Component Performance Studies

Turbine-Driven Pumps

1987–2002

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 1987 through 2002, 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*.

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 and for the 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 1987-2002.

				Failure Probability		
Component	Estimated Number of Demands	Failure Mode	Number of Failures	Lower Bound	MLE	Upper Bound
Turbine-driven pump	18776	Failure on demand	231	1.10E-02	1.23E-02	1.37E-02
	18776	Failure to start	165	7.72E-03	8.79E-03	9.96E-03

1.2 Unavailability Trend

A highly statistically significant[1] 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 fiscal year of the TDP failure on demand calculated from the 1987–2002 experience. Table 2 shows the data points for Figure 1. A 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

1. The term “statistically significant” means that the data are too closely correlated to be attributed to chances and consequently have a systematic relationship. A p-value of less than 0.05 is generally considered to be statistically significant.

unavailability. Table 3 shows the data points for Figure 2. Each figure is annotated with the p-value[2].

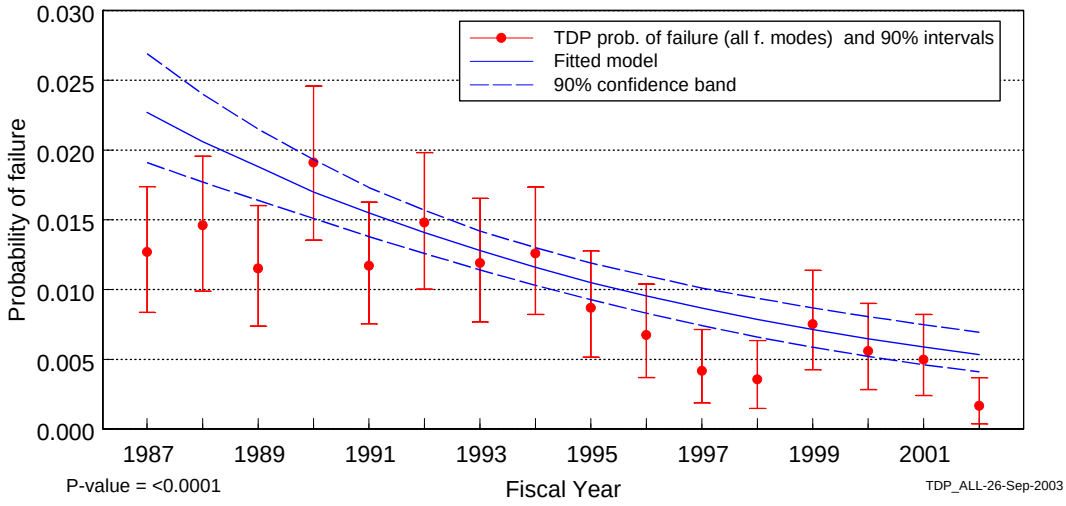

Figure 1. Turbine-driven pump failure on demand.

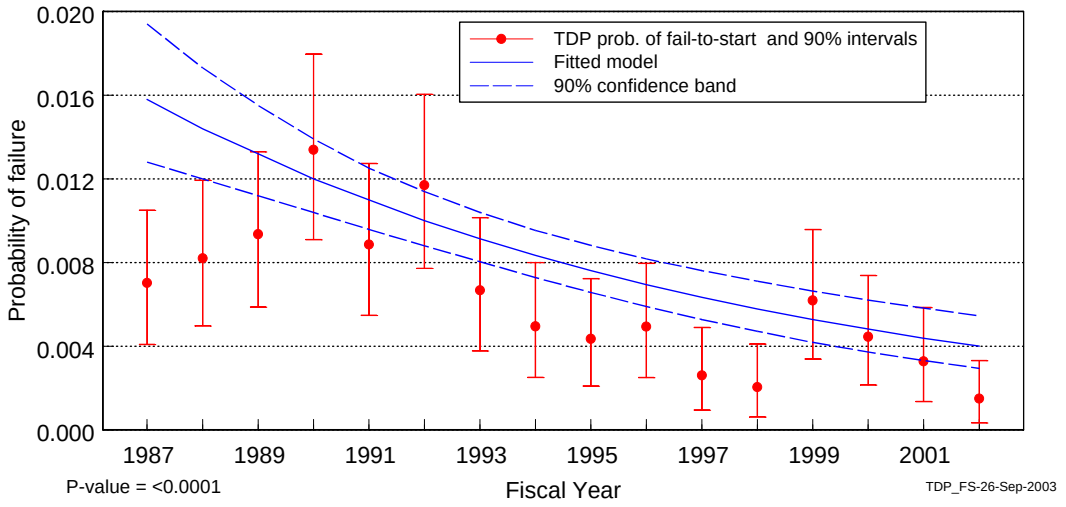

Figure 2. Turbine-driven pump fail-to-start.

