Reliability Study Update

High Pressure Core Spray

1987–2004

This report presents a performance evaluation of the high-pressure core spray (HPCS) system at eight U.S. commercial boiling water reactors (BWRs). The evaluation is based on the operating experience from 1987 through 2004, as reported in Licensee Event Reports (LERs). This is the latest update to NUREG/CR-5500 Volume 8, updating data, availability and reliability estimates, trends, and figures.

This report calculates two basic models for the HPCS system. The FTS model includes the start and recovery of the pump, the start and recovery of the diesel generator, and the opening and recovery of the injection valve. The 8-hour mission model includes the HPCS system start model and the run of the pump and diesel generator for 8 hours and transfer from recirculation to injection. Both models include failures due to the unavailability while in maintenance. See the HPCS Fault Tree Description document for more detail.

1 LATEST VALUES AND TRENDS

1.1 Industry-Wide Unavailability and Unreliability

The industry-wide unavailability and unreliability of the HPCS system have been estimated from operating experience. A failure to start (FTS) unavailability and an 8-hour mission unreliability were evaluated, see Table 1. The estimates are based on failures that occurred during unplanned demands, and cyclic and quarterly surveillance tests.

Table 1. Industry-wide values.

Model	Lower (5%)	Mean	Upper (95%)
Failure-to-Start (Unavailability)	3.19E-02	8.24E-02	1.50E-01
8-hour Mission (Unreliability)	4.22E-02	9.48E-02	1.62E-01

1.2 Fail to Start Model Results

Individual plant result unavailability has been calculated for the FTS model. The estimates of HPCS system unavailability using operating experience from LERs and fault tree analyses are plotted in Figure 1 (FTS model). Table 2 shows the data points for Figure 1.

