

Component Performance Study

Motor-Driven Pumps

1998–2008

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 2008 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 (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 FTS trend. (see Figure 1)
- Normally running systems, industry-wide MDP FTS trend. (see Figure 4)
- 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 FTS events, standby MDPs. (see Figure 12)
- Frequency (failures 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.

Table 1. MDP systems.

System	Description	Total	Standby	Normally Running
AFW	Auxiliary feedwater	116	116	
CCW	Component cooling water	284		284
CDS	Condensate system	140		140
CRD	Control rod drive	46		46
CSR	Containment spray recirculation	152	152	
CVC	Chemical and volume control	128		128
EPS	Emergency power supply	16	16	
HCI	High pressure coolant injection	2	2	
HCS	High pressure core spray	9	9	
HPI	High pressure injection	175	175	
LCS	Low pressure core spray	68	68	
MFW	Main feedwater	57		57
RHR	Residual heat removal	310	310	
SLC	Standby liquid control	66	66	
SWN	Emergency service water (Standby)	312		312
SWS	Standby service water	230	230	
Total		2111	1144	967

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.

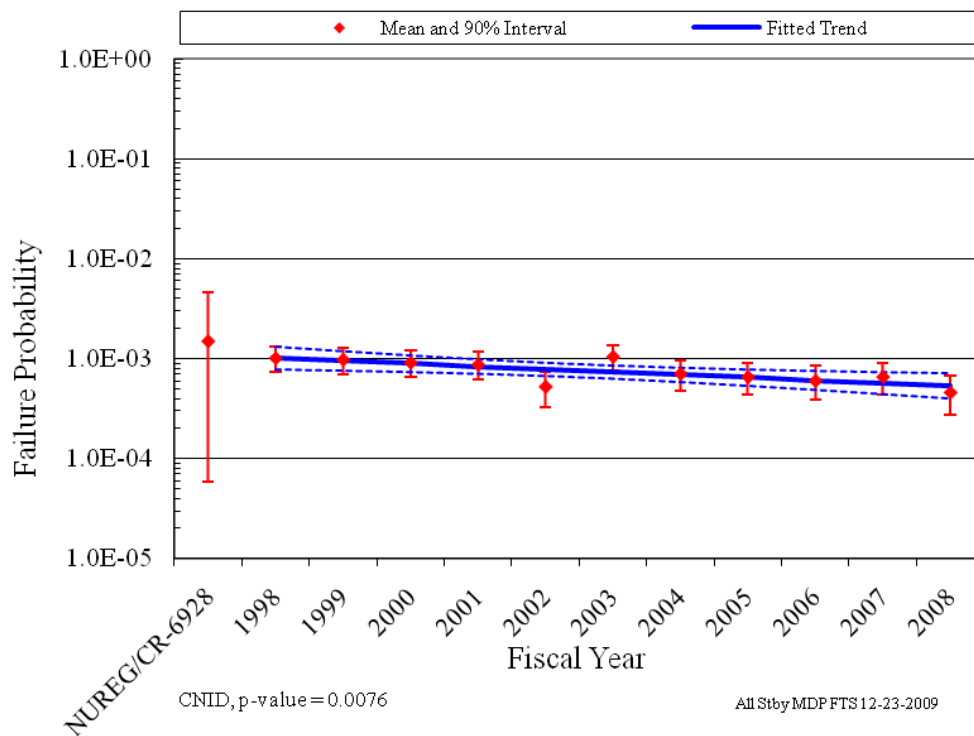


Figure 1. Standby systems, industry-wide MDP FTS trend.

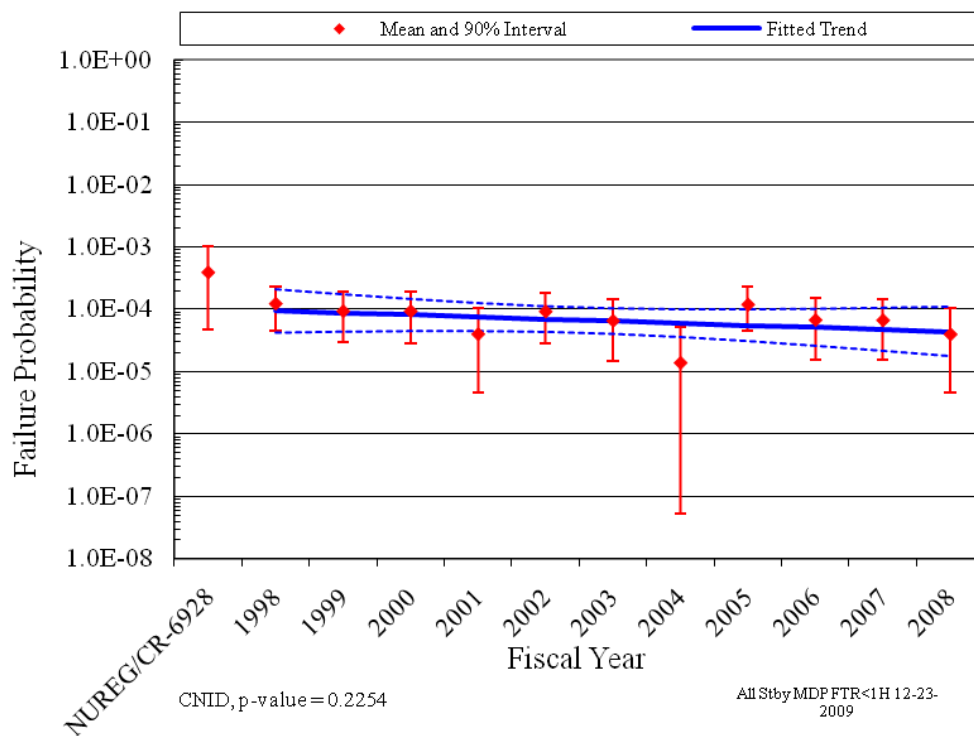


Figure 2. Standby systems, industry-wide MDP FTR $\leq$ 1H trend.

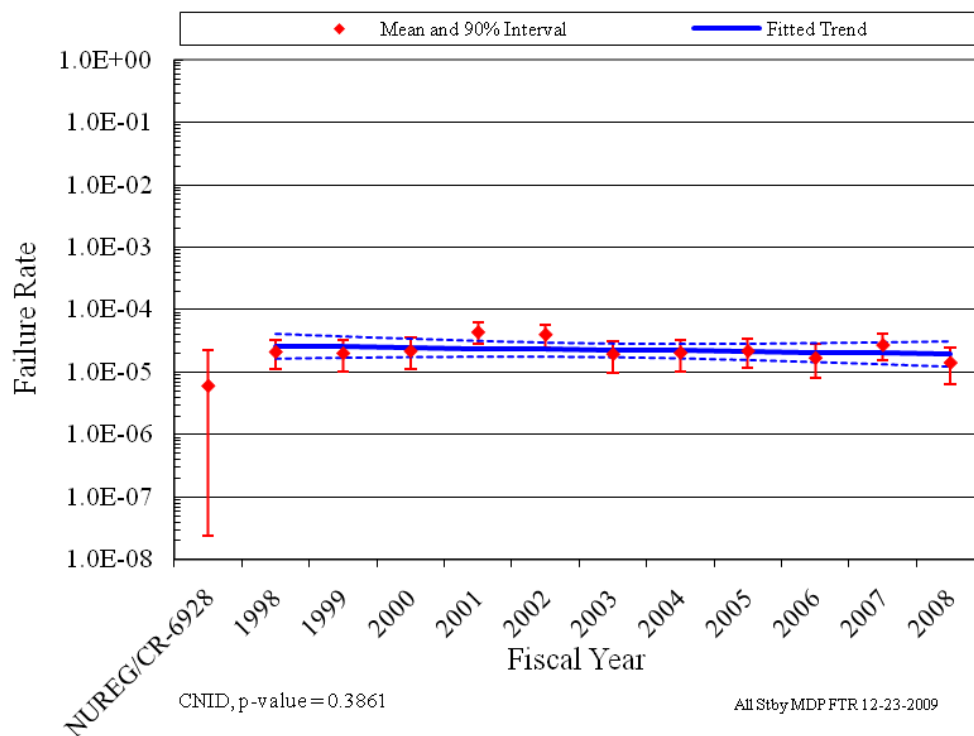


Figure 3. Standby systems, industry-wide MDP FTR $>$ 1H trend.

