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Enhanced Component Performance Study: Motor-Driven Pumps 1998–2016

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ABSTRACT

This report presents an enhanced performance evaluation of motor-driven pumps (MDPs) at U.S. commercial nuclear power plants. The data used in this study are based on the operating experience failure reports from calendar year 1998 through 2016 as reported in the Institute of Nuclear Power Operations (INPO) Consolidated Events Database (ICES). The MDP failure modes considered for standby systems are failure to start, failure to run less than or equal to one hour, and failure to run more than one hour; for normally running systems, the failure modes considered are failure to start and failure to run. An eight hour 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 study period. Highly statistically significant increasing trend was identified in normally running MDP run hours per reactor year.

CONTENTS

FIGURES

TABLES

ACRONYMS

AFW	auxiliary feed water
BWR	boiling water reactor
CCW	closed cooling water
CNID	constrained non-informative prior distribution
CY	calendar year
EPIX	Equipment Performance and Information Exchange Database
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
HCS	high pressure core spray
HPI	high pressure safety injection
ICES	INPO Consolidated Events Database
INPO	Institute of Nuclear Power Operations
MDP	motor-driven pump
MSPI	Mitigating Systems Performance Index
NPRDS	Nuclear Plant Reliability Data System
OLS	ordinary least squares
PRA	probabilistic risk assessment
PWR	pressurized water reactor
RHR	residual heat removal
UA	unavailability

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1. INTRODUCTION

This report presents a performance evaluation of motor-driven pumps (MDPs) at U.S. commercial nuclear power plants from 1998 through 2016. The objective of the updated component performance studies is to obtain annual performance trends of failure rates and probabilities and to present an analysis of factors that could influence the component trends. This year's update has two changes from previous year's updates: 1) This year's results are based on calendar year (CY) instead of fiscal year (FY), and 2) The failure events included in this update are now all considered "hard" failures, which is to say the p-values indicating the likelihood the component would have failed during a 24-hour mission are now all 1.0. Previous updates include lesser p-values indicating a degraded condition that probably would have caused failure during a 24-hour mission.

The enhanced component performance studies are conducted for the following component types: MDPs, turbine-driven pumps (TDPs), motor-operated valves (MOVs), air-operated valves (AOVs), and emergency diesel generators (EDGs). The MDP performance analysis was originally published as NUREG-1715, Volume 2 in June 2000 [1] and then updated annually in a series of reports, with the last one being documented in INL/EXT-16-37937, *Enhanced Component Performance Study: Motor-Driven Pumps 1998-2014* [2]. The Nuclear Regulatory Commission (NRC) Reactor Operational Experience Results and Databases web page provides the links to the historical and current results of component performance studies (http://nrcoe.inl.gov/resultsdb/CompPerf). An overview of the trending methods, glossary of terms, and abbreviations is documented in the paper Overview and Reference [3] that can also be found in the same web page.

The data used in this study are based on the operating experience failure reports from Institute of Nuclear Power Operations (INPO) Consolidated Events Database (ICES), formerly the Equipment Performance and Information Exchange Database (EPIX) [4]. Maintenance unavailability (UA) performance data comes from the Reactor Oversight Program Mitigating Systems Performance Index (MSPI) [5] and ICES. Previously, the study relied on operating experience obtained from licensee event reports, Nuclear Plant Reliability Data System (NPRDS), and ICES. The ICES database (which includes the MSPI designated devices as a subset) 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 in current ICES database is much larger than the population used in the previous study.

MDPs are categorized as either standby or normally running. The MDP failure modes considered for standby systems are: failure to start (FTS), failure to run less than or equal to one hour (FTR≤1H), and failure to run greater than one hour (FTR>1H). The MDP failure modes considered for normally running systems are: FTS, and failure-to-run (FTR). Annual failure probabilities (failures per demand) are provided for FTS and FTR≤1H events. Annual failure rates (failures per run hour) are provided for FTR > 1H and FTR events. MDP train maintenance unavailability probabilities are also considered. In addition to the presentation of the component failure mode data and the UA data, an 8-hour total unreliability is calculated and trended. Each of the estimates is trended for the most recent 10-year period while yearly estimates are provided for the entire study period.

While this report provides an overview of operational data and evaluate component performance over time, it makes no attempt to estimate values for use in probabilistic risk assessments (PRAs). The 2015 Component Reliability Update [6], which is an update to NUREG/CR-6928, *Industry-Average Performance for Components and Initiating Events at U.S Commercial Nuclear Power Plants* [7], reports the MDP unreliability and UA estimates for PRA. Estimates from that report are included herein, for comparison. These estimates are labelled “2015 Update” (or “Update 2015”) in the associated tables and figures.

Section 2 of this report presents the summary of findings from the study, with particular interest in the existence of any statistically significant increasing or decreasing trends in component performances. Section 3 provides annual estimates of failure probabilities and rates related to MDPs as well as the trending of the estimates. Section 4 provides MDP train UA estimates and their trends. Section 5 estimates the annual total unreliability and the trends for MDP. Section 6 presents various engineering analyses performed for MDP such as the trend for demands/run hours per plant reactor year, the trend for failures per plant reactor year, and the breakdown of MDP failures by sub-components, failure causes, detection methods, and recovery possibility, etc. A comparison of ICES MDP unplanned demand results with the industry-average results for standby MDPs is also conducted in Section 6 in order to determine whether the current data are consistent with the estimated values used in PRA. Section 7 provides the MDP assembly information. Section 8 presents the plot data for various figures in previous sections.

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.

2.1 Increasing Trends

2.1.1 Extremely Statistically Significant

- None.

2.1.2 Highly Statistically Significant

- A highly statistically significant increasing trend was identified for frequency of run hours (hours per reactor year) for normally running MDPs (see Figure 16).

2.1.3 Statistically Significant

- None

2.2 Decreasing Trends

2.2.1 Extremely Statistically Significant

- None

2.2.2 Highly Statistically Significant

- None

2.2.3 Statistically Significant

- None

2.3 Consistency Check Results

An ongoing concern in the nuclear risk assessment field is whether industry failure rate estimates that are largely derived from test data adequately predict component performance during unplanned (ESF) demands. Section 6.3 provides the results of the consistency check between ESF detected failure observations and failure predictions based on the industry-average failure rate estimates. The FTS, FTR≤ 1H, and FTR>1H failure observations on ESF demand are shown to fall within the uncertainty estimates of the industry-average failure rate distributions.

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 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 NUREG/CR-6823 [8], 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 MDPs from Reference [6], or the 2015 Update. The 2015 Update results are provided for comparison purposes and are important because they are intended for use in PRA. The results in this section demonstrate the extent to which the 2015 Update results remain suitable estimates for use in PRA.

The MDPs are assumed to operate both when the reactor is critical and during shutdown periods. The number of MDPs in operation is the number that have been in operation at some time during the study period. So new devices put in service during the period are included, as are devices that were in service at one time but have since been removed from service. All demand types are considered—testing, non-testing, and, as applicable, ESF demands.

Table 1. MDP systems.

System	Description	Total	Standby	Normally Running
AFW	Auxiliary feedwater	128	128	
CCW	Component cooling water	301		301
CDS	Condensate system	143		143
CRD	Control rod drive	52	9	43
CSR	Containment spray recirculation	157	157	
CVC	Chemical and volume control	8		8
HCS	High pressure core spray	9	9	
HPI	High pressure injection	168	168	
LCS	Low pressure core spray	75	70	5
MFW	Main feedwater	44		44
RHR	Residual Heat Removal (LCI in BWRs; LPI in PWRs)	293	293	
SWN	Normally operating service water	106		106
SWS	Standby service water	447	447	
	Total	1931	1281	650

Table 2. Industry-wide distributions of p (failure probability) and λ (hourly rate) for MDPs, from the 2015 Update

Operation	Failure Mode	5%	Median	Mean	95%	Distribution Type	α	β
Standby	FTS	1.70E-4	6.87E-4	7.96E-4	1.80E-3	Beta	2.33	2.92E+03
	FTR≤1H	3.36E-6	7.83E-5	1.25E-4	4.08E-4	Gamma	0.80	6.34E+03
	FTR>1H	1.37E-7	6.31E-6	1.15E-5	4.07E-5	Gamma	0.63	5.49E+04
Running/ Alternating	FTS	2.73E-4	9.69E-4	1.10E-3	2.38E-3	Beta	2.71	2.46E+03
	FTR	1.10E-6	3.42E-6	3.81E-6	7.85E-6	Gamma	3.21	8.42E+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–Figure 3. The data for the trend plots are provided in Table 11 to Table 13, respectively. 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 provided in Table 14 and Table 15, respectively.

The failure probability and failure rate estimates in the plots were obtained from a Bayesian update process. The means from the posterior distributions were plotted for each year. The 5th and 95th percentiles from the posterior distributions are also provided and give an indication of the relative uncertainty in the estimated parameters from year to year. 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 sometimes strongly influenced by the prior distribution. In each plot, a relatively "weak" constrained non-informative prior distribution (CNID) is used, which has large bounds [8]. The mean of such a prior distribution is the number of failures plus 0.5 divided by the number of demands plus 1.0 (for probabilities) or reactor hours (for rates).

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 bands 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 a trend exists. 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, this study uses the "Michelin Guide" scale: p-value < 0.05 (statistically significant), p-value < 0.01 (highly statistically significant); p-value < 0.001 (extremely statistically significant).

The regression methods are all based on "ordinary least squares" (OLS); which minimizes the square of the vertical distance between the annual data points and the regression line. The p-values assume normal distributions for the data in each year, with a constant variance across the years. In the case where the data involve failure counts, the method of iterative reweighing accounts for the fact that count data are not expected to have a constant variance (for example, the variance for Poisson-distributed counts is equal to the expected number of counts). Further information on the trending methods is provided in Section 2 of the Overview and Reference document [3].

A final feature of the trend graphs is that the 2015 Update baseline industry values from Table 2 are shown for comparison.

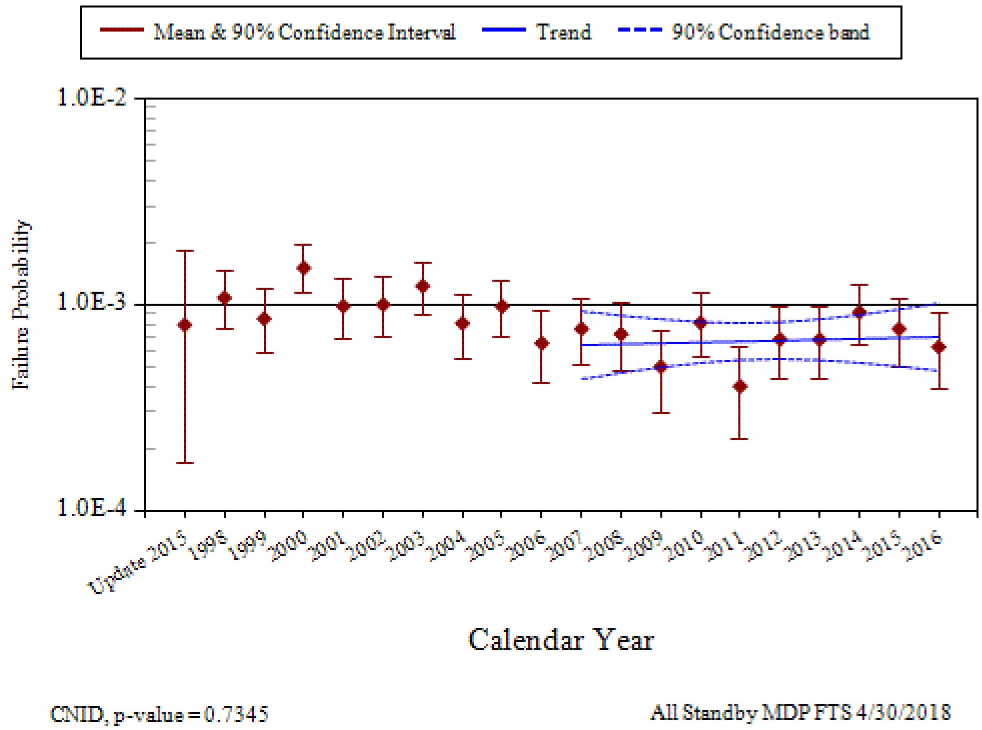


Figure 1. Failure probability estimate trend for standby systems, industry-wide MDP FTS.

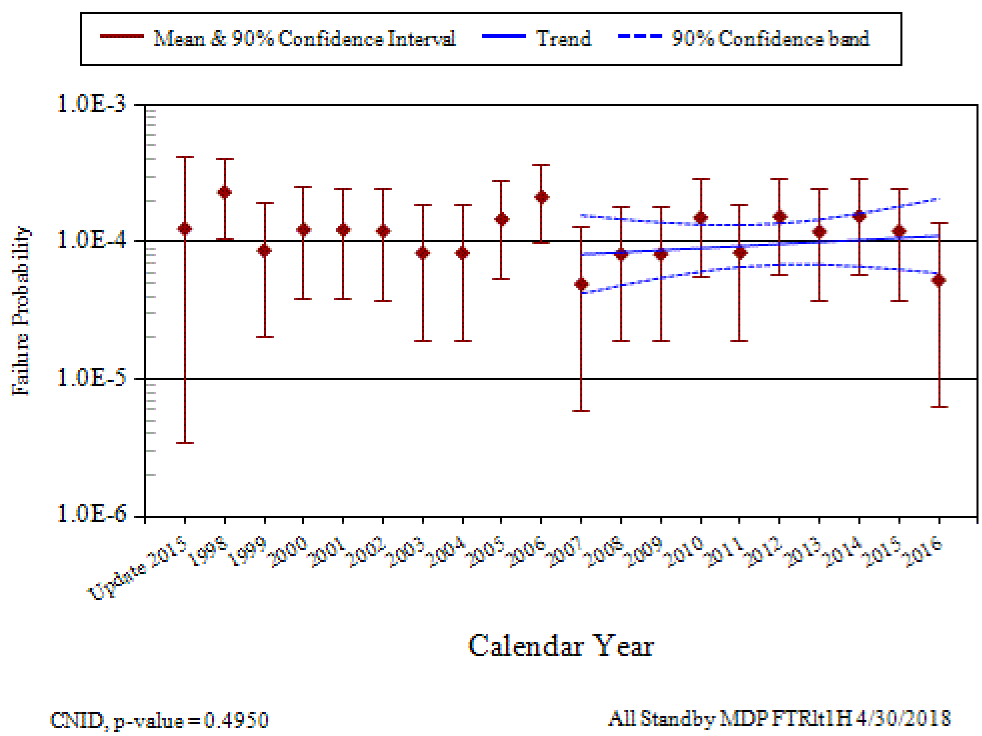


Figure 2. Failure probability estimate trend for standby systems, industry-wide MDP FTR≤1H.

