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# Enhanced Component Performance Study: Motor-Driven Pumps 1998–2020

March 2022

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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 2020 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≤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≤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≤1H failure probability
- Normally running MDP FTR failure rate
- Standby MDP unavailability
- Normally running MDP total unreliability (8-hour mission)
- Standby MDP frequency of FTR≤1H events (failures per reactor year)
- Normally running MDP frequency of FTR events.

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# CONTENTS

# FIGURES



# TABLES

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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≤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 1998–2020

## 1. INTRODUCTION

This report presents an enhanced performance evaluation of motor-driven pumps (MDPs) at U.S. commercial nuclear power plants from 1998 through 2020. 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 (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-19-54610, *Enhanced Component Performance Study: Motor-Driven Pumps 1998-2018* [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)* [3], 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. In addition, the population of data in current IRIS 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 fail to start (FTS), fail to run (FTR) for one hour of operation (FTR≤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≤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 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 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). This is a new trend that was not observed in the *2018 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 *2018 MDP update* study.

### 2.1.2 Highly Statistically Significant

- None.

### 2.1.3 Statistically Significant

- A 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 0.0133 (see Figure 9). This is a new trend that was not observed in the *2018 MDP update* study.
- A statistically significant **increasing trend** was identified in the **frequency of run ≤ 1H hours** estimates for **standby MDPs** with a p-value of 0.0133 (see Figure 10). This is a new trend that was not observed in the *2018 MDP update* study.

## 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). This trend was observed in the *2018 MDP Update* study as highly statistically significant.

### 2.2.2 Highly Statistically Significant

- None.

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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 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≤1H failure probability** estimates with a p-value of 0.0303 (see Figure 2). This is a new trend that was not observed in the *2018 MDP Update* study.
- A statistically significant **decreasing trend** was identified in the **normally running MDP FTR failure rate** estimates with a p-value of 0.0112 (see Figure 5). The same trend was observed in the *2018 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 0.0439 (see Figure 8). This is a new trend that was not observed in the *2018 MDP Update* study.
- A statistically significant **decreasing trend** was identified in the **frequency of FTR≤1H events** (failures per reactor year) estimates for **standby MDPs** with a p-value of 0.0336 (see Figure 13). This is a new trend that was not observed in the *2018 MDP Update* study.
- A statistically significant **decreasing trend** was identified in the **frequency of FTR events** estimates for **normally running MDPs** with a p-value of 0.0133 (see Figure 18). The same trend was observed in the *2018 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 test 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≤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 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 IRIS includes MDPs in the systems listed in Table 1. This report follows the definition of these categories in NUREG/CR-6823 [9], 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.

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 | 459 | 459 | |
| | Total | 1959 | 1310 | 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** | $\alpha$ | $\beta$ |
| Standby | FTS | 1.09E-4 | 4.96E-4 | 5.88E-4 | 1.38E-3 | Beta | 2.07 | 3.52E+03 |

| Operation | Failure Mode | 5% | Median | Mean | 95% | Distribution | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | **Type** | $\alpha$ | $\beta$ |
| | FTR≤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 2020. 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 did not create large changes in the data.

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

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

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 ($\mu_i$) can be calculated as:

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

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

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

where $f_i$ and $D_i$ are the failures and demands for the $i^{th}$ year, respectively. The CNID shape parameter ($\alpha$) 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 ($\mu_i$) can be calculated as:

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

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 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 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≤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≤1H, and FTR>1H events in the most recent 10-year period:

- **Decreasing trend** in the **standby MDP FTR≤1H failure probability** estimates, which is statistically significant with a p-value of 0.0303 (see Figure 2). This is a new trend that was not observed in the *2018 MDP Update* study [2].
- **Decreasing trend** in the **normally running MDP FTR failure rate** estimates, which is statistically significant with a p-value of 0.0112 (see Figure 5). The same trend was observed in the *2018 MDP Update* study.

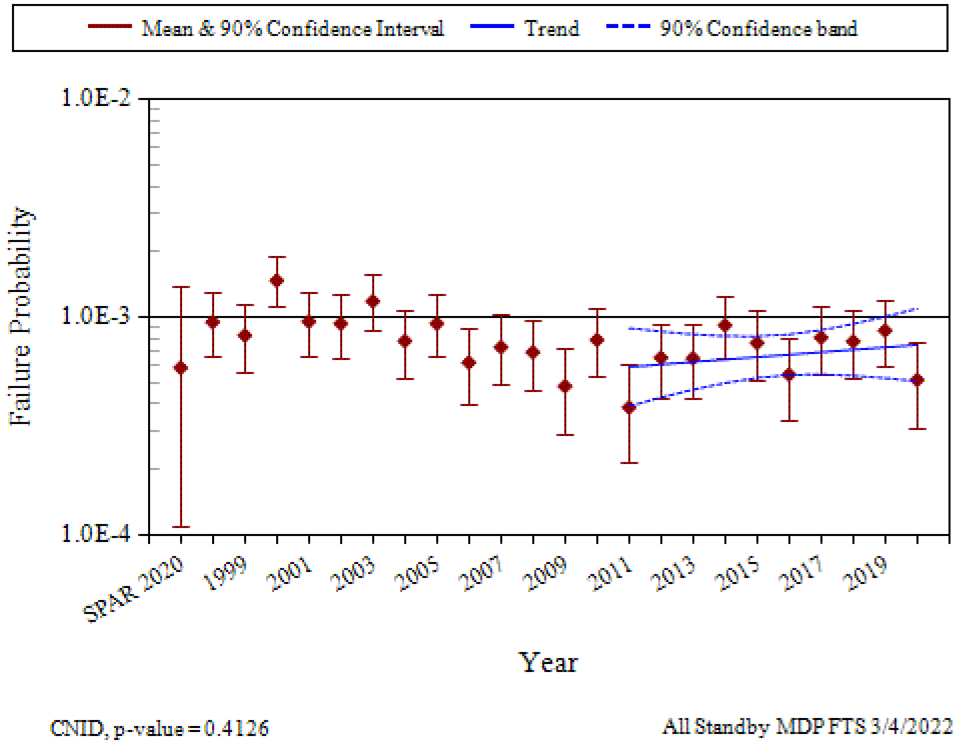


Figure 1. Failure probability estimate trend for standby MDP FTS.

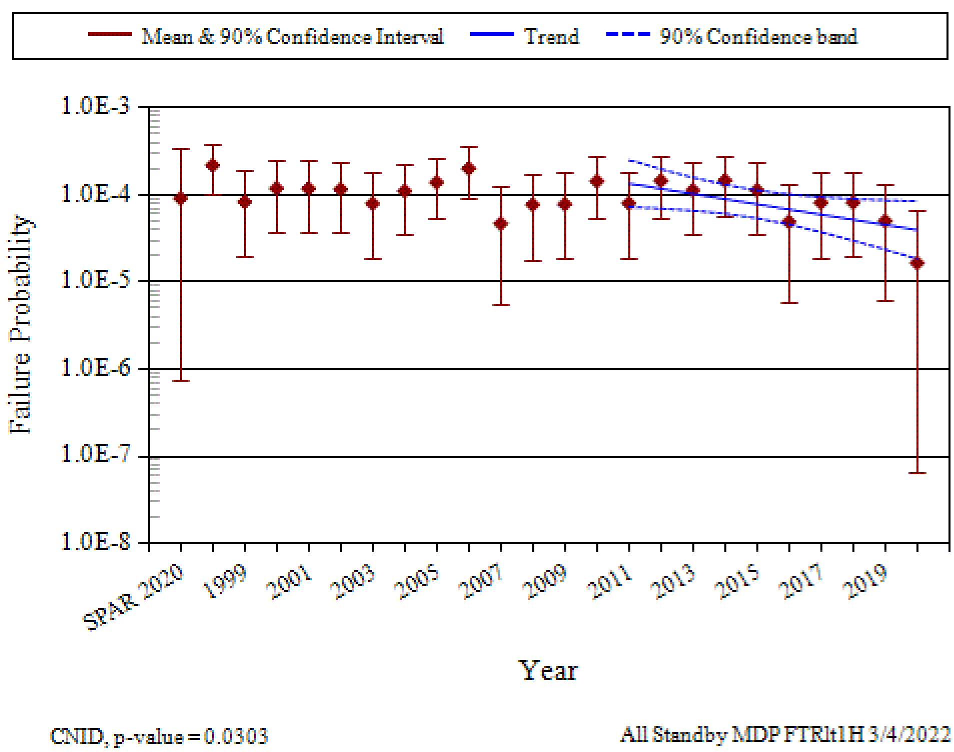


Figure 2. Failure probability estimate trend for standby MDP FTR≤1H.

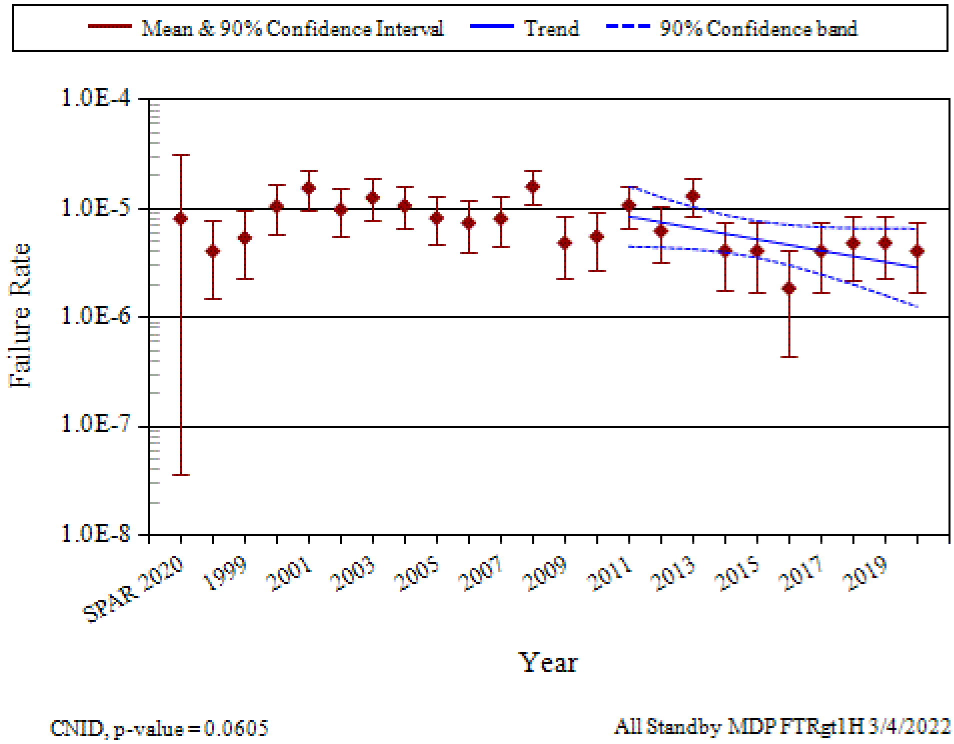


Figure 3. Failure rate estimate trend for standby MDP FTR>1H.

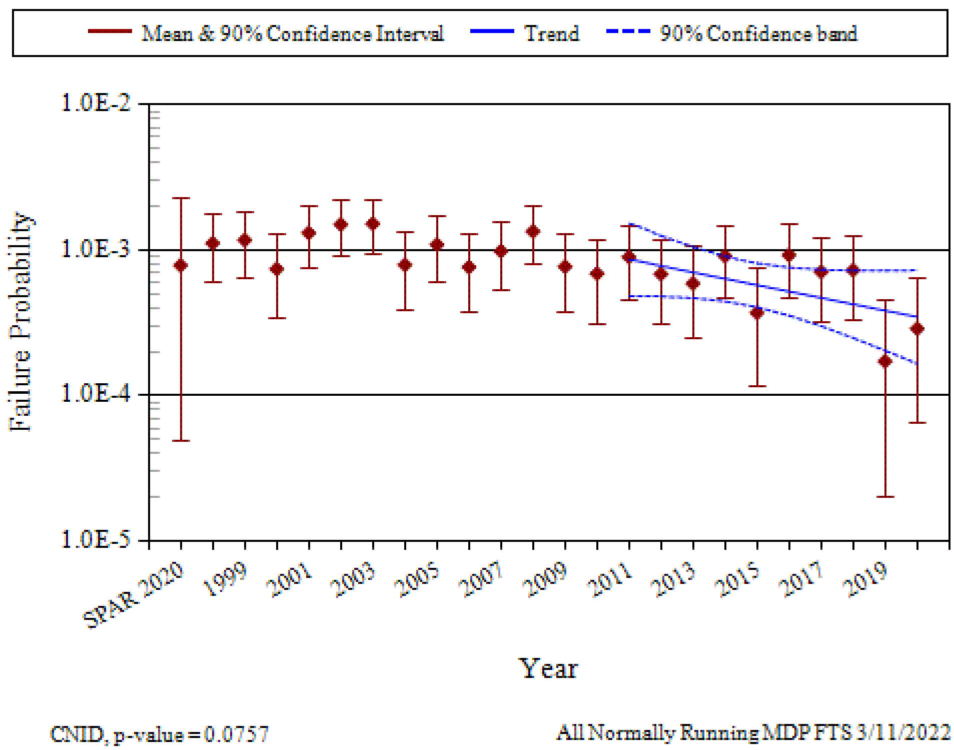


Figure 4. Failure probability estimate trend for normally running MDP FTS.

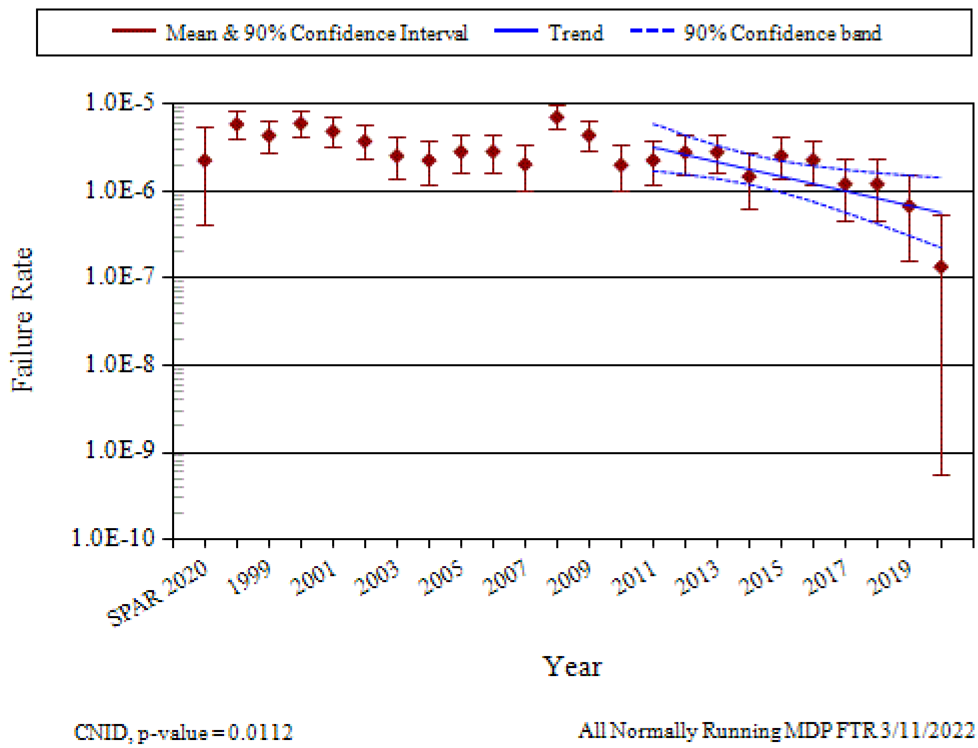


Figure 5. Failure rate estimate trend for normally running MDP FTR.

# 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 1998–2020 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 (e.g., AFW, HPCS, HPSI, and RHR) are pooled and trended. The trend chart shows the results of using data for each year's component UA data over time. The yearly (1998–2020) UA and reactor critical hour data were obtained from the Reactor Oversight Process program (1998 to 2001) and IRIS (2002 to 2020) 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 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 *Overview and Reference* provides further information [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:

- **Decreasing trend** in the **standby MDP unavailability** estimates, which is extremely statistically significant with a p-value of 0.0001 (see Figure 6). This is a new trend that was not observed in the *2018 MDP Update* study as highly statistically significant [2].

