# Reliability Study Update

# Reactor Core Isolation Cooling

# 1987–2002

This report presents a performance evaluation of the reactor core isolation cooling (RCIC) system at 30 U.S. commercial boiling water reactors (BWRs). The evaluation is based on the operating experience from 1987 through 2002, as reported in Licensee Event Reports (LERs). This is the latest update to NUREG/CR 5500 Volume 7.

This report calculates two basic models for the RCIC system. The FTS model includes the start and recovery of the pump and the initial opening of the injection valve. The 8-hour mission model includes the RCIC system start and operation for 8 hours. Restart of the RCIC turbine, multiple injections, transfer from recirculation to injection, and recovery actions are included. Both models include failures due to the unavailability while in maintenance. See the RCIC 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 RCIC system have been estimated from operating experience. A failure to start (FTS) model and an 8-hour mission model were evaluated for each of these models, 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) | 6.21E-03 | 1.93E-02 | 3.81E-02 |
| 8-hour Mission (Unreliability) | 2.39E-02 | 6.11E-02 | 1.11E-01 |

### 1.2 Fail to Start Model Results

Individual plant result unavailability has been calculated for the FTS model. The estimates of RCIC 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.

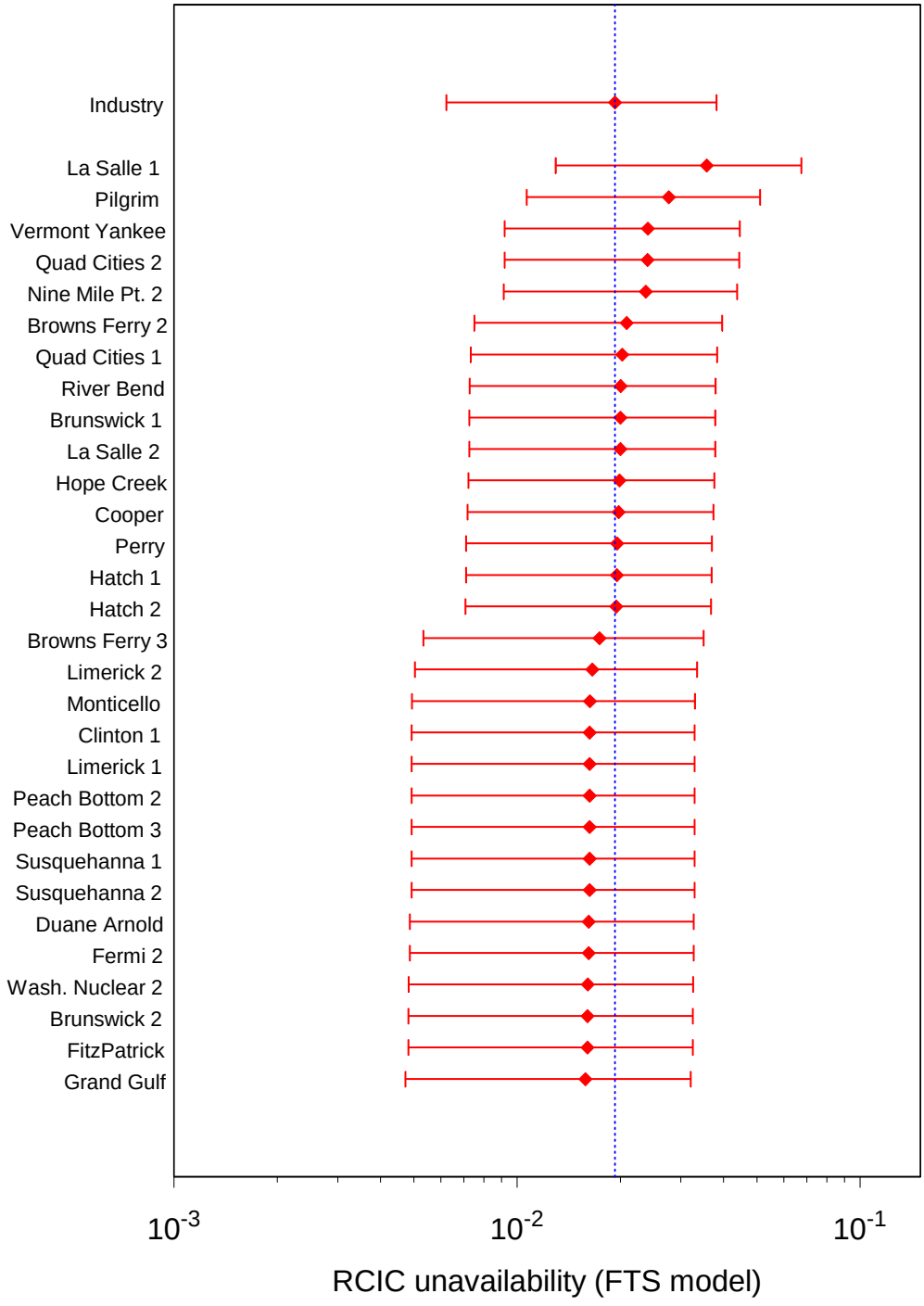


**Figure 1. Plant-specific estimates of RCIC system unavailability for FTS model.**

**Table 2. RCIC plant unavailability FTS model.**

| Plant | Lower (5%) | Mean | Upper (95%) |
|---|---|---|---|
| Industry | 6.21E-03 | 1.93E-02 | 3.81E-02 |
| Grand Gulf | 4.72E-03 | 1.58E-02 | 3.21E-02 |
| Fitzpatrick | 4.83E-03 | 1.61E-02 | 3.25E-02 |
| Brunswick 2 | 4.83E-03 | 1.61E-02 | 3.25E-02 |
| Columbia Nuclear 2 | 4.84E-03 | 1.61E-02 | 3.26E-02 |
| Fermi 2 | 4.87E-03 | 1.62E-02 | 3.27E-02 |
| Duane Arnold | 4.87E-03 | 1.62E-02 | 3.27E-02 |
| Susquehanna 2 | 4.91E-03 | 1.63E-02 | 3.29E-02 |
| Susquehanna 1 | 4.91E-03 | 1.63E-02 | 3.29E-02 |
| Peach Bottom 3 | 4.91E-03 | 1.63E-02 | 3.29E-02 |
| Peach Bottom 2 | 4.91E-03 | 1.63E-02 | 3.29E-02 |
| Limerick 1 | 4.91E-03 | 1.63E-02 | 3.29E-02 |
| Clinton 1 | 4.91E-03 | 1.63E-02 | 3.29E-02 |
| Monticello | 4.93E-03 | 1.63E-02 | 3.30E-02 |
| Limerick 2 | 5.03E-03 | 1.66E-02 | 3.34E-02 |
| Browns Ferry 3 | 5.33E-03 | 1.74E-02 | 3.49E-02 |
| Hatch 2 | 7.05E-03 | 1.94E-02 | 3.67E-02 |
| Hatch 1 | 7.09E-03 | 1.95E-02 | 3.69E-02 |
| Perry | 7.10E-03 | 1.96E-02 | 3.70E-02 |
| Cooper | 7.16E-03 | 1.98E-02 | 3.73E-02 |
| Hope Creek | 7.21E-03 | 1.99E-02 | 3.76E-02 |
| La Salle 2 | 7.24E-03 | 2.00E-02 | 3.78E-02 |
| Brunswick 1 | 7.24E-03 | 2.00E-02 | 3.78E-02 |
| River Bend | 7.26E-03 | 2.00E-02 | 3.79E-02 |
| Quad Cities 1 | 7.32E-03 | 2.02E-02 | 3.83E-02 |
| Browns Ferry 2 | 7.50E-03 | 2.09E-02 | 3.96E-02 |
| Nine Mile Pt. 2 | 9.13E-03 | 2.37E-02 | 4.38E-02 |
| Quad Cities 2 | 9.17E-03 | 2.40E-02 | 4.44E-02 |
| Vermont Yankee | 9.18E-03 | 2.41E-02 | 4.45E-02 |
| Pilgrim | 1.07E-02 | 2.77E-02 | 5.10E-02 |
| La Salle 1 | 1.30E-02 | 3.57E-02 | 6.73E-02 |

A statistically significant[1] decreasing trend within the industry estimates of RCIC 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.

