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System Study: Reactor Core Isolation Cooling 1998–2012

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ABSTRACT

This report presents an unreliability evaluation of the reactor core isolation cooling (RCIC) system at 31 U.S. commercial boiling water reactors. Demand, run hours, and failure data from fiscal year 1998 through 2012 for selected components were obtained from the Equipment Performance and Information Exchange (EPIX). 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 trend was identified in the HPCI results. Statistically significant decreasing trends were identified for RCIC start-only and 8-hour trends.

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ACRONYMS

BWR	boiling water reactor
CCF	common-cause failure
CST	condensate storage tank
EPIX	Equipment Performance and Information Exchange
FY	fiscal year
MSPI	Mitigating Systems Performance Index
PRA	probabilistic risk assessment
RCIC	reactor core isolation cooling
SPAR	standardized plant analysis risk
SSU	safety system unavailability

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1. INTRODUCTION

This report presents an unreliability evaluation of the reactor core isolation cooling (RCIC) system at 31 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-12 for selected components in the RCIC system were obtained from the Equipment Performance and Information Exchange (EPIX) database. 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-12). 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 i), which is an update to Reference ii (NUREG/CR-6928). Baseline RCIC unreliability results using basic event values from that report are summarized in Section 0. Trend results for HPCI (using system-specific data) are presented in Section 3. Similar to previous system study updates, Section 4 contains importance information (using the baseline results from Section 0), and Section 6 describes the RCIC.

The RCIC 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 RCIC 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 RCIC system are calculated. The RCIC start-only model is the SPAR RCIC 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 suppression pool to False, and setting all cooling basic events to False. The 8-hour mission model includes all basic events in the SPAR RCIC model.

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

Plant	Version
Duane Arnold	8.22
Browns Ferry 1	8.22
Browns Ferry 2	8.22
Browns Ferry 3	8.18
Brunswick 1	8.20
Brunswick 2	8.20
Clinton 1	8.17
Columbia 2	8.16
Cooper	8.22
Fermi 2	8.20
FitzPatrick	8.17
Grand Gulf	8.22
Hatch 1	8.20
Hatch 2	8.20
Hope Creek	8.18
Limerick 1	8.20
Limerick 2	8.19
La Salle 1	8.21
La Salle 2	8.21
Monticello	8.20
Nine Mile Pt. 2	8.17
Peach Bottom 2	8.25
Peach Bottom 3	8.21
Perry	8.19
Pilgrim	8.21
Quad Cities 1	8.18
Quad Cities 2	8.18
River Bend	8.20
Susquehanna 1	8.23
Susquehanna 2	8.21
Vermont Yankee	8.19

2. SUMMARY OF FINDINGS

The results of this RCIC 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 RCIC unreliability trend results. In addition, this update identified statistically significant decreasing trends in the RCIC results for both the RCIC start-only and 8-hour trends.

The industry-wide RCIC start-only and 8-hour basic event group importances were evaluated and are shown in Figure 3. In both cases, the leading contributor to RCIC system unreliability is the RCIC turbine-driven pump group of basic events. Recovery, restart, and the suppression pool are important to the 8-hour mission model.

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[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 RCIC fault trees from the SPAR models were evaluated for each of the 31 operating U.S. commercial boiling water nuclear power plants with a RCIC system.

The industry-wide unreliability of the RCIC 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 RCIC show both plant design variability and parameter uncertainty from the industry-wide component failure data (FY-98 through FY-10).[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 RCIC 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	1.09E−02	2.36E−02	2.94E−02	6.62E−02
8-hour	2.59E−02	5.11E−02	5.72E−02	1.08E−01

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[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-98 through FY-12) failure and demand or run time data were obtained from EPIX for the RCIC system. RCIC 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 RCIC 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 RCIC system specific component and failure mode combination that was varied in the model. These data were loaded into the RCIC system fault tree in each SPAR model with a RCIC 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 from this update (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 and failure modes that were varied in the RCIC model are

RCIC turbine-driven pump start, run, and test and maintenance.

RCIC injection MOV fail-to-open.

