

System Study: High-Pressure Coolant Injection 1998–2014

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ABSTRACT

This report presents an unreliability evaluation of the high-pressure coolant injection system (HPCI) at 25 U.S. commercial boiling water reactors. Demand, run hours, and failure data from fiscal year 1998 through 2014 for selected components were obtained from the Institute of Nuclear Power Operations (INPO) Consolidated Events Database (ICES). The unreliability results are trended for the most recent 10-year period while yearly estimates for system unreliability are provided for the entire active period. No statistically significant increasing or decreasing trends were identified in the HPCI results.

CONTENTS

ABSTRACT.....	iii
ACRONYMS.....	vii
1. INTRODUCTION	1
2. SUMMARY OF FINDINGS	3
3. INDUSTRY-WIDE UNRELIABILITY	5
4. INDUSTRY-WIDE TRENDS	7
5. BASIC EVENT GROUP IMPORTANCES	9
6. DATA TABLES	11
7. SYSTEM DESCRIPTION	19
8. REFERENCES.....	21

FIGURES

1. Trend of HPCI system unreliability (start-only model), as a function of fiscal year.....	8
2. Trend of HPCI system unreliability (8-hour model), as a function of fiscal year.....	8
3. HPCI basic event group importances.....	9
4. HPCI system diagram.	20

TABLES

1. BWR plants with a HPCI system selected for the study.....	2
2. Industry-wide unreliability values.	5
3. HPCI model basic event importance group descriptions.....	10
4. Plot data for HPCI start-only trend, Figure 1.....	11
5. Plot data for HPCI 8-hour trend, Figure 2.	12

6. Basic event reliability trending data.....	13
7. Basic event UA trending data.	17
8. Failure mode acronyms.....	17

ACRONYMS

BWR	boiling water reactor
CCF	common-cause failure
CST	condensate storage tank
EPIX	Equipment Performance and Information Exchange
FY	fiscal year
HPCI	high-pressure coolant injection
ICES	INPO Consolidated Events Database
INPO	Institute of Nuclear Power Operations
MOV	motor-operated valve
MSPI	Mitigating Systems Performance Index
PRA	probabilistic risk assessment
RPV	reactor pressure vessel
SPAR	standardized plant analysis risk
SSU	safety system unavailability

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1. INTRODUCTION

This report presents an unreliability evaluation of the high-pressure coolant injection (HPCI) systems at the 25 U.S. commercial boiling water reactors (BWRs) listed in Table 1. For each plant, the corresponding Standardized Plant Analysis Risk (SPAR) model (version model indicated in Table 1) was used in the yearly calculations. Demand, run hours, and failure data from fiscal year (FY)-98 through FY-14 for selected components in the HPCI system were obtained from the Institute of Nuclear Power Operations (INPO) Consolidated Events Database (ICES). Train unavailability data (outages from test or maintenance) were obtained from the Reactor Oversight Process Safety System Unavailability (SSU) database (FY-98 through FY-01) and the Mitigating Systems Performance Index (MSPI) database (FY-02 through FY-14). Common-cause failure (CCF) data used in the models are from the 2010 update to the CCF database. The system unreliability results are trended for the most recent 10-year period while yearly estimates for system unreliability are provided for the entire active period.

This report does not attempt to estimate basic event values for use in a probabilistic risk assessment (PRA). Suggested values for such use are presented in the [2010 Component Reliability Update](#) (Reference 1), which is an update to Reference 2 ([NUREG/CR-6928](#)). Baseline HPCI unreliability results using basic event values from that report are summarized in Section 3. Trend results for HPCI (using system-specific data) are presented in Section 4. Similar to previous system study updates, Section 5 contains importance information (using the baseline results from Section 3), and Section 7 describes the HPCI.

The HPCI model is evaluated using the transient flag set in the SPAR model. The transient flag set assumes all support systems are available and that the HPCI system is required to perform to mitigate the effects of the transient initiating event. All models include failures due to unavailability while in test or maintenance. Human error has not been included in the SPAR model logic. An overview of the trending methods, glossary of terms, and abbreviations can be found in the [Overview and Reference document](#) on the Reactor Operational Experience Results and Databases web page.

Two modes of the models for the HPCI system are calculated. The HPCI start-only model is the HPCI SPAR model modified by setting all fail-to-run basic events to zero (False), setting all recovery events to False, setting the suction transfer to the torus to False, and setting all cooling basic events to False. The 8-hour mission model includes all basic events in the HPCI SPAR model.

Table 1. BWR plants with a HPCI system selected for the study.

Plant	Version
Browns Ferry 1	8.22
Browns Ferry 2	8.22
Browns Ferry 3	8.18
Brunswick 1	8.20
Brunswick 2	8.20
Cooper	8.22
Dresden 2	8.18
Dresden 3	8.18
Duane Arnold	8.22
Fermi 2	8.20
FitzPatrick	8.17
Hatch 1	8.20
Hatch 2	8.20
Hope Creek	8.18
Limerick 1	8.20
Limerick 2	8.19
Monticello	8.20
Peach Bottom 2	8.25
Peach Bottom 3	8.21
Pilgrim	8.21
Quad Cities 1	8.18
Quad Cities 2	8.18
Susquehanna 1	8.23
Susquehanna 2	8.21
Vermont Yankee	8.19

2. SUMMARY OF FINDINGS

The results of this HPCI system unreliability study are summarized in this section. Of particular interest is the existence of any statistically significant^a increasing trends. In this update, no statistically significant increasing trends were identified in the HPCI unreliability trend results. No statistically significant decreasing trends within the industry-wide estimates of HPCI system unreliability on a per fiscal year basis were identified.

