

System Study: High-Pressure Coolant Injection 1998–2016

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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 1998 through 2016 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.

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ACRONYMS

BWR	boiling water reactor
CCF	common-cause failure
CST	condensate storage tank
CY	calendar year
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. Different from previous year's updates, this year's results are based on calendar year (CY) instead of fiscal year (FY). Demand, run hours, and failure data from 1998 through 2016 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 (1998 through 2001) and the Mitigating Systems Performance Index (MSPI) database (2002 through 2016). 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.^a 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.

^a Note that the 2015 Component Reliability Update (Reference 3) is now available to report more current estimated basic event values for use in a PRA. Estimates from the 2015 Update will be used in the next system study.

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 calendar 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 (from 1998 through 2016) 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 trend within the industry-wide estimates of HPCI system unreliability (start-only) was 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 trend within the industry-wide estimates of HPCI system unreliability (8-hour mission) was identified.

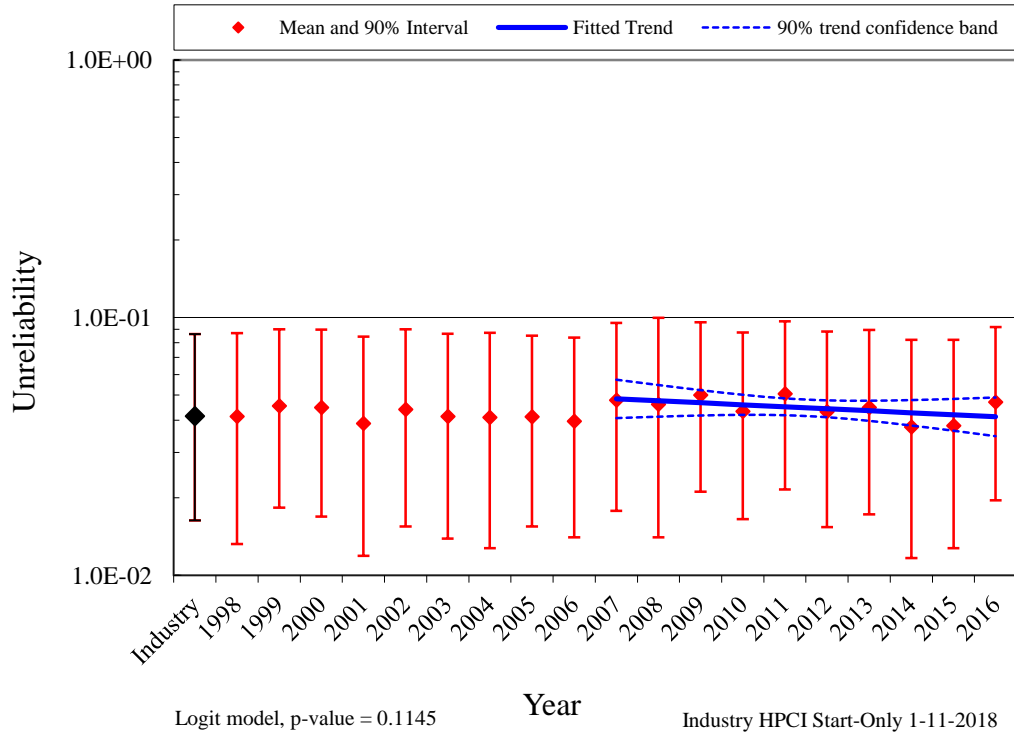


Figure 1. Trend of HPCI system unreliability (start-only model), as a function of year.