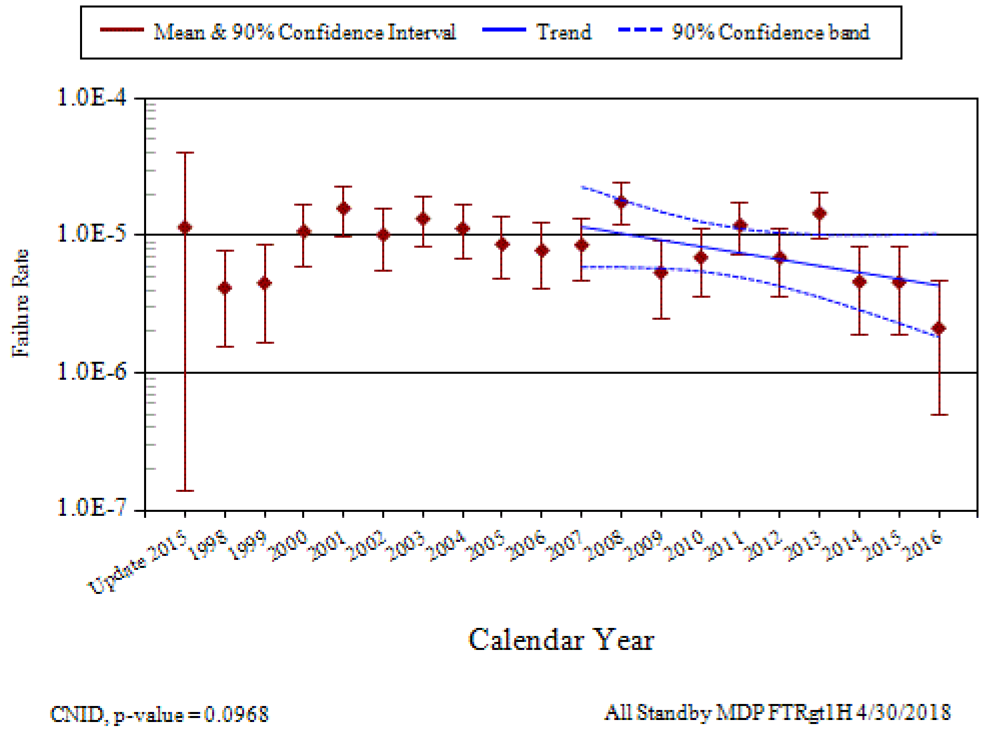


Figure 3. Failure rate estimate trend for standby systems, industry-wide MDP FTR>1H.

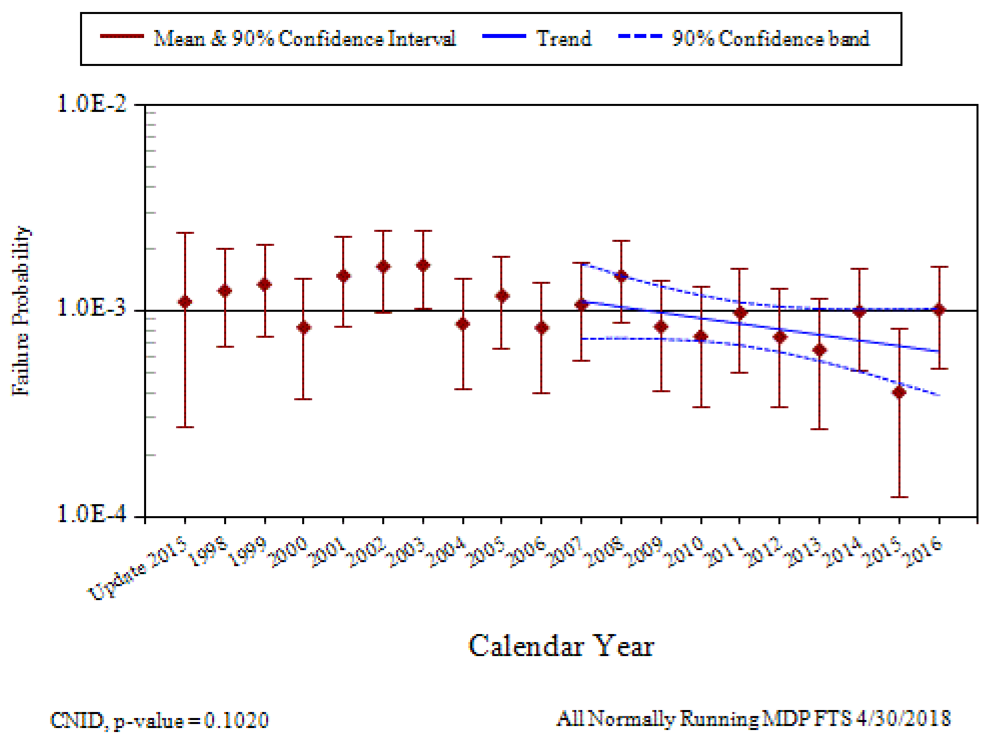


Figure 4. Failure probability estimate trend for normally running systems, industry-wide MDP FTS.

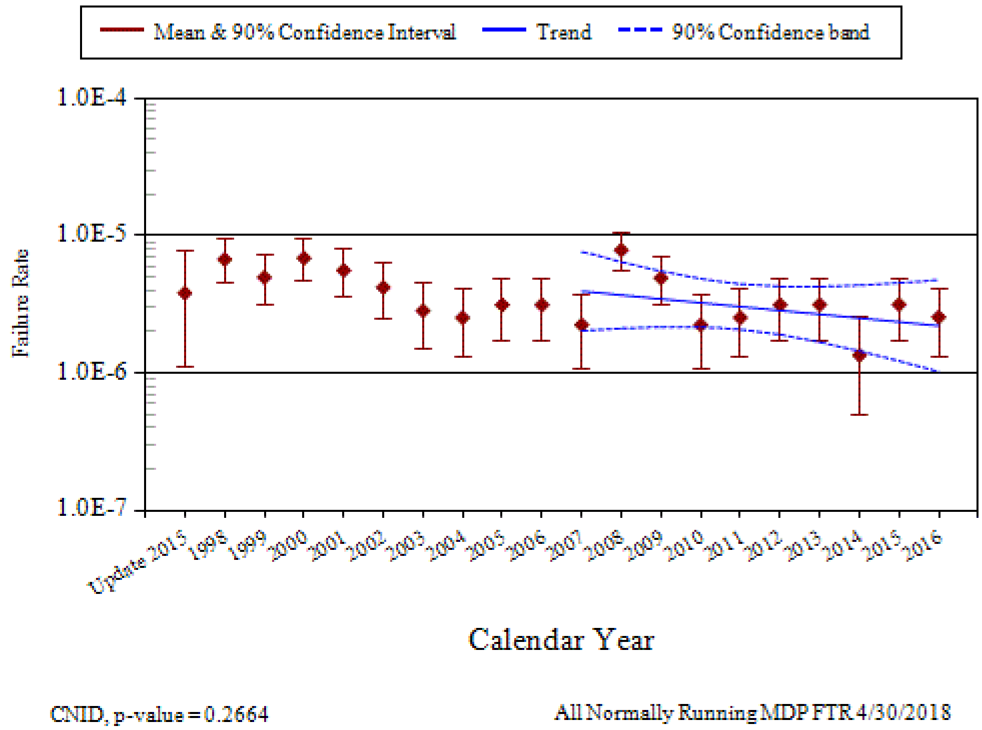


Figure 5. Failure rate estimate trend for normally running systems, industry-wide MDP FTR.

4. UNAVAILABILITY

4.1 Overview

The industry-average test or maintenance UA of MDP trains has been calculated from the operating experience. UA data for MDP trains may 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 the 2015 Update [6] based on UA data from MSPI Basis Documents, covering 2002 to 2015. In the calculations, planned and unplanned unavailable hours for a train are combined.

Table 3. Industry-average unavailability estimates for MDPs, from the 2015 Update.

Description	Distribution	Mean	α	β
Motor Driven Pump Test And Maintenance (ALL)	Normal	6.22E-3	0.0062	0.0045
Motor Driven Pump Test And Maintenance (AFW)	Normal	3.34E-3	0.0033	0.0019
Motor Driven Pump Test And Maintenance (CCW)	Normal	4.46E-3	0.0045	0.0039
Motor Driven Pump Test And Maintenance (ESW)	Normal	9.69E-3	0.0097	0.0117
Motor Driven Pump Test And Maintenance (HCS)	Normal	7.35E-3	0.0073	0.0023
Motor Driven Pump Test And Maintenance (HPI)	Normal	3.32E-3	0.0033	0.0020
Motor Driven Pump Test And Maintenance (RHR-BWR)	Normal	5.90E-3	0.0059	0.0020
Motor Driven Pump Test And Maintenance (RHR-PWR)	Normal	4.81E-3	0.0048	0.0026

4.2 MDP Unavailability Trends

The following presents overall maintenance UA data for the CY 1998–2016 period. Note that these data do not supersede the data in Table 3 for use in risk assessments.

The trend in standby MDP train UA 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 UA data currently analyzed). The trend chart shows the results of using data for each year's component UA data over time. The yearly (1998–2016) UA and reactor critical hour data were obtained from the Reactor Oversight Program (1998 to 2001) and ICES (2002 to 2016) 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. UA 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 UA's 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 [3] provides further information. In the lower left hand corner of the trend figures, the p-value is reported. There is no statistically significant trend identified in the MDP unavailability estimates for the most recent 10-year period.

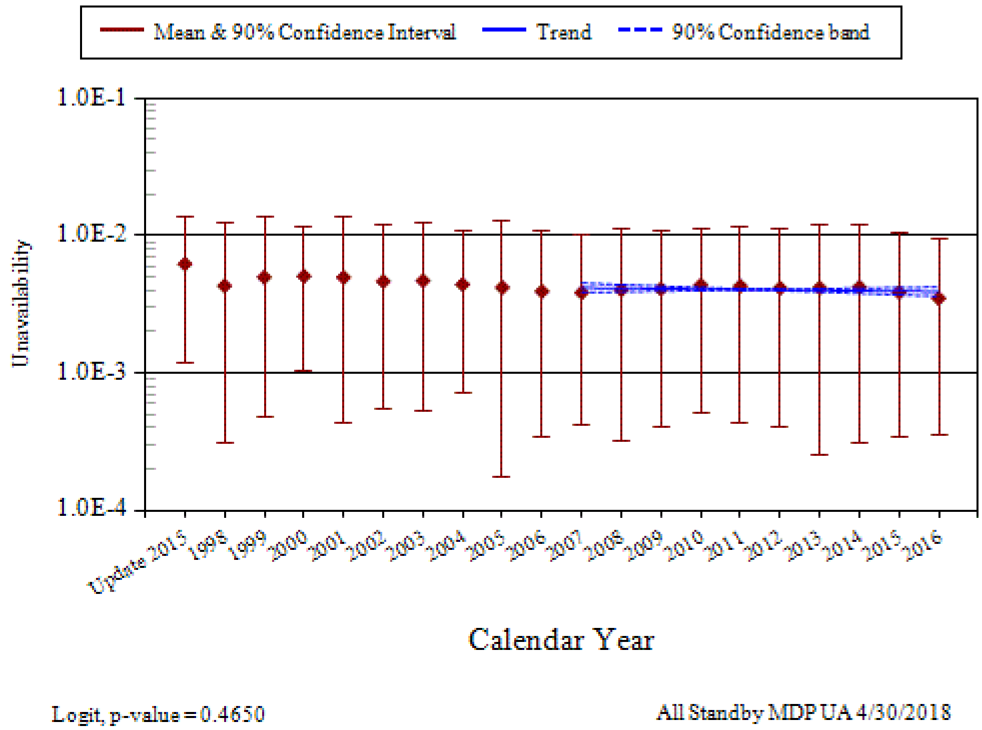


Figure 6. Pooled AFW, HPI, HCS, and RHR MDP UA trend.

5. MDP TOTAL UNRELIABILITY TRENDS

Trends in total component unreliability for standby and normally running systems MDP are shown in Figure 7 and Figure 8, respectively. 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 seven hours and the FTR is calculated for eight hours to provide the results for an eight 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 [3]. In the lower left hand corner of the trend figures, the p-value is reported. There are no statistically significant trends identified in the MDP total unreliability estimates for the most recent 10-year period.

There is no total unreliability estimates in the 2015 Update and so there is no 2015 Update baseline industry values shown in Figure 7 and Figure 8 for comparison purpose.

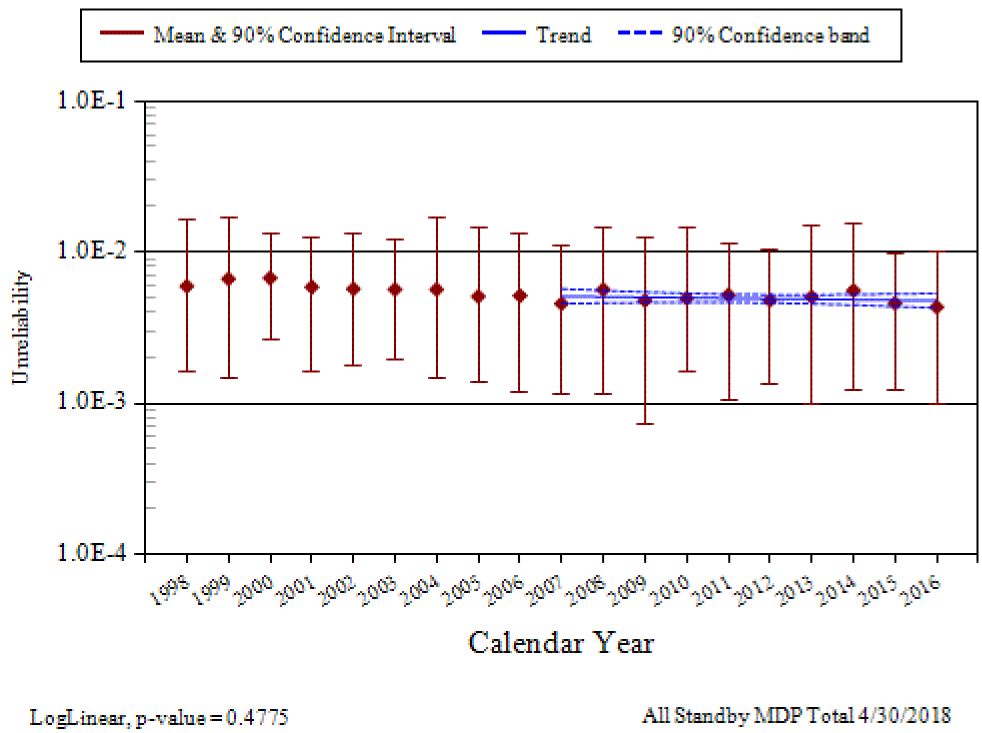


Figure 7. Standby systems, industry-wide MDP total unreliability trend (8-hour mission).

