Reliability Study Update

High Pressure Safety Injection

1987–2004

This report presents a performance evaluation of the High Pressure Safety Injection (HPI) system at 69 operating United States commercial pressurized-water reactors (PWRs). The evaluation is based on the operating experience from 1987 through 2004, from 74 PWRs, as reported in Licensee Event Reports (LERs). This is the latest update to NUREG/CR-5500 Volume 9, updating data, availability and reliability estimates, trends, and figures.

This report calculates two basic models for the HPI system. The first model, failure to start (FTS), models the HPI system start and injection. The second model, 8-hour mission, models the HPI system start, injection, and pump run for 8 hours. See the HPI Fault Tree Description document for more detail.

The HPI system has been categorized into six groups. The groupings are based on the number of injection points (as measured by the number of steam generators (SGs) or the number of cold legs), the number of high-head safety injection (HHSI) pumps, and the number of intermediate-head safety injection pumps (IHSI). Table 1 summarizes those groups. Information that is more detailed, including segment counts and success criteria, can be found in Section 5.

Table 1. HPI design class summary.

	Number of Plants	
HPI Design Class	In Study	Operating
1 - (2 HHSI or 2 IHSI; 2 SGs)	20	19
2 - (3 HHSI or 3 IHSI; 2 SGs)	8	8
3 - (2 HHSI or 2 IHSI; 3 SGs)	12	11
4 - (4 IHSI; 3 SGs)	2	2
5 - (3 IHSI; 4 SGs)	4	4
6 - (2 HHSI, 2 IHSI; 4 SGs)	28	25

1 LATEST VALUES AND TRENDS

1.1 Industry-Wide Unavailability and Unreliability

The industry-wide unavailability and unreliability of the HPI system have been estimated from operating experience. A failure to start (FTS) unavailability and an 8-hour mission unreliability were evaluated, see Table 2. The estimates are based on failures that occurred during safety injection demands.

Table 2. Industry-wide values.

Model	Lower (5%)	Mean	Upper (95%)
Failure-to-Start (Unavailability)	1.95E-05	1.73E-04	5.48E-04
8-hour Mission (Unreliability)	4.44E-05	1.09E-03	4.05E-03

1.2 Fail to Start Model Results

The unavailability of the HPI system for each design class has been calculated from the operating experience for the failure to start (FTS) mission. The waterfall plot is shown in Figure 1 and the data table is shown in Table 3. Due to the sparseness of the data, between-plant variation of failure probabilities is not meaningful and the plant waterfall plot is not shown.

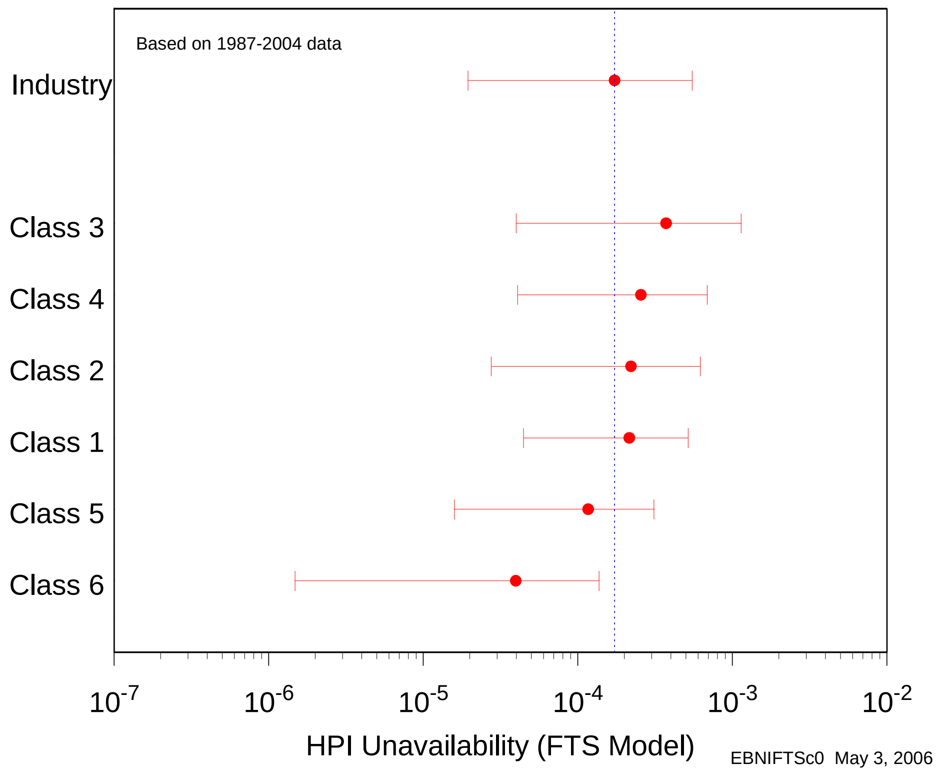

Figure 1. HPI design class unavailability (FTS model).

Table 3. HPI unavailability (start only model) by design class.

Design Class	Lower (5%)	Mean	Upper (95%)
Industry	1.95E-05	1.73E-04	5.48E-04
Class 3	3.99E-05	3.73E-04	1.14E-03
Class 4	4.07E-05	2.56E-04	6.87E-04
Class 2	2.75E-05	2.21E-04	6.20E-04
Class 1	4.45E-05	2.15E-04	5.19E-04
Class 5	1.59E-05	1.17E-04	3.11E-04
Class 6	1.48E-06	3.97E-05	1.37E-04

Figure 2 displays the trend by fiscal year of the HPI system FTS unavailability calculated from the 1987–2004 experience. Table 8 shows the data points for Figure 2. The trend is not considered statistically significant.[1]

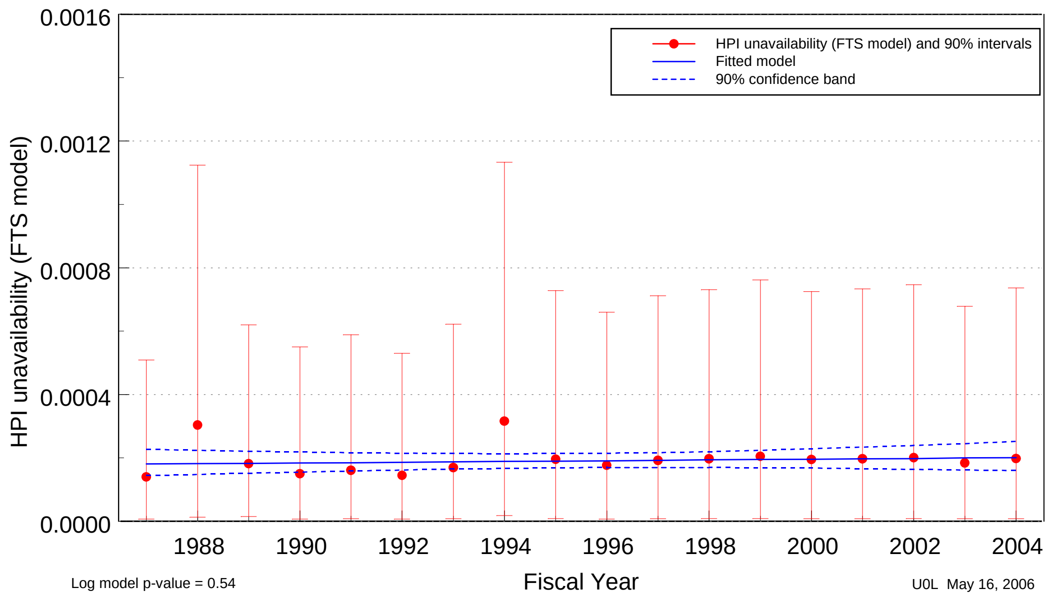

Figure 2. Trend of HPI system unavailability (FTS model), as a function of fiscal year.

1.3 Fail to Operate for 8-Hour Model

The unreliability of the HPI system for each design class has been calculated from the operating experience for the 8-hour mission. The waterfall plot is shown in Figure 3 and the data table is shown in Table 4. Due to the sparseness of the data, between-plant variation of failure rates is not meaningful and the plant waterfall plot is not shown.

[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).

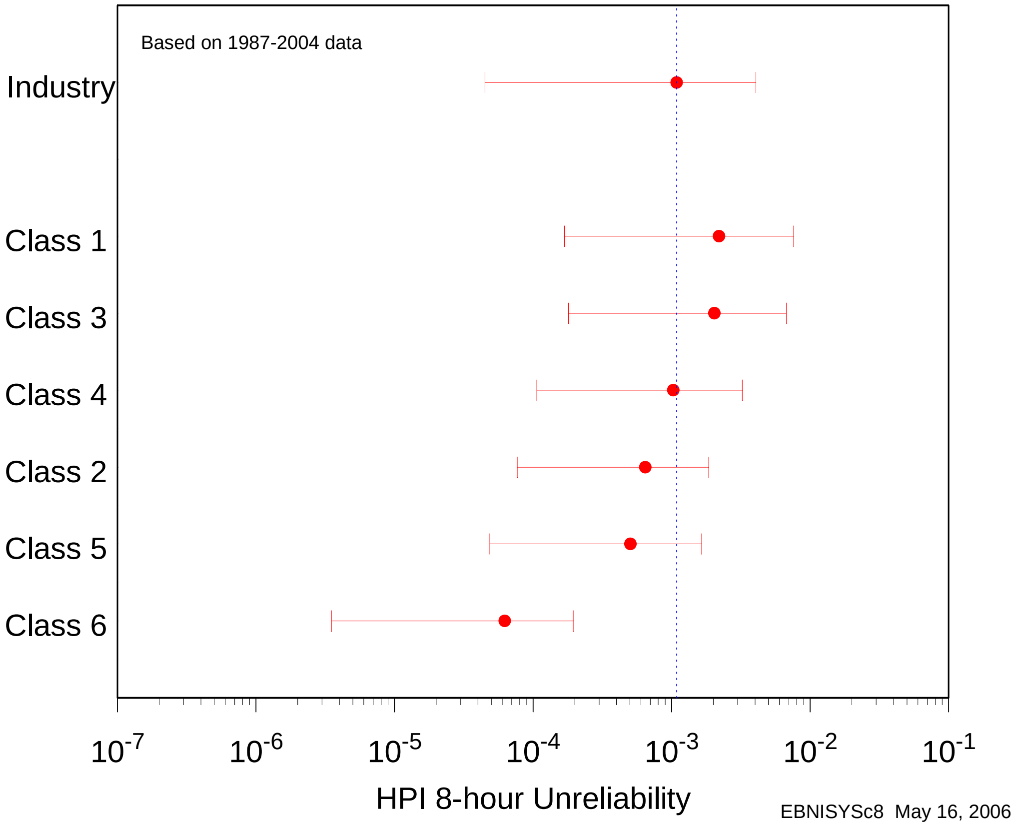

Figure 3. HPI design class unreliability (8-hour model).