The industry-wide HPCI start-only and 8-hour basic event group importances were evaluated and are shown in Figure 3. In both cases, the leading contributor to HPCI system unreliability is the HPCI turbine-driven pump group of basic events. The 8-hour model also has the injection and recovery as important segments.

a. 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).

3. INDUSTRY-WIDE UNRELIABILITY

The HPCI fault trees from the SPAR models were evaluated for each of the 25 operating U.S. commercial boiling water nuclear power plants with a HPCI system.

The industry-wide unreliability of the HPCI system has been estimated for two modes of operation. A failure to start (start-only) model and an 8-hour mission model were evaluated. The uncertainty distributions for HPCI show both plant design variability and parameter uncertainty from the industry-wide component failure data (1998–2010).^a

Table 2 shows the percentiles and mean of the aggregated sample data (Latin hypercube, 1000 samples for each model) collected from the uncertainty calculations of the HPCI fault trees in the SPAR models. The lower and upper bounds are based directly on the samples (Latin hypercube) from the uncertainty calculations in the SPAR models. For the industry-level results, the SPAR samples were combined into one large sample in order to determine the industry-level bounds, mean, and median.

Table 2. Industry-wide unreliability values.

Model	Lower (5%)	Median	Mean	Upper (95%)
Start	1.63E-02	3.58E-02	4.15E-02	8.62E-02
8-hour	2.60E-02	5.11E-02	5.63E-02	1.05E-01

a. By using industry-wide component failure data, individual plant performance is not included in the distribution of results.

4. INDUSTRY-WIDE TRENDS

The yearly (FY 1998–FY 2014) failure and demand or run time data were obtained from EPIX for the HPCI system. HPCI train maintenance unavailability data for trending are from the same time period, as reported in the ROP and EPIX. The component basic event uncertainty was calculated for the HPCI system components using the trending methods described in Section 1 and 2 of the Overview and Reference document. Tables 6 and 7 show the yearly data values for each HPCI system specific component and failure mode combination that was varied in the model. These data were loaded into the HPCI system fault tree in each SPAR model with a HPCI system (see Table 1).

The trend charts show the results of varying component reliability data over time and updating generic, relatively-flat prior distributions using data for each year. In addition, for comparison, the calculated industry-wide system reliability this update (current SPAR/EPIX) is shown. Section 4 of the Overview and Reference link on the System Studies main web page provides more detailed discussion of the trending methods. In the lower left hand corner of the trend figures, the regression method is reported.

The components that were varied in the HPCI model are:

- HPCI turbine-driven pump start, run, and test and maintenance.
- HPCI motor-operated valve, fail to operate.

Figure 1 shows the trend in the start-only model unreliability. Table 4 shows the data points for Figure 1. No statistically significant decreasing trends within the industry-wide estimates of HPCI system unreliability (start-only) on a per fiscal year basis were identified.

Figure 2 shows the trend in the 8-hour mission unreliability. Table 5 shows the data points for Figure 2. No statistically significant decreasing trends within the industry-wide estimates of HPCI system unreliability (8-hour mission) on a per fiscal year basis were identified.

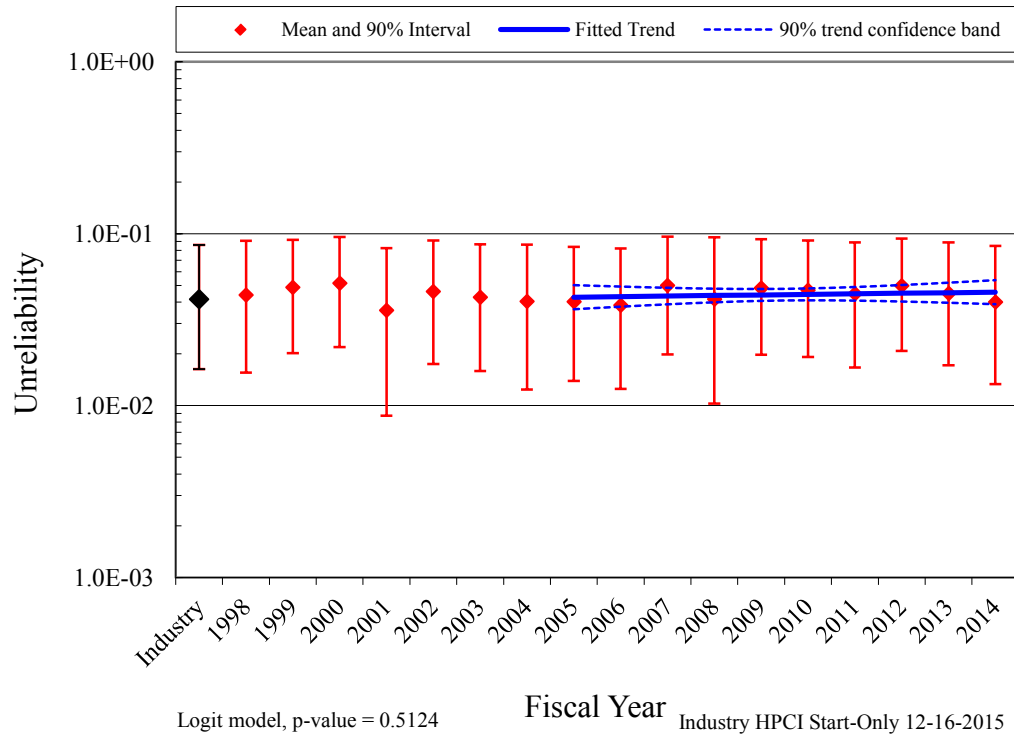


Figure 1. Trend of HPCI system unreliability (start-only model), as a function of fiscal year.

