INL/EXT-15-34432

Enhanced Component Performance Study: Motor-Driven Pumps 1998–2013

John A. Schroeder

February 2015

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John A. Schroeder

Update Completed October 2014

Idaho National Laboratory
Risk Assessment and Management Services Department
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
Division of Risk Assessment
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
NRC Agreement Number NRC-HQ-14-D-0018

ABSTRACT

This report presents an enhanced performance evaluation of motor-driven pumps at U.S. commercial nuclear power plants. The data used in this study are based on the operating experience failure reports from fiscal year 1998 through 2013 for the component reliability as reported in the Institute of Nuclear Power Operations (INPO) Consolidated Events Database (ICES). The motor-driven pump failure modes considered for standby systems are failure to start, failure to run less than or equal to 1 hour, and failure to run more than 1 hour; for normally running systems, the failure modes considered are failure to start and failure to run. An 8-hr unreliability estimate is also calculated and trended. The component reliability estimates and the reliability data are trended for the most recent 10-year period while yearly estimates for reliability are provided for the entire active period. One statistically significant increasing trend was identified in the standby pump run hours per reactor year. Statistically significant decreasing trends were identified for standby systems industry-wide frequency of start demands, run hours per reactor year for runs of less than or equal to 1 hour, and frequency of fail to start events per reactor year.

CONTENTS

FIGURES

TABLES

ACRONYMS

AFW	auxiliary feedwater
BWR	boiling water reactor
CCW	closed cooling water
CNID	constrained noninformative prior distribution
EPIX	Equipment Performance and Information Exchange
ESF	engineered safety feature
ESW	essential service water
FTR≤1H	failure to run ≤ 1 hour
FTR>1H	failure to run > 1 hour
FTR	failure to run
FTS	failure to start
FY	fiscal year
HPCS	high-pressure core spray
HPSI	high -pressure safety injection
ICES	INPO Consolidated Events Database
INPO	Institute of Nuclear Power Operations
MDP	motor-driven pump
MSPI	Mitigating Systems Performance Index
PRA	probabilistic risk assessment
PWR	pressurized water reactor
RHR	residual heat removal
UA	unavailability

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1. INTRODUCTION

This report presents an enhanced performance evaluation of 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. The 2010 Component Reliability Update (Reference 1), which is an update to Industry-Average Performance for Components and Initiating Events at U.S Commercial Nuclear Power Plants (Reference 2), reports the MDP unreliability estimates using Institute of Nuclear Power Operations (INPO) Consolidated Events Database (ICES) data from 1998 through 2010 and maintenance unavailability (UA) performance data using Mitigating Systems Performance Index (MSPI) Basis Document data from 2002 through 2010.

The data used in this study are based on the operating experience failure reports from fiscal year (FY)-98 through FY-13 as reported in ICES. The MDP failure modes considered for standby systems are: failure to start (FTS), failure to run ≤ 1 hour (FTR≤1H), and failure to run > 1 hour (FTR>1H). The MDP failure modes considered for normally running systems are: FTS, and failure-to-run (FTR). MDP train maintenance unavailability data are trended from the same time period, as reported in the Reactor Oversight Program and ICES. In addition to the presentation of the component failure mode data and the UA data, an 8-hr unreliability is calculated and trended. The component reliability estimates and the reliability data are trended for the most recent 10-yr period while yearly estimates for reliability are provided for the entire active period.

Previously, the study relied on operating experience obtained from licensee event reports, Nuclear Plant Reliability Data System, and ICES. The ICES database (which includes as a subset the 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 [engineered safety feature (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[a] increasing trends. In this update, the following statistically significant increasing trend was identified in the MDP results:

- Standby MDP run hours per reactor year (see Figure 11)

This trend is not an adverse trend; it only indicates an increase in run hours for standby pumps. Standby MDP run hours appear to have made a step change in the upward direction in FY 2002 and FY 2003, which coincides with the start of the MSPI program. This influences an increasing trend over the 2003 to 2013 period.

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

- Standby systems, industry-wide MDP frequency of start demands (see Figure 9)
- Standby systems, industry-wide MDP run hours per reactor year for runs of ≤ 1 hour (see Figure 10)
- Frequency (failures per reactor year) of FTS events, standby MDPs (see Figure 12)

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. The FTS, FTR≤ 1H, and FTR>1H failure mode distributions as well as the total unreliability (8 hours) detected under ESF are consistent with the industry average distribution.

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a. 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).

3. FAILURE PROBABILITIES AND FAILURE RATES

3.1 Overview

MDPs are categorized as either standby or normally running. The industry-wide failure probabilities and failure rates have been calculated from the operating experience for standby pump FTS, FTR≤1H, and FTR>1H, and for normally running pumps for FTS, and FTR. The MDP data set obtained from ICES includes MDPs in the systems listed in Table 1. 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 the 2010 update results for industry-wide failure probabilities and failure rates for MDPs as provided by Reference 1.

Table 1. MDP systems.

System	Description	Total	Standby	Normally Running
AFW	Auxiliary feedwater	123	123	
CCW	Component cooling water	287		287
CDS	Condensate system	140		140
CRD	Control rod drive	47	8	39
CSR	Containment spray recirculation	156	156	
CVC	Chemical and volume control	8		8
HCS	High pressure core spray	9	9	
HPI	High pressure injection	170	163	7
LCS	Low pressure core spray	75	70	5
MFW	Main feedwater	43		43
RHR	Residual heat removal	292	292	
SWN	Normally running service water	96		96
SWS	Standby service water	396	395	1
	Total	1842	1216	626

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, ESF demands.

Table 2. 2010 Update 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	1.63E−04	7.91E−04	9.47E−04	2.27E−03	Beta	1.95	2.054E+03
	FTR≤1H	1.93E−05	1.01E−04	1.23E−04	3.01E−04	Beta	1.82	1.479E+04
	FTR>1H	2.64E−07	6.44E−06	1.04E−05	3.41E−05	Gamma	0.78	7.501E+04
Running/ Alternating	FTS	4.01E−04	1.23E−03	1.36E−03	2.79E−03	Beta	3.28	2.406E+03
	FTR	7.36E−07	3.03E−06	3.53E−06	8.02E−06	Gamma	2.29	6.496E+05

3.2 MDP Failure Probability and Failure Rate Trends

The trends are shown for industry standby and for industry normally running 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.

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.

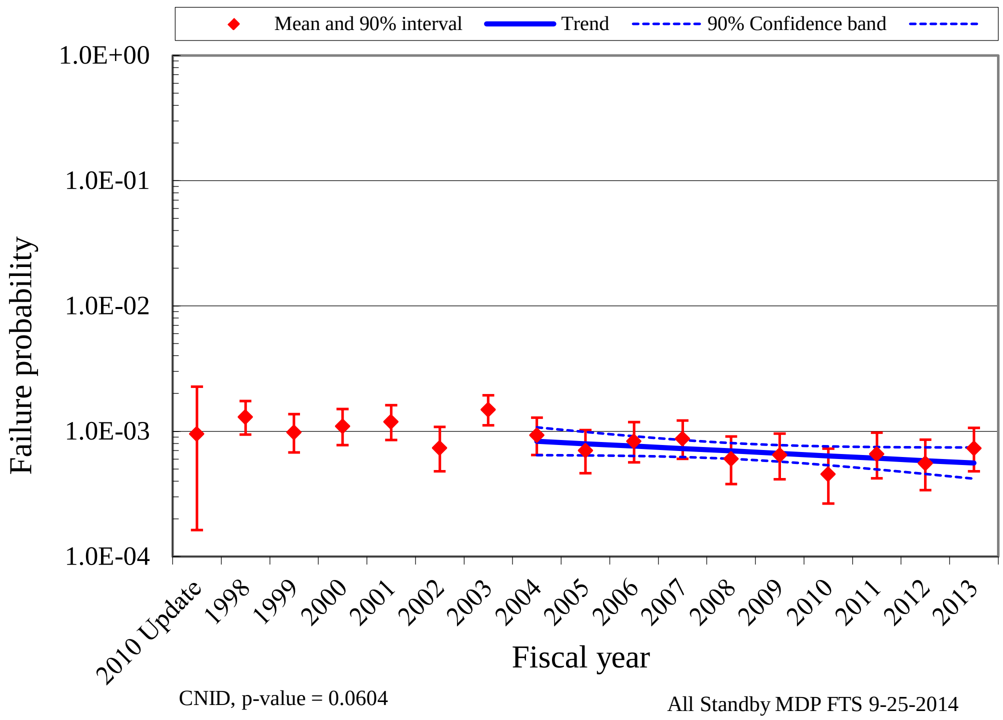

Figure 1. Failure probability estimate trend for standby systems, industry-wide MDP FTS trend.

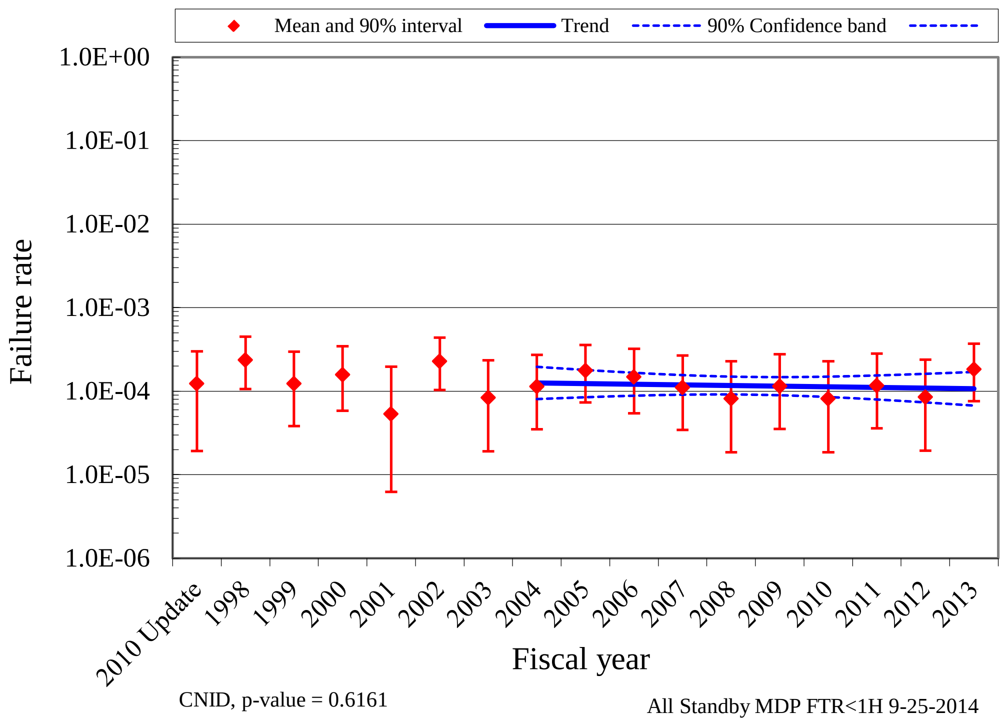

Figure 2. Failure probability estimate trend for standby systems, industry-wide MDP FTR≤1H trend.

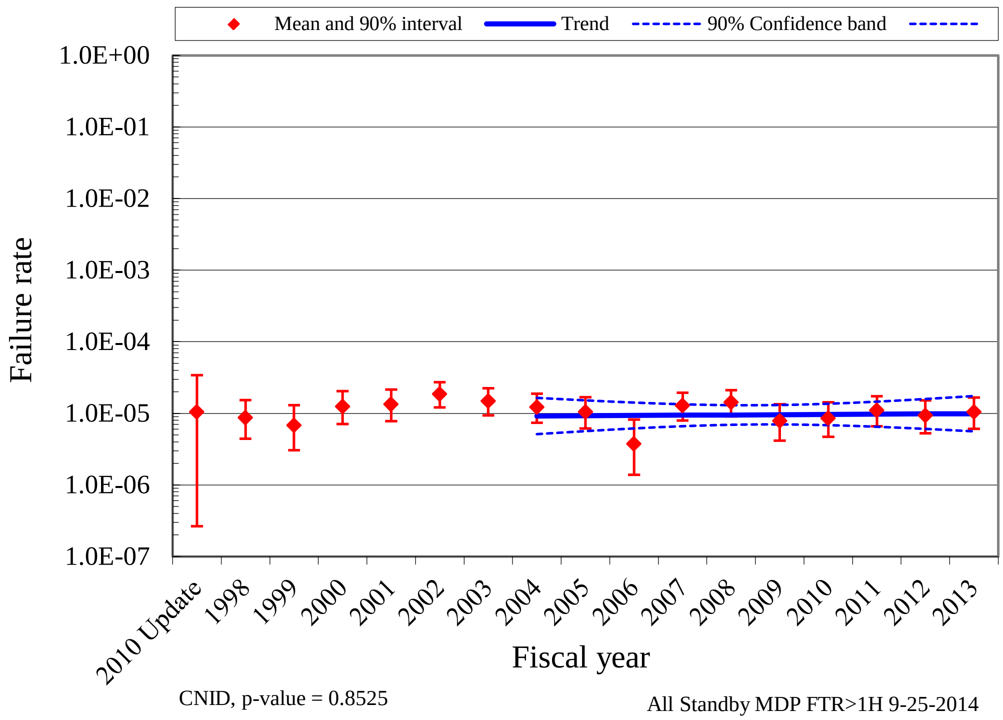

Figure 3. Failure rate estimate trend for standby systems, industry-wide MDP FTR>1H trend.

