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Enhanced Component Performance Study: Motor-Driven Pumps 1998–2018

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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 2018 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 (FTS), failure to run less than or equal to one hour (FTR≤1H), failure to run more than one hour (FTR>1H), and for normally running systems FTS and failure to run (FTR). 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.

An extremely statistically significant increasing trend was identified for the frequency of run hours (hours per reactor year) for normally running MDPs. A highly statistically significant decreasing trend was identified in the standby MDP unavailability estimates. Statistically significant decreasing trends were identified for the normally running MDP FTR, in the standby MDP total unreliability estimates, and for the frequency of FTR events (events per reactor year) for normally running MDPs.

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TABLES

ACRONYMS

AFW	auxiliary feedwater
AOV	air-operated valve
BWR	boiling water reactor
CCW	component cooling water
CDS	condensate system
CNID	constrained non-informative prior distribution
CRD	control rod drive
CSR	containment spray recirculation
CVC	chemical and volume control
CY	calendar year
EDG	emergency diesel generator
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
HPCS	high pressure core spray
HPSI	high pressure safety injection
ICES	INPO Consolidated Events Database
INL	Idaho National Laboratory
INPO	Institute of Nuclear Power Operations
IRIS	Industry Reporting and Information System
LPCI	low pressure coolant injection
LPCS	low pressure core spray
LPSI	low pressure safety injection
MDP	motor-driven pump
MFW	main feedwater
MOV	motor-operated valve
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

SWN	normally operating service water
SWS	standby service water
TDP	turbine-driven pump
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 2018. 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 continues with the two changes implemented in the 2016 update that are different from earlier updates: (1) the update results are based on calendar year (CY) instead of the federal fiscal year (FY), and (2) The failure events included in the update are "hard" failures, i.e., the p-values indicating the likelihood the component would have failed during a 24-hour mission are 1.0. Previous updates (2015 and before) included lesser p-values indicating a degraded condition that probably would have caused failure during a 24-hour mission but were not quite hard failures at their outset.

The enhanced component performance studies are conducted for the following component types: air-operated valves (AOVs), emergency diesel generators (EDGs), MDPs, motor-operated valves (MOVs), and turbine-driven pumps (TDPs). 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-18-44363, *Enhanced Component Performance Study: Motor-Driven Pumps 1998-2016* [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 on that 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) [4], formerly the Equipment Performance and Information Exchange Database (EPIX) and now upgraded again to IRIS, the Industry Reporting and Information System. Maintenance unavailability (UA) performance data came from the Reactor Oversight Program Mitigating Systems Performance Index (MSPI) program [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, now IRIS, (which includes the MSPI designated devices as a subset) has matured to the point where both component availability and reliability can be estimated with a high degree of accuracy. In addition, the population of data in current ICES database is much larger than the population available 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 evaluates 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. Those estimates from the 2015 parameter update 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 emphasis on the existence of any statistically significant increasing or decreasing trends in component performance. 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 trends. Section 5 estimates the annual total unreliability and 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 2015 Update 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

- An extremely statistically significant **increasing trend** was identified for the **frequency of run hours** (hours per reactor year) for **normally running MDPs**, with a p-value of 0.0001 (see Figure 16). This trend was observed in the 2016 MDP update study [2] as highly statistically significant.

2.1.2 Highly Statistically Significant

- None.

2.1.3 Statistically Significant

- None.

2.2 Decreasing Trends

2.2.1 Extremely Statistically Significant

- None.

2.2.2 Highly Statistically Significant

- A highly statistically significant **decreasing trend** was identified in the **standby MDP unavailability** estimates, with a p-value of 0.0063 (see Figure 6). This is a new trend that was not observed in the 2016 MDP update study.

2.2.3 Statistically Significant

- A statistically significant **decreasing trend** was identified for the **normally running MDP FTR**, with a p-value of 0.0244 (see Figure 5). This is a new trend that was not observed in the 2016 MDP update study.
- A statistically significant **decreasing trend** was identified in the **standby MDP total unreliability** (see Section 5 for definition of total unreliability) estimates, with a p-value of 0.0236 (see Figure 7). This is a new trend that was not observed in the 2016 MDP update study.
- A statistically significant **decreasing trend** was identified for the **frequency of FTR events** (events per reactor year) for **normally running MDPs**, with a p-value of 0.0327 (see Figure 18). This is a new trend that was not observed in the 2016 MDP update study.

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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).

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 a consistency check that compare failure predictions obtained via simulation test on industry-average parameters from the 2015 Update against operational failure counts obtained from actual MDP performance with ESF demands. These consistency checks show that the FTS, FTR≤ 1H, and FTR>1H failure observations in the non-test, operational ESF demand data lie within their corresponding industry-average failure estimate distributions, provided in the 2015 Update (Table 2), that were based on both test and non-test operational ESF demands.

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, or the HOPE manual [8], which determines the status by evaluating the number of run-hours per demand. The pumps with low run-hours per demand (≤360) are considered standby while those with higher run-hours per demand (>360) are considered normally running.

Table 2 shows industry-wide failure probability and failure rate results for MDPs from Reference [6], the 2015 Update. The 2015 Update results are provided for comparison purposes and 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
HPCS	High pressure core spray	9	9	
HPSI	High pressure safety injection	169	169	
LPCS	Low pressure core spray	75	74	1
MFW	Main feedwater	44		44
RHR	Residual Heat Removal (LPCI in BWRs; LPSI in PWRs)	293	293	
SWN	Normally operating service water	106		106
SWS	Standby service water	446	446	
	Total	1931	1285	646

Table 2. 2015 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	1.70E-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

This section estimates trends in industry-wide annual failure probabilities and failure rates for standby and normally running MDPs in the entire study period which covers 1998 through 2018. The estimates are trended for the most recent 10-year period.

The failure probability and failure rate estimates in this section 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 is larger than the interval for years when there are one or more failures because of the form of the posterior variance. Each update utilizes a relatively "flat" constrained non-informative prior distribution (CNID), which has wide bounds [3, 8]. CNID is a compromise between an informative prior and the Jeffreys noninformative prior. The mean of the CNID uses prior belief and is based on a pooling of the component or event type data for the years going into the plot (i.e., the most recent 10-year period), but the dispersion is defined to correspond to little information (i.e., relatively flat by set) so that the prior distributions did not create large changes in the data.

For **failure rates** or Poisson data, the CNID is a gamma distribution, with the mean (μ) given by prior belief and calculated as:

$$\mu = \frac{\sum f_i + 0.5}{\sum T_i} \tag{1}$$

where f_i and T_i are the failures and operating/standby time for the i^{th} year, respectively. The CNID shape parameter = 0.5. The posterior distribution mean for the i^{th} year (μ_i) can be calculated as:

$$\mu_i = \frac{f_i + 0.5}{\frac{0.5}{\mu} + T_i} \tag{2}$$

For **failure probabilities** or binomial data, the CNID is a beta approximation, with the mean given by prior belief and calculated as:

$$\mu = \frac{\sum f_i + 0.5}{\sum D_i + 1} \tag{3}$$

where f_i and D_i are the failures and demands for the i^{th} year, respectively. The CNID shape parameter (α) is a number between 0.3 and 0.5 based on the mean μ (see Table C.8 of [8]). The posterior distribution mean for the i^{th} year (μ_i) can be calculated as:

$$\mu_i = \frac{f_i + \alpha}{\frac{\alpha}{\mu} + D_i} \tag{4}$$

The horizontal curves plotted around the regression lines in the graphs form 90% simultaneous confidence bands for the fitted lines. The bounds are larger than ordinary confidence bands for the individual coefficients because they form a confidence band for 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 to assess evidence against the slope of the regression line being zero. Low p-values indicate strong evidence that the slopes are not zero, and suggest a trend does exist. 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 residuals, or the square of the vertical distance between the annual data points and the fitted regression line. The p-values assume normal distributions for the residuals, with the same variability in the residuals across the years. In the case where the data involve failure counts, the iterative reweighted least squares is used to account 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, which is expected to vary proportionally 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 to Figure 5 provide the plots for industry-wide failure probabilities/rates of standby and normally running MDPs. The data for these plots are provided in Section 8.

- Figure 1 shows the failure probability estimate trends for standby MDP FTS.
- Figure 2 shows the failure probability estimate trends for standby MDP FTR≤1H.
- Figure 3 shows the failure rate estimate trends for standby MDP FTR>1H.
- Figure 4 shows the failure probability estimate trends for normally running MDP FTS.
- Figure 5 shows the failure rate estimate trends for normally running MDP FTR.

The following trend was identified for the most recent 10-year period:

- Statistically significant **decreasing trend** for the **normally running MDP FTR**, with a p-value of 0.0244 (see Figure 5). This is a new trend that was not observed in the 2016 MDP update study [2].

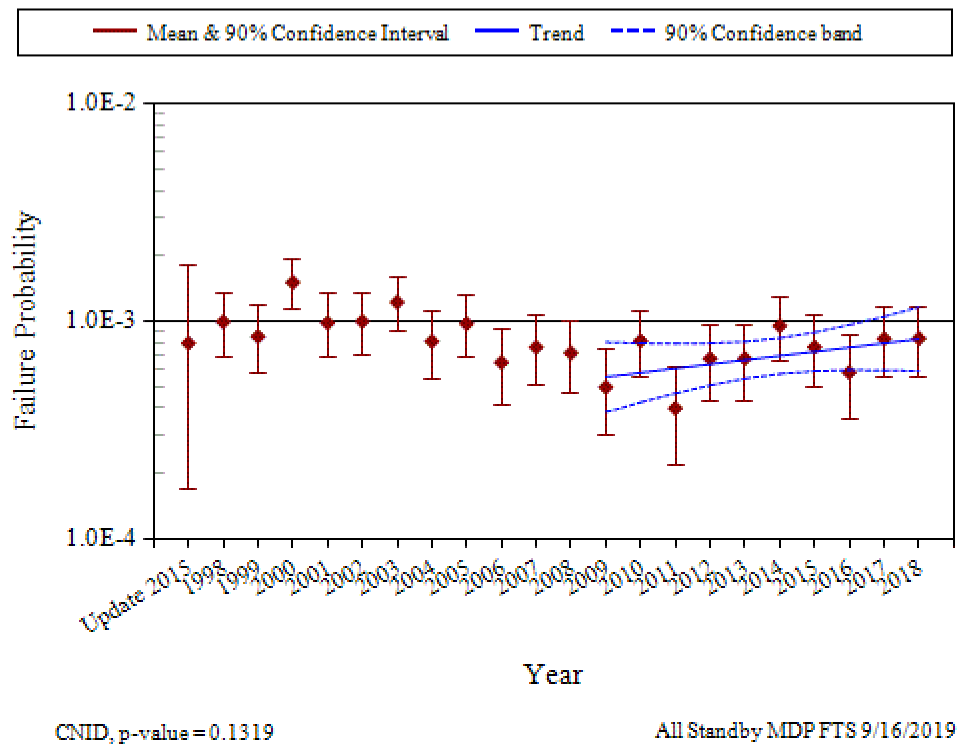

Figure 1. Failure probability estimate trend for standby MDP FTS.

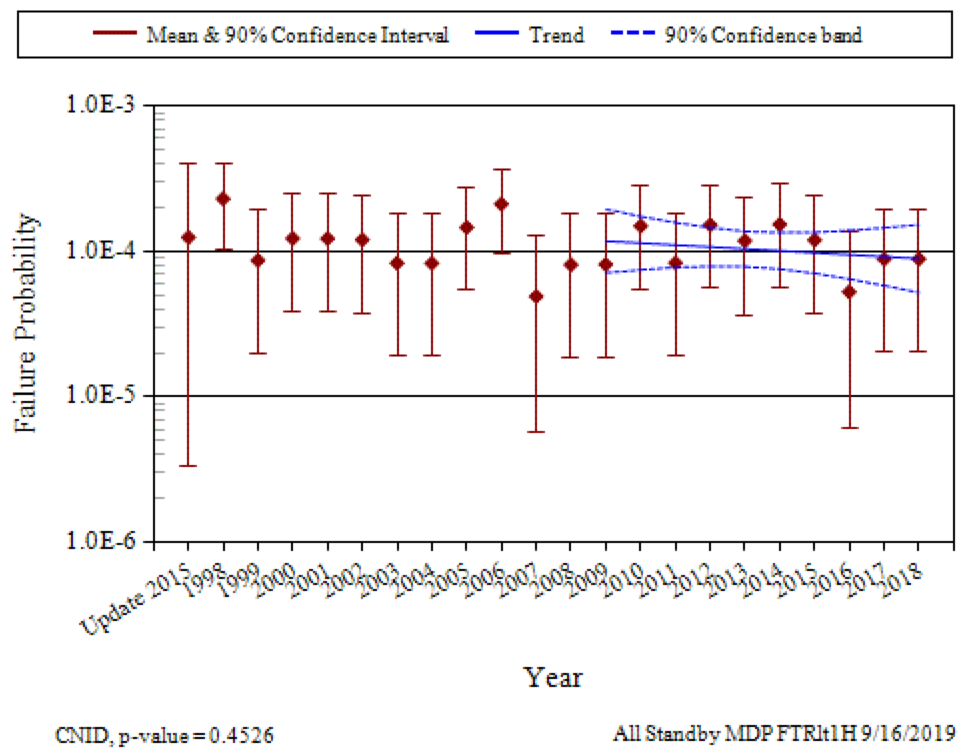

Figure 2. Failure probability estimate trend for standby MDP FTR≤1H.

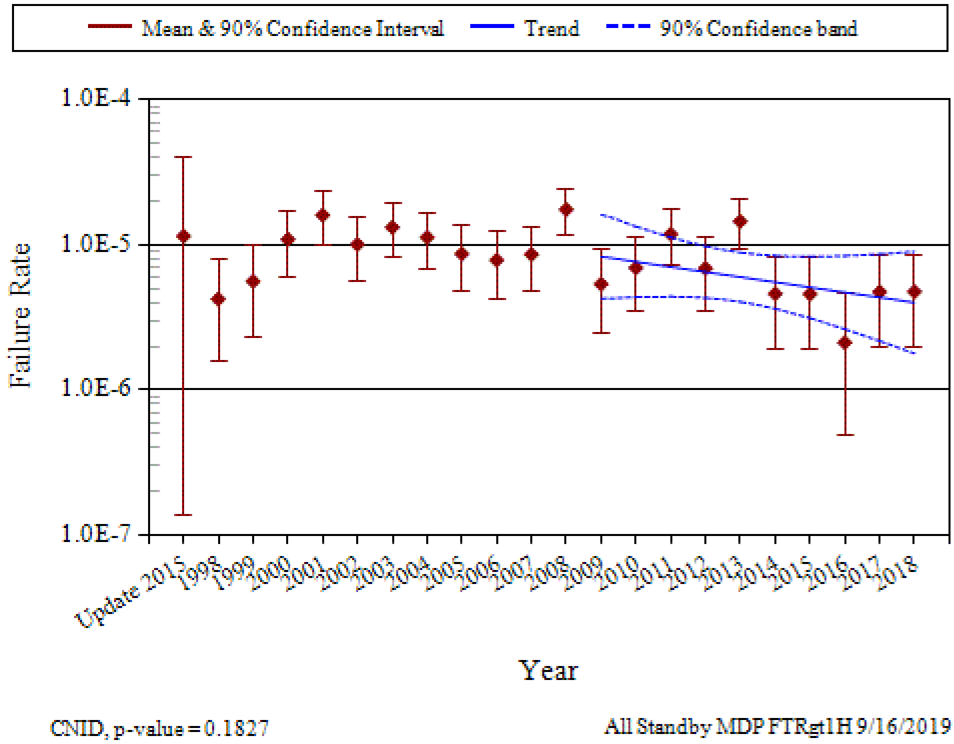

Figure 3. Failure rate estimate trend for standby MDP FTR>1H.