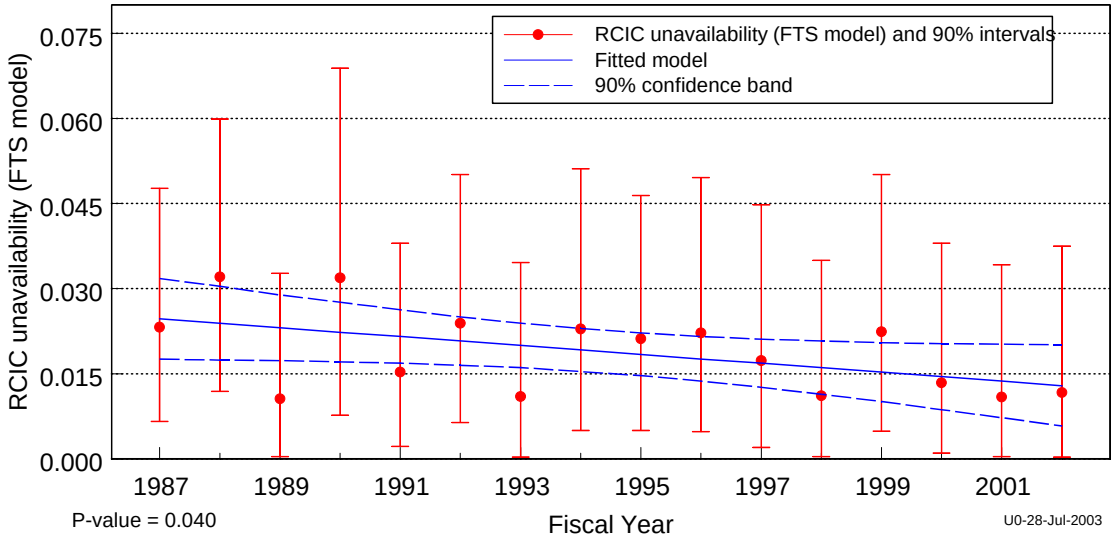


**Figure 2. Trend of RCIC system unavailability (FTS model), as a function of fiscal year.**

[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 statistically significant.

The leading contributor to RCIC system short-term unavailability, after the maintenance out of service, is the failure of the turbine to start. Figure 3 shows the distribution of segment failure contributions for the FTS model.

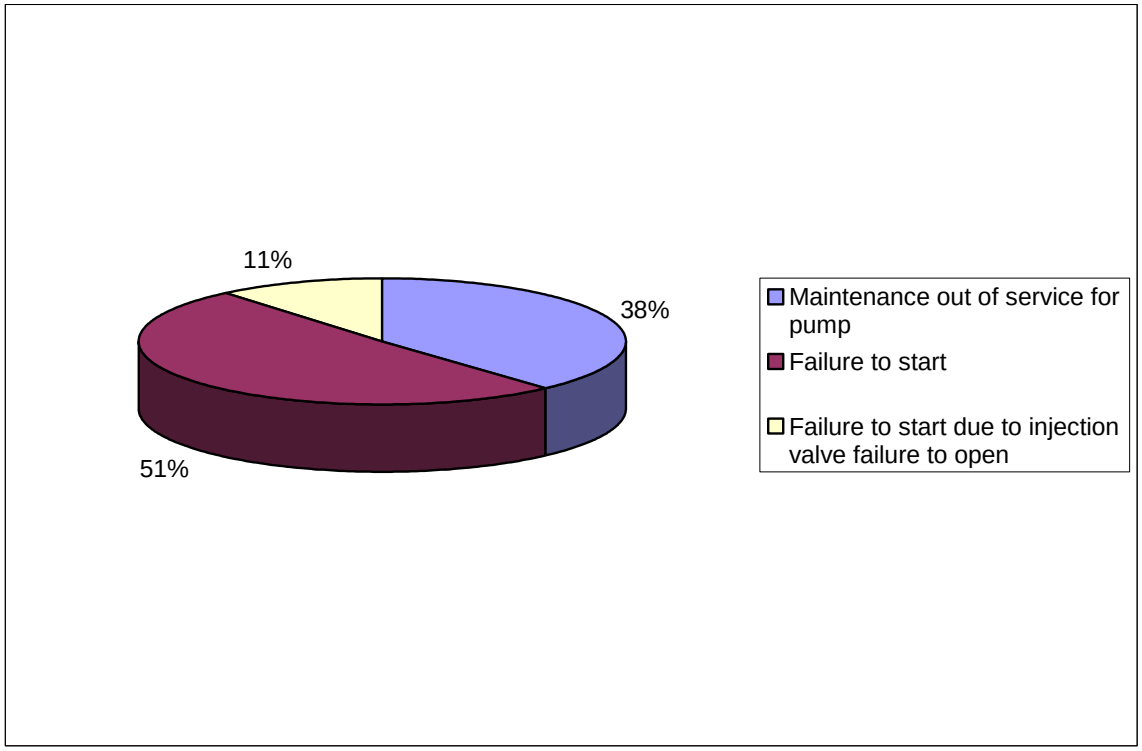


**Figure 3. Segment failure distribution, FTS model.**

## 1.3 Fail to Operate for 8-Hour Model

Individual plant result unreliability has been calculated for the 8-hour mission. The estimates of RCIC 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.