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

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

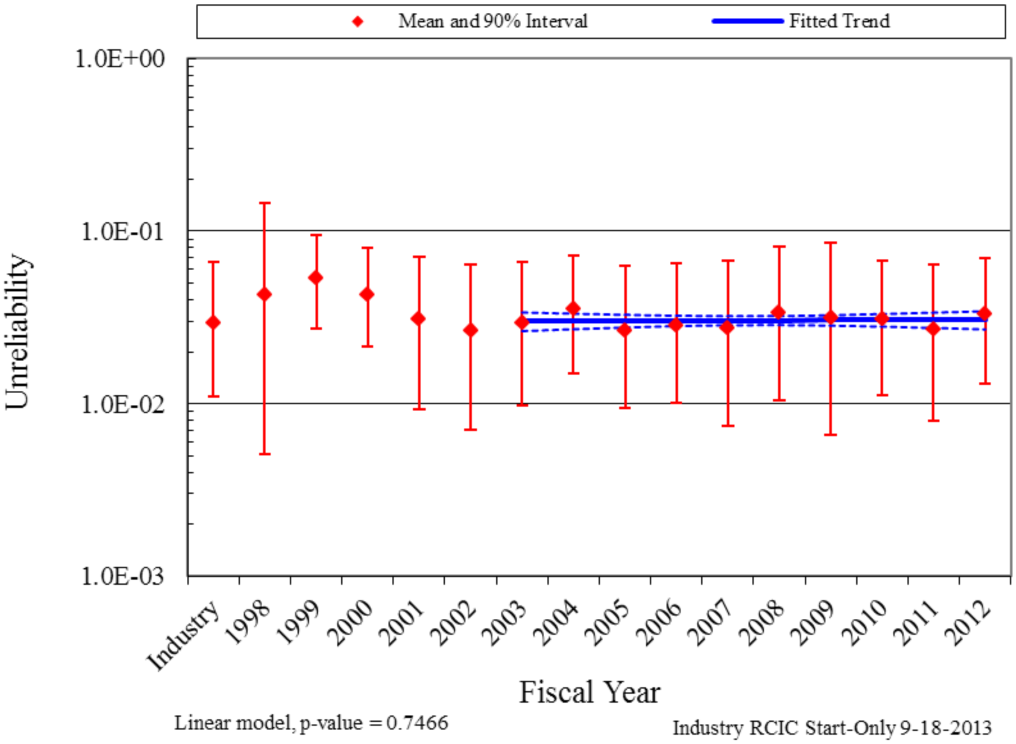


Figure 1. Trend of RCIC system unreliability (start-only model), as a function of fiscal year.

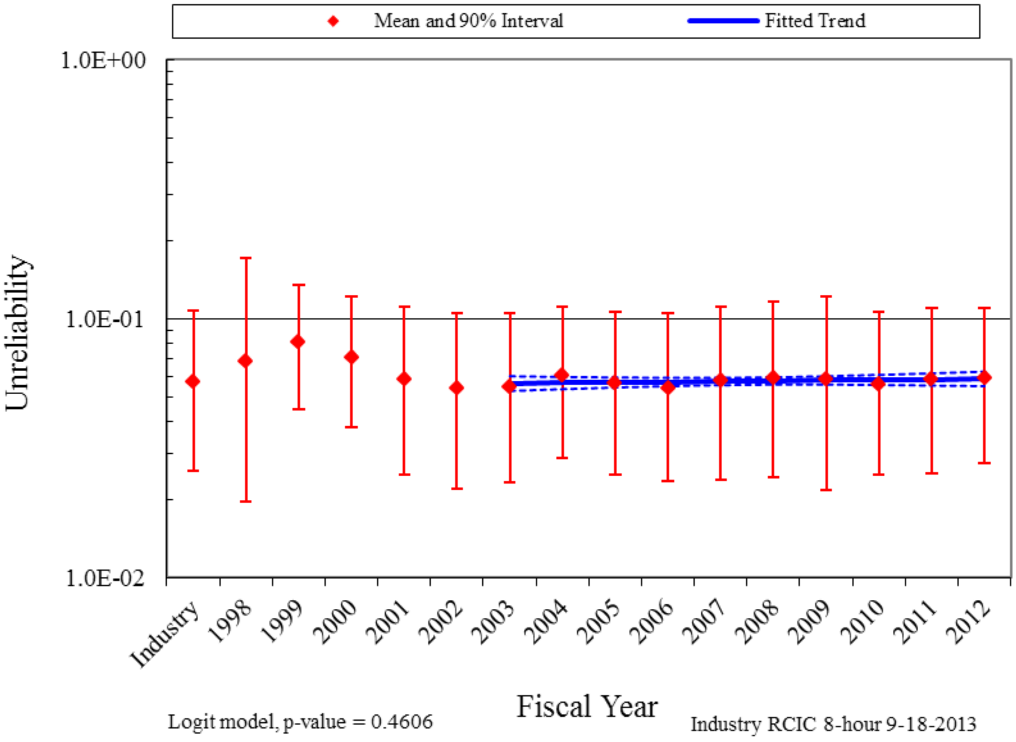


Figure 2. Trend of RCIC system unreliability (8-hour model), as a function of fiscal year.

5. BASIC EVENT GROUP IMPORTANCES

The RCIC 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 RCIC start-only and 8-hour basic event group importances are shown in Figure 3.

In both cases, the leading contributor to RCIC system unreliability is the RCIC turbine-driven pump group of basic events. Recovery, restart, and the suppression pool are important to the 8-hour mission model. For more discussion on the RCIC turbine-driven pumps, see the turbine-driven pump component reliability study at NRC Reactor Operational Experience Results and Databases web site. Table 3 shows the SPAR model RCIC importance groups and their descriptions.