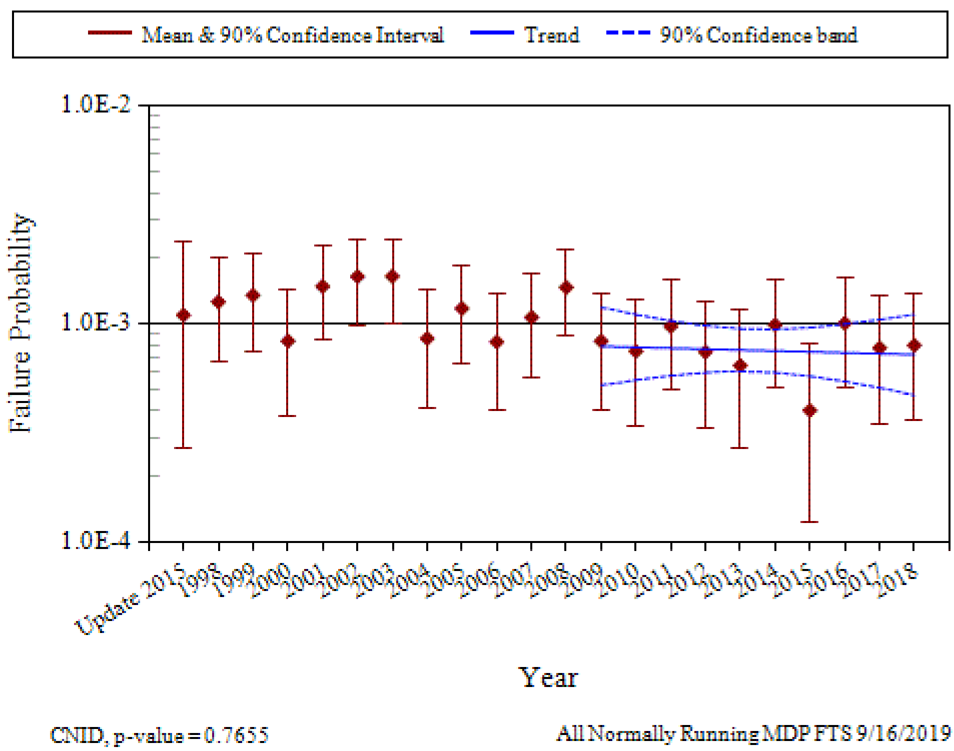

Figure 4. Failure probability estimate trend for normally running MDP FTS.

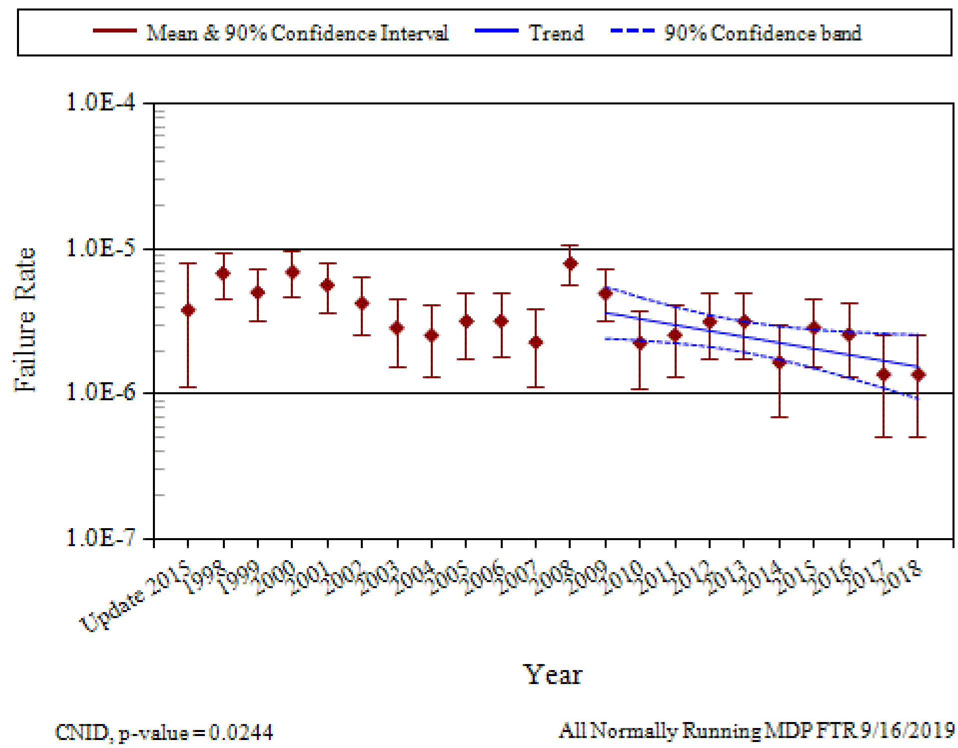

Figure 5. Failure rate estimate trend for normally running MDP FTR.

4. UNAVAILABILITY

4.1 Overview

The industry-average test or maintenance UA of MDP trains has been calculated from 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] which based on UA data from from the MSPI program and ICES. In the calculations, planned and unplanned unavailable hours for a train are combined.

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

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

4.2 MDP Unavailability Trends

This section presents overall maintenance UA data for the 1998–2018 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 provided in Section 8. The MDPs in systems AFW, HPCS, HPSI, 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 (1998–2018) UA and reactor critical hour data were obtained from the Reactor Oversight Process program (1998 to 2001) and ICES (2002 to 2018) 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. A review of these p-value identified the following trends for the most recent 10-year period:

- Highly statistically significant **decreasing trend** in the **standby MDP unavailability** estimates, with a p-value of 0.0063 (see Figure 6). This is a new trend that was not observed in the 2016 MDP update study [2].

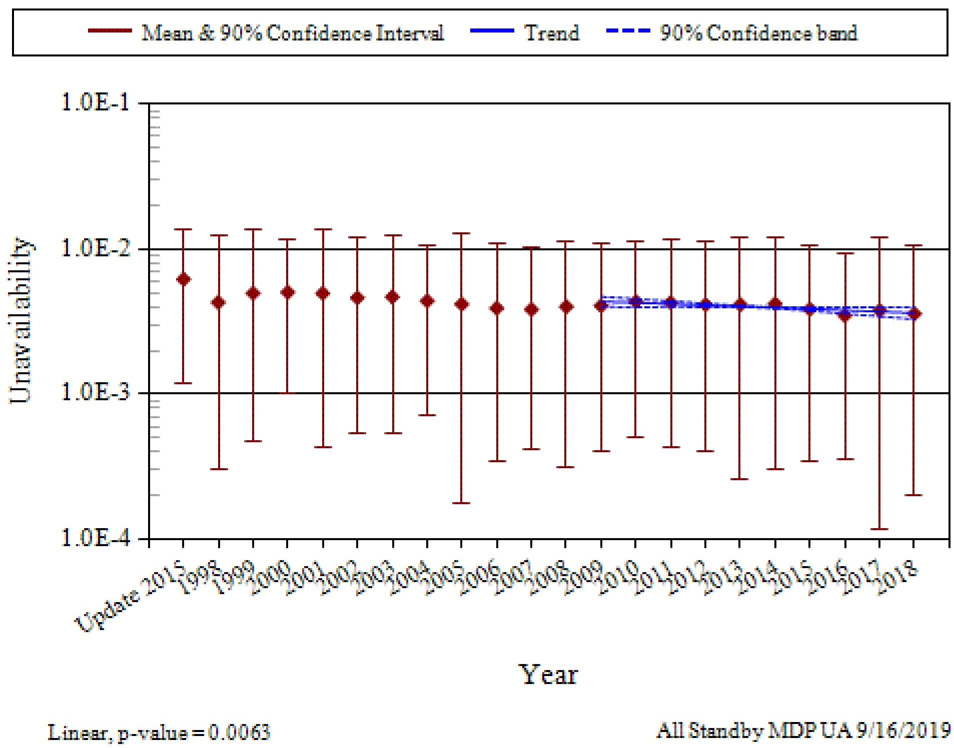

Figure 6. Pooled standby MDP UA trend.

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 provided in Section 8. 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. A review of these p-value identified the following trends for the most recent 10-year period:

- Statistically significant **decreasing trend** in the **standby MDP total unreliability** estimates, with a p-value of 0.0236 (see Figure 7). This is a new trend that was not observed in the 2016 MDP update study [2].

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.

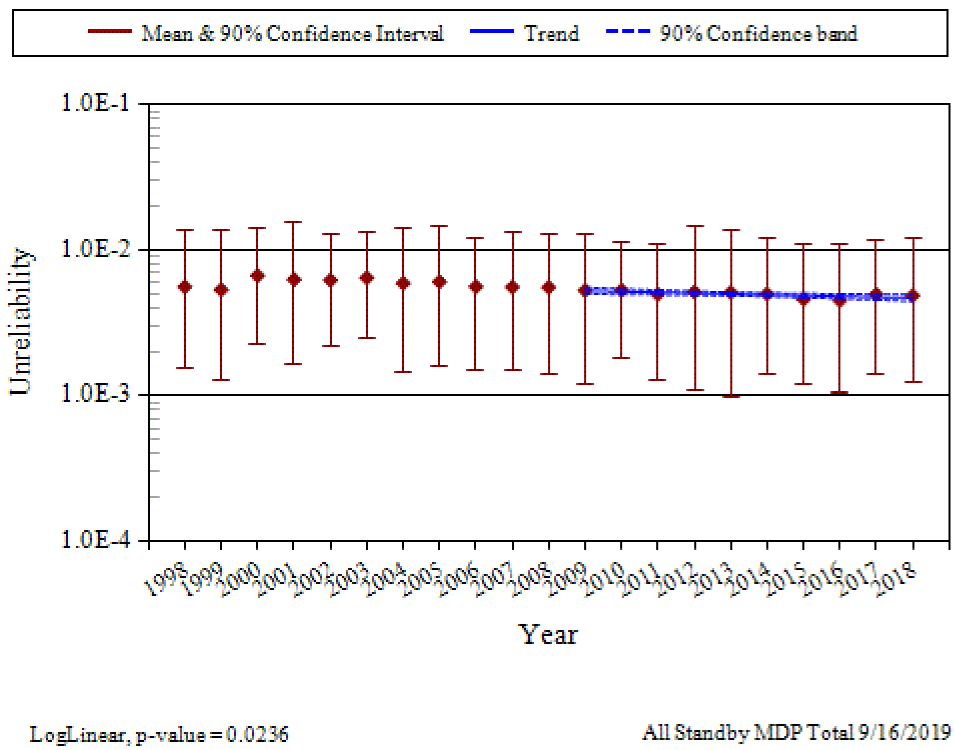

Figure 7. Standby MDP total unreliability trend (8-hour mission).

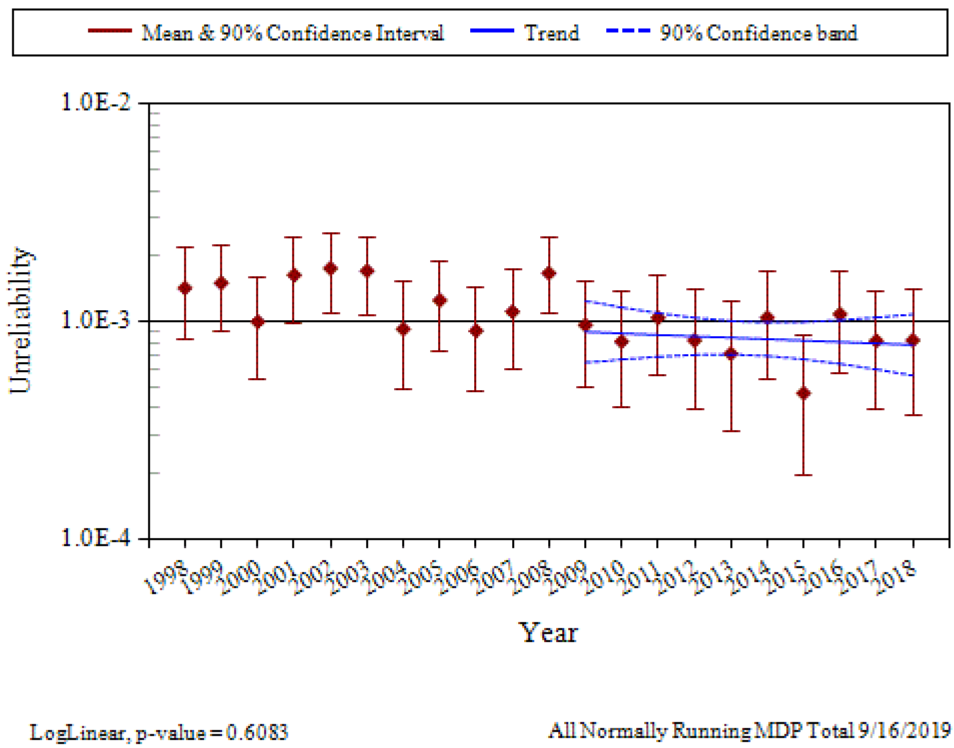

Figure 8. Normally running MDP total unreliability trend (8-hour mission).

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 2015 Update 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 presents frequency trends for standby 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.
- 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.
- Figure 14 shows the trend for standby MDP FTR events per reactor year.

The data for the above figures are provided in Section 8. 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 to Table 6 provide a summary of standby MDP FTS, FTR≤1H, and FTR>1H failure counts by system and year during the most recent 10-year period.

- Table 4 presents the standby MDP FTS failure counts by system and year.
- Table 5 presents the standby MDP FTR≤1H failure counts by system and year.
- Table 6 presents the standby MDP FTR>1H failure counts by system and year.

