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

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ABSTRACT

This report presents an enhanced performance evaluation of turbine-driven pumps (TDPs) at U.S. commercial nuclear power plants. The data used in this study are based on the operating experience failure reports from calendar year 1998 through 2018 as reported in the Institute of Nuclear Power Operations (INPO) Consolidated Events Database (ICES). The TDP failure modes considered for standby systems are failure to start (FTS), failure to run less than or equal to one hour (FTR≤1H), failure to run more than one hour (FTR>1H), and for normally running systems FTS and failure to run (FTR). An eight-hour unreliability estimate is also calculated and trended. The component reliability estimates and the reliability data are trended for the most recent 10-year period while yearly estimates for reliability are provided for the entire study period.

A highly statistically significant decreasing trend was identified in the standby TDP unavailability estimates.

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FIGURES

TABLES

ACRONYMS

AFW	auxiliary feed water
AOV	air-operated valve
CNID	constrained non-informative prior distribution
CY	calendar year
EDG	emergency diesel generator
EPIX	Equipment Performance and Information Exchange
EPS	emergency power supply
ESF	engineered safety feature
FTR≤1H	failure to run less than or equal to one hour
FTR>1H	failure to run greater than one hour
FTR	failure to run
FTS	failure to start
FY	fiscal year
HPCI	high-pressure coolant injection
HPCS	high-pressure core spray
ICES	INPO Consolidated Events Database
INL	Idaho National Laboratory
INPO	Institute of Nuclear Power Operations
IRIS	Industry Reporting and Information System
MDP	motor-driven pump
MFW	main feed water
MOV	motor-operated valve
MSPI	Mitigating Systems Performance Index
NPRDS	Nuclear Plant Reliability Data System
OLS	ordinary least squares
PRA	probabilistic risk assessment
RCIC	reactor core isolation cooling
TDP	turbine-driven pump
UA	unavailability

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1. INTRODUCTION

This report presents an enhanced performance evaluation of turbine-driven pumps (TDPs) at U.S. commercial nuclear power plants from 1998 through 2018. The objective of each updated component performance study is to obtain annual performance trends of failure rates and probabilities and to present an analysis of factors that could influence the component trends. This year's update continues with the two changes implemented in the 2016 update that are different from earlier updates: (1) the update results are based on calendar year (CY) instead of the federal fiscal year (FY), and (2) The failure events included in the update are "hard" failures, i.e., the p-values indicating the likelihood the component would have failed during a 24-hour mission are 1.0. Previous updates (2015 and before) include 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), motor-driven pumps (MDPs), motor-operated valves (MOVs), and TDPs. The TDP performance analysis was originally published as NUREG-1715, Volume 1 in April 2000 [1] and then updated annually in a series of reports, with the last one being documented in INL/EXT-17-441163, *Enhanced Component Performance Study: Turbine-Driven Pumps 1998-2016* [2]. The Nuclear Regulatory Commission (NRC) Reactor Operational Experience Results and Databases web page provides the links to the historical and current results of component performance studies (http://nrcoe.inl.gov/resultsdb/CompPerf). An overview of the trending methods, glossary of terms, and abbreviations is documented in the paper Overview and Reference [3] that can also be found on that web page.

The data used in this study are based on the operating experience failure reports from Institute of Nuclear Power Operations (INPO) Consolidated Events Database (ICES) [4], formerly the Equipment Performance and Information Exchange Database (EPIX) and now upgraded again to IRIS, the Industry Reporting and Information System. Maintenance unavailability (UA) performance data came from the Reactor Oversight Process program's Mitigating Systems Performance Index (MSPI) program [5] and ICES. Previously, the study relied on operating experience obtained from licensee event reports, Nuclear Plant Reliability Data System (NPRDS), and ICES. The ICES database, now IRIS, (which includes the MSPI designated devices as a subset) has matured to the point where both component availability and reliability can be estimated with a high degree of accuracy. In addition, the population of data in current ICES database is much larger than the population available in the previous study.

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

While this report provides an overview of operational data and evaluates component performance over time, it makes no attempt to estimate values for use in probabilistic risk assessments (PRAs). The

2015 Component Reliability Update [6], is an update to NUREG/CR-6928, *Industry-Average Performance for Components and Initiating Events at U.S Commercial Nuclear Power Plants* [7], and reports the TDP unreliability estimates for probabilistic risk assessments. Estimates from that report are included herein, for comparison. Those estimates are labelled “2015 Update” (or “Update 2015”) in the associated tables and figures.

Section 2 of this report presents the summary of findings from the study, with particular interest in the existence of any statistically significant increasing or decreasing trends in component performances. Section 3 provides annual estimates of failure probabilities and rates related to TDPs as well as the trending of the estimates. Section 4 provides TDP train UA estimates and their trends. Section 5 estimates the annual total unreliability and the trends for TDP. Section 6 presents various engineering analyses performed for TDP such as the trend for demands/run hours per plant reactor year, the trend for failures per plant reactor year, and the breakdown of TDP failures by sub-components, failure causes, detection methods, and recovery possibility, etc. A comparison of ICES TDP unplanned demand results with the 2015 Update industry-average results for standby TDPs is also conducted in Section 6 in order to determine whether the current data are consistent with the estimated values used in PRA. Section 7 provides the TDP assembly information. Section 8 presents the plot data for various figures in previous sections.

2. SUMMARY OF FINDINGS

The results of this study are summarized in this section. Of particular interest is the existence of any statistically significant[a] increasing trends.

2.1 Increasing Trends

2.1.1 Extremely Statistically Significant

- None.

2.1.2 Highly Statistically Significant

- None.

2.1.3 Statistically Significant

- None.

2.2 Decreasing Trends

2.2.1 Extremely Statistically Significant

- None.

2.2.2 Highly Statistically Significant

- A highly statistically significant **decreasing trend** in the **standby TDP unavailability** estimates was identified with a p-value of 0.0058 (see Figure 6). This is a new trend that was not observed in the 2016 TDP update study [2].

2.2.3 Statistically Significant

- None.

2.3 Consistency Check Results

An ongoing concern in the industry is whether industry average failure estimates adequately predict standby component performance during unplanned (ESF) demands. Section 6.3 provides the results of a consistency check that compare failure predictions obtained via simulation test on industry-average parameters from the 2015 Update against operational failure counts obtained from actual TDP performance with ESF demands. These consistency checks show that the FTS and FTR>1H failure observations in the non-test, operational ESF demand data lie within their corresponding industry-average failure estimate distributions, provided in the 2015 Update (Table 2), that were based on both test and non-test operational ESF demands. However, the FTR≤1H failure observations are not consistent with the

a. Statistically significant is defined in terms of the ‘p-value.’ A p-value is a probability indicating whether to accept or reject the null hypothesis that there is no trend in the data. P-values of less than or equal to 0.05 indicate that we are 95% confident that there is a trend in the data (reject the null hypothesis of no trend.) By convention, we use the "Michelin Guide" scale: p-value < 0.05 (statistically significant), p-value < 0.01 (highly statistically significant); p-value < 0.001 (extremely statistically significant).

industry-average failure estimate distributions, which means that the TDP performs worse on a non-test, operational ESF demand than on a test demand.

3. FAILURE PROBABILITIES AND FAILURE RATES

3.1 Overview

TDPs 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 TDP data set obtained from ICES includes TDPs in the systems listed in Table 1. This report follows the definition of these categories in NUREG/CR-6823 [8], which determines the status by evaluating the number of run-hours per demand. 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 the TDP from Reference [6], or the 2015 Update. The 2015 Update results are provided for comparison purposes and are important because they are intended for use in PRA. The results in this section demonstrate the extent to which the 2015 Update results remain suitable estimates for use in PRA.

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

Table 1. TDP systems.

System	Description	Total	Normally Running	Standby
AFW	Auxiliary feed water	74		74
HPCI	High pressure coolant injection	28		28
MFW	Main feed water	43	43	
RCIC	Reactor core isolation cooling	31		31
	Total	176	43	133

Table 2. 2015 Update industry-wide distributions of p (failure probability) and λ (hourly rate) for TDPs.

Operation	Failure Mode	5%	Median	Mean	95%	Distribution		
						Type	α	β
Standby	FTS	5.35E-4	4.51E-3	5.93E-3	1.62E-2	Beta	1.29	2.16E+02
	FTR≤1H	1.51E-4	2.48E-3	3.71E-3	1.15E-2	Gamma	0.91	2.46E+02
	FTR>1H	1.51E-3	2.17E-3	2.20E-3	2.99E-3	Gamma	23.50	1.07E+04
Running/ Alternating	FTS	4.01E-4	6.20E-3	9.16E-3	2.78E-2	Beta	0.94	1.02E+02
	FTR	1.52E-6	8.68E-6	1.07E-5	2.67E-5	Gamma	1.70	1.59E+05

3.2 TDP Failure Probability and Failure Rate Trends

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

The failure probability and failure rate estimates in this section were obtained from a Bayesian update process. The means from the posterior distributions were plotted for each year. The 5th and 95th percentiles from the posterior distributions are also provided and give an indication of the relative uncertainty in the estimated parameters from year to year. When there are no failures, the interval is larger than the interval for years when there are one or more failures because of the form of the posterior variance. Each update utilizes a relatively "flat" constrained non-informative prior distribution (CNID), which has wide bounds [3, 8]. CNID is a compromise between an informative prior and the Jeffreys noninformative prior. The mean of the CNID uses prior belief and is based on a pooling of the component or event type data for the years going into the plot (i.e., the most recent 10-year period), but the dispersion is defined to correspond to little information (i.e., relatively flat by set) so that the prior distributions did not create large changes in the data.

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

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

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

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

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

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

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

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

The horizontal curves plotted around the regression lines in the graphs form 90% simultaneous confidence bands for the fitted lines. The bounds are larger than ordinary confidence bands for the individual coefficients because they form a confidence band for the entire line. In the lower left hand corner of the trend figures, the regression p-values are reported. They come from a statistical test to assess evidence against the slope of the regression line being zero. Low p-values indicate strong evidence that the slopes are not zero, and suggest a trend does exist. P-values of less than or equal to 0.05 indicate that we are 95% confident that there is a trend in the data (reject the null hypothesis of no trend.) By convention, this study uses the "Michelin Guide" scale: p-value < 0.05 (statistically significant), p-value < 0.01 (highly statistically significant); p-value < 0.001 (extremely statistically significant).

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

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

Figure 1 to Figure 5 provide the plots for industry-wide failure probabilities/rates of standby and normally running TDPs. The data for these plots are provided in Section 8.

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

No trends were identified for TDP failure probabilities/rates for FTS, FTR≤1H, FTR>1H, and FTR events in the most recent 10-year period.

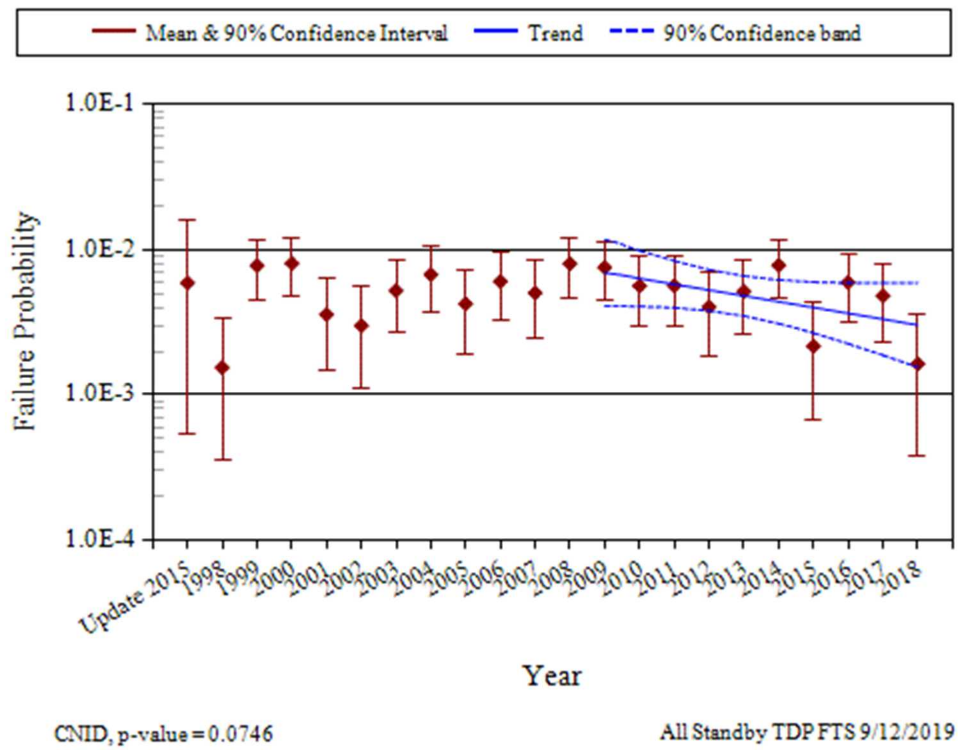

Figure 1. Failure probability estimate trend for standby TDP FTS.

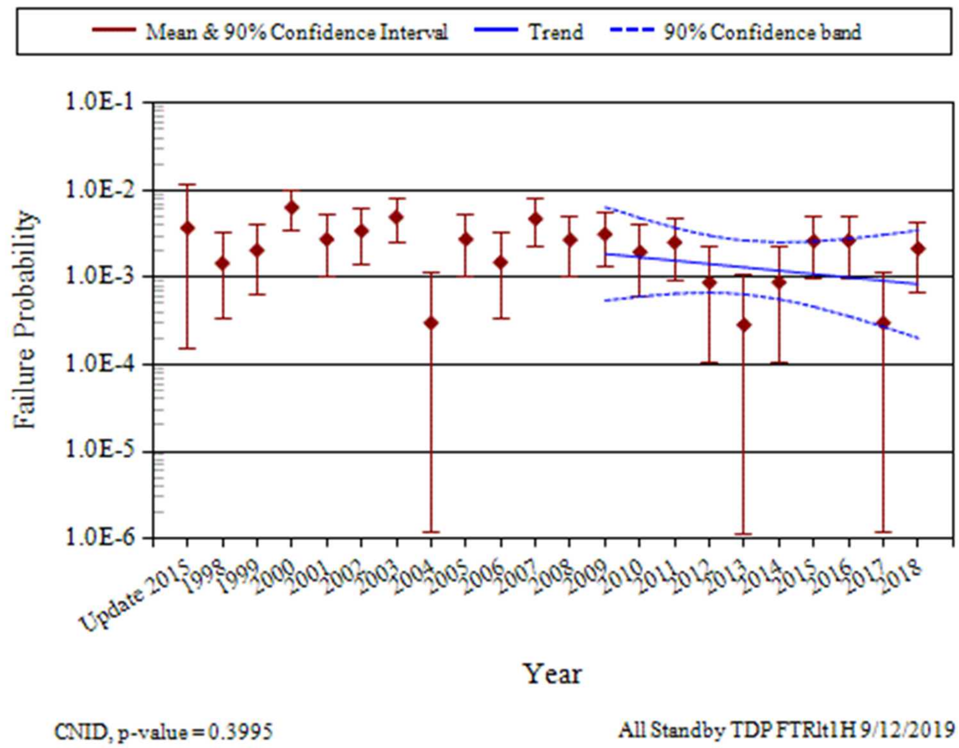

Figure 2. Failure probability estimate trend for standby TDP FTR≤1H.