Table 4. HPI unreliability (8-hour model) by design class.

Design Class	Lower (5%)	Mean	Upper (95%)
Industry	4.45E-05	1.09E-03	4.05E-03
Class 1	1.68E-04	2.20E-03	7.60E-03
Class 3	1.80E-04	2.04E-03	6.74E-03
Class 4	1.06E-04	1.03E-03	3.23E-03
Class 2	7.69E-05	6.46E-04	1.85E-03
Class 5	4.88E-05	5.05E-04	1.65E-03
Class 6	3.51E-06	6.24E-05	1.95E-04

Normally, there would be a system unreliability trend in this section. However, the HPI unplanned demand data set for the 8-hour mission time is extremely sparse. In fact, no failures to run of HPI pumps during safety injection demands (the highest contribution to system failure for the 8-h unreliability is motor-driven pump failure-to-run, Section 3.1.2) were observed during the 1987–2004 period. Therefore, with no observed failures to run, trending the estimated industry average fail to run unreliability is not meaningful. The current estimated industry average unreliability is 1.09 E-03.

2 DATA TRENDS

2.1 Unplanned Demand Trend

Trends were identified in the frequency of HPI unplanned safety injection (SI) demands (Figure 4). When modeled as a function of fiscal year, the unplanned SI demand frequency exhibited an extremely statistically significant decreasing trend. Table 9 shows the LERs that are represented in the figure.

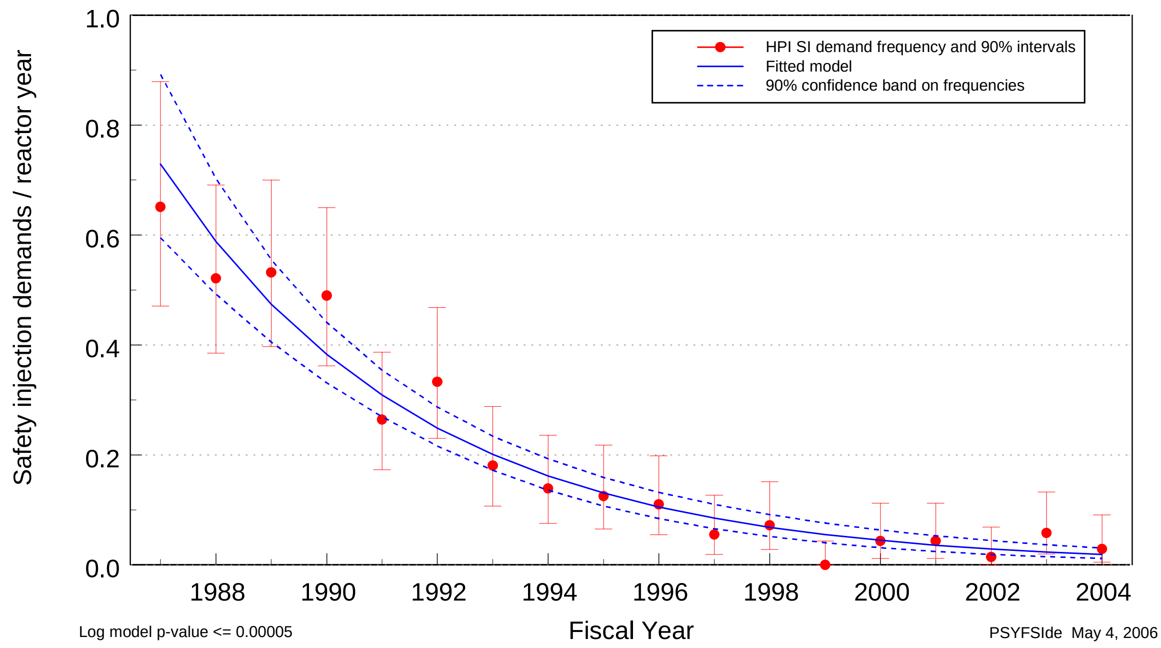

Figure 4. Frequency (events per reactor year) of unplanned SI demands, as a function of fiscal year.

2.2 Failure Trend

The frequency of all failures (unplanned SI 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 5. Trends for HPI 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.

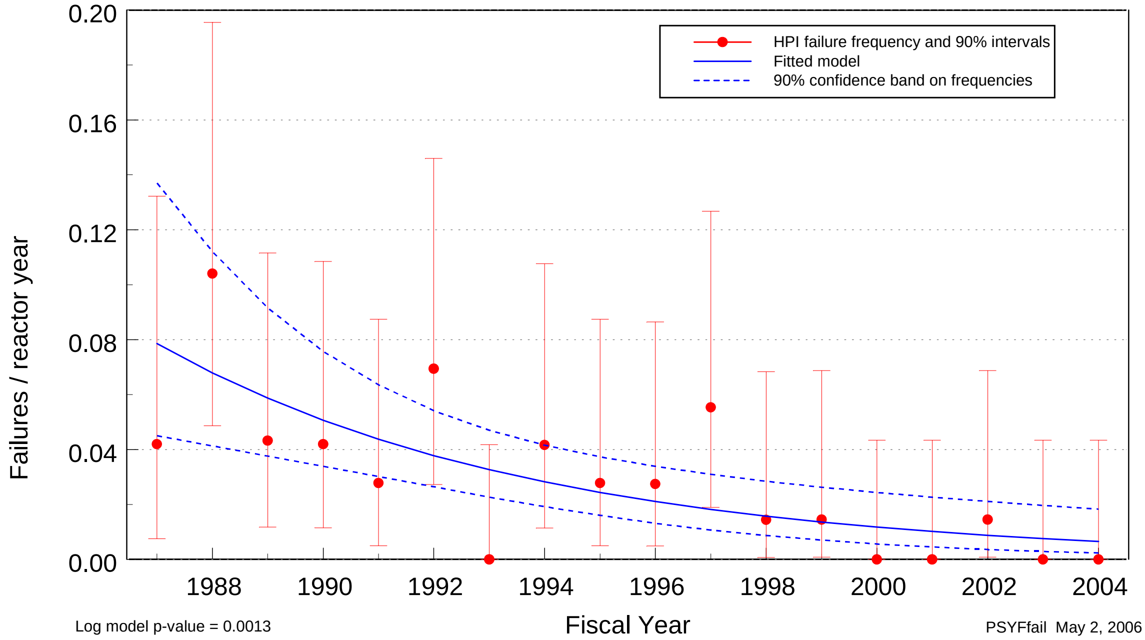

Figure 5. Frequency (events per reactor year) of failures, as a function of fiscal year.

3 MAJOR CONTRIBUTORS TO SYSTEM UNRELIABILITY AND UNAVAILABILITY

3.1 Segment Failure Contribution to Design Class Models

The segment failure importance has been determined by calculating the Fussell-Veseley importance of groups of basic events for each design class fault tree model.

3.1.1 Fail to Start Model

Figure 6 through Figure 11 show the distributions of segment importances for the FTS model. The top segment importance varies between the Design Classes. Design Classes 1 and 5 have the common-cause pump fail-to-start as the top segment importance. Design Classes 2, 3, and 4 have the common-cause injection header MOVs as the top segment importance. Design Class 6 shows the actuation channel as the top segment importance (Design Classes 3 and 6 have a running charging pump and do not require any pump start for this model, except on failure of the running pump).

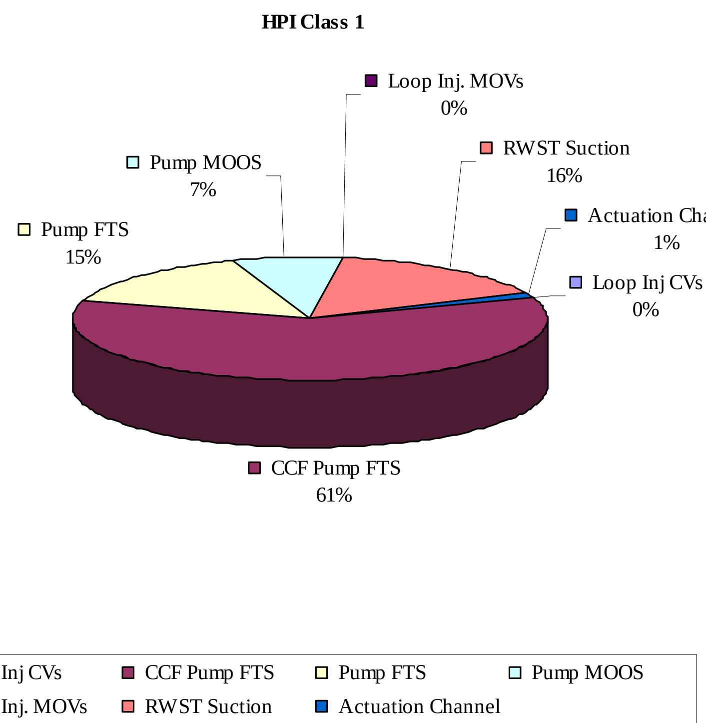

Figure 6. Segment importance distribution, FTS model Design Class 1.