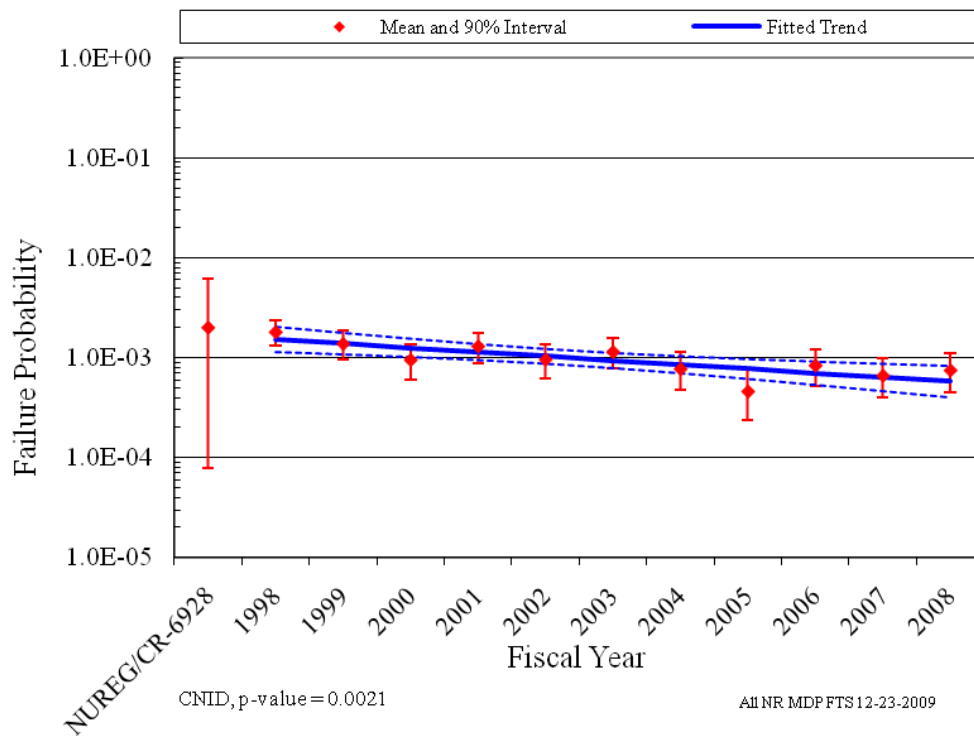


Figure 4. Normally running systems, industry-wide MDP FTS trend.

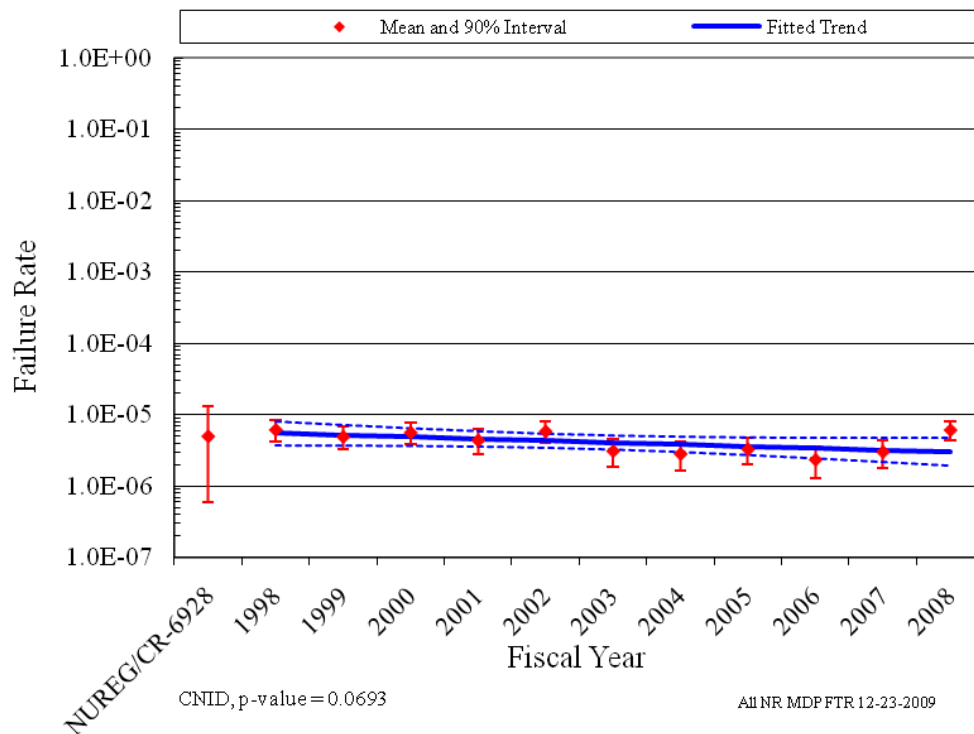


Figure 5. Normally running systems, industry-wide MDP FTR trend.

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 1998-2008 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 (1998–2008) unavailability and reactor critical hour data were obtained from the ROP (1998 to 2001) and EPIX (2002 to 2008) 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.

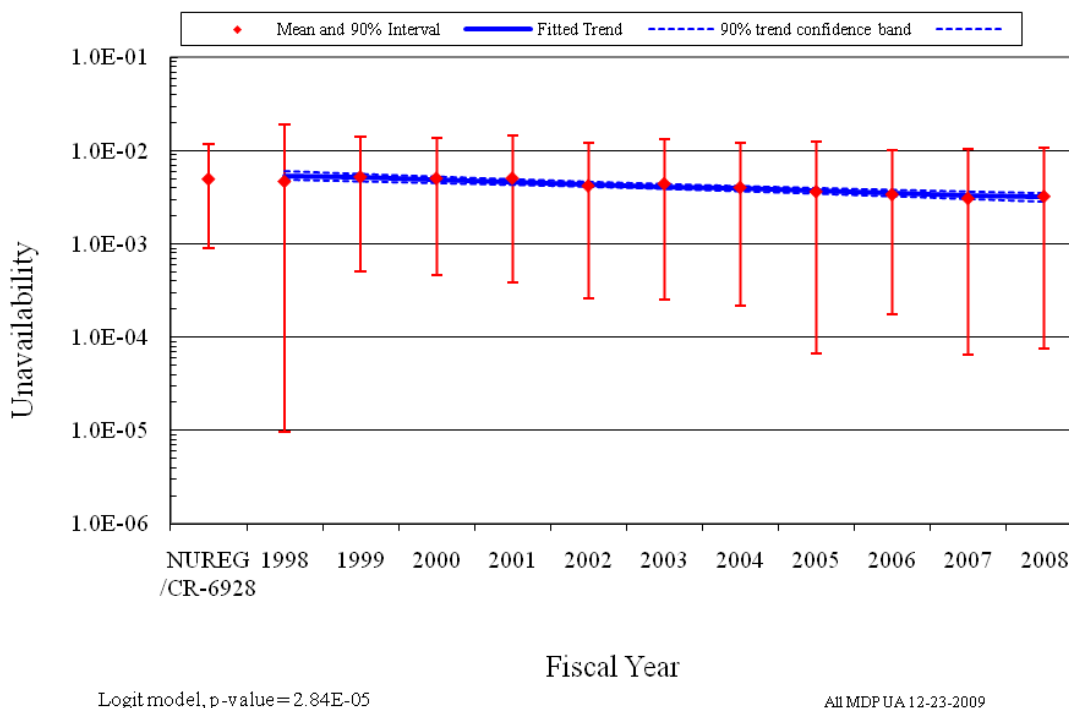


Figure 6. Pooled AFW, HPI, and HCS MDP UA trend.

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 $\text{logit}(P)=a+bt$, 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.

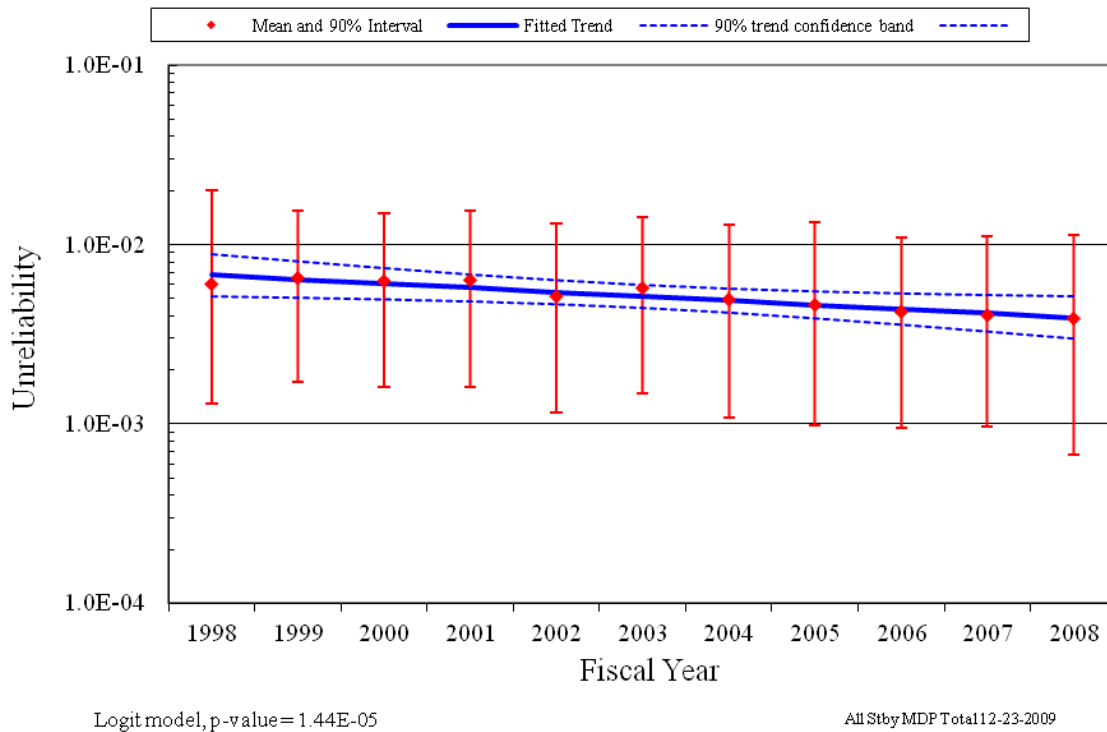


Figure 7. Standby systems, industry-wide MDP unreliability trend (8-hour mission).

