Enhanced Component Performance Study

Motor-Driven Pumps

1998–2009

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 2009 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.

The objective of the enhanced component performance study is to present an analysis of factors that could influence the system and component trends in addition to annual performance trends of failure rates and probabilities. The factors analyzed for the MDP component are the differences in failures between total demands and actual unplanned (ESF) demands (Section 6.3). Statistical analyses of the differences are performed and results showing whether pooling is acceptable across these factors are shown. In addition, engineering analyses were performed with respect to time period and failure mode (Section 6.4). The factors analyzed are: sub-component, failure cause, recovery, and detection method.

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.

- Standby MDP run hours per reactor critical year. (see Figure 11)
- Frequency (demands per reactor year) of start demands, normally running MDPs. (see Figure 15)

These trends are not adverse trends; they only indicate an increase in and run hours for standby pumps and demands for normally running pumps. Standby MDP run hours appear to have made a step change in the upward direction in FY 2003, which coincides with the start of the MSPI program. This gives an increasing trend over the 1998 to 2009 period. Normally running MDP start demands have increased from approximately 26 to 28 start demands per reactor year. The trend is significant, but the increase is not. 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)

An ongoing concern in the industry is whether industry data adequately represent standby component performance during unplanned (ESF) demands. Section 6.3 shows the results of the consistency check between industry data and ESF detected failure data. Two failure mode observations (FTS and FTR) and the Total MDP unreliability are not consistent and lie in the lower 95% (degraded performance compared to the industry average). The FTR<1H failure mode observation is better than the industry average distribution.

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. MDPs are categorized as either standby or normally running. This report follows the definition of these categories in Reference 1, which determines the status by evaluating the number of run-hours per demand. Those pumps with low run-hours per demand are standby (≤360) and those that are high are normally running (>360). Table 2 shows industry-wide failure probability and failure rate results for the MDP from Reference 1.

[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).

Table 1. MDP systems.

System	Description	Total	Standby	Normally Running
AFW	Auxiliary feedwater	123	123	
CCW	Component cooling water	277	188	89
CDS	Condensate system	142	3	139
CRD	Control rod drive	48	8	40
CSR	Containment spray recirculation	152	152	
CVC	Chemical and volume control	62	58	4
HCS	High pressure core spray	9	9	
HPI	High pressure injection	167	164	3
LCS	Low pressure core spray	72	67	5
MFW	Main feedwater	47	14	33
RHR	Residual heat removal	302	302	
SWN	Emergency service water (Standby)	279	197	82
SWS	Standby service water	206	192	14
	Total	1886	1477	409

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 11 to Table 13. 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 14 and Table 15.

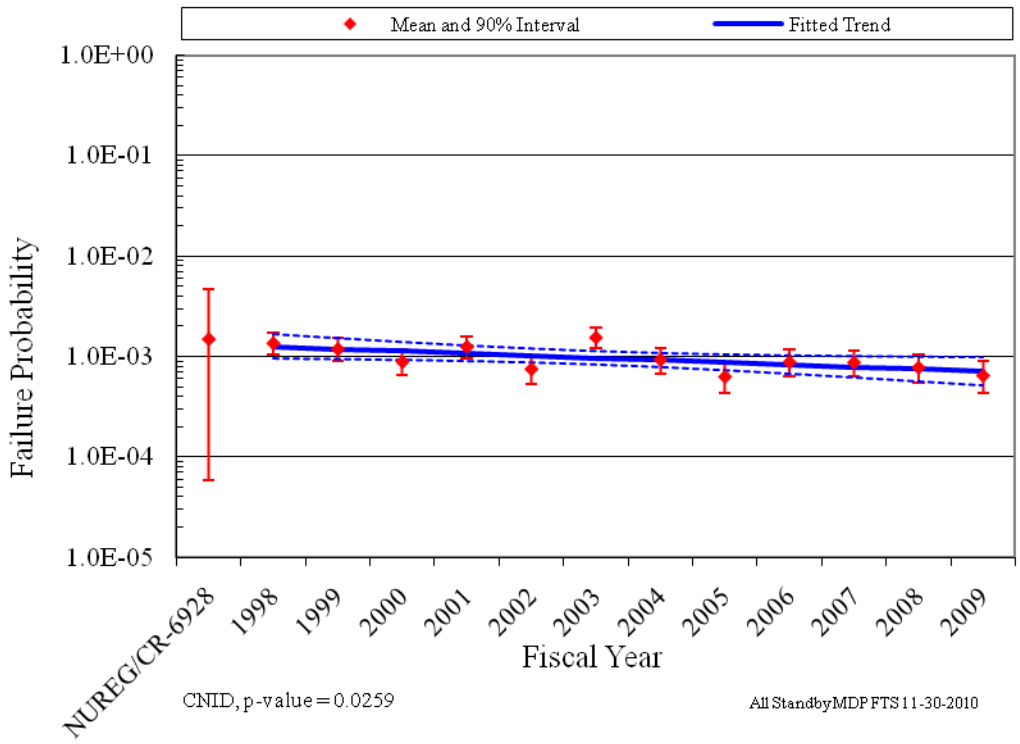

Figure 1. Standby systems, industry-wide MDP FTS trend.

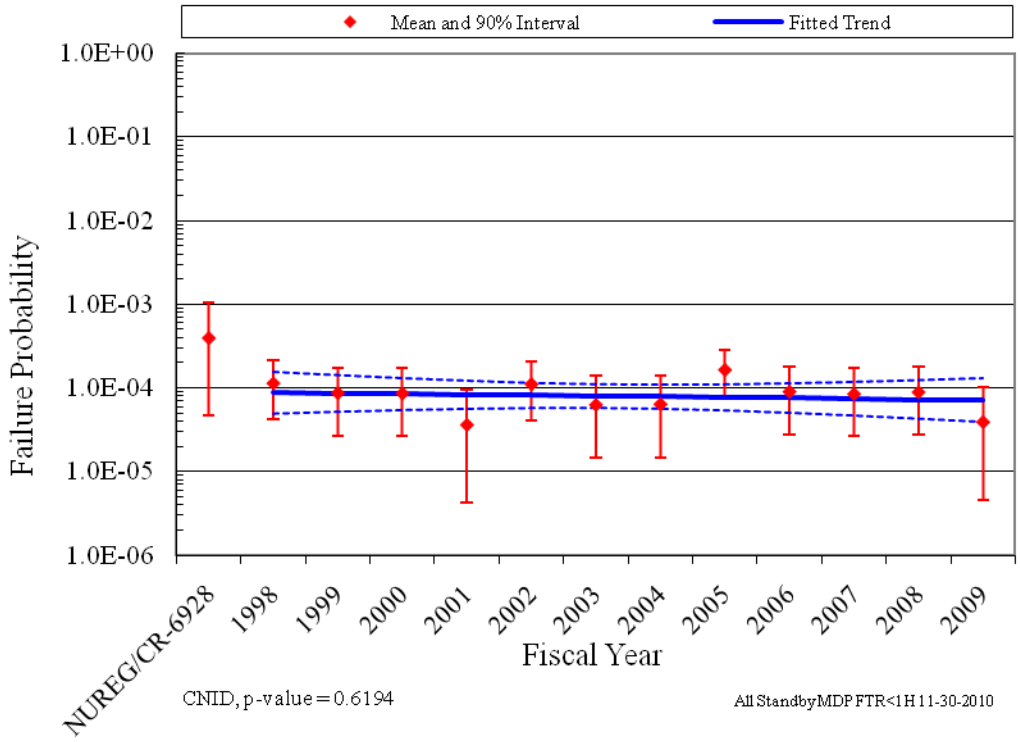

Figure 2. Standby systems, industry-wide MDP FTR≤1H trend.

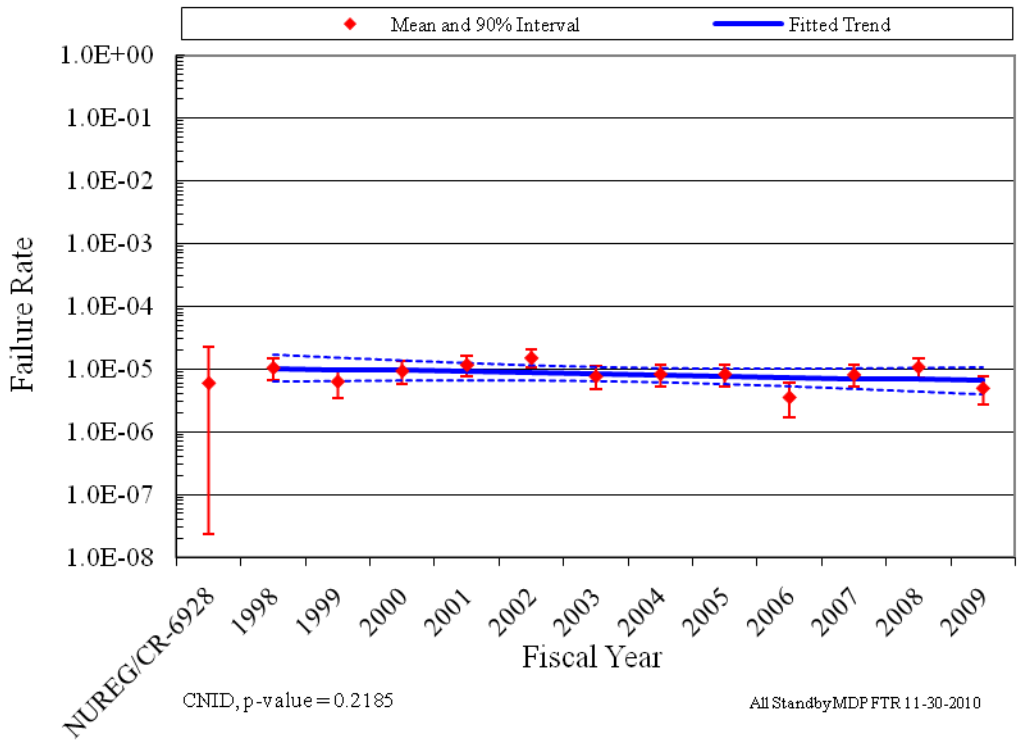

Figure 3. Standby systems, industry-wide MDP FTR>1H trend.

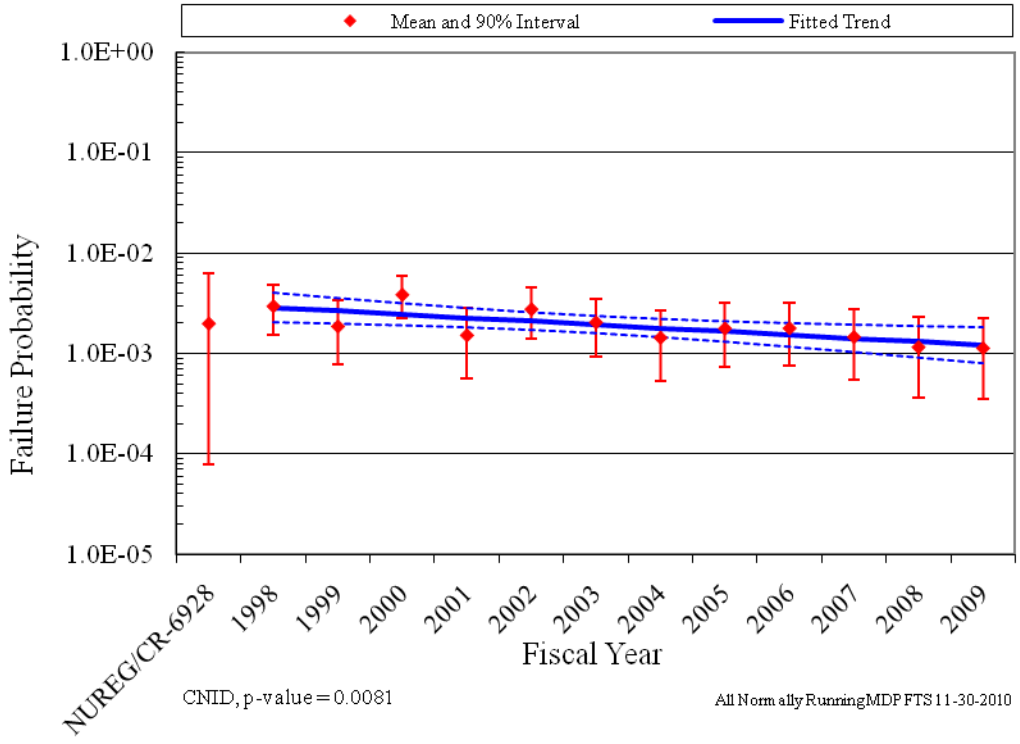

Figure 4. Normally running systems, industry-wide MDP FTS trend.