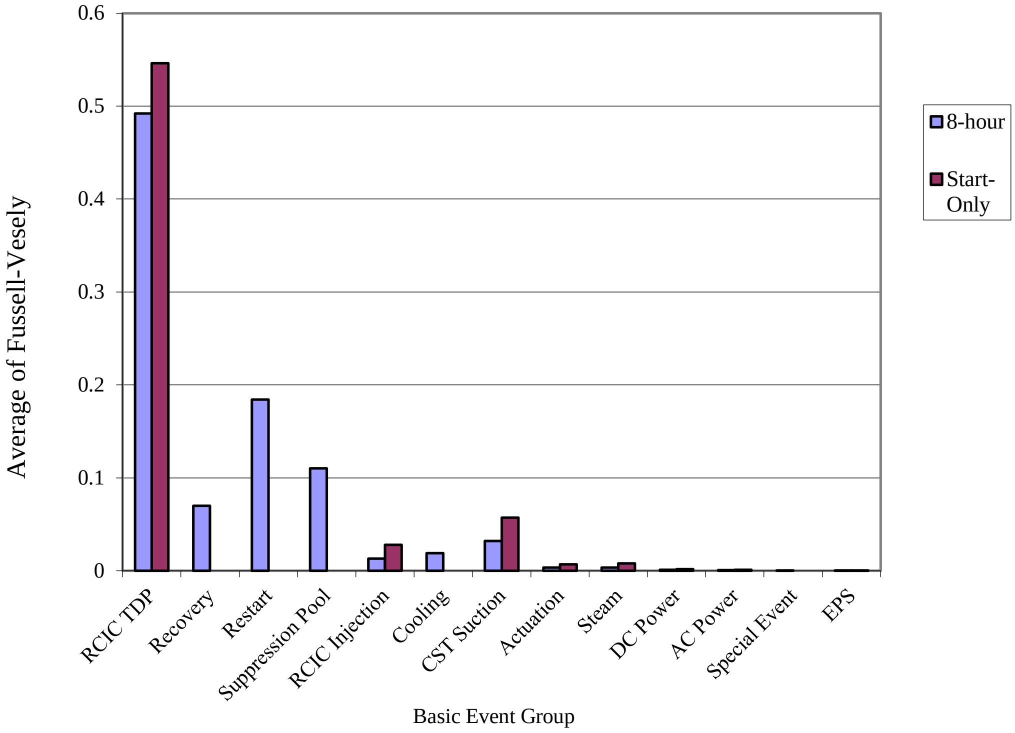


Figure 3. RCIC basic event group importances.

Table 3. RCIC 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 motor-operated valves.
Actuation	ESF actuation circuitry.
Cooling	The pumps, valves, and heat exchangers that provide heat removal to the RCIC turbine-driven pump and the RCIC room.
CST Suction	The motor-operated valves and air-operated valves in the condensate storage tank suction path. Includes the failure of the condensate storage tank.
DC Power	The batteries and battery chargers that supply power to the RCIC turbine-driven pump control circuitry.
EPS	RCIC dependency on the emergency power system.
RCIC Injection	The motor-operated valves and check valves in the RCIC injection path.
RCIC TDP	All basic events associated with the turbine-driven pumps. The start, run, common-cause, and test and maintenance are included in this group of basic events.
Recovery	The operator recovery of the TDP FTS, FTR, and other specialized modeled recovery events.
Restart	The required restart of the RCIC turbine-driven pump. Includes the probability that restart is required and the probability that the turbine-driven pump will restart.
Special Event	Various events used in the models that are not directly associated with the RCIC system.
Steam	The turbine steam supply valves.
Suppression Pool	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 RCIC start-only trend, Figure 1.

	Regression Curve Data Points			Plot Trend Error Bar Points		
FY/Source	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
SPAR/ EPIX				1.09E−02	6.62E−02	2.94E−02
1998				5.13E−03	1.45E−01	4.27E−02
1999				2.71E−02	9.56E−02	5.37E−02
2000				2.13E−02	8.00E−02	4.27E−02
2001				9.21E−03	7.11E−02	3.09E−02
2002				7.10E−03	6.41E−02	2.66E−02
2003	3.01E−02	2.64E−02	3.38E−02	9.75E−03	6.66E−02	2.95E−02
2004	3.02E−02	2.71E−02	3.33E−02	1.49E−02	7.21E−02	3.53E−02
2005	3.02E−02	2.77E−02	3.28E−02	9.50E−03	6.28E−02	2.67E−02
2006	3.03E−02	2.82E−02	3.24E−02	1.01E−02	6.48E−02	2.84E−02
2007	3.04E−02	2.85E−02	3.22E−02	7.38E−03	6.75E−02	2.77E−02
2008	3.04E−02	2.86E−02	3.23E−02	1.04E−02	8.13E−02	3.40E−02
2009	3.05E−02	2.84E−02	3.26E−02	6.56E−03	8.61E−02	3.13E−02
2010	3.06E−02	2.80E−02	3.31E−02	1.12E−02	6.76E−02	3.08E−02
2011	3.06E−02	2.75E−02	3.37E−02	7.91E−03	6.45E−02	2.72E−02
2012	3.07E−02	2.70E−02	3.44E−02	1.30E−02	6.98E−02	3.30E−02