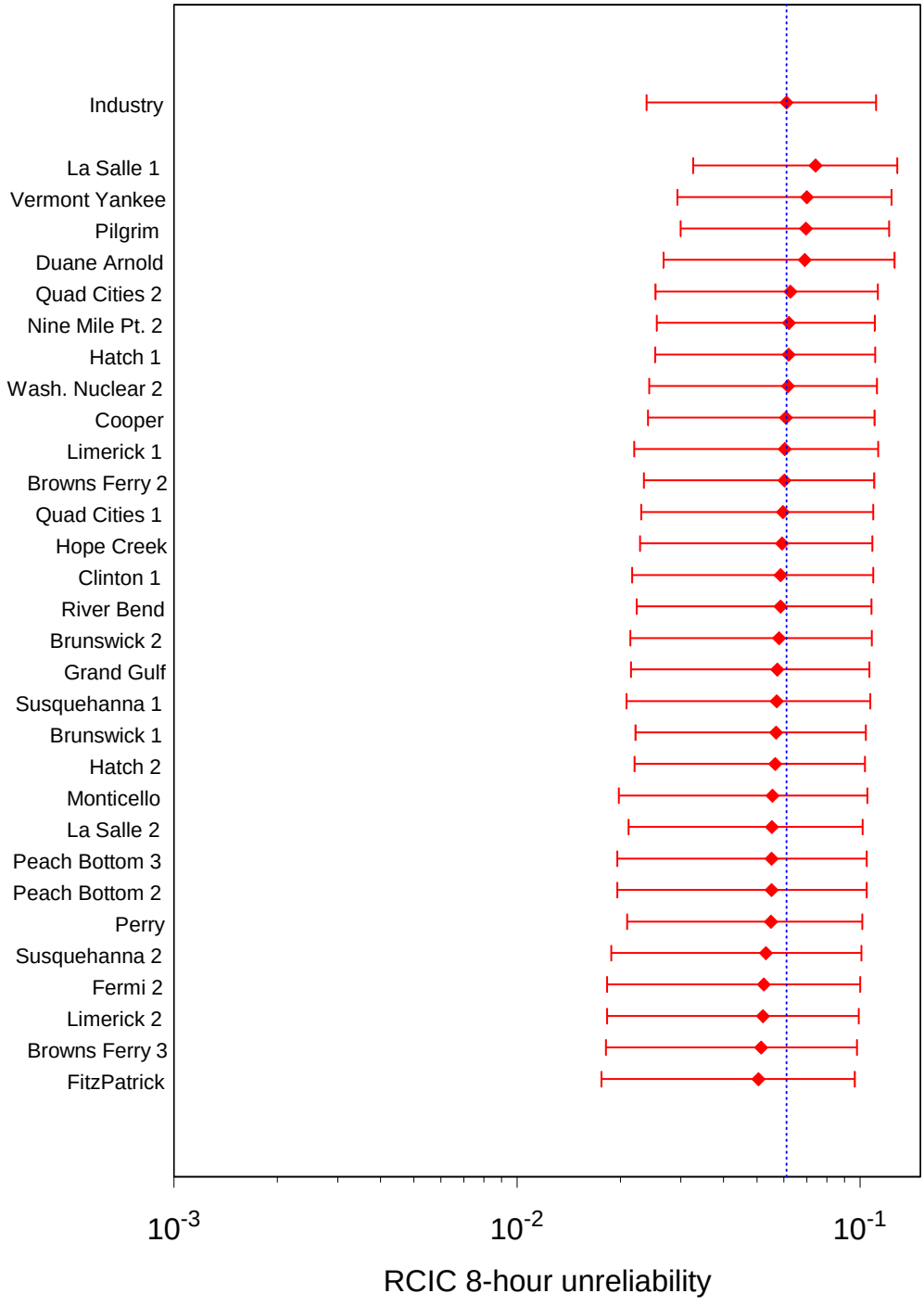


**Figure 4. Plant-specific estimates of RCIC system unreliability for an 8-hour mission.**

**Table 3. RCIC plant unreliability data.**

| Plant | Lower (5%) | Mean | Upper (95%) |
|---|---|---|---|
| Industry | 2.39E-02 | 6.11E-02 | 1.11E-01 |
| La Salle 1 | 3.26E-02 | 7.42E-02 | 1.28E-01 |
| Vermont Yankee | 2.93E-02 | 7.00E-02 | 1.24E-01 |
| Pilgrim | 2.99E-02 | 6.96E-02 | 1.21E-01 |
| Duane Arnold | 2.67E-02 | 6.90E-02 | 1.26E-01 |
| Quad Cities 2 | 2.53E-02 | 6.27E-02 | 1.13E-01 |
| Nine Mile Pt. 2 | 2.55E-02 | 6.20E-02 | 1.10E-01 |
| Hatch 1 | 2.53E-02 | 6.19E-02 | 1.11E-01 |
| Columbia Nuclear 2 | 2.42E-02 | 6.17E-02 | 1.12E-01 |
| Cooper | 2.41E-02 | 6.08E-02 | 1.10E-01 |
| Limerick 1 | 2.20E-02 | 6.03E-02 | 1.13E-01 |
| Browns Ferry 2 | 2.34E-02 | 6.02E-02 | 1.10E-01 |
| Quad Cities 1 | 2.30E-02 | 5.96E-02 | 1.09E-01 |
| Hope Creek | 2.28E-02 | 5.92E-02 | 1.08E-01 |
| River Bend | 2.23E-02 | 5.86E-02 | 1.08E-01 |
| Clinton 1 | 2.16E-02 | 5.86E-02 | 1.09E-01 |
| Brunswick 2 | 2.14E-02 | 5.80E-02 | 1.08E-01 |
| Grand Gulf | 2.15E-02 | 5.74E-02 | 1.06E-01 |
| Susquehanna 1 | 2.08E-02 | 5.72E-02 | 1.07E-01 |
| Brunswick 1 | 2.21E-02 | 5.70E-02 | 1.04E-01 |
| Hatch 2 | 2.20E-02 | 5.65E-02 | 1.03E-01 |
| Monticello | 1.98E-02 | 5.55E-02 | 1.05E-01 |
| Peach Bottom 2 | 1.96E-02 | 5.53E-02 | 1.05E-01 |
| Peach Bottom 3 | 1.96E-02 | 5.53E-02 | 1.05E-01 |
| La Salle 2 | 2.11E-02 | 5.53E-02 | 1.02E-01 |
| Perry | 2.09E-02 | 5.51E-02 | 1.01E-01 |
| Susquehanna 2 | 1.88E-02 | 5.32E-02 | 1.01E-01 |
| Fermi 2 | 1.83E-02 | 5.24E-02 | 9.99E-02 |
| Limerick 2 | 1.83E-02 | 5.21E-02 | 9.89E-02 |
| Browns Ferry 3 | 1.82E-02 | 5.15E-02 | 9.78E-02 |
| Fitzpatrick | 1.76E-02 | 5.06E-02 | 9.65E-02 |

No statistically significant trend within the industry estimates of RCIC system unreliability (8-hour mission) on a per fiscal year basis was identified. Figure 5 displays the trend by fiscal year of the RCIC system unreliability calculated from the 1987–2002 experience. Table 8 shows the data points for Figure 5.