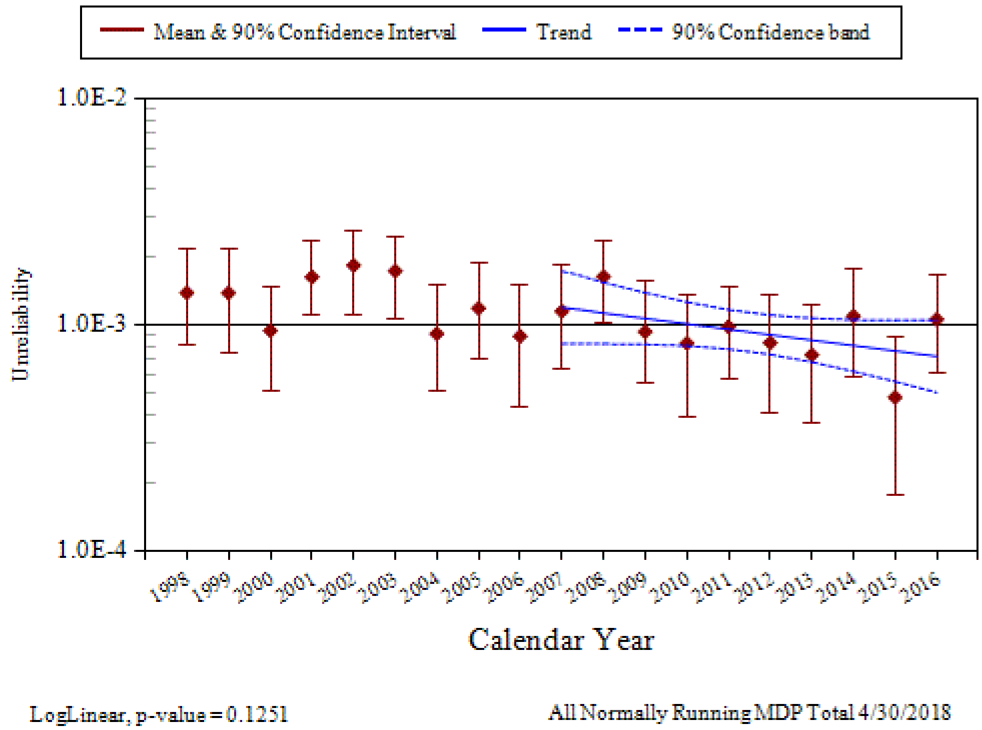


Figure 8. Normally running systems, industry-wide MDP total unreliability trend (eight hour mission).

6. ENGINEERING ANALYSIS

This section presents various engineering analyses performed for MDP. Frequency trends of component failures and demands are presented in Sections 6.1 and 6.2 for standby and normally running MDPs, respectively. The data are normalized by reactor year for plants that have the equipment being trended. A comparison of ICES MDP unplanned demand results with the industry-average results for standby MDPs is presented in Section 6.3 to determine whether the current data are consistent with the estimated values used in PRA. An engineering analysis of MDP failure breakdown by failure mode and other factors is presented in Section 6.4. The factors analyzed are sub-components, failure causes, detection methods, and recovery possibility.

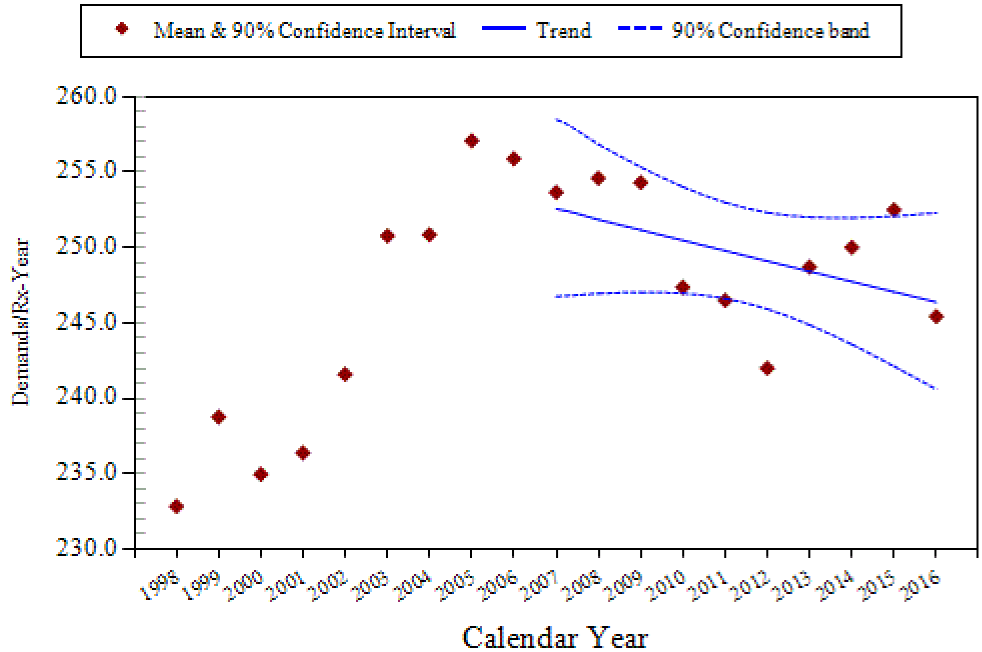
6.1 Standby MDP Engineering Trends

This section and Section 6.2 present frequency trends for MDP failures and demands. The data are normalized by reactor year for plants that report data for the equipment being trended. The trends provide an overview of the demand counts and failure counts associated with each failure mode across the years. Figure 9 shows the trend for standby MDP frequency of start demands (demands per reactor year). Figure 10 shows the trend for standby MDP run hours per reactor year of run ≤ 1H hours. Figure 11 shows the trend for standby MDP run hours per reactor year. Table 19, Table 20, and Table 21 provide the plot data, respectively.

Figure 12 shows the trend for standby MDP frequency of FTS events (i.e., FTS events per reactor year). Figure 13 shows the trend for standby MDP FTR≤1H events per reactor year, and Figure 14 shows the trend for standby MDP FTR events per reactor year. Tables 22, 23, and 24 provide the plot data, respectively. The standby systems from Table 2 are trended together for each figure.

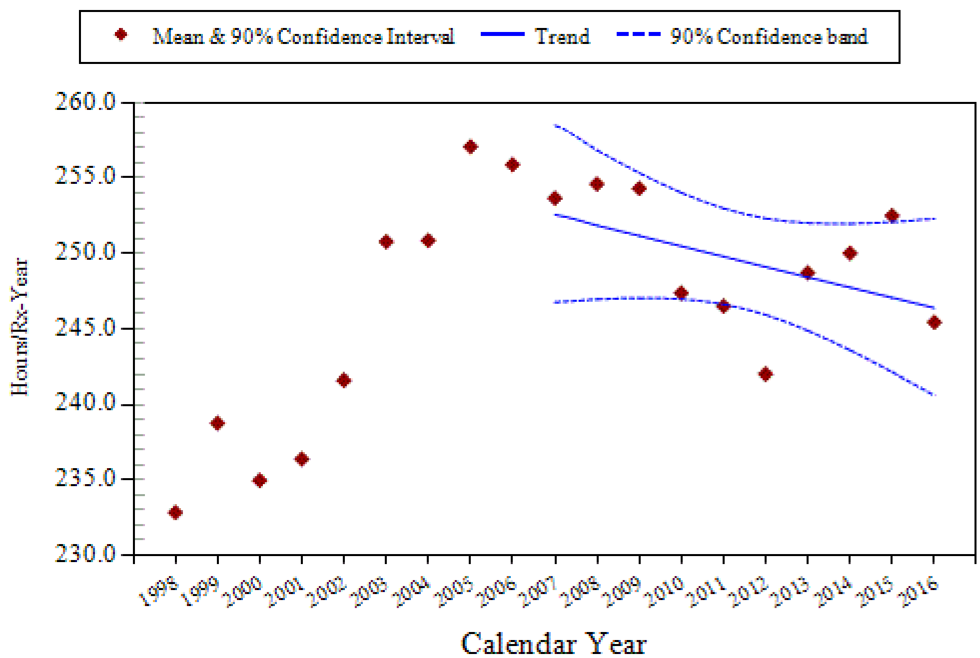
In the lower left hand corner of the above trend figure, the regression p-values are reported. A review of these p-values shows that there are no statistically significant trends existing in the standby MDP engineering trends for the most recent 10-year period.

Table 4 summarizes the standby MDP failure counts by system and year for the FTS failure mode for the most recent 10-year period. Table 5 summarizes the standby MDP failure counts by system and year for the FTR≤1H failure mode. Table 6 summarizes the standby MDP failure counts by system and year for the FTR>1H failure mode.



CNID, p-value = 0.1587 All Standby MDP FTS 4/30/2018

Figure 9. Frequency of start demands (deamnds per reactor year) trend for standby MDPs.



CNID, p-value = 0.1587 All Standby MDP FTRlt1H 4/30/2018

Figure 10. Frequency of run ≤ 1H hours (hours per reactor year) trend for standby MDPs.

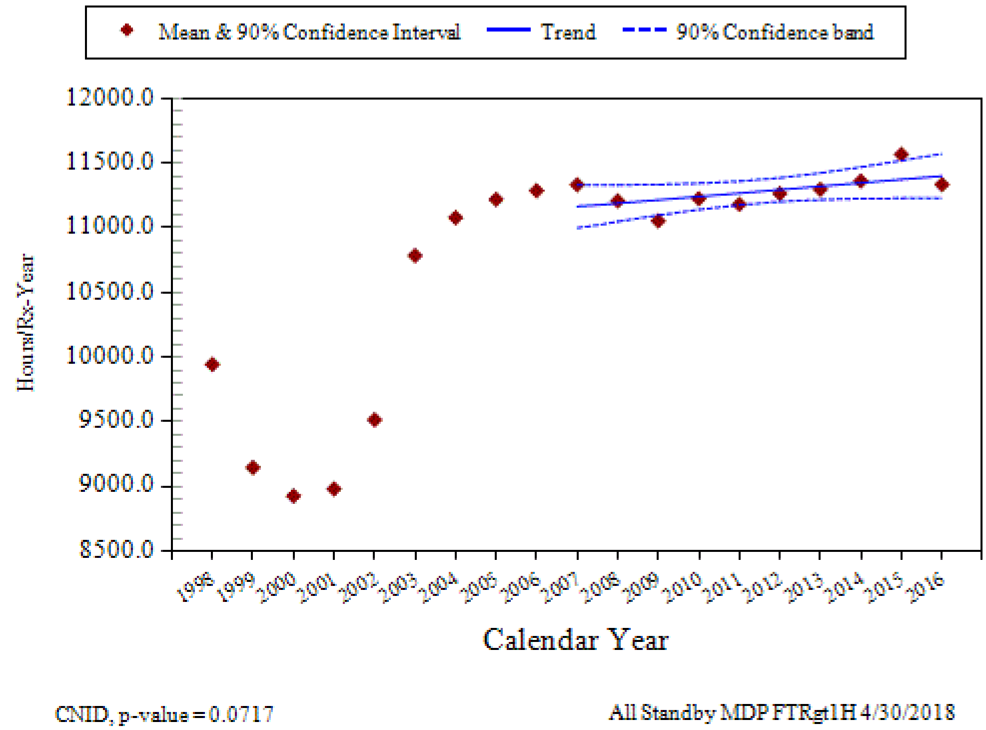


Figure 11. Frequency of run > 1H hours (hours per reactor year) trend for standby MDPs.

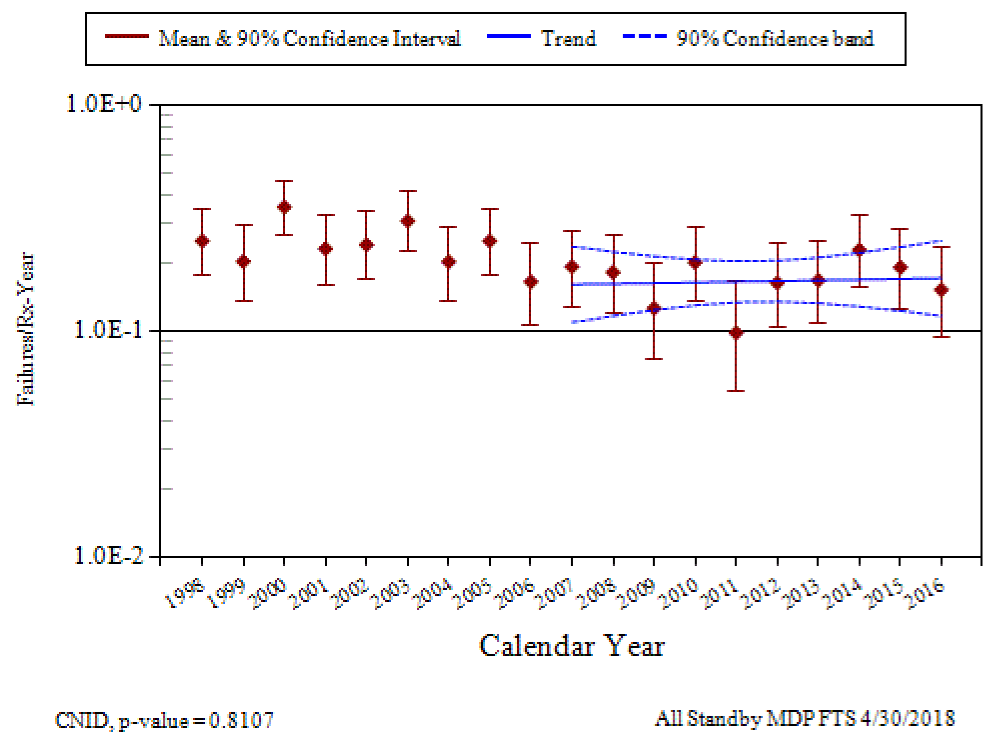


Figure 12. Frequency of FTS events (events per reactor year) trend for standby MDPs.