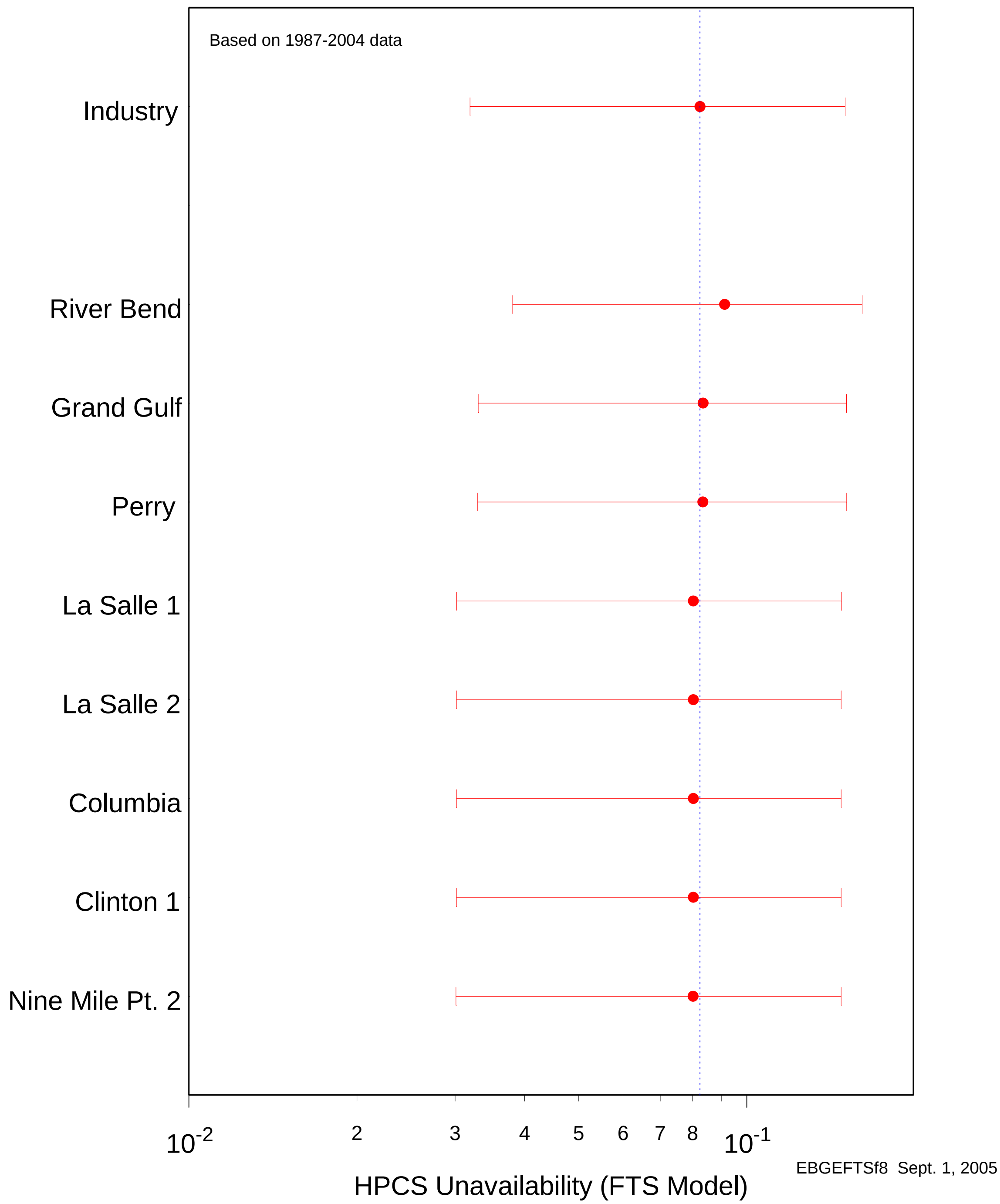

Figure 1. Plant-specific estimates of HPCS system unavailability for FTS model.

Table 2. HPCS plant unavailability FTS model.

Plant	Lower (5%)	Mean	Upper (95%)
Industry	3.19E-02	8.24E-02	1.50E-01
River Bend	3.81E-02	9.14E-02	1.61E-01
Grand Gulf	3.30E-02	8.36E-02	1.51E-01
Perry	3.29E-02	8.35E-02	1.51E-01
La Salle 1	3.02E-02	8.03E-02	1.48E-01
Columbia	3.02E-02	8.02E-02	1.48E-01
La Salle 2	3.02E-02	8.02E-02	1.48E-01
Clinton 1	3.02E-02	8.02E-02	1.48E-01
Nine Mile Pt. 2	3.01E-02	8.01E-02	1.48E-01

No statistically significant[1] trend within the industry estimates of HPCS system unavailability (FTS) on a per fiscal year basis was identified. Figure 2 shows the trend in the FTS model unavailability. Table 7 shows the data points for Figure 2.

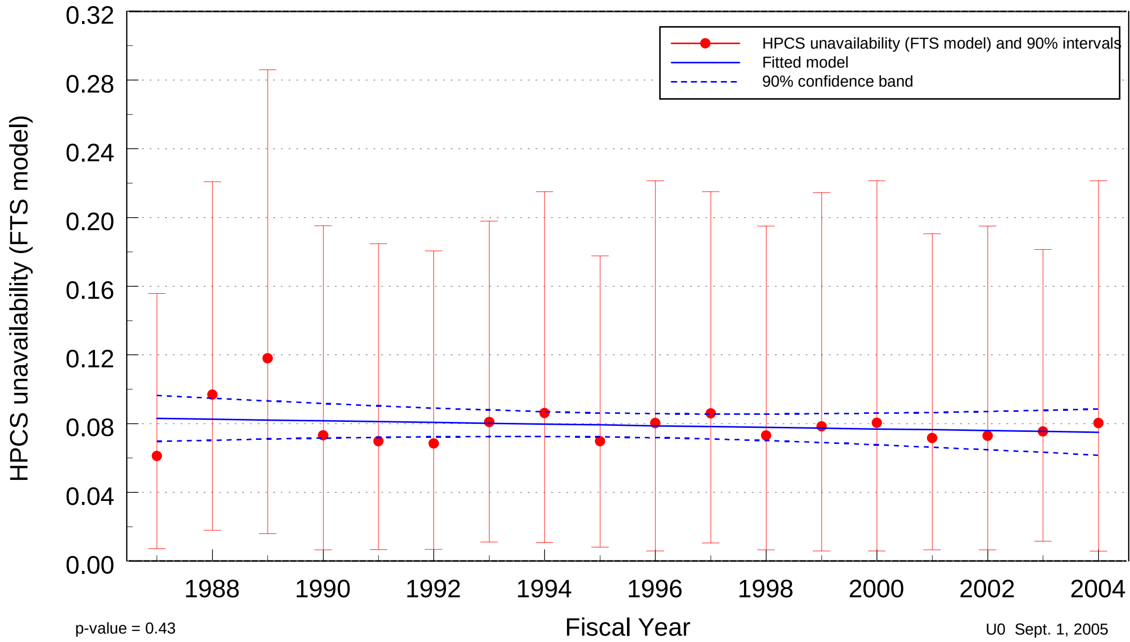

Figure 2. Trend of HPCS system unavailability (FTS model), as a function of fiscal year.

[1] 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).

The leading contributor to HPCS system short-term unavailability, after pump or diesel maintenance out of service, is the failure of the injection valve. Figure 3 shows the distribution of segment failure contributions for the FTS model.