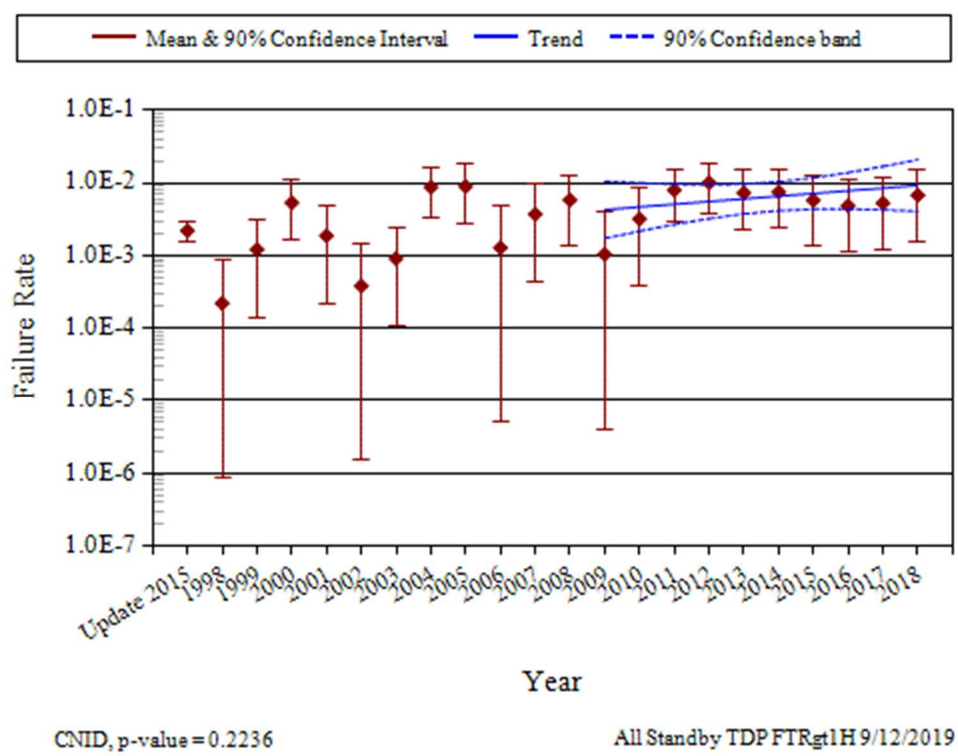

Figure 3. Failure rate estimate trend for standby TDP FTR>1H.

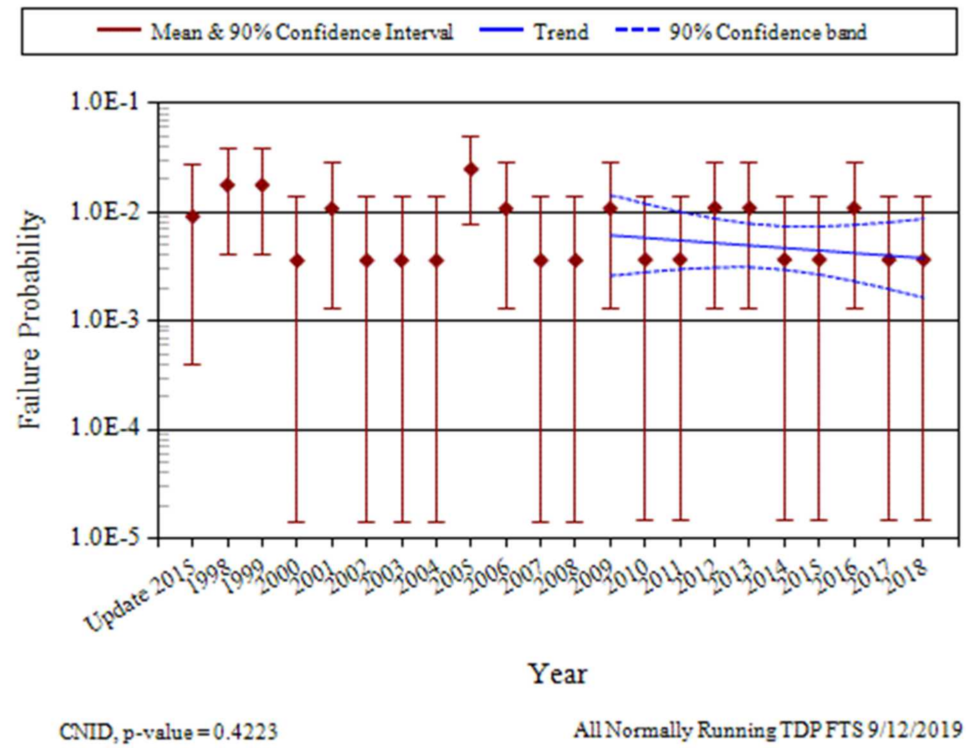

Figure 4. Failure probability estimate trend for normally running TDP FTS.

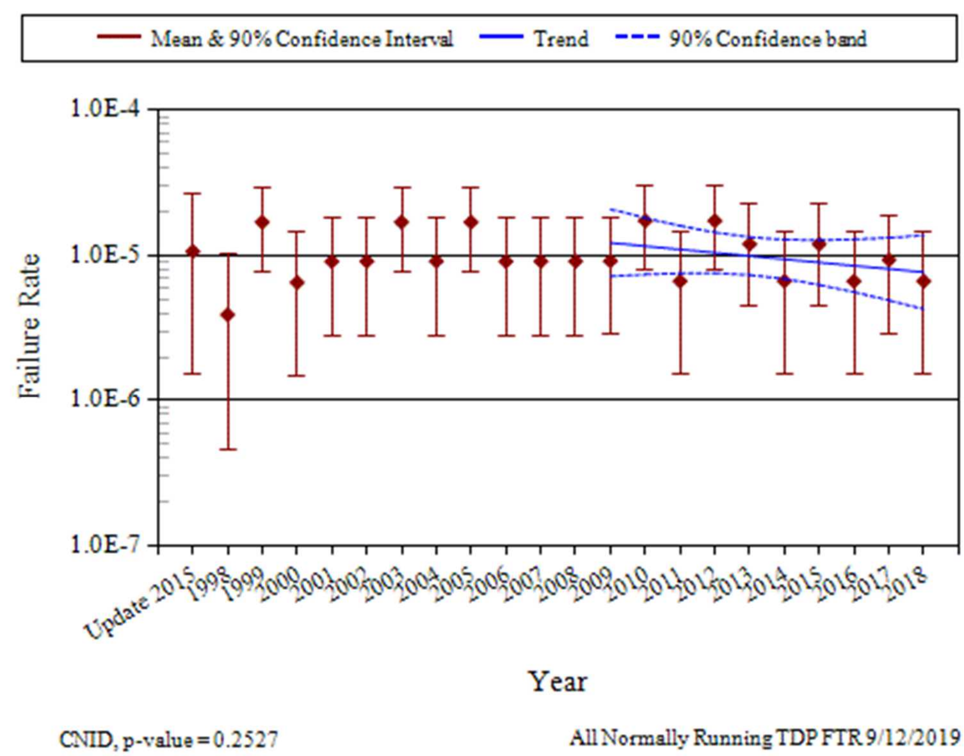

Figure 5. Failure rate estimate trend for normally running TDP FTR.

4. UNAVAILABILITY

4.1 Overview

The industry-wide test or maintenance UA of TDP trains has been calculated from operating experience. UA data are for TDP trains, which can include more than just the TDP. However, in most cases the TDP contributes the majority of the UA reported. Table 3 shows overall results for the TDP from the 2015 Update [6] which based on UA data from the MSPI program and ICES. In the calculations, planned and unplanned unavailable hours for a train are combined.

Table 3. 2015 Update industry-average distributions of unavailability for TDPs.

Description	Distribution	Mean	α	β
TDP Test or Maintenance (AFW)	Normal	5.24E-3	0.0052	0.0030
TDP Test or Maintenance (HPCI)	Normal	1.17E-2	0.0117	0.0027
TDP Test or Maintenance (RCIC)	Normal	1.04E-2	0.0104	0.0046
TDP Test or Maintenance (All)	Normal	7.25E-3	0.0072	0.0042

4.2 TDP Unavailability Trends

This section presents overall maintenance UA data for the 1998–2018 period. Note that these data do not supersede the data in Table 3 for use in risk assessments.

The trend in standby TDP train unavailability is shown in Figure 6. The data for this figure is in Section 8. The TDPs in systems AFW, HPCI, and RCIC are pooled and trended (these are the systems with maintenance unavailability data currently analyzed). The trend chart shows the results of using data for each year's component unavailability data over time. The yearly (1998–2018) unavailability and reactor critical hour data were obtained from the Reactor Oversight Process program (1998 to 2001) and ICES (2002 to 2018) data for the TDP component. The total downtimes during operation for each plant and year were summed, and divided by the corresponding number of TDP-reactor critical hours. Unavailability data for shutdown periods are not reported.

The mean and variance for each year is the sample mean and variance calculated from the plant-level unavailabilities for that year. The vertical bar spans the calculated 5th to 95th percentiles of the beta distribution with matching means.

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

- Highly statistically significant **decreasing trend** in the **standby TDP unavailability** estimates, with a p-value of 0.0058 (see Figure 6). This is a new trend that was not observed in the 2016 TDP update study [2].

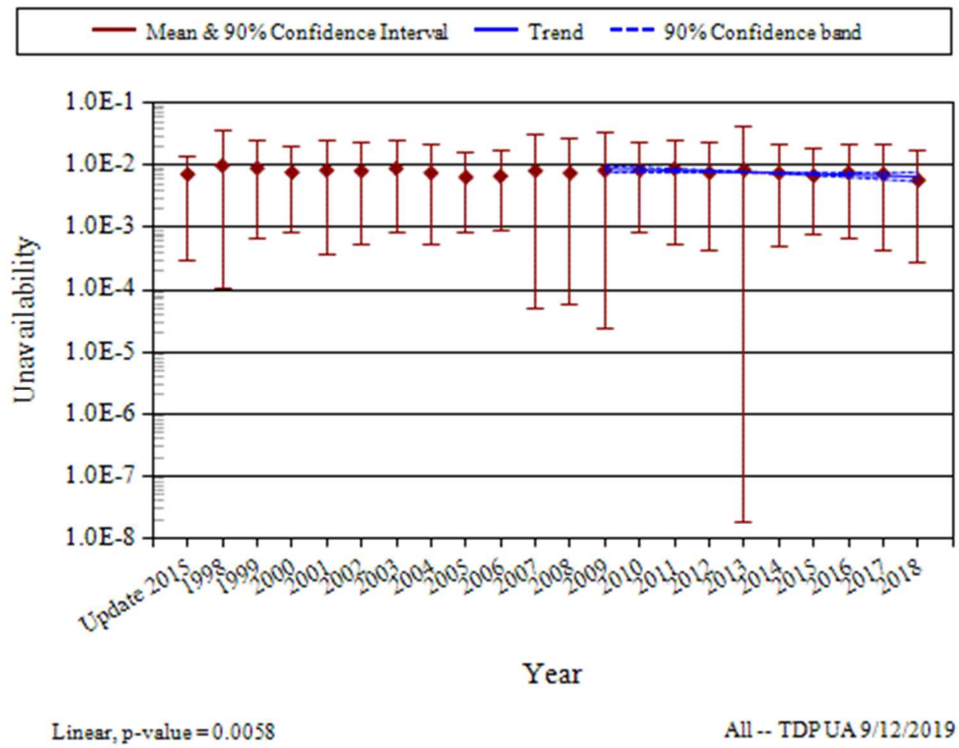

Figure 6. Pooled standby TDP UA trend.

5. TDP UNRELIABILITY TRENDS

Trends in total component unreliability are shown in Figure 7 and Figure 8. Plot data for these figures are in Section 8. Total unreliability is defined as the result of the union of the UA, FTS, FTR≤1H, and FTR >1H (or FTR) failure probabilities. The FTR>1H is calculated for 7 hours and the FTR is calculated for 8 hours to provide the results for an 8-hour mission. Since the normally running systems TDP components do not have UA data or the FTR≤1H data, there is no UA or FTR≤1H for that calculation. The trending method is described in more detail in Section 4 of the Overview and Reference document [3]. In the lower left hand corner of the trend figures, the regression method is reported. There are no statistically significant trends identified in the TDP total unreliability estimates for the most recent 10-year period.

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

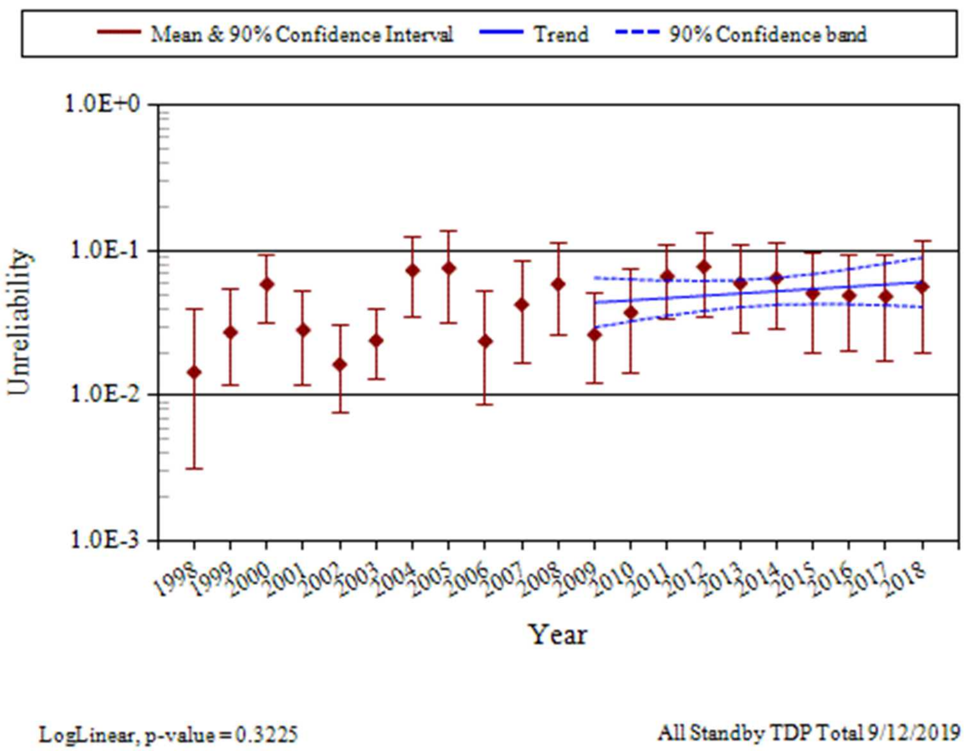

Figure 7. Standby TDP unreliability trend (8-hour mission).

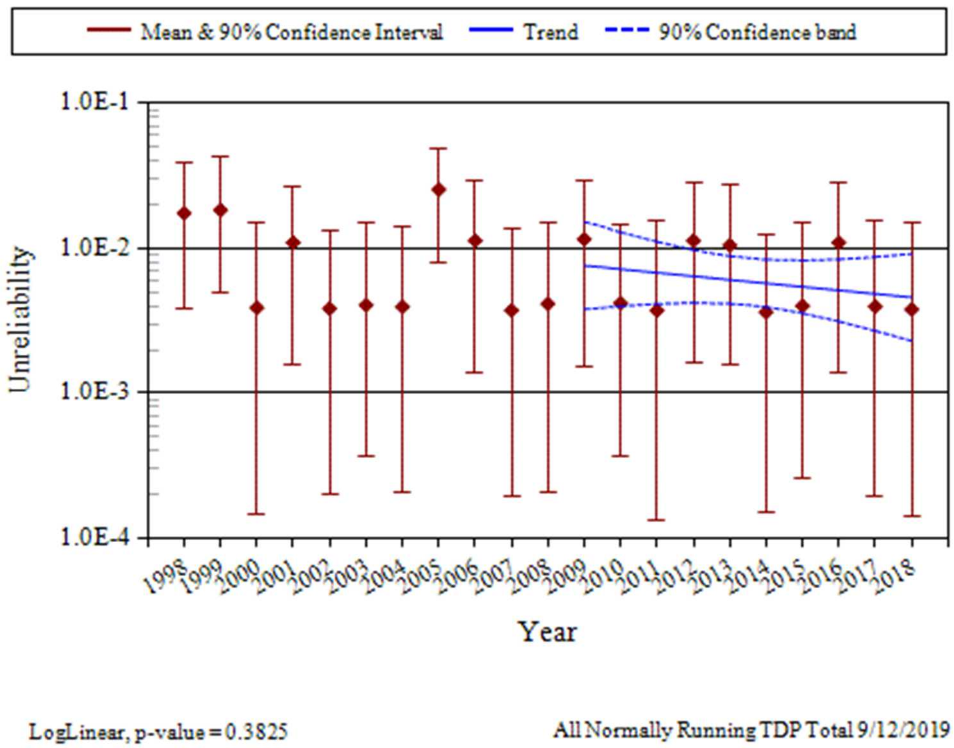

Figure 8. Normally running TDP unreliability trend (8-hour mission).

