INL/EXT-17-44116

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

John A. Schroeder

April 2018

The INL is a U.S. Department of Energy National Laboratory
operated by Battelle Energy Alliance

INL/EXT-17-44116

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

John A. Schroeder

Update Completed April 2018

Idaho National Laboratory
Risk Assessment and Management Services Department
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
Division of Risk Assessment
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
NRC Agreement Number NRC-HQ-14-D-0018

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 2016 as reported in the Institute of Nuclear Power Operations (INPO) Consolidated Events Database (ICES). The TDP failure modes considered 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 normally running systems FTS and failure to run (FTR). 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. Statistically significant increasing trends were identified for TDP unavailability, for frequency of start demands for standby TDPs, and for run hours in the first hour after start. Statistically significant decreasing trends were identified for start demands for normally running TDPs, and for run hours per reactor critical year for normally running TDPs.

CONTENTS

FIGURES

TABLES

ACRONYMS

AFW	auxiliary feed water
CNID	constrained non-informative prior distribution
CY	calendar year
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
INPO	Institute of Nuclear Power Operations
MFW	main feed water
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

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

1. INTRODUCTION

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

The data used in this study were based on the operating experience failure reports from the Institute of Nuclear Power Operations' (INPO) and Consolidated Events Database (ICES) Database [1]; formerly the Equipment Performance and Information Exchange Database (EPIX). Maintenance unavailability (UA) performance data comes from Mitigating Systems Performance Index (MSPI) data from 2002 through 2016 [2]. The TDP failure modes considered are, for standby systems: failure to start (FTS), failure to run less than or equal to one hour (FTR≤1H), failure to run greater than one hour (FTR>1H); and for normally running systems: FTS and failure to run (FTR) (see Section 7). TDP train maintenance unavailability data for trending are from the same time period, as reported in the Reactor Oversight Program and ICES. In addition to the presentation of the component failure mode data and the UA data, 8-hour unreliability is calculated and trended.

Each of the estimates are trended for the most recent 10-year period while yearly estimates are provided for the entire study period.

This study is modeled on the web page updates associated with the NUREG-1715 series of reports [3] which were published around 2000. Those studies relied on operating experience obtained from licensee event reports, the Nuclear Plant Reliability Data System (NPRDS), and ICES. The ICES database, which includes the Mitigating Systems Performance Index (MSPI) as a subset, has matured to the point where component availability and reliability can be estimated with a higher degree of accuracy. In addition, the population of data in ICES has been growing and is much larger than the population used in the previous studies.

While this report provides an overview of operational data and evaluate component performance over time, it makes no attempt to estimate values for use in probabilistic risk assessments (PRAs). The 2015 Component Reliability Update [4], is an update to NUREG/CR-6928, *Industry-Average Performance for Components and Initiating Events at U.S Commercial Nuclear Power Plants* [5], and reports the TDP unreliability estimates for probabilistic risk assessments. Estimates from that report are included herein, for comparison. These estimates are labelled "2015 Update" (or "Update 2015") in the associated tables and figures.

Engineering analyses were also performed with respect to time period and failure modes. 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 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.

An overview of the trending methods, glossary of terms, and abbreviations can be found in the Overview and Reference document [7] on the Reactor Operational Experience Results and Databases web page (http://nrcoe.inl.gov/resultsdb).

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

- A statistically significant increasing trend for start demands for standby TDPs (see Figure 9).
- A statistically significant increasing trend for run hours for the first hour for standby TDPs (see Figure 10).

These two increasing trends are providing essentially the same information since each start demand is assumed to result in the accumulation of one hour towards the exposure for FTR≤1H.

2.2 Decreasing Trends

2.2.1 Extremely Statistically Significant

- None.

2.2.2 Highly Statistically Significant

- A highly statistically significant decreasing trend for start demands for normally running TDPs (see Figure 15) was identified using an iteratively re-weighted least squares routine. When independently re-evaluated using a normal generalized linear regression the trend was not significant.
- A highly statistically significant decreasing trend for run hours per reactor critical year for normally running TDPs (see Figure 16).

Both of the decreasing trends are only significant because of the consistent (lack of variation) values year-to-year. The actual decrease is less than 5% for both trends over the most recent 10-year period.

2.2.3 Statistically Significant

- None

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

2.3 Consistency Check Results

An ongoing concern in the industry is whether industry average failure estimates adequately predict standby component performance during unplanned (ESF) demands. Section 6.3 shows the results of the consistency check between industry-average failure rate count predictions and ESF detected failure observations. The consistency checks using unplanned demand data indicate that FTS, FTR≤1H, and FTR>1H failure observations are consistent with the industry-average failure predictions. However, the unplanned demand failure mode observation FTR≤1H is not consistent with the industry-average distribution, which means that the TDP performs worse on an unexpected demand than predicted by the industry-average failure rate distribution.

3. FAILURE PROBABILITIES AND FAILURE RATES

3.1 Overview

The industry-wide failure probabilities and failure rates of TDPs have been calculated from the operating experience for FTS, FTR≤1H, FTR>1H, and FTR. The TDP data set obtained from ICES includes TDPs in the systems listed in Table 1. Table 2 shows industry-wide failure probability and failure rate results for the TDP from Reference [4], or the 2015 Update.

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

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 2. 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

The trends are shown for industry standby and for industry normally running results. Trends in the standby TDP failure probabilities and failure rates are shown in Figure 1 to Figure 3. The data for the trend plots are contained in Table 9 to Table 11. The standby systems from Table 1 are trended together for each failure mode. Trends in the failure probabilities and failure rates for normally operating TDPs are shown in Figure 4 and Figure 5. The data for the trend plots are contained in Table 12 and Table 13.

The failure probability and failure rate estimates in the plots were obtained from a Bayesian update process. The means from the posterior distributions were plotted for each year. The 5th and 95th percentiles from the posterior distributions are also provided and give an indication of the relative uncertainty in the estimated parameters from year to year. When there are no failures, the interval tends to be larger than the interval for years when there are one or more failures. The larger interval reflects the uncertainty that comes from having little information in that year's data. Such uncertainty intervals are determined by the prior distribution. In each plot, a relatively "flat" constrained non-informative prior distribution (CNID) is used, which has large bounds [7]. For failure probabilities, the posterior means for each year are calculated from

$$mean = \frac{failures + 0.5}{demands + 1} \quad (1)$$

For failure rates, the posterior means for each year are calculated from

$$mean = \frac{failures + 0.5}{operting\ hours} \quad (2)$$

The horizontal curves plotted around the regression lines in the graphs show 90 percent simultaneous confidence bands for the fitted lines. The simultaneous confidence band bounds are larger than ordinary confidence bands for the trended values because they form a band that has a 90% probability of containing the entire line. In the lower left hand corner of the trend figures, the regression p-values are reported. They come from a statistical test on whether the slope of the regression line might be zero. Low p-values indicate that the slopes are not likely to be zero, and that trends 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 square of the vertical distance between the annual data points and the regression line. The p-values assume normal distributions for the data in each year, with a constant variance across the years. In the case where the data involve failure counts, the method of iterative reweighing accounts for the fact that count data are not expected to have a constant variance (for example, the variance for Poisson-distributed counts is equal to the expected number of counts). Further information on the trending methods is provided in Section 2 of the Overview and Reference document [6].

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

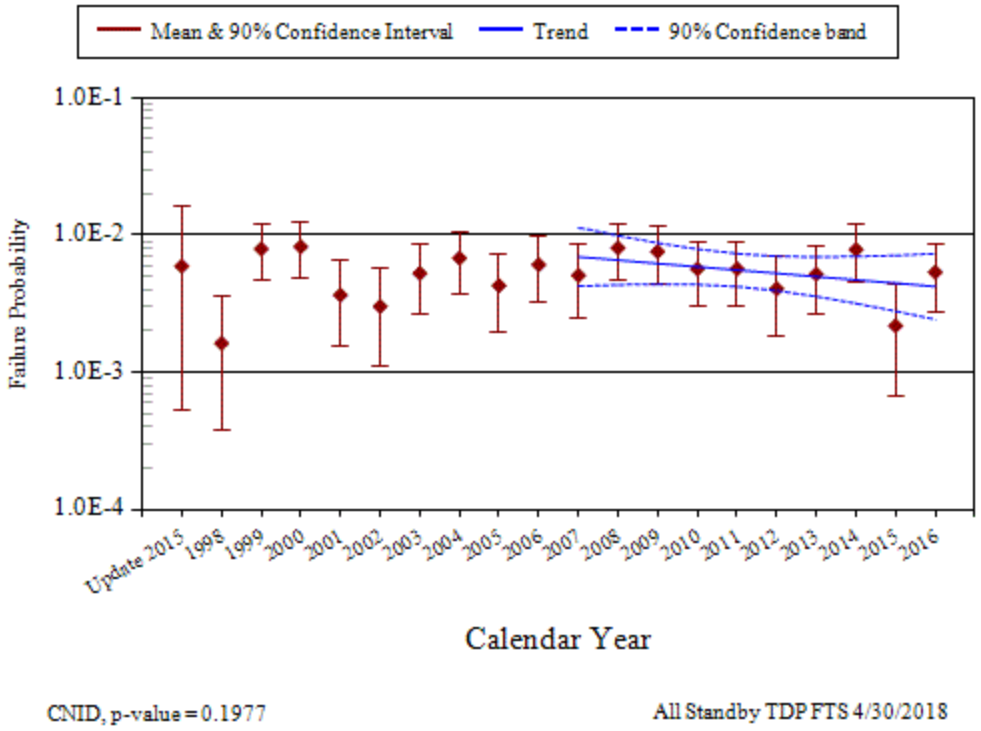

Figure 1. Failure probability estimate trend for standby systems, industry-wide TDP FTS.

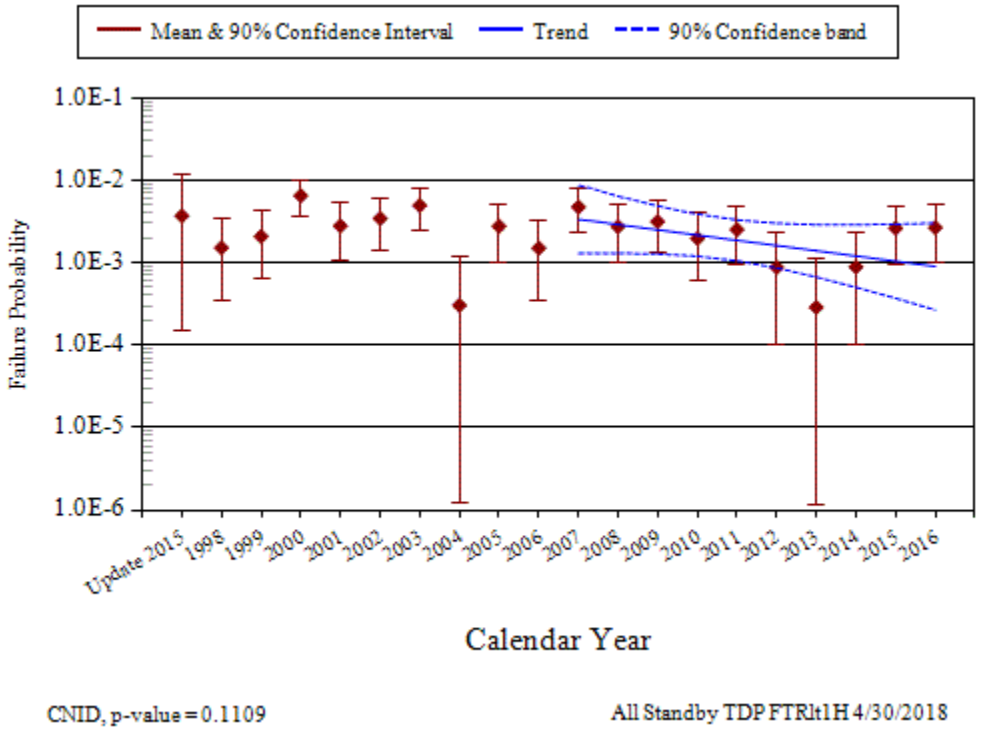

Figure 2. Failure probability estimate trend for standby systems, industry-wide TDP FTR≤1H.