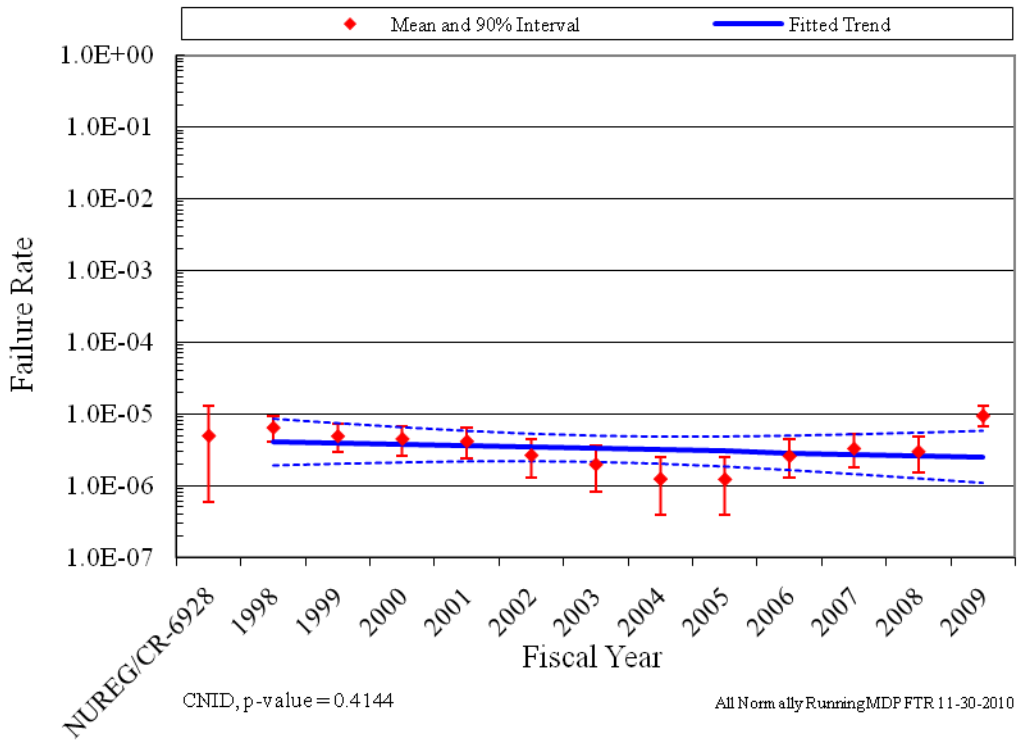

Figure 5. Normally running systems, industry-wide MDP FTR trend.

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 1998-2009 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 16. 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 (1998–2009) unavailability and reactor critical hour data were obtained from the ROP (1998 to 2001) and EPIX (2002 to 2009) 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.

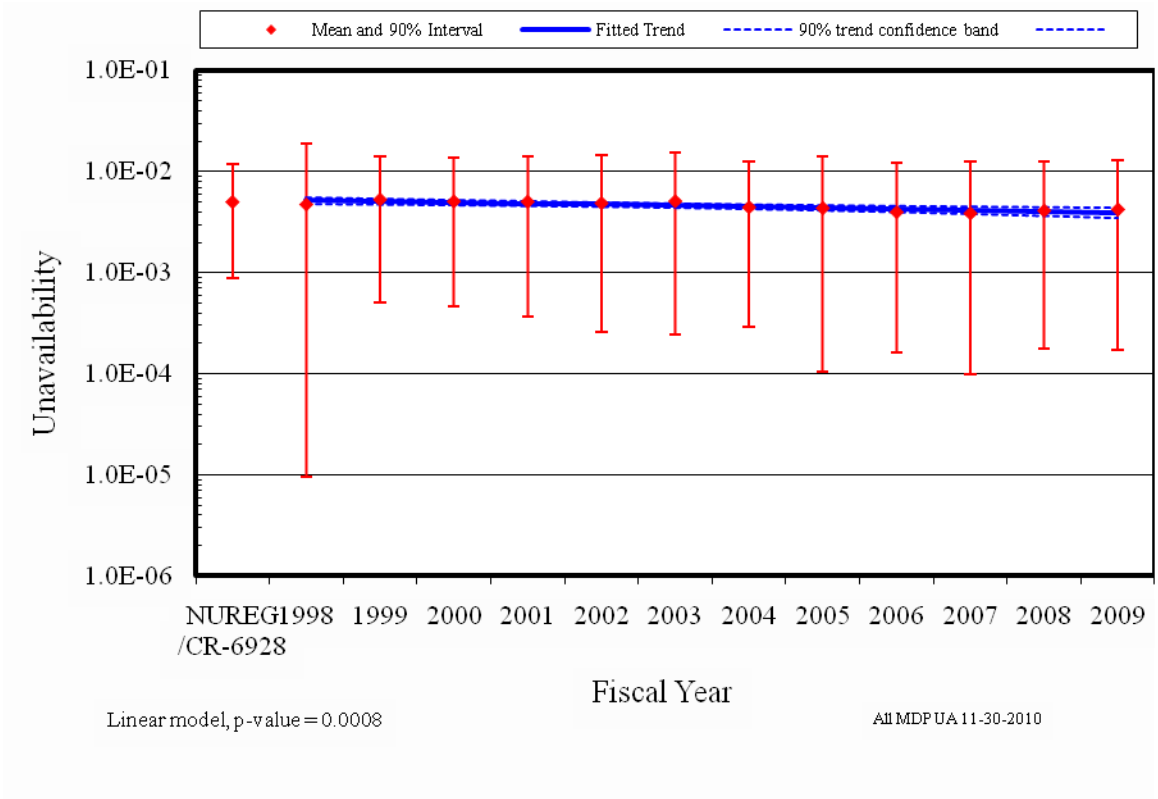

Figure 6. Pooled AFW, HPI, and HCS MDP UA trend.

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 17 and Table 18, 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 and shown in Figure 7. The normally running systems from Table 2 are trended together and shown in Figure 8.

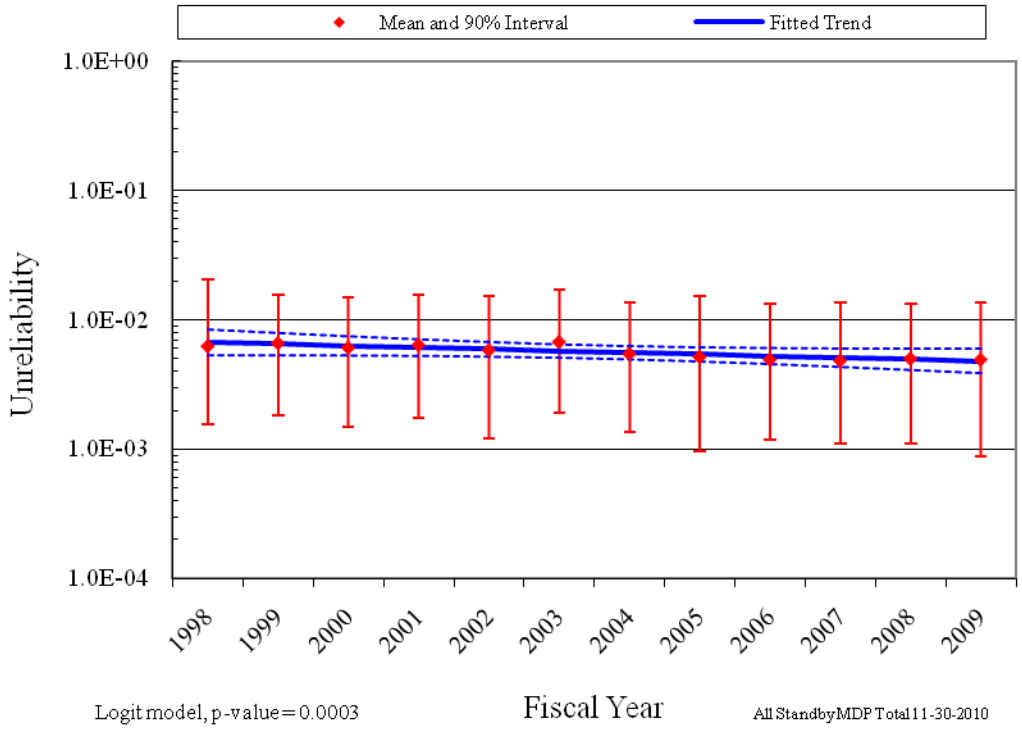

Figure 7. Standby systems, industry-wide MDP unreliability trend (8-hour mission).

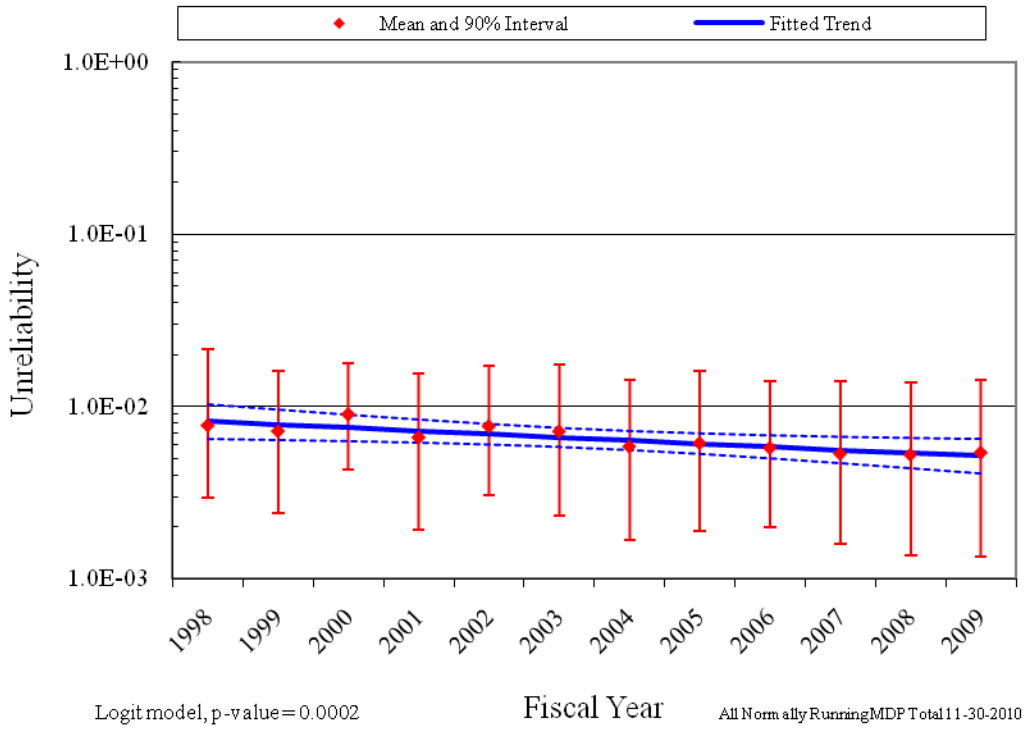

Figure 8. Normally running systems (MFW), industry-wide MDP unreliability trend (8-hour mission).

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 19, Table 20, and Table 21 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 22, Table 24, and Table 25 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. The red highlighted values in the percent of total failures column show the five most significant contributors.

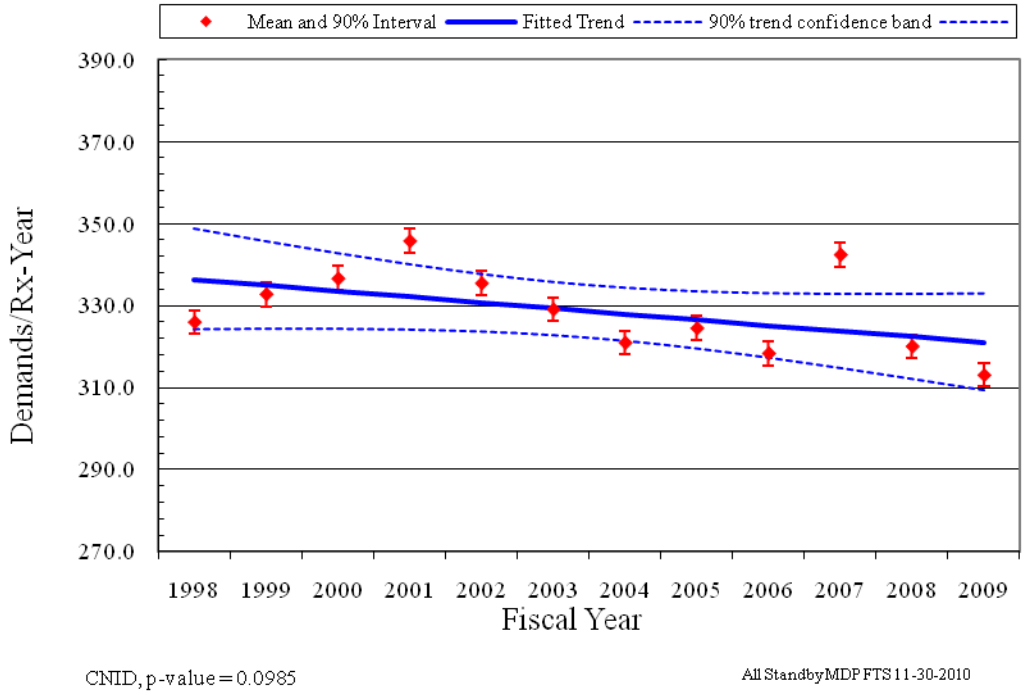

Figure 9. Frequency (demands per reactor year) of start demands, standby MDPs.