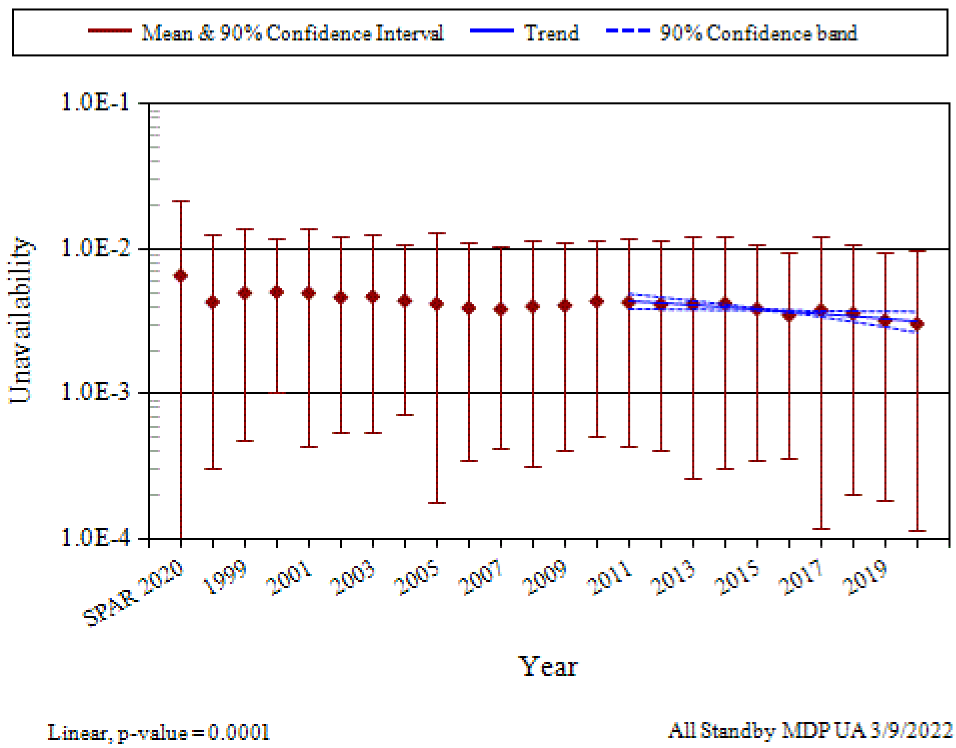


Figure 6. Pooled standby MDP UA trend.

# 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 8-hour mission. Since the normally running systems MDP components do not have UA data or the FTR≤1H data, there is no UA or FTR≤1H input to the OR gate for that calculation. The trending method is described in more detail in Section 4 of *Overview and Reference* [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:

- **Decreasing trend** in the **normally running MDP total unreliability (8-hour mission)** estimates, which is statistically significant with a p-value of 0.0439 (see Figure 8). This is a new trend that was not observed in the *2018 MDP Update* study [2].

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.

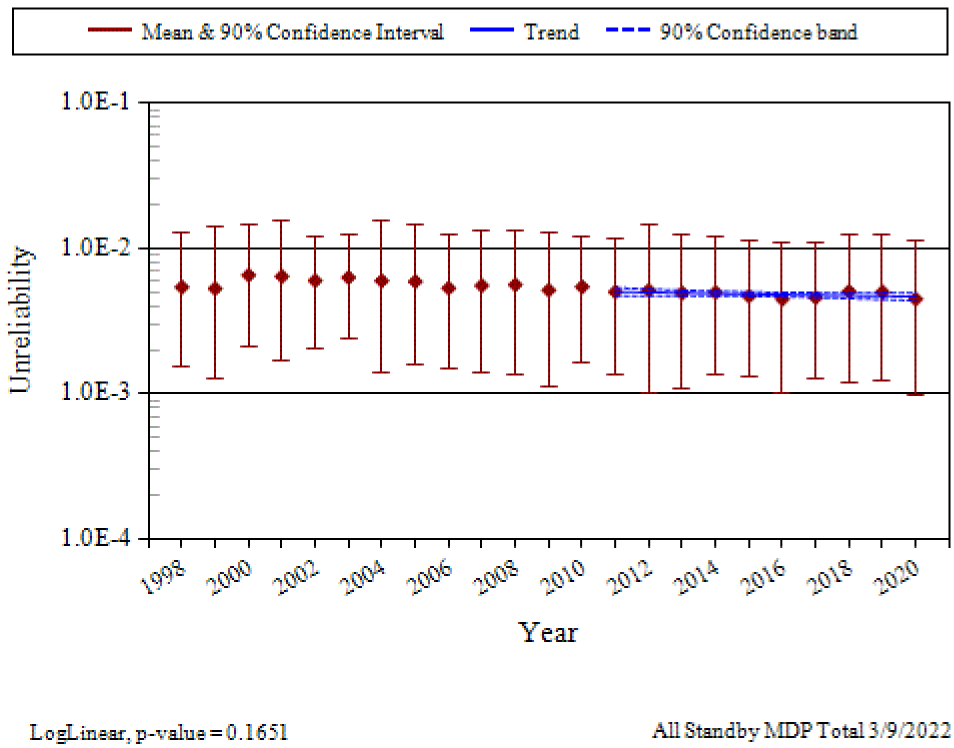


Figure 7. Standby MDP total unreliability trend (8-hour mission).

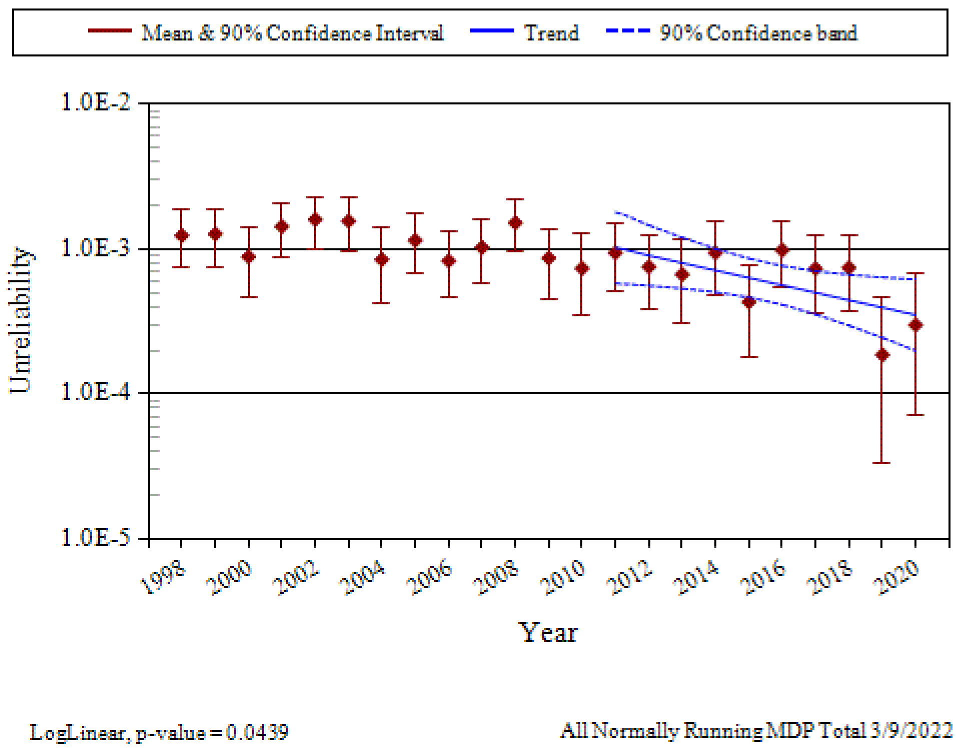


Figure 8. Normally running MDP total unreliability trend (8-hour mission).

# 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≤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 ≤ 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≤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. 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 statistically significant with a p-value of 0.0133 (see Figure 9). This is a new trend that was not observed in the *2018 MDP Update* study [2]
- **Increasing trend** in the **standby MDP frequency of run ≤ 1H hours** estimates, which is statistically significant with a p-value of 0.0133 (see Figure 10). This is a new trend that was not observed in the *2018 MDP Update* study
- **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). This is a new trend that was not observed in the *2018 MDP Update* study
- **Decreasing trend** in the **standby MDP frequency of FTR≤1H events** estimates, which is statistically significant with a p-value of 0.0336 (see Figure 13). This is a new trend that was not observed in the *2018 MDP Update* study.

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.

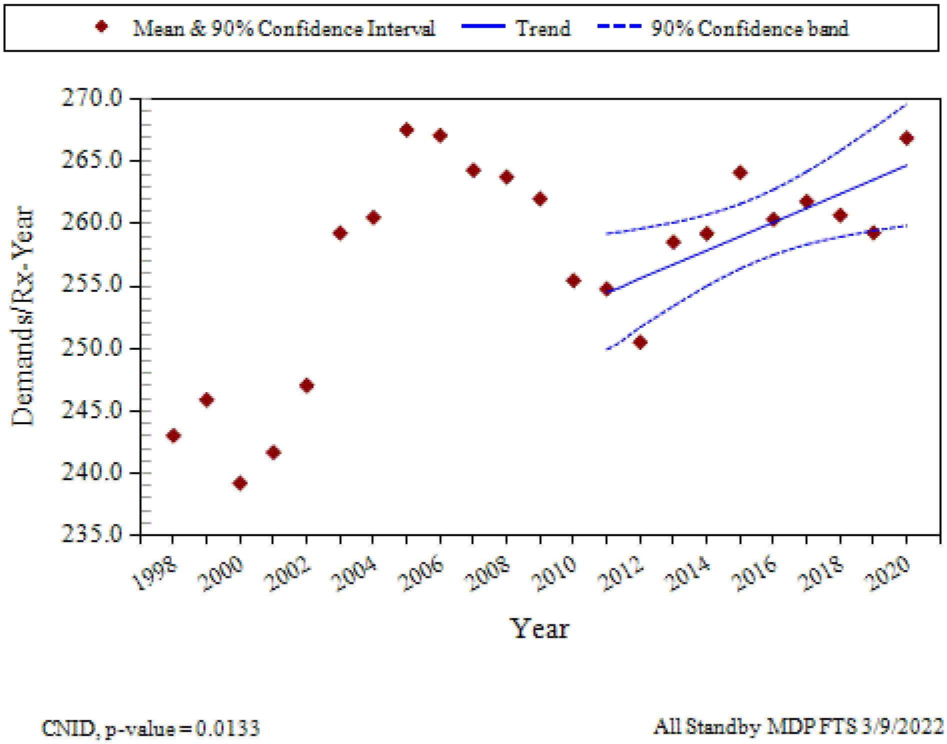


Figure 9. Frequency of start demands (demands per reactor year) trend for standby MDPs.

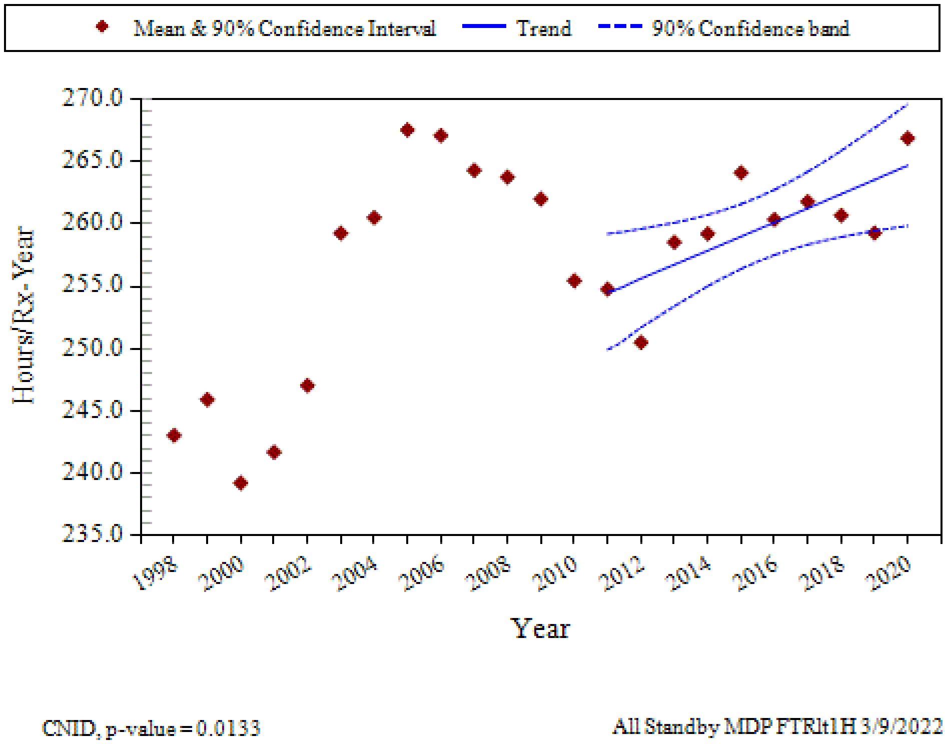


Figure 10. Frequency of run ≤ 1H hours (hours per reactor year) trend for standby MDPs.

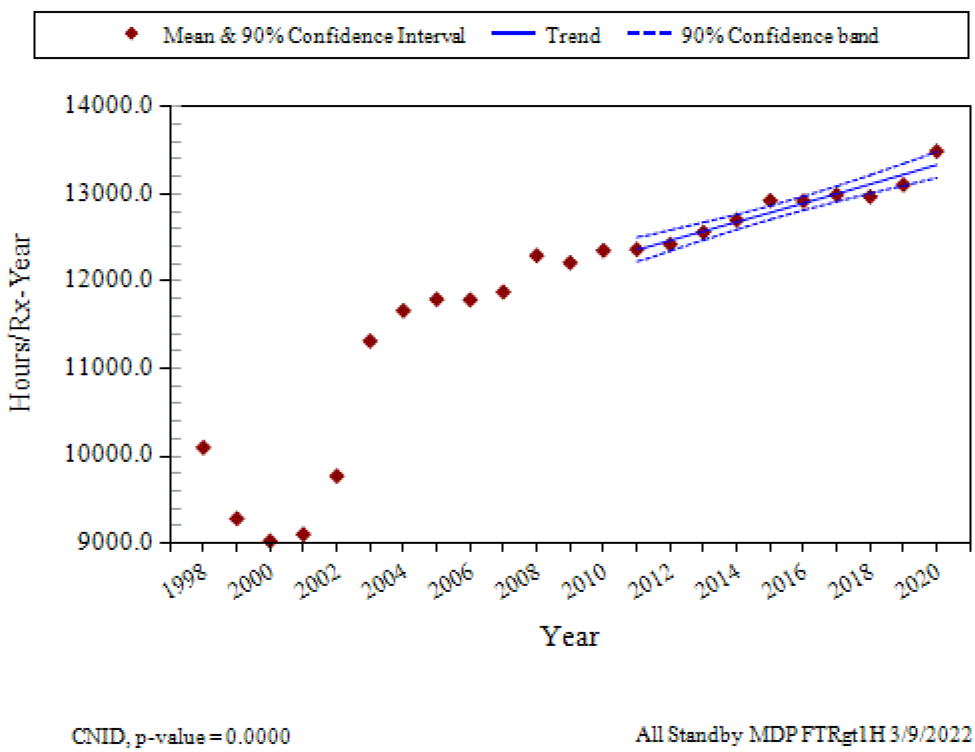


Figure 11. Frequency of run > 1H hours (hours per reactor year) trend for standby MDPs.