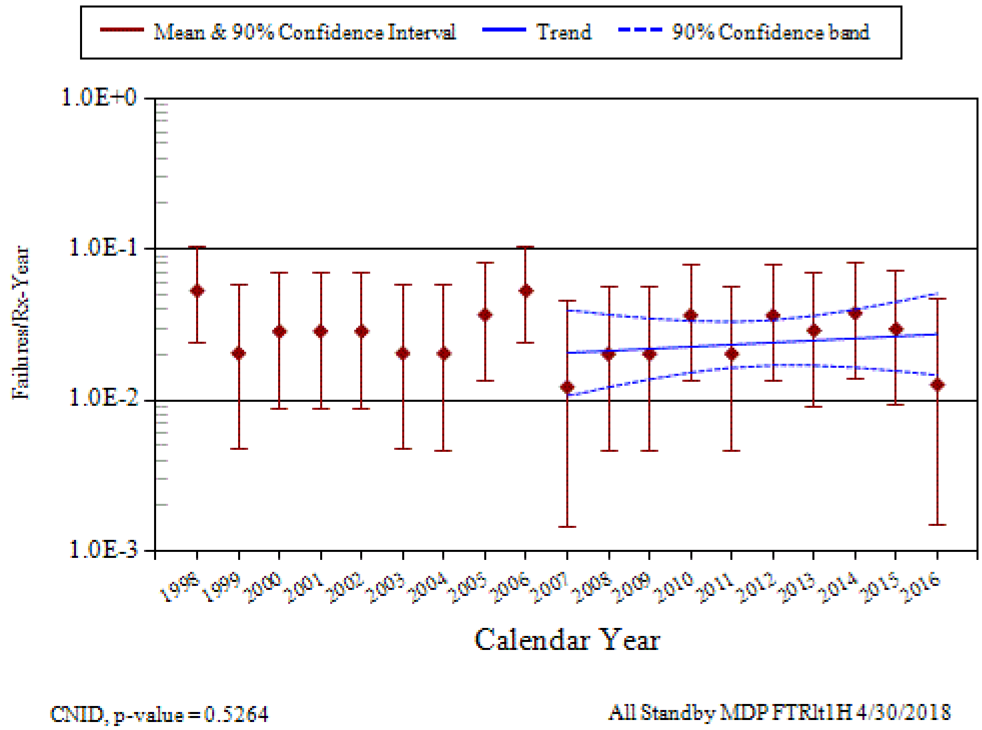


Figure 13. Frequency of FTR≤1H events (events per reactor year) trend for standby MDPs.

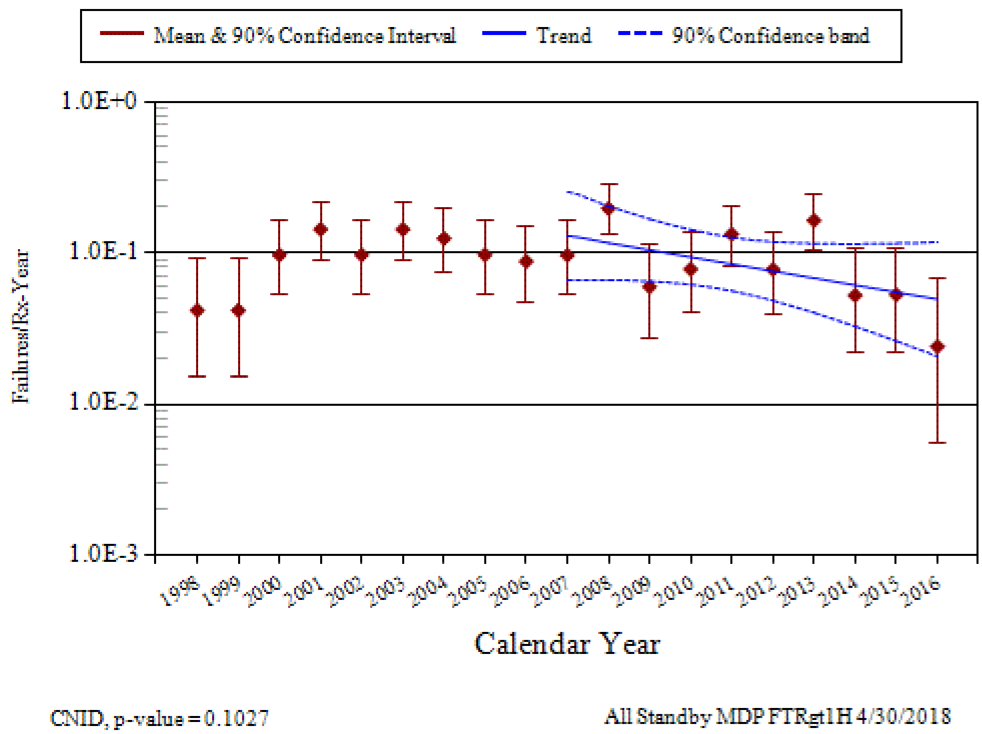


Figure 14. Frequency of FTR>1H events (events per reactor year) trend for standby MDPs.

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

System Code	MDP Count	MDP Percent	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	Percent of Failures
AFW	128	10.0 %	2		1	1	3	4	1	2	4	1	19	10.9 %
CRD	9	0.7 %											0	0.0 %
CSR	157	12.3 %	1			2			1	1	3		8	4.6 %
HCS	9	0.7 %				1							1	0.6 %
HPI	168	13.1 %	4	5	1	6	2	2	3	2	1	1	27	15.5 %
LCS	70	5.5 %		1		2				2	1	2	8	4.6 %
RHR	293	22.9 %	5	3	1	4	1	3	1	1	6	5	30	17.2 %
SWS	447	34.9 %	8	10	10	5	4	8	11	15	4	6	81	46.6 %
Total	1281	100%	20	19	13	21	10	17	17	23	19	15	174	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	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	Percent of Failures
AFW	128	10.0 %				1			2				3	11.5 %
CRD	9	0.7 %											0	0.0 %
CSR	157	12.3 %			1			1					2	7.7 %
HCS	9	0.7 %											0	0.0 %
HPI	168	13.1 %	1		1								2	7.7 %
LCS	70	5.5 %									1		1	3.8 %
RHR	293	22.9 %						2		2			4	15.4 %
SWS	447	34.9 %		2		3	2	1	1	2	2	1	14	53.8 %
Total	1281	100%	1	2	2	4	2	4	3	4	3	1	26	100%

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

System Code	MDP Count	MDP Percent	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	Percent of Failures
AFW	128	10.0 %							3		2	1	6	6.3 %
CRD	9	0.7 %											0	0.0 %
CSR	157	12.3 %		1			1		2				4	4.2 %
HCS	9	0.7 %											0	0.0 %
HPI	168	13.1 %	1	1			1		2	2			7	7.3 %
LCS	70	5.5 %			1	2							3	3.1 %
RHR	293	22.9 %	1	2	1	1	2	3	3		2	1	16	16.7 %
SWS	447	34.9 %	8	17	4	5	10	5	7	3	1		60	62.5 %
Total	1281	100%	10	21	6	8	14	8	17	5	5	2	96	100%

6.2 Normally Running MDP Engineering Trends

Figure 15 shows the trend for normally running MDP frequency of start demands (demands per reactor year). Figure 16 shows the trend for normally running MDP run hours per reactor year. Table 25 and Table 26 provide the plot data, respectively.

Figure 17 shows the trend for normally running MDP frequency of FTS events (i.e., FTS events per reactor year). Figure 18 shows the trend for normally running MDP FTR events per reactor year.

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

In the lower left hand corner of the above trend figure, the regression p-values are reported. A review of these p-values shows that there is a statistically significant increase trend in run hours per reactor year for normally running MDPs for the most recent 10-year period.

Table 7 summarizes the normally running MDP failure counts by system and year for the FTS failure mode for the most recent 10-year period.

Table 8 summarizes the normally running MDP failure counts by system and year for the FTR failure mode.

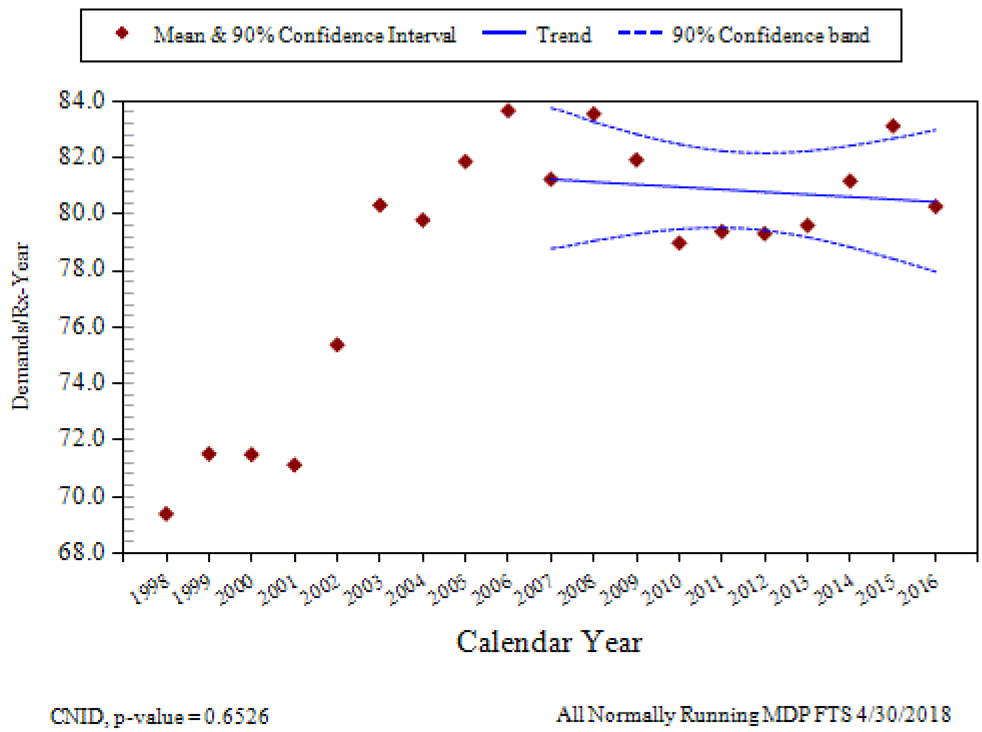


Figure 15. Frequency of start demands (demands per reactor year) trend for normally running MDPs.

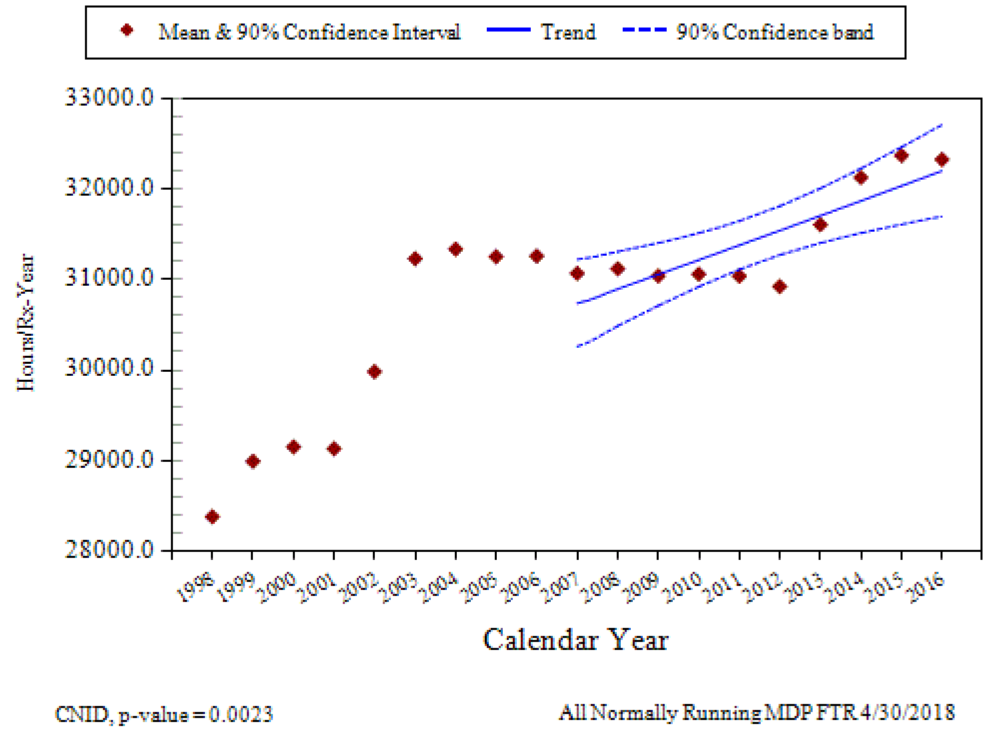


Figure 16. Frequency of run hours (hours per reactor year) trend for normally running MDPs.

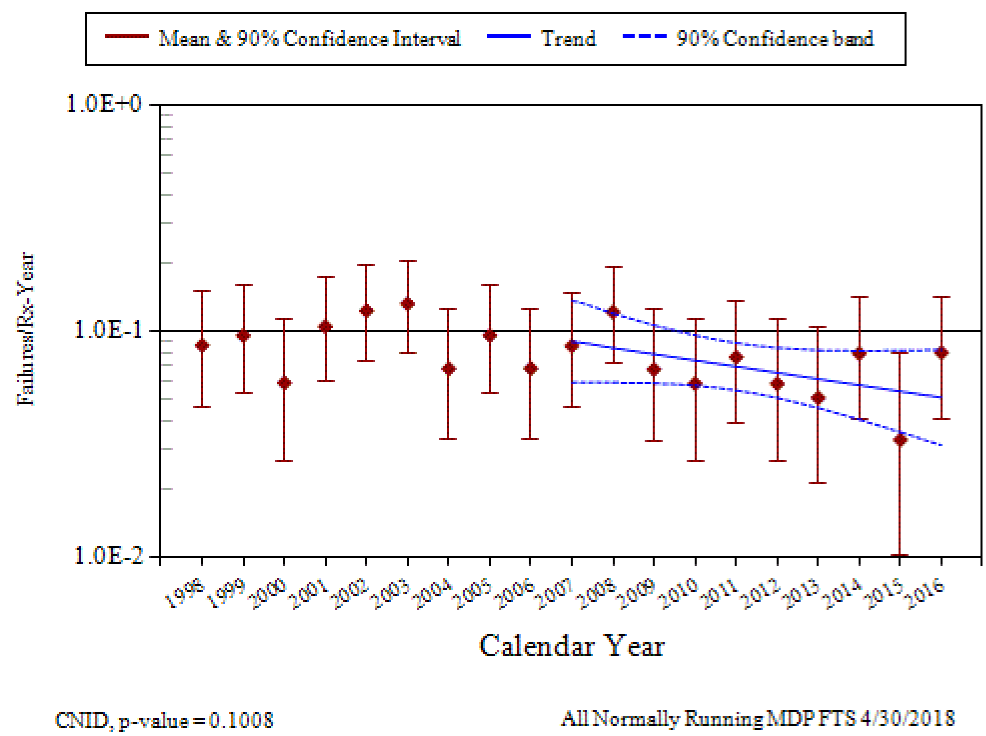


Figure 17. Frequency of FTS events (events per reactor year) trend for normally running MDPs.