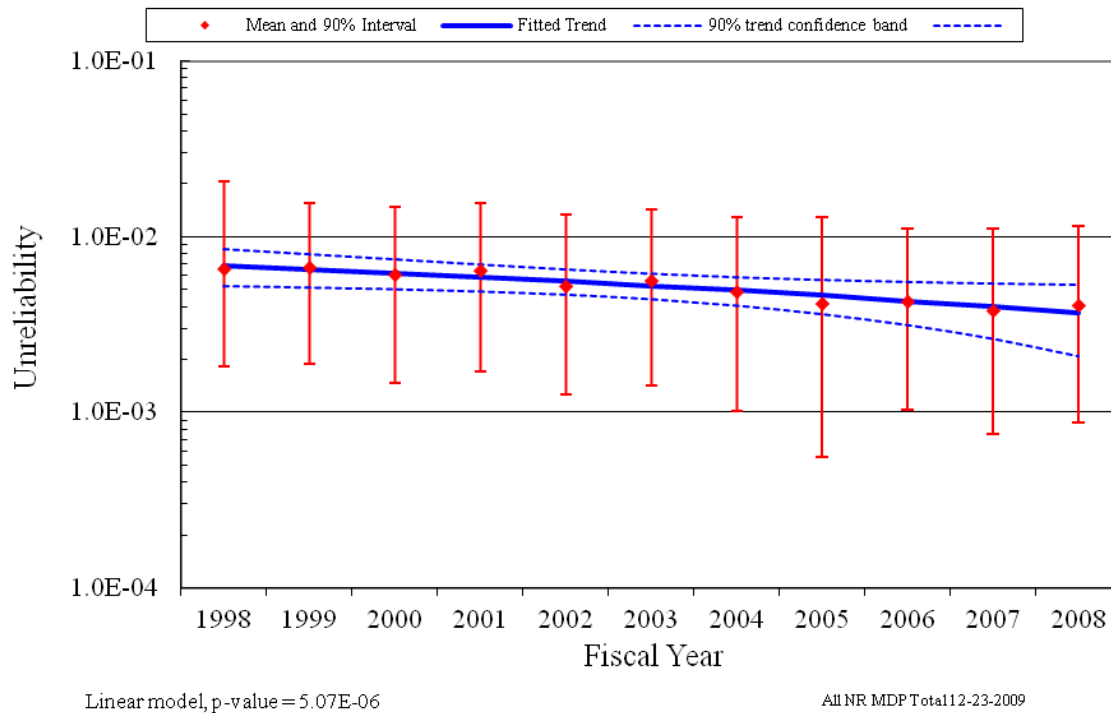


Figure 8. Normally running systems (MFW), industry-wide MDP unreliability trend (8-hour mission).

6 ENGINEERING TRENDS

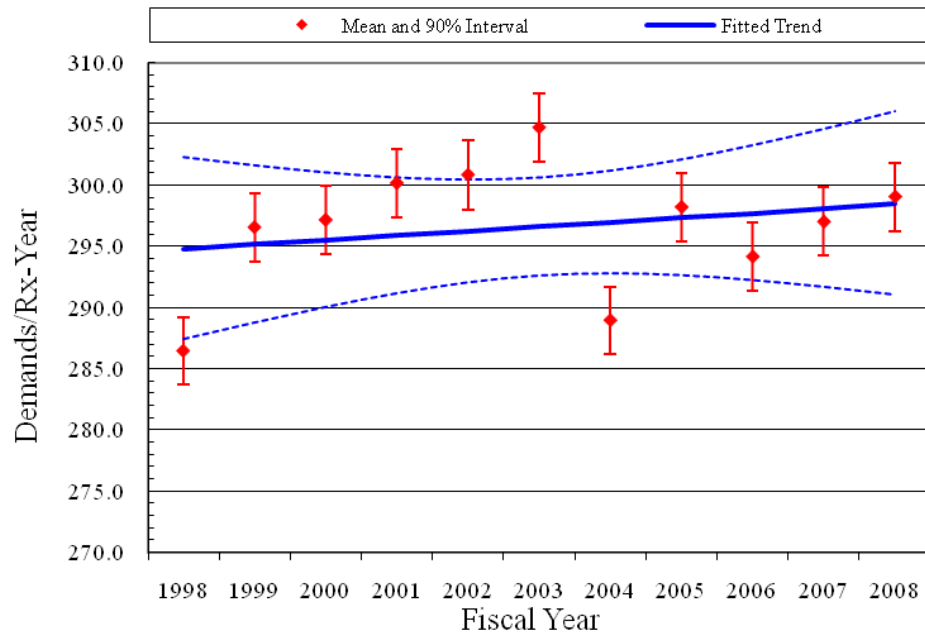
This section presents frequency trends for MDP failures and demands. The data are normalized by reactor year for plants that have the equipment being trended. The rate methods described in Section 2 of the [Overview and Reference](#) document are used.

6.1 Standby MDP Engineering Trends

Figure 9 shows the trend for standby MDP 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 ≤ 1 H 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.

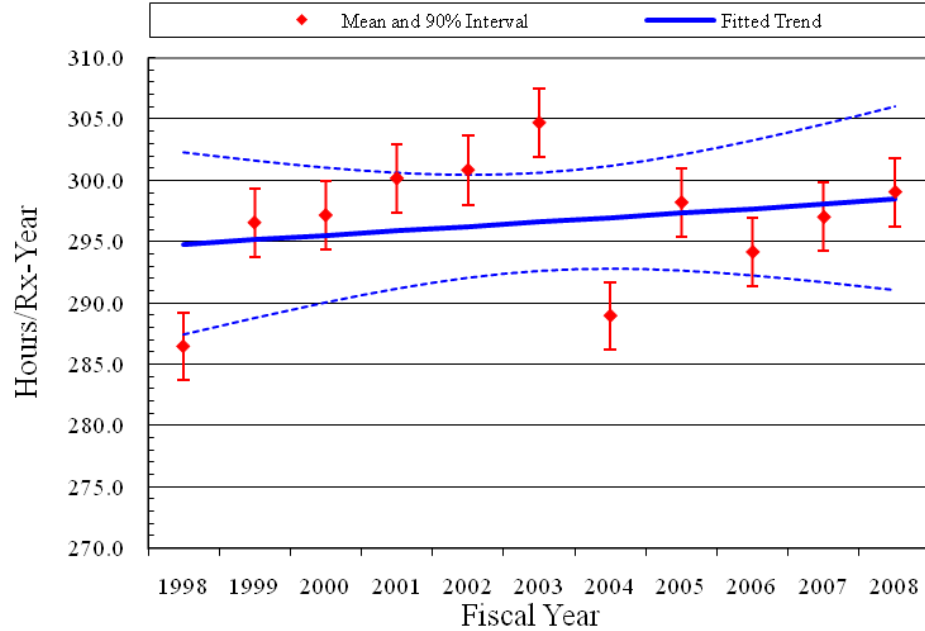
Table 4 summarizes the failures by system and year for the FTS failure mode. Table 5 summarizes the failures by system and year for the FTR ≤ 1 H failure mode. Table 6 summarizes the failures by system and year for the FTR > 1 H failure mode.