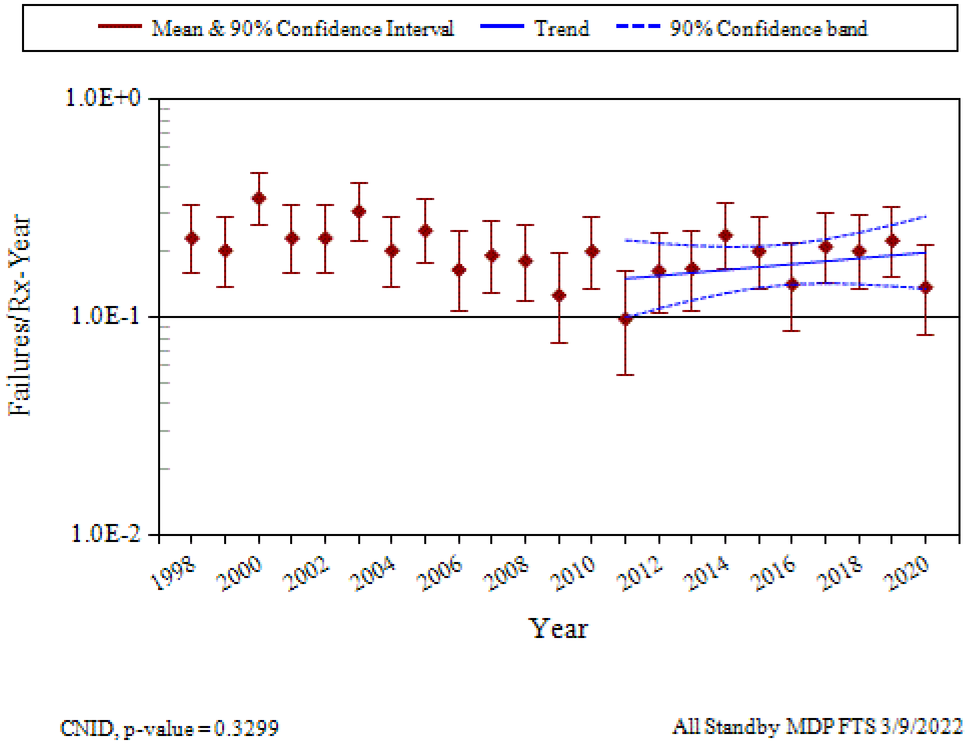


Figure 12. Frequency of FTS events (events per reactor year) trend for standby MDPs.

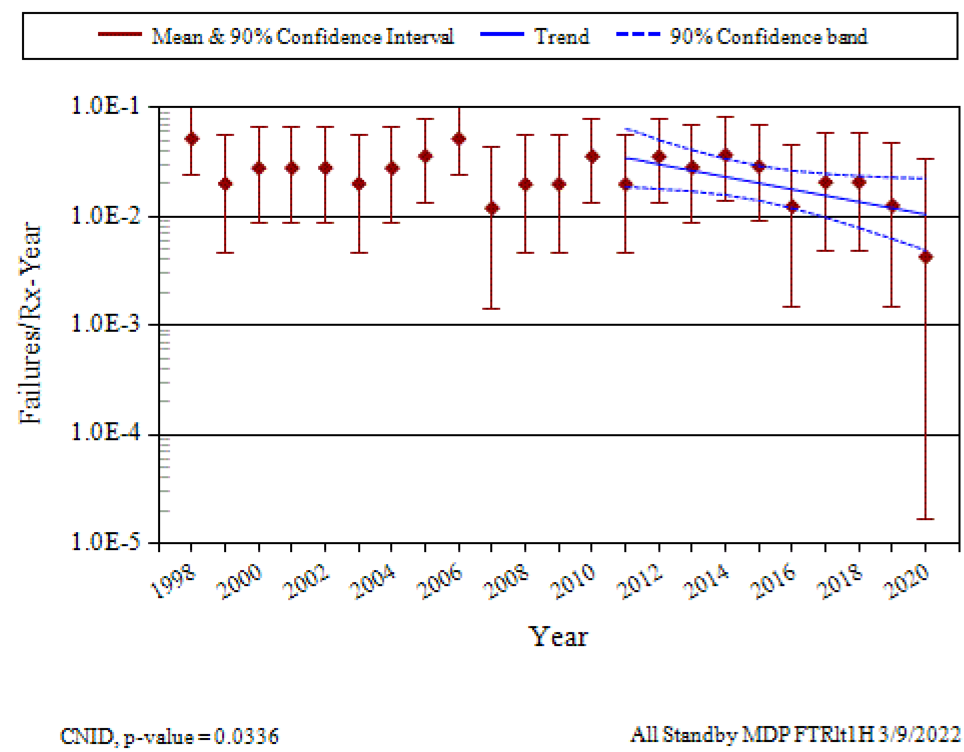


Figure 13. Frequency of FTR≤1H events (events per reactor year) trend for standby MDPs.

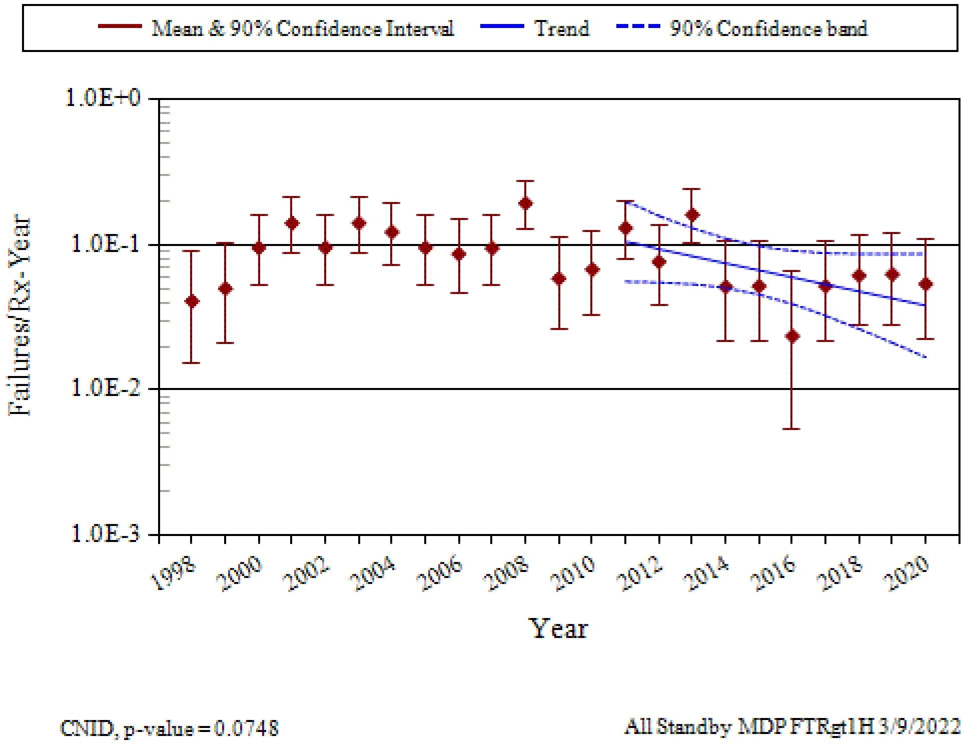


Figure 14. Frequency of FTR>1H events (events per reactor year) trend for standby MDPs.

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

| System | MDP Count | MDP Percent | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Total | Percent of Failures |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AFW | 130 | 9.9% | 3 | 4 | 1 | 2 | 4 | 1 | 2 | 1 | 1 | 1 | 20 | 11.2% |
| CRD | 9 | 0.7% | | | | | | | | | | | 0 | 0.0% |
| CSR | 159 | 12.1% | | | 1 | 1 | 3 | | 3 | 1 | 2 | | 11 | 6.2% |
| HPCS | 9 | 0.7% | | | | | | | | 1 | 1 | | 2 | 1.1% |
| HPSI | 175 | 13.4% | 2 | 2 | 3 | 2 | 1 | 1 | 4 | 1 | 4 | 4 | 24 | 13.5% |
| LPCS | 74 | 5.6% | | | | 2 | 1 | 2 | 1 | 1 | | | 7 | 3.9% |
| RHR | 295 | 22.5% | 1 | 3 | 1 | 1 | 6 | 4 | 3 | 6 | 5 | | 30 | 16.9% |
| SWS | 459 | 35.0% | 4 | 8 | 11 | 16 | 5 | 6 | 8 | 9 | 9 | 8 | 84 | 47.2% |
| Total | 1310 | 100% | 10 | 17 | 17 | 24 | 20 | 14 | 21 | 20 | 22 | 13 | 178 | 100% |

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

| System | MDP Count | MDP Percent | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Total | Percent of Failures |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AFW | 130 | 9.9% | | | 2 | | | | | | | | 2 | 9.1% |
| CRD | 9 | 0.7% | | | | | | | | | | | 0 | 0.0% |
| CSR | 159 | 12.1% | | 1 | | | | | | | | | 1 | 4.5% |
| HPCS | 9 | 0.7% | | | | | | | | | | | 0 | 0.0% |
| HPSI | 175 | 13.4% | | | | | | | | | | | 0 | 0.0% |

| System | MDP Count | MDP Percent | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Total | Percent of Failures |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LPCS | 74 | 5.6% | | | | | 1 | | 1 | | | | 2 | 9.1% |
| RHR | 295 | 22.5% | | 2 | | 2 | | | | | | | 4 | 18.2% |
| SWS | 459 | 35.0% | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 1 | | 13 | 59.1% |
| Total | 1310 | 100.0% | 2 | 4 | 3 | 4 | 3 | 1 | 2 | 2 | 1 | 0 | 22 | 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 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Total | Percent of Failures |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AFW | 130 | 9.9% | | | 3 | | 2 | 1 | | 1 | | | 7 | 9.6% |
| CRD | 9 | 0.7% | | | | | | | | | | | 0 | 0.0% |
| CSR | 159 | 12.1% | 1 | | 2 | | | | | | | | 3 | 4.1% |
| HPCS | 9 | 0.7% | | | | | | | | | | | 0 | 0.0% |
| HPSI | 175 | 13.4% | 1 | | 2 | 2 | | | 2 | 1 | | 1 | 9 | 12.3% |
| LPCS | 74 | 5.6% | | | | | | | | | | | 0 | 0.0% |
| RHR | 295 | 22.5% | 2 | 3 | 3 | | 2 | 1 | | 1 | 1 | 1 | 14 | 19.2% |
| SWS | 459 | 35.0% | 10 | 5 | 7 | 3 | 1 | | 3 | 3 | 5 | 3 | 40 | 54.8% |
| Total | 1310 | 100.0% | 14 | 8 | 17 | 5 | 5 | 2 | 5 | 6 | 6 | 5 | 73 | 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. 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 *2018 MDP Update* study [2]
- **Decreasing trend** in the **normally running MDP frequency of FTR events** (events per reactor year) estimates, which is statistically significant with a p-value of 0.0133 (see Figure 18). The same trend was observed in the *2018 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.

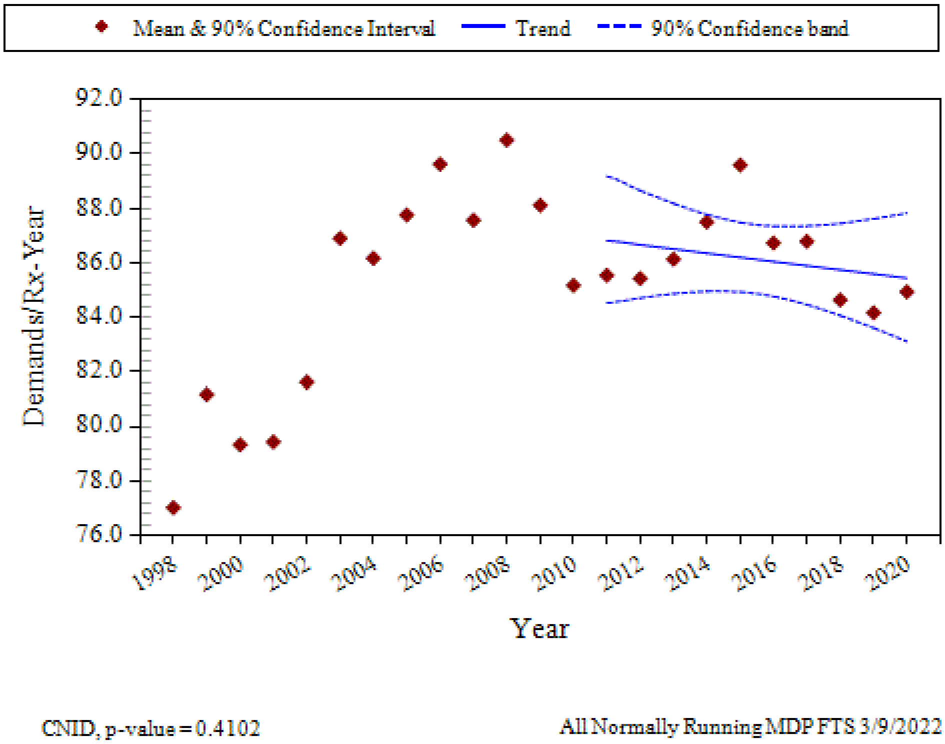


Figure 15. Frequency of start demands (demands per reactor year) trend for normally running MDPs.

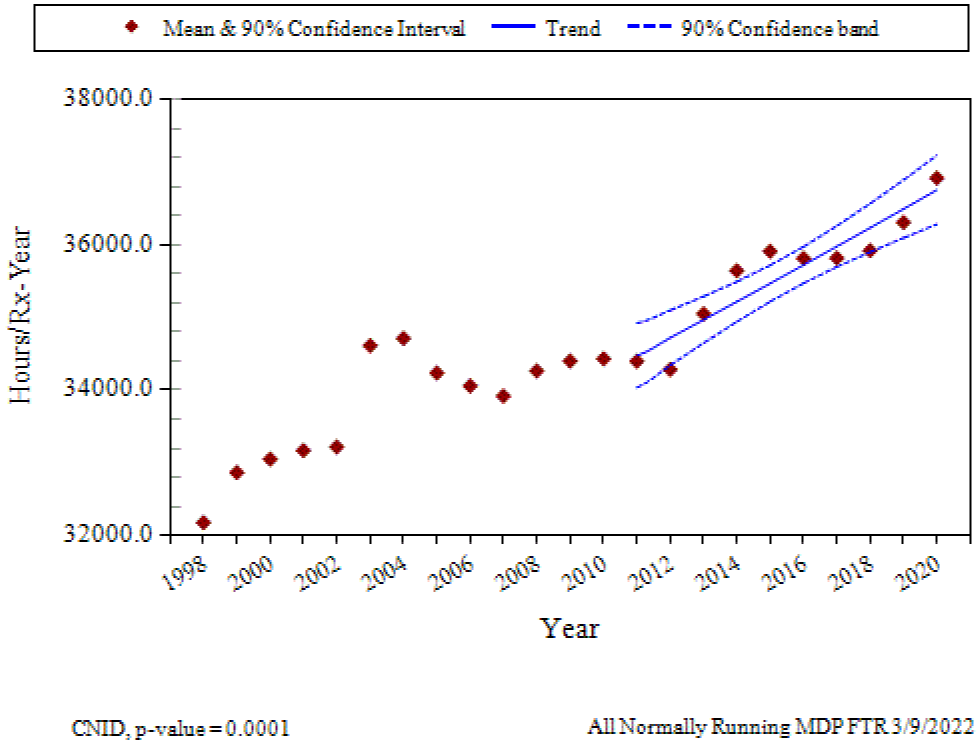


Figure 16. Frequency of run hours (hours per reactor year) trend for normally running MDPs.

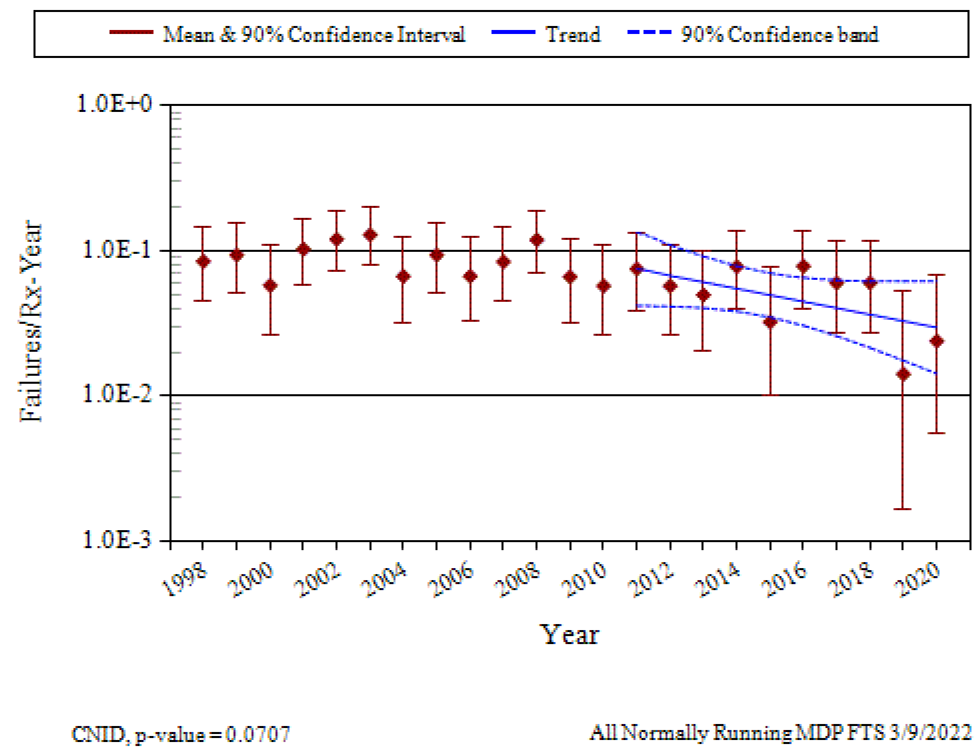


Figure 17. Frequency of FTS events (events per reactor year) trend for normally running MDPs.