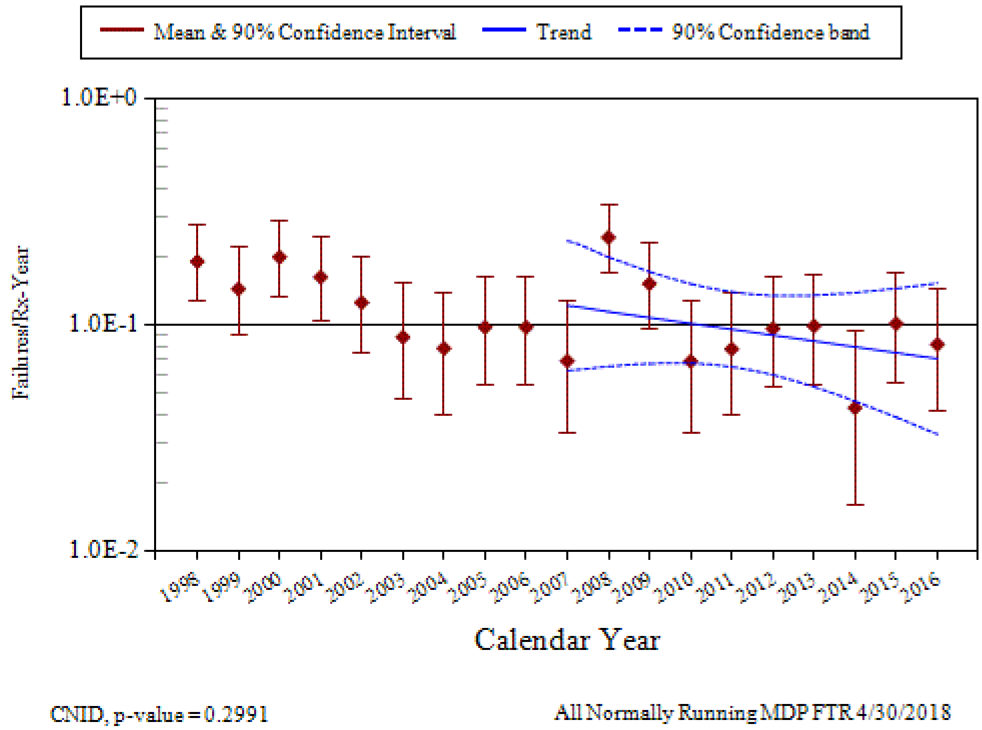


Figure 18. Frequency of FTR events (events per reactor year) trend for normally running MDPs.

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

System Code	MDP Count	MDP Percent	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	Percent of Failures
CCW	301	46.2 %	4	7	5	4	5	1		5		1	32	43.8 %
CDS	143	21.9 %	1			1		2	1	1		3	9	12.3 %
CRD	43	6.6 %	1				1			1			3	4.1 %
CVC	8	1.2 %								1	1	1	3	4.1 %
LCS	5	0.8 %											0	0.0 %
MFW	44	6.7 %	2	3	1		2	1	2		1	1	13	17.8 %
SWN	106	16.3 %	1	3	1	1		2	2		1	2	13	17.8 %
Total	650	100%	9	13	7	6	8	6	5	8	3	8	73	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	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	Percent of Failures
CCW	301	46.2 %	2	5	7	2	1	2	5		4	2	30	28.6 %
CDS	143	21.9 %	1	4	6	3		1	1	2	1	1	20	19.0 %
CRD	43	6.6 %				1	2	4					7	6.7 %
CVC	8	1.2 %											0	0.0 %
LCS	5	0.8 %											0	0.0 %
MFW	44	6.7 %	1	1				1	3	1	1	1	9	8.6 %
SWN	106	16.3 %	3	16	3	1	5	2	1	1	3	4	39	37.1 %
Total	650	100%	7	26	16	7	8	10	10	4	9	8	105	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 produce failure estimates that adequately predict 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 CY 2003 to present since the ESF demand reporting in ICES is inconsistent prior to CY 2003.

The standby MDP ESF unplanned demand data covering CY 2003 through 2016 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 [8].

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 the "Observed Failures" column of Table 9) was compared with this 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.

The consistency checks using unplanned demand data indicate that none of the failure observations are inconsistent with their industry-average distribution from Table 2.

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

Failure Modes	Plants	Demands or Hours	Observed Failures	Expected Failures	Probability of ≥ Failures	Consistent with Industry-Average Performance [a]?
FTS	105	1388	0	1.1	1.00	Yes [b]
FTR≤1H	105	1133	0	0.1	1.00	Yes [c]
FTR>1H	105	24026	1	0.3	0.21	Yes

a. If the probability of observing the actual failures or greater is ≥ 0.05 and ≤ 0.95, then the observed performance is considered to be consistent with the industry-average performance estimate.
b. P(X=0) = 0.40 which is considered consistent with industry experience.
c. P(X=0) = 0.89 which is considered consistent with industry experience.

6.4 MDP Engineering Analysis by Failure Modes

The engineering analysis of the MDP failure breakdown by failure mode and other factors such as sub-components, failure 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. Then the events are further divided by the failure modes and factors such as sub-components, failure causes, detection methods, and recovery possibility. The failure modes are determined after the 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 categories are similar to those used in the CCF database. The driver sub-component has the highest percentage contributions to failures for the FTS failure mode.

The driver sub-component is also the highest contributor for the FTR≤1H and FTR>1H failure modes followed closely by the pump.

MDP failure cause group contributions to the three failure modes are presented in Figure 20. The failure 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 for 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 FTS and FTR is non-testing.

MDP recovery fractions for 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 error or inadequacy	Used when a design error is made.
	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.
	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 action procedure	Used when the correct procedure is not followed or the wrong procedure is followed. For example: when a missed step or incorrect step in a surveillance procedure results in a component failure.
	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 environment	The internal environment led to the failure. Debris/Foreign material as well as an operating medium chemistry issue.
	Set point drift	Used when the cause of a failure is the result of setpoint drift or adjustment.
	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 (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.

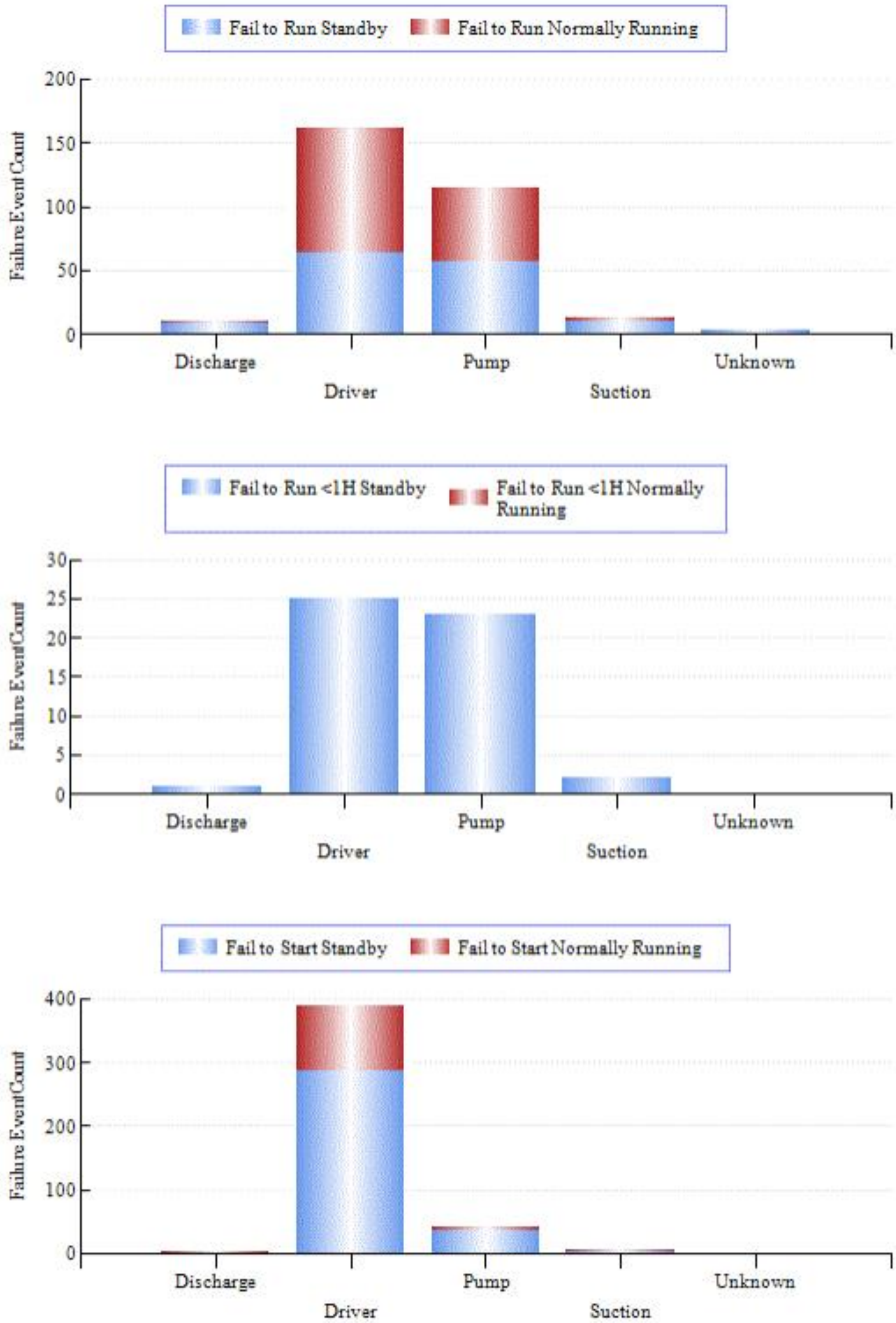


Figure 19. MDP failure breakdown by failure mode and sub component.

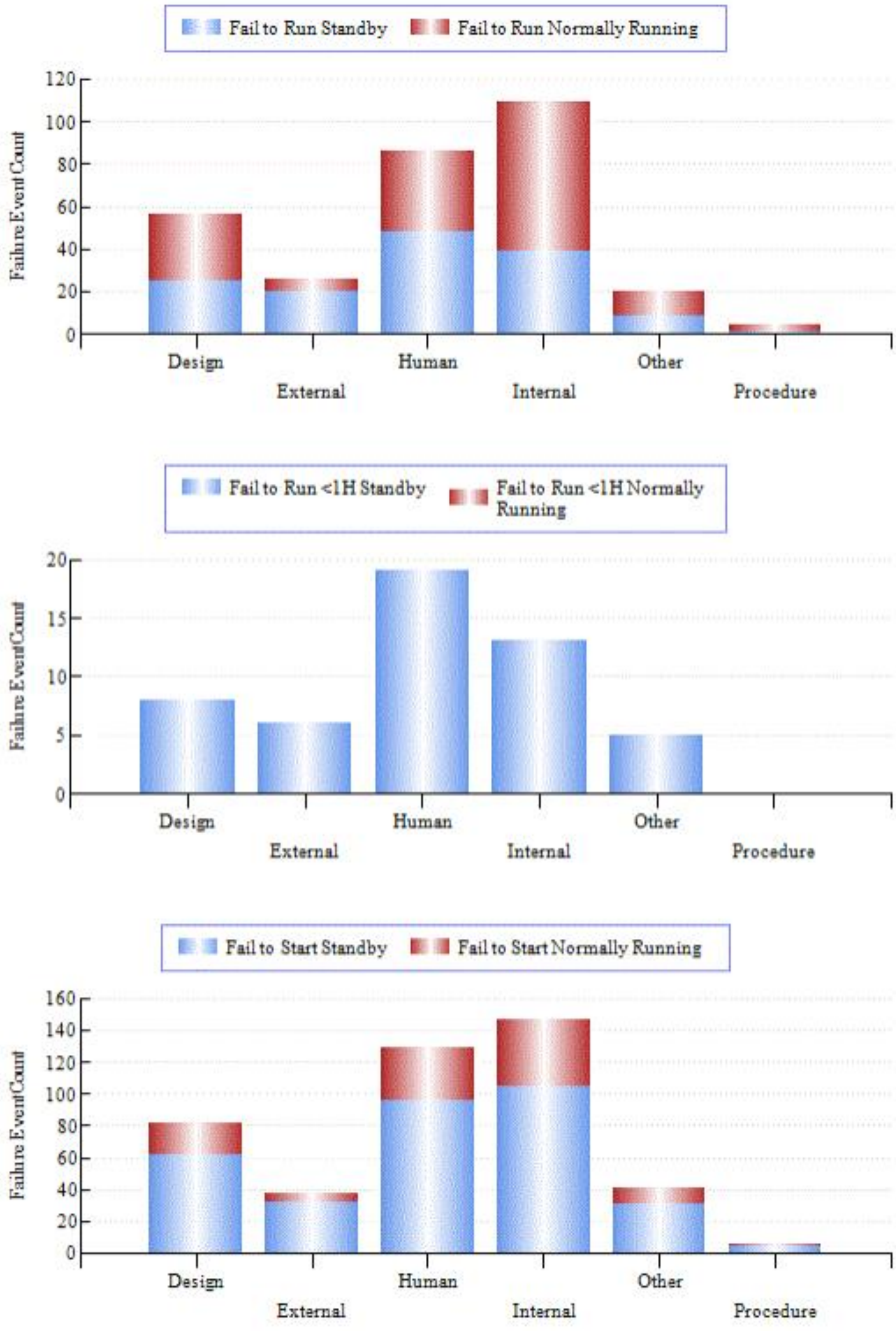


Figure 20. MDP failure breakdown by failure mode and cause group.

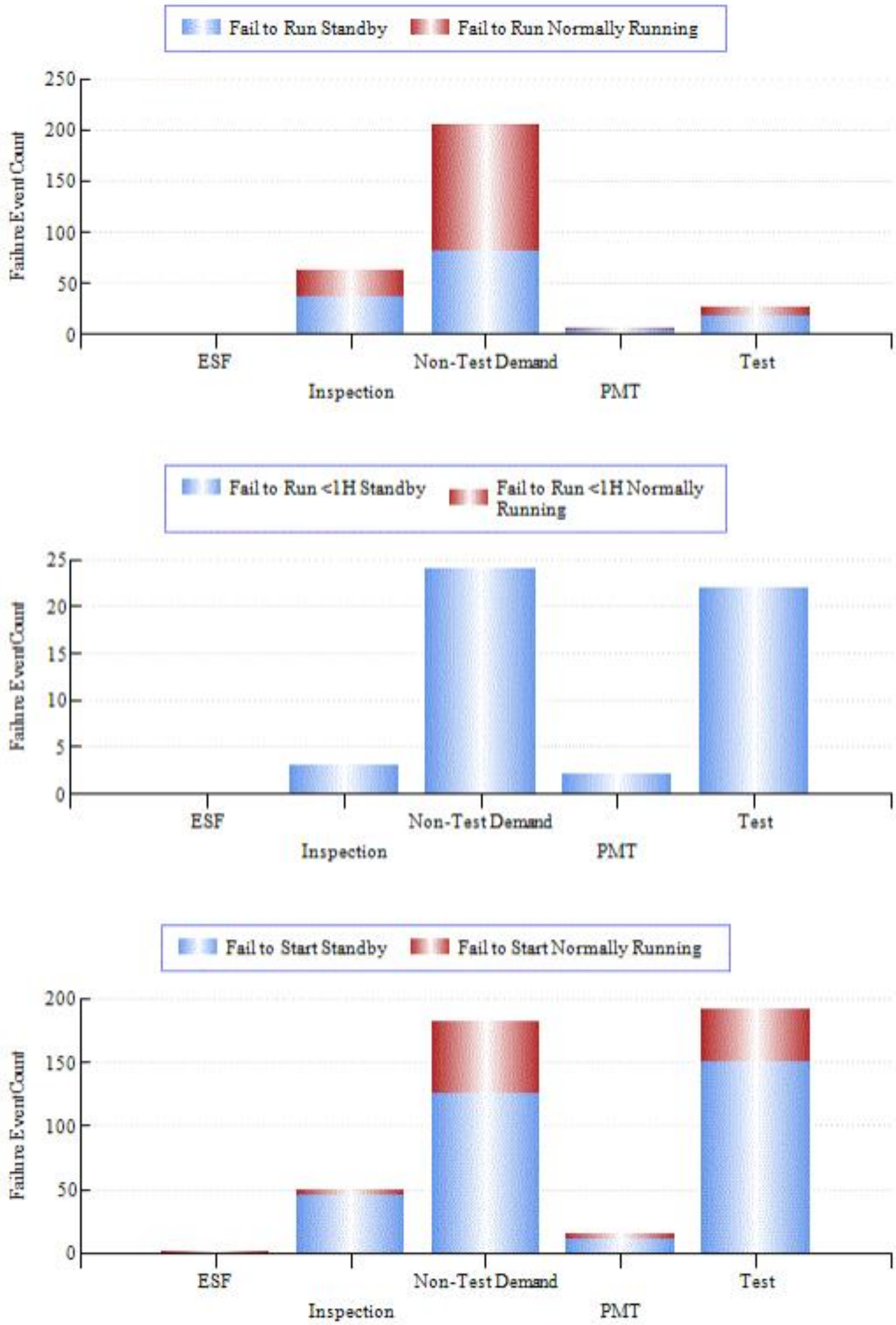


Figure 21. MDP failure breakdown by failure mode and method of detection.