2. A p-value is a probability, with a value between zero and one, which is a measure of statistical significance. The smaller the p-value, the greater the significance. A p-value of less than 0.05 is generally considered statistically significant.

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 a highly statistically significant decreasing trend. Table 4 shows the plot data.

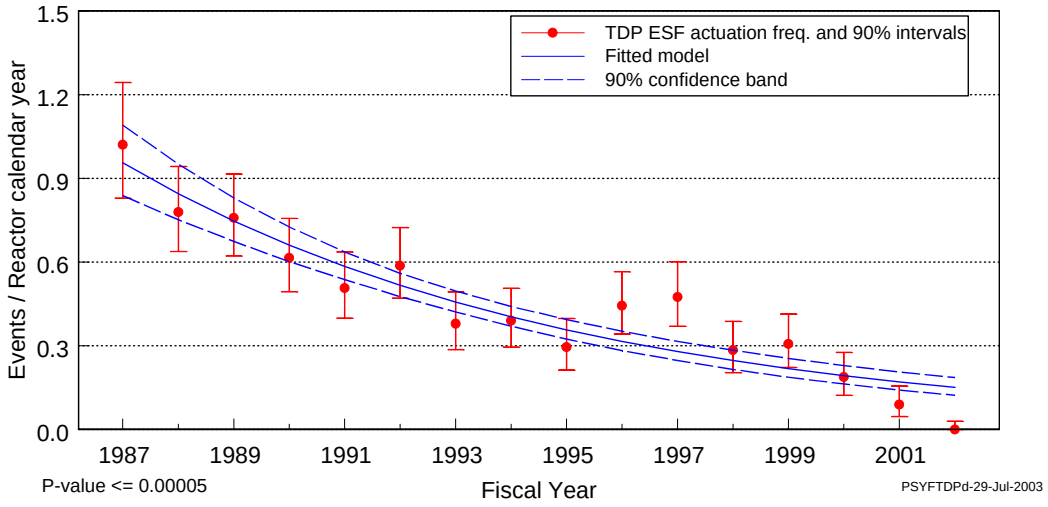

Figure 3. Frequency (events per operating year) of unplanned demands, as a function of fiscal year.

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, a highly 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.

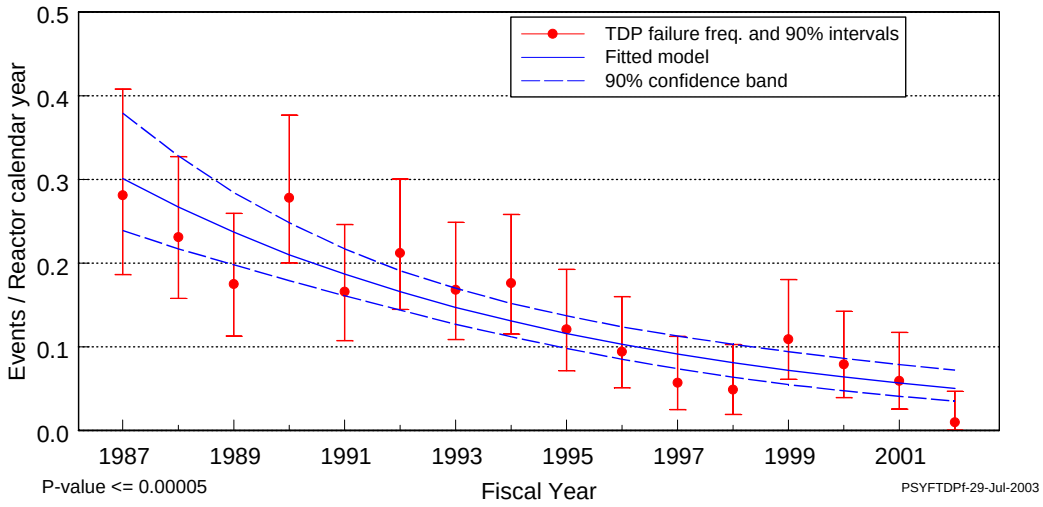

Figure 4. Frequency (events per operating year) of failures, as a function of fiscal year.

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.