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

	Regression Curve Data Points			Plot Trend Error Bar Points		
FY/Source	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
SPAR/ EPIX				2.59E−02	1.08E−01	5.72E−02
1998				1.96E−02	1.72E−01	6.88E−02
1999				4.48E−02	1.35E−01	8.13E−02
2000				3.82E−02	1.22E−01	7.11E−02
2001				2.49E−02	1.11E−01	5.84E−02
2002				2.21E−02	1.05E−01	5.39E−02
2003	5.62E−02	5.26E−02	6.00E−02	2.33E−02	1.05E−01	5.44E−02
2004	5.64E−02	5.34E−02	5.96E−02	2.90E−02	1.11E−01	6.05E−02
2005	5.67E−02	5.42E−02	5.93E−02	2.51E−02	1.07E−01	5.61E−02
2006	5.70E−02	5.49E−02	5.91E−02	2.37E−02	1.05E−01	5.40E−02
2007	5.72E−02	5.54E−02	5.91E−02	2.39E−02	1.11E−01	5.76E−02
2008	5.75E−02	5.57E−02	5.94E−02	2.44E−02	1.16E−01	5.93E−02
2009	5.78E−02	5.57E−02	5.99E−02	2.18E−02	1.21E−01	5.86E−02
2010	5.80E−02	5.55E−02	6.07E−02	2.50E−02	1.07E−01	5.60E−02
2011	5.83E−02	5.52E−02	6.16E−02	2.53E−02	1.10E−01	5.83E−02
2012	5.86E−02	5.49E−02	6.25E−02	2.76E−02	1.10E−01	5.92E−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	74.19	0.00089439	1.112	1242.19	Beta
FTOC	AOV	1999	0	75.36	0.00089355	1.112	1243.36	Beta
FTOC	AOV	2000	0	75.36	0.00089355	1.112	1243.36	Beta
FTOC	AOV	2001	0	75.36	0.00089355	1.112	1243.36	Beta
FTOC	AOV	2002	0	75.36	0.00089355	1.112	1243.36	Beta
FTOC	AOV	2003	0	75.12	0.00089372	1.112	1243.12	Beta
FTOC	AOV	2004	0	75.36	0.00089355	1.112	1243.36	Beta
FTOC	AOV	2005	0	75.36	0.00089355	1.112	1243.36	Beta
FTOC	AOV	2006	0	73.02	0.00089524	1.112	1241.02	Beta
FTOC	AOV	2007	0	71.68	0.0008962	1.112	1239.68	Beta
FTOC	AOV	2008	1	74.82	0.00169784	2.112	1241.82	Beta
FTOC	AOV	2009	0	76.2	0.00089295	1.112	1244.2	Beta
FTOC	AOV	2010	0	76.2	0.00089295	1.112	1244.2	Beta
FTOC	AOV	2011	0	76.2	0.00089295	1.112	1244.2	Beta
FTOC	AOV	2012	0	76.2	0.00089295	1.112	1244.2	Beta
FTOC	MOV	1998	3	2396.01	0.00111611	5.046	4516.01	Beta
FTOC	MOV	1999	7	2491.29	0.00195956	9.046	4607.29	Beta
FTOC	MOV	2000	4	2517.11	0.00130241	6.046	4636.11	Beta
FTOC	MOV	2001	5	2703.81	0.00145915	7.046	4821.81	Beta
FTOC	MOV	2002	3	2788.44	0.00102697	5.046	4908.44	Beta
FTOC	MOV	2003	2	3397.36	0.00073265	4.046	5518.36	Beta
FTOC	MOV	2004	2	2609.3	0.00085461	4.046	4730.3	Beta
FTOC	MOV	2005	4	2670.81	0.00126067	6.046	4789.81	Beta
FTOC	MOV	2006	3	2655.23	0.00105559	5.046	4775.23	Beta
FTOC	MOV	2007	3	2707.89	0.00104409	5.046	4827.89	Beta
FTOC	MOV	2008	2	2783.74	0.00082424	4.046	4904.74	Beta
FTOC	MOV	2009	2	2683.9	0.00084135	4.046	4804.9	Beta
FTOC	MOV	2010	1	2651.3	0.00063773	3.046	4773.3	Beta
FTOC	MOV	2011	2	2584.58	0.00085909	4.046	4705.58	Beta
FTOC	MOV	2012	3	2682.45	0.00104961	5.046	4802.45	Beta
FTOP	AOV	1998	0	61320	2.4583E−07	1.421	5780320	Gamma
FTOP	AOV	1999	0	61320	2.4583E−07	1.421	5780320	Gamma
FTOP	AOV	2000	0	61320	2.4583E−07	1.421	5780320	Gamma
FTOP	AOV	2001	0	61320	2.4583E−07	1.421	5780320	Gamma
FTOP	AOV	2002	0	61320	2.4583E−07	1.421	5780320	Gamma
FTOP	AOV	2003	0	61320	2.4583E−07	1.421	5780320	Gamma
FTOP	AOV	2004	0	61320	2.4583E−07	1.421	5780320	Gamma
FTOP	AOV	2005	0	61320	2.4583E−07	1.421	5780320	Gamma
FTOP	AOV	2006	0	61320	2.4583E−07	1.421	5780320	Gamma
FTOP	AOV	2007	0	52560	2.4621E−07	1.421	5771560	Gamma
FTOP	AOV	2008	0	52560	2.4621E−07	1.421	5771560	Gamma

Table 6. (continued).