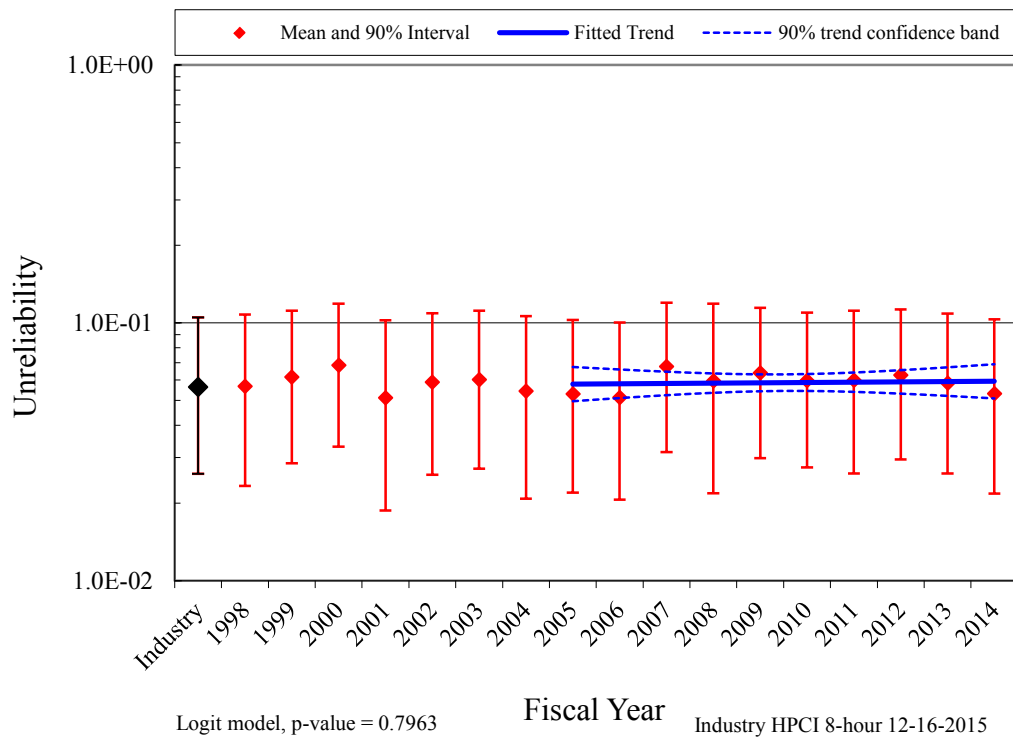


Figure 2. Trend of HPCI system unreliability (8-hour model), as a function of fiscal year.

5. BASIC EVENT GROUP IMPORTANCES

The HPCI basic event group Fussell-Vesely importances were calculated for the start-only and 8-hour modes for each plant using the industry-wide data (1998–2010). These basic event group importances were then averaged across all plants to represent an industry-wide basic event group importance. The industry-wide HPCI start-only and 8-hour basic event group importances are shown in Figure 3.

In both cases, the leading contributor to HPCI system unreliability is the HPCI turbine-driven pump group of basic events. The 8-hour model also has the injection and recovery as important segments. For more discussion on the HPCI turbine-driven pumps, see the turbine-driven pump component reliability study at NRC Reactor Operational Experience Results and Databases. Table 3 shows the SPAR model HPCI importance groups and their descriptions.

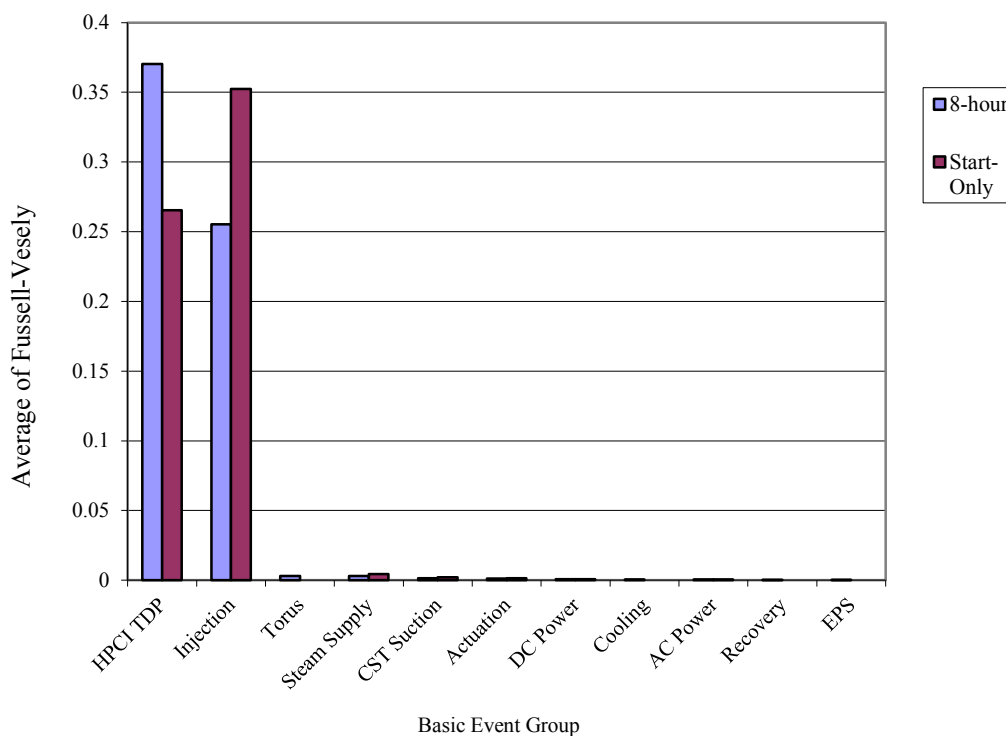


Figure 3. HPCI basic event group importances.