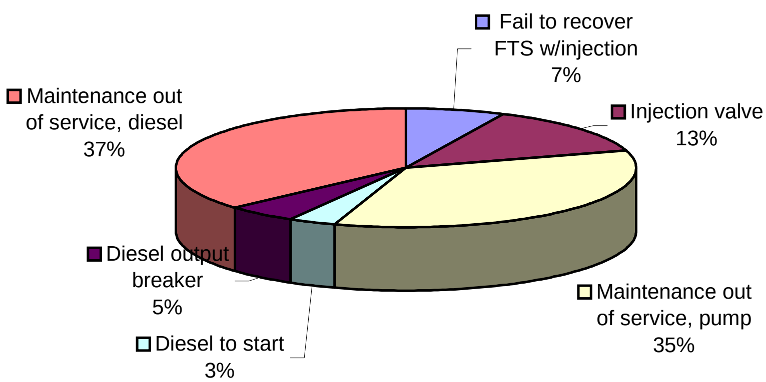

Figure 3. Segment failure distribution, FTS model.

1.3 Fail to Operate for 8-Hour Model

Individual plant result unreliability has been calculated for the 8-hour mission. The estimates of HPCS system unreliability using operating experience from LERs and fault tree analyses are plotted in Figure 4 (8-hour mission model). Table 3 shows the data points used in Figure 4.

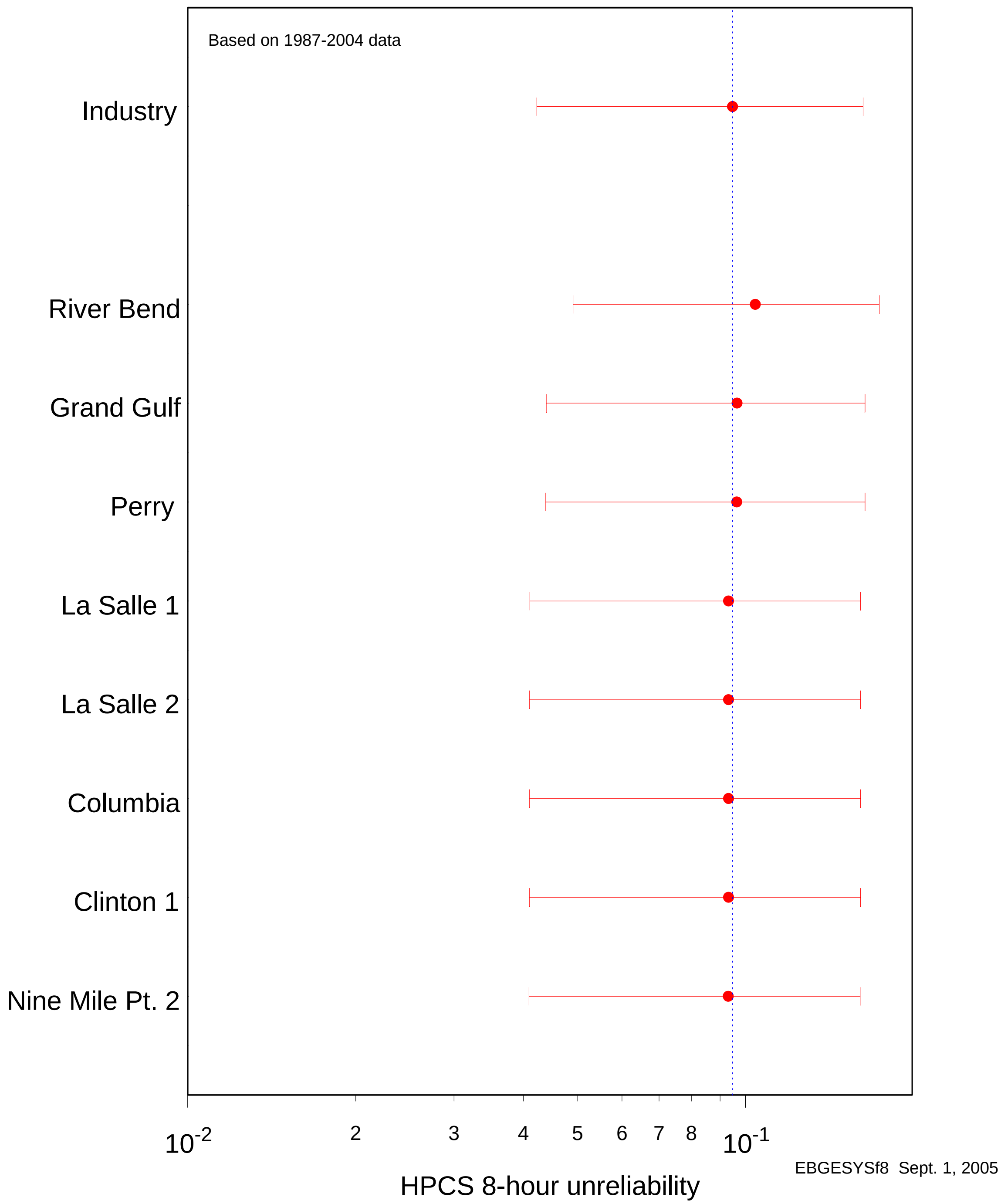

Figure 4. Plant-specific estimates of HPCS system unreliability for an 8-hour mission.

