Reliability Study Update

High Pressure Core Spray

1987–2003

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 2003, as reported in Licensee Event Reports (LERs). This is the latest update to NUREG/CR 5500 Volume 8.

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)	3.24E-02	8.32E-02	1.51E-01
8-hour Mission (Unreliability)	4.33E-02	9.63E-02	1.64E-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.

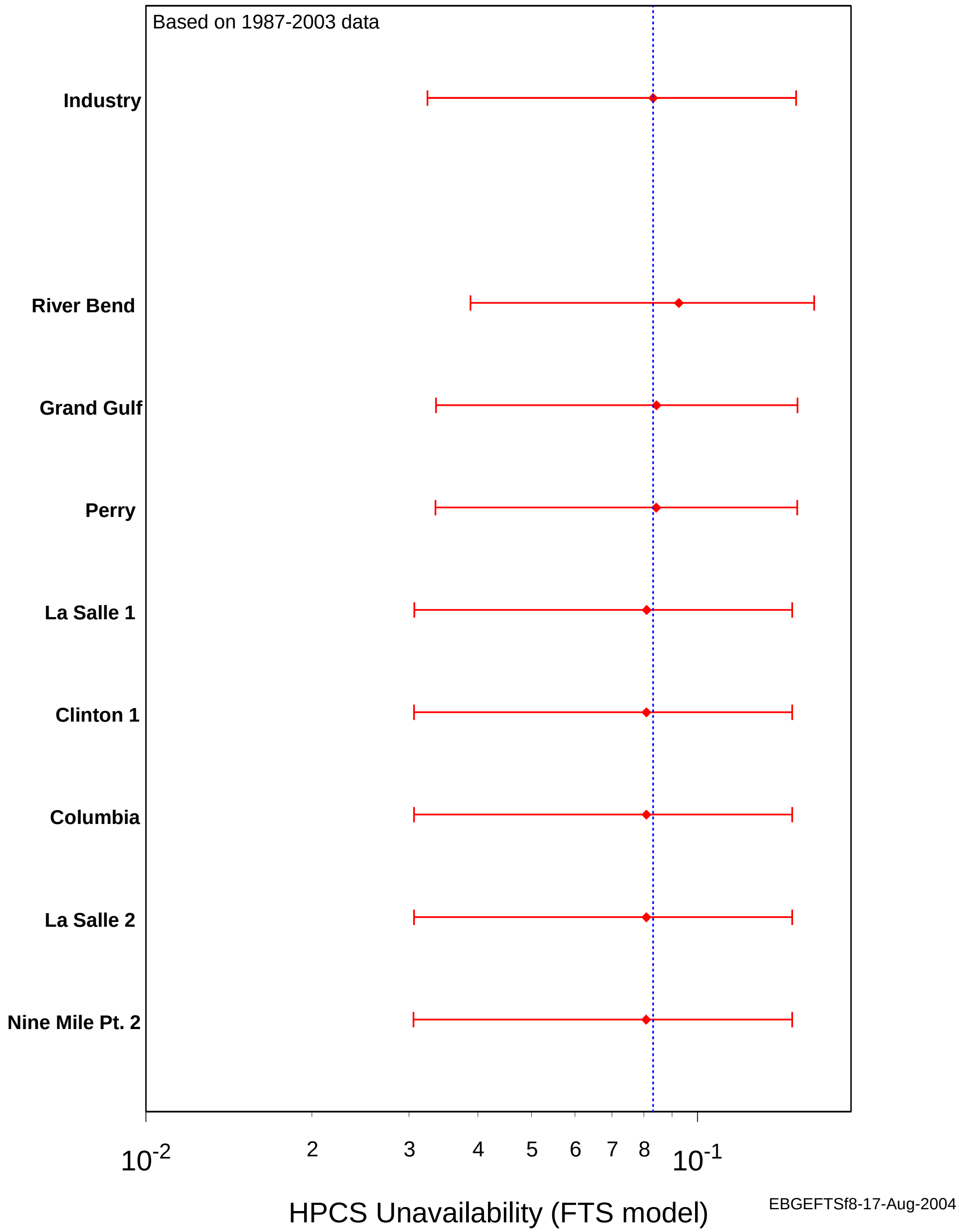

Figure 1. Plant-specific estimates of HPCS system unavailability for FTS model.