Failure Mode	Component	Year	Number of Failures	Demands/ Run Hours	Bayesian Update			
					Mean	Post A	Post B	Distribution
FTOP	AOV	2009	0	52560	2.4621E−07	1.421	5771560	Gamma
FTOP	AOV	2010	0	52560	2.4621E−07	1.421	5771560	Gamma
FTOP	AOV	2011	0	52560	2.4621E−07	1.421	5771560	Gamma
FTOP	AOV	2012	1	52560	4.1947E−07	2.421	5771560	Gamma
FTOP	MOV	1998	0	2522880	5.9334E−08	1.458	24572880	Gamma
FTOP	MOV	1999	2	2549160	1.4057E−07	3.458	24599160	Gamma
FTOP	MOV	2000	0	2575440	5.9207E−08	1.458	24625440	Gamma
FTOP	MOV	2001	0	2549160	5.927E−08	1.458	24599160	Gamma
FTOP	MOV	2002	0	2549160	5.927E−08	1.458	24599160	Gamma
FTOP	MOV	2003	0	2549160	5.927E−08	1.458	24599160	Gamma
FTOP	MOV	2004	0	2549160	5.927E−08	1.458	24599160	Gamma
FTOP	MOV	2005	0	2549160	5.927E−08	1.458	24599160	Gamma
FTOP	MOV	2006	0	2566680	5.9228E−08	1.458	24616680	Gamma
FTOP	MOV	2007	0	2566680	5.9228E−08	1.458	24616680	Gamma
FTOP	MOV	2008	0	2566680	5.9228E−08	1.458	24616680	Gamma
FTOP	MOV	2009	0	2566680	5.9228E−08	1.458	24616680	Gamma
FTOP	MOV	2010	0	2654280	5.9018E−08	1.458	24704280	Gamma
FTOP	MOV	2011	0	2645520	5.9039E−08	1.458	24695520	Gamma
FTOP	MOV	2012	0	2592960	5.9165E−08	1.458	24642960	Gamma
FTR<1H	TDP	1998	0	241.87	0.00209876	0.9618	458.27	Gamma
FTR<1H	TDP	1999	1	239.4	0.00430408	1.9618	455.8	Gamma
FTR<1H	TDP	2000	2	279.27	0.00597535	2.9618	495.67	Gamma
FTR<1H	TDP	2001	1	283.18	0.0039269	1.9618	499.58	Gamma
FTR<1H	TDP	2002	1	291.57	0.00386204	1.9618	507.97	Gamma
FTR<1H	TDP	2003	0	366.36	0.00165042	0.9618	582.76	Gamma
FTR<1H	TDP	2004	0	277.02	0.00194925	0.9618	493.42	Gamma
FTR<1H	TDP	2005	2	287.56	0.00587705	2.9618	503.96	Gamma
FTR<1H	TDP	2006	0	273.92	0.00196158	0.9618	490.32	Gamma
FTR<1H	TDP	2007	2	287.07	0.00588277	2.9618	503.47	Gamma
FTR<1H	TDP	2008	0	262.09	0.00201007	0.9618	478.49	Gamma
FTR<1H	TDP	2009	1	258.87	0.00412776	1.9618	475.27	Gamma
FTR<1H	TDP	2010	0	267.77	0.00198649	0.9618	484.17	Gamma
FTR<1H	TDP	2011	3	268.33	0.00817321	3.9618	484.73	Gamma
FTR<1H	TDP	2012	0	274.01	0.00196122	0.9618	490.41	Gamma
FTR>1H	TDP	1998	1	53.82	0.00167047	13.5	8081.56	Gamma
FTR>1H	TDP	1999	0	64.19	0.00154475	12.5	8091.93	Gamma
FTR>1H	TDP	2000	0	46.96	0.00154805	12.5	8074.7	Gamma
FTR>1H	TDP	2001	0	157.33	0.00152717	12.5	8185.07	Gamma
FTR>1H	TDP	2002	0	53.98	0.0015467	12.5	8081.72	Gamma
FTR>1H	TDP	2003	0	86.41	0.00154052	12.5	8114.15	Gamma
FTR>1H	TDP	2004	0	33.35	0.00155066	12.5	8061.09	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	2005	0	34.39	0.00155046	12.5	8062.13	Gamma
FTR>1H	TDP	2006	0	40.52	0.00154928	12.5	8068.26	Gamma
FTR>1H	TDP	2007	1	36.41	0.00167408	13.5	8064.15	Gamma
FTR>1H	TDP	2008	0	58.65	0.00154581	12.5	8086.39	Gamma
FTR>1H	TDP	2009	0	38.54	0.00154966	12.5	8066.28	Gamma
FTR>1H	TDP	2010	0	74.12	0.00154286	12.5	8101.86	Gamma
FTR>1H	TDP	2011	0	33.69	0.00155059	12.5	8061.43	Gamma
FTR>1H	TDP	2012	1	72.58	0.0016666	13.5	8100.32	Gamma
FTS	TDP	1998	1	241.87	0.00501949	1.9421	384.97	Beta
FTS	TDP	1999	9	239.4	0.02586111	9.9421	374.5	Beta
FTS	TDP	2000	7	279.27	0.01871759	7.9421	416.37	Beta
FTS	TDP	2001	2	283.18	0.0068705	2.9421	425.28	Beta
FTS	TDP	2002	0	291.57	0.00215775	0.9421	435.67	Beta
FTS	TDP	2003	2	366.36	0.00575301	2.9421	508.46	Beta
FTS	TDP	2004	5	277.02	0.01407873	5.9421	416.12	Beta
FTS	TDP	2005	2	287.56	0.00680094	2.9421	429.66	Beta
FTS	TDP	2006	2	273.92	0.00702235	2.9421	416.02	Beta
FTS	TDP	2007	2	287.07	0.00680865	2.9421	429.17	Beta
FTS	TDP	2008	4	262.09	0.01213881	4.9421	402.19	Beta
FTS	TDP	2009	2	258.87	0.00728401	2.9421	400.97	Beta
FTS	TDP	2010	3	267.77	0.00954938	3.9421	408.87	Beta
FTS	TDP	2011	1	268.33	0.00469819	1.9421	411.43	Beta
FTS	TDP	2012	3	274.01	0.00940718	3.9421	415.11	Beta
SO	AOV	1998	0	61320	1.2899E−07	0.6801	5272320	Gamma
SO	AOV	1999	0	61320	1.2899E−07	0.6801	5272320	Gamma
SO	AOV	2000	0	61320	1.2899E−07	0.6801	5272320	Gamma
SO	AOV	2001	0	61320	1.2899E−07	0.6801	5272320	Gamma
SO	AOV	2002	0	61320	1.2899E−07	0.6801	5272320	Gamma
SO	AOV	2003	0	61320	1.2899E−07	0.6801	5272320	Gamma
SO	AOV	2004	0	61320	1.2899E−07	0.6801	5272320	Gamma
SO	AOV	2005	0	61320	1.2899E−07	0.6801	5272320	Gamma
SO	AOV	2006	0	61320	1.2899E−07	0.6801	5272320	Gamma
SO	AOV	2007	0	52560	1.2921E−07	0.6801	5263560	Gamma
SO	AOV	2008	0	52560	1.2921E−07	0.6801	5263560	Gamma
SO	AOV	2009	0	52560	1.2921E−07	0.6801	5263560	Gamma
SO	AOV	2010	0	52560	1.2921E−07	0.6801	5263560	Gamma
SO	AOV	2011	0	52560	1.2921E−07	0.6801	5263560	Gamma
SO	AOV	2012	0	52560	1.2921E−07	0.6801	5263560	Gamma
SO	MOV	1998	0	2522880	2.9453E−08	0.5703	19362880	Gamma
SO	MOV	1999	0	2549160	2.9413E−08	0.5703	19389160	Gamma
SO	MOV	2000	3	2575440	1.8389E−07	3.5703	19415440	Gamma