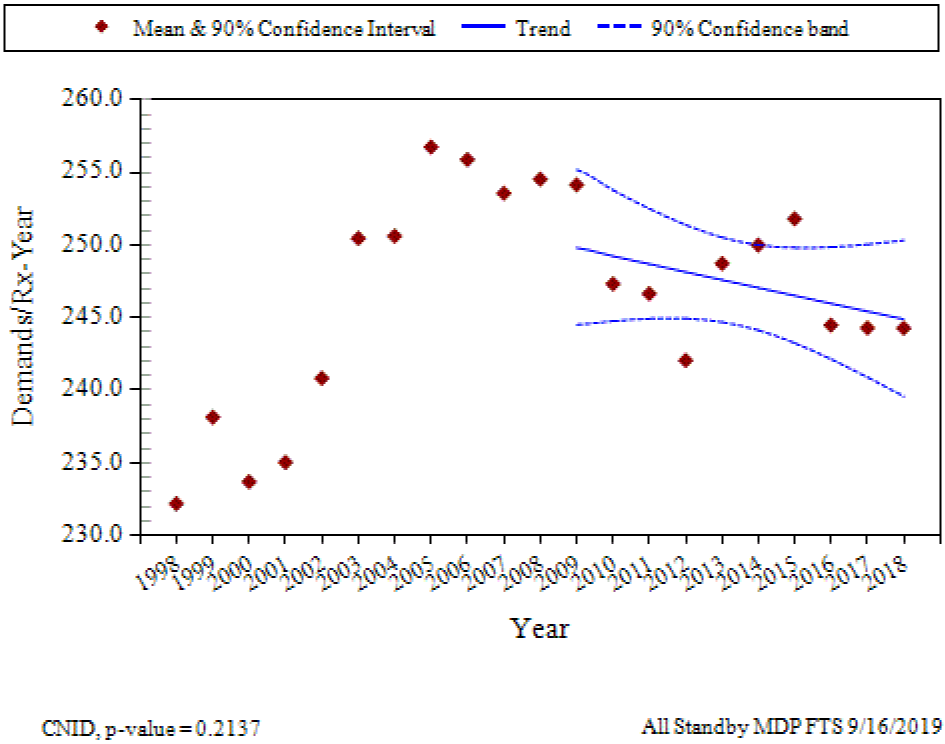

Figure 9. Frequency of start demands (demands per reactor year) trend for standby MDPs.

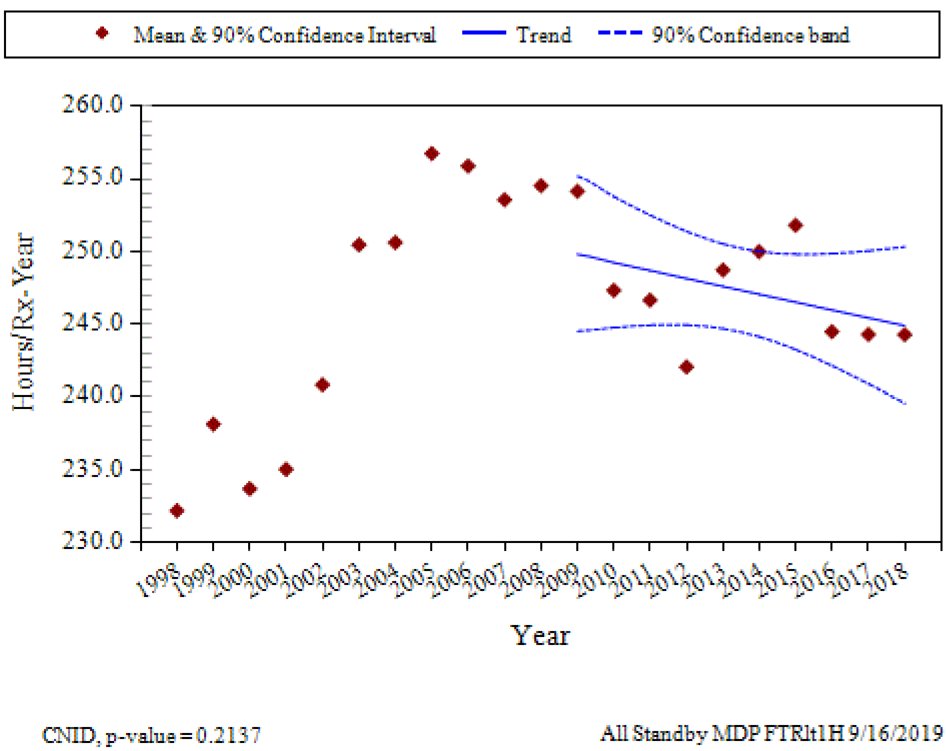

Figure 10. Frequency of run ≤ 1H hours (hours per reactor year) trend for standby MDPs.

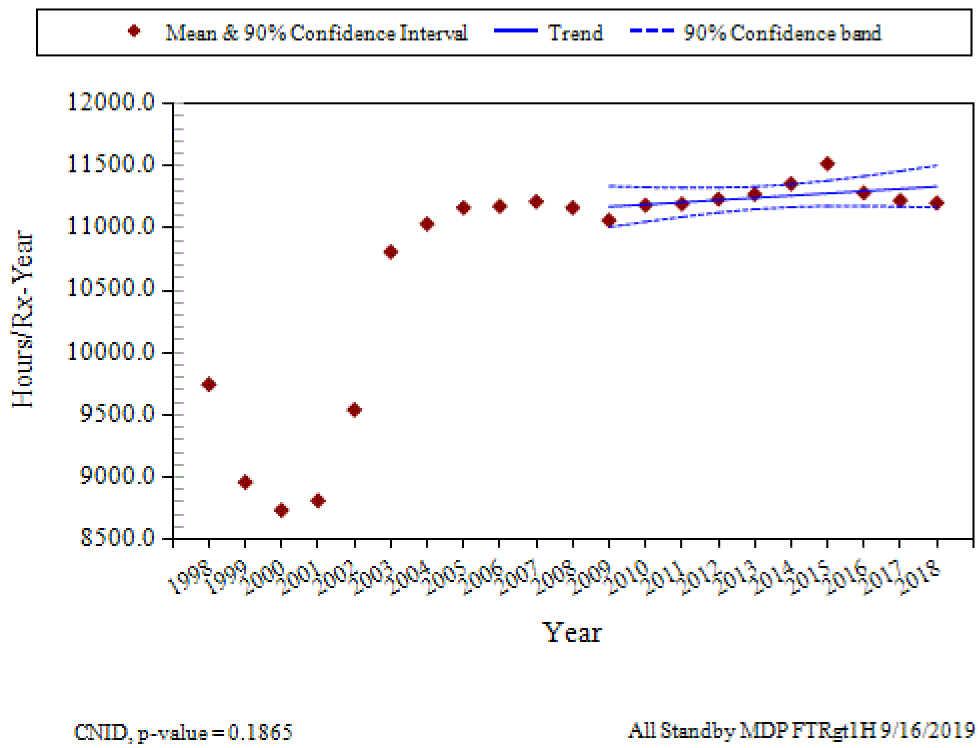

Figure 11. Frequency of run > 1H hours (hours per reactor year) trend for standby MDPs.

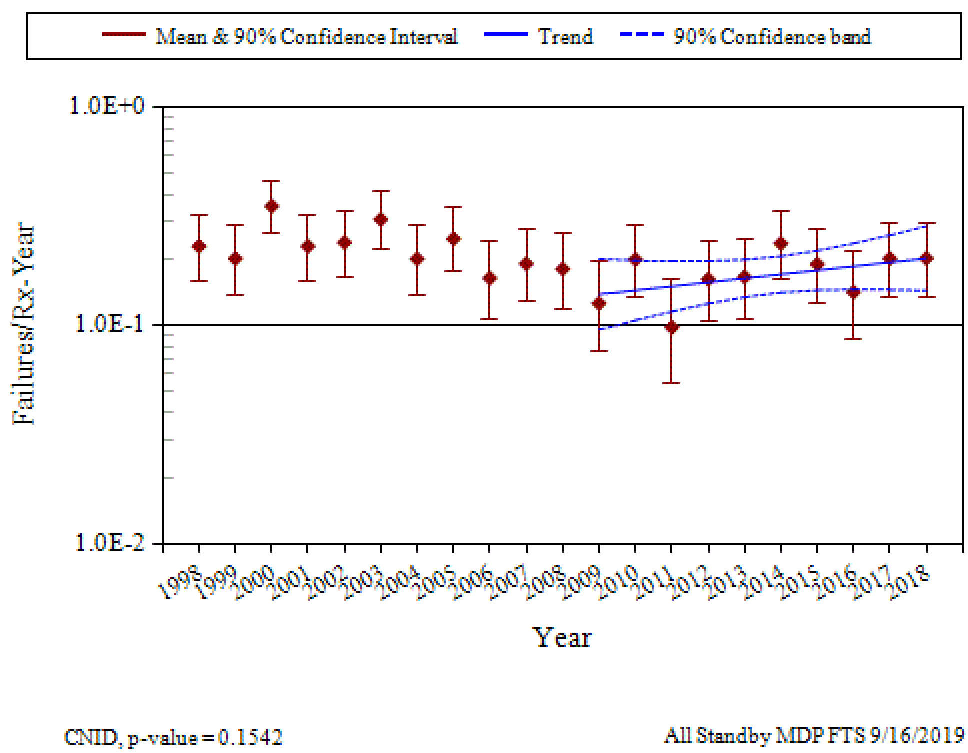

Figure 12. Frequency of FTS events (events per reactor year) trend for standby MDPs.

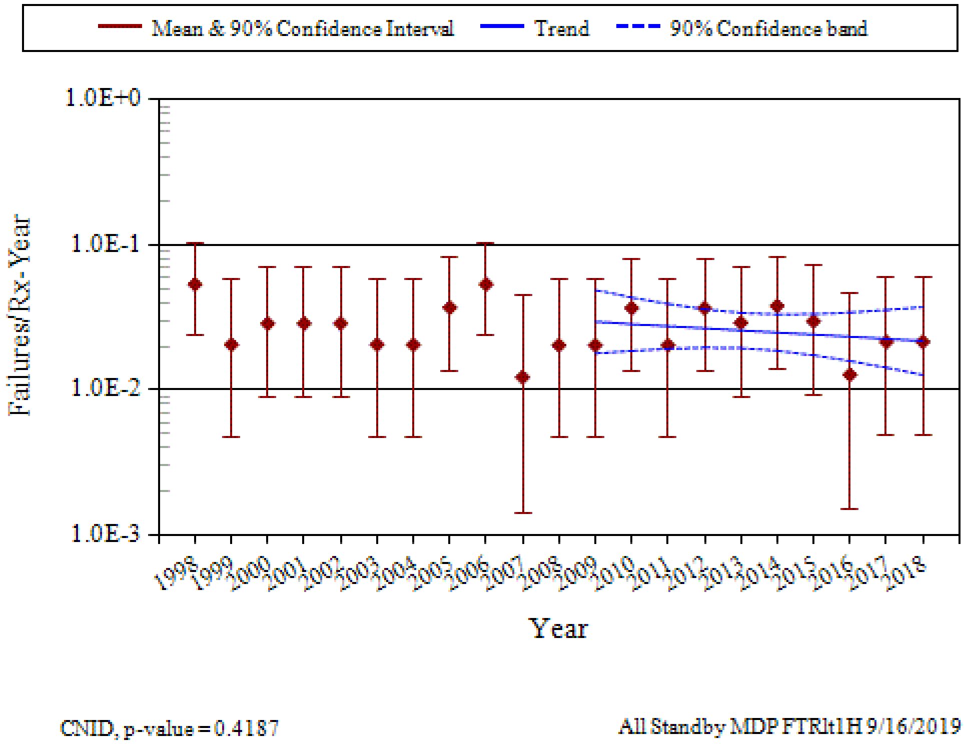

Figure 13. Frequency of FTR≤1H events (events per reactor year) trend for standby MDPs.

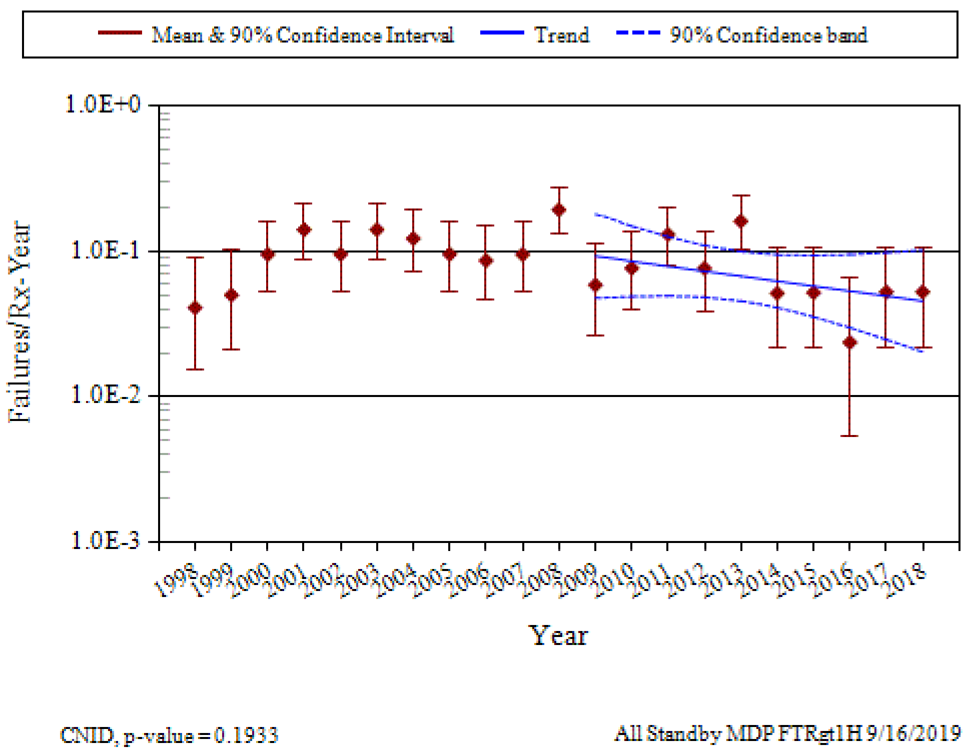

Figure 14. Frequency of FTR>1H events (events per reactor year) trend for standby MDPs.