Table 3. HPCS plant unreliability data.

Plant	Lower (5%)	Mean	Upper (95%)
Industry	4.22E-02	9.48E-02	1.62E-01
River Bend	4.91E-02	1.04E-01	1.74E-01
Grand Gulf	4.39E-02	9.66E-02	1.64E-01
Perry	4.38E-02	9.65E-02	1.64E-01
La Salle 1	4.10E-02	9.33E-02	1.61E-01
Columbia	4.10E-02	9.33E-02	1.61E-01
La Salle 2	4.10E-02	9.33E-02	1.61E-01
Clinton 1	4.10E-02	9.32E-02	1.61E-01
Nine Mile Pt. 2	4.09E-02	9.32E-02	1.61E-01

No statistically significant trend within the industry estimates of HPCS system unreliability (8-hour mission) on a per fiscal year basis was identified. Figure 5 displays the trend by fiscal year of the HPCS system unreliability calculated from the 1987–2004 experience. Table 8 shows the data points for Figure 5.

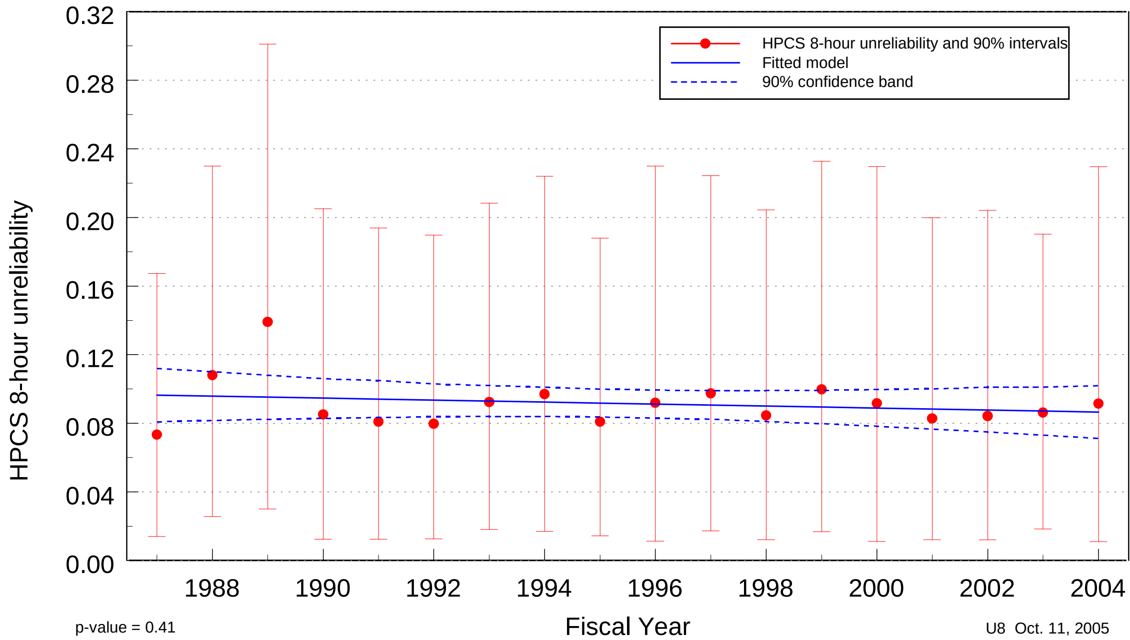

Figure 5. Trend of HPCS system unreliability (8-hour mission), as a function of fiscal year.

The leading contributor to HPCS system long-term unavailability, after pump or diesel generator maintenance out of service, is the failure of the injection valve. Figure 6 shows the distribution of segment failures for the 8-hour mission.