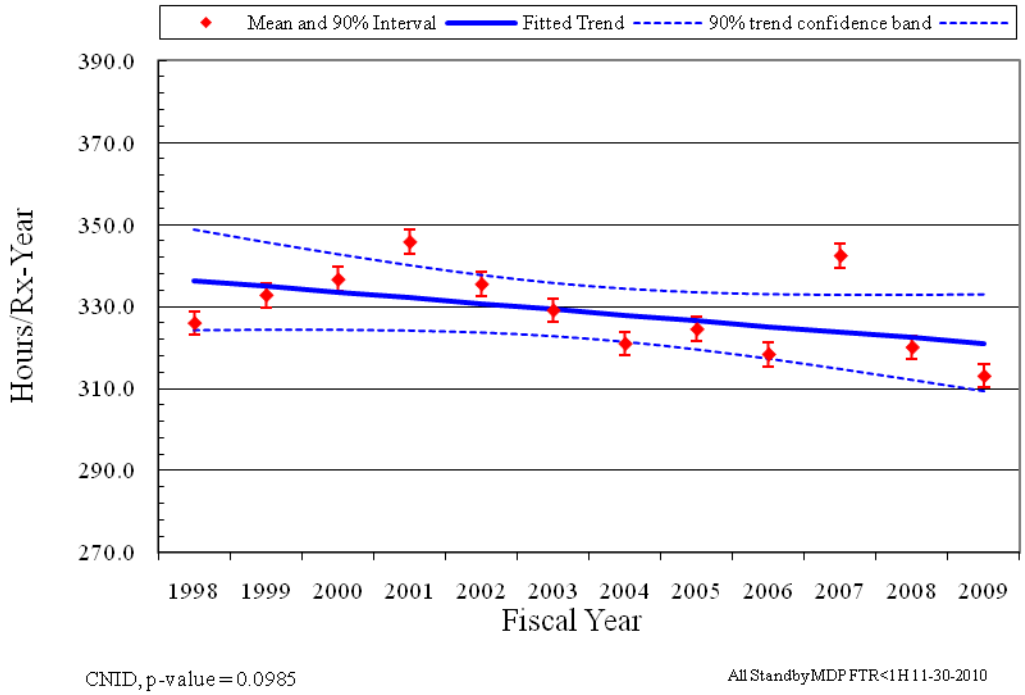

Figure 10. Standby MDP run hours per reactor critical year of run ≤ 1H hours.

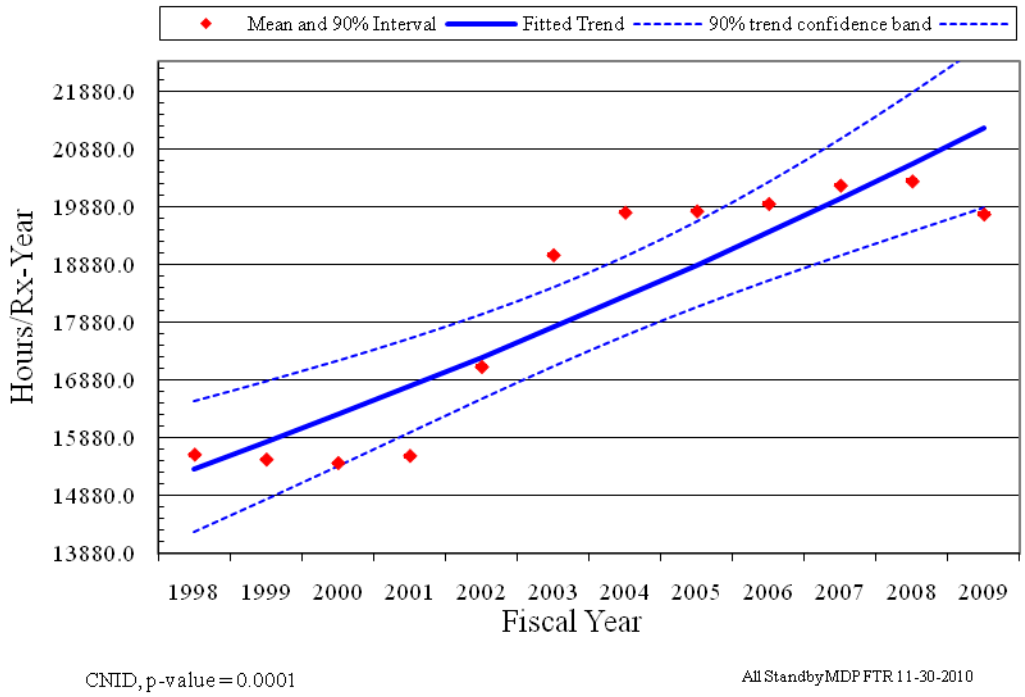

Figure 11. Standby MDP run hours per reactor critical year.

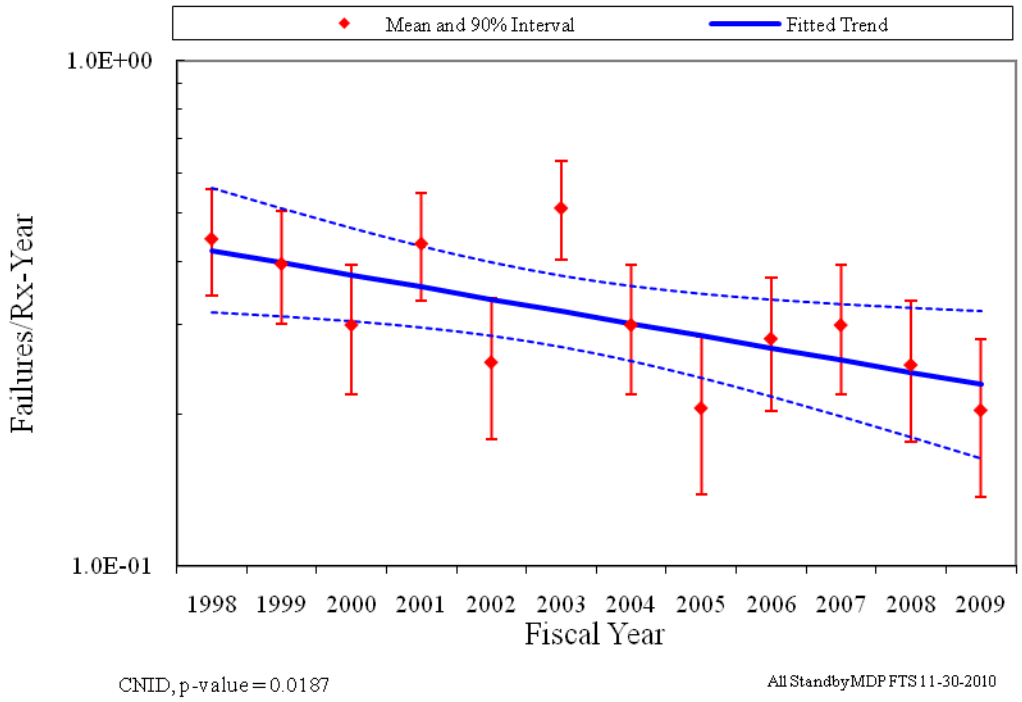

Figure 12. Frequency (failures per reactor year) of FTS events, standby MDPs.

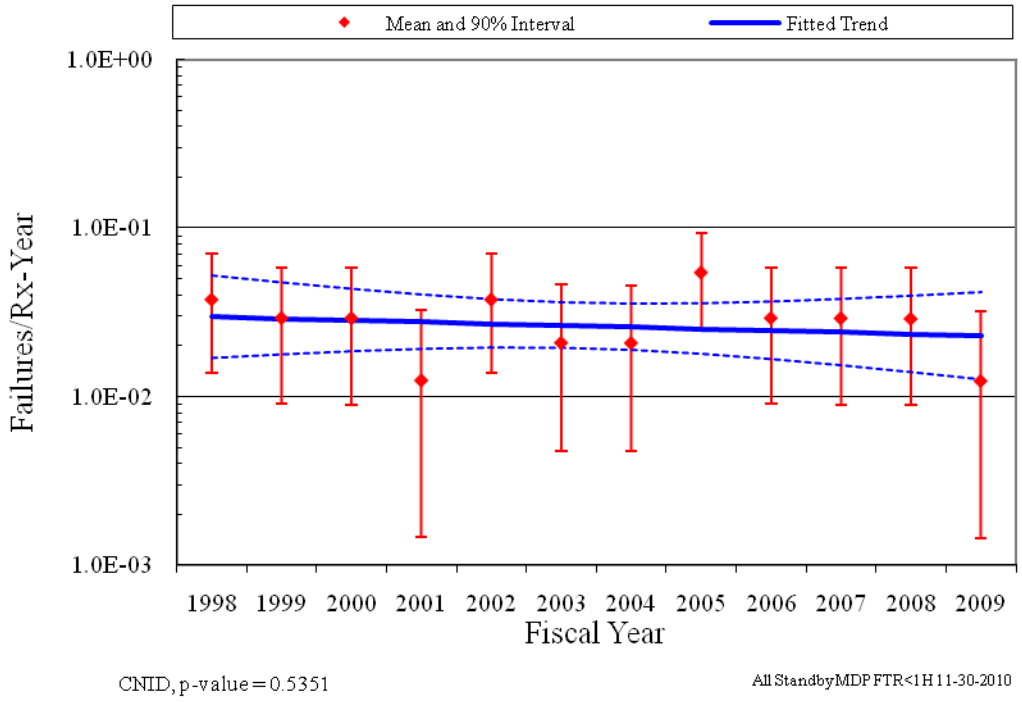

Figure 13. Frequency (failures per reactor year) of FTR≤1H events, standby MDPs.

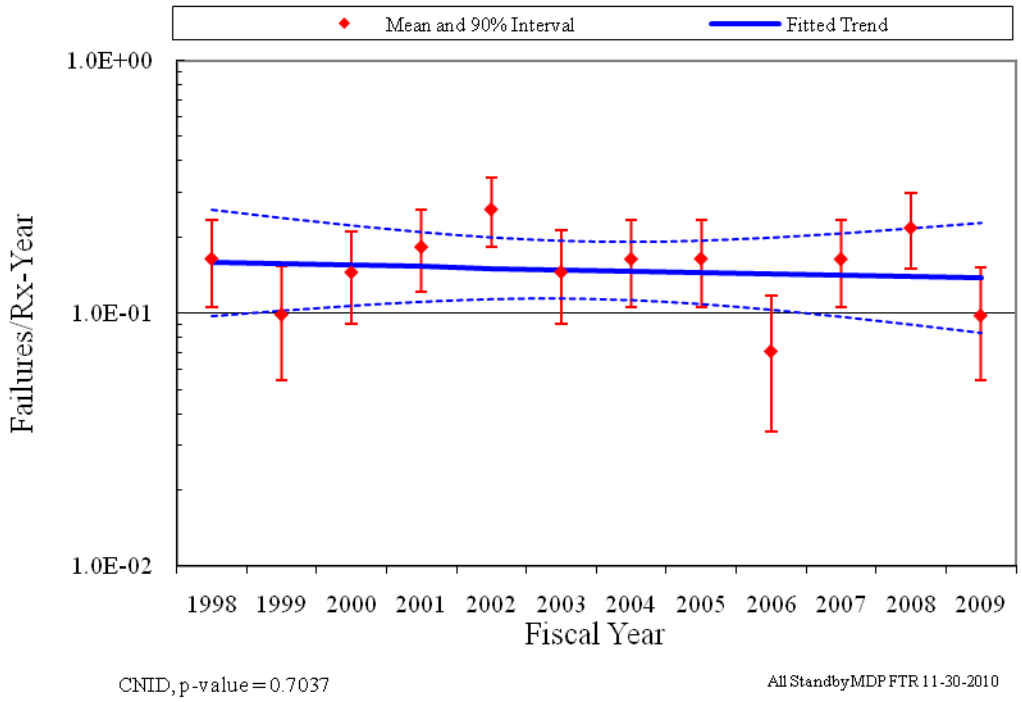

Figure 14. Frequency (failures per reactor year) of FTR>1H events, standby MDPs.

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 25 and Table 26 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 27 and Table 28 provide the plot data respectively. The normally running systems from Table 2 are trended for each figure.

Table 7 summarizes the failures by system and year for the FTS failure mode. Table 8 summarizes the failures by system and year for the FTR failure mode. The red highlighted values in the percent of total failures column show the five most significant contributors.