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

System	MDP Count	MDP Percent	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total	Percent of Failures
AFW	128	10.0 %	1	1	3	4	1	2	4	1	2	1	20	11.4 %
CRD	9	0.7 %											0	0.0 %
CSR	157	12.2 %		2			1	1	3		3	1	11	6.3 %
HPCS	9	0.7 %		1								1	2	1.1 %
HPSI	169	13.2 %	1	6	2	2	3	2	1	1	4	2	24	13.7 %
LPCS	74	5.8 %		2				2	1	2	1	1	9	5.1 %
RHR	293	22.8 %	1	4	1	3	1	1	6	4	3	6	30	17.1 %
SWS	446	34.7 %	10	5	4	8	11	16	4	6	7	8	79	45.1 %
Total	1285	100.0%	13	21	10	17	17	24	19	14	20	20	175	100.0%

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

System	MDP Count	MDP Percent	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total	Percent of Failures
AFW	128	10.0 %		1			2						3	11.1 %
CRD	9	0.7 %											0	0.0 %
CSR	157	12.2 %	1			1							2	7.4 %
HPCS	9	0.7 %											0	0.0 %
HPSI	169	13.2 %	1										1	3.7 %
LPCS	74	5.8 %							1		1		2	7.4 %
RHR	293	22.8 %				2		2					4	14.8 %
SWS	446	34.7 %		3	2	1	1	2	2	1	1	2	15	55.6 %
Total	1285	100.0%	2	4	2	4	3	4	3	1	2	2	27	100.0%

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

System	MDP Count	MDP Percent	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total	Percent of Failures
AFW	128	10.0 %					3		2	1			6	8.0 %
CRD	9	0.7 %											0	0.0 %
CSR	157	12.2 %			1		2						3	4.0 %
HPCS	9	0.7 %											0	0.0 %
HPSI	169	13.2 %			1		2	2			2	1	8	10.7 %
LPCS	74	5.8 %	1	2									3	4.0 %
RHR	293	22.8 %	1	1	2	3	3		2	1		1	14	18.7 %
SWS	446	34.7 %	4	5	10	5	7	3	1		3	3	41	54.7 %
Total	1285	100.0%	6	8	14	8	17	5	5	2	5	5	75	100.0%

6.2 Normally Running MDP Engineering Trends

This section presents frequency trends for normally running MDP failures and demands.

- 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.

- 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.

The data for the above figures are provided in Section 8. The normally running 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 identified the following trends for the most recent 10-year period:

- Extremely statistically significant **increasing trend** for the **frequency of run hours** (hours per reactor year) for **normally running MDPs**, with a p-value of 0.0001 (see Figure 16). This trend was observed in the 2016 MDP update study [2] as highly statistically significant.
- Statistically significant **decreasing trend** for the **frequency of FTR events** (events per reactor year) for **normally running MDPs**, with a p-value of 0.0327 (see Figure 18). This is a new trend that was not observed in the 2016 MDP update study.

Table 7 and Table 8 provide a summary of normally running MDP FTS and FTR failure counts by system and year during the most recent 10-year period, respectively.

- Table 7 presents the normally running MDP FTS failure counts by system and year.
- Table 8 presents the normally running MDP FTR failure counts by system and year.

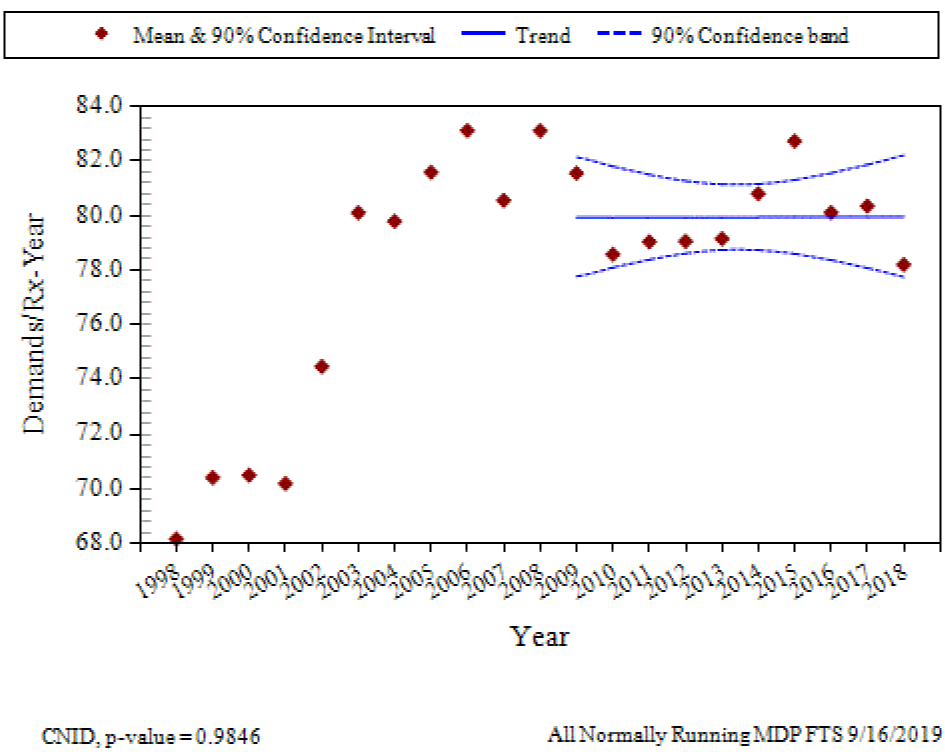

Figure 15. Frequency of start demands (demands per reactor year) trend for normally running MDPs.

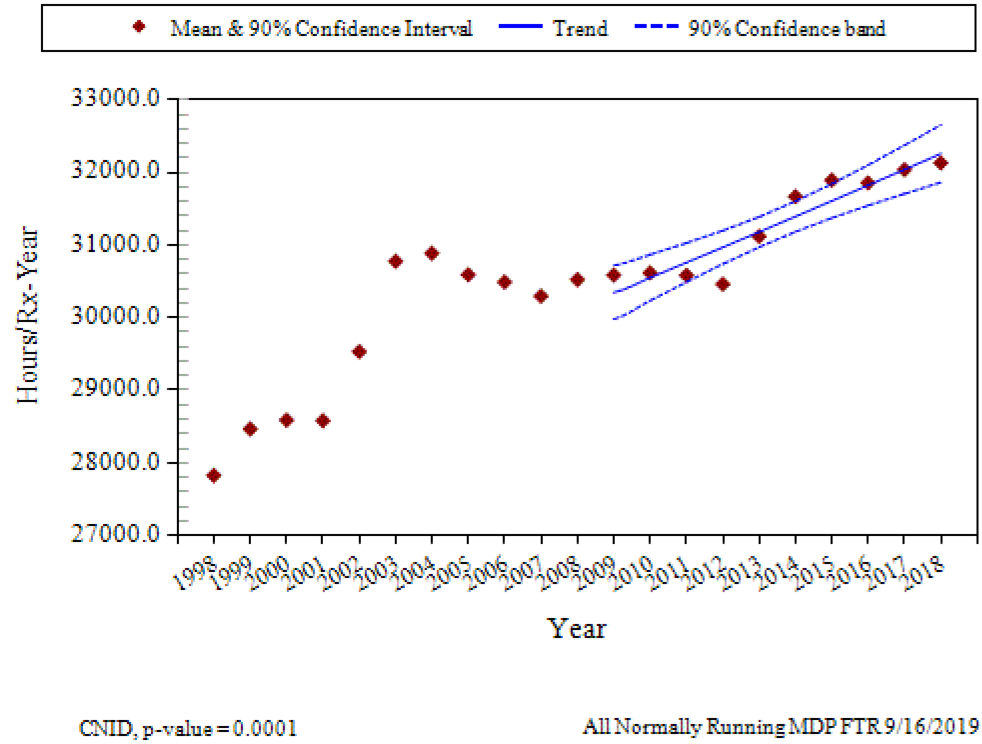

Figure 16. Frequency of run hours (hours per reactor year) trend for normally running MDPs.

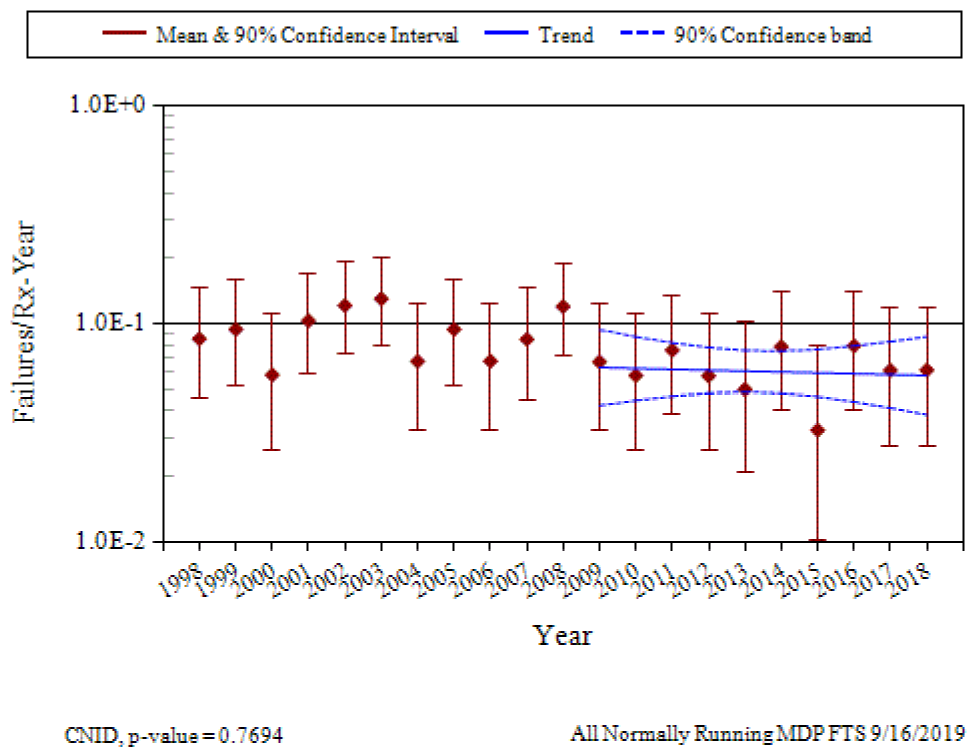

Figure 17. Frequency of FTS events (events per reactor year) trend for normally running MDPs.

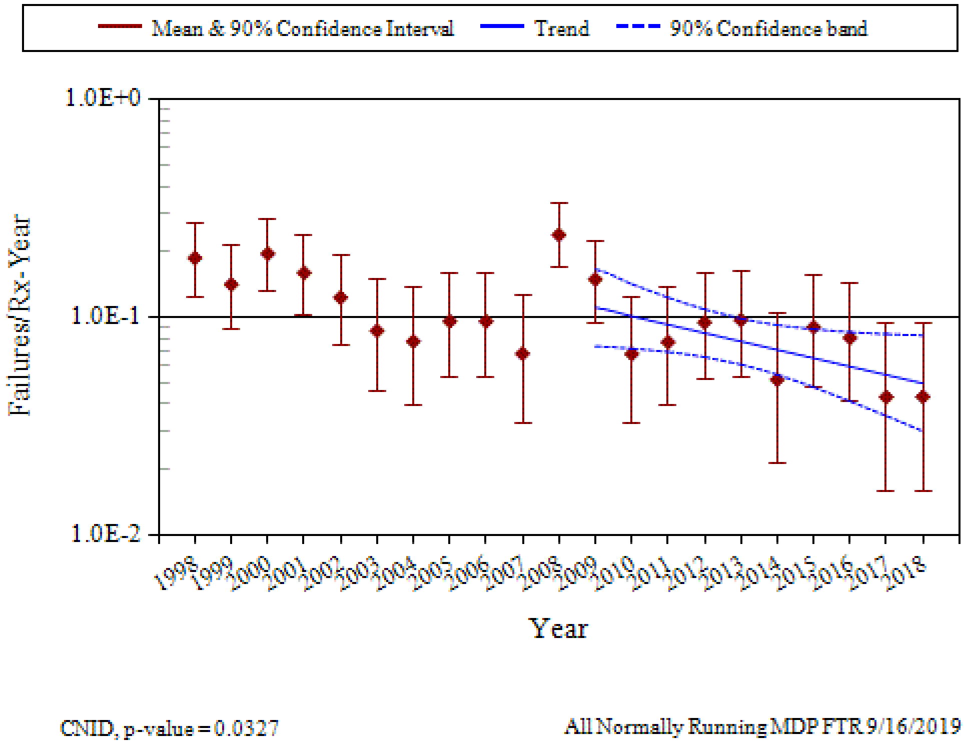

Figure 18. Frequency of FTR events (events per reactor year) trend for normally running MDPs.

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

System Code	MDP Count	MDP Percent	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total	Percent of Failures
CCW	301	46.6 %	5	4	5	1		5		1	1		22	34.9 %
CDS	143	22.1 %		1		2	1	1		3	1	1	10	15.9 %
CRD	43	6.7 %			1			1					2	3.2 %
CVC	8	1.2 %						1	1	1			3	4.8 %
LPCS	1	0.2 %											0	0.0 %
MFW	44	6.8 %	1		2	1	2		1	1			8	12.7 %
SWN	106	16.4 %	1	1		2	2		1	2	4	5	18	28.6 %
Total	646	100.0%	7	6	8	6	5	8	3	8	6	6	63	100.0%

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

System Code	MDP Count	MDP Percent	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total	Percent of Failures
CCW	301	46.6 %	7	2	1	2	5		4	2	1	1	25	30.9 %
CDS	143	22.1 %	6	3		1	1	2	1	1	2	1	18	22.2 %
CRD	43	6.7 %		1	2	4					1	1	9	11.1 %
CVC	8	1.2 %											0	0.0 %
LPCS	1	0.2 %											0	0.0 %
MFW	44	6.8 %				1	3	1	1	1			7	8.6 %
SWN	106	16.4 %	3	1	5	2	1	2	3	4		1	22	27.2 %
Total	646	100.0%	16	7	8	10	10	5	9	8	4	4	81	100.0%

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 2003.

The standby MDP ESF unplanned demand data covering 2003 through 2018 are summarized in Table 9. Consistency between the unplanned demand data and 2015 Update 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 could 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.

These consistency checks show that the FTS, FTLR, and FTR failure observations in the non-test, operational ESF demand data lie within their corresponding industry-average failure estimate distributions, provided in the 2015 Update (Table 2), that were based on both test and non-test operational ESF demands.

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	106	1448	0	1.2	1.00	Yes [b]
FTR<1H	106	1188	0	0.1	1.00	Yes [c]
FTR>1H	106	25371	1	0.3	0.23	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 Idaho National Laboratory (INL) 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 all failure modes (FTS, FTR≤1H, FTR>1H or FTR). The pump sub-component is also a key contributor for the FTR≤1H and FTR>1H failure modes.

MDP failure cause group contributions to the three failure modes are presented in Figure 20. The cause groups have been re-arranged in this update study in order to align with those currently 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 human errors, component issues, and design issues. The Human cause group is primarily influenced by maintenance and operating procedures and practices. The Component cause group includes the causes that were related to something internal to the component or an aging or worn out part, which were categorized as the Internal cause group in previous studies [2]. The Design cause group is influenced by manufacturing, installation, and design issues.

MDP failure 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 FTS is testing demand followed closely by non-testing demand. The most likely detection methods for FTR≤1H are non-test demand and testing demand. The most likely detection method for FTR>1H is non-test demand.

Normally running—the most likely detection method for FTS and FTR is non-test demand.

MDP recovery fractions for the three failure modes are presented in Figure 22. The overall non-recovery to recovery ratio is approximately 7:1, meaning that 7 of every 8 failures were not recovered.