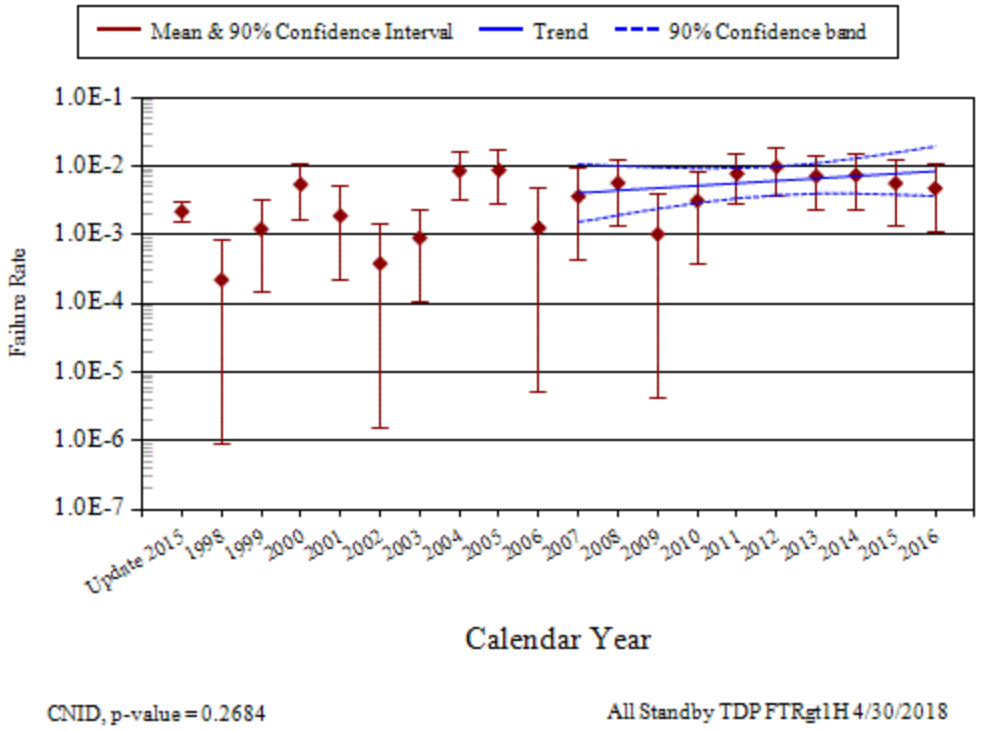

Figure 3. Failure rate estimate trend for standby systems, industry-wide TDP FTR>1H.

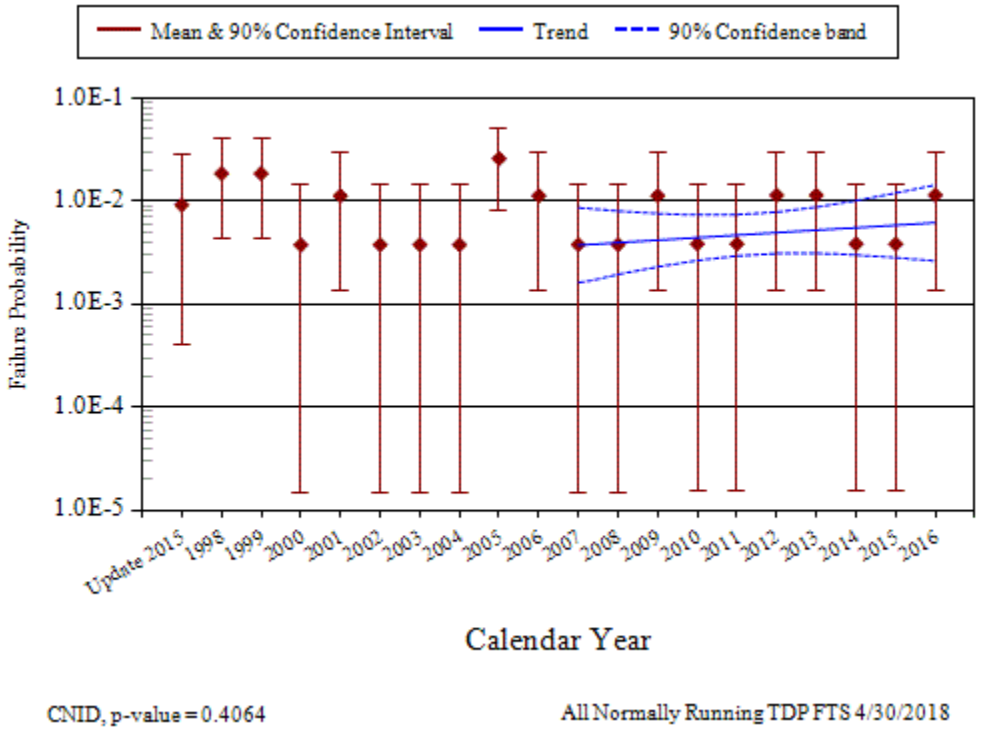

Figure 4. Failure probability estimate trend for normally running systems, industry-wide TDP FTS.

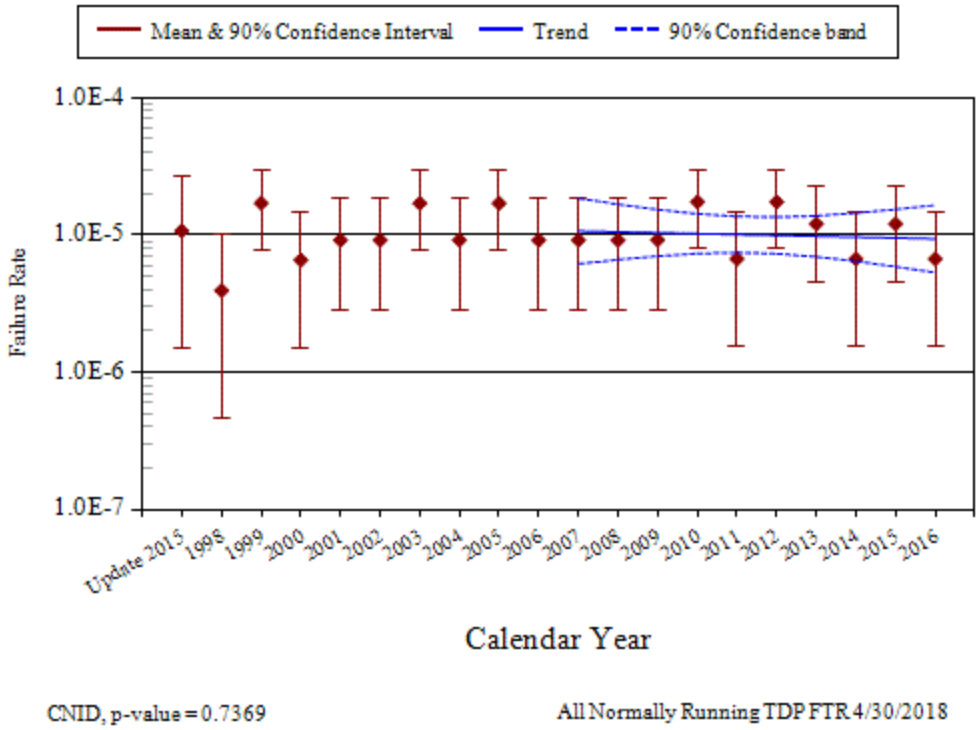

Figure 5. Failure rate estimate trend for normally running systems, industry-wide TDP FTR.

4. UNAVAILABILITY

4.1 Overview

The industry-wide test or maintenance UA of TDP trains has been calculated from the 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 Reference [4] based on UA data from MSPI Basis Documents, covering 2002 to 2015. In the calculations, planned and unplanned unavailable hours for a train are combined.

Table 3. Industry-average 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 (RCI)	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

For the 1998–2016 period, the following are overall maintenance unavailability data. 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 Table 14. 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 (1998–2016) unavailability and reactor critical hour data were obtained from the Reactor Oversight Program (1998 to 2001) and ICES (2002 to 2016) 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 [6]. In the lower left hand corner of the trend figures, the p-value is reported.

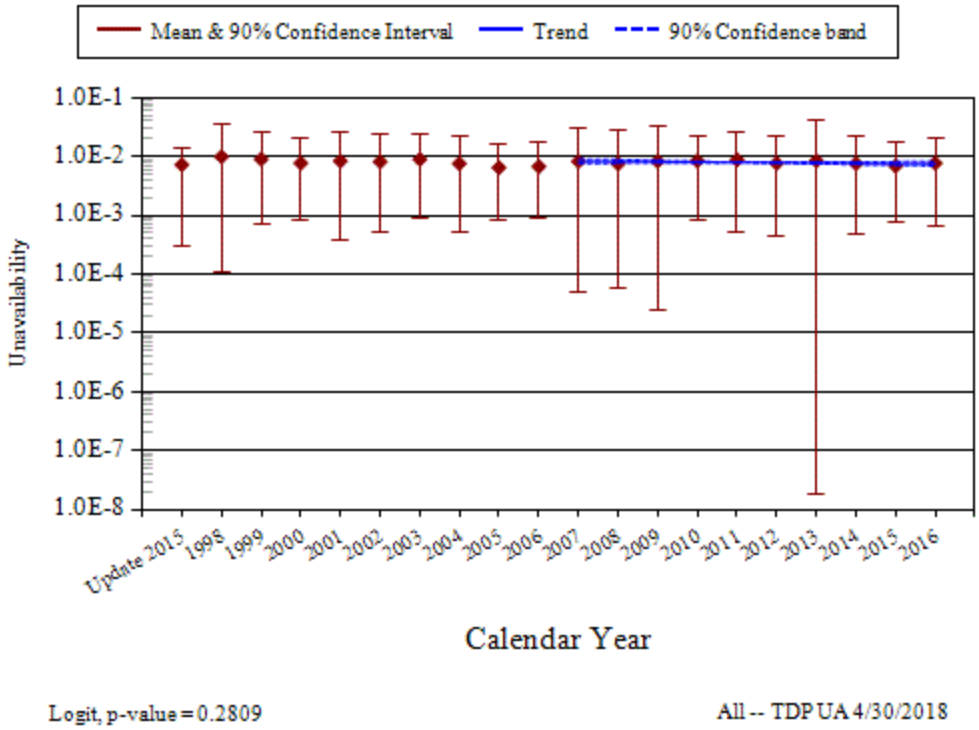

Figure 6. Pooled AFW, HPCI, and RCIC TDP UA trend.

5. TDP UNRELIABILITY TRENDS

Trends in total component unreliability are shown in Figure 7 and Figure 8. Plot data for these figures are in Table 15 and Table 16, respectively. 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 [7]. In the lower left hand corner of the trend figures, the regression method is reported.

No "2015 Update" data for use in risk assessments are cited for TDP unreliability because these data are not published. The risk assessment models compute unreliability as an output rather than an input. Additionally the standby systems from Table 2 are trended together.

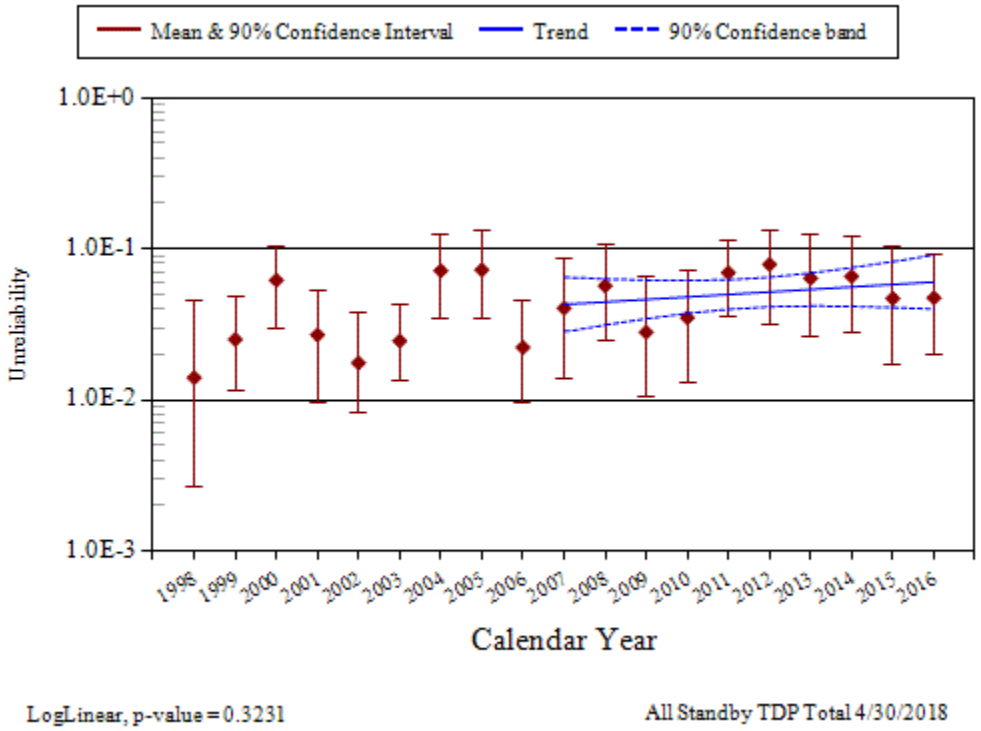

Figure 7. Standby systems, industry-wide TDP unreliability trend (8-hour mission).