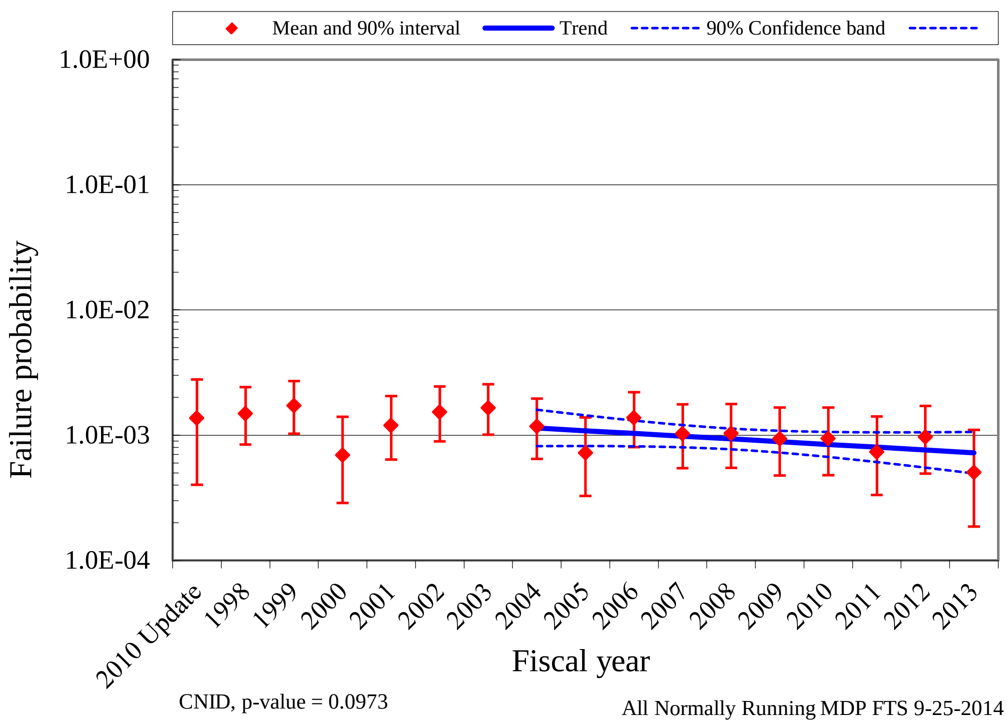

Figure 4. Failure probability estimate trend for normally running systems, industry-wide MDP FTS trend.

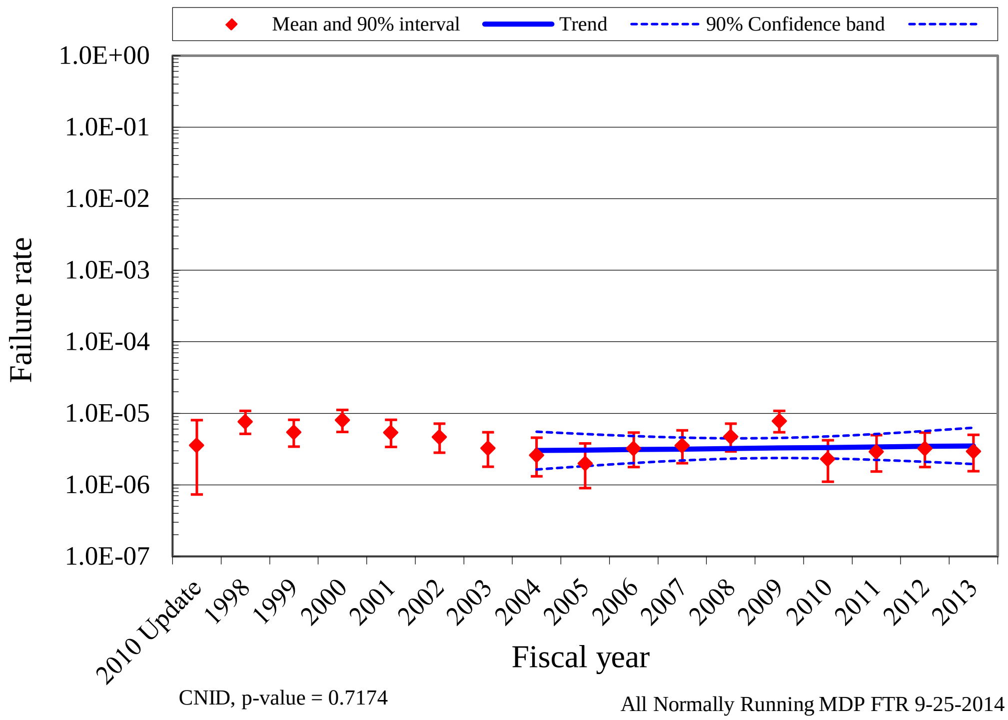

Figure 5. Failure rate estimate trend for normally running systems, industry-wide MDP FTR trend.

4. UNAVAILABILITY

4.1 Overview

The industry-wide test or maintenance 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 2010. 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 And Maintenance (AFW)	3.63E−03	Beta	2.58	710.22
Motor Driven Pump Test And Maintenance (ALL)	7.00E−03	Beta	1.08	153.78
Motor Driven Pump Test And Maintenance (CCW)	4.79E−03	Beta	1.18	244.83
Motor Driven Pump Test And Maintenance (ESW)	1.32E−02	Beta	1.00	74.55
Motor Driven Pump Test And Maintenance (HPCS)	7.05E−03	Beta	6.70	943.80
Motor Driven Pump Test And Maintenance (HPSI)	3.45E−03	Beta	2.45	707.96
Motor Driven Pump Test And Maintenance (RHR-BWR)	5.74E−03	Beta	6.23	1078.64
Motor Driven Pump Test And Maintenance (RHR-PWR)	5.15E−03	Beta	2.62	506.37

4.2 MDP Unavailability Trends

For the 1998–2013 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, HCS, HPI, and RHR 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 (1998–2013) unavailability and reactor critical hour data were obtained from the Reactor Oversight Program (1998 to 2001) and ICES (2002 to 2013) 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.

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 5^{th} to 95^{th} percentiles of the beta distribution with matching means.

For the trend graphs, a least squares fit is sought for the linear or logit model. 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.

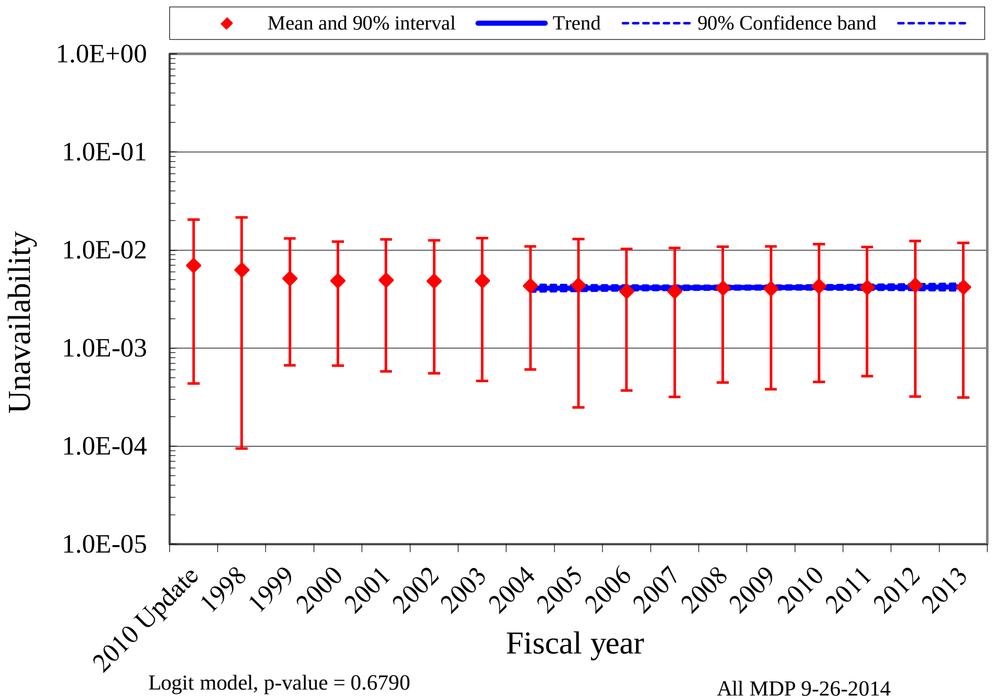

Figure 6. Pooled AFW, HPI, HCS, and RHR MDP UA trend.

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 union of FTS, FTR≤1H, FTR >1H (or FTR), and UA events. 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.

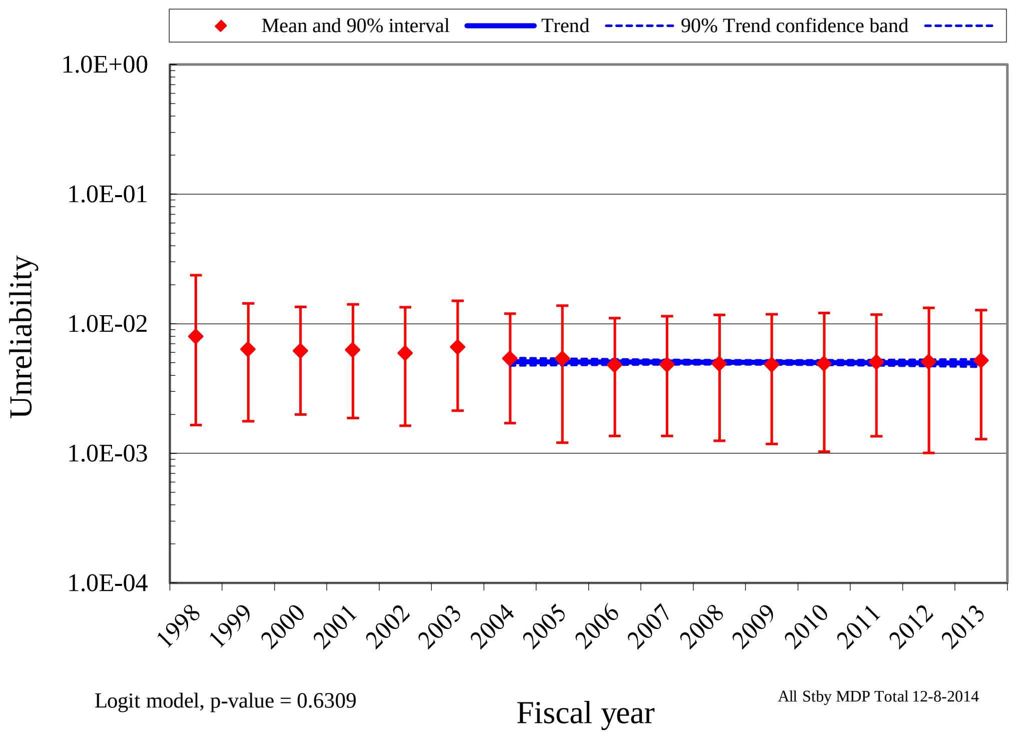

Figure 7. Standby systems, industry-wide MDP unreliability trend (8-hour mission).

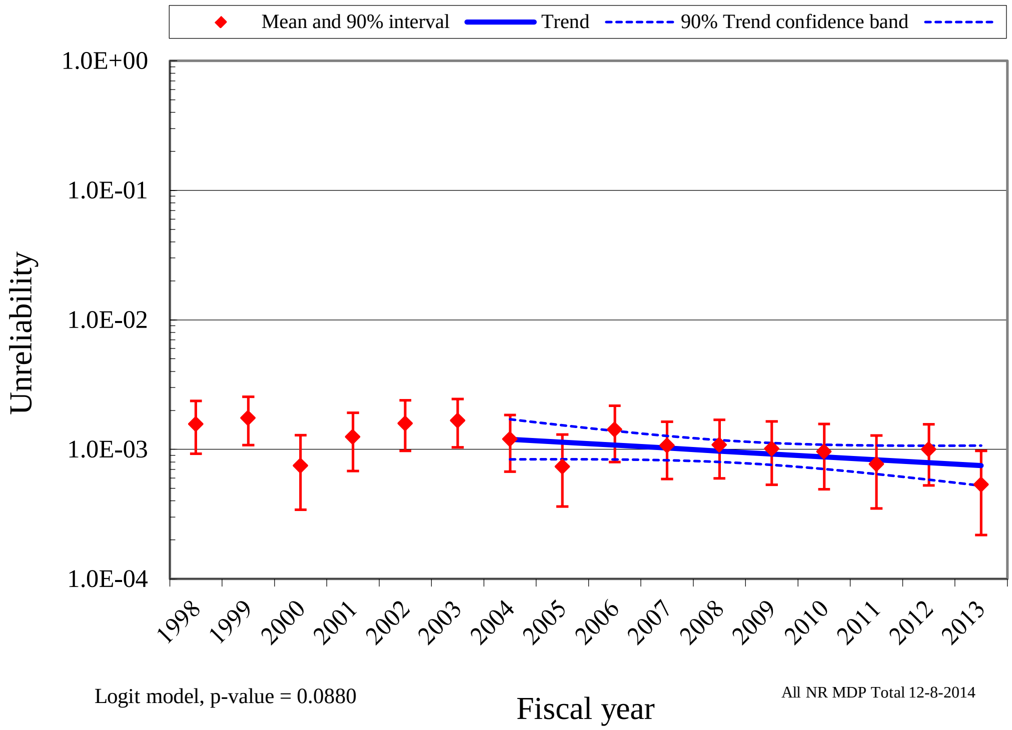

Figure 8. Normally running systems, industry-wide MDP unreliability trend (8-hour mission).

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. Tables 22, 23, and 24 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 bold values in the percent of total failures column show the contributors that make up at least 50% of the failures. Tables 4–6 only include systems where failures of that failure mode have been detected.