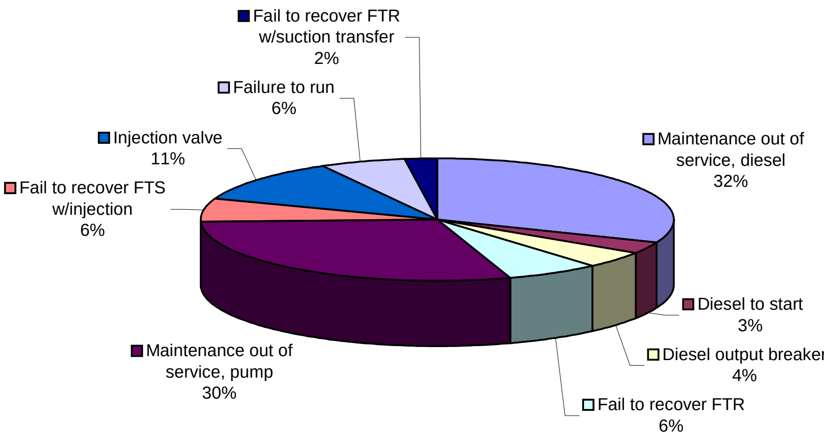

Figure 6. Segment failure distribution, 8-hour mission.

2 DATA TRENDS

The raw actuation and failure data were trended for event counts over time.

2.1 Unplanned Demand Trend

Trends were identified in the frequency of HPCS unplanned demands (Figure 7). When modeled as a function of fiscal year, the unplanned demand frequency exhibited an extremely statistically significant decreasing trend. Table 9 shows the LERs that are represented in the figure.

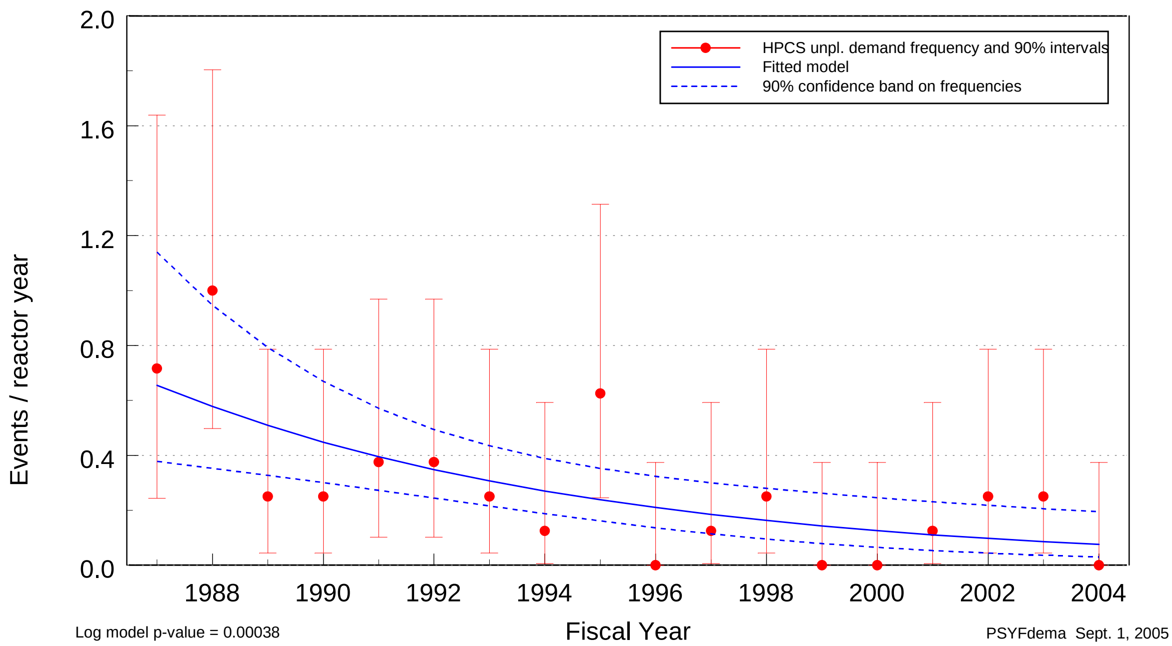

Figure 7. Frequency (events per year) of unplanned demands, as a function of fiscal year.

2.2 Failure Trend

The frequency of all failures (unplanned demands, surveillance tests, inspections, etc.) resulting in train unavailability identified in the experience was analyzed to determine trends. When modeled as a function of fiscal year, no statistically significant trend was identified. The fitted frequency is plotted against fiscal year in Figure 8. Trends for HPCS failures are plotted without regard to method of detection (the trend excludes maintenance out of service and support system failures). Table 10 shows the LERs that are represented in the figure.