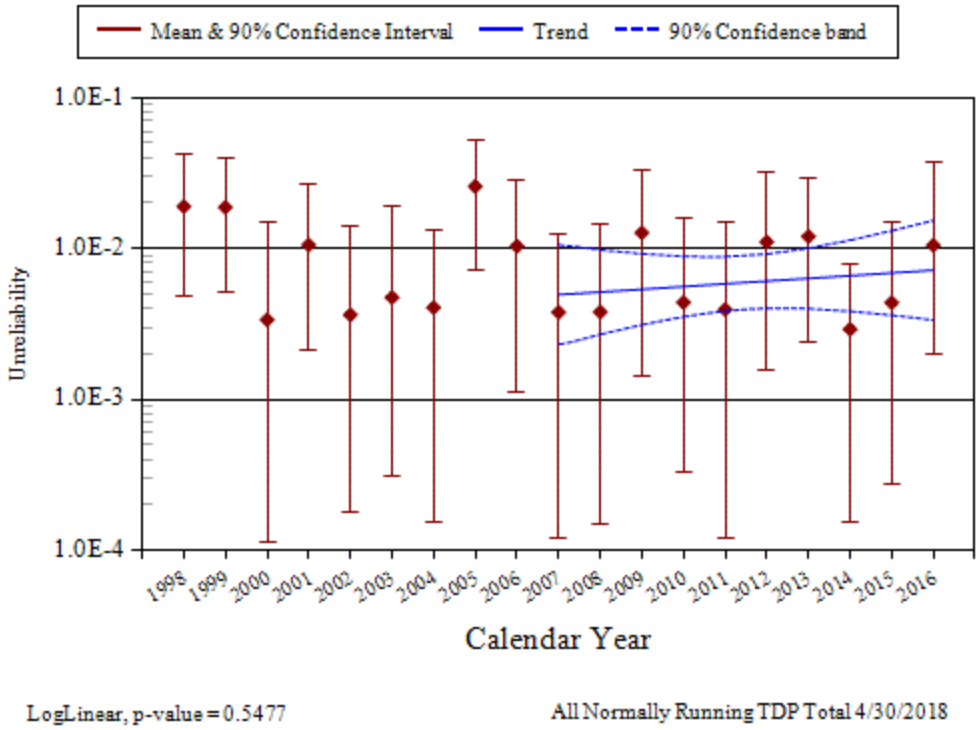

Figure 8. Normally running systems, industry-wide TDP unreliability trend (8-hour mission).

6. ENGINEERING ANALYSIS

6.1 Standby TDP Engineering Trends

This section and Section 6.2 present frequency trends for 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 start demands. Figure 10 shows the trend for TDP run ≤1 hour demands. Figure 11 shows the trend for the TDP run hours. Table 17, Table 18, and Table 19 provide the plot data, respectively.

Figure 12 shows the trend for TDP FTS events. Figure 13 shows the trend for TDP FTR≤1H events, and Figure 14 shows the trend for the TDP FTR>1H events. Table 20, Table 22, and Table 23 provide the plot data, respectively. The standby systems from Table 2 are trended together for each figure.

Table 4 summarizes the failures by system and year for the FTS failure mode. Table 5 summarizes the failures by system and year for the FTR≤1H failure mode. Table 6 summarizes the failures by system and year for the FTR>1H failure mode. Table 4, Table 5, and Table 6 only include systems where failures of that failure mode have been detected.

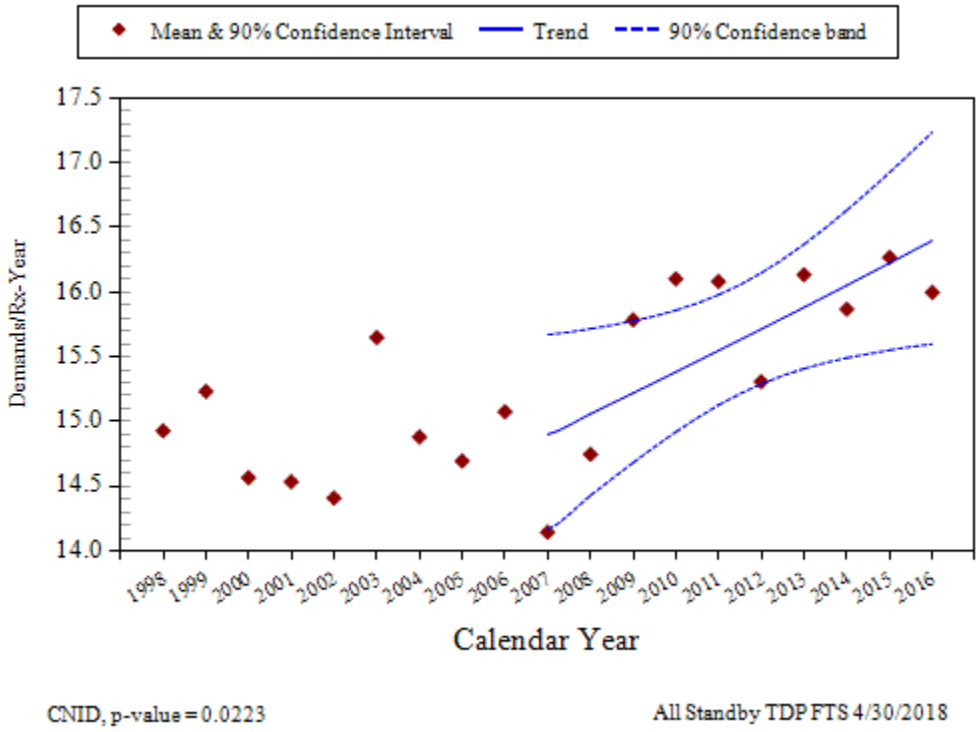

Figure 9. Frequency of start demands (demands per reactor year) for standby TDPs.

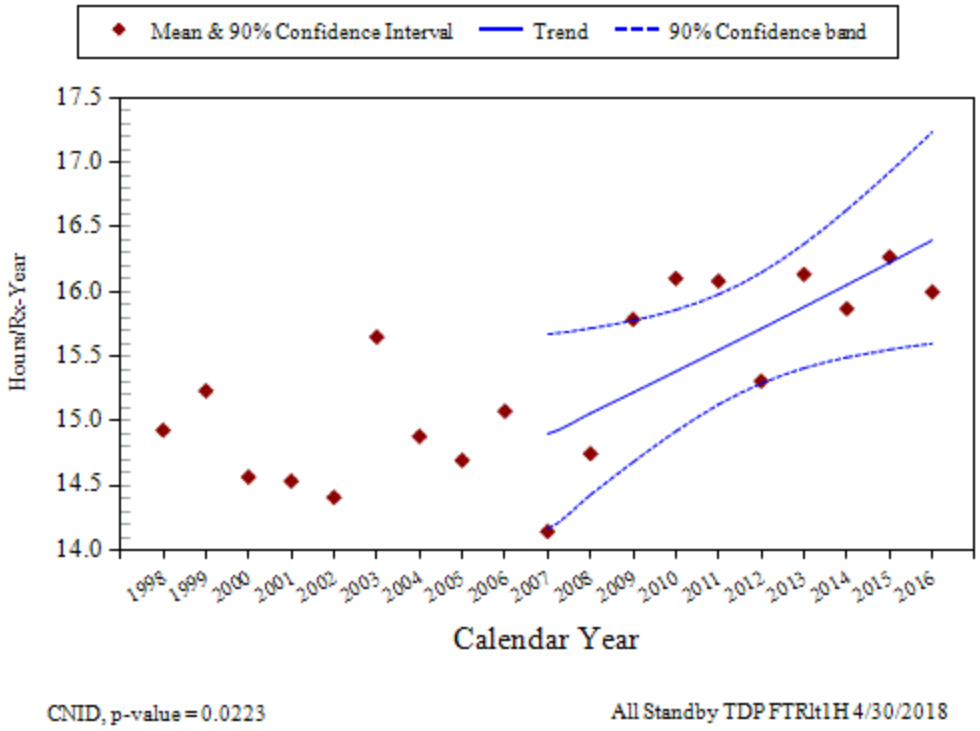

Figure 10. Frequency of run ≤ 1H hours (hours per reactor year) trend for standby TDPs.

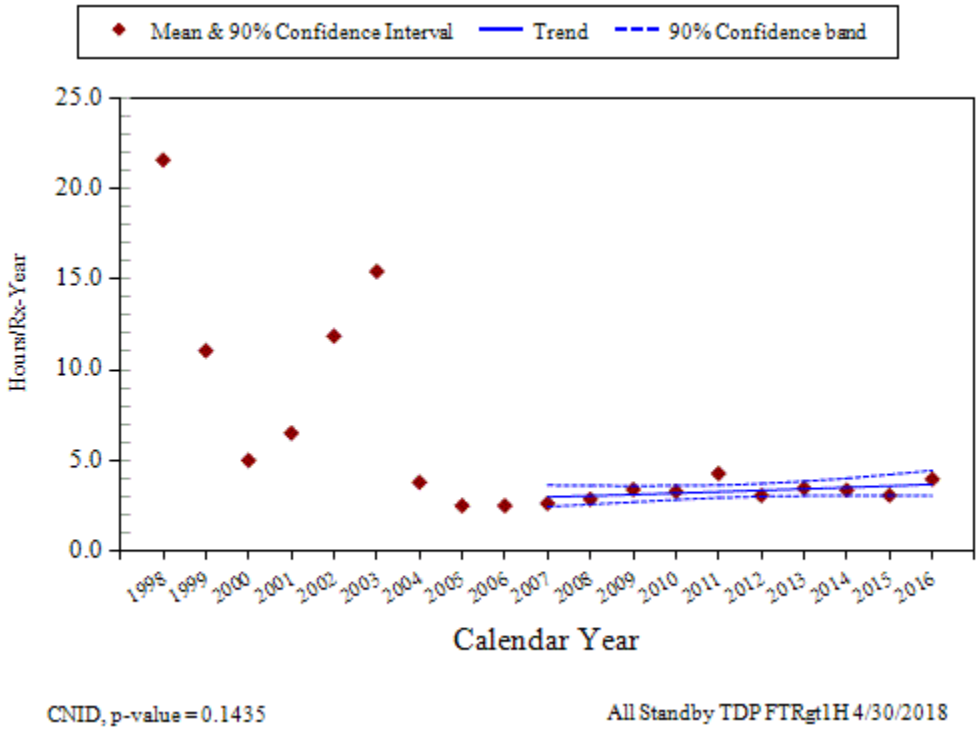

Figure 11. Frequency of run > 1H hours (hours per reactor year) trend for standby TDPs.

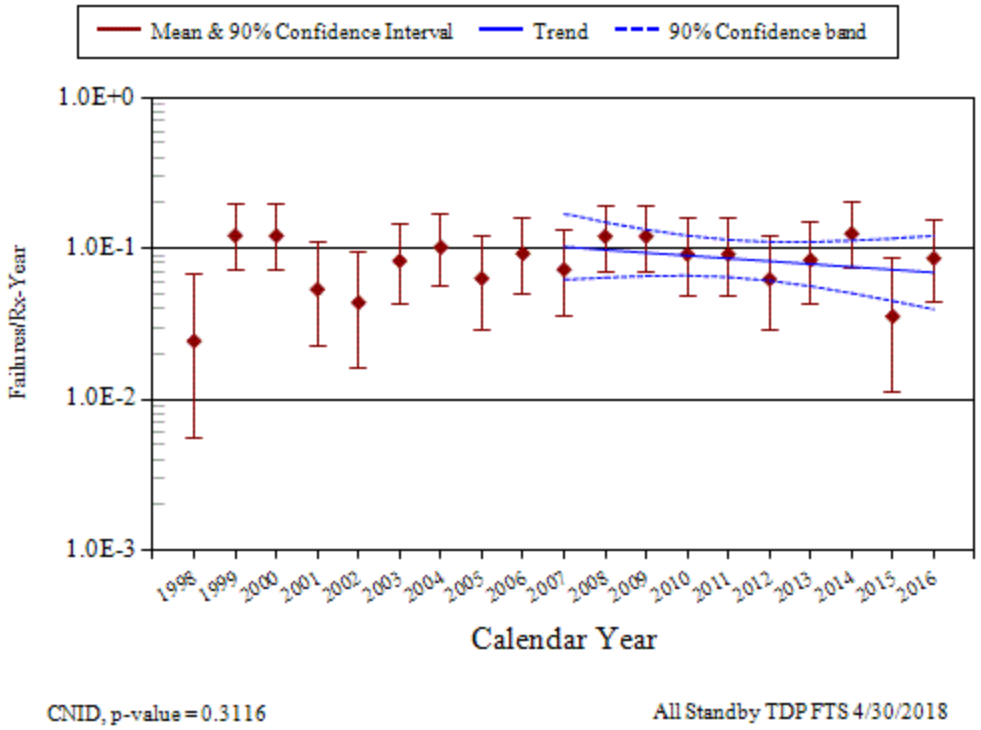

Figure 12. Frequency of FTS events (events per reactor year) trend for standby TDPs.

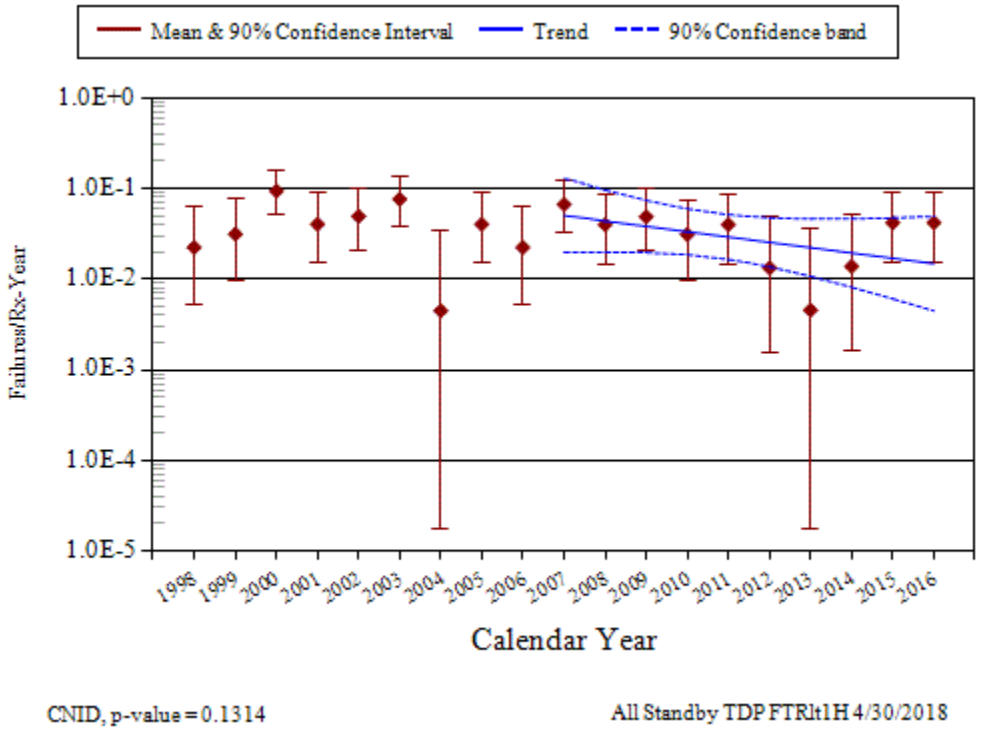

Figure 13. Frequency of FTR≤1H events (events per reactor year) trend for standby TDPs.