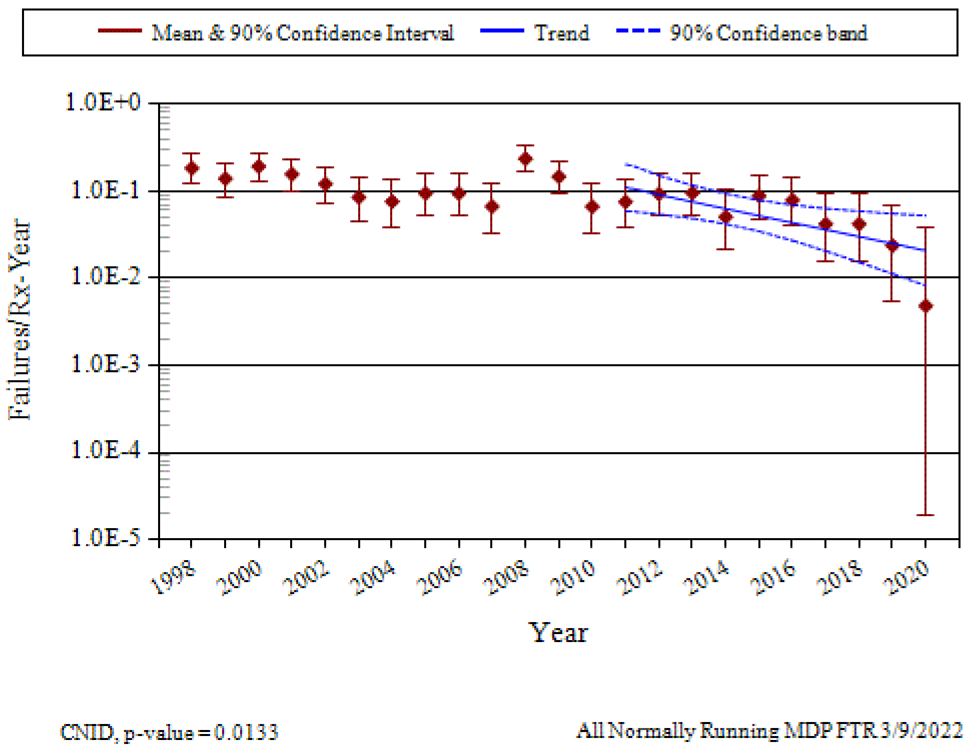


Figure 18. Frequency of FTR events (events per reactor year) trend for normally running MDPs.

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

| System Code | MDP Count | MDP Percent | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Total | Percent of Failures |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CCW | 303 | 46.7% | 5 | 1 | | 5 | | 1 | 1 | | | | 13 | 24.5% |
| CDS | 143 | 22.0% | | 2 | 1 | 1 | | 3 | 1 | 1 | | 1 | 10 | 18.9% |
| CRD | 43 | 6.6% | 1 | | | 1 | | | | | | 1 | 3 | 5.7% |
| CVC | 8 | 1.2% | | | | 1 | 1 | 1 | | | | | 3 | 5.7% |
| LPCS | 2 | 0.3% | | | | | | | | | | | 0 | 0.0% |
| MFW | 44 | 6.8% | 2 | 1 | 2 | | 1 | 1 | | | | | 7 | 13.2% |
| SWN | 106 | 16.3% | | 2 | 2 | | 1 | 2 | 4 | 5 | 1 | | 17 | 32.1% |
| Total | 649 | 100.0% | 8 | 6 | 5 | 8 | 3 | 8 | 6 | 6 | 1 | 2 | 53 | 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 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Total | Percent of Failures |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CCW | 303 | 46.7% | 1 | 2 | 5 | | 4 | 2 | 1 | 1 | 1 | | 17 | 28.3% |
| CDS | 143 | 22.0% | | 1 | 1 | 2 | 1 | 1 | 2 | 1 | | | 9 | 15.0% |
| CRD | 43 | 6.6% | 2 | 4 | | | | | 1 | 1 | | | 8 | 13.3% |
| CVC | 8 | 1.2% | | | | | | | | | | | 0 | 0.0% |

| System Code | MDP Count | MDP Percent | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Total | Percent of Failures |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LPCS | 2 | 0.3% | | | | | | | | | | | 0 | 0.0% |
| MFW | 44 | 6.8% | | 1 | 3 | 1 | 1 | 1 | | | | | 7 | 11.7% |
| SWN | 106 | 16.3% | 5 | 2 | 1 | 2 | 3 | 4 | | 1 | 1 | | 19 | 31.7% |
| Total | 649 | 100.0% | 8 | 10 | 10 | 5 | 9 | 8 | 4 | 4 | 2 | 0 | 60 | 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 actual 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 ESF demand and 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 2020 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 | 1611 | 0 | 1.0 | 1.00 | Yes [b] |
| FTR<1H | 107 | 1326 | 0 | 0.1 | 1.00 | Yes [c] |
| FTR>1H | 107 | 31220 | 1 | 0.3 | 0.18 | 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≤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≤1H, FTR>1H or FTR). The pump subcomponent 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 are similar to those used in the CCF database. Table 10 shows the breakdown of the cause groups with the specific causes that were coded during the data collection. The most likely causes are **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. A failure can be detected during inspection, testing, post maintenance testing (PMT), non-test demand, or engineered safety feature (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** 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 seven of every eight 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. |

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

| Group | Specific Cause | Description |
|---|---|---|
| | 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 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. |

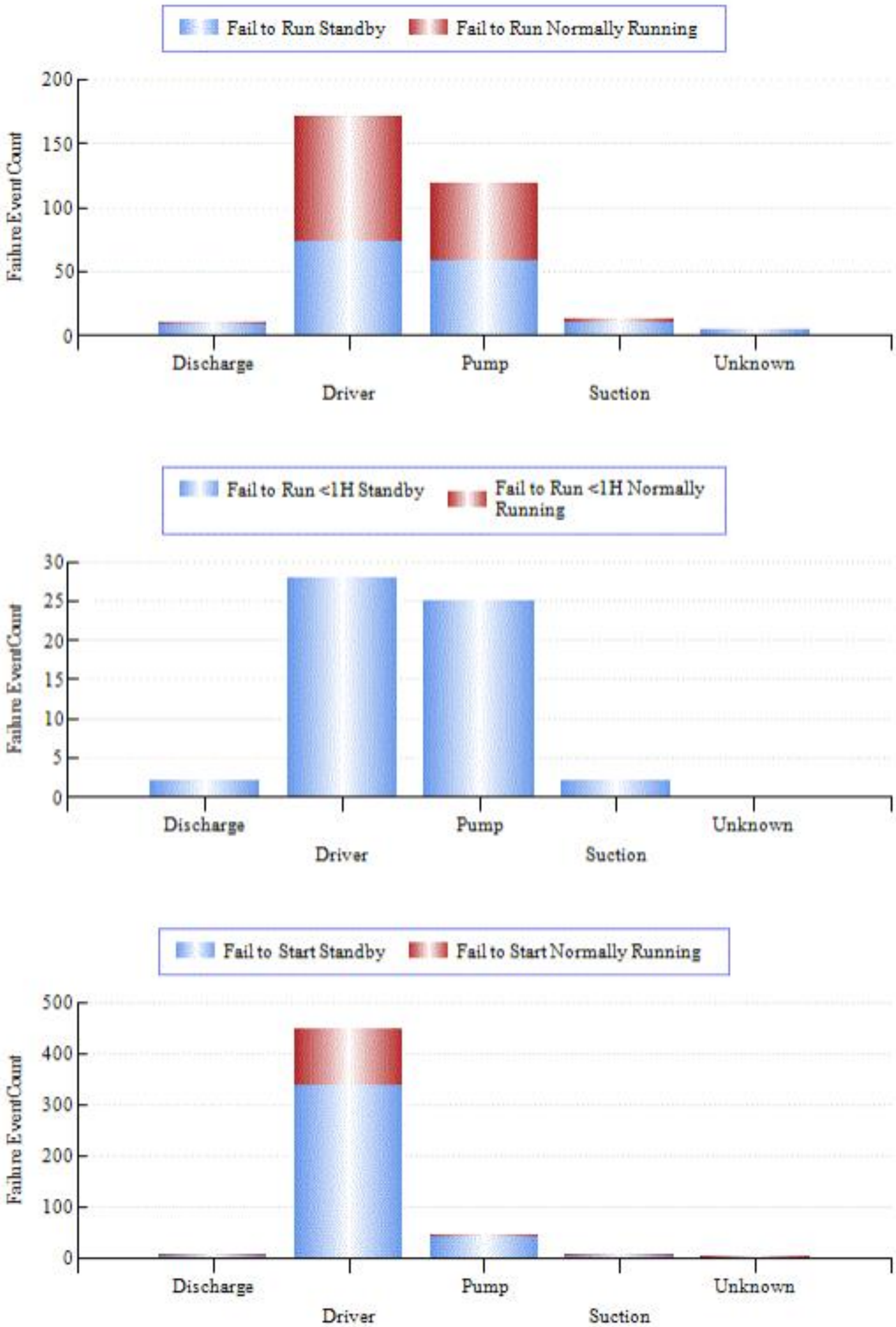


Figure 19. MDP failure breakdown by failure mode and subcomponent.

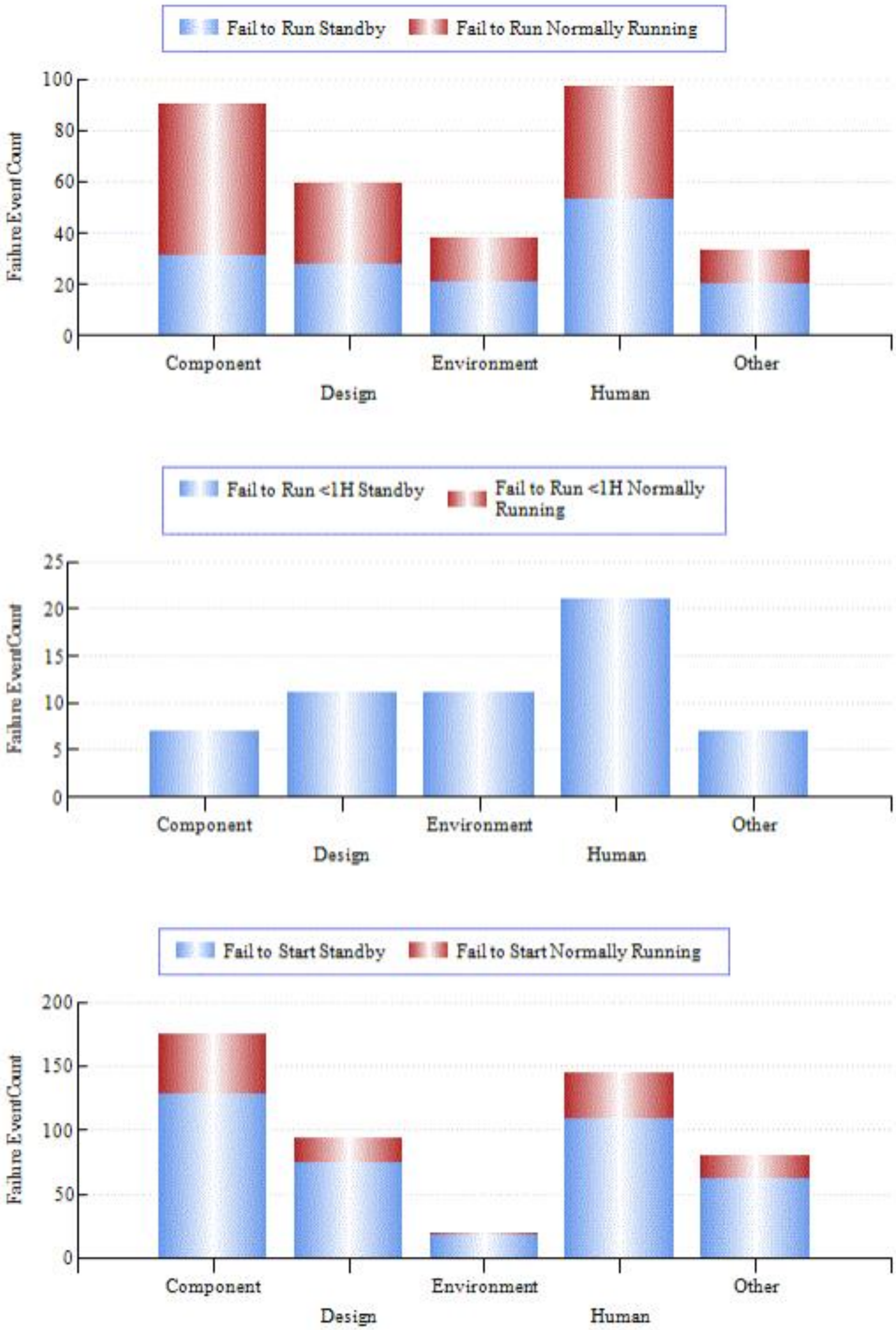


Figure 20. MDP failure breakdown by failure mode and cause group.

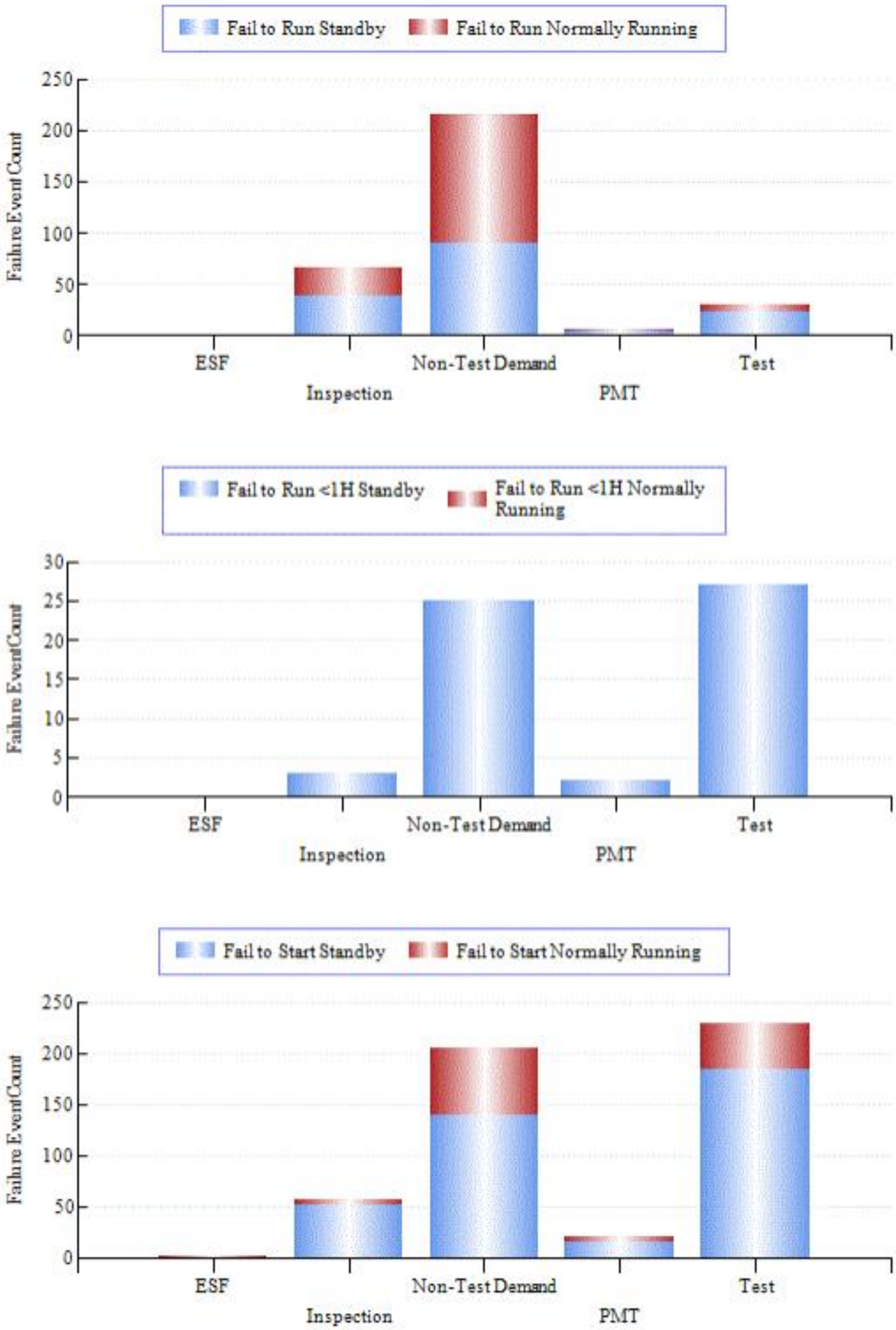


Figure 21. MDP failure breakdown by failure mode and method of detection.