CNID, p-value=0.4904

All StbyMDP FTS 12-23-2009

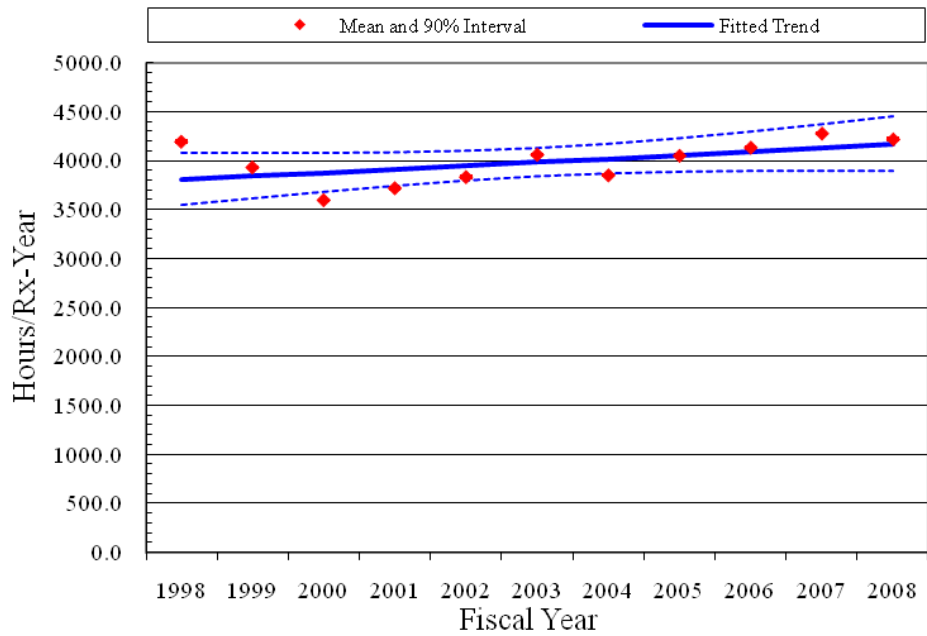
Figure 9. Frequency (demands per reactor year) of start demands, standby MDPs.



CNID, p-value=0.4904

All StbyMDP FTR<1H 12-23-2009

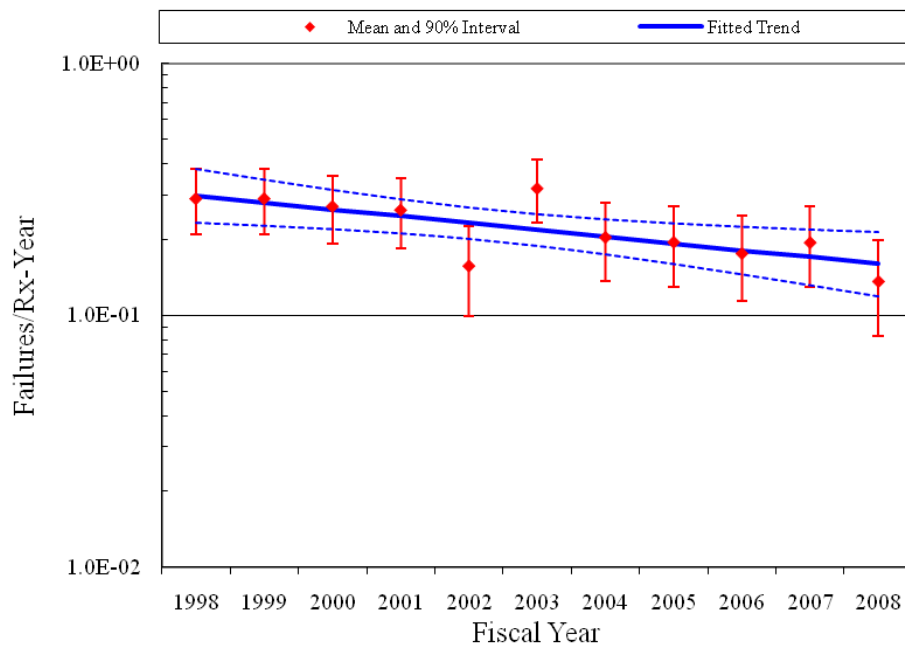
Figure 10. Standby MDP run hours per reactor critical year of run ≤ 1 H hours.



CNID, p-value=0.0904

All StbyMDP FTR 12-23-2009

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



CNID, p-value=0.0087

All StbyMDP FTS 12-23-2009

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

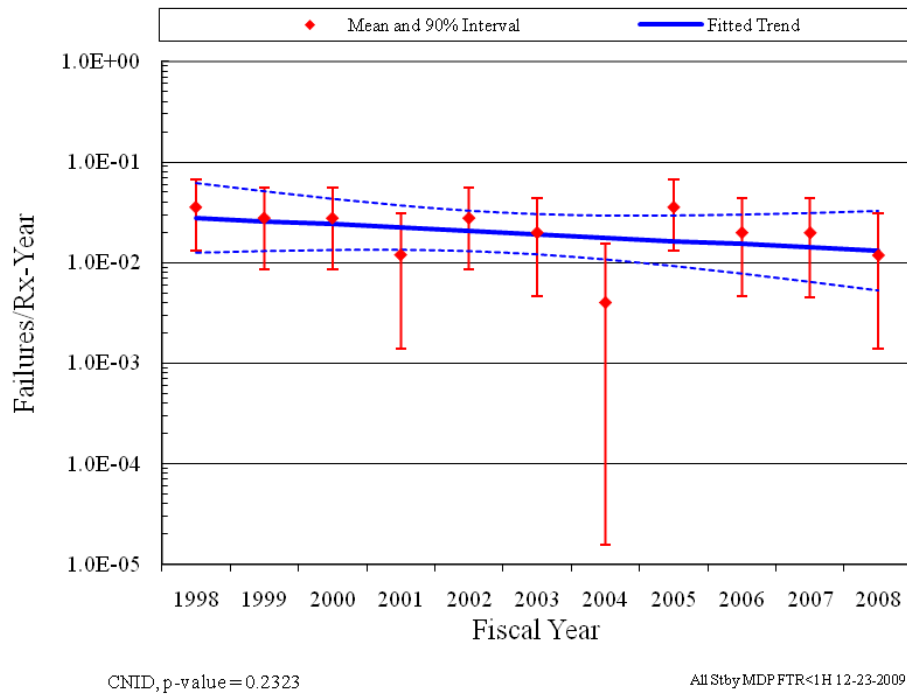


Figure 13. Frequency (failures per reactor year) of $FTR \leq 1H$ events, standby MDPs.

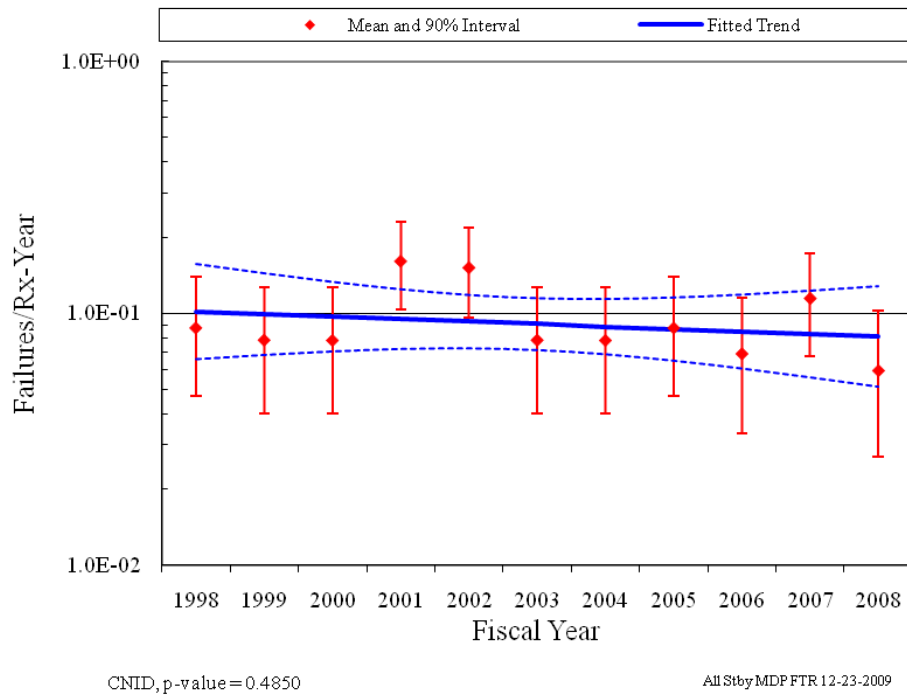


Figure 14. Frequency (failures per reactor year) of $FTR > 1H$ events, standby MDPs.

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.

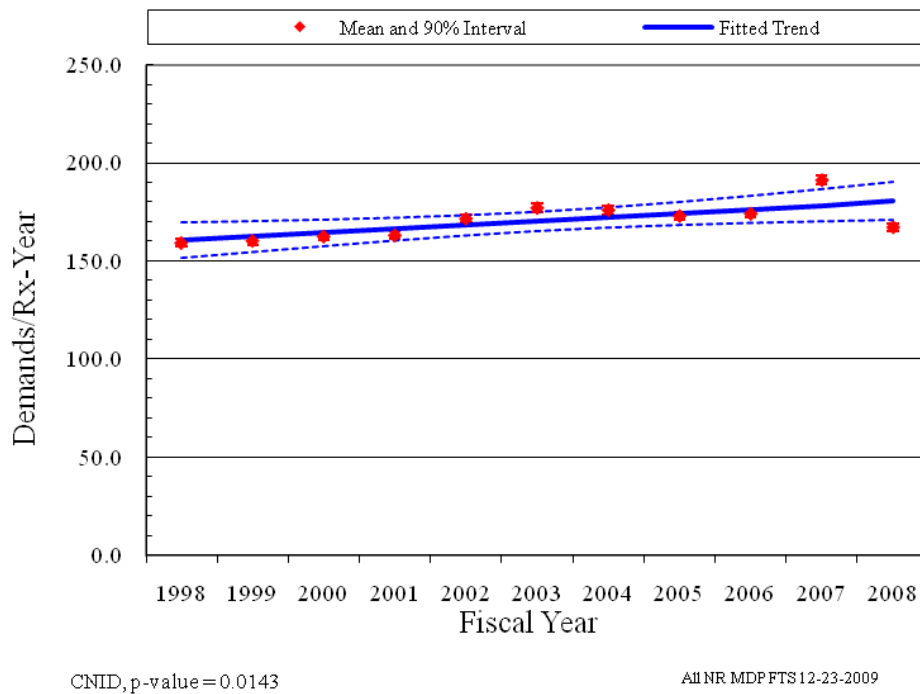


Figure 15. Frequency (demands per reactor year) of start demands, normally running MDPs.