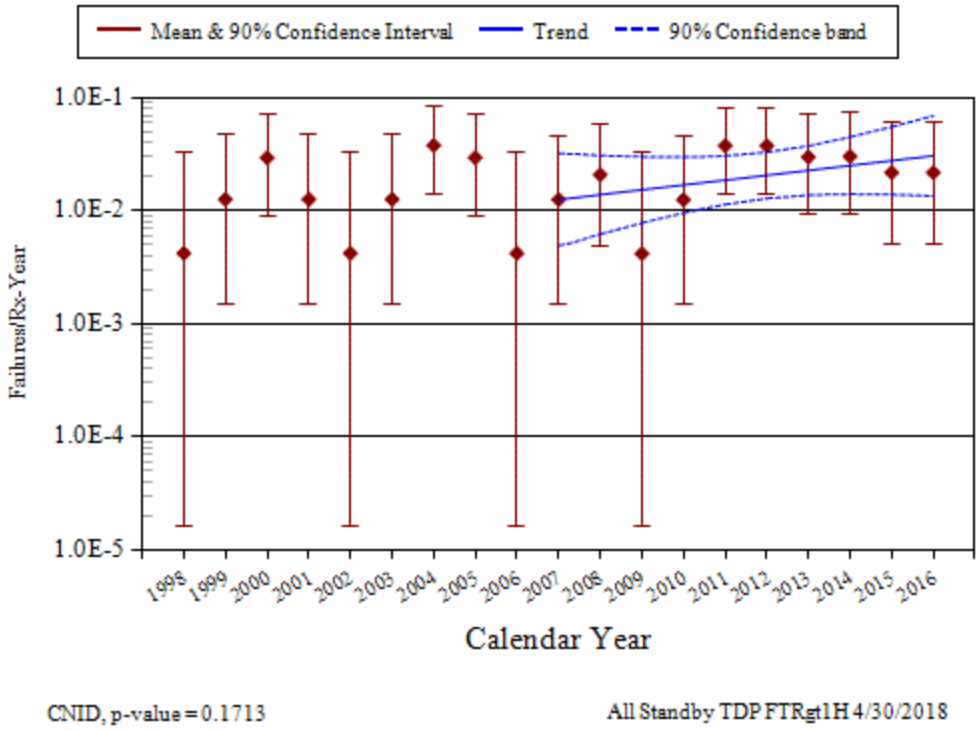

Figure 14. Frequency of FTR>1H events (events per reactor year) trend for standby TDPs.

6.2 Normally Running TDP Engineering Trends

Figure 15 shows the trend for TDP start demands and Figure 16 shows the trend for the TDP run hours. Table 23 and Table 24 provide the plot data, respectively.

Figure 17 shows the trend for TDP FTS events and Figure 18 shows the trend for the TDP FTR events. Table 25 and Table 26 provide the plot data, respectively. The normally running system (MFW) from Table 2 is trended for each figure.

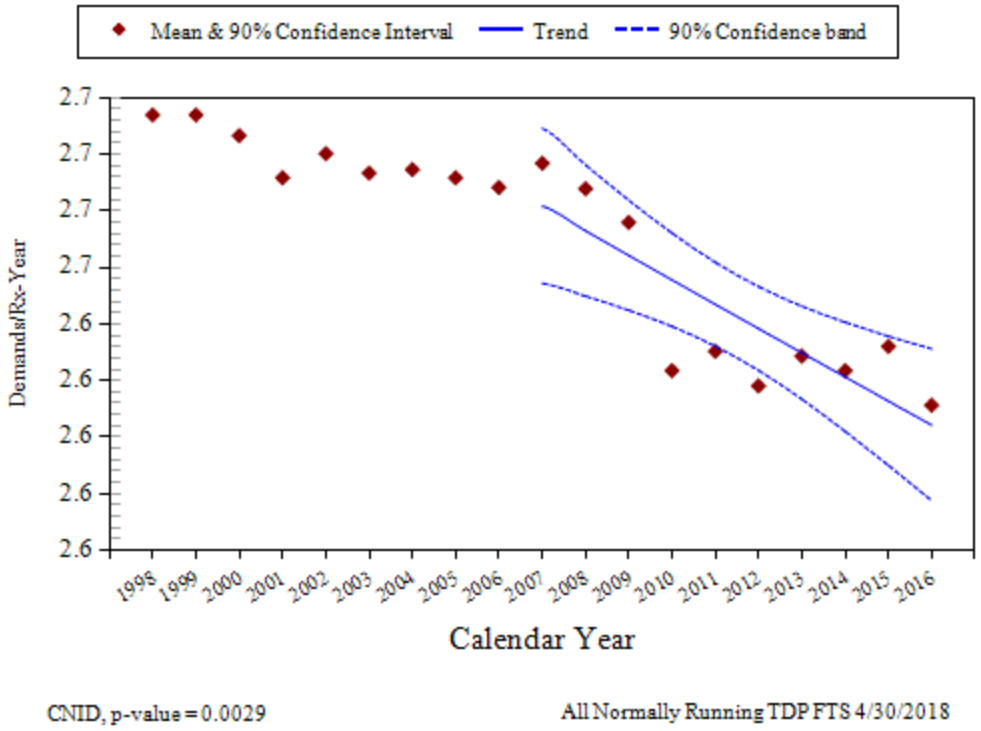

Figure 15. Frequency of start demands (demands per reactor year) trend for normally running TDPs.

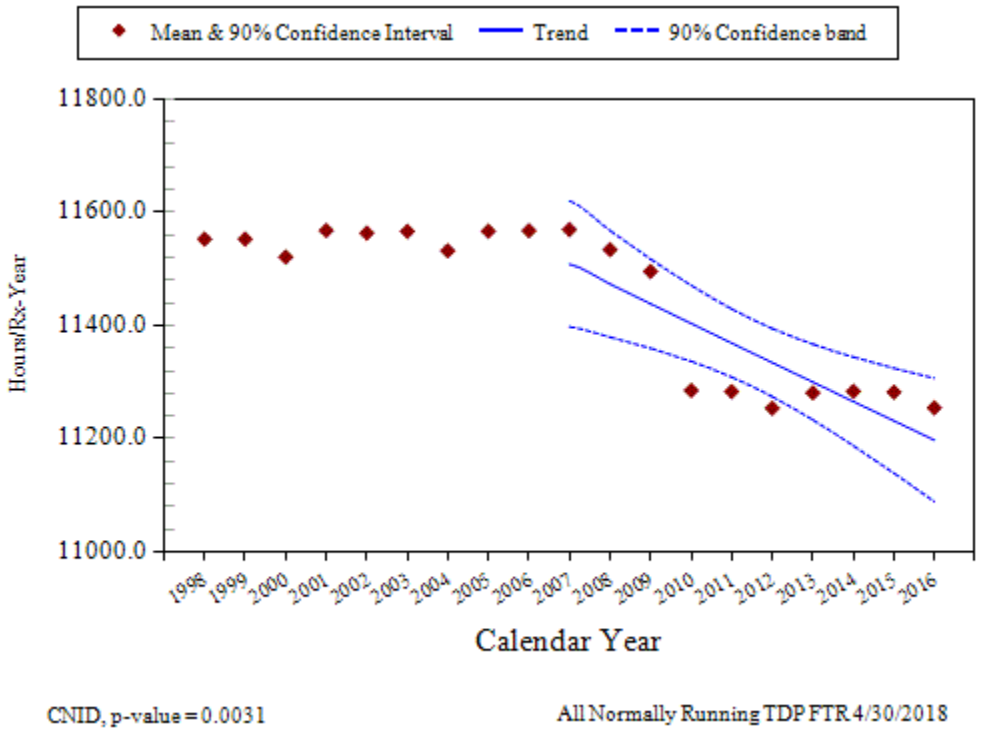

Figure 16. Frequency of run hours (hours per reactor year) trend for normally running TDPs.

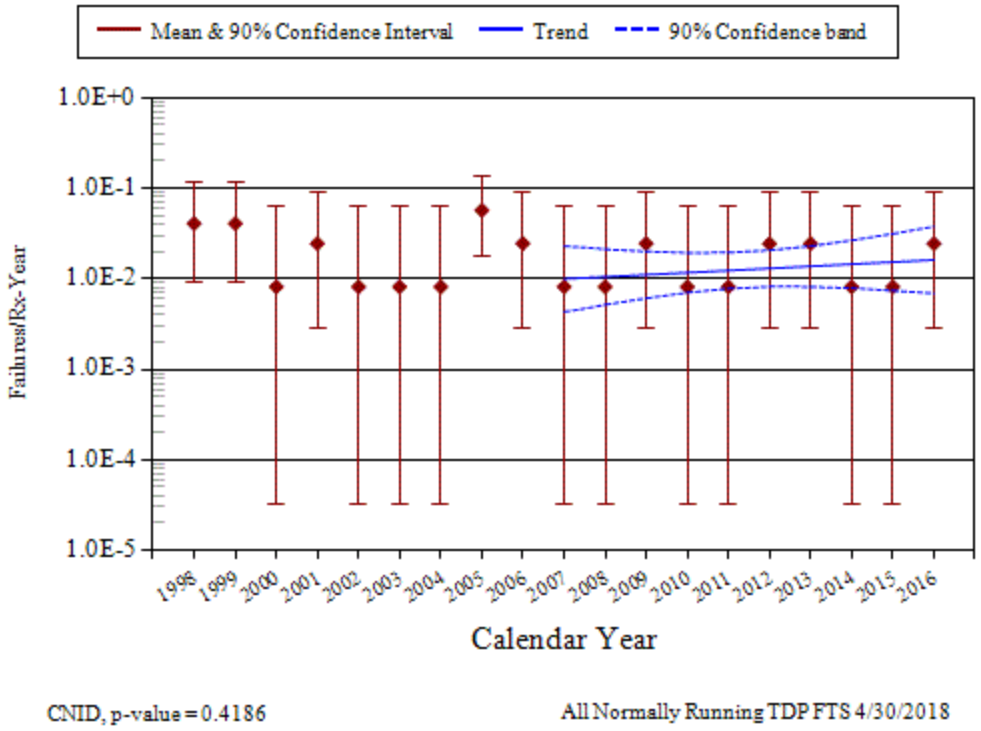

Figure 17. Frequency of FTS events (events per reactor year) trend for normally running TDPs.

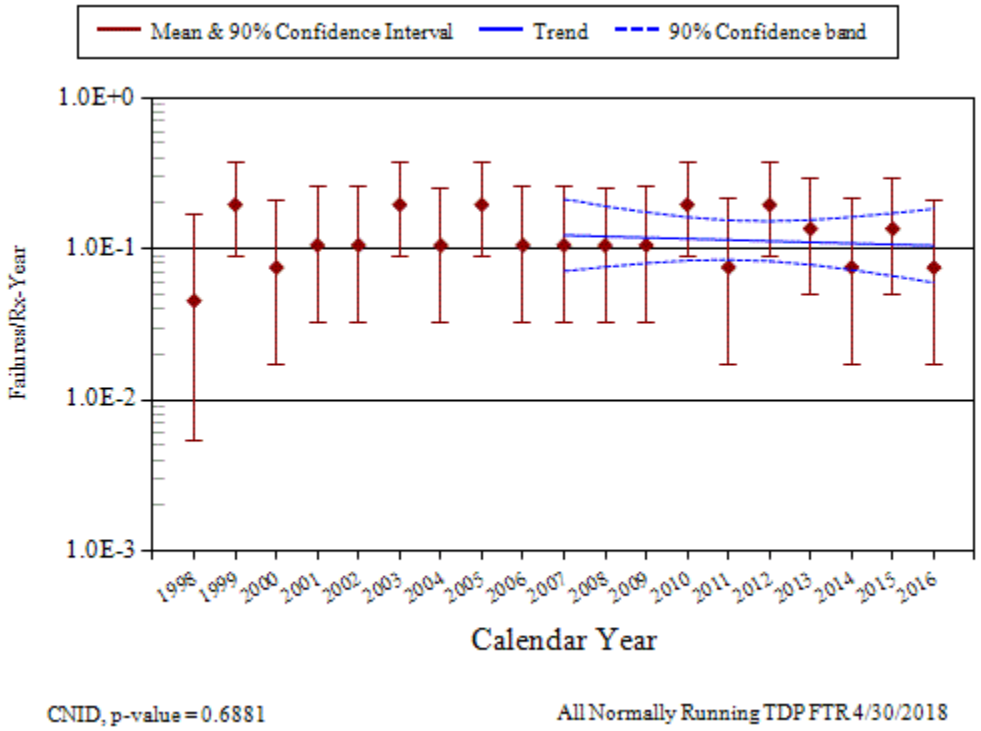

Figure 18. Frequency of FTR events (events per reactor year) trend for normally running TDPs.