Table 2. HPCS plant unavailability FTS model.

Plant	Lower (5%)	Mean	Upper (95%)
Industry	3.24E-02	8.32E-02	1.51E-01
River Bend	3.88E-02	9.25E-02	1.63E-01
Grand Gulf	3.35E-02	8.44E-02	1.52E-01
Perry	3.35E-02	8.42E-02	1.52E-01
La Salle 1	3.06E-02	8.09E-02	1.49E-01
Clinton 1	3.06E-02	8.08E-02	1.49E-01
Columbia	3.06E-02	8.08E-02	1.49E-01
La Salle 2	3.06E-02	8.08E-02	1.49E-01
Nine Mile Pt. 2	3.05E-02	8.07E-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.

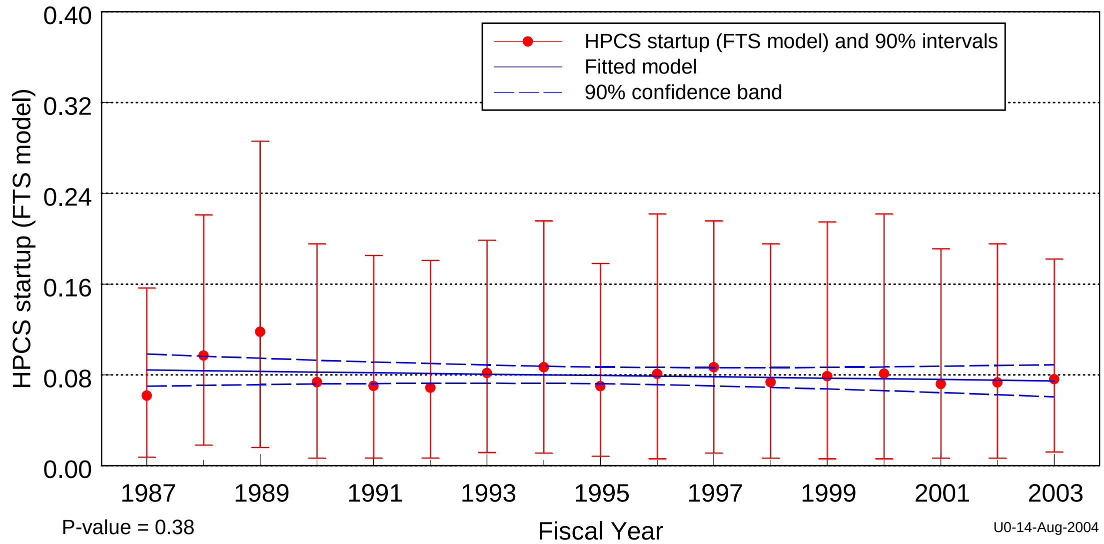

Figure 2. Trend of HPCS system unavailability (FTS model), as a function of fiscal year.

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.

[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).

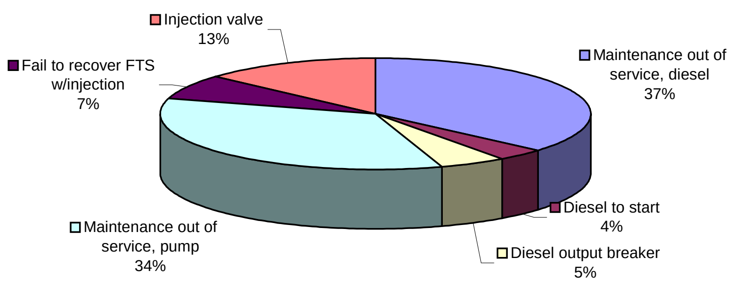

Figure 3. Segment failure distribution, FTS model.

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.