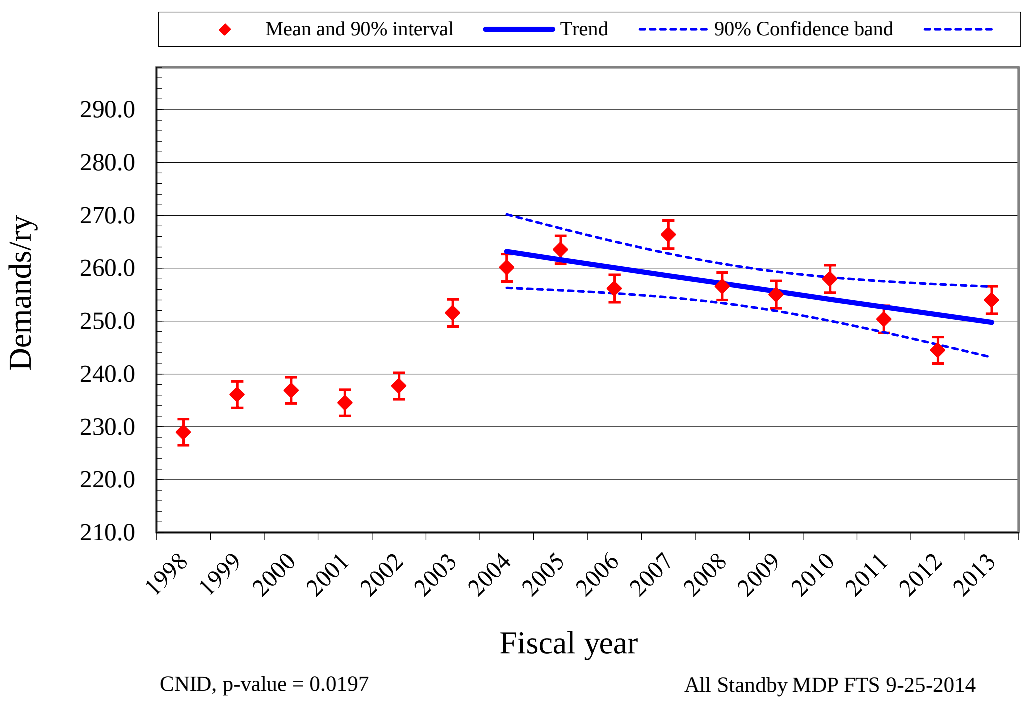

Figure 9. Frequency (demands per reactor year) of start demands, standby MDPs.

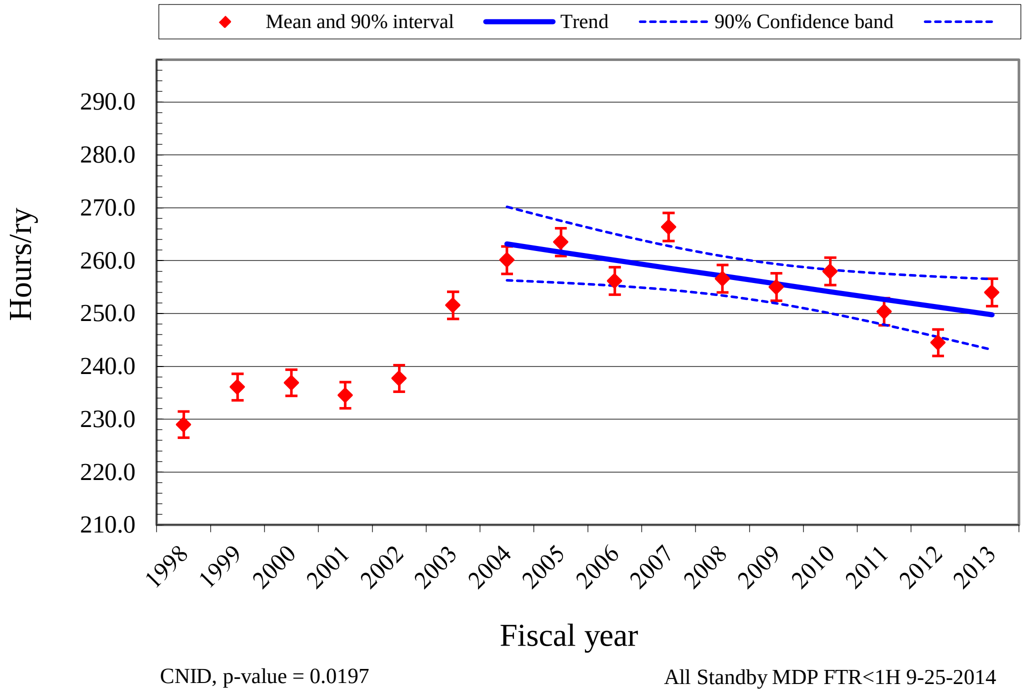

Figure 10. Standby MDP run hours per reactor year of run ≤ 1H hours.

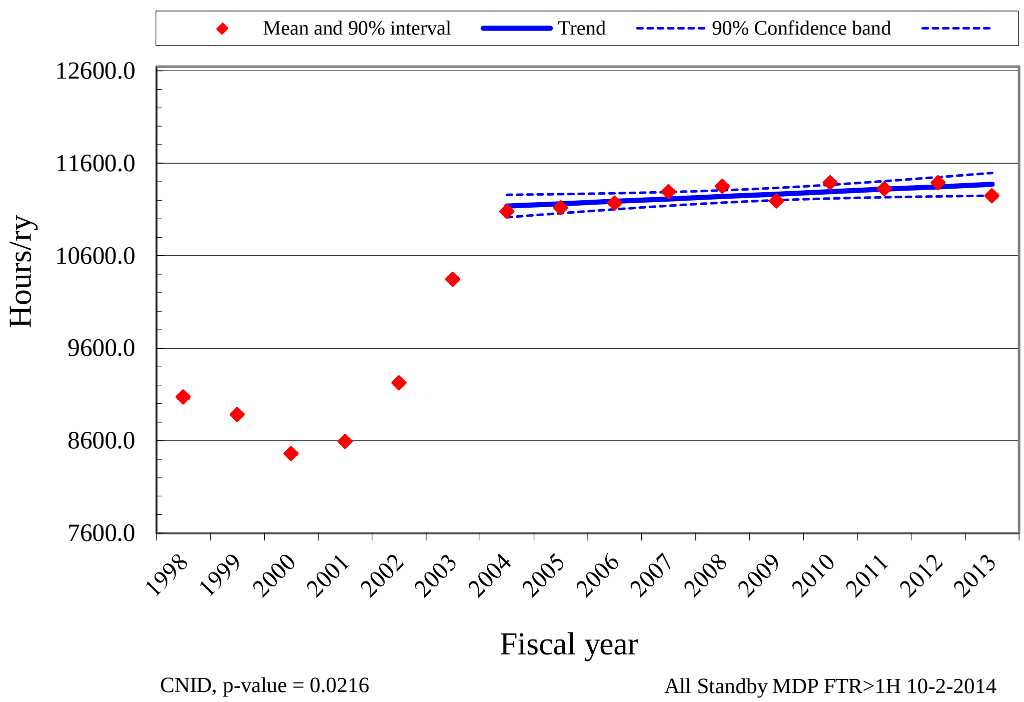

Figure 11. Standby MDP run hours per reactor year.

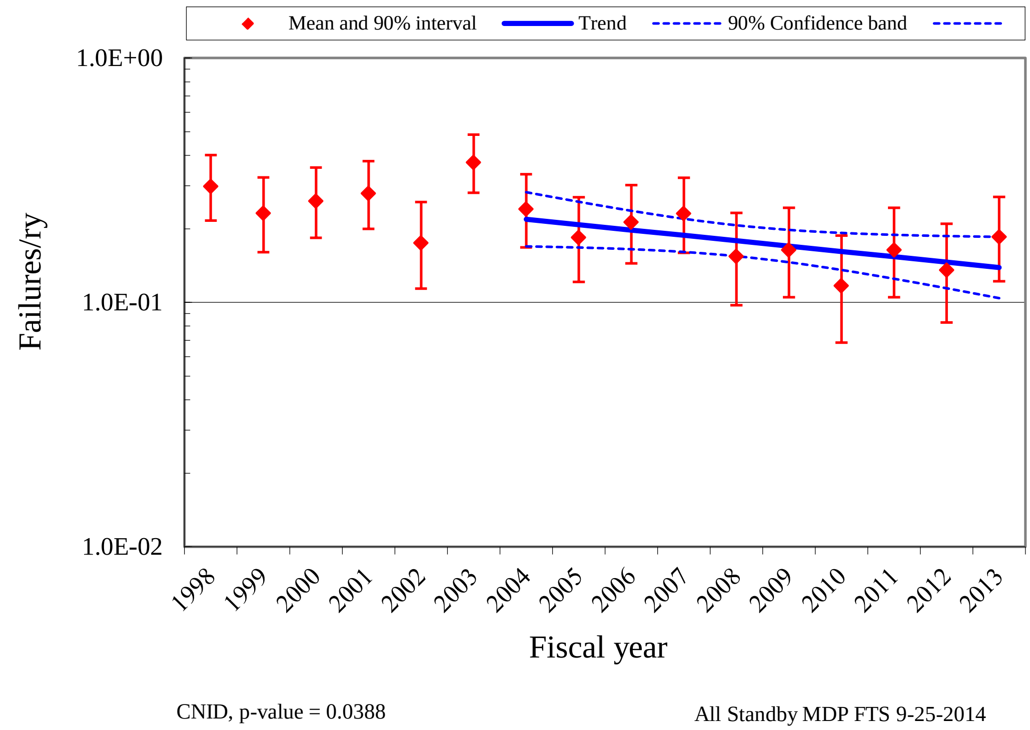

Figure 12. Frequency (failures per reactor year) of FTS events, standby MDPs.

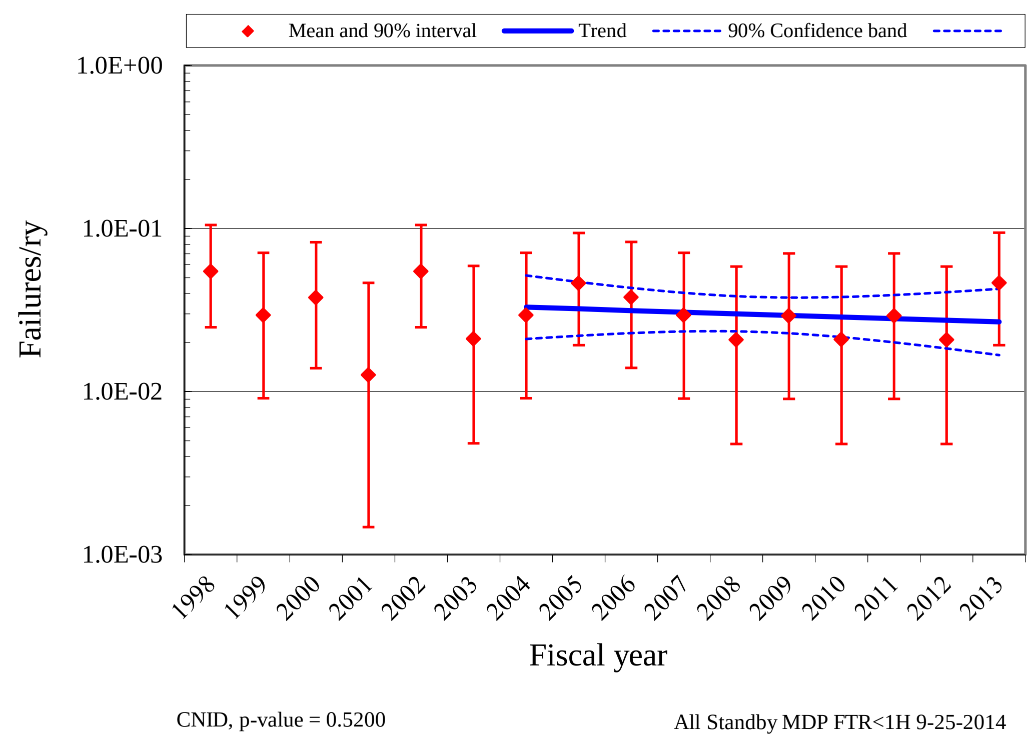

Figure 13. Frequency (failures per reactor year) of FTR≤1H events, standby MDPs.