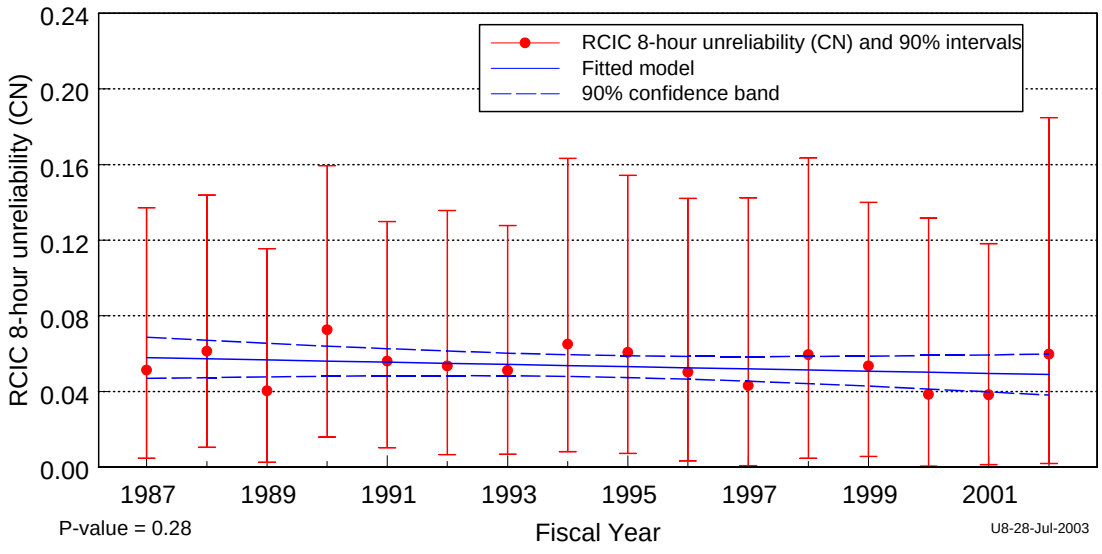


**Figure 5. Trend of RCIC system unreliability (8-hour mission), as a function of fiscal year.**

The leading segment failure contributor to the RCIC system unreliability, after the maintenance out of service, is the failure to run of the pump and turbine. Figure 6 shows the distribution of segment failures for the 8-hour mission.

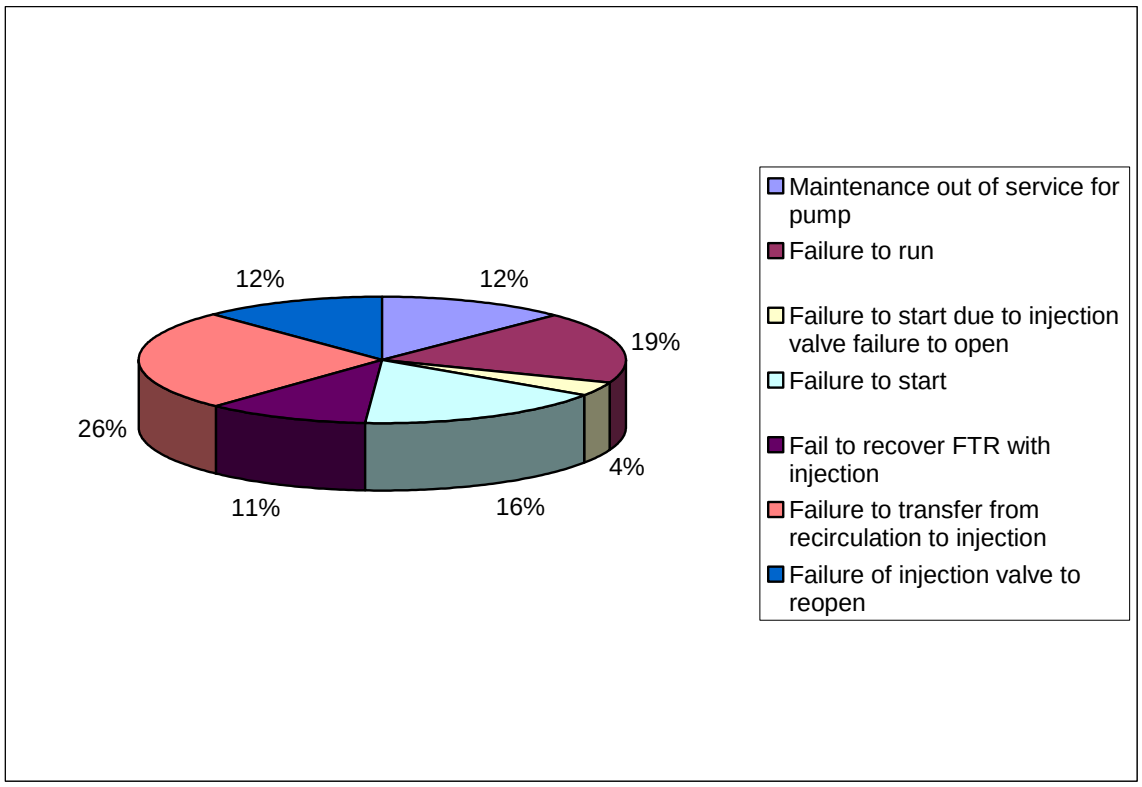


**Figure 6. Segment failure distribution, 8-hour mission.**

# 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 RCIC 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.

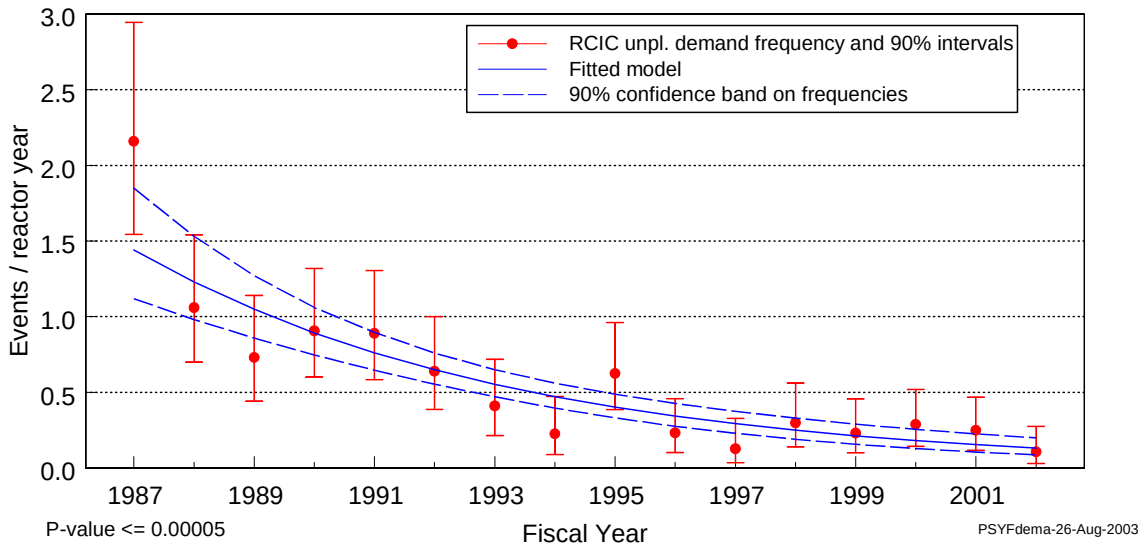


**Figure 7. Frequency (events per operating year) of unplanned demands, as a function of fiscal year.**

## 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, a highly statistically significant decreasing trend was identified. The fitted frequency is plotted against fiscal year in Figure 8. Trends for RCIC 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.