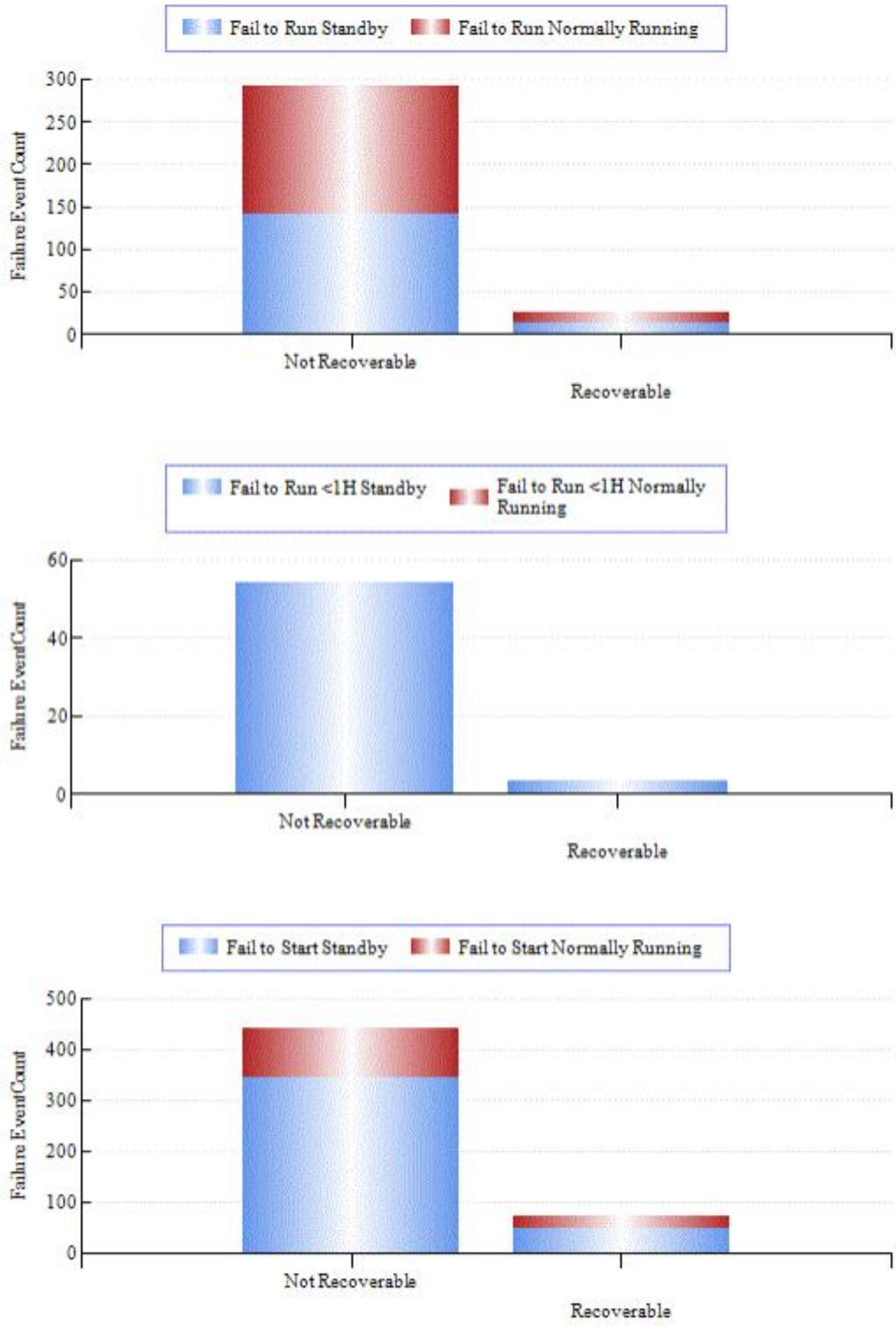


Figure 22. MDP failure breakdown by failure mode and recovery possibility.

# 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≤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≤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≤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 |
| SPAR 2020 | | -- | -- | -- | -- | 1.09E-04 | 1.38E-03 | 5.88E-04 |
| 1998 | 24 | 25,032 | -- | -- | -- | 6.61E-04 | 1.29E-03 | 9.54E-04 |
| 1999 | 21 | 25,328 | -- | -- | -- | 5.58E-04 | 1.14E-03 | 8.28E-04 |
| 2000 | 37 | 24,706 | -- | -- | -- | 1.10E-03 | 1.90E-03 | 1.48E-03 |
| 2001 | 24 | 24,893 | -- | -- | -- | 6.64E-04 | 1.30E-03 | 9.59E-04 |
| 2002 | 24 | 25,444 | -- | -- | -- | 6.50E-04 | 1.27E-03 | 9.39E-04 |
| 2003 | 32 | 26,705 | -- | -- | -- | 8.67E-04 | 1.55E-03 | 1.19E-03 |
| 2004 | 21 | 26,907 | -- | -- | -- | 5.26E-04 | 1.08E-03 | 7.80E-04 |
| 2005 | 26 | 27,560 | -- | -- | -- | 6.61E-04 | 1.26E-03 | 9.39E-04 |
| 2006 | 17 | 27,514 | -- | -- | -- | 3.99E-04 | 8.84E-04 | 6.21E-04 |
| 2007 | 20 | 27,388 | -- | -- | -- | 4.87E-04 | 1.02E-03 | 7.31E-04 |
| 2008 | 19 | 27,509 | -- | -- | -- | 4.56E-04 | 9.69E-04 | 6.93E-04 |
| 2009 | 13 | 27,250 | -- | -- | -- | 2.90E-04 | 7.19E-04 | 4.84E-04 |
| 2010 | 21 | 26,567 | -- | -- | -- | 5.32E-04 | 1.09E-03 | 7.90E-04 |
| 2011 | 10 | 26,496 | 5.94E-04 | 3.95E-04 | 8.94E-04 | 2.14E-04 | 6.02E-04 | 3.87E-04 |
| 2012 | 17 | 26,125 | 6.10E-04 | 4.31E-04 | 8.63E-04 | 4.20E-04 | 9.30E-04 | 6.54E-04 |
| 2013 | 17 | 26,261 | 6.26E-04 | 4.67E-04 | 8.38E-04 | 4.17E-04 | 9.25E-04 | 6.50E-04 |
| 2014 | 24 | 25,923 | 6.42E-04 | 5.01E-04 | 8.22E-04 | 6.38E-04 | 1.25E-03 | 9.22E-04 |
| 2015 | 20 | 26,150 | 6.59E-04 | 5.29E-04 | 8.20E-04 | 5.10E-04 | 1.06E-03 | 7.65E-04 |
| 2016 | 14 | 25,834 | 6.76E-04 | 5.45E-04 | 8.37E-04 | 3.34E-04 | 8.04E-04 | 5.48E-04 |
| 2017 | 21 | 25,919 | 6.93E-04 | 5.49E-04 | 8.76E-04 | 5.45E-04 | 1.12E-03 | 8.09E-04 |
| 2018 | 20 | 25,744 | 7.12E-04 | 5.41E-04 | 9.35E-04 | 5.18E-04 | 1.08E-03 | 7.77E-04 |
| 2019 | 22 | 25,150 | 7.30E-04 | 5.27E-04 | 1.01E-03 | 5.93E-04 | 1.19E-03 | 8.72E-04 |
| 2020 | 13 | 25,447 | 7.49E-04 | 5.10E-04 | 1.10E-03 | 3.10E-04 | 7.69E-04 | 5.17E-04 |
| Total | 477 | 601,853 | -- | -- | -- | -- | -- | -- |

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 | 25,032 | -- | -- | -- | 9.90E-05 | 3.76E-04 | 2.18E-04 |
| 1999 | 2 | 25,328 | -- | -- | -- | 1.90E-05 | 1.84E-04 | 8.31E-05 |
| 2000 | 3 | 24,706 | -- | -- | -- | 3.68E-05 | 2.39E-04 | 1.19E-04 |
| 2001 | 3 | 24,893 | -- | -- | -- | 3.66E-05 | 2.37E-04 | 1.18E-04 |
| 2002 | 3 | 25,444 | -- | -- | -- | 3.59E-05 | 2.33E-04 | 1.16E-04 |
| 2003 | 2 | 26,705 | -- | -- | -- | 1.82E-05 | 1.76E-04 | 7.95E-05 |
| 2004 | 3 | 26,907 | -- | -- | -- | 3.42E-05 | 2.22E-04 | 1.11E-04 |
| 2005 | 4 | 27,560 | -- | -- | -- | 5.15E-05 | 2.62E-04 | 1.39E-04 |
| 2006 | 6 | 27,514 | -- | -- | -- | 9.13E-05 | 3.47E-04 | 2.02E-04 |
| 2007 | 1 | 27,388 | -- | -- | -- | 5.48E-06 | 1.22E-04 | 4.67E-05 |
| 2008 | 2 | 27,509 | -- | -- | -- | 1.78E-05 | 1.72E-04 | 7.75E-05 |
| 2009 | 2 | 27,250 | -- | -- | -- | 1.79E-05 | 1.73E-04 | 7.82E-05 |
| 2010 | 4 | 26,567 | -- | -- | -- | 5.31E-05 | 2.70E-04 | 1.44E-04 |
| 2011 | 2 | 26,496 | 1.35E-04 | 7.26E-05 | 2.49E-04 | 1.83E-05 | 1.77E-04 | 8.00E-05 |
| 2012 | 4 | 26,125 | 1.17E-04 | 6.99E-05 | 1.97E-04 | 5.39E-05 | 2.74E-04 | 1.46E-04 |
| 2013 | 3 | 26,261 | 1.03E-04 | 6.62E-05 | 1.59E-04 | 3.50E-05 | 2.27E-04 | 1.13E-04 |
| 2014 | 4 | 25,923 | 8.95E-05 | 6.10E-05 | 1.31E-04 | 5.42E-05 | 2.76E-04 | 1.47E-04 |
| 2015 | 3 | 26,150 | 7.81E-05 | 5.40E-05 | 1.13E-04 | 3.51E-05 | 2.28E-04 | 1.13E-04 |
| 2016 | 1 | 25,834 | 6.82E-05 | 4.58E-05 | 1.02E-04 | 5.75E-06 | 1.28E-04 | 4.91E-05 |
| 2017 | 2 | 25,919 | 5.95E-05 | 3.75E-05 | 9.46E-05 | 1.87E-05 | 1.81E-04 | 8.15E-05 |
| 2018 | 2 | 25,744 | 5.20E-05 | 3.00E-05 | 9.01E-05 | 1.88E-05 | 1.82E-04 | 8.20E-05 |
| 2019 | 1 | 25,150 | 4.54E-05 | 2.36E-05 | 8.71E-05 | 5.89E-06 | 1.31E-04 | 5.02E-05 |
| 2020 | 0 | 25,447 | 3.96E-05 | 1.85E-05 | 8.49E-05 | 6.51E-08 | 6.36E-05 | 1.66E-05 |
| Total | 63 | 601,853 | -- | -- | -- | -- | -- | -- |

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 | 1,039,948 | -- | -- | -- | 1.50E-06 | 7.65E-06 | 4.07E-06 |
| 1999 | 5 | 956,050 | -- | -- | -- | 2.24E-06 | 9.62E-06 | 5.38E-06 |
| 2000 | 10 | 931,921 | -- | -- | -- | 5.81E-06 | 1.64E-05 | 1.05E-05 |
| 2001 | 15 | 937,369 | -- | -- | -- | 9.61E-06 | 2.24E-05 | 1.54E-05 |
| 2002 | 10 | 1,006,349 | -- | -- | -- | 5.40E-06 | 1.52E-05 | 9.79E-06 |
| 2003 | 15 | 1,165,347 | -- | -- | -- | 7.83E-06 | 1.83E-05 | 1.26E-05 |
| 2004 | 13 | 1,204,408 | -- | -- | -- | 6.36E-06 | 1.58E-05 | 1.06E-05 |
| 2005 | 10 | 1,214,508 | -- | -- | -- | 4.53E-06 | 1.28E-05 | 8.20E-06 |
| 2006 | 9 | 1,213,946 | -- | -- | -- | 3.95E-06 | 1.18E-05 | 7.42E-06 |
| 2007 | 10 | 1,230,509 | -- | -- | -- | 4.47E-06 | 1.26E-05 | 8.10E-06 |
| 2008 | 21 | 1,282,025 | -- | -- | -- | 1.07E-05 | 2.20E-05 | 1.59E-05 |
| 2009 | 6 | 1,270,031 | -- | -- | -- | 2.20E-06 | 8.37E-06 | 4.86E-06 |
| 2010 | 7 | 1,284,544 | -- | -- | -- | 2.69E-06 | 9.25E-06 | 5.55E-06 |
| 2011 | 14 | 1,285,895 | 8.44E-06 | 4.49E-06 | 1.59E-05 | 6.55E-06 | 1.57E-05 | 1.07E-05 |
| 2012 | 8 | 1,295,516 | 7.49E-06 | 4.41E-06 | 1.27E-05 | 3.18E-06 | 1.01E-05 | 6.24E-06 |
| 2013 | 17 | 1,275,755 | 6.64E-06 | 4.25E-06 | 1.04E-05 | 8.37E-06 | 1.86E-05 | 1.30E-05 |
| 2014 | 5 | 1,270,079 | 5.89E-06 | 3.97E-06 | 8.75E-06 | 1.71E-06 | 7.36E-06 | 4.12E-06 |
| 2015 | 5 | 1,279,529 | 5.23E-06 | 3.55E-06 | 7.70E-06 | 1.70E-06 | 7.31E-06 | 4.09E-06 |
| 2016 | 2 | 1,281,806 | 4.64E-06 | 3.03E-06 | 7.10E-06 | 4.25E-07 | 4.11E-06 | 1.85E-06 |
| 2017 | 5 | 1,286,127 | 4.12E-06 | 2.50E-06 | 6.78E-06 | 1.69E-06 | 7.28E-06 | 4.07E-06 |
| 2018 | 6 | 1,280,708 | 3.65E-06 | 2.01E-06 | 6.63E-06 | 2.19E-06 | 8.30E-06 | 4.83E-06 |
| 2019 | 6 | 1,271,180 | 3.24E-06 | 1.60E-06 | 6.57E-06 | 2.20E-06 | 8.36E-06 | 4.86E-06 |
| 2020 | 5 | 1,286,103 | 2.88E-06 | 1.26E-06 | 6.55E-06 | 1.69E-06 | 7.28E-06 | 4.07E-06 |
| Total | 208 | 27,549,654 | -- | -- | -- | -- | -- | -- |