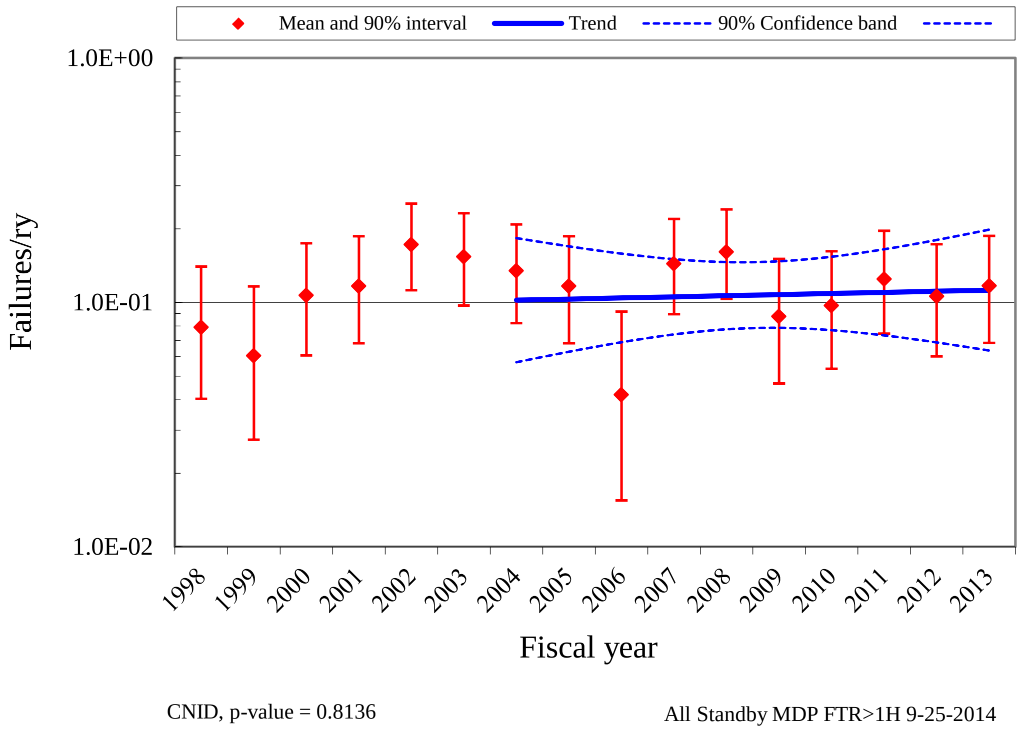

Figure 14. Frequency (failures per reactor year) of FTR>1H events, standby MDPs.

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 bold values in the percent of total failures column show the contributors that make up at least 50% of the failures.

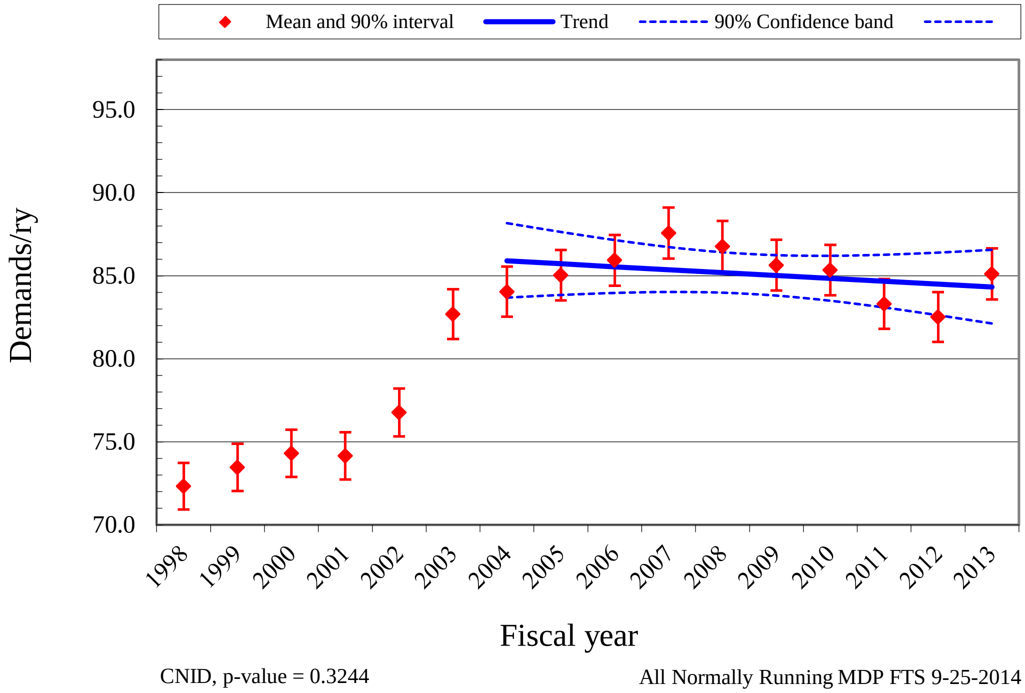

Figure 15. Frequency (demands per reactor year) of start demands, normally running MDPs.

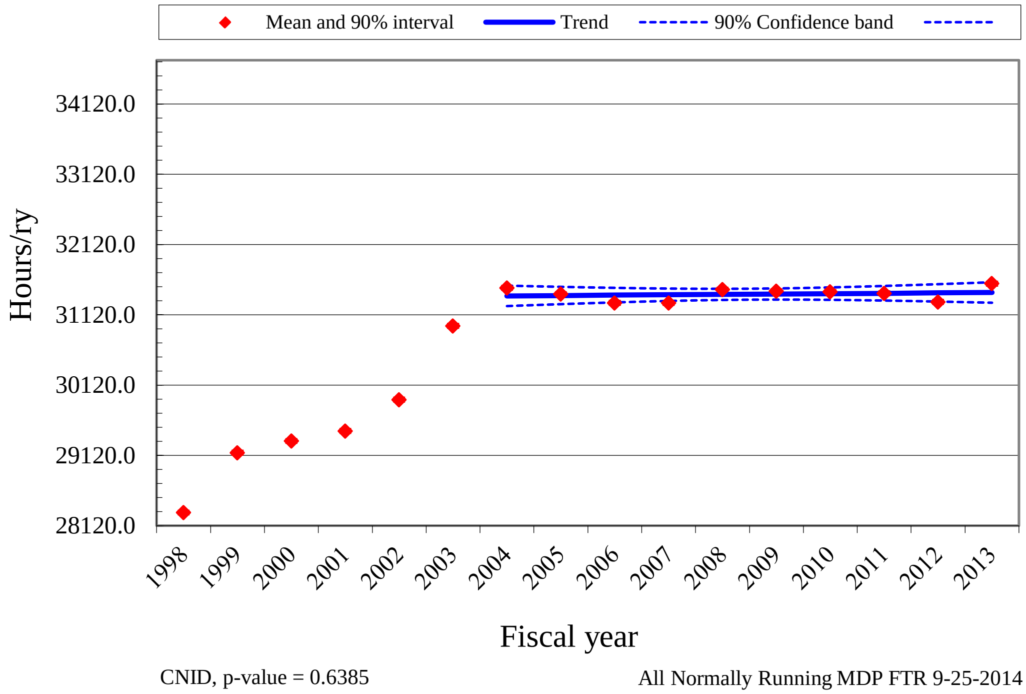

Figure 16. Normally running MDP run hours per reactor critical year.

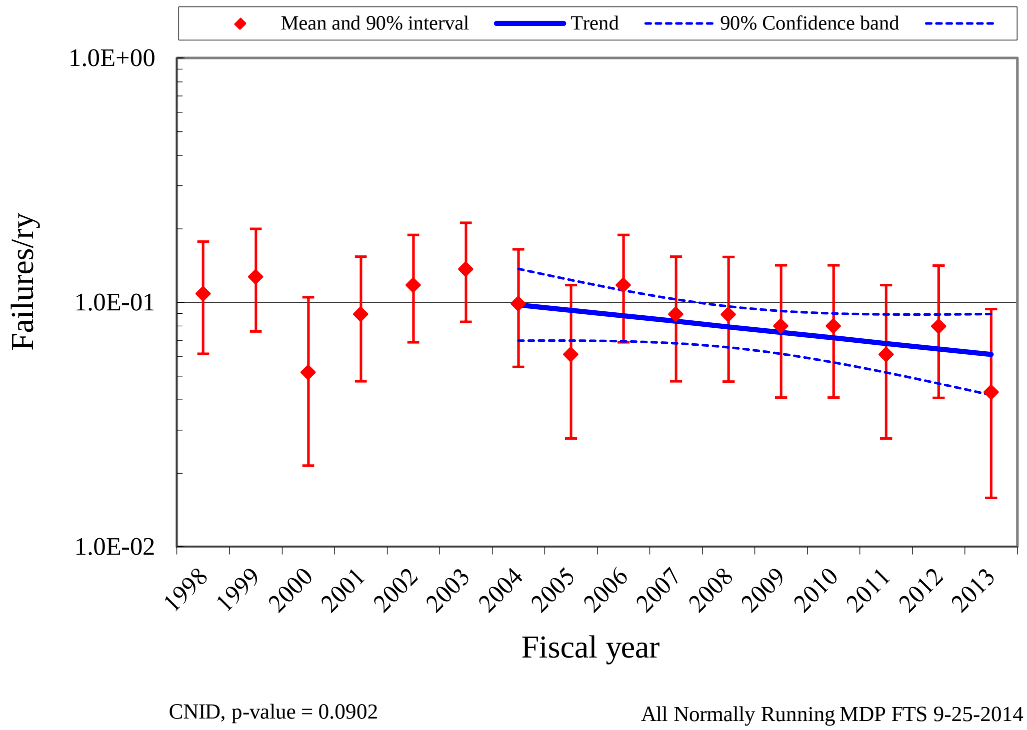

Figure 17. Frequency (failures per reactor year) of FTS events, normally running MDPs.

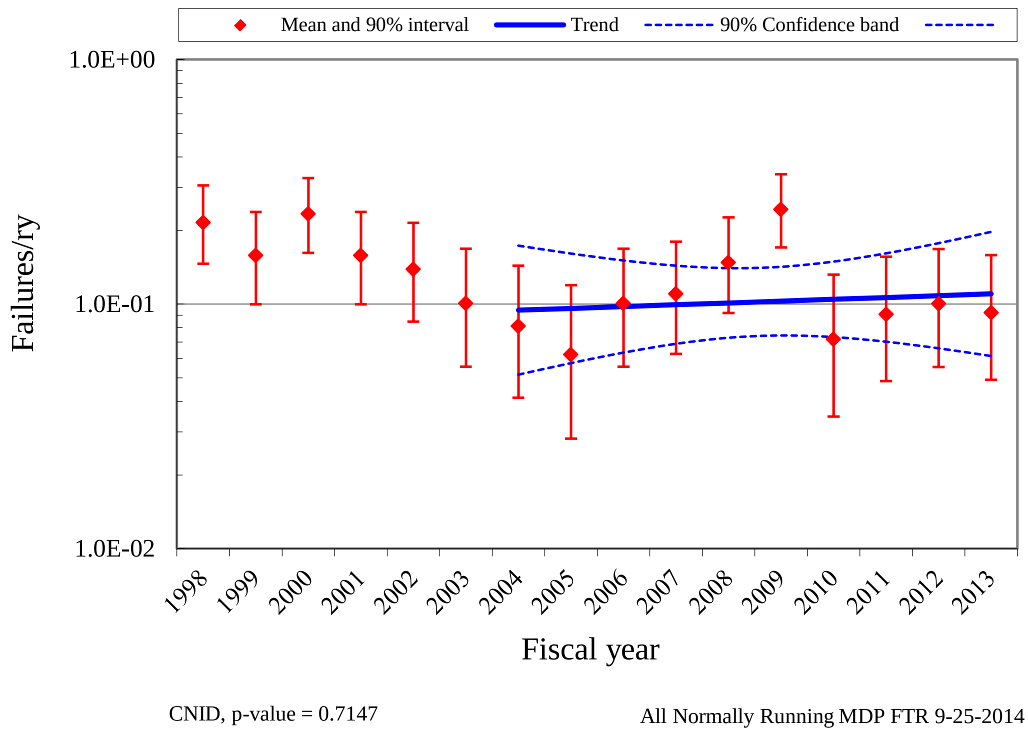

Figure 18. Frequency (failures per reactor year) of FTR events, normally running MDPs.

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

System Code	MDP Count	MDP Percent	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total	
AFW	123	10.2%		3	4	4		1	1	2	3	3	21	12.2%
CSR	156	12.9%	4	2	1		1			1	1	1	11	6.4%
HCS	9	0.7%			1								1	0.6%
HPI	163	13.5%	7	2	2	3	4	3	1	7	2		31	**18.0%**
LCS	70	5.8%					1		1	1			3	1.7%
RHR	292	24.2%	5	5	3	5	3	2	3	2	1	2	31	**18.0%**
SWS	395	32.7%	9	7	11	12	7	11	6	4	5	2	74	**43.0%**
Total	1208	100%	25	19	22	24	16	17	12	17	12	8	172	100%

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

System Code	MDP Count	MDP Percent	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total	
AFW	123	10.8%		1									1	0.9%
CSR	156	13.7%	1				1		1	1			4	3.7%
HCS	9	0.8%		1									1	0.9%
HPI	163	14.3%	3	1	1	2		1		1		2	11	**10.3%**
RHR	292	25.7%						1	1	1			3	2.8%
SWS	395	34.7%	2	1		3	2	1		2	4		15	**14.0%**
Total	1138	100%	8	8	3	10	14	6	8	8	6	1	72	**67.3%**

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

System Code	MDP Count	MDP Percent	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total	
AFW	123	10.2%	1	2		1			1				5	**16.7%**
CSR	156	12.9%		2	1			1				1	5	**16.7%**
HCS	9	0.7%								1			1	3.3%
HPI	163	13.5%				1		1					2	6.7%
LCS	70	5.8%									1	1	2	6.7%
RHR	292	24.2%	2	1	3	1	2	1	1	2	2		15	**50.0%**
SWS	395	32.7%	3	5	4	3	2	3	2	3	3	2	30	100%
Total	1208	100%	1	2	0	1	0	0	1	0	0	0	5	**16.7%**

Table 7. Summary of normally running MDP failure counts for the FTS failure mode over time by system.

System Code	MDP Count	MDP Percent	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total	Percent of Failures
CCW	287	46.7%	5		7	4	7	3	6	3	2		37	**49.3%**
CDS	140	22.8%			2	1				1	1		5	6.7%
CRD	39	6.3%				1				1			2	2.7%
CVC	10	1.6%	1										1	1.3%
MFW	43	7.0%	1	2	1	2	2	2		1	2		13	**17.3%**
SWN	96	15.6%	3	4	2	1		3	2		2		17	**22.7%**
Total	615	100%	10	6	12	9	9	8	8	6	7	0	75	100%

Table 8. Summary of normally running MDP failure counts for the FTR failure mode over time by system.