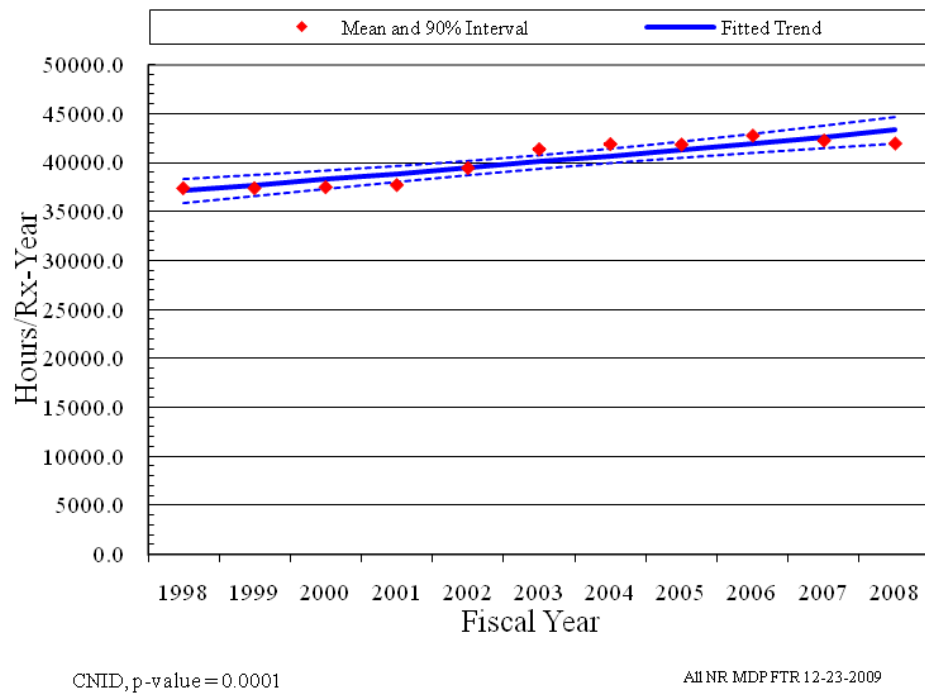


Figure 16. Normally running MDP run hours per reactor critical year.

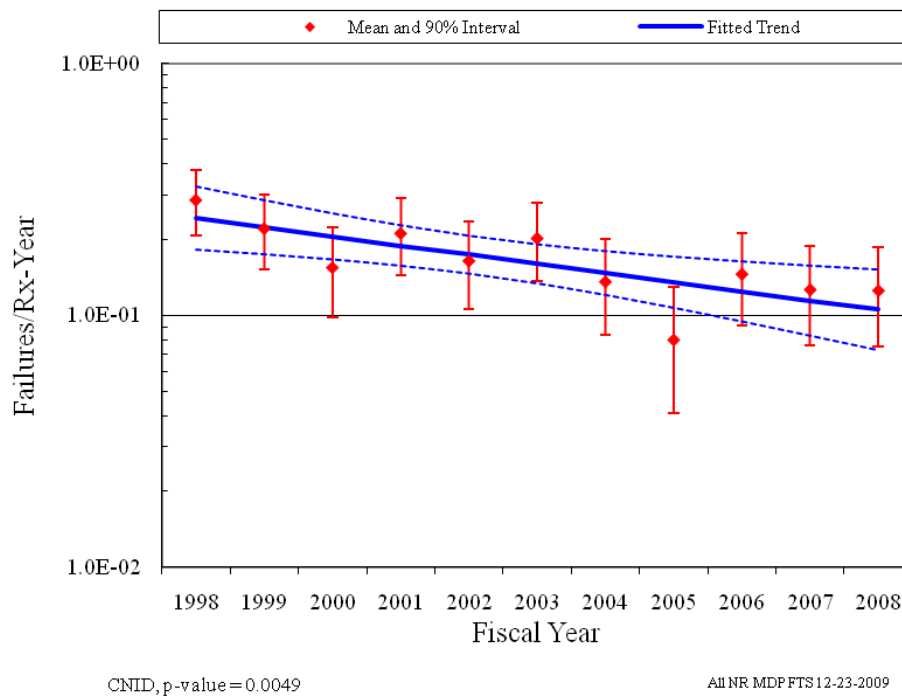


Figure 17. Frequency (failures per reactor year) of FTS events, normally running MDPs.

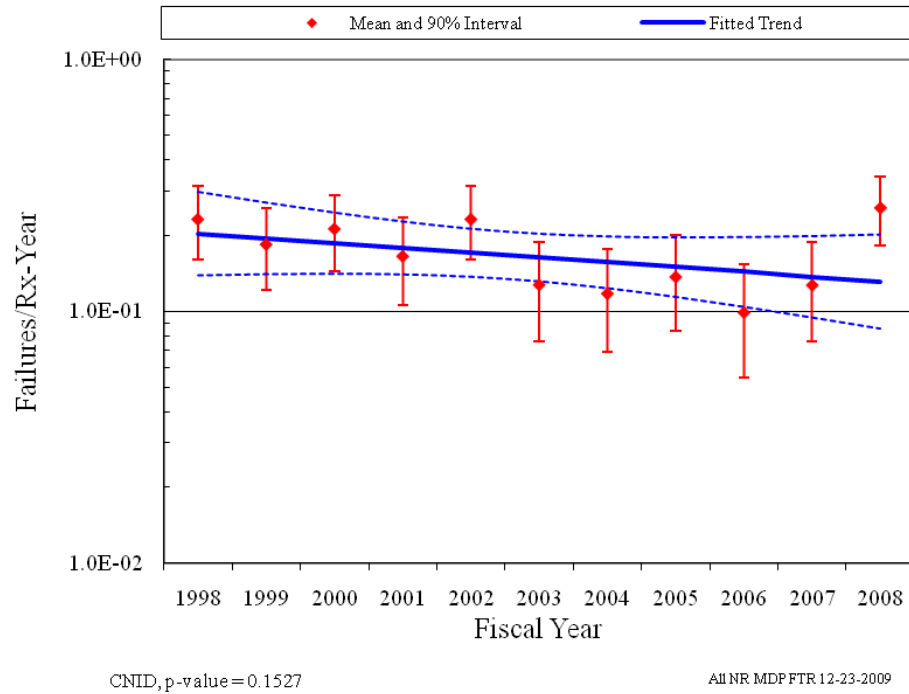


Figure 18. Frequency (failures per reactor year) of FTR events, normally running MDPs.

