Component Reliability Data Sheets

Update 2010

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UPDATE NOTES

This file represents the first update to the original set of component reliability data sheets, which was completed in February 2007. The original set of component reliability data sheets were extracted from NUREG/CR-6928 [Reference 14] and generally contained data from the date range of 1998 to 2002. This file generally represents reliability results using a date range of 1998 to 2010 directly analyzed using the Reliability and Availability Data System (RADS).

The date of each reliability update sheet is in the footer of the reliability data sheet. Some of the reliability data sheets have not been updated since the original NUREG/CR-6928 since the particular piece of data is not maintained (e.g., Reactor Protection System (RPS) components) and have February 2007 in the footer.

There have been several major enhancements to the collection and analysis of reliability data since the original issue of NUREG/CR-6928. The following is a summary of those changes:

1. Most of the reliability results, included herein, are taken directly from RADS. The Equipment Performance Information Exchange (EPIX) data loaded into RADS has undergone significant review and scrutiny by the staff at the Idaho National Engineering Laboratory (INL) to prepare the data to be useful in probabilistic risk assessments (PRAs). Most of the EPIX failure data are being updated to reflect the results of the data collection and coding taken at the INL. In addition, the demand and run-hour data have been scrutinized before data load to remove or correct suspect data entries.
2. The overall performance of RADS has undergone extensive verification and validation. RADS performs database searches for component failure data. These searches have been independently verified to be accurate for all combinations of search criteria.
3. NUREG/CR-6928 introduced the concepts of high and low-demand components as well as standby and normally running equipment. Off-line analysis of data was required to produce segregated results for these component partitions. Currently the identification of high and low-demand components as well as standby and normally running equipment is taken care of before the data is loaded into RADS.

This update incorporates several component and failure mode combinations that were not reported in the original NUREG/CR-6928. These are to support the SPAR data load and are listed here to provide a reference.

There have been several minor changes to the component reliability data sheets to enhance readability and simplify the product:

1. The tables from each section that compare the maximum likelihood estimators (MLE) and various methods of estimating uncertainty have been removed. Most readers were confused as to which of many possible estimates for reliability were valid and the NUREG/CR-6928 never used the component variability.
2. In many places, the text reiterated what was obvious in the figure or the table or described the selection of low-demand data. The text has been removed.
3. The selected industry distribution table showing the rounded results has been removed. The user may round the data to suit their current needs.
4. The last section generally showed limited results for systems. Since we do not recommend the use of these results without further analysis, this section has been deleted.
5. Many results (leakage, operation, etc) depend on an exposure time that is independent of whether the plant is critical or shutdown. Previously, no allowance was made for whether the plant was operational, now the exposure time is based on reactor years.

6. The first column in the tables has been changed to "Pooling Group". The pooling group indicates whether any refinements ("All" means no refinements) were made to the data search beyond what was discussed in the introduction.

The original NUREG/CR-6928 used some arbitrary statistical adjustments to data that have been modified to be less arbitrary:

1. The use of the SCNID distribution (a simplified version of the constrained non-informative distribution [CNID]) has been discontinued. The Jefferies update replaces that distribution. The SCNID had the property of producing a result with a highly uncertain distribution, which was supposed to enhance the use of the reliability results as the prior to a plant-specific update. The primary use of these results is to support SPAR and the use of highly uncertain distributions leads to more uncertainty in the final CDF.
2. There was a decision made when the empirical Bayes (EB) analysis produced a result that had a low (<0.3) α parameter to the beta or gamma distribution, that the α parameter was reset to 0.3 and β and the mean were recalculated. This action was motivated since the EB could produce extremely wide distributions that nobody believed were valid. This update revises the decision-making and the alternative method of obtaining a reasonable distribution. The decision point is now whether the difference between the 5^{th} percentile and the mean is greater than 4 orders of magnitude (this happens to approximate the decision point of $\alpha < 0.3$). When the decision point is reached, instead of creating an arbitrary distribution, the Jeffries distribution is used, which is the same decision that is made when the EB does not return a result.
3. The abbreviations used to describe the distributions in this update are the empirical Bayes-plant level-Kass-Steffey (EB/PL/KS) and the Jeffries non-informative distribution at the industry level (JNID/IL).

Table 1 summarizes the top 10 percent of higher estimates of reliability in this update. Table 2 shows the top 10 percent of the lower estimates of reliability in this update. The tables show the original estimate in the column labeled "Original" and summarizes data leading to the estimate presented in this update. The In the comments section, references to the original estimates or the original NUREG refer to NUREG/CR-6928 and the estimates shown in that reference.

Table 1. Summary of significantly increased unreliability estimates.

Section	Description	Original UR	Current Data				Difference	Comments
			Failures	Demands/Time	Components	Current UR		
2.4	Positive Displacement Pump (Standby) Fail to Run After First Hour of Operation	2.50E-05	2	1174.91	74	2.13E-03	8420%	Original FTR>1H was estimated as 6% of the FTR<1H value. This greatly under-estimates the rates since these pumps are rarely run for more than 1 hour and we now have 2 failures.
10.1	Engine-Driven Compressor (Running) Fail to Run	9.00E-05	15	5686.77	5	2.73E-03	4097%	EDC was estimated from the MDC. We now do a direct calculation of the EDC.
2.3	Engine-Driven Pump (Standby) Fail to Run After First Hour of Operation	9.00E-05	9	4182.08	36	2.27E-03	2422%	Original FTR>1H was estimated as 6% of the FTR<1H value. This greatly under-estimates the rates since these pumps are rarely run for more than 1 hour and we now have 9 failures..
2.2	Turbine-Driven Pump (Standby) Fail to Run After First Hour of Operation	7.00E-05	12	8027.74	133	1.56E-03	2129%	The new FTR>1H calculation uses the lesser of run hours or demands and reduces the run hours after the first hour by the number of run <1H demands. For rarely run devices, this leads to lower than before estimates for the FTR>1H count. In addition there is an increasing trend.
1.10	Manual Valve Plug	6.00E-09	8	100961448	886	8.42E-08	1303%	The current database identifies many more manual valves than were in the original NUREG analysis. This leads to more failures identified.
4.2	PWR Code Safety Fails to Reclose	7.00E-05	1	2048.26	147	7.32E-04	946%	The original NUREG pooled the RCS and MSS code safety relief valves for this estimate. The comparison is based on the RCS code safety relief valve, which have fewer demands than the MSS code safety relief valves. This leads to a higher estimate of this reliability.
3.3	Combustion Turbine Generator (Standby) Fail to Run After First Hour of Operation	8.00E-04	3	473.2	3	7.40E-03	825%	The original NUREG estimated this based on the other types of EDGs. The current estimate is based on only the CTG component.

Section	Description	Original UR	Current Data				Difference	Comments
			Failures	Demands/Time	Components	Current UR		
10.4	Cooling Tower Fan (Running) Fail to Start	1.00E-04	1	1940.64	20	7.73E-04	673%	The 2010 update includes 20 normally running CTF devices instead of 34. Many of the CTFs that were considered normally running are now considered standby. This leads to higher UR estimates.
10.4	Cooling Tower Fan (Running) Fail to Run	6.00E-07	2	1086739.676	20	2.30E-06	283%	The 2010 update includes 20 normally running CTF devices instead of 34. Many of the CTFs that were considered normally running are now considered standby. This leads to higher UR estimates.

Table 2. Summary of significantly decreased unreliability estimates.

Section	Description	Original UR	Current Data				Difference	Comments
			Failures	Demands/Time	Components	Current UR		
1.1	Air-Operated Valve Fail to Control	3.00E-06	266	1171601352	10283	2.27E-07	-92%	The original NUREG did not estimate the fail to control of valves from data. The value was based on another data source.
1.1	Flow Control Valve Fail to Control	3.00E-06	266	1171601352	10283	2.27E-07	-92%	The original NUREG did not estimate the fail to control of valves from data. The value was based on another data source.
1.1	Air-Operated Valve Fail to Control	3.00E-06	266	1171601352	10283	2.27E-07	-92%	The original NUREG did not estimate the fail to control of valves from data. The value was based on another data source.
1.1	Air-Operated Valve Fail to Control	3.00E-06	266	1171601352	10283	2.27E-07	-92%	The original NUREG did not estimate the fail to control of valves from data. The value was based on another data source.

Section	Description	Original UR	Current Data				Difference	Comments
			Failures	Demands/Time	Components	Current UR		
5.5	VAC Inverter Fails	1.20E-04	95	25981056	228	3.68E-06	-95%	The original NUREG had only 23 devices. The 2010 update has 228 devices. That and the increased exposure time, has led to a decreased reliability estimate.
1.2	Motor-Operated Valve Fail to Control	3.00E-06	105	1571522275	13807	6.71E-08	-98%	The original NUREG did not estimate the fail to control of valves from data. The value was based on another data source.
9.1	Damper Fails To Remain Open	2.40E-06	0	10825440	95	4.62E-08	-98%	The original value is based on a SPAR value with no reference. The current value is based on the data in RADS.
6.3	Containment Sump Plugging	5.00E-05	5	10825440	95	5.08E-07	-99%	The original value is based on a SPAR value with no reference. The current value is based on the data in RADS.
3.3	Combustion Turbine Generator (Standby) Fail to Load and Run During First Hour of Operation	2.00E-03	2	156296	3	1.60E-05	-99%	Checking of the run hour data for the CTG led to a more reliable estimate of the run hours for the unreliability calculations.

Finally, the structure of the document has been changed to include high-level section descriptors that help the user to navigate to the desired information.

The RADS-based results in this update can be directly obtained from RADS Version 4.5.2010.12 and the set of rules that are available on the RADS down load web site.

1 Valves

The valve component boundary includes the valve, the valve operator, local circuit breaker, and local instrumentation and control circuitry. The failure modes for valves are listed in Table 1-1.

The selected ELL mean is the ELS mean multiplied by 0.07, with an assumed α of 0.3. The selected ILL mean is the ILS mean multiplied by 0.02, with an assumed α of 0.3. The 0.07 and 0.02 multipliers are based on limited EPIX data for large leaks as explained in Section A.1 in Reference 14.

Table 1-1. Valve failure modes.

Pooling Group	Failure Mode	Parameter	Units	Description
Standby	FTO/C	p	-	Failure to open or failure to close
	SOP	λ	1/h	Spurious operation
	ELS	λ	1/h	External leak small
	ELL	λ	1/h	External leak large
	ILS	λ	1/h	Internal leak small
	ILL	λ	1/h	Internal leak large
Control	FC	λ	1/h	Fail to control

1.1 Air-Operated Valve (AOV)

1.1.1 Component Description

The air-operated valve (AOV) component boundary includes the valve, the valve operator (including the associated solenoid operated valves), local circuit breaker, and local instrumentation and control circuitry.

1.1.2 Data Collection and Review

The data for AOV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010 using RADS. The systems included in the AOV data collection are listed in Table 1-2 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 1-2. AOV systems.