System Code	MDP Count	MDP Percent	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total	Percent of Failures
CCW	287	46.7%	2	3	1	4	4	6	3	2	1		26	**25.7%**
CDS	140	22.8%		1	2	2	1	8	2	2	1		19	**18.8%**
CRD	39	6.3%							1	2	3		6	5.9%
CVC	10	1.6%											0	0.0%
MFW	43	7.0%	2		1	2	1		1		1		8	7.9%
SWN	96	15.6%	4	2	6	3	9	11	1	3	3		42	**41.6%**
Total	615	100%	8	6	10	11	15	25	8	9	9	0	101	100%

6.3 Comparison of ICES 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 represents 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 ICES. The data are further limited to FY 2003 to present since the ESF demand reporting in ICES is inconsistent prior to FY 2003.

The standby MDP ESF unplanned demand data covering FY 2003 – 2013 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 3].

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 ICES 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[a]?
FTS	105	1239	1	1.2	0.58	Yes
FTR≤1H	105	830	0	0.1	1.000	Yes[b]
FTR>1H	105	20,620	0	0.2	1.000	Yes[c]

a. If the probability of observing the actual failures or greater is ≥ 0.05 and ≤ 0.95, then the performance is considered to be consistent with the industry-average performance.
b. P(X=0) = 0.91 which is considered consistent with industry experience.
c. P(X=0) = 0.83 which is considered consistent with industry experience.

The consistency checks using unplanned demand data indicate that none of the failure observations are consistent with their industry-average distribution from Table 2. The FTS, FTR≤1H, FTR>1H, and Total UR observations are superior (smaller) 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. First, each analysis divides the events into two categories: Standby and Normally running MDPs. Note that the FTR≤1H failure mode only applies to standby MDPs and therefore only shows the Standby category data.

The second division of the events is by the failure mode determined after ICES 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 failure mode.

The pump sub-component is the highest for the FTR≤1H failure mode followed closely by the driver.

For the FTR>1H failure mode there is a difference in importance between the standby and normally running categories. The standby category has the pump as the highest contributor and the normally running has the driver as the highest contributor.

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. The human cause group is primarily influenced by maintenance and operating procedures and practices. The design cause group is influenced by manufacturing, installation, and design issues.

MDP detection methods to the three failure modes are presented in Figure 21. There are differences in the detection method based on the Standby and normally running categories.

Standby—the most likely detection method for FTR≤1H and FTR>1H is non-testing. The prevalent FTS detection is test demands.

Normally running—the most likely detection method for FTR is non-testing. The prevalent FTS detection is non-test demands.

MDP recovery to the three failure modes are presented in Figure 22. The overall non-recovery to recovery ratio is approximately 7:1.

Table 10. 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.
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.

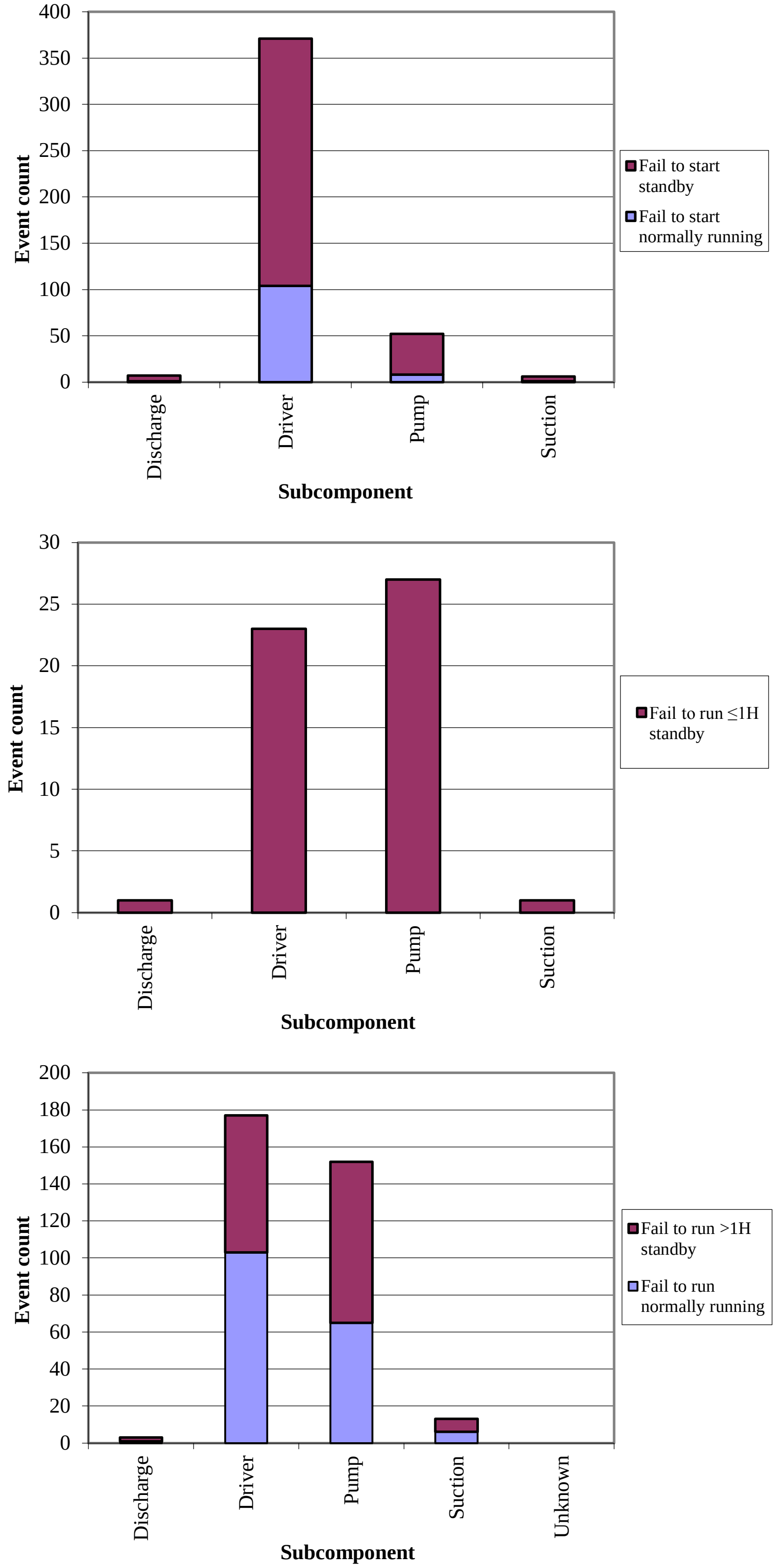

Figure 19. MDP failure breakdown by failure mode and sub component.

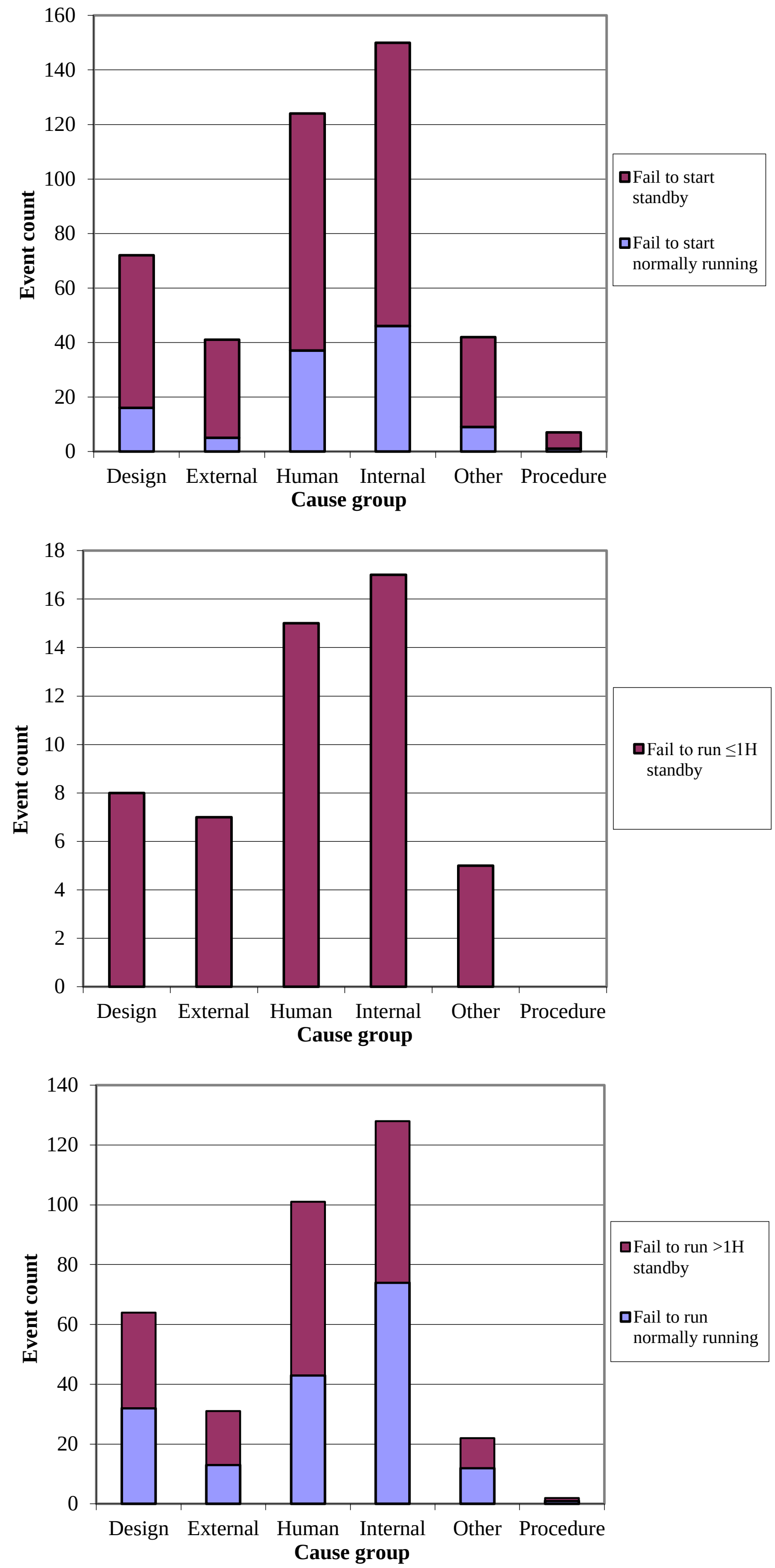

Figure 20. MDP breakdown by failure mode and cause group.

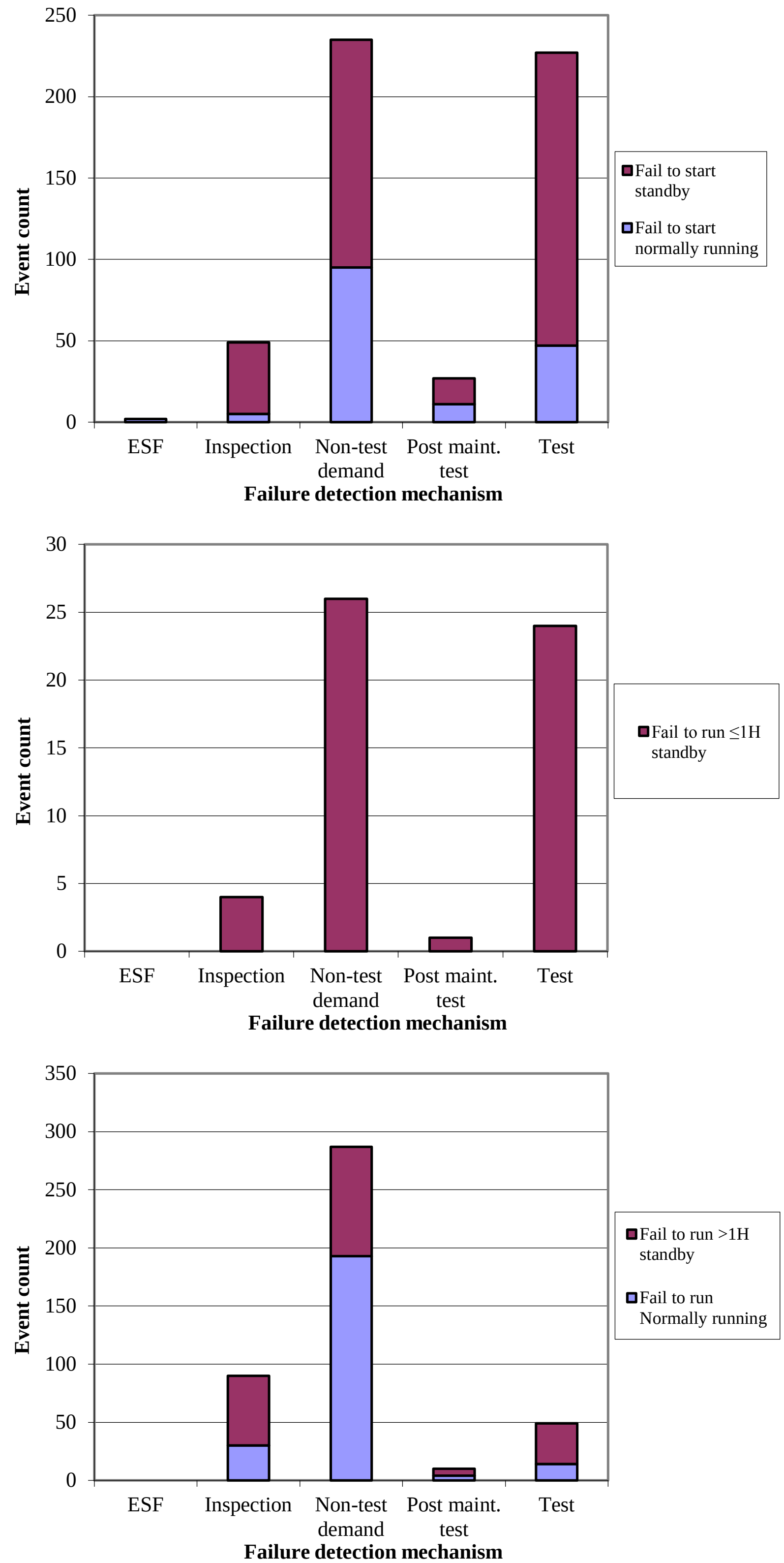

Figure 21. MDP component failure distribution by failure mode and method of detection.