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 | 7,933 | -- | -- | -- | 5.95E-04 | 1.77E-03 | 1.12E-03 |
| 1999 | 10 | 8,361 | -- | -- | -- | 6.48E-04 | 1.83E-03 | 1.17E-03 |
| 2000 | 6 | 8,194 | -- | -- | -- | 3.36E-04 | 1.27E-03 | 7.41E-04 |
| 2001 | 11 | 8,182 | -- | -- | -- | 7.47E-04 | 2.01E-03 | 1.31E-03 |
| 2002 | 13 | 8,407 | -- | -- | -- | 8.99E-04 | 2.23E-03 | 1.50E-03 |
| 2003 | 14 | 8,951 | -- | -- | -- | 9.29E-04 | 2.23E-03 | 1.52E-03 |
| 2004 | 7 | 8,900 | -- | -- | -- | 3.83E-04 | 1.32E-03 | 7.91E-04 |
| 2005 | 10 | 9,039 | -- | -- | -- | 6.03E-04 | 1.70E-03 | 1.09E-03 |
| 2006 | 7 | 9,232 | -- | -- | -- | 3.70E-04 | 1.27E-03 | 7.65E-04 |
| 2007 | 9 | 9,073 | -- | -- | -- | 5.24E-04 | 1.56E-03 | 9.84E-04 |
| 2008 | 13 | 9,439 | -- | -- | -- | 8.06E-04 | 2.00E-03 | 1.35E-03 |
| 2009 | 7 | 9,164 | -- | -- | -- | 3.73E-04 | 1.28E-03 | 7.70E-04 |
| 2010 | 6 | 8,858 | -- | -- | -- | 3.12E-04 | 1.19E-03 | 6.89E-04 |
| 2011 | 8 | 8,897 | 8.60E-04 | 4.85E-04 | 1.53E-03 | 4.58E-04 | 1.46E-03 | 8.97E-04 |
| 2012 | 6 | 8,909 | 7.77E-04 | 4.81E-04 | 1.26E-03 | 3.11E-04 | 1.18E-03 | 6.85E-04 |
| 2013 | 5 | 8,748 | 7.03E-04 | 4.69E-04 | 1.05E-03 | 2.45E-04 | 1.06E-03 | 5.90E-04 |
| 2014 | 8 | 8,750 | 6.35E-04 | 4.45E-04 | 9.08E-04 | 4.65E-04 | 1.48E-03 | 9.11E-04 |
| 2015 | 3 | 8,870 | 5.74E-04 | 4.05E-04 | 8.14E-04 | 1.15E-04 | 7.45E-04 | 3.71E-04 |
| 2016 | 8 | 8,605 | 5.19E-04 | 3.55E-04 | 7.60E-04 | 4.72E-04 | 1.50E-03 | 9.26E-04 |
| 2017 | 6 | 8,592 | 4.69E-04 | 3.00E-04 | 7.34E-04 | 3.21E-04 | 1.22E-03 | 7.09E-04 |
| 2018 | 6 | 8,358 | 4.24E-04 | 2.49E-04 | 7.24E-04 | 3.30E-04 | 1.25E-03 | 7.28E-04 |
| 2019 | 1 | 8,163 | 3.84E-04 | 2.04E-04 | 7.23E-04 | 2.01E-05 | 4.47E-04 | 1.72E-04 |
| 2020 | 2 | 8,098 | 3.47E-04 | 1.66E-04 | 7.27E-04 | 6.60E-05 | 6.38E-04 | 2.88E-04 |
| Total | 175 | 199,727 | -- | -- | -- | -- | -- | -- |

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 | 3,314,069 | -- | -- | -- | 3.92E-06 | 8.17E-06 | 5.89E-06 |
| 1999 | 15 | 3,385,035 | -- | -- | -- | 2.71E-06 | 6.33E-06 | 4.36E-06 |
| 2000 | 21 | 3,413,378 | -- | -- | -- | 4.04E-06 | 8.28E-06 | 6.00E-06 |
| 2001 | 17 | 3,416,384 | -- | -- | -- | 3.13E-06 | 6.95E-06 | 4.88E-06 |
| 2002 | 13 | 3,421,554 | -- | -- | -- | 2.25E-06 | 5.59E-06 | 3.76E-06 |
| 2003 | 9 | 3,565,088 | -- | -- | -- | 1.35E-06 | 4.04E-06 | 2.54E-06 |
| 2004 | 8 | 3,585,229 | -- | -- | -- | 1.15E-06 | 3.67E-06 | 2.26E-06 |
| 2005 | 10 | 3,526,234 | -- | -- | -- | 1.57E-06 | 4.42E-06 | 2.84E-06 |
| 2006 | 10 | 3,507,953 | -- | -- | -- | 1.58E-06 | 4.44E-06 | 2.86E-06 |
| 2007 | 7 | 3,514,380 | -- | -- | -- | 9.86E-07 | 3.39E-06 | 2.04E-06 |
| 2008 | 26 | 3,573,390 | -- | -- | -- | 4.98E-06 | 9.49E-06 | 7.08E-06 |
| 2009 | 16 | 3,577,643 | -- | -- | -- | 2.78E-06 | 6.33E-06 | 4.40E-06 |
| 2010 | 7 | 3,580,909 | -- | -- | -- | 9.68E-07 | 3.33E-06 | 2.00E-06 |
| 2011 | 8 | 3,577,300 | 3.17E-06 | 1.71E-06 | 5.88E-06 | 1.16E-06 | 3.68E-06 | 2.27E-06 |
| 2012 | 10 | 3,575,450 | 2.62E-06 | 1.56E-06 | 4.38E-06 | 1.55E-06 | 4.36E-06 | 2.80E-06 |
| 2013 | 10 | 3,560,183 | 2.16E-06 | 1.40E-06 | 3.35E-06 | 1.55E-06 | 4.38E-06 | 2.82E-06 |
| 2014 | 5 | 3,564,608 | 1.79E-06 | 1.20E-06 | 2.66E-06 | 6.13E-07 | 2.63E-06 | 1.47E-06 |
| 2015 | 9 | 3,555,386 | 1.47E-06 | 9.77E-07 | 2.23E-06 | 1.36E-06 | 4.05E-06 | 2.55E-06 |
| 2016 | 8 | 3,553,732 | 1.22E-06 | 7.60E-07 | 1.95E-06 | 1.16E-06 | 3.71E-06 | 2.28E-06 |
| 2017 | 4 | 3,546,182 | 1.01E-06 | 5.72E-07 | 1.77E-06 | 4.48E-07 | 2.28E-06 | 1.21E-06 |
| 2018 | 4 | 3,547,270 | 8.31E-07 | 4.23E-07 | 1.63E-06 | 4.47E-07 | 2.28E-06 | 1.21E-06 |
| 2019 | 2 | 3,521,928 | 6.86E-07 | 3.09E-07 | 1.52E-06 | 1.55E-07 | 1.50E-06 | 6.77E-07 |
| 2020 | 0 | 3,520,085 | 5.66E-07 | 2.24E-07 | 1.43E-06 | 5.33E-10 | 5.21E-07 | 1.36E-07 |
| Total | 239 | 80,903,370 | -- | -- | -- | -- | -- | -- |

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 | 4.39E-03 | 3.87E-03 | 4.91E-03 | 4.27E-04 | 1.15E-02 | 4.29E-03 |
| 2012 | 18,465 | 4,177,351 | 4.25E-03 | 3.85E-03 | 4.66E-03 | 4.06E-04 | 1.12E-02 | 4.15E-03 |
| 2013 | 18,987 | 4,225,814 | 4.12E-03 | 3.83E-03 | 4.41E-03 | 2.57E-04 | 1.21E-02 | 4.17E-03 |
| 2014 | 18,473 | 4,271,783 | 3.99E-03 | 3.81E-03 | 4.16E-03 | 3.08E-04 | 1.20E-02 | 4.22E-03 |
| 2015 | 16,379 | 4,245,641 | 3.85E-03 | 3.79E-03 | 3.91E-03 | 3.48E-04 | 1.06E-02 | 3.86E-03 |
| 2016 | 14,590 | 4,247,600 | 3.72E-03 | 3.66E-03 | 3.77E-03 | 3.55E-04 | 9.36E-03 | 3.50E-03 |
| 2017 | 15,265 | 4,168,826 | 3.58E-03 | 3.41E-03 | 3.75E-03 | 1.16E-04 | 1.21E-02 | 3.79E-03 |
| 2018 | 14,645 | 4,169,042 | 3.45E-03 | 3.16E-03 | 3.73E-03 | 2.01E-04 | 1.06E-02 | 3.60E-03 |
| 2019 | 13,313 | 4,159,098 | 3.31E-03 | 2.91E-03 | 3.71E-03 | 1.84E-04 | 9.46E-03 | 3.21E-03 |
| 2020 | 12,125 | 4,054,351 | 3.18E-03 | 2.66E-03 | 3.70E-03 | 1.14E-04 | 9.52E-03 | 3.05E-03 |
| Total | 379,787 | 91,647,030 | -- | -- | -- | -- | -- | -- |

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 | -- | -- | -- | 1.53E-03 | 1.29E-02 | 5.41E-03 |
| 1999 | -- | -- | -- | 1.29E-03 | 1.40E-02 | 5.29E-03 |
| 2000 | -- | -- | -- | 2.07E-03 | 1.44E-02 | 6.55E-03 |
| 2001 | -- | -- | -- | 1.69E-03 | 1.53E-02 | 6.42E-03 |
| 2002 | -- | -- | -- | 2.07E-03 | 1.21E-02 | 6.00E-03 |
| 2003 | -- | -- | -- | 2.36E-03 | 1.25E-02 | 6.30E-03 |
| 2004 | -- | -- | -- | 1.41E-03 | 1.54E-02 | 5.99E-03 |
| 2005 | -- | -- | -- | 1.60E-03 | 1.44E-02 | 5.92E-03 |
| 2006 | -- | -- | -- | 1.49E-03 | 1.26E-02 | 5.33E-03 |
| 2007 | -- | -- | -- | 1.41E-03 | 1.30E-02 | 5.56E-03 |
| 2008 | -- | -- | -- | 1.35E-03 | 1.33E-02 | 5.61E-03 |
| 2009 | -- | -- | -- | 1.13E-03 | 1.30E-02 | 5.16E-03 |
| 2010 | -- | -- | -- | 1.61E-03 | 1.20E-02 | 5.44E-03 |
| 2011 | 5.02E-03 | 4.72E-03 | 5.34E-03 | 1.34E-03 | 1.15E-02 | 5.02E-03 |
| 2012 | 4.98E-03 | 4.72E-03 | 5.25E-03 | 1.00E-03 | 1.48E-02 | 5.15E-03 |
| 2013 | 4.94E-03 | 4.72E-03 | 5.16E-03 | 1.08E-03 | 1.23E-02 | 4.94E-03 |
| 2014 | 4.90E-03 | 4.72E-03 | 5.09E-03 | 1.36E-03 | 1.20E-02 | 4.99E-03 |
| 2015 | 4.86E-03 | 4.69E-03 | 5.02E-03 | 1.29E-03 | 1.12E-02 | 4.69E-03 |
| 2016 | 4.82E-03 | 4.66E-03 | 4.98E-03 | 1.02E-03 | 1.11E-02 | 4.48E-03 |
| 2017 | 4.78E-03 | 4.60E-03 | 4.96E-03 | 1.28E-03 | 1.11E-02 | 4.59E-03 |
| 2018 | 4.74E-03 | 4.53E-03 | 4.95E-03 | 1.20E-03 | 1.24E-02 | 5.06E-03 |
| 2019 | 4.70E-03 | 4.46E-03 | 4.95E-03 | 1.23E-03 | 1.23E-02 | 5.01E-03 |
| 2020 | 4.66E-03 | 4.38E-03 | 4.96E-03 | 9.87E-04 | 1.13E-02 | 4.48E-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 | -- | -- | -- | 7.42E-04 | 1.89E-03 | 1.24E-03 |
| 1999 | -- | -- | -- | 7.60E-04 | 1.89E-03 | 1.27E-03 |
| 2000 | -- | -- | -- | 4.70E-04 | 1.43E-03 | 8.87E-04 |
| 2001 | -- | -- | -- | 8.83E-04 | 2.09E-03 | 1.43E-03 |
| 2002 | -- | -- | -- | 9.83E-04 | 2.29E-03 | 1.60E-03 |
| 2003 | -- | -- | -- | 9.76E-04 | 2.26E-03 | 1.56E-03 |
| 2004 | -- | -- | -- | 4.25E-04 | 1.41E-03 | 8.49E-04 |
| 2005 | -- | -- | -- | 6.71E-04 | 1.77E-03 | 1.15E-03 |
| 2006 | -- | -- | -- | 4.59E-04 | 1.30E-03 | 8.31E-04 |
| 2007 | -- | -- | -- | 5.77E-04 | 1.60E-03 | 1.03E-03 |
| 2008 | -- | -- | -- | 9.78E-04 | 2.20E-03 | 1.52E-03 |
| 2009 | -- | -- | -- | 4.54E-04 | 1.36E-03 | 8.68E-04 |
| 2010 | -- | -- | -- | 3.53E-04 | 1.27E-03 | 7.37E-04 |
| 2011 | 1.02E-03 | 5.77E-04 | 1.79E-03 | 5.12E-04 | 1.49E-03 | 9.42E-04 |
| 2012 | 9.04E-04 | 5.59E-04 | 1.46E-03 | 3.79E-04 | 1.26E-03 | 7.55E-04 |
| 2013 | 8.03E-04 | 5.36E-04 | 1.20E-03 | 3.04E-04 | 1.16E-03 | 6.69E-04 |
| 2014 | 7.14E-04 | 5.06E-04 | 1.01E-03 | 4.74E-04 | 1.54E-03 | 9.44E-04 |
| 2015 | 6.34E-04 | 4.66E-04 | 8.64E-04 | 1.81E-04 | 7.74E-04 | 4.32E-04 |
| 2016 | 5.64E-04 | 4.14E-04 | 7.68E-04 | 5.48E-04 | 1.55E-03 | 9.84E-04 |
| 2017 | 5.01E-04 | 3.55E-04 | 7.06E-04 | 3.62E-04 | 1.24E-03 | 7.35E-04 |
| 2018 | 4.45E-04 | 2.97E-04 | 6.67E-04 | 3.77E-04 | 1.25E-03 | 7.45E-04 |
| 2019 | 3.96E-04 | 2.45E-04 | 6.39E-04 | 3.31E-05 | 4.60E-04 | 1.87E-04 |
| 2020 | 3.52E-04 | 2.00E-04 | 6.19E-04 | 7.19E-05 | 6.84E-04 | 3.00E-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 | 25,032 | 103.0 | -- | -- | -- | 2.41E+02 | 2.46E+02 | 2.43E+02 |
| 1999 | 25,328 | 103.0 | -- | -- | -- | 2.43E+02 | 2.48E+02 | 2.46E+02 |
| 2000 | 24,706 | 103.3 | -- | -- | -- | 2.37E+02 | 2.42E+02 | 2.39E+02 |
| 2001 | 24,893 | 103.0 | -- | -- | -- | 2.39E+02 | 2.44E+02 | 2.42E+02 |
| 2002 | 25,444 | 103.0 | -- | -- | -- | 2.44E+02 | 2.50E+02 | 2.47E+02 |
| 2003 | 26,705 | 103.0 | -- | -- | -- | 2.57E+02 | 2.62E+02 | 2.59E+02 |
| 2004 | 26,907 | 103.3 | -- | -- | -- | 2.58E+02 | 2.63E+02 | 2.61E+02 |
| 2005 | 27,560 | 103.0 | -- | -- | -- | 2.65E+02 | 2.70E+02 | 2.68E+02 |
| 2006 | 27,514 | 103.0 | -- | -- | -- | 2.64E+02 | 2.70E+02 | 2.67E+02 |
| 2007 | 27,388 | 103.6 | -- | -- | -- | 2.62E+02 | 2.67E+02 | 2.64E+02 |
| 2008 | 27,509 | 104.3 | -- | -- | -- | 2.61E+02 | 2.66E+02 | 2.64E+02 |
| 2009 | 27,250 | 104.0 | -- | -- | -- | 2.59E+02 | 2.65E+02 | 2.62E+02 |
| 2010 | 26,567 | 104.0 | -- | -- | -- | 2.53E+02 | 2.58E+02 | 2.55E+02 |
| 2011 | 26,496 | 104.0 | 2.55E+02 | 2.50E+02 | 2.59E+02 | 2.52E+02 | 2.57E+02 | 2.55E+02 |
| 2012 | 26,125 | 104.3 | 2.56E+02 | 2.52E+02 | 2.60E+02 | 2.48E+02 | 2.53E+02 | 2.51E+02 |
| 2013 | 26,261 | 101.6 | 2.57E+02 | 2.53E+02 | 2.60E+02 | 2.56E+02 | 2.61E+02 | 2.59E+02 |
| 2014 | 25,923 | 100.0 | 2.58E+02 | 2.55E+02 | 2.61E+02 | 2.57E+02 | 2.62E+02 | 2.59E+02 |
| 2015 | 26,150 | 99.0 | 2.59E+02 | 2.56E+02 | 2.62E+02 | 2.61E+02 | 2.67E+02 | 2.64E+02 |
| 2016 | 25,834 | 99.2 | 2.60E+02 | 2.58E+02 | 2.63E+02 | 2.58E+02 | 2.63E+02 | 2.60E+02 |
| 2017 | 25,919 | 99.0 | 2.61E+02 | 2.58E+02 | 2.64E+02 | 2.59E+02 | 2.64E+02 | 2.62E+02 |
| 2018 | 25,744 | 98.7 | 2.62E+02 | 2.59E+02 | 2.66E+02 | 2.58E+02 | 2.63E+02 | 2.61E+02 |
| 2019 | 25,150 | 97.0 | 2.64E+02 | 2.59E+02 | 2.68E+02 | 2.57E+02 | 2.62E+02 | 2.59E+02 |
| 2020 | 25,447 | 95.3 | 2.65E+02 | 2.60E+02 | 2.70E+02 | 2.64E+02 | 2.70E+02 | 2.67E+02 |
| Total | 601,853 | 2,341.6 | -- | -- | -- | -- | -- | -- |