Pooling Group	**System**	**Number of Components**		
		High/ Unknown Demand	**Low Demand**	**Total**
All	Auxiliary feedwater (AFW)	272	213	485
	Chemical and volume control (CVC)	1384	352	1736
	Circulating water system (CWS)	10	2	12
	Component cooling water (CCW)	855	305	1160
	Condensate system (CDS)	86	19	105
	Condensate transfer system (CTS)	1		1
	Containment fan cooling (CFC)	176	26	202
	Containment isolation system (CIS)	7	9	16
	Containment spray recirculation (CSR)	36	32	68
	Control rod drive (CRD)	468	86	554
	Emergency power supply (EPS)	329	25	354
	Engineered safety features actuation (ESF)	1		1

Pooling Group	System	Number of Components		
		High/ Unknown Demand	**Low Demand**	**Total**
	Firewater (FWS)	4	1	5
	Fuel handling (FHS)	2		2
	Heating ventilation and air conditioning (HVC)	739	108	847
	High pressure coolant injection (HCI)	80	8	88
	High pressure core spray (HCS)	33		33
	High pressure injection (HPI)	235	75	310
	Instrument air (IAS)	26	21	47
	Isolation condenser (ISO)	12	6	18
	Low pressure core spray (LCS)	45	12	57
	Main feedwater (MFW)	830	174	1004
	Main steam (MSS)	979	106	1085
	Normally operating service water (SWN)	709	330	1039
	Reactor coolant (RCS)	238	56	294
	Reactor core isolation (RCI)	82	7	89
	Reactor protection (RPS)	8	15	23
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	538	163	701
	Standby liquid control (SLC)	4	1	5
	Standby service water (SWS)	159	22	181
	Vapor suppression (VSS)	12	33	45
	Grand Total	**8360**	**2207**	**10567**

Table 1-3 summarizes the data used in the AOV analysis. Note that the hours for FC, SOP, ELS, and ILS are reactor-year hours.

Table 1-3. AOV unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO	73	173117	2207	98	2.6%	36.7%
	FTC	63	173117	2207	98	2.4%	35.7%
	FTO/C	146	173117	2207	98	5.3%	53.1%
	FC	266	1171601352 h	10283	104	2.2%	78.8%
	SOP	140	1171601352 h	10283	104	1.2%	51.9%
	ILS	113	1171601352 h	10283	104	1.0%	41.3%
	ELS	64	1171601352 h	10283	104	0.6%	32.7%

Figure 1-1 shows the range of valve demands per year in the AOV data set (limited to low-demand components only).

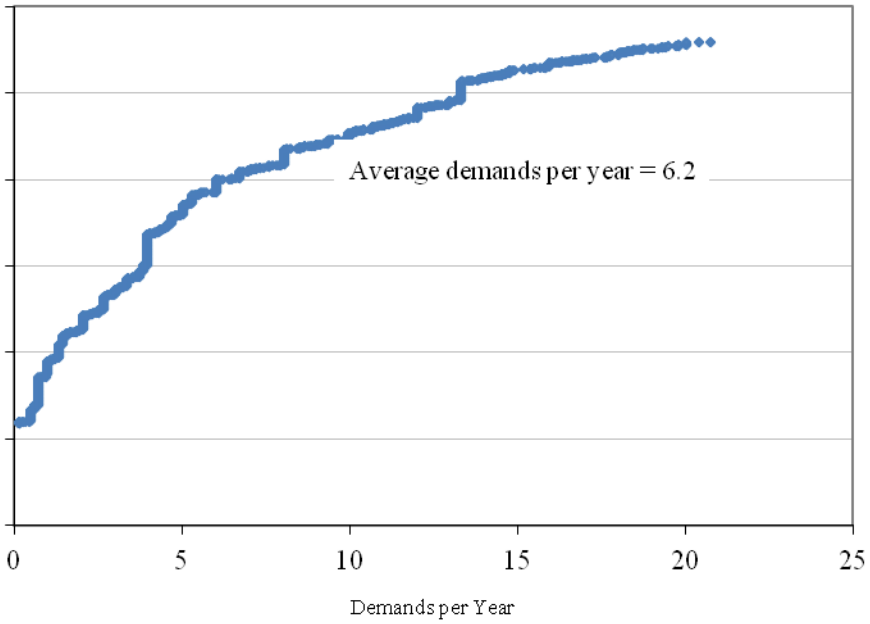

Figure 1-1. AOV demands per year distribution.

1.1.3 Industry-Average Baselines

Table 1-4 lists the selected industry distributions of p and λ for the AOV failure modes. These industry-average failure rates do not account for any recovery.

Table 1-4. Selected industry distributions of p and λ for AOVs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO/C	EB/PL/KS	6.27E-05	6.86E-04	9.51E-04	2.74E-03	Beta	1.11	1.168E+03
	FC	EB/PL/KS	2.66E-08	1.93E-07	2.49E-07	6.59E-07	Gamma	1.42	5.719E+06
	SOP	EB/PL/KS	2.04E-09	7.46E-08	1.31E-07	4.49E-07	Gamma	0.68	5.211E+06
	ILS	JNID/IL	8.24E-08	9.66E-08	9.69E-08	1.12E-07	Gamma	113.50	1.172E+09
	ILL	JNID/IL	2.07E-13	4.72E-10	1.94E-09	8.87E-09	Gamma	0.30	1.548E+08
	ELS	JNID/IL	4.43E-08	5.48E-08	5.51E-08	6.68E-08	Gamma	64.50	1.172E+09
	ELL	JNID/IL	4.13E-13	9.40E-10	3.86E-09	1.76E-08	Gamma	0.30	7.778E+07

1.2 Motor-Operated Valve (MOV)

1.2.1 Component Description

The motor-operated valve (MOV) component boundary includes the valve, the valve operator, local circuit breaker, and local instrumentation and control circuitry. The failure modes for MOV are listed in Table 1-1.

1.2.2 Data Collection and Review

The data for MOV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010 using RADS. The systems included in the MOV data collection are listed in Table 1-5 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 1-5. MOV systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
All	Auxiliary feedwater (AFW)	212	483	695
	Chemical and volume control (CVC)	326	538	864
	Circulating water system (CWS)	70	73	143
	Component cooling water (CCW)	737	696	1433
	Condensate system (CDS)	43	1	44
	Condensate transfer system (CTS)		6	6
	Containment fan cooling (CFC)	34	7	41
	Containment isolation system (CIS)	15	19	34
	Containment spray recirculation (CSR)	204	328	532
	Control rod drive (CRD)	69	15	84
	Emergency power supply (EPS)	62	1	63
	Firewater (FWS)	10	8	18
	Heating ventilation and air conditioning (HVC)	187	24	211
	High pressure coolant injection (HCI)	99	249	348
	High pressure core spray (HCS)	44	29	73
	High pressure injection (HPI)	247	980	1227
	Instrument air (IAS)	16	14	30
	Isolation condenser (ISO)	5	19	24
	Low pressure core spray (LCS)	96	209	305
	Main feedwater (MFW)	871	293	1164
	Main steam (MSS)	707	169	876
	Normally operating service water (SWN)	898	739	1637
	Reactor coolant (RCS)	212	162	374
	Reactor core isolation (RCI)	134	309	443
	Reactor protection (RPS)	10	4	14
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	917	1835	2752
	Standby liquid control (SLC)	5	23	28
	Standby service water (SWS)	275	198	473
	Vapor suppression (VSS)	9	14	23

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
Grand Total		**6514**	**7445**	**13959**

Table 1-6 summarizes the data used in the MOV analysis. Note that the hours for FC, SOP, ELS, and ILS are reactor-year hours.

Table 1-6. MOV unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO	248	602223	7445	104	3.0%	81.7%
	FTC	221	602223	7445	104	2.6%	73.1%
	FTO/C	532	602223	7445	104	6.2%	90.4%
	FC	105	1571522275 h	13807	104	0.7%	54.8%
	SOP	52	1571522275 h	13807	104	0.4%	29.8%
	ILS	145	1571522275 h	13807	104	0.9%	54.8%
	ELS	51	1571522275 h	13807	104	0.3%	28.8%

Figure 1-2 shows the range of valve demands per year in the MOV data set (limited to low-demand components only).

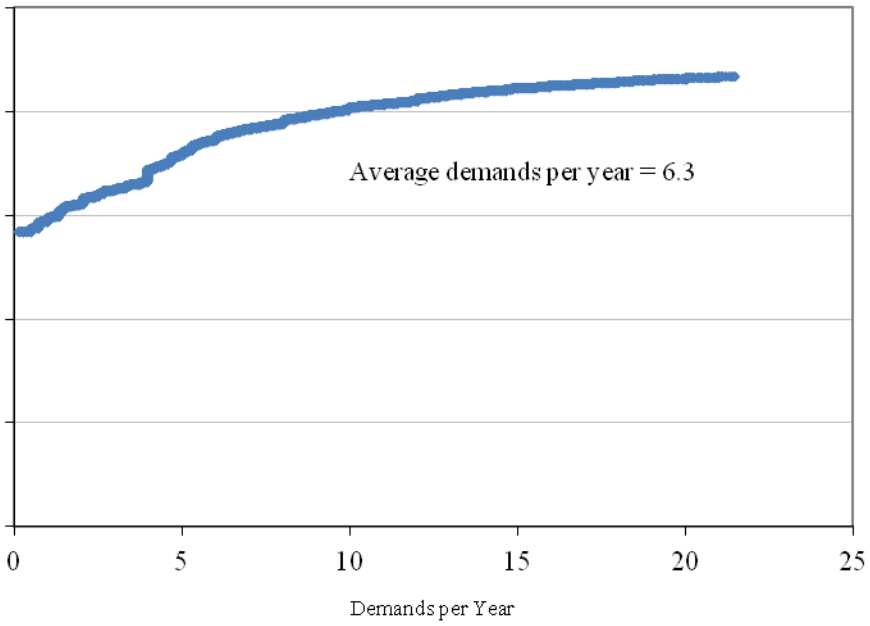

Figure 1-2. MOV demands per year distribution.

1.2.3 Industry-Average Baselines

Table 1-7 lists the selected industry distributions of p and λ for the MOV failure modes. These industry-average failure rates do not account for any recovery.

Table 1-7. Selected industry distributions of p and λ for MOVs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO/C	EB/PL/KS	1.76E-04	8.12E-04	9.63E-04	2.27E-03	Beta	2.05	2.123E+03
	FC	EB/PL/KS	7.40E-09	5.18E-08	6.62E-08	1.74E-07	Gamma	1.46	2.205E+07
	SOP	EB/PL/KS	2.54E-10	1.72E-08	3.39E-08	1.24E-07	Gamma	0.57	1.684E+07
	ILS	EB/PL/KS	1.36E-09	5.64E-08	1.01E-07	3.52E-07	Gamma	0.65	6.477E+06
	ILL	EB/PL/KS	2.16E-13	4.92E-10	2.02E-09	9.24E-09	Gamma	0.30	1.485E+08
	ELS	EB/PL/KS	9.81E-11	1.42E-08	3.28E-08	1.28E-07	Gamma	0.48	1.451E+07
	ELL	EB/PL/KS	2.46E-13	5.59E-10	2.29E-09	1.05E-08	Gamma	0.30	1.308E+08

1.3 Hydraulic-Operated Valve (HOV)

1.3.1 Component Description

The hydraulic-operated valve (HOV) component boundary includes the valve, the valve operator, and local instrumentation and control circuitry. The failure modes for HOV are listed in Table 1-1.