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

System Code	TDP Count	TDP Percent	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	Percent of Failures
AFW	74	42.0%	3	6	6	5	4	2	4	11	2	2	45	50.0%
HCI	28	15.9%	2	2	4	2	4	1	3			3	21	23.3%
RCI	31	17.6%	2	4	2	2	1	3	1	1	1	3	20	22.2%
MFW	43	24.4%			1			1	1			1	4	4.4%
Total	176	100.0%	7	12	13	9	9	7	9	12	3	9	90	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	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	Percent of Failures
AFW	74	55.6%	2	2	4	2	2			1	3	1	17	51.5%
HCI	28	21.1%	3	1	1						1	2	8	24.2%
RCI	31	23.3%	2	1		1	2	1				1	8	24.2%
Total	133	100.0%	7	4	5	3	4	1	0	1	4	4	33	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	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	Percent of Failures
AFW	74	42.0%		1			2	3	1	2	2		11	19.3%
HCI	28	15.9%		1		1	2		1			1	6	10.5%
RCI	31	17.6%	1					1	1	1		1	5	8.8%
MFW	43	24.4%	3	3	3	6	2	6	4	2	4	2	35	61.4%
Total	176	100.0%	4	5	3	7	6	10	7	5	6	4	57	100.0%

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 2016 are summarized in Table 7. Consistency between the unplanned demand data and industry-average performance from Table 2 was evaluated using the predictive distribution approach outlined in the Handbook of Parameter Estimation for 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	674	4	4.0	0.43	Yes
FTR≤1H	98	422	7	1.6	0.03	No
FTR>1H	98	1004	1	2.2	0.88	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.

The unplanned demand FTS and FTR>1H are consistent with the industry-average distribution. However, the unplanned demand failure mode observation FTR≤1H is not consistent with the industry-average distribution, which means that the TDP performs worse on an unexpected demand than predicted by the industry-average failure rate distribution.

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 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 three failure modes.

TDP 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 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 internal faults. Internal means that the cause was related to something within the TDP component such as a worn out part or the normal internal environment. The human cause group is primarily influenced by maintenance and operating procedures and practices. The design cause group is influenced by manufacturing, installation, and design issues.

TDP 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 5:1.

Table 8. Component failure cause groups.

Group	Specific Cause	Description
Design	Construction/installation error or inadequacy	Used when a construction or installation error is made during the original or modification installation. This includes specification of incorrect component or material.
	Design error or inadequacy	Used when a design error is made.
	Manufacturing error or inadequacy	Used when a manufacturing error is made during component manufacture.
External	State of other component	Used when the cause of a failure is the result of a component state that is not associated with the component that failed. An example would be the diesel failed due to no fuel in the fuel storage tanks.
	Ambient environmental stress	Used when the cause of a failure is the result of an environmental condition from the location of the component.
Human	Accidental action (unintentional or undesired human errors)	Used when a human error (during the performance of an activity) results in an unintentional or undesired action.
	Human action procedure	Used when the correct procedure is not followed or the wrong procedure is followed. For example: when a missed step or incorrect step in a surveillance procedure results in a component failure.
	Inadequate maintenance	Used when a human error (during the performance of maintenance) results in an unintentional or undesired action.
Internal	Internal to component, piece-part	Used when the cause of a failure is a non-specific result of a failure internal to the component that failed other than aging or wear.
	Internal environment	The internal environment led to the failure. Debris/Foreign material as well as an operating medium chemistry issue.
	Set point drift	Used when the cause of a failure is the result of set point drift or adjustment.
	Age/Wear	Used when the cause of the failure is a non-specific aging or wear issue.
Other	Unknown	Used when the cause of the failure is not known.
	Other (stated cause does not fit other categories)	Used when the cause of a failure is provided but it does not meet any one of the descriptions.
Procedure	Inadequate procedure	Used when the cause of a failure is the result of an inadequate procedure operating or maintenance.

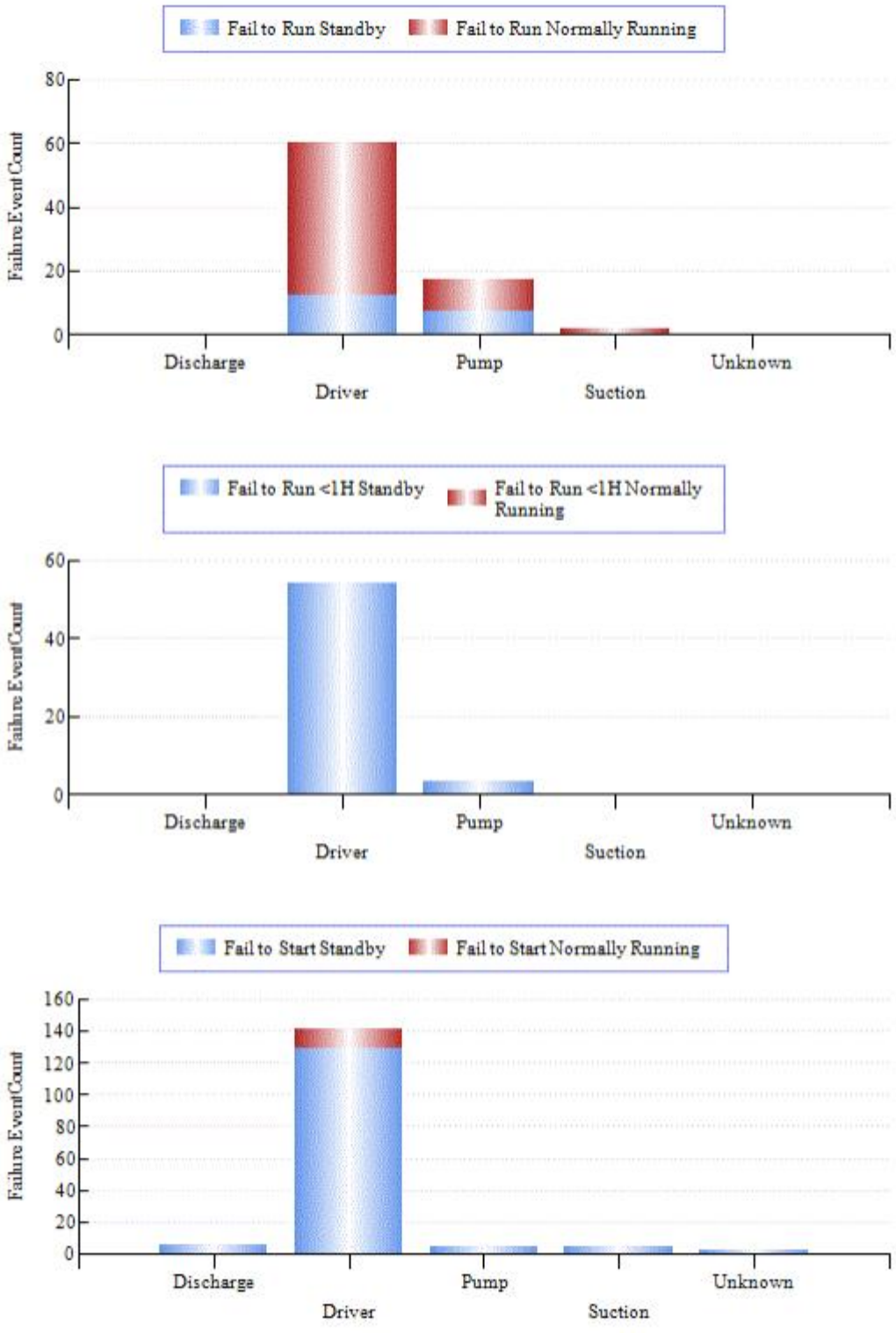

Figure 19. TDP failure event breakdown by subcomponent, failure mode, and operational status.

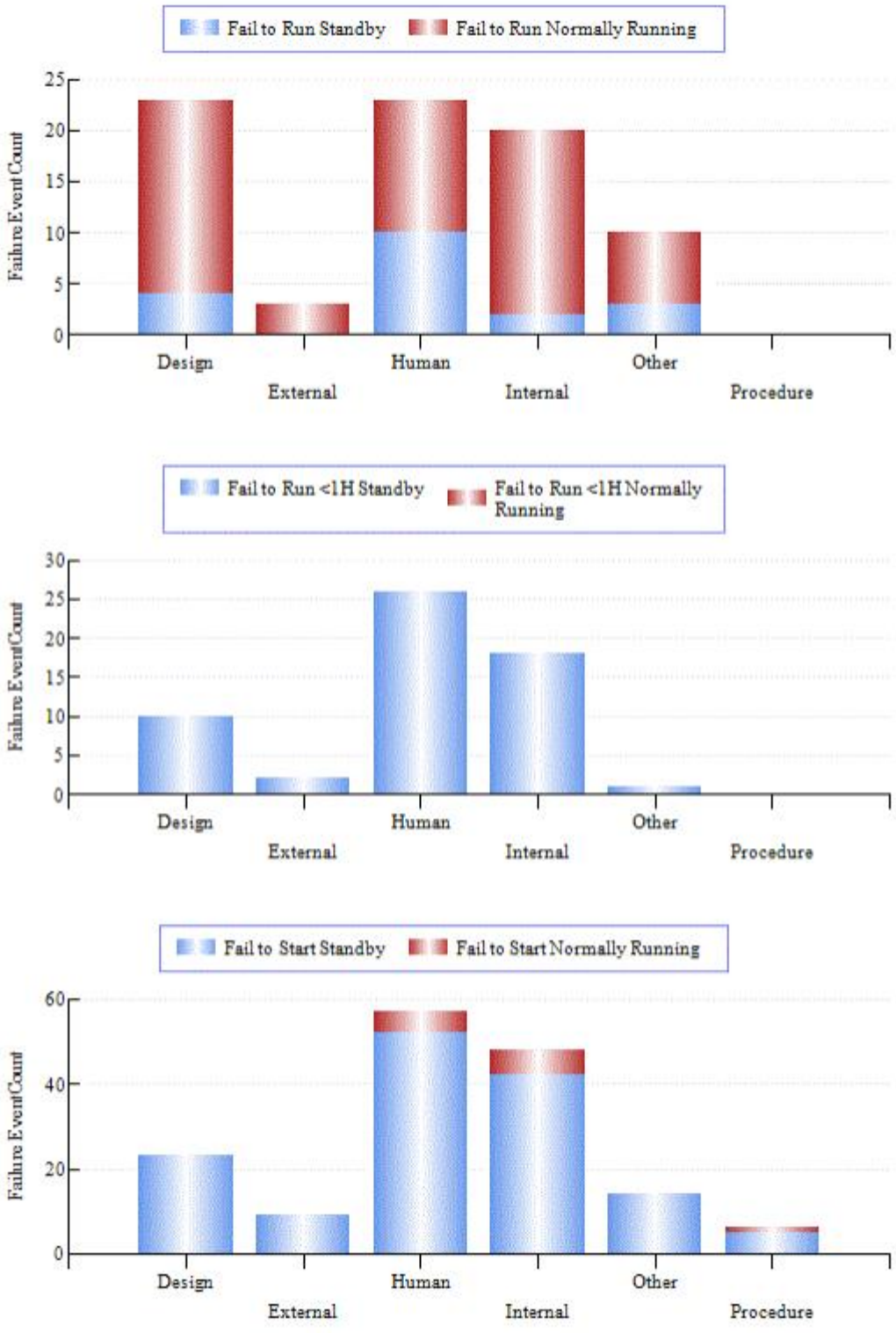

Figure 20. TDP failure event breakdown by cause group, failure mode, and operational status.

