



Enhanced Component Performance Study: Motor-Driven Pumps 1998–2022

July 2023

Zhegang Ma

Regulatory Support, Idaho National Laboratory



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Regulatory Support, Idaho National Laboratory**

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**Idaho National Laboratory
Regulatory Support Department
Idaho Falls, Idaho 83415**

<http://www.inl.gov>

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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 2022 as reported in the Institute of Nuclear Power Operations (INPO) Industry Reporting and Information System (IRIS). The MDP failure modes considered for standby systems are fail to start (FTS), fail to run (FTR) for one hour of operation ($FTR \leq 1H$), FTR after one hour of operation ($FTR > 1H$), and for normally running systems FTS and 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.

The following increasing trends were identified for MDPs for the most recent 10-year period:

- Standby MDP frequency of start demands (demands per reactor year)
- Standby MDP frequency of $FTR \leq 1H$ hours (hours per reactor year)
- Standby MDP frequency of $FTR > 1H$ hours
- Normally running MDP frequency of run hours.

The following decreasing trends were identified for MDPs for the most recent 10-year period:

- Standby MDP $FTR \leq 1H$ failure probability
- Normally running MDP FTR failure rate
- Standby MDP unavailability
- Standby MDP total unreliability (8-hour mission)
- Normally running MDP total unreliability (8-hour mission)

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ACRONYMS

AFW	auxiliary feedwater
AOV	air-operated valve
BWR	boiling water reactor
CCF	common-cause failure
CCW	component cooling water
CDS	condensate system
CNID	constrained noninformative prior distribution
CRD	control rod drive
CSR	containment spray recirculation
CVC	chemical and volume control
EDG	emergency diesel generator
EPIX	Equipment Performance and Information Exchange Database
ESF	engineered safety feature
ESW	essential service water
FTR \leq 1H	fail to run for one hour of operation
FTR $>$ 1H	fail to run after one hour of operation
FTR	fail to run
FTS	fail to start
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
NRC	Nuclear Regulatory Commission

OLS	ordinary least squares
PMT	post maintenance testing
PRA	probabilistic risk assessment
PWR	pressurized water reactor
RHR	residual heat removal
SPAR	standardized plant analysis risk
SWN	normally operating service water
SWS	standby service water
TDP	turbine-driven pump
UA	unavailability

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Enhanced Component Performance Study: Motor-Driven Pumps 1998–2022

1. INTRODUCTION

This report presents an enhanced performance evaluation of motor-driven pumps (MDPs) at U.S. commercial nuclear power plants from 1998 through 2022. 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 instead of the federal fiscal year, 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 (MOV), 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/RPT-22-66599, *Enhanced Component Performance Study: Motor-Driven Pumps 1998-2020* [2]. The Nuclear Regulatory Commission (NRC) Reactor Operational Experience Results and Databases webpage provides the link to the historical and current results of component performance studies (<http://nrcoe.inl.gov/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 from <https://nrcoe.inl.gov/>.

The data used in this study are based on the operating experience failure reports from Institute of Nuclear Power Operations (INPO) *Industry Reporting and Information System (IRIS)* [4], formerly the Equipment Performance and Information Exchange Database (EPIX) and INPO Consolidated Events Database (ICES) [5]. Maintenance unavailability (UA) performance data came from the Reactor Oversight Process program's Mitigating Systems Performance Index (MSPI) program and IRIS [6]. Previously, the study relied on operating experience obtained from licensee event reports, Nuclear Plant Reliability Data System (NPRDS), and EPIX. The IRIS database (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.

MDPs are categorized as either standby or normally running. The MDP failure modes considered for standby systems are fail to start (FTS), fail to run (FTR) for one hour of operation ($FTR \leq 1H$), and FTR after one hour of operation ($FTR > 1H$). The MDP failure modes considered for normally running systems are FTS and FTR. Annual failure probabilities (failures per demand) are provided for FTS and $FTR \leq 1H$ 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) or Standardized Plant Analysis Risk (SPAR) models. The *2020 Parameter Update* documented in INL/EXT-21-65055 [7] is the most recent update to NUREG/CR-6928, *Industry-Average Performance for Components and Initiating Events at U.S Commercial Nuclear Power Plants* [8], using data through 2020 and provides component unreliability estimates for SPAR models. Estimates from that report are included herein for comparison. Those estimates are labelled “SPAR 2020” 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 the 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 MDPs. Section 6 presents various engineering analyses performed for MDPs 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 subcomponents, failure causes, detection methods, and recovery possibility, etc. A comparison of IRIS MDP unplanned demand results with the *2020 Parameter Update* industry-average results for standby MDPs is also conducted in Section 6 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 in the **frequency of run > 1H hours** (hours per reactor year) estimates for **standby MDPs** with a p-value of 0.0000 (see Figure 11). The same trend was observed in the *2020 MDP update* study [2].
- An extremely statistically significant **increasing trend** was identified in the **frequency of run hours** estimates for **normally running MDPs** with a p-value of 0.0001 (see Figure 16). The same trend was observed in the *2020 MDP update* study.

2.1.2 Highly Statistically Significant

- A highly statistically significant **increasing trend** was identified in the **frequency of start demands** (demands per reactor year) estimates for **standby MDPs** with a p-value of 0.0029 (see Figure 9). The same trend was observed in the *2020 MDP update* study as statistically significant.
- A highly statistically significant **increasing trend** was identified in the **frequency of run ≤ 1H hours** estimates for **standby MDPs** with a p-value of 0.0029 (see Figure 10). The same trend was observed in the *2020 MDP update* study as statistically significant.

2.1.3 Statistically Significant

- None.

2.2 Decreasing Trends

2.2.1 Extremely Statistically Significant

- An extremely statistically significant **decreasing trend** was identified in the **standby MDP unavailability** estimates with a p-value of 0.0001 (see Figure 6). The same trend was observed in the *2020 MDP Update* study.
- An extremely statistically significant **decreasing trend** was identified in the **standby MDP unreliability (8-hour mission)** estimates with a p-value of 0.0001 (see Figure 7). This is a new trend that was not observed in the *2020 MDP Update* study.

2.2.2 Highly Statistically Significant

- None.

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 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).

2.2.3 Statistically Significant

- A statistically significant **decreasing trend** was identified in the **standby MDP FTR \leq 1H failure probability** estimates with a p-value of 0.0462 (see Figure 2). The same trend was observed in the *2020 MDP Update* study.
- A statistically significant **decreasing trend** was identified in the **normally running MDP FTR failure rate** estimates with a p-value of 0.0474 (see Figure 5). The same trend was observed in the *2020 MDP Update* study.
- A statistically significant **decreasing trend** was identified in the **normally running MDP total unreliability (8-hour mission)** estimates with a p-value of 0.0238 (see Figure 8). The same trend was observed in the *2020 MDP Update* study.

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 tests on industry-average parameters from the *2020 Parameter Update* against operational failure counts obtained from actual MDP performance with ESF demands. These consistency checks show that the FTS, FTR \leq 1H, and FTR $>$ 1H failure observations in the non-test, operational ESF demand data lie within the corresponding industry-average failure estimate distributions, provided in the *2020 Parameter Update* (Table 2) that were based on both test and actual 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, $FTR \leq 1H$, and $FTR > 1H$, and for normally running pumps FTS and FTR. The MDP data set obtained from IRIS includes MDPs in the systems listed in Table 1. This report follows the definition of these categories in previous studies, 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 the *2020 Parameter Update* [7]. The *2020 Parameter 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 *2020 Parameter 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 any time during the study period. 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. Non-test demands are those actual plant demands that are not ESF demands.

Table 1. MDP systems.

System	Description	Total	Standby	Normally Running
AFW	Auxiliary feedwater	130	130	
CCW	Component cooling water	303		303
CDS	Condensate system	143		143
CRD	Control rod drive	52	9	43
CSR	Containment spray recirculation	159	159	
CVC	Chemical and volume control	8		8
HPCS	High pressure core spray	9	9	
HPSI	High pressure safety injection	175	175	
LPCS	Low pressure core spray	76	74	2
MFW	Main feedwater	44		44
RHR	Residual heat removal (LPCI in BWRs; LPSI in PWRs)	295	295	
SWN	Normally operating service water	106		106
SWS	Standby service water	458	458	
	Total	1958	1309	649

Table 2. Industry-wide distributions of p (failure probability) and λ (hourly rate) in the 2020 *Parameter Update* for MDPs [7].

Operation	Failure Mode	5%	Median	Mean	95%	Distribution		
						Type	α	β
Standby	FTS	1.09E-4	4.96E-4	5.88E-4	1.38E-3	Beta	2.07	3.52E+03
	FTR \leq 1H	7.34E-7	4.68E-5	9.13E-5	3.33E-4	Gamma	0.58	6.34E+03
	FTR $>$ 1H	3.58E-8	3.77E-6	8.12E-6	3.10E-5	Gamma	0.51	6.29E+04
Running/ Alternating	FTS	4.86E-5	5.62E-4	7.86E-4	2.30E-3	Beta	1.08	1.37E+03
	FTR	3.94E-7	1.89E-6	2.26E-6	5.38E-6	Gamma	1.97	8.72E+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 2022. 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 noninformative prior distribution (CNID), which has wide bounds [3, 9]. 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 do 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:

$$\mu = \frac{\sum f_i + 0.5}{\sum T_i} \quad (1)$$

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

$$\mu_i = \frac{f_i + 0.5}{\frac{0.5}{\mu} + T_i} \quad (2)$$

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

$$\mu = \frac{\sum f_i + 0.5}{\sum D_i + 1} \quad (3)$$

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 [9]). The posterior distribution mean for the i^{th} year (μ_i) can be calculated as:

$$\mu_i = \frac{f_i + \alpha}{\frac{\alpha}{\mu} + D_i} \quad (4)$$

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, therefore, suggest a trend does exist. P-values of less than or equal to 0.05 indicate strong evidence 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 method 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 *Overview and Reference* [3].

A final feature of the trend graphs includes the baseline industry values from the *2020 Parameter Update* (Table 2) are shown as “SPAR 2020” in the graphs 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 \leq 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 trends were identified for MDP failure probabilities/rates for FTS, FTR \leq 1H, and FTR $>$ 1H events in the most recent 10-year period:

- **Decreasing trend in the standby MDP FTR \leq 1H failure probability** estimates, which is statistically significant with a p-value of 0.0462 (see Figure 2). The same trend was observed in the *2020 MDP Update* study [2].
- **Decreasing trend in the normally running MDP FTR failure rate** estimates, which is statistically significant with a p-value of 0.0474 (see Figure 5). The same trend was observed in the *2020 MDP Update* study.

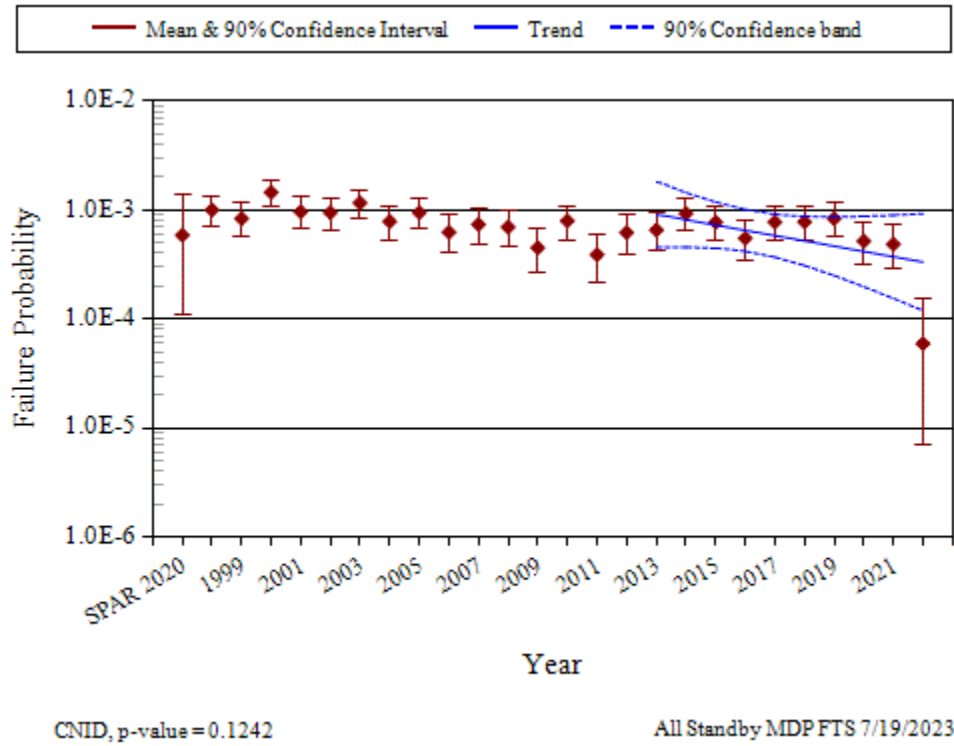


Figure 1. Failure probability estimate trend for standby MDP FTS.

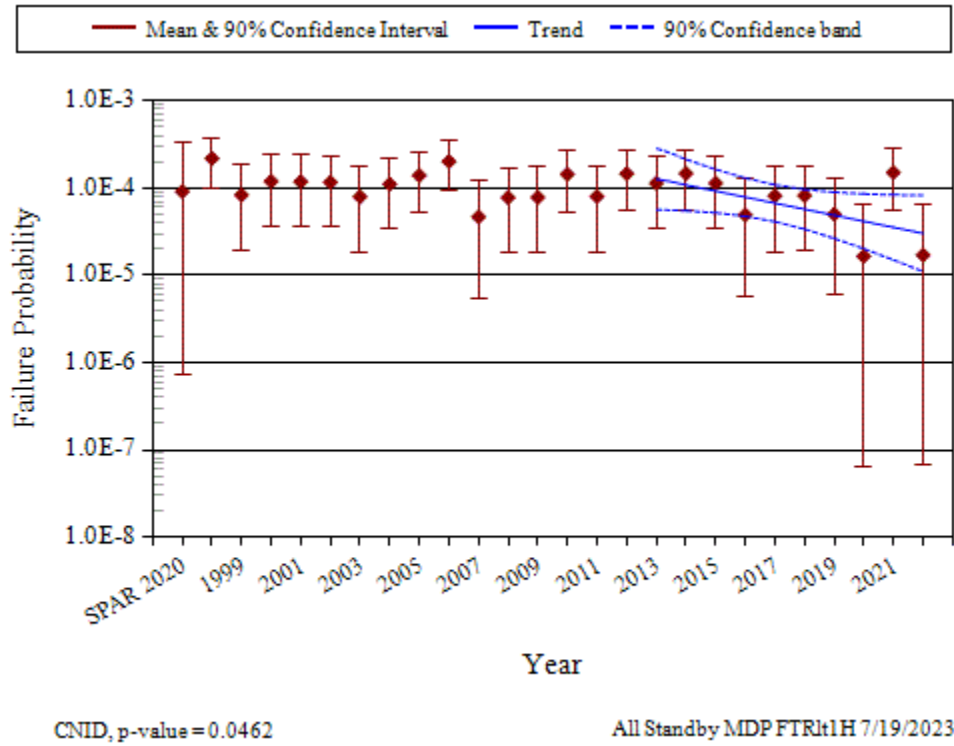


Figure 2. Failure probability estimate trend for standby MDP FTR ≤ 1H.