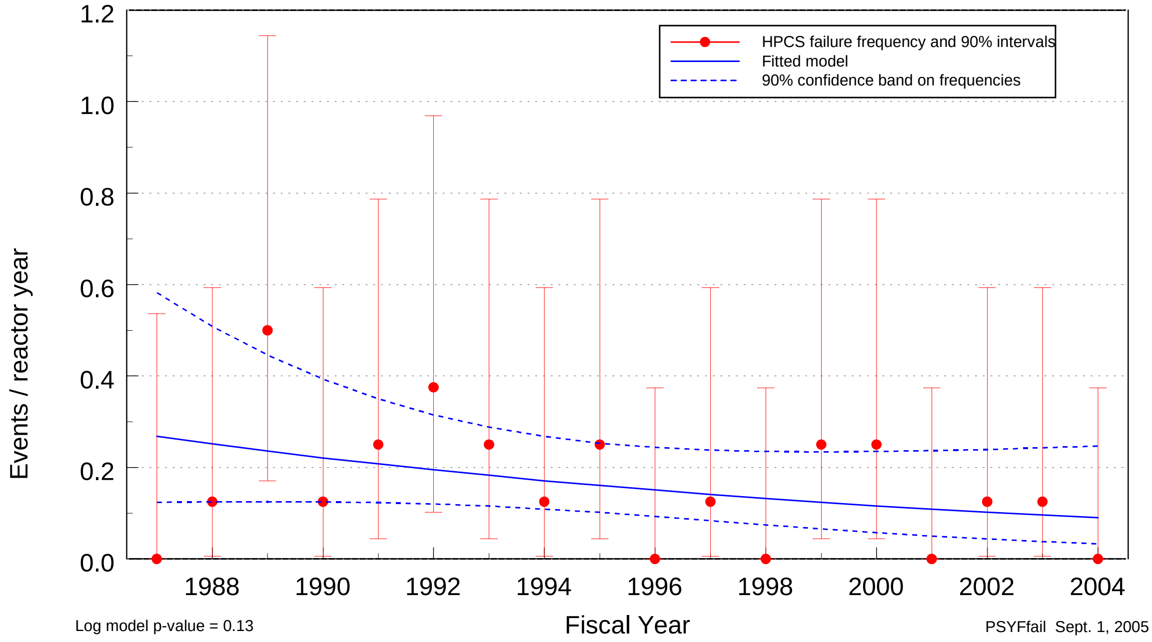

Figure 8. Frequency (events per year) of failures, as a function of fiscal year.

2.3 Failure Cause and Discovery Method Summary

The raw failure data were sliced to show the distribution of the failure causes and the discovery methods by the affected segment.

2.3.1 Leading Segment Failures.

The motor operated valves (23%) and the generator (14%) were the leading segment failures identified in the database. See Table 4.

2.3.2 Leading Discovery Methods

Periodic surveillance (50%) and inspection/review (36%) were the leading methods of discovery. See Table 4.

2.3.3 Leading Causes of Failure.

Fifty percent of the failures in the HPCS system were attributed to hardware-related problems. Personnel errors were the cause of 41% of all HPCS segment failures. See Table 6.

Table 4. Comparison of failed segment with the method of discovery.[2]

Segment	Maintenance on system	Periodic surveillance on system	Alarm/ indicator	Inspection/ review	Total	Percent
Air Handling Unit (Room Cooler)				1	1	5%
Circuit Breaker		1	1		2	9%
Controller, I&C (includes entire instrument loop except for transmitters (XMTR))	1				1	5%
Generator		2		1	3	14%
Governor		1			1	5%
Misc, Elect - wires, connections, fuses		1			1	5%
Misc, Mechanical				1	1	5%
Motor		1		1	2	9%
Relay, Other		2			2	9%
Transmitter (inc. sensors & switches, code with subsystem not I&C)				2	2	9%
Unknown		1			1	5%
Valve, Motor Operated (includes limit switches)	1	2		2	5	23%
Total	2	11	1	8	22	100%
Percent	9%	50%	5%	36%	100%	

Table 5. Discovery method description.

Discovery Method	Description	Used in the Failure Calculations
Actual/unplanned demand	The demand for the system was ESF, inadvertent. If the demand was inadvertent, the demand should mimic an ESF demand.	✓
Periodic surveillance on subject system	Normally scheduled surveillance. These surveillances are to satisfy scheduled Technical Specification requirements.	✓
Maintenance on subject system	The failed condition was discovered during maintenance on the system. These include latent failures as well as maintenance-induced failures.	
Inspection/review	The failure was discovered during operator duties such as walk downs, inspections, etc.	

[2] The discovery method is the activity that is ongoing at the time of the failure.

Discovery Method	Description	Used in the Failure Calculations
Alarm/indicator	The failure was evidenced by an alarm or by other indications.	

