Component Performance Studies

Turbine-Driven Pumps

1987–2005

This report presents a performance evaluation of the turbine-driven pumps (TDPs) at United States commercial reactors. The evaluation is based on the operating experience from fiscal year 1987 through 2005, as reported in Licensee Event Reports (LERs), Nuclear Plant Reliability Data System (NPRDS), and Equipment Performance and Information Exchange (EPIX). This is the latest update to *NUREG-1715, Volume 1*, updating data, availability estimates, trends, and figures.

1 LATEST UNAVAILABILITY VALUES AND TRENDS

1.1 Overall Unavailability

The industry-wide unavailability of TDPs has been calculated from the operating experience for failure on demand[1] and failure-to-start (FTS). The estimates are based on failures that occurred during unplanned demands, and cyclic and quarterly surveillance tests.

Table 1 shows overall results for the TDP. Two primary failure modes were identified. Failure probability estimates for the resulting failure modes combinations are given in the table. Both ESF actuations and surveillance tests were treated as opportunities to observe possible failures.

Table 1. Component performance data from fiscal year 1987-2005.

Component	Estimated Number of Demands	Failure Mode	Number of Failures	Failure Probability		
				Lower Bound	MLE	Upper Bound
Turbine-driven pump	22029	Fail to start	191	3.41E-05	8.67E-03	3.33E-02
	22029	Fail on demand	266	4.75E-05	1.21E-02	4.64E-02

1.2 Unavailability Trend

An extremely statistically significant[2] decreasing trend within the industry estimates of TDP failure on demand on a per fiscal year basis was identified. Figure 1 displays the trend by

[1] The term “failure on demand” is used to denote the combined failure to start and the failure to run failure modes. The failure to run portion is a probability the pump succeeds with the run phase and is not correlated with a specific failure rate per hour.

2. 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

fiscal year of the TDP failure on demand calculated from the 1987–2005 experience. Table 2 shows the data points for Figure 1.

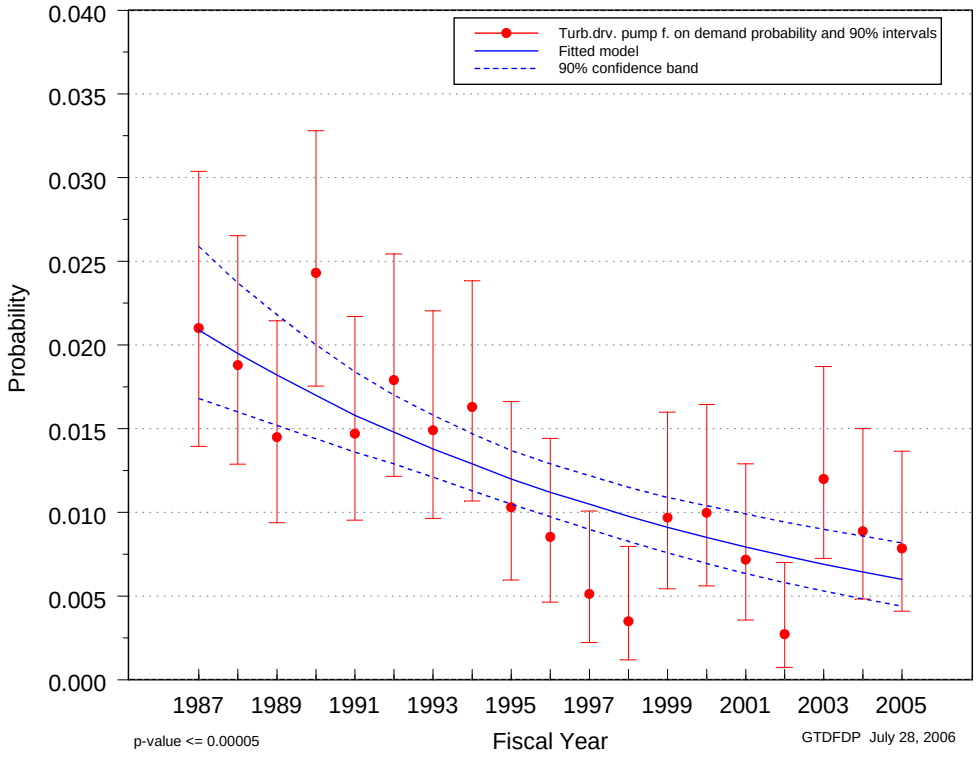

Figure 1. Turbine-driven pump failure on demand.