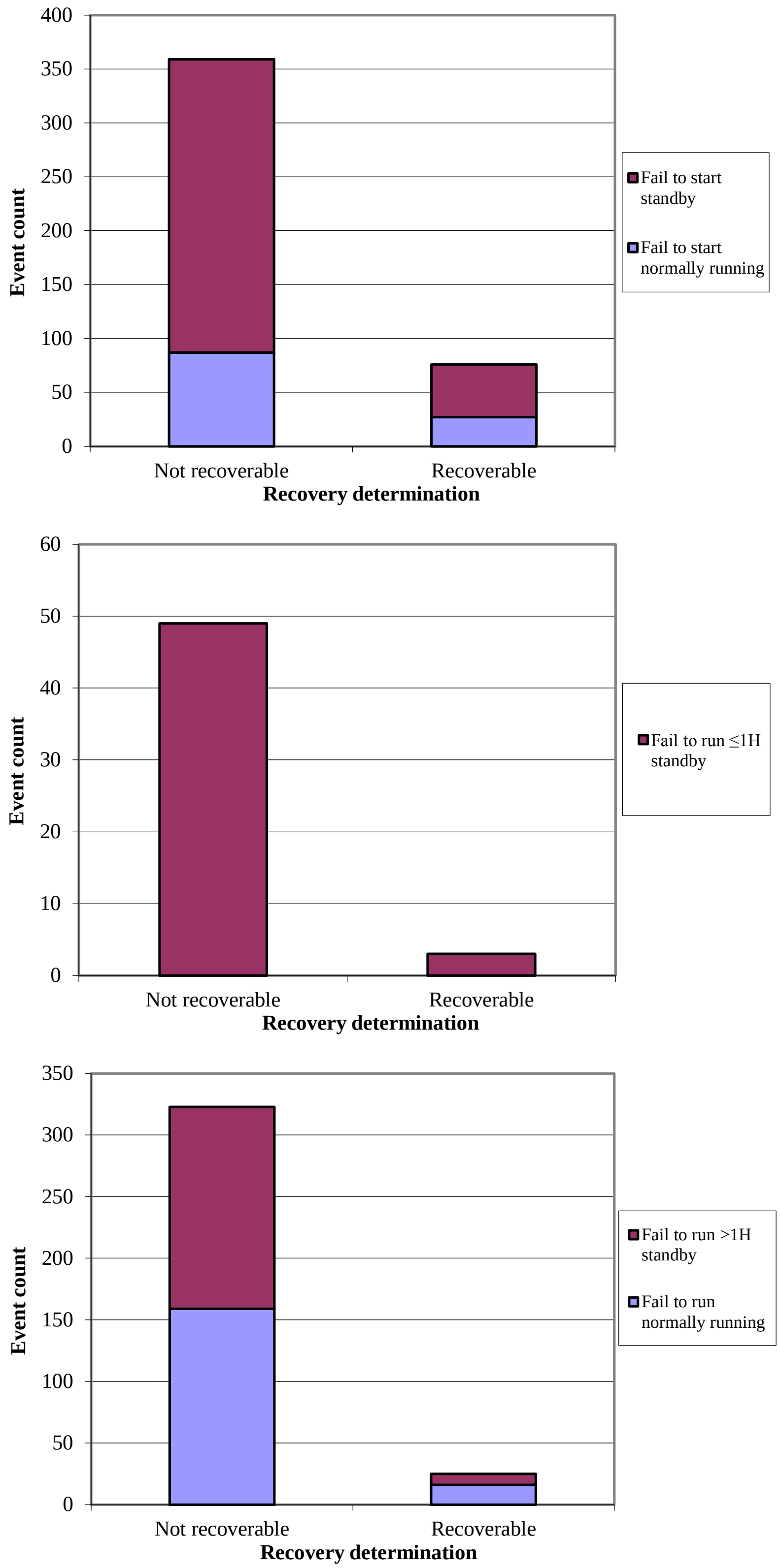

Figure 22. MDP component failure distribution by failure mode and recovery determination.

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 FTS, FTR≤1H, and 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 ICES 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 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 ICES 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 Figure 1, standby MDP FTS industry trend.

			Regression Curve Data Points			Plot Trend Error Bar Points		
FY	Failures	Demands	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2010 Update						1.63E-04	2.27E-03	9.47E-04
1998	31	23,585.4				9.41E-04	1.74E-03	1.30E-03
1999	24	24,313.5				6.78E-04	1.37E-03	9.79E-04
2000	27	24,467.1				7.74E-04	1.50E-03	1.09E-03
2001	29	24,156.1				8.51E-04	1.61E-03	1.19E-03
2002	18	24,481.5				4.78E-04	1.08E-03	7.34E-04
2003	39	25,909.6				1.12E-03	1.93E-03	1.48E-03
2004	25	26,862.2	8.32E-04	6.44E-04	1.07E-03	6.46E-04	1.29E-03	9.25E-04
2005	19	27,140.3	7.96E-04	6.41E-04	9.87E-04	4.61E-04	1.02E-03	7.00E-04
2006	22	26,382.8	7.61E-04	6.35E-04	9.12E-04	5.65E-04	1.18E-03	8.30E-04
2007	24	27,529.8	7.28E-04	6.23E-04	8.51E-04	6.01E-04	1.22E-03	8.67E-04
2008	16	26,754.3	6.96E-04	6.02E-04	8.05E-04	3.80E-04	9.06E-04	6.01E-04
2009	17	26,520.3	6.66E-04	5.72E-04	7.75E-04	4.12E-04	9.58E-04	6.43E-04
2010	12	26,827.0	6.37E-04	5.35E-04	7.57E-04	2.65E-04	7.28E-04	4.54E-04
2011	17	26,031.8	6.09E-04	4.96E-04	7.48E-04	4.20E-04	9.75E-04	6.54E-04
2012	14	25,492.6	5.82E-04	4.56E-04	7.44E-04	3.38E-04	8.58E-04	5.53E-04
2013	19	26,049.6	5.57E-04	4.18E-04	7.42E-04	4.80E-04	1.06E-03	7.29E-04
Total	353	412,503.9						

Table 12. Plot data for Figure 2, standby MDP FTR ≤ 1H industry trend.

			Regression Curve Data Points			Plot Trend Error Bar Points		
FY	**Failures**	**Hours**	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
2010 Update						1.93E-05	3.01E-04	1.23E-04
1998	6	23,585.4				1.06E-04	4.52E-04	2.35E-04
1999	3	24,313.5				3.82E-05	2.98E-04	1.23E-04
2000	4	24,467.1				5.82E-05	3.45E-04	1.58E-04
2001	1	24,156.1				6.23E-06	1.96E-04	5.31E-05
2002	6	24,481.5				1.03E-04	4.37E-04	2.28E-04
2003	2	25,909.6				1.91E-05	2.34E-04	8.33E-05
2004	3	26,862.2	1.26E-04	8.05E-05	1.96E-04	3.50E-05	2.73E-04	1.13E-04
2005	5	27,140.3	1.23E-04	8.47E-05	1.80E-04	7.33E-05	3.58E-04	1.76E-04
2006	4	26,382.8	1.21E-04	8.83E-05	1.66E-04	5.46E-05	3.23E-04	1.48E-04
2007	3	27,529.8	1.19E-04	9.08E-05	1.56E-04	3.43E-05	2.68E-04	1.11E-04
2008	2	26,754.3	1.17E-04	9.14E-05	1.49E-04	1.86E-05	2.28E-04	8.11E-05
2009	3	26,520.3	1.15E-04	8.95E-05	1.47E-04	3.54E-05	2.76E-04	1.14E-04
2010	2	26,827.0	1.13E-04	8.52E-05	1.49E-04	1.85E-05	2.28E-04	8.09E-05
2011	3	26,031.8	1.11E-04	7.96E-05	1.54E-04	3.60E-05	2.81E-04	1.16E-04
2012	2	25,492.6	1.09E-04	7.34E-05	1.61E-04	1.94E-05	2.38E-04	8.45E-05
2013	5	26,049.6	1.07E-04	6.72E-05	1.70E-04	7.59E-05	3.71E-04	1.83E-04
Total	54	412,503.9						

Table 13. Plot data for Figure 3, standby MDP FTR > 1H industry trend.

			Regression Curve Data Points			Plot Trend Error Bar Points		
FY	Failures	Run Time (hr)	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2010 Update						2.64E-07	3.41E-05	1.04E-05
1998	8	934,293.4				4.41E-06	1.53E-05	8.64E-06
1999	6	914,918.2				3.05E-06	1.30E-05	6.74E-06
2000	11	873,796.3				7.09E-06	2.04E-05	1.25E-05
2001	12	885,009.3				7.82E-06	2.15E-05	1.34E-05
2002	18	950,098.3				1.20E-05	2.73E-05	1.85E-05
2003	16	1,065,570.8				9.36E-06	2.23E-05	1.48E-05
2004	14	1,144,110.3	9.18E-06	5.12E-06	1.64E-05	7.42E-06	1.88E-05	1.21E-05
2005	12	1,145,217.5	9.25E-06	5.64E-06	1.52E-05	6.11E-06	1.68E-05	1.05E-05
2006	4	1,150,317.8	9.33E-06	6.15E-06	1.41E-05	1.39E-06	8.20E-06	3.75E-06
2007	15	1,167,225.5	9.41E-06	6.61E-06	1.34E-05	7.92E-06	1.95E-05	1.27E-05
2008	17	1,183,497.2	9.49E-06	6.92E-06	1.30E-05	9.11E-06	2.12E-05	1.42E-05
2009	9	1,163,777.0	9.57E-06	7.00E-06	1.31E-05	4.17E-06	1.35E-05	7.83E-06
2010	10	1,184,181.8	9.64E-06	6.83E-06	1.36E-05	4.70E-06	1.43E-05	8.51E-06
2011	13	1,177,390.0	9.73E-06	6.49E-06	1.46E-05	6.58E-06	1.73E-05	1.10E-05
2012	11	1,187,627.9	9.81E-06	6.06E-06	1.59E-05	5.29E-06	1.52E-05	9.29E-06
2013	12	1,153,728.3	9.89E-06	5.60E-06	1.74E-05	6.07E-06	1.67E-05	1.04E-05
Total	188	17,280,759.4						

Table 14. Plot data for Figure 4, normally running MDP FTS industry trend.

			Regression Curve Data Points			Plot Trend Error Bar Points		
FY	**Failures**	**Demands**	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
2010 Update						4.01E-04	2.79E-03	1.36E-03
1998	11	7,231.7				8.44E-04	2.43E-03	1.48E-03
1999	13	7,345.3				1.03E-03	2.70E-03	1.71E-03
2000	5	7,449.7				2.87E-04	1.40E-03	6.89E-04
2001	9	7,415.0				6.37E-04	2.06E-03	1.20E-03
2002	12	7,675.7				8.91E-04	2.44E-03	1.52E-03
2003	14	8,268.2				1.01E-03	2.56E-03	1.65E-03
2004	10	8,426.1	1.14E-03	8.17E-04	1.60E-03	6.47E-04	1.96E-03	1.17E-03
2005	6	8,502.6	1.09E-03	8.19E-04	1.44E-03	3.26E-04	1.38E-03	7.20E-04
2006	12	8,592.1	1.03E-03	8.14E-04	1.31E-03	8.01E-04	2.20E-03	1.37E-03
2007	9	8,755.7	9.81E-04	8.00E-04	1.20E-03	5.45E-04	1.76E-03	1.02E-03
2008	9	8,698.6	9.33E-04	7.70E-04	1.13E-03	5.48E-04	1.77E-03	1.03E-03
2009	8	8,562.6	8.87E-04	7.25E-04	1.08E-03	4.77E-04	1.66E-03	9.35E-04
2010	8	8,533.2	8.43E-04	6.70E-04	1.06E-03	4.79E-04	1.66E-03	9.38E-04
2011	6	8,329.3	8.01E-04	6.10E-04	1.05E-03	3.33E-04	1.41E-03	7.34E-04
2012	8	8,272.9	7.62E-04	5.50E-04	1.05E-03	4.93E-04	1.71E-03	9.66E-04
2013	4	8,389.2	7.24E-04	4.94E-04	1.06E-03	1.86E-04	1.10E-03	5.05E-04
Total	144	130,447.9						

Table 15. Plot data for Figure 5, normally running MDP FTR industry trend.