Table 20. Plot data for Figure 10, frequency of run ≤ 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 | 25,032 | 103.0 | -- | -- | -- | 2.41E+02 | 2.46E+02 | 2.43E+02 |
| 1999 | 25,328 | 103.0 | -- | -- | -- | 2.43E+02 | 2.48E+02 | 2.46E+02 |
| 2000 | 24,706 | 103.3 | -- | -- | -- | 2.37E+02 | 2.42E+02 | 2.39E+02 |
| 2001 | 24,893 | 103.0 | -- | -- | -- | 2.39E+02 | 2.44E+02 | 2.42E+02 |
| 2002 | 25,444 | 103.0 | -- | -- | -- | 2.44E+02 | 2.50E+02 | 2.47E+02 |
| 2003 | 26,705 | 103.0 | -- | -- | -- | 2.57E+02 | 2.62E+02 | 2.59E+02 |
| 2004 | 26,907 | 103.3 | -- | -- | -- | 2.58E+02 | 2.63E+02 | 2.61E+02 |
| 2005 | 27,560 | 103.0 | -- | -- | -- | 2.65E+02 | 2.70E+02 | 2.68E+02 |
| 2006 | 27,514 | 103.0 | -- | -- | -- | 2.64E+02 | 2.70E+02 | 2.67E+02 |
| 2007 | 27,388 | 103.6 | -- | -- | -- | 2.62E+02 | 2.67E+02 | 2.64E+02 |
| 2008 | 27,509 | 104.3 | -- | -- | -- | 2.61E+02 | 2.66E+02 | 2.64E+02 |
| 2009 | 27,250 | 104.0 | -- | -- | -- | 2.59E+02 | 2.65E+02 | 2.62E+02 |
| 2010 | 26,567 | 104.0 | -- | -- | -- | 2.53E+02 | 2.58E+02 | 2.55E+02 |
| 2011 | 26,496 | 104.0 | 2.55E+02 | 2.50E+02 | 2.59E+02 | 2.52E+02 | 2.57E+02 | 2.55E+02 |
| 2012 | 26,125 | 104.3 | 2.56E+02 | 2.52E+02 | 2.60E+02 | 2.48E+02 | 2.53E+02 | 2.51E+02 |
| 2013 | 26,261 | 101.6 | 2.57E+02 | 2.53E+02 | 2.60E+02 | 2.56E+02 | 2.61E+02 | 2.59E+02 |
| 2014 | 25,923 | 100.0 | 2.58E+02 | 2.55E+02 | 2.61E+02 | 2.57E+02 | 2.62E+02 | 2.59E+02 |
| 2015 | 26,150 | 99.0 | 2.59E+02 | 2.56E+02 | 2.62E+02 | 2.61E+02 | 2.67E+02 | 2.64E+02 |
| 2016 | 25,834 | 99.2 | 2.60E+02 | 2.58E+02 | 2.63E+02 | 2.58E+02 | 2.63E+02 | 2.60E+02 |
| 2017 | 25,919 | 99.0 | 2.61E+02 | 2.58E+02 | 2.64E+02 | 2.59E+02 | 2.64E+02 | 2.62E+02 |
| 2018 | 25,744 | 98.7 | 2.62E+02 | 2.59E+02 | 2.66E+02 | 2.58E+02 | 2.63E+02 | 2.61E+02 |
| 2019 | 25,150 | 97.0 | 2.64E+02 | 2.59E+02 | 2.68E+02 | 2.57E+02 | 2.62E+02 | 2.59E+02 |
| 2020 | 25,447 | 95.3 | 2.65E+02 | 2.60E+02 | 2.70E+02 | 2.64E+02 | 2.70E+02 | 2.67E+02 |
| Total | 601,853 | 2,341.6 | -- | -- | -- | -- | -- | -- |

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 | 1,039,948 | 103.0 | -- | -- | -- | 1.01E+04 | 1.01E+04 | 1.01E+04 |
| 1999 | 956,050 | 103.0 | -- | -- | -- | 9.27E+03 | 9.30E+03 | 9.28E+03 |
| 2000 | 931,921 | 103.3 | -- | -- | -- | 9.01E+03 | 9.04E+03 | 9.02E+03 |
| 2001 | 937,369 | 103.0 | -- | -- | -- | 9.09E+03 | 9.12E+03 | 9.10E+03 |
| 2002 | 1,006,349 | 103.0 | -- | -- | -- | 9.76E+03 | 9.79E+03 | 9.77E+03 |
| 2003 | 1,165,347 | 103.0 | -- | -- | -- | 1.13E+04 | 1.13E+04 | 1.13E+04 |
| 2004 | 1,204,408 | 103.3 | -- | -- | -- | 1.16E+04 | 1.17E+04 | 1.17E+04 |
| 2005 | 1,214,508 | 103.0 | -- | -- | -- | 1.18E+04 | 1.18E+04 | 1.18E+04 |
| 2006 | 1,213,946 | 103.0 | -- | -- | -- | 1.18E+04 | 1.18E+04 | 1.18E+04 |
| 2007 | 1,230,509 | 103.6 | -- | -- | -- | 1.19E+04 | 1.19E+04 | 1.19E+04 |
| 2008 | 1,282,025 | 104.3 | -- | -- | -- | 1.23E+04 | 1.23E+04 | 1.23E+04 |
| 2009 | 1,270,031 | 104.0 | -- | -- | -- | 1.22E+04 | 1.22E+04 | 1.22E+04 |
| 2010 | 1,284,544 | 104.0 | -- | -- | -- | 1.23E+04 | 1.24E+04 | 1.24E+04 |
| 2011 | 1,285,895 | 104.0 | 1.24E+04 | 1.22E+04 | 1.25E+04 | 1.23E+04 | 1.24E+04 | 1.24E+04 |
| 2012 | 1,295,516 | 104.3 | 1.25E+04 | 1.24E+04 | 1.26E+04 | 1.24E+04 | 1.24E+04 | 1.24E+04 |
| 2013 | 1,275,755 | 101.6 | 1.26E+04 | 1.25E+04 | 1.27E+04 | 1.25E+04 | 1.26E+04 | 1.26E+04 |
| 2014 | 1,270,079 | 100.0 | 1.27E+04 | 1.26E+04 | 1.28E+04 | 1.27E+04 | 1.27E+04 | 1.27E+04 |
| 2015 | 1,279,529 | 99.0 | 1.28E+04 | 1.27E+04 | 1.29E+04 | 1.29E+04 | 1.29E+04 | 1.29E+04 |
| 2016 | 1,281,806 | 99.2 | 1.29E+04 | 1.28E+04 | 1.30E+04 | 1.29E+04 | 1.29E+04 | 1.29E+04 |
| 2017 | 1,286,127 | 99.0 | 1.30E+04 | 1.29E+04 | 1.31E+04 | 1.30E+04 | 1.30E+04 | 1.30E+04 |
| 2018 | 1,280,708 | 98.7 | 1.31E+04 | 1.30E+04 | 1.32E+04 | 1.30E+04 | 1.30E+04 | 1.30E+04 |
| 2019 | 1,271,180 | 97.0 | 1.32E+04 | 1.31E+04 | 1.33E+04 | 1.31E+04 | 1.31E+04 | 1.31E+04 |
| 2020 | 1,286,103 | 95.3 | 1.33E+04 | 1.32E+04 | 1.35E+04 | 1.35E+04 | 1.35E+04 | 1.35E+04 |
| Total | 27,549,654 | 2,341.6 | -- | -- | -- | -- | -- | -- |

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 | 3.25E-01 | 2.32E-01 |
| 1999 | 21 | 103.0 | -- | -- | -- | 1.37E-01 | 2.91E-01 | 2.03E-01 |
| 2000 | 37 | 103.3 | -- | -- | -- | 2.64E-01 | 4.64E-01 | 3.54E-01 |
| 2001 | 24 | 103.0 | -- | -- | -- | 1.60E-01 | 3.25E-01 | 2.32E-01 |
| 2002 | 24 | 103.0 | -- | -- | -- | 1.60E-01 | 3.25E-01 | 2.32E-01 |
| 2003 | 32 | 103.0 | -- | -- | -- | 2.24E-01 | 4.12E-01 | 3.07E-01 |
| 2004 | 21 | 103.3 | -- | -- | -- | 1.37E-01 | 2.91E-01 | 2.03E-01 |
| 2005 | 26 | 103.0 | -- | -- | -- | 1.76E-01 | 3.46E-01 | 2.50E-01 |
| 2006 | 17 | 103.0 | -- | -- | -- | 1.06E-01 | 2.47E-01 | 1.65E-01 |
| 2007 | 20 | 103.6 | -- | -- | -- | 1.28E-01 | 2.79E-01 | 1.93E-01 |
| 2008 | 19 | 104.3 | -- | -- | -- | 1.20E-01 | 2.66E-01 | 1.82E-01 |
| 2009 | 13 | 104.0 | -- | -- | -- | 7.56E-02 | 1.99E-01 | 1.26E-01 |
| 2010 | 21 | 104.0 | -- | -- | -- | 1.36E-01 | 2.89E-01 | 2.01E-01 |
| 2011 | 10 | 104.0 | 1.51E-01 | 1.01E-01 | 2.26E-01 | 5.43E-02 | 1.65E-01 | 9.83E-02 |
| 2012 | 17 | 104.3 | 1.56E-01 | 1.10E-01 | 2.19E-01 | 1.05E-01 | 2.44E-01 | 1.63E-01 |
| 2013 | 17 | 101.6 | 1.60E-01 | 1.20E-01 | 2.14E-01 | 1.08E-01 | 2.50E-01 | 1.68E-01 |
| 2014 | 24 | 100.0 | 1.65E-01 | 1.29E-01 | 2.11E-01 | 1.65E-01 | 3.34E-01 | 2.38E-01 |
| 2015 | 20 | 99.0 | 1.71E-01 | 1.37E-01 | 2.12E-01 | 1.34E-01 | 2.91E-01 | 2.01E-01 |
| 2016 | 14 | 99.2 | 1.76E-01 | 1.42E-01 | 2.18E-01 | 8.68E-02 | 2.20E-01 | 1.42E-01 |
| 2017 | 21 | 99.0 | 1.81E-01 | 1.44E-01 | 2.29E-01 | 1.42E-01 | 3.03E-01 | 2.11E-01 |
| 2018 | 20 | 98.7 | 1.87E-01 | 1.42E-01 | 2.46E-01 | 1.35E-01 | 2.92E-01 | 2.02E-01 |
| 2019 | 22 | 97.0 | 1.93E-01 | 1.39E-01 | 2.67E-01 | 1.53E-01 | 3.21E-01 | 2.25E-01 |
| 2020 | 13 | 95.3 | 1.99E-01 | 1.36E-01 | 2.92E-01 | 8.23E-02 | 2.17E-01 | 1.38E-01 |
| Total | 477 | 2,341.6 | -- | -- | -- | -- | -- | -- |

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 | -- | -- | -- | 2.35E-02 | 9.98E-02 | 5.19E-02 |
| 1999 | 2 | 103.0 | -- | -- | -- | 4.58E-03 | 5.62E-02 | 2.00E-02 |
| 2000 | 3 | 103.3 | -- | -- | -- | 8.64E-03 | 6.74E-02 | 2.79E-02 |
| 2001 | 3 | 103.0 | -- | -- | -- | 8.66E-03 | 6.76E-02 | 2.80E-02 |
| 2002 | 3 | 103.0 | -- | -- | -- | 8.66E-03 | 6.76E-02 | 2.80E-02 |
| 2003 | 2 | 103.0 | -- | -- | -- | 4.58E-03 | 5.62E-02 | 2.00E-02 |
| 2004 | 3 | 103.3 | -- | -- | -- | 8.64E-03 | 6.74E-02 | 2.79E-02 |
| 2005 | 4 | 103.0 | -- | -- | -- | 1.33E-02 | 7.86E-02 | 3.59E-02 |
| 2006 | 6 | 103.0 | -- | -- | -- | 2.35E-02 | 9.98E-02 | 5.19E-02 |
| 2007 | 1 | 103.6 | -- | -- | -- | 1.40E-03 | 4.40E-02 | 1.19E-02 |
| 2008 | 2 | 104.3 | -- | -- | -- | 4.53E-03 | 5.56E-02 | 1.98E-02 |
| 2009 | 2 | 104.0 | -- | -- | -- | 4.54E-03 | 5.57E-02 | 1.98E-02 |
| 2010 | 4 | 104.0 | -- | -- | -- | 1.32E-02 | 7.80E-02 | 3.57E-02 |
| 2011 | 2 | 104.0 | 3.43E-02 | 1.86E-02 | 6.35E-02 | 4.54E-03 | 5.57E-02 | 1.98E-02 |
| 2012 | 4 | 104.3 | 3.01E-02 | 1.79E-02 | 5.05E-02 | 1.31E-02 | 7.78E-02 | 3.56E-02 |
| 2013 | 3 | 101.6 | 2.64E-02 | 1.70E-02 | 4.08E-02 | 8.76E-03 | 6.84E-02 | 2.83E-02 |
| 2014 | 4 | 100.0 | 2.31E-02 | 1.58E-02 | 3.39E-02 | 1.36E-02 | 8.05E-02 | 3.68E-02 |
| 2015 | 3 | 99.0 | 2.02E-02 | 1.40E-02 | 2.93E-02 | 8.94E-03 | 6.98E-02 | 2.89E-02 |
| 2016 | 1 | 99.2 | 1.77E-02 | 1.19E-02 | 2.64E-02 | 1.45E-03 | 4.56E-02 | 1.24E-02 |
| 2017 | 2 | 99.0 | 1.55E-02 | 9.80E-03 | 2.47E-02 | 4.73E-03 | 5.80E-02 | 2.06E-02 |
| 2018 | 2 | 98.7 | 1.36E-02 | 7.86E-03 | 2.36E-02 | 4.74E-03 | 5.82E-02 | 2.07E-02 |
| 2019 | 1 | 97.0 | 1.19E-02 | 6.23E-03 | 2.29E-02 | 1.48E-03 | 4.64E-02 | 1.26E-02 |
| 2020 | 0 | 95.3 | 1.05E-02 | 4.89E-03 | 2.24E-02 | 1.67E-05 | 3.32E-02 | 4.25E-03 |
| Total | 63 | 2,341.6 | -- | -- | -- | -- | -- | -- |