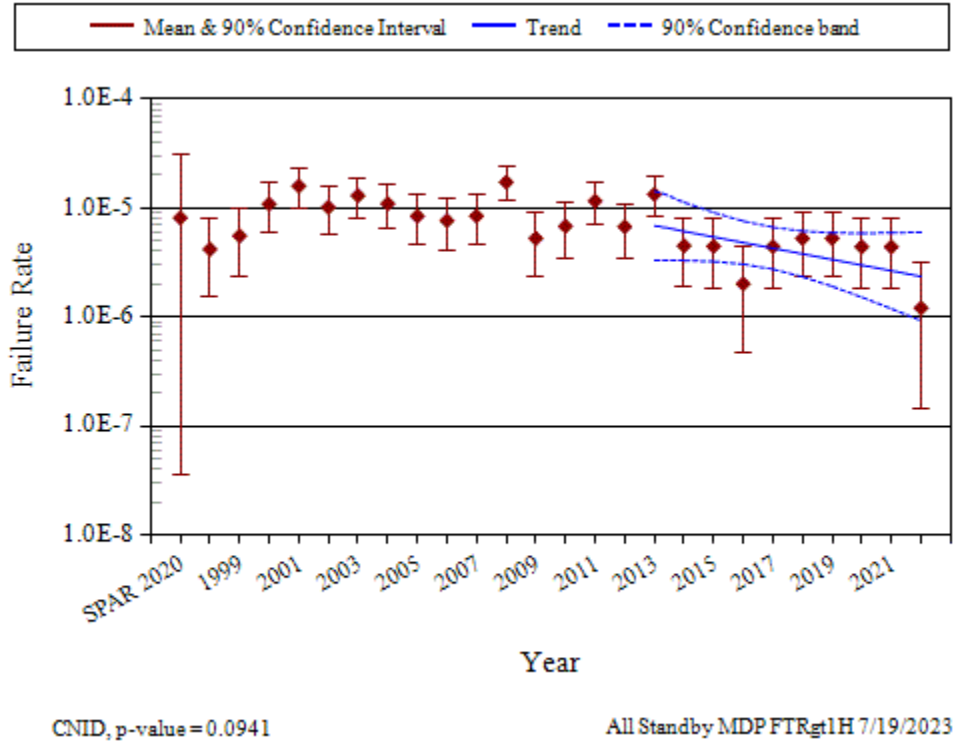


Figure 3. Failure rate estimate trend for standby MDP FTR>1H.

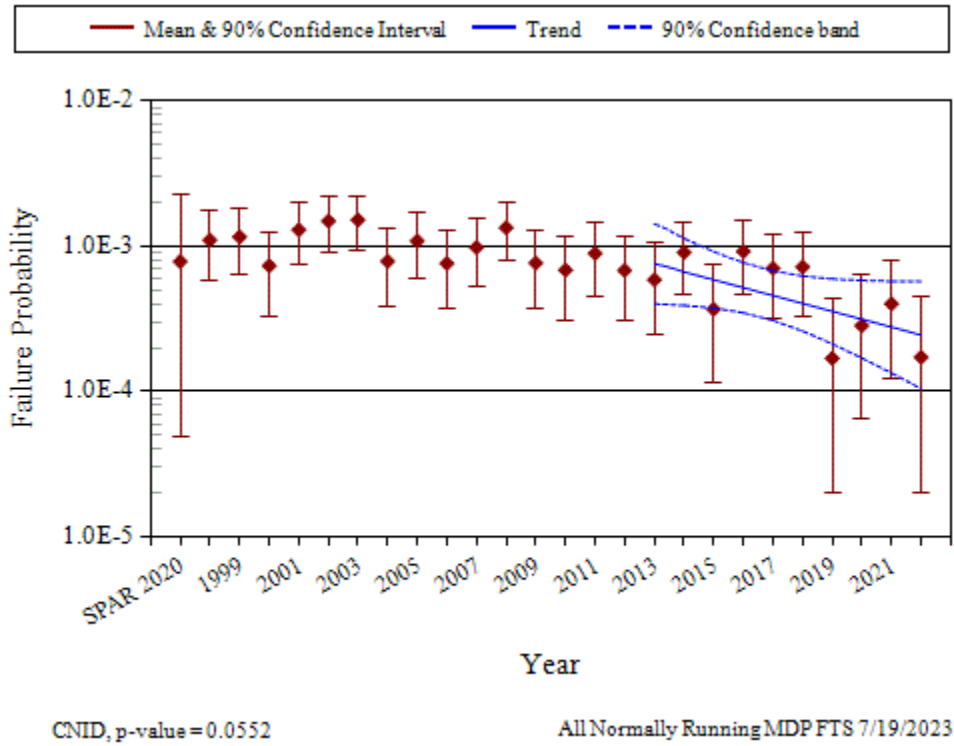


Figure 4. Failure probability estimate trend for normally running MDP FTS.

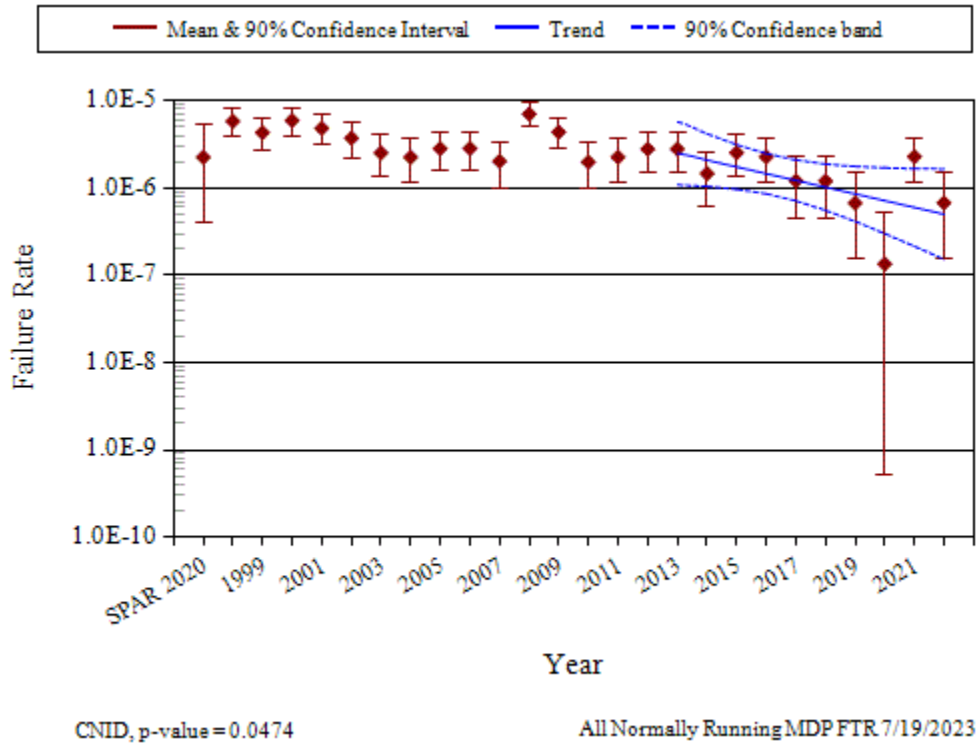


Figure 5. Failure rate estimate trend for normally running MDP FTR.

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 *2020 Parameter Update* [7] which based on UA data from the IRIS database (which includes the MSPI designated devices as a subset). In the calculations, planned and unplanned unavailable hours for a train are combined.

Table 3. Industry-average unavailability estimates in the *2020 Parameter Update* for MDPs [7].

Description	Distribution	Mean	α	β
MDP Test and Maintenance (ALL)	Normal	6.56E-3	0.0066	0.0091
MDP Test and Maintenance (AFW)	Normal	3.14E-3	0.0031	0.0020
MDP Test and Maintenance (CCW)	Normal	4.82E-3	0.0048	0.0063
MDP Test and Maintenance (ESW)	Normal	1.24E-2	0.0124	0.0144
MDP Test and Maintenance (HPSI)	Normal	2.99E-3	0.0030	0.0021
MDP Test and Maintenance (RHR-BWR)	Normal	5.92E-3	0.0059	0.0025
MDP Test and Maintenance (RHR-PWR)	Normal	4.63E-3	0.0046	0.0030

4.2 MDP Unavailability Trends

This section presents overall maintenance UA data for the 1998–2022 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 the systems with maintenance UA data currently analyzed (AFW, HPCS, CCW, ESW, HPSI, and RHR) are pooled and trended. The trend chart shows the results using data for each year’s component UA data over time. The yearly (1998–2022) UA and reactor critical hour data were obtained from the Reactor Oversight Process program (1998 to 2001) and IRIS (2002 to 2022) 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 UAs for that year. The vertical bar spans the calculated 5th to 95th percentiles of the beta distribution with matching means.

For the trend graphs, a least squares fit is sought for the linear or logit model depending upon which is more appropriate. Section 3 in *Overview and Reference* provides further information [3]. In the lower left-hand corner of the trend figures, the regression method and the p-value are reported. A review of these p-value identified the following trends for the most recent 10-year period:

- **Decreasing trend** in the **standby MDP unavailability** estimates, which is extremely statistically significant with a p-value of 0.0001 (see Figure 6). The same trend was observed in the *2020 MDP Update* study [2].

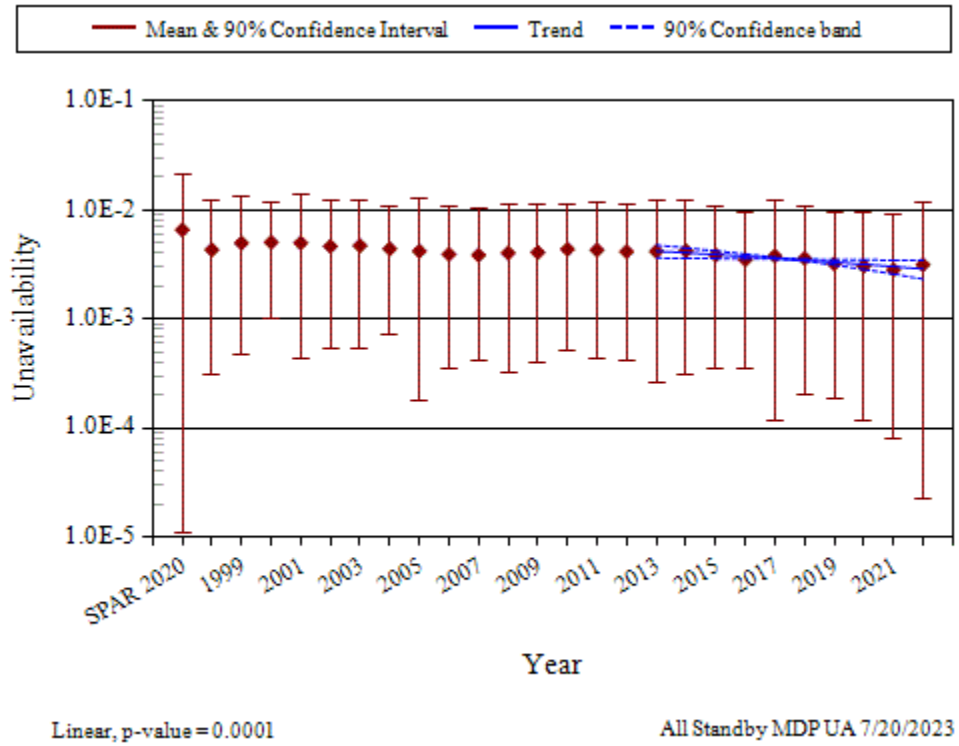


Figure 6. Pooled standby MDP UA trend.

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, $FTR \leq 1H$, $FTR > 1H$ (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 8-hour mission. Since the normally running systems MDP components do not have UA data or the $FTR \leq 1H$ data, there is no UA or $FTR \leq 1H$ input to the OR gate for that calculation. The trending method is described in more detail in Section 4 of *Overview and Reference* [3]. In the lower left-hand corner of the trend figures, the regression method and the p-value are reported. A review of these p-value identified the following trends for the most recent 10-year period:

- **Decreasing trend in the standby running MDP total unreliability (8-hour mission) estimates**, which is extremely statistically significant with a p-value of 0.0001 (see Figure 7). This is a new trend that was not observed in the *2020 MDP Update* study [2].
- **Decreasing trend in the normally running MDP total unreliability (8-hour mission) estimates**, which is statistically significant with a p-value of 0.0238 (see Figure 8). The same trend was observed in the *2020 MDP Update* study.

Because there is no total unreliability estimates in the *2020 Parameter Update*, there is no baseline industry values shown in Figure 7 and Figure 8 for comparison purpose.

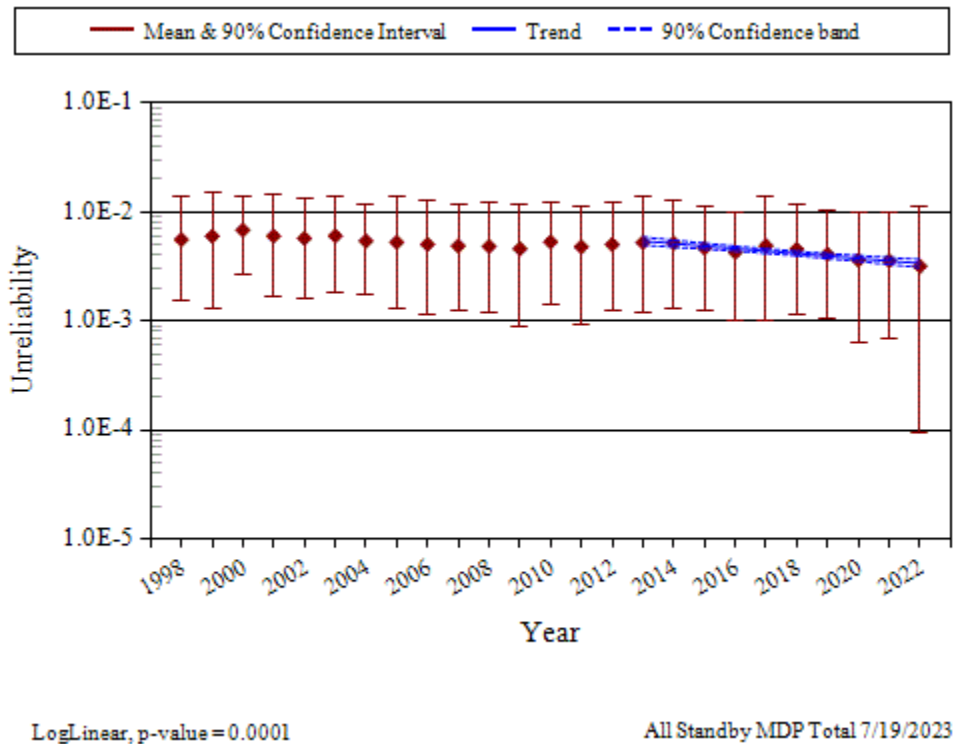


Figure 7. Standby MDP total unreliability trend (8-hour mission).

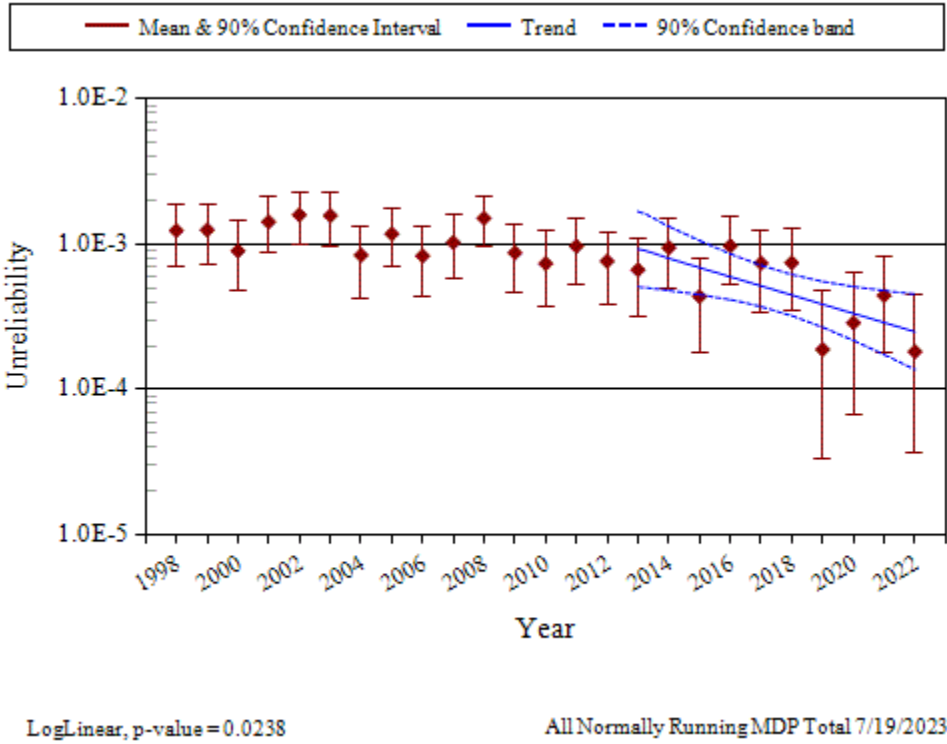


Figure 8. Normally running MDP total unreliability trend (8-hour mission).