An extremely statistically significant decreasing trend within the industry estimates of TDP FTS on a per fiscal year basis was identified. Figure 2 shows the trend in the TDP FTS unavailability. Table 3 shows the data points for Figure 2.

"Michelin Guide" scale: p-value < 0.05 (statistically significant), p-value < 0.01 (highly statistically significant); p-value < 0.001 (extremely statistically significant).

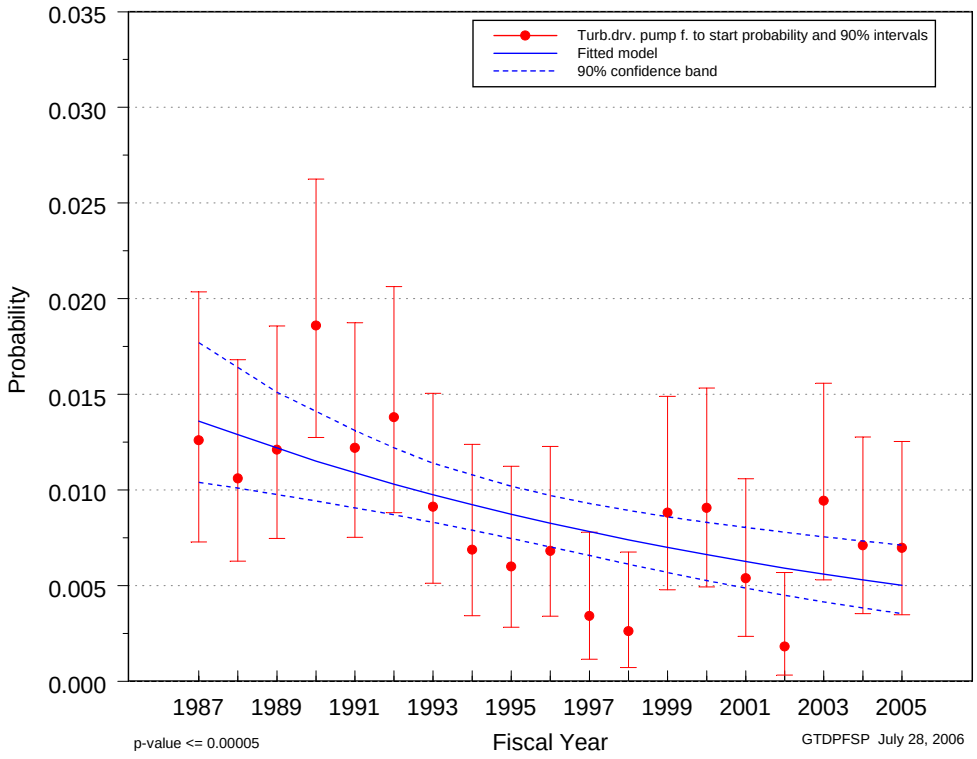

Figure 2. Turbine-driven pump fail-to-start.

1.3 Unplanned Demand Trend

Trends were identified in the frequency of TDP unplanned demands Figure 3. When modeled as a function of fiscal year, the unplanned demand frequency exhibited an extremely statistically significant decreasing trend. The noticeable increase in TDP demands in FY-2003 through FY-2005 is related to the significant increase in scrams and ECCS actuations in FY-2003 to FY-2005 compared to recent history. Table 4 shows the plot data.