1.3.2 Data Collection and Review

The data for HOV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010 using RADS. The systems included in the HOV data collection are listed in Table 1-8 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 1-8. HOV systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
All	Auxiliary feedwater (AFW)	33	24	57
	Chemical and volume control (CVC)		2	2
	Circulating water system (CWS)	5	3	8
	Component cooling water (CCW)	4		4
	Condensate system (CDS)	3		3
	Containment isolation system (CIS)	3		3
	Control rod drive (CRD)		178	178
	Emergency power supply (EPS)	12		12
	Heating ventilation and air conditioning (HVC)	9	1	10
	High pressure coolant injection (HCI)	20	7	27
	High pressure injection (HPI)		6	6
	Instrument air (IAS)	1		1
	Main feedwater (MFW)	39	78	117
	Main steam (MSS)	198	100	298
	Normally operating service water (SWN)	6	5	11
	Reactor coolant (RCS)		3	3
	Reactor core isolation (RCI)	9	7	16
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	10	9	19
	Standby service water (SWS)	5	4	9
	Vapor suppression (VSS)		1	1
	Grand Total	**357**	**428**	**785**

Table 1-9 summarizes the data used in the HOV analysis. Note that the hours for FC, SOP, ELS, and ILS are reactor-year hours.

Table 1-9. HOV unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO/C	24	20476	428	51	4.7%	29.4%
	FC	42	87527799 h	771	77	4.0%	27.3%
	SOP	17	87527799 h	771	77	1.6%	11.7%
	ILS	2	87527799 h	771	77	0.3%	2.6%
	ELS	19	87527799 h	771	77	1.8%	9.1%

Figure 1-3 shows the range of valve demands per year in the HOV data set (limited to low-demand components only).

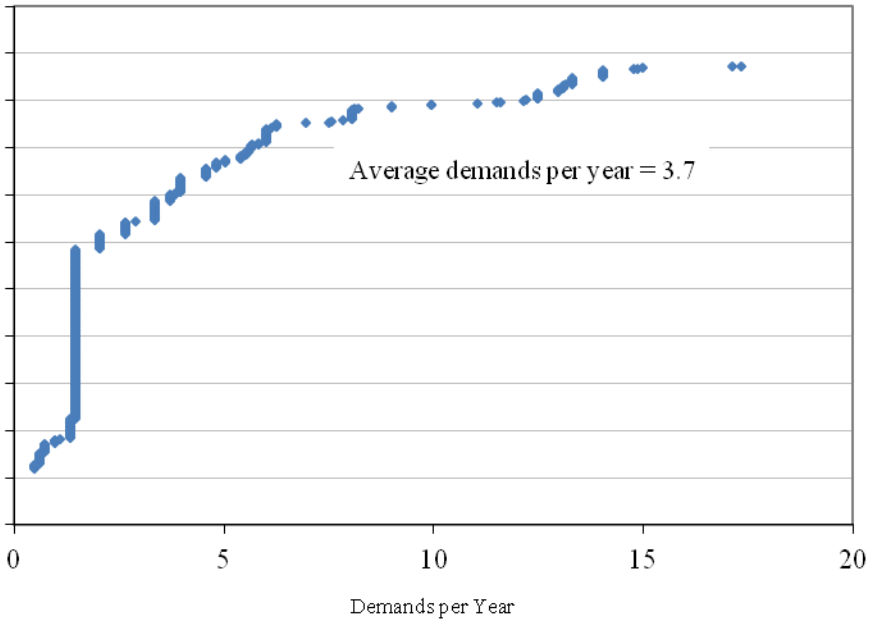

Figure 1-3. HOV demands per year distribution.

1.3.3 Industry-Average Baselines

Table 1-10 lists the selected industry distributions of p and λ for the HOV failure modes. These industry-average failure rates do not account for any recovery.

Table 1-10. Selected industry distributions of p and λ for HOVs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO/C	JNID/IL	8.29E-04	1.18E-03	1.20E-03	1.62E-03	Beta	24.50	2.045E+04
	FC	JNID/IL	3.70E-07	4.82E-07	4.86E-07	6.14E-07	Gamma	42.50	8.753E+07
	SOP	JNID/IL	1.28E-07	1.96E-07	2.00E-07	2.84E-07	Gamma	17.50	8.753E+07
	ILS	JNID/IL	6.54E-09	2.49E-08	2.86E-08	6.32E-08	Gamma	2.50	8.753E+07
	ILL	JNID/IL	6.12E-14	1.39E-10	5.72E-10	2.62E-09	Gamma	0.30	5.245E+08
	ELS	JNID/IL	1.47E-07	2.19E-07	2.23E-07	3.12E-07	Gamma	19.50	8.753E+07
	ELL	JNID/IL	1.67E-12	3.81E-09	1.56E-08	7.14E-08	Gamma	0.30	1.922E+07

1.4 Solenoid-Operated Valve (SOV)

1.4.1 Component Description

The solenoid-operated valve (SOV) component boundary includes the valve, the valve operator, and local instrumentation and control circuitry. The failure modes for SOV are listed in Table 1-1.

1.4.2 Data Collection and Review

The data for SOV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010 using RADS. The systems included in the SOV data collection are listed in Table 1-11 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 1-11. SOV systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
All	Auxiliary feedwater (AFW)	24	32	56
	Chemical and volume control (CVC)	33	23	56
	Component cooling water (CCW)	10		10
	Condensate system (CDS)	3		3
	Containment fan cooling (CFC)	6		6
	Containment spray recirculation (CSR)	18	3	21
	Control rod drive (CRD)	22	401	423
	Emergency power supply (EPS)	55	21	76
	Engineered safety features actuation (ESF)	5		5
	Firewater (FWS)	48	1	49
	Fuel handling (FHS)	2		2
	Heating ventilation and air conditioning (HVC)	20	47	67
	High pressure coolant injection (HCI)	11	8	19
	High pressure injection (HPI)	31	6	37
	Instrument air (IAS)	40	39	79
	Low pressure core spray (LCS)		2	2
	Main feedwater (MFW)	15	6	21
	Main steam (MSS)	28	39	67
	Normally operating service water (SWN)	13	14	27
	Reactor coolant (RCS)	13	80	93
	Reactor core isolation (RCI)	1	2	3
	Reactor protection (RPS)	8	14	22
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	20	35	55
	Standby service water (SWS)	3		3
	Vapor suppression (VSS)		2	2
	Grand Total	**429**	**775**	**1204**

Table 1-12 summarizes the data used in the SOV analysis.

Table 1-12. SOV unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO/C	30	25650	775	60	3.2%	16.7%
	FC	61	131304380 h	1153	83	4.9%	27.7%
	SOP	4	131304380 h	1153	83	0.3%	3.6%
	ILS	23	131304380 h	1153	83	1.8%	15.7%
	ELS	4	131304380 h	1153	83	0.3%	4.8%

Figure 1-4 shows the range of valve demands per year in the SOV data set (limited to low-demand components only).

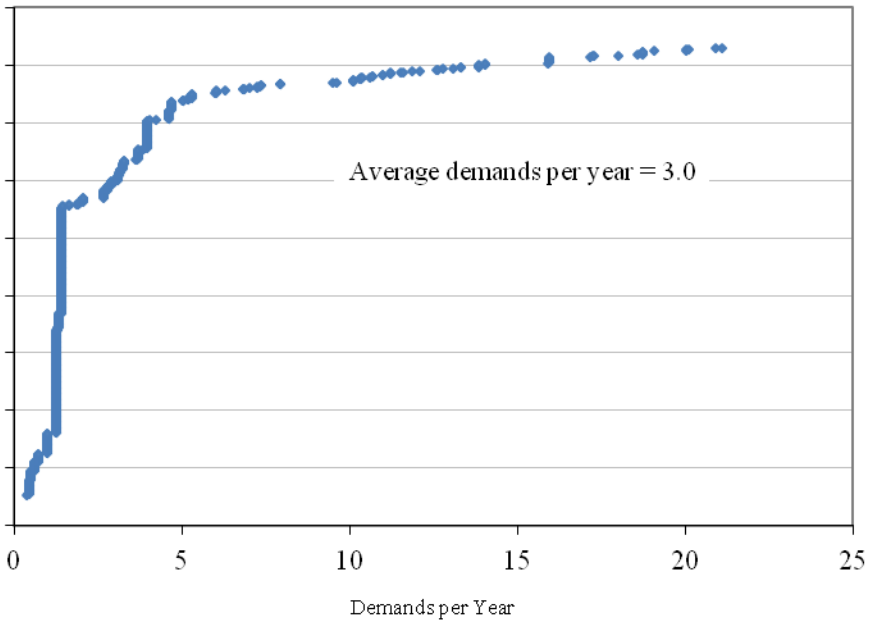

Figure 1-4. SOV demands per year distribution.

1.4.3 Industry-Average Baselines

Table 1-13 lists the selected industry distributions of p and λ for the SOV failure modes. These industry-average failure rates do not account for any recovery.

Table 1-13. Selected industry distributions of p and λ for SOVs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO/C	JNID/IL	8.59E-04	1.18E-03	1.19E-03	1.56E-03	Beta	30.50	2.562E+04
	FC	JNID/IL	3.75E-07	4.66E-07	4.68E-07	5.71E-07	Gamma	61.50	1.313E+08
	SOP	JNID/IL	1.27E-08	3.18E-08	3.43E-08	6.44E-08	Gamma	4.50	1.313E+08
	ILS	JNID/IL	1.23E-07	1.76E-07	1.79E-07	2.44E-07	Gamma	23.50	1.313E+08
	ILL	JNID/IL	3.83E-13	8.73E-10	3.58E-09	1.64E-08	Gamma	0.30	8.380E+07
	ELS	JNID/IL	1.27E-08	3.18E-08	3.43E-08	6.44E-08	Gamma	4.50	1.313E+08
	ELL	JNID/IL	2.57E-13	5.85E-10	2.40E-09	1.10E-08	Gamma	0.30	1.249E+08

1.5 Explosive-Operated Valve (EOV)

1.5.1 Component Description

The explosive-operated valve (EOV) component boundary includes the valve and local instrumentation and control circuitry. The failure mode for EOV is listed in Table 1-1.

1.5.2 Data Collection and Review

Data for EOV UR baseline was obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010 using RADS. The systems included in the EOV data collection are listed in Table 1-14 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 1-14. EOV systems.

Pooling Group	**System**	**Number of Components**		
		High/ Unknown Demand	**Low Demand**	**Total**
All	Standby liquid control (SLC)	12	60	72
	Grand Total	**12**	**60**	**72**

Table 1-15 summarizes the data used in the EOV analysis.

Table 1-15. EOV unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO	1	583	60	29	1.7%	3.4%

Figure 1-5 shows the range of valve demands per year in the EOV data set (limited to low-demand components only).