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 IRIS 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 *2020 Parameter 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 include subcomponents, 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 to Figure 14 provide the plot for frequency (per reactor year) of standby MDP start demands, run < 1H hours, run > 1H hours, FTS events, FTR \leq 1H events, and FTR>1H events:

- Figure 9 shows the trend for standby MDP frequency of start demands
- Figure 10 shows the trend for standby MDP run hours per reactor year of run \leq 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
- Figure 13 shows the trend for standby MDP FTR \leq 1H events per reactor year
- Figure 14 shows the trend for standby MDP FTR events per reactor year.

The data for the figures listed above are provided in Section 8. The standby systems from Table 1 are trended together for each figure.

In the lower left-hand corner of the trend figures, the regression p-values are reported along with the prior distribution used in the Bayesian update. A review of these p-values identified the following trends for standby MDP for the most recent 10-year period:

- **Increasing trend** in the **standby MDP frequency of start demands** estimates, which is highly statistically significant with a p-value of 0.0029 (see Figure 9). The same trend was observed in the *2020 MDP update* study as statistically significant [2]
- **Increasing trend** in the **standby MDP frequency of run \leq 1H hours** estimates, which is highly statistically significant with a p-value of 0.0029 (see Figure 10). The same trend was observed in the *2020 MDP update* study as statistically significant
- **Increasing trend** in the **standby MDP frequency of run > 1H hours** estimates, which is extremely statistically significant with a p-value of 0.0000 (see Figure 11). The same trend was observed in the *2020 MDP Update* study.

Table 4 to Table 6 provide a summary of standby MDP FTS, FTR \leq 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 \leq 1H failure counts by system and year
- Table 6 presents the standby MDP FTR>1H failure counts by system and year.

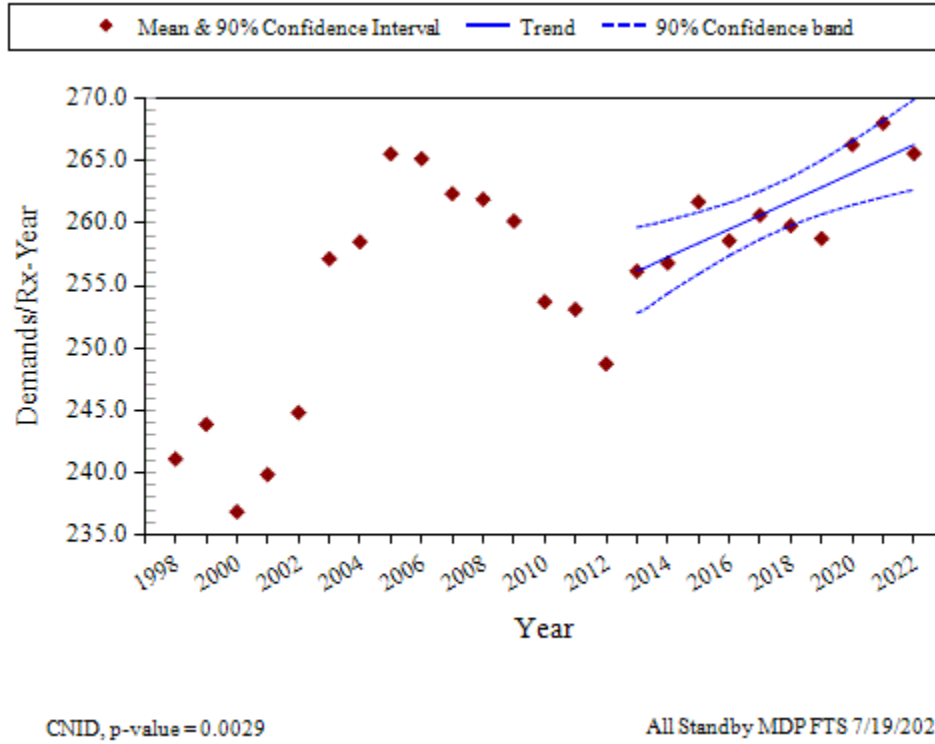


Figure 9. Frequency of start demands (demands per reactor year) trend for standby MDPs.

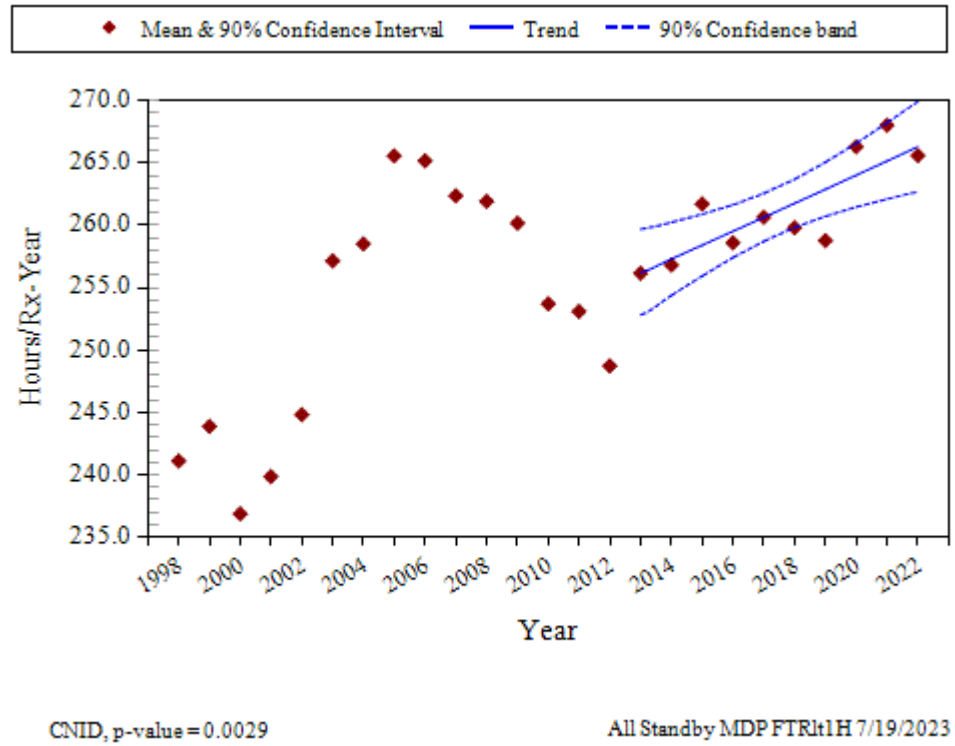


Figure 10. Frequency of run \leq 1H hours (hours per reactor year) trend for standby MDPs.

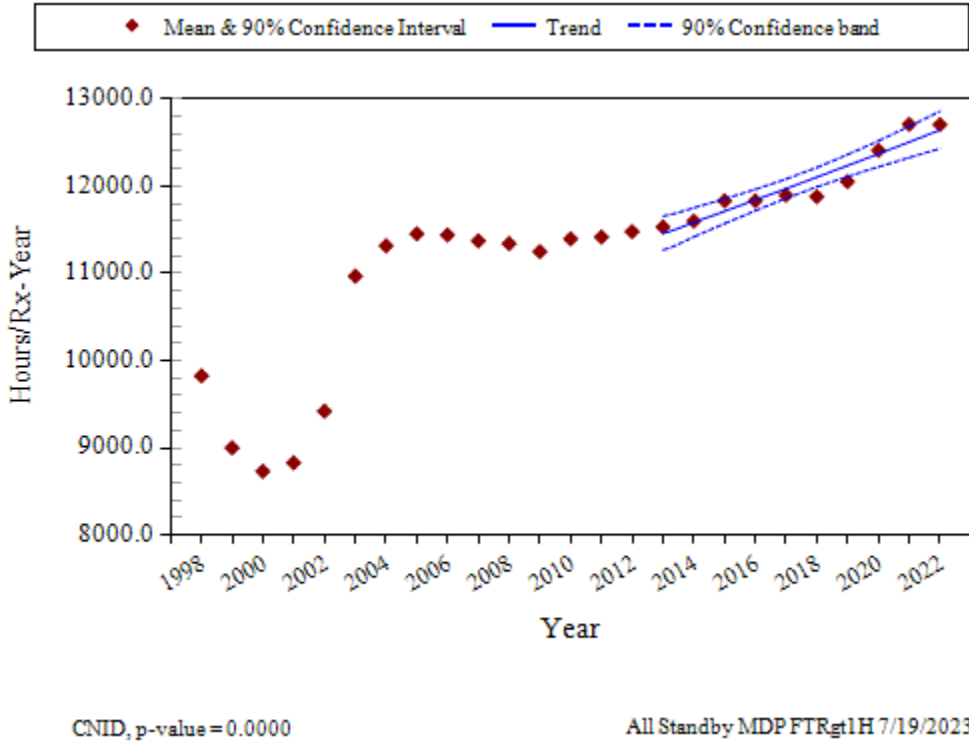


Figure 11. Frequency of run > 1H hours (hours per reactor year) trend for standby MDPs.

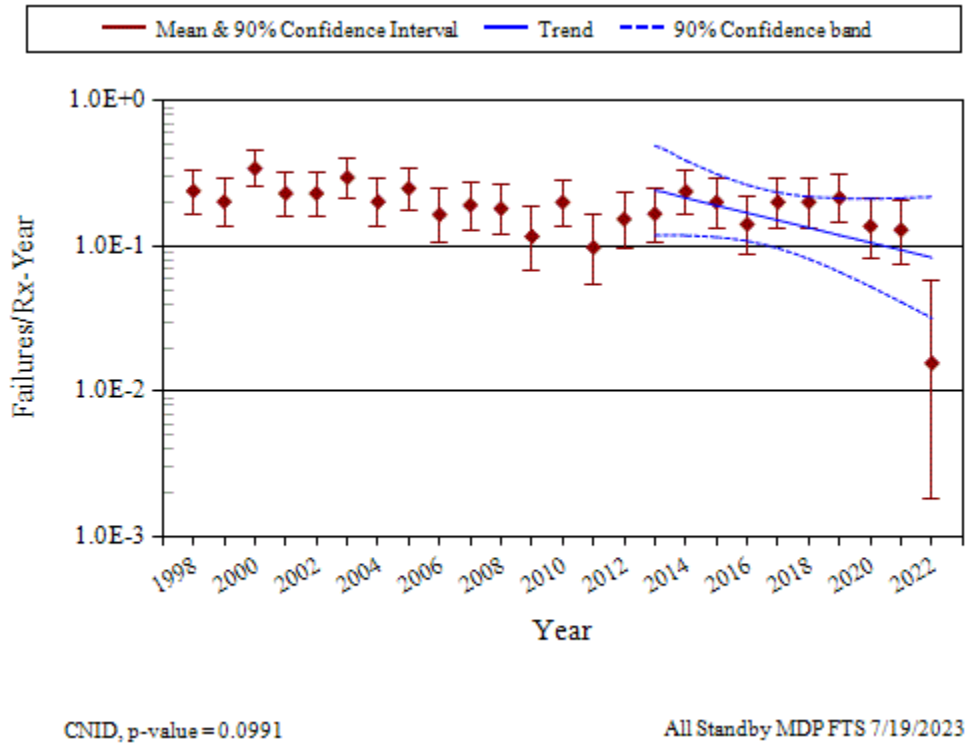


Figure 12. Frequency of FTS events (events per reactor year) trend for standby MDPs.

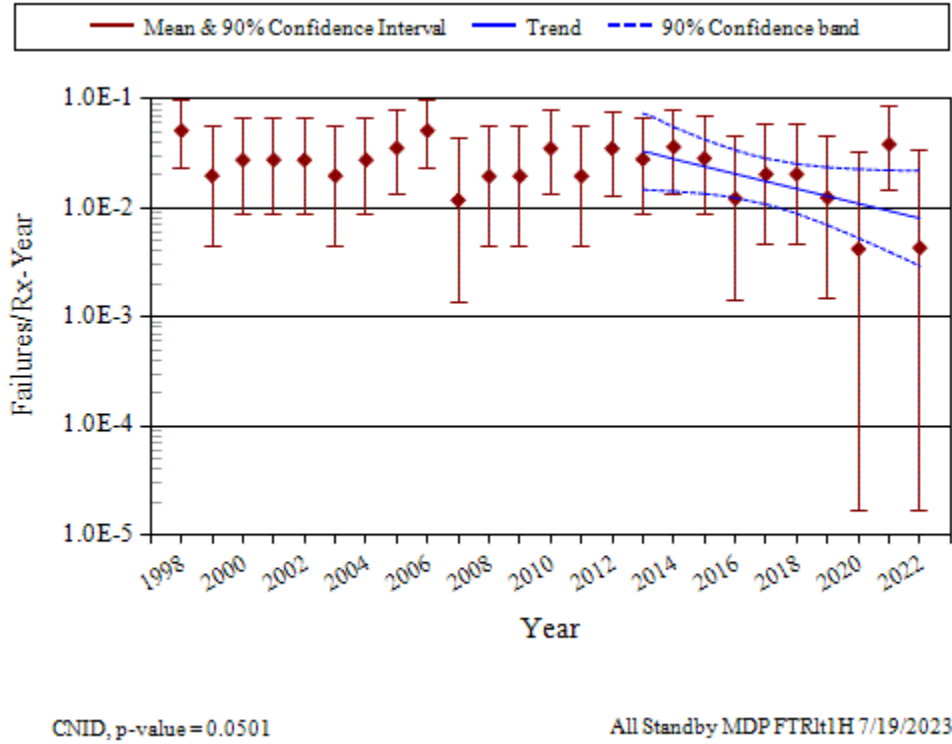


Figure 13. Frequency of FTR_{≤1H} events (events per reactor year) trend for standby MDPs.

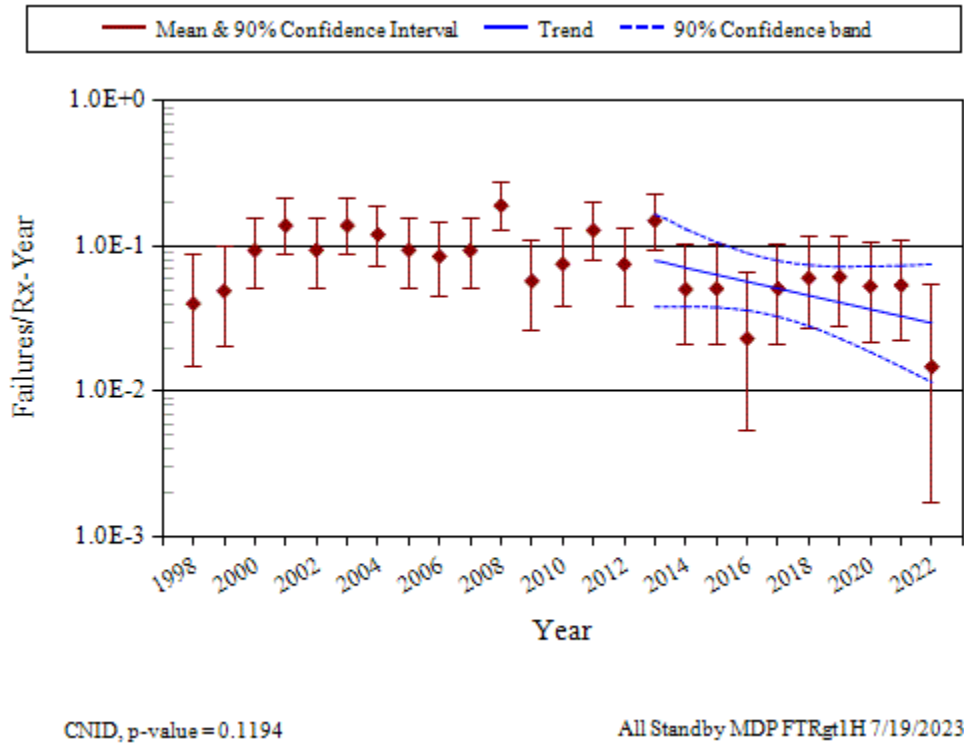


Figure 14. Frequency of FTR_{>1H} events (events per reactor year) trend for standby MDPs.