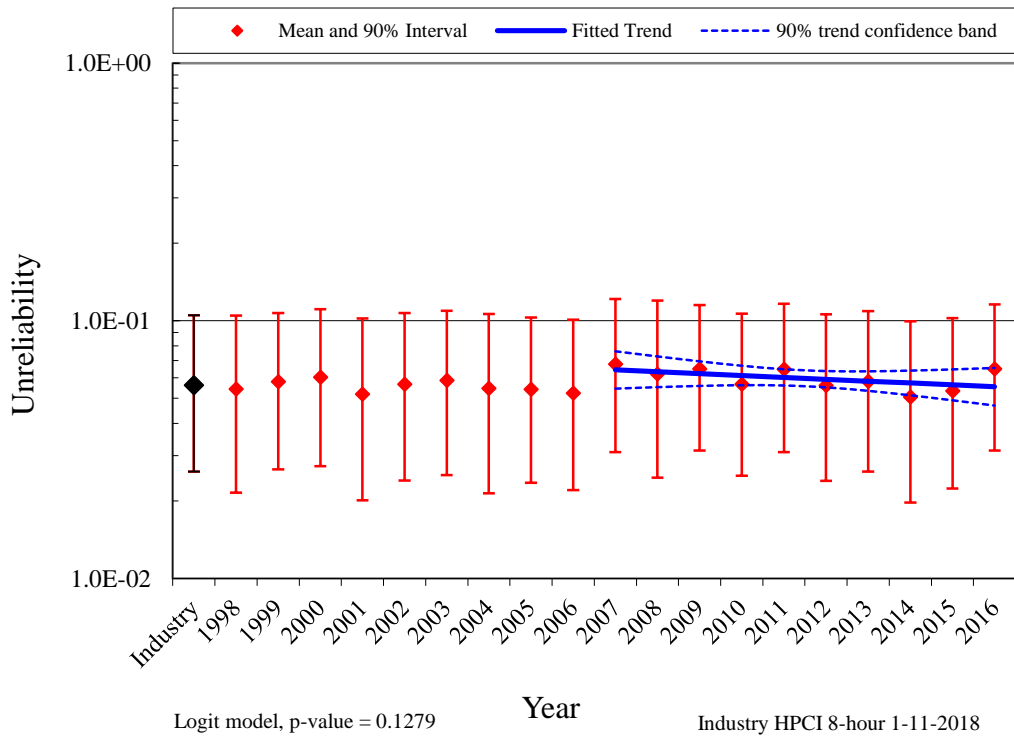


Figure 2. Trend of HPCI system unreliability (8-hour model), as a function of year.

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.

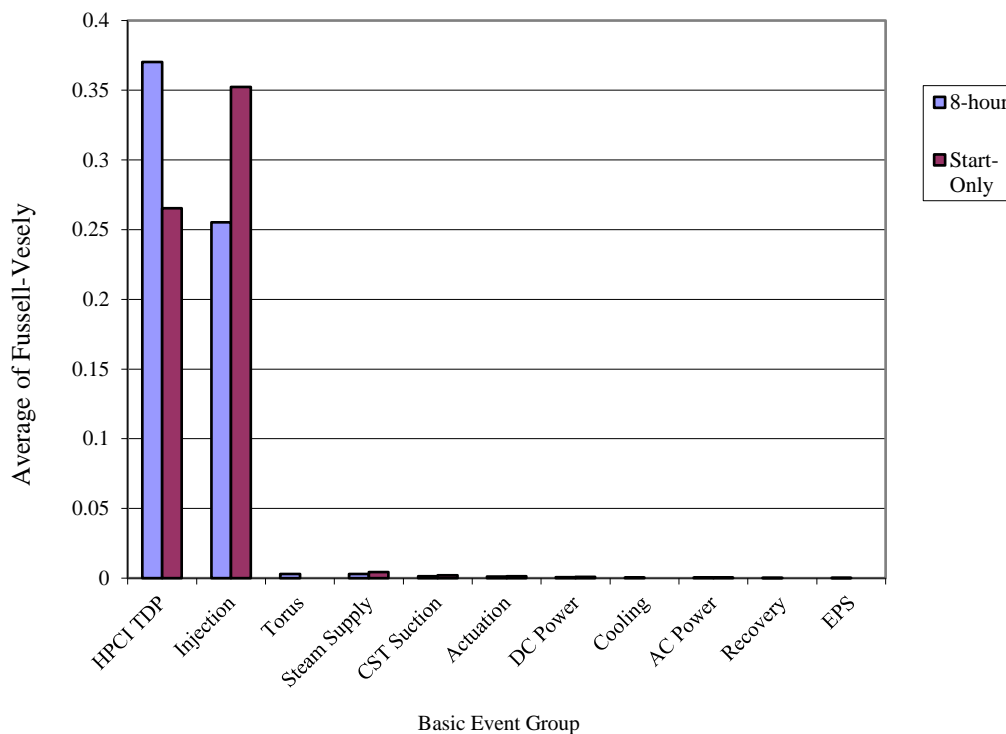


Figure 3. HPCI basic event group importances.

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.