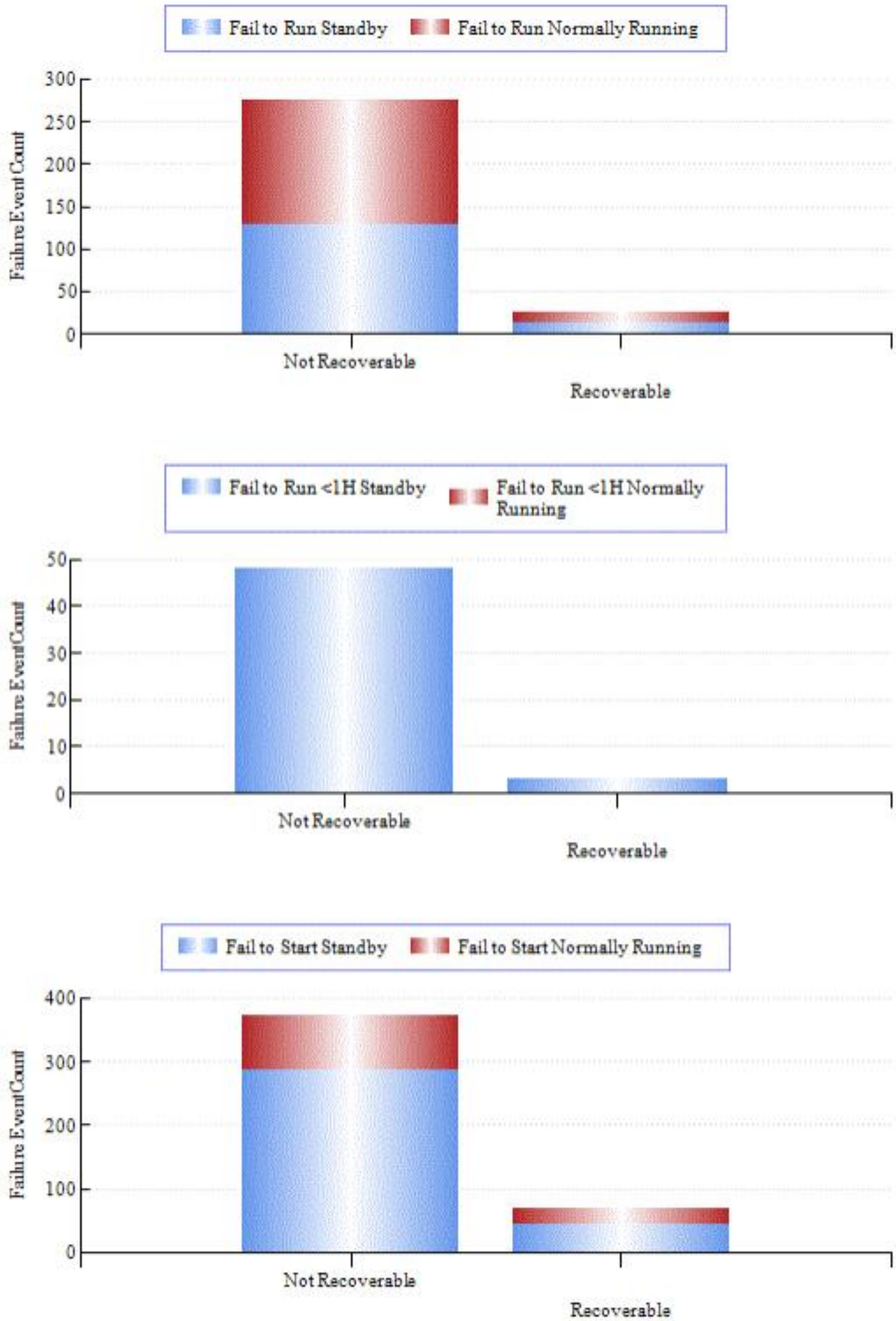


Figure 22. MDP failure breakdown by failure mode and recovery possibility.

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 for standby systems, FTS and FTR for normally running systems. 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 (FTR for normally running components) 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 FTR), 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

In this section, the plot data for Figure 1 to Figure 18 in previous sections are provided in Table 11 to Table 28, respectively.

Table 11. Plot data for Figure 1, standby MDP FTS industry trend.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	**Failures**	**Demands**	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
2015 Update						1.70E-04	1.80E-03	7.96E-04
1998	26	23,983				7.54E-04	1.48E-03	1.07E-03
1999	21	24,593				5.72E-04	1.22E-03	8.49E-04
2000	37	24,268				1.12E-03	1.97E-03	1.50E-03
2001	24	24,348				6.77E-04	1.37E-03	9.77E-04
2002	25	24,885				6.95E-04	1.39E-03	9.95E-04
2003	32	25,830				8.93E-04	1.64E-03	1.22E-03
2004	21	25,910				5.44E-04	1.16E-03	8.07E-04
2005	26	26,480				6.85E-04	1.35E-03	9.74E-04
2006	17	26,356				4.15E-04	9.63E-04	6.46E-04
2007	20	26,282	6.36E-04	4.36E-04	9.27E-04	5.06E-04	1.10E-03	7.59E-04
2008	19	26,552	6.42E-04	4.67E-04	8.84E-04	4.71E-04	1.04E-03	7.15E-04
2009	13	26,449	6.49E-04	4.96E-04	8.48E-04	2.97E-04	7.83E-04	4.97E-04
2010	21	25,726	6.55E-04	5.21E-04	8.23E-04	5.47E-04	1.16E-03	8.13E-04
2011	10	25,636	6.62E-04	5.39E-04	8.13E-04	2.20E-04	6.67E-04	3.98E-04
2012	17	25,239	6.68E-04	5.44E-04	8.21E-04	4.33E-04	1.00E-03	6.74E-04
2013	17	25,261	6.75E-04	5.37E-04	8.48E-04	4.32E-04	1.00E-03	6.73E-04
2014	23	25,001	6.82E-04	5.21E-04	8.91E-04	6.27E-04	1.29E-03	9.13E-04
2015	19	24,998	6.88E-04	5.00E-04	9.47E-04	4.99E-04	1.11E-03	7.58E-04
2016	15	24,302	6.95E-04	4.77E-04	1.01E-03	3.85E-04	9.47E-04	6.19E-04
Total	403	482,096						

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

Year	Failures	Hours	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						3.36E-06	4.08E-04	1.25E-04
1998	6	23,983				1.02E-04	4.34E-04	2.26E-04
1999	2	24,593				1.95E-05	2.39E-04	8.50E-05
2000	3	24,268				3.73E-05	2.91E-04	1.20E-04
2001	3	24,348				3.72E-05	2.90E-04	1.20E-04
2002	3	24,885				3.65E-05	2.85E-04	1.18E-04
2003	2	25,830				1.87E-05	2.29E-04	8.16E-05
2004	2	25,910				1.86E-05	2.29E-04	8.14E-05
2005	4	26,480				5.31E-05	3.14E-04	1.44E-04
2006	6	26,356				9.45E-05	4.01E-04	2.08E-04
2007	1	26,282	8.14E-05	4.24E-05	1.56E-04	5.66E-06	1.78E-04	4.82E-05
2008	2	26,552	8.42E-05	4.84E-05	1.47E-04	1.83E-05	2.24E-04	7.97E-05
2009	2	26,449	8.71E-05	5.47E-05	1.39E-04	1.83E-05	2.25E-04	8.00E-05
2010	4	25,726	9.02E-05	6.07E-05	1.34E-04	5.44E-05	3.22E-04	1.47E-04
2011	2	25,636	9.33E-05	6.57E-05	1.33E-04	1.88E-05	2.31E-04	8.21E-05
2012	4	25,239	9.66E-05	6.83E-05	1.36E-04	5.53E-05	3.27E-04	1.50E-04
2013	3	25,261	9.99E-05	6.83E-05	1.46E-04	3.60E-05	2.81E-04	1.16E-04
2014	4	25,001	1.03E-04	6.63E-05	1.61E-04	5.58E-05	3.30E-04	1.51E-04
2015	3	24,998	1.07E-04	6.31E-05	1.82E-04	3.63E-05	2.84E-04	1.17E-04
2016	1	24,302	1.11E-04	5.93E-05	2.07E-04	6.04E-06	1.90E-04	5.15E-05
Total	57	482,096						

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

Year	Failures	Run Time (hr)	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						1.37E-07	4.07E-05	1.15E-05
1998	4	1,024,127				1.53E-06	9.08E-06	4.15E-06
1999	4	941,977				1.66E-06	9.82E-06	4.49E-06
2000	10	921,897				5.90E-06	1.79E-05	1.07E-05
2001	15	924,957				9.79E-06	2.41E-05	1.57E-05
2002	10	979,998				5.57E-06	1.69E-05	1.01E-05
2003	15	1,110,777				8.24E-06	2.02E-05	1.32E-05
2004	13	1,144,053				6.71E-06	1.77E-05	1.12E-05
2005	10	1,155,478				4.77E-06	1.45E-05	8.64E-06
2006	9	1,162,531				4.14E-06	1.34E-05	7.77E-06
2007	10	1,174,094	1.15E-05	5.91E-06	2.26E-05	4.70E-06	1.43E-05	8.51E-06
2008	21	1,168,734	1.04E-05	5.91E-06	1.82E-05	1.18E-05	2.51E-05	1.75E-05
2009	6	1,149,456	9.29E-06	5.79E-06	1.49E-05	2.44E-06	1.03E-05	5.38E-06
2010	8	1,167,300	8.33E-06	5.49E-06	1.26E-05	3.53E-06	1.23E-05	6.93E-06
2011	14	1,162,841	7.47E-06	4.97E-06	1.12E-05	7.24E-06	1.84E-05	1.19E-05
2012	8	1,174,756	6.70E-06	4.29E-06	1.05E-05	3.51E-06	1.22E-05	6.88E-06
2013	17	1,147,382	6.01E-06	3.56E-06	1.02E-05	9.30E-06	2.16E-05	1.45E-05
2014	5	1,136,095	5.39E-06	2.88E-06	1.01E-05	1.91E-06	9.35E-06	4.60E-06
2015	5	1,145,072	4.83E-06	2.30E-06	1.02E-05	1.90E-06	9.28E-06	4.56E-06
2016	2	1,122,214	4.34E-06	1.82E-06	1.03E-05	4.85E-07	5.95E-06	2.11E-06
Total	186	20,913,740						

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

Year	Failures	Demands	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						2.73E-04	2.38E-03	1.10E-03
1998	9	7,148				6.56E-04	2.12E-03	1.23E-03
1999	10	7,366				7.31E-04	2.22E-03	1.32E-03
2000	6	7,384				3.71E-04	1.57E-03	8.18E-04
2001	11	7,326				8.30E-04	2.39E-03	1.46E-03
2002	13	7,764				9.70E-04	2.55E-03	1.62E-03
2003	14	8,273				1.00E-03	2.54E-03	1.64E-03
2004	7	8,241				4.12E-04	1.57E-03	8.52E-04
2005	10	8,432				6.44E-04	1.95E-03	1.17E-03
2006	7	8,618				3.95E-04	1.50E-03	8.17E-04
2007	9	8,417	1.10E-03	7.29E-04	1.67E-03	5.63E-04	1.82E-03	1.06E-03
2008	13	8,713	1.04E-03	7.31E-04	1.47E-03	8.71E-04	2.29E-03	1.46E-03
2009	7	8,520	9.75E-04	7.26E-04	1.31E-03	4.00E-04	1.52E-03	8.26E-04
2010	6	8,214	9.16E-04	7.10E-04	1.18E-03	3.36E-04	1.42E-03	7.41E-04
2011	8	8,256	8.61E-04	6.77E-04	1.09E-03	4.92E-04	1.71E-03	9.64E-04
2012	6	8,271	8.09E-04	6.28E-04	1.04E-03	3.34E-04	1.41E-03	7.36E-04
2013	5	8,085	7.60E-04	5.68E-04	1.02E-03	2.65E-04	1.29E-03	6.36E-04
2014	8	8,117	7.14E-04	5.05E-04	1.01E-03	5.00E-04	1.74E-03	9.79E-04
2015	3	8,229	6.71E-04	4.45E-04	1.01E-03	1.23E-04	9.62E-04	3.98E-04
2016	8	7,948	6.31E-04	3.89E-04	1.02E-03	5.10E-04	1.77E-03	9.99E-04
Total	160	153,324						

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

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	**Failures**	**Run Time (hr)**	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
2015 Update						1.10E-06	7.85E-06	3.81E-06
1998	20	2,922,986				4.44E-06	9.65E-06	6.67E-06
1999	15	2,986,122				3.07E-06	7.55E-06	4.94E-06
2000	21	3,010,608				4.58E-06	9.75E-06	6.80E-06
2001	17	3,000,432				3.56E-06	8.28E-06	5.55E-06
2002	13	3,088,161				2.49E-06	6.57E-06	4.17E-06
2003	9	3,216,609				1.50E-06	4.85E-06	2.82E-06
2004	8	3,236,193				1.28E-06	4.45E-06	2.51E-06
2005	10	3,218,859				1.72E-06	5.22E-06	3.12E-06
2006	10	3,219,607				1.72E-06	5.22E-06	3.11E-06
2007	7	3,218,919	3.93E-06	2.03E-06	7.60E-06	1.08E-06	4.09E-06	2.23E-06
2008	26	3,245,229	3.69E-06	2.11E-06	6.43E-06	5.49E-06	1.08E-05	7.80E-06
2009	16	3,228,042	3.46E-06	2.17E-06	5.52E-06	3.09E-06	7.37E-06	4.88E-06
2010	7	3,230,011	3.24E-06	2.16E-06	4.86E-06	1.07E-06	4.08E-06	2.22E-06
2011	8	3,227,901	3.04E-06	2.08E-06	4.45E-06	1.28E-06	4.46E-06	2.52E-06
2012	10	3,224,906	2.85E-06	1.90E-06	4.27E-06	1.72E-06	5.21E-06	3.11E-06
2013	10	3,209,977	2.67E-06	1.68E-06	4.26E-06	1.72E-06	5.23E-06	3.12E-06
2014	4	3,212,702	2.51E-06	1.44E-06	4.36E-06	4.94E-07	2.92E-06	1.34E-06
2015	10	3,204,506	2.35E-06	1.22E-06	4.53E-06	1.73E-06	5.24E-06	3.13E-06
2016	8	3,200,745	2.21E-06	1.02E-06	4.76E-06	1.29E-06	4.50E-06	2.54E-06
Total	229	60,102,518						

Table 16. Plot data for Figure 6, pooled standby MDP UA trend.

