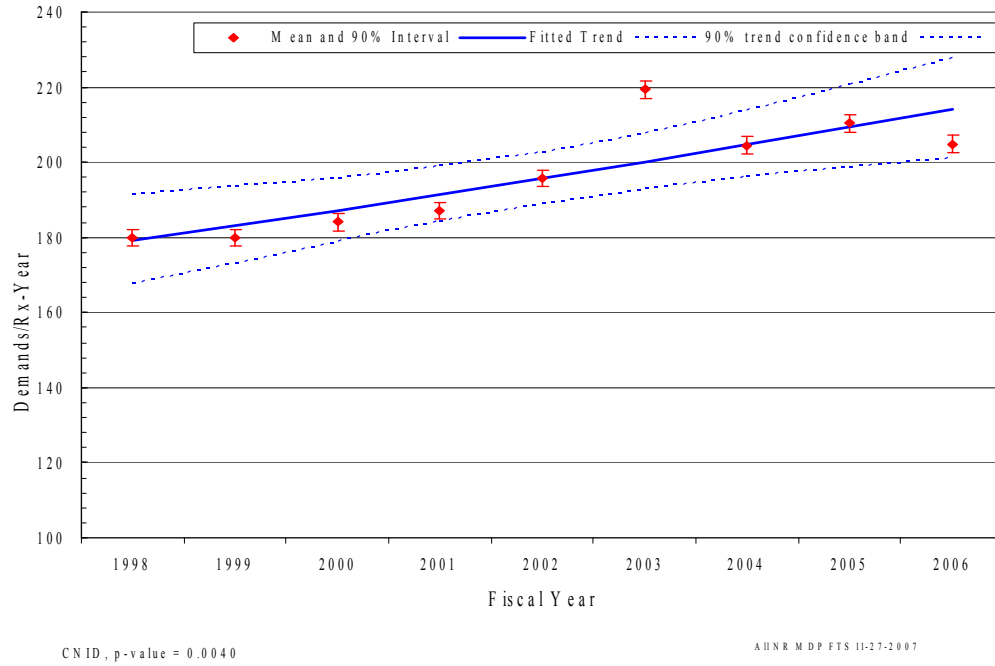


Figure 15. Frequency (events per reactor year) of start demands, normally running MDPs.

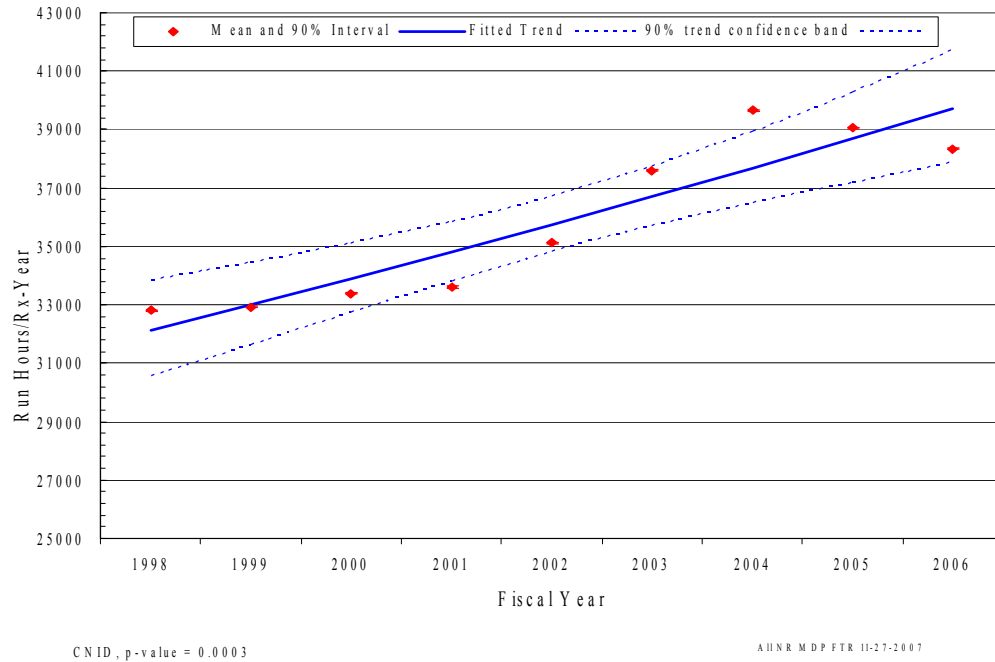


Figure 16. Normally running MDP run hours per reactor critical year.