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

System	MDP Count	MDP Percent	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total	Percent of Failures
AFW	130	9.9%	1	2	4	1	2	1	1	1	2		15	9.3%
CRD	9	0.7%											0	0.0%
CSR	159	12.1%	1	1	3		3	1	2		1	1	13	8.0%
HPCS	9	0.7%						1	1				2	1.2%
HPSI	175	13.4%	3	2	1	1	4	1	4	4	1		21	13.0%
LPCS	74	5.7%		2	1	2	1	1					7	4.3%
RHR	295	22.5%	1	1	6	4	3	6	5		2		28	17.3%
SWS	458	35.0%	11	16	5	6	7	9	8	8	6		76	46.9%
Total	1309	100.0%	17	24	20	14	20	20	21	13	12	1	162	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	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total	Percent of Failures
AFW	130	9.9%	2								1		3	15.0%
CRD	9	0.7%											0	0.0%
CSR	159	12.1%											0	0.0%
HPCS	9	0.7%											0	0.0%
HPSI	175	13.4%									1		1	5.0%
LPCS	74	5.7%			1		1						2	10.0%
RHR	295	22.5%		2							1		3	15.0%
SWS	458	35.0%	1	2	2	1	1	2	1		1		11	55.0%
Total	1309	100.0%	3	4	3	1	2	2	1	0	4	0	20	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	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total	Percent of Failures
AFW	130	9.9%	3		2	1		1			1		8	14.3%
CRD	9	0.7%											0	0.0%
CSR	159	12.1%	2										2	3.6%
HPCS	9	0.7%											0	0.0%
HPSI	175	13.4%	2	2			2	1		1			8	14.3%
LPCS	74	5.7%											0	0.0%
RHR	295	22.5%	3		2	1		1	1	1	1		10	17.9%
SWS	458	35.0%	6	3	1		3	3	5	3	3	1	28	50.0%
Total	1309	100.0%	16	5	5	2	5	6	6	5	5	1	56	100.0%

6.2 Normally Running MDP Engineering Trends

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

Figure 15 to Figure 18 provide the plot for frequency (per reactor year) of normally running MDP start demands, run hours, FTS events, and FTR events:

- Figure 15 shows the trend for normally running MDP frequency of start demands
- 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
- 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 1 are trended together for each figure.

In the lower left-hand corner of the trend figures, the regression p-values are reported along with the prior distribution used in the Bayesian update. A review of these p-values identified the following trends for normally running MDP for the most recent 10-year period:

- **Increasing trend in the normally running MDP frequency of run hours** (hours per reactor year) estimates, which is extremely statistically significant with a p-value of 0.0001 (see Figure 16). The same trend was observed in the *2020 MDP Update* study [2].

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.

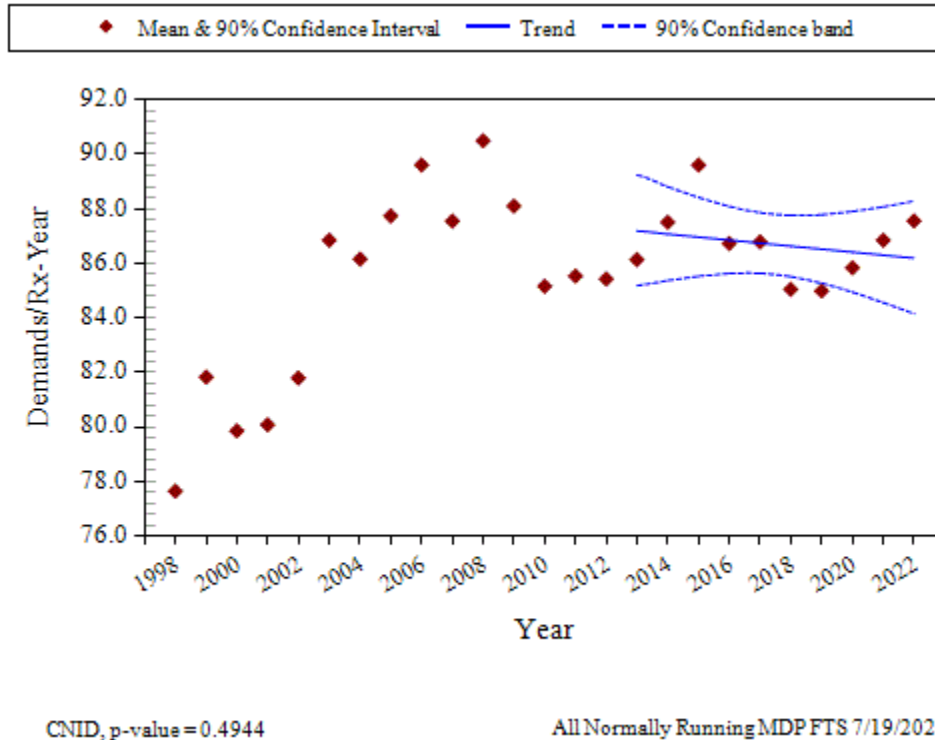


Figure 15. Frequency of start demands (demands per reactor year) trend for normally running MDPs.

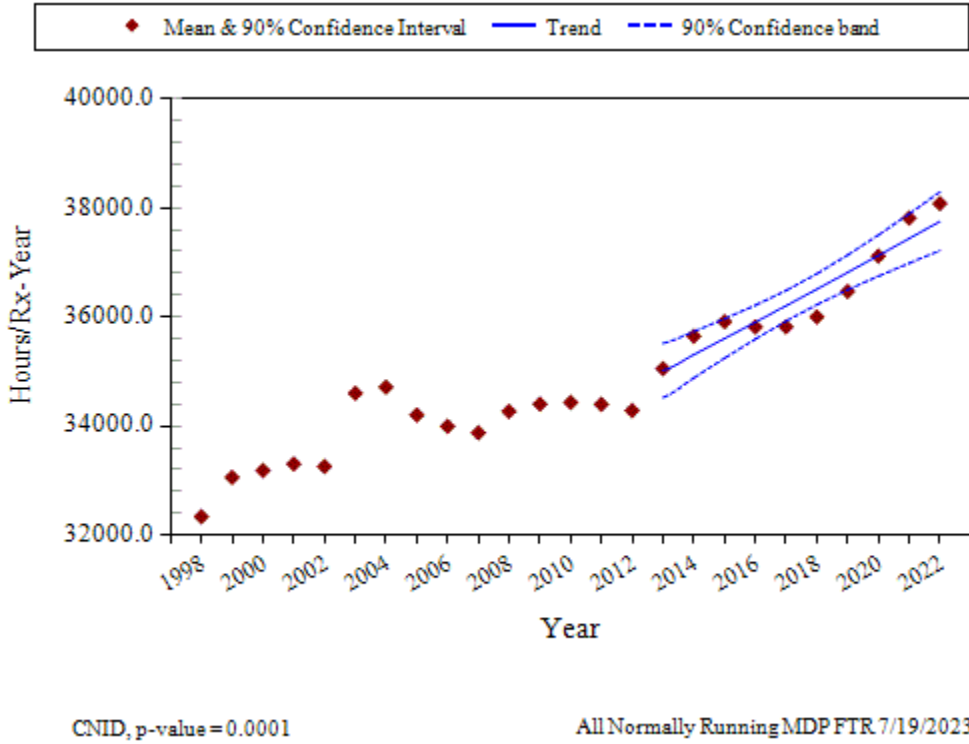


Figure 16. Frequency of run hours (hours per reactor year) trend for normally running MDPs.

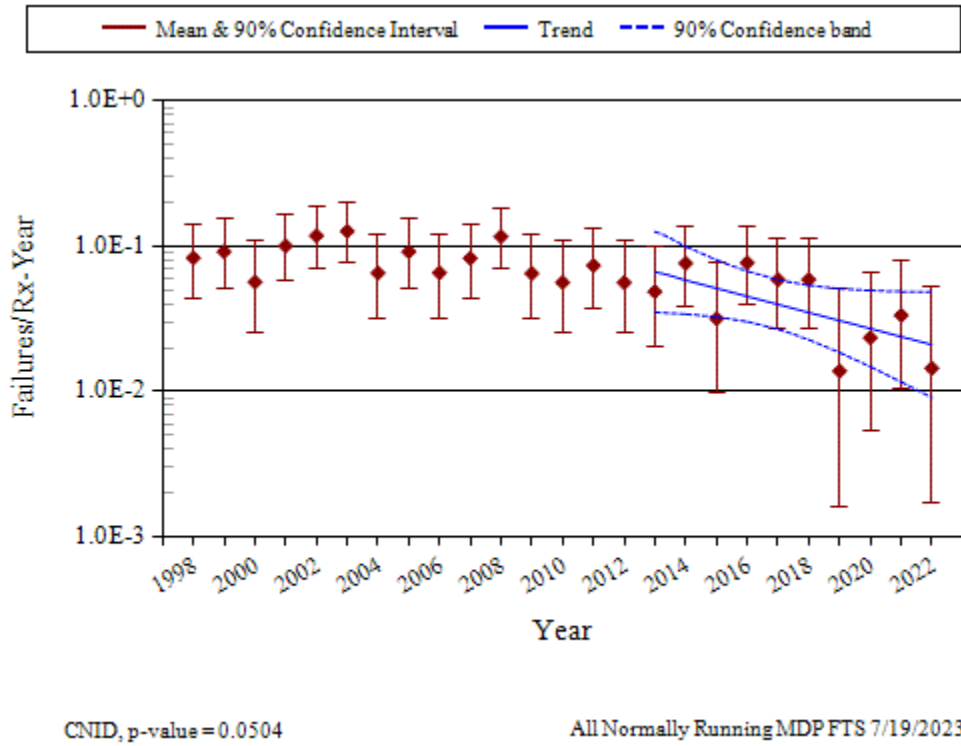
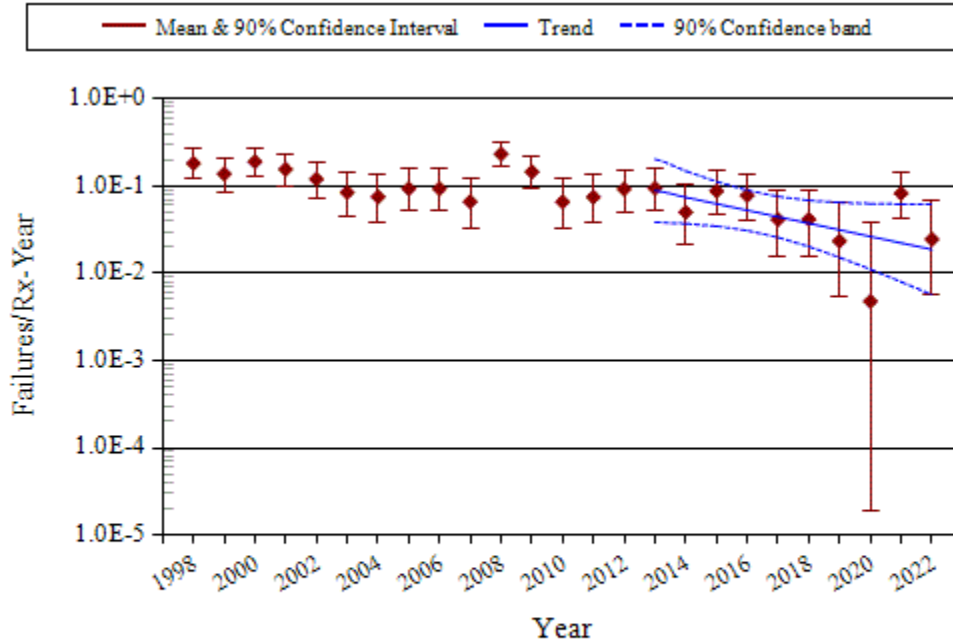


Figure 17. Frequency of FTS events (events per reactor year) trend for normally running MDPs.



CNID, p-value = 0.0543

All Normally Running MDP FTR 7/19/2023

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	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total	Percent of Failures
CCW	303	46.7%		5		1	1				1		8	18.6%
CDS	143	22.0%	1	1		3	1	1		1			8	18.6%
CRD	43	6.6%		1						1			2	4.7%
CVC	8	1.2%		1	1	1							3	7.0%
LPCS	2	0.3%											0	0.0%
MFW	44	6.8%	2		1	1							4	9.3%
SWN	106	16.3%	2		1	2	4	5	1		2	1	18	41.9%
Total	649	100.0%	5	8	3	8	6	6	1	2	3	1	43	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	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total	Percent of Failures
CCW	303	46.7%	5		4	2	1	1	1		3	1	18	34.6%
CDS	143	22.0%	1	2	1	1	2	1			1		9	17.3%
CRD	43	6.6%					1	1					2	3.8%
CVC	8	1.2%										1	1	1.9%

System Code	MDP Count	MDP Percent	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total	Percent of Failures
LPCS	2	0.3%											0	0.0%
MFW	44	6.8%	3	1	1	1					1		7	13.5%
SWN	106	16.3%	1	2	3	4		1	1		3		15	28.8%
Total	649	100.0%	10	5	9	8	4	4	2	0	8	2	52	100.0%

6.3 Comparison of IRIS 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 ESF demand data produce failure estimates that adequately predict standby component performance during unplanned demands. This comparison evaluates the same dataset for standby components used for the overall trends shown in this document but limits the failure data to those discovered during an actual unplanned ESF demand using the ESF demands reported in IRIS. The data are further limited to 2003 to present since the ESF demand reporting in IRIS is inconsistent prior to 2003.

The standby MDP ESF unplanned demand data covering 2003 through 2022 are summarized in Table 9. Consistency between the unplanned demand data and the industry-average performance from *2020 Parameter Update* (Table 2) was evaluated using the predictive distribution approach outlined in the NUREG/CR-6823, “Handbook of Parameter Estimation for Probabilistic Risk Assessment,” Sections 6.2.3.5 and 6.3.3.4 [9].

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 1,000 times (Latin hypercube sampling), each time obtaining a total number of predicted failures. The 1,000 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 is consistent with the industry-average distribution obtained from the IRIS 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 *2020 Parameter 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 \geq Observed Failures	Consistent with Industry-Average Performance? ^a
FTS	107	1698	0	1.0	1.00	Yes ^b
FTR<1H	107	1374	0	0.1	1.00	Yes ^c
FTR>1H	107	34231	1	0.3	0.20	Yes

Note:

- 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 subcomponents, 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 $FTR \leq 1H$ failure mode only applies to standby MDPs and therefore only shows the standby category data. The events are further divided by the failure modes and factors such as subcomponents, failure causes, detection methods, and recovery possibility. The failure modes are determined as a result of the IRIS data review by Idaho National Laboratory (INL) staff. See Section 7 for further description of failure modes.

MDP subcomponent contributions to the three failure modes are presented in Figure 19. The subcomponent categories are similar to those used in the common-cause failure (CCF) database. The **driver** subcomponent has the highest percentage contributions to failures for all failure modes (FTS, $FTR \leq 1H$, $FTR > 1H$ or FTR). The pump subcomponent is also a key contributor for the $FTR \leq 1H$ and $FTR > 1H$ failure modes.

MDP failure cause group contributions to the three failure modes are presented in Figure 20. The cause groups are similar to those used in the CCF database. Table 10 shows the breakdown of the cause groups with the specific causes that were coded during the data collection. The most likely cause groups are **Human** (for all three failure modes), **Component** (for FTS and FTR), **Design** (for all three failure modes), and **Environment** (for $FTR \leq 1H$ and FTR). 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. A failure can be detected during inspection, testing, post maintenance testing (PMT), non-test demand, or ESF demand. There are differences in the detection method based on the standby and normally running categories.

- **Standby:** the most likely detection method for **FTS** and **$FTR \leq 1H$** is **test demand** followed by non-test 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 8:1, meaning that eight of every nine failures were not recovered.

Table 10. Component failure cause groups.^b

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.

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

Group	Specific Cause	Description
	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 an 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.