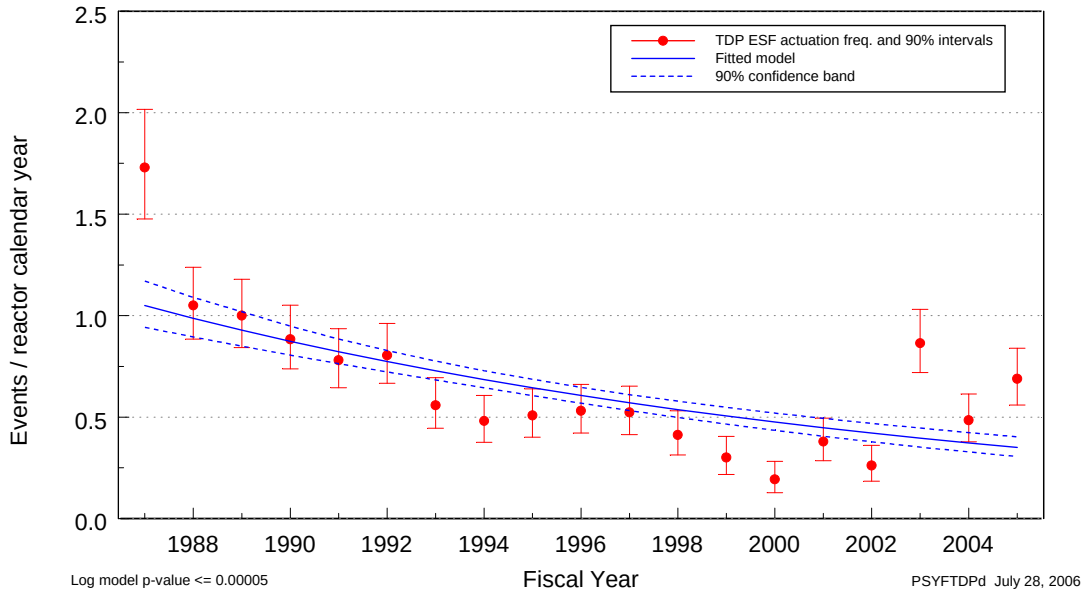

Figure 3. Frequency (events per operating year) of unplanned demands, as a function of fiscal year.

1.4 Failure Trend

The frequency of all failures (unplanned demands, surveillance tests, inspections, etc.) resulting in component unavailability identified in the experience was analyzed to determine trends. When modeled as a function of fiscal year, an extremely statistically significant decreasing trend was identified. The fitted frequency is plotted against fiscal year in Figure 4. Trends for TDP failures are plotted without regard to method of detection (the trend excludes maintenance out of service and support system failures). Table 5 shows the plot data.

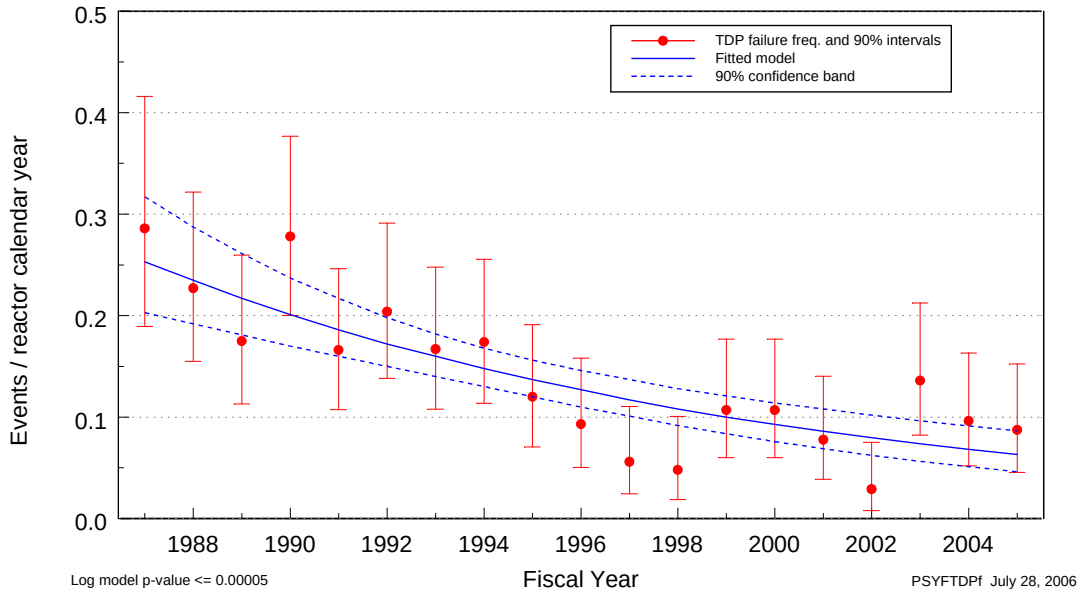

Figure 4. Frequency (events per operating year) of failures, as a function of fiscal year.