Year/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				1.32E-02	8.70E-02	4.14E-02
1999				1.83E-02	9.01E-02	4.55E-02
2000				1.69E-02	8.99E-02	4.47E-02
2001				1.19E-02	8.43E-02	3.89E-02
2002				1.55E-02	8.99E-02	4.40E-02
2003				1.39E-02	8.64E-02	4.13E-02
2004				1.27E-02	8.73E-02	4.10E-02
2005				1.55E-02	8.52E-02	4.12E-02
2006				1.40E-02	8.36E-02	3.97E-02
2007	4.84E-02	4.07E-02	5.74E-02	1.78E-02	9.53E-02	4.78E-02
2008	4.75E-02	4.13E-02	5.47E-02	1.40E-02	9.99E-02	4.61E-02
2009	4.67E-02	4.17E-02	5.23E-02	2.11E-02	9.59E-02	5.01E-02
2010	4.59E-02	4.20E-02	5.01E-02	1.65E-02	8.75E-02	4.32E-02
2011	4.51E-02	4.18E-02	4.85E-02	2.15E-02	9.66E-02	5.07E-02
2012	4.43E-02	4.11E-02	4.77E-02	1.54E-02	8.83E-02	4.31E-02
2013	4.35E-02	3.97E-02	4.75E-02	1.72E-02	8.96E-02	4.47E-02
2014	4.27E-02	3.81E-02	4.78E-02	1.17E-02	8.20E-02	3.76E-02
2015	4.19E-02	3.64E-02	4.83E-02	1.27E-02	8.20E-02	3.81E-02
2016	4.12E-02	3.46E-02	4.89E-02	1.95E-02	9.18E-02	4.71E-02

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

Year/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				2.15E-02	1.05E-01	5.43E-02
1999				2.65E-02	1.07E-01	5.81E-02
2000				2.73E-02	1.11E-01	6.04E-02
2001				2.01E-02	1.02E-01	5.19E-02
2002				2.40E-02	1.07E-01	5.68E-02
2003				2.52E-02	1.09E-01	5.87E-02
2004				2.14E-02	1.06E-01	5.47E-02
2005				2.35E-02	1.03E-01	5.42E-02
2006				2.20E-02	1.01E-01	5.24E-02
2007	6.44E-02	5.45E-02	7.60E-02	3.09E-02	1.21E-01	6.79E-02
2008	6.34E-02	5.52E-02	7.26E-02	2.46E-02	1.20E-01	6.21E-02
2009	6.23E-02	5.58E-02	6.95E-02	3.14E-02	1.15E-01	6.51E-02
2010	6.13E-02	5.62E-02	6.68E-02	2.50E-02	1.07E-01	5.67E-02
2011	6.03E-02	5.60E-02	6.48E-02	3.09E-02	1.17E-01	6.48E-02
2012	5.93E-02	5.51E-02	6.37E-02	2.39E-02	1.06E-01	5.61E-02
2013	5.83E-02	5.34E-02	6.36E-02	2.60E-02	1.09E-01	5.83E-02
2014	5.73E-02	5.13E-02	6.40E-02	1.97E-02	9.94E-02	5.06E-02
2015	5.64E-02	4.91E-02	6.47E-02	2.24E-02	1.02E-01	5.34E-02
2016	5.54E-02	4.68E-02	6.55E-02	3.13E-02	1.16E-01	6.51E-02

Table 6. Basic event reliability trending data.