Table 6. (continued).

Failure Mode	Component	Year	Number of Failures	Demands/ Run Hours	Bayesian Update Mean	Post A	Post B	Distribution
SO	MOV	2001	0	2549160	2.9413E−08	0.5703	19389160	Gamma
SO	MOV	2002	1	2549160	8.0989E−08	1.5703	19389160	Gamma
SO	MOV	2003	0	2549160	2.9413E−08	0.5703	19389160	Gamma
SO	MOV	2004	0	2549160	2.9413E−08	0.5703	19389160	Gamma
SO	MOV	2005	0	2549160	2.9413E−08	0.5703	19389160	Gamma
SO	MOV	2006	0	2566680	2.9387E−08	0.5703	19406680	Gamma
SO	MOV	2007	0	2566680	2.9387E−08	0.5703	19406680	Gamma
SO	MOV	2008	1	2566680	8.0915E−08	1.5703	19406680	Gamma
SO	MOV	2009	1	2566680	8.0915E−08	1.5703	19406680	Gamma
SO	MOV	2010	0	2654280	2.9255E−08	0.5703	19494280	Gamma
SO	MOV	2011	0	2645520	2.9268E−08	0.5703	19485520	Gamma
SO	MOV	2012	0	2592960	2.9347E−08	0.5703	19432960	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	3131.6	154326.6	2.57E−02	0.3	9.9	Beta
UA	TDP	1999	3319.7	227439.9	1.51E−02	1.4	94.2	Beta
UA	TDP	2000	2706.7	243437.4	1.12E−02	3.1	270.1	Beta
UA	TDP	2001	2754.0	245991.8	1.14E−02	1.0	90.7	Beta
UA	TDP	2002	2994.9	246142.9	1.23E−02	2.0	161.6	Beta
UA	TDP	2003	2899.3	242005.8	1.21E−02	2.2	178.4	Beta
UA	TDP	2004	2373.6	249749.7	9.51E−03	1.8	191.4	Beta
UA	TDP	2005	1755.8	241269.1	7.45E−03	2.4	323.3	Beta
UA	TDP	2006	2319.1	248995.0	9.26E−03	2.4	255.7	Beta
UA	TDP	2007	2131.8	244139.3	8.71E−03	0.7	82.5	Beta
UA	TDP	2008	2498.6	246900.5	1.02E−02	0.4	42.4	Beta
UA	TDP	2009	2847.7	241882.6	1.22E−02	0.4	29.4	Beta
UA	TDP	2010	2400.5	247135.2	9.81E−03	1.9	195.9	Beta
UA	TDP	2011	2461.2	238519.8	1.06E−02	1.8	165.7	Beta
UA	TDP	2012	2847.5	242703.2	1.16E−02	2.5	215.2	Beta

Table 8. Failure mode acronyms.