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

System Code	MDP Count	MDP Percent	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	Total	Percent of Failures
AFW	116	5.5%	3	7	4	3		4		2	4	4		31	5.3%
CCW	284	13.5%	11	10	3	8	4	10	5		7	5	5	68	11.7%
CDS	140	6.6%	2	2	5	1	1	3	2		1	1	1	19	3.3%
CRD	46	2.2%	2	2	3	5	2					1		15	2.6%
CSR	152	7.2%	3	3	1	6	1	10	4	4	1	2	1	36	6.2%
CVC	128	6.1%	23	11	2	13	4	11	6	3	9	10	8	100	17.2%
EPS	16	0.8%		1	1	1	1			1	2		3	10	1.7%
HCI	2	0.1%		1	1									2	0.3%
HCS	9	0.4%						1			1			2	0.3%
HPI	175	8.3%	5	3	3	6	6	2	7	2	2	3	3	42	7.2%
LCS	68	3.2%	2				2	3				2	1	10	1.7%
MFW	57	2.7%	2	1	4	2	1	1	1	1	1	2	2	18	3.1%
RHR	310	14.7%	10	10	9	7	3	8	5	6	3	5	3	69	11.9%
SLC	66	3.1%	1	2	1	3			1	3	1		1	13	2.2%
SWN	312	14.8%	11	5	6	6	9	8	8	6	6	6	4	75	12.9%
SWS	230	10.9%	7	9	11	7	6	7	5	6	5	6	3	72	12.4%
Total	2111	100.0%	82	67	54	68	40	68	44	34	43	47	35	582	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	FY 07	Total	Percent of Failures
AFW	116	6.1%		2	1		1			1		1	6	14.0%
CCW	284	14.9%				1	1			1		1	5	11.6%
CDS	140	7.3%										1	1	2.3%
CSR	152	8.0%	1							2	1		5	11.6%
CVC	128	6.7%								3	2		6	14.0%
HCI	2	0.1%										1	1	2.3%
HPI	175	9.2%						1					1	2.3%
MFW	57	3.0%				1						1	2	4.7%
RHR	310	16.3%					1						2	4.7%
SWN	312	16.4%		1	1		1						3	7.0%
SWS	230	12.1%					2	1	3		2	1	11	25.6%
Total	1906	100.0%	3		1		1	1		1	1		43	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	FY 07	FY 08	Total	Percent of Failures
AFW	116	5.5%	2			5	1	2		3		1		14	3.7%
CCW	284	13.5%	2	8	7	4	5	5	3	3	1	3	5	46	12.1%
CDS	140	6.6%	8	5	1	2	3	1		1	2	2	1	26	6.9%
CRD	46	2.2%	2	1	4	1	1	1						10	2.6%
CSR	152	7.2%	1		1	1	2	1	1					7	1.8%
CVC	128	6.1%	9	8	8	6	11	8	6	4	2	2	6	70	18.5%
EPS	16	0.8%		2		1						1	1	5	1.3%
HCI	2	0.1%			1									1	0.3%
HCS	9	0.4%								1				1	0.3%
HPI	175	8.3%	1	4	3	3	4	2	3	1	2	2		25	6.6%
LCS	68	3.2%	1			1								2	0.5%
MFW	57	2.7%	8		1	2			2	1	2	3	1	20	5.3%
RHR	310	14.7%	2		1	1	2	3	1	1	1	3		15	4.0%
SLC	66	3.1%		1										1	0.3%
SWN	312	14.8%	6	8	7	7	12	6	7	7	6	9	18	93	24.5%
SWS	230	10.9%	2	2	4	5	7	1	3	3	4	7	5	43	11.3%
Total	2111	100.0%	44	39	38	39	48	30	26	25	20	33	37	379	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	29503.2	1.02E-03	7.93E-04	1.30E-03	7.30E-04	1.33E-03	1.01E-03
1999	30	30542.7	9.53E-04	7.71E-04	1.18E-03	7.05E-04	1.28E-03	9.78E-04
2000	28	30689.4	8.94E-04	7.46E-04	1.07E-03	6.48E-04	1.21E-03	9.09E-04
2001	27	30915.4	8.38E-04	7.17E-04	9.81E-04	6.17E-04	1.16E-03	8.71E-04
2002	16	30985.2	7.86E-04	6.81E-04	9.09E-04	3.30E-04	7.49E-04	5.21E-04
2003	33	31383.4	7.38E-04	6.38E-04	8.53E-04	7.67E-04	1.36E-03	1.05E-03
2004	21	29842.0	6.92E-04	5.89E-04	8.13E-04	4.75E-04	9.72E-04	7.05E-04
2005	20	30712.9	6.49E-04	5.39E-04	7.82E-04	4.35E-04	9.07E-04	6.54E-04
2006	18	30296.0	6.09E-04	4.89E-04	7.57E-04	3.89E-04	8.43E-04	5.98E-04
2007	20	30697.3	5.71E-04	4.42E-04	7.37E-04	4.36E-04	9.07E-04	6.54E-04
2008	14	31184.4	5.35E-04	3.99E-04	7.18E-04	2.78E-04	6.68E-04	4.55E-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	4	29503.2	9.45E-05	4.26E-05	2.10E-04	4.60E-05	2.34E-04	1.25E-04
1999	3	30542.7	8.76E-05	4.43E-05	1.73E-04	2.92E-05	1.89E-04	9.42E-05
2000	3	30689.4	8.12E-05	4.53E-05	1.45E-04	2.91E-05	1.89E-04	9.39E-05
2001	1	30915.4	7.52E-05	4.54E-05	1.25E-04	4.69E-06	1.04E-04	4.00E-05
2002	3	30985.2	6.97E-05	4.40E-05	1.10E-04	2.88E-05	1.87E-04	9.31E-05
2003	2	31383.4	6.46E-05	4.09E-05	1.02E-04	1.51E-05	1.46E-04	6.58E-05
2004	0	29842.0	5.98E-05	3.64E-05	9.84E-05	5.39E-08	5.27E-05	1.37E-05
2005	4	30712.9	5.54E-05	3.13E-05	9.82E-05	4.46E-05	2.27E-04	1.21E-04
2006	2	30296.0	5.14E-05	2.63E-05	1.00E-04	1.55E-05	1.50E-04	6.78E-05
2007	2	30697.3	4.76E-05	2.18E-05	1.04E-04	1.54E-05	1.48E-04	6.70E-05
2008	1	31184.4	4.41E-05	1.79E-05	1.09E-04	4.66E-06	1.03E-04	3.97E-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	9	431936.7	2.62E-05	1.67E-05	4.10E-05	1.12E-05	3.33E-05	2.10E-05
1999	8	404874.1	2.54E-05	1.73E-05	3.75E-05	1.02E-05	3.24E-05	2.00E-05
2000	8	371417.9	2.47E-05	1.77E-05	3.44E-05	1.11E-05	3.52E-05	2.17E-05
2001	17	383009.8	2.40E-05	1.80E-05	3.20E-05	2.78E-05	6.17E-05	4.33E-05
2002	16	394752.0	2.33E-05	1.80E-05	3.01E-05	2.51E-05	5.70E-05	3.97E-05
2003	8	418197.6	2.27E-05	1.77E-05	2.91E-05	9.88E-06	3.14E-05	1.94E-05
2004	8	397603.0	2.20E-05	1.69E-05	2.87E-05	1.04E-05	3.30E-05	2.03E-05
2005	9	417126.3	2.14E-05	1.58E-05	2.89E-05	1.15E-05	3.44E-05	2.17E-05
2006	7	425648.4	2.08E-05	1.46E-05	2.95E-05	8.13E-06	2.80E-05	1.68E-05
2007	12	441978.9	2.02E-05	1.34E-05	3.04E-05	1.58E-05	4.07E-05	2.70E-05
2008	6	439777.9	1.96E-05	1.22E-05	3.15E-05	6.40E-06	2.43E-05	1.41E-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	30	16385.6	1.52E-03	1.13E-03	2.04E-03	1.30E-03	2.37E-03	1.81E-03
1999	23	16501.6	1.38E-03	1.08E-03	1.78E-03	9.48E-04	1.88E-03	1.38E-03
2000	16	16778.4	1.26E-03	1.01E-03	1.56E-03	6.03E-04	1.37E-03	9.55E-04
2001	22	16791.7	1.14E-03	9.46E-04	1.37E-03	8.84E-04	1.78E-03	1.30E-03
2002	17	17669.0	1.04E-03	8.70E-04	1.23E-03	6.18E-04	1.37E-03	9.63E-04
2003	21	18233.8	9.40E-04	7.87E-04	1.12E-03	7.72E-04	1.58E-03	1.15E-03
2004	14	18172.3	8.54E-04	7.01E-04	1.04E-03	4.74E-04	1.14E-03	7.76E-04
2005	8	17814.9	7.75E-04	6.16E-04	9.75E-04	2.37E-04	7.53E-04	4.64E-04
2006	15	17929.8	7.04E-04	5.38E-04	9.21E-04	5.23E-04	1.22E-03	8.41E-04
2007	13	19768.8	6.39E-04	4.67E-04	8.75E-04	3.98E-04	9.89E-04	6.66E-04
2008	13	17431.3	5.80E-04	4.04E-04	8.33E-04	4.50E-04	1.12E-03	7.53E-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	24	3852411.0	5.52E-06	3.69E-06	8.24E-06	4.27E-06	8.36E-06	6.17E-06
1999	19	3853407.0	5.19E-06	3.68E-06	7.32E-06	3.24E-06	6.87E-06	4.91E-06