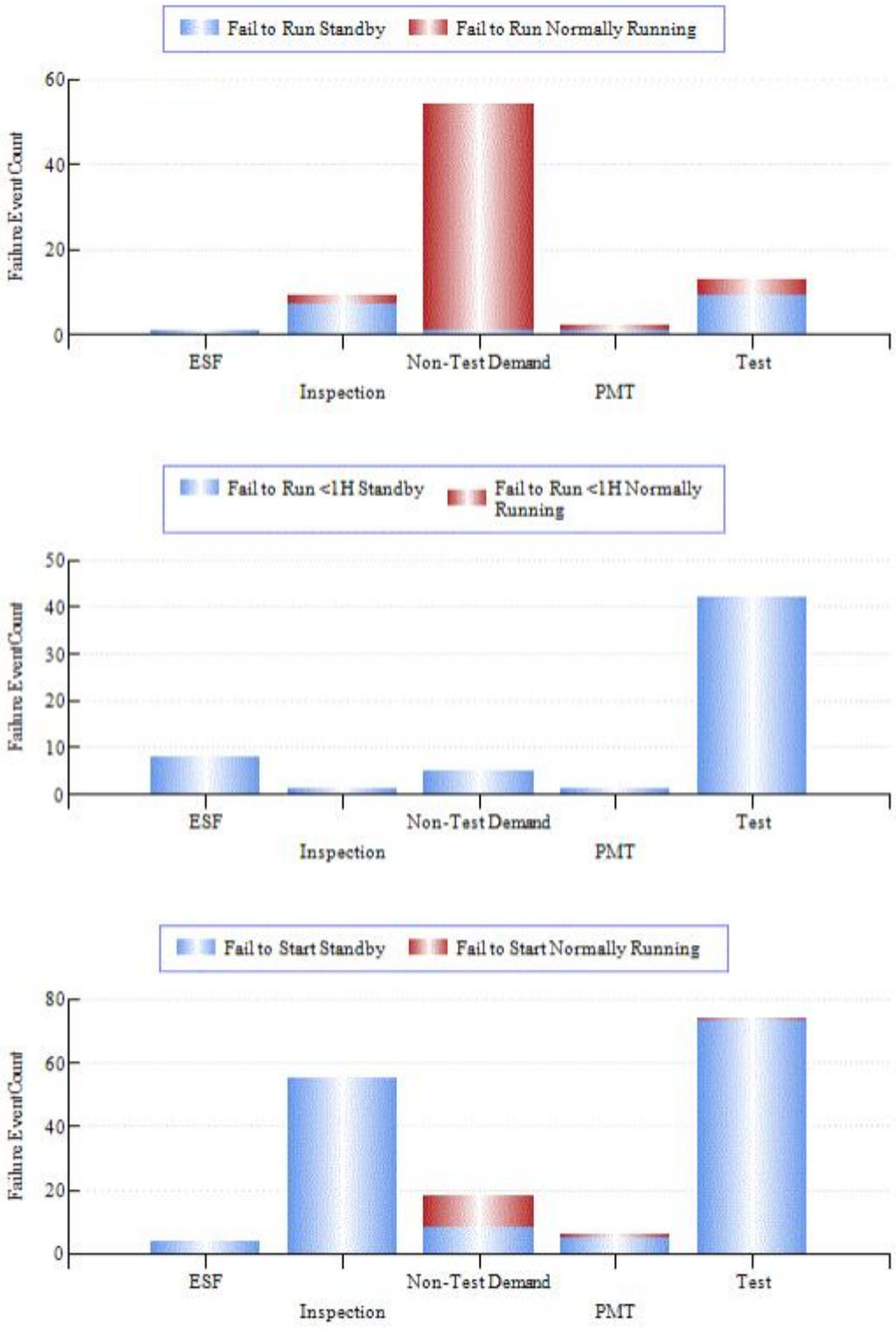

Figure 21. TDP failure event breakdown by failure detection method, failure mode, and operational status.

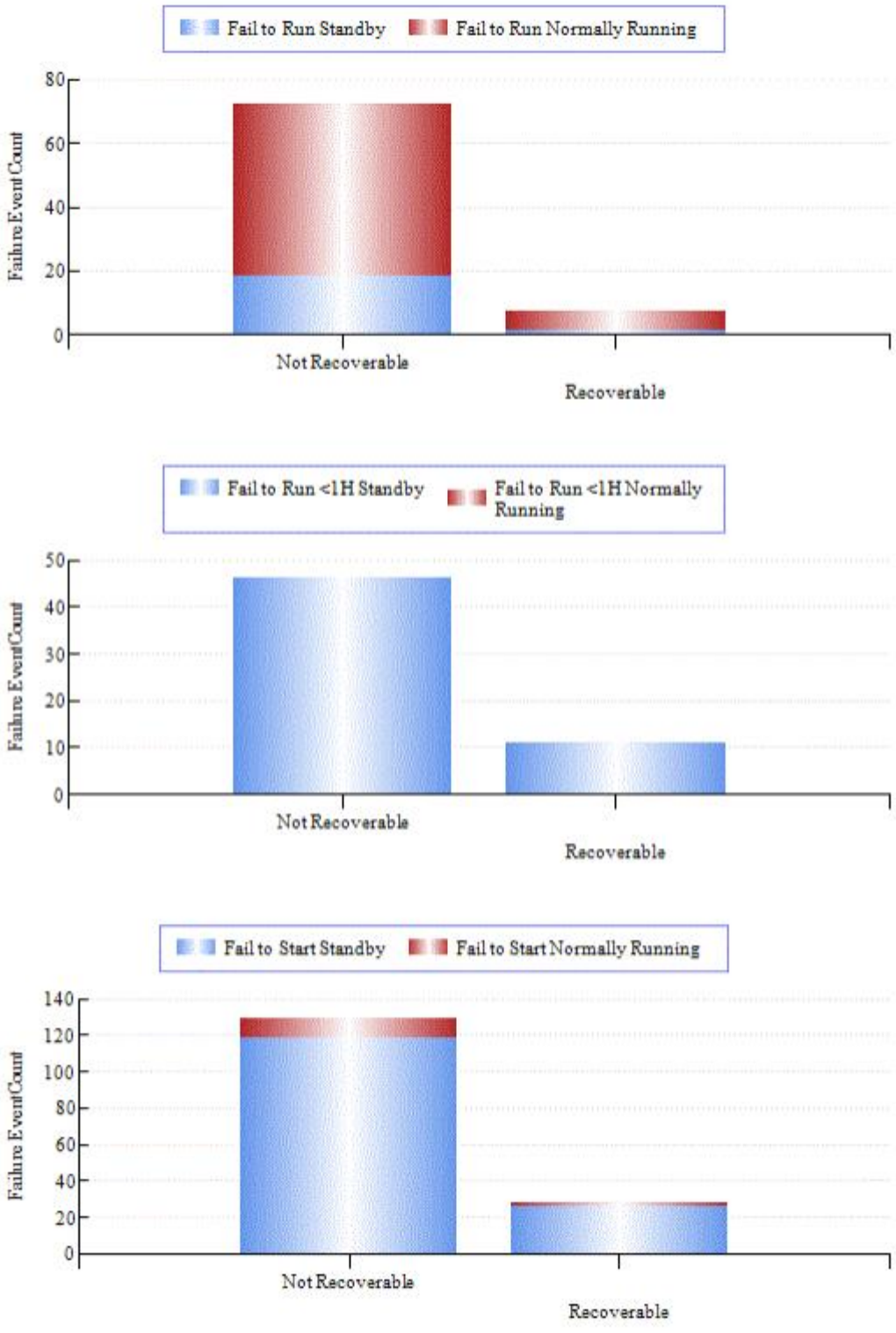

Figure 22. TDP failure event breakdown by recoverability determination, failure mode, and operational status.

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 [5] 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

Table 9. Plot data for Figure 1, standby TDP FTS industry trend.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Demands	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						5.35E-04	1.62E-02	5.93E-03
1998	2	1,448				3.73E-04	4.57E-03	1.63E-03
1999	12	1,478				4.68E-03	1.28E-02	7.99E-03
2000	12	1,417				4.87E-03	1.33E-02	8.31E-03
2001	5	1,410				1.53E-03	7.46E-03	3.67E-03
2002	4	1,398				1.12E-03	6.61E-03	3.03E-03
2003	8	1,518				2.70E-03	9.37E-03	5.30E-03
2004	10	1,447				3.78E-03	1.14E-02	6.84E-03
2005	6	1,425				1.95E-03	8.25E-03	4.30E-03
2006	9	1,462				3.27E-03	1.05E-02	6.13E-03
2007	7	1,381	6.92E-03	4.24E-03	1.13E-02	2.48E-03	9.38E-03	5.11E-03
2008	12	1,449	6.55E-03	4.33E-03	9.88E-03	4.76E-03	1.30E-02	8.14E-03
2009	12	1,547	6.20E-03	4.38E-03	8.75E-03	4.48E-03	1.22E-02	7.65E-03
2010	9	1,578	5.86E-03	4.35E-03	7.89E-03	3.04E-03	9.79E-03	5.71E-03
2011	9	1,576	5.55E-03	4.21E-03	7.32E-03	3.04E-03	9.80E-03	5.71E-03
2012	6	1,504	5.25E-03	3.93E-03	7.01E-03	1.85E-03	7.84E-03	4.08E-03
2013	8	1,542	4.97E-03	3.57E-03	6.92E-03	2.66E-03	9.23E-03	5.22E-03
2014	12	1,492	4.70E-03	3.17E-03	6.98E-03	4.63E-03	1.27E-02	7.92E-03
2015	3	1,513	4.45E-03	2.78E-03	7.12E-03	6.78E-04	5.28E-03	2.19E-03
2016	8	1,488	4.21E-03	2.42E-03	7.31E-03	2.76E-03	9.55E-03	5.40E-03
Total	154	28,072						

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

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Demands	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						1.51E-04	1.15E-02	3.71E-03
1998	2	1,448				3.42E-04	4.20E-03	1.49E-03
1999	3	1,478				6.37E-04	4.97E-03	2.06E-03
2000	10	1,417				3.53E-03	1.07E-02	6.40E-03
2001	4	1,410				1.02E-03	6.02E-03	2.75E-03
2002	5	1,398				1.41E-03	6.89E-03	3.39E-03
2003	8	1,518				2.49E-03	8.65E-03	4.88E-03
2004	0	1,447				1.18E-06	2.34E-03	2.99E-04
2005	4	1,425				1.01E-03	5.96E-03	2.73E-03
2006	2	1,462				3.39E-04	4.17E-03	1.48E-03
2007	7	1,381	3.36E-03	1.30E-03	8.67E-03	2.26E-03	8.59E-03	4.67E-03
2008	4	1,449	2.90E-03	1.31E-03	6.43E-03	9.93E-04	5.88E-03	2.69E-03
2009	5	1,547	2.51E-03	1.28E-03	4.90E-03	1.29E-03	6.31E-03	3.10E-03
2010	3	1,578	2.17E-03	1.20E-03	3.91E-03	6.01E-04	4.69E-03	1.94E-03
2011	4	1,576	1.87E-03	1.06E-03	3.32E-03	9.23E-04	5.46E-03	2.50E-03
2012	1	1,504	1.62E-03	8.66E-04	3.02E-03	1.02E-04	3.20E-03	8.67E-04
2013	0	1,542	1.40E-03	6.73E-04	2.91E-03	1.11E-06	2.21E-03	2.83E-04
2014	1	1,492	1.21E-03	5.04E-04	2.90E-03	1.02E-04	3.22E-03	8.74E-04
2015	4	1,513	1.04E-03	3.70E-04	2.95E-03	9.57E-04	5.66E-03	2.59E-03
2016	4	1,488	9.03E-04	2.69E-04	3.03E-03	9.71E-04	5.74E-03	2.63E-03
Total	71	28,072						

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

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Hours	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						1.51E-03	2.99E-03	2.20E-03
1998	0	2,095				9.07E-07	1.80E-03	2.31E-04
1999	1	1,073				1.54E-04	4.84E-03	1.31E-03
2000	3	486				1.94E-03	1.52E-02	6.28E-03
2001	1	631				2.50E-04	7.88E-03	2.13E-03
2002	0	1,151				1.61E-06	3.20E-03	4.09E-04
2003	1	1,498				1.12E-04	3.53E-03	9.56E-04
2004	4	368				3.78E-03	2.24E-02	1.02E-02
2005	3	242				3.46E-03	2.70E-02	1.12E-02
2006	0	242				6.28E-06	1.25E-02	1.60E-03
2007	1	256	4.11E-03	1.56E-03	1.08E-02	5.37E-04	1.69E-02	4.58E-03
2008	2	281	4.46E-03	1.96E-03	1.02E-02	1.63E-03	2.00E-02	7.10E-03
2009	0	332	4.83E-03	2.42E-03	9.66E-03	4.88E-06	9.69E-03	1.24E-03
2010	1	321	5.24E-03	2.92E-03	9.38E-03	4.49E-04	1.41E-02	3.82E-03
2011	4	419	5.68E-03	3.42E-03	9.43E-03	3.39E-03	2.01E-02	9.19E-03
2012	4	301	6.16E-03	3.80E-03	9.96E-03	4.47E-03	2.64E-02	1.21E-02
2013	3	331	6.67E-03	4.00E-03	1.11E-02	2.69E-03	2.10E-02	8.70E-03
2014	3	316	7.23E-03	4.00E-03	1.31E-02	2.80E-03	2.18E-02	9.04E-03
2015	2	286	7.84E-03	3.87E-03	1.59E-02	1.60E-03	1.97E-02	7.00E-03
2016	2	369	8.50E-03	3.68E-03	1.97E-02	1.30E-03	1.60E-02	5.68E-03
Total	35	10,997						

Table 12. Plot data for Figure 4, normally running TDP FTS industry trend.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Demands	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						4.01E-04	2.78E-02	9.16E-03
1998	2	79				3.50E-03	4.23E-02	1.52E-02
1999	2	79				3.50E-03	4.23E-02	1.52E-02
2000	0	79				1.20E-05	2.36E-02	3.05E-03
2001	1	78				1.08E-03	3.35E-02	9.18E-03
2002	0	78				1.20E-05	2.36E-02	3.06E-03
2003	0	78				1.20E-05	2.37E-02	3.06E-03
2004	0	78				1.20E-05	2.36E-02	3.05E-03
2005	3	78				6.66E-03	5.10E-02	2.14E-02
2006	1	78				1.08E-03	3.35E-02	9.18E-03
2007	0	78	3.73E-03	1.62E-03	8.59E-03	1.20E-05	2.36E-02	3.06E-03
2008	0	78	3.94E-03	1.94E-03	8.00E-03	1.20E-05	2.36E-02	3.06E-03
2009	1	78	4.17E-03	2.30E-03	7.56E-03	1.08E-03	3.36E-02	9.21E-03
2010	0	76	4.41E-03	2.65E-03	7.32E-03	1.22E-05	2.40E-02	3.10E-03
2011	0	76	4.66E-03	2.94E-03	7.37E-03	1.21E-05	2.39E-02	3.09E-03
2012	1	76	4.93E-03	3.10E-03	7.82E-03	1.09E-03	3.39E-02	9.29E-03
2013	1	76	5.21E-03	3.10E-03	8.72E-03	1.09E-03	3.38E-02	9.28E-03
2014	0	76	5.50E-03	2.99E-03	1.01E-02	1.22E-05	2.40E-02	3.10E-03
2015	0	76	5.82E-03	2.82E-03	1.20E-02	1.21E-05	2.39E-02	3.09E-03
2016	1	76	6.15E-03	2.62E-03	1.44E-02	1.09E-03	3.39E-02	9.30E-03
Total	13	1,472						