Year	UA Hours	Critical Hours	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						1.20E-03	1.36E-02	6.22E-03
1998	10,542.6	2,323,282.0				3.08E-04	1.22E-02	4.31E-03
1999	12,670.1	2,453,902.5				4.70E-04	1.35E-02	4.98E-03
2000	13,371.9	2,519,626.7				1.03E-03	1.16E-02	5.06E-03
2001	12,969.1	2,581,219.2				4.30E-04	1.37E-02	4.97E-03
2002	19,347.4	4,235,045.1				5.42E-04	1.21E-02	4.63E-03
2003	20,976.3	4,296,511.4				5.36E-04	1.23E-02	4.70E-03
2004	20,045.9	4,497,453.5				7.13E-04	1.07E-02	4.41E-03
2005	18,084.0	4,430,849.1				1.77E-04	1.29E-02	4.19E-03
2006	18,250.3	4,432,225.4				3.43E-04	1.08E-02	3.92E-03
2007	17,239.6	4,521,448.3	3.86E-03	4.51E-03	4.17E-03	4.12E-04	1.02E-02	3.85E-03
2008	17,845.1	4,450,273.2	3.90E-03	4.40E-03	4.14E-03	3.19E-04	1.13E-02	4.03E-03
2009	18,666.1	4,397,190.2	3.94E-03	4.29E-03	4.11E-03	4.04E-04	1.10E-02	4.08E-03
2010	19,132.3	4,473,513.0	3.98E-03	4.19E-03	4.09E-03	5.09E-04	1.14E-02	4.36E-03
2011	18,404.4	4,314,939.4	4.02E-03	4.09E-03	4.06E-03	4.27E-04	1.15E-02	4.29E-03
2012	18,464.7	4,177,350.9	3.99E-03	4.06E-03	4.03E-03	4.06E-04	1.12E-02	4.15E-03
2013	18,987.2	4,225,813.8	3.90E-03	4.10E-03	4.00E-03	2.57E-04	1.21E-02	4.17E-03
2014	18,482.1	4,271,782.8	3.80E-03	4.14E-03	3.97E-03	3.09E-04	1.20E-02	4.22E-03
2015	16,359.6	4,245,640.9	3.71E-03	4.19E-03	3.94E-03	3.47E-04	1.06E-02	3.86E-03
2016	14,563.8	4,247,599.7	3.63E-03	4.23E-03	3.92E-03	3.52E-04	9.36E-03	3.49E-03
Total	324,402.4	75,095,667.0						

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

	Regression Curve Data Points			Yearly Estimate Data Points		
Year	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998				1.62E-03	1.62E-02	5.93E-03
1999				1.45E-03	1.71E-02	6.65E-03
2000				2.61E-03	1.31E-02	6.74E-03
2001				1.63E-03	1.23E-02	5.87E-03
2002				1.77E-03	1.34E-02	5.70E-03
2003				1.91E-03	1.20E-02	5.65E-03
2004				1.47E-03	1.70E-02	5.65E-03
2005				1.38E-03	1.44E-02	5.08E-03
2006				1.19E-03	1.33E-02	5.14E-03
2007	5.09E-03	4.55E-03	5.69E-03	1.14E-03	1.09E-02	4.55E-03
2008	5.05E-03	4.59E-03	5.55E-03	1.15E-03	1.43E-02	5.64E-03
2009	5.01E-03	4.63E-03	5.43E-03	7.27E-04	1.23E-02	4.78E-03
2010	4.98E-03	4.65E-03	5.33E-03	1.59E-03	1.43E-02	4.95E-03
2011	4.94E-03	4.65E-03	5.25E-03	1.06E-03	1.12E-02	5.20E-03
2012	4.91E-03	4.62E-03	5.22E-03	1.36E-03	1.05E-02	4.80E-03
2013	4.87E-03	4.55E-03	5.21E-03	9.86E-04	1.51E-02	5.03E-03
2014	4.84E-03	4.47E-03	5.24E-03	1.22E-03	1.53E-02	5.56E-03
2015	4.80E-03	4.37E-03	5.28E-03	1.22E-03	9.82E-03	4.58E-03
2016	4.77E-03	4.26E-03	5.33E-03	9.87E-04	1.02E-02	4.32E-03

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

Year	Regression Curve Data Points			Yearly Estimate Data Points		
	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998				8.14E-04	2.16E-03	1.38E-03
1999				7.55E-04	2.16E-03	1.38E-03
2000				5.12E-04	1.48E-03	9.41E-04
2001				1.10E-03	2.32E-03	1.62E-03
2002				1.11E-03	2.61E-03	1.83E-03
2003				1.07E-03	2.47E-03	1.73E-03
2004				5.14E-04	1.48E-03	9.12E-04
2005				7.04E-04	1.87E-03	1.18E-03
2006				4.34E-04	1.49E-03	8.89E-04
2007	1.19E-03	8.23E-04	1.72E-03	6.44E-04	1.82E-03	1.15E-03
2008	1.13E-03	8.24E-04	1.54E-03	1.02E-03	2.34E-03	1.63E-03
2009	1.07E-03	8.20E-04	1.38E-03	5.53E-04	1.55E-03	9.31E-04
2010	1.01E-03	8.07E-04	1.26E-03	3.94E-04	1.34E-03	8.28E-04
2011	9.54E-04	7.81E-04	1.17E-03	5.79E-04	1.46E-03	9.80E-04
2012	9.03E-04	7.39E-04	1.10E-03	4.05E-04	1.36E-03	8.33E-04
2013	8.55E-04	6.84E-04	1.07E-03	3.66E-04	1.22E-03	7.36E-04
2014	8.09E-04	6.23E-04	1.05E-03	5.88E-04	1.78E-03	1.09E-03
2015	7.66E-04	5.61E-04	1.05E-03	1.77E-04	8.77E-04	4.78E-04
2016	7.25E-04	5.02E-04	1.05E-03	6.15E-04	1.66E-03	1.06E-03

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

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	**Demands**	**Reactor Years**	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
1998	23,983	103.0				2.30E+02	2.35E+02	2.33E+02
1999	24,593	103.0				2.36E+02	2.41E+02	2.39E+02
2000	24,268	103.3				2.32E+02	2.37E+02	2.35E+02
2001	24,348	103.0				2.34E+02	2.39E+02	2.36E+02
2002	24,885	103.0				2.39E+02	2.44E+02	2.42E+02
2003	25,830	103.0				2.48E+02	2.53E+02	2.51E+02
2004	25,910	103.3				2.48E+02	2.53E+02	2.51E+02
2005	26,480	103.0				2.54E+02	2.60E+02	2.57E+02
2006	26,356	103.0				2.53E+02	2.58E+02	2.56E+02
2007	26,282	103.6	2.53E+02	2.47E+02	2.58E+02	2.51E+02	2.56E+02	2.54E+02
2008	26,552	104.3	2.52E+02	2.47E+02	2.57E+02	2.52E+02	2.57E+02	2.55E+02
2009	26,449	104.0	2.51E+02	2.47E+02	2.55E+02	2.52E+02	2.57E+02	2.54E+02
2010	25,726	104.0	2.50E+02	2.47E+02	2.54E+02	2.45E+02	2.50E+02	2.47E+02
2011	25,636	104.0	2.50E+02	2.47E+02	2.53E+02	2.44E+02	2.49E+02	2.46E+02
2012	25,239	104.3	2.49E+02	2.46E+02	2.52E+02	2.40E+02	2.45E+02	2.42E+02
2013	25,261	101.6	2.48E+02	2.45E+02	2.52E+02	2.46E+02	2.51E+02	2.49E+02
2014	25,001	100.0	2.48E+02	2.44E+02	2.52E+02	2.47E+02	2.53E+02	2.50E+02
2015	24,998	99.0	2.47E+02	2.42E+02	2.52E+02	2.50E+02	2.55E+02	2.53E+02
2016	24,302	99.0	2.46E+02	2.41E+02	2.52E+02	2.43E+02	2.48E+02	2.45E+02
Total	482,096	1,951.3						

Table 20. Plot data for Figure 10, standby MDP run ≤1H hours per reactor year trend.

Year	Hours	Reactor Years	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	23,983	103.0				2.30E+02	2.35E+02	2.33E+02
1999	24,593	103.0				2.36E+02	2.41E+02	2.39E+02
2000	24,268	103.3				2.32E+02	2.37E+02	2.35E+02
2001	24,348	103.0				2.34E+02	2.39E+02	2.36E+02
2002	24,885	103.0				2.39E+02	2.44E+02	2.42E+02
2003	25,830	103.0				2.48E+02	2.53E+02	2.51E+02
2004	25,910	103.3				2.48E+02	2.53E+02	2.51E+02
2005	26,480	103.0				2.54E+02	2.60E+02	2.57E+02
2006	26,356	103.0				2.53E+02	2.58E+02	2.56E+02
2007	26,282	103.6	2.53E+02	2.47E+02	2.58E+02	2.51E+02	2.56E+02	2.54E+02
2008	26,552	104.3	2.52E+02	2.47E+02	2.57E+02	2.52E+02	2.57E+02	2.55E+02
2009	26,449	104.0	2.51E+02	2.47E+02	2.55E+02	2.52E+02	2.57E+02	2.54E+02
2010	25,726	104.0	2.50E+02	2.47E+02	2.54E+02	2.45E+02	2.50E+02	2.47E+02
2011	25,636	104.0	2.50E+02	2.47E+02	2.53E+02	2.44E+02	2.49E+02	2.46E+02
2012	25,239	104.3	2.49E+02	2.46E+02	2.52E+02	2.40E+02	2.45E+02	2.42E+02
2013	25,261	101.6	2.48E+02	2.45E+02	2.52E+02	2.46E+02	2.51E+02	2.49E+02
2014	25,001	100.0	2.48E+02	2.44E+02	2.52E+02	2.47E+02	2.53E+02	2.50E+02
2015	24,998	99.0	2.47E+02	2.42E+02	2.52E+02	2.50E+02	2.55E+02	2.53E+02
2016	24,302	99.0	2.46E+02	2.41E+02	2.52E+02	2.43E+02	2.48E+02	2.45E+02
Total	482,096	1,951.3						

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

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	**Run Hours**	**Reactor Years**	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
1998	1,024,127	103.0				9.93E+03	9.96E+03	9.94E+03
1999	941,977	103.0				9.13E+03	9.16E+03	9.15E+03
2000	921,897	103.3				8.91E+03	8.94E+03	8.93E+03
2001	924,957	103.0				8.97E+03	9.00E+03	8.98E+03
2002	979,998	103.0				9.50E+03	9.53E+03	9.51E+03
2003	1,110,777	103.0				1.08E+04	1.08E+04	1.08E+04
2004	1,144,053	103.3				1.11E+04	1.11E+04	1.11E+04
2005	1,155,478	103.0				1.12E+04	1.12E+04	1.12E+04
2006	1,162,531	103.0				1.13E+04	1.13E+04	1.13E+04
2007	1,174,094	103.6	1.12E+04	1.10E+04	1.13E+04	1.13E+04	1.13E+04	1.13E+04
2008	1,168,734	104.3	1.12E+04	1.10E+04	1.13E+04	1.12E+04	1.12E+04	1.12E+04
2009	1,149,456	104.0	1.12E+04	1.11E+04	1.13E+04	1.10E+04	1.11E+04	1.11E+04
2010	1,167,300	104.0	1.12E+04	1.11E+04	1.13E+04	1.12E+04	1.12E+04	1.12E+04
2011	1,162,841	104.0	1.13E+04	1.12E+04	1.14E+04	1.12E+04	1.12E+04	1.12E+04
2012	1,174,756	104.3	1.13E+04	1.12E+04	1.14E+04	1.13E+04	1.13E+04	1.13E+04
2013	1,147,382	101.6	1.13E+04	1.12E+04	1.14E+04	1.13E+04	1.13E+04	1.13E+04
2014	1,136,095	100.0	1.13E+04	1.12E+04	1.15E+04	1.13E+04	1.14E+04	1.14E+04
2015	1,145,072	99.0	1.14E+04	1.12E+04	1.15E+04	1.16E+04	1.16E+04	1.16E+04
2016	1,122,214	99.0	1.14E+04	1.12E+04	1.16E+04	1.13E+04	1.14E+04	1.13E+04
Total	20,913,740	1,951.3						

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

Year	Failures	Reactor Years	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	26	103.0				1.76E-01	3.46E-01	2.50E-01
1999	21	103.0				1.37E-01	2.91E-01	2.03E-01
2000	37	103.3				2.64E-01	4.64E-01	3.53E-01
2001	24	103.0				1.60E-01	3.24E-01	2.31E-01
2002	25	103.0				1.68E-01	3.35E-01	2.41E-01
2003	32	103.0				2.24E-01	4.11E-01	3.07E-01
2004	21	103.3				1.36E-01	2.90E-01	2.02E-01
2005	26	103.0				1.76E-01	3.46E-01	2.50E-01
2006	17	103.0				1.06E-01	2.46E-01	1.65E-01
2007	20	103.6	1.61E-01	1.09E-01	2.36E-01	1.28E-01	2.78E-01	1.92E-01
2008	19	104.3	1.62E-01	1.17E-01	2.24E-01	1.20E-01	2.66E-01	1.82E-01
2009	13	104.0	1.63E-01	1.24E-01	2.14E-01	7.55E-02	1.99E-01	1.26E-01
2010	21	104.0	1.64E-01	1.30E-01	2.07E-01	1.35E-01	2.88E-01	2.01E-01
2011	10	104.0	1.65E-01	1.34E-01	2.04E-01	5.42E-02	1.64E-01	9.82E-02
2012	17	104.3	1.66E-01	1.35E-01	2.05E-01	1.05E-01	2.43E-01	1.63E-01
2013	17	101.6	1.68E-01	1.33E-01	2.11E-01	1.07E-01	2.50E-01	1.67E-01
2014	23	100.0	1.69E-01	1.28E-01	2.22E-01	1.57E-01	3.22E-01	2.28E-01
2015	19	99.0	1.70E-01	1.23E-01	2.35E-01	1.26E-01	2.79E-01	1.91E-01
2016	15	99.0	1.71E-01	1.17E-01	2.51E-01	9.46E-02	2.32E-01	1.52E-01
Total	403	1,951.3						