2000	22	3874614.0	4.88E-06	3.64E-06	6.55E-06	3.84E-06	7.72E-06	5.64E-06
2001	17	3885930.0	4.60E-06	3.56E-06	5.93E-06	2.81E-06	6.22E-06	4.37E-06
2002	24	4063770.0	4.33E-06	3.43E-06	5.45E-06	4.06E-06	7.93E-06	5.86E-06
2003	13	4260278.0	4.07E-06	3.24E-06	5.12E-06	1.85E-06	4.58E-06	3.08E-06
2004	12	4325737.0	3.83E-06	2.99E-06	4.91E-06	1.64E-06	4.24E-06	2.81E-06
2005	14	4309052.0	3.60E-06	2.71E-06	4.80E-06	2.00E-06	4.81E-06	3.28E-06
2006	10	4402364.0	3.39E-06	2.43E-06	4.74E-06	1.28E-06	3.61E-06	2.32E-06
2007	13	4366579.0	3.19E-06	2.16E-06	4.72E-06	1.80E-06	4.47E-06	3.01E-06
2008	27	4374650.0	3.00E-06	1.91E-06	4.72E-06	4.34E-06	8.16E-06	6.12E-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	5.42E-03	4.92E-03	5.98E-03	9.65E-06	1.89E-02	4.72E-03
1999	12906.2	2452646.0	5.14E-03	4.72E-03	5.60E-03	5.07E-04	1.43E-02	5.28E-03
2000	13106.3	2527489.0	4.87E-03	4.53E-03	5.24E-03	4.70E-04	1.39E-02	5.10E-03
2001	12594.7	2486451.0	4.62E-03	4.34E-03	4.92E-03	3.88E-04	1.44E-02	5.10E-03
2002	11211.2	2621261.0	4.38E-03	4.14E-03	4.63E-03	2.64E-04	1.23E-02	4.23E-03
2003	11454.8	2595146.0	4.15E-03	3.94E-03	4.37E-03	2.55E-04	1.31E-02	4.46E-03
2004	10839.6	2665222.0	3.93E-03	3.72E-03	4.16E-03	2.17E-04	1.21E-02	4.06E-03
2005	9682.4	2660611.0	3.73E-03	3.50E-03	3.97E-03	6.63E-05	1.24E-02	3.67E-03
2006	9269.9	2691934.0	3.53E-03	3.29E-03	3.80E-03	1.74E-04	1.02E-02	3.41E-03
2007	8241.2	2683588.0	3.35E-03	3.08E-03	3.65E-03	6.45E-05	1.04E-02	3.10E-03
2008	8413.7	2563482.0	3.18E-03	2.88E-03	3.50E-03	7.61E-05	1.07E-02	3.26E-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	6.75E-03	5.17E-03	8.83E-03	1.30E-03	2.01E-02	6.00E-03
1999	6.40E-03	5.08E-03	8.06E-03	1.72E-03	1.55E-02	6.49E-03
2000	6.06E-03	4.97E-03	7.38E-03	1.60E-03	1.50E-02	6.25E-03
2001	5.73E-03	4.84E-03	6.79E-03	1.61E-03	1.55E-02	6.32E-03
2002	5.43E-03	4.67E-03	6.31E-03	1.15E-03	1.32E-02	5.12E-03
2003	5.14E-03	4.45E-03	5.93E-03	1.49E-03	1.43E-02	5.71E-03
2004	4.87E-03	4.19E-03	5.66E-03	1.09E-03	1.29E-02	4.93E-03
2005	4.61E-03	3.89E-03	5.46E-03	9.86E-04	1.33E-02	4.60E-03
2006	4.36E-03	3.58E-03	5.32E-03	9.51E-04	1.09E-02	4.21E-03
2007	4.13E-03	3.28E-03	5.21E-03	9.69E-04	1.12E-02	4.02E-03
2008	3.91E-03	2.99E-03	5.12E-03	6.73E-04	1.13E-02	3.85E-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	6.83E-03	5.22E-03	8.44E-03	1.83E-03	2.06E-02	6.58E-03
1999	6.51E-03	5.12E-03	7.90E-03	1.88E-03	1.56E-02	6.69E-03
2000	6.20E-03	5.01E-03	7.38E-03	1.46E-03	1.48E-02	6.09E-03
2001	5.88E-03	4.86E-03	6.90E-03	1.70E-03	1.56E-02	6.43E-03
2002	5.57E-03	4.66E-03	6.47E-03	1.26E-03	1.33E-02	5.23E-03
2003	5.25E-03	4.39E-03	6.11E-03	1.43E-03	1.42E-02	5.62E-03
2004	4.94E-03	4.03E-03	5.84E-03	1.01E-03	1.28E-02	4.86E-03
2005	4.62E-03	3.60E-03	5.64E-03	5.54E-04	1.28E-02	4.15E-03
2006	4.31E-03	3.12E-03	5.49E-03	1.03E-03	1.11E-02	4.27E-03
2007	3.99E-03	2.61E-03	5.38E-03	7.54E-04	1.10E-02	3.79E-03
2008	3.68E-03	2.07E-03	5.29E-03	8.73E-04	1.15E-02	4.06E-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	29503	103.0	2.95E+02	2.87E+02	3.02E+02	2.84E+02	2.89E+02	2.86E+02
1999	30543	103.0	2.95E+02	2.89E+02	3.02E+02	2.94E+02	2.99E+02	2.97E+02
2000	30689	103.3	2.95E+02	2.90E+02	3.01E+02	2.94E+02	3.00E+02	2.97E+02
2001	30915	103.0	2.96E+02	2.91E+02	3.01E+02	2.97E+02	3.03E+02	3.00E+02
2002	30985	103.0	2.96E+02	2.92E+02	3.00E+02	2.98E+02	3.04E+02	3.01E+02
2003	31383	103.0	2.97E+02	2.93E+02	3.01E+02	3.02E+02	3.08E+02	3.05E+02
2004	29842	103.3	2.97E+02	2.93E+02	3.01E+02	2.86E+02	2.92E+02	2.89E+02
2005	30713	103.0	2.97E+02	2.93E+02	3.02E+02	2.95E+02	3.01E+02	2.98E+02
2006	30296	103.0	2.98E+02	2.92E+02	3.03E+02	2.91E+02	2.97E+02	2.94E+02
2007	30697	103.4	2.98E+02	2.92E+02	3.05E+02	2.94E+02	3.00E+02	2.97E+02
2008	31184	104.3	2.98E+02	2.91E+02	3.06E+02	2.96E+02	3.02E+02	2.99E+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	29503	103.0	2.95E+02	2.87E+02	3.02E+02	2.84E+02	2.89E+02	2.86E+02
1999	30543	103.0	2.95E+02	2.89E+02	3.02E+02	2.94E+02	2.99E+02	2.97E+02
2000	30689	103.3	2.95E+02	2.90E+02	3.01E+02	2.94E+02	3.00E+02	2.97E+02
2001	30915	103.0	2.96E+02	2.91E+02	3.01E+02	2.97E+02	3.03E+02	3.00E+02
2002	30985	103.0	2.96E+02	2.92E+02	3.00E+02	2.98E+02	3.04E+02	3.01E+02
2003	31383	103.0	2.97E+02	2.93E+02	3.01E+02	3.02E+02	3.08E+02	3.05E+02
2004	29842	103.3	2.97E+02	2.93E+02	3.01E+02	2.86E+02	2.92E+02	2.89E+02
2005	30713	103.0	2.97E+02	2.93E+02	3.02E+02	2.95E+02	3.01E+02	2.98E+02
2006	30296	103.0	2.98E+02	2.92E+02	3.03E+02	2.91E+02	2.97E+02	2.94E+02
2007	30697	103.4	2.98E+02	2.92E+02	3.05E+02	2.94E+02	3.00E+02	2.97E+02
2008	31184	104.3	2.98E+02	2.91E+02	3.06E+02	2.96E+02	3.02E+02	2.99E+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	431937	103.0	3.81E+03	3.55E+03	4.08E+03	4.18E+03	4.20E+03	4.19E+03
1999	404874	103.0	3.84E+03	3.62E+03	4.08E+03	3.92E+03	3.94E+03	3.93E+03
2000	371418	103.3	3.88E+03	3.68E+03	4.08E+03	3.59E+03	3.61E+03	3.60E+03
2001	383010	103.0	3.91E+03	3.74E+03	4.09E+03	3.71E+03	3.73E+03	3.72E+03
2002	394752	103.0	3.95E+03	3.80E+03	4.10E+03	3.82E+03	3.84E+03	3.83E+03
2003	418198	103.0	3.98E+03	3.84E+03	4.13E+03	4.05E+03	4.07E+03	4.06E+03
2004	397603	103.3	4.02E+03	3.87E+03	4.17E+03	3.84E+03	3.86E+03	3.85E+03
2005	417126	103.0	4.05E+03	3.88E+03	4.23E+03	4.04E+03	4.06E+03	4.05E+03
2006	425648	103.0	4.09E+03	3.89E+03	4.30E+03	4.12E+03	4.14E+03	4.13E+03
2007	441979	103.4	4.13E+03	3.89E+03	4.37E+03	4.27E+03	4.29E+03	4.28E+03
2008	439778	104.3	4.16E+03	3.89E+03	4.45E+03	4.21E+03	4.23E+03	4.22E+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	103.0	2.99E-01	2.33E-01	3.83E-01	2.09E-01	3.81E-01	2.90E-01