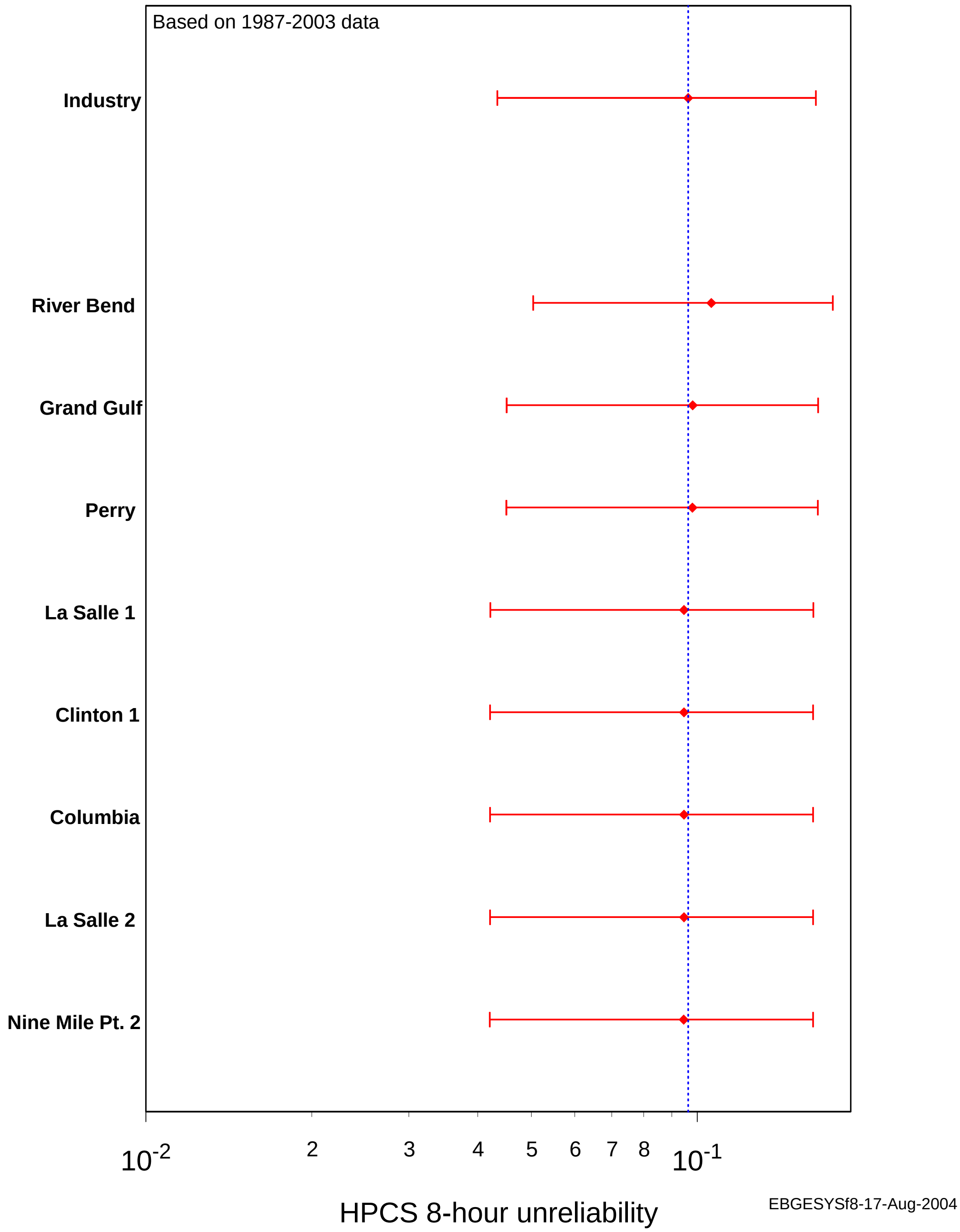

Figure 4. Plant-specific estimates of HPCS system unreliability for an 8-hour mission.

Table 3. HPCS plant unreliability data.