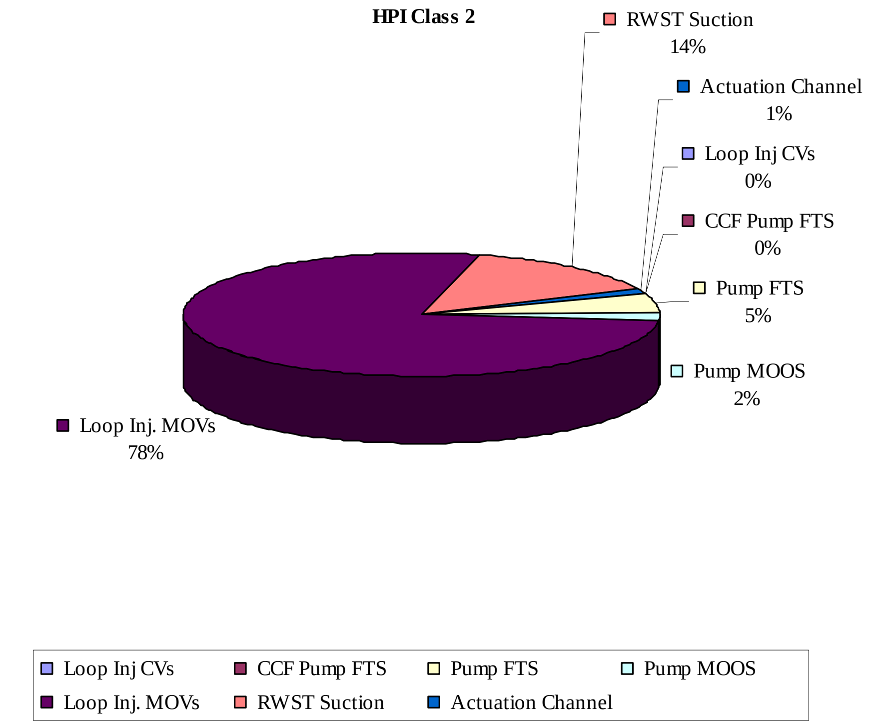

Figure 7. Segment importance distribution, FTS model Design Class 2.

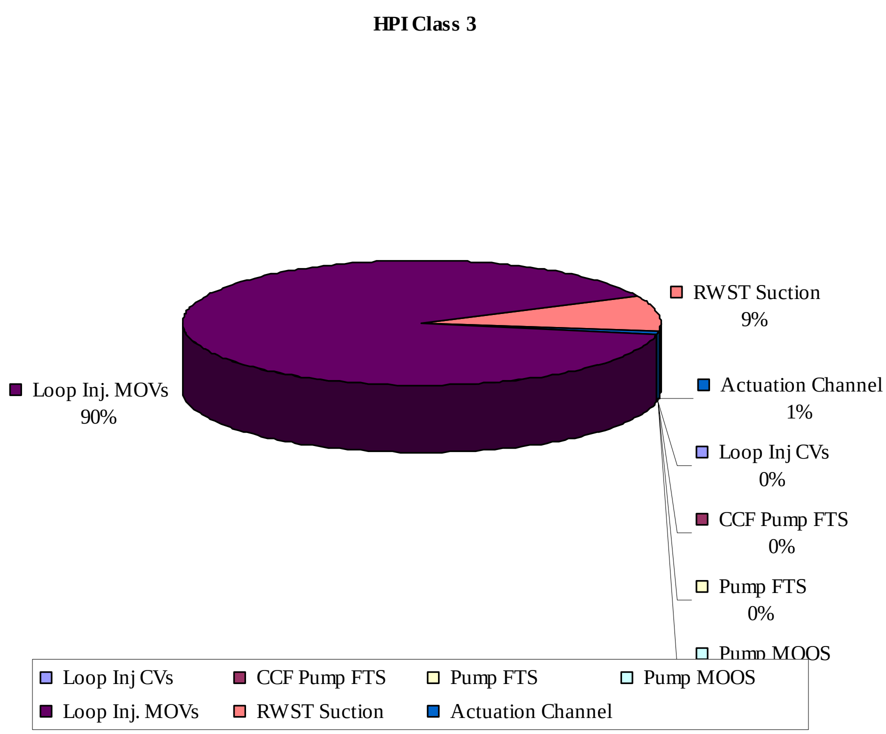

Figure 8. Segment importance distribution, FTS model Design Class 3.

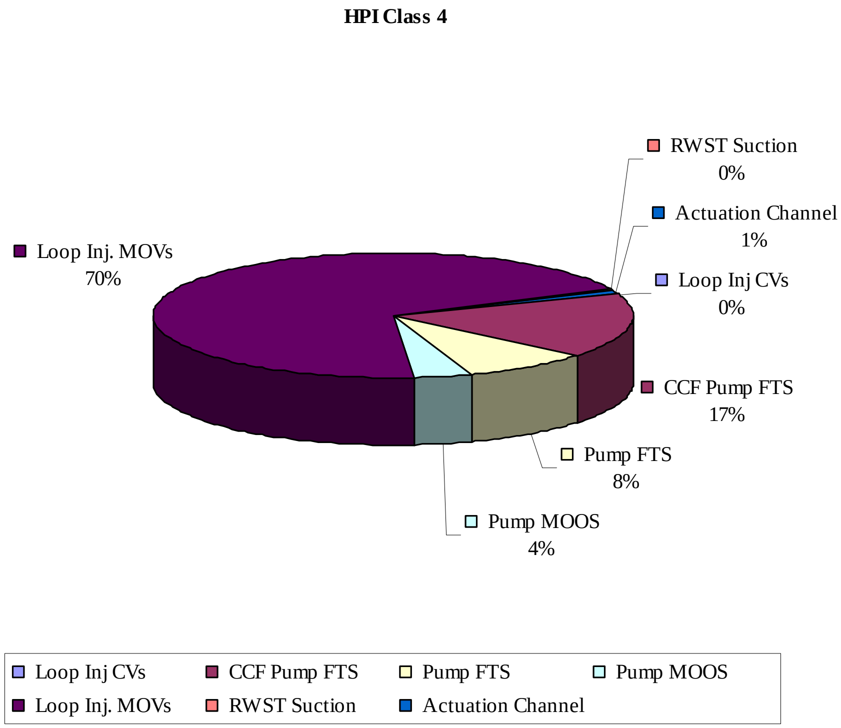

Figure 9. Segment importance distribution, FTS model Design Class 4.

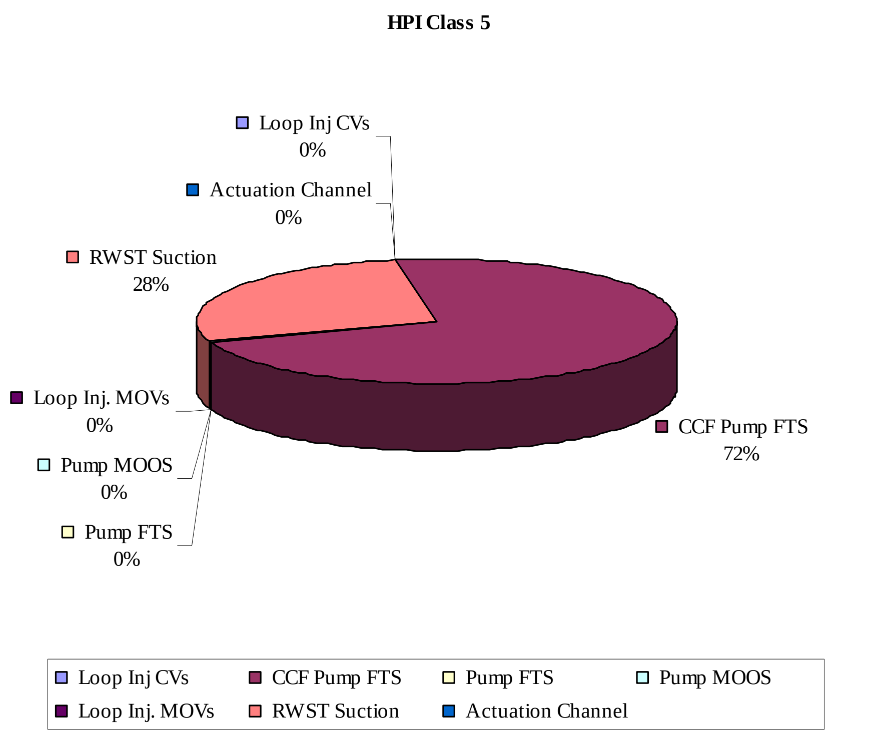

Figure 10. Segment importance distribution, FTS model Design Class 5.