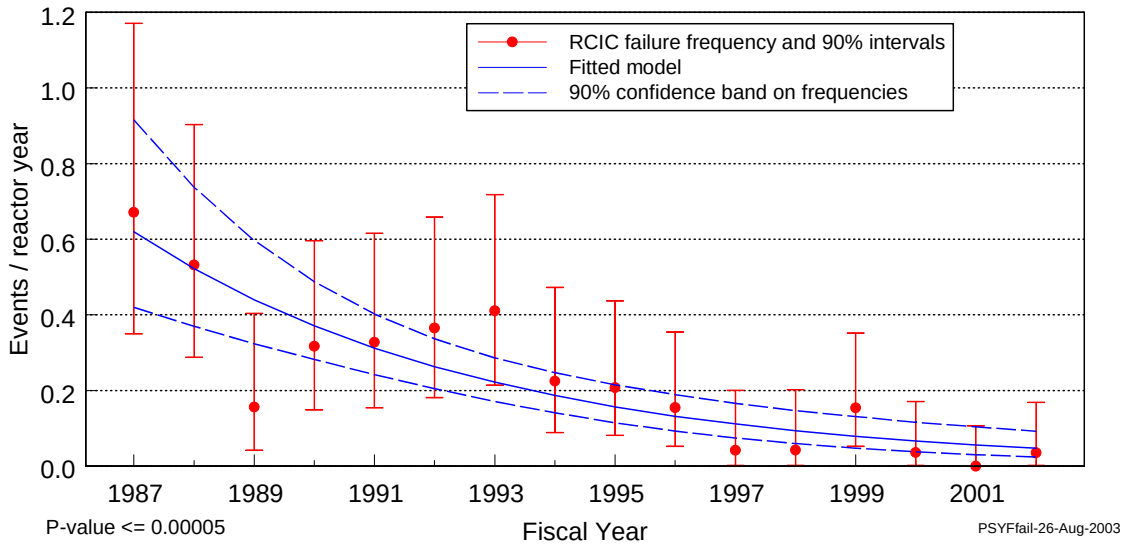


**Figure 8. Frequency (events per operating year) of failures, as a function of fiscal year.**

## 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 steam supply (35%) and the turbine and turbine control (28%) were the leading segment failures identified in the database. See Table 4.

### 2.3.2 Leading Discovery Methods

Periodic surveillance (26%) and unplanned demand (20%) were the leading methods of discovery. See Table 4.

### 2.3.3 Leading Causes of Failure.

Seventy five percent of the failures of the RCIC system observed in the experience were attributed to hardware-related problems. Personnel errors caused 15% of all RCIC system failures. However, 50% of these failures were immediately identified, meaning that the failures were of the nature where plant personnel were able to respond to the failures immediately after they occurred. See Table 6

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

| Segment | Actual/ unplanned demand | Alarm/ indicator | I&C functional test | Inspection/ review | Other (not counted) surveillance test | Periodic surveillance on system | Post-maintenance testing | Unscheduled TS required surveillance | Total | Percent |
|---|---|---|---|---|---|---|---|---|---|---|
| Electrical | 1 | 2 | | | | | 1 | | 4 | 4% |
| HVAC | | | | 1 | | | | | 1 | 1% |
| I&C | 2 | | 2 | 2 | | 1 | | | 7 | 8% |
| Injection (Discharge) | 5 | | | 1 | | 3 | 1 | 1 | 11 | 12% |
| Injection (Suction) | | | | | | 1 | | | 1 | 1% |
| Lube Oil | | | | | | 3 | | 1 | 4 | 4% |
| Service Water | | 1 | | | | | | | 1 | 1% |
| Steam Supply | 4 | 5 | 3 | 5 | 1 | 2 | 7 | 5 | 32 | 35% |
| Turbine & Turbine Control | 4 | | | 4 | | 11 | 5 | 2 | 26 | 28% |
| Turbine Exhausts & drains | 2 | | | | | 3 | | | 5 | 5% |
| Total | 18 | 8 | 5 | 13 | 1 | 24 | 14 | 9 | 92 | 100% |
| | 20% | 9% | 5% | 14% | 1% | 26% | 15% | 10% | 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. | ✓ |
| Design review | Because of a design review, a deficiency was noted in the system. | |

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

| Discovery Method | Description | Used in the Failure Calculations |
|---|---|---|
| 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. | |
| Alarm/indicator | The failure was evidenced by an alarm or by other indications. | |
| I&C functional test | The failure was discovered during testing of the instrumentation and control system for the subject system or another system. | |
| Post-maintenance testing | Failed condition was discovered during post-maintenance testing. The technical specification surveillance tests can be used for this testing, but cannot be counted. | |
| Unscheduled TS required surveillance | Failed condition was discovered during technical specification required testing. Tests are performed to show system operability per the technical specifications and are not scheduled. The technical specification surveillance tests can be used for this testing, but cannot be counted. | |
| Other (not counted) surveillance test | All others discovered by testing. | |

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

| Segment | Contamination | Design | Hardware | Personnel | Procedure | Total | Percent |
|---|---|---|---|---|---|---|---|
| Electrical | | 1 | 3 | | | 4 | 4% |
| HVAC | | | 1 | | | 1 | 1% |
| I&C | | | 3 | 4 | | 7 | 8% |
| Injection (Discharge) | | 1 | 8 | 1 | 1 | 11 | 12% |
| Injection (Suction) | | | | | 1 | 1 | 1% |
| Lube Oil | 1 | 1 | | 2 | | 4 | 4% |
| Service Water | | | 1 | | | 1 | 1% |
| Steam Supply | | | 31 | 1 | | 32 | 35% |
| Turbine & Turbine Control | | | 20 | 5 | 1 | 26 | 28% |
| Turbine Exhausts & drains | 1 | 1 | 2 | 1 | | 5 | 5% |
| Total | 2 | 4 | 69 | 14 | 3 | 92 | 100% |
| | 2% | 4% | 75% | 15% | 3% | 100% | |

- Contamination–The failure was the result of foreign material affecting the component.
- 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 RCIC system unavailability, FTS model. Figure 5**

| | Plot Trend Error Bar Points | | | Regression Curve Data Points | | |
|---|---|---|---|---|---|---|
| Fiscal Year | Lower (5%) | Mean | Upper (95%) | Lower (5%) | Mean | Upper (95%) |
| 1987 | 6.60E-03 | 2.32E-02 | 4.77E-02 | 1.76E-02 | 2.47E-02 | 3.18E-02 |
| 1988 | 1.20E-02 | 3.21E-02 | 5.99E-02 | 1.74E-02 | 2.39E-02 | 3.04E-02 |
| 1989 | 4.25E-04 | 1.06E-02 | 3.27E-02 | 1.73E-02 | 2.31E-02 | 2.89E-02 |
| 1990 | 7.72E-03 | 3.19E-02 | 6.89E-02 | 1.71E-02 | 2.23E-02 | 2.76E-02 |
| 1991 | 2.20E-03 | 1.53E-02 | 3.80E-02 | 1.69E-02 | 2.16E-02 | 2.63E-02 |
| 1992 | 6.39E-03 | 2.39E-02 | 5.01E-02 | 1.65E-02 | 2.08E-02 | 2.50E-02 |
| 1993 | 3.88E-04 | 1.10E-02 | 3.46E-02 | 1.61E-02 | 2.00E-02 | 2.39E-02 |
| 1994 | 4.98E-03 | 2.29E-02 | 5.11E-02 | 1.54E-02 | 1.92E-02 | 2.30E-02 |
| 1995 | 4.92E-03 | 2.12E-02 | 4.64E-02 | 1.47E-02 | 1.84E-02 | 2.22E-02 |
| 1996 | 4.85E-03 | 2.22E-02 | 4.96E-02 | 1.37E-02 | 1.76E-02 | 2.16E-02 |
| 1997 | 2.03E-03 | 1.73E-02 | 4.48E-02 | 1.26E-02 | 1.69E-02 | 2.11E-02 |
| 1998 | 3.75E-04 | 1.11E-02 | 3.50E-02 | 1.14E-02 | 1.61E-02 | 2.08E-02 |
| 1999 | 4.85E-03 | 2.24E-02 | 5.01E-02 | 1.01E-02 | 1.53E-02 | 2.05E-02 |
| 2000 | 9.53E-04 | 1.34E-02 | 3.80E-02 | 8.68E-03 | 1.45E-02 | 2.03E-02 |
| 2001 | 3.87E-04 | 1.09E-02 | 3.42E-02 | 7.25E-03 | 1.37E-02 | 2.02E-02 |
| 2002 | 3.44E-04 | 1.17E-02 | 3.75E-02 | 5.79E-03 | 1.29E-02 | 2.01E-02 |