6. ENGINEERING ANALYSIS

This section presents various engineering analyses performed for TDP. Frequency trends of component failures and demands are presented in Sections 6.1 and 6.2 for standby and normally running TDPs, respectively. The data are normalized by reactor year for plants that have the equipment being trended. A comparison of ICES TDP unplanned demand results with the industry-average results for standby TDPs is presented in Section 6.3 to determine whether the current data are consistent with the 2015 Update values used in PRA. An engineering analysis of TDP failure breakdown by failure mode and other factors is presented in Section 6.4. The factors analyzed are sub-components, failure causes, detection methods, and recovery possibility.

6.1 Standby TDP Engineering Trends

This section presents frequency trends for standby TDP failures and demands. The data are normalized by reactor year for plants that have the equipment being trended. The trends provide an overview of the demand counts and failure counts associated with each failure mode across the years.

- Figure 9 shows the trend for standby TDP frequency of start demands (demands per reactor year).
- Figure 10 shows the trend for standby TDP run hours per reactor year of run ≤ 1H hours.
- Figure 11 shows the trend for standby TDP run hours per reactor year.
- Figure 12 shows the trend for standby TDP frequency of FTS events (i.e., FTS events per reactor year).
- Figure 13 shows the trend for standby TDP FTR≤1H events per reactor year.
- Figure 14 shows the trend for standby TDP FTR events per reactor year.

The data for the above figures 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 above trend figure, the regression p-values are reported. A review of these p-values shows that there are no statistically significant trends existing in the standby TDP engineering trends for the most recent 10-year period.

Table 4 to Table 6 provide a summary of TDP (both standby and normally running) FTS, FTR≤1H, and FTR>1H failure counts by system and year during the most recent 10-year period.

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

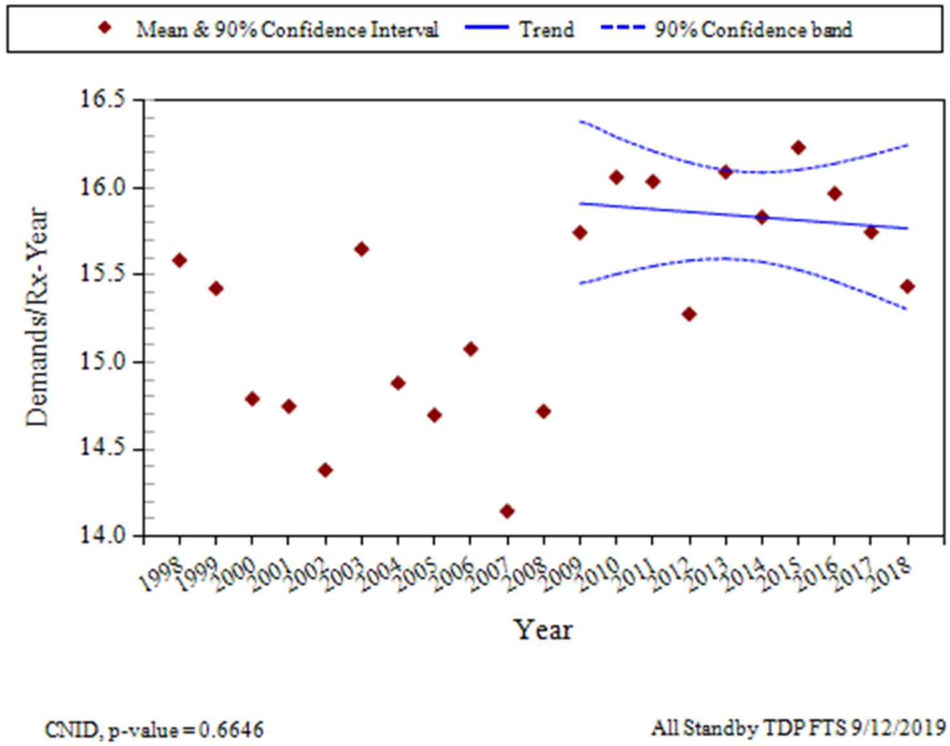

Figure 9. Frequency of start demands (demands per reactor year) for standby TDPs.

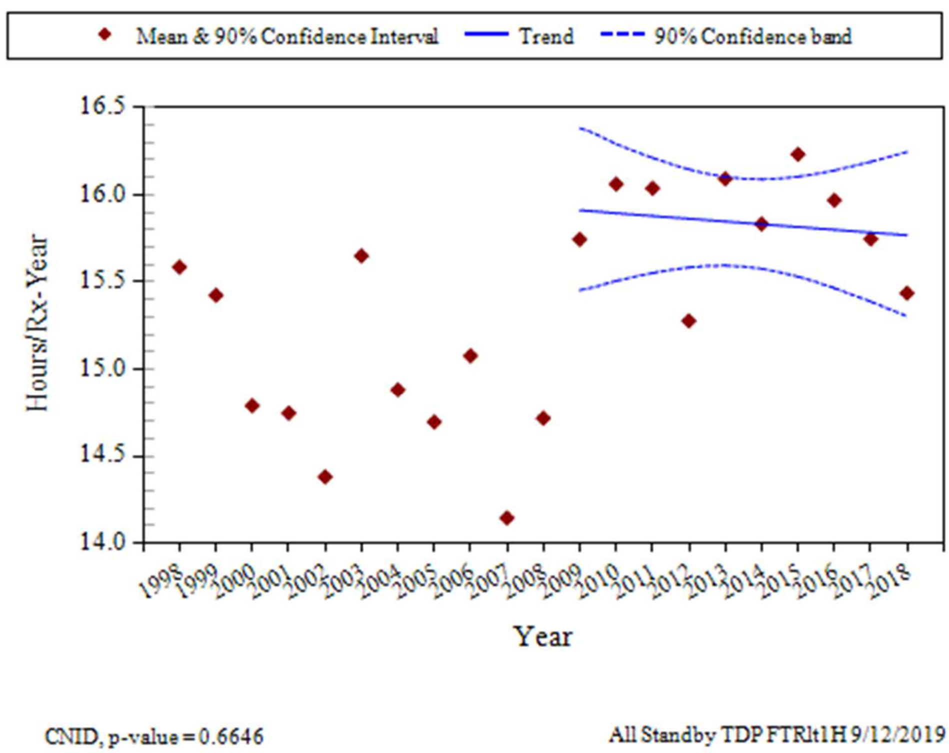

Figure 10. Frequency of run ≤ 1H hours (hours per reactor year) trend for standby TDPs.

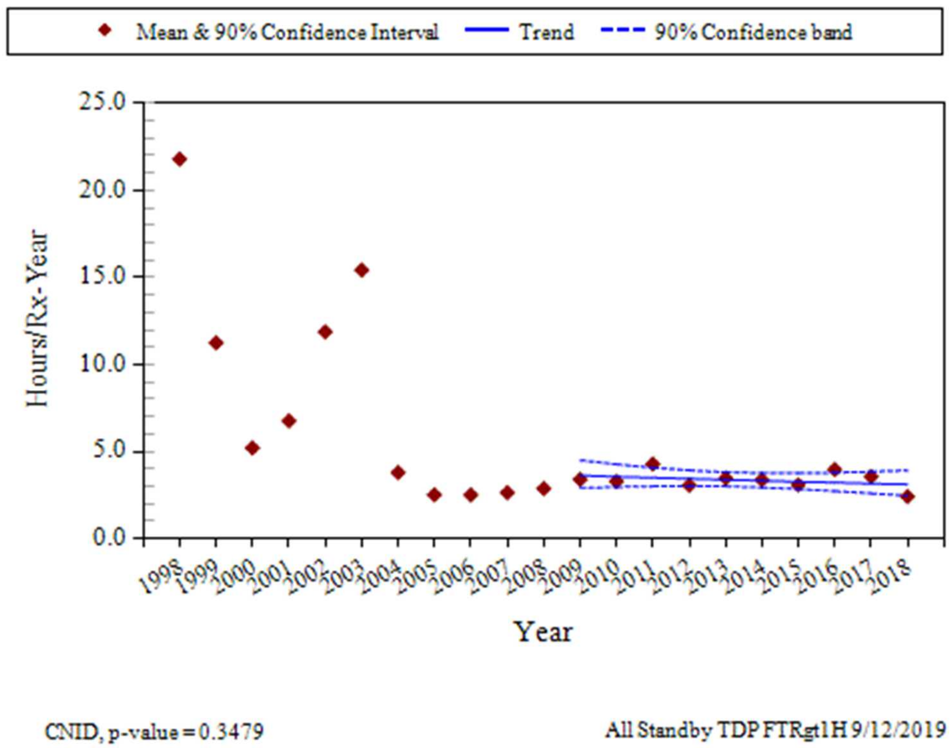

Figure 11. Frequency of run > 1H hours (hours per reactor year) trend for standby TDPs.

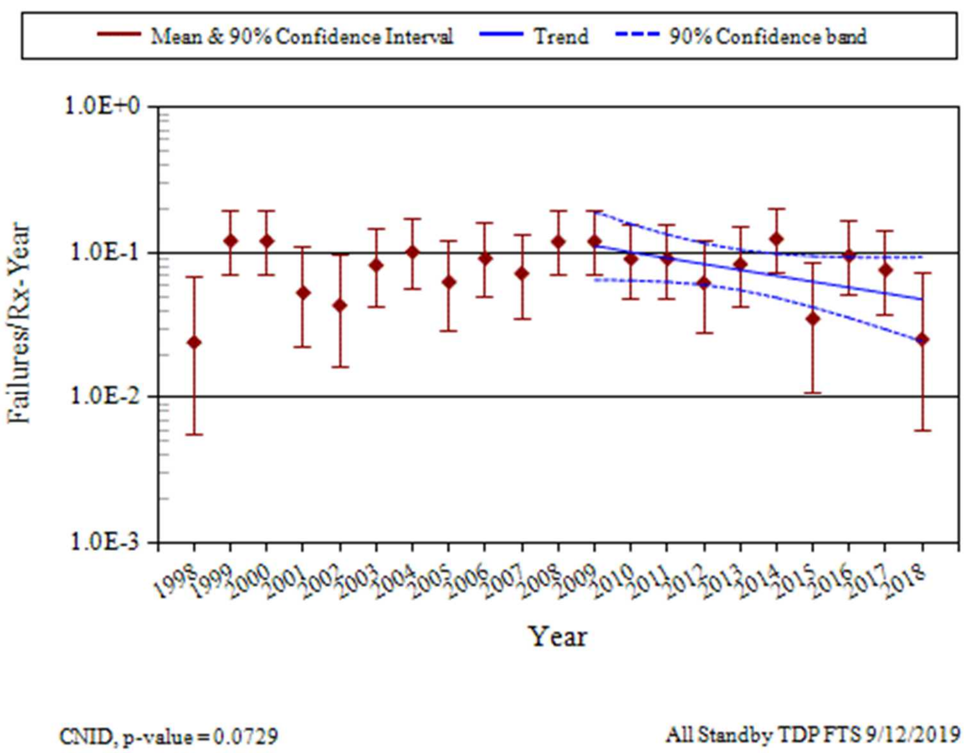

Figure 12. Frequency of FTS events (events per reactor year) trend for standby TDPs.

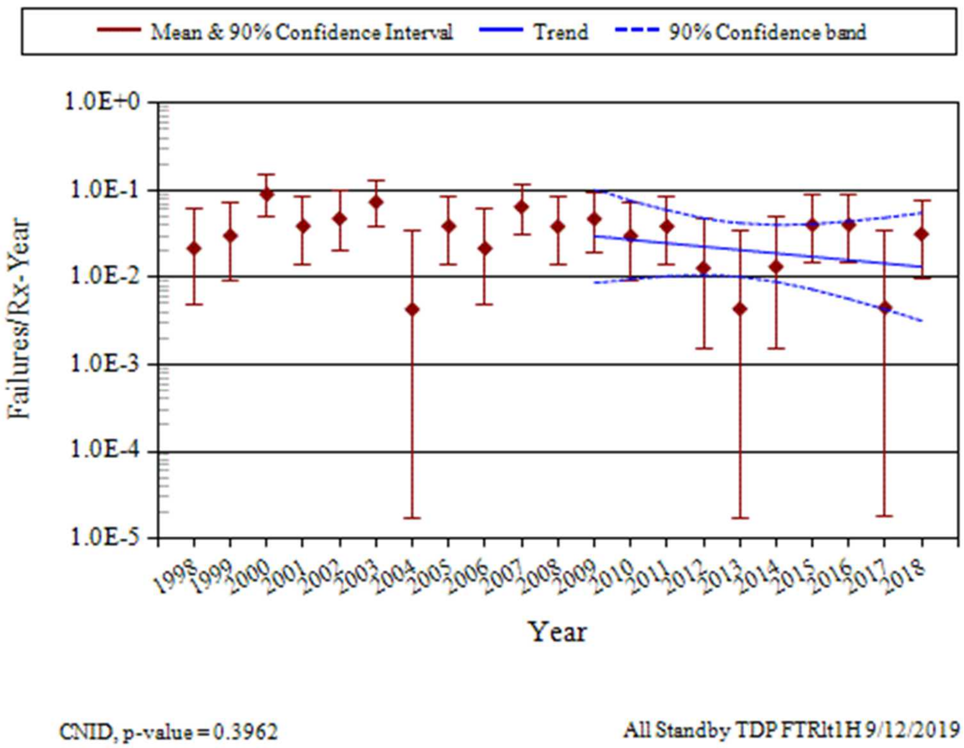

Figure 13. Frequency of FTR≤1H events (events per reactor year) trend for standby TDPs.

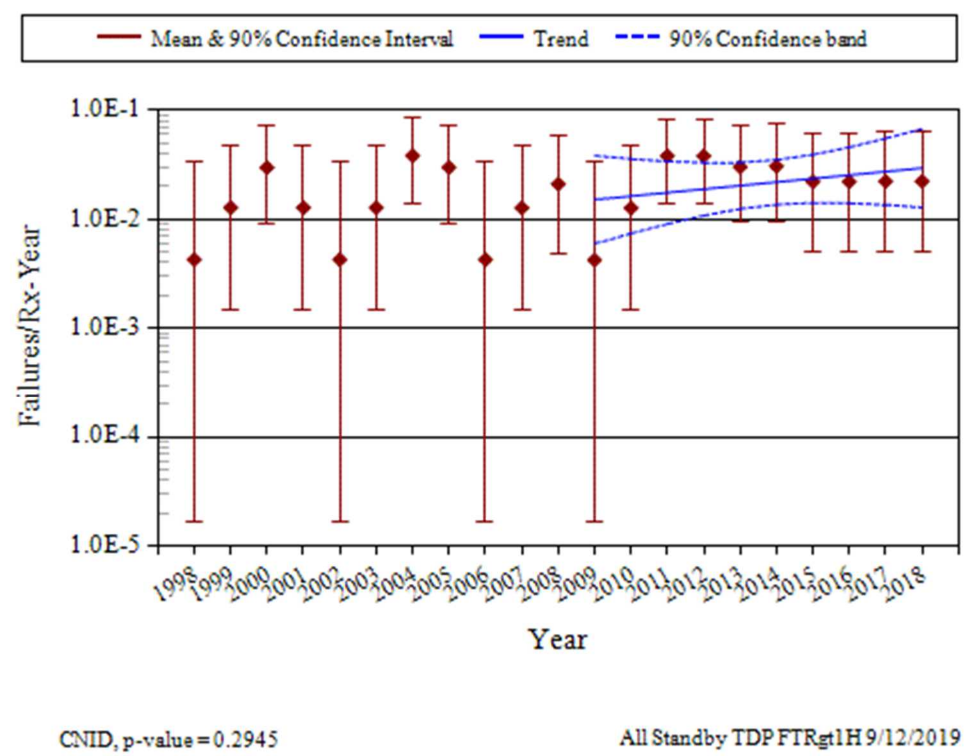

Figure 14. Frequency of FTR>1H events (events per reactor year) trend for standby TDPs.