1999	30	103.0	2.81E-01	2.27E-01	3.47E-01	2.09E-01	3.81E-01	2.90E-01
2000	28	103.3	2.64E-01	2.20E-01	3.16E-01	1.93E-01	3.58E-01	2.70E-01
2001	27	103.0	2.48E-01	2.12E-01	2.90E-01	1.85E-01	3.48E-01	2.61E-01
2002	16	103.0	2.33E-01	2.01E-01	2.69E-01	9.92E-02	2.25E-01	1.57E-01
2003	33	103.0	2.19E-01	1.89E-01	2.53E-01	2.34E-01	4.14E-01	3.18E-01
2004	21	103.3	2.05E-01	1.75E-01	2.41E-01	1.37E-01	2.81E-01	2.04E-01
2005	20	103.0	1.93E-01	1.60E-01	2.33E-01	1.30E-01	2.71E-01	1.95E-01
2006	18	103.0	1.81E-01	1.46E-01	2.26E-01	1.14E-01	2.48E-01	1.76E-01
2007	20	103.4	1.70E-01	1.32E-01	2.20E-01	1.29E-01	2.70E-01	1.94E-01
2008	14	104.3	1.60E-01	1.19E-01	2.15E-01	8.31E-02	2.00E-01	1.36E-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	103.0	2.79E-02	1.25E-02	6.22E-02	1.33E-02	6.75E-02	3.59E-02
1999	3	103.0	2.59E-02	1.30E-02	5.15E-02	8.65E-03	5.62E-02	2.79E-02
2000	3	103.3	2.40E-02	1.33E-02	4.32E-02	8.63E-03	5.60E-02	2.79E-02
2001	1	103.0	2.22E-02	1.34E-02	3.70E-02	1.40E-03	3.12E-02	1.20E-02
2002	3	103.0	2.06E-02	1.30E-02	3.28E-02	8.65E-03	5.62E-02	2.79E-02
2003	2	103.0	1.91E-02	1.21E-02	3.03E-02	4.57E-03	4.42E-02	2.00E-02
2004	0	103.3	1.77E-02	1.07E-02	2.93E-02	1.57E-05	1.53E-02	3.98E-03
2005	4	103.0	1.64E-02	9.23E-03	2.93E-02	1.33E-02	6.75E-02	3.59E-02
2006	2	103.0	1.52E-02	7.75E-03	3.00E-02	4.57E-03	4.42E-02	2.00E-02
2007	2	103.4	1.41E-02	6.42E-03	3.11E-02	4.56E-03	4.41E-02	1.99E-02
2008	1	104.3	1.31E-02	5.27E-03	3.26E-02	1.39E-03	3.09E-02	1.19E-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	9	103.0	1.01E-01	6.57E-02	1.57E-01	4.67E-02	1.39E-01	8.78E-02
1999	8	103.0	9.92E-02	6.83E-02	1.44E-01	4.01E-02	1.27E-01	7.85E-02
2000	8	103.3	9.70E-02	7.05E-02	1.33E-01	4.00E-02	1.27E-01	7.83E-02
2001	17	103.0	9.48E-02	7.20E-02	1.25E-01	1.04E-01	2.30E-01	1.62E-01
2002	16	103.0	9.27E-02	7.25E-02	1.19E-01	9.64E-02	2.19E-01	1.52E-01
2003	8	103.0	9.07E-02	7.14E-02	1.15E-01	4.01E-02	1.27E-01	7.85E-02
2004	8	103.3	8.86E-02	6.87E-02	1.14E-01	4.00E-02	1.27E-01	7.83E-02
2005	9	103.0	8.67E-02	6.48E-02	1.16E-01	4.67E-02	1.39E-01	8.78E-02
2006	7	103.0	8.48E-02	6.04E-02	1.19E-01	3.35E-02	1.15E-01	6.93E-02
2007	12	103.4	8.29E-02	5.57E-02	1.23E-01	6.73E-02	1.73E-01	1.15E-01
2008	6	104.3	8.10E-02	5.12E-02	1.28E-01	2.69E-02	1.02E-01	5.94E-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	16386	103.0	1.61E+02	1.52E+02	1.70E+02	1.57E+02	1.61E+02	1.59E+02
1999	16502	103.0	1.62E+02	1.55E+02	1.71E+02	1.58E+02	1.62E+02	1.60E+02
2000	16778	103.3	1.64E+02	1.58E+02	1.71E+02	1.60E+02	1.65E+02	1.62E+02
2001	16792	103.0	1.66E+02	1.60E+02	1.72E+02	1.61E+02	1.65E+02	1.63E+02
2002	17669	103.0	1.68E+02	1.63E+02	1.74E+02	1.69E+02	1.74E+02	1.72E+02
2003	18234	103.0	1.70E+02	1.65E+02	1.75E+02	1.75E+02	1.79E+02	1.77E+02
2004	18172	103.3	1.72E+02	1.67E+02	1.78E+02	1.74E+02	1.78E+02	1.76E+02
2005	17815	103.0	1.74E+02	1.68E+02	1.80E+02	1.71E+02	1.75E+02	1.73E+02
2006	17930	103.0	1.76E+02	1.69E+02	1.84E+02	1.72E+02	1.76E+02	1.74E+02
2007	19769	103.4	1.78E+02	1.70E+02	1.87E+02	1.89E+02	1.94E+02	1.91E+02
2008	17431	104.3	1.80E+02	1.71E+02	1.91E+02	1.65E+02	1.69E+02	1.67E+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	3852411	103.0	3.71E+04	3.59E+04	3.83E+04	3.74E+04	3.74E+04	3.74E+04
1999	3853407	103.0	3.77E+04	3.66E+04	3.88E+04	3.74E+04	3.74E+04	3.74E+04
2000	3874614	103.3	3.83E+04	3.74E+04	3.92E+04	3.75E+04	3.75E+04	3.75E+04
2001	3885930	103.0	3.89E+04	3.81E+04	3.97E+04	3.77E+04	3.78E+04	3.77E+04
2002	4063770	103.0	3.95E+04	3.88E+04	4.02E+04	3.94E+04	3.95E+04	3.95E+04
2003	4260278	103.0	4.01E+04	3.94E+04	4.08E+04	4.13E+04	4.14E+04	4.14E+04
2004	4325737	103.3	4.07E+04	4.00E+04	4.14E+04	4.19E+04	4.19E+04	4.19E+04
2005	4309052	103.0	4.13E+04	4.05E+04	4.22E+04	4.18E+04	4.19E+04	4.18E+04
2006	4402364	103.0	4.20E+04	4.10E+04	4.30E+04	4.27E+04	4.28E+04	4.27E+04
2007	4366579	103.4	4.26E+04	4.15E+04	4.38E+04	4.22E+04	4.23E+04	4.22E+04
2008	4374650	104.3	4.33E+04	4.20E+04	4.47E+04	4.19E+04	4.20E+04	4.20E+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	30	103.0	2.43E-01	1.82E-01	3.26E-01	2.08E-01	3.79E-01	2.88E-01
1999	23	103.0	2.24E-01	1.75E-01	2.87E-01	1.52E-01	3.02E-01	2.22E-01
2000	16	103.3	2.06E-01	1.67E-01	2.55E-01	9.82E-02	2.23E-01	1.55E-01
2001	22	103.0	1.89E-01	1.57E-01	2.28E-01	1.44E-01	2.91E-01	2.12E-01
2002	17	103.0	1.74E-01	1.46E-01	2.07E-01	1.06E-01	2.35E-01	1.65E-01
2003	21	103.0	1.60E-01	1.34E-01	1.91E-01	1.37E-01	2.80E-01	2.03E-01
2004	14	103.3	1.47E-01	1.21E-01	1.80E-01	8.34E-02	2.00E-01	1.36E-01
2005	8	103.0	1.35E-01	1.07E-01	1.71E-01	4.09E-02	1.30E-01	8.02E-02
2006	15	103.0	1.25E-01	9.49E-02	1.63E-01	9.10E-02	2.12E-01	1.46E-01
2007	13	103.4	1.15E-01	8.35E-02	1.57E-01	7.60E-02	1.89E-01	1.27E-01
2008	13	104.3	1.05E-01	7.32E-02	1.52E-01	7.53E-02	1.87E-01	1.26E-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	24	103.0	2.04E-01	1.39E-01	3.00E-01	1.60E-01	3.13E-01	2.31E-01
1999	19	103.0	1.95E-01	1.40E-01	2.72E-01	1.21E-01	2.58E-01	1.84E-01
2000	22	103.3	1.87E-01	1.41E-01	2.48E-01	1.44E-01	2.90E-01	2.12E-01
2001	17	103.0	1.79E-01	1.40E-01	2.28E-01	1.06E-01	2.35E-01	1.65E-01
2002	24	103.0	1.71E-01	1.37E-01	2.14E-01	1.60E-01	3.13E-01	2.31E-01
2003	13	103.0	1.64E-01	1.32E-01	2.04E-01	7.63E-02	1.89E-01	1.27E-01
2004	12	103.3	1.57E-01	1.24E-01	1.99E-01	6.88E-02	1.77E-01	1.18E-01
2005	14	103.0	1.50E-01	1.14E-01	1.97E-01	8.36E-02	2.01E-01	1.37E-01
2006	10	103.0	1.44E-01	1.04E-01	1.98E-01	5.47E-02	1.54E-01	9.91E-02
2007	13	103.4	1.37E-01	9.45E-02	2.00E-01	7.60E-02	1.89E-01	1.27E-01
2008	27	104.3	1.31E-01	8.54E-02	2.03E-01	1.82E-01	3.42E-01	2.57E-01

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.