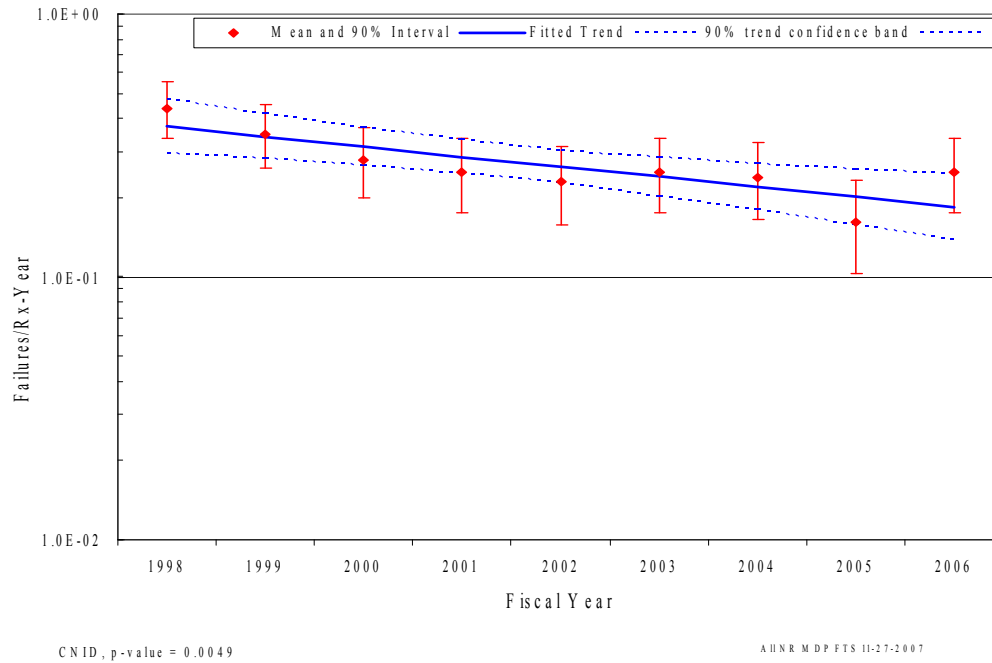


Figure 17. Frequency (events per reactor year) of FTS events, normally running MDPs.

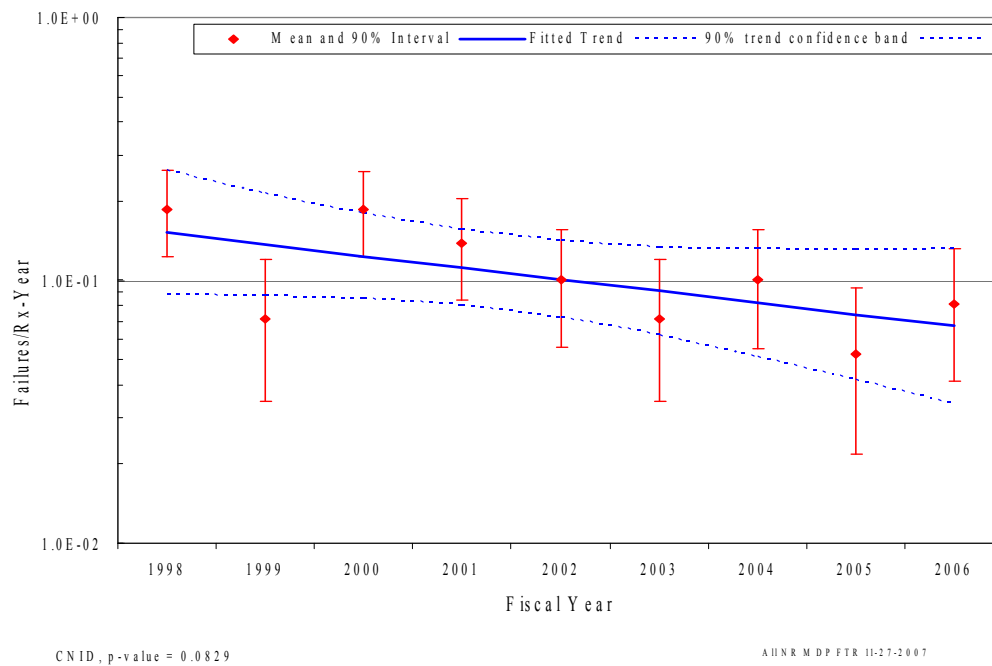


Figure 18. Frequency (events per reactor year) of FTR events, normally running MDPs.