Table 3. HPCI model basic event importance group descriptions.

Group	Description
AC Power	The ac buses and circuit breakers that supply power to the service water pumps and the HPCI motor-operated valves.
Actuation	ESF actuation circuitry.
Cooling	The pumps, valves, and heat exchangers that provide heat removal to the HPCI turbine-driven pump.
CST Suction	Suction path and condensate storage tank.
DC Power	The batteries and battery chargers that supply power to the HPCI turbine-driven pump control circuitry.
EPS	HPCI dependency on the emergency power system.
HPCI TDP	All basic events associated with the turbine-driven pumps. The start, run, common-cause, and test and maintenance are included in the group of basic events.
Injection	The motor-operated valves and check valves in the HPCI injection path.
Recovery	Recovery of the HPCI turbine fail-to-start.
Steam Supply	The steam supply valves to the HPCI turbine.
Torus	The suppression pool motor-operated valves, check valves, and strainers required when a need to transfer to the suppression pool (torus) occurs.

6. DATA TABLES

Table 4. Plot data for HPCI start-only trend, Figure 1.

FY/Source	Regression Curve Data Points			Annual Estimate Data Points		
	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
SPAR/EPIX				1.63E-02	8.56E-02	4.15E-02
1998				1.55E-02	9.09E-02	4.40E-02
1999				2.02E-02	9.22E-02	4.87E-02
2000				2.19E-02	9.56E-02	5.14E-02
2001				8.74E-03	8.25E-02	3.58E-02
2002				1.74E-02	9.12E-02	4.60E-02
2003				1.59E-02	8.68E-02	4.27E-02
2004				1.24E-02	8.63E-02	4.02E-02
2005	4.27E-02	3.63E-02	5.02E-02	1.39E-02	8.38E-02	4.00E-02
2006	4.31E-02	3.76E-02	4.93E-02	1.25E-02	8.22E-02	3.83E-02
2007	4.34E-02	3.88E-02	4.85E-02	1.99E-02	9.62E-02	4.99E-02
2008	4.37E-02	3.99E-02	4.79E-02	1.03E-02	9.52E-02	4.16E-02
2009	4.40E-02	4.07E-02	4.77E-02	1.97E-02	9.29E-02	4.82E-02
2010	4.44E-02	4.10E-02	4.80E-02	1.92E-02	9.12E-02	4.67E-02
2011	4.47E-02	4.08E-02	4.90E-02	1.66E-02	8.90E-02	4.47E-02
2012	4.50E-02	4.03E-02	5.03E-02	2.08E-02	9.37E-02	4.96E-02
2013	4.54E-02	3.97E-02	5.19E-02	1.71E-02	8.91E-02	4.48E-02
2014	4.57E-02	3.89E-02	5.37E-02	1.33E-02	8.49E-02	4.00E-02

Table 5. Plot data for HPCI 8-hour trend, Figure 2.

FY/Source	Regression Curve Data Points			Plot Trend Error Bar Points		
	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
SPAR/ EPIX				2.60E-02	1.05E-01	5.63E-02
1998				2.33E-02	1.08E-01	5.67E-02
1999				2.86E-02	1.11E-01	6.15E-02
2000				3.31E-02	1.19E-01	6.83E-02
2001				1.87E-02	1.02E-01	5.11E-02
2002				2.57E-02	1.09E-01	5.88E-02
2003				2.72E-02	1.11E-01	6.02E-02
2004				2.08E-02	1.06E-01	5.42E-02
2005	5.79E-02	4.96E-02	6.74E-02	2.19E-02	1.03E-01	5.29E-02
2006	5.81E-02	5.11E-02	6.59E-02	2.06E-02	1.00E-01	5.13E-02
2007	5.82E-02	5.24E-02	6.46E-02	3.15E-02	1.20E-01	6.76E-02
2008	5.84E-02	5.35E-02	6.36E-02	2.18E-02	1.19E-01	5.95E-02
2009	5.85E-02	5.43E-02	6.31E-02	2.99E-02	1.14E-01	6.39E-02
2010	5.87E-02	5.44E-02	6.33E-02	2.75E-02	1.10E-01	5.95E-02
2011	5.89E-02	5.40E-02	6.42E-02	2.61E-02	1.11E-01	5.97E-02
2012	5.90E-02	5.31E-02	6.55E-02	2.95E-02	1.13E-01	6.25E-02
2013	5.92E-02	5.21E-02	6.72E-02	2.60E-02	1.08E-01	5.82E-02
2014	5.94E-02	5.09E-02	6.91E-02	2.17E-02	1.03E-01	5.30E-02

Table 6. Basic event reliability trending data.