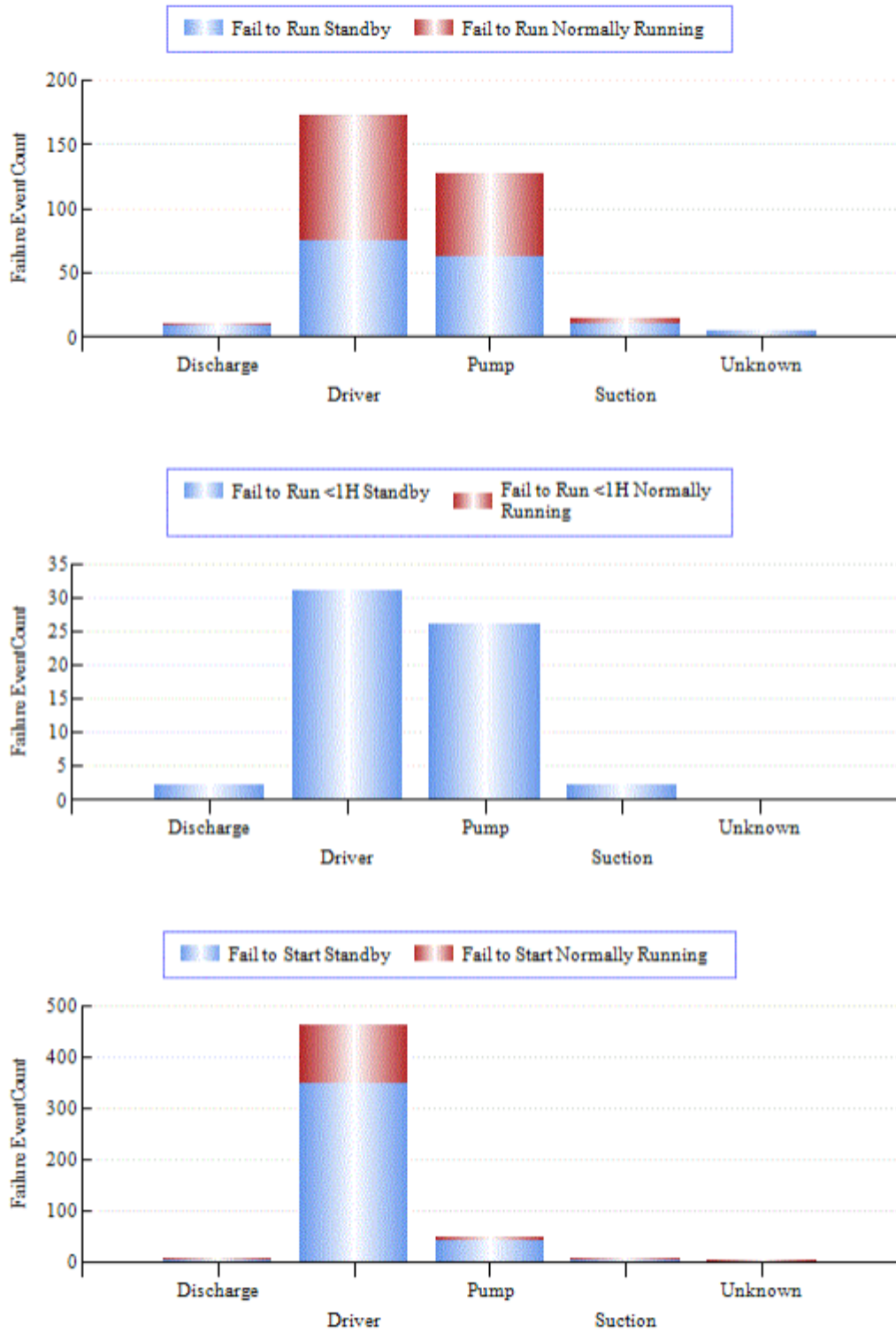


Figure 19. MDP failure breakdown by failure mode and subcomponent.

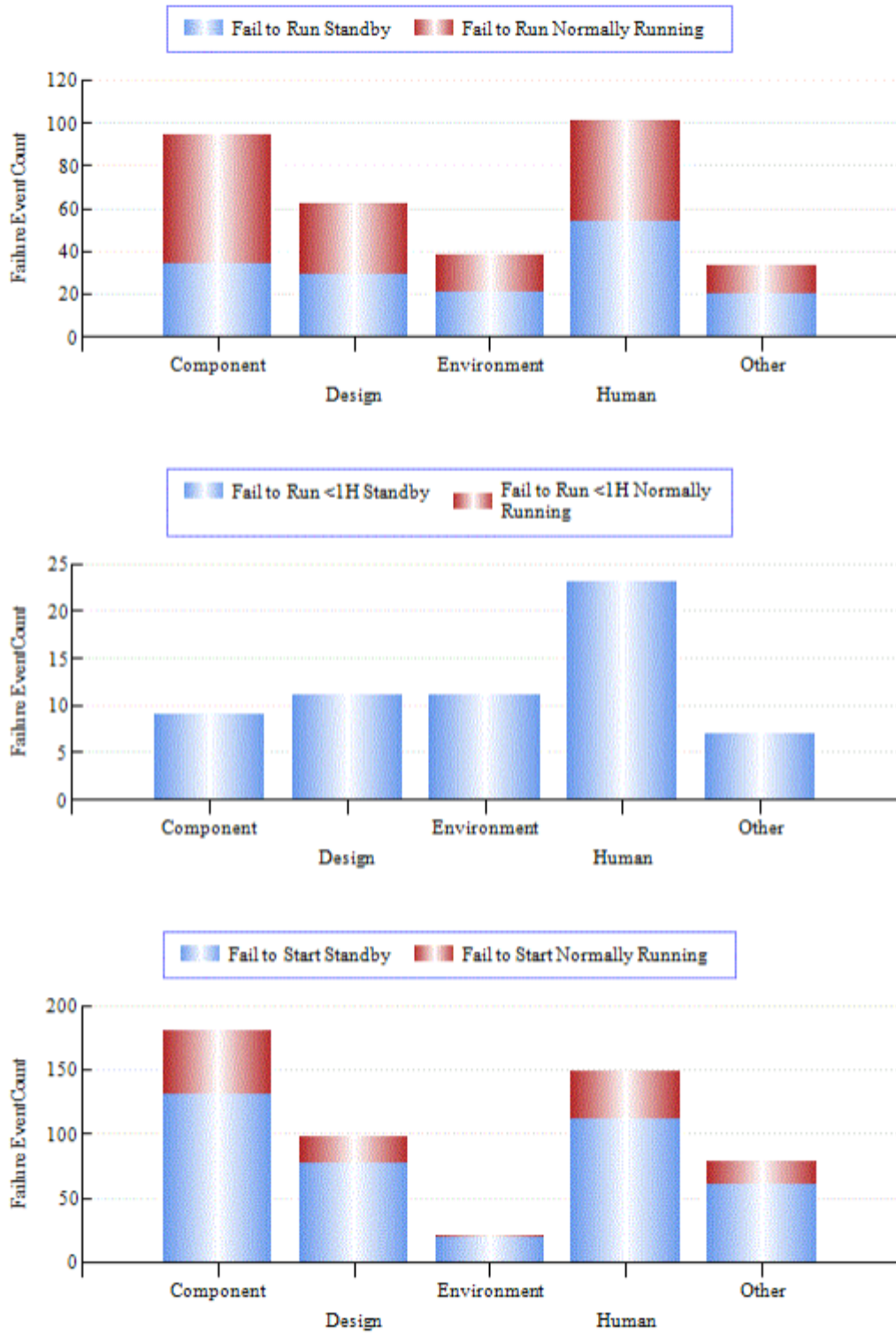


Figure 20. MDP failure breakdown by failure mode and cause group.

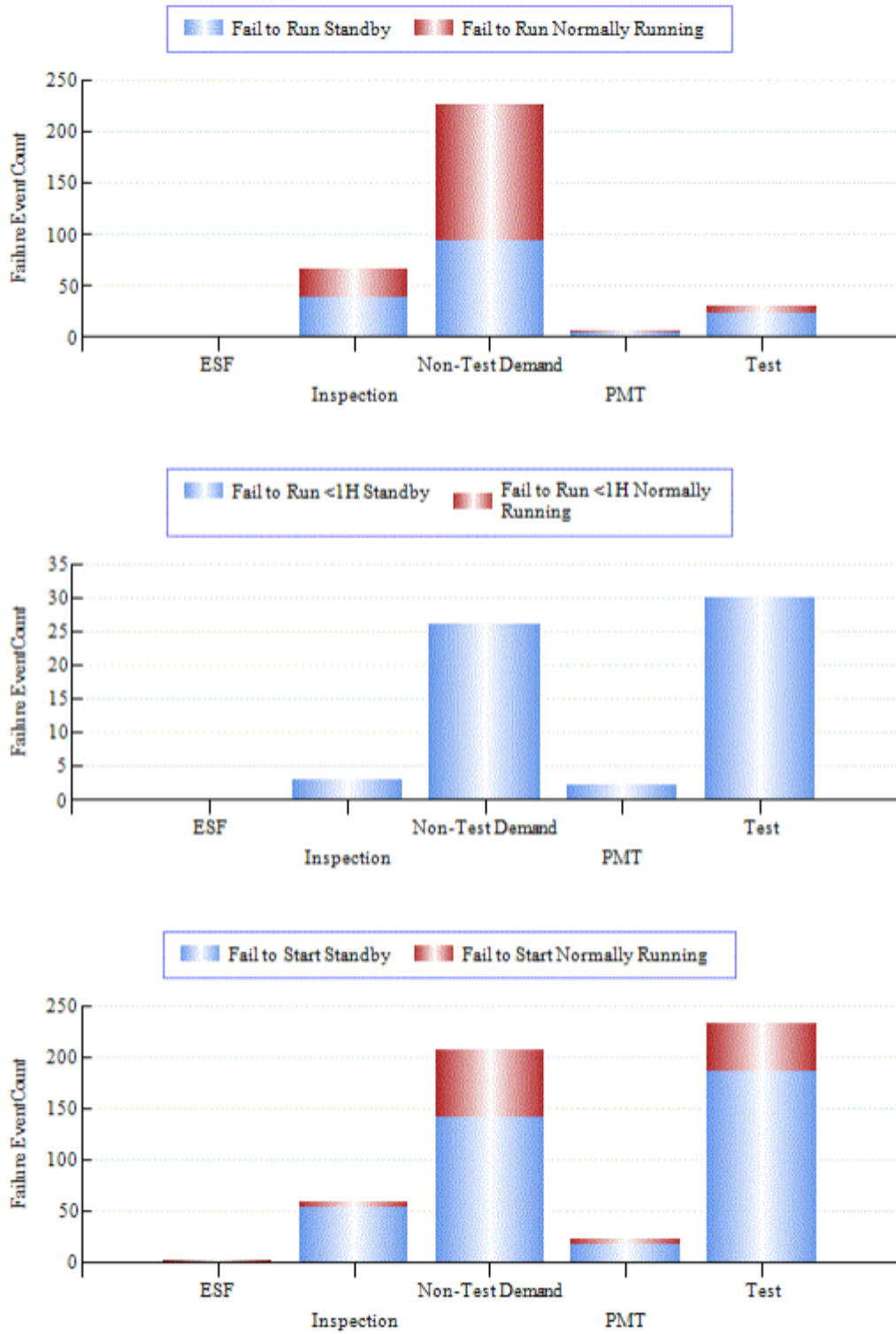


Figure 21. MDP failure breakdown by failure mode and method of detection.

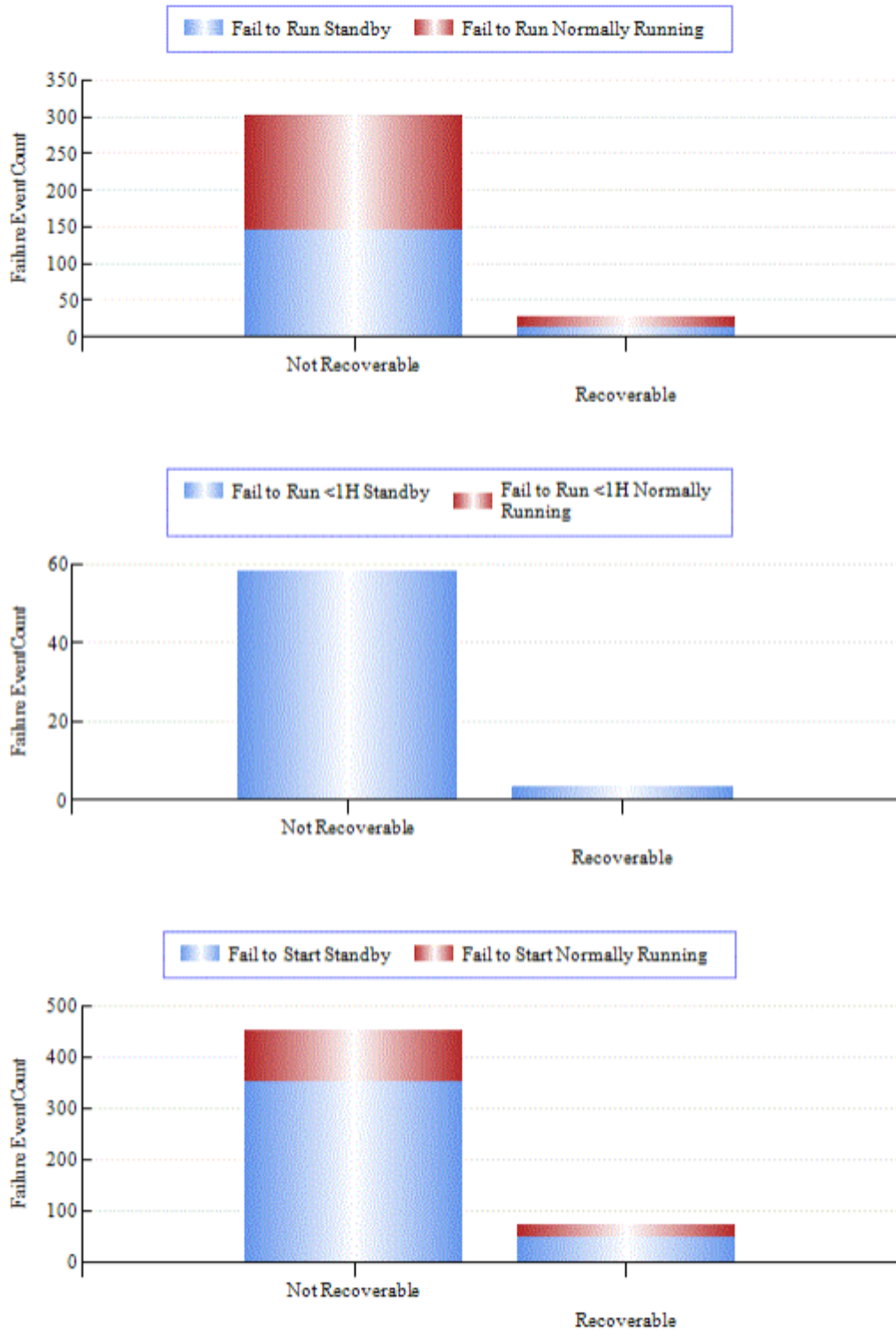


Figure 22. MDP failure breakdown by failure mode and recovery possibility.

7. MDP ASSEMBLY DESCRIPTION

The MDP consists of the pump, motor-driver, and circuit breaker subcomponents. 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, then it is treated as a subcomponent.

The MDP failure modes include FTS, $FTR \leq 1H$, 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 IRIS is to be included in FTS, $FTR \leq 1H$, 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. Run failures that occur beyond the typical 24-hour mission time in PRAs are included. However, certain events are excluded, e.g., events with slow starting times that do not exceed the PRA success criteria, events 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. Events occurring during maintenance or post-maintenance testing that are related to the actual maintenance activities are excluded. All MDP events within IRIS were reviewed to ensure that they were binned to the correct failure mode – FTS, $FTR \leq 1H$, $FTR > 1H$ (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, but exclude those during maintenance and post-maintenance.