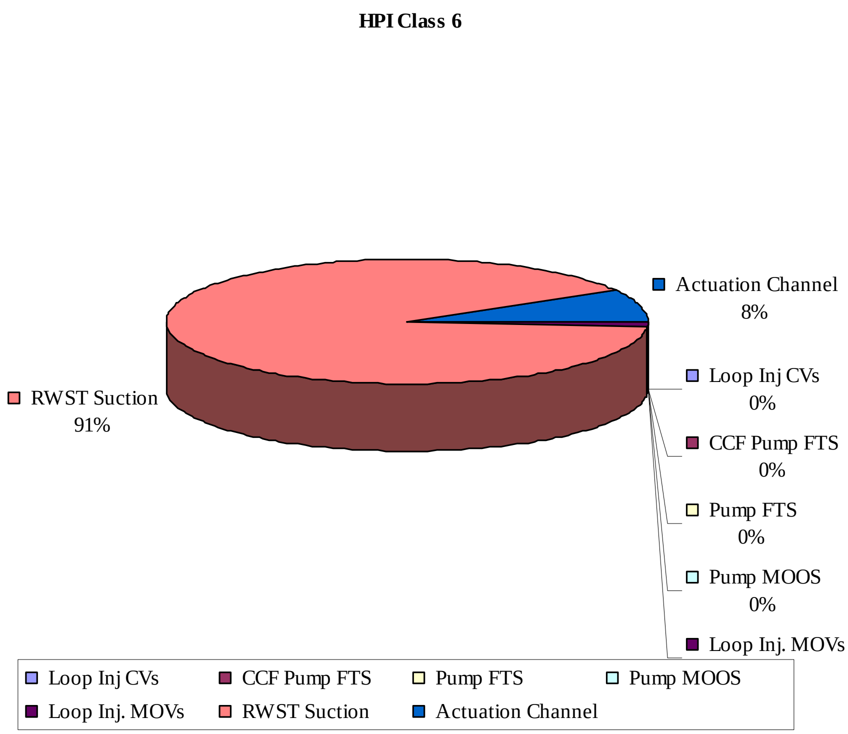

Figure 11. Segment importance distribution, FTS model Design Class 6.

3.1.2 Fail to Operate for 8–hour Model

Figure 12 through Figure 17 show the distributions of segment importances for the 8-hour model. The pump fail-to-run and common-cause fail to run segment importances are the highest contributors for each of the design classes except Design Class 6. Design Class 6 (which has the lowest unreliability) shows the RWST suction failure as the most important segment because other, more likely, failures of pumps and valves do not apply since there is a running pump.

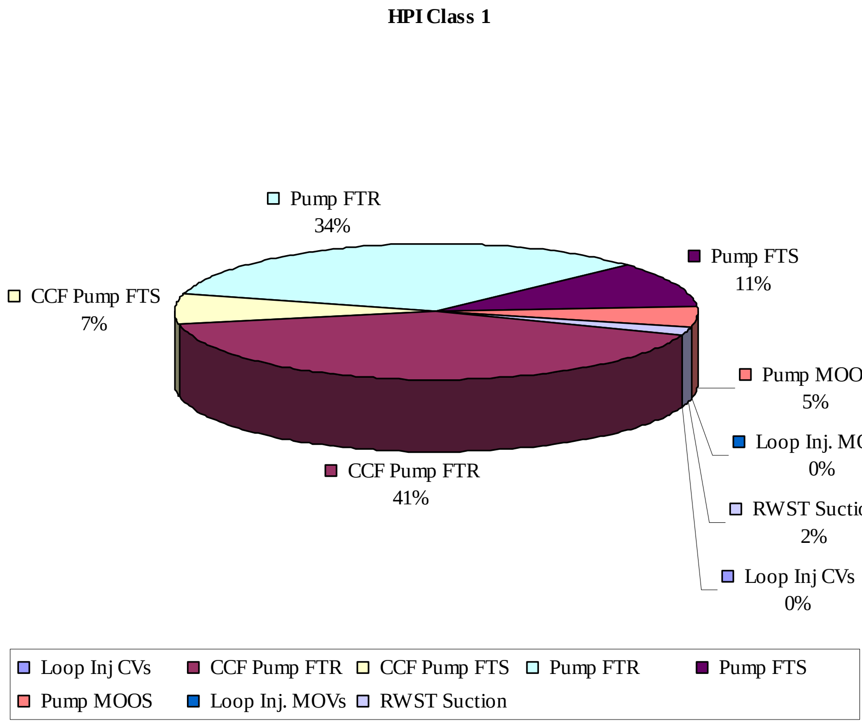

Figure 12. Segment importance distribution, 8-hour mission Design Class 1.

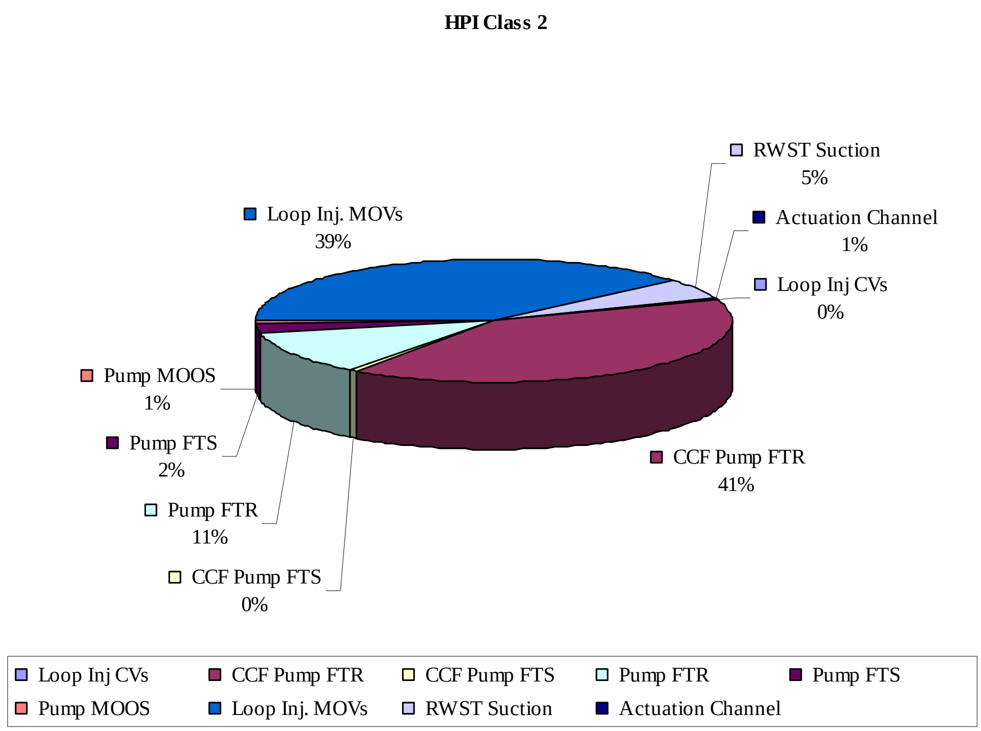

Figure 13. Segment importance distribution, 8-hour mission Design Class 2.

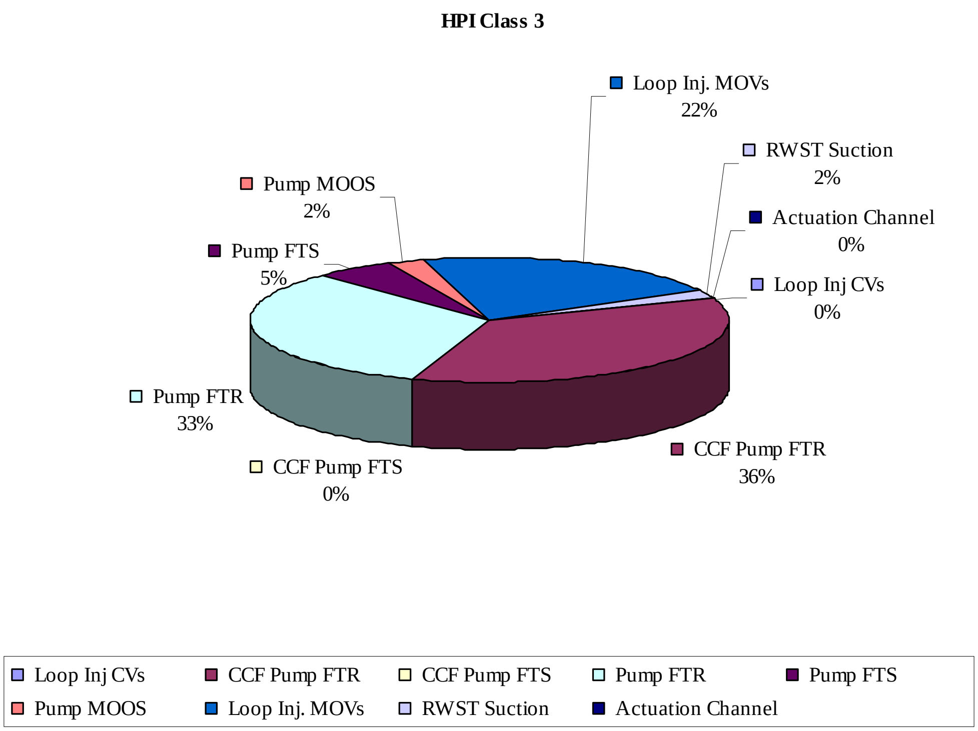

Figure 14. Segment importance distribution, 8-hour mission Design Class 3.