Table 10. Component failure cause groups.[a]

Group	Specific Cause	Description
Component	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.
	Set point drift	Used when the cause of a failure is the result of set point drift or adjustment.
	Age/Wear	Used when the cause of the failure is a non-specific aging or wear issue.
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.
Environment	Ambient environmental stress	Used when the cause of a failure is the result of an environmental condition from the location of the component.
	Internal environment	The internal environment led to the failure. Debris/Foreign material as well as an operating medium chemistry issue.
	Extreme environmental stress	Used when the cause of a failure is the result of an environmental condition that places a higher than expected load on the equipment and is transitory in nature.
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.
	Inadequate procedure	Used when the cause of a failure is the result of an inadequate procedure operating or maintenance.
Other	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 empty fuel storage tanks.
	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.
	Unknown	Used when the cause of the failure is not known.

[a] . The cause groups have been re-arranged in order to align with those currently used in the CCF database.

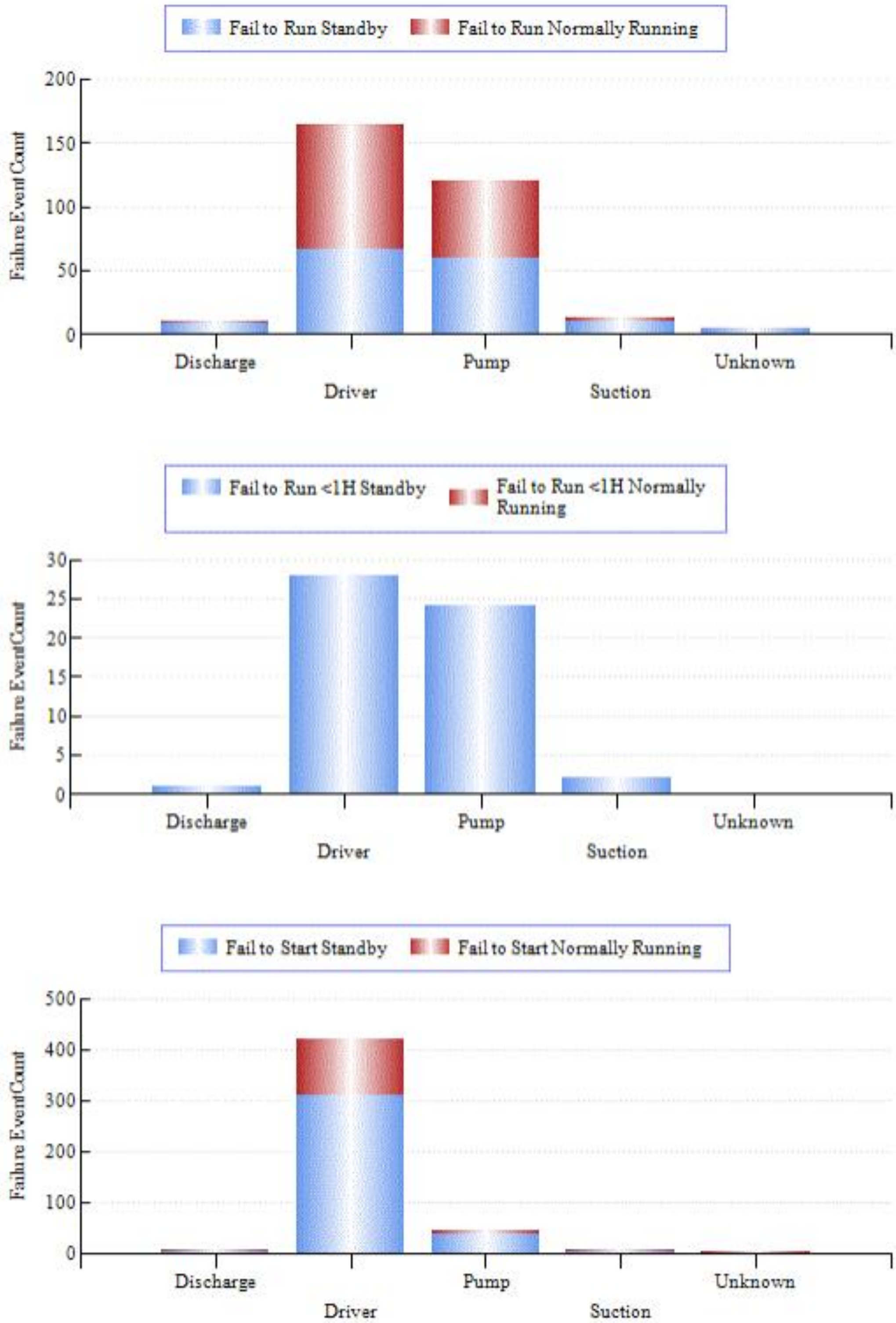

Figure 19. MDP failure breakdown by failure mode and sub component.

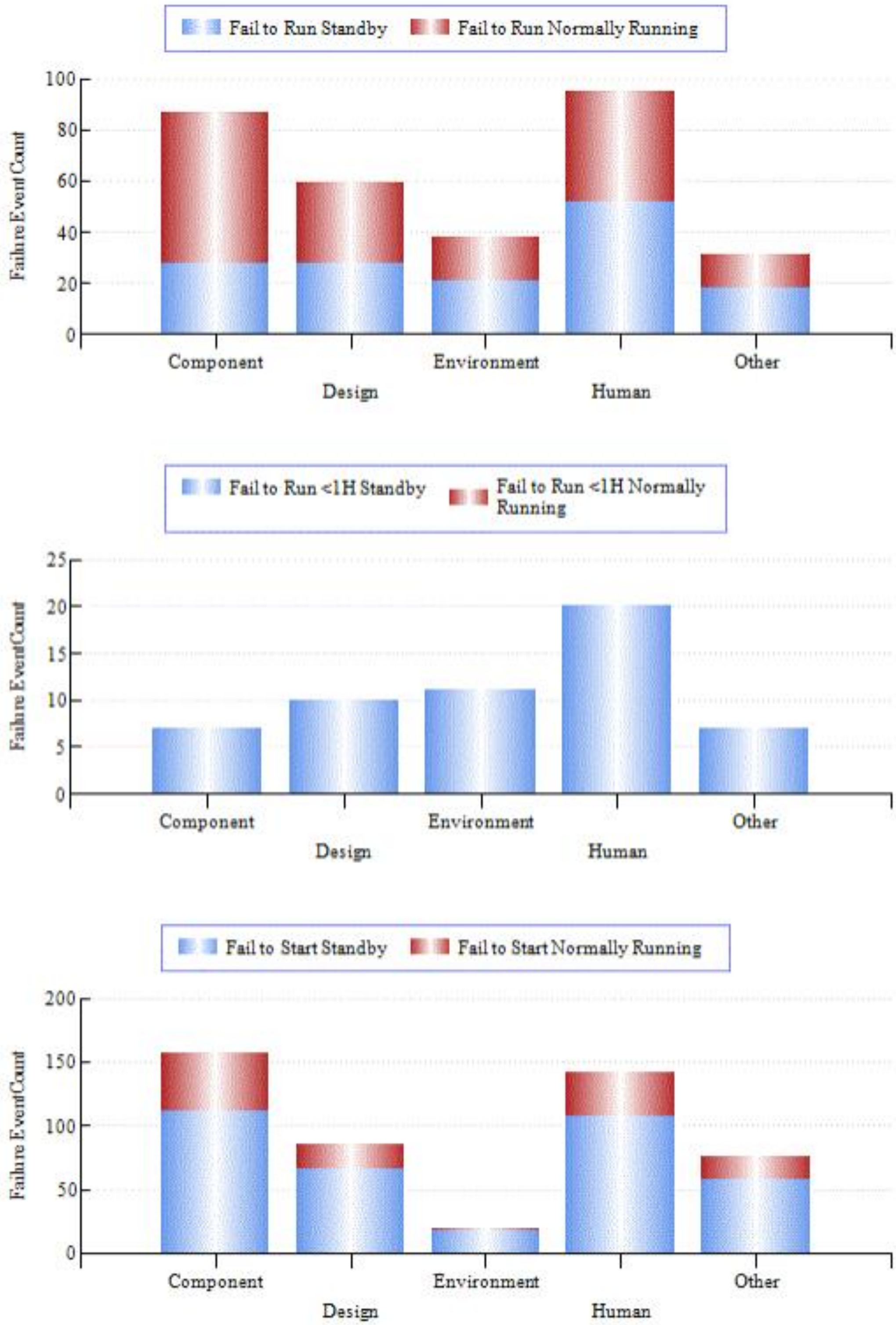

Figure 20. MDP failure breakdown by failure mode and cause group.

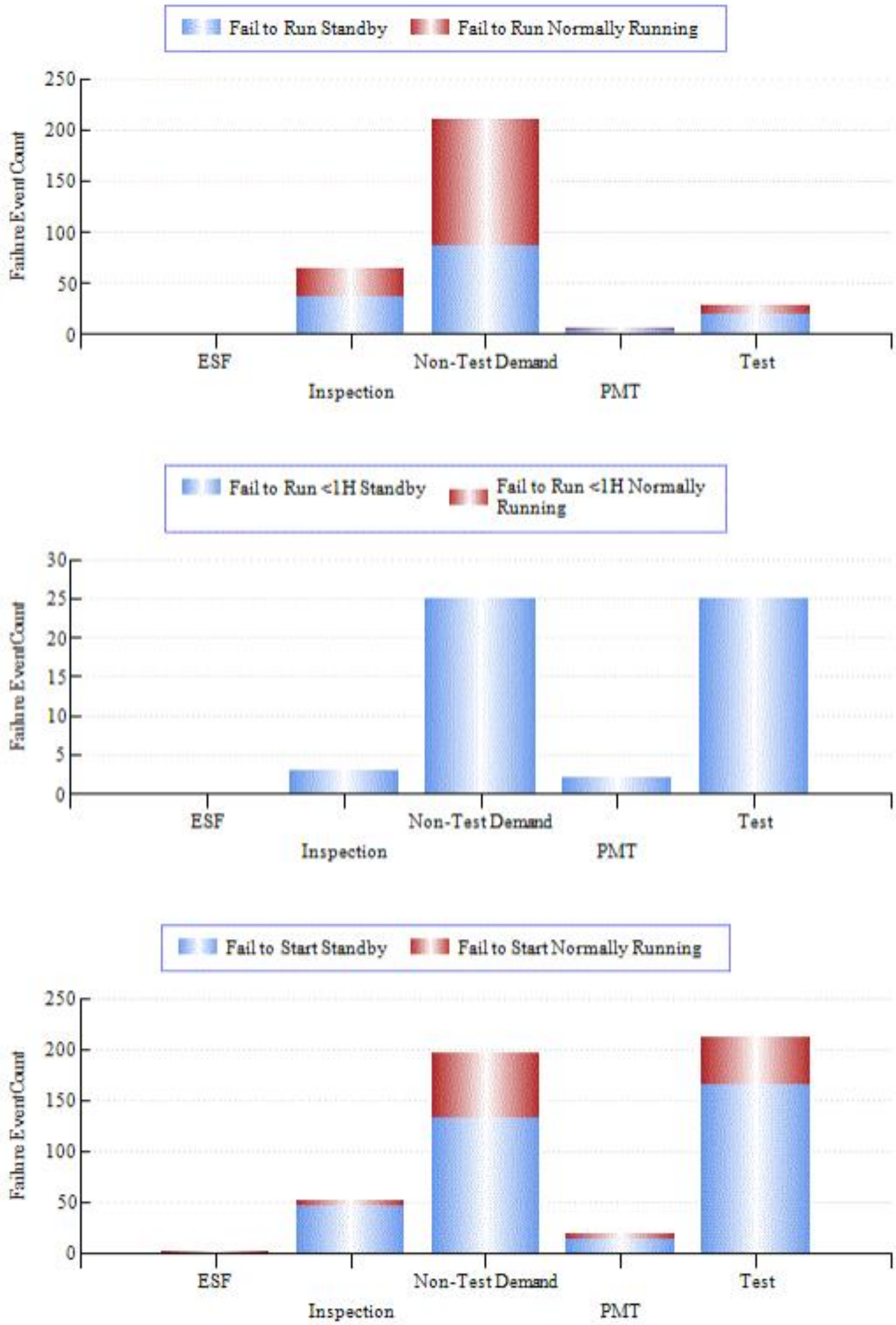

Figure 21. MDP failure breakdown by failure mode and method of detection.

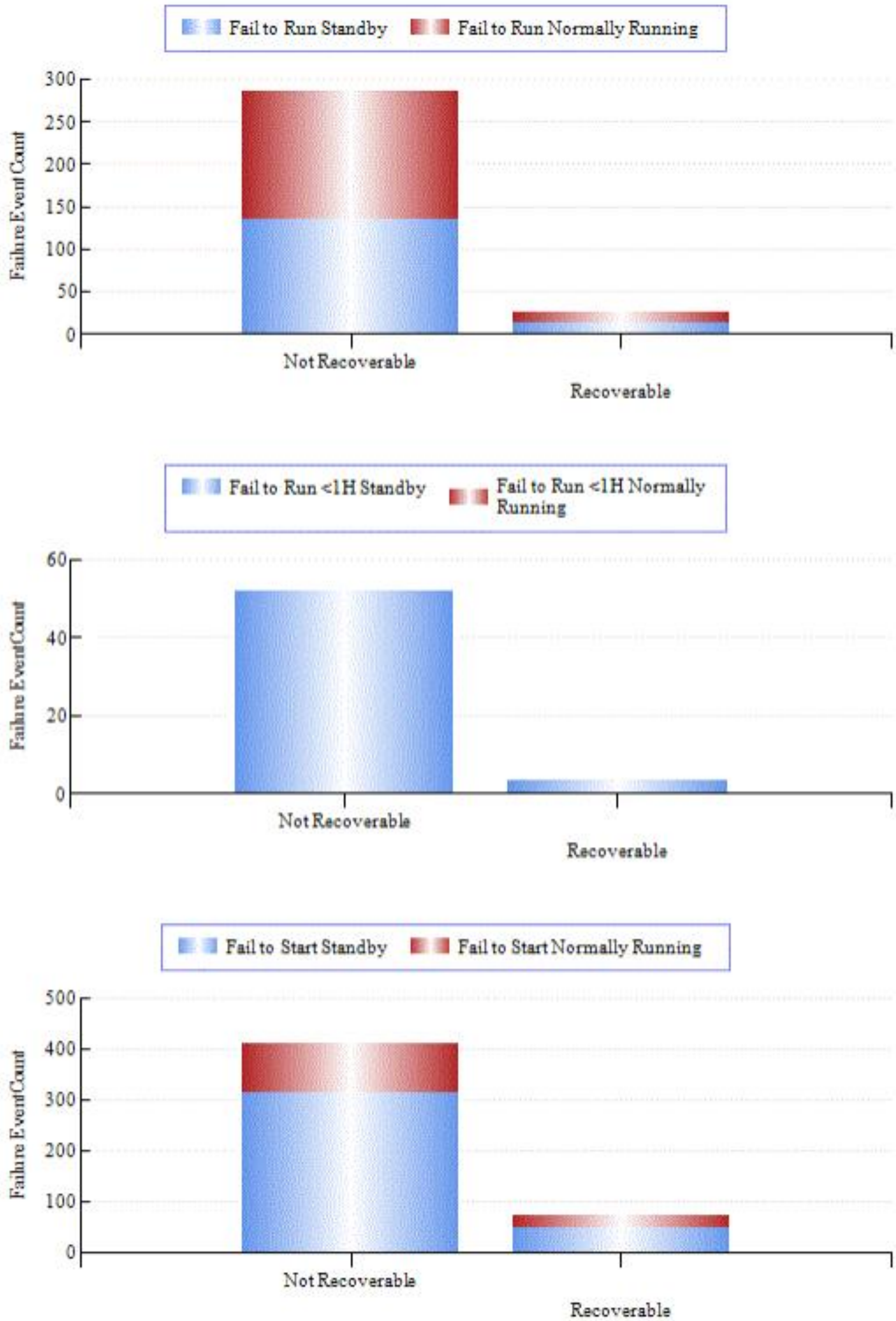

Figure 22. MDP failure breakdown by failure mode and recovery possibility.