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 \leq 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 \leq 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 \leq 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
SPAR 2020		--	--	--	--	1.09E-04	1.38E-03	5.88E-04
1998	25	24,834	--	--	--	6.97E-04	1.34E-03	9.99E-04
1999	21	25,119	--	--	--	5.61E-04	1.15E-03	8.33E-04
2000	36	24,464	--	--	--	1.08E-03	1.87E-03	1.45E-03
2001	24	24,704	--	--	--	6.68E-04	1.31E-03	9.65E-04
2002	24	25,216	--	--	--	6.55E-04	1.28E-03	9.46E-04
2003	31	26,487	--	--	--	8.41E-04	1.52E-03	1.16E-03
2004	21	26,701	--	--	--	5.29E-04	1.08E-03	7.85E-04
2005	26	27,355	--	--	--	6.65E-04	1.27E-03	9.45E-04
2006	17	27,315	--	--	--	4.01E-04	8.89E-04	6.25E-04
2007	20	27,187	--	--	--	4.90E-04	1.02E-03	7.35E-04
2008	19	27,317	--	--	--	4.59E-04	9.74E-04	6.96E-04
2009	12	27,059	--	--	--	2.63E-04	6.79E-04	4.51E-04
2010	21	26,387	--	--	--	5.35E-04	1.10E-03	7.94E-04
2011	10	26,323	--	--	--	2.15E-04	6.05E-04	3.89E-04
2012	16	25,939	--	--	--	3.92E-04	8.90E-04	6.20E-04
2013	17	26,018	9.07E-04	4.55E-04	1.81E-03	4.21E-04	9.32E-04	6.55E-04
2014	24	25,683	8.11E-04	4.57E-04	1.44E-03	6.43E-04	1.26E-03	9.29E-04
2015	20	25,911	7.26E-04	4.47E-04	1.18E-03	5.14E-04	1.07E-03	7.71E-04
2016	14	25,661	6.50E-04	4.18E-04	1.01E-03	3.36E-04	8.08E-04	5.50E-04
2017	20	25,806	5.81E-04	3.69E-04	9.15E-04	5.16E-04	1.07E-03	7.74E-04
2018	20	25,657	5.20E-04	3.09E-04	8.74E-04	5.19E-04	1.08E-03	7.78E-04
2019	21	25,101	4.65E-04	2.50E-04	8.65E-04	5.62E-04	1.15E-03	8.34E-04
2020	13	25,369	4.16E-04	1.98E-04	8.76E-04	3.10E-04	7.70E-04	5.18E-04
2021	12	25,017	3.72E-04	1.55E-04	8.97E-04	2.84E-04	7.33E-04	4.86E-04
2022	1	24,546	3.33E-04	1.20E-04	9.27E-04	6.96E-06	1.55E-04	5.95E-05
Total	485	647,175	--	--	--	--	--	--

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

Year	Failures	Hours	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
SPAR 2020		--	--	--	--	7.34E-07	3.33E-04	9.13E-05
1998	6	24,834	--	--	--	9.94E-05	3.77E-04	2.19E-04
1999	2	25,119	--	--	--	1.91E-05	1.85E-04	8.36E-05
2000	3	24,464	--	--	--	3.70E-05	2.40E-04	1.20E-04
2001	3	24,704	--	--	--	3.67E-05	2.38E-04	1.19E-04
2002	3	25,216	--	--	--	3.61E-05	2.34E-04	1.17E-04
2003	2	26,487	--	--	--	1.83E-05	1.77E-04	7.99E-05
2004	3	26,701	--	--	--	3.44E-05	2.23E-04	1.11E-04
2005	4	27,355	--	--	--	5.17E-05	2.63E-04	1.40E-04
2006	6	27,315	--	--	--	9.17E-05	3.48E-04	2.02E-04
2007	1	27,187	--	--	--	5.50E-06	1.22E-04	4.69E-05
2008	2	27,317	--	--	--	1.78E-05	1.72E-04	7.79E-05
2009	2	27,059	--	--	--	1.80E-05	1.74E-04	7.85E-05
2010	4	26,387	--	--	--	5.33E-05	2.71E-04	1.44E-04
2011	2	26,323	--	--	--	1.84E-05	1.78E-04	8.03E-05
2012	4	25,939	--	--	--	5.41E-05	2.75E-04	1.46E-04
2013	3	26,018	1.27E-04	5.70E-05	2.85E-04	3.52E-05	2.28E-04	1.14E-04
2014	4	25,683	1.09E-04	5.52E-05	2.14E-04	5.46E-05	2.78E-04	1.48E-04
2015	3	25,911	9.25E-05	5.23E-05	1.64E-04	3.53E-05	2.29E-04	1.14E-04
2016	1	25,661	7.89E-05	4.77E-05	1.30E-04	5.78E-06	1.28E-04	4.93E-05
2017	2	25,806	6.72E-05	4.14E-05	1.09E-04	1.87E-05	1.81E-04	8.17E-05
2018	2	25,657	5.73E-05	3.39E-05	9.69E-05	1.88E-05	1.82E-04	8.21E-05
2019	1	25,101	4.89E-05	2.65E-05	8.99E-05	5.88E-06	1.31E-04	5.02E-05
2020	0	25,369	4.17E-05	2.02E-05	8.61E-05	6.52E-08	6.37E-05	1.66E-05
2021	4	25,017	3.55E-05	1.50E-05	8.38E-05	5.58E-05	2.84E-04	1.51E-04
2022	0	24,546	3.03E-05	1.11E-05	8.26E-05	6.70E-08	6.55E-05	1.70E-05
Total	67	647,175	--	--	--	--	--	--

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
SPAR 2020		--	--	--	--	3.58E-08	3.10E-05	8.12E-06
1998	4	1,011,928	--	--	--	1.54E-06	7.85E-06	4.18E-06
1999	5	926,913	--	--	--	2.30E-06	9.91E-06	5.54E-06
2000	10	901,625	--	--	--	5.99E-06	1.69E-05	1.09E-05
2001	15	909,219	--	--	--	9.89E-06	2.31E-05	1.59E-05
2002	10	970,195	--	--	--	5.59E-06	1.58E-05	1.01E-05
2003	15	1,129,711	--	--	--	8.06E-06	1.88E-05	1.30E-05
2004	13	1,168,702	--	--	--	6.54E-06	1.62E-05	1.09E-05
2005	10	1,179,662	--	--	--	4.65E-06	1.31E-05	8.43E-06
2006	9	1,178,274	--	--	--	4.07E-06	1.21E-05	7.64E-06
2007	10	1,178,298	--	--	--	4.66E-06	1.31E-05	8.44E-06
2008	21	1,182,644	--	--	--	1.16E-05	2.38E-05	1.72E-05
2009	6	1,169,908	--	--	--	2.38E-06	9.05E-06	5.26E-06
2010	8	1,185,189	--	--	--	3.47E-06	1.10E-05	6.79E-06
2011	14	1,187,359	--	--	--	7.07E-06	1.70E-05	1.16E-05
2012	8	1,197,084	--	--	--	3.43E-06	1.09E-05	6.73E-06
2013	16	1,171,233	6.88E-06	3.31E-06	1.43E-05	8.43E-06	1.92E-05	1.33E-05
2014	5	1,159,906	6.10E-06	3.31E-06	1.13E-05	1.87E-06	8.03E-06	4.49E-06
2015	5	1,171,407	5.42E-06	3.23E-06	9.09E-06	1.85E-06	7.95E-06	4.45E-06
2016	2	1,174,018	4.81E-06	3.05E-06	7.58E-06	4.62E-07	4.46E-06	2.02E-06
2017	5	1,177,745	4.27E-06	2.74E-06	6.65E-06	1.84E-06	7.91E-06	4.42E-06
2018	6	1,173,028	3.79E-06	2.34E-06	6.15E-06	2.38E-06	9.03E-06	5.25E-06
2019	6	1,168,894	3.37E-06	1.91E-06	5.93E-06	2.39E-06	9.06E-06	5.26E-06
2020	5	1,182,127	2.99E-06	1.52E-06	5.87E-06	1.83E-06	7.88E-06	4.41E-06
2021	5	1,186,008	2.65E-06	1.19E-06	5.91E-06	1.83E-06	7.86E-06	4.39E-06
2022	1	1,174,226	2.35E-06	9.24E-07	6.00E-06	1.42E-07	3.15E-06	1.21E-06
Total	214	28,215,302	--	--	--	--	--	--

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
SPAR 2020		--	--	--	--	4.86E-05	2.30E-03	7.86E-04
1998	9	7,997	--	--	--	5.88E-04	1.75E-03	1.10E-03
1999	10	8,428	--	--	--	6.41E-04	1.81E-03	1.16E-03
2000	6	8,248	--	--	--	3.33E-04	1.26E-03	7.34E-04
2001	11	8,248	--	--	--	7.39E-04	1.98E-03	1.30E-03
2002	13	8,425	--	--	--	8.94E-04	2.22E-03	1.49E-03
2003	14	8,946	--	--	--	9.26E-04	2.22E-03	1.52E-03
2004	7	8,899	--	--	--	3.82E-04	1.31E-03	7.89E-04
2005	10	9,037	--	--	--	6.01E-04	1.69E-03	1.09E-03
2006	7	9,230	--	--	--	3.69E-04	1.27E-03	7.62E-04
2007	9	9,072	--	--	--	5.23E-04	1.56E-03	9.81E-04
2008	13	9,438	--	--	--	8.04E-04	1.99E-03	1.34E-03
2009	7	9,163	--	--	--	3.72E-04	1.28E-03	7.67E-04
2010	6	8,857	--	--	--	3.11E-04	1.18E-03	6.87E-04
2011	8	8,896	--	--	--	4.56E-04	1.45E-03	8.94E-04
2012	6	8,909	--	--	--	3.10E-04	1.17E-03	6.83E-04
2013	5	8,749	7.56E-04	4.02E-04	1.42E-03	2.44E-04	1.05E-03	5.88E-04
2014	8	8,752	6.67E-04	3.93E-04	1.13E-03	4.63E-04	1.47E-03	9.08E-04
2015	3	8,871	5.89E-04	3.76E-04	9.20E-04	1.14E-04	7.42E-04	3.69E-04
2016	8	8,606	5.19E-04	3.49E-04	7.73E-04	4.71E-04	1.50E-03	9.22E-04
2017	6	8,593	4.58E-04	3.09E-04	6.79E-04	3.20E-04	1.21E-03	7.06E-04
2018	6	8,399	4.05E-04	2.62E-04	6.26E-04	3.27E-04	1.24E-03	7.22E-04
2019	1	8,244	3.57E-04	2.13E-04	5.97E-04	1.98E-05	4.41E-04	1.69E-04
2020	2	8,177	3.15E-04	1.70E-04	5.82E-04	6.52E-05	6.30E-04	2.85E-04
2021	3	8,106	2.78E-04	1.34E-04	5.75E-04	1.24E-04	8.07E-04	4.02E-04
2022	1	8,091	2.45E-04	1.05E-04	5.73E-04	2.02E-05	4.49E-04	1.72E-04
Total	179	216,380	--	--	--	--	--	--

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
SPAR 2020		--	--	--	--	3.94E-07	5.38E-06	2.26E-06
1998	20	3,330,654	--	--	--	3.90E-06	8.12E-06	5.85E-06
1999	15	3,404,841	--	--	--	2.69E-06	6.28E-06	4.33E-06
2000	21	3,427,139	--	--	--	4.02E-06	8.23E-06	5.97E-06
2001	17	3,430,235	--	--	--	3.11E-06	6.90E-06	4.85E-06
2002	13	3,425,415	--	--	--	2.24E-06	5.57E-06	3.75E-06
2003	9	3,563,793	--	--	--	1.35E-06	4.03E-06	2.54E-06
2004	8	3,585,229	--	--	--	1.15E-06	3.67E-06	2.26E-06
2005	10	3,522,610	--	--	--	1.57E-06	4.42E-06	2.84E-06
2006	10	3,501,288	--	--	--	1.58E-06	4.44E-06	2.86E-06
2007	7	3,509,840	--	--	--	9.85E-07	3.39E-06	2.03E-06
2008	26	3,573,582	--	--	--	4.97E-06	9.47E-06	7.07E-06
2009	16	3,577,643	--	--	--	2.78E-06	6.31E-06	4.40E-06
2010	7	3,580,909	--	--	--	9.66E-07	3.33E-06	2.00E-06
2011	8	3,577,300	--	--	--	1.16E-06	3.67E-06	2.26E-06
2012	10	3,575,450	--	--	--	1.54E-06	4.35E-06	2.80E-06
2013	10	3,560,183	2.51E-06	1.09E-06	5.76E-06	1.55E-06	4.37E-06	2.81E-06
2014	5	3,564,608	2.10E-06	1.05E-06	4.20E-06	6.11E-07	2.63E-06	1.47E-06
2015	9	3,555,386	1.75E-06	9.74E-07	3.16E-06	1.36E-06	4.04E-06	2.55E-06
2016	8	3,553,732	1.47E-06	8.62E-07	2.50E-06	1.16E-06	3.70E-06	2.28E-06
2017	4	3,546,182	1.23E-06	7.15E-07	2.10E-06	4.47E-07	2.27E-06	1.21E-06
2018	4	3,554,969	1.03E-06	5.58E-07	1.89E-06	4.46E-07	2.27E-06	1.21E-06
2019	2	3,537,325	8.58E-07	4.16E-07	1.77E-06	1.54E-07	1.49E-06	6.73E-07
2020	0	3,535,482	7.18E-07	3.02E-07	1.71E-06	5.30E-10	5.17E-07	1.35E-07
2021	8	3,529,136	6.01E-07	2.15E-07	1.67E-06	1.17E-06	3.72E-06	2.29E-06
2022	2	3,519,176	5.02E-07	1.52E-07	1.66E-06	1.55E-07	1.50E-06	6.76E-07
Total	249	88,042,105	--	--	--	--	--	--

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
SPAR 2020		--	--	-	--	-8.39E-03	2.15E-02	6.56E-03
1998	10,543	2,323,282	--	--	--	3.08E-04	1.22E-02	4.31E-03
1999	12,670	2,453,902	--	--	--	4.70E-04	1.35E-02	4.98E-03
2000	13,372	2,519,627	--	--	--	1.03E-03	1.16E-02	5.06E-03
2001	12,969	2,581,219	--	--	--	4.30E-04	1.37E-02	4.97E-03
2002	19,347	4,235,045	--	--	--	5.42E-04	1.21E-02	4.63E-03
2003	20,976	4,296,511	--	--	--	5.36E-04	1.23E-02	4.70E-03
2004	20,046	4,497,454	--	--	--	7.13E-04	1.07E-02	4.41E-03
2005	18,084	4,430,849	--	--	--	1.77E-04	1.29E-02	4.19E-03
2006	18,250	4,432,225	--	--	--	3.43E-04	1.08E-02	3.92E-03
2007	17,240	4,521,494	--	--	--	4.12E-04	1.02E-02	3.85E-03
2008	17,845	4,450,273	--	--	--	3.19E-04	1.13E-02	4.03E-03
2009	18,666	4,397,190	--	--	--	4.04E-04	1.10E-02	4.08E-03
2010	19,132	4,473,513	--	--	--	5.09E-04	1.14E-02	4.36E-03
2011	18,404	4,314,939	--	--	--	4.27E-04	1.15E-02	4.29E-03
2012	18,465	4,177,351	--	--	--	4.06E-04	1.12E-02	4.15E-03
2013	18,987	4,225,814	4.19E-03	3.63E-03	4.76E-03	2.57E-04	1.21E-02	4.17E-03
2014	18,473	4,271,783	4.05E-03	3.61E-03	4.49E-03	3.08E-04	1.20E-02	4.22E-03
2015	16,379	4,245,641	3.90E-03	3.59E-03	4.21E-03	3.48E-04	1.06E-02	3.86E-03
2016	14,590	4,247,600	3.76E-03	3.57E-03	3.94E-03	3.55E-04	9.36E-03	3.50E-03
2017	15,265	4,168,826	3.61E-03	3.55E-03	3.67E-03	1.16E-04	1.21E-02	3.79E-03
2018	14,645	4,169,042	3.46E-03	3.40E-03	3.53E-03	2.01E-04	1.06E-02	3.60E-03
2019	13,313	4,159,098	3.32E-03	3.13E-03	3.51E-03	1.84E-04	9.46E-03	3.21E-03
2020	12,127	4,054,351	3.17E-03	2.86E-03	3.49E-03	1.15E-04	9.52E-03	3.05E-03
2021	10,700	3,945,663	3.03E-03	2.59E-03	3.46E-03	7.84E-05	9.14E-03	2.83E-03
2022	11,556	3,899,611	2.88E-03	2.32E-03	3.44E-03	2.21E-05	1.16E-02	3.14E-03
Total	402,045	99,492,303	--	--	--	--	--	--