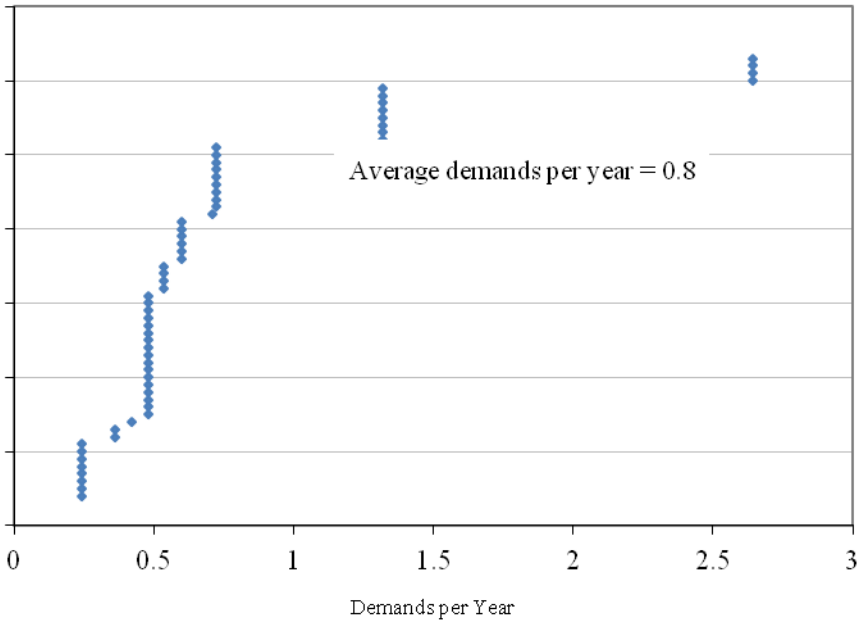

Figure 1-5. EOV demands per year distribution.

1.5.3 Industry-Average Baselines

Table 1-16 lists the industry-average failure rate distribution for the EOV FTO failure mode. This industry-average failure rate does not account for any recovery.

Table 1-16. Selected industry distributions of p and λ for EOVs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	JNID/IL	3.02E-04	2.03E-03	2.57E-03	6.68E-03	Beta	1.50	5.827E+02

1.6 Vacuum Breaker Valve (VBV)

1.6.1 Component Description

The vacuum breaker valve (VBV) component boundary includes the valve, the valve operator, local circuit breaker, and local instrumentation and control circuitry. The failure modes for VBV are listed in Table 1-1.

1.6.2 Data Collection and Review

Data for VBV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010 using RADS. The systems included in the VBV data collection are listed in Table 1-17 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 1-17. VBV systems.

Pooling Group	**System**	**Number of Components**		
		High/ Unknown Demand	**Low Demand**	**Total**
All	Vapor suppression (VSS)	174	167	341
	Grand Total	**174**	**167**	**341**

Table 1-18 summarizes the data used in the VBV analysis.

Table 1-18. VBV unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO	4	20108	167	17	2.4%	23.5%
	FTC	6	20108	167	17	3.6%	23.5%
	ILS	15	37300280 h	336	30	4.5%	10.0%

Figure 1-6 shows the range of valve demands per year in the VBV data set (limited to low-demand components only).

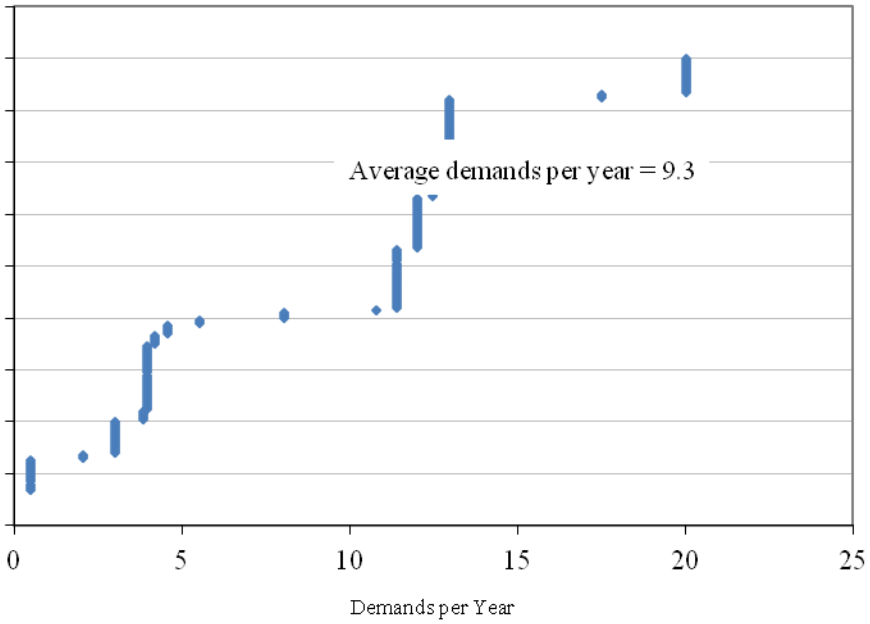

Figure 1-6. VBV demands per year distribution.

1.6.3 Industry-Average Baselines

Table 1-19 lists the selected industry distributions of p and λ for the VBV failure modes. These industry-average failure rates do not account for any recovery.

Table 1-19. Selected industry distributions of p and λ for VBVs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	JNID/IL	8.27E-05	2.07E-04	2.24E-04	4.21E-04	Beta	4.50	2.010E+04
	FTC	EB/PL/KS	5.55E-06	1.75E-04	2.97E-04	1.00E-03	Beta	0.71	2.402E+03
	ILS	JNID/IL	2.58E-07	4.07E-07	4.16E-07	6.03E-07	Gamma	15.50	3.730E+07
	ILL	JNID/IL	8.91E-13	2.03E-09	8.32E-09	3.81E-08	Gamma	0.30	3.606E+07

1.7 Turbine Bypass Valve (TBV)

1.7.1 Component Description

The turbine bypass valve (TBV) component boundary includes the valve, the valve operator (including the associated solenoid operated valves), local circuit breaker, and local instrumentation and control circuitry. The failure modes for TBV are listed in Table 1-1.

1.7.2 Data Collection and Review

The data for TBV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010 using RADS. The systems included in the TBV data collection are listed in Table 1-20 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 1-20. TBV systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
All	Main steam (MSS)	79	77	156
	Grand Total	**79**	**77**	**156**

Table 1-21 summarizes the data used in the AOV analysis. Note that the hours for FC are reactor-year hours.

Table 1-21. TBV unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO	8	2023	77	16	9.1%	25.0%
	FTC	0	2023	77	16	0.0%	0.0%
	FTO/C	10	2023	77	16	10.4%	31.3%
	FC	18	17548608 h	154	26	8.4%	30.8%

Figure 1-7 shows the range of valve demands per year in the TBV data set (limited to low-demand components only).

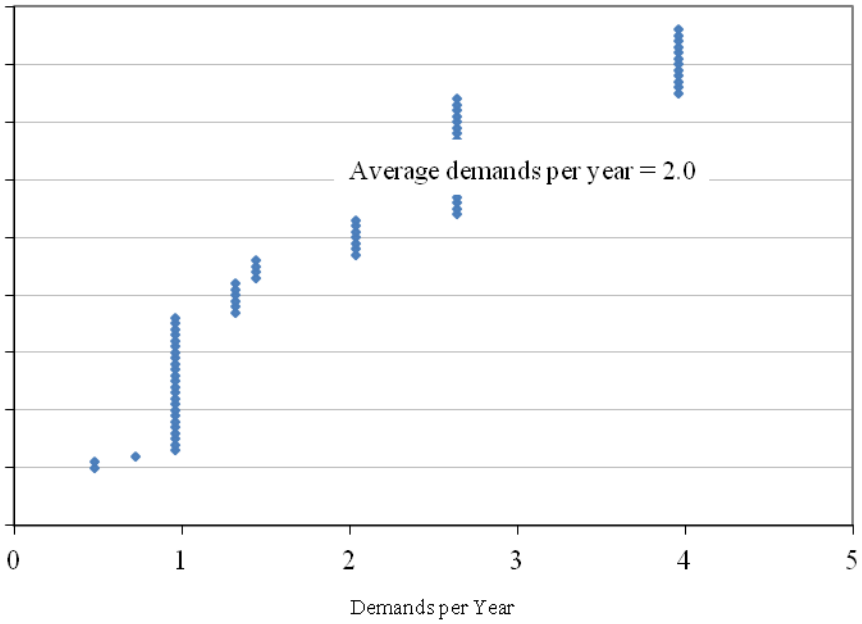

Figure 1-7. TBV demands per year distribution.

1.7.3 Industry-Average Baselines

Table 1-22 lists the selected industry distributions of p and λ for the TBV failure modes. These industry-average failure rates do not account for any recovery.

Table 1-22. Selected industry distributions of p and λ for TBV s.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	JNID/IL	2.14E-03	4.04E-03	4.20E-03	6.81E-03	Beta	8.50	2.016E+03
	FTC	JNID/IL	9.72E-07	1.12E-04	2.47E-04	9.49E-04	Beta	0.50	2.024E+03
	FTO/C	JNID/IL	2.87E-03	5.02E-03	5.19E-03	8.06E-03	Beta	10.50	2.014E+03
	FC	JNID/IL	6.86E-07	1.04E-06	1.05E-06	1.49E-06	Gamma	18.50	1.755E+07

1.8 Main Steam Isolation Valve (MSV)

1.8.1 Component Description

The motor-operated valve (MSV) component boundary includes the valve, the valve operator, local circuit breaker, and local instrumentation and control circuitry. The failure modes for MOV are listed in Table 1-1.

1.8.2 Data Collection and Review

The data for MSV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010 using RADS. The systems included in the MOV data collection are listed in Table 1-23 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 1-23. MSV systems.

Pooling Group	**System**	**Number of Components**		
		High/ Unknown Demand	**Low Demand**	**Total**
All	Main steam (MSS)	101	401	502
	Grand Total	**101**	**401**	**502**

Table 1-24 summarizes the data used in the MSV analysis. Note that the hours for SOP, ELS, and ILS are reactor-year hours.

Table 1-24. MSV unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO/C	23	30182	401	78	4.5%	19.2%
	SOP	21	55836292 h	490	94	3.7%	13.8%
	ILS	84	55836292 h	490	94	12.9%	26.6%
	ELS	7	55836292 h	490	94	1.4%	7.4%

Figure 1-8 shows the range of valve demands per year in the MSV data set (limited to low-demand components only).