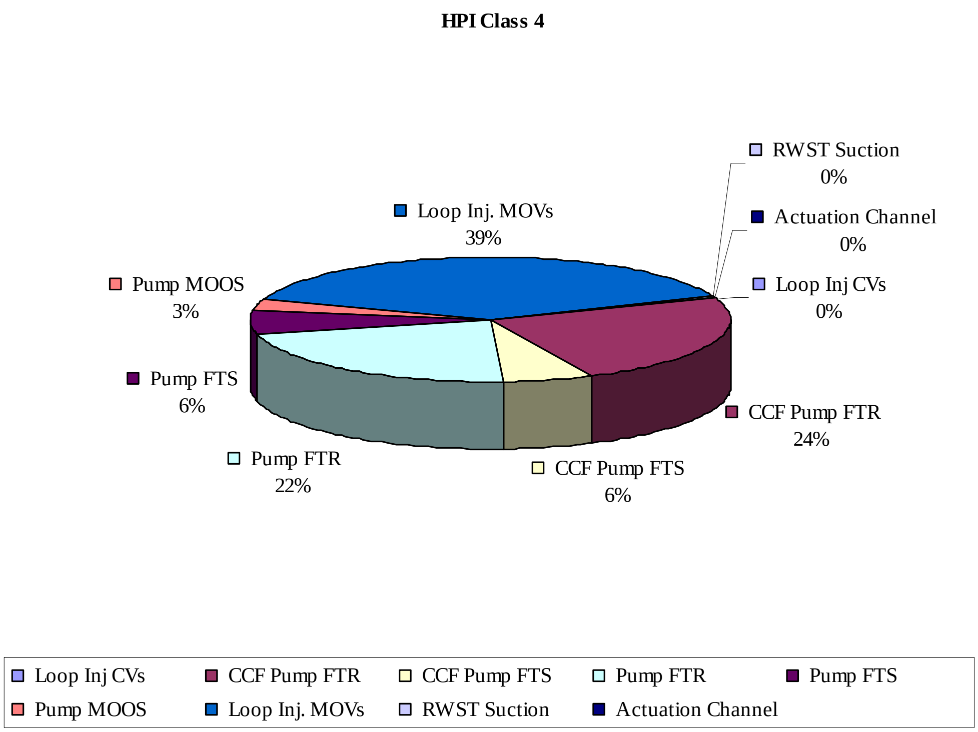

Figure 15. Segment importance distribution, 8-hour mission Design Class 4.

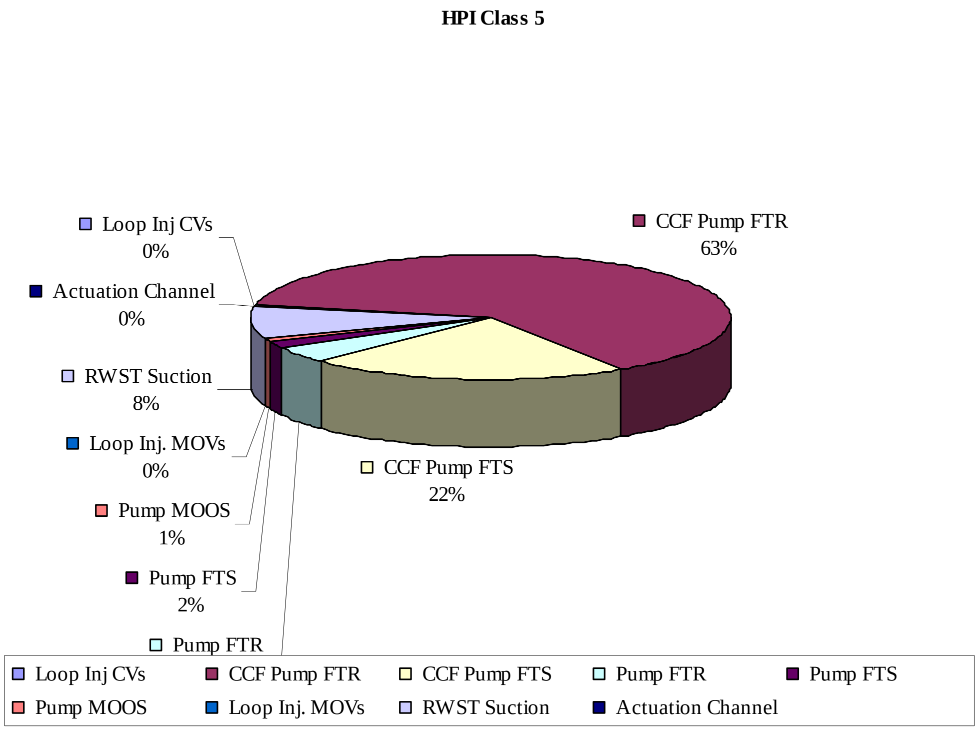

Figure 16. Segment importance distribution, 8-hour mission Design Class 5.

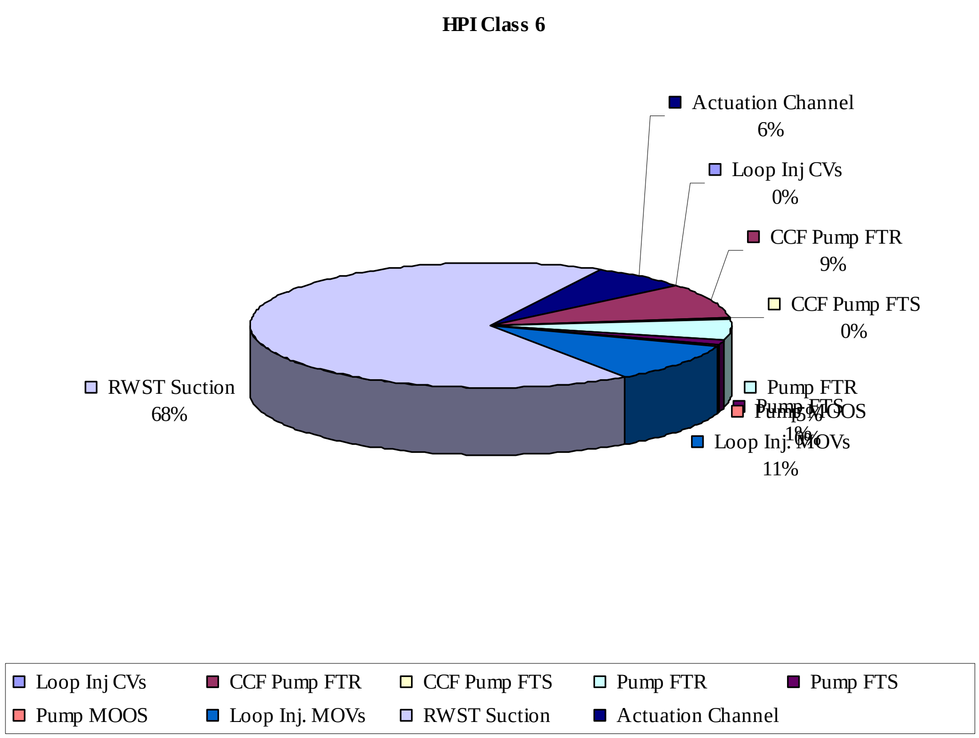

Figure 17. Segment importance distribution, 8-hour mission Design Class 6.

3.2 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.

3.2.1 Leading Segment Failures

The pump (79%) and the actuation circuit (9%) were the leading segment failures identified in the database. See Table 5. Table 6 shows the description of the discovery method and whether that discovery method is used in the calculations.

3.2.2 Leading Discovery Methods

Periodic surveillance (27%) and Non-SI demand (27%) were the leading methods of discovery. See Table 5.

3.2.3 Leading Causes of Failure

Fifty-two percent of the failures of the HPI system observed in the experience were attributed to hardware-related problems. Personnel errors led to 24% of all HPI segment failures. However, half of those failures were immediately identified and either recovered or were recoverable, meaning that the failures were of the nature where plant personnel were able to respond to the failures immediately after they occurred. See Table 7.

Table 5. Comparison of failed segment with the method of discovery.[2]

Segment	SI Demand	non-SI Demand	Alarm/ indicator	Inspection/ review	Other (not counted) surveillance test	Periodic surveillance	Total	Percent
Actuation Circuit	3						3	9%
Motor		1					1	3%
Other						1	1	3%
Pump	1	8	7	1	1	8	26	79%
Valve	1				1		2	6%
Total	5	9	7	1	2	9	33	100%
Percent	15%	27%	21%	3%	6%	27%	100%	

Table 6. Discovery method description.

Discovery Method	Description	Used in the Failure Calculations
SI Demand	The failure was discovered during a safety injection demand.	✓
Non-SI Demand	The failure was discovered during any other type of demand than SI.	
Periodic surveillance on subject system	Normally scheduled surveillance. These surveillances are to satisfy scheduled Technical Specification requirements.	✓
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.	
Other (not counted) surveillance test	All others discovered by testing.	

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

Table 7. Comparison of failed segment and failure cause.[3]

Segment	Design	Gas Binding	Hardware	Maintenance	Personnel	Procedure	Total	Percent
Actuation Circuit	1		1		1		3	9%
Motor			1				1	3%
Other			1				1	3%
Pump	1	4	13	1	6	1	26	79%
Valve			1		1		2	6%
Total	2	4	17	1	8	1	33	100%
Percent	6%	12%	52%	3%	24%	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.
- Gas Binding–The failure was the result of gases coming out of solution in the pump suction. This cause is used only in the HPI study.
- Maintenance–The failure was the result of improper maintenance.

[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.