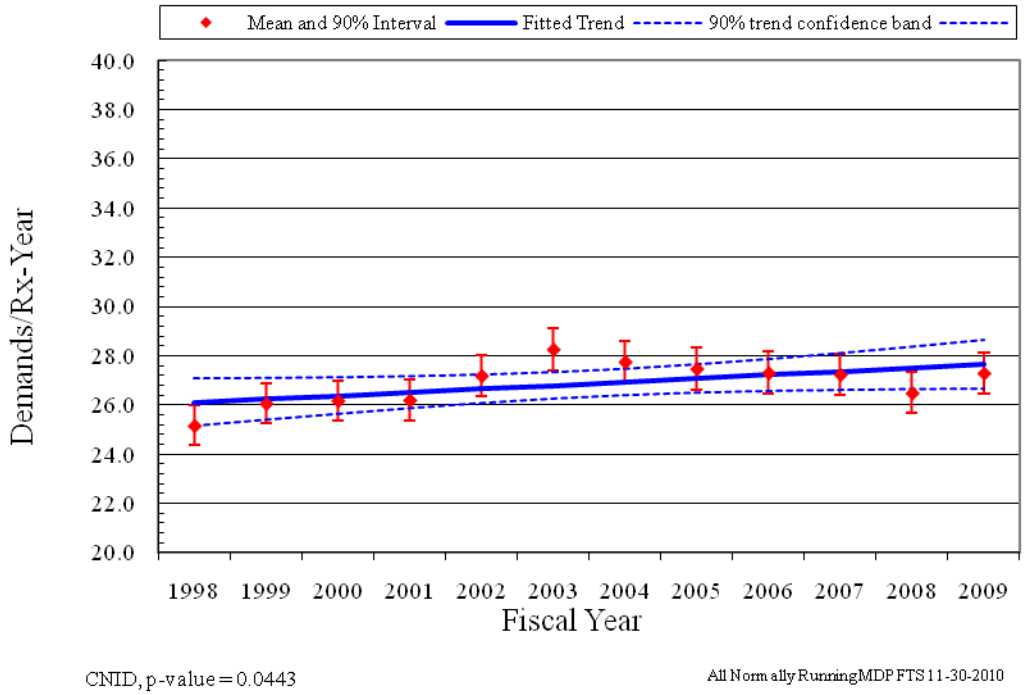

Figure 15. Frequency (demands per reactor year) of start demands, normally running MDPs.

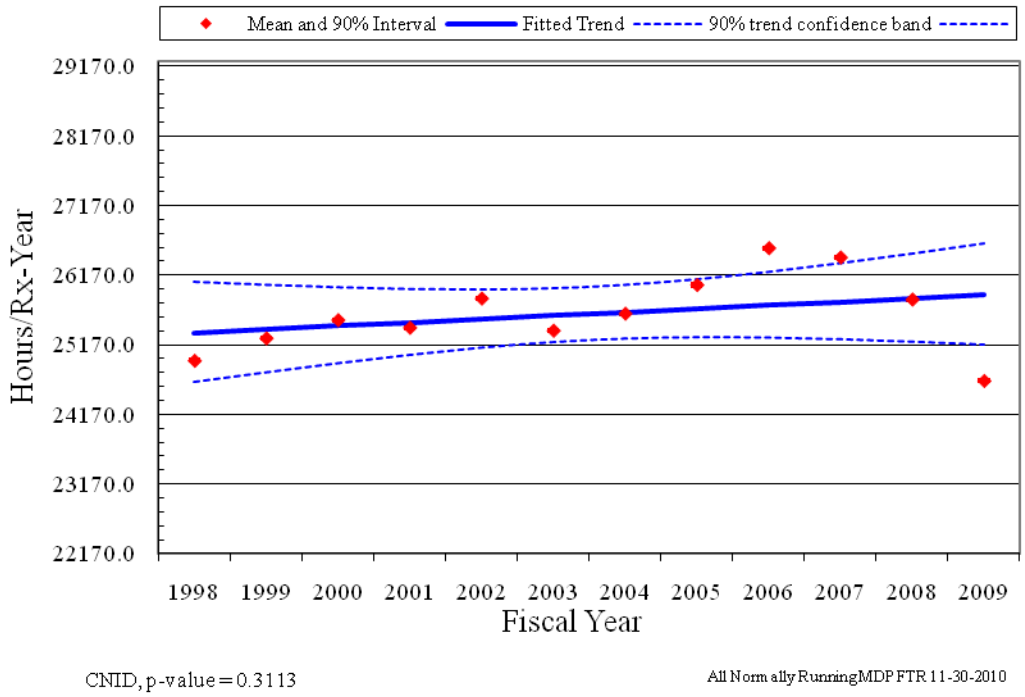

Figure 16. Normally running MDP run hours per reactor critical year.

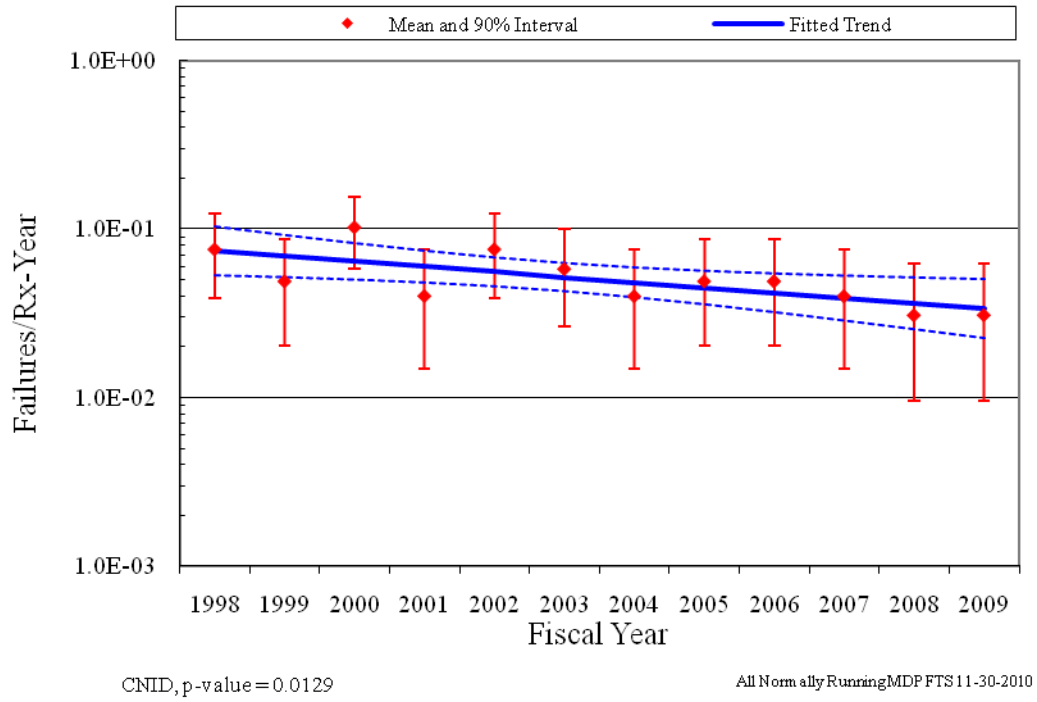

Figure 17. Frequency (failures per reactor year) of FTS events, normally running MDPs.

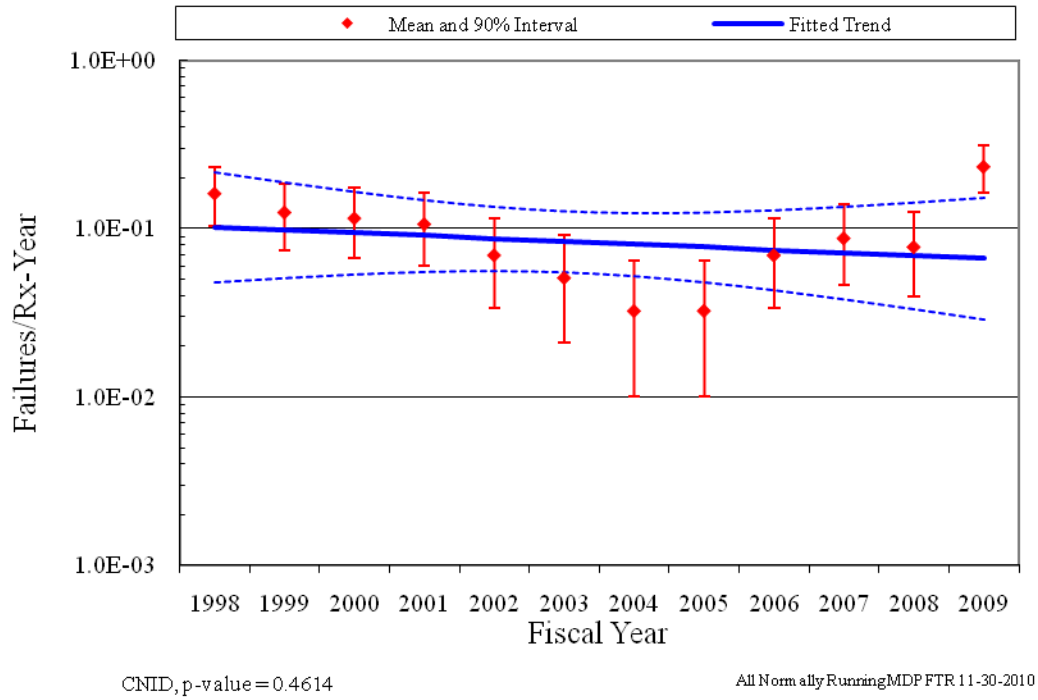

Figure 18. Frequency (failures per reactor year) of FTR events, normally running MDPs.

Table 4. Summary of standby 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*	*FY 09*	*Total*	*Percent of Failures*
AFW	123	8.4%	3	6	3	3		4		3	4	4		3	33	8.2%
CCW	188	12.8%	8	10	1	6	4	8	3		5	4	4	2	55	13.7%
CDS	3	0.2%									1	1	1		3	0.7%
CRD	8	0.5%		1		3									4	1.0%
CSR	152	10.3%	2	1		3		9	4	2	1		1		23	5.7%
CVC	58	3.9%	5	3		2	2	4	1	1	1	1	1		21	5.2%
HCS	9	0.6%						1			1				2	0.5%
HPI	164	11.2%	4	2	3	6	4	2	7	2	2	3	4	4	43	10.7%
LCS	67	4.6%	2				2	2				2	1		9	2.2%
MFW	14	1.0%				1			1				2	1	5	1.2%
RHR	302	20.6%	10	8	9	7	3	9	5	6	3	5	5	2	72	18.0%
SWN	197	13.4%	7	3	5	7	5	8	5	3	4	6	4	5	62	15.5%
SWS	192	13.1%	5	7	10	7	6	6	5	4	7	5	3	4	69	17.2%
Total	1477	100.0%	46	41	31	45	26	53	31	21	29	31	26	21	401	100.0%

Table 5. Summary of standby 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*	*FY 08*	*FY 09*	*Total*	*Percent of Failures*
AFW	123	8.8%		2	1		1			2		1			7	20.0%
CCW	188	13.5%					1			1			1		3	8.6%
CSR	152	10.9%	1							2	1			1	5	14.3%
CVC	58	4.2%									1				1	2.9%
HPI	164	11.8%				1						1			2	5.7%
MFW	14	1.0%											1		1	2.9%
RHR	302	21.7%		1	1		1								3	8.6%
SWN	197	14.2%						1	2			1			4	11.4%
SWS	192	13.8%	3		1		1	1		1	1		1		9	25.7%
Total	1390	100.0%	4	3	3	1	4	2	2	6	3	3	3	1	35	100.0%

Table 6. Summary of standby 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*	*FY 08*	*FY 09*	*Total*	*Percent of Failures*
AFW	123	8.4%	3	6	3	3		4		3	4	4		3	33	8.2%
CCW	188	12.8%	8	10	1	6	4	8	3		5	4	4	2	55	13.7%
CDS	3	0.2%									1	1	1		3	0.7%
CRD	8	0.5%		1		3									4	1.0%
CSR	152	10.3%	2	1		3		9	4	2	1		1		23	5.7%
CVC	58	3.9%	5	3		2	2	4	1	1	1	1	1		21	5.2%
HCS	9	0.6%						1			1				2	0.5%
HPI	164	11.2%	4	2	3	6	4	2	7	2	2	3	4	4	43	10.7%
LCS	67	4.6%	2				2	2				2	1		9	2.2%
MFW	14	1.0%				1			1				2	1	5	1.2%
RHR	302	20.6%	10	8	9	7	3	9	5	6	3	5	5	2	72	18.0%
SWN	197	13.4%	7	3	5	7	5	8	5	3	4	6	4	5	62	15.5%
SWS	192	13.1%	5	7	10	7	6	6	5	4	7	5	3	4	69	17.2%
Total	1477	100.0%	46	41	31	45	26	53	31	21	29	31	26	21	401	100.0%

Table 7. Summary of normally running 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*	*FY 09*	*Total*	*Percent of Failures*
CCW	89	22.4%	1			1		1	1		2		3		9	13.6%
CDS	139	35.0%	2	2	4	1	1	1							11	16.7%
CRD	40	10.1%	2	1	3	1	2					1			10	15.2%
MFW	33	8.3%	1		3		1	1		1	1	2			10	15.2%
SWN	82	20.7%	1	2	1	1	4	1	3	3	2			3	21	31.8%
SWS	14	3.5%	1					2		1		1			5	7.6%
Total	397	100.0%	8	5	11	4	8	6	4	5	5	4	3	3	66	100.0%

Table 8. Summary of normally running MDP failure counts for the 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*	*FY 09*	*Total*	*Percent of Failures*
CCW	89	22.3%		2	3		1	2				2		3	13	10.8%
CDS	139	34.8%	8	4	1	2	3	1		1	3	2	1	8	34	28.3%
CRD	40	10.0%	2	1	4	1	1	1							10	8.3%
HPI	3	0.8%		1											1	0.8%
MFW	33	8.3%	4	1	1	1						1			8	6.7%
SWN	82	20.5%	3	3	3	6	2	1	3	2	4	3	7	14	51	42.5%
SWS	14	3.5%		1		1						1			3	2.5%
Total	400	100.0%	17	13	12	11	7	5	3	3	7	9	8	25	120	100.0%

6.3 Comparison of EPIX MDP Unplanned Demand Results with Industry Results for Standby Components

An ongoing concern in the industry is whether a combination of test, non-test demand, and actual demand data adequately represent standby component performance during unplanned demands. This comparison evaluates the same dataset for standby components that is used for the overall trends shown in this document, but limits the failure data to those that are discovered during an ESF demand and the ESF demands reported in EPIX. The data are further limited to FY 2003 to present since the ESF demand reporting in EPIX is inconsistent prior to FY 2003.