Failure Mode	Component	Year	Number of Failures	Demands/Run Hours	Bayesian Update			
					Mean	Post A	Post B	Distribution
FTOC	AOV	1998	0	67.4	8.99E-04	1.112	1235	Beta
FTOC	AOV	1999	0	67.2	8.99E-04	1.112	1235	Beta
FTOC	AOV	2000	0	67.2	8.99E-04	1.112	1235	Beta
FTOC	AOV	2001	0	67.4	8.99E-04	1.112	1235	Beta
FTOC	AOV	2002	0	68.2	8.99E-04	1.112	1236	Beta
FTOC	AOV	2003	0	68.2	8.99E-04	1.112	1236	Beta
FTOC	AOV	2004	0	68.2	8.99E-04	1.112	1236	Beta
FTOC	AOV	2005	0	68.2	8.99E-04	1.112	1236	Beta
FTOC	AOV	2006	0	68.2	8.99E-04	1.112	1236	Beta
FTOC	AOV	2007	0	68.2	8.99E-04	1.112	1236	Beta
FTOC	AOV	2008	0	68.2	8.99E-04	1.112	1236	Beta
FTOC	AOV	2009	0	68.2	8.99E-04	1.112	1236	Beta
FTOC	AOV	2010	0	68.2	8.99E-04	1.112	1236	Beta
FTOC	AOV	2011	0	68.2	8.99E-04	1.112	1236	Beta
FTOC	AOV	2012	0	68.2	8.99E-04	1.112	1236	Beta
FTOC	AOV	2013	0	68.2	8.99E-04	1.112	1236	Beta
FTOC	AOV	2014	0	68.2	8.99E-04	1.112	1236	Beta
FTOC	MOV	1998	4	2080.3	1.44E-03	6.046	4199	Beta
FTOC	MOV	1999	2	1985.1	9.84E-04	4.046	4106	Beta
FTOC	MOV	2000	2	2034.2	9.73E-04	4.046	4155	Beta
FTOC	MOV	2001	3	1959.4	1.24E-03	5.046	4079	Beta
FTOC	MOV	2002	2	2028.4	9.74E-04	4.046	4149	Beta
FTOC	MOV	2003	2	2138.5	9.49E-04	4.046	4259	Beta
FTOC	MOV	2004	2	2042.0	9.71E-04	4.046	4163	Beta
FTOC	MOV	2005	2	2051.5	9.69E-04	4.046	4172	Beta
FTOC	MOV	2006	3	2029.6	1.21E-03	5.046	4150	Beta
FTOC	MOV	2007	8	2114.1	2.37E-03	10.046	4229	Beta
FTOC	MOV	2008	0	2097.9	4.84E-04	2.046	4221	Beta
FTOC	MOV	2009	8	2125.0	2.36E-03	10.046	4240	Beta
FTOC	MOV	2010	1	2087.2	7.23E-04	3.046	4209	Beta
FTOC	MOV	2011	0	2049.4	4.90E-04	2.046	4172	Beta
FTOC	MOV	2012	3	2039.1	1.21E-03	5.046	4159	Beta
FTOC	MOV	2013	1	2083.1	7.24E-04	3.046	4205	Beta
FTOC	MOV	2014	1	2017.7	7.35E-04	3.046	4140	Beta
FTOP	AOV	1998	0	61320.0	2.46E-07	1.421	5780320	Gamma
FTOP	AOV	1999	0	61320.0	2.46E-07	1.421	5780320	Gamma
FTOP	AOV	2000	0	61320.0	2.46E-07	1.421	5780320	Gamma
FTOP	AOV	2001	0	61320.0	2.46E-07	1.421	5780320	Gamma
FTOP	AOV	2002	0	61320.0	2.46E-07	1.421	5780320	Gamma
FTOP	AOV	2003	0	61320.0	2.46E-07	1.421	5780320	Gamma
FTOP	AOV	2004	0	61320.0	2.46E-07	1.421	5780320	Gamma

Table 6. (continued).

Failure Mode	Component	Year	Number of Failures	Demands/Run Hours	Bayesian Update			
					Mean	Post A	Post B	Distribution
FTOP	AOV	2005	0	61320.0	2.46E-07	1.421	5780320	Gamma
FTOP	AOV	2006	0	61320.0	2.46E-07	1.421	5780320	Gamma
FTOP	AOV	2007	0	61320.0	2.46E-07	1.421	5780320	Gamma
FTOP	AOV	2008	0	61320.0	2.46E-07	1.421	5780320	Gamma
FTOP	AOV	2009	0	61320.0	2.46E-07	1.421	5780320	Gamma
FTOP	AOV	2010	0	61320.0	2.46E-07	1.421	5780320	Gamma
FTOP	AOV	2011	0	61320.0	2.46E-07	1.421	5780320	Gamma
FTOP	AOV	2012	0	61320.0	2.46E-07	1.421	5780320	Gamma
FTOP	AOV	2013	0	61320.0	2.46E-07	1.421	5780320	Gamma
FTOP	AOV	2014	0	61320.0	2.46E-07	1.421	5780320	Gamma
FTOP	MOV	1998	0	2146200.0	6.03E-08	1.458	24196200	Gamma
FTOP	MOV	1999	0	2137440.0	6.03E-08	1.458	24187440	Gamma
FTOP	MOV	2000	0	2137440.0	6.03E-08	1.458	24187440	Gamma
FTOP	MOV	2001	0	2137440.0	6.03E-08	1.458	24187440	Gamma
FTOP	MOV	2002	0	2137440.0	6.03E-08	1.458	24187440	Gamma
FTOP	MOV	2003	0	2137440.0	6.03E-08	1.458	24187440	Gamma
FTOP	MOV	2004	0	2146200.0	6.03E-08	1.458	24196200	Gamma
FTOP	MOV	2005	0	2146200.0	6.03E-08	1.458	24196200	Gamma
FTOP	MOV	2006	0	2146200.0	6.03E-08	1.458	24196200	Gamma
FTOP	MOV	2007	1	2146200.0	1.02E-07	2.458	24196200	Gamma
FTOP	MOV	2008	0	2146200.0	6.03E-08	1.458	24196200	Gamma
FTOP	MOV	2009	0	2146200.0	6.03E-08	1.458	24196200	Gamma
FTOP	MOV	2010	0	2163720.0	6.02E-08	1.458	24213720	Gamma
FTOP	MOV	2011	0	2198760.0	6.01E-08	1.458	24248760	Gamma
FTOP	MOV	2012	0	2198760.0	6.01E-08	1.458	24248760	Gamma
FTOP	MOV	2013	1	2146200.0	1.02E-07	2.458	24196200	Gamma
FTOP	MOV	2014	0	2146200.0	6.03E-08	1.458	24196200	Gamma
FTR<1H	TDP	1998	0	231.4	2.15E-03	0.962	448	Gamma
FTR<1H	TDP	1999	0	209.0	2.26E-03	0.962	425	Gamma
FTR<1H	TDP	2000	2	214.6	6.87E-03	2.962	431	Gamma
FTR<1H	TDP	2001	1	184.1	4.90E-03	1.962	400	Gamma
FTR<1H	TDP	2002	0	199.6	2.31E-03	0.962	416	Gamma
FTR<1H	TDP	2003	2	201.4	7.09E-03	2.962	418	Gamma
FTR<1H	TDP	2004	0	189.6	2.37E-03	0.962	406	Gamma
FTR<1H	TDP	2005	0	207.9	2.27E-03	0.962	424	Gamma
FTR<1H	TDP	2006	0	198.8	2.32E-03	0.962	415	Gamma
FTR<1H	TDP	2007	2	212.0	6.91E-03	2.962	428	Gamma
FTR<1H	TDP	2008	2	205.0	7.03E-03	2.962	421	Gamma
FTR<1H	TDP	2009	1	197.0	4.75E-03	1.962	413	Gamma
FTR<1H	TDP	2010	0	193.9	2.34E-03	0.962	410	Gamma
FTR<1H	TDP	2011	0	203.4	2.29E-03	0.962	420	Gamma
FTR<1H	TDP	2012	0	197.7	2.32E-03	0.962	414	Gamma