1.5 Major Contributors to System Unreliability and Unavailability

1.5.1 Leading Component Failures.

The governor had the most failures in the turbine-driven pump data. Figure 5 shows the distribution of sub-component failures.

1.5.2 Leading Systems.

Figure 6 shows the distribution of TDP failures by system and by the fiscal year they occurred in.

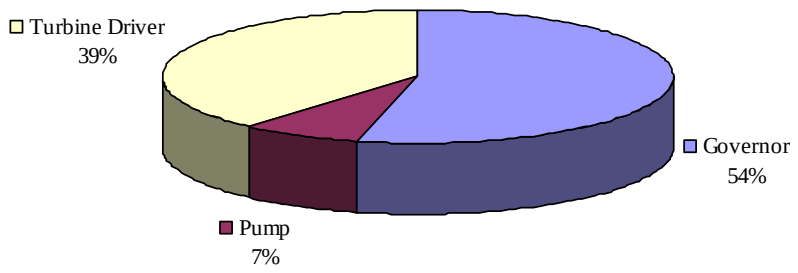

Figure 5. TDP sub-component failure distribution

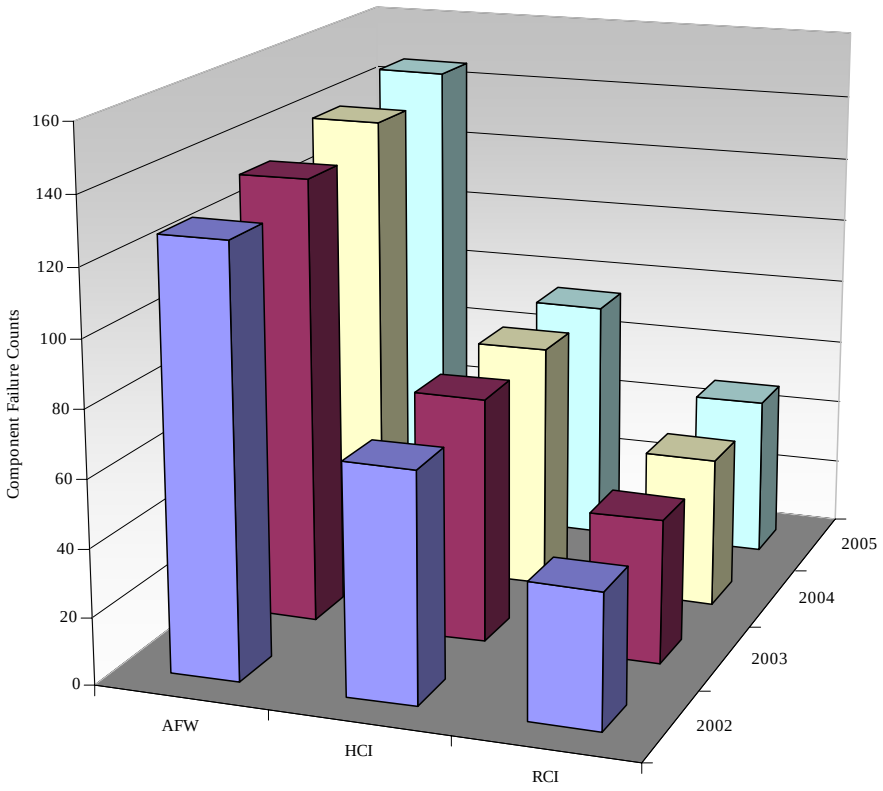

Figure 6. TDP system failures distribution

2 DATA TABLES

This section contains the data tables that support the charts in the first sections.