The standby MDP ESF unplanned demand data covering FY 2003 – 2009 are summarized in Table 9. Consistency between the unplanned demand data and industry-average performance from Table 2 was evaluated using the predictive distribution approach outlined in the *Handbook of Parameter Estimation for Probabilistic Risk Assessment*, NUREG/CR-6823, Sections 6.2.3.5 and 6.3.3.4 [Reference 2]. Simulation is required.

The unplanned demand data were aggregated at the plant and system level (failures and demands). Assuming each plant and system can have a different failure probability, the industry-average distribution (from Table 2) was sampled for each plant and system. The predicted number of failure events for each plant and system was evaluated using the binomial distribution with the plant-specific failure probability and its associated number of demands. Then the total number of predicted failures was obtained by summing the individual plant results. This process was repeated 1000 times (Latin hypercube sampling), each time obtaining a total number of predicted failures. The 1000 sample results were ordered from high to low. Then the actual number of unplanned demand failures observed (listed in Table 9) was compared with this ordered sample to determine the probability of observing this number of failures or greater. If the probability was greater than 0.05 and less than 0.95, then the unplanned demand performance was considered to be consistent with the industry-average distribution obtained from the EPIX data analysis.

Table 9. Standby MDP unplanned demand performance comparison with industry-average performance.

Failure Modes	Plants	Demands or Hours	Failures	Expected Failures	Probability of ≥ Failures	Consistent with Industry-Average Performance?
FTS	104	1684	2	2.5	0.00	No
FTR<1H	104	1684	0	0.6	1.00	No
FTR	104	28251	2	1.3	0.00	No
Total MDP Unreliability (8 hours)	104	1,684 and 28,251.4 h	4	4.4	0.00	No

The consistency checks using unplanned demand data indicate that none of the failure observations are consistent with their industry-average distribution from Table 2. Two failure mode observations (FTS and FTR) and the Total MDP unreliability are not consistent and lie in the lower 95% (degraded performance). The FTR<1H failure mode observation is better than the industry average distribution.

6.4 MDP Engineering Analysis by Failure Modes

The engineering analysis of the standby MDP failure sub-components, causes, detection methods, and recovery possibility are presented in this section. Each analysis divides the events into two periods:

before July 2003 and after July 2003 (the start of the data begins in FY 1998 and the last date is FY 2009). This breakdown was chosen for two reasons: first, July 2003 represents a point in which the MSPI data collection attains a "higher level" of scrutiny; second, this date represents a point about half way through the full data period.

The second division of the events is by the failure mode determined after EPIX data review by the staff. See Section 7 for more description of failure modes.

MDP sub-component contributions to the three failure modes are presented in Figure 19. The sub-component contributions are similar to those used in the CCF database. The driver has the highest percentage contributions to failures for the fail to start and the FTR failure modes. The pump subcomponent is the highest for the FTR≤1H failure mode.

MDP cause group contributions to the three failure modes are presented in Figure 20. The cause groups are similar to those used in the CCF database. Table 10 shows the breakdown of the cause groups with the specific causes that were coded during the data collection. The most likely causes are internal faults, human errors, and design issues. Internal means that the cause was related to something within the MDP component such as a worn out part or the normal internal environment.

MDP detection methods to the three failure modes are presented in Figure 21. The most likely detection method for FTS and FTR is non-testing. The prevalent FTR detection is test demands.

MDP recovery to the three failure modes are presented in Figure 22. The overall non-recovery to recovery ratio is approximately 4:1.

Table 10. MDP component failure cause groups.

Group	Specific Cause	Description
Design	Construction/installation error or inadequacy	Used when a construction or installation error is made during the original or modification installation. This includes specification of incorrect component or material.
Design	Design error or inadequacy	Used when a design error is made.
Design	Manufacturing error or inadequacy	Used when a manufacturing error is made during component manufacture.
External	State of other component	Used when the cause of a failure is the result of a component state that is not associated with the component that failed. An example would be the diesel failed due to no fuel in the fuel storage tanks.
External	Ambient environmental stress	Used when the cause of a failure is the result of an environmental condition from the location of the component.
Human	Accidental action (unintentional or undesired human errors)	Used when a human error (during the performance of an activity) results in an unintentional or undesired action.
Human	Human action procedure	Used when the procedure is not followed or the procedure is incorrect. For example: when a missed step or incorrect step in a surveillance procedure results in a component failure.
Human	Inadequate maintenance	Used when a human error (during the performance of maintenance) results in an unintentional or undesired action.
Internal	Internal to component, piece-part	Used when the cause of a failure is a non-specific result of a failure internal to the component that failed other than aging or wear.
Internal	Internal environment	The internal environment led to the failure. Debris/Foreign material as well as an operating medium chemistry issue.
Internal	Setpoint drift	Used when the cause of a failure is the result of setpoint drift or adjustment.
Internal	Age/Wear	Used when the cause of the failure is a non-specific aging or wear issue.
Other	Unknown	Used when the cause of the failure is not known.

Group	Specific Cause	Description
Other	Other (stated cause does not fit other categories)	Used when the cause of a failure is provided but it does not meet any one of the descriptions.
Procedure	Inadequate procedure	Used when the cause of a failure is the result of an inadequate procedure operating or maintenance.

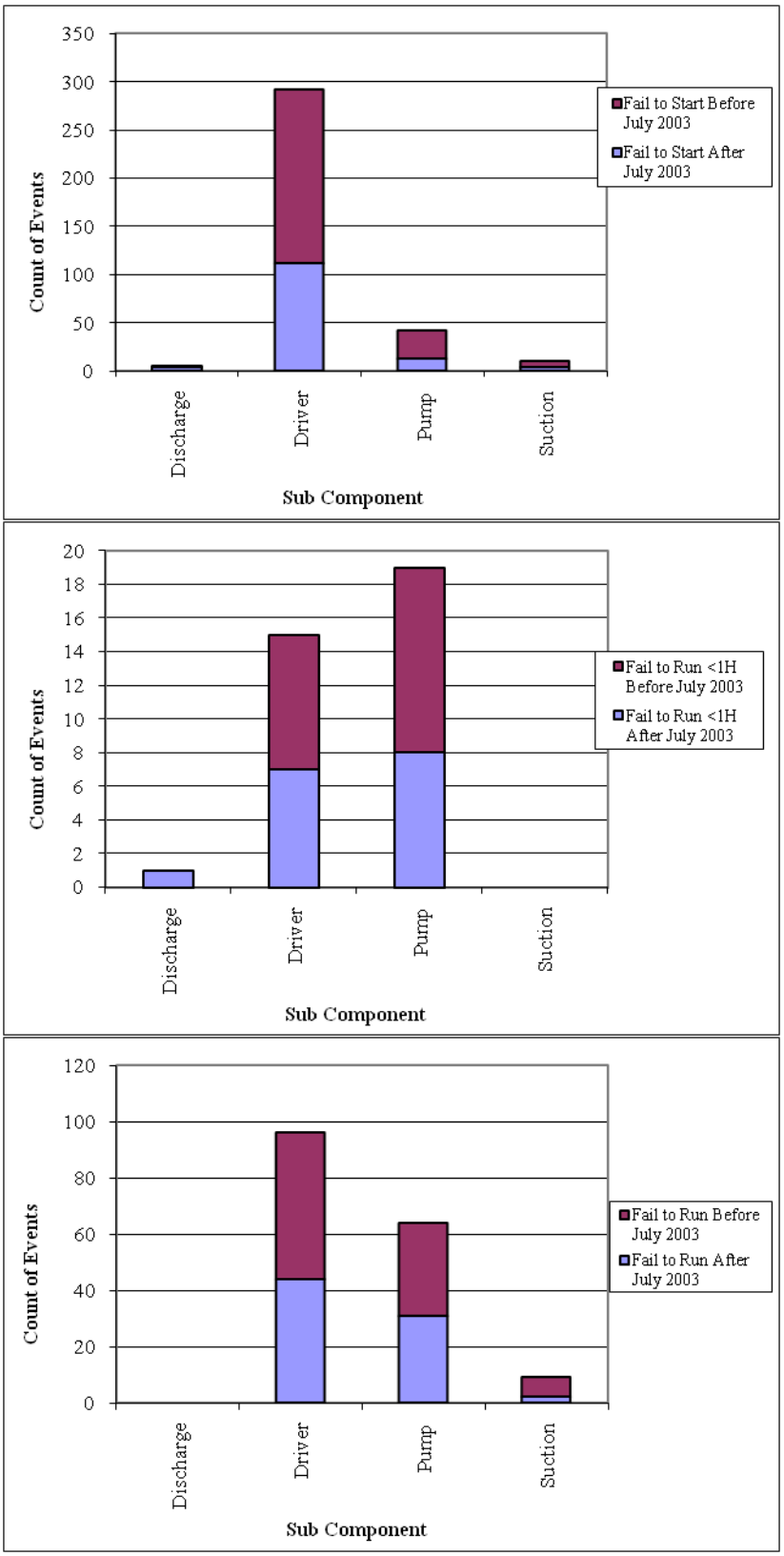

Figure 19. MDP failure breakdown by period, sub component, and failure mode.

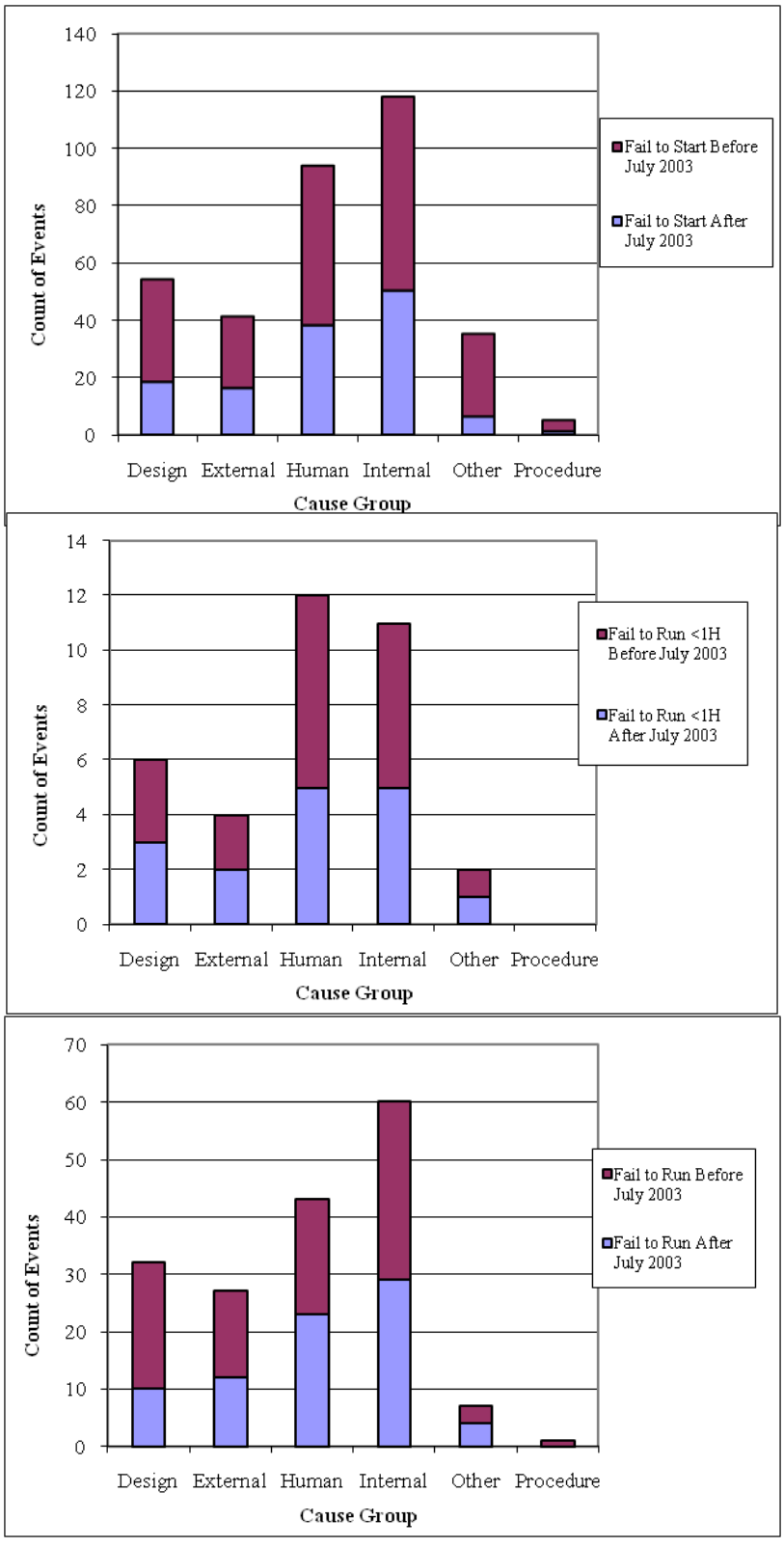

Figure 20. MDP breakdown by time period, cause group, and failure mode.