Failure Mode	Component	Year	Number of Failures	Demands/Run Hours	Mean	Bayesian Update		Distribution
						Post A	Post B	
FTOC	AOV	1998	0	62.52	9.03E-04	1.112	1230.52	Beta
FTOC	AOV	1999	0	62.52	9.03E-04	1.112	1230.52	Beta
FTOC	AOV	2000	0	62.52	9.03E-04	1.112	1230.52	Beta
FTOC	AOV	2001	0	63	9.03E-04	1.112	1231	Beta
FTOC	AOV	2002	0	63.48	9.02E-04	1.112	1231.48	Beta
FTOC	AOV	2003	0	63.48	9.02E-04	1.112	1231.48	Beta
FTOC	AOV	2004	0	63.48	9.02E-04	1.112	1231.48	Beta
FTOC	AOV	2005	0	63.48	9.02E-04	1.112	1231.48	Beta
FTOC	AOV	2006	0	63.48	9.02E-04	1.112	1231.48	Beta
FTOC	AOV	2007	0	63.48	9.02E-04	1.112	1231.48	Beta
FTOC	AOV	2008	0	63.48	9.02E-04	1.112	1231.48	Beta
FTOC	AOV	2009	0	63.48	9.02E-04	1.112	1231.48	Beta
FTOC	AOV	2010	0	63.48	9.02E-04	1.112	1231.48	Beta
FTOC	AOV	2011	0	63.48	9.02E-04	1.112	1231.48	Beta
FTOC	AOV	2012	0	63.48	9.02E-04	1.112	1231.48	Beta
FTOC	AOV	2013	0	63.48	9.02E-04	1.112	1231.48	Beta
FTOC	AOV	2014	0	80.87	8.90E-04	1.112	1248.87	Beta
FTOC	AOV	2015	0	84	8.87E-04	1.112	1252	Beta
FTOC	AOV	2016	0	84	8.87E-04	1.112	1252	Beta
FTOC	MOV	1998	5	2182.05	1.64E-03	7.046	4300.05	Beta
FTOC	MOV	1999	1	2002.02	7.38E-04	3.046	4124.02	Beta
FTOC	MOV	2000	1	2050.74	7.29E-04	3.046	4172.74	Beta
FTOC	MOV	2001	4	2028.73	1.46E-03	6.046	4147.73	Beta
FTOC	MOV	2002	1	1976.07	7.43E-04	3.046	4098.07	Beta
FTOC	MOV	2003	1	2131.83	7.16E-04	3.046	4253.83	Beta
FTOC	MOV	2004	2	2016.51	9.77E-04	4.046	4137.51	Beta
FTOC	MOV	2005	4	2016.12	1.46E-03	6.046	4135.12	Beta
FTOC	MOV	2006	1	2021.47	7.35E-04	3.046	4143.47	Beta
FTOC	MOV	2007	8	2058.37	2.40E-03	10.046	4173.37	Beta
FTOC	MOV	2008	4	2054.49	1.45E-03	6.046	4173.49	Beta
FTOC	MOV	2009	4	2070.02	1.44E-03	6.046	4189.02	Beta
FTOC	MOV	2010	1	2038.11	7.32E-04	3.046	4160.11	Beta
FTOC	MOV	2011	0	1983.23	4.98E-04	2.046	4106.23	Beta
FTOC	MOV	2012	3	2009.58	1.22E-03	5.046	4129.58	Beta
FTOC	MOV	2013	1	2011.83	7.36E-04	3.046	4133.83	Beta
FTOC	MOV	2014	1	1976.74	7.43E-04	3.046	4098.74	Beta
FTOC	MOV	2015	1	1954.31	7.47E-04	3.046	4076.31	Beta
FTOC	MOV	2016	1	1988.31	7.41E-04	3.046	4110.31	Beta
FTOP	AOV	1998	0	52560	2.46E-07	1.421	5771560	Gamma
FTOP	AOV	1999	0	52560	2.46E-07	1.421	5771560	Gamma
FTOP	AOV	2000	0	52560	2.46E-07	1.421	5771560	Gamma

Table 6. (continued).