Table 2. Plot data table for TDP failure on demand. Figure 1

FY	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1987	1.40E-02	2.10E-02	3.04E-02	1.68E-02	2.09E-02	2.59E-02
1988	1.29E-02	1.88E-02	2.65E-02	1.60E-02	1.95E-02	2.37E-02
1989	9.41E-03	1.45E-02	2.15E-02	1.52E-02	1.82E-02	2.18E-02
1990	1.75E-02	2.43E-02	3.28E-02	1.44E-02	1.70E-02	2.00E-02
1991	9.50E-03	1.47E-02	2.17E-02	1.36E-02	1.58E-02	1.84E-02
1992	1.21E-02	1.79E-02	2.54E-02	1.29E-02	1.48E-02	1.70E-02
1993	9.67E-03	1.49E-02	2.21E-02	1.21E-02	1.38E-02	1.58E-02
1994	1.07E-02	1.63E-02	2.39E-02	1.13E-02	1.29E-02	1.47E-02
1995	5.95E-03	1.03E-02	1.66E-02	1.05E-02	1.20E-02	1.37E-02
1996	4.63E-03	8.53E-03	1.44E-02	9.74E-03	1.12E-02	1.29E-02
1997	2.23E-03	5.12E-03	1.01E-02	8.99E-03	1.05E-02	1.22E-02
1998	1.19E-03	3.49E-03	7.96E-03	8.27E-03	9.77E-03	1.15E-02
1999	5.44E-03	9.69E-03	1.60E-02	7.59E-03	9.11E-03	1.09E-02
2000	5.60E-03	9.97E-03	1.65E-02	6.95E-03	8.50E-03	1.04E-02
2001	3.58E-03	7.17E-03	1.29E-02	6.35E-03	7.93E-03	9.89E-03
2002	7.41E-04	2.72E-03	7.01E-03	5.80E-03	7.40E-03	9.43E-03
2003	7.28E-03	1.20E-02	1.87E-02	5.30E-03	6.90E-03	8.99E-03
2004	4.82E-03	8.87E-03	1.50E-02	4.83E-03	6.44E-03	8.57E-03
2005	4.10E-03	7.85E-03	1.37E-02	4.40E-03	6.00E-03	8.18E-03

Table 3. Plot data table for TDP fail-to-start. Figure 2

FY	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1987	7.30E-03	1.26E-02	2.04E-02	1.04E-02	1.36E-02	1.77E-02
1988	6.29E-03	1.06E-02	1.68E-02	1.01E-02	1.29E-02	1.64E-02
1989	7.48E-03	1.21E-02	1.86E-02	9.76E-03	1.22E-02	1.51E-02
1990	1.28E-02	1.86E-02	2.63E-02	9.42E-03	1.15E-02	1.41E-02
1991	7.55E-03	1.22E-02	1.88E-02	9.07E-03	1.09E-02	1.31E-02
1992	8.82E-03	1.38E-02	2.06E-02	8.70E-03	1.03E-02	1.22E-02
1993	5.12E-03	9.12E-03	1.51E-02	8.31E-03	9.75E-03	1.14E-02
1994	3.43E-03	6.88E-03	1.24E-02	7.90E-03	9.23E-03	1.08E-02
1995	2.82E-03	6.00E-03	1.12E-02	7.47E-03	8.73E-03	1.02E-02
1996	3.40E-03	6.82E-03	1.23E-02	7.02E-03	8.26E-03	9.71E-03
1997	1.17E-03	3.41E-03	7.79E-03	6.57E-03	7.81E-03	9.29E-03
1998	7.13E-04	2.62E-03	6.75E-03	6.12E-03	7.39E-03	8.93E-03
1999	4.79E-03	8.81E-03	1.49E-02	5.69E-03	6.99E-03	8.60E-03
2000	4.93E-03	9.07E-03	1.53E-02	5.27E-03	6.62E-03	8.31E-03
2001	2.35E-03	5.38E-03	1.06E-02	4.87E-03	6.26E-03	8.04E-03
2002	3.22E-04	1.81E-03	5.69E-03	4.50E-03	5.92E-03	7.79E-03
2003	5.30E-03	9.44E-03	1.56E-02	4.15E-03	5.60E-03	7.55E-03
2004	3.54E-03	7.10E-03	1.28E-02	3.83E-03	5.30E-03	7.33E-03
2005	3.48E-03	6.97E-03	1.25E-02	3.53E-03	5.01E-03	7.12E-03