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

7. SYSTEM DESCRIPTION

This is a generic description of the RCIC system. The models in SPAR incorporate plant-specific features that may not be described here.

The RCIC system is a single train standby system required by plant technical specifications for safe shut down of the plant. The system is not considered part of the emergency core cooling system, and does not have a loss-of-coolant accident function. The RCIC system is designed to ensure that sufficient reactor water inventory is maintained in the vessel to permit adequate core cooling. This prevents the reactor fuel from overheating in the event that one of the following occurs:

- A complete plant shut down occurs under conditions of a loss of the feedwater system before the reactor is depressurized to a point where the shutdown cooling system can be placed into operation
- The reactor pressure vessel is isolated in conjunction with a loss of coolant flow from the feedwater system
- A station blackout event occurs.

Following a normal reactor shut down, core fission product decay heat causes steam generation to continue, albeit at a reduced rate. During this time, the turbine bypass system diverts the steam to the main condenser, and the RCIC system supplies the makeup water required to maintain reactor vessel inventory. (Note that the RCIC system is just one of a number of systems capable of performing this function.) The turbine-driven pump supplies makeup water from the condensate storage tank (CST) to the reactor vessel. An alternate source of water is available from the suppression pool. The turbine is driven by a portion of the steam generated by the decay heat and exhausts to the suppression pool. This operation continues until the vessel pressure and temperature is reduced to the point that the residual heat removal system can be placed into operation.

The RCIC system is a single train standby system that contains a single 100% capacity steam turbine-driven pump. The RCIC system is capable of delivering reactor grade water from the CST to the reactor pressure vessel using reactor-decay-heat-generated steam as a source of energy to drive the turbine-driven pump. In the event that CST water is not available, an alternate source of water is available from the suppression pool. 19H19HFigure 4 provides a simplified diagram of a typical RCIC system.

The RCIC system steam turbines (at all plants) are Dresser-Rand Terry-Turbodyne (Terry) turbines designed for constant capacity over varying ranges of inlet steam pressure, typically 1040 psig to 50 psig. These turbines have horsepower ratings that vary from 460 to 875 with associated pump flow rates from 400 to 800 gpm, depending on plant design. All Terry turbines that drive RCIC pumps use Woodward governors (type EG-M with EGR actuators) for speed control, including prevention of overspeed during “cold quick-starts.” The ratings for the RCIC system varies by plant design class, with the older Design Class II plants having the smaller capacity systems and the newer Design Class VI plants having the higher capacity systems. However, because of the overall similarities of the system in the various design classes (same equipment manufacturer), no distinction was made in this report between the different design classes.

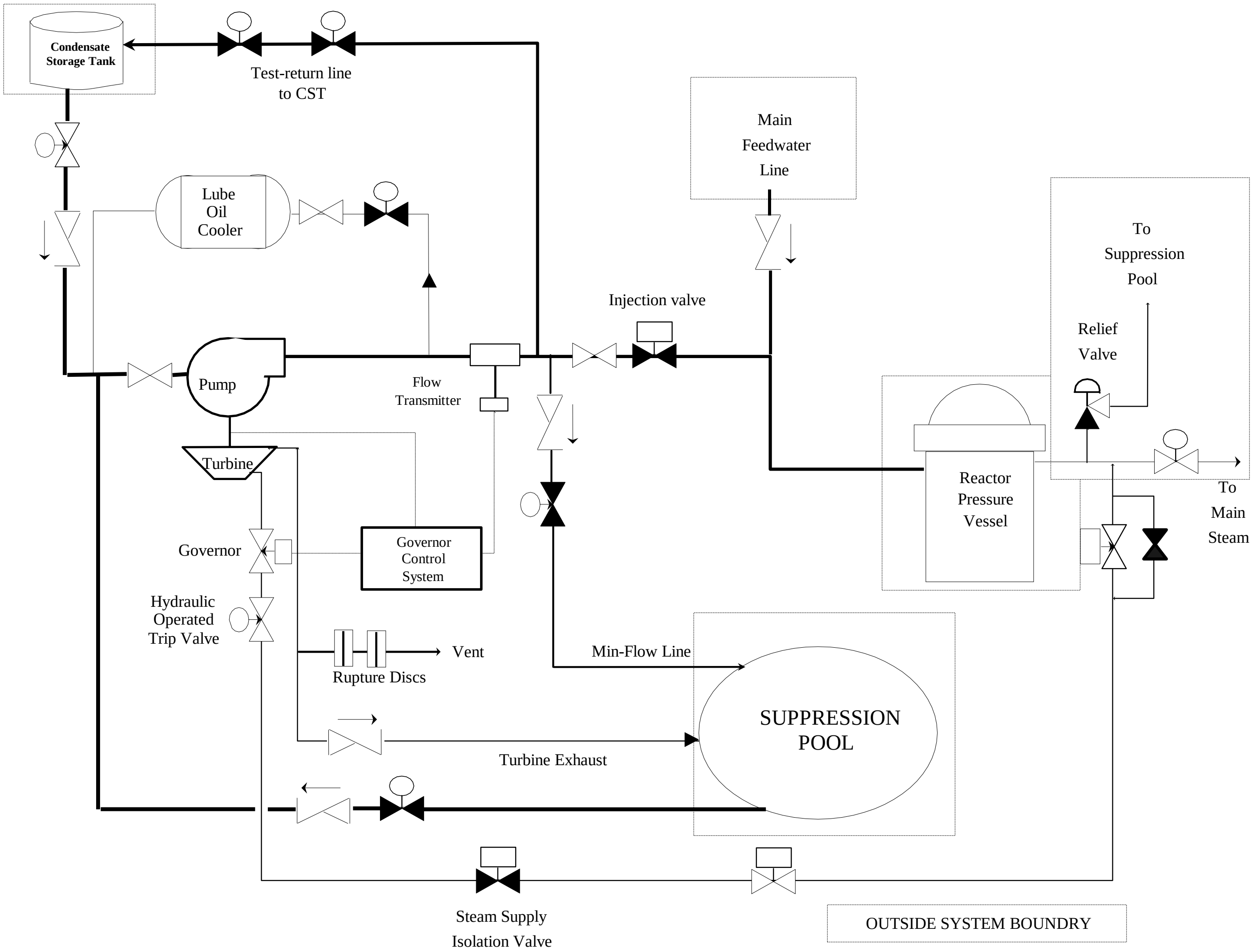
Turbine “cold quick-starts” are required to meet pump starting time limits in Safety Analysis Reports, and other requirements specified to meet the reactor safety analyses of the nuclear steam supply system vendor. A cold start is considered a start that occurs when a turbine has not been operated for at least 72 hours. Turbine “quick-starts” occur when the turbine is required to reach rated speed and pump flow in 30 to 120 seconds. Since standby turbines are idle for extended periods, lubricating oil drains from the turbine bearings, leaving the bearings vulnerable to excessive wear. Standby turbines supplied by Terry typically also use turbine lubricating oil as the hydraulic operating fluid for the governors and actuators. To provide bearing lubrication and governor oil on quick starts, a pressurized lubrication oil system is provided, which uses a shaft-driven lubrication oil pump. The shaft-driven pump provides lubrication oil to the turbine bearings and governor assembly as soon as the turbine begins to roll, enhancing both turbine lubrication and governor response.