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, binning required some judgment and involved 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.

Figure	Table	Analysis
Figure 1	Table 11	Failure probability estimate trend for standby MDP FTS
Figure 2	Table 12	Failure probability estimate trend for standby MDP FTR≤1H
Figure 3	Table 13	Failure rate estimate trend for standby MDP FTR>1H
Figure 4	Table 14	Failure probability estimate trend for normally running MDP FTS
Figure 5	Table 15	Failure rate estimate trend for normally running MDP FTR
Figure 6	Table 16	Pooled standby MDP UA trend
Figure 7	Table 17	Standby MDP total unreliability trend (8-hour mission)
Figure 8	Table 18	Normally running MDP total unreliability trend (8-hour mission)
Figure 9	Table 19	Frequency of start demands (demands per reactor year) trend for standby MDPs
Figure 10	Table 20	Frequency of run ≤ 1H hours (hours per reactor year) trend for standby MDPs
Figure 11	Table 21	Frequency of run > 1H hours (hours per reactor year) trend for standby MDPs
Figure 12	Table 22	Frequency of FTS events (events per reactor year) trend for standby MDPs
Figure 13	Table 23	Frequency of FTR≤1H events (events per reactor year) trend for standby MDPs
Figure 14	Table 24	Frequency of FTR>1H events (events per reactor year) trend for standby MDPs
Figure 15	Table 25	Frequency of start demands (demands per reactor year) trend for normally running MDPs
Figure 16	Table 26	Frequency of run hours (hours per reactor year) trend for normally running MDPs
Figure 17	Table 27	Frequency of FTS events (events per reactor year) trend for normally running MDPs
Figure 18	Table 28	Frequency of FTR events (events per reactor year) trend for normally running MDPs

Table 11. Plot data for Figure 1, failure probability estimate trend for standby MDP FTS.

Year	Failures	Demands	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						1.70E-04	1.80E-03	7.96E-04
1998	24	23,914	--	--	--	6.89E-04	1.39E-03	9.95E-04
1999	21	24,527	--	--	--	5.74E-04	1.22E-03	8.52E-04
2000	37	24,136	--	--	--	1.13E-03	1.98E-03	1.51E-03
2001	24	24,207	--	--	--	6.81E-04	1.38E-03	9.83E-04
2002	25	24,804	--	--	--	6.98E-04	1.39E-03	9.99E-04
2003	32	25,798	--	--	--	8.95E-04	1.64E-03	1.23E-03
2004	21	25,884	--	--	--	5.45E-04	1.16E-03	8.08E-04
2005	26	26,445	--	--	--	6.86E-04	1.35E-03	9.76E-04
2006	17	26,356	--	--	--	4.15E-04	9.64E-04	6.47E-04
2007	20	26,272	--	--	--	5.06E-04	1.10E-03	7.60E-04
2008	19	26,544	--	--	--	4.71E-04	1.04E-03	7.15E-04
2009	13	26,431	5.57E-04	3.86E-04	8.05E-04	2.98E-04	7.84E-04	4.97E-04
2010	21	25,721	5.83E-04	4.26E-04	7.97E-04	5.48E-04	1.17E-03	8.13E-04
2011	10	25,651	6.09E-04	4.68E-04	7.93E-04	2.20E-04	6.67E-04	3.98E-04
2012	17	25,243	6.37E-04	5.10E-04	7.96E-04	4.33E-04	1.01E-03	6.74E-04
2013	17	25,262	6.66E-04	5.47E-04	8.10E-04	4.32E-04	1.00E-03	6.74E-04
2014	24	24,998	6.96E-04	5.76E-04	8.42E-04	6.60E-04	1.34E-03	9.53E-04
2015	19	24,929	7.28E-04	5.92E-04	8.94E-04	5.01E-04	1.11E-03	7.60E-04
2016	14	24,208	7.61E-04	5.99E-04	9.67E-04	3.55E-04	9.02E-04	5.82E-04
2017	20	23,940	7.95E-04	5.98E-04	1.06E-03	5.54E-04	1.20E-03	8.32E-04
2018	20	23,877	8.32E-04	5.93E-04	1.17E-03	5.56E-04	1.21E-03	8.34E-04
Total	441	529,146						

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

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Hours	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						3.36E-06	4.08E-04	1.25E-04
1998	6	23,914	--	--	--	1.03E-04	4.39E-04	2.28E-04
1999	2	24,527	--	--	--	1.97E-05	2.42E-04	8.60E-05
2000	3	24,136	--	--	--	3.78E-05	2.95E-04	1.22E-04
2001	3	24,207	--	--	--	3.77E-05	2.94E-04	1.22E-04
2002	3	24,804	--	--	--	3.69E-05	2.88E-04	1.19E-04
2003	2	25,798	--	--	--	1.89E-05	2.32E-04	8.24E-05
2004	2	25,884	--	--	--	1.88E-05	2.31E-04	8.21E-05
2005	4	26,445	--	--	--	5.36E-05	3.17E-04	1.45E-04
2006	6	26,356	--	--	--	9.53E-05	4.04E-04	2.10E-04
2007	1	26,272	--	--	--	5.71E-06	1.80E-04	4.87E-05
2008	2	26,544	--	--	--	1.84E-05	2.26E-04	8.04E-05
2009	2	26,431	1.18E-04	7.14E-05	1.94E-04	1.85E-05	2.27E-04	8.07E-05
2010	4	25,721	1.14E-04	7.48E-05	1.74E-04	5.49E-05	3.25E-04	1.49E-04
2011	2	25,651	1.11E-04	7.76E-05	1.58E-04	1.90E-05	2.33E-04	8.28E-05
2012	4	25,243	1.07E-04	7.91E-05	1.46E-04	5.58E-05	3.30E-04	1.51E-04
2013	3	25,262	1.04E-04	7.87E-05	1.38E-04	3.64E-05	2.84E-04	1.17E-04
2014	4	24,998	1.01E-04	7.57E-05	1.35E-04	5.63E-05	3.33E-04	1.52E-04
2015	3	24,929	9.79E-05	7.07E-05	1.36E-04	3.68E-05	2.87E-04	1.19E-04
2016	1	24,208	9.49E-05	6.46E-05	1.40E-04	6.12E-06	1.92E-04	5.22E-05
2017	2	23,940	9.21E-05	5.83E-05	1.46E-04	2.01E-05	2.47E-04	8.77E-05
2018	2	23,877	8.93E-05	5.21E-05	1.53E-04	2.01E-05	2.47E-04	8.79E-05
Total	61	529,146						

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

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	1,003,772	--	--	--	1.54E-06	9.12E-06	4.17E-06
1999	5	922,746	--	--	--	2.29E-06	1.12E-05	5.51E-06
2000	10	902,056	--	--	--	5.93E-06	1.80E-05	1.07E-05
2001	15	907,396	--	--	--	9.81E-06	2.41E-05	1.58E-05
2002	10	982,669	--	--	--	5.48E-06	1.66E-05	9.92E-06
2003	15	1,113,518	--	--	--	8.11E-06	1.99E-05	1.30E-05
2004	13	1,139,814	--	--	--	6.65E-06	1.75E-05	1.11E-05
2005	10	1,150,098	--	--	--	4.73E-06	1.44E-05	8.57E-06
2006	9	1,151,302	--	--	--	4.12E-06	1.33E-05	7.74E-06
2007	10	1,162,006	--	--	--	4.68E-06	1.42E-05	8.49E-06
2008	21	1,164,438	--	--	--	1.17E-05	2.49E-05	1.73E-05
2009	6	1,150,676	8.30E-06	4.27E-06	1.61E-05	2.40E-06	1.02E-05	5.30E-06
2010	8	1,163,416	7.65E-06	4.38E-06	1.34E-05	3.50E-06	1.22E-05	6.86E-06
2011	14	1,164,452	7.06E-06	4.41E-06	1.13E-05	7.14E-06	1.81E-05	1.17E-05
2012	8	1,171,689	6.51E-06	4.32E-06	9.81E-06	3.48E-06	1.21E-05	6.82E-06
2013	17	1,144,997	6.01E-06	4.06E-06	8.88E-06	9.20E-06	2.14E-05	1.43E-05
2014	5	1,135,925	5.54E-06	3.64E-06	8.43E-06	1.89E-06	9.23E-06	4.54E-06
2015	5	1,140,546	5.11E-06	3.14E-06	8.32E-06	1.88E-06	9.20E-06	4.52E-06
2016	2	1,117,515	4.71E-06	2.64E-06	8.43E-06	4.80E-07	5.90E-06	2.10E-06
2017	5	1,100,035	4.35E-06	2.18E-06	8.66E-06	1.95E-06	9.51E-06	4.68E-06
2018	5	1,095,156	4.01E-06	1.79E-06	8.99E-06	1.95E-06	9.55E-06	4.70E-06
Total	197	22,984,223						

Table 14. Plot data for Figure 4, failure probability estimate trend for normally running MDP FTS.

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	7,020	--	--	--	6.61E-04	2.13E-03	1.24E-03
1999	10	7,253	--	--	--	7.35E-04	2.23E-03	1.33E-03
2000	6	7,281	--	--	--	3.72E-04	1.58E-03	8.21E-04
2001	11	7,230	--	--	--	8.32E-04	2.39E-03	1.46E-03
2002	13	7,669	--	--	--	9.73E-04	2.56E-03	1.63E-03
2003	14	8,251	--	--	--	9.96E-04	2.53E-03	1.63E-03
2004	7	8,241	--	--	--	4.09E-04	1.55E-03	8.45E-04
2005	10	8,404	--	--	--	6.41E-04	1.94E-03	1.16E-03
2006	7	8,562	--	--	--	3.95E-04	1.50E-03	8.15E-04
2007	9	8,347	--	--	--	5.63E-04	1.82E-03	1.06E-03
2008	13	8,668	--	--	--	8.68E-04	2.29E-03	1.45E-03
2009	7	8,482	7.90E-04	5.25E-04	1.19E-03	3.98E-04	1.51E-03	8.22E-04
2010	6	8,172	7.82E-04	5.54E-04	1.11E-03	3.34E-04	1.42E-03	7.38E-04
2011	8	8,220	7.75E-04	5.79E-04	1.04E-03	4.90E-04	1.70E-03	9.60E-04
2012	6	8,245	7.67E-04	5.99E-04	9.84E-04	3.32E-04	1.41E-03	7.32E-04
2013	5	8,039	7.60E-04	6.06E-04	9.53E-04	2.64E-04	1.29E-03	6.34E-04
2014	8	8,081	7.53E-04	5.99E-04	9.47E-04	4.97E-04	1.73E-03	9.75E-04
2015	3	8,191	7.46E-04	5.76E-04	9.64E-04	1.23E-04	9.58E-04	3.96E-04
2016	8	7,933	7.38E-04	5.45E-04	1.00E-03	5.06E-04	1.76E-03	9.92E-04
2017	6	7,874	7.31E-04	5.10E-04	1.05E-03	3.46E-04	1.47E-03	7.64E-04
2018	6	7,644	7.24E-04	4.74E-04	1.11E-03	3.56E-04	1.51E-03	7.85E-04
Total	172	167,809						

Table 15. Plot data for Figure 5, failure rate estimate trend for normally running MDP FTR.

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						1.10E-06	7.85E-06	3.81E-06
1998	20	2,865,838	--	--	--	4.46E-06	9.69E-06	6.70E-06
1999	15	2,931,796	--	--	--	3.08E-06	7.58E-06	4.96E-06
2000	21	2,952,453	--	--	--	4.60E-06	9.80E-06	6.83E-06
2001	17	2,943,464	--	--	--	3.58E-06	8.32E-06	5.58E-06
2002	13	3,041,551	--	--	--	2.50E-06	6.58E-06	4.17E-06
2003	9	3,169,901	--	--	--	1.50E-06	4.86E-06	2.82E-06
2004	8	3,189,948	--	--	--	1.28E-06	4.45E-06	2.51E-06
2005	10	3,150,929	--	--	--	1.73E-06	5.26E-06	3.14E-06
2006	10	3,140,404	--	--	--	1.74E-06	5.27E-06	3.15E-06
2007	7	3,138,813	--	--	--	1.09E-06	4.14E-06	2.25E-06
2008	26	3,183,062	--	--	--	5.52E-06	1.09E-05	7.85E-06
2009	16	3,180,894	3.64E-06	2.43E-06	5.47E-06	3.09E-06	7.38E-06	4.89E-06
2010	7	3,184,120	3.31E-06	2.36E-06	4.66E-06	1.07E-06	4.08E-06	2.22E-06
2011	8	3,180,550	3.01E-06	2.26E-06	4.01E-06	1.28E-06	4.47E-06	2.52E-06
2012	10	3,176,576	2.74E-06	2.13E-06	3.52E-06	1.72E-06	5.22E-06	3.12E-06
2013	10	3,160,484	2.49E-06	1.96E-06	3.17E-06	1.73E-06	5.24E-06	3.13E-06
2014	5	3,166,609	2.27E-06	1.74E-06	2.95E-06	6.81E-07	3.33E-06	1.64E-06
2015	9	3,157,387	2.06E-06	1.52E-06	2.80E-06	1.51E-06	4.87E-06	2.83E-06
2016	8	3,154,294	1.87E-06	1.30E-06	2.70E-06	1.29E-06	4.50E-06	2.54E-06
2017	4	3,139,625	1.70E-06	1.11E-06	2.63E-06	4.99E-07	2.95E-06	1.35E-06
2018	4	3,140,713	1.55E-06	9.35E-07	2.57E-06	4.99E-07	2.95E-06	1.35E-06
Total	237	65,349,410						

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	--	--	--	4.12E-04	1.02E-02	3.85E-03
2008	17,845.1	4,450,273.2	--	--	--	3.19E-04	1.13E-02	4.03E-03
2009	18,666.1	4,397,190.2	4.36E-03	4.01E-03	4.71E-03	4.04E-04	1.10E-02	4.08E-03
2010	19,132.3	4,473,513.0	4.28E-03	4.01E-03	4.55E-03	5.09E-04	1.14E-02	4.36E-03
2011	18,404.4	4,314,939.4	4.20E-03	4.01E-03	4.39E-03	4.27E-04	1.15E-02	4.29E-03
2012	18,464.7	4,177,350.9	4.12E-03	4.00E-03	4.24E-03	4.06E-04	1.12E-02	4.15E-03
2013	18,987.2	4,225,813.8	4.04E-03	4.00E-03	4.08E-03	2.57E-04	1.21E-02	4.17E-03
2014	18,472.8	4,271,782.8	3.96E-03	3.92E-03	4.00E-03	3.08E-04	1.20E-02	4.22E-03
2015	16,379.2	4,245,640.9	3.88E-03	3.77E-03	4.00E-03	3.48E-04	1.06E-02	3.86E-03
2016	14,583.0	4,247,599.7	3.80E-03	3.61E-03	4.00E-03	3.54E-04	9.36E-03	3.50E-03
2017	15,265.0	4,168,826.1	3.72E-03	3.45E-03	3.99E-03	1.16E-04	1.21E-02	3.79E-03
2018	14,652.4	4,169,041.7	3.64E-03	3.29E-03	3.99E-03	2.00E-04	1.06E-02	3.60E-03
Total	354,349.3	83,433,534.8						

Table 17. Plot data for Figure 7, standby MDP total unreliability trend (8-hour mission).