Plant	Lower (5%)	Mean	Upper (95%)
Industry	4.34E-02	9.63E-02	1.64E-01
River Bend	5.04E-02	1.06E-01	1.76E-01
Grand Gulf	4.51E-02	9.81E-02	1.66E-01
Perry	4.50E-02	9.80E-02	1.66E-01
La Salle 1	4.21E-02	9.47E-02	1.62E-01
Clinton 1	4.21E-02	9.47E-02	1.62E-01
Columbia	4.21E-02	9.47E-02	1.62E-01
La Salle 2	4.21E-02	9.47E-02	1.62E-01
Nine Mile Pt. 2	4.20E-02	9.46E-02	1.62E-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 1987–2003 experience. Table 8 shows the data points for Figure 5.

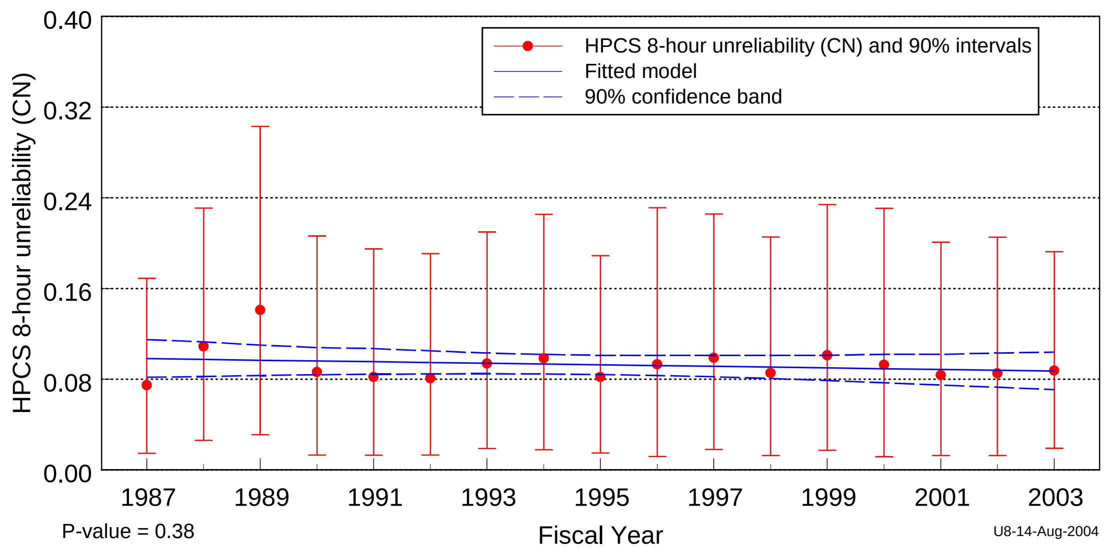

Figure 5. Trend of HPCS system unreliability (8-hour mission), as a function of fiscal year.

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.

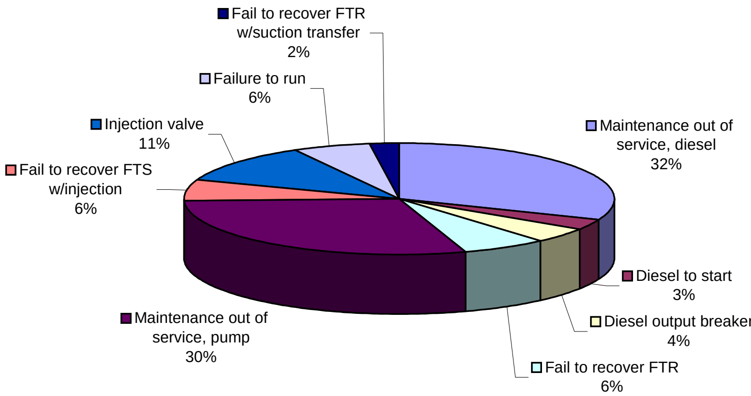

Figure 6. Segment failure distribution, 8-hour mission.

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 a highly statistically significant decreasing trend. Table 9 shows the LERs that are represented in the figure.