4 DATA TABLES

4.1 Data Tables for Unreliability and Unavailability Trends

Table 8. Plot data table for HPI system unavailability, FTS model. Figure 2

	Plot Trend Error Bar Points			Regression Curve Data Points		
Fiscal Year	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1987	7.27E-03	6.12E-02	1.56E-01	6.91E-02	8.08E-02	9.44E-02
1988	1.80E-02	9.68E-02	2.21E-01	6.98E-02	8.05E-02	9.29E-02
1989	1.61E-02	1.18E-01	2.86E-01	7.04E-02	8.02E-02	9.13E-02
1990	6.54E-03	7.32E-02	1.96E-01	7.10E-02	7.99E-02	8.99E-02
1991	6.63E-03	6.98E-02	1.85E-01	7.15E-02	7.96E-02	8.86E-02
1992	6.73E-03	6.85E-02	1.80E-01	7.19E-02	7.93E-02	8.74E-02
1993	1.12E-02	8.09E-02	1.98E-01	7.22E-02	7.90E-02	8.64E-02
1994	1.07E-02	8.61E-02	2.15E-01	7.23E-02	7.87E-02	8.56E-02
1995	8.10E-03	6.97E-02	1.78E-01	7.22E-02	7.84E-02	8.50E-02
1996	5.90E-03	8.04E-02	2.21E-01	7.20E-02	7.81E-02	8.47E-02
1997	1.06E-02	8.60E-02	2.15E-01	7.15E-02	7.78E-02	8.46E-02
1998	6.50E-03	7.31E-02	1.95E-01	7.08E-02	7.75E-02	8.48E-02
1999	5.97E-03	7.85E-02	2.15E-01	7.00E-02	7.72E-02	8.51E-02
2000	5.90E-03	8.05E-02	2.21E-01	6.90E-02	7.69E-02	8.56E-02
2001	6.53E-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	6.70E-02	7.63E-02	8.69E-02
2003	1.16E-02	7.54E-02	1.81E-01	6.59E-02	7.60E-02	8.77E-02
2004	5.87E-03	8.04E-02	2.21E-01	6.48E-02	7.57E-02	8.85E-02

4.2 Data Tables for Failure and Demand Trends

Table 9. LER listing for demand trend figure. Figure 4

FY	Plant Name	LER	Event Date
1989	Arkansas 1	3131989002	1/20/1989
1994	Arkansas 1	3131994002	4/11/1994
1996	Arkansas 1	3131996005	5/19/1996
1988	Arkansas 2	3681988003	3/10/1988
1988	Arkansas 2	3681988007	4/23/1988
1988	Arkansas 2	3681988011	8/1/1988
1989	Arkansas 2	3681988020	12/1/1988
1989	Arkansas 2	3681989012	6/26/1989
1990	Arkansas 2	3681989018	10/17/1989
1992	Arkansas 2	3681992006	9/9/1992
1988	Beaver Valley 1	3341988007	6/7/1988
1989	Beaver Valley 1	3341989007	5/18/1989
1990	Beaver Valley 1	3341989015	12/13/1989
1995	Beaver Valley 1	3341995003	2/19/1995
2003	Beaver Valley 1	3342003001	2/24/2003
1987	Beaver Valley 2	4121987002	6/29/1987
1987	Beaver Valley 2	4121987011	7/30/1987
1987	Beaver Valley 2	4121987024	9/29/1987
1988	Beaver Valley 2	4121988004	2/1/1988
1989	Beaver Valley 2	4121989005	3/22/1989
1992	Beaver Valley 2	4121992006	5/1/1992
1993	Beaver Valley 2	4121993002	1/30/1993
1994	Beaver Valley 2	4121994004	3/15/1994
1988	Braidwood 1	4561987062	12/11/1987
1988	Braidwood 1	4561988002	1/25/1988
1989	Braidwood 1	4561989002	4/16/1989
1990	Braidwood 1	4561989014	10/30/1989
1990	Braidwood 1	4561990018	9/29/1990
1993	Braidwood 1	4561992013	10/23/1992
1990	Braidwood 2	4571990002	3/18/1990
1990	Braidwood 2	4571990003	4/5/1990
1987	Byron 1	4541987004	2/25/1987
1987	Byron 1	4541987009	4/8/1987
1987	Byron 1	4541987019	8/12/1987
1992	Byron 1	4541991004	10/16/1991
1987	Byron 2	4551987016	8/31/1987
1989	Byron 2	4551989001	2/11/1989
1990	Byron 2	4551990001	1/18/1990
1990	Byron 2	4551990006	9/3/1990
1993	Byron 2	4551993004	9/5/1993
1988	Callaway	4831988004	2/13/1988
1989	Callaway	4831989005	5/18/1989
2004	Callaway	4832004004	2/11/2004
1988	Calvert Cliffs 1	3171988002	5/2/1988
1989	Calvert Cliffs 1	3171989003	3/19/1989
1989	Calvert Cliffs 1	3171989004	3/20/1989
1990	Calvert Cliffs 1	3171990003	3/8/1990
1990	Calvert Cliffs 1	3171990023	8/2/1990
1995	Calvert Cliffs 1	3171997005	5/27/1995
1991	Calvert Cliffs 2	3181991002	3/27/1991
2004	Calvert Cliffs 2	3182004001	1/23/2004
1988	Catawba 1	4131988007	1/23/1988
1989	Catawba 1	4131989008	3/5/1989
1998	Catawba 1	4131997011	12/30/1997
2001	Catawba 1	4132000006	11/10/2000
1988	Catawba 2	4141988003	2/9/1988
1989	Catawba 2	4141989003	2/21/1989
1989	Catawba 2	4141989004	2/21/1989
1996	Catawba 2	4141996001	2/6/1996
1998	Catawba 2	4141998004	9/6/1998
1990	Comanche Peak 1	4451990004	3/12/1990
1990	Comanche Peak 1	4451990020	7/26/1990
1990	Comanche Peak 1	4451990021	7/30/1990
1991	Comanche Peak 1	4451990037	11/5/1990
1991	Comanche Peak 1	4451991022	9/4/1991
1992	Comanche Peak 1	4451992016	6/23/1992
1993	Comanche Peak 1	4451993003	2/26/1993
1996	Comanche Peak 1	4451996001	1/17/1996
1988	Cook 2	3161987011	10/2/1987
1987	Crystal River 3	3021987011	7/10/1987
1988	Crystal River 3	3021987022	11/6/1987
1988	Crystal River 3	3021987030	11/20/1987
1989	Crystal River 3	3021988021	10/14/1988
1992	Crystal River 3	3021991018	12/8/1991
1993	Crystal River 3	3021993009	9/18/1993
1990	Diablo Canyon 1	2751989009	10/6/1989
1991	Diablo Canyon 1	2751990017	12/24/1990
1991	Diablo Canyon 1	2751991005	3/23/1991
1991	Diablo Canyon 1	2751991009	5/17/1991
1987	Diablo Canyon 2	3231987003	3/21/1987
1987	Diablo Canyon 2	3231987004	4/3/1987
1987	Diablo Canyon 2	3231987016	7/14/1987
1988	Diablo Canyon 2	3231988008	7/17/1988
1992	Diablo Canyon 2	3231991007	10/6/1991
1998	Diablo Canyon 2	3231997005	10/24/1997
1990	Farley 1	3481989006	11/12/1989
1989	Farley 2	3641989005	4/29/1989
1991	Farley 2	3641990004	11/16/1990
1992	Farley 2	3641992003	5/2/1992
1993	Farley 2	3641993001	2/5/1993
1987	Fort Calhoun	2851987006	3/27/1987
1987	Fort Calhoun	2851987012	4/13/1987
1987	Fort Calhoun	2851987011	4/28/1987
1987	Fort Calhoun	2851987015	5/20/1987
1989	Fort Calhoun	2851988038	12/31/1988
1990	Fort Calhoun	2851990008	3/6/1990
1990	Fort Calhoun	2851990011	4/2/1990
1992	Fort Calhoun	2851992023	7/3/1992
1994	Fort Calhoun	2851994001	2/11/1994
1988	Ginna	2441988005	6/1/1988
1989	Ginna	2441989003	5/18/1989
1990	Ginna	2441990006	5/5/1990
1995	Ginna	2441995003	4/7/1995
1998	Ginna	2441997005	10/31/1997
1995	Haddam Neck	2131995016	7/27/1995
1988	Harris	4001987062	11/7/1987
1996	Harris	4001995009	10/5/1995
1996	Harris	4001995011	11/5/1995
1997	Harris	4001997014	5/14/1997
2000	Harris	4002000003	5/4/2000

FY	Plant Name	LER	Event Date
1988	Indian Point 2	2471988001	1/17/1988
1992	Indian Point 2	2471992002	1/27/1992
1997	Indian Point 2	2471997010	5/1/1997
1997	Indian Point 2	2471997009	5/2/1997
2000	Indian Point 2	2472000001	2/15/2000
1987	Indian Point 3	2861987002	2/11/1987
1987	Indian Point 3	2861987004	4/17/1987
1987	Indian Point 3	2861987010	9/3/1987
1989	Indian Point 3	2861989001	2/4/1989
1995	Indian Point 3	2861995009	4/29/1995
1988	Kewaunee	3051988002	3/28/1988
1989	Maine Yankee	3091988011	12/22/1988
1990	Maine Yankee	3091990002	4/14/1990
1992	Maine Yankee	3091992002	2/25/1992
1987	McGuire 1	3691987012	7/9/1987
1987	McGuire 1	3691987017	8/16/1987
1988	McGuire 1	3691988005	3/23/1988
1989	McGuire 1	3691989004	3/7/1989
1991	McGuire 1	3691991001	2/11/1991
1992	McGuire 1	3691991015	10/13/1991
1993	McGuire 2	3701993003	3/22/1993
1994	McGuire 2	3701993008	12/27/1993
1997	McGuire 2	3701997001	5/27/1997
1990	Millstone 2	3361990015	9/19/1990
1994	Millstone 2	3361994010	5/13/1994
2003	Millstone 2	3362003003	3/7/2003
1987	Millstone 3	4231987016	3/25/1987
1988	Millstone 3	4231988001	1/5/1988
1989	Millstone 3	4231989005	2/17/1989
1990	Millstone 3	4231989033	12/5/1989
1990	Millstone 3	4231989034	12/11/1989
1990	Millstone 3	4231990002	1/9/1990
1995	Millstone 3	4231995007	4/16/1995
1987	North Anna 1	3381987017	7/15/1987
1991	North Anna 1	3381991015	7/14/1991
1991	North Anna 1	3381991017	8/8/1991
1988	North Anna 2	3391987013	10/26/1987
1988	North Anna 2	3391988002	7/26/1988
1991	North Anna 2	3391991009	9/20/1991
1992	North Anna 2	3391992007	8/6/1992
1989	Oconee 1	2691989001	1/2/1989
1989	Oconee 1	2691989002	1/3/1989
1990	Oconee 1	2691990007	5/16/1990
1991	Oconee 1	2691991006	5/16/1991
1994	Oconee 1	2691993010	11/3/1993
1994	Oconee 1	2691994002	2/26/1994
1987	Oconee 2	2701987001	1/18/1987
1987	Oconee 2	2701987002	3/26/1987
1989	Oconee 2	2701989002	2/3/1989
1989	Oconee 2	2701989003	2/5/1989
1993	Oconee 2	2701992004	10/19/1992
1994	Oconee 2	2701993007	10/24/1993
1994	Oconee 2	2701994002	4/6/1994
1995	Oconee 2	2701995002	4/14/1995
1997	Oconee 2	2701997002	7/6/1997
1989	Oconee 3	2871989002	3/6/1989
1989	Oconee 3	2871989004	8/18/1989
1990	Oconee 3	2871989005	11/14/1989
1990	Oconee 3	2871990002	3/7/1990
1991	Oconee 3	2871990003	11/13/1990
1991	Oconee 3	2871991007	7/3/1991