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

System Code	TDP Count	TDP Percent	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total	Percent of Failures
AFW	74	42.0 %	6	5	4	2	4	11	2	2	4	1	41	50.6 %
HPCI	28	15.9 %	4	2	4	1	3			4	1	1	20	24.7 %
MFW	43	24.4 %	1			1	1			1			4	4.9 %
RCIC	31	17.6 %	2	2	1	3	1	1	1	3	2		16	19.8 %
Total	176	100.0%	13	9	9	7	9	12	3	10	7	2	81	100.0%

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

System Code	TDP Count	TDP Percent	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total	Percent of Failures
AFW	74	55.6 %	4	2	2			1	3	1		1	14	56.0 %
HPCI	28	21.1 %	1						1	2			4	16.0 %
RCIC	31	23.3 %		1	2	1				1		2	7	28.0 %
Total	133	100.0%	5	3	4	1	0	1	4	4	0	3	25	100.0%

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

System Code	TDP Count	TDP Percent	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total	Percent of Failures
AFW	74	42.0 %			2	3	1	2	2		1	2	13	22.8 %
HPCI	28	15.9 %		1	2		1			1			5	8.8 %
MFW	43	24.4 %	3	6	2	6	4	2	4	2	3	2	34	59.6 %
RCIC	31	17.6 %				1	1	1		1	1		5	8.8 %
Total	176	100.0%	3	7	6	10	7	5	6	4	5	4	57	100.0%

6.2 Normally Running TDP Engineering Trends

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

- Figure 15 shows the trend for normally running TDP frequency of start demands (demands per reactor year).
- Figure 16 shows the trend for normally running TDP run hours per reactor year.
- Figure 17 shows the trend for normally running TDP frequency of FTS events (i.e., FTS events per reactor year).
- Figure 18 shows the trend for normally running TDP FTR events per reactor year.

The data for the above figures are provided in Section 8. The normally running system (MFW) from Table 2 is trended for each figure.

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

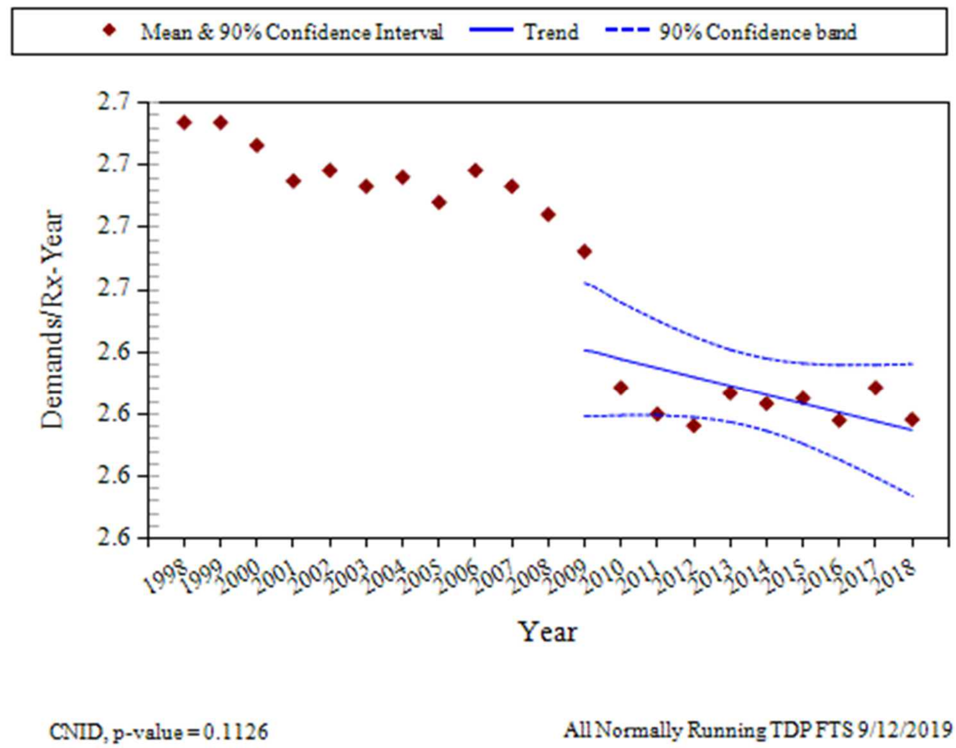

Figure 15. Frequency of start demands (demands per reactor year) trend for normally running TDPs.

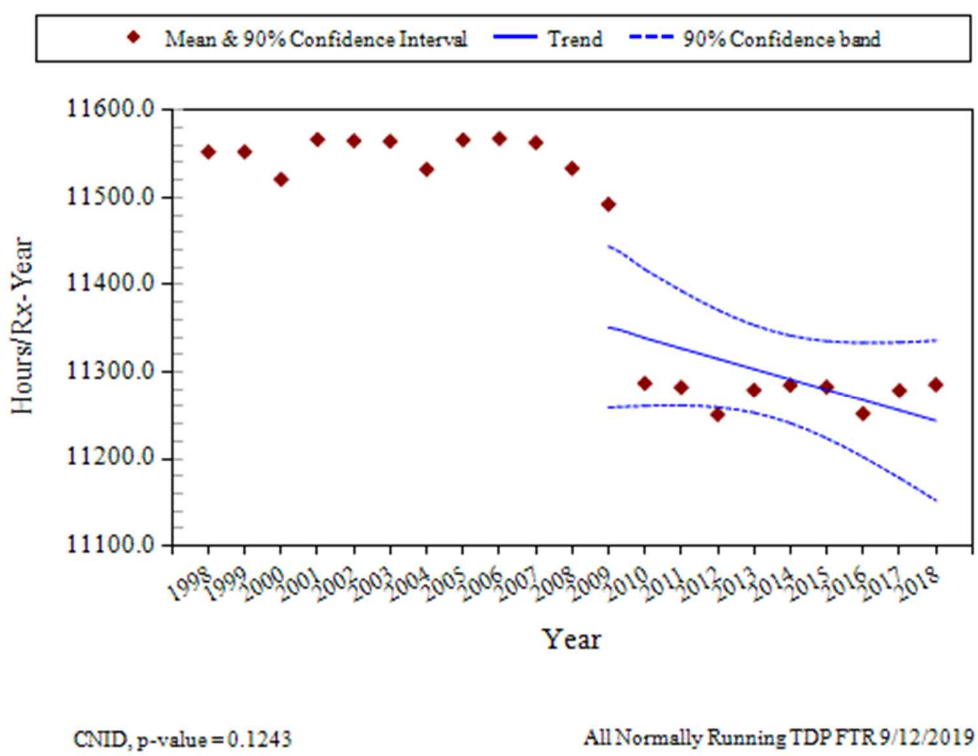

Figure 16. Frequency of run hours (hours per reactor year) trend for normally running TDPs.

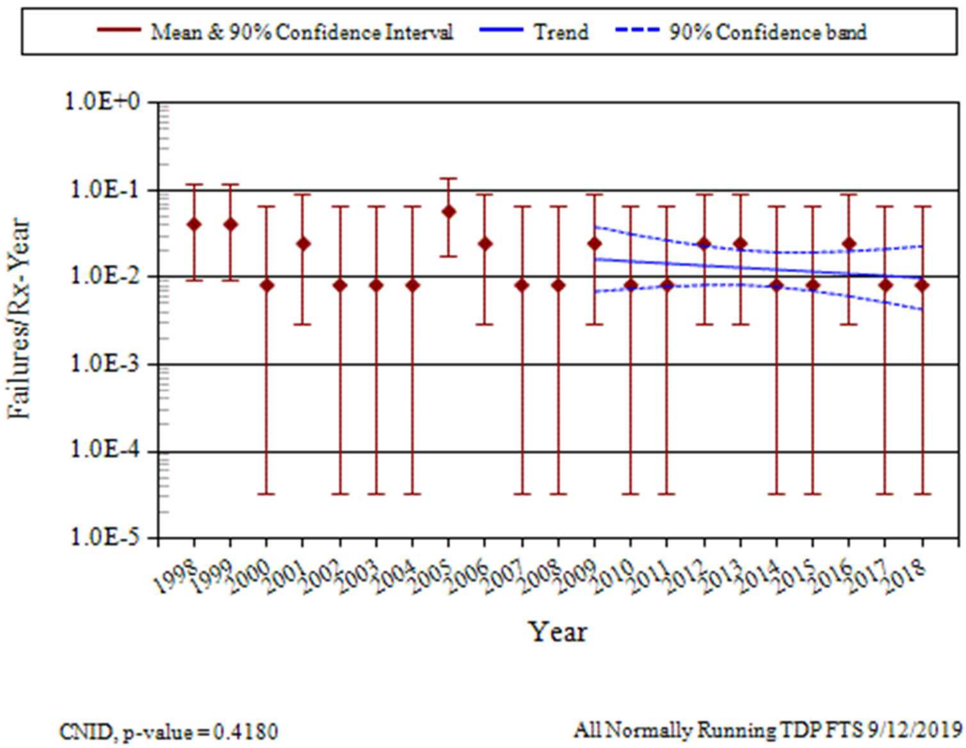

Figure 17. Frequency of FTS events (events per reactor year) trend for normally running TDPs.

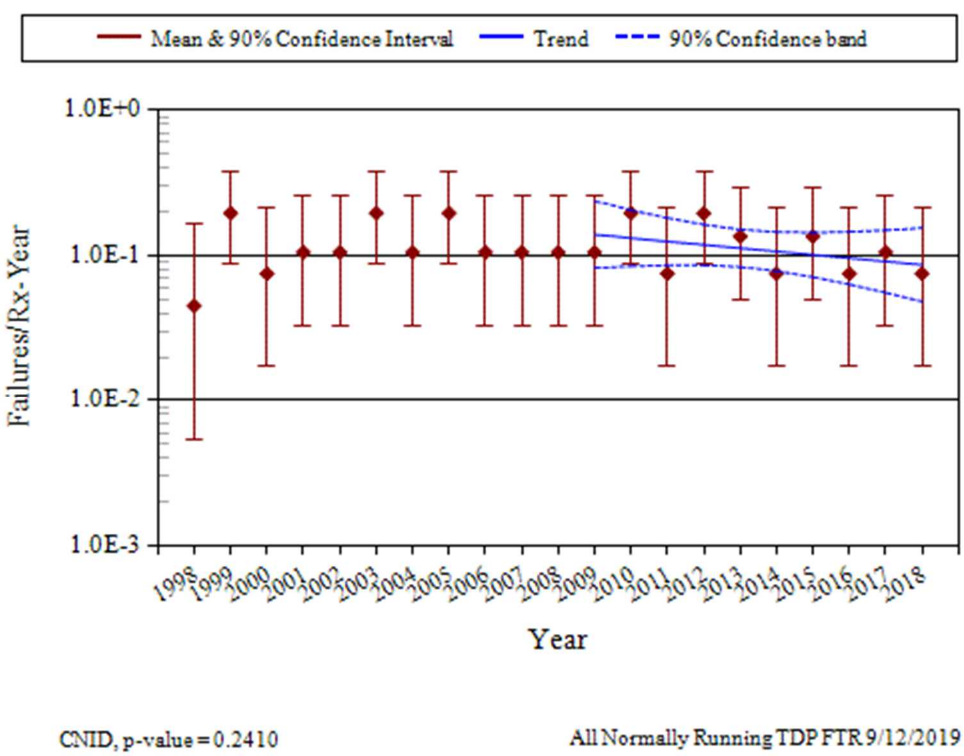

Figure 18. Frequency of FTR events (events per reactor year) trend for normally running TDPs.

6.3 Comparison of ICES TDP Unplanned Demand Results with Industry Results

An ongoing concern in the industry is whether a combination of test, non-test demand, and actual demand data adequately represents standby component performance during unplanned demands. This comparison evaluates the same dataset for standby components that is used for the overall trends shown in this document, but limits the failure data to those that are discovered during an ESF demand and the ESF demands reported in ICES. The data are further limited to 2003 to present since the ESF demand reporting in ICES is inconsistent prior to 2003.

The standby TDP ESF unplanned demand data covering 2003 through 2018 are summarized in Table 7. Consistency between the unplanned demand data and 2015 Update industry-average performance from Table 2 was evaluated using the predictive distribution approach outlined in the Handbook of Parameter Estimation for PRA, NUREG/CR-6823, Sections 6.2.3.5 and 6.3.3.4 [8].

The unplanned demand data were aggregated at the plant and system level (failures and demands). Assuming each plant and system can have a different failure probability, the industry-average distribution (from Table 2) was sampled for each plant and system. The predicted number of failure events for each plant and system was evaluated using the binomial distribution with the plant-specific failure probability and its associated number of demands. Then the total number of predicted failures was obtained by summing the individual plant results. This process was repeated 1000 times, each time obtaining a total number of predicted failures. The 1000 sample results were ordered from high to low. Then the actual number of unplanned demand failures observed (listed in the "Observed Failures" column of Table 7) was compared with this sample to determine the probability of observing this number of failures or greater. If the probability was greater than 0.05 and less than 0.95, then the unplanned demand performance was considered to be consistent with the industry-average distribution obtained from the ICES data analysis.

Table 7. Standby TDP unplanned demand performance comparison with industry-average performance.

Failure Modes	Plants	Demands or Hours	Observed Failures	Expected Failures	Probability of ≥ Failures	Consistent with Industry-Average Performance? [a]
FTS	98	717	4	4.3	0.45	Yes
FTR≤1H	98	450	7	1.7	0.05	No
FTR>1H	98	1103	1	2.4	0.90	Yes

a. If the probability of observing the actual failures or greater is ≥ 0.05 and ≤ 0.95, then the observed failure count is considered to be consistent with the industry-average performance.

These consistency checks show that the FTS and FTR>1H failure observations in the non-test, operational ESF demand data lie within their corresponding industry-average failure estimate distributions, provided in the 2015 Update (Table 2), that were based on both test and non-test operational ESF demands. However, the FTR≤1H failure observations are not consistent with the industry-average failure estimate distributions, which means that the TDP performs worse on a non-test, operational ESF demand than on a test demand.

6.4 TDP Engineering Analysis by Failure Modes

The engineering analysis of TDP failure sub-components, causes, detection methods, and recovery possibility are presented in this section. First, each analysis divides the events into two categories: standby and normally running TDPs. Note that the FTR≤1H failure mode only applies to standby TDPs and therefore only shows the Standby category data.

The second division of the events is by the failure mode determined after ICES data review by the Idaho National Laboratory (INL) staff. See Section 7 for more description of failure modes.

TDP sub-component contributions to the three failure modes are presented in Figure 19. The sub-component categories are similar to those used in the CCF database. The driver (specifically the governor) has the highest percentage contributions to failures for all the failure modes.

TDP failure cause group contributions to the three failure modes are presented in Figure 20. The cause groups have been re-arranged in this update study in order to align with those currently used in the CCF database. Table 8 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, design issues, and component 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.