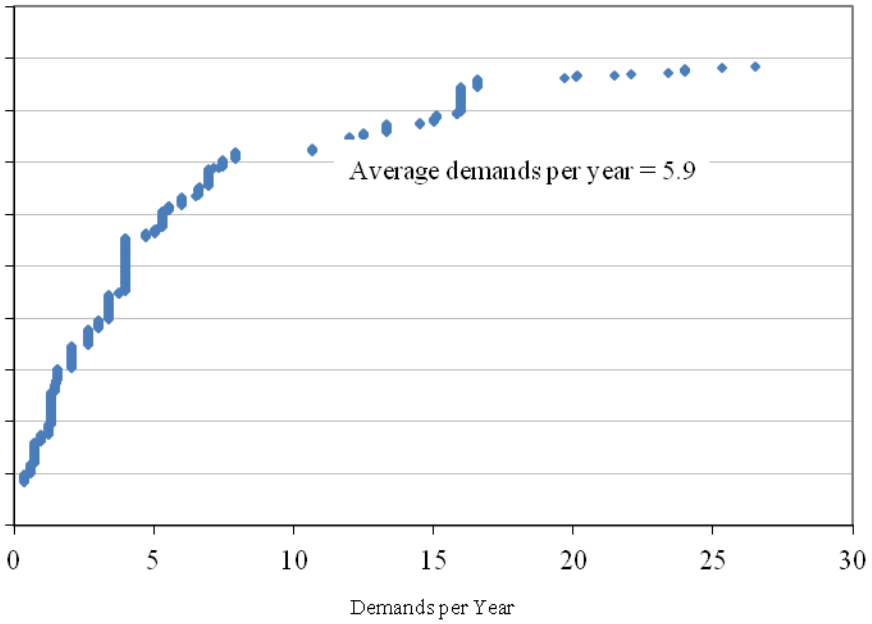

Figure 1-8. MSV demands per year distribution.

1.8.3 Industry-Average Baselines

Table 1-25 lists the selected industry distributions of p and λ for the MSV failure modes. These industry-average failure rates do not account for any recovery.

Table 1-25. Selected industry distributions of p and λ for MSVs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO/C	JNID/IL	5.35E-04	7.68E-04	7.79E-04	1.06E-03	Beta	23.50	3.016E+04
	SOP	JNID/IL	2.59E-07	3.79E-07	3.85E-07	5.31E-07	Gamma	21.50	5.584E+07
	ILS	JNID/IL	1.25E-06	1.51E-06	1.51E-06	1.79E-06	Gamma	84.50	5.584E+07
	ILL	JNID/IL	3.23E-12	7.36E-09	3.02E-08	1.38E-07	Gamma	0.30	9.934E+06
	ELS	JNID/IL	6.50E-08	1.28E-07	1.34E-07	2.24E-07	Gamma	7.50	5.584E+07
	ELL	JNID/IL	1.00E-12	2.29E-09	9.38E-09	4.29E-08	Gamma	0.30	3.198E+07

1.9 Check Valve (CKV)

1.9.1 Component Description

The check valve (CKV) component boundary includes the valve and no other supporting components. The failure modes for CKV are listed in Table 1-1.

1.9.2 Data Collection and Review

Data for CKV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010 using RADS. The systems included in the CKV data collection are listed in Table 1-26 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 1-26. CKV systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
All	Auxiliary feedwater (AFW)	938	32	970
	Chemical and volume control (CVC)	970	55	1025
	Circulating water system (CWS)	7		7
	Component cooling water (CCW)	561	42	603
	Condensate system (CDS)	90		90
	Condensate transfer system (CTS)	3		3
	Containment fan cooling (CFC)	2	1	3
	Containment isolation system (CIS)		1	1
	Containment spray recirculation (CSR)	313	52	365
	Control rod drive (CRD)	356	3	359
	Emergency power supply (EPS)	662	26	688
	Engineered safety features actuation (ESF)	2		2
	Firewater (FWS)	33		33
	Fuel handling (FHS)	33		33
	Heating ventilation and air conditioning (HVC)	21	4	25
	High pressure coolant injection (HCI)	178	12	190
	High pressure core spray (HCS)	73		73
	High pressure injection (HPI)	955	149	1104
	Instrument air (IAS)	235		235
	Isolation condenser (ISO)		1	1
	Low pressure core spray (LCS)	127	5	132
	Main feedwater (MFW)	231	27	258
	Main steam (MSS)	255	21	276
	Normally operating service water (SWN)	574	10	584
	Reactor coolant (RCS)	205	7	212
	Reactor core isolation (RCI)	165	12	177
	Reactor recirculation (RRS)		1	1
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	1036	111	1147
	Standby liquid control (SLC)	94	7	101
	Standby service water (SWS)	181	16	197
	Vapor suppression (VSS)	10	4	14

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
	Ice condenser (ICS)	2		2
	Grand Total	**8312**	**599**	**8911**

Table 1-27 summarizes the data used in the CKV analysis. Note that the hours for SOP, SC, ELS, and ILS are reactor-year hours.

Table 1-27. CKV unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO	0	46841	599	47	0.0%	0.0%
	FTC	8	46841	599	47	1.2%	12.8%
	SOP	3	1004642562 h	8820	104	0.0%	1.9%
	SC	5	1004642562 h	8820	104	0.0%	1.0%
	ILS	204	1004642562 h	8820	104	2.0%	62.5%
	ELS	10	1004642562 h	8820	104	0.1%	7.7%

Figure 1-9 shows the range of valve demands per year in the CKV data set (limited to low-demand components only).

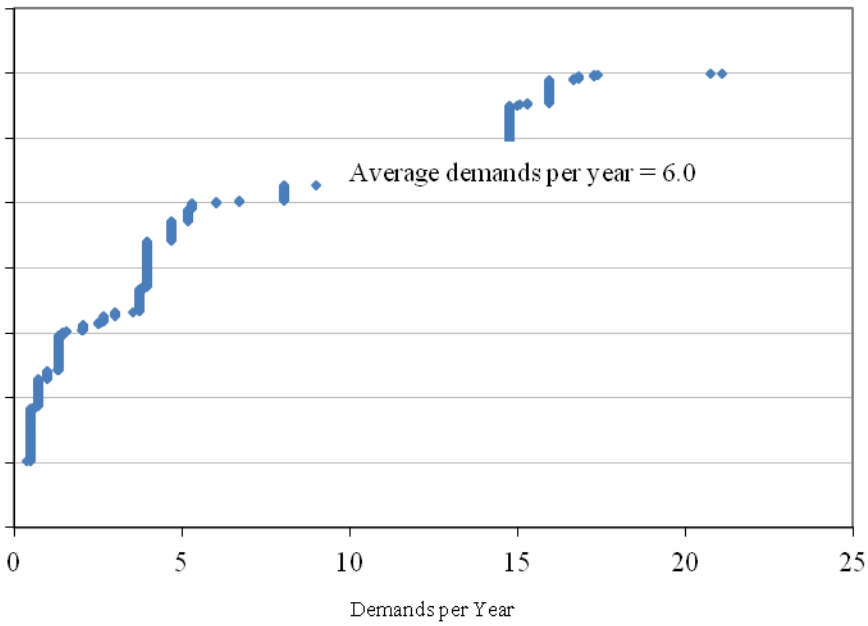

Figure 1-9. CKV demands per year distribution.

1.9.3 Industry-Average Baselines

Table 1-28 lists the selected industry distributions of p and λ for the CKV failure modes. These industry-average failure rates do not account for any recovery.

Table 1-28. Selected industry distributions of p and λ for CKVs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	JNID/IL	4.20E-08	4.86E-06	1.07E-05	4.10E-05	Beta	0.50	4.684E+04
	FTC	EB/PL/KS	6.68E-06	1.50E-04	2.38E-04	7.70E-04	Beta	0.81	3.384E+03
	SOP	JNID/IL	1.08E-09	3.16E-09	3.48E-09	7.00E-09	Gamma	3.50	1.005E+09
	SC	JNID/IL	2.28E-09	5.15E-09	5.47E-09	9.79E-09	Gamma	5.50	1.005E+09
	ILS	EB/PL/KS	2.32E-09	1.56E-07	3.08E-07	1.13E-06	Gamma	0.57	1.856E+06
	ILL	EB/PL/KS	6.58E-13	1.50E-09	6.15E-09	2.81E-08	Gamma	0.30	4.876E+07
	ELS	JNID/IL	5.77E-09	1.01E-08	1.05E-08	1.63E-08	Gamma	10.50	1.005E+09
	ELL	JNID/IL	7.87E-14	1.79E-10	7.35E-10	3.36E-09	Gamma	0.30	4.082E+08

1.10 Manual Valve (XVM)

1.10.1 Component Description

The manual valve (XVM) component boundary includes the valve and valve operator. The failure modes for XVM are listed in Table 1-1.

1.10.2 Data Collection and Review

Data for XVM UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1997–2004 using RADS. The systems included in the XVM data collection are listed in Table 1-29 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 1-29. XVM systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
All	Auxiliary feedwater (AFW)	94	5	99
	Chemical and volume control (CVC)	62	10	72
	Circulating water system (CWS)	4		4
	Component cooling water (CCW)	179	19	198
	Condensate system (CDS)	2		2
	Condensate transfer system (CTS)	1		1
	Containment spray recirculation (CSR)	30	2	32
	Control rod drive (CRD)	5		5
	Emergency power supply (EPS)	18		18
	Firewater (FWS)	5		5
	Heating ventilation and air conditioning (HVC)	6		6
	High pressure coolant injection (HCI)	3		3
	High pressure core spray (HCS)	29		29
	High pressure injection (HPI)	26	1	27
	Instrument air (IAS)	6		6
	Isolation condenser (ISO)	24		24
	Low pressure core spray (LCS)	12		12
	Main feedwater (MFW)	5	1	6
	Main steam (MSS)	21	6	27
	Normally operating service water (SWN)	58	6	64
	Reactor coolant (RCS)	9		9
	Reactor core isolation (RCI)	13		13
	Reactor protection (RPS)	2		2
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	124	14	138
	Standby liquid control (SLC)	8	4	12
	Standby service water (SWS)	110	8	118
	Grand Total	**856**	**76**	**932**

Table 1-30 summarizes the data used in the XVM analysis. Note that the hours for SOP, ELS, and ILS are reactor-year hours.

Table 1-30. XVM unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO/C	0	2605	76	10	0.0%	0.0%
	SOP	8	100961448 h	886	76	0.9%	10.5%
	ILS	13	100961448 h	886	76	1.5%	15.8%
	ELS	26	100961448 h	886	76	2.8%	25.0%

Figure 1-10 shows the range of valve demands per year in the XVM data set (limited to low-demand components only).

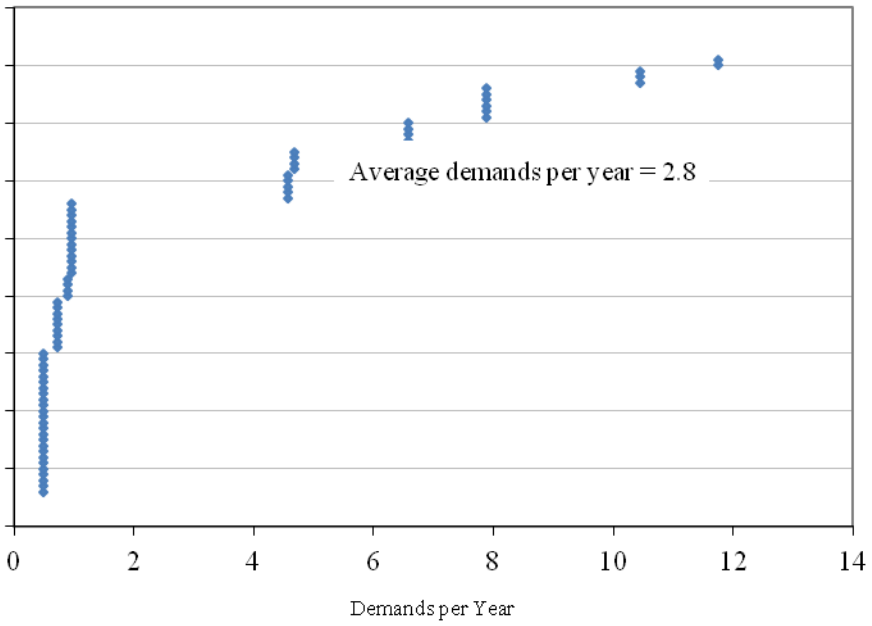

Figure 1-10. XVM demands per year distribution.