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

System Code	MDP Count	MDP Percent	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	Total	Percent of Failures
AFW	112	6.6%	3	6	4	5	0	5	0	3	3	29	6.7%
CCW	247	14.6%	11	9	2	9	5	5	3	0	8	52	12.0%
CDS	137	8.1%	2	3	2	1	2	1	2	0	1	14	3.2%
CRD	42	2.5%	2	2	2	4	2	0	0	0	0	12	2.8%
CSR	143	8.5%	2	2	1	5	0	5	2	3	1	21	4.8%
CVC	45	2.7%	4	3	0	1	2	4	1	1	1	17	3.9%
EPS	5	0.3%	0	0	0	0	0	0	0	0	0	0	0.0%
ESW	95	5.6%	4	5	7	5	3	3	1	4	3	35	8.0%
HPCS	9	0.5%	0	0	0	0	0	1	1	1	1	4	0.9%
HPSI	155	9.2%	12	3	4	8	6	1	7	5	1	47	10.8%
LPCI	126	7.5%	3	3	6	4	0	2	1	2	2	23	5.3%
LPCS	67	4.0%	2	0	0	0	2	1	0	1	0	6	1.4%
LPI	142	8.4%	4	1	2	2	3	4	4	4	1	25	5.7%
MFW	50	3.0%	2	1	2	1	0	1	1	1	1	10	2.3%
NSW	312	18.5%	23	17	20	9	12	14	17	14	14	140	32.2%
Total	1687	100.0%	74	55	52	54	37	47	40	39	37	435	100.0%

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

System Code	MDP Count	MDP Percent	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	Total	Percent of Failures
AFW	112	13.1%	0	1	1	0	1	1	0	1	0	5	31.3%
CSR	143	16.7%	1	0	0	0	0	0	0	2	1	4	25.0%
EPS	5	0.6%	0	0	0	0	0	0	0	0	0	0	0.0%
ESW	95	11.1%	2	0	0	0	0	0	0	0	0	2	12.5%
HPCS	9	1.1%	0	0	0	0	0	0	0	0	0	0	0.0%
HPSI	155	18.1%	0	0	0	1	0	0	0	0	0	1	6.3%
LPCI	126	14.8%	0	0	0	0	0	0	0	1	0	1	6.3%
LPCS	67	7.8%	0	0	0	0	0	0	0	0	0	0	0.0%
LPI	142	16.6%	0	0	1	0	1	0	0	0	1	3	18.8%
Total	854	100.0%	3	1	2	1	2	1	0	4	2	16	100.0%

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

System Code	MDP Count	MDP Percent	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	Total	Percent of Failures
AFW	112	6.6%	1	0	0	1	0	0	0	0	0	2	1.7%
CCW	247	14.6%	4	1	7	1	1	1	1	1	1	18	15.4%
CDS	137	8.1%	6	3	1	1	2	1	0	1	2	17	14.5%
CRD	42	2.5%	2	1	3	1	1	1	0	0	0	9	7.7%
CSR	143	8.5%	0	1	0	0	0	0	0	0	0	1	0.9%
CVC	45	2.7%	1	0	0	1	2	0	0	0	0	4	3.4%
EPS	5	0.3%	0	0	0	0	0	0	0	0	0	0	0.0%
ESW	95	5.6%	0	0	0	0	1	0	0	1	1	3	2.6%
HPCS	9	0.5%	0	0	0	0	0	0	0	0	0	0	0.0%
HPSI	155	9.2%	0	3	0	0	0	1	0	1	1	6	5.1%