TDP failure detection methods for the three failure modes are presented in Figure 21. There are differences in the detection method based on the standby and normally running categories.

Standby—the most likely detection method for all three failure modes is testing. Inspection is also important for the FTS failure mode. The incidence of inspection for the FTS failure mode indicates that the equipment was observed to be unable to start without a demand (e.g., an alarmed condition, leaking oil, state of another component, etc.).

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

TDP recovery fractions for the three failure modes are presented in Figure 22. The overall non-recovery to recovery ratio is approximately 6:1, meaning that 6 of every 7 failures were not recovered.

Table 8. Component failure cause groups.[a]

Group	Specific Cause	Description
Component	Internal to component, piece-part	Used when the cause of a failure is a non-specific result of a failure internal to the component that failed other than aging or wear.
	Set point drift	Used when the cause of a failure is the result of set point drift or adjustment.
	Age/Wear	Used when the cause of the failure is a non-specific aging or wear issue.
Design	Construction/installation error or inadequacy	Used when a construction or installation error is made during the original or modification installation. This includes specification of incorrect component or material.
	Design error or inadequacy	Used when a design error is made.
	Manufacturing error or inadequacy	Used when a manufacturing error is made during component manufacture.
Environment	Ambient environmental stress	Used when the cause of a failure is the result of an environmental condition from the location of the component.
	Internal environment	The internal environment led to the failure. Debris/Foreign material as well as an operating medium chemistry issue.
	Extreme environmental stress	Used when the cause of a failure is the result of an environmental condition that places a higher than expected load on the equipment and is transitory in nature.
Human	Accidental action (unintentional or undesired human errors)	Used when a human error (during the performance of an activity) results in an unintentional or undesired action.
	Human action procedure	Used when the correct procedure is not followed or the wrong procedure is followed. For example: when a missed step or incorrect step in a surveillance procedure results in a component failure.
	Inadequate maintenance	Used when a human error (during the performance of maintenance) results in an unintentional or undesired action.
	Inadequate procedure	Used when the cause of a failure is the result of an inadequate procedure operating or maintenance.
Other	State of other component	Used when the cause of a failure is the result of a component state that is not associated with the component that failed. An example would be the diesel failed due to empty fuel storage tanks.
	Other (stated cause does not fit other categories)	Used when the cause of a failure is provided but it does not meet any one of the descriptions.
	Unknown	Used when the cause of the failure is not known.

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

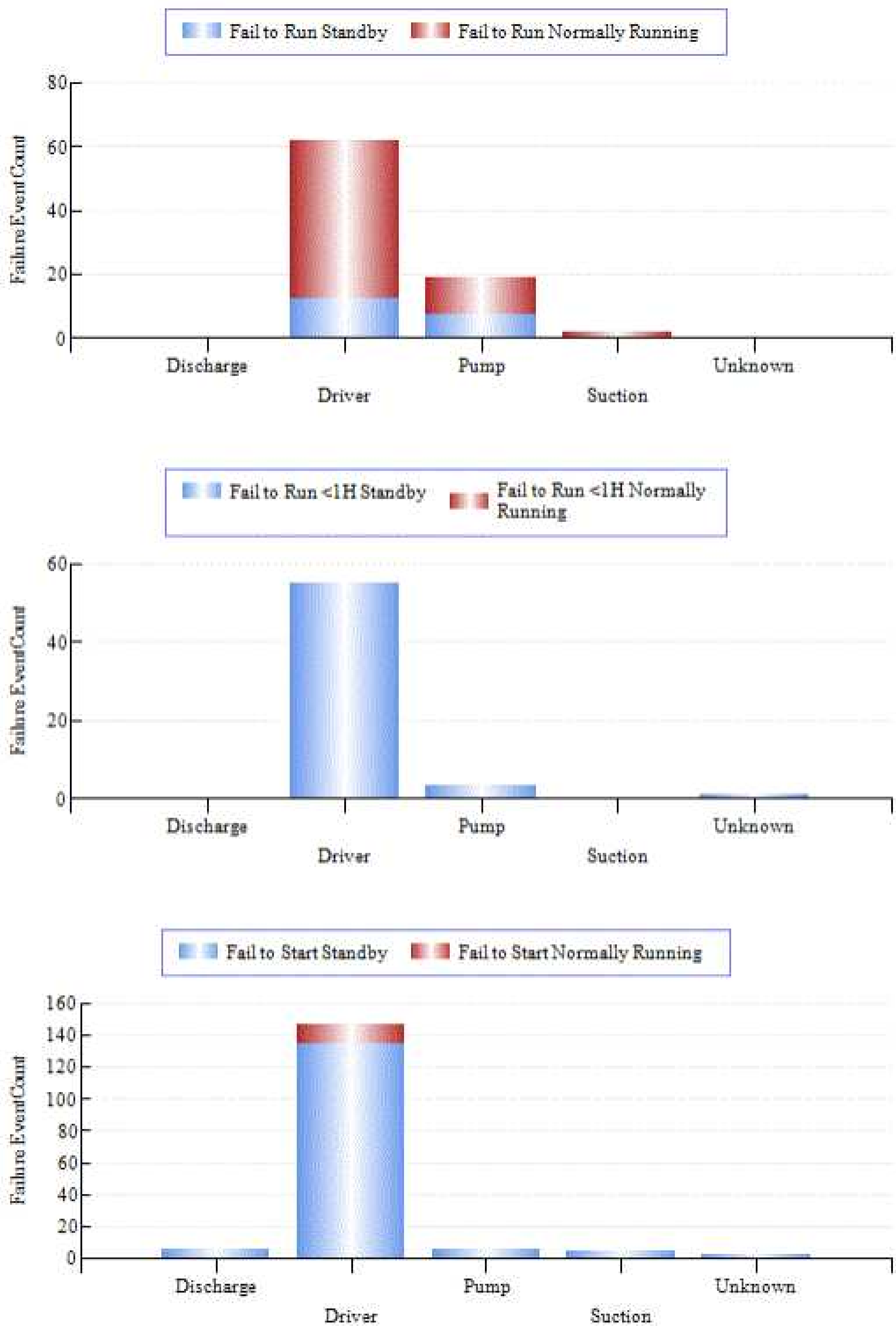

Figure 19. TDP failure event breakdown by subcomponent, failure mode, and operational status.

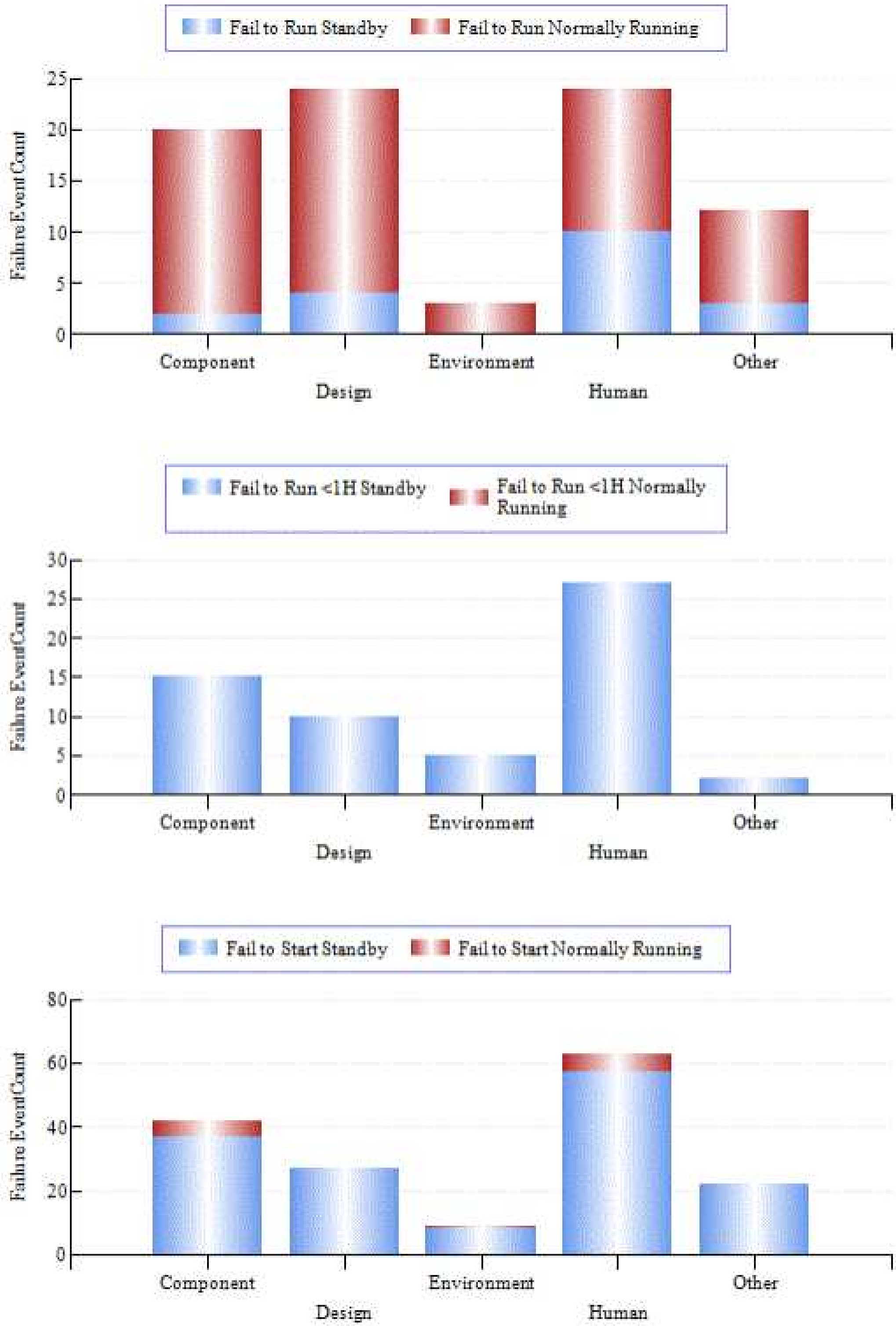

Figure 20. TDP failure event breakdown by cause group, failure mode, and operational status.

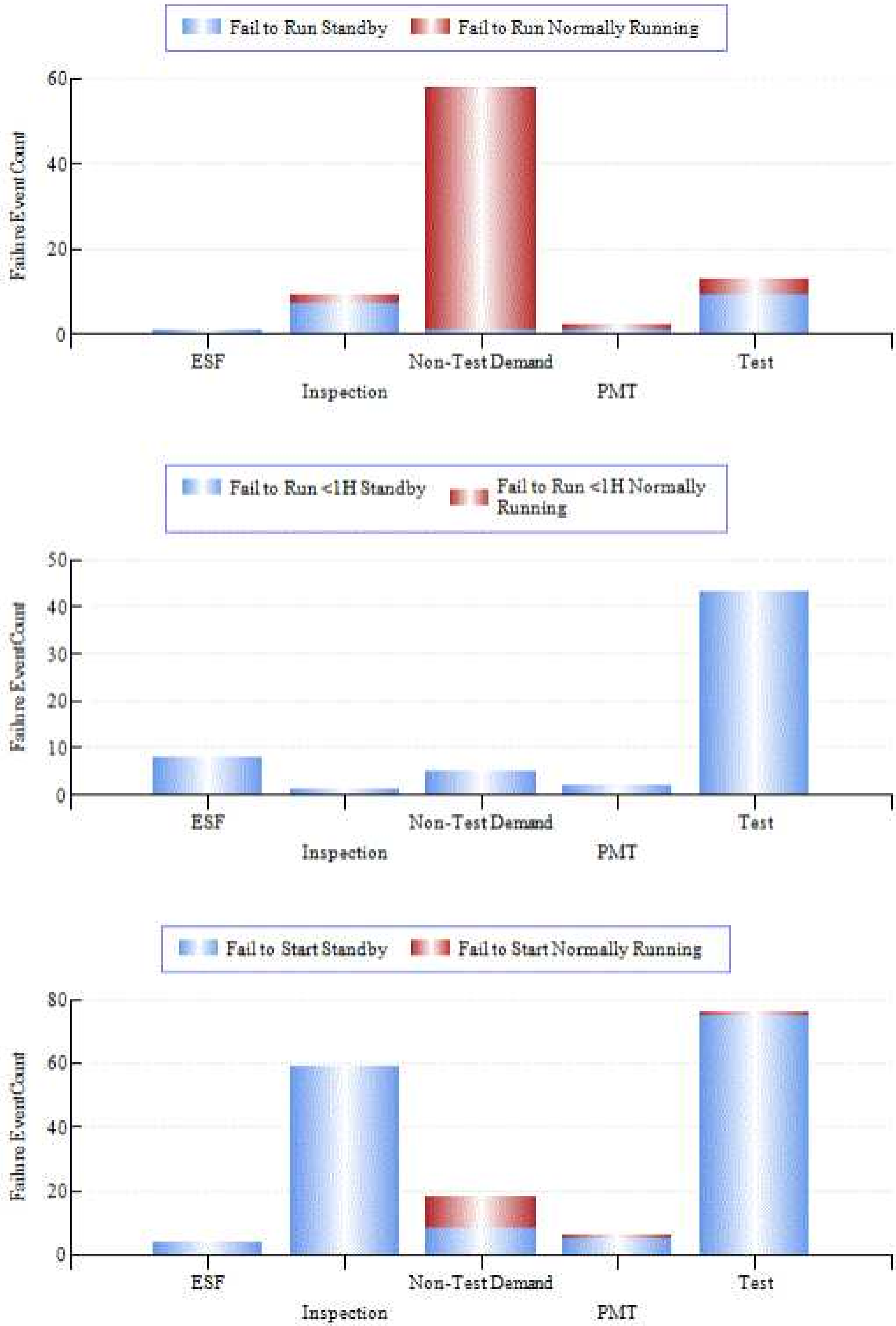

Figure 21. TDP failure event breakdown by failure detection method, failure mode, and operational status.