Table 4. Plot data for demand trend. Figure 3

FY	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1987	1.47E+00	1.73E+00	2.02E+00	9.42E-01	1.05E+00	1.17E+00
1988	8.85E-01	1.05E+00	1.24E+00	8.95E-01	9.87E-01	1.09E+00
1989	8.45E-01	1.00E+00	1.18E+00	8.50E-01	9.29E-01	1.01E+00
1990	7.38E-01	8.84E-01	1.05E+00	8.06E-01	8.74E-01	9.48E-01
1991	6.45E-01	7.80E-01	9.36E-01	7.64E-01	8.23E-01	8.85E-01
1992	6.67E-01	8.04E-01	9.62E-01	7.24E-01	7.74E-01	8.29E-01
1993	4.45E-01	5.59E-01	6.94E-01	6.84E-01	7.29E-01	7.77E-01
1994	3.76E-01	4.81E-01	6.08E-01	6.45E-01	6.86E-01	7.29E-01
1995	4.01E-01	5.09E-01	6.39E-01	6.07E-01	6.46E-01	6.86E-01
1996	4.21E-01	5.31E-01	6.62E-01	5.70E-01	6.08E-01	6.48E-01
1997	4.13E-01	5.23E-01	6.53E-01	5.34E-01	5.72E-01	6.12E-01
1998	3.15E-01	4.12E-01	5.32E-01	5.00E-01	5.38E-01	5.80E-01
1999	2.18E-01	3.01E-01	4.06E-01	4.67E-01	5.07E-01	5.49E-01
2000	1.29E-01	1.94E-01	2.82E-01	4.36E-01	4.77E-01	5.21E-01
2001	2.85E-01	3.79E-01	4.95E-01	4.07E-01	4.49E-01	4.95E-01
2002	1.93E-01	2.72E-01	3.73E-01	3.79E-01	4.22E-01	4.70E-01
2003	7.19E-01	8.64E-01	1.03E+00	3.53E-01	3.97E-01	4.47E-01
2004	3.78E-01	4.85E-01	6.14E-01	3.29E-01	3.74E-01	4.25E-01
2005	5.61E-01	6.89E-01	8.40E-01	3.07E-01	3.52E-01	4.04E-01

Table 5. Plot data for failure trend. Figure 4

FY	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1987	1.90E-01	2.86E-01	4.16E-01	2.03E-01	2.53E-01	3.17E-01
1988	1.55E-01	2.27E-01	3.22E-01	1.92E-01	2.35E-01	2.87E-01
1989	1.13E-01	1.75E-01	2.60E-01	1.81E-01	2.17E-01	2.61E-01
1990	2.00E-01	2.78E-01	3.77E-01	1.70E-01	2.01E-01	2.37E-01
1991	1.07E-01	1.66E-01	2.46E-01	1.60E-01	1.86E-01	2.17E-01
1992	1.38E-01	2.04E-01	2.91E-01	1.50E-01	1.72E-01	1.98E-01
1993	1.08E-01	1.67E-01	2.48E-01	1.40E-01	1.60E-01	1.82E-01
1994	1.14E-01	1.74E-01	2.56E-01	1.30E-01	1.48E-01	1.68E-01
1995	7.12E-02	1.20E-01	1.91E-01	1.20E-01	1.37E-01	1.56E-01
1996	5.06E-02	9.32E-02	1.58E-01	1.10E-01	1.27E-01	1.46E-01
1997	2.44E-02	5.60E-02	1.11E-01	1.01E-01	1.17E-01	1.37E-01
1998	1.89E-02	4.80E-02	1.01E-01	9.18E-02	1.08E-01	1.28E-01
1999	5.99E-02	1.07E-01	1.77E-01	8.35E-02	1.00E-01	1.21E-01
2000	5.99E-02	1.07E-01	1.77E-01	7.59E-02	9.30E-02	1.14E-01
2001	3.86E-02	7.77E-02	1.40E-01	6.89E-02	8.61E-02	1.08E-01
2002	7.94E-03	2.91E-02	7.53E-02	6.24E-02	7.97E-02	1.02E-01
2003	8.22E-02	1.36E-01	2.12E-01	5.65E-02	7.38E-02	9.64E-02
2004	5.22E-02	9.62E-02	1.63E-01	5.11E-02	6.83E-02	9.13E-02
2005	4.56E-02	8.74E-02	1.52E-01	4.63E-02	6.32E-02	8.65E-02

3 COMPONENT DESCRIPTIONS AND BOUNDARIES

3.1 TDP Assembly Description and Boundaries

The TDP is 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 overspeed 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 has 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. 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 component boundaries are the TDP assembly, its sub-component, and piece-parts described above, that are supplied as part of the TDP assembly. Other system components, such as steam inlet valves to the turbine, pump suction and discharge valves, flow instrumentation and controls, and remote electrical controls, are considered outside the component boundary for the TDP study.