1.10.3 Industry-Average Baselines

Table 1-31 lists the selected industry distributions of p and λ for the XVM failure modes. These industry-average failure rates do not account for any recovery.

Table 1-31. Selected industry distributions of p and λ for XVMs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTO/C	JNID/IL	7.55E-07	8.73E-05	1.92E-04	7.37E-04	Beta	0.50	2.606E+03
	SOP	JNID/IL	4.29E-08	8.09E-08	8.42E-08	1.37E-07	Gamma	8.50	1.010E+08
	ILS	JNID/IL	8.00E-08	1.30E-07	1.34E-07	1.99E-07	Gamma	13.50	1.010E+08
	ILL	JNID/IL	2.87E-13	6.53E-10	2.68E-09	1.23E-08	Gamma	0.30	1.119E+08
	ELS	JNID/IL	1.85E-07	2.59E-07	2.62E-07	3.52E-07	Gamma	26.50	1.010E+08
	ELL	JNID/IL	1.96E-12	4.47E-09	1.83E-08	8.39E-08	Gamma	0.30	1.636E+07

2 Pumps

The pump boundary includes the pump, driver, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for pumps are listed in Table 2-1.

The selected ELL mean is the ELS mean multiplied by 0.07, with an assumed α of 0.3. The selected ILL mean is the ILS mean multiplied by 0.02, with an assumed α of 0.3. The 0.07 and 0.02 multipliers are based on limited EPIX data for large leaks as explained in Section A.1 in Reference 14.

Table 2-1. Pump failure modes.

Pooling Group	Failure Mode	Parameter	Units	Description
Standby	FTS	p	-	Failure to start
	FTR≤1H	λ	1/h	Failure to run for 1 h
	FTR>1H	λ	1/h	Fail to run beyond 1 h
Running/Alternating	FTS	p	-	Failure to start
	FTR	λ	1/h	Fail to run
All	ELS	λ	1/h	External leak small
	ELL	λ	1/h	External leak large

2.1 Motor-Driven Pump (MDP)

2.1.1 Component Description

The motor-driven pump (MDP) boundary includes the pump, motor, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The motor-driven pump component data in this section includes only centrifugal type pumps. Component data for positive displacement (also motor-driven) are presented in Section 2.4. The failure modes for MDP are listed in Table 2-1.

2.1.2 Data Collection and Review

Data for MDP UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems and operational status included in the MDP data collection are listed in Table 2-2 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤200 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 2-2. MDP systems.

Pooling Group	**System**	**Number of Components**		
		High/ Unknown Demand	**Low Demand**	**Total**
Normally Running	Chemical and volume control (CVC)	25	123	148
	Chilled water system (CHW)	1	2	3
	Circulating water system (CWS)	104	32	136
	Component cooling water (CCW)	98	281	379
	Condensate system (CDS)	5	142	147
	Condensate transfer system (CTS)	3		3

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
	Containment spray recirculation (CSR)	31		31
	Control rod drive (CRD)	5	41	46
	Emergency power supply (EPS)	6		6
	Firewater (FWS)	3		3
	Fuel Oil Transfer (FOT)	152		152
	Heating ventilation and air conditioning (HVC)	2		2
	High pressure coolant injection (HCI)	1		1
	High pressure injection (HPI)	5	5	10
	Instrument air (IAS)	2		2
	Low pressure core spray (LCS)	14	5	19
	Main feedwater (MFW)	7	42	49
	Normally operating service water (SWN)	50	88	138
	Reactor protection (RPS)	2		2
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	2		2
	Standby liquid control (SLC)	1		1
	Standby service water (SWS)	24	15	39
	Normally Running Total	**543**	**776**	**1319**
Standby	Auxiliary feedwater (AFW)		124	124
	Containment spray recirculation (CSR)		152	152
	Control rod drive (CRD)		9	9
	Emergency power supply (EPS)		16	16
	Firewater (FWS)		1	1
	Fuel Oil Transfer (FOT)		62	62
	High pressure core spray (HCS)		9	9
	High pressure injection (HPI)		170	170
	Low pressure core spray (LCS)		67	67
	Normally operating service water (SWN)		216	216
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)		308	308
	Standby liquid control (SLC)		70	70
	Standby service water (SWS)	2	211	213
	Standby Total	**2**	**1415**	**1417**
	Grand Total	**545**	**2191**	**2736**

Table 2-3 summarizes the data obtained from EPIX and used in the MDP analysis. Note that the hours for ELS are reactor-year hours.

Table 2-3. MDP unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTS	315	363935	1341	106	18.1%	84.0%
	FTR≤1H	38	326023 h	1341	106	2.7%	29.2%
	FTR>1H	110	14219837 h	1341	106	7.4%	50.9%
Running/ Alternating	FTS	150	114473	706	101	17.0%	66.3%
	FTR	149	45853637 h	704	101	16.2%	68.3%
All	ELS	93	258455367 h	2271	104	3.1%	43.3%

Figure 2-1a shows the range of start demands per year in the standby MDP data set. Figure 2-1b shows the range of start demands per year in the running MDP data set. Figure 2-2a shows the range of run hours per demand in the standby MDP data set. Figure 2-2b shows the range of run hours per demands in the running MDP data set.

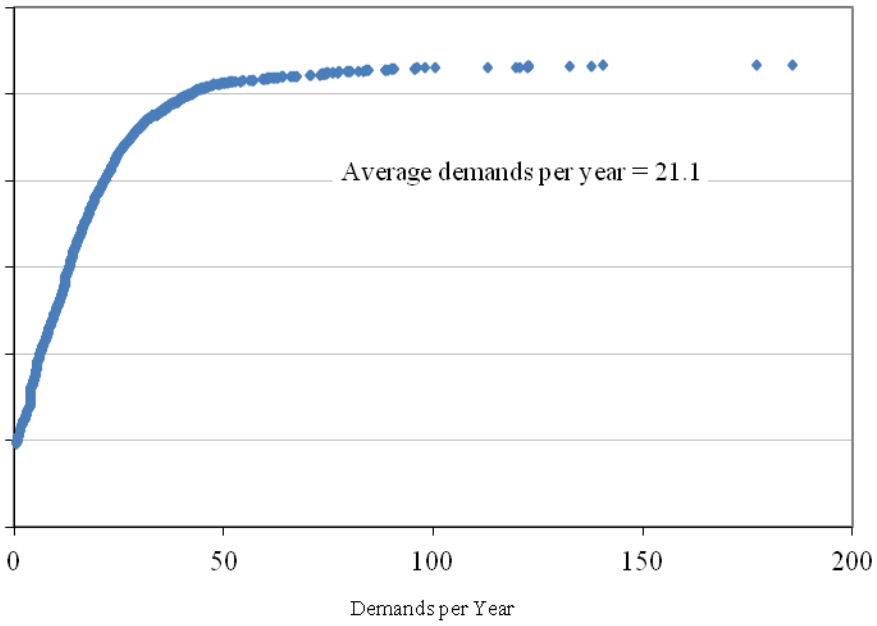

Figure 2-1a. Standby MDP demands per year distribution.

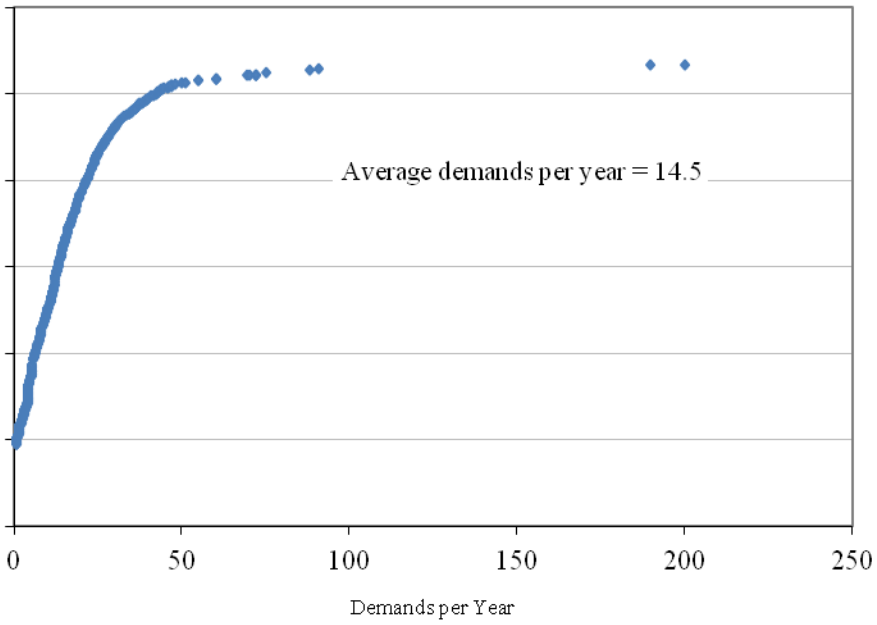

Figure 2-1b. Running/alternating MDP demands per year distribution.

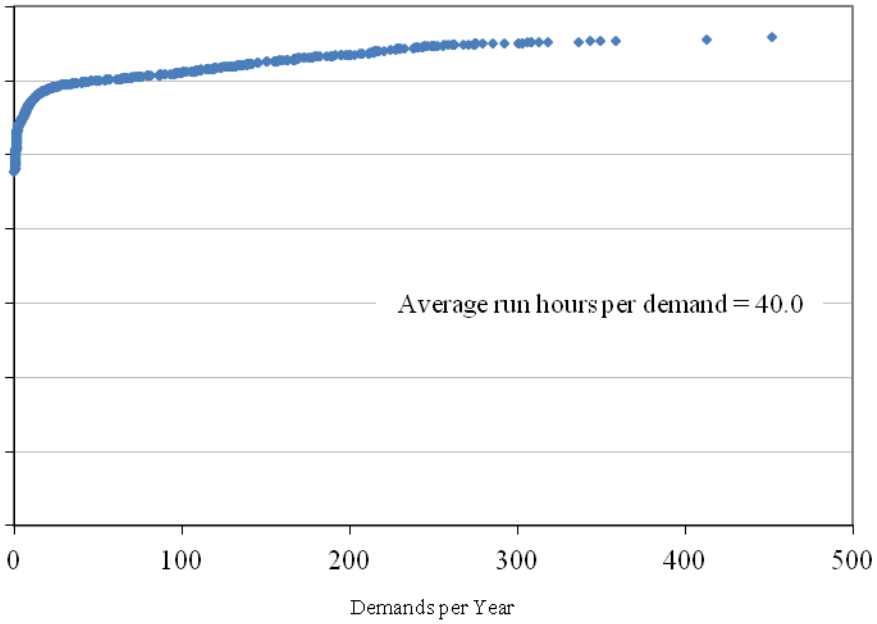

Figure 2-2a. Standby MDP run hours per demand distribution.