FY	Failures	Run Time (hr)	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
2010 Update						7.37E-07	8.02E-06	3.53E-06
1998	22	2,830,563.1				5.15E-06	1.08E-05	7.57E-06
1999	16	2,915,639.6				3.41E-06	8.14E-06	5.40E-06
2000	24	2,940,263.6				5.50E-06	1.11E-05	7.95E-06
2001	16	2,946,525.5				3.38E-06	8.06E-06	5.34E-06
2002	14	2,991,219.5				2.83E-06	7.18E-06	4.63E-06
2003	10	3,096,041.8				1.79E-06	5.43E-06	3.24E-06
2004	8	3,158,837.8	3.01E-06	1.64E-06	5.53E-06	1.31E-06	4.57E-06	2.58E-06
2005	6	3,141,350.1	3.06E-06	1.83E-06	5.13E-06	8.97E-07	3.81E-06	1.98E-06
2006	10	3,128,786.7	3.11E-06	2.02E-06	4.80E-06	1.77E-06	5.38E-06	3.21E-06
2007	11	3,128,657.1	3.17E-06	2.19E-06	4.57E-06	2.00E-06	5.76E-06	3.52E-06
2008	15	3,156,337.4	3.22E-06	2.32E-06	4.47E-06	2.92E-06	7.19E-06	4.70E-06
2009	25	3,145,421.3	3.27E-06	2.37E-06	4.52E-06	5.41E-06	1.08E-05	7.76E-06
2010	7	3,144,509.8	3.33E-06	2.33E-06	4.75E-06	1.10E-06	4.20E-06	2.28E-06
2011	9	3,142,410.9	3.39E-06	2.23E-06	5.13E-06	1.54E-06	4.97E-06	2.89E-06
2012	10	3,138,812.1	3.44E-06	2.10E-06	5.65E-06	1.77E-06	5.36E-06	3.20E-06
2013	9	3,111,323.3	3.50E-06	1.95E-06	6.28E-06	1.55E-06	5.02E-06	2.92E-06
Total	212	49,116,699.6						

Table 16. Plot data for Figure 6, all standby MDP unavailability trend.

FY	UA Hours	Critical Hours	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2010 Update						3.59E−04	2.10E−02	7.00E−03
1998	10,607.8	1,713,843.7				9.44E-05	2.16E-02	6.28E-03
1999	12,906.2	2,452,645.5				6.69E-04	1.31E-02	5.16E-03
2000	13,130.0	2,537,111.3				6.63E-04	1.22E-02	4.86E-03
2001	12,728.1	2,542,239.9				5.77E-04	1.28E-02	4.94E-03
2002	18,010.2	3,819,764.7				5.55E-04	1.26E-02	4.83E-03
2003	21,358.6	4,290,105.7				4.63E-04	1.32E-02	4.88E-03
2004	19,662.9	4,473,656.1	4.09E-03	3.78E-03	4.42E-03	6.05E-04	1.09E-02	4.34E-03
2005	19,004.5	4,413,226.1	4.10E-03	3.84E-03	4.38E-03	2.48E-04	1.29E-02	4.39E-03
2006	17,693.4	4,488,097.5	4.11E-03	3.89E-03	4.35E-03	3.71E-04	1.02E-02	3.80E-03
2007	17,015.5	4,464,312.7	4.13E-03	3.93E-03	4.33E-03	3.18E-04	1.05E-02	3.80E-03
2008	18,367.5	4,459,856.1	4.14E-03	3.96E-03	4.32E-03	4.46E-04	1.08E-02	4.09E-03
2009	18,776.7	4,474,114.8	4.15E-03	3.98E-03	4.33E-03	3.81E-04	1.09E-02	4.03E-03
2010	18,862.9	4,393,087.5	4.16E-03	3.97E-03	4.37E-03	4.53E-04	1.14E-02	4.31E-03
2011	18,248.9	4,337,722.4	4.18E-03	3.95E-03	4.42E-03	5.17E-04	1.08E-02	4.18E-03
2012	19,184.4	4,251,724.3	4.19E-03	3.92E-03	4.48E-03	3.22E-04	1.24E-02	4.37E-03
2013	18,491.5	4,174,218.6	4.20E-03	3.88E-03	4.54E-03	3.15E-04	1.18E-02	4.18E-03
Total	274,049.2	61,285,726.8						

Table 17. Plot data for Figure 7, standby MDP unreliability trend.

	Regression Curve Data Points			Plot Trend Error Bar Points		
FY	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
1998				1.51E-03	2.32E-02	7.81E-03
1999				2.31E-03	1.49E-02	6.88E-03
2000				1.53E-03	1.31E-02	5.75E-03
2001				1.82E-03	1.41E-02	6.20E-03
2002				2.05E-03	1.43E-02	6.37E-03
2003				2.04E-03	1.48E-02	6.52E-03
2004	5.33E-03	3.16E-03	8.95E-03	1.80E-03	1.21E-02	5.57E-03
2005	5.30E-03	3.41E-03	8.22E-03	1.07E-03	1.39E-02	5.26E-03
2006	5.27E-03	3.63E-03	7.63E-03	1.70E-03	1.16E-02	5.20E-03
2007	5.24E-03	3.82E-03	7.18E-03	1.38E-03	1.16E-02	4.91E-03
2008	5.22E-03	3.92E-03	6.92E-03	1.54E-03	1.19E-02	5.23E-03
2009	5.19E-03	3.90E-03	6.88E-03	1.42E-03	1.21E-02	5.13E-03
2010	5.16E-03	3.76E-03	7.07E-03	1.46E-03	1.24E-02	5.34E-03
2011	5.13E-03	3.54E-03	7.43E-03	1.37E-03	1.17E-02	5.06E-03
2012	5.10E-03	3.28E-03	7.92E-03	1.35E-03	1.35E-02	5.46E-03
2013	5.08E-03	3.01E-03	8.53E-03	9.72E-04	1.24E-02	4.86E-03

Table 18. Plot data for Figure 8, normally running MDP unreliability trend.

FY	Regression Curve Data Points			Plot Trend Error Bar Points		
	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998				1.51E-03	2.33E-02	7.84E-03
1999				2.30E-03	1.48E-02	6.84E-03
2000				1.53E-03	1.32E-02	5.77E-03
2001				1.82E-03	1.42E-02	6.23E-03
2002				2.02E-03	1.41E-02	6.37E-03
2003				2.03E-03	1.47E-02	6.47E-03
2004	5.33E-03	5.31E-03	5.35E-03	1.80E-03	1.22E-02	5.59E-03
2005	5.31E-03	5.29E-03	5.32E-03	1.07E-03	1.38E-02	5.24E-03
2006	5.28E-03	5.26E-03	5.29E-03	1.71E-03	1.17E-02	5.21E-03
2007	5.25E-03	5.23E-03	5.26E-03	1.39E-03	1.17E-02	4.94E-03
2008	5.22E-03	5.21E-03	5.23E-03	1.53E-03	1.20E-02	5.24E-03
2009	5.19E-03	5.18E-03	5.20E-03	1.42E-03	1.20E-02	5.11E-03
2010	5.16E-03	5.15E-03	5.17E-03	1.45E-03	1.25E-02	5.35E-03
2011	5.14E-03	5.12E-03	5.15E-03	1.37E-03	1.17E-02	5.07E-03
2012	5.11E-03	5.09E-03	5.12E-03	1.35E-03	1.34E-02	5.44E-03
2013	5.08E-03	5.06E-03	5.10E-03	9.76E-04	1.26E-02	4.88E-03

Table 19. Plot data for Figure 9, standby MDP start demands trend.

			Regression Curve Data Points			Plot Trend Error Bar Points		
FY	**Demands**	**Reactor Years**	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
1998	23,585	103.0				2.27E+02	2.31E+02	2.29E+02
1999	24,314	103.0				2.34E+02	2.39E+02	2.36E+02
2000	24,467	103.3				2.34E+02	2.39E+02	2.37E+02
2001	24,156	103.0				2.32E+02	2.37E+02	2.35E+02
2002	24,482	103.0				2.35E+02	2.40E+02	2.38E+02
2003	25,910	103.0				2.49E+02	2.54E+02	2.52E+02
2004	26,862	103.3	2.63E+02	2.56E+02	2.70E+02	2.57E+02	2.63E+02	2.60E+02
2005	27,140	103.0	2.62E+02	2.56E+02	2.68E+02	2.61E+02	2.66E+02	2.63E+02
2006	26,383	103.0	2.60E+02	2.55E+02	2.65E+02	2.54E+02	2.59E+02	2.56E+02
2007	27,530	103.4	2.59E+02	2.54E+02	2.63E+02	2.64E+02	2.69E+02	2.66E+02
2008	26,754	104.3	2.57E+02	2.53E+02	2.61E+02	2.54E+02	2.59E+02	2.57E+02
2009	26,520	104.0	2.56E+02	2.52E+02	2.59E+02	2.52E+02	2.58E+02	2.55E+02
2010	26,827	104.0	2.54E+02	2.50E+02	2.58E+02	2.55E+02	2.61E+02	2.58E+02
2011	26,032	104.0	2.53E+02	2.48E+02	2.58E+02	2.48E+02	2.53E+02	2.50E+02
2012	25,493	104.3	2.51E+02	2.46E+02	2.57E+02	2.42E+02	2.47E+02	2.44E+02
2013	26,050	102.6	2.50E+02	2.43E+02	2.57E+02	2.51E+02	2.57E+02	2.54E+02
Total	412,504	1,654.1						

Table 20. Plot data for Figure 10, standby MDP run ≤1-hour run-hours trend.

			Regression Curve Data Points			Plot Trend Error Bar Points		
FY	Hours	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	23,585	103.0				2.27E+02	2.31E+02	2.29E+02
1999	24,314	103.0				2.34E+02	2.39E+02	2.36E+02
2000	24,467	103.3				2.34E+02	2.39E+02	2.37E+02
2001	24,156	103.0				2.32E+02	2.37E+02	2.35E+02
2002	24,482	103.0				2.35E+02	2.40E+02	2.38E+02
2003	25,910	103.0				2.49E+02	2.54E+02	2.52E+02
2004	26,862	103.3	2.63E+02	2.56E+02	2.70E+02	2.57E+02	2.63E+02	2.60E+02
2005	27,140	103.0	2.62E+02	2.56E+02	2.68E+02	2.61E+02	2.66E+02	2.63E+02
2006	26,383	103.0	2.60E+02	2.55E+02	2.65E+02	2.54E+02	2.59E+02	2.56E+02
2007	27,530	103.4	2.59E+02	2.54E+02	2.63E+02	2.64E+02	2.69E+02	2.66E+02
2008	26,754	104.3	2.57E+02	2.53E+02	2.61E+02	2.54E+02	2.59E+02	2.57E+02
2009	26,520	104.0	2.56E+02	2.52E+02	2.59E+02	2.52E+02	2.58E+02	2.55E+02
2010	26,827	104.0	2.54E+02	2.50E+02	2.58E+02	2.55E+02	2.61E+02	2.58E+02
2011	26,032	104.0	2.53E+02	2.48E+02	2.58E+02	2.48E+02	2.53E+02	2.50E+02
2012	25,493	104.3	2.51E+02	2.46E+02	2.57E+02	2.42E+02	2.47E+02	2.44E+02
2013	26,050	102.6	2.50E+02	2.43E+02	2.57E+02	2.51E+02	2.57E+02	2.54E+02
Total	412,504	1,654.1						

Table 21. Plot data for Figure 11, standby MDP run-hours trend.

FY	Run Hours	Reactor Years	Regression Curve Data Points Mean	Regression Curve Data Points Lower (5%)	Regression Curve Data Points Upper (95%)	Plot Trend Error Bar Points Lower (5%)	Plot Trend Error Bar Points Upper (95%)	Plot Trend Error Bar Points Mean
1998	934,293	103.0				9.06E+03	9.09E+03	9.07E+03
1999	914,918	103.0				8.87E+03	8.90E+03	8.88E+03
2000	873,796	103.3				8.45E+03	8.48E+03	8.46E+03
2001	885,009	103.0				8.58E+03	8.61E+03	8.59E+03
2002	950,098	103.0				9.21E+03	9.24E+03	9.22E+03
2003	1,065,571	103.0				1.03E+04	1.04E+04	1.03E+04
2004	1,144,110	103.3	1.11E+04	1.10E+04	1.13E+04	1.11E+04	1.11E+04	1.11E+04
2005	1,145,218	103.0	1.12E+04	1.11E+04	1.13E+04	1.11E+04	1.11E+04	1.11E+04
2006	1,150,318	103.0	1.12E+04	1.11E+04	1.13E+04	1.12E+04	1.12E+04	1.12E+04
2007	1,167,225	103.4	1.12E+04	1.11E+04	1.13E+04	1.13E+04	1.13E+04	1.13E+04
2008	1,183,497	104.3	1.12E+04	1.12E+04	1.13E+04	1.13E+04	1.14E+04	1.13E+04
2009	1,163,777	104.0	1.13E+04	1.12E+04	1.13E+04	1.12E+04	1.12E+04	1.12E+04
2010	1,184,182	104.0	1.13E+04	1.12E+04	1.14E+04	1.14E+04	1.14E+04	1.14E+04
2011	1,177,390	104.0	1.13E+04	1.12E+04	1.14E+04	1.13E+04	1.13E+04	1.13E+04
2012	1,187,628	104.3	1.13E+04	1.12E+04	1.15E+04	1.14E+04	1.14E+04	1.14E+04
2013	1,153,728	102.6	1.14E+04	1.12E+04	1.15E+04	1.12E+04	1.13E+04	1.12E+04
Total	17,280,759	1,654.1						

Table 22. Plot data for Figure 12, standby MDP FTS events trend.