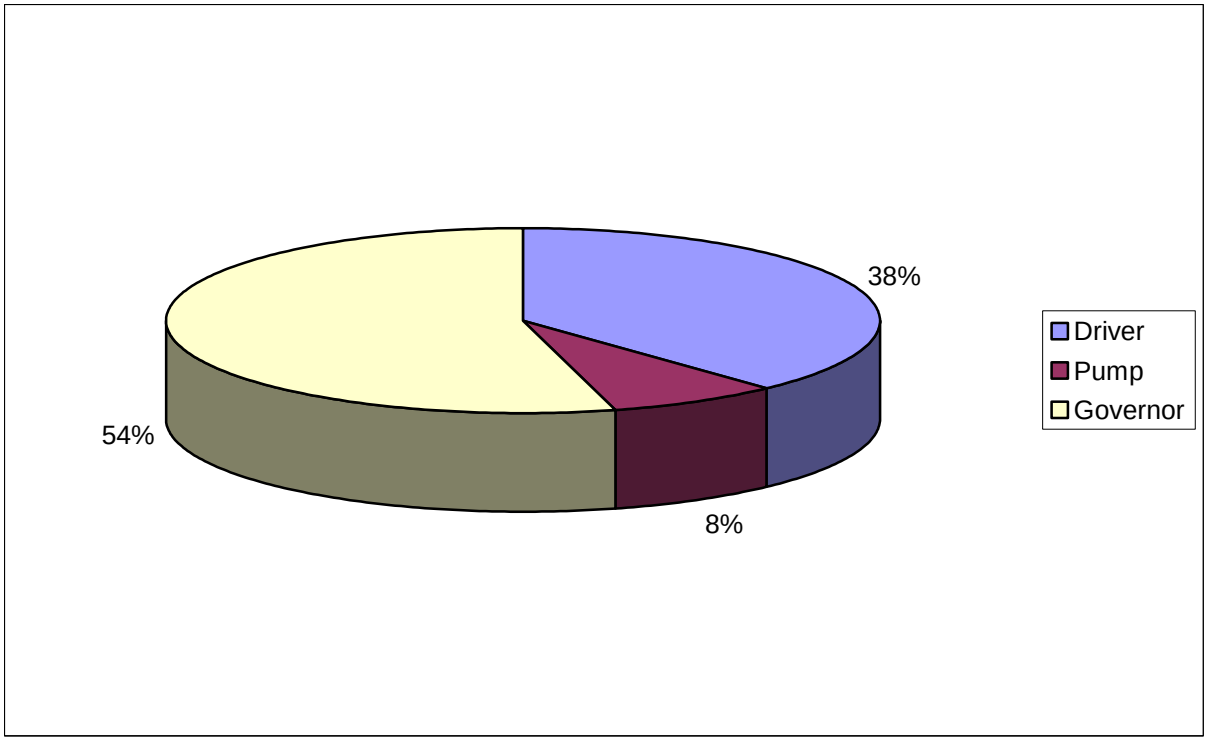

Figure 5. TDP sub-component distribution

1.5.2 Leading Systems.

Figure 6 shows the distribution of systems.