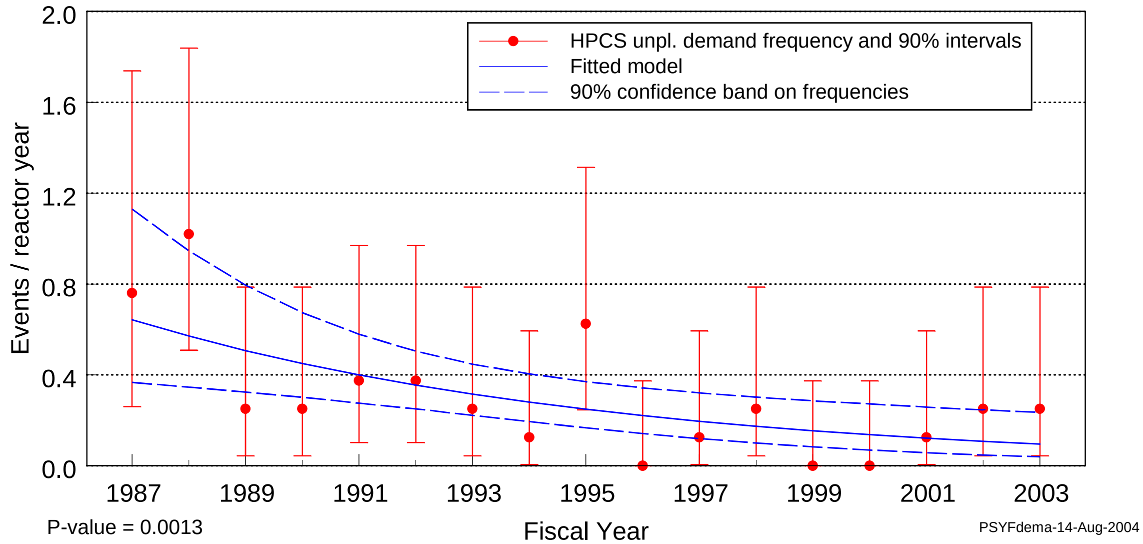

Figure 7. Frequency (events per operating year) of unplanned demands, as a function of fiscal year.

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.

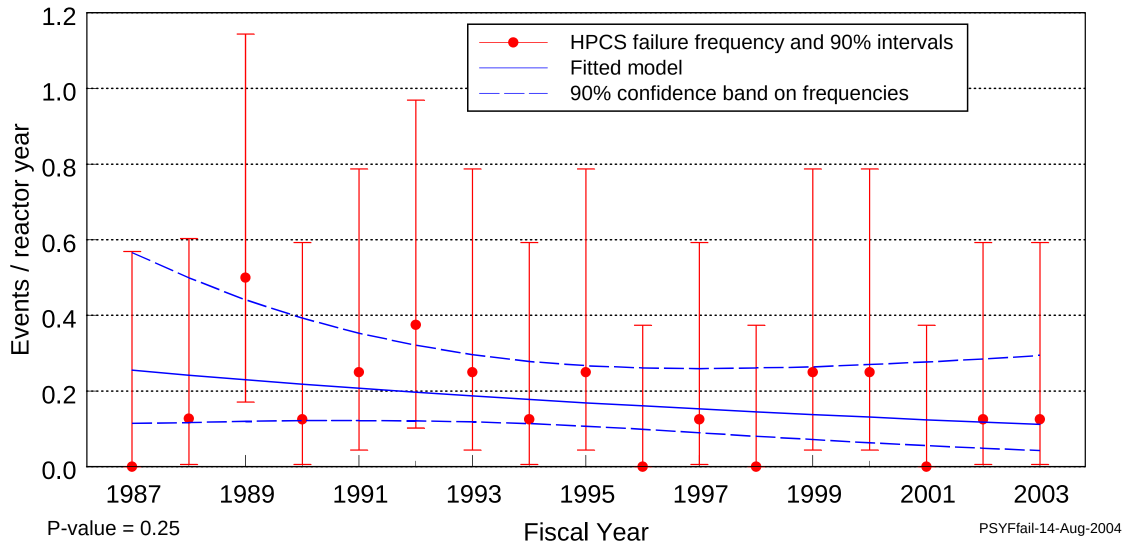

Figure 8. Frequency (events per operating year) of failures, as a function of fiscal year.

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, TBs, 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, TBs, 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.