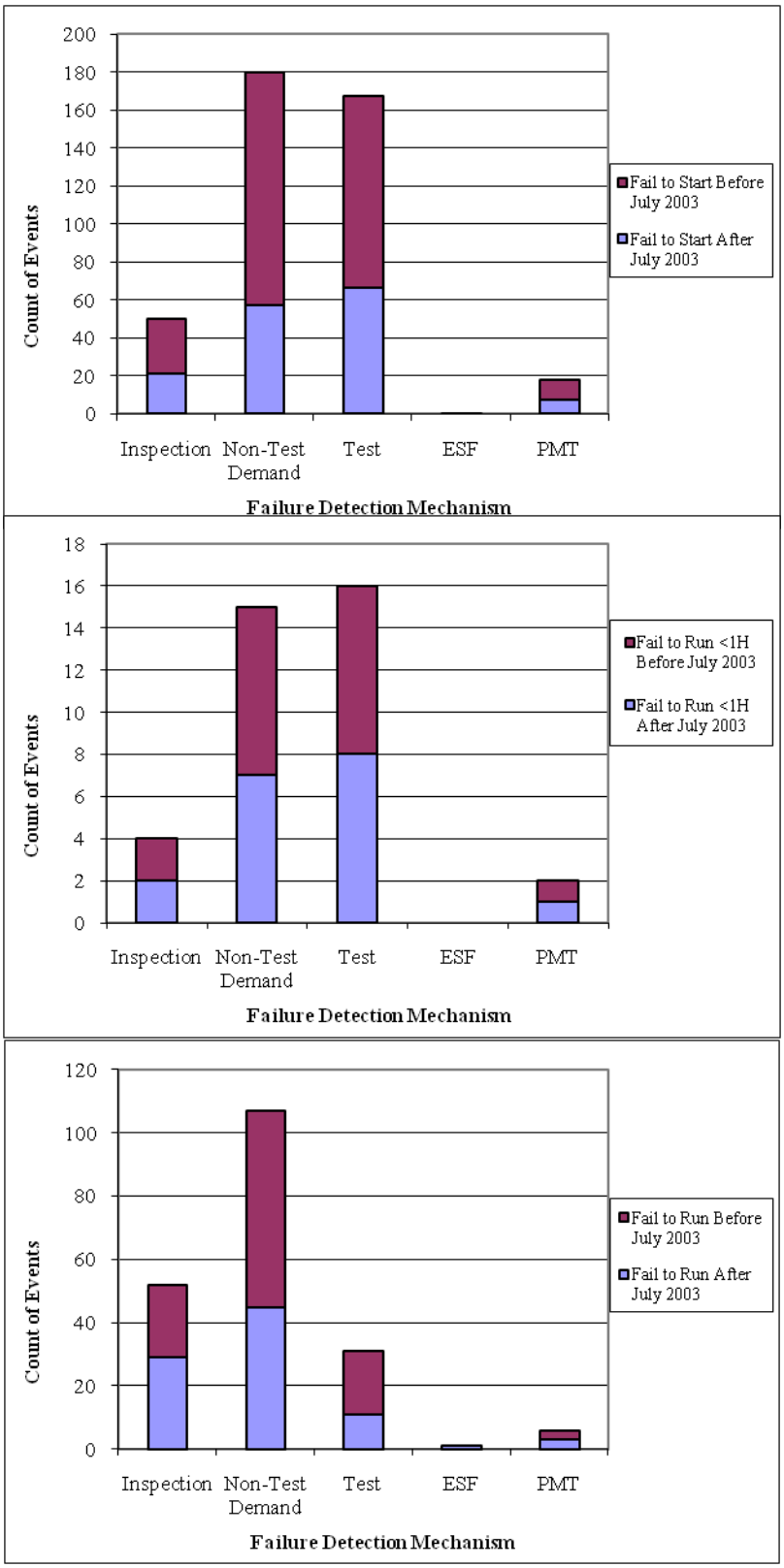

Figure 21. MDP component failure distribution by period, failure mode, and method of detection.

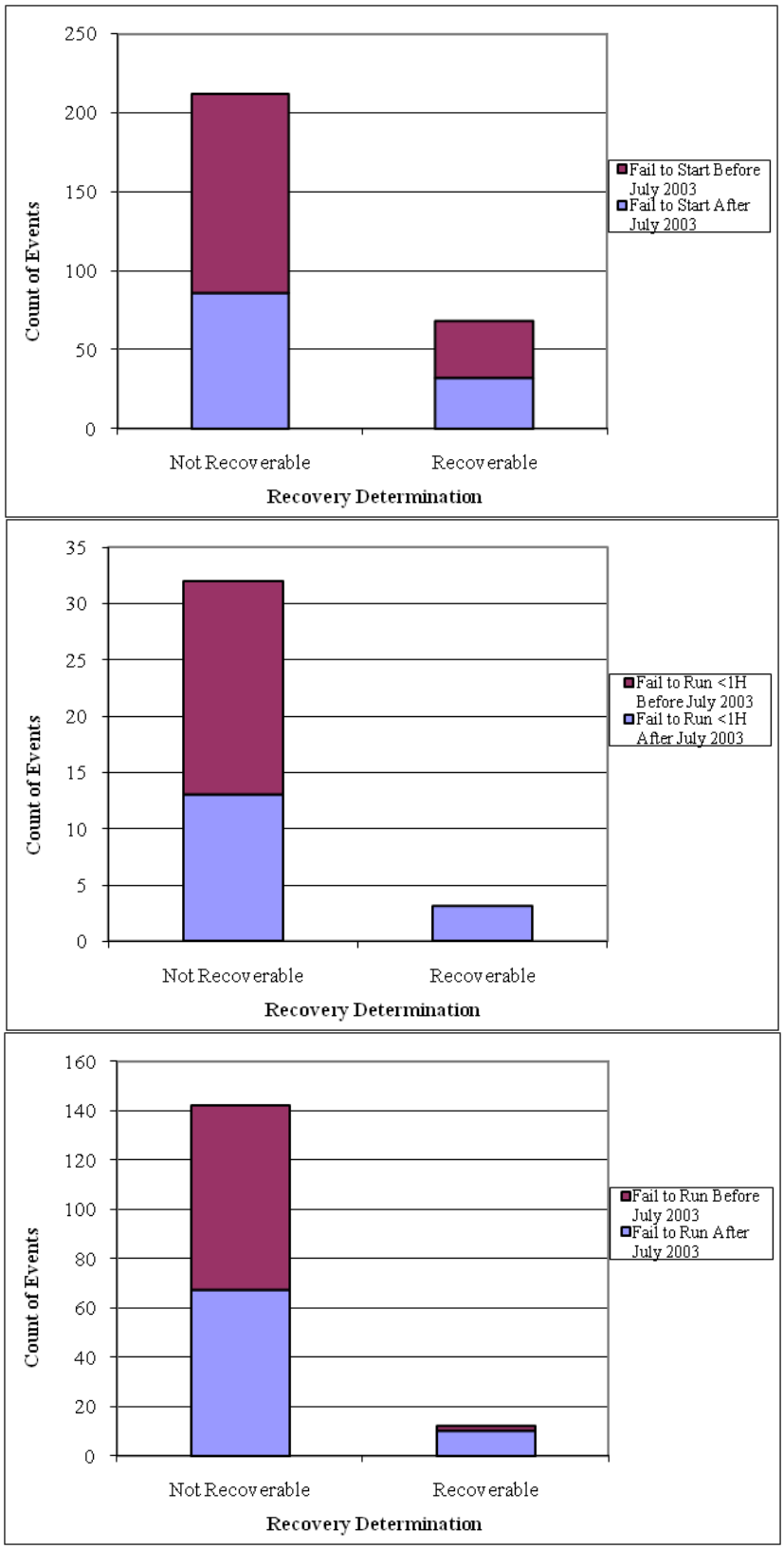

Figure 22. MDP component failure distribution by period, failure mode, and recovery.

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. If the MDP assembly includes a speed increaser, it is treated as a sub-component.

The MDP failure modes include fail to start (FTS), fail to run for less or equal to one hour (FTR<1H), and fail to run beyond one hour (FTR>1H). These failure modes were used in NUREG/CR-6928 and are similar to those used in the MSPI Program.

Guidelines for determining whether a component event reported in EPIX is to be included in FTS, FTR<1H, or FTR>1H are similar to those used in the MSPI Program. In general, any circumstance in which the component is not able to meet the performance requirements defined in the probabilistic risk assessment (PRA) is counted. This includes conditions revealed through testing, operational demands, unplanned demands, or discovery. Also, run failures that occur beyond the typical 24-hour mission time in PRAs are included. However, certain events are excluded: slow starting times that do not exceed the PRA success criteria, conditions that are annunciated immediately in the control room without a demand, and run events that are shown to not have caused an actual run failure within 24 hours. Also, events occurring during maintenance or post-maintenance testing that are related to the actual maintenance activities are excluded. All of the MDP events within EPIX were reviewed to ensure that they were binned to the correct failure mode – FTS, FTR<1H, FTR>1H, or no failure. However, even given detailed descriptions of failure events, this binning still required some judgment and involves some uncertainty.

Guidelines for counting demands and run hours are similar to those in the MSPI Program. Start and run demands include those resulting from tests, operational demands, and unplanned demands. Demands during maintenance and post-maintenance testing are excluded. Similarly, run hours include those from tests, operational demands, and unplanned demands.