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

Year	Failures	Reactor Years	Regression Curve Data Points Mean	Regression Curve Data Points Lower (5%)	Regression Curve Data Points Upper (95%)	Yearly Estimate Data Points Lower (5%)	Yearly Estimate Data Points Upper (95%)	Yearly Estimate Data Points Mean
1998	6	103.0				2.41E-02	1.02E-01	5.31E-02
1999	2	103.0				4.68E-03	5.75E-02	2.04E-02
2000	3	103.3				8.84E-03	6.90E-02	2.85E-02
2001	3	103.0				8.86E-03	6.92E-02	2.86E-02
2002	3	103.0				8.86E-03	6.92E-02	2.86E-02
2003	2	103.0				4.68E-03	5.75E-02	2.04E-02
2004	2	103.3				4.67E-03	5.74E-02	2.04E-02
2005	4	103.0				1.36E-02	8.04E-02	3.68E-02
2006	6	103.0				2.41E-02	1.02E-01	5.31E-02
2007	1	103.6	2.06E-02	1.07E-02	3.94E-02	1.43E-03	4.50E-02	1.22E-02
2008	2	104.3	2.12E-02	1.22E-02	3.69E-02	4.63E-03	5.69E-02	2.02E-02
2009	2	104.0	2.19E-02	1.38E-02	3.48E-02	4.64E-03	5.70E-02	2.03E-02
2010	4	104.0	2.26E-02	1.52E-02	3.35E-02	1.35E-02	7.98E-02	3.65E-02
2011	2	104.0	2.33E-02	1.64E-02	3.31E-02	4.64E-03	5.70E-02	2.03E-02
2012	4	104.3	2.41E-02	1.71E-02	3.40E-02	1.35E-02	7.96E-02	3.64E-02
2013	3	101.6	2.49E-02	1.70E-02	3.63E-02	8.96E-03	7.00E-02	2.90E-02
2014	4	100.0	2.57E-02	1.65E-02	4.00E-02	1.39E-02	8.25E-02	3.77E-02
2015	3	99.0	2.65E-02	1.56E-02	4.49E-02	9.16E-03	7.15E-02	2.96E-02
2016	1	99.0	2.73E-02	1.47E-02	5.09E-02	1.49E-03	4.68E-02	1.27E-02
Total	57	1,951.3						

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

Year	Failures	Reactor Years	Regression Curve Data Points Mean	Regression Curve Data Points Lower (5%)	Regression Curve Data Points Upper (95%)	Yearly Estimate Data Points Lower (5%)	Yearly Estimate Data Points Upper (95%)	Yearly Estimate Data Points Mean
1998	4	103.0				1.54E-02	9.08E-02	4.15E-02
1999	4	103.0				1.54E-02	9.08E-02	4.15E-02
2000	10	103.3				5.34E-02	1.62E-01	9.67E-02
2001	15	103.0				8.90E-02	2.19E-01	1.43E-01
2002	10	103.0				5.35E-02	1.62E-01	9.69E-02
2003	15	103.0				8.90E-02	2.19E-01	1.43E-01
2004	13	103.3				7.44E-02	1.96E-01	1.24E-01
2005	10	103.0				5.35E-02	1.62E-01	9.69E-02
2006	9	103.0				4.67E-02	1.51E-01	8.77E-02
2007	10	103.6	1.29E-01	6.60E-02	2.53E-01	5.32E-02	1.61E-01	9.64E-02
2008	21	104.3	1.16E-01	6.61E-02	2.04E-01	1.32E-01	2.81E-01	1.96E-01
2009	6	104.0	1.04E-01	6.49E-02	1.68E-01	2.70E-02	1.14E-01	5.95E-02
2010	8	104.0	9.37E-02	6.17E-02	1.42E-01	3.97E-02	1.38E-01	7.78E-02
2011	14	104.0	8.42E-02	5.60E-02	1.27E-01	8.10E-02	2.06E-01	1.33E-01
2012	8	104.3	7.56E-02	4.83E-02	1.18E-01	3.96E-02	1.38E-01	7.76E-02
2013	17	101.6	6.80E-02	4.01E-02	1.15E-01	1.05E-01	2.44E-01	1.64E-01
2014	5	100.0	6.11E-02	3.26E-02	1.14E-01	2.17E-02	1.06E-01	5.22E-02
2015	5	99.0	5.49E-02	2.60E-02	1.16E-01	2.19E-02	1.07E-01	5.27E-02
2016	2	99.0	4.93E-02	2.06E-02	1.18E-01	5.49E-03	6.74E-02	2.40E-02
Total	186	1,951.3						

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

Year	Demands	Reactor Years	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	7,148	103.0				6.81E+01	7.08E+01	6.94E+01
1999	7,366	103.0				7.02E+01	7.29E+01	7.15E+01
2000	7,384	103.3				7.01E+01	7.29E+01	7.15E+01
2001	7,326	103.0				6.98E+01	7.25E+01	7.11E+01
2002	7,764	103.0				7.40E+01	7.68E+01	7.54E+01
2003	8,273	103.0				7.89E+01	8.18E+01	8.03E+01
2004	8,241	103.3				7.84E+01	8.13E+01	7.98E+01
2005	8,432	103.0				8.04E+01	8.33E+01	8.19E+01
2006	8,618	103.0				8.22E+01	8.52E+01	8.37E+01
2007	8,417	103.6	8.12E+01	7.88E+01	8.37E+01	7.98E+01	8.27E+01	8.12E+01
2008	8,713	104.3	8.11E+01	7.91E+01	8.33E+01	8.21E+01	8.50E+01	8.36E+01
2009	8,520	104.0	8.11E+01	7.93E+01	8.28E+01	8.05E+01	8.34E+01	8.19E+01
2010	8,214	104.0	8.10E+01	7.95E+01	8.25E+01	7.76E+01	8.04E+01	7.90E+01
2011	8,256	104.0	8.09E+01	7.95E+01	8.22E+01	7.80E+01	8.08E+01	7.94E+01
2012	8,271	104.3	8.08E+01	7.94E+01	8.22E+01	7.79E+01	8.08E+01	7.93E+01
2013	8,085	101.6	8.07E+01	7.92E+01	8.22E+01	7.82E+01	8.11E+01	7.96E+01
2014	8,117	100.0	8.06E+01	7.88E+01	8.24E+01	7.97E+01	8.27E+01	8.12E+01
2015	8,229	99.0	8.05E+01	7.84E+01	8.27E+01	8.16E+01	8.46E+01	8.31E+01
2016	7,948	99.0	8.04E+01	7.80E+01	8.30E+01	7.88E+01	8.18E+01	8.03E+01
Total	153,324	1,951.3						

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

Year	Run Hours	Reactor Years	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	2,922,986	103.0				2.84E+04	2.84E+04	2.84E+04
1999	2,986,122	103.0				2.90E+04	2.90E+04	2.90E+04
2000	3,010,608	103.3				2.91E+04	2.92E+04	2.91E+04
2001	3,000,432	103.0				2.91E+04	2.92E+04	2.91E+04
2002	3,088,161	103.0				3.00E+04	3.00E+04	3.00E+04
2003	3,216,609	103.0				3.12E+04	3.13E+04	3.12E+04
2004	3,236,193	103.3				3.13E+04	3.14E+04	3.13E+04
2005	3,218,859	103.0				3.12E+04	3.13E+04	3.13E+04
2006	3,219,607	103.0				3.12E+04	3.13E+04	3.13E+04
2007	3,218,919	103.6	3.07E+04	3.03E+04	3.12E+04	3.10E+04	3.11E+04	3.11E+04
2008	3,245,229	104.3	3.09E+04	3.05E+04	3.13E+04	3.11E+04	3.11E+04	3.11E+04
2009	3,228,042	104.0	3.11E+04	3.07E+04	3.14E+04	3.10E+04	3.11E+04	3.10E+04
2010	3,230,011	104.0	3.12E+04	3.09E+04	3.15E+04	3.10E+04	3.11E+04	3.11E+04
2011	3,227,901	104.0	3.14E+04	3.11E+04	3.16E+04	3.10E+04	3.11E+04	3.10E+04
2012	3,224,906	104.3	3.15E+04	3.13E+04	3.18E+04	3.09E+04	3.10E+04	3.09E+04
2013	3,209,977	101.6	3.17E+04	3.14E+04	3.20E+04	3.16E+04	3.16E+04	3.16E+04
2014	3,212,702	100.0	3.19E+04	3.15E+04	3.22E+04	3.21E+04	3.22E+04	3.21E+04
2015	3,204,506	99.0	3.20E+04	3.16E+04	3.25E+04	3.23E+04	3.24E+04	3.24E+04
2016	3,200,745	99.0	3.22E+04	3.17E+04	3.27E+04	3.23E+04	3.24E+04	3.23E+04
Total	60,102,518	1,951.3						

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

Year	Failures	Reactor Years	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	9	103.0				4.60E-02	1.49E-01	8.64E-02
1999	10	103.0				5.27E-02	1.60E-01	9.55E-02
2000	6	103.3				2.67E-02	1.13E-01	5.90E-02
2001	11	103.0				5.95E-02	1.71E-01	1.05E-01
2002	13	103.0				7.34E-02	1.93E-01	1.23E-01
2003	14	103.0				8.05E-02	2.05E-01	1.32E-01
2004	7	103.3				3.29E-02	1.25E-01	6.80E-02
2005	10	103.0				5.27E-02	1.60E-01	9.55E-02
2006	7	103.0				3.30E-02	1.25E-01	6.82E-02
2007	9	103.6	8.95E-02	5.90E-02	1.36E-01	4.57E-02	1.48E-01	8.59E-02
2008	13	104.3	8.41E-02	5.92E-02	1.19E-01	7.26E-02	1.91E-01	1.21E-01
2009	7	104.0	7.89E-02	5.88E-02	1.06E-01	3.27E-02	1.24E-01	6.76E-02
2010	6	104.0	7.41E-02	5.74E-02	9.57E-02	2.65E-02	1.13E-01	5.86E-02
2011	8	104.0	6.96E-02	5.47E-02	8.85E-02	3.91E-02	1.36E-01	7.66E-02
2012	6	104.3	6.54E-02	5.06E-02	8.43E-02	2.65E-02	1.12E-01	5.84E-02
2013	5	101.6	6.14E-02	4.57E-02	8.23E-02	2.11E-02	1.03E-01	5.07E-02
2014	8	100.0	5.76E-02	4.06E-02	8.17E-02	4.05E-02	1.41E-01	7.95E-02
2015	3	99.0	5.41E-02	3.57E-02	8.19E-02	1.02E-02	7.98E-02	3.30E-02
2016	8	99.0	5.08E-02	3.12E-02	8.26E-02	4.09E-02	1.42E-01	8.02E-02
Total	160	1,951.3						

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

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	20	103.0				1.27E-01	2.75E-01	1.90E-01
1999	15	103.0				8.94E-02	2.20E-01	1.44E-01
2000	21	103.3				1.34E-01	2.85E-01	1.99E-01
2001	17	103.0				1.04E-01	2.42E-01	1.62E-01
2002	13	103.0				7.49E-02	1.97E-01	1.25E-01
2003	9	103.0				4.69E-02	1.52E-01	8.81E-02
2004	8	103.3				4.01E-02	1.39E-01	7.86E-02
2005	10	103.0				5.38E-02	1.63E-01	9.74E-02
2006	10	103.0				5.38E-02	1.63E-01	9.74E-02
2007	7	103.6	1.21E-01	6.26E-02	2.34E-01	3.35E-02	1.27E-01	6.92E-02
2008	26	104.3	1.14E-01	6.55E-02	1.99E-01	1.71E-01	3.36E-01	2.43E-01
2009	16	104.0	1.08E-01	6.74E-02	1.72E-01	9.59E-02	2.29E-01	1.52E-01
2010	7	104.0	1.01E-01	6.76E-02	1.52E-01	3.34E-02	1.27E-01	6.89E-02
2011	8	104.0	9.54E-02	6.52E-02	1.40E-01	3.99E-02	1.39E-01	7.81E-02
2012	10	104.3	8.99E-02	6.01E-02	1.34E-01	5.31E-02	1.61E-01	9.62E-02
2013	10	101.6	8.47E-02	5.32E-02	1.35E-01	5.45E-02	1.65E-01	9.87E-02
2014	4	100.0	7.98E-02	4.59E-02	1.39E-01	1.59E-02	9.39E-02	4.29E-02
2015	10	99.0	7.52E-02	3.90E-02	1.45E-01	5.58E-02	1.69E-01	1.01E-01
2016	8	99.0	7.08E-02	3.28E-02	1.53E-01	4.18E-02	1.45E-01	8.19E-02
Total	229	1,951.3						

9. REFERENCES

[1] J. R. Houghton, H. G. Hamzehee, "Component Performance Study – Motor-Driven Pumps, 1987-1998," NUREG-1715, Vol. 2, U.S. Nuclear Regulatory Commission, June 2000.

[2] J. A. Schroeder, "Enhanced Component Performance Study: Motor-Driven Pumps 1998-2014," INL/EXT-16-37937, Idaho National laboratory, February 2016.

[3] C. D. Gentillion, "Overview and Reference Document for Operational Experience Results and Databases Trending," February 2016. [Online]. Available: https://nrcoe.inel.gov/resultsdb/publicdocs/Overview-and-Reference.pdf.

[4] J. C. Lane, "NRC Operating Experience (OpE) Programs," Office of Nuclear Regulatory Research, July 2015. [Online]. Available: http://pbadupws.nrc.gov/docs/ML1518/ML15189A345.pdf. [Accessed 2015].

[5] Nuclear Energy Institute, "Regulatory Assessment Performance Indicator Guideline," NEI 99-02, Revision 7, August 2013.

[6] United States Nuclear Regulatory Commission, "Component Reliability Data Sheets Update 2015," February 2017. [Online]. Available: http://nrcoe.inl.gov/resultsdb/publicdocs/AvgPerf/ComponentReliabilityDataSheets2015.pdf.

[7] S. A. Eide, T. E. Wierman, C. D. Gentillon, D. M. Rasmuson and C. L. Atwood, "Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants," NUREG/CR-6928, U.S. Nuclear Regulatory Commission, February 2007.

[8] C. L. Atwood, etc., "Handbook of Parameter Estimation for Probabilistic Risk Assessment," NUREG/CR-6823, U.S. Nuclear Regulatory Commission, September 2003.