	Plot Trend Error Bar Points			Regression Curve Data Points		
FY	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1987	7.52E-03	6.18E-02	1.57E-01	7.01E-02	8.43E-02	9.84E-02
1988	1.82E-02	9.72E-02	2.21E-01	7.08E-02	8.37E-02	9.65E-02
1989	1.63E-02	1.18E-01	2.86E-01	7.14E-02	8.31E-02	9.47E-02
1990	6.74E-03	7.37E-02	1.96E-01	7.20E-02	8.25E-02	9.30E-02
1991	6.82E-03	7.03E-02	1.85E-01	7.24E-02	8.19E-02	9.14E-02
1992	6.92E-03	6.89E-02	1.81E-01	7.27E-02	8.13E-02	9.00E-02
1993	1.16E-02	8.17E-02	1.99E-01	7.28E-02	8.07E-02	8.87E-02
1994	1.11E-02	8.69E-02	2.16E-01	7.26E-02	8.01E-02	8.77E-02
1995	8.34E-03	7.02E-02	1.78E-01	7.22E-02	7.95E-02	8.69E-02
1996	6.08E-03	8.09E-02	2.21E-01	7.14E-02	7.90E-02	8.65E-02
1997	1.10E-02	8.69E-02	2.16E-01	7.04E-02	7.84E-02	8.63E-02
1998	6.69E-03	7.36E-02	1.96E-01	6.91E-02	7.78E-02	8.64E-02
1999	6.15E-03	7.90E-02	2.15E-01	6.77E-02	7.72E-02	8.67E-02
2000	6.08E-03	8.10E-02	2.22E-01	6.61E-02	7.66E-02	8.71E-02
2001	6.71E-03	7.21E-02	1.91E-01	6.44E-02	7.60E-02	8.77E-02
2002	6.65E-03	7.35E-02	1.96E-01	6.26E-02	7.54E-02	8.83E-02
2003	1.20E-02	7.62E-02	1.82E-01	6.07E-02	7.48E-02	8.90E-02

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

	Plot Trend Error Bar Points			Regression Curve Data Points		
FY	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1987	1.47E-02	7.47E-02	1.69E-01	8.17E-02	9.82E-02	1.15E-01
1988	2.64E-02	1.09E-01	2.31E-01	8.25E-02	9.75E-02	1.13E-01
1989	3.14E-02	1.41E-01	3.03E-01	8.32E-02	9.68E-02	1.10E-01
1990	1.31E-02	8.63E-02	2.07E-01	8.39E-02	9.61E-02	1.08E-01
1991	1.29E-02	8.19E-02	1.95E-01	8.44E-02	9.55E-02	1.07E-01
1992	1.32E-02	8.08E-02	1.91E-01	8.47E-02	9.48E-02	1.05E-01
1993	1.90E-02	9.39E-02	2.10E-01	8.48E-02	9.41E-02	1.03E-01
1994	1.78E-02	9.84E-02	2.26E-01	8.46E-02	9.34E-02	1.02E-01
1995	1.50E-02	8.20E-02	1.89E-01	8.41E-02	9.27E-02	1.01E-01
1996	1.19E-02	9.31E-02	2.31E-01	8.33E-02	9.21E-02	1.01E-01
1997	1.81E-02	9.88E-02	2.26E-01	8.21E-02	9.14E-02	1.01E-01
1998	1.28E-02	8.56E-02	2.06E-01	8.06E-02	9.07E-02	1.01E-01
1999	1.77E-02	1.01E-01	2.34E-01	7.89E-02	9.00E-02	1.01E-01
2000	1.16E-02	9.28E-02	2.31E-01	7.70E-02	8.93E-02	1.02E-01
2001	1.27E-02	8.38E-02	2.01E-01	7.50E-02	8.86E-02	1.02E-01
2002	1.26E-02	8.53E-02	2.06E-01	7.29E-02	8.80E-02	1.03E-01
2003	1.91E-02	8.76E-02	1.92E-01	7.08E-02	8.73E-02	1.04E-01

3.2 Data Tables for Failure and Demand Trends

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

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

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

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