Table 6. Comparison of failed segment and failure cause.[3]

Segment	Design	Hardware	Personnel	Procedure	Total	Percent
Air Handling Unit (Room Cooler)			1		1	5%
Circuit Breaker		1		1	2	9%
Controller, I&C (includes entire instrument loop except for transmitters (XMTR))	1				1	5%
Generator		1	2		3	14%
Governor		1			1	5%
Misc, Elect - wires, connections, fuses		1			1	5%
Misc, Mechanical		1			1	5%
Motor			2		2	9%
Relay, Other		2			2	9%
Transmitter (inc. sensors & switches, code with subsystem not I&C)			2		2	9%
Unknown		1			1	5%
Valve, Motor Operated (includes limit switches)		3	2		5	23%
Total	1	11	9	1	22	100%
Percent	5%	50%	41%	5%	100%	

- Design–The failure was the result of a flawed design.
- Hardware–The failure was the result of some aspect of the equipment. Typically, this is used for normal wear of the component.
- Personnel–The failure was the result of personnel error, by either commission or omission.
- Procedure–The failure was the result of an incorrect procedure.

[3] The cause of the failure is assigned to a broadly defined cause classification. The cause classifications are design, environment, hardware (e.g., aging, wear, manufacturing defects), personnel, and procedure. The cause classification assigned is based on the immediate cause of the failure and not the root cause. Generally, root cause is only determined through a detailed investigation and analysis of the failure. Specifically, the mechanism that actually resulted in the failure of the segment or component is captured as the cause.

3 DATA TABLES

3.1 Data Tables for Unreliability and Unavailability Trends

Table 7. Plot data table for HPCS system unavailability, FTS model, Figure 2.

FY	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1987	7.16E-03	6.10E-02	1.56E-01	6.90E-02	8.07E-02	9.44E-02
1988	1.80E-02	9.67E-02	2.21E-01	6.97E-02	8.04E-02	9.28E-02
1989	1.61E-02	1.18E-01	2.86E-01	7.03E-02	8.01E-02	9.13E-02
1990	6.54E-03	7.32E-02	1.96E-01	7.09E-02	7.98E-02	8.99E-02
1991	6.63E-03	6.98E-02	1.85E-01	7.14E-02	7.95E-02	8.86E-02
1992	6.72E-03	6.84E-02	1.80E-01	7.18E-02	7.92E-02	8.74E-02
1993	1.11E-02	8.08E-02	1.98E-01	7.21E-02	7.89E-02	8.64E-02
1994	1.06E-02	8.60E-02	2.15E-01	7.22E-02	7.86E-02	8.56E-02
1995	8.08E-03	6.96E-02	1.78E-01	7.22E-02	7.83E-02	8.50E-02
1996	5.90E-03	8.03E-02	2.21E-01	7.19E-02	7.80E-02	8.47E-02
1997	1.06E-02	8.60E-02	2.15E-01	7.14E-02	7.77E-02	8.46E-02
1998	6.49E-03	7.31E-02	1.95E-01	7.07E-02	7.74E-02	8.48E-02
1999	5.97E-03	7.85E-02	2.15E-01	6.99E-02	7.71E-02	8.51E-02
2000	5.89E-03	8.05E-02	2.21E-01	6.90E-02	7.69E-02	8.56E-02
2001	6.52E-03	7.16E-02	1.91E-01	6.80E-02	7.66E-02	8.62E-02
2002	6.46E-03	7.30E-02	1.95E-01	6.69E-02	7.63E-02	8.69E-02
2003	1.15E-02	7.53E-02	1.81E-01	6.59E-02	7.60E-02	8.77E-02
2004	5.86E-03	8.04E-02	2.21E-01	6.47E-02	7.57E-02	8.85E-02

Table 8. Plot data table for HPCS system unreliability, operational mission, Figure 5.

FY	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1987	1.38E-02	7.30E-02	1.67E-01	8.05E-02	9.37E-02	1.09E-01
1988	2.57E-02	1.08E-01	2.30E-01	8.12E-02	9.33E-02	1.07E-01
1989	3.03E-02	1.39E-01	3.01E-01	8.18E-02	9.30E-02	1.06E-01
1990	1.25E-02	8.51E-02	2.05E-01	8.24E-02	9.26E-02	1.04E-01
1991	1.23E-02	8.08E-02	1.94E-01	8.30E-02	9.22E-02	1.02E-01
1992	1.26E-02	7.97E-02	1.90E-01	8.34E-02	9.18E-02	1.01E-01
1993	1.81E-02	9.23E-02	2.08E-01	8.37E-02	9.14E-02	9.99E-02
1994	1.70E-02	9.69E-02	2.24E-01	8.38E-02	9.10E-02	9.89E-02
1995	1.43E-02	8.08E-02	1.87E-01	8.37E-02	9.06E-02	9.82E-02
1996	1.13E-02	9.19E-02	2.30E-01	8.33E-02	9.03E-02	9.78E-02
1997	1.72E-02	9.73E-02	2.24E-01	8.27E-02	8.99E-02	9.77E-02
1998	1.22E-02	8.44E-02	2.05E-01	8.19E-02	8.95E-02	9.78E-02
1999	1.68E-02	9.96E-02	2.32E-01	8.10E-02	8.91E-02	9.81E-02
2000	1.11E-02	9.16E-02	2.30E-01	7.99E-02	8.88E-02	9.86E-02
2001	1.22E-02	8.27E-02	2.00E-01	7.87E-02	8.84E-02	9.93E-02
2002	1.21E-02	8.41E-02	2.04E-01	7.75E-02	8.80E-02	1.00E-01
2003	1.83E-02	8.62E-02	1.91E-01	7.62E-02	8.77E-02	1.01E-01
2004	1.09E-02	9.14E-02	2.30E-01	7.49E-02	8.73E-02	1.02E-01