FY	Failures	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	31	103.0				2.16E-01	4.01E-01	2.98E-01
1999	24	103.0				1.60E-01	3.25E-01	2.32E-01
2000	27	103.3				1.84E-01	3.56E-01	2.59E-01
2001	29	103.0				2.00E-01	3.79E-01	2.79E-01
2002	18	103.0				1.14E-01	2.58E-01	1.75E-01
2003	39	103.0				2.81E-01	4.87E-01	3.73E-01
2004	25	103.3	2.19E-01	1.70E-01	2.83E-01	1.68E-01	3.35E-01	2.40E-01
2005	19	103.0	2.08E-01	1.68E-01	2.58E-01	1.21E-01	2.69E-01	1.84E-01
2006	22	103.0	1.98E-01	1.65E-01	2.37E-01	1.45E-01	3.02E-01	2.13E-01
2007	24	103.4	1.88E-01	1.61E-01	2.20E-01	1.60E-01	3.23E-01	2.31E-01
2008	16	104.3	1.79E-01	1.55E-01	2.07E-01	9.74E-02	2.33E-01	1.54E-01
2009	17	104.0	1.70E-01	1.46E-01	1.98E-01	1.05E-01	2.44E-01	1.64E-01
2010	12	104.0	1.62E-01	1.36E-01	1.93E-01	6.84E-02	1.88E-01	1.17E-01
2011	17	104.0	1.54E-01	1.25E-01	1.89E-01	1.05E-01	2.44E-01	1.64E-01
2012	14	104.3	1.46E-01	1.14E-01	1.87E-01	8.27E-02	2.10E-01	1.35E-01
2013	19	102.6	1.39E-01	1.04E-01	1.86E-01	1.22E-01	2.70E-01	1.85E-01
Total	353	1,654.1						

Table 23. Plot data for Figure 13, standby MDP FTR ≤ 1H events trend.

			Regression Curve Data Points			Plot Trend Error Bar Points		
FY	Failures	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	6	103.0				2.48E-02	1.05E-01	5.47E-02
1999	3	103.0				9.11E-03	7.11E-02	2.94E-02
2000	4	103.3				1.39E-02	8.25E-02	3.77E-02
2001	1	103.0				1.48E-03	4.65E-02	1.26E-02
2002	6	103.0				2.48E-02	1.05E-01	5.47E-02
2003	2	103.0				4.82E-03	5.91E-02	2.10E-02
2004	3	103.3	3.29E-02	2.10E-02	5.16E-02	9.09E-03	7.10E-02	2.94E-02
2005	5	103.0	3.22E-02	2.20E-02	4.71E-02	1.92E-02	9.40E-02	4.62E-02
2006	4	103.0	3.15E-02	2.29E-02	4.33E-02	1.40E-02	8.27E-02	3.78E-02
2007	3	103.4	3.07E-02	2.34E-02	4.04E-02	9.08E-03	7.09E-02	2.93E-02
2008	2	104.3	3.00E-02	2.34E-02	3.85E-02	4.76E-03	5.85E-02	2.08E-02
2009	3	104.0	2.93E-02	2.28E-02	3.78E-02	9.04E-03	7.05E-02	2.92E-02
2010	2	104.0	2.87E-02	2.16E-02	3.81E-02	4.78E-03	5.86E-02	2.08E-02
2011	3	104.0	2.80E-02	2.01E-02	3.91E-02	9.04E-03	7.05E-02	2.92E-02
2012	2	104.3	2.74E-02	1.84E-02	4.07E-02	4.76E-03	5.85E-02	2.08E-02
2013	5	102.6	2.67E-02	1.68E-02	4.27E-02	1.93E-02	9.43E-02	4.64E-02
Total	54	1,654.1						

Table 24. Plot data for Figure 14, standby MDP FTR > 1H events trend.

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				4.04E-02	1.40E-01	7.91E-02
1999	6	103.0				2.74E-02	1.16E-01	6.05E-02
2000	11	103.3				6.08E-02	1.75E-01	1.07E-01
2001	12	103.0				6.80E-02	1.87E-01	1.16E-01
2002	18	103.0				1.12E-01	2.54E-01	1.72E-01
2003	16	103.0				9.71E-02	2.32E-01	1.54E-01
2004	14	103.3	1.02E-01	5.69E-02	1.83E-01	8.22E-02	2.09E-01	1.35E-01
2005	12	103.0	1.03E-01	6.28E-02	1.70E-01	6.80E-02	1.87E-01	1.16E-01
2006	4	103.0	1.04E-01	6.87E-02	1.58E-01	1.55E-02	9.16E-02	4.19E-02
2007	15	103.4	1.05E-01	7.40E-02	1.50E-01	8.95E-02	2.20E-01	1.44E-01
2008	17	104.3	1.07E-01	7.77E-02	1.46E-01	1.03E-01	2.40E-01	1.61E-01
2009	9	104.0	1.08E-01	7.87E-02	1.47E-01	4.67E-02	1.51E-01	8.76E-02
2010	10	104.0	1.09E-01	7.70E-02	1.54E-01	5.35E-02	1.62E-01	9.69E-02
2011	13	104.0	1.10E-01	7.33E-02	1.65E-01	7.45E-02	1.96E-01	1.25E-01
2012	11	104.3	1.11E-01	6.86E-02	1.80E-01	6.02E-02	1.73E-01	1.06E-01
2013	12	102.6	1.12E-01	6.36E-02	1.99E-01	6.83E-02	1.87E-01	1.17E-01
Total	188	1,654.1						

Table 25. Plot data for Figure 15, normally running MDP start demands trend.

			Regression Curve Data Points			Plot Trend Error Bar Points		
FY	Demands	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	7,232	100.0				7.09E+01	7.37E+01	7.23E+01
1999	7,345	100.0				7.20E+01	7.49E+01	7.35E+01
2000	7,450	100.3				7.29E+01	7.57E+01	7.43E+01
2001	7,415	100.0				7.27E+01	7.56E+01	7.42E+01
2002	7,676	100.0				7.53E+01	7.82E+01	7.68E+01
2003	8,268	100.0				8.12E+01	8.42E+01	8.27E+01
2004	8,426	100.3	8.59E+01	8.37E+01	8.82E+01	8.25E+01	8.56E+01	8.40E+01
2005	8,503	100.0	8.57E+01	8.38E+01	8.76E+01	8.35E+01	8.66E+01	8.50E+01
2006	8,592	100.0	8.55E+01	8.40E+01	8.71E+01	8.44E+01	8.75E+01	8.59E+01
2007	8,756	100.0	8.54E+01	8.40E+01	8.67E+01	8.60E+01	8.91E+01	8.76E+01
2008	8,699	100.3	8.52E+01	8.40E+01	8.64E+01	8.52E+01	8.83E+01	8.67E+01
2009	8,563	100.0	8.50E+01	8.38E+01	8.62E+01	8.41E+01	8.72E+01	8.56E+01
2010	8,533	100.0	8.48E+01	8.35E+01	8.62E+01	8.38E+01	8.69E+01	8.53E+01
2011	8,329	100.0	8.47E+01	8.31E+01	8.63E+01	8.18E+01	8.48E+01	8.33E+01
2012	8,273	100.3	8.45E+01	8.26E+01	8.64E+01	8.10E+01	8.40E+01	8.25E+01
2013	8,389	98.6	8.43E+01	8.21E+01	8.66E+01	8.36E+01	8.66E+01	8.51E+01
Total	130,448	1,599.7						

Table 26. Plot data for Figure 16, normally running MDP run hours trend.

			Regression Curve Data Points			Plot Trend Error Bar Points		
FY	Run Hours	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	2,830,563	100.0				2.83E+04	2.83E+04	2.83E+04
1999	2,915,640	100.0				2.91E+04	2.92E+04	2.92E+04
2000	2,940,264	100.3				2.93E+04	2.94E+04	2.93E+04
2001	2,946,525	100.0				2.94E+04	2.95E+04	2.95E+04
2002	2,991,219	100.0				2.99E+04	2.99E+04	2.99E+04
2003	3,096,042	100.0				3.09E+04	3.10E+04	3.10E+04
2004	3,158,838	100.3	3.14E+04	3.12E+04	3.15E+04	3.15E+04	3.15E+04	3.15E+04
2005	3,141,350	100.0	3.14E+04	3.13E+04	3.15E+04	3.14E+04	3.14E+04	3.14E+04
2006	3,128,787	100.0	3.14E+04	3.13E+04	3.15E+04	3.13E+04	3.13E+04	3.13E+04
2007	3,128,657	100.0	3.14E+04	3.13E+04	3.15E+04	3.13E+04	3.13E+04	3.13E+04
2008	3,156,337	100.3	3.14E+04	3.13E+04	3.15E+04	3.15E+04	3.15E+04	3.15E+04
2009	3,145,421	100.0	3.14E+04	3.13E+04	3.15E+04	3.14E+04	3.15E+04	3.15E+04
2010	3,144,510	100.0	3.14E+04	3.13E+04	3.15E+04	3.14E+04	3.15E+04	3.14E+04
2011	3,142,411	100.0	3.14E+04	3.13E+04	3.15E+04	3.14E+04	3.15E+04	3.14E+04
2012	3,138,812	100.3	3.14E+04	3.13E+04	3.16E+04	3.13E+04	3.13E+04	3.13E+04
2013	3,111,323	98.6	3.14E+04	3.13E+04	3.16E+04	3.15E+04	3.16E+04	3.16E+04
Total	49,116,700	1,599.7						

Table 27. Plot data for Figure 17, normally running MDP FTS events trend.

			Regression Curve Data Points			Plot Trend Error Bar Points		
FY	**Failures**	**Reactor Years**	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
1998	11	100.0				6.16E-02	1.77E-01	1.08E-01
1999	13	100.0				7.60E-02	2.00E-01	1.27E-01
2000	5	100.3				2.15E-02	1.05E-01	5.17E-02
2001	9	100.0				4.76E-02	1.54E-01	8.94E-02
2002	12	100.0				6.88E-02	1.89E-01	1.18E-01
2003	14	100.0				8.34E-02	2.12E-01	1.37E-01
2004	10	100.3	9.78E-02	6.98E-02	1.37E-01	5.44E-02	1.65E-01	9.86E-02
2005	6	100.0	9.29E-02	6.98E-02	1.24E-01	2.77E-02	1.18E-01	6.12E-02
2006	12	100.0	8.82E-02	6.93E-02	1.12E-01	6.88E-02	1.89E-01	1.18E-01
2007	9	100.0	8.37E-02	6.80E-02	1.03E-01	4.76E-02	1.54E-01	8.94E-02
2008	9	100.3	7.94E-02	6.55E-02	9.63E-02	4.75E-02	1.53E-01	8.92E-02
2009	8	100.0	7.54E-02	6.16E-02	9.23E-02	4.08E-02	1.42E-01	8.00E-02
2010	8	100.0	7.16E-02	5.68E-02	9.02E-02	4.08E-02	1.42E-01	8.00E-02
2011	6	100.0	6.79E-02	5.17E-02	8.93E-02	2.77E-02	1.18E-01	6.12E-02
2012	8	100.3	6.45E-02	4.66E-02	8.93E-02	4.07E-02	1.42E-01	7.98E-02
2013	4	98.6	6.12E-02	4.18E-02	8.97E-02	1.59E-02	9.39E-02	4.29E-02
Total	144	1,599.7						

Table 28. Plot data for Figure 18, normally running MDP FTR events trend.

FY	Failures	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	22	100.0				1.46E-01	3.06E-01	2.15E-01
1999	16	100.0				9.98E-02	2.38E-01	1.58E-01
2000	24	100.3				1.62E-01	3.28E-01	2.34E-01
2001	16	100.0				9.98E-02	2.38E-01	1.58E-01
2002	14	100.0				8.47E-02	2.15E-01	1.39E-01
2003	10	100.0				5.55E-02	1.68E-01	1.00E-01
2004	8	100.3	9.45E-02	5.15E-02	1.73E-01	4.14E-02	1.44E-01	8.11E-02
2005	6	100.0	9.61E-02	5.74E-02	1.61E-01	2.82E-02	1.20E-01	6.22E-02
2006	10	100.0	9.77E-02	6.33E-02	1.51E-01	5.55E-02	1.68E-01	1.00E-01
2007	11	100.0	9.94E-02	6.88E-02	1.44E-01	6.26E-02	1.80E-01	1.10E-01
2008	15	100.3	1.01E-01	7.29E-02	1.40E-01	9.20E-02	2.26E-01	1.48E-01
2009	25	100.0	1.03E-01	7.45E-02	1.42E-01	1.70E-01	3.40E-01	2.44E-01
2010	7	100.0	1.05E-01	7.33E-02	1.49E-01	3.47E-02	1.32E-01	7.18E-02
2011	9	100.0	1.06E-01	7.02E-02	1.61E-01	4.84E-02	1.56E-01	9.09E-02
2012	10	100.3	1.08E-01	6.60E-02	1.78E-01	5.53E-02	1.68E-01	1.00E-01
2013	9	98.6	1.10E-01	6.13E-02	1.97E-01	4.91E-02	1.58E-01	9.21E-02
Total	212	1,599.7						

9. REFERENCES

1. Nuclear Regulatory Commission, *Component Reliability Data Sheets Update 2010*, January 2012, http://nrcoe.inl.gov/resultsdb/publicdocs/AvgPerf/ComponentReliabilityDataSheets2010.pdf

2. S.A. Eide et al., *Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants*, NUREG/CR-6928, Nuclear Regulatory Commission, February 2007.

3. C.L. Atwood, et al. *Handbook of Parameter Estimation for Probabilistic Risk Assessment*, NUREG/CR-6823, September 2003.