System Code	MDP Count	MDP Percent	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	Total	Percent of Failures
LPCI	126	7.5%	0	0	0	0	0	1	0	0	0	1	0.9%
LPCS	67	4.0%	0	0	0	0	0	0	1	0	0	1	0.9%
LPI	142	8.4%	0	0	1	0	1	2	0	0	0	4	3.4%
MFW	50	3.0%	3	0	1	2	0	0	1	0	1	8	6.8%
NSW	312	18.5%	3	2	7	8	4	4	8	3	4	43	36.8%
Total	1687	100.0%	20	11	20	15	12	11	11	7	10	117	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	30	21197.4	1.21E-03	8.50E-04	1.73E-03	1.01E-03	1.84E-03	1.40E-03
1999	20	22410.7	1.13E-03	8.40E-04	1.51E-03	5.95E-04	1.24E-03	8.94E-04
2000	24	22674.2	1.05E-03	8.21E-04	1.33E-03	7.30E-04	1.43E-03	1.06E-03
2001	29	22549.8	9.71E-04	7.86E-04	1.20E-03	9.16E-04	1.69E-03	1.28E-03
2002	14	22612.5	9.02E-04	7.31E-04	1.11E-03	3.82E-04	9.19E-04	6.26E-04
2003	22	23437.1	8.37E-04	6.61E-04	1.06E-03	6.38E-04	1.28E-03	9.39E-04
2004	16	22072.3	7.77E-04	5.84E-04	1.03E-03	4.61E-04	1.05E-03	7.30E-04
2005	23	23945.3	7.22E-04	5.10E-04	1.02E-03	6.59E-04	1.31E-03	9.60E-04
2006	12	21970.3	6.70E-04	4.43E-04	1.01E-03	3.24E-04	8.36E-04	5.55E-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	3	21197.4	7.57E-05	2.67E-05	2.14E-04	3.96E-05	2.57E-04	1.28E-04
1999	1	22410.7	7.38E-05	3.11E-05	1.75E-04	6.16E-06	1.37E-04	5.25E-05
2000	2	22674.2	7.19E-05	3.53E-05	1.47E-04	1.99E-05	1.92E-04	8.67E-05
2001	1	22549.8	7.00E-05	3.82E-05	1.28E-04	6.13E-06	1.36E-04	5.23E-05
2002	2	22612.5	6.82E-05	3.86E-05	1.21E-04	1.99E-05	1.92E-04	8.69E-05
2003	1	23437.1	6.65E-05	3.59E-05	1.23E-04	5.95E-06	1.32E-04	5.07E-05
2004	0	22072.3	6.48E-05	3.12E-05	1.35E-04	6.97E-08	6.81E-05	1.77E-05
2005	4	23945.3	6.31E-05	2.60E-05	1.53E-04	5.52E-05	2.81E-04	1.50E-04
2006	2	21970.3	6.15E-05	2.12E-05	1.79E-04	2.04E-05	1.97E-04	8.89E-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	1	235463.2	7.36E-06	3.58E-06	1.51E-05	6.13E-07	1.36E-05	5.23E-06
1999	4	242701.9	7.68E-06	4.22E-06	1.40E-05	5.65E-06	2.88E-05	1.53E-05
2000	1	207320.5	8.01E-06	4.88E-06	1.31E-05	6.80E-07	1.51E-05	5.80E-06
2001	1	207962.2	8.36E-06	5.50E-06	1.27E-05	6.78E-07	1.51E-05	5.78E-06
2002	2	203566.9	8.72E-06	5.92E-06	1.28E-05	2.25E-06	2.17E-05	9.80E-06
2003	4	214712.6	9.09E-06	6.03E-06	1.37E-05	6.25E-06	3.18E-05	1.69E-05
2004	1	188328.5	9.49E-06	5.85E-06	1.54E-05	7.34E-07	1.63E-05	6.26E-06
2005	2	240660.3	9.89E-06	5.51E-06	1.78E-05	1.96E-06	1.90E-05	8.56E-06
2006	2	162047.3	1.03E-05	5.10E-06	2.09E-05	2.68E-06	2.59E-05	1.17E-05