FY	Plant Name	LER	Event Date
1990	Palisades	2551989025	11/21/1989
1995	Palisades	2551995001	3/2/1995
1995	Palisades	2551995005	7/21/1995
1992	Palo Verde 1	5281991010	10/27/1991
1992	Palo Verde 1	5281992007	5/6/1992
1987	Palo Verde 2	5291987010	6/4/1987
1988	Palo Verde 2	5291988005	2/21/1988
1989	Palo Verde 2	5291989003	2/16/1989
1989	Palo Verde 2	5291989009	7/12/1989
1992	Palo Verde 2	5291991008	12/23/1991
1993	Palo Verde 2	5291992006	11/13/1992
1993	Palo Verde 2	5291993001	3/14/1993
1997	Palo Verde 2	5291997005	9/23/1997
2003	Palo Verde 2	5292003001	7/29/2003
1989	Palo Verde 3	5301989001	3/3/1989
1993	Palo Verde 3	5301993001	2/4/1993
1988	Point Beach 1	2661987005	11/21/1987
1991	Point Beach 1	2661991008	6/29/1991
1996	Point Beach 1	2661996001	4/5/1996
1999	Point Beach 1	2661999005	5/14/1999
1988	Point Beach 2	3011988001	4/7/1988
1990	Point Beach 2	3011989007	10/27/1989
2003	Point Beach 2	3012003005	7/11/2003
1987	Prairie Island 1	2821987004	3/30/1987
2002	Prairie Island 2	3062002901	2/26/2002
1988	Robinson 2	2611988005	2/13/1988
1989	Robinson 2	2611988026	11/14/1988
1989	Robinson 2	2611989004	2/27/1989
1992	Robinson 2	2611992014	7/9/1992
1992	Robinson 2	2611992017	8/22/1992
1989	Salem 1	2721989024	6/9/1989
1991	Salem 1	2721991027	8/15/1991
1994	Salem 1	2721994007	4/7/1994
1988	Salem 2	3111988014	6/22/1988
1989	Salem 2	3111989005	3/12/1989
1990	Salem 2	3111990017	5/1/1990
1990	Salem 2	3111990037	9/22/1990
1991	Salem 2	3111991012	8/26/1991
1993	Salem 2	3111993006	4/15/1993
2002	Salem 2	3112001008	12/31/2001
1991	San Onofre 2	3611990014	11/20/1990
1987	San Onofre 3	3621987011	6/21/1987
1988	San Onofre 3	3621988002	2/19/1988
1989	San Onofre 3	3621989001	1/6/1989
1991	Seabrook	4431991012	9/27/1991
1994	Seabrook	4431994001	1/25/1994
1988	Sequoyah 1	3271988016	3/24/1988
1992	Sequoyah 1	3271992011	4/29/1992
1992	Sequoyah 1	3271992017	8/31/1992
1998	Sequoyah 1	3271998001	5/19/1998
1992	Sequoyah 2	3281992011	8/21/1992
2000	Sequoyah 2	3282000001	1/18/2000
1988	South Texas 1	4981988022	2/28/1988
1988	South Texas 1	4981988026	3/30/1988
1988	South Texas 1	4981988049	8/26/1988
1989	South Texas 1	4981988059	10/6/1988
1989	South Texas 1	4981988018	2/12/1988
1991	South Texas 1	4981991002	1/26/1991
1994	South Texas 1	4981994011	3/10/1994
2001	South Texas 1	4982000007	12/16/2000
1989	South Texas 2	4991989011	4/10/1989

FY	Plant Name	LER	Event Date
1990	South Texas 2	4991990001	1/8/1990
1992	South Texas 2	4991991010	12/24/1991
2003	South Texas 2	4992003002	3/9/2003
1987	St. Lucie 1	3351987003	2/12/1987
1987	St. Lucie 1	3351987010	4/14/1987
1993	St. Lucie 1	3351993001	1/8/1993
1995	St. Lucie 1	3351994009	11/22/1994
1995	St. Lucie 1	3351994010	11/24/1994
1996	St. Lucie 1	3351996008	7/3/1996
1991	St. Lucie 2	3891990004	11/9/1990
1988	Summer	3951988006	5/12/1988
1989	Summer	3951988013	12/11/1988
1987	Surry 1	2801987023	9/1/1987
1987	Surry 1	2801987024	9/20/1987
1988	Surry 1	2801988029	8/15/1988
1989	Surry 1	2801989006	2/8/1989
1991	Surry 1	2801990018	12/3/1990
1993	Surry 1	2801993001	1/8/1993
1998	Surry 1	2801997008	10/11/1997
2000	Surry 1	2801999007	10/9/1999
1988	Surry 2	2811988004	3/27/1988
1988	Surry 2	2811988010	5/16/1988
1991	Surry 2	2811991007	8/2/1991
1990	Three Mile Isl 1	2891989001	10/30/1989
1990	Three Mile Isl 1	2891990006	7/2/1990
1987	Turkey Point 3	2501987016	5/27/1987
1987	Turkey Point 3	2501987021	7/1/1987
1987	Turkey Point 3	2501987023	9/13/1987
1989	Turkey Point 3	2501989011	6/17/1989
1990	Turkey Point 3	2501990008	4/15/1990
1994	Turkey Point 3	2501994002	5/5/1994
1996	Turkey Point 3	2501996007	3/29/1996
1989	Turkey Point 4	2511989002	4/12/1989
1989	Turkey Point 4	2511989011	9/15/1989
1992	Turkey Point 4	2511992004	3/26/1992
2001	Turkey Point 4	2512000004	10/21/2000
1989	Vogtle 1	4241988028	10/16/1988
1993	Vogtle 1	4241993006	4/18/1993
1994	Vogtle 1	4241994001	2/2/1994
1989	Vogtle 2	4251989006	3/18/1989
1991	Vogtle 2	4251991009	8/13/1991
1992	Vogtle 2	4251992004	4/23/1992
1990	Waterford 3	3821989024	12/23/1989
1991	Waterford 3	3821991019	8/25/1991
1992	Waterford 3	3821991022	11/17/1991
1993	Waterford 3	3821992012	10/2/1992
1987	Wolf Creek	4821987002	1/8/1987
1991	Wolf Creek	4821990023	10/23/1990
1993	Wolf Creek	4821993009	5/4/1993
1999	Wolf Creek	4821999005	5/12/1999
2002	Wolf Creek	4822002005	9/9/2002
1987	Zion 1	2951987009	4/30/1987
1991	Zion 1	2951991008	5/10/1991
1992	Zion 1	2951991016	11/7/1991
1993	Zion 1	2951992019	10/8/1992
1996	Zion 1	2951995022	11/12/1995
1987	Zion 2	3041987006	7/29/1987
1989	Zion 2	3041988012	12/11/1988
1998	Zion 2	3041997009	12/2/1997

Table 10. LER listing for failure trend figure. Figure 5

FY	Plant Name	LER	Event Date
1992	Calvert Cliffs 1	3171991009	11/26/1991
1990	Catawba 1	4131989027	11/20/1989
1989	Catawba 2	4141989011	5/13/1989
1995	Cook 1	3151995011	9/12/1995
1992	Crystal River 3	3021991018	12/8/1991
1992	Diablo Canyon 1	2751992010	6/2/1992
1989	Ginna	2441989003	5/18/1989
1988	Ginna	2441987008	12/23/1987
1990	Haddam Neck	2131990012	8/2/1990
1998	Indian Point 2	2471997024	10/31/1997
1995	Kewaunee	3051995006	4/20/1995
1996	Maine Yankee	3091996020	8/17/1996
1988	McGuire 1	3691988020	8/12/1988
1997	North Anna 1	3381996006	10/3/1996
1991	North Anna 1	3381990011	11/1/1990
1997	Oconee 3	2871997003	5/3/1997
1989	Palisades	2551989010	6/2/1989
1997	Palisades	2551997004	2/21/1997
1996	Palisades	2551996010	7/17/1996
1988	Palo Verde 2	5291988005	2/21/1988
2002	Point Beach 2	3012002001	2/22/2002
1987	Prairie Island 1	2821987009	6/18/1987
1988	Salem 2	3111988012	6/18/1988
1994	Salem 2	3111994010	9/22/1994
1992	Sequoyah 1	3271992014	8/10/1992
1991	Sequoyah 1	3271991003	2/18/1991
1999	Sequoyah 1	3271999001	4/15/1999
1990	Sequoyah 2	3281990012	8/22/1990
1994	Sequoyah 2	3281994002	1/8/1994
1988	Sequoyah 2	3281988005	2/12/1988
1992	South Texas 2	4991991010	12/24/1991
1987	Surry 2	2811987001	3/12/1987
1994	Turkey Point 3	2501994002	5/5/1994

5 DESIGN-CLASSES

Differences within a design class due to system configuration were categorized first by number of steam generators (SGs) (which correlates to cold legs) and then by number of HPI pump trains. Table 11 shows individual plant configurations and the design class they have been assigned.