**Table 8. Plot data table for RCIC system unreliability, 8-hour mission. Figure 2**

| | Plot Trend Error Bar Points | | | Regression Curve Data Points | | |
|---|---|---|---|---|---|---|
| Fiscal Year | Lower (5%) | Mean | Upper (95%) | Lower (5%) | Mean | Upper (95%) |
| 1987 | 4.78E-03 | 5.13E-02 | 1.37E-01 | 4.70E-02 | 5.79E-02 | 6.87E-02 |
| 1988 | 1.06E-02 | 6.13E-02 | 1.44E-01 | 4.74E-02 | 5.73E-02 | 6.71E-02 |
| 1989 | 2.52E-03 | 4.03E-02 | 1.15E-01 | 4.78E-02 | 5.67E-02 | 6.55E-02 |
| 1990 | 1.60E-02 | 7.26E-02 | 1.59E-01 | 4.81E-02 | 5.61E-02 | 6.40E-02 |
| 1991 | 1.03E-02 | 5.61E-02 | 1.30E-01 | 4.83E-02 | 5.55E-02 | 6.26E-02 |
| 1992 | 6.58E-03 | 5.35E-02 | 1.36E-01 | 4.84E-02 | 5.49E-02 | 6.14E-02 |
| 1993 | 6.80E-03 | 5.12E-02 | 1.28E-01 | 4.83E-02 | 5.43E-02 | 6.03E-02 |
| 1994 | 8.20E-03 | 6.50E-02 | 1.63E-01 | 4.80E-02 | 5.37E-02 | 5.95E-02 |
| 1995 | 7.25E-03 | 6.07E-02 | 1.54E-01 | 4.74E-02 | 5.31E-02 | 5.89E-02 |
| 1996 | 3.34E-03 | 5.02E-02 | 1.42E-01 | 4.66E-02 | 5.25E-02 | 5.85E-02 |
| 1997 | 8.48E-04 | 4.31E-02 | 1.42E-01 | 4.55E-02 | 5.20E-02 | 5.84E-02 |
| 1998 | 4.70E-03 | 5.95E-02 | 1.63E-01 | 4.42E-02 | 5.14E-02 | 5.85E-02 |
| 1999 | 5.66E-03 | 5.36E-02 | 1.40E-01 | 4.28E-02 | 5.08E-02 | 5.87E-02 |
| 2000 | 5.43E-04 | 3.85E-02 | 1.32E-01 | 4.13E-02 | 5.02E-02 | 5.91E-02 |
| 2001 | 1.38E-03 | 3.82E-02 | 1.18E-01 | 3.98E-02 | 4.96E-02 | 5.94E-02 |
| 2002 | 1.95E-03 | 5.97E-02 | 1.85E-01 | 3.81E-02 | 4.90E-02 | 5.99E-02 |

## 3.2 Data Tables for Failure and Demand Trends

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

| FY | Plant | Date | LER |
|---|---|---|---|
| 1997 | Browns Ferry 2 | 4/24/1997 | 2601997001 |
| 1996 | Browns Ferry 2 | 5/10/1996 | 2601996005 |
| 2000 | Browns Ferry 3 | 4/15/2000 | 2962000001 |
| 2000 | Browns Ferry 3 | 5/24/2000 | 2962000005 |
| 1996 | Browns Ferry 3 | 4/21/1996 | 2961996002 |
| 1996 | Browns Ferry 3 | 5/1/1996 | 2961996003 |
| 1995 | Brunswick 1 | 7/13/1995 | 3251995015 |
| 1995 | Brunswick 1 | 9/30/1995 | 3251995018 |
| 1992 | Brunswick 1 | 1/17/1992 | 3251992003 |
| 1992 | Brunswick 1 | 2/29/1992 | 3251992005 |
| 1991 | Brunswick 1 | 7/18/1991 | 3251991018 |
| 1987 | Brunswick 1 | 7/1/1987 | 3251987019 |
| 1992 | Brunswick 2 | 2/2/1992 | 3241992001 |
| 1991 | Brunswick 2 | 10/12/1990 | 3241990016 |
| 1991 | Brunswick 2 | 1/25/1991 | 3241991001 |
| 1990 | Brunswick 2 | 8/16/1990 | 3241990008 |
| 1990 | Brunswick 2 | 8/19/1990 | 3241990009 |
| 1990 | Brunswick 2 | 9/27/1990 | 3241990015 |
| 1989 | Brunswick 2 | 11/16/1988 | 3241988018 |
| 1989 | Brunswick 2 | 6/17/1989 | 3241989009 |
| 1987 | Brunswick 2 | 1/5/1987 | 3241987001 |
| 1987 | Brunswick 2 | 3/11/1987 | 3241987004 |
| 2001 | Clinton 1 | 12/18/2000 | 4612000007 |
| 2000 | Clinton 1 | 5/17/2000 | 4612000001 |
| 1989 | Clinton 1 | 7/14/1989 | 4611989029 |
| 1988 | Clinton 1 | 7/12/1988 | 4611988019 |
| 1998 | Columbia Nuclear 2 | 3/11/1998 | 3971998002 |
| 1998 | Columbia Nuclear 2 | 3/11/1998 | 3971998003 |
| 1995 | Columbia Nuclear 2 | 2/18/1995 | 3971995002 |
| 1993 | Columbia Nuclear 2 | 8/3/1993 | 3971993027 |
| 1988 | Columbia Nuclear 2 | 2/4/1988 | 3971988003 |
| 1988 | Columbia Nuclear 2 | 2/13/1988 | 3971988006 |
| 1987 | Columbia Nuclear 2 | 3/22/1987 | 3971987002 |
| 1987 | Columbia Nuclear 2 | 7/2/1987 | 3971987020 |
| 1987 | Columbia Nuclear 2 | 7/6/1987 | 3971987022 |
| 2001 | Cooper | 3/3/2001 | 2982001002 |
| 1996 | Cooper | 10/14/1995 | 2981995012 |
| 1994 | Cooper | 12/14/1993 | 2981993038 |
| 1994 | Cooper | 3/2/1994 | 2981994004 |
| 1991 | Cooper | 10/17/1990 | 2981990011 |
| 1990 | Cooper | 11/25/1989 | 2981989026 |
| 1988 | Cooper | 8/25/1988 | 2981988021 |
| 1987 | Cooper | 1/7/1987 | 2981987003 |
| 1987 | Cooper | 1/10/1987 | 2981987006 |
| 1987 | Cooper | 2/18/1987 | 2981987009 |
| 1987 | Cooper | 5/17/1987 | 2981987011 |
| 2002 | Duane Arnold | 10/17/2001 | 3312001006 |
| 1991 | Duane Arnold | 10/19/1990 | 3311990019 |
| 1990 | Duane Arnold | 3/29/1990 | 3311990002 |
| 1989 | Duane Arnold | 3/5/1989 | 3311989008 |
| 1989 | Duane Arnold | 8/26/1989 | 3311989011 |
| 1995 | Fermi 2 | 4/9/1995 | 3411995004 |
| 1993 | Fermi 2 | 11/18/1992 | 3411992012 |
| 1993 | Fermi 2 | 8/13/1993 | 3411993010 |
| 1988 | Fermi 2 | 1/10/1988 | 3411988004 |
| 1987 | Fermi 2 | 5/13/1987 | 3411987017 |
| 1987 | Fermi 2 | 6/25/1987 | 3411987025 |
| 2000 | Fitzpatrick | 10/14/1999 | 3331999010 |
| 1998 | Fitzpatrick | 5/1/1998 | 3331998004 |
| 1998 | Fitzpatrick | 8/3/1998 | 3331998008 |
| 1996 | Fitzpatrick | 2/22/1996 | 3331996003 |
| 1996 | Fitzpatrick | 9/16/1996 | 3331996010 |
| 1995 | Fitzpatrick | 9/5/1995 | 3331995013 |
| 1993 | Fitzpatrick | 4/20/1993 | 3331993009 |
| 1990 | Fitzpatrick | 11/5/1989 | 3331989020 |
| 1990 | Fitzpatrick | 3/19/1990 | 3331990009 |
| 1987 | Fitzpatrick | 6/10/1987 | 3331987008 |
| 2001 | Grand Gulf | 8/7/2001 | 4162001003 |
| 2000 | Grand Gulf | 9/15/2000 | 4162000005 |
| 1999 | Grand Gulf | 2/21/1999 | 4161999003 |
| 1998 | Grand Gulf | 1/28/1998 | 4161998001 |
| 1995 | Grand Gulf | 7/3/1995 | 4161995007 |
| 1995 | Grand Gulf | 7/12/1995 | 4161995008 |
| 1992 | Grand Gulf | 6/18/1992 | 4161992013 |
| 1991 | Grand Gulf | 12/10/1990 | 4161990028 |
| 1991 | Grand Gulf | 12/18/1990 | 4161990029 |
| 1991 | Grand Gulf | 6/11/1991 | 4161991004 |
| 1991 | Grand Gulf | 6/17/1991 | 4161991005 |
| 1991 | Grand Gulf | 7/28/1991 | 4161991007 |
| 1990 | Grand Gulf | 11/7/1989 | 4161989016 |
| 1990 | Grand Gulf | 12/30/1989 | 4161989019 |
| 1990 | Grand Gulf | 7/24/1990 | 4161990011 |
| 1990 | Grand Gulf | 9/16/1990 | 4161990017 |
| 1989 | Grand Gulf | 5/5/1989 | 4161989006 |
| 1989 | Grand Gulf | 7/22/1989 | 4161989010 |
| 1989 | Grand Gulf | 8/14/1989 | 4161989012 |