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	44	17994.3	2.09E-03	1.63E-03	2.67E-03	1.86E-03	3.04E-03	2.42E-03
1999	35	17990.9	1.87E-03	1.53E-03	2.29E-03	1.43E-03	2.49E-03	1.93E-03
2000	28	18459.2	1.67E-03	1.41E-03	1.98E-03	1.08E-03	2.01E-03	1.51E-03
2001	25	18701.2	1.50E-03	1.29E-03	1.73E-03	9.33E-04	1.80E-03	1.34E-03
2002	23	19572.9	1.34E-03	1.15E-03	1.55E-03	8.09E-04	1.60E-03	1.18E-03
2003	25	21936.3	1.20E-03	1.01E-03	1.42E-03	7.98E-04	1.54E-03	1.14E-03
2004	24	20510.1	1.07E-03	8.75E-04	1.31E-03	8.12E-04	1.59E-03	1.17E-03
2005	16	21039.5	9.58E-04	7.49E-04	1.22E-03	4.87E-04	1.11E-03	7.71E-04
2006	25	20480.2	8.57E-04	6.39E-04	1.15E-03	8.53E-04	1.65E-03	1.22E-03

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	19	3280237.0	4.69E-06	2.70E-06	8.15E-06	3.73E-06	7.93E-06	5.66E-06
1999	7	3292723.0	4.13E-06	2.62E-06	6.51E-06	1.05E-06	3.62E-06	2.17E-06
2000	19	3346570.0	3.63E-06	2.49E-06	5.30E-06	3.66E-06	7.78E-06	5.56E-06
2001	14	3360176.0	3.20E-06	2.29E-06	4.47E-06	2.51E-06	6.04E-06	4.12E-06
2002	10	3512536.0	2.81E-06	2.00E-06	3.95E-06	1.58E-06	4.45E-06	2.86E-06
2003	7	3759097.0	2.48E-06	1.67E-06	3.66E-06	9.26E-07	3.19E-06	1.91E-06
2004	10	3976475.0	2.18E-06	1.36E-06	3.50E-06	1.40E-06	3.95E-06	2.54E-06
2005	5	3905543.0	1.92E-06	1.08E-06	3.40E-06	5.62E-07	2.42E-06	1.35E-06
2006	8	3834403.0	1.69E-06	8.51E-07	3.34E-06	1.08E-06	3.45E-06	2.13E-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	7723.4	1737244.0	5.32E-03	4.71E-03	6.00E-03	9.54E-06	1.88E-02	4.70E-03
1999	12906.2	2476019.0	5.07E-03	4.59E-03	5.61E-03	5.04E-04	1.42E-02	5.24E-03
2000	13130.0	2548442.0	4.84E-03	4.46E-03	5.26E-03	4.60E-04	1.37E-02	5.04E-03
2001	12728.1	2563935.0	4.62E-03	4.31E-03	4.96E-03	3.66E-04	1.41E-02	4.99E-03
2002	11222.3	2604613.0	4.41E-03	4.13E-03	4.72E-03	2.68E-04	1.24E-02	4.28E-03
2003	11438.8	2538836.0	4.21E-03	3.93E-03	4.52E-03	2.57E-04	1.34E-02	4.55E-03
2004	10771.4	2595313.0	4.02E-03	3.70E-03	4.37E-03	2.43E-04	1.22E-02	4.17E-03
2005	9512.4	2572150.0	3.84E-03	3.47E-03	4.25E-03	7.00E-05	1.26E-02	3.73E-03
2006	8943.0	2606154.0	3.67E-03	3.25E-03	4.14E-03	1.74E-04	1.02E-02	3.40E-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	6.60E-03	4.84E-03	8.37E-03	1.43E-03	2.04E-02	6.27E-03
1999	6.34E-03	4.87E-03	7.81E-03	1.53E-03	1.52E-02	6.29E-03
2000	6.07E-03	4.86E-03	7.28E-03	1.64E-03	1.50E-02	6.22E-03
2001	5.80E-03	4.78E-03	6.83E-03	1.72E-03	1.55E-02	6.36E-03
2002	5.54E-03	4.58E-03	6.50E-03	1.04E-03	1.32E-02	5.06E-03
2003	5.27E-03	4.24E-03	6.30E-03	1.36E-03	1.45E-02	5.65E-03
2004	5.01E-03	3.79E-03	6.22E-03	1.02E-03	1.30E-02	4.96E-03
2005	4.74E-03	3.27E-03	6.21E-03	1.19E-03	1.38E-02	4.90E-03
2006	4.47E-03	2.71E-03	6.24E-03	8.83E-04	1.09E-02	4.12E-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	2.07E-03	1.53E-03	2.78E-03	1.91E-03	3.09E-03	2.47E-03
1999	1.86E-03	1.45E-03	2.39E-03	1.45E-03	2.52E-03	1.95E-03
2000	1.68E-03	1.37E-03	2.06E-03	1.12E-03	2.05E-03	1.56E-03
2001	1.52E-03	1.27E-03	1.80E-03	9.66E-04	1.84E-03	1.37E-03
2002	1.37E-03	1.16E-03	1.61E-03	8.33E-04	1.63E-03	1.20E-03
2003	1.23E-03	1.04E-03	1.47E-03	8.14E-04	1.56E-03	1.16E-03
2004	1.11E-03	9.06E-04	1.36E-03	8.33E-04	1.61E-03	1.19E-03
2005	1.00E-03	7.82E-04	1.28E-03	4.98E-04	1.12E-03	7.82E-04
2006	9.04E-04	6.71E-04	1.22E-03	8.70E-04	1.66E-03	1.24E-03