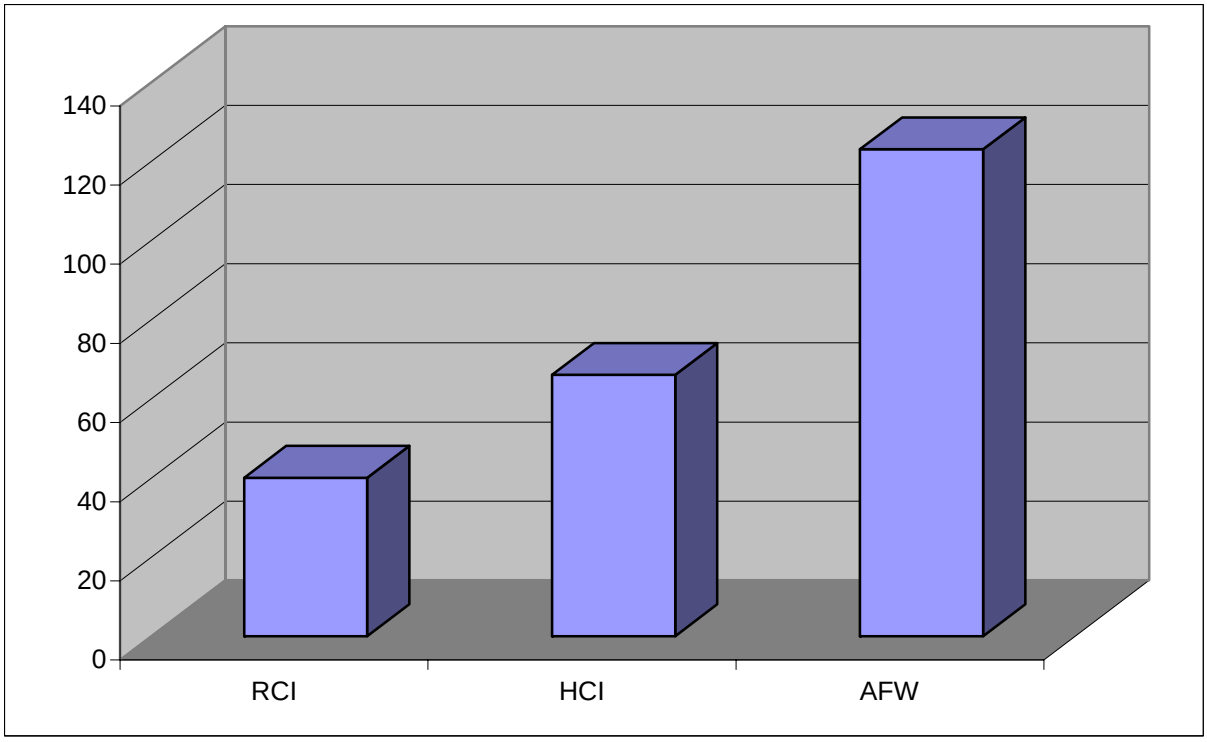

Figure 6. TDP system failures distribution

2 DATA TABLES

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

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

	Plot Trend Error Bar Points			Regression Curve Data Points		
Fiscal Year	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1987	8.37E-03	1.27E-02	1.74E-02	1.91E-02	2.27E-02	2.69E-02
1988	9.93E-03	1.46E-02	1.96E-02	1.77E-02	2.06E-02	2.40E-02
1989	7.44E-03	1.15E-02	1.61E-02	1.64E-02	1.88E-02	2.15E-02
1990	1.36E-02	1.91E-02	2.46E-02	1.51E-02	1.70E-02	1.93E-02
1991	7.52E-03	1.17E-02	1.62E-02	1.38E-02	1.55E-02	1.73E-02
1992	1.00E-02	1.48E-02	1.98E-02	1.26E-02	1.41E-02	1.57E-02
1993	7.65E-03	1.19E-02	1.65E-02	1.14E-02	1.28E-02	1.42E-02
1994	8.20E-03	1.26E-02	1.73E-02	1.03E-02	1.16E-02	1.30E-02
1995	5.16E-03	8.68E-03	1.28E-02	9.28E-03	1.05E-02	1.19E-02
1996	3.70E-03	6.74E-03	1.04E-02	8.30E-03	9.55E-03	1.10E-02
1997	1.88E-03	4.17E-03	7.14E-03	7.41E-03	8.67E-03	1.01E-02
1998	1.47E-03	3.56E-03	6.34E-03	6.59E-03	7.87E-03	9.38E-03
1999	4.25E-03	7.51E-03	1.14E-02	5.86E-03	7.14E-03	8.69E-03
2000	2.84E-03	5.59E-03	9.01E-03	5.21E-03	6.48E-03	8.06E-03
2001	2.39E-03	4.97E-03	8.23E-03	4.62E-03	5.88E-03	7.48E-03
2002	3.76E-04	1.66E-03	3.67E-03	4.10E-03	5.34E-03	6.94E-03

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

	Plot Trend Error Bar Points			Regression Curve Data Points		
Fiscal Year	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1987	4.09E-03	7.03E-03	1.05E-02	1.28E-02	1.58E-02	1.94E-02
1988	4.98E-03	8.21E-03	1.19E-02	1.20E-02	1.44E-02	1.73E-02
1989	5.87E-03	9.36E-03	1.33E-02	1.12E-02	1.32E-02	1.55E-02
1990	9.09E-03	1.34E-02	1.80E-02	1.04E-02	1.20E-02	1.39E-02
1991	5.48E-03	8.87E-03	1.27E-02	9.58E-03	1.10E-02	1.25E-02
1992	7.73E-03	1.17E-02	1.60E-02	8.80E-03	1.00E-02	1.14E-02
1993	3.78E-03	6.68E-03	1.01E-02	8.04E-03	9.14E-03	1.04E-02
1994	2.52E-03	4.96E-03	8.00E-03	7.29E-03	8.34E-03	9.54E-03
1995	2.10E-03	4.36E-03	7.24E-03	6.57E-03	7.61E-03	8.82E-03
1996	2.51E-03	4.94E-03	7.97E-03	5.90E-03	6.95E-03	8.18E-03
1997	9.62E-04	2.61E-03	4.90E-03	5.28E-03	6.34E-03	7.62E-03
1998	6.31E-04	2.05E-03	4.11E-03	4.71E-03	5.78E-03	7.11E-03
1999	3.41E-03	6.20E-03	9.58E-03	4.19E-03	5.28E-03	6.64E-03
2000	2.15E-03	4.46E-03	7.39E-03	3.73E-03	4.82E-03	6.21E-03
2001	1.36E-03	3.29E-03	5.86E-03	3.32E-03	4.39E-03	5.82E-03
2002	3.41E-04	1.50E-03	3.32E-03	2.95E-03	4.01E-03	5.45E-03