Table 11. Listing of the HPI design classes, Units associated with each design class, the number and type of HPI trains, the number of cold-legs, and the success criterion for a small LOCA (as stated in the IPEs).

HPI Class	Plant	Centrifugal Charging Pumps (CCP)	Intermediate Head Safety Injection Pumps (IHSI)	Total High-Pressure Motor Trains	IHSI and CCP for ES Auto or Immediate Manual Start	Cold Leg Injection Paths	Steam Generators	Small LOCA success for HPI (injection phase)
1	Arkansas Nuclear One 2	—	3 (1 swing pump never operates unless one of the two is in maintenance)	3	2	4	2	1/3 pumps; 2/4 injection paths
1	Calvert Cliffs 1 & 2	—	3 (backup pump requires operator)	3	2	4	2	1/2 pumps to 2/4injection paths;
1	Davis-Besse	—	2	2	2	4	2	1/2 HPI pumps and flow to associated R/X nozzle
1	Kewaunee	—	2	2	2	2	2	1/2 HPIs to 1/2 cold legs, also allow for manual start of comp that didn't auto start
1	Millstone 2	—	3 (one pump is a swing pump that requires operator)	3	2	8; 4per sys	2	1/3 HPIs to 3 of 3 unfaulted loops OR 2/3 HPI supplying 2/3 unfaulted loops
1	Palisades	—	2	2	2	4	2	1/2 HPIs to 1/3 intact headers; assume SBLOCA fails fourth header
1	Palo Verde 1, 2, & 3	—	2	2	2	4	2	1/2 HPIs to 3/6 injection headers that feed the 3 RCS SI cold legs; SBLOCA assumed to fault one cold leg path
1	Point Beach 1 & 2	—	2	2	2	2	2	1/2 HPIs to the unfaulted loop initially takes suction from BAST then auto switch to RWST
1	Prairie Island 1 & 2	—	2	2	2	2	2	1/2 HPIs to 1/2 cold legs
1	San Onofre 1 [4], 2, & 3	—	3 (one requires operator to manual realign)	3	2	4	2	1/3 HPIs to 2/4 cold legs
1	St. Lucie 1 & 2	—	2	2	2	4	2	1/2 HPIs to 1/4 cold legs

[4] Decommissioned November 1992.

HPI Class	Plant	Centrifugal Charging Pumps (CCP)	Intermediate Head Safety Injection Pumps (IHSI)	Total High-Pressure Motor Trains	IHSI and CCP for ES Auto or Immediate Manual Start	Cold Leg Injection Paths	Steam Generators	Small LOCA success for HPI (injection phase)
1	Waterford 3	—	3 (one needs operator; installed spare)	3	2	4	2	1/2 HPIs to 2 intact cold leg injection paths
2	Arkansas Nuclear One 1	3 (1 pump running; 1 swing pump never operates unless one of the two is in maintenance)	—	3	2	4	2	1/3 pumps; 2/4 injection paths; the swing pump has to be manually aligned to EDG and SW
2	Crystal River 3	3 (1 pump running)	—	3	3	4	2	1/3 MUPs to 1/4 injection paths
2	Fort Calhoun	—	3	3	3	4	2	1/3 HPI to 2/4 legs
2	Ginna	—	3	3	3	2	2	1/3 HPI to 1/2 legs
2	Oconee 1, 2, & 3	3 (1 pump running)	—	3	3	4	2	1/3 HPIs to 1/4 RCS injection nozzles
2	Three Mile Island 1	3 (1 pump running)	—	3	3	4	2	1/3 HPIs through 1/4 injection paths
3	Beaver Valley 1 & 2	3 (1 pump spare)	—	3	2	3	3	1/3 Charging/HHSI pumps to 3/3 cold legs; model as 1/2CCPs to 3/3 cold legs since spare pump is unpowered
3	Farley 1 & 2	3 (serves as HPI; one requires operator)	—	3	2	3	3	1/2 HPI pumps to 2/3 cold legs for 4 hours; 1 normally operating, 1 in standby, 1 as backup to be aligned if one of the others is not available
3	H.B. Robinson	—	3 (1 pump breaker is racked out)	2	2	3	3	1/2 HPIs; 1 HPI pump is at time of IPE undergoing major overhaul hence disabled.
3	Maine Yankee [5]	3 (1 pump run, 1 pump standby, 1 pump spare)	—	3	2	3	3	1/2 HPSI trains to 1/2 intact cold water loops from RWST; no credit for spare

[5] Decommissioned August 1997.

HPI Class	Plant	Centrifugal Charging Pumps (CCP)	Intermediate Head Safety Injection Pumps (IHSI)	Total High-Pressure Motor Trains	IHSI and CCP for ES Auto or Immediate Manual Start	Cold Leg Injection Paths	Steam Generators	Small LOCA success for HPI (injection phase)
3	North Anna 1 & 2	3 (1 pump running; 1 needs operator)	—	3	2	3	3	1/3 HHIs; model as 1/2 HHIs since third pump needs manual alignment
3	Shearon Harris 1	3 (1 pump running; 1 pump spare)	—	3	2	3	3	1/2 HPIs *(one normally operating; have a spare pump that can be available in 8 hours)
3	Summer 1	3 (1 pump running; 1 pump breaker is racked out)	—	3	2	3	3	1/2 HPSIs to 2/3 cold legs
3	Surry 1 & 2	3 (1 pump is in “pull-to –lock”)	—	3	2	3	3	1/3 HHSIs to 1/3 cold legs; HHSI limited to simultaneous operation of 2 of 3 HHSI pumps
4	Turkey Point 3 & 4	—	4 (2 per unit)	4 (2 per unit)	2	3	3	2/4 HHSI trains to 1/3 cold legs; taking credit for other units pumps
5	Indian Point 2	—	3	3	3	4	4	1/3 HPIs to 1/4 cold legs
5	Indian Point 3	—	3	3	3	8	4	1/3 HPIs to 1/4 cold legs
5	South Texas 1 & 2	—	3	3	3	3	4	1/3 HPSIs to 1/3 cold legs
6	Braidwood 1&2	2	2	4	4	8; 4per sys	4	1/4 CC or SI pumps to 2/4 injection paths
6	Byron 1 & 2	2	2	4	4	8; 4per sys	4	1/4 CC or SI pumps to 2/4 injection paths
6	Callaway	2	2	4	4	8; 4per sys	4	1/4 CC or SI pumps to 2/4 injection paths
6	Catawba 1 & 2	2 (1 pump running)	2	4	4	8; 4per sys	4	1/4 NI or NV pumps to 2/4 injection paths
6	Comanche Peak 1 & 2	2	2	4	4	8; 4per sys	4	1/4 pumps to 2/4 injection paths
6	Cook 1 & 2	2	2	4	4	8; 4per sys	4	1/2 CCPs AND 1/2 SI pumps to 1/3 intact loops
6	Diablo Canyon 1 & 2	2	2	4	4	8; 4per sys	4	1/4 CCPs or SI pumps to 1/4 RCS cold legs

HPI Class	Plant	Centrifugal Charging Pumps (CCP)	Intermediate Head Safety Injection Pumps (IHSI)	Total High-Pressure Motor Trains	IHSI and CCP for ES Auto or Immediate Manual Start	Cold Leg Injection Paths	Steam Generators	Small LOCA success for HPI (injection phase)
6	Haddam Neck [6]	2	2	4	4	5	4	(1/2 HPIs to 3 of 3 unfaulted legs OR 2/2 HPIs to 2 of 3 unfaulted legs) AND 1/2 CCPs to # 2 cold leg
6	McGuire 1 & 2	2 (1 pump running)	2	4	4	8; 4per sys	4	1/4 CC or SI pumps to 2/4 injection paths
6	Millstone 3	3 (1 pump running, 1 needs operator)	2	5	4	8; 4per sys	4	1/4 HPIs to 3/3 unfaulted RCS cold legs
6	Salem 1 & 2	2	2	4	4	8; 4per sys	4	1/4 centrifugal charging or SJS pumps
6	Seabrook	2	2	4	4	8; 4per sys	4	1/4 HPI trains (SI or CVCS) to 2/4 cold legs
6	Sequoyah 1 & 2	2	2	4	4	8; 4per sys	4	1/4 HPI trains (SI or CVCS) to 2/4 cold legs
6	Vogtle 1 & 2	2 (1 pump running)	2	4	4	8; 4per sys	4	1/2 CCPs through 3/4 cold legs for 3 hrs. OR 1/2 SIs through 3/4 cold legs for 6 hours
6	Watts Bar	2	2	4	4	8; 4per sys	4	1/4 HPS is to 3/4 cold legs
6	Wolf Creek	2	2	4	4	8; 4per sys	4	1/4 HPS is to 3/4 cold legs
6	Zion 1[7] & 2 [8]	2 (1 pump running)	2	4	4	8; 4per sys	4	1 CCP (high-pressure) or 1 SIP (medium pressure)

[6] Decommissioned August 1997.

[7] Decommissioned December 1997.

[8] Decommissioned December 1997.