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	21197	102.0	2.16E+02	2.04E+02	2.28E+02	2.05E+02	2.10E+02	2.08E+02
1999	22411	102.0	2.17E+02	2.07E+02	2.27E+02	2.17E+02	2.22E+02	2.20E+02
2000	22674	102.3	2.18E+02	2.10E+02	2.27E+02	2.19E+02	2.24E+02	2.22E+02
2001	22550	102.0	2.20E+02	2.13E+02	2.27E+02	2.19E+02	2.24E+02	2.21E+02
2002	22612	102.0	2.21E+02	2.14E+02	2.27E+02	2.19E+02	2.24E+02	2.22E+02
2003	23437	102.0	2.22E+02	2.15E+02	2.29E+02	2.27E+02	2.32E+02	2.30E+02
2004	22072	102.3	2.23E+02	2.15E+02	2.32E+02	2.13E+02	2.18E+02	2.16E+02
2005	23945	102.0	2.24E+02	2.14E+02	2.35E+02	2.32E+02	2.37E+02	2.35E+02
2006	21970	102.0	2.26E+02	2.14E+02	2.38E+02	2.13E+02	2.18E+02	2.15E+02

Table 16. Plot data for standby MDP run $\leq$ 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	21197	102.0	2.16E+02	2.04E+02	2.28E+02	2.05E+02	2.10E+02	2.08E+02
1999	22411	102.0	2.17E+02	2.07E+02	2.27E+02	2.17E+02	2.22E+02	2.20E+02
2000	22674	102.3	2.18E+02	2.10E+02	2.27E+02	2.19E+02	2.24E+02	2.22E+02
2001	22550	102.0	2.20E+02	2.13E+02	2.27E+02	2.19E+02	2.24E+02	2.21E+02
2002	22612	102.0	2.21E+02	2.14E+02	2.27E+02	2.19E+02	2.24E+02	2.22E+02
2003	23437	102.0	2.22E+02	2.15E+02	2.29E+02	2.27E+02	2.32E+02	2.30E+02
2004	22072	102.3	2.23E+02	2.15E+02	2.32E+02	2.13E+02	2.18E+02	2.16E+02
2005	23945	102.0	2.24E+02	2.14E+02	2.35E+02	2.32E+02	2.37E+02	2.35E+02
2006	21970	102.0	2.26E+02	2.14E+02	2.38E+02	2.13E+02	2.18E+02	2.15E+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	235463	102.0	2.30E+03	1.95E+03	2.71E+03	2.30E+03	2.32E+03	2.31E+03
1999	242702	102.0	2.24E+03	1.95E+03	2.56E+03	2.37E+03	2.39E+03	2.38E+03
2000	207321	102.3	2.17E+03	1.94E+03	2.43E+03	2.02E+03	2.03E+03	2.03E+03
2001	207962	102.0	2.11E+03	1.92E+03	2.33E+03	2.03E+03	2.05E+03	2.04E+03
2002	203567	102.0	2.06E+03	1.88E+03	2.25E+03	1.99E+03	2.00E+03	2.00E+03
2003	214713	102.0	2.00E+03	1.81E+03	2.21E+03	2.10E+03	2.11E+03	2.11E+03
2004	188329	102.3	1.94E+03	1.72E+03	2.19E+03	1.83E+03	1.85E+03	1.84E+03
2005	240660	102.0	1.89E+03	1.64E+03	2.19E+03	2.35E+03	2.37E+03	2.36E+03
2006	162047	102.0	1.84E+03	1.54E+03	2.19E+03	1.58E+03	1.60E+03	1.59E+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	30	102.0	2.63E-01	1.82E-01	3.79E-01	2.11E-01	3.84E-01	2.92E-01
1999	20	102.0	2.45E-01	1.81E-01	3.31E-01	1.31E-01	2.73E-01	1.96E-01