Table 4. Plot data for demand trend. Figure 3

Fiscal Year	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1987	8.25E-01	1.02E+00	1.24E+00	8.38E-01	9.56E-01	1.09E+00
1988	6.38E-01	7.79E-01	9.43E-01	7.52E-01	8.45E-01	9.50E-01
1989	6.22E-01	7.58E-01	9.16E-01	6.74E-01	7.47E-01	8.29E-01
1990	4.94E-01	6.15E-01	7.57E-01	6.02E-01	6.61E-01	7.25E-01
1991	3.99E-01	5.07E-01	6.37E-01	5.37E-01	5.84E-01	6.36E-01
1992	4.71E-01	5.87E-01	7.24E-01	4.76E-01	5.17E-01	5.60E-01
1993	2.86E-01	3.79E-01	4.94E-01	4.21E-01	4.57E-01	4.96E-01
1994	2.96E-01	3.90E-01	5.07E-01	3.70E-01	4.04E-01	4.41E-01
1995	2.14E-01	2.95E-01	3.98E-01	3.24E-01	3.57E-01	3.94E-01
1996	3.42E-01	4.43E-01	5.65E-01	2.83E-01	3.16E-01	3.52E-01
1997	3.70E-01	4.75E-01	6.02E-01	2.47E-01	2.79E-01	3.16E-01
1998	2.03E-01	2.84E-01	3.87E-01	2.15E-01	2.47E-01	2.84E-01
1999	2.22E-01	3.07E-01	4.14E-01	1.87E-01	2.18E-01	2.55E-01
2000	1.23E-01	1.88E-01	2.75E-01	1.63E-01	1.93E-01	2.29E-01
2001	4.65E-02	8.91E-02	1.55E-01	1.41E-01	1.71E-01	2.06E-01
2002	0.00E+00	0.00E+00	2.97E-02	1.23E-01	1.51E-01	1.86E-01

Table 5. Plot data for failure trend. Figure 4

Fiscal Year	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1987	1.86E-01	2.81E-01	4.08E-01	2.39E-01	3.01E-01	3.79E-01
1988	1.58E-01	2.31E-01	3.27E-01	2.17E-01	2.67E-01	3.28E-01
1989	1.13E-01	1.75E-01	2.60E-01	1.98E-01	2.37E-01	2.84E-01
1990	2.00E-01	2.78E-01	3.77E-01	1.79E-01	2.10E-01	2.48E-01
1991	1.07E-01	1.66E-01	2.46E-01	1.61E-01	1.87E-01	2.17E-01
1992	1.45E-01	2.12E-01	3.01E-01	1.44E-01	1.66E-01	1.91E-01
1993	1.08E-01	1.68E-01	2.48E-01	1.27E-01	1.47E-01	1.70E-01
1994	1.15E-01	1.76E-01	2.58E-01	1.12E-01	1.31E-01	1.52E-01
1995	7.19E-02	1.21E-01	1.93E-01	9.80E-02	1.16E-01	1.37E-01
1996	5.11E-02	9.42E-02	1.60E-01	8.52E-02	1.03E-01	1.24E-01
1997	2.48E-02	5.71E-02	1.13E-01	7.38E-02	9.14E-02	1.13E-01
1998	1.93E-02	4.89E-02	1.03E-01	6.38E-02	8.11E-02	1.03E-01
1999	6.11E-02	1.09E-01	1.80E-01	5.50E-02	7.20E-02	9.43E-02
2000	3.93E-02	7.90E-02	1.43E-01	4.74E-02	6.39E-02	8.62E-02
2001	2.59E-02	5.94E-02	1.17E-01	4.08E-02	5.68E-02	7.89E-02
2002	5.08E-04	9.90E-03	4.70E-02	3.51E-02	5.04E-02	7.23E-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 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. Piece-parts of all governors include a turbine stop valve and a governor valve, while the EG-M usually includes a ramp generator/signal converted 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.