Table 6. (continued).

Failure Mode	Component	Year	Number of Failures	Demands/Run Hours	Bayesian Update			
					Mean	Post A	Post B	Distribution
FTR<1H	TDP	2013	0	192.0	2.35E-03	0.962	408	Gamma
FTR<1H	TDP	2014	0	182.5	2.41E-03	0.962	399	Gamma
FTR>1H	TDP	1998	0	37.4	1.55E-03	12.500	8065	Gamma
FTR>1H	TDP	1999	0	54.1	1.55E-03	12.500	8082	Gamma
FTR>1H	TDP	2000	0	32.8	1.55E-03	12.500	8061	Gamma
FTR>1H	TDP	2001	0	36.8	1.55E-03	12.500	8065	Gamma
FTR>1H	TDP	2002	0	27.7	1.55E-03	12.500	8055	Gamma
FTR>1H	TDP	2003	0	34.7	1.55E-03	12.500	8062	Gamma
FTR>1H	TDP	2004	1	37.2	1.67E-03	13.500	8065	Gamma
FTR>1H	TDP	2005	0	31.4	1.55E-03	12.500	8059	Gamma
FTR>1H	TDP	2006	0	27.0	1.55E-03	12.500	8055	Gamma
FTR>1H	TDP	2007	0	23.7	1.55E-03	12.500	8051	Gamma
FTR>1H	TDP	2008	1	26.8	1.68E-03	13.500	8055	Gamma
FTR>1H	TDP	2009	0	127.6	1.53E-03	12.500	8155	Gamma
FTR>1H	TDP	2010	0	64.7	1.54E-03	12.500	8092	Gamma
FTR>1H	TDP	2011	3	38.5	1.92E-03	15.500	8066	Gamma
FTR>1H	TDP	2012	0	30.4	1.55E-03	12.500	8058	Gamma
FTR>1H	TDP	2013	1	39.8	1.67E-03	13.500	8068	Gamma
FTR>1H	TDP	2014	0	32.4	1.55E-03	12.500	8060	Gamma
FTS	TDP	1998	0	231.4	2.50E-03	0.942	376	Beta
FTS	TDP	1999	4	209.0	1.40E-02	4.942	349	Beta
FTS	TDP	2000	5	214.6	1.65E-02	5.942	354	Beta
FTS	TDP	2001	0	184.1	2.86E-03	0.942	328	Beta
FTS	TDP	2002	3	199.6	1.14E-02	3.942	341	Beta
FTS	TDP	2003	1	201.4	5.61E-03	1.942	344	Beta
FTS	TDP	2004	1	189.6	5.80E-03	1.942	333	Beta
FTS	TDP	2005	2	207.9	8.33E-03	2.942	350	Beta
FTS	TDP	2006	1	198.8	5.65E-03	1.942	342	Beta
FTS	TDP	2007	3	212.0	1.10E-02	3.942	353	Beta
FTS	TDP	2008	1	205.0	5.55E-03	1.942	348	Beta
FTS	TDP	2009	3	197.0	1.15E-02	3.942	338	Beta
FTS	TDP	2010	3	193.9	1.16E-02	3.942	335	Beta
FTS	TDP	2011	2	203.4	8.44E-03	2.942	346	Beta
FTS	TDP	2012	3	197.7	1.15E-02	3.942	339	Beta
FTS	TDP	2013	3	192.0	1.17E-02	3.942	333	Beta
FTS	TDP	2014	1	182.5	5.93E-03	1.942	326	Beta
SO	AOV	1998	0	61320.0	1.29E-07	0.680	5272320	Gamma
SO	AOV	1999	0	61320.0	1.29E-07	0.680	5272320	Gamma
SO	AOV	2000	0	61320.0	1.29E-07	0.680	5272320	Gamma
SO	AOV	2001	0	61320.0	1.29E-07	0.680	5272320	Gamma
SO	AOV	2002	0	61320.0	1.29E-07	0.680	5272320	Gamma
SO	AOV	2003	0	61320.0	1.29E-07	0.680	5272320	Gamma

Table 6. (continued).