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 | -- | -- | -- | 1.51E-02 | 8.96E-02 | 4.10E-02 |
| 1999 | 5 | 103.0 | -- | -- | -- | 2.08E-02 | 1.02E-01 | 5.01E-02 |
| 2000 | 10 | 103.3 | -- | -- | -- | 5.27E-02 | 1.60E-01 | 9.54E-02 |
| 2001 | 15 | 103.0 | -- | -- | -- | 8.78E-02 | 2.16E-01 | 1.41E-01 |
| 2002 | 10 | 103.0 | -- | -- | -- | 5.28E-02 | 1.60E-01 | 9.56E-02 |
| 2003 | 15 | 103.0 | -- | -- | -- | 8.78E-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 | 9.56E-02 |
| 2006 | 9 | 103.0 | -- | -- | -- | 4.61E-02 | 1.49E-01 | 8.65E-02 |
| 2007 | 10 | 103.6 | -- | -- | -- | 5.25E-02 | 1.59E-01 | 9.51E-02 |
| 2008 | 21 | 104.3 | -- | -- | -- | 1.30E-01 | 2.78E-01 | 1.94E-01 |
| 2009 | 6 | 104.0 | -- | -- | -- | 2.66E-02 | 1.13E-01 | 5.87E-02 |
| 2010 | 7 | 104.0 | -- | -- | -- | 3.28E-02 | 1.25E-01 | 6.77E-02 |
| 2011 | 14 | 104.0 | 1.05E-01 | 5.58E-02 | 1.96E-01 | 7.99E-02 | 2.03E-01 | 1.31E-01 |
| 2012 | 8 | 104.3 | 9.36E-02 | 5.52E-02 | 1.59E-01 | 3.90E-02 | 1.36E-01 | 7.65E-02 |
| 2013 | 17 | 101.6 | 8.37E-02 | 5.37E-02 | 1.31E-01 | 1.04E-01 | 2.41E-01 | 1.62E-01 |
| 2014 | 5 | 100.0 | 7.48E-02 | 5.05E-02 | 1.11E-01 | 2.14E-02 | 1.05E-01 | 5.15E-02 |
| 2015 | 5 | 99.0 | 6.69E-02 | 4.55E-02 | 9.84E-02 | 2.16E-02 | 1.06E-01 | 5.20E-02 |
| 2016 | 2 | 99.2 | 5.99E-02 | 3.92E-02 | 9.14E-02 | 5.40E-03 | 6.63E-02 | 2.36E-02 |
| 2017 | 5 | 99.0 | 5.35E-02 | 3.25E-02 | 8.80E-02 | 2.16E-02 | 1.06E-01 | 5.20E-02 |
| 2018 | 6 | 98.7 | 4.79E-02 | 2.64E-02 | 8.67E-02 | 2.79E-02 | 1.18E-01 | 6.16E-02 |
| 2019 | 6 | 97.0 | 4.28E-02 | 2.12E-02 | 8.65E-02 | 2.84E-02 | 1.20E-01 | 6.26E-02 |
| 2020 | 5 | 95.3 | 3.83E-02 | 1.68E-02 | 8.70E-02 | 2.24E-02 | 1.09E-01 | 5.39E-02 |
| Total | 208 | 2,341.6 | -- | -- | -- | -- | -- | -- |

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 | 7,933 | 103.0 | -- | -- | -- | 7.56E+01 | 7.85E+01 | 7.70E+01 |
| 1999 | 8,361 | 103.0 | -- | -- | -- | 7.97E+01 | 8.27E+01 | 8.12E+01 |
| 2000 | 8,194 | 103.3 | -- | -- | -- | 7.79E+01 | 8.08E+01 | 7.93E+01 |
| 2001 | 8,182 | 103.0 | -- | -- | -- | 7.80E+01 | 8.09E+01 | 7.94E+01 |
| 2002 | 8,407 | 103.0 | -- | -- | -- | 8.02E+01 | 8.31E+01 | 8.16E+01 |
| 2003 | 8,951 | 103.0 | -- | -- | -- | 8.54E+01 | 8.84E+01 | 8.69E+01 |
| 2004 | 8,900 | 103.3 | -- | -- | -- | 8.47E+01 | 8.77E+01 | 8.62E+01 |
| 2005 | 9,039 | 103.0 | -- | -- | -- | 8.62E+01 | 8.93E+01 | 8.78E+01 |
| 2006 | 9,232 | 103.0 | -- | -- | -- | 8.81E+01 | 9.12E+01 | 8.96E+01 |
| 2007 | 9,073 | 103.6 | -- | -- | -- | 8.61E+01 | 8.91E+01 | 8.76E+01 |
| 2008 | 9,439 | 104.3 | -- | -- | -- | 8.90E+01 | 9.21E+01 | 9.05E+01 |
| 2009 | 9,164 | 104.0 | -- | -- | -- | 8.66E+01 | 8.96E+01 | 8.81E+01 |
| 2010 | 8,858 | 104.0 | -- | -- | -- | 8.37E+01 | 8.67E+01 | 8.52E+01 |
| 2011 | 8,897 | 104.0 | 8.68E+01 | 8.45E+01 | 8.92E+01 | 8.41E+01 | 8.71E+01 | 8.55E+01 |
| 2012 | 8,909 | 104.3 | 8.67E+01 | 8.47E+01 | 8.87E+01 | 8.39E+01 | 8.69E+01 | 8.54E+01 |
| 2013 | 8,748 | 101.6 | 8.65E+01 | 8.49E+01 | 8.82E+01 | 8.46E+01 | 8.77E+01 | 8.61E+01 |
| 2014 | 8,750 | 100.0 | 8.64E+01 | 8.50E+01 | 8.78E+01 | 8.60E+01 | 8.91E+01 | 8.75E+01 |
| 2015 | 8,870 | 99.0 | 8.62E+01 | 8.49E+01 | 8.75E+01 | 8.80E+01 | 9.12E+01 | 8.96E+01 |
| 2016 | 8,605 | 99.2 | 8.61E+01 | 8.48E+01 | 8.73E+01 | 8.52E+01 | 8.83E+01 | 8.67E+01 |
| 2017 | 8,592 | 99.0 | 8.59E+01 | 8.45E+01 | 8.73E+01 | 8.53E+01 | 8.83E+01 | 8.68E+01 |
| 2018 | 8,358 | 98.7 | 8.57E+01 | 8.41E+01 | 8.75E+01 | 8.31E+01 | 8.62E+01 | 8.46E+01 |
| 2019 | 8,163 | 97.0 | 8.56E+01 | 8.36E+01 | 8.76E+01 | 8.26E+01 | 8.57E+01 | 8.42E+01 |
| 2020 | 8,098 | 95.3 | 8.54E+01 | 8.31E+01 | 8.78E+01 | 8.34E+01 | 8.65E+01 | 8.49E+01 |
| Total | 199,727 | 2,341.6 | -- | -- | -- | -- | -- | -- |

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 | 3,314,069 | 103.0 | -- | -- | -- | 3.22E+04 | 3.22E+04 | 3.22E+04 |
| 1999 | 3,385,035 | 103.0 | -- | -- | -- | 3.28E+04 | 3.29E+04 | 3.29E+04 |
| 2000 | 3,413,378 | 103.3 | -- | -- | -- | 3.30E+04 | 3.31E+04 | 3.30E+04 |
| 2001 | 3,416,384 | 103.0 | -- | -- | -- | 3.31E+04 | 3.32E+04 | 3.32E+04 |
| 2002 | 3,421,554 | 103.0 | -- | -- | -- | 3.32E+04 | 3.32E+04 | 3.32E+04 |
| 2003 | 3,565,088 | 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 | 3,526,234 | 103.0 | -- | -- | -- | 3.42E+04 | 3.43E+04 | 3.42E+04 |
| 2006 | 3,507,953 | 103.0 | -- | -- | -- | 3.40E+04 | 3.41E+04 | 3.41E+04 |
| 2007 | 3,514,380 | 103.6 | -- | -- | -- | 3.39E+04 | 3.39E+04 | 3.39E+04 |
| 2008 | 3,573,390 | 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 | 3.45E+04 | 3.40E+04 | 3.49E+04 | 3.44E+04 | 3.44E+04 | 3.44E+04 |
| 2012 | 3,575,450 | 104.3 | 3.47E+04 | 3.43E+04 | 3.51E+04 | 3.43E+04 | 3.43E+04 | 3.43E+04 |
| 2013 | 3,560,183 | 101.6 | 3.50E+04 | 3.47E+04 | 3.53E+04 | 3.50E+04 | 3.51E+04 | 3.51E+04 |
| 2014 | 3,564,608 | 100.0 | 3.52E+04 | 3.49E+04 | 3.55E+04 | 3.56E+04 | 3.57E+04 | 3.56E+04 |
| 2015 | 3,555,386 | 99.0 | 3.55E+04 | 3.52E+04 | 3.57E+04 | 3.59E+04 | 3.59E+04 | 3.59E+04 |
| 2016 | 3,553,732 | 99.2 | 3.57E+04 | 3.55E+04 | 3.60E+04 | 3.58E+04 | 3.58E+04 | 3.58E+04 |
| 2017 | 3,546,182 | 99.0 | 3.60E+04 | 3.57E+04 | 3.63E+04 | 3.58E+04 | 3.59E+04 | 3.58E+04 |
| 2018 | 3,547,270 | 98.7 | 3.62E+04 | 3.59E+04 | 3.66E+04 | 3.59E+04 | 3.60E+04 | 3.59E+04 |
| 2019 | 3,521,928 | 97.0 | 3.65E+04 | 3.61E+04 | 3.69E+04 | 3.63E+04 | 3.63E+04 | 3.63E+04 |
| 2020 | 3,520,085 | 95.3 | 3.68E+04 | 3.63E+04 | 3.72E+04 | 3.69E+04 | 3.70E+04 | 3.69E+04 |
| Total | 80,903,370 | 2,341.6 | -- | -- | -- | -- | -- | -- |

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 | -- | -- | -- | 4.50E-02 | 1.45E-01 | 8.46E-02 |
| 1999 | 10 | 103.0 | -- | -- | -- | 5.16E-02 | 1.57E-01 | 9.35E-02 |
| 2000 | 6 | 103.3 | -- | -- | -- | 2.62E-02 | 1.11E-01 | 5.77E-02 |
| 2001 | 11 | 103.0 | -- | -- | -- | 5.83E-02 | 1.68E-01 | 1.02E-01 |
| 2002 | 13 | 103.0 | -- | -- | -- | 7.19E-02 | 1.89E-01 | 1.20E-01 |
| 2003 | 14 | 103.0 | -- | -- | -- | 7.88E-02 | 2.00E-01 | 1.29E-01 |
| 2004 | 7 | 103.3 | -- | -- | -- | 3.22E-02 | 1.22E-01 | 6.66E-02 |
| 2005 | 10 | 103.0 | -- | -- | -- | 5.16E-02 | 1.57E-01 | 9.35E-02 |
| 2006 | 7 | 103.0 | -- | -- | -- | 3.23E-02 | 1.23E-01 | 6.68E-02 |
| 2007 | 9 | 103.6 | -- | -- | -- | 4.48E-02 | 1.45E-01 | 8.41E-02 |
| 2008 | 13 | 104.3 | -- | -- | -- | 7.11E-02 | 1.87E-01 | 1.19E-01 |
| 2009 | 7 | 104.0 | -- | -- | -- | 3.20E-02 | 1.22E-01 | 6.62E-02 |
| 2010 | 6 | 104.0 | -- | -- | -- | 2.60E-02 | 1.10E-01 | 5.74E-02 |
| 2011 | 8 | 104.0 | 7.47E-02 | 4.18E-02 | 1.33E-01 | 3.83E-02 | 1.33E-01 | 7.50E-02 |
| 2012 | 6 | 104.3 | 6.74E-02 | 4.14E-02 | 1.10E-01 | 2.59E-02 | 1.10E-01 | 5.72E-02 |
| 2013 | 5 | 101.6 | 6.08E-02 | 4.03E-02 | 9.16E-02 | 2.06E-02 | 1.01E-01 | 4.96E-02 |
| 2014 | 8 | 100.0 | 5.48E-02 | 3.83E-02 | 7.86E-02 | 3.97E-02 | 1.38E-01 | 7.77E-02 |
| 2015 | 3 | 99.0 | 4.95E-02 | 3.49E-02 | 7.02E-02 | 1.00E-02 | 7.81E-02 | 3.23E-02 |
| 2016 | 8 | 99.2 | 4.47E-02 | 3.05E-02 | 6.53E-02 | 3.99E-02 | 1.39E-01 | 7.83E-02 |
| 2017 | 6 | 99.0 | 4.03E-02 | 2.59E-02 | 6.28E-02 | 2.72E-02 | 1.15E-01 | 6.00E-02 |
| 2018 | 6 | 98.7 | 3.64E-02 | 2.14E-02 | 6.17E-02 | 2.73E-02 | 1.16E-01 | 6.01E-02 |
| 2019 | 1 | 97.0 | 3.28E-02 | 1.75E-02 | 6.14E-02 | 1.65E-03 | 5.21E-02 | 1.41E-02 |
| 2020 | 2 | 95.3 | 2.96E-02 | 1.42E-02 | 6.16E-02 | 5.47E-03 | 6.72E-02 | 2.39E-02 |
| Total | 175 | 2,341.6 | -- | -- | -- | -- | -- | -- |

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 | -- | -- | -- | 1.23E-01 | 2.67E-01 | 1.84E-01 |
| 1999 | 15 | 103.0 | -- | -- | -- | 8.67E-02 | 2.13E-01 | 1.39E-01 |
| 2000 | 21 | 103.3 | -- | -- | -- | 1.30E-01 | 2.76E-01 | 1.93E-01 |
| 2001 | 17 | 103.0 | -- | -- | -- | 1.01E-01 | 2.35E-01 | 1.57E-01 |
| 2002 | 13 | 103.0 | -- | -- | -- | 7.26E-02 | 1.91E-01 | 1.21E-01 |
| 2003 | 9 | 103.0 | -- | -- | -- | 4.55E-02 | 1.47E-01 | 8.54E-02 |
| 2004 | 8 | 103.3 | -- | -- | -- | 3.89E-02 | 1.35E-01 | 7.62E-02 |
| 2005 | 10 | 103.0 | -- | -- | -- | 5.21E-02 | 1.58E-01 | 9.44E-02 |
| 2006 | 10 | 103.0 | -- | -- | -- | 5.21E-02 | 1.58E-01 | 9.44E-02 |
| 2007 | 7 | 103.6 | -- | -- | -- | 3.25E-02 | 1.23E-01 | 6.70E-02 |
| 2008 | 26 | 104.3 | -- | -- | -- | 1.66E-01 | 3.26E-01 | 2.35E-01 |
| 2009 | 16 | 104.0 | -- | -- | -- | 9.29E-02 | 2.22E-01 | 1.47E-01 |
| 2010 | 7 | 104.0 | -- | -- | -- | 3.23E-02 | 1.23E-01 | 6.68E-02 |
| 2011 | 8 | 104.0 | 1.09E-01 | 5.90E-02 | 2.03E-01 | 3.86E-02 | 1.34E-01 | 7.57E-02 |
| 2012 | 10 | 104.3 | 9.09E-02 | 5.44E-02 | 1.52E-01 | 5.15E-02 | 1.56E-01 | 9.33E-02 |
| 2013 | 10 | 101.6 | 7.56E-02 | 4.89E-02 | 1.17E-01 | 5.28E-02 | 1.60E-01 | 9.56E-02 |
| 2014 | 5 | 100.0 | 6.29E-02 | 4.22E-02 | 9.37E-02 | 2.11E-02 | 1.03E-01 | 5.08E-02 |
| 2015 | 9 | 99.0 | 5.23E-02 | 3.47E-02 | 7.90E-02 | 4.72E-02 | 1.52E-01 | 8.86E-02 |
| 2016 | 8 | 99.2 | 4.35E-02 | 2.72E-02 | 6.97E-02 | 4.03E-02 | 1.40E-01 | 7.91E-02 |
| 2017 | 4 | 99.0 | 3.62E-02 | 2.06E-02 | 6.36E-02 | 1.55E-02 | 9.17E-02 | 4.20E-02 |
| 2018 | 4 | 98.7 | 3.01E-02 | 1.54E-02 | 5.91E-02 | 1.55E-02 | 9.19E-02 | 4.21E-02 |
| 2019 | 2 | 97.0 | 2.50E-02 | 1.13E-02 | 5.55E-02 | 5.44E-03 | 6.68E-02 | 2.38E-02 |
| 2020 | 0 | 95.3 | 2.08E-02 | 8.27E-03 | 5.25E-02 | 1.90E-05 | 3.77E-02 | 4.83E-03 |
| Total | 239 | 2,341.6 | -- | -- | -- | -- | -- | -- |

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