| FY | Plant | Date | LER |
|---|---|---|---|
| 1988 | Grand Gulf | 1/20/1988 | 4161988006 |
| 2001 | Hatch 1 | 3/28/2001 | 3212001002 |
| 2000 | Hatch 1 | 1/26/2000 | 3212000002 |
| 2000 | Hatch 1 | 9/29/2000 | 3212000011 |
| 1996 | Hatch 1 | 5/26/1996 | 3211996009 |
| 1994 | Hatch 1 | 10/22/1993 | 3211993013 |
| 1994 | Hatch 1 | 12/7/1993 | 3211993016 |
| 1992 | Hatch 1 | 8/27/1992 | 3211992021 |
| 1992 | Hatch 1 | 9/30/1992 | 3211992024 |
| 1991 | Hatch 1 | 10/15/1990 | 3211990021 |
| 1991 | Hatch 1 | 1/18/1991 | 3211991001 |
| 1991 | Hatch 1 | 9/11/1991 | 3211991017 |
| 1990 | Hatch 1 | 6/20/1990 | 3211990013 |
| 1989 | Hatch 1 | 12/17/1988 | 3211988018 |
| 1988 | Hatch 1 | 9/4/1988 | 3211988013 |
| 1987 | Hatch 1 | 7/23/1987 | 3211987011 |
| 1987 | Hatch 1 | 8/3/1987 | 3211987013 |
| 1999 | Hatch 2 | 6/15/1999 | 3661999006 |
| 1999 | Hatch 2 | 6/28/1999 | 3661999007 |
| 1998 | Hatch 2 | 11/20/1997 | 3661997010 |
| 1997 | Hatch 2 | 4/22/1997 | 3661997007 |
| 1995 | Hatch 2 | 4/11/1995 | 3661995001 |
| 1994 | Hatch 2 | 8/30/1994 | 3661994007 |
| 1992 | Hatch 2 | 6/25/1992 | 3661992009 |
| 1991 | Hatch 2 | 2/14/1991 | 3661991004 |
| 1990 | Hatch 2 | 1/12/1990 | 3661990001 |
| 1989 | Hatch 2 | 9/3/1989 | 3661989005 |
| 1988 | Hatch 2 | 3/21/1988 | 3661988008 |
| 1988 | Hatch 2 | 4/17/1988 | 3661988011 |
| 1988 | Hatch 2 | 5/27/1988 | 3661988017 |
| 1988 | Hatch 2 | 8/5/1988 | 3661988020 |
| 1987 | Hatch 2 | 1/26/1987 | 3661987003 |
| 1987 | Hatch 2 | 4/22/1987 | 3661987008 |
| 1987 | Hatch 2 | 7/26/1987 | 3661987006 |
| 1987 | Hatch 2 | 8/3/1987 | 3661987009 |
| 1990 | Hope Creek | 3/19/1990 | 3541990003 |
| 1989 | Hope Creek | 10/15/1988 | 3541988027 |
| 1989 | Hope Creek | 11/1/1988 | 3541988029 |
| 1988 | Hope Creek | 4/30/1988 | 3541988012 |
| 1987 | Hope Creek | 2/24/1987 | 3541987017 |
| 1987 | Hope Creek | 7/30/1987 | 3541987034 |
| 1987 | Hope Creek | 8/16/1987 | 3541987037 |
| 1987 | Hope Creek | 8/29/1987 | 3541987039 |
| 1993 | La Salle 1 | 9/14/1993 | 3731993015 |
| 1992 | La Salle 1 | 3/1/1992 | 3731992003 |
| 2001 | La Salle 2 | 4/6/2001 | 3742001001 |
| 2001 | La Salle 2 | 9/3/2001 | 3742001003 |
| 1995 | La Salle 2 | 10/19/1994 | 3741994008 |
| 1995 | La Salle 2 | 12/14/1994 | 3741994010 |
| 1995 | La Salle 2 | 1/12/1995 | 3741995001 |
| 1992 | La Salle 2 | 8/27/1992 | 3741992012 |
| 1999 | Limerick 1 | 4/20/1999 | 3521999003 |
| 1991 | Limerick 1 | 4/12/1991 | 3521991009 |