Failure Mode	Component	Year	Number of Failures	Demands/Run Hours	Bayesian Update			Distribution
					Mean	Post A	Post B	
FTOP	AOV	2001	0	52560	2.46E-07	1.421	5771560	Gamma
FTOP	AOV	2002	0	52560	2.46E-07	1.421	5771560	Gamma
FTOP	AOV	2003	0	52560	2.46E-07	1.421	5771560	Gamma
FTOP	AOV	2004	0	52560	2.46E-07	1.421	5771560	Gamma
FTOP	AOV	2005	0	52560	2.46E-07	1.421	5771560	Gamma
FTOP	AOV	2006	0	52560	2.46E-07	1.421	5771560	Gamma
FTOP	AOV	2007	0	52560	2.46E-07	1.421	5771560	Gamma
FTOP	AOV	2008	0	52560	2.46E-07	1.421	5.77E+06	Gamma
FTOP	AOV	2009	0	52560	2.46E-07	1.421	5.77E+06	Gamma
FTOP	AOV	2010	0	52560	2.46E-07	1.421	5.77E+06	Gamma
FTOP	AOV	2011	0	52560	2.46E-07	1.421	5.77E+06	Gamma
FTOP	AOV	2012	0	52560	2.46E-07	1.421	5.77E+06	Gamma
FTOP	AOV	2013	0	52560	2.46E-07	1.421	5.77E+06	Gamma
FTOP	AOV	2014	0	61320	2.46E-07	1.421	5.78E+06	Gamma
FTOP	AOV	2015	0	61320	2.46E-07	1.421	5.78E+06	Gamma
FTOP	AOV	2016	0	61320	2.46E-07	1.421	5.78E+06	Gamma
FTOP	MOV	1998	0	2154960	6.02E-08	1.458	2.42E+07	Gamma
FTOP	MOV	1999	0	2146200	6.03E-08	1.458	2.42E+07	Gamma
FTOP	MOV	2000	0	2146200	6.03E-08	1.458	2.42E+07	Gamma
FTOP	MOV	2001	0	2146200	6.03E-08	1.458	2.42E+07	Gamma
FTOP	MOV	2002	0	2146200	6.03E-08	1.458	2.42E+07	Gamma
FTOP	MOV	2003	0	2146200	6.03E-08	1.458	2.42E+07	Gamma
FTOP	MOV	2004	0	2154960	6.02E-08	1.458	2.42E+07	Gamma
FTOP	MOV	2005	0	2154960	6.02E-08	1.458	2.42E+07	Gamma
FTOP	MOV	2006	0	2154960	6.02E-08	1.458	2.42E+07	Gamma
FTOP	MOV	2007	1	2154960	1.02E-07	2.458	2.42E+07	Gamma
FTOP	MOV	2008	0	2154960	6.02E-08	1.458	2.42E+07	Gamma
FTOP	MOV	2009	0	2172480	6.02E-08	1.458	2.42E+07	Gamma
FTOP	MOV	2010	0	2225040	6.01E-08	1.458	2.43E+07	Gamma
FTOP	MOV	2011	0	2163720	6.02E-08	1.458	2.42E+07	Gamma
FTOP	MOV	2012	0	2207520	6.01E-08	1.458	2.43E+07	Gamma
FTOP	MOV	2013	1	2163720	1.02E-07	2.458	2.42E+07	Gamma
FTOP	MOV	2014	0	2163720	6.02E-08	1.458	2.42E+07	Gamma
FTOP	MOV	2015	1	2181240	1.01E-07	2.458	2.42E+07	Gamma
FTOP	MOV	2016	0	2128680	6.03E-08	1.458	2.42E+07	Gamma
FTR<1H	TDP	1998	0	219.66	2.21E-03	0.9618	436.06	Gamma
FTR<1H	TDP	1999	0	212.79	2.24E-03	0.9618	429.19	Gamma
FTR<1H	TDP	2000	1	202.41	4.68E-03	1.9618	418.81	Gamma
FTR<1H	TDP	2001	0	191.04	2.36E-03	0.9618	407.44	Gamma
FTR<1H	TDP	2002	0	185.82	2.39E-03	0.9618	402.22	Gamma
FTR<1H	TDP	2003	2	192.26	7.25E-03	2.9618	408.66	Gamma
FTR<1H	TDP	2004	0	188.54	2.38E-03	0.9618	404.94	Gamma

Table 6. (continued).