	Regression Curve Data Points			Yearly Estimate Data Points		
Year	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
1998	--	--	--	1.55E-03	1.35E-02	5.57E-03
1999	--	--	--	1.25E-03	1.35E-02	5.33E-03
2000	--	--	--	2.21E-03	1.43E-02	6.67E-03
2001	--	--	--	1.64E-03	1.56E-02	6.26E-03
2002	--	--	--	2.18E-03	1.27E-02	6.20E-03
2003	--	--	--	2.45E-03	1.31E-02	6.43E-03
2004	--	--	--	1.43E-03	1.41E-02	5.91E-03
2005	--	--	--	1.59E-03	1.46E-02	6.05E-03
2006	--	--	--	1.51E-03	1.21E-02	5.59E-03
2007	--	--	--	1.47E-03	1.32E-02	5.55E-03
2008	--	--	--	1.41E-03	1.28E-02	5.53E-03
2009	5.24E-03	4.98E-03	5.52E-03	1.19E-03	1.30E-02	5.27E-03
2010	5.18E-03	4.95E-03	5.41E-03	1.77E-03	1.12E-02	5.28E-03
2011	5.11E-03	4.93E-03	5.30E-03	1.26E-03	1.10E-02	4.96E-03
2012	5.05E-03	4.89E-03	5.21E-03	1.07E-03	1.47E-02	5.14E-03
2013	4.98E-03	4.85E-03	5.13E-03	9.91E-04	1.37E-02	5.10E-03
2014	4.92E-03	4.79E-03	5.06E-03	1.41E-03	1.19E-02	4.98E-03
2015	4.86E-03	4.71E-03	5.02E-03	1.19E-03	1.09E-02	4.58E-03
2016	4.80E-03	4.63E-03	4.98E-03	1.06E-03	1.08E-02	4.49E-03
2017	4.74E-03	4.54E-03	4.95E-03	1.38E-03	1.17E-02	4.95E-03
2018	4.68E-03	4.45E-03	4.93E-03	1.21E-03	1.21E-02	4.84E-03

Table 18. Plot data for Figure 8, normally running MDP total unreliability trend (8-hour mission).

	Regression Curve Data Points			Yearly Estimate Data Points		
Year	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
1998	--	--	--	8.34E-04	2.18E-03	1.43E-03
1999	--	--	--	8.99E-04	2.26E-03	1.51E-03
2000	--	--	--	5.38E-04	1.61E-03	1.00E-03
2001	--	--	--	9.93E-04	2.45E-03	1.64E-03
2002	--	--	--	1.10E-03	2.54E-03	1.76E-03
2003	--	--	--	1.06E-03	2.45E-03	1.72E-03
2004	--	--	--	4.87E-04	1.53E-03	9.27E-04
2005	--	--	--	7.26E-04	1.89E-03	1.26E-03
2006	--	--	--	4.81E-04	1.44E-03	9.10E-04
2007	--	--	--	5.99E-04	1.75E-03	1.11E-03
2008	--	--	--	1.08E-03	2.43E-03	1.67E-03
2009	8.98E-04	6.49E-04	1.24E-03	4.99E-04	1.53E-03	9.66E-04
2010	8.84E-04	6.72E-04	1.16E-03	4.01E-04	1.38E-03	8.11E-04
2011	8.71E-04	6.91E-04	1.10E-03	5.64E-04	1.64E-03	1.04E-03
2012	8.58E-04	7.05E-04	1.04E-03	3.97E-04	1.41E-03	8.21E-04
2013	8.45E-04	7.08E-04	1.01E-03	3.17E-04	1.23E-03	7.14E-04
2014	8.33E-04	6.98E-04	9.94E-04	5.42E-04	1.69E-03	1.05E-03
2015	8.20E-04	6.74E-04	9.98E-04	1.98E-04	8.61E-04	4.70E-04
2016	8.08E-04	6.41E-04	1.02E-03	5.81E-04	1.70E-03	1.09E-03
2017	7.96E-04	6.05E-04	1.05E-03	3.93E-04	1.38E-03	8.18E-04
2018	7.84E-04	5.67E-04	1.08E-03	3.70E-04	1.39E-03	8.22E-04

Table 19. Plot data for Figure 9, frequency of start demands (demands per reactor year) trend for standby MDPs.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	**Demands**	**Reactor Years**	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
1998	23,914	103.0	--	--	--	2.30E+02	2.35E+02	2.32E+02
1999	24,527	103.0	--	--	--	2.36E+02	2.41E+02	2.38E+02
2000	24,136	103.3	--	--	--	2.31E+02	2.36E+02	2.34E+02
2001	24,207	103.0	--	--	--	2.33E+02	2.38E+02	2.35E+02
2002	24,804	103.0	--	--	--	2.38E+02	2.43E+02	2.41E+02
2003	25,798	103.0	--	--	--	2.48E+02	2.53E+02	2.50E+02
2004	25,884	103.3	--	--	--	2.48E+02	2.53E+02	2.51E+02
2005	26,445	103.0	--	--	--	2.54E+02	2.59E+02	2.57E+02
2006	26,356	103.0	--	--	--	2.53E+02	2.58E+02	2.56E+02
2007	26,272	103.6	--	--	--	2.51E+02	2.56E+02	2.54E+02
2008	26,544	104.3	--	--	--	2.52E+02	2.57E+02	2.55E+02
2009	26,431	104.0	2.50E+02	2.44E+02	2.55E+02	2.52E+02	2.57E+02	2.54E+02
2010	25,721	104.0	2.49E+02	2.45E+02	2.54E+02	2.45E+02	2.50E+02	2.47E+02
2011	25,651	104.0	2.49E+02	2.45E+02	2.52E+02	2.44E+02	2.49E+02	2.47E+02
2012	25,243	104.3	2.48E+02	2.45E+02	2.51E+02	2.40E+02	2.45E+02	2.42E+02
2013	25,262	101.6	2.48E+02	2.45E+02	2.51E+02	2.46E+02	2.51E+02	2.49E+02
2014	24,998	100.0	2.47E+02	2.44E+02	2.50E+02	2.47E+02	2.53E+02	2.50E+02
2015	24,929	99.0	2.47E+02	2.43E+02	2.50E+02	2.49E+02	2.54E+02	2.52E+02
2016	24,208	99.0	2.46E+02	2.42E+02	2.50E+02	2.42E+02	2.47E+02	2.44E+02
2017	23,940	98.0	2.45E+02	2.41E+02	2.50E+02	2.42E+02	2.47E+02	2.44E+02
2018	23,877	97.7	2.45E+02	2.40E+02	2.50E+02	2.42E+02	2.47E+02	2.44E+02
Total	529,146	2,147.1						

Table 20. Plot data for Figure 10, frequency of run ≤ 1H hours (hours per reactor year) trend for standby MDPs.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	**Hours**	**Reactor Years**	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
1998	23,914	103.0	--	--	--	2.30E+02	2.35E+02	2.32E+02
1999	24,527	103.0	--	--	--	2.36E+02	2.41E+02	2.38E+02
2000	24,136	103.3	--	--	--	2.31E+02	2.36E+02	2.34E+02
2001	24,207	103.0	--	--	--	2.33E+02	2.38E+02	2.35E+02
2002	24,804	103.0	--	--	--	2.38E+02	2.43E+02	2.41E+02
2003	25,798	103.0	--	--	--	2.48E+02	2.53E+02	2.50E+02
2004	25,884	103.3	--	--	--	2.48E+02	2.53E+02	2.51E+02
2005	26,445	103.0	--	--	--	2.54E+02	2.59E+02	2.57E+02
2006	26,356	103.0	--	--	--	2.53E+02	2.58E+02	2.56E+02
2007	26,272	103.6	--	--	--	2.51E+02	2.56E+02	2.54E+02
2008	26,544	104.3	--	--	--	2.52E+02	2.57E+02	2.55E+02
2009	26,431	104.0	2.50E+02	2.44E+02	2.55E+02	2.52E+02	2.57E+02	2.54E+02
2010	25,721	104.0	2.49E+02	2.45E+02	2.54E+02	2.45E+02	2.50E+02	2.47E+02
2011	25,651	104.0	2.49E+02	2.45E+02	2.52E+02	2.44E+02	2.49E+02	2.47E+02
2012	25,243	104.3	2.48E+02	2.45E+02	2.51E+02	2.40E+02	2.45E+02	2.42E+02
2013	25,262	101.6	2.48E+02	2.45E+02	2.51E+02	2.46E+02	2.51E+02	2.49E+02
2014	24,998	100.0	2.47E+02	2.44E+02	2.50E+02	2.47E+02	2.53E+02	2.50E+02
2015	24,929	99.0	2.47E+02	2.43E+02	2.50E+02	2.49E+02	2.54E+02	2.52E+02
2016	24,208	99.0	2.46E+02	2.42E+02	2.50E+02	2.42E+02	2.47E+02	2.44E+02
2017	23,940	98.0	2.45E+02	2.41E+02	2.50E+02	2.42E+02	2.47E+02	2.44E+02
2018	23,877	97.7	2.45E+02	2.40E+02	2.50E+02	2.42E+02	2.47E+02	2.44E+02
Total	529,146	2,147.1						

Table 21. Plot data for Figure 11, frequency of run > 1H hours (hours per reactor year) trend for standby MDPs.

Year	Run Hours	Reactor Years	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	1,003,772	103.0	--	--	--	9.73E+03	9.76E+03	9.75E+03
1999	922,746	103.0	--	--	--	8.94E+03	8.97E+03	8.96E+03
2000	902,056	103.3	--	--	--	8.72E+03	8.75E+03	8.73E+03
2001	907,396	103.0	--	--	--	8.80E+03	8.82E+03	8.81E+03
2002	982,669	103.0	--	--	--	9.53E+03	9.56E+03	9.54E+03
2003	1,113,518	103.0	--	--	--	1.08E+04	1.08E+04	1.08E+04
2004	1,139,814	103.3	--	--	--	1.10E+04	1.11E+04	1.10E+04
2005	1,150,098	103.0	--	--	--	1.12E+04	1.12E+04	1.12E+04
2006	1,151,302	103.0	--	--	--	1.12E+04	1.12E+04	1.12E+04
2007	1,162,006	103.6	--	--	--	1.12E+04	1.12E+04	1.12E+04
2008	1,164,438	104.3	--	--	--	1.12E+04	1.12E+04	1.12E+04
2009	1,150,676	104.0	1.12E+04	1.10E+04	1.13E+04	1.10E+04	1.11E+04	1.11E+04
2010	1,163,416	104.0	1.12E+04	1.11E+04	1.13E+04	1.12E+04	1.12E+04	1.12E+04
2011	1,164,452	104.0	1.12E+04	1.11E+04	1.13E+04	1.12E+04	1.12E+04	1.12E+04
2012	1,171,689	104.3	1.12E+04	1.11E+04	1.13E+04	1.12E+04	1.13E+04	1.12E+04
2013	1,144,997	101.6	1.12E+04	1.12E+04	1.13E+04	1.13E+04	1.13E+04	1.13E+04
2014	1,135,925	100.0	1.13E+04	1.12E+04	1.14E+04	1.13E+04	1.14E+04	1.14E+04
2015	1,140,546	99.0	1.13E+04	1.12E+04	1.14E+04	1.15E+04	1.15E+04	1.15E+04
2016	1,117,515	99.0	1.13E+04	1.12E+04	1.14E+04	1.13E+04	1.13E+04	1.13E+04
2017	1,100,035	98.0	1.13E+04	1.12E+04	1.15E+04	1.12E+04	1.12E+04	1.12E+04
2018	1,095,156	97.7	1.13E+04	1.12E+04	1.15E+04	1.12E+04	1.12E+04	1.12E+04
Total	22,984,223	2,147.1						

Table 22. Plot data for Figure 12, frequency of FTS events (events per reactor year) trend for standby MDPs.