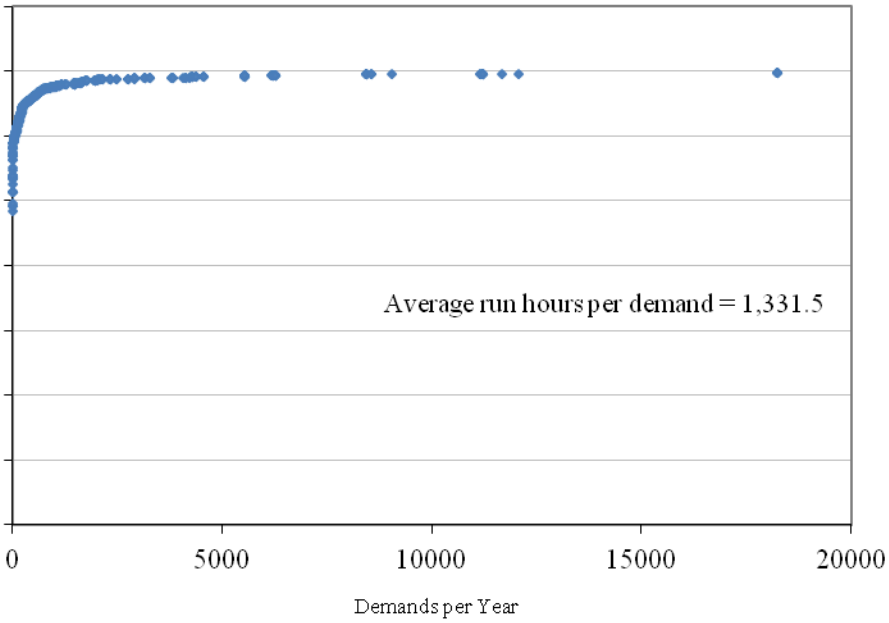

Figure 2-2b. Running/alternating MDP run hours per demand distribution.

2.1.3 Industry-Average Baselines

Table 2-4 lists the selected industry distributions of p and λ for the MDP failure modes. These industry-average failure rates do not account for any recovery.

Table 2-4. Selected industry distributions of p and λ for MDPs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/PL/KS	1.63E-04	7.91E-04	9.47E-04	2.27E-03	Beta	1.95	2.054E+03
	FTR≤1H	EB/PL/KS	1.93E-05	1.01E-04	1.23E-04	3.01E-04	Beta	1.82	1.479E+04
	FTR>1H	EB/PL/KS	2.64E-07	6.44E-06	1.04E-05	3.41E-05	Gamma	0.78	7.501E+04
Running/ Alternating	FTS	EB/PL/KS	4.01E-04	1.23E-03	1.36E-03	2.79E-03	Beta	3.28	2.406E+03
	FTR	EB/PL/KS	7.36E-07	3.03E-06	3.53E-06	8.02E-06	Gamma	2.29	6.496E+05
All	ELS	EB/PL/KS	6.94E-09	2.04E-07	3.42E-07	1.15E-06	Gamma	0.73	2.136E+06
	ELL	JNID/IL	2.56E-12	5.84E-09	2.40E-08	1.10E-07	Gamma	0.30	1.252E+07

2.2 Turbine-Driven Pump (TDP)

2.2.1 Component Description

The TDP boundary includes the pump, turbine, governor control, steam emission valve, local lubrication or cooling systems, and local instrumentation and controls. The failure modes for TDP are listed in Table 2-1.

2.2.2 Data Collection and Review

Data for TDP UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems and operational status included in the TDP data collection are listed in Table 2-5 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤200 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 2-5. TDP systems.

Pooling Group	**System**	**Number of Components**		
		High/ Unknown Demand	**Low Demand**	**Total**
Normally Running	Main feedwater (MFW)	4	42	46
	Normally Running Total	**4**	**42**	**46**
Standby	Auxiliary feedwater (AFW)		74	74
	High pressure coolant injection (HCI)		28	28
	Reactor core isolation (RCI)		31	31
	Standby Total		**133**	**133**
	Grand Total	4	42	46

Table 2-6 summarizes the data obtained from EPIX and used in the TDP analysis. Note that the hours for ELS are reactor-year hours.

Table 2-6. TDP unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTS	117	19760	133	98	48.1%	53.1%
	FTR≤1H	54	13062 h	133	98	29.3%	35.7%
	FTR>1H	12	8028 h	133	98	9.0%	12.2%
Running/ Alternating	FTS	8	957	42	20	16.7%	30.0%
	FTR	39	4276404 h	42	20	54.8%	80.0%
All	ELS	14	20036597 h	178	102	5.6%	9.8%

Figure 2-3a shows the range of start demands per year in the standby TDP data set. Figure 2-3b shows the range of start demands per year in the running/alternating TDP data set. Figure 2-4a shows the range of run hours per demand in the standby TDP data set. Figure 2-4b shows the range of run hours per demands in the running TDP data set.

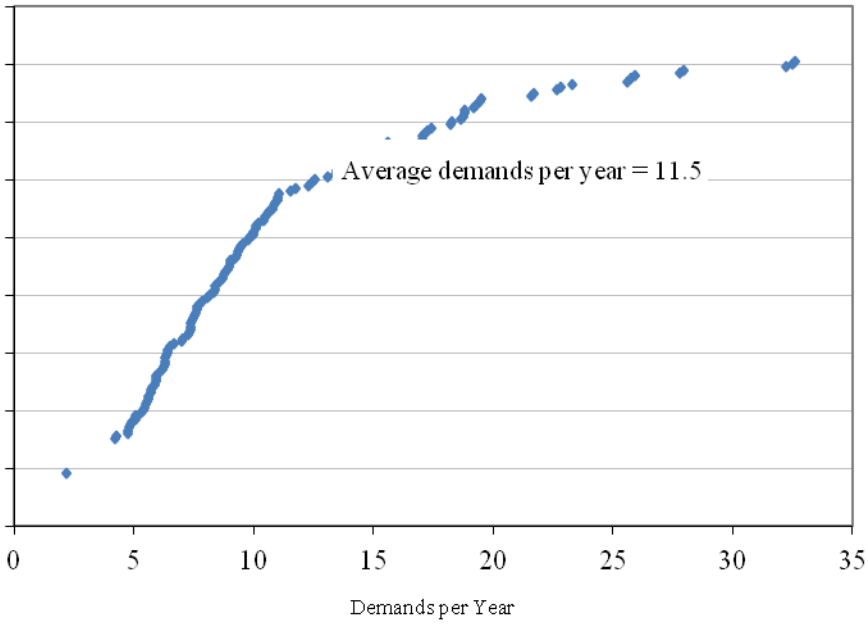

Figure 2-3a. Standby TDP demands per year distribution.

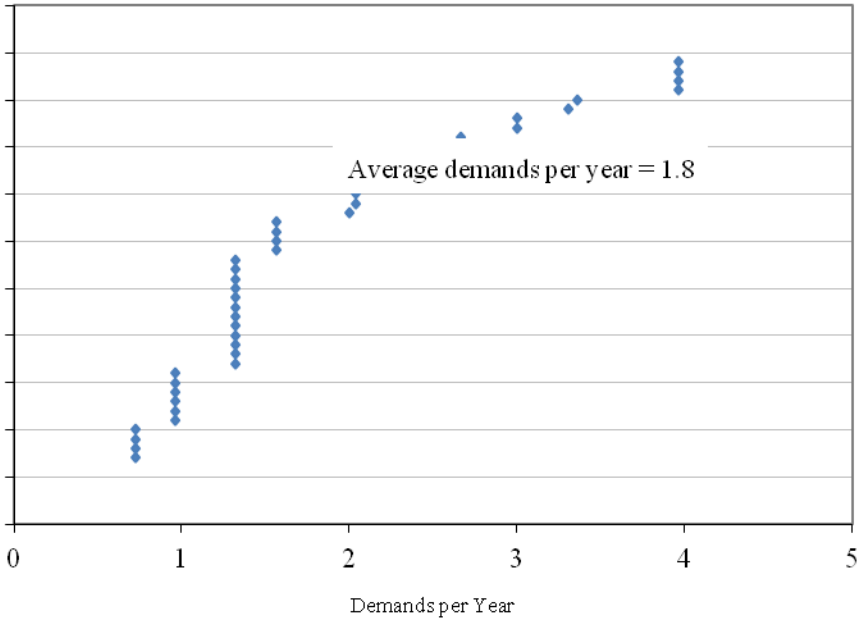

Figure 2-3b. Running/alternating TDP demands per year distribution.

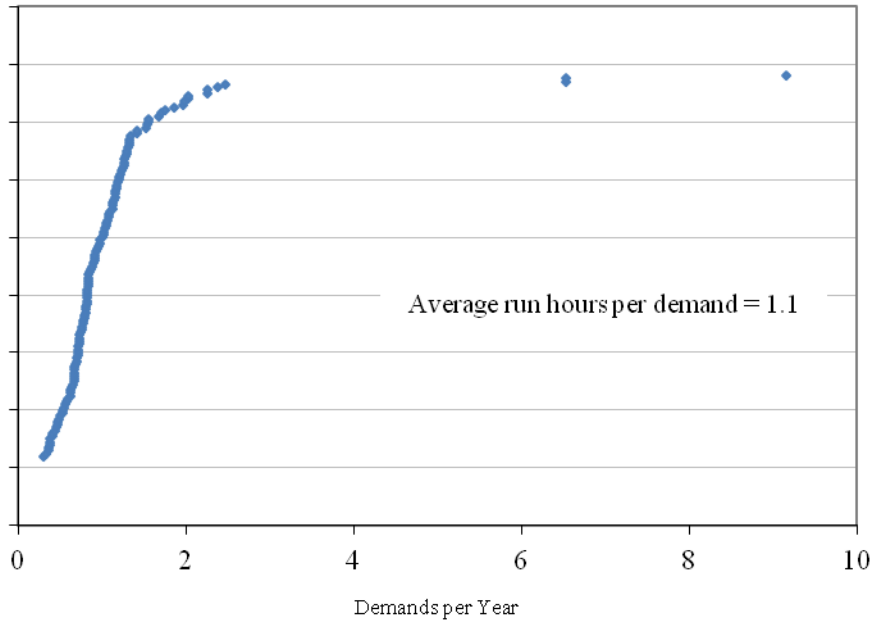

Figure 2-4a. Standby TDP run hours per demand distribution.