8 DATA TABLES

Table 11. 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	46	33576.1	1.25E-03	9.45E-04	1.67E-03	1.05E-03	1.71E-03	1.36E-03
1999	41	34278.0	1.19E-03	9.32E-04	1.52E-03	9.05E-04	1.51E-03	1.19E-03
2000	31	34767.3	1.13E-03	9.15E-04	1.40E-03	6.48E-04	1.17E-03	8.93E-04
2001	45	35617.6	1.07E-03	8.93E-04	1.29E-03	9.68E-04	1.58E-03	1.26E-03
2002	26	34555.3	1.02E-03	8.63E-04	1.21E-03	5.31E-04	1.01E-03	7.56E-04
2003	53	33897.5	9.70E-04	8.24E-04	1.14E-03	1.22E-03	1.92E-03	1.56E-03
2004	31	33149.4	9.21E-04	7.76E-04	1.09E-03	6.79E-04	1.22E-03	9.36E-04
2005	21	33422.9	8.75E-04	7.22E-04	1.06E-03	4.27E-04	8.73E-04	6.34E-04
2006	29	32789.2	8.31E-04	6.66E-04	1.04E-03	6.35E-04	1.17E-03	8.86E-04
2007	31	35397.3	7.89E-04	6.11E-04	1.02E-03	6.37E-04	1.15E-03	8.77E-04
2008	26	33377.8	7.49E-04	5.59E-04	1.01E-03	5.50E-04	1.05E-03	7.82E-04
2009	21	32555.3	7.12E-04	5.09E-04	9.94E-04	4.38E-04	8.96E-04	6.50E-04

Table 12. 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	33576.1	8.82E-05	4.97E-05	1.57E-04	4.23E-05	2.15E-04	1.14E-04
1999	3	34278.0	8.66E-05	5.25E-05	1.43E-04	2.71E-05	1.76E-04	8.75E-05
2000	3	34767.3	8.49E-05	5.51E-05	1.31E-04	2.68E-05	1.74E-04	8.64E-05
2001	1	35617.6	8.33E-05	5.72E-05	1.21E-04	4.25E-06	9.45E-05	3.63E-05
2002	4	34555.3	8.17E-05	5.85E-05	1.14E-04	4.13E-05	2.10E-04	1.12E-04
2003	2	33897.5	8.02E-05	5.86E-05	1.10E-04	1.45E-05	1.40E-04	6.31E-05
2004	2	33149.4	7.86E-05	5.72E-05	1.08E-04	1.47E-05	1.42E-04	6.43E-05
2005	6	33422.9	7.72E-05	5.45E-05	1.09E-04	7.52E-05	2.86E-04	1.66E-04
2006	3	32789.2	7.57E-05	5.10E-05	1.12E-04	2.81E-05	1.83E-04	9.08E-05
2007	3	35397.3	7.42E-05	4.70E-05	1.17E-04	2.63E-05	1.71E-04	8.51E-05
2008	3	33377.8	7.28E-05	4.30E-05	1.23E-04	2.77E-05	1.80E-04	8.95E-05
2009	1	32555.3	7.15E-05	3.92E-05	1.30E-04	4.59E-06	1.02E-04	3.92E-05

Table 13. 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	17	1605943.0	1.03E-05	6.31E-06	1.67E-05	6.75E-06	1.50E-05	1.05E-05
1999	10	1597117.0	9.86E-06	6.45E-06	1.51E-05	3.50E-06	9.87E-06	6.34E-06
2000	15	1595206.0	9.46E-06	6.55E-06	1.37E-05	5.83E-06	1.36E-05	9.38E-06
2001	19	1603715.0	9.08E-06	6.60E-06	1.25E-05	7.73E-06	1.64E-05	1.17E-05
2002	27	1762658.0	8.71E-06	6.57E-06	1.15E-05	1.07E-05	2.01E-05	1.51E-05
2003	15	1962431.0	8.36E-06	6.42E-06	1.09E-05	4.77E-06	1.11E-05	7.67E-06
2004	17	2044140.0	8.02E-06	6.15E-06	1.05E-05	5.34E-06	1.18E-05	8.33E-06
2005	17	2040819.0	7.69E-06	5.76E-06	1.03E-05	5.35E-06	1.19E-05	8.34E-06
2006	7	2053934.0	7.38E-06	5.31E-06	1.03E-05	1.72E-06	5.92E-06	3.55E-06
2007	17	2094142.0	7.08E-06	4.84E-06	1.04E-05	5.22E-06	1.16E-05	8.13E-06
2008	23	2120376.0	6.79E-06	4.38E-06	1.05E-05	7.41E-06	1.47E-05	1.08E-05
2009	10	2055016.0	6.51E-06	3.94E-06	1.08E-05	2.74E-06	7.73E-06	4.97E-06

Table 14. 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	8	2591.3	2.85E-03	2.04E-03	3.98E-03	1.52E-03	4.84E-03	2.99E-03
1999	5	2684.2	2.64E-03	1.97E-03	3.53E-03	7.78E-04	3.34E-03	1.87E-03
2000	11	2702.6	2.44E-03	1.90E-03	3.14E-03	2.21E-03	5.93E-03	3.90E-03
2001	4	2698.2	2.26E-03	1.82E-03	2.81E-03	5.63E-04	2.86E-03	1.53E-03
2002	8	2800.4	2.09E-03	1.71E-03	2.55E-03	1.42E-03	4.51E-03	2.79E-03
2003	6	2910.3	1.94E-03	1.59E-03	2.35E-03	9.31E-04	3.53E-03	2.06E-03
2004	4	2865.9	1.79E-03	1.46E-03	2.20E-03	5.33E-04	2.71E-03	1.44E-03
2005	5	2829.2	1.66E-03	1.32E-03	2.09E-03	7.42E-04	3.19E-03	1.79E-03
2006	5	2811.5	1.53E-03	1.18E-03	2.00E-03	7.46E-04	3.21E-03	1.80E-03
2007	4	2814.5	1.42E-03	1.04E-03	1.93E-03	5.42E-04	2.75E-03	1.47E-03
2008	3	2761.8	1.31E-03	9.22E-04	1.87E-03	3.59E-04	2.33E-03	1.16E-03
2009	3	2838.3	1.22E-03	8.12E-04	1.82E-03	3.50E-04	2.27E-03	1.13E-03

Table 15. 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	17	2569176.0	4.06E-06	1.91E-06	8.64E-06	4.16E-06	9.22E-06	6.48E-06
1999	13	2602254.0	3.89E-06	2.02E-06	7.50E-06	2.95E-06	7.34E-06	4.94E-06
2000	12	2636130.0	3.72E-06	2.11E-06	6.57E-06	2.64E-06	6.80E-06	4.52E-06
2001	11	2617716.0	3.57E-06	2.18E-06	5.84E-06	2.38E-06	6.40E-06	4.18E-06
2002	7	2660694.0	3.41E-06	2.19E-06	5.32E-06	1.30E-06	4.48E-06	2.69E-06
2003	5	2613516.0	3.27E-06	2.14E-06	4.99E-06	8.33E-07	3.58E-06	2.00E-06
2004	3	2645710.0	3.13E-06	2.02E-06	4.85E-06	3.90E-07	2.53E-06	1.26E-06
2005	3	2680595.0	3.00E-06	1.85E-06	4.87E-06	3.85E-07	2.50E-06	1.24E-06
2006	7	2734657.0	2.87E-06	1.65E-06	5.00E-06	1.27E-06	4.36E-06	2.62E-06
2007	9	2730579.0	2.75E-06	1.45E-06	5.22E-06	1.77E-06	5.27E-06	3.32E-06
2008	8	2692373.0	2.63E-06	1.26E-06	5.51E-06	1.54E-06	4.88E-06	3.01E-06
2009	25	2564274.0	2.52E-06	1.08E-06	5.86E-06	6.60E-06	1.27E-05	9.46E-06

Table 16. 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	5.20E-03	4.78E-03	5.62E-03	9.65E-06	1.89E-02	4.72E-03
1999	12906.2	2452646.0	5.09E-03	4.72E-03	5.46E-03	5.07E-04	1.43E-02	5.28E-03
2000	13130.0	2537111.0	4.97E-03	4.65E-03	5.29E-03	4.59E-04	1.38E-02	5.06E-03
2001	12728.1	2542240.0	4.86E-03	4.58E-03	5.14E-03	3.69E-04	1.43E-02	5.04E-03
2002	18010.2	3819765.0	4.74E-03	4.50E-03	4.99E-03	2.61E-04	1.44E-02	4.86E-03
2003	21358.6	4290106.0	4.63E-03	4.40E-03	4.86E-03	2.45E-04	1.53E-02	5.08E-03
2004	19662.9	4473656.0	4.51E-03	4.29E-03	4.74E-03	2.89E-04	1.27E-02	4.42E-03
2005	19004.5	4413226.0	4.40E-03	4.16E-03	4.64E-03	1.05E-04	1.42E-02	4.33E-03
2006	17693.4	4488098.0	4.29E-03	4.01E-03	4.56E-03	1.61E-04	1.22E-02	3.95E-03
2007	16991.2	4464313.0	4.17E-03	3.85E-03	4.49E-03	9.95E-05	1.25E-02	3.83E-03
2008	18302.1	4459856.0	4.06E-03	3.69E-03	4.42E-03	1.77E-04	1.25E-02	4.08E-03
2009	18738.8	4474115.0	3.94E-03	3.52E-03	4.36E-03	1.70E-04	1.30E-02	4.21E-03

Table 17. 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	6.63E-03	5.26E-03	7.99E-03	1.55E-03	2.04E-02	6.27E-03
1999	6.46E-03	5.27E-03	7.65E-03	1.82E-03	1.55E-02	6.61E-03
2000	6.29E-03	5.26E-03	7.33E-03	1.49E-03	1.49E-02	6.11E-03
2001	6.12E-03	5.23E-03	7.02E-03	1.74E-03	1.56E-02	6.41E-03
2002	5.95E-03	5.16E-03	6.75E-03	1.21E-03	1.53E-02	5.84E-03
2003	5.79E-03	5.05E-03	6.52E-03	1.90E-03	1.69E-02	6.76E-03
2004	5.62E-03	4.88E-03	6.35E-03	1.36E-03	1.37E-02	5.48E-03
2005	5.45E-03	4.66E-03	6.24E-03	9.62E-04	1.51E-02	5.18E-03
2006	5.28E-03	4.38E-03	6.18E-03	1.18E-03	1.31E-02	4.95E-03
2007	5.11E-03	4.08E-03	6.14E-03	1.12E-03	1.35E-02	4.85E-03
2008	4.94E-03	3.75E-03	6.14E-03	1.11E-03	1.34E-02	5.03E-03
2009	4.77E-03	3.41E-03	6.14E-03	8.88E-04	1.37E-02	4.94E-03

Table 18. 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	8.19E-03	6.55E-03	1.02E-02	2.94E-03	2.17E-02	7.75E-03
1999	7.85E-03	6.46E-03	9.55E-03	2.42E-03	1.62E-02	7.19E-03
2000	7.53E-03	6.36E-03	8.92E-03	4.32E-03	1.79E-02	8.99E-03
2001	7.22E-03	6.23E-03	8.36E-03	1.92E-03	1.57E-02	6.62E-03
2002	6.92E-03	6.08E-03	7.88E-03	3.08E-03	1.72E-02	7.66E-03
2003	6.64E-03	5.89E-03	7.49E-03	2.35E-03	1.74E-02	7.16E-03
2004	6.37E-03	5.64E-03	7.18E-03	1.69E-03	1.42E-02	5.86E-03
2005	6.11E-03	5.36E-03	6.95E-03	1.89E-03	1.60E-02	6.13E-03
2006	5.85E-03	5.05E-03	6.78E-03	1.98E-03	1.39E-02	5.76E-03
2007	5.61E-03	4.74E-03	6.65E-03	1.60E-03	1.40E-02	5.33E-03
2008	5.38E-03	4.42E-03	6.55E-03	1.36E-03	1.37E-02	5.26E-03
2009	5.16E-03	4.12E-03	6.46E-03	1.35E-03	1.42E-02	5.40E-03

Table 19. 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	33576	103.0	3.36E+02	3.24E+02	3.49E+02	3.23E+02	3.29E+02	3.26E+02
1999	34278	103.0	3.35E+02	3.24E+02	3.46E+02	3.30E+02	3.36E+02	3.33E+02
2000	34767	103.3	3.34E+02	3.24E+02	3.43E+02	3.34E+02	3.40E+02	3.37E+02
2001	35618	103.0	3.32E+02	3.24E+02	3.40E+02	3.43E+02	3.49E+02	3.46E+02
2002	34555	103.0	3.31E+02	3.24E+02	3.38E+02	3.33E+02	3.38E+02	3.35E+02
2003	33897	103.0	3.29E+02	3.23E+02	3.36E+02	3.26E+02	3.32E+02	3.29E+02
2004	33149	103.3	3.28E+02	3.22E+02	3.34E+02	3.18E+02	3.24E+02	3.21E+02
2005	33423	103.0	3.27E+02	3.20E+02	3.34E+02	3.22E+02	3.27E+02	3.24E+02
2006	32789	103.0	3.25E+02	3.17E+02	3.33E+02	3.15E+02	3.21E+02	3.18E+02
2007	35397	103.4	3.24E+02	3.15E+02	3.33E+02	3.39E+02	3.45E+02	3.42E+02
2008	33378	104.3	3.22E+02	3.12E+02	3.33E+02	3.17E+02	3.23E+02	3.20E+02
2009	32555	104.0	3.21E+02	3.10E+02	3.33E+02	3.10E+02	3.16E+02	3.13E+02

Table 20. 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	33576	103.0	3.36E+02	3.24E+02	3.49E+02	3.23E+02	3.29E+02	3.26E+02
1999	34278	103.0	3.35E+02	3.24E+02	3.46E+02	3.30E+02	3.36E+02	3.33E+02
2000	34767	103.3	3.34E+02	3.24E+02	3.43E+02	3.34E+02	3.40E+02	3.37E+02
2001	35618	103.0	3.32E+02	3.24E+02	3.40E+02	3.43E+02	3.49E+02	3.46E+02
2002	34555	103.0	3.31E+02	3.24E+02	3.38E+02	3.33E+02	3.38E+02	3.35E+02
2003	33897	103.0	3.29E+02	3.23E+02	3.36E+02	3.26E+02	3.32E+02	3.29E+02
2004	33149	103.3	3.28E+02	3.22E+02	3.34E+02	3.18E+02	3.24E+02	3.21E+02
2005	33423	103.0	3.27E+02	3.20E+02	3.34E+02	3.22E+02	3.27E+02	3.24E+02
2006	32789	103.0	3.25E+02	3.17E+02	3.33E+02	3.15E+02	3.21E+02	3.18E+02
2007	35397	103.4	3.24E+02	3.15E+02	3.33E+02	3.39E+02	3.45E+02	3.42E+02
2008	33378	104.3	3.22E+02	3.12E+02	3.33E+02	3.17E+02	3.23E+02	3.20E+02
2009	32555	104.0	3.21E+02	3.10E+02	3.33E+02	3.10E+02	3.16E+02	3.13E+02