Failure Mode	Component	Year	Number of Failures	Demands/Run Hours	Bayesian Update			
					Mean	Post A	Post B	Distribution
SO	AOV	2004	0	61320.0	1.29E-07	0.680	5272320	Gamma
SO	AOV	2005	0	61320.0	1.29E-07	0.680	5272320	Gamma
SO	AOV	2006	0	61320.0	1.29E-07	0.680	5272320	Gamma
SO	AOV	2007	0	61320.0	1.29E-07	0.680	5272320	Gamma
SO	AOV	2008	0	61320.0	1.29E-07	0.680	5272320	Gamma
SO	AOV	2009	0	61320.0	1.29E-07	0.680	5272320	Gamma
SO	AOV	2010	0	61320.0	1.29E-07	0.680	5272320	Gamma
SO	AOV	2011	0	61320.0	1.29E-07	0.680	5272320	Gamma
SO	AOV	2012	0	61320.0	1.29E-07	0.680	5272320	Gamma
SO	AOV	2013	0	61320.0	1.29E-07	0.680	5272320	Gamma
SO	AOV	2014	0	61320.0	1.29E-07	0.680	5272320	Gamma
SO	MOV	1998	1	2146200.0	8.27E-08	1.570	18986200	Gamma
SO	MOV	1999	0	2137440.0	3.01E-08	0.570	18977440	Gamma
SO	MOV	2000	0	2137440.0	3.01E-08	0.570	18977440	Gamma
SO	MOV	2001	1	2137440.0	8.27E-08	1.570	18977440	Gamma
SO	MOV	2002	0	2137440.0	3.01E-08	0.570	18977440	Gamma
SO	MOV	2003	0	2137440.0	3.01E-08	0.570	18977440	Gamma
SO	MOV	2004	0	2146200.0	3.00E-08	0.570	18986200	Gamma
SO	MOV	2005	0	2146200.0	3.00E-08	0.570	18986200	Gamma
SO	MOV	2006	0	2146200.0	3.00E-08	0.570	18986200	Gamma
SO	MOV	2007	1	2146200.0	8.27E-08	1.570	18986200	Gamma
SO	MOV	2008	0	2146200.0	3.00E-08	0.570	18986200	Gamma
SO	MOV	2009	0	2146200.0	3.00E-08	0.570	18986200	Gamma
SO	MOV	2010	1	2163720.0	8.26E-08	1.570	19003720	Gamma
SO	MOV	2011	0	2198760.0	3.00E-08	0.570	19038760	Gamma
SO	MOV	2012	0	2198760.0	3.00E-08	0.570	19038760	Gamma
SO	MOV	2013	0	2146200.0	3.00E-08	0.570	18986200	Gamma
SO	MOV	2014	1	2146200.0	8.27E-08	1.570	18986200	Gamma

Table 7. Basic event UA trending data.

Failure Mode	Component	Year	UA Hours	Critical Hours	Bayesian Update			
					Mean	Post A	Post B	Distribution
UA	TDP	1998	2209.3	136702.2	1.68E-02	2.283	133.9	Beta
UA	TDP	1999	2235.6	191024.8	1.16E-02	1.896	160.9	Beta
UA	TDP	2000	2366.7	195331.6	1.21E-02	1.486	121.8	Beta
UA	TDP	2001	1724.8	198783.3	8.75E-03	0.697	78.9	Beta
UA	TDP	2002	2194.5	197131.1	1.12E-02	1.423	125.3	Beta
UA	TDP	2003	2630.1	194669.7	1.35E-02	3.067	223.9	Beta
UA	TDP	2004	2159.7	199136.1	1.09E-02	1.022	92.8	Beta
UA	TDP	2005	1500.3	192534.4	7.96E-03	1.613	201.0	Beta
UA	TDP	2006	1666.3	198637.4	8.52E-03	1.622	188.8	Beta
UA	TDP	2007	2702.1	196123.2	1.40E-02	1.464	103.4	Beta
UA	TDP	2008	2576.8	198317.3	1.29E-02	0.542	41.5	Beta
UA	TDP	2009	2302.3	194422.1	1.19E-02	1.668	138.1	Beta
UA	TDP	2010	2334.0	198022.4	1.19E-02	2.599	215.7	Beta
UA	TDP	2011	2585.6	192018.8	1.35E-02	2.117	155.2	Beta
UA	TDP	2012	2893.2	195768.3	1.47E-02	2.549	171.0	Beta
UA	TDP	2013	1899.2	189111.5	1.01E-02	1.950	192.1	Beta
UA	TDP	2014	2109.5	198456.7	1.06E-02	1.948	181.6	Beta

Table 8. Failure mode acronyms.

Failure Mode	Failure Mode Description
FTOC	Fail to open/close
FTOP	Fail to operate
FTR>1H	Fail to run greater than one hour
FTR<1H	Fail to run less than one hour (after start)
FTS	Fail to start
SO	Spurious operation
UA	Unavailability (maintenance or state of another component)

7. SYSTEM DESCRIPTION

The HPCI system is a single-train system that provides a reliable source of high-pressure coolant for cases where there is a loss of normal core coolant inventory. Figure 4 provides a simplified schematic diagram of the system.

The HPCI system consists of a steam turbine-driven pump, valves, and valve operators, and associated piping, including that from the normal and alternate pump suction sources and the pump discharge up to the penetration of the main feedwater line. For this study, the part of the main feedwater line from the check valve upstream of the HPCI connection to the reactor vessel, including the check valve, was considered part of the HPCI system. The steam turbine-driven pump includes all steam piping from the main steam line penetration to the turbine, and turbine exhaust piping to the suppression pool, valves and valve operators, gland sealing steam, and the turbine auxiliary oil system.