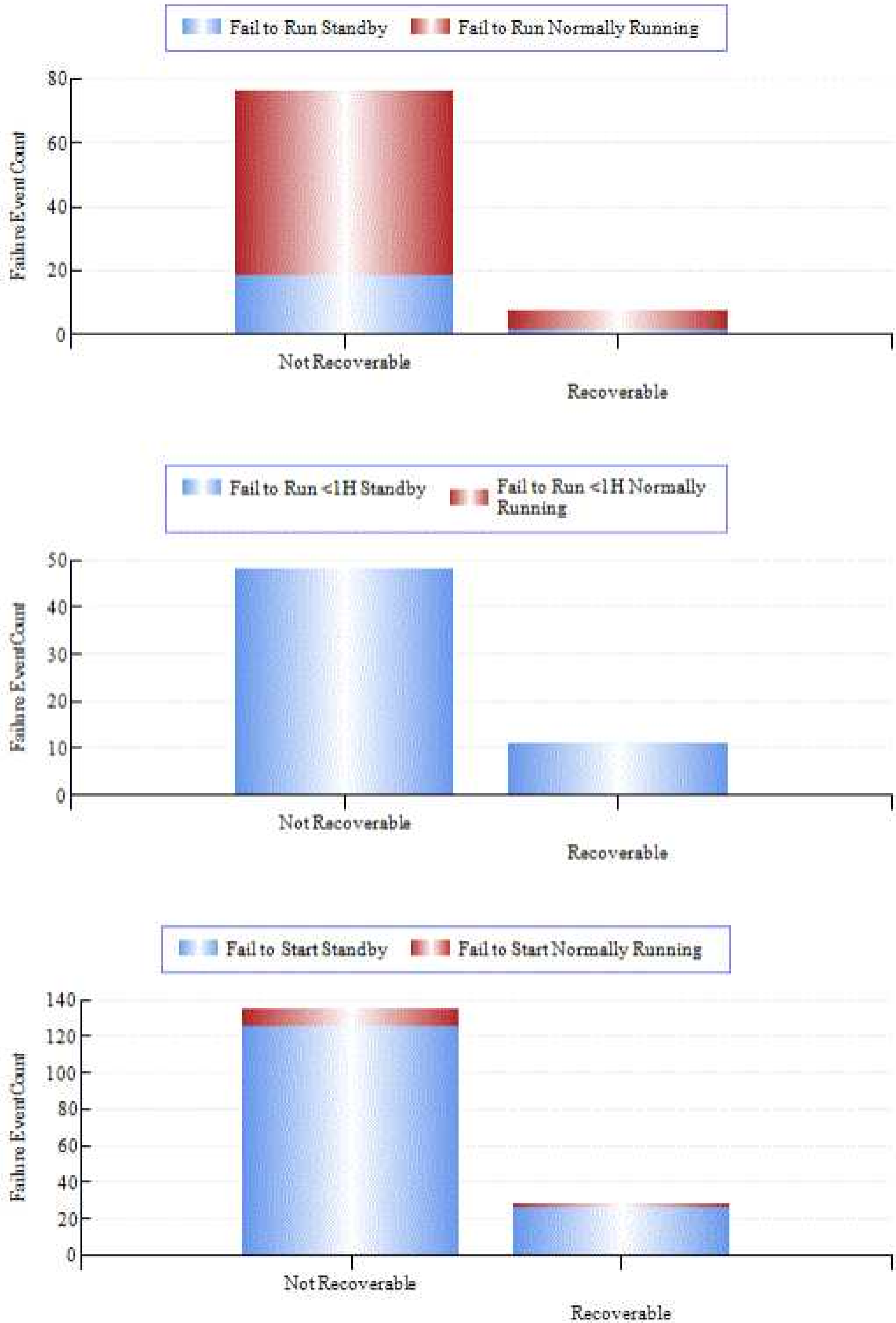

Figure 22. TDP failure event breakdown by recoverability determination, failure mode, and operational status.

7. TDP ASSEMBLY DESCRIPTION

The TDP is generally comprised of a pump, a turbine driver, and a governor. Most plant designs use a single stage "Terry Turbine", whose piece-parts include a turbine trip and throttle valve, a mechanical over speed trip mechanism, and a lubrication system. The various types of governors used for turbine speed control are mostly manufactured by the Woodward Corporation. For the AFW system TDP, the governors are predominantly mechanical/hydraulic; pressure-compensated, and have a pneumatic remote speed-setting capability. For the RCIC and HPCI systems, the TDPs typically have a Woodward type EG-M electric/electronic governor and EGR hydraulic actuators. Piece-parts of all governors include a turbine stop valve and a governor valve, while the EG-M usually includes a ramp generator/signal converter and other electrical controls.

The TDP failure modes include FTS, FTR≤1H, and FTR>1H. These failure modes were used in NUREG/CR-6928 [7] and are similar to those used in the MSPI Program.

Guidelines for determining whether a component event reported in ICES is to be included in FTS, FTR≤1H, or FTR>1H are similar to those used in the MSPI Program. In general, any circumstance in which the component is not able to meet the performance requirements defined in the PRA is counted. This includes conditions revealed through testing, operational demands, unplanned demands, or discovery. Also, run failures that occur beyond the typical 24-hour mission time in PRAs are included. However, certain events are excluded: slow starting times that do not exceed the PRA success criteria, conditions that are annunciated immediately in the control room without a demand, and run events that are shown to not have caused an actual run failure within 24 hours. Also, events occurring during maintenance or post-maintenance testing that are related to the actual maintenance activities are excluded. All of the TDP events within ICES were reviewed to ensure that they were binned to the correct failure mode—FTS, FTR≤1H, FTR>1H, or no failure. However, even given detailed descriptions of failure events, this binning still required some judgment and involves some uncertainty.

Guidelines for counting demands and run hours are similar to those in the MSPI Program. Start and run demands include those resulting from tests, operational demands, and unplanned demands. Demands during maintenance and post-maintenance testing are excluded. Similarly, run hours include those from tests, operational demands, and unplanned demands.

8. DATA TABLES

In this section, the plot data for Figure 1 to Figure 18 in previous sections are provided in Table 9 to Table 26, respectively.

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

Table 9. Plot data for Figure 1, failure probability estimate trend for standby TDP FTS.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	**Failures**	**Demands**	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
2015 Update						5.35E-04	1.62E-02	5.93E-03
1998	2	1,512	--	--	--	3.56E-04	4.36E-03	1.55E-03
1999	12	1,496	--	--	--	4.59E-03	1.26E-02	7.84E-03
2000	12	1,438	--	--	--	4.76E-03	1.30E-02	8.14E-03
2001	5	1,430	--	--	--	1.50E-03	7.31E-03	3.60E-03
2002	4	1,395	--	--	--	1.11E-03	6.58E-03	3.02E-03
2003	8	1,518	--	--	--	2.69E-03	9.31E-03	5.26E-03
2004	10	1,447	--	--	--	3.76E-03	1.14E-02	6.80E-03
2005	6	1,425	--	--	--	1.94E-03	8.19E-03	4.27E-03
2006	9	1,462	--	--	--	3.25E-03	1.05E-02	6.09E-03
2007	7	1,381	--	--	--	2.46E-03	9.31E-03	5.07E-03
2008	12	1,446	--	--	--	4.74E-03	1.30E-02	8.10E-03
2009	12	1,543	6.98E-03	4.13E-03	1.18E-02	4.46E-03	1.22E-02	7.62E-03
2010	9	1,574	6.36E-03	4.09E-03	9.88E-03	3.03E-03	9.75E-03	5.68E-03
2011	9	1,572	5.81E-03	4.00E-03	8.41E-03	3.03E-03	9.77E-03	5.69E-03
2012	6	1,501	5.30E-03	3.82E-03	7.34E-03	1.84E-03	7.80E-03	4.07E-03
2013	8	1,538	4.83E-03	3.52E-03	6.62E-03	2.65E-03	9.20E-03	5.20E-03
2014	12	1,488	4.41E-03	3.12E-03	6.22E-03	4.61E-03	1.26E-02	7.88E-03
2015	3	1,510	4.02E-03	2.69E-03	6.01E-03	6.75E-04	5.26E-03	2.18E-03
2016	9	1,485	3.67E-03	2.27E-03	5.93E-03	3.20E-03	1.03E-02	6.00E-03
2017	7	1,449	3.34E-03	1.89E-03	5.91E-03	2.35E-03	8.90E-03	4.85E-03
2018	2	1,420	3.05E-03	1.56E-03	5.94E-03	3.78E-04	4.63E-03	1.65E-03
Total	164	31,031						

Table 10. Plot data for Figure 2, failure probability estimate trend for standby TDP FTR≤1H.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	**Failures**	**Demands**	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
2015 Update						1.51E-04	1.15E-02	3.71E-03
1998	2	1,512	--	--	--	3.17E-04	3.89E-03	1.38E-03
1999	3	1,496	--	--	--	6.05E-04	4.72E-03	1.95E-03
2000	10	1,438	--	--	--	3.34E-03	1.01E-02	6.06E-03
2001	4	1,430	--	--	--	9.63E-04	5.70E-03	2.61E-03
2002	5	1,395	--	--	--	1.35E-03	6.61E-03	3.25E-03
2003	8	1,518	--	--	--	2.39E-03	8.31E-03	4.69E-03
2004	0	1,447	--	--	--	1.13E-06	2.24E-03	2.87E-04
2005	4	1,425	--	--	--	9.66E-04	5.72E-03	2.61E-03
2006	2	1,462	--	--	--	3.26E-04	4.00E-03	1.42E-03
2007	7	1,381	--	--	--	2.17E-03	8.23E-03	4.47E-03
2008	4	1,446	--	--	--	9.54E-04	5.65E-03	2.58E-03
2009	5	1,543	1.87E-03	5.47E-04	6.37E-03	1.24E-03	6.08E-03	2.99E-03
2010	3	1,574	1.71E-03	6.07E-04	4.81E-03	5.80E-04	4.52E-03	1.87E-03
2011	4	1,572	1.56E-03	6.54E-04	3.73E-03	8.90E-04	5.27E-03	2.41E-03
2012	1	1,501	1.43E-03	6.72E-04	3.04E-03	9.79E-05	3.08E-03	8.35E-04
2013	0	1,538	1.31E-03	6.44E-04	2.66E-03	1.07E-06	2.13E-03	2.73E-04
2014	1	1,488	1.20E-03	5.66E-04	2.54E-03	9.86E-05	3.10E-03	8.41E-04
2015	4	1,510	1.10E-03	4.63E-04	2.60E-03	9.21E-04	5.45E-03	2.49E-03
2016	4	1,485	1.00E-03	3.61E-04	2.79E-03	9.34E-04	5.52E-03	2.53E-03
2017	0	1,449	9.19E-04	2.73E-04	3.09E-03	1.13E-06	2.24E-03	2.87E-04
2018	3	1,420	8.41E-04	2.03E-04	3.49E-03	6.32E-04	4.93E-03	2.04E-03
Total	74	31,031						

Table 11. Plot data for Figure 3, failure rate estimate trend for standby TDP FTR>1H.

Year	Failures	Hours	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						1.51E-03	2.99E-03	2.20E-03
1998	0	2,117	--	--	--	9.00E-07	1.79E-03	2.29E-04
1999	1	1,092	--	--	--	1.52E-04	4.77E-03	1.29E-03
2000	3	506	--	--	--	1.89E-03	1.47E-02	6.09E-03
2001	1	655	--	--	--	2.43E-04	7.65E-03	2.07E-03
2002	0	1,154	--	--	--	1.61E-06	3.20E-03	4.09E-04
2003	1	1,498	--	--	--	1.12E-04	3.53E-03	9.57E-04
2004	4	368	--	--	--	3.80E-03	2.25E-02	1.03E-02
2005	3	243	--	--	--	3.48E-03	2.72E-02	1.12E-02
2006	0	242	--	--	--	6.32E-06	1.26E-02	1.61E-03
2007	1	256	--	--	--	5.42E-04	1.70E-02	4.62E-03
2008	2	282	--	--	--	1.64E-03	2.01E-02	7.14E-03
2009	0	332	4.30E-03	1.76E-03	1.05E-02	4.90E-06	9.75E-03	1.25E-03
2010	1	321	4.68E-03	2.19E-03	1.00E-02	4.52E-04	1.42E-02	3.85E-03
2011	4	419	5.09E-03	2.69E-03	9.65E-03	3.41E-03	2.02E-02	9.23E-03
2012	4	301	5.54E-03	3.24E-03	9.50E-03	4.50E-03	2.66E-02	1.22E-02
2013	3	331	6.04E-03	3.76E-03	9.68E-03	2.71E-03	2.12E-02	8.77E-03
2014	3	317	6.57E-03	4.16E-03	1.04E-02	2.81E-03	2.20E-02	9.08E-03
2015	2	286	7.16E-03	4.36E-03	1.17E-02	1.62E-03	1.98E-02	7.06E-03
2016	2	368	7.79E-03	4.37E-03	1.39E-02	1.31E-03	1.61E-02	5.73E-03
2017	2	326	8.49E-03	4.26E-03	1.69E-02	1.45E-03	1.78E-02	6.33E-03
2018	2	222	9.24E-03	4.08E-03	2.09E-02	1.97E-03	2.42E-02	8.62E-03
Total	39	11,636						

Table 12. Plot data for Figure 4, failure probability estimate trend for normally running TDP FTS.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Demands	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						4.01E-04	2.78E-02	9.16E-03
1998	2	79	--	--	--	3.51E-03	4.24E-02	1.53E-02
1999	2	79	--	--	--	3.51E-03	4.24E-02	1.53E-02
2000	0	79	--	--	--	1.20E-05	2.36E-02	3.06E-03
2001	1	78	--	--	--	1.08E-03	3.35E-02	9.20E-03
2002	0	78	--	--	--	1.20E-05	2.37E-02	3.07E-03
2003	0	78	--	--	--	1.20E-05	2.37E-02	3.07E-03
2004	0	78	--	--	--	1.20E-05	2.37E-02	3.06E-03
2005	3	78	--	--	--	6.69E-03	5.12E-02	2.15E-02
2006	1	78	--	--	--	1.08E-03	3.35E-02	9.20E-03
2007	0	78	--	--	--	1.20E-05	2.37E-02	3.07E-03
2008	0	78	--	--	--	1.21E-05	2.37E-02	3.07E-03
2009	1	78	6.13E-03	2.62E-03	1.43E-02	1.08E-03	3.37E-02	9.24E-03
2010	0	76	5.81E-03	2.82E-03	1.19E-02	1.22E-05	2.40E-02	3.10E-03
2011	0	76	5.51E-03	3.00E-03	1.01E-02	1.22E-05	2.40E-02	3.11E-03
2012	1	76	5.22E-03	3.11E-03	8.74E-03	1.09E-03	3.40E-02	9.32E-03
2013	1	76	4.95E-03	3.12E-03	7.85E-03	1.09E-03	3.40E-02	9.32E-03
2014	0	76	4.69E-03	2.96E-03	7.42E-03	1.22E-05	2.40E-02	3.11E-03
2015	0	76	4.45E-03	2.68E-03	7.38E-03	1.22E-05	2.40E-02	3.11E-03
2016	1	76	4.22E-03	2.33E-03	7.63E-03	1.09E-03	3.40E-02	9.32E-03
2017	0	76	4.00E-03	1.97E-03	8.09E-03	1.22E-05	2.40E-02	3.10E-03
2018	0	76	3.79E-03	1.64E-03	8.71E-03	1.22E-05	2.40E-02	3.11E-03
Total	13	1,624						

Table 13. Plot data for Figure 5, failure rate estimate trend for normally running TDP FTR.

Year	Failures	Hours	Regression Curve Data Points Mean	Regression Curve Data Points Lower (5%)	Regression Curve Data Points Upper (95%)	Yearly Estimate Data Points Lower (5%)	Yearly Estimate Data Points Upper (95%)	Yearly Estimate Data Points Mean
2015 Update						1.52E-06	2.67E-05	1.07E-05
1998	1	335,022	--	--	--	4.60E-07	1.45E-05	3.92E-06
1999	6	335,022	--	--	--	7.70E-06	3.27E-05	1.70E-05
2000	2	335,022	--	--	--	1.50E-06	1.84E-05	6.54E-06
2001	3	335,432	--	--	--	2.83E-06	2.21E-05	9.14E-06
2002	3	335,387	--	--	--	2.83E-06	2.21E-05	9.14E-06
2003	6	335,371	--	--	--	7.69E-06	3.26E-05	1.70E-05
2004	3	335,356	--	--	--	2.83E-06	2.21E-05	9.14E-06
2005	6	335,417	--	--	--	7.69E-06	3.26E-05	1.70E-05
2006	3	335,463	--	--	--	2.83E-06	2.21E-05	9.14E-06
2007	3	335,326	--	--	--	2.83E-06	2.21E-05	9.14E-06
2008	3	335,387	--	--	--	2.83E-06	2.21E-05	9.14E-06
2009	3	333,274	1.22E-05	7.21E-06	2.07E-05	2.85E-06	2.22E-05	9.19E-06
2010	6	327,318	1.16E-05	7.43E-06	1.81E-05	7.86E-06	3.33E-05	1.73E-05
2011	2	327,181	1.10E-05	7.58E-06	1.60E-05	1.53E-06	1.88E-05	6.67E-06
2012	6	327,166	1.05E-05	7.59E-06	1.45E-05	7.86E-06	3.34E-05	1.73E-05
2013	4	327,089	9.95E-06	7.38E-06	1.34E-05	4.44E-06	2.63E-05	1.20E-05
2014	2	327,257	9.45E-06	6.93E-06	1.29E-05	1.53E-06	1.88E-05	6.67E-06
2015	4	327,196	8.98E-06	6.31E-06	1.28E-05	4.44E-06	2.63E-05	1.20E-05
2016	2	327,196	8.53E-06	5.62E-06	1.30E-05	1.53E-06	1.88E-05	6.67E-06
2017	3	327,074	8.10E-06	4.93E-06	1.33E-05	2.89E-06	2.26E-05	9.34E-06
2018	2	327,272	7.70E-06	4.30E-06	1.38E-05	1.53E-06	1.88E-05	6.67E-06
Total	73	6,966,227						

Table 14. Plot data for Figure 6, pooled standby TDP UA trend.