To control turbine speed, a governor valve is provided for the turbine; the valve is typically supplied by Terry. The governor valve is fully open at the beginning of a quick-start and is designed to assume speed control during the startup when the turbine speed reaches the governor's minimum speed setting (approximately 2000 rpm). During a quick start the turbine steam admission valve opens fully and the turbine accelerates rapidly to the governor's minimum speed setting. At the minimum speed setting the governor starts to control turbine speed by throttling closed the governor valve. This limits the acceleration of the turbine to prevent an overspeed trip of the turbine. The closing of the governor valve slows the turbine to a speed less than the minimum speed. At this point the governor in conjunction with the ramp-generator increases turbine speed in a controlled manner to rated speed by slowly opening the governor valve. The ramp-generator controls and limits the time for the turbine to reach rated speed to approximately 30 seconds after the governor gains control. If inlet steam flow is excessive during a quick start, the governor valve cannot close sufficiently to limit speed before the turbine overspeeds.

The RCIC system instrumentation and control consists of system initiation and containment isolation circuitry. These two circuits provide different functions, both of which can contribute to system unreliability. The purpose of the initiation circuitry is to initiate actions (that is, start up the RCIC system) to ensure adequate core cooling when the reactor vessel is isolated from its primary heat sink and normal coolant makeup flow from the feedwater system is insufficient or unavailable. The purpose of the containment isolation circuitry is to initiate closure of appropriate containment isolation valves to limit fission product release should a RCIC steam line rupture occur.

The RCIC system initiation circuit allows for manual and automatic initiation of the system. Automatic initiation occurs for conditions of low reactor water level. The low reactor water level parameter is monitored by four transmitters that are connected to relays whose contacts are arranged in a one-out-of-two taken twice logic arrangement. Once initiated, the RCIC logic seals in and can be reset by the operator only when the reactor vessel level signals have cleared. Upon system initiation, the turbine steam supply valve opens to supply steam to the turbine, and the injection valve and the suction valve from the CST open to supply coolant flow to the reactor pressure vessel. In addition, the test-return line isolation valve is closed to allow full system flow and maintain primary containment isolation. Failure of any one of these valves to function during an initiation results in a failure of the system.

The RCIC system containment isolation circuitry typically provides automatic closure of the RCIC turbine steam supply isolation valves and turbine exhaust valve in the event of a steam line failure (high energy line break). The parameters monitored typically include high steam flow, low steam line pressure, high room delta-temperature, and high area temperature. Isolation of these valves disables the RCIC injection function: however, failure of this circuit to close these valves would not preclude operation of the system. During system standby a spurious isolation of the steam supply line caused by this circuit contributes to system unavailability, and during system operation the spurious isolation can contribute to system unreliability.



BWR Reactor Core Isolation Cooling

Figure 4. Simplified RCIC system schematic.

8. REFERENCES

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