Failure Mode	Component	Year	Number of Failures	Demands/Run Hours	Bayesian Update			Distribution
					Mean	Post A	Post B	
FTR<1H	TDP	2005	0	193.64	2.35E-03	0.9618	410.04	Gamma
FTR<1H	TDP	2006	0	204.74	2.28E-03	0.9618	421.14	Gamma
FTR<1H	TDP	2007	3	197.18	9.58E-03	3.9618	413.58	Gamma
FTR<1H	TDP	2008	1	196.44	4.75E-03	1.9618	412.84	Gamma
FTR<1H	TDP	2009	1	197.73	4.74E-03	1.9618	414.13	Gamma
FTR<1H	TDP	2010	0	194.7	2.34E-03	0.9618	411.1	Gamma
FTR<1H	TDP	2011	0	196.28	2.33E-03	0.9618	412.68	Gamma
FTR<1H	TDP	2012	0	190.3	2.36E-03	0.9618	406.7	Gamma
FTR<1H	TDP	2013	0	186.36	2.39E-03	0.9618	402.76	Gamma
FTR<1H	TDP	2014	0	175.36	2.46E-03	0.9618	391.76	Gamma
FTR<1H	TDP	2015	1	177.36	4.98E-03	1.9618	393.76	Gamma
FTR<1H	TDP	2016	2	193.36	7.23E-03	2.9618	409.76	Gamma
FTR>1H	TDP	1998	0	37.4	1.55E-03	12.5	8065.14	Gamma
FTR>1H	TDP	1999	0	52.32	1.55E-03	12.5	8080.06	Gamma
FTR>1H	TDP	2000	1	34.57	1.67E-03	13.5	8062.31	Gamma
FTR>1H	TDP	2001	0	37.79	1.55E-03	12.5	8065.53	Gamma
FTR>1H	TDP	2002	0	22.6	1.55E-03	12.5	8050.34	Gamma
FTR>1H	TDP	2003	0	22.9	1.55E-03	12.5	8050.64	Gamma
FTR>1H	TDP	2004	1	31.69	1.68E-03	13.5	8059.43	Gamma
FTR>1H	TDP	2005	0	24.93	1.55E-03	12.5	8052.67	Gamma
FTR>1H	TDP	2006	0	18.22	1.55E-03	12.5	8045.96	Gamma
FTR>1H	TDP	2007	0	18.21	1.55E-03	12.5	8045.95	Gamma
FTR>1H	TDP	2008	1	22.19	1.68E-03	13.5	8049.93	Gamma
FTR>1H	TDP	2009	0	116.31	1.53E-03	12.5	8144.05	Gamma
FTR>1H	TDP	2010	1	57.28	1.67E-03	13.5	8085.02	Gamma
FTR>1H	TDP	2011	2	28.46	1.80E-03	14.5	8056.2	Gamma
FTR>1H	TDP	2012	0	19.11	1.55E-03	12.5	8046.85	Gamma
FTR>1H	TDP	2013	1	32.72	1.67E-03	13.5	8060.46	Gamma
FTR>1H	TDP	2014	0	19.06	1.55E-03	12.5	8046.8	Gamma
FTR>1H	TDP	2015	0	22.46	1.55E-03	12.5	8050.2	Gamma
FTR>1H	TDP	2016	1	30.27	1.68E-03	13.5	8058.01	Gamma
FTS	TDP	1998	0	219.66	2.58E-03	0.9421	363.76	Beta
FTS	TDP	1999	3	212.79	1.10E-02	3.9421	353.89	Beta
FTS	TDP	2000	3	202.41	1.13E-02	3.9421	343.51	Beta
FTS	TDP	2001	1	191.04	5.78E-03	1.9421	334.14	Beta
FTS	TDP	2002	2	185.82	8.89E-03	2.9421	327.92	Beta
FTS	TDP	2003	1	192.26	5.76E-03	1.9421	335.36	Beta
FTS	TDP	2004	1	188.54	5.82E-03	1.9421	331.64	Beta
FTS	TDP	2005	2	193.64	8.69E-03	2.9421	335.74	Beta
FTS	TDP	2006	2	204.74	8.41E-03	2.9421	346.84	Beta
FTS	TDP	2007	2	197.18	8.60E-03	2.9421	339.28	Beta
FTS	TDP	2008	2	196.44	8.62E-03	2.9421	338.54	Beta

Table 6. (continued).