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

Year	Regression Curve Data Points			Yearly Estimate Data Points		
	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	--	--	--	1.56E-03	1.39E-02	5.58E-03
1999	--	--	--	1.30E-03	1.50E-02	5.99E-03
2000	--	--	--	2.64E-03	1.40E-02	6.82E-03
2001	--	--	--	1.68E-03	1.42E-02	6.00E-03
2002	--	--	--	1.63E-03	1.30E-02	5.73E-03
2003	--	--	--	1.85E-03	1.37E-02	6.03E-03
2004	--	--	--	1.73E-03	1.15E-02	5.41E-03
2005	--	--	--	1.29E-03	1.36E-02	5.27E-03
2006	--	--	--	1.16E-03	1.28E-02	5.05E-03
2007	--	--	--	1.24E-03	1.17E-02	4.87E-03
2008	--	--	--	1.17E-03	1.20E-02	4.83E-03
2009	--	--	--	8.70E-04	1.18E-02	4.60E-03
2010	--	--	--	1.40E-03	1.22E-02	5.31E-03
2011	--	--	--	9.45E-04	1.12E-02	4.78E-03
2012	--	--	--	1.23E-03	1.20E-02	5.03E-03
2013	5.39E-03	4.96E-03	5.87E-03	1.18E-03	1.38E-02	5.24E-03
2014	5.12E-03	4.77E-03	5.50E-03	1.31E-03	1.30E-02	5.17E-03
2015	4.86E-03	4.58E-03	5.16E-03	1.24E-03	1.12E-02	4.67E-03
2016	4.62E-03	4.38E-03	4.86E-03	9.95E-04	9.68E-03	4.25E-03
2017	4.38E-03	4.18E-03	4.59E-03	9.91E-04	1.36E-02	4.90E-03
2018	4.16E-03	3.97E-03	4.36E-03	1.17E-03	1.17E-02	4.55E-03
2019	3.95E-03	3.75E-03	4.16E-03	1.04E-03	1.02E-02	4.09E-03
2020	3.75E-03	3.53E-03	3.98E-03	6.46E-04	1.00E-02	3.62E-03
2021	3.56E-03	3.31E-03	3.82E-03	7.02E-04	9.89E-03	3.57E-03
2022	3.38E-03	3.10E-03	3.68E-03	9.46E-05	1.10E-02	3.17E-03

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

Year	Regression Curve Data Points			Yearly Estimate Data Points		
	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	--	--	--	6.93E-04	1.90E-03	1.24E-03
1999	--	--	--	7.28E-04	1.89E-03	1.25E-03
2000	--	--	--	4.74E-04	1.48E-03	9.00E-04
2001	--	--	--	8.82E-04	2.14E-03	1.43E-03
2002	--	--	--	9.81E-04	2.30E-03	1.59E-03
2003	--	--	--	9.78E-04	2.29E-03	1.58E-03
2004	--	--	--	4.17E-04	1.33E-03	8.42E-04
2005	--	--	--	7.04E-04	1.76E-03	1.18E-03
2006	--	--	--	4.30E-04	1.33E-03	8.32E-04
2007	--	--	--	5.75E-04	1.61E-03	1.03E-03
2008	--	--	--	9.72E-04	2.15E-03	1.51E-03
2009	--	--	--	4.71E-04	1.39E-03	8.74E-04
2010	--	--	--	3.72E-04	1.23E-03	7.37E-04
2011	--	--	--	5.31E-04	1.52E-03	9.69E-04
2012	--	--	--	3.89E-04	1.22E-03	7.65E-04
2013	9.24E-04	5.08E-04	1.68E-03	3.16E-04	1.11E-03	6.68E-04
2014	7.99E-04	4.81E-04	1.33E-03	5.03E-04	1.51E-03	9.48E-04
2015	6.91E-04	4.51E-04	1.06E-03	1.79E-04	8.07E-04	4.37E-04
2016	5.98E-04	4.16E-04	8.60E-04	5.20E-04	1.56E-03	9.75E-04
2017	5.17E-04	3.73E-04	7.17E-04	3.43E-04	1.25E-03	7.42E-04
2018	4.47E-04	3.23E-04	6.20E-04	3.54E-04	1.29E-03	7.47E-04
2019	3.87E-04	2.69E-04	5.56E-04	3.39E-05	4.77E-04	1.89E-04
2020	3.34E-04	2.18E-04	5.12E-04	6.79E-05	6.37E-04	2.88E-04
2021	2.89E-04	1.74E-04	4.80E-04	1.77E-04	8.13E-04	4.45E-04
2022	2.50E-04	1.38E-04	4.55E-04	3.66E-05	4.54E-04	1.82E-04

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

Year	Demands	Reactor Years	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	24,834	103.0	--	--	--	2.39E+02	2.44E+02	2.41E+02
1999	25,119	103.0	--	--	--	2.41E+02	2.46E+02	2.44E+02
2000	24,464	103.3	--	--	--	2.34E+02	2.39E+02	2.37E+02
2001	24,704	103.0	--	--	--	2.37E+02	2.42E+02	2.40E+02
2002	25,216	103.0	--	--	--	2.42E+02	2.47E+02	2.45E+02
2003	26,487	103.0	--	--	--	2.55E+02	2.60E+02	2.57E+02
2004	26,701	103.3	--	--	--	2.56E+02	2.61E+02	2.59E+02
2005	27,355	103.0	--	--	--	2.63E+02	2.68E+02	2.66E+02
2006	27,315	103.0	--	--	--	2.63E+02	2.68E+02	2.65E+02
2007	27,187	103.6	--	--	--	2.60E+02	2.65E+02	2.62E+02
2008	27,317	104.3	--	--	--	2.59E+02	2.65E+02	2.62E+02
2009	27,059	104.0	--	--	--	2.58E+02	2.63E+02	2.60E+02
2010	26,387	104.0	--	--	--	2.51E+02	2.56E+02	2.54E+02
2011	26,323	104.0	--	--	--	2.51E+02	2.56E+02	2.53E+02
2012	25,939	104.3	--	--	--	2.46E+02	2.51E+02	2.49E+02
2013	26,018	101.6	2.56E+02	2.53E+02	2.60E+02	2.54E+02	2.59E+02	2.56E+02
2014	25,683	100.0	2.57E+02	2.54E+02	2.60E+02	2.54E+02	2.59E+02	2.57E+02
2015	25,911	99.0	2.58E+02	2.56E+02	2.61E+02	2.59E+02	2.64E+02	2.62E+02
2016	25,661	99.2	2.60E+02	2.57E+02	2.62E+02	2.56E+02	2.61E+02	2.59E+02
2017	25,806	99.0	2.61E+02	2.59E+02	2.63E+02	2.58E+02	2.63E+02	2.61E+02
2018	25,657	98.7	2.62E+02	2.60E+02	2.64E+02	2.57E+02	2.63E+02	2.60E+02
2019	25,101	97.0	2.63E+02	2.61E+02	2.65E+02	2.56E+02	2.61E+02	2.59E+02
2020	25,369	95.3	2.64E+02	2.61E+02	2.67E+02	2.64E+02	2.69E+02	2.66E+02
2021	25,017	93.3	2.65E+02	2.62E+02	2.68E+02	2.65E+02	2.71E+02	2.68E+02
2022	24,546	92.4	2.66E+02	2.63E+02	2.70E+02	2.63E+02	2.68E+02	2.66E+02
Total	647,175	2,527.3	--	--	--	--	--	--

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

Year	Hours	Reactor Years	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	24,834	103.0	--	--	--	2.39E+02	2.44E+02	2.41E+02
1999	25,119	103.0	--	--	--	2.41E+02	2.46E+02	2.44E+02
2000	24,464	103.3	--	--	--	2.34E+02	2.39E+02	2.37E+02
2001	24,704	103.0	--	--	--	2.37E+02	2.42E+02	2.40E+02
2002	25,216	103.0	--	--	--	2.42E+02	2.47E+02	2.45E+02
2003	26,487	103.0	--	--	--	2.55E+02	2.60E+02	2.57E+02
2004	26,701	103.3	--	--	--	2.56E+02	2.61E+02	2.59E+02
2005	27,355	103.0	--	--	--	2.63E+02	2.68E+02	2.66E+02
2006	27,315	103.0	--	--	--	2.63E+02	2.68E+02	2.65E+02
2007	27,187	103.6	--	--	--	2.60E+02	2.65E+02	2.62E+02
2008	27,317	104.3	--	--	--	2.59E+02	2.65E+02	2.62E+02
2009	27,059	104.0	--	--	--	2.58E+02	2.63E+02	2.60E+02
2010	26,387	104.0	--	--	--	2.51E+02	2.56E+02	2.54E+02
2011	26,323	104.0	--	--	--	2.51E+02	2.56E+02	2.53E+02
2012	25,939	104.3	--	--	--	2.46E+02	2.51E+02	2.49E+02
2013	26,018	101.6	2.56E+02	2.53E+02	2.60E+02	2.54E+02	2.59E+02	2.56E+02
2014	25,683	100.0	2.57E+02	2.54E+02	2.60E+02	2.54E+02	2.59E+02	2.57E+02
2015	25,911	99.0	2.58E+02	2.56E+02	2.61E+02	2.59E+02	2.64E+02	2.62E+02
2016	25,661	99.2	2.60E+02	2.57E+02	2.62E+02	2.56E+02	2.61E+02	2.59E+02
2017	25,806	99.0	2.61E+02	2.59E+02	2.63E+02	2.58E+02	2.63E+02	2.61E+02
2018	25,657	98.7	2.62E+02	2.60E+02	2.64E+02	2.57E+02	2.63E+02	2.60E+02
2019	25,101	97.0	2.63E+02	2.61E+02	2.65E+02	2.56E+02	2.61E+02	2.59E+02
2020	25,369	95.3	2.64E+02	2.61E+02	2.67E+02	2.64E+02	2.69E+02	2.66E+02
2021	25,017	93.3	2.65E+02	2.62E+02	2.68E+02	2.65E+02	2.71E+02	2.68E+02
2022	24,546	92.4	2.66E+02	2.63E+02	2.70E+02	2.63E+02	2.68E+02	2.66E+02
Total	647,175	2,527.3	--	--	--	--	--	--

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	1,011,928	103.0	--	--	--	9.81E+03	9.84E+03	9.82E+03
1999	926,913	103.0	--	--	--	8.99E+03	9.01E+03	9.00E+03
2000	901,625	103.3	--	--	--	8.72E+03	8.74E+03	8.73E+03
2001	909,219	103.0	--	--	--	8.81E+03	8.84E+03	8.83E+03
2002	970,195	103.0	--	--	--	9.41E+03	9.43E+03	9.42E+03
2003	1,129,711	103.0	--	--	--	1.10E+04	1.10E+04	1.10E+04
2004	1,168,702	103.3	--	--	--	1.13E+04	1.13E+04	1.13E+04
2005	1,179,662	103.0	--	--	--	1.14E+04	1.15E+04	1.15E+04
2006	1,178,274	103.0	--	--	--	1.14E+04	1.15E+04	1.14E+04
2007	1,178,298	103.6	--	--	--	1.14E+04	1.14E+04	1.14E+04
2008	1,182,644	104.3	--	--	--	1.13E+04	1.14E+04	1.13E+04
2009	1,169,908	104.0	--	--	--	1.12E+04	1.13E+04	1.12E+04
2010	1,185,189	104.0	--	--	--	1.14E+04	1.14E+04	1.14E+04
2011	1,187,359	104.0	--	--	--	1.14E+04	1.14E+04	1.14E+04
2012	1,197,084	104.3	--	--	--	1.15E+04	1.15E+04	1.15E+04
2013	1,171,233	101.6	1.15E+04	1.13E+04	1.17E+04	1.15E+04	1.15E+04	1.15E+04
2014	1,159,906	100.0	1.16E+04	1.14E+04	1.18E+04	1.16E+04	1.16E+04	1.16E+04
2015	1,171,407	99.0	1.17E+04	1.16E+04	1.19E+04	1.18E+04	1.19E+04	1.18E+04
2016	1,174,018	99.2	1.18E+04	1.17E+04	1.20E+04	1.18E+04	1.19E+04	1.18E+04
2017	1,177,745	99.0	1.20E+04	1.19E+04	1.21E+04	1.19E+04	1.19E+04	1.19E+04
2018	1,173,028	98.7	1.21E+04	1.20E+04	1.22E+04	1.19E+04	1.19E+04	1.19E+04
2019	1,168,894	97.0	1.22E+04	1.21E+04	1.24E+04	1.20E+04	1.21E+04	1.21E+04
2020	1,182,127	95.3	1.24E+04	1.22E+04	1.25E+04	1.24E+04	1.24E+04	1.24E+04
2021	1,186,008	93.3	1.25E+04	1.23E+04	1.27E+04	1.27E+04	1.27E+04	1.27E+04
2022	1,174,226	92.4	1.26E+04	1.24E+04	1.29E+04	1.27E+04	1.27E+04	1.27E+04
Total	28,215,302	2,527.3	--	--	--	--	--	--

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	25	103.0	--	--	--	1.68E-01	3.35E-01	2.41E-01
1999	21	103.0	--	--	--	1.37E-01	2.91E-01	2.03E-01
2000	36	103.3	--	--	--	2.56E-01	4.53E-01	3.43E-01
2001	24	103.0	--	--	--	1.60E-01	3.24E-01	2.31E-01
2002	24	103.0	--	--	--	1.60E-01	3.24E-01	2.31E-01
2003	31	103.0	--	--	--	2.16E-01	4.00E-01	2.97E-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	--	--	--	1.28E-01	2.78E-01	1.92E-01
2008	19	104.3	--	--	--	1.20E-01	2.65E-01	1.82E-01
2009	12	104.0	--	--	--	6.83E-02	1.87E-01	1.17E-01
2010	21	104.0	--	--	--	1.35E-01	2.88E-01	2.01E-01
2011	10	104.0	--	--	--	5.42E-02	1.64E-01	9.81E-02
2012	16	104.3	--	--	--	9.72E-02	2.32E-01	1.54E-01
2013	17	101.6	2.41E-01	1.19E-01	4.90E-01	1.07E-01	2.50E-01	1.67E-01
2014	24	100.0	2.15E-01	1.19E-01	3.88E-01	1.65E-01	3.33E-01	2.38E-01
2015	20	99.0	1.91E-01	1.16E-01	3.14E-01	1.34E-01	2.91E-01	2.01E-01
2016	14	99.2	1.70E-01	1.09E-01	2.65E-01	8.66E-02	2.20E-01	1.42E-01
2017	20	99.0	1.51E-01	9.69E-02	2.35E-01	1.34E-01	2.91E-01	2.01E-01
2018	20	98.7	1.34E-01	8.20E-02	2.19E-01	1.34E-01	2.91E-01	2.01E-01
2019	21	97.0	1.19E-01	6.66E-02	2.13E-01	1.45E-01	3.08E-01	2.15E-01
2020	13	95.3	1.06E-01	5.28E-02	2.13E-01	8.22E-02	2.17E-01	1.37E-01
2021	12	93.3	9.42E-02	4.13E-02	2.15E-01	7.58E-02	2.08E-01	1.30E-01
2022	1	92.4	8.38E-02	3.20E-02	2.19E-01	1.84E-03	5.80E-02	1.57E-02
Total	485	2,527.3	--	--	--	--	--	--