2000	24	102.3	2.28E-01	1.78E-01	2.93E-01	1.62E-01	3.17E-01	2.34E-01
2001	29	102.0	2.13E-01	1.71E-01	2.65E-01	2.03E-01	3.73E-01	2.83E-01
2002	14	102.0	1.99E-01	1.60E-01	2.47E-01	8.48E-02	2.04E-01	1.39E-01
2003	22	102.0	1.85E-01	1.45E-01	2.37E-01	1.47E-01	2.95E-01	2.15E-01
2004	16	102.3	1.73E-01	1.29E-01	2.32E-01	9.97E-02	2.26E-01	1.58E-01
2005	23	102.0	1.61E-01	1.13E-01	2.31E-01	1.55E-01	3.06E-01	2.25E-01
2006	12	102.0	1.50E-01	9.80E-02	2.31E-01	7.00E-02	1.80E-01	1.20E-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	3	102.0	1.66E-02	5.81E-03	4.71E-02	8.35E-03	5.42E-02	2.70E-02
1999	1	102.0	1.62E-02	6.78E-03	3.85E-02	1.35E-03	3.01E-02	1.16E-02
2000	2	102.3	1.58E-02	7.70E-03	3.23E-02	4.40E-03	4.25E-02	1.92E-02
2001	1	102.0	1.54E-02	8.36E-03	2.84E-02	1.35E-03	3.01E-02	1.16E-02
2002	2	102.0	1.50E-02	8.46E-03	2.68E-02	4.41E-03	4.26E-02	1.93E-02
2003	1	102.0	1.47E-02	7.87E-03	2.74E-02	1.35E-03	3.01E-02	1.16E-02
2004	0	102.3	1.43E-02	6.85E-03	3.00E-02	1.51E-05	1.48E-02	3.84E-03
2005	4	102.0	1.40E-02	5.71E-03	3.43E-02	1.28E-02	6.52E-02	3.47E-02
2006	2	102.0	1.37E-02	4.66E-03	4.01E-02	4.41E-03	4.26E-02	1.93E-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	1	102.0	1.63E-02	7.62E-03	3.50E-02	1.39E-03	3.08E-02	1.18E-02
1999	4	102.0	1.67E-02	8.86E-03	3.15E-02	1.31E-02	6.67E-02	3.55E-02
2000	1	102.3	1.71E-02	1.01E-02	2.88E-02	1.38E-03	3.07E-02	1.18E-02
2001	1	102.0	1.75E-02	1.12E-02	2.72E-02	1.39E-03	3.08E-02	1.18E-02
2002	2	102.0	1.79E-02	1.19E-02	2.69E-02	4.52E-03	4.36E-02	1.97E-02
2003	4	102.0	1.83E-02	1.19E-02	2.82E-02	1.31E-02	6.67E-02	3.55E-02
2004	1	102.3	1.87E-02	1.13E-02	3.11E-02	1.38E-03	3.07E-02	1.18E-02
2005	2	102.0	1.92E-02	1.04E-02	3.54E-02	4.52E-03	4.36E-02	1.97E-02
2006	2	102.0	1.96E-02	9.36E-03	4.10E-02	4.52E-03	4.36E-02	1.97E-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	17994	100.0	1.79E+02	1.68E+02	1.91E+02	1.78E+02	1.82E+02	1.80E+02
1999	17991	100.0	1.83E+02	1.73E+02	1.93E+02	1.78E+02	1.82E+02	1.80E+02
2000	18459	100.3	1.87E+02	1.79E+02	1.96E+02	1.82E+02	1.86E+02	1.84E+02
2001	18701	100.0	1.91E+02	1.84E+02	1.99E+02	1.85E+02	1.89E+02	1.87E+02
2002	19573	100.0	1.96E+02	1.89E+02	2.03E+02	1.93E+02	1.98E+02	1.96E+02
2003	21936	100.0	2.00E+02	1.93E+02	2.08E+02	2.17E+02	2.22E+02	2.19E+02