Failure Mode	Component	Year	Number of Failures	Demands/Run Hours	Bayesian Update			Distribution
					Mean	Post A	Post B	
FTS	TDP	2009	4	197.73	1.44E-02	4.9421	337.83	Beta
FTS	TDP	2010	2	194.7	8.66E-03	2.9421	336.8	Beta
FTS	TDP	2011	4	196.28	1.45E-02	4.9421	336.38	Beta
FTS	TDP	2012	1	190.3	5.79E-03	1.9421	3.33E+02	Beta
FTS	TDP	2013	3	186.36	1.19E-02	3.9421	3.27E+02	Beta
FTS	TDP	2014	0	175.36	2.94E-03	0.9421	3.19E+02	Beta
FTS	TDP	2015	0	177.36	2.92E-03	0.9421	3.21E+02	Beta
FTS	TDP	2016	3	193.36	1.16E-02	3.9421	3.34E+02	Beta
SO	AOV	1998	0	52560	1.29E-07	0.6801	5.26E+06	Gamma
SO	AOV	1999	0	52560	1.29E-07	0.6801	5.26E+06	Gamma
SO	AOV	2000	0	52560	1.29E-07	0.6801	5.26E+06	Gamma
SO	AOV	2001	0	52560	1.29E-07	0.6801	5.26E+06	Gamma
SO	AOV	2002	0	52560	1.29E-07	0.6801	5.26E+06	Gamma
SO	AOV	2003	0	52560	1.29E-07	0.6801	5.26E+06	Gamma
SO	AOV	2004	0	52560	1.29E-07	0.6801	5.26E+06	Gamma
SO	AOV	2005	0	52560	1.29E-07	0.6801	5.26E+06	Gamma
SO	AOV	2006	0	52560	1.29E-07	0.6801	5.26E+06	Gamma
SO	AOV	2007	0	52560	1.29E-07	0.6801	5.26E+06	Gamma
SO	AOV	2008	0	52560	1.29E-07	0.6801	5.26E+06	Gamma
SO	AOV	2009	0	52560	1.29E-07	0.6801	5.26E+06	Gamma
SO	AOV	2010	0	52560	1.29E-07	0.6801	5.26E+06	Gamma
SO	AOV	2011	0	52560	1.29E-07	0.6801	5.26E+06	Gamma
SO	AOV	2012	0	52560	1.29E-07	0.6801	5.26E+06	Gamma
SO	AOV	2013	0	52560	1.29E-07	0.6801	5.26E+06	Gamma
SO	AOV	2014	0	61320	1.29E-07	0.6801	5.27E+06	Gamma
SO	AOV	2015	0	61320	1.29E-07	0.6801	5.27E+06	Gamma
SO	AOV	2016	0	61320	1.29E-07	0.6801	5.27E+06	Gamma
SO	MOV	1998	0	2154960	3.00E-08	0.5703	1.90E+07	Gamma
SO	MOV	1999	0	2146200	3.00E-08	0.5703	1.90E+07	Gamma
SO	MOV	2000	1	2146200	8.27E-08	1.5703	1.90E+07	Gamma
SO	MOV	2001	0	2146200	3.00E-08	0.5703	1.90E+07	Gamma
SO	MOV	2002	0	2146200	3.00E-08	0.5703	1.90E+07	Gamma
SO	MOV	2003	1	2146200	8.27E-08	1.5703	1.90E+07	Gamma
SO	MOV	2004	0	2154960	3.00E-08	0.5703	1.90E+07	Gamma
SO	MOV	2005	0	2154960	3.00E-08	0.5703	1.90E+07	Gamma
SO	MOV	2006	0	2154960	3.00E-08	0.5703	1.90E+07	Gamma
SO	MOV	2007	1	2154960	8.27E-08	1.5703	1.90E+07	Gamma
SO	MOV	2008	0	2154960	3.00E-08	0.5703	1.90E+07	Gamma
SO	MOV	2009	0	2172480	3.00E-08	0.5703	1.90E+07	Gamma
SO	MOV	2010	1	2225040	8.24E-08	1.5703	1.91E+07	Gamma
SO	MOV	2011	0	2163720	3.00E-08	0.5703	1.90E+07	Gamma
SO	MOV	2012	0	2207520	2.99E-08	0.5703	1.90E+07	Gamma

Table 6. (continued).

Failure Mode	Component	Year	Number of Failures	Demands/Run Hours	Mean	Bayesian Update		Distribution
						Post A	Post B	
SO	MOV	2013	0	2163720	3.00E-08	0.5703	1.90E+07	Gamma
SO	MOV	2014	1	2163720	8.26E-08	1.5703	1.90E+07	Gamma
SO	MOV	2015	0	2181240	3.00E-08	0.5703	1.90E+07	Gamma
SO	MOV	2016	0	2128680	3.01E-08	0.5703	1.90E+07	Gamma

Table 7. Basic event UA trending data.

Failure Mode	Component	Year	UA Hours	Critical Hours	Bayesian Update			Distribution
					Mean	Post A	Post B	
UA	TDP	1998	2417.366	182188.2	1.42E-02	1.72253	119.6236	Beta
UA	TDP	1999	2263.647	195032.9	1.16E-02	2.395257	204.7883	Beta
UA	TDP	2000	2046.777	196239.8	1.04E-02	1.557902	148.1525	Beta
UA	TDP	2001	1735.021	195741.7	9.03E-03	0.955677	104.8613	Beta
UA	TDP	2002	2403.082	199988.7	1.21E-02	1.385625	113.0491	Beta
UA	TDP	2003	2378.24	194267.3	1.23E-02	1.759461	141.1044	Beta
UA	TDP	2004	2239.69	196465.3	1.16E-02	1.120674	95.13361	Beta
UA	TDP	2005	1626.882	195610.3	8.34E-03	2.118428	251.7593	Beta
UA	TDP	2006	1534.99	197941.4	7.81E-03	1.914931	243.3799	Beta
UA	TDP	2007	2758.37	196270.4	0.0141583	1.240662	86.38724	Beta
UA	TDP	2008	2718.49	199398.5	1.36E-02	0.582337	42.2021	Beta
UA	TDP	2009	2341.58	193543.9	1.20E-02	1.742351	143.0284	Beta
UA	TDP	2010	2263.44	197083.1	1.14E-02	2.50445	216.3027	Beta
UA	TDP	2011	2681.81	192786	1.40E-02	2.295593	161.9944	Beta
UA	TDP	2012	2631.7	192525	1.35E-02	2.036211	148.477	Beta
UA	TDP	2013	1924.92	193671.9	1.00E-02	1.777554	175.7393	Beta
UA	TDP	2014	2197.6	196708.4	1.12E-02	2.118918	186.9407	Beta
UA	TDP	2015	2246.72	189557.2	1.17E-02	3.009665	253.9717	Beta
UA	TDP	2016	2452.4	192415.1	1.26E-02	2.753159	214.954	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.