Year	Failures	Reactor Years	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	24	103.0	--	--	--	1.60E-01	3.24E-01	2.31E-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	2.03E-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	--	--	--	1.28E-01	2.78E-01	1.93E-01
2008	19	104.3	--	--	--	1.20E-01	2.66E-01	1.82E-01
2009	13	104.0	1.39E-01	9.60E-02	2.02E-01	7.56E-02	1.99E-01	1.26E-01
2010	21	104.0	1.45E-01	1.06E-01	1.99E-01	1.35E-01	2.88E-01	2.01E-01
2011	10	104.0	1.51E-01	1.16E-01	1.98E-01	5.42E-02	1.65E-01	9.82E-02
2012	17	104.3	1.58E-01	1.26E-01	1.98E-01	1.05E-01	2.43E-01	1.63E-01
2013	17	101.6	1.65E-01	1.35E-01	2.01E-01	1.08E-01	2.50E-01	1.68E-01
2014	24	100.0	1.72E-01	1.42E-01	2.08E-01	1.65E-01	3.34E-01	2.38E-01
2015	19	99.0	1.79E-01	1.46E-01	2.21E-01	1.26E-01	2.79E-01	1.91E-01
2016	14	99.0	1.87E-01	1.47E-01	2.38E-01	8.69E-02	2.21E-01	1.42E-01
2017	20	98.0	1.95E-01	1.46E-01	2.60E-01	1.35E-01	2.94E-01	2.03E-01
2018	20	97.7	2.03E-01	1.45E-01	2.86E-01	1.36E-01	2.95E-01	2.04E-01
Total	441	2,147.1						

Table 23. Plot data for Figure 13, frequency of FTR≤1H events (events per reactor year) trend for standby MDPs.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	**Failures**	**Reactor Years**	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
1998	6	103.0	--	--	--	2.43E-02	1.03E-01	5.35E-02
1999	2	103.0	--	--	--	4.72E-03	5.79E-02	2.06E-02
2000	3	103.3	--	--	--	8.91E-03	6.95E-02	2.88E-02
2001	3	103.0	--	--	--	8.93E-03	6.97E-02	2.88E-02
2002	3	103.0	--	--	--	8.93E-03	6.97E-02	2.88E-02
2003	2	103.0	--	--	--	4.72E-03	5.79E-02	2.06E-02
2004	2	103.3	--	--	--	4.71E-03	5.78E-02	2.05E-02
2005	4	103.0	--	--	--	1.37E-02	8.10E-02	3.71E-02
2006	6	103.0	--	--	--	2.43E-02	1.03E-01	5.35E-02
2007	1	103.6	--	--	--	1.44E-03	4.54E-02	1.23E-02
2008	2	104.3	--	--	--	4.67E-03	5.73E-02	2.04E-02
2009	2	104.0	2.95E-02	1.79E-02	4.85E-02	4.68E-03	5.75E-02	2.04E-02
2010	4	104.0	2.85E-02	1.87E-02	4.35E-02	1.36E-02	8.04E-02	3.68E-02
2011	2	104.0	2.76E-02	1.93E-02	3.93E-02	4.68E-03	5.75E-02	2.04E-02
2012	4	104.3	2.67E-02	1.97E-02	3.62E-02	1.36E-02	8.02E-02	3.67E-02
2013	3	101.6	2.58E-02	1.95E-02	3.41E-02	9.03E-03	7.05E-02	2.92E-02
2014	4	100.0	2.49E-02	1.87E-02	3.33E-02	1.40E-02	8.31E-02	3.80E-02
2015	3	99.0	2.41E-02	1.74E-02	3.34E-02	9.23E-03	7.21E-02	2.98E-02
2016	1	99.0	2.33E-02	1.59E-02	3.43E-02	1.50E-03	4.71E-02	1.28E-02
2017	2	98.0	2.26E-02	1.43E-02	3.57E-02	4.92E-03	6.04E-02	2.15E-02
2018	2	97.7	2.18E-02	1.28E-02	3.74E-02	4.93E-03	6.06E-02	2.15E-02
Total	61	2,147.1						

Table 24. Plot data for Figure 14, frequency of FTR>1H events (events per reactor year) trend for standby MDPs.

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	--	--	--	1.52E-02	8.97E-02	4.10E-02
1999	5	103.0	--	--	--	2.09E-02	1.02E-01	5.01E-02
2000	10	103.3	--	--	--	5.27E-02	1.60E-01	9.55E-02
2001	15	103.0	--	--	--	8.79E-02	2.16E-01	1.41E-01
2002	10	103.0	--	--	--	5.28E-02	1.60E-01	9.57E-02
2003	15	103.0	--	--	--	8.79E-02	2.16E-01	1.41E-01
2004	13	103.3	--	--	--	7.34E-02	1.93E-01	1.23E-01
2005	10	103.0	--	--	--	5.28E-02	1.60E-01	9.57E-02
2006	9	103.0	--	--	--	4.61E-02	1.49E-01	8.66E-02
2007	10	103.6	--	--	--	5.25E-02	1.59E-01	9.52E-02
2008	21	104.3	--	--	--	1.30E-01	2.78E-01	1.94E-01
2009	6	104.0	9.25E-02	4.76E-02	1.80E-01	2.66E-02	1.13E-01	5.87E-02
2010	8	104.0	8.55E-02	4.89E-02	1.49E-01	3.92E-02	1.36E-01	7.68E-02
2011	14	104.0	7.90E-02	4.94E-02	1.26E-01	8.00E-02	2.03E-01	1.31E-01
2012	8	104.3	7.30E-02	4.85E-02	1.10E-01	3.91E-02	1.36E-01	7.66E-02
2013	17	101.6	6.75E-02	4.56E-02	9.99E-02	1.04E-01	2.41E-01	1.62E-01
2014	5	100.0	6.24E-02	4.10E-02	9.50E-02	2.14E-02	1.05E-01	5.15E-02
2015	5	99.0	5.77E-02	3.54E-02	9.40E-02	2.16E-02	1.06E-01	5.20E-02
2016	2	99.0	5.33E-02	2.98E-02	9.54E-02	5.42E-03	6.65E-02	2.36E-02
2017	5	98.0	4.93E-02	2.47E-02	9.83E-02	2.18E-02	1.07E-01	5.25E-02
2018	5	97.7	4.56E-02	2.03E-02	1.02E-01	2.19E-02	1.07E-01	5.27E-02
Total	197	2,147.1						

Table 25. Plot data for Figure 15, frequency of start demands (demands per reactor year) trend for normally running MDPs.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	**Demands**	**Reactor Years**	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
1998	7,020	103.0	--	--	--	6.68E+01	6.95E+01	6.82E+01
1999	7,253	103.0	--	--	--	6.91E+01	7.18E+01	7.04E+01
2000	7,281	103.3	--	--	--	6.91E+01	7.19E+01	7.05E+01
2001	7,230	103.0	--	--	--	6.88E+01	7.16E+01	7.02E+01
2002	7,669	103.0	--	--	--	7.31E+01	7.59E+01	7.45E+01
2003	8,251	103.0	--	--	--	7.87E+01	8.16E+01	8.01E+01
2004	8,241	103.3	--	--	--	7.84E+01	8.13E+01	7.98E+01
2005	8,404	103.0	--	--	--	8.01E+01	8.31E+01	8.16E+01
2006	8,562	103.0	--	--	--	8.17E+01	8.46E+01	8.31E+01
2007	8,347	103.6	--	--	--	7.91E+01	8.20E+01	8.06E+01
2008	8,668	104.3	--	--	--	8.17E+01	8.46E+01	8.31E+01
2009	8,482	104.0	7.99E+01	7.78E+01	8.21E+01	8.01E+01	8.30E+01	8.16E+01
2010	8,172	104.0	7.99E+01	7.81E+01	8.18E+01	7.72E+01	8.00E+01	7.86E+01
2011	8,220	104.0	7.99E+01	7.84E+01	8.15E+01	7.76E+01	8.05E+01	7.90E+01
2012	8,245	104.3	7.99E+01	7.86E+01	8.13E+01	7.76E+01	8.05E+01	7.91E+01
2013	8,039	101.6	7.99E+01	7.87E+01	8.12E+01	7.77E+01	8.06E+01	7.92E+01
2014	8,081	100.0	7.99E+01	7.87E+01	8.12E+01	7.93E+01	8.23E+01	8.08E+01
2015	8,191	99.0	7.99E+01	7.86E+01	8.13E+01	8.12E+01	8.43E+01	8.27E+01
2016	7,933	99.0	8.00E+01	7.84E+01	8.16E+01	7.86E+01	8.16E+01	8.01E+01
2017	7,874	98.0	8.00E+01	7.81E+01	8.19E+01	7.89E+01	8.19E+01	8.04E+01
2018	7,644	97.7	8.00E+01	7.77E+01	8.22E+01	7.67E+01	7.97E+01	7.82E+01
Total	167,809	2,147.1						

Table 26. Plot data for Figure 16, frequency of run hours (hours per reactor year) trend for normally running MDPs.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Run Hours	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	2,865,838	103.0	--	--	--	2.78E+04	2.79E+04	2.78E+04
1999	2,931,796	103.0	--	--	--	2.84E+04	2.85E+04	2.85E+04
2000	2,952,453	103.3	--	--	--	2.86E+04	2.86E+04	2.86E+04
2001	2,943,464	103.0	--	--	--	2.86E+04	2.86E+04	2.86E+04
2002	3,041,551	103.0	--	--	--	2.95E+04	2.96E+04	2.95E+04
2003	3,169,901	103.0	--	--	--	3.08E+04	3.08E+04	3.08E+04
2004	3,189,948	103.3	--	--	--	3.09E+04	3.09E+04	3.09E+04
2005	3,150,929	103.0	--	--	--	3.06E+04	3.06E+04	3.06E+04
2006	3,140,404	103.0	--	--	--	3.05E+04	3.05E+04	3.05E+04
2007	3,138,813	103.6	--	--	--	3.03E+04	3.03E+04	3.03E+04
2008	3,183,062	104.3	--	--	--	3.05E+04	3.06E+04	3.05E+04
2009	3,180,894	104.0	3.03E+04	3.00E+04	3.07E+04	3.06E+04	3.06E+04	3.06E+04
2010	3,184,120	104.0	3.06E+04	3.02E+04	3.09E+04	3.06E+04	3.06E+04	3.06E+04
2011	3,180,550	104.0	3.08E+04	3.05E+04	3.10E+04	3.06E+04	3.06E+04	3.06E+04
2012	3,176,576	104.3	3.10E+04	3.07E+04	3.12E+04	3.04E+04	3.05E+04	3.05E+04
2013	3,160,484	101.6	3.12E+04	3.10E+04	3.14E+04	3.11E+04	3.11E+04	3.11E+04
2014	3,166,609	100.0	3.14E+04	3.12E+04	3.16E+04	3.16E+04	3.17E+04	3.17E+04
2015	3,157,387	99.0	3.16E+04	3.14E+04	3.18E+04	3.19E+04	3.19E+04	3.19E+04
2016	3,154,294	99.0	3.18E+04	3.15E+04	3.21E+04	3.18E+04	3.19E+04	3.19E+04
2017	3,139,625	98.0	3.20E+04	3.17E+04	3.24E+04	3.20E+04	3.21E+04	3.20E+04
2018	3,140,713	97.7	3.23E+04	3.19E+04	3.27E+04	3.21E+04	3.22E+04	3.21E+04
Total	65,349,410	2,147.1						

Table 27. Plot data for Figure 17, frequency of FTS events (events per reactor year) trend for normally running MDPs.

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	--	--	--	4.56E-02	1.47E-01	8.56E-02
1999	10	103.0	--	--	--	5.22E-02	1.58E-01	9.46E-02
2000	6	103.3	--	--	--	2.65E-02	1.12E-01	5.84E-02
2001	11	103.0	--	--	--	5.90E-02	1.70E-01	1.04E-01
2002	13	103.0	--	--	--	7.28E-02	1.92E-01	1.22E-01
2003	14	103.0	--	--	--	7.98E-02	2.03E-01	1.31E-01
2004	7	103.3	--	--	--	3.26E-02	1.24E-01	6.74E-02
2005	10	103.0	--	--	--	5.22E-02	1.58E-01	9.46E-02
2006	7	103.0	--	--	--	3.27E-02	1.24E-01	6.76E-02
2007	9	103.6	--	--	--	4.53E-02	1.46E-01	8.51E-02
2008	13	104.3	--	--	--	7.19E-02	1.90E-01	1.20E-01
2009	7	104.0	6.31E-02	4.25E-02	9.37E-02	3.24E-02	1.23E-01	6.70E-02
2010	6	104.0	6.25E-02	4.48E-02	8.74E-02	2.63E-02	1.12E-01	5.81E-02
2011	8	104.0	6.20E-02	4.68E-02	8.21E-02	3.87E-02	1.35E-01	7.59E-02
2012	6	104.3	6.14E-02	4.83E-02	7.81E-02	2.62E-02	1.11E-01	5.79E-02
2013	5	101.6	6.08E-02	4.89E-02	7.57E-02	2.09E-02	1.02E-01	5.02E-02
2014	8	100.0	6.03E-02	4.83E-02	7.53E-02	4.02E-02	1.40E-01	7.87E-02
2015	3	99.0	5.97E-02	4.66E-02	7.66E-02	1.01E-02	7.91E-02	3.27E-02
2016	8	99.0	5.92E-02	4.41E-02	7.94E-02	4.05E-02	1.41E-01	7.95E-02
2017	6	98.0	5.87E-02	4.14E-02	8.31E-02	2.78E-02	1.18E-01	6.13E-02
2018	6	97.7	5.81E-02	3.85E-02	8.76E-02	2.79E-02	1.18E-01	6.15E-02
Total	172	2,147.1						

Table 28. Plot data for Figure 18, frequency of FTR events (events per reactor year) trend for normally running MDPs.

			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	--	--	--	1.25E-01	2.72E-01	1.88E-01
1999	15	103.0	--	--	--	8.83E-02	2.17E-01	1.42E-01
2000	21	103.3	--	--	--	1.32E-01	2.82E-01	1.96E-01
2001	17	103.0	--	--	--	1.03E-01	2.39E-01	1.60E-01
2002	13	103.0	--	--	--	7.40E-02	1.95E-01	1.24E-01
2003	9	103.0	--	--	--	4.63E-02	1.50E-01	8.70E-02
2004	8	103.3	--	--	--	3.96E-02	1.38E-01	7.76E-02
2005	10	103.0	--	--	--	5.31E-02	1.61E-01	9.61E-02
2006	10	103.0	--	--	--	5.31E-02	1.61E-01	9.61E-02
2007	7	103.6	--	--	--	3.31E-02	1.26E-01	6.83E-02
2008	26	104.3	--	--	--	1.69E-01	3.32E-01	2.40E-01
2009	16	104.0	1.11E-01	7.38E-02	1.66E-01	9.47E-02	2.26E-01	1.50E-01
2010	7	104.0	1.01E-01	7.20E-02	1.43E-01	3.29E-02	1.25E-01	6.81E-02
2011	8	104.0	9.27E-02	6.96E-02	1.24E-01	3.93E-02	1.37E-01	7.71E-02
2012	10	104.3	8.49E-02	6.60E-02	1.09E-01	5.25E-02	1.59E-01	9.50E-02
2013	10	101.6	7.77E-02	6.10E-02	9.90E-02	5.38E-02	1.63E-01	9.74E-02
2014	5	100.0	7.11E-02	5.47E-02	9.25E-02	2.15E-02	1.05E-01	5.18E-02
2015	9	99.0	6.51E-02	4.79E-02	8.84E-02	4.81E-02	1.55E-01	9.03E-02
2016	8	99.0	5.96E-02	4.13E-02	8.58E-02	4.12E-02	1.43E-01	8.08E-02
2017	4	98.0	5.45E-02	3.54E-02	8.41E-02	1.60E-02	9.44E-02	4.32E-02
2018	4	97.7	4.99E-02	3.01E-02	8.28E-02	1.60E-02	9.46E-02	4.33E-02
Total	237	2,147.1						

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