Table 13. Plot data for Figure 5, normally running TDP FTR industry trend.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Hours	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						1.52E-06	2.67E-05	1.07E-05
1998	1	335,022				4.61E-07	1.45E-05	3.93E-06
1999	6	335,022				7.72E-06	3.28E-05	1.70E-05
2000	2	335,022				1.50E-06	1.84E-05	6.55E-06
2001	3	335,463				2.84E-06	2.22E-05	9.17E-06
2002	3	335,326				2.84E-06	2.22E-05	9.17E-06
2003	6	335,417				7.72E-06	3.27E-05	1.70E-05
2004	3	335,341				2.84E-06	2.22E-05	9.17E-06
2005	6	335,432				7.72E-06	3.27E-05	1.70E-05
2006	3	335,448				2.84E-06	2.22E-05	9.17E-06
2007	3	335,508	1.07E-05	6.18E-06	1.85E-05	2.84E-06	2.21E-05	9.16E-06
2008	3	335,402	1.05E-05	6.62E-06	1.68E-05	2.84E-06	2.22E-05	9.17E-06
2009	3	333,366	1.04E-05	7.03E-06	1.53E-05	2.85E-06	2.23E-05	9.22E-06
2010	6	327,272	1.02E-05	7.33E-06	1.43E-05	7.88E-06	3.34E-05	1.74E-05
2011	2	327,211	1.01E-05	7.45E-06	1.36E-05	1.53E-06	1.88E-05	6.69E-06
2012	6	327,257	9.94E-06	7.31E-06	1.35E-05	7.88E-06	3.34E-05	1.74E-05
2013	4	327,150	9.80E-06	6.95E-06	1.38E-05	4.45E-06	2.63E-05	1.20E-05
2014	2	327,226	9.65E-06	6.44E-06	1.45E-05	1.53E-06	1.88E-05	6.69E-06
2015	4	327,181	9.51E-06	5.88E-06	1.54E-05	4.45E-06	2.63E-05	1.20E-05
2016	2	327,272	9.38E-06	5.32E-06	1.65E-05	1.53E-06	1.88E-05	6.69E-06
Total	68	6,312,337						

Table 14. Plot data for Figure 6, all standby TDP unavailability trend.

Year	UA Hours	Critical Hours	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						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	7.67E-03	9.13E-03	8.37E-03	4.91E-05	3.07E-02	8.26E-03
2008	7,332.2	971,611.9	7.73E-03	8.86E-03	8.27E-03	5.97E-05	2.74E-02	7.53E-03
2009	7,832.5	954,932.0	7.80E-03	8.59E-03	8.18E-03	2.41E-05	3.26E-02	8.33E-03
2010	8,166.7	964,326.7	7.86E-03	8.33E-03	8.09E-03	8.02E-04	2.29E-02	8.46E-03
2011	8,040.6	937,925.5	7.93E-03	8.08E-03	8.00E-03	5.32E-04	2.58E-02	8.84E-03
2012	7,351.7	921,716.4	7.84E-03	7.99E-03	7.92E-03	4.34E-04	2.26E-02	7.68E-03
2013	8,161.4	927,539.5	7.60E-03	8.06E-03	7.83E-03	1.85E-08	4.32E-02	8.48E-03
2014	7,040.8	938,778.0	7.38E-03	8.13E-03	7.74E-03	4.84E-04	2.20E-02	7.60E-03
2015	6,387.5	924,171.6	7.15E-03	8.20E-03	7.66E-03	7.86E-04	1.80E-02	6.90E-03
2016	7,176.2	932,914.0	6.94E-03	8.27E-03	7.57E-03	6.73E-04	2.12E-02	7.71E-03
Total	143,235.6	17,966,398.2						

Table 15. Plot data for Figure 7, standby TDP unreliability trend.

	Regression Curve Data Points			Yearly Estimate Data Points		
Year	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998				2.67E-03	4.58E-02	1.41E-02
1999				1.13E-02	4.88E-02	2.51E-02
2000				3.01E-02	1.03E-01	6.21E-02
2001				9.70E-03	5.37E-02	2.70E-02
2002				8.19E-03	3.76E-02	1.76E-02
2003				1.33E-02	4.30E-02	2.46E-02
2004				3.50E-02	1.26E-01	7.18E-02
2005				3.41E-02	1.31E-01	7.26E-02
2006				9.47E-03	4.55E-02	2.23E-02
2007	4.29E-02	2.84E-02	6.49E-02	1.37E-02	8.54E-02	4.05E-02
2008	4.46E-02	3.14E-02	6.33E-02	2.47E-02	1.07E-01	5.69E-02
2009	4.63E-02	3.45E-02	6.22E-02	1.03E-02	6.65E-02	2.81E-02
2010	4.81E-02	3.74E-02	6.18E-02	1.29E-02	7.19E-02	3.51E-02
2011	5.00E-02	3.99E-02	6.26E-02	3.60E-02	1.13E-01	6.96E-02
2012	5.19E-02	4.14E-02	6.50E-02	3.19E-02	1.31E-01	7.90E-02
2013	5.39E-02	4.20E-02	6.93E-02	2.59E-02	1.23E-01	6.40E-02
2014	5.60E-02	4.17E-02	7.52E-02	2.76E-02	1.20E-01	6.57E-02
2015	5.82E-02	4.10E-02	8.26E-02	1.73E-02	1.03E-01	4.70E-02
2016	6.04E-02	4.00E-02	9.13E-02	2.01E-02	9.16E-02	4.75E-02

Table 16. Plot data for Figure 8, normally running TDP unreliability trend.

	Regression Curve Data Points			Yearly Estimate Data Points		
Year	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998				4.82E-03	4.17E-02	1.90E-02
1999				5.15E-03	4.00E-02	1.88E-02
2000				1.12E-04	1.49E-02	3.37E-03
2001				2.10E-03	2.67E-02	1.06E-02
2002				1.78E-04	1.42E-02	3.64E-03
2003				3.10E-04	1.89E-02	4.75E-03
2004				1.55E-04	1.33E-02	4.06E-03
2005				7.22E-03	5.27E-02	2.58E-02
2006				1.12E-03	2.84E-02	1.04E-02
2007	4.94E-03	2.31E-03	1.06E-02	1.21E-04	1.23E-02	3.78E-03
2008	5.15E-03	2.70E-03	9.82E-03	1.50E-04	1.43E-02	3.80E-03
2009	5.37E-03	3.12E-03	9.24E-03	1.42E-03	3.33E-02	1.27E-02
2010	5.60E-03	3.53E-03	8.89E-03	3.33E-04	1.61E-02	4.39E-03
2011	5.84E-03	3.86E-03	8.85E-03	1.19E-04	1.48E-02	3.95E-03
2012	6.09E-03	4.02E-03	9.22E-03	1.56E-03	3.22E-02	1.11E-02
2013	6.35E-03	4.00E-03	1.01E-02	2.36E-03	2.91E-02	1.20E-02
2014	6.62E-03	3.85E-03	1.14E-02	1.54E-04	7.80E-03	2.91E-03
2015	6.90E-03	3.62E-03	1.31E-02	2.75E-04	1.51E-02	4.38E-03
2016	7.19E-03	3.36E-03	1.54E-02	2.01E-03	3.74E-02	1.05E-02

Table 17. Plot data for Figure 9, standby TDP start demands trend.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Demands	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	1,448	97.0				1.43E+01	1.56E+01	1.49E+01
1999	1,478	97.0				1.46E+01	1.59E+01	1.52E+01
2000	1,417	97.3				1.39E+01	1.52E+01	1.46E+01
2001	1,410	97.0				1.39E+01	1.52E+01	1.45E+01
2002	1,398	97.0				1.38E+01	1.51E+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	1.49E+01	1.42E+01	1.57E+01	1.35E+01	1.48E+01	1.41E+01
2008	1,449	98.3	1.51E+01	1.44E+01	1.57E+01	1.41E+01	1.54E+01	1.47E+01
2009	1,547	98.0	1.52E+01	1.47E+01	1.58E+01	1.51E+01	1.65E+01	1.58E+01
2010	1,578	98.0	1.54E+01	1.49E+01	1.59E+01	1.54E+01	1.68E+01	1.61E+01
2011	1,576	98.0	1.55E+01	1.51E+01	1.60E+01	1.54E+01	1.68E+01	1.61E+01
2012	1,504	98.3	1.57E+01	1.53E+01	1.61E+01	1.47E+01	1.60E+01	1.53E+01
2013	1,542	95.6	1.59E+01	1.54E+01	1.64E+01	1.55E+01	1.68E+01	1.61E+01
2014	1,492	94.0	1.61E+01	1.55E+01	1.66E+01	1.52E+01	1.66E+01	1.59E+01
2015	1,513	93.0	1.62E+01	1.56E+01	1.69E+01	1.56E+01	1.70E+01	1.63E+01
2016	1,488	93.0	1.64E+01	1.56E+01	1.72E+01	1.53E+01	1.67E+01	1.60E+01
Total	28,072	1,837.3						

Table 18. Plot data for Figure 10, standby TDP run ≤1hour run-hours trend.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Hours	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	1,448	97.0				1.43E+01	1.56E+01	1.49E+01
1999	1,478	97.0				1.46E+01	1.59E+01	1.52E+01
2000	1,417	97.3				1.39E+01	1.52E+01	1.46E+01
2001	1,410	97.0				1.39E+01	1.52E+01	1.45E+01
2002	1,398	97.0				1.38E+01	1.51E+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	1.49E+01	1.42E+01	1.57E+01	1.35E+01	1.48E+01	1.41E+01
2008	1,449	98.3	1.51E+01	1.44E+01	1.57E+01	1.41E+01	1.54E+01	1.47E+01
2009	1,547	98.0	1.52E+01	1.47E+01	1.58E+01	1.51E+01	1.65E+01	1.58E+01
2010	1,578	98.0	1.54E+01	1.49E+01	1.59E+01	1.54E+01	1.68E+01	1.61E+01
2011	1,576	98.0	1.55E+01	1.51E+01	1.60E+01	1.54E+01	1.68E+01	1.61E+01
2012	1,504	98.3	1.57E+01	1.53E+01	1.61E+01	1.47E+01	1.60E+01	1.53E+01
2013	1,542	95.6	1.59E+01	1.54E+01	1.64E+01	1.55E+01	1.68E+01	1.61E+01
2014	1,492	94.0	1.61E+01	1.55E+01	1.66E+01	1.52E+01	1.66E+01	1.59E+01
2015	1,513	93.0	1.62E+01	1.56E+01	1.69E+01	1.56E+01	1.70E+01	1.63E+01
2016	1,488	93.0	1.64E+01	1.56E+01	1.72E+01	1.53E+01	1.67E+01	1.60E+01
Total	28,072	1,837.3						

Table 19. Plot data for Figure 11, standby TDP run > 1 hour run-hours trend.

Year	Run Hours	Reactor Years	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	2,095	97.0				2.08E+01	2.24E+01	2.16E+01
1999	1,073	97.0				1.05E+01	1.16E+01	1.10E+01
2000	486	97.3				4.63E+00	5.38E+00	4.99E+00
2001	631	97.0				6.09E+00	6.95E+00	6.51E+00
2002	1,151	97.0				1.13E+01	1.24E+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	3.78E+00
2005	242	97.0				2.24E+00	2.78E+00	2.50E+00
2006	242	97.0				2.24E+00	2.78E+00	2.49E+00
2007	256	97.6	2.97E+00	2.44E+00	3.62E+00	2.36E+00	2.91E+00	2.62E+00
2008	281	98.3	3.04E+00	2.57E+00	3.60E+00	2.58E+00	3.15E+00	2.86E+00
2009	332	98.0	3.11E+00	2.70E+00	3.59E+00	3.09E+00	3.71E+00	3.39E+00
2010	321	98.0	3.19E+00	2.83E+00	3.59E+00	2.98E+00	3.59E+00	3.27E+00
2011	419	98.0	3.26E+00	2.94E+00	3.63E+00	3.93E+00	4.63E+00	4.27E+00
2012	301	98.3	3.34E+00	3.01E+00	3.71E+00	2.78E+00	3.37E+00	3.06E+00
2013	331	95.6	3.42E+00	3.05E+00	3.84E+00	3.16E+00	3.79E+00	3.46E+00
2014	316	94.0	3.50E+00	3.06E+00	4.01E+00	3.06E+00	3.69E+00	3.36E+00
2015	286	93.0	3.59E+00	3.06E+00	4.21E+00	2.78E+00	3.39E+00	3.07E+00
2016	369	93.0	3.67E+00	3.04E+00	4.44E+00	3.63E+00	4.32E+00	3.96E+00
Total	10,997	1,837.3						

Table 20. Plot data for Figure 12, standby TDP FTS events trend.