| FY | Plant | Date | LER |
|---|---|---|---|
| 1987 | Limerick 1 | 9/19/1987 | 3521987048 |
| 1995 | Limerick 2 | 10/19/1994 | 3531994010 |
| 1995 | Limerick 2 | 8/8/1995 | 3531995008 |
| 1995 | Limerick 2 | 8/20/1995 | 3531995010 |
| 1990 | Limerick 2 | 9/10/1990 | 3531990015 |
| 1991 | Monticello | 8/25/1991 | 2631991019 |
| 1987 | Monticello | 4/3/1987 | 2631987009 |
| 2000 | Nine Mile Pt. 2 | 3/3/2000 | 4102000002 |
| 1999 | Nine Mile Pt. 2 | 4/24/1999 | 4101999005 |
| 1999 | Nine Mile Pt. 2 | 6/24/1999 | 4101999010 |
| 1992 | Nine Mile Pt. 2 | 12/12/1991 | 4101991023 |
| 1991 | Nine Mile Pt. 2 | 8/13/1991 | 4101991017 |
| 1989 | Nine Mile Pt. 2 | 4/13/1989 | 4101989014 |
| 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 |
| 1992 | Peach Bottom 2 | 7/4/1992 | 2771992010 |
| 1992 | Peach Bottom 2 | 7/17/1992 | 2771992012 |
| 1990 | Peach Bottom 2 | 12/20/1989 | 2771989033 |
| 1993 | Peach Bottom 3 | 10/15/1992 | 2781992008 |
| 1990 | Peach Bottom 3 | 1/28/1990 | 2781990002 |
| 1990 | Peach Bottom 3 | 7/27/1990 | 2781990008 |
| 2001 | Perry | 4/29/2001 | 4402001001 |
| 2001 | Perry | 7/11/2001 | 4402001003 |
| 1998 | Perry | 7/1/1998 | 4401998002 |
| 1997 | Perry | 1/7/1997 | 4401997001 |
| 1995 | Perry | 8/31/1995 | 4401995005 |
| 1995 | Perry | 9/11/1995 | 4401995008 |
| 1993 | Perry | 3/26/1993 | 4401993010 |
| 1992 | Perry | 9/10/1992 | 4401992017 |
| 1990 | Perry | 1/7/1990 | 4401990002 |
| 1988 | Perry | 10/27/1987 | 4401987072 |
| 1988 | Perry | 4/27/1988 | 4401988012 |
| 1988 | Perry | 6/8/1988 | 4401988023 |
| 1987 | Perry | 3/2/1987 | 4401987012 |
| 1987 | Perry | 6/17/1987 | 4401987042 |
| 1987 | Perry | 9/9/1987 | 4401987064 |
| 2001 | Pilgrim | 4/21/2001 | 2932001003 |
| 1993 | Pilgrim | 3/13/1993 | 2931993004 |
| 1993 | Pilgrim | 9/10/1993 | 2931993022 |
| 1992 | Pilgrim | 10/30/1991 | 2931991025 |
| 1990 | Pilgrim | 9/2/1990 | 2931990013 |
| 1990 | Quad Cities 1 | 3/10/1990 | 2541990004 |
| 2001 | Quad Cities 2 | 8/2/2001 | 2652001001 |
| 1988 | Quad Cities 2 | 10/19/1987 | 2651987013 |
| 1987 | Quad Cities 2 | 8/1/1987 | 2651987009 |
| 2002 | River Bend | 9/18/2002 | 4582002001 |
| 1994 | River Bend | 9/8/1994 | 4581994023 |
| 1989 | River Bend | 2/25/1989 | 4581989008 |
| 1988 | River Bend | 8/25/1988 | 4581988018 |
| 1988 | River Bend | 9/6/1988 | 4581988021 |
| 1999 | Susquehanna 1 | 7/1/1999 | 3871999003 |
| 1991 | Susquehanna 1 | 7/31/1991 | 3871991008 |

| FY | Plant | Date | LER |
|---|---|---|---|
| 1987 | Susquehanna 1 | 4/2/1987 | 3871987013 |
| 1996 | Susquehanna 2 | 7/14/1996 | 3881996004 |
| 1990 | Susquehanna 2 | 5/28/1990 | 3881990005 |
| 1987 | Susquehanna 2 | 4/16/1987 | 3881987006 |
| 1998 | Vermont Yankee | 6/9/1998 | 2711998016 |
| 1991 | Vermont Yankee | 4/23/1991 | 2711991009 |

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

| FY | Plant | Date | LER |
|---|---|---|---|
| 1996 | Browns Ferry 2 | 5/10/1996 | 2601996005 |
| 1988 | Brunswick 1 | 9/15/1988 | 3251988020 |
| 1987 | Brunswick 2 | 1/5/1987 | 3241987001 |
| 1990 | Brunswick 2 | 8/19/1990 | 3241990009 |
| 1988 | Columbia Nuclear 2 | 2/4/1988 | 3971988003 |
| 1999 | Cooper | 12/17/1998 | 2981998012 |
| 1995 | Fitzpatrick | 10/30/1994 | 3331994007 |
| 1990 | Grand Gulf | 11/7/1989 | 4161989016 |
| 1991 | Hatch 1 | 1/18/1991 | 3211991001 |
| 1989 | Hatch 1 | 12/17/1988 | 3211988018 |
| 1987 | Hatch 1 | 7/23/1987 | 3211987011 |
| 1988 | Hatch 2 | 5/27/1988 | 3661988017 |
| 1998 | Hope Creek | 12/5/1997 | 3541997032 |
| 1997 | Hope Creek | 12/28/1996 | 3541996029 |
| 1993 | La Salle 1 | 1/29/1993 | 3731993003 |
| 1990 | La Salle 1 | 6/18/1990 | 3731990007 |
| 1991 | La Salle 1 | 7/29/1991 | 3731991012 |
| 1992 | La Salle 1 | 4/6/1992 | 3731992005 |
| 1992 | La Salle 1 | 10/23/1991 | 3731991017 |
| 1995 | La Salle 1 | 11/14/1994 | 3731994013 |
| 1992 | La Salle 2 | 8/27/1992 | 3741992012 |
| 1994 | La Salle 2 | 2/21/1994 | 3741994002 |
| 1999 | Nine Mile Pt. 2 | 4/24/1999 | 4101999005 |
| 2000 | Nine Mile Pt. 2 | 3/3/2000 | 4102000002 |
| 1987 | Perry | 3/2/1987 | 4401987012 |
| 1994 | Pilgrim | 8/3/1994 | 2931994004 |
| 1990 | Pilgrim | 9/2/1990 | 2931990013 |
| 1992 | Pilgrim | 10/30/1991 | 2931991025 |
| 1996 | Pilgrim | 4/3/1996 | 2931996003 |
| 1988 | Quad Cities 1 | 12/23/1987 | 2541987032 |
| 1987 | Quad Cities 2 | 8/1/1987 | 2651987009 |
| 1992 | Quad Cities 2 | 5/12/1992 | 2651992015 |
| 1994 | River Bend | 9/8/1994 | 4581994023 |
| 1991 | Vermont Yankee | 4/23/1991 | 2711991009 |
| 1988 | Vermont Yankee | 11/14/1987 | 2711987018 |
| 1995 | Vermont Yankee | 5/2/1995 | 2711995006 |