2004	20510	100.3	2.05E+02	1.96E+02	2.14E+02	2.02E+02	2.07E+02	2.05E+02
2005	21039	100.0	2.09E+02	1.99E+02	2.21E+02	2.08E+02	2.13E+02	2.10E+02
2006	20480	100.0	2.14E+02	2.01E+02	2.28E+02	2.02E+02	2.07E+02	2.05E+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	3280237	100.0	3.21E+04	3.05E+04	3.38E+04	3.28E+04	3.28E+04	3.28E+04
1999	3292723	100.0	3.30E+04	3.16E+04	3.44E+04	3.29E+04	3.30E+04	3.29E+04
2000	3346570	100.3	3.39E+04	3.27E+04	3.51E+04	3.34E+04	3.34E+04	3.34E+04
2001	3360176	100.0	3.48E+04	3.38E+04	3.58E+04	3.36E+04	3.36E+04	3.36E+04
2002	3512536	100.0	3.57E+04	3.48E+04	3.67E+04	3.51E+04	3.52E+04	3.51E+04
2003	3759097	100.0	3.67E+04	3.57E+04	3.77E+04	3.76E+04	3.76E+04	3.76E+04
2004	3976475	100.3	3.77E+04	3.65E+04	3.89E+04	3.96E+04	3.97E+04	3.97E+04
2005	3905543	100.0	3.87E+04	3.72E+04	4.03E+04	3.90E+04	3.91E+04	3.91E+04
2006	3834403	100.0	3.97E+04	3.79E+04	4.17E+04	3.83E+04	3.84E+04	3.83E+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	44	100.0	3.73E-01	2.94E-01	4.73E-01	3.35E-01	5.50E-01	4.37E-01
1999	35	100.0	3.42E-01	2.81E-01	4.16E-01	2.58E-01	4.50E-01	3.49E-01
2000	28	100.3	3.13E-01	2.66E-01	3.68E-01	1.99E-01	3.70E-01	2.79E-01
2001	25	100.0	2.86E-01	2.48E-01	3.31E-01	1.75E-01	3.37E-01	2.50E-01
2002	23	100.0	2.62E-01	2.27E-01	3.03E-01	1.58E-01	3.14E-01	2.31E-01
2003	25	100.0	2.40E-01	2.03E-01	2.84E-01	1.75E-01	3.37E-01	2.50E-01
2004	24	100.3	2.20E-01	1.80E-01	2.69E-01	1.66E-01	3.25E-01	2.40E-01
2005	16	100.0	2.01E-01	1.58E-01	2.57E-01	1.02E-01	2.33E-01	1.62E-01
2006	25	100.0	1.84E-01	1.38E-01	2.47E-01	1.75E-01	3.37E-01	2.50E-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	19	100.0	1.52E-01	8.78E-02	2.62E-01	1.23E-01	2.61E-01	1.87E-01
1999	7	100.0	1.37E-01	8.73E-02	2.15E-01	3.47E-02	1.20E-01	7.18E-02
2000	19	100.3	1.24E-01	8.51E-02	1.79E-01	1.23E-01	2.60E-01	1.86E-01
2001	14	100.0	1.12E-01	8.01E-02	1.55E-01	8.47E-02	2.04E-01	1.39E-01
2002	10	100.0	1.01E-01	7.20E-02	1.41E-01	5.54E-02	1.56E-01	1.00E-01
2003	7	100.0	9.10E-02	6.18E-02	1.34E-01	3.47E-02	1.20E-01	7.18E-02
2004	10	100.3	8.22E-02	5.14E-02	1.31E-01	5.53E-02	1.56E-01	1.00E-01
2005	5	100.0	7.42E-02	4.20E-02	1.31E-01	2.19E-02	9.41E-02	5.26E-02
2006	8	100.0	6.70E-02	3.40E-02	1.32E-01	4.15E-02	1.32E-01	8.13E-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.