			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				5.58E-03	6.86E-02	2.44E-02
1999	12	97.0				7.12E-02	1.96E-01	1.22E-01
2000	12	97.3				7.10E-02	1.95E-01	1.22E-01
2001	5	97.0				2.23E-02	1.09E-01	5.36E-02
2002	4	97.0				1.62E-02	9.59E-02	4.39E-02
2003	8	97.0				4.23E-02	1.47E-01	8.29E-02
2004	10	97.3				5.64E-02	1.71E-01	1.02E-01
2005	6	97.0				2.87E-02	1.22E-01	6.34E-02
2006	9	97.0				4.93E-02	1.59E-01	9.26E-02
2007	7	97.6	1.02E-01	6.20E-02	1.69E-01	3.52E-02	1.34E-01	7.27E-02
2008	12	98.3	9.80E-02	6.42E-02	1.50E-01	7.04E-02	1.93E-01	1.20E-01
2009	12	98.0	9.39E-02	6.58E-02	1.34E-01	7.05E-02	1.94E-01	1.21E-01
2010	9	98.0	8.99E-02	6.62E-02	1.22E-01	4.88E-02	1.58E-01	9.17E-02
2011	9	98.0	8.61E-02	6.48E-02	1.14E-01	4.88E-02	1.58E-01	9.17E-02
2012	6	98.3	8.25E-02	6.13E-02	1.11E-01	2.84E-02	1.20E-01	6.26E-02
2013	8	95.6	7.90E-02	5.63E-02	1.11E-01	4.29E-02	1.49E-01	8.40E-02
2014	12	94.0	7.57E-02	5.06E-02	1.13E-01	7.34E-02	2.01E-01	1.26E-01
2015	3	93.0	7.25E-02	4.49E-02	1.17E-01	1.10E-02	8.58E-02	3.55E-02
2016	8	93.0	6.94E-02	3.96E-02	1.22E-01	4.40E-02	1.53E-01	8.62E-02
Total	154	1,837.3						

Table 21. Plot data for Figure 13, standby TDP FTR≤1H events trend.

			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				5.14E-03	6.31E-02	2.24E-02
1999	3	97.0				9.73E-03	7.59E-02	3.14E-02
2000	10	97.3				5.19E-02	1.58E-01	9.40E-02
2001	4	97.0				1.49E-02	8.83E-02	4.04E-02
2002	5	97.0				2.05E-02	1.00E-01	4.94E-02
2003	8	97.0				3.89E-02	1.35E-01	7.63E-02
2004	0	97.3				1.76E-05	3.50E-02	4.48E-03
2005	4	97.0				1.49E-02	8.83E-02	4.04E-02
2006	2	97.0				5.14E-03	6.31E-02	2.24E-02
2007	7	97.6	5.01E-02	1.96E-02	1.28E-01	3.24E-02	1.23E-01	6.70E-02
2008	4	98.3	4.38E-02	1.99E-02	9.61E-02	1.48E-02	8.73E-02	3.99E-02
2009	5	98.0	3.82E-02	1.97E-02	7.42E-02	2.04E-02	9.95E-02	4.89E-02
2010	3	98.0	3.34E-02	1.86E-02	5.99E-02	9.64E-03	7.53E-02	3.11E-02
2011	4	98.0	2.92E-02	1.65E-02	5.15E-02	1.48E-02	8.75E-02	4.00E-02
2012	1	98.3	2.55E-02	1.37E-02	4.75E-02	1.56E-03	4.91E-02	1.33E-02
2013	0	95.6	2.23E-02	1.07E-02	4.61E-02	1.79E-05	3.55E-02	4.55E-03
2014	1	94.0	1.94E-02	8.16E-03	4.63E-02	1.62E-03	5.11E-02	1.38E-02
2015	4	93.0	1.70E-02	6.07E-03	4.75E-02	1.55E-02	9.16E-02	4.19E-02
2016	4	93.0	1.48E-02	4.46E-03	4.94E-02	1.55E-02	9.16E-02	4.19E-02
Total	71	1,837.3						

Table 22. Plot data for Figure 14, standby TDP FTR>1H events trend.

			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				1.66E-05	3.30E-02	4.22E-03
1999	1	97.0				1.49E-03	4.67E-02	1.27E-02
2000	3	97.3				9.13E-03	7.13E-02	2.95E-02
2001	1	97.0				1.49E-03	4.67E-02	1.27E-02
2002	0	97.0				1.66E-05	3.30E-02	4.22E-03
2003	1	97.0				1.49E-03	4.67E-02	1.27E-02
2004	4	97.3				1.40E-02	8.29E-02	3.79E-02
2005	3	97.0				9.15E-03	7.14E-02	2.96E-02
2006	0	97.0				1.66E-05	3.30E-02	4.22E-03
2007	1	97.6	1.26E-02	4.93E-03	3.22E-02	1.48E-03	4.65E-02	1.26E-02
2008	2	98.3	1.39E-02	6.24E-03	3.10E-02	4.79E-03	5.88E-02	2.09E-02
2009	0	98.0	1.54E-02	7.82E-03	3.01E-02	1.65E-05	3.27E-02	4.19E-03
2010	1	98.0	1.69E-02	9.60E-03	2.99E-02	1.47E-03	4.64E-02	1.26E-02
2011	4	98.0	1.87E-02	1.14E-02	3.07E-02	1.39E-02	8.24E-02	3.77E-02
2012	4	98.3	2.07E-02	1.29E-02	3.31E-02	1.39E-02	8.22E-02	3.76E-02
2013	3	95.6	2.28E-02	1.38E-02	3.77E-02	9.26E-03	7.23E-02	2.99E-02
2014	3	94.0	2.52E-02	1.41E-02	4.50E-02	9.39E-03	7.33E-02	3.03E-02
2015	2	93.0	2.78E-02	1.40E-02	5.54E-02	5.01E-03	6.15E-02	2.19E-02
2016	2	93.0	3.07E-02	1.36E-02	6.95E-02	5.01E-03	6.15E-02	2.18E-02
Total	35	1,837.3						

Table 23. Plot data for Figure 15, normally running TDP start demands trend.

			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				2.21E+00	3.25E+00	2.69E+00
2002	78	29.0				2.22E+00	3.26E+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	2.69E+00
2005	78	29.0				2.21E+00	3.25E+00	2.69E+00
2006	78	29.0				2.21E+00	3.24E+00	2.69E+00
2007	78	29.0	2.68E+00	2.65E+00	2.71E+00	2.22E+00	3.25E+00	2.70E+00
2008	78	29.1	2.67E+00	2.65E+00	2.70E+00	2.21E+00	3.24E+00	2.69E+00
2009	78	29.0	2.66E+00	2.64E+00	2.68E+00	2.20E+00	3.23E+00	2.68E+00
2010	76	29.0	2.66E+00	2.64E+00	2.67E+00	2.15E+00	3.17E+00	2.62E+00
2011	76	29.0	2.65E+00	2.63E+00	2.66E+00	2.16E+00	3.18E+00	2.63E+00
2012	76	29.1	2.64E+00	2.62E+00	2.65E+00	2.15E+00	3.17E+00	2.62E+00
2013	76	29.0	2.63E+00	2.61E+00	2.65E+00	2.16E+00	3.18E+00	2.63E+00
2014	76	29.0	2.62E+00	2.60E+00	2.64E+00	2.15E+00	3.17E+00	2.62E+00
2015	76	29.0	2.61E+00	2.59E+00	2.64E+00	2.16E+00	3.18E+00	2.63E+00
2016	76	29.1	2.60E+00	2.58E+00	2.63E+00	2.14E+00	3.16E+00	2.61E+00
Total	1,472	551.4						

Table 24. Plot data for Figure 16, normally running TDP run hours trend.

Year	Run Hours	Reactor Years	Regression Curve Data Points			Yearly Estimate Data Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	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	335,463	29.0				1.15E+04	1.16E+04	1.16E+04
2002	335,326	29.0				1.15E+04	1.16E+04	1.16E+04
2003	335,417	29.0				1.15E+04	1.16E+04	1.16E+04
2004	335,341	29.1				1.15E+04	1.16E+04	1.15E+04
2005	335,432	29.0				1.15E+04	1.16E+04	1.16E+04
2006	335,448	29.0				1.15E+04	1.16E+04	1.16E+04
2007	335,508	29.0	1.15E+04	1.14E+04	1.16E+04	1.15E+04	1.16E+04	1.16E+04
2008	335,402	29.1	1.15E+04	1.14E+04	1.16E+04	1.15E+04	1.16E+04	1.15E+04
2009	333,366	29.0	1.14E+04	1.14E+04	1.15E+04	1.15E+04	1.15E+04	1.15E+04
2010	327,272	29.0	1.14E+04	1.13E+04	1.15E+04	1.13E+04	1.13E+04	1.13E+04
2011	327,211	29.0	1.14E+04	1.13E+04	1.14E+04	1.13E+04	1.13E+04	1.13E+04
2012	327,257	29.1	1.13E+04	1.13E+04	1.14E+04	1.12E+04	1.13E+04	1.13E+04
2013	327,150	29.0	1.13E+04	1.12E+04	1.14E+04	1.13E+04	1.13E+04	1.13E+04
2014	327,226	29.0	1.13E+04	1.12E+04	1.13E+04	1.13E+04	1.13E+04	1.13E+04
2015	327,181	29.0	1.12E+04	1.11E+04	1.13E+04	1.13E+04	1.13E+04	1.13E+04
2016	327,272	29.1	1.12E+04	1.11E+04	1.13E+04	1.12E+04	1.13E+04	1.13E+04
Total	6,312,337	551.4						

Table 25. Plot data for Figure 17, normally running TDP FTS events trend.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Reactor Years	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	5.71E-02
2006	1	29.0				2.87E-03	9.04E-02	2.45E-02
2007	0	29.0	9.93E-03	4.32E-03	2.29E-02	3.21E-05	6.38E-02	8.16E-03
2008	0	29.1	1.05E-02	5.17E-03	2.12E-02	3.21E-05	6.37E-02	8.15E-03
2009	1	29.0	1.11E-02	6.11E-03	2.00E-02	2.87E-03	9.04E-02	2.45E-02
2010	0	29.0	1.17E-02	7.03E-03	1.94E-02	3.21E-05	6.38E-02	8.16E-03
2011	0	29.0	1.23E-02	7.79E-03	1.95E-02	3.21E-05	6.38E-02	8.16E-03
2012	1	29.1	1.30E-02	8.19E-03	2.07E-02	2.87E-03	9.03E-02	2.45E-02
2013	1	29.0	1.37E-02	8.19E-03	2.30E-02	2.87E-03	9.04E-02	2.45E-02
2014	0	29.0	1.45E-02	7.89E-03	2.66E-02	3.21E-05	6.38E-02	8.16E-03
2015	0	29.0	1.53E-02	7.42E-03	3.15E-02	3.21E-05	6.38E-02	8.16E-03
2016	1	29.1	1.61E-02	6.89E-03	3.78E-02	2.87E-03	9.03E-02	2.45E-02
Total	13	551.4						

Table 26. Plot data for Figure 18, normally running TDP FTR events trend.

			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				5.32E-03	1.67E-01	4.53E-02
1999	6	29.0				8.90E-02	3.78E-01	1.96E-01
2000	2	29.1				1.73E-02	2.12E-01	7.54E-02
2001	3	29.0				3.28E-02	2.56E-01	1.06E-01
2002	3	29.0				3.28E-02	2.56E-01	1.06E-01
2003	6	29.0				8.90E-02	3.78E-01	1.96E-01
2004	3	29.1				3.27E-02	2.55E-01	1.06E-01
2005	6	29.0				8.90E-02	3.78E-01	1.96E-01
2006	3	29.0				3.28E-02	2.56E-01	1.06E-01
2007	3	29.0	1.23E-01	7.13E-02	2.12E-01	3.28E-02	2.56E-01	1.06E-01
2008	3	29.1	1.21E-01	7.62E-02	1.92E-01	3.27E-02	2.55E-01	1.06E-01
2009	3	29.0	1.19E-01	8.06E-02	1.75E-01	3.28E-02	2.56E-01	1.06E-01
2010	6	29.0	1.17E-01	8.38E-02	1.63E-01	8.90E-02	3.78E-01	1.96E-01
2011	2	29.0	1.15E-01	8.49E-02	1.55E-01	1.73E-02	2.13E-01	7.56E-02
2012	6	29.1	1.13E-01	8.31E-02	1.53E-01	8.88E-02	3.77E-01	1.96E-01
2013	4	29.0	1.11E-01	7.88E-02	1.56E-01	5.02E-02	2.97E-01	1.36E-01
2014	2	29.0	1.09E-01	7.28E-02	1.63E-01	1.73E-02	2.13E-01	7.56E-02
2015	4	29.0	1.07E-01	6.63E-02	1.73E-01	5.02E-02	2.97E-01	1.36E-01
2016	2	29.1	1.05E-01	5.99E-02	1.85E-01	1.73E-02	2.12E-01	7.54E-02
Total	68	551.4						

9. REFERENCES

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

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

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

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

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

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

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