Year	UA Hours	Critical Hours	Regression Curve Data Points Mean	Regression Curve Data Points Lower (5%)	Regression Curve Data Points Upper (95%)	Yearly Estimate Data Points Lower (5%)	Yearly Estimate Data Points Upper (95%)	Yearly Estimate Data Points Mean
2015 Update						2.92E-04	1.41E-02	7.25E-03
1998	8,302.7	866,019.5	--	--	--	1.06E-04	3.54E-02	9.96E-03
1999	8,368.3	932,826.8	--	--	--	6.85E-04	2.55E-02	9.06E-03
2000	7,171.6	953,904.4	--	--	--	8.55E-04	2.05E-02	7.77E-03
2001	7,895.0	960,556.3	--	--	--	3.67E-04	2.56E-02	8.39E-03
2002	7,870.1	962,744.5	--	--	--	5.37E-04	2.36E-02	8.19E-03
2003	8,371.1	939,190.1	--	--	--	8.62E-04	2.42E-02	8.97E-03
2004	7,232.5	972,700.8	--	--	--	5.32E-04	2.17E-02	7.62E-03
2005	6,151.5	962,532.6	--	--	--	8.19E-04	1.66E-02	6.50E-03
2006	6,545.3	965,328.7	--	--	--	9.07E-04	1.71E-02	6.78E-03
2007	7,837.8	976,679.0	--	--	--	4.91E-05	3.07E-02	8.26E-03
2008	7,332.2	971,611.9	--	--	--	5.97E-05	2.74E-02	7.53E-03
2009	7,832.5	954,932.0	8.80E-03	7.74E-03	9.86E-03	2.41E-05	3.26E-02	8.33E-03
2010	8,166.7	964,326.7	8.55E-03	7.73E-03	9.38E-03	8.02E-04	2.29E-02	8.46E-03
2011	8,040.6	937,925.5	8.31E-03	7.72E-03	8.90E-03	5.32E-04	2.58E-02	8.84E-03
2012	7,351.7	921,716.4	8.07E-03	7.72E-03	8.42E-03	4.34E-04	2.26E-02	7.68E-03
2013	8,161.4	927,539.5	7.83E-03	7.71E-03	7.94E-03	1.85E-08	4.32E-02	8.48E-03
2014	7,050.1	938,778.0	7.58E-03	7.46E-03	7.70E-03	4.90E-04	2.20E-02	7.61E-03
2015	6,364.8	924,171.6	7.34E-03	6.99E-03	7.69E-03	7.69E-04	1.80E-02	6.88E-03
2016	7,131.4	932,914.0	7.10E-03	6.51E-03	7.68E-03	6.79E-04	2.10E-02	7.66E-03
2017	6,744.6	926,540.3	6.85E-03	6.03E-03	7.68E-03	4.12E-04	2.15E-02	7.30E-03
2018	5,270.6	920,288.2	6.61E-03	5.55E-03	7.67E-03	2.73E-04	1.76E-02	5.80E-03
Total	155,192.6	19,813,226.7						

Table 15. Plot data for Figure 7, standby TDP 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	--	--	--	3.10E-03	4.01E-02	1.47E-02
1999	--	--	--	1.19E-02	5.49E-02	2.76E-02
2000	--	--	--	3.13E-02	9.34E-02	5.90E-02
2001	--	--	--	1.19E-02	5.28E-02	2.86E-02
2002	--	--	--	7.58E-03	3.05E-02	1.66E-02
2003	--	--	--	1.32E-02	3.92E-02	2.42E-02
2004	--	--	--	3.49E-02	1.24E-01	7.35E-02
2005	--	--	--	3.16E-02	1.37E-01	7.61E-02
2006	--	--	--	8.70E-03	5.26E-02	2.39E-02
2007	--	--	--	1.67E-02	8.43E-02	4.28E-02
2008	--	--	--	2.61E-02	1.12E-01	5.92E-02
2009	4.41E-02	2.99E-02	6.52E-02	1.22E-02	5.12E-02	2.65E-02
2010	4.58E-02	3.29E-02	6.37E-02	1.42E-02	7.37E-02	3.77E-02
2011	4.74E-02	3.59E-02	6.26E-02	3.36E-02	1.10E-01	6.71E-02
2012	4.92E-02	3.88E-02	6.23E-02	3.46E-02	1.33E-01	7.79E-02
2013	5.10E-02	4.12E-02	6.31E-02	2.68E-02	1.08E-01	5.99E-02
2014	5.28E-02	4.27E-02	6.54E-02	2.92E-02	1.12E-01	6.49E-02
2015	5.48E-02	4.32E-02	6.94E-02	1.95E-02	9.74E-02	5.11E-02
2016	5.68E-02	4.30E-02	7.49E-02	2.05E-02	9.46E-02	4.94E-02
2017	5.88E-02	4.23E-02	8.19E-02	1.74E-02	9.39E-02	4.87E-02
2018	6.10E-02	4.13E-02	9.00E-02	2.00E-02	1.18E-01	5.67E-02

Table 16. Plot data for Figure 8, normally running TDP 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	--	--	--	3.83E-03	3.85E-02	1.75E-02
1999	--	--	--	4.88E-03	4.26E-02	1.84E-02
2000	--	--	--	1.45E-04	1.51E-02	3.91E-03
2001	--	--	--	1.58E-03	2.70E-02	1.10E-02
2002	--	--	--	1.99E-04	1.34E-02	3.86E-03
2003	--	--	--	3.67E-04	1.51E-02	4.07E-03
2004	--	--	--	2.08E-04	1.41E-02	3.97E-03
2005	--	--	--	7.92E-03	4.89E-02	2.55E-02
2006	--	--	--	1.40E-03	2.95E-02	1.13E-02
2007	--	--	--	1.94E-04	1.36E-02	3.75E-03
2008	--	--	--	2.05E-04	1.51E-02	4.16E-03
2009	7.61E-03	3.82E-03	1.52E-02	1.56E-03	2.91E-02	1.16E-02
2010	7.20E-03	4.01E-03	1.29E-02	3.69E-04	1.47E-02	4.20E-03
2011	6.81E-03	4.16E-03	1.11E-02	1.35E-04	1.53E-02	3.75E-03
2012	6.44E-03	4.24E-03	9.79E-03	1.63E-03	2.83E-02	1.13E-02
2013	6.09E-03	4.18E-03	8.88E-03	1.59E-03	2.73E-02	1.05E-02
2014	5.76E-03	3.95E-03	8.40E-03	1.51E-04	1.26E-02	3.64E-03
2015	5.45E-03	3.58E-03	8.28E-03	2.61E-04	1.51E-02	4.02E-03
2016	5.15E-03	3.15E-03	8.43E-03	1.38E-03	2.86E-02	1.10E-02
2017	4.88E-03	2.72E-03	8.75E-03	1.92E-04	1.57E-02	3.99E-03
2018	4.61E-03	2.31E-03	9.19E-03	1.44E-04	1.49E-02	3.81E-03

Table 17. Plot data for Figure 9, frequency of start demands (demands per reactor year) trend for standby TDPs.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	**Demands**	**Reactor Years**	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
1998	1,512	97.0	--	--	--	1.49E+01	1.63E+01	1.56E+01
1999	1,496	97.0	--	--	--	1.48E+01	1.61E+01	1.54E+01
2000	1,438	97.3	--	--	--	1.42E+01	1.54E+01	1.48E+01
2001	1,430	97.0	--	--	--	1.41E+01	1.54E+01	1.47E+01
2002	1,395	97.0	--	--	--	1.38E+01	1.50E+01	1.44E+01
2003	1,518	97.0	--	--	--	1.50E+01	1.63E+01	1.56E+01
2004	1,447	97.3	--	--	--	1.42E+01	1.55E+01	1.49E+01
2005	1,425	97.0	--	--	--	1.41E+01	1.54E+01	1.47E+01
2006	1,462	97.0	--	--	--	1.44E+01	1.57E+01	1.51E+01
2007	1,381	97.6	--	--	--	1.35E+01	1.48E+01	1.41E+01
2008	1,446	98.3	--	--	--	1.41E+01	1.54E+01	1.47E+01
2009	1,543	98.0	1.59E+01	1.55E+01	1.64E+01	1.51E+01	1.64E+01	1.57E+01
2010	1,574	98.0	1.59E+01	1.55E+01	1.63E+01	1.54E+01	1.67E+01	1.61E+01
2011	1,572	98.0	1.59E+01	1.56E+01	1.62E+01	1.54E+01	1.67E+01	1.60E+01
2012	1,501	98.3	1.59E+01	1.56E+01	1.61E+01	1.46E+01	1.59E+01	1.53E+01
2013	1,538	95.6	1.58E+01	1.56E+01	1.61E+01	1.54E+01	1.68E+01	1.61E+01
2014	1,488	94.0	1.58E+01	1.56E+01	1.61E+01	1.52E+01	1.65E+01	1.58E+01
2015	1,510	93.0	1.58E+01	1.55E+01	1.61E+01	1.56E+01	1.69E+01	1.62E+01
2016	1,485	93.0	1.58E+01	1.55E+01	1.61E+01	1.53E+01	1.67E+01	1.60E+01
2017	1,449	92.0	1.58E+01	1.54E+01	1.62E+01	1.51E+01	1.64E+01	1.57E+01
2018	1,420	92.0	1.58E+01	1.53E+01	1.62E+01	1.48E+01	1.61E+01	1.54E+01
Total	31,031	2,021.3						

Table 18. Plot data for Figure 10, frequency of run ≤ 1H hours (hours per reactor year) trend for standby TDPs.

Year	Hours	Reactor Years	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	1,512	97.0	--	--	--	1.49E+01	1.63E+01	1.56E+01
1999	1,496	97.0	--	--	--	1.48E+01	1.61E+01	1.54E+01
2000	1,438	97.3	--	--	--	1.42E+01	1.54E+01	1.48E+01
2001	1,430	97.0	--	--	--	1.41E+01	1.54E+01	1.47E+01
2002	1,395	97.0	--	--	--	1.38E+01	1.50E+01	1.44E+01
2003	1,518	97.0	--	--	--	1.50E+01	1.63E+01	1.56E+01
2004	1,447	97.3	--	--	--	1.42E+01	1.55E+01	1.49E+01
2005	1,425	97.0	--	--	--	1.41E+01	1.54E+01	1.47E+01
2006	1,462	97.0	--	--	--	1.44E+01	1.57E+01	1.51E+01
2007	1,381	97.6	--	--	--	1.35E+01	1.48E+01	1.41E+01
2008	1,446	98.3	--	--	--	1.41E+01	1.54E+01	1.47E+01
2009	1,543	98.0	1.59E+01	1.55E+01	1.64E+01	1.51E+01	1.64E+01	1.57E+01
2010	1,574	98.0	1.59E+01	1.55E+01	1.63E+01	1.54E+01	1.67E+01	1.61E+01
2011	1,572	98.0	1.59E+01	1.56E+01	1.62E+01	1.54E+01	1.67E+01	1.60E+01
2012	1,501	98.3	1.59E+01	1.56E+01	1.61E+01	1.46E+01	1.59E+01	1.53E+01
2013	1,538	95.6	1.58E+01	1.56E+01	1.61E+01	1.54E+01	1.68E+01	1.61E+01
2014	1,488	94.0	1.58E+01	1.56E+01	1.61E+01	1.52E+01	1.65E+01	1.58E+01
2015	1,510	93.0	1.58E+01	1.55E+01	1.61E+01	1.56E+01	1.69E+01	1.62E+01
2016	1,485	93.0	1.58E+01	1.55E+01	1.61E+01	1.53E+01	1.67E+01	1.60E+01
2017	1,449	92.0	1.58E+01	1.54E+01	1.62E+01	1.51E+01	1.64E+01	1.57E+01
2018	1,420	92.0	1.58E+01	1.53E+01	1.62E+01	1.48E+01	1.61E+01	1.54E+01
Total	31,031	2,021.3						

Table 19. Plot data for Figure 11, frequency of run > 1H hours (hours per reactor year) trend for standby TDPs.

Year	Run Hours	Reactor Years	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	2,117	97.0	--	--	--	2.10E+01	2.26E+01	2.18E+01
1999	1,092	97.0	--	--	--	1.07E+01	1.18E+01	1.13E+01
2000	506	97.3	--	--	--	4.83E+00	5.60E+00	5.20E+00
2001	655	97.0	--	--	--	6.32E+00	7.19E+00	6.74E+00
2002	1,154	97.0	--	--	--	1.13E+01	1.25E+01	1.19E+01
2003	1,498	97.0	--	--	--	1.48E+01	1.61E+01	1.54E+01
2004	368	97.3	--	--	--	3.47E+00	4.13E+00	3.79E+00
2005	243	97.0	--	--	--	2.25E+00	2.79E+00	2.51E+00
2006	242	97.0	--	--	--	2.24E+00	2.78E+00	2.50E+00
2007	256	97.6	--	--	--	2.36E+00	2.91E+00	2.63E+00
2008	282	98.3	--	--	--	2.59E+00	3.16E+00	2.87E+00
2009	332	98.0	3.61E+00	2.91E+00	4.47E+00	3.09E+00	3.71E+00	3.39E+00
2010	321	98.0	3.55E+00	2.96E+00	4.26E+00	2.98E+00	3.59E+00	3.27E+00
2011	419	98.0	3.49E+00	2.99E+00	4.07E+00	3.93E+00	4.63E+00	4.27E+00
2012	301	98.3	3.43E+00	3.01E+00	3.91E+00	2.78E+00	3.37E+00	3.06E+00
2013	331	95.6	3.37E+00	2.99E+00	3.80E+00	3.15E+00	3.79E+00	3.46E+00
2014	317	94.0	3.32E+00	2.93E+00	3.75E+00	3.06E+00	3.70E+00	3.37E+00
2015	286	93.0	3.26E+00	2.84E+00	3.75E+00	2.78E+00	3.39E+00	3.07E+00
2016	368	93.0	3.21E+00	2.72E+00	3.78E+00	3.62E+00	4.31E+00	3.96E+00
2017	326	92.0	3.16E+00	2.60E+00	3.84E+00	3.23E+00	3.89E+00	3.55E+00
2018	222	92.0	3.10E+00	2.47E+00	3.91E+00	2.15E+00	2.69E+00	2.41E+00
Total	11,636	2,021.3						

Table 20. Plot data for Figure 12, frequency of FTS events (events per reactor year) trend for standby TDPs.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	2	97.0	--	--	--	5.55E-03	6.82E-02	2.42E-02
1999	12	97.0	--	--	--	7.08E-02	1.94E-01	1.21E-01
2000	12	97.3	--	--	--	7.07E-02	1.94E-01	1.21E-01
2001	5	97.0	--	--	--	2.22E-02	1.08E-01	5.33E-02
2002	4	97.0	--	--	--	1.61E-02	9.54E-02	4.36E-02
2003	8	97.0	--	--	--	4.20E-02	1.46E-01	8.24E-02
2004	10	97.3	--	--	--	5.60E-02	1.70E-01	1.02E-01
2005	6	97.0	--	--	--	2.86E-02	1.21E-01	6.30E-02
2006	9	97.0	--	--	--	4.90E-02	1.58E-01	9.21E-02
2007	7	97.6	--	--	--	3.50E-02	1.33E-01	7.23E-02
2008	12	98.3	--	--	--	7.00E-02	1.92E-01	1.20E-01
2009	12	98.0	1.11E-01	6.53E-02	1.89E-01	7.02E-02	1.93E-01	1.20E-01
2010	9	98.0	1.01E-01	6.47E-02	1.58E-01	4.86E-02	1.57E-01	9.12E-02
2011	9	98.0	9.21E-02	6.33E-02	1.34E-01	4.86E-02	1.57E-01	9.12E-02
2012	6	98.3	8.39E-02	6.04E-02	1.17E-01	2.82E-02	1.20E-01	6.23E-02
2013	8	95.6	7.65E-02	5.56E-02	1.05E-01	4.26E-02	1.48E-01	8.36E-02
2014	12	94.0	6.97E-02	4.93E-02	9.84E-02	7.30E-02	2.00E-01	1.25E-01
2015	3	93.0	6.35E-02	4.24E-02	9.50E-02	1.09E-02	8.53E-02	3.53E-02
2016	9	93.0	5.78E-02	3.57E-02	9.36E-02	5.10E-02	1.65E-01	9.58E-02
2017	7	92.0	5.27E-02	2.98E-02	9.33E-02	3.70E-02	1.41E-01	7.64E-02
2018	2	92.0	4.80E-02	2.46E-02	9.36E-02	5.84E-03	7.17E-02	2.55E-02
Total	164	2,021.3						

Table 21. Plot data for Figure 13, frequency of FTR≤1H events (events per reactor year) trend for standby TDPs.