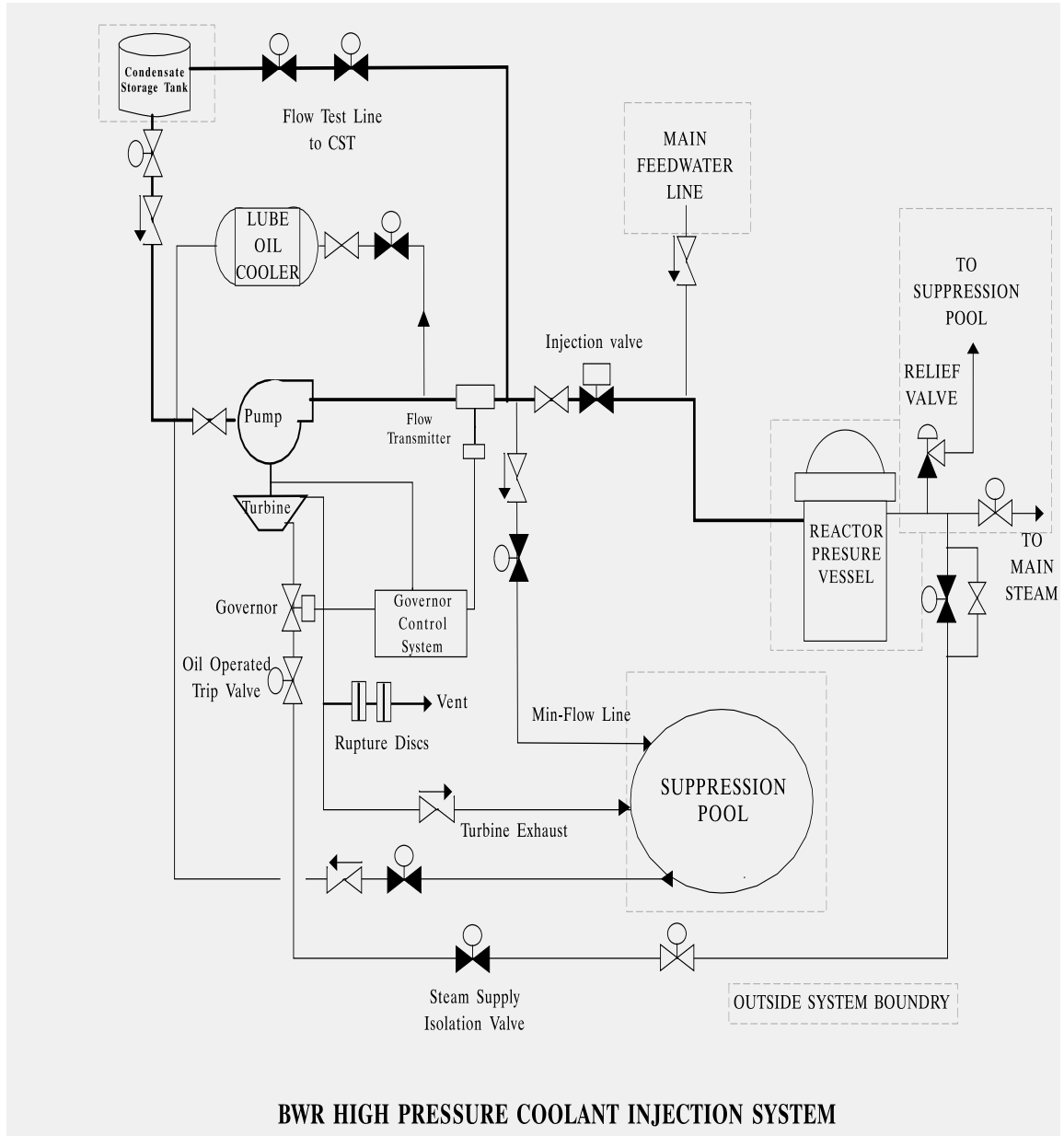


Figure 4. HPCI system diagram.

8. REFERENCES

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