Table 23. Plot data for Figure 13, frequency of FTR≤1H 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	6	103.0	--	--	--	2.32E-02	9.86E-02	5.13E-02
1999	2	103.0	--	--	--	4.52E-03	5.55E-02	1.97E-02
2000	3	103.3	--	--	--	8.53E-03	6.66E-02	2.75E-02
2001	3	103.0	--	--	--	8.55E-03	6.67E-02	2.76E-02
2002	3	103.0	--	--	--	8.55E-03	6.67E-02	2.76E-02
2003	2	103.0	--	--	--	4.52E-03	5.55E-02	1.97E-02
2004	3	103.3	--	--	--	8.53E-03	6.66E-02	2.75E-02
2005	4	103.0	--	--	--	1.31E-02	7.76E-02	3.55E-02
2006	6	103.0	--	--	--	2.32E-02	9.86E-02	5.13E-02
2007	1	103.6	--	--	--	1.38E-03	4.34E-02	1.18E-02
2008	2	104.3	--	--	--	4.47E-03	5.49E-02	1.95E-02
2009	2	104.0	--	--	--	4.48E-03	5.50E-02	1.96E-02
2010	4	104.0	--	--	--	1.30E-02	7.70E-02	3.52E-02
2011	2	104.0	--	--	--	4.48E-03	5.50E-02	1.96E-02
2012	4	104.3	--	--	--	1.30E-02	7.68E-02	3.51E-02
2013	3	101.6	3.28E-02	1.47E-02	7.32E-02	8.64E-03	6.75E-02	2.79E-02
2014	4	100.0	2.80E-02	1.42E-02	5.51E-02	1.34E-02	7.95E-02	3.64E-02
2015	3	99.0	2.40E-02	1.35E-02	4.24E-02	8.83E-03	6.89E-02	2.85E-02
2016	1	99.2	2.05E-02	1.24E-02	3.39E-02	1.43E-03	4.50E-02	1.22E-02
2017	2	99.0	1.75E-02	1.08E-02	2.85E-02	4.66E-03	5.73E-02	2.04E-02
2018	2	98.7	1.50E-02	8.87E-03	2.53E-02	4.67E-03	5.74E-02	2.04E-02
2019	1	97.0	1.28E-02	6.96E-03	2.36E-02	1.46E-03	4.58E-02	1.24E-02
2020	0	95.3	1.10E-02	5.30E-03	2.27E-02	1.65E-05	3.28E-02	4.20E-03
2021	4	93.3	9.38E-03	3.97E-03	2.22E-02	1.42E-02	8.40E-02	3.84E-02
2022	0	92.4	8.02E-03	2.94E-03	2.19E-02	1.69E-05	3.36E-02	4.30E-03
Total	67	2,527.3	--	--	--	--	--	--

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			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	4	103.0	--	--	--	1.49E-02	8.81E-02	4.03E-02
1999	5	103.0	--	--	--	2.05E-02	1.00E-01	4.93E-02
2000	10	103.3	--	--	--	5.18E-02	1.57E-01	9.38E-02
2001	15	103.0	--	--	--	8.64E-02	2.12E-01	1.39E-01
2002	10	103.0	--	--	--	5.19E-02	1.58E-01	9.41E-02
2003	15	103.0	--	--	--	8.64E-02	2.12E-01	1.39E-01
2004	13	103.3	--	--	--	7.22E-02	1.90E-01	1.21E-01
2005	10	103.0	--	--	--	5.19E-02	1.58E-01	9.41E-02
2006	9	103.0	--	--	--	4.53E-02	1.46E-01	8.51E-02
2007	10	103.6	--	--	--	5.16E-02	1.57E-01	9.35E-02
2008	21	104.3	--	--	--	1.28E-01	2.73E-01	1.90E-01
2009	6	104.0	--	--	--	2.62E-02	1.11E-01	5.77E-02
2010	8	104.0	--	--	--	3.85E-02	1.34E-01	7.55E-02
2011	14	104.0	--	--	--	7.86E-02	2.00E-01	1.29E-01
2012	8	104.3	--	--	--	3.84E-02	1.33E-01	7.53E-02
2013	16	101.6	7.93E-02	3.82E-02	1.64E-01	9.47E-02	2.26E-01	1.50E-01
2014	5	100.0	7.10E-02	3.85E-02	1.31E-01	2.11E-02	1.03E-01	5.06E-02
2015	5	99.0	6.37E-02	3.80E-02	1.07E-01	2.13E-02	1.04E-01	5.11E-02
2016	2	99.2	5.71E-02	3.62E-02	8.99E-02	5.31E-03	6.52E-02	2.32E-02
2017	5	99.0	5.12E-02	3.29E-02	7.96E-02	2.13E-02	1.04E-01	5.11E-02
2018	6	98.7	4.59E-02	2.83E-02	7.44E-02	2.74E-02	1.16E-01	6.05E-02
2019	6	97.0	4.11E-02	2.33E-02	7.25E-02	2.79E-02	1.18E-01	6.15E-02
2020	5	95.3	3.68E-02	1.87E-02	7.25E-02	2.20E-02	1.08E-01	5.29E-02
2021	5	93.3	3.30E-02	1.48E-02	7.36E-02	2.24E-02	1.10E-01	5.39E-02
2022	1	92.4	2.96E-02	1.16E-02	7.55E-02	1.74E-03	5.48E-02	1.48E-02
Total	214	2,527.3	--	--	--	--	--	--

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

Year	Demands	Reactor Years	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	7,997	103.0	--	--	--	7.62E+01	7.91E+01	7.76E+01
1999	8,428	103.0	--	--	--	8.04E+01	8.33E+01	8.18E+01
2000	8,248	103.3	--	--	--	7.84E+01	8.13E+01	7.99E+01
2001	8,248	103.0	--	--	--	7.86E+01	8.15E+01	8.01E+01
2002	8,425	103.0	--	--	--	8.03E+01	8.33E+01	8.18E+01
2003	8,946	103.0	--	--	--	8.53E+01	8.84E+01	8.69E+01
2004	8,899	103.3	--	--	--	8.47E+01	8.77E+01	8.62E+01
2005	9,037	103.0	--	--	--	8.62E+01	8.93E+01	8.77E+01
2006	9,230	103.0	--	--	--	8.81E+01	9.12E+01	8.96E+01
2007	9,072	103.6	--	--	--	8.60E+01	8.91E+01	8.76E+01
2008	9,438	104.3	--	--	--	8.90E+01	9.20E+01	9.05E+01
2009	9,163	104.0	--	--	--	8.66E+01	8.96E+01	8.81E+01
2010	8,857	104.0	--	--	--	8.37E+01	8.67E+01	8.52E+01
2011	8,896	104.0	--	--	--	8.41E+01	8.70E+01	8.55E+01
2012	8,909	104.3	--	--	--	8.39E+01	8.69E+01	8.54E+01
2013	8,749	101.6	8.72E+01	8.52E+01	8.92E+01	8.46E+01	8.77E+01	8.61E+01
2014	8,752	100.0	8.71E+01	8.54E+01	8.88E+01	8.60E+01	8.91E+01	8.75E+01
2015	8,871	99.0	8.70E+01	8.55E+01	8.84E+01	8.81E+01	9.12E+01	8.96E+01
2016	8,606	99.2	8.69E+01	8.56E+01	8.81E+01	8.52E+01	8.83E+01	8.67E+01
2017	8,593	99.0	8.67E+01	8.56E+01	8.79E+01	8.53E+01	8.83E+01	8.68E+01
2018	8,399	98.7	8.66E+01	8.55E+01	8.78E+01	8.35E+01	8.66E+01	8.51E+01
2019	8,244	97.0	8.65E+01	8.53E+01	8.78E+01	8.35E+01	8.65E+01	8.50E+01
2020	8,177	95.3	8.64E+01	8.49E+01	8.79E+01	8.43E+01	8.74E+01	8.58E+01
2021	8,106	93.3	8.63E+01	8.46E+01	8.81E+01	8.53E+01	8.85E+01	8.69E+01
2022	8,091	92.4	8.62E+01	8.42E+01	8.83E+01	8.60E+01	8.92E+01	8.76E+01
Total	216,380	2,527.3	--	--	--	--	--	--

Table 26. Plot data for Figure 16, frequency of run hours (hours per reactor year) trend for normally running 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	3,330,654	103.0	--	--	--	3.23E+04	3.24E+04	3.23E+04
1999	3,404,841	103.0	--	--	--	3.30E+04	3.31E+04	3.31E+04
2000	3,427,139	103.3	--	--	--	3.32E+04	3.32E+04	3.32E+04
2001	3,430,235	103.0	--	--	--	3.33E+04	3.33E+04	3.33E+04
2002	3,425,415	103.0	--	--	--	3.32E+04	3.33E+04	3.33E+04
2003	3,563,793	103.0	--	--	--	3.46E+04	3.46E+04	3.46E+04
2004	3,585,229	103.3	--	--	--	3.47E+04	3.47E+04	3.47E+04
2005	3,522,610	103.0	--	--	--	3.42E+04	3.42E+04	3.42E+04
2006	3,501,288	103.0	--	--	--	3.40E+04	3.40E+04	3.40E+04
2007	3,509,840	103.6	--	--	--	3.39E+04	3.39E+04	3.39E+04
2008	3,573,582	104.3	--	--	--	3.42E+04	3.43E+04	3.43E+04
2009	3,577,643	104.0	--	--	--	3.44E+04	3.44E+04	3.44E+04
2010	3,580,909	104.0	--	--	--	3.44E+04	3.45E+04	3.44E+04
2011	3,577,300	104.0	--	--	--	3.44E+04	3.44E+04	3.44E+04
2012	3,575,450	104.3	--	--	--	3.43E+04	3.43E+04	3.43E+04
2013	3,560,183	101.6	3.50E+04	3.45E+04	3.55E+04	3.50E+04	3.51E+04	3.51E+04
2014	3,564,608	100.0	3.53E+04	3.49E+04	3.57E+04	3.56E+04	3.57E+04	3.56E+04
2015	3,555,386	99.0	3.56E+04	3.52E+04	3.60E+04	3.59E+04	3.59E+04	3.59E+04
2016	3,553,732	99.2	3.59E+04	3.56E+04	3.62E+04	3.58E+04	3.58E+04	3.58E+04
2017	3,546,182	99.0	3.62E+04	3.59E+04	3.65E+04	3.58E+04	3.59E+04	3.58E+04
2018	3,554,969	98.7	3.65E+04	3.62E+04	3.68E+04	3.60E+04	3.60E+04	3.60E+04
2019	3,537,325	97.0	3.68E+04	3.65E+04	3.71E+04	3.64E+04	3.65E+04	3.65E+04
2020	3,535,482	95.3	3.71E+04	3.68E+04	3.75E+04	3.71E+04	3.71E+04	3.71E+04
2021	3,529,136	93.3	3.74E+04	3.70E+04	3.79E+04	3.78E+04	3.78E+04	3.78E+04
2022	3,519,176	92.4	3.78E+04	3.72E+04	3.83E+04	3.81E+04	3.81E+04	3.81E+04
Total	88,042,105	2,527.3	--	--	--	--	--	--

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	--	--	--	4.43E-02	1.43E-01	8.32E-02
1999	10	103.0	--	--	--	5.07E-02	1.54E-01	9.19E-02
2000	6	103.3	--	--	--	2.57E-02	1.09E-01	5.68E-02
2001	11	103.0	--	--	--	5.73E-02	1.65E-01	1.01E-01
2002	13	103.0	--	--	--	7.07E-02	1.86E-01	1.18E-01
2003	14	103.0	--	--	--	7.75E-02	1.97E-01	1.27E-01
2004	7	103.3	--	--	--	3.17E-02	1.20E-01	6.55E-02
2005	10	103.0	--	--	--	5.07E-02	1.54E-01	9.19E-02
2006	7	103.0	--	--	--	3.18E-02	1.21E-01	6.57E-02
2007	9	103.6	--	--	--	4.41E-02	1.42E-01	8.27E-02
2008	13	104.3	--	--	--	6.99E-02	1.84E-01	1.17E-01
2009	7	104.0	--	--	--	3.15E-02	1.20E-01	6.51E-02
2010	6	104.0	--	--	--	2.56E-02	1.08E-01	5.64E-02
2011	8	104.0	--	--	--	3.76E-02	1.31E-01	7.38E-02
2012	6	104.3	--	--	--	2.55E-02	1.08E-01	5.63E-02
2013	5	101.6	6.63E-02	3.50E-02	1.26E-01	2.03E-02	9.91E-02	4.88E-02
2014	8	100.0	5.84E-02	3.42E-02	9.97E-02	3.90E-02	1.36E-01	7.64E-02
2015	3	99.0	5.14E-02	3.27E-02	8.07E-02	9.83E-03	7.68E-02	3.18E-02
2016	8	99.2	4.52E-02	3.03E-02	6.74E-02	3.93E-02	1.36E-01	7.70E-02
2017	6	99.0	3.98E-02	2.69E-02	5.89E-02	2.67E-02	1.13E-01	5.90E-02
2018	6	98.7	3.50E-02	2.28E-02	5.39E-02	2.68E-02	1.14E-01	5.91E-02
2019	1	97.0	3.08E-02	1.86E-02	5.11E-02	1.63E-03	5.12E-02	1.39E-02
2020	2	95.3	2.71E-02	1.48E-02	4.97E-02	5.38E-03	6.61E-02	2.35E-02
2021	3	93.3	2.39E-02	1.17E-02	4.89E-02	1.04E-02	8.09E-02	3.35E-02
2022	1	92.4	2.10E-02	9.11E-03	4.85E-02	1.70E-03	5.34E-02	1.45E-02
Total	179	2,527.3	--	--	--	--	--	--

Table 28. Plot data for Figure 18, frequency of FTR 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	20	103.0	--	--	--	1.22E-01	2.64E-01	1.83E-01
1999	15	103.0	--	--	--	8.58E-02	2.11E-01	1.38E-01
2000	21	103.3	--	--	--	1.29E-01	2.74E-01	1.91E-01
2001	17	103.0	--	--	--	1.00E-01	2.32E-01	1.56E-01
2002	13	103.0	--	--	--	7.19E-02	1.89E-01	1.20E-01
2003	9	103.0	--	--	--	4.50E-02	1.45E-01	8.46E-02
2004	8	103.3	--	--	--	3.85E-02	1.34E-01	7.55E-02
2005	10	103.0	--	--	--	5.16E-02	1.57E-01	9.35E-02
2006	10	103.0	--	--	--	5.16E-02	1.57E-01	9.35E-02
2007	7	103.6	--	--	--	3.22E-02	1.22E-01	6.64E-02
2008	26	104.3	--	--	--	1.64E-01	3.23E-01	2.33E-01
2009	16	104.0	--	--	--	9.21E-02	2.20E-01	1.46E-01
2010	7	104.0	--	--	--	3.20E-02	1.22E-01	6.62E-02
2011	8	104.0	--	--	--	3.83E-02	1.33E-01	7.50E-02
2012	10	104.3	--	--	--	5.10E-02	1.55E-01	9.24E-02
2013	10	101.6	8.84E-02	3.85E-02	2.03E-01	5.23E-02	1.59E-01	9.47E-02
2014	5	100.0	7.44E-02	3.72E-02	1.49E-01	2.09E-02	1.02E-01	5.03E-02
2015	9	99.0	6.27E-02	3.48E-02	1.13E-01	4.67E-02	1.51E-01	8.77E-02
2016	8	99.2	5.28E-02	3.10E-02	8.97E-02	4.00E-02	1.39E-01	7.83E-02
2017	4	99.0	4.44E-02	2.59E-02	7.62E-02	1.54E-02	9.08E-02	4.16E-02
2018	4	98.7	3.74E-02	2.03E-02	6.89E-02	1.54E-02	9.11E-02	4.17E-02
2019	2	97.0	3.15E-02	1.52E-02	6.51E-02	5.39E-03	6.62E-02	2.35E-02
2020	0	95.3	2.65E-02	1.11E-02	6.32E-02	1.88E-05	3.74E-02	4.78E-03
2021	8	93.3	2.23E-02	7.99E-03	6.23E-02	4.23E-02	1.47E-01	8.28E-02
2022	2	92.4	1.88E-02	5.69E-03	6.20E-02	5.63E-03	6.92E-02	2.46E-02
Total	249	2,527.3	--	--	--	--	--	--

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