The HPCI system is actuated by either a low reactor water level or a high drywell pressure. Initially the system operates in an open loop mode, taking suction from the condensate storage tank (CST) and injecting water into the reactor pressure vessel (RPV) via one of the main feedwater lines. When the level in the CST reaches a low-level set point, the HPCI pump suction is aligned to the suppression pool. To maintain RPV level after the initial recovery, the HPCI system is placed in manual control, which may involve controlling turbine speed, diverting flow through minimum-flow or test lines, cycling the injection motor-operated valve (MOV), or complete stop-start cycles.

The HPCI system is also manually used to help control RPV pressure following a transient. Although this is not part of the ECCS design function, it is depended on, in approximately 90% of the PRA/individual plant examinations. However, only approximately 10% of the PRA/ individual plant examinations that depend on this function model the pressure control operation. In this mode, the turbine-driven pump is operated manually with the injection valve closed and the full-flow test-line MOV open. Turbine operation with the injection line isolated and the test line open allows the turbine to draw steam from the RPV, thereby reducing RPV pressure. Operation of the system in the pressure control mode may also occur with intermittent injection of coolant to the RPV. As steam is being drawn off the RPV, the RPV water inventory is reduced, resulting in the need for level restoration. When level restoration is required, the injection valve is opened and the test-line MOV is closed. Upon restoration of RPV water inventory, the system is returned to the pressure control line-up. This cycling between injection and pressure control can be repeated as necessary.

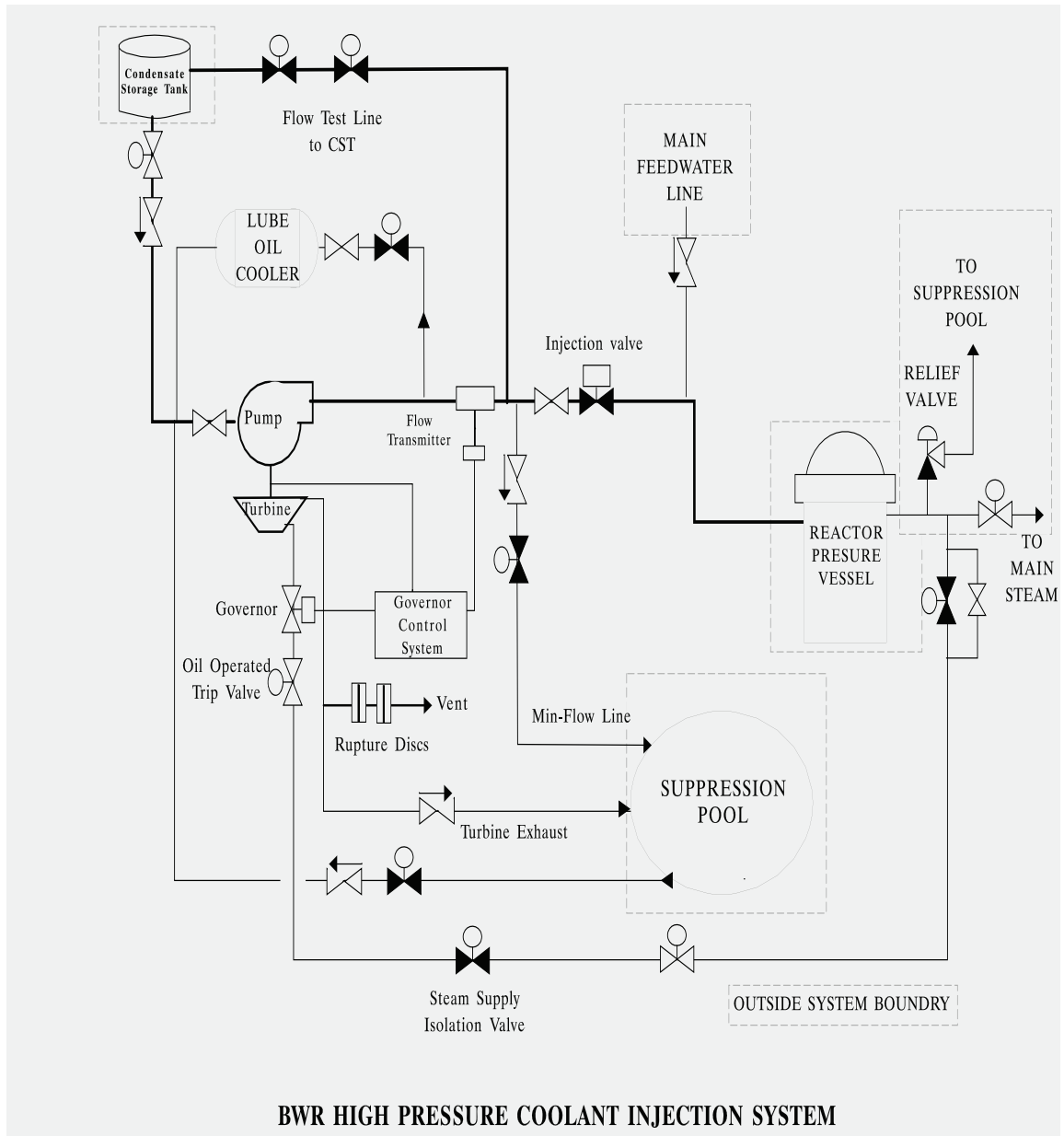


Figure 4. HPCI system diagram.

8. REFERENCES

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