3.2 Data Tables for Failure and Demand Trends

Table 9. LER listing for demand trend. Figure 7.

FY	Plant	LER	Date
1987	Clinton 1	4611987022	4/7/1987
1988	Clinton 1	4611988022	9/1/1988
1987	Columbia 2	3971987002	3/22/1987
1989	Columbia 2	3971989025	6/17/1989
1992	Columbia 2	3971991032	11/19/1991
1998	Columbia 2	3971998002	3/11/1998
1988	Grand Gulf	4161988006	1/20/1988
1989	Grand Gulf	4161988019	10/10/1988
1990	Grand Gulf	4161990017	9/16/1990
1991	Grand Gulf	4161990028	12/10/1990
1991	Grand Gulf	4161991005	6/17/1991
1991	Grand Gulf	4161991007	7/28/1991
1993	Grand Gulf	4161993008	9/13/1993
1995	Grand Gulf	4161995007	7/3/1995
1995	Grand Gulf	4161995009	7/17/1995
1995	Grand Gulf	4161995011	9/17/1995
2003	Grand Gulf	4162003001	1/30/2003
1995	La Salle 2	3741995009	5/3/1995
2001	La Salle 2	3742001003	9/3/2001
1988	Nine Mile Pt. 2	4101988001	1/20/1988
1988	Nine Mile Pt. 2	4101988012	3/5/1988
1988	Nine Mile Pt. 2	4101988014	3/13/1988
1989	Nine Mile Pt. 2	4101989014	4/13/1989
1992	Nine Mile Pt. 2	4101991023	12/12/1991
1999	Nine Mile Pt. 2	4101999005	4/24/1999
2002	Nine Mile Pt. 2	4102001004	10/15/2001
1987	Perry	4401987012	3/2/1987
1987	Perry	4401987064	9/9/1987
1988	Perry	4401987072	10/27/1987
1990	Perry	4401990001	1/7/1990
1992	Perry	4401992017	9/10/1992
1993	Perry	4401993012	6/7/1993
1995	Perry	4401995007	9/2/1995
1996	Perry	4401996002	2/18/1996
1997	Perry	4401997001	1/7/1997
1998	Perry	4401998002	7/1/1998
2001	Perry	4402001001	4/29/2001
2002	Perry	4402001005	12/15/2001
2003	Perry	4402003002	8/14/2003
1988	River Bend	4581988018	8/25/1988
1988	River Bend	4581988021	9/6/1988
1994	River Bend	4581994023	9/8/1994

Table 10. LER listing for failure trend. Figure 8.

FY	Plant	LER	Date
1988	Clinton 1	4611988018	7/7/1988
2000	Clinton 1	4612000002	2/28/2000
1989	Columbia 2	3971989030	2/10/1989
1990	Columbia 2	3971990004	2/8/1990
1992	Columbia 2	3971992025	5/22/1992
1989	Grand Gulf	4161988020	12/6/1988
1994	Grand Gulf	4161993019	11/22/1993
1999	Grand Gulf	4161999004	9/9/1999
1989	La Salle 1	3731989009	3/4/1989
1993	La Salle 1	3731993010	4/14/1993
1995	La Salle 1	3731994014	11/23/1994
1989	La Salle 2	3741989008	6/14/1989
2000	La Salle 2	3742000001	2/9/2000
2002	La Salle 2	3742002002	5/30/2002
1991	Perry	4401990041	12/12/1990
1992	Perry	4401991017	10/2/1991
1992	Perry	4401992015	7/1/1992
2003	Perry	4402002002	10/23/2002
1991	River Bend	4581990029	10/6/1990
1993	River Bend	4581993013	6/29/1993
1995	River Bend	4581995005	6/27/1995
1997	River Bend	4581997003	7/22/1997
1999	River Bend	4582000002	3/16/1999