Year	Failures	Reactor Years	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	2	97.0	--	--	--	4.95E-03	6.08E-02	2.16E-02
1999	3	97.0	--	--	--	9.37E-03	7.31E-02	3.03E-02
2000	10	97.3	--	--	--	5.00E-02	1.52E-01	9.06E-02
2001	4	97.0	--	--	--	1.44E-02	8.51E-02	3.89E-02
2002	5	97.0	--	--	--	1.98E-02	9.67E-02	4.76E-02
2003	8	97.0	--	--	--	3.75E-02	1.30E-01	7.35E-02
2004	0	97.3	--	--	--	1.70E-05	3.37E-02	4.31E-03
2005	4	97.0	--	--	--	1.44E-02	8.51E-02	3.89E-02
2006	2	97.0	--	--	--	4.95E-03	6.08E-02	2.16E-02
2007	7	97.6	--	--	--	3.12E-02	1.19E-01	6.45E-02
2008	4	98.3	--	--	--	1.42E-02	8.41E-02	3.85E-02
2009	5	98.0	2.96E-02	8.68E-03	1.01E-01	1.96E-02	9.58E-02	4.71E-02
2010	3	98.0	2.71E-02	9.62E-03	7.62E-02	9.29E-03	7.25E-02	3.00E-02
2011	4	98.0	2.48E-02	1.04E-02	5.92E-02	1.43E-02	8.43E-02	3.86E-02
2012	1	98.3	2.27E-02	1.07E-02	4.82E-02	1.50E-03	4.73E-02	1.28E-02
2013	0	95.6	2.07E-02	1.02E-02	4.22E-02	1.72E-05	3.42E-02	4.38E-03
2014	1	94.0	1.90E-02	8.96E-03	4.01E-02	1.56E-03	4.91E-02	1.33E-02
2015	4	93.0	1.73E-02	7.33E-03	4.11E-02	1.49E-02	8.81E-02	4.03E-02
2016	4	93.0	1.59E-02	5.70E-03	4.41E-02	1.49E-02	8.81E-02	4.03E-02
2017	0	92.0	1.45E-02	4.31E-03	4.89E-02	1.78E-05	3.53E-02	4.52E-03
2018	3	92.0	1.33E-02	3.20E-03	5.51E-02	9.79E-03	7.64E-02	3.16E-02
Total	74	2,021.3						

Table 22. Plot data for Figure 14, frequency of FTR>1H events (events per reactor year) trend for standby TDPs.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	0	97.0	--	--	--	1.68E-05	3.33E-02	4.26E-03
1999	1	97.0	--	--	--	1.50E-03	4.72E-02	1.28E-02
2000	3	97.3	--	--	--	9.22E-03	7.20E-02	2.98E-02
2001	1	97.0	--	--	--	1.50E-03	4.72E-02	1.28E-02
2002	0	97.0	--	--	--	1.68E-05	3.33E-02	4.26E-03
2003	1	97.0	--	--	--	1.50E-03	4.72E-02	1.28E-02
2004	4	97.3	--	--	--	1.41E-02	8.37E-02	3.83E-02
2005	3	97.0	--	--	--	9.24E-03	7.21E-02	2.99E-02
2006	0	97.0	--	--	--	1.68E-05	3.33E-02	4.26E-03
2007	1	97.6	--	--	--	1.49E-03	4.70E-02	1.27E-02
2008	2	98.3	--	--	--	4.83E-03	5.93E-02	2.11E-02
2009	0	98.0	1.51E-02	6.03E-03	3.81E-02	1.66E-05	3.30E-02	4.23E-03
2010	1	98.0	1.63E-02	7.44E-03	3.57E-02	1.49E-03	4.68E-02	1.27E-02
2011	4	98.0	1.76E-02	9.07E-03	3.40E-02	1.41E-02	8.32E-02	3.81E-02
2012	4	98.3	1.89E-02	1.08E-02	3.30E-02	1.40E-02	8.30E-02	3.80E-02
2013	3	95.6	2.04E-02	1.25E-02	3.32E-02	9.36E-03	7.30E-02	3.02E-02
2014	3	94.0	2.19E-02	1.37E-02	3.51E-02	9.49E-03	7.40E-02	3.06E-02
2015	2	93.0	2.36E-02	1.42E-02	3.92E-02	5.06E-03	6.21E-02	2.21E-02
2016	2	93.0	2.54E-02	1.41E-02	4.59E-02	5.06E-03	6.21E-02	2.21E-02
2017	2	92.0	2.73E-02	1.35E-02	5.52E-02	5.10E-03	6.27E-02	2.23E-02
2018	2	92.0	2.94E-02	1.28E-02	6.76E-02	5.10E-03	6.27E-02	2.23E-02
Total	39	2,021.3						

Table 23. Plot data for Figure 15, frequency of start demands (demands per reactor year) trend for normally running TDPs.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Demands	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	79	29.0	--	--	--	2.23E+00	3.27E+00	2.71E+00
1999	79	29.0	--	--	--	2.23E+00	3.27E+00	2.71E+00
2000	79	29.1	--	--	--	2.23E+00	3.26E+00	2.71E+00
2001	78	29.0	--	--	--	2.22E+00	3.25E+00	2.70E+00
2002	78	29.0	--	--	--	2.22E+00	3.25E+00	2.70E+00
2003	78	29.0	--	--	--	2.21E+00	3.25E+00	2.69E+00
2004	78	29.1	--	--	--	2.22E+00	3.25E+00	2.70E+00
2005	78	29.0	--	--	--	2.21E+00	3.24E+00	2.69E+00
2006	78	29.0	--	--	--	2.22E+00	3.25E+00	2.70E+00
2007	78	29.0	--	--	--	2.21E+00	3.25E+00	2.69E+00
2008	78	29.1	--	--	--	2.21E+00	3.24E+00	2.68E+00
2009	78	29.0	2.64E+00	2.62E+00	2.66E+00	2.19E+00	3.23E+00	2.67E+00
2010	76	29.0	2.64E+00	2.62E+00	2.66E+00	2.16E+00	3.18E+00	2.63E+00
2011	76	29.0	2.63E+00	2.62E+00	2.65E+00	2.15E+00	3.17E+00	2.62E+00
2012	76	29.1	2.63E+00	2.62E+00	2.64E+00	2.14E+00	3.16E+00	2.62E+00
2013	76	29.0	2.63E+00	2.62E+00	2.64E+00	2.15E+00	3.18E+00	2.63E+00
2014	76	29.0	2.63E+00	2.61E+00	2.64E+00	2.15E+00	3.17E+00	2.62E+00
2015	76	29.0	2.62E+00	2.61E+00	2.64E+00	2.15E+00	3.17E+00	2.63E+00
2016	76	29.1	2.62E+00	2.61E+00	2.64E+00	2.15E+00	3.17E+00	2.62E+00
2017	76	29.0	2.62E+00	2.60E+00	2.64E+00	2.16E+00	3.18E+00	2.63E+00
2018	76	29.0	2.61E+00	2.59E+00	2.64E+00	2.15E+00	3.17E+00	2.62E+00
Total	1,624	609.4						

Table 24. Plot data for Figure 16, frequency of run hours (hours per reactor year) trend for normally running TDPs.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	**Run Hours**	**Reactor Years**	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
1998	335,022	29.0	--	--	--	1.15E+04	1.16E+04	1.16E+04
1999	335,022	29.0	--	--	--	1.15E+04	1.16E+04	1.16E+04
2000	335,022	29.1	--	--	--	1.15E+04	1.16E+04	1.15E+04
2001	335,432	29.0	--	--	--	1.15E+04	1.16E+04	1.16E+04
2002	335,387	29.0	--	--	--	1.15E+04	1.16E+04	1.16E+04
2003	335,371	29.0	--	--	--	1.15E+04	1.16E+04	1.16E+04
2004	335,356	29.1	--	--	--	1.15E+04	1.16E+04	1.15E+04
2005	335,417	29.0	--	--	--	1.15E+04	1.16E+04	1.16E+04
2006	335,463	29.0	--	--	--	1.15E+04	1.16E+04	1.16E+04
2007	335,326	29.0	--	--	--	1.15E+04	1.16E+04	1.16E+04
2008	335,387	29.1	--	--	--	1.15E+04	1.16E+04	1.15E+04
2009	333,274	29.0	1.14E+04	1.13E+04	1.14E+04	1.15E+04	1.15E+04	1.15E+04
2010	327,318	29.0	1.13E+04	1.13E+04	1.14E+04	1.13E+04	1.13E+04	1.13E+04
2011	327,181	29.0	1.13E+04	1.13E+04	1.14E+04	1.13E+04	1.13E+04	1.13E+04
2012	327,166	29.1	1.13E+04	1.13E+04	1.14E+04	1.12E+04	1.13E+04	1.13E+04
2013	327,089	29.0	1.13E+04	1.13E+04	1.14E+04	1.12E+04	1.13E+04	1.13E+04
2014	327,257	29.0	1.13E+04	1.12E+04	1.13E+04	1.13E+04	1.13E+04	1.13E+04
2015	327,196	29.0	1.13E+04	1.12E+04	1.13E+04	1.13E+04	1.13E+04	1.13E+04
2016	327,196	29.1	1.13E+04	1.12E+04	1.13E+04	1.12E+04	1.13E+04	1.13E+04
2017	327,074	29.0	1.13E+04	1.12E+04	1.13E+04	1.12E+04	1.13E+04	1.13E+04
2018	327,272	29.0	1.12E+04	1.12E+04	1.13E+04	1.13E+04	1.13E+04	1.13E+04
Total	6,966,227	609.4						

Table 25. Plot data for Figure 17, frequency of FTS events (events per reactor year) trend for normally running TDPs.

Year	Failures	Reactor Years	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	2	29.0	--	--	--	9.35E-03	1.15E-01	4.08E-02
1999	2	29.0	--	--	--	9.35E-03	1.15E-01	4.08E-02
2000	0	29.1	--	--	--	3.21E-05	6.37E-02	8.15E-03
2001	1	29.0	--	--	--	2.87E-03	9.04E-02	2.45E-02
2002	0	29.0	--	--	--	3.21E-05	6.38E-02	8.16E-03
2003	0	29.0	--	--	--	3.21E-05	6.38E-02	8.16E-03
2004	0	29.1	--	--	--	3.21E-05	6.37E-02	8.15E-03
2005	3	29.0	--	--	--	1.77E-02	1.38E-01	5.72E-02
2006	1	29.0	--	--	--	2.87E-03	9.04E-02	2.45E-02
2007	0	29.0	--	--	--	3.21E-05	6.38E-02	8.16E-03
2008	0	29.1	--	--	--	3.21E-05	6.37E-02	8.15E-03
2009	1	29.0	1.61E-02	6.89E-03	3.78E-02	2.87E-03	9.04E-02	2.45E-02
2010	0	29.0	1.53E-02	7.43E-03	3.15E-02	3.21E-05	6.38E-02	8.16E-03
2011	0	29.0	1.45E-02	7.89E-03	2.66E-02	3.21E-05	6.38E-02	8.16E-03
2012	1	29.1	1.37E-02	8.19E-03	2.30E-02	2.87E-03	9.03E-02	2.45E-02
2013	1	29.0	1.30E-02	8.19E-03	2.07E-02	2.87E-03	9.04E-02	2.45E-02
2014	0	29.0	1.23E-02	7.79E-03	1.95E-02	3.21E-05	6.38E-02	8.16E-03
2015	0	29.0	1.17E-02	7.04E-03	1.94E-02	3.21E-05	6.38E-02	8.16E-03
2016	1	29.1	1.11E-02	6.11E-03	2.00E-02	2.87E-03	9.03E-02	2.45E-02
2017	0	29.0	1.05E-02	5.18E-03	2.12E-02	3.21E-05	6.38E-02	8.16E-03
2018	0	29.0	9.93E-03	4.32E-03	2.28E-02	3.21E-05	6.38E-02	8.16E-03
Total	13	609.4						

Table 26. Plot data for Figure 18, frequency of FTR events (events per reactor year) trend for normally running TDPs.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	1	29.0	--	--	--	5.30E-03	1.67E-01	4.52E-02
1999	6	29.0	--	--	--	8.87E-02	3.76E-01	1.96E-01
2000	2	29.1	--	--	--	1.72E-02	2.11E-01	7.51E-02
2001	3	29.0	--	--	--	3.26E-02	2.55E-01	1.05E-01
2002	3	29.0	--	--	--	3.26E-02	2.55E-01	1.05E-01
2003	6	29.0	--	--	--	8.87E-02	3.76E-01	1.96E-01
2004	3	29.1	--	--	--	3.26E-02	2.54E-01	1.05E-01
2005	6	29.0	--	--	--	8.87E-02	3.76E-01	1.96E-01
2006	3	29.0	--	--	--	3.26E-02	2.55E-01	1.05E-01
2007	3	29.0	--	--	--	3.26E-02	2.55E-01	1.05E-01
2008	3	29.1	--	--	--	3.26E-02	2.54E-01	1.05E-01
2009	3	29.0	1.39E-01	8.21E-02	2.35E-01	3.26E-02	2.55E-01	1.05E-01
2010	6	29.0	1.32E-01	8.45E-02	2.05E-01	8.87E-02	3.76E-01	1.96E-01
2011	2	29.0	1.25E-01	8.61E-02	1.82E-01	1.72E-02	2.12E-01	7.53E-02
2012	6	29.1	1.19E-01	8.60E-02	1.64E-01	8.85E-02	3.75E-01	1.95E-01
2013	4	29.0	1.13E-01	8.36E-02	1.52E-01	5.01E-02	2.96E-01	1.36E-01
2014	2	29.0	1.07E-01	7.84E-02	1.45E-01	1.72E-02	2.12E-01	7.53E-02
2015	4	29.0	1.01E-01	7.13E-02	1.44E-01	5.01E-02	2.96E-01	1.36E-01
2016	2	29.1	9.61E-02	6.34E-02	1.46E-01	1.72E-02	2.11E-01	7.51E-02
2017	3	29.0	9.12E-02	5.56E-02	1.50E-01	3.26E-02	2.55E-01	1.05E-01
2018	2	29.0	8.65E-02	4.84E-02	1.55E-01	1.72E-02	2.12E-01	7.53E-02
Total	73	609.4						

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