Table 21. 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	1605943	103.0	1.54E+04	1.43E+04	1.65E+04	1.56E+04	1.56E+04	1.56E+04
1999	1597117	103.0	1.58E+04	1.48E+04	1.69E+04	1.55E+04	1.55E+04	1.55E+04
2000	1595206	103.3	1.63E+04	1.54E+04	1.72E+04	1.54E+04	1.55E+04	1.54E+04
2001	1603715	103.0	1.68E+04	1.60E+04	1.76E+04	1.56E+04	1.56E+04	1.56E+04
2002	1762658	103.0	1.73E+04	1.66E+04	1.80E+04	1.71E+04	1.71E+04	1.71E+04
2003	1962431	103.0	1.78E+04	1.71E+04	1.85E+04	1.90E+04	1.91E+04	1.91E+04
2004	2044140	103.3	1.83E+04	1.77E+04	1.90E+04	1.98E+04	1.98E+04	1.98E+04
2005	2040819	103.0	1.89E+04	1.82E+04	1.96E+04	1.98E+04	1.98E+04	1.98E+04
2006	2053934	103.0	1.95E+04	1.86E+04	2.03E+04	1.99E+04	2.00E+04	1.99E+04
2007	2094142	103.4	2.00E+04	1.90E+04	2.11E+04	2.02E+04	2.03E+04	2.03E+04
2008	2120376	104.3	2.06E+04	1.95E+04	2.19E+04	2.03E+04	2.04E+04	2.03E+04
2009	2055016	104.0	2.13E+04	1.99E+04	2.27E+04	1.97E+04	1.98E+04	1.98E+04

Table 22. 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	46	103.0	4.21E-01	3.17E-01	5.61E-01	3.43E-01	5.57E-01	4.45E-01
1999	41	103.0	3.99E-01	3.11E-01	5.11E-01	3.01E-01	5.03E-01	3.97E-01
2000	31	103.3	3.77E-01	3.04E-01	4.67E-01	2.18E-01	3.94E-01	3.00E-01
2001	45	103.0	3.57E-01	2.96E-01	4.30E-01	3.35E-01	5.47E-01	4.35E-01
2002	26	103.0	3.37E-01	2.85E-01	4.00E-01	1.78E-01	3.40E-01	2.53E-01
2003	53	103.0	3.19E-01	2.71E-01	3.76E-01	4.02E-01	6.32E-01	5.12E-01
2004	31	103.3	3.02E-01	2.54E-01	3.59E-01	2.18E-01	3.94E-01	3.01E-01
2005	21	103.0	2.86E-01	2.35E-01	3.46E-01	1.39E-01	2.84E-01	2.06E-01
2006	29	103.0	2.70E-01	2.16E-01	3.37E-01	2.02E-01	3.73E-01	2.82E-01
2007	31	103.4	2.56E-01	1.98E-01	3.30E-01	2.18E-01	3.93E-01	3.00E-01
2008	26	104.3	2.42E-01	1.80E-01	3.25E-01	1.76E-01	3.35E-01	2.50E-01
2009	21	104.0	2.29E-01	1.63E-01	3.20E-01	1.37E-01	2.81E-01	2.04E-01

Table 23. 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	2.98E-02	1.69E-02	5.24E-02	1.38E-02	7.02E-02	3.74E-02
1999	3	103.0	2.91E-02	1.78E-02	4.76E-02	9.00E-03	5.84E-02	2.91E-02
2000	3	103.3	2.84E-02	1.85E-02	4.35E-02	8.98E-03	5.83E-02	2.90E-02
2001	1	103.0	2.77E-02	1.91E-02	4.02E-02	1.46E-03	3.24E-02	1.25E-02
2002	4	103.0	2.71E-02	1.95E-02	3.76E-02	1.38E-02	7.02E-02	3.74E-02
2003	2	103.0	2.64E-02	1.94E-02	3.60E-02	4.75E-03	4.60E-02	2.08E-02
2004	2	103.3	2.58E-02	1.89E-02	3.53E-02	4.74E-03	4.58E-02	2.07E-02
2005	6	103.0	2.52E-02	1.79E-02	3.55E-02	2.45E-02	9.28E-02	5.40E-02
2006	3	103.0	2.46E-02	1.67E-02	3.64E-02	9.00E-03	5.84E-02	2.91E-02
2007	3	103.4	2.40E-02	1.53E-02	3.77E-02	8.97E-03	5.82E-02	2.90E-02
2008	3	104.3	2.35E-02	1.40E-02	3.95E-02	8.90E-03	5.78E-02	2.88E-02
2009	1	104.0	2.29E-02	1.27E-02	4.15E-02	1.45E-03	3.22E-02	1.24E-02

Table 24. 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	17	103.0	1.58E-01	9.78E-02	2.57E-01	1.06E-01	2.34E-01	1.65E-01
1999	10	103.0	1.56E-01	1.03E-01	2.38E-01	5.46E-02	1.54E-01	9.89E-02
2000	15	103.3	1.55E-01	1.07E-01	2.23E-01	9.05E-02	2.11E-01	1.46E-01
2001	19	103.0	1.53E-01	1.11E-01	2.10E-01	1.21E-01	2.57E-01	1.84E-01
2002	27	103.0	1.51E-01	1.14E-01	2.00E-01	1.83E-01	3.45E-01	2.59E-01
2003	15	103.0	1.49E-01	1.15E-01	1.94E-01	9.08E-02	2.12E-01	1.46E-01
2004	17	103.3	1.47E-01	1.13E-01	1.92E-01	1.06E-01	2.34E-01	1.64E-01
2005	17	103.0	1.45E-01	1.09E-01	1.94E-01	1.06E-01	2.34E-01	1.65E-01
2006	7	103.0	1.44E-01	1.03E-01	1.99E-01	3.42E-02	1.18E-01	7.06E-02
2007	17	103.4	1.42E-01	9.72E-02	2.07E-01	1.05E-01	2.34E-01	1.64E-01
2008	23	104.3	1.40E-01	9.06E-02	2.17E-01	1.50E-01	2.98E-01	2.19E-01
2009	10	104.0	1.38E-01	8.41E-02	2.28E-01	5.41E-02	1.52E-01	9.80E-02

Table 25. 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	2591	103.0	2.61E+01	2.52E+01	2.71E+01	2.43E+01	2.60E+01	2.52E+01
1999	2684	103.0	2.62E+01	2.54E+01	2.71E+01	2.52E+01	2.69E+01	2.61E+01
2000	2703	103.3	2.64E+01	2.57E+01	2.71E+01	2.53E+01	2.70E+01	2.62E+01
2001	2698	103.0	2.65E+01	2.59E+01	2.72E+01	2.54E+01	2.70E+01	2.62E+01
2002	2800	103.0	2.67E+01	2.61E+01	2.72E+01	2.63E+01	2.80E+01	2.72E+01
2003	2910	103.0	2.68E+01	2.63E+01	2.73E+01	2.74E+01	2.91E+01	2.83E+01
2004	2866	103.3	2.69E+01	2.64E+01	2.75E+01	2.69E+01	2.86E+01	2.77E+01
2005	2829	103.0	2.71E+01	2.65E+01	2.76E+01	2.66E+01	2.83E+01	2.75E+01
2006	2812	103.0	2.72E+01	2.66E+01	2.79E+01	2.65E+01	2.82E+01	2.73E+01
2007	2815	103.4	2.74E+01	2.66E+01	2.81E+01	2.64E+01	2.81E+01	2.72E+01
2008	2762	104.3	2.75E+01	2.67E+01	2.84E+01	2.57E+01	2.73E+01	2.65E+01
2009	2838	104.0	2.77E+01	2.67E+01	2.87E+01	2.65E+01	2.81E+01	2.73E+01

Table 26. 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	2569176	103.0	2.53E+04	2.46E+04	2.61E+04	2.49E+04	2.50E+04	2.49E+04
1999	2602254	103.0	2.54E+04	2.48E+04	2.60E+04	2.52E+04	2.53E+04	2.53E+04
2000	2636130	103.3	2.54E+04	2.49E+04	2.60E+04	2.55E+04	2.55E+04	2.55E+04
2001	2617716	103.0	2.55E+04	2.50E+04	2.60E+04	2.54E+04	2.54E+04	2.54E+04
2002	2660694	103.0	2.55E+04	2.51E+04	2.60E+04	2.58E+04	2.59E+04	2.58E+04
2003	2613516	103.0	2.56E+04	2.52E+04	2.60E+04	2.54E+04	2.54E+04	2.54E+04
2004	2645710	103.3	2.56E+04	2.53E+04	2.60E+04	2.56E+04	2.56E+04	2.56E+04
2005	2680595	103.0	2.57E+04	2.53E+04	2.61E+04	2.60E+04	2.61E+04	2.60E+04
2006	2734657	103.0	2.57E+04	2.53E+04	2.62E+04	2.65E+04	2.66E+04	2.66E+04
2007	2730579	103.4	2.58E+04	2.52E+04	2.63E+04	2.64E+04	2.64E+04	2.64E+04
2008	2692373	104.3	2.58E+04	2.52E+04	2.65E+04	2.58E+04	2.58E+04	2.58E+04
2009	2564274	104.0	2.59E+04	2.52E+04	2.66E+04	2.46E+04	2.47E+04	2.47E+04

Table 27. 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	8	103.0	7.42E-02	5.29E-02	1.04E-01	3.86E-02	1.23E-01	7.57E-02
1999	5	103.0	6.90E-02	5.15E-02	9.26E-02	2.04E-02	8.76E-02	4.90E-02
2000	11	103.3	6.43E-02	4.98E-02	8.29E-02	5.81E-02	1.56E-01	1.02E-01
2001	4	103.0	5.98E-02	4.79E-02	7.47E-02	1.48E-02	7.53E-02	4.01E-02
2002	8	103.0	5.57E-02	4.55E-02	6.81E-02	3.86E-02	1.23E-01	7.57E-02
2003	6	103.0	5.18E-02	4.26E-02	6.31E-02	2.62E-02	9.95E-02	5.79E-02
2004	4	103.3	4.82E-02	3.92E-02	5.94E-02	1.48E-02	7.51E-02	4.00E-02
2005	5	103.0	4.49E-02	3.55E-02	5.67E-02	2.04E-02	8.76E-02	4.90E-02
2006	5	103.0	4.18E-02	3.19E-02	5.47E-02	2.04E-02	8.76E-02	4.90E-02
2007	4	103.4	3.89E-02	2.85E-02	5.31E-02	1.48E-02	7.51E-02	3.99E-02
2008	3	104.3	3.62E-02	2.53E-02	5.17E-02	9.54E-03	6.19E-02	3.08E-02
2009	3	104.0	3.37E-02	2.24E-02	5.06E-02	9.56E-03	6.21E-02	3.09E-02

Table 28. 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	17	103.0	1.02E-01	4.82E-02	2.16E-01	1.04E-01	2.30E-01	1.62E-01
1999	13	103.0	9.81E-02	5.11E-02	1.88E-01	7.47E-02	1.85E-01	1.25E-01
2000	12	103.3	9.44E-02	5.37E-02	1.66E-01	6.74E-02	1.74E-01	1.15E-01
2001	11	103.0	9.08E-02	5.56E-02	1.48E-01	6.05E-02	1.63E-01	1.06E-01
2002	7	103.0	8.74E-02	5.63E-02	1.36E-01	3.36E-02	1.16E-01	6.94E-02
2003	5	103.0	8.41E-02	5.53E-02	1.28E-01	2.12E-02	9.10E-02	5.09E-02
2004	3	103.3	8.09E-02	5.24E-02	1.25E-01	9.99E-03	6.49E-02	3.23E-02
2005	3	103.0	7.78E-02	4.82E-02	1.26E-01	1.00E-02	6.50E-02	3.24E-02
2006	7	103.0	7.49E-02	4.33E-02	1.30E-01	3.36E-02	1.16E-01	6.94E-02
2007	9	103.4	7.20E-02	3.82E-02	1.36E-01	4.66E-02	1.39E-01	8.76E-02
2008	8	104.3	6.93E-02	3.34E-02	1.44E-01	3.96E-02	1.26E-01	7.77E-02
2009	25	104.0	6.67E-02	2.90E-02	1.53E-01	1.63E-01	3.15E-01	2.34E-01

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