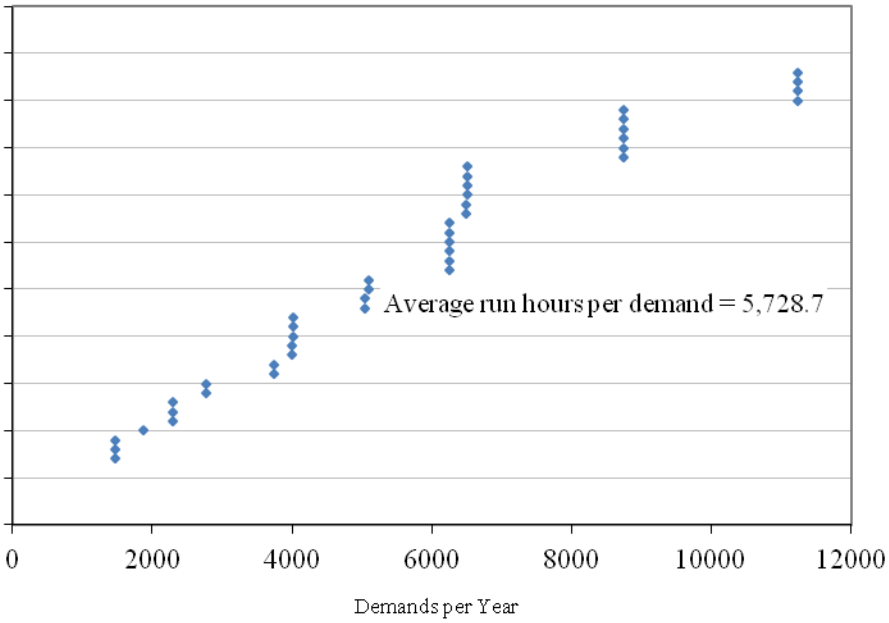

Figure 2-4b. Running/alternating TDP run hours per demand distribution.

2.2.3 Industry-Average Baselines

Table 2-7 lists the selected industry distributions of p and λ for the TDP failure modes. These industry-average failure rates do not account for any recovery.

Table 2-7. Selected industry distributions of p and λ for TDPs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/PL/KS	2.88E-04	4.41E-03	6.49E-03	1.98E-02	Beta	0.94	1.441E+02
	FTR≤1H	EB/PL/KS	2.07E-04	3.03E-03	4.43E-03	1.34E-02	Beta	0.96	2.164E+02
	FTR>1H	JNID/IL	9.10E-04	1.52E-03	1.56E-03	2.35E-03	Gamma	12.50	8.028E+03
Running/ Alternating	FTS	EB/PL/KS	3.25E-04	5.89E-03	8.93E-03	2.79E-02	Beta	0.88	9.728E+01
	FTR	EB/PL/KS	1.44E-06	7.67E-06	9.34E-06	2.29E-05	Gamma	1.79	1.919E+05
All	ELS	JNID/IL	4.42E-07	7.07E-07	7.24E-07	1.06E-06	Gamma	14.50	2.004E+07
	ELL	JNID/IL	5.42E-12	1.24E-08	5.07E-08	2.32E-07	Gamma	0.30	5.919E+06

2.3 Engine-Driven Pump (EDP)

2.3.1 Component Description

The diesel-driven pump (EDP) boundary includes the pump, diesel engine, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for DDP are listed in Table 2-1.

2.3.2 Data Collection and Review

Data for EDP UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems and operational status included in the EDP data collection are listed in Table 2-8 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤200 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 2-8. EDP systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
Normally Running	Auxiliary feedwater (AFW)	1		1
	Firewater (FWS)	18	5	23
	Fuel Oil Transfer (FOT)	2		2
	Main feedwater (MFW)	1		1
	Standby service water (SWS)	3		3
	Normally Running Total	**25**	**5**	**30**
Standby	Auxiliary feedwater (AFW)		5	5
	Emergency power supply (EPS)		1	1
	Firewater (FWS)		20	20
	Standby service water (SWS)		10	10
	Standby Total		**36**	**36**
	Grand Total	**25**	**41**	**66**

Table 2-9 summarizes the data obtained from EPIX and used in the EDP analysis.

Table 2-9. EDP unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTS	44	13647	41	26	51.2%	61.5%
	FTR≤1H	8	7698 h	36	24	19.4%	25.0%
	FTR>1H	9	4182 h	36	24	22.2%	29.2%
All	ELS	7	6267335 h	55	36	12.7%	16.7%
AFW	FTS	6	1132	5	5	40.0%	40.0%
	FTR≤1H	4	584 h	5	5	60.0%	60.0%
	FTR>1H	0	231 h	5	5	0.0%	0.0%

Figure 2-5 shows the range of start demands per year in the standby EDP data set. Figure 2-6 shows the range of run hours per demand in the standby EDP data set.

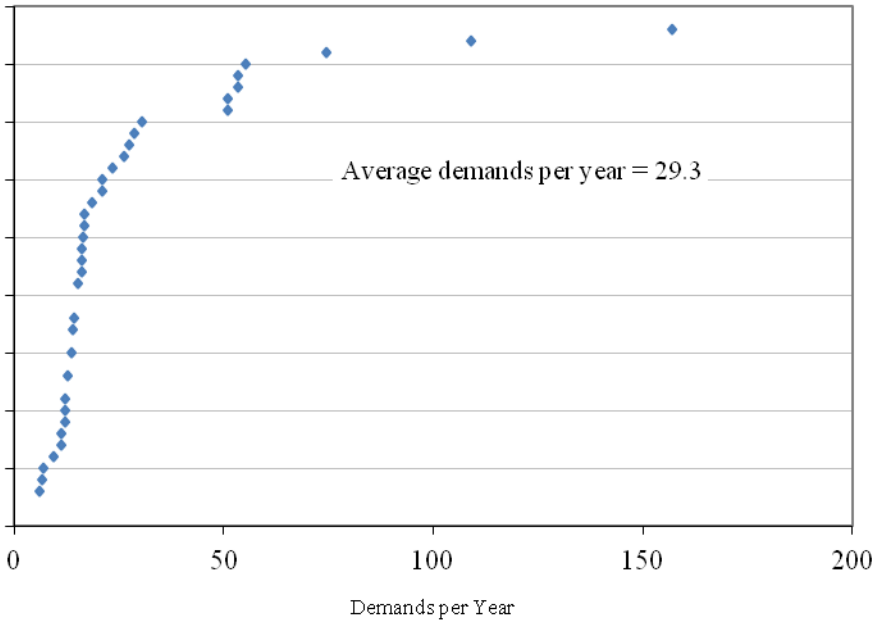

Figure 2-5. Standby EDP demands per year distribution.

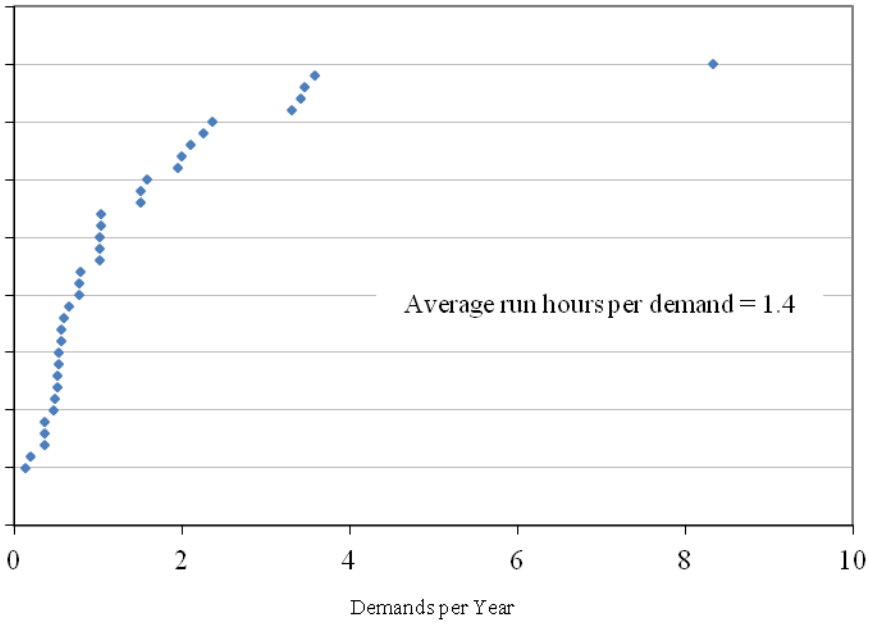

Figure 2-6. Standby EDP run hours per demand distribution.

2.3.3 Industry-Average Baselines

Table 2-10 lists the selected industry distributions of p and λ for the EDP failure modes. These industry-average failure rates do not account for any recovery.

Table 2-10. Selected industry distributions of p and λ for EDPs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/PL/KS	1.04E-04	3.06E-03	5.09E-03	1.70E-02	Beta	0.73	1.429E+02
	FTR≤1H	EB/PL/KS	8.26E-06	6.23E-04	1.26E-03	4.64E-03	Beta	0.55	4.411E+02
	FTR>1H	JNID/IL	1.21E-03	2.19E-03	2.27E-03	3.60E-03	Gamma	9.50	4.182E+03
All	ELS	JNID/IL	5.79E-07	1.14E-06	1.20E-06	1.99E-06	Gamma	7.50	6.267E+06
	ELL	JNID/IL	8.99E-12	2.05E-08	8.40E-08	3.84E-07	Gamma	0.30	3.571E+06
AFW	FTS	EB/PL/KS	5.78E-05	2.68E-03	4.88E-03	1.72E-02	Beta	0.63	1.291E+02
	FTR≤1H	JNID/IL	2.85E-03	7.14E-03	7.70E-03	1.44E-02	Beta	4.50	5.800E+02
	FTR>1H	JNID/IL	8.51E-06	9.84E-04	2.16E-03	8.31E-03	Gamma	0.50	2.311E+02

2.4 Positive Displacement Pump (PDP)

2.4.1 Component Description

The positive displacement pump (PDP) boundary includes the pump, motor, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for PDP are listed in Table 2-1.

2.4.2 Data Collection and Review

Data for PDP UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems and operational status included in the PDP data collection are listed in Table 2-11 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤200 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 2-11. PDP systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
Normally Running	Chemical and volume control (CVC)	24	61	85
	Containment spray recirculation (CSR)	6		6
	Emergency power supply (EPS)	4		4
	Fuel Oil Transfer (FOT)	3		3
	High pressure injection (HPI)	3		3
	Instrument air (IAS)	2		2
	Main feedwater (MFW)	2	1	3
	Standby liquid control (SLC)	1		1
	Normally Running Total	**45**	**62**	**107**
Standby	Emergency power supply (EPS)		2	2
	High pressure injection (HPI)		2	2
	Standby liquid control (SLC)		70	70
	Standby Total		**74**	**74**
	Grand Total	**45**	**136**	**181**

Table 2-12 summarizes the data obtained from EPIX and used in the PDP analysis. Note that the hours for ELS are reactor-year hours.

Table 2-12. PDP unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTS	14	8079	74	35	16.2%	34.3%
	FTR≤1H	2	3527 h	74	35	2.7%	5.7%
	FTR>1H	2	1175 h	74	35	2.7%	5.7%
Running/ Alternating	FTS	62	25438	62	27	50.0%	63.0%
	FTR	48	2216149 h	59	26	42.4%	50.0%
All	ELS	1	11633280 h	166	63	1.4%	3.4%

Figure 2-7a shows the range of start demands per year in the standby PDP data set. Figure 2-7b shows the range of start demands per year in the running PDP data set. Figure 2-8a shows the range of run hours per demand in the standby PDP data set. Figure 2-8b shows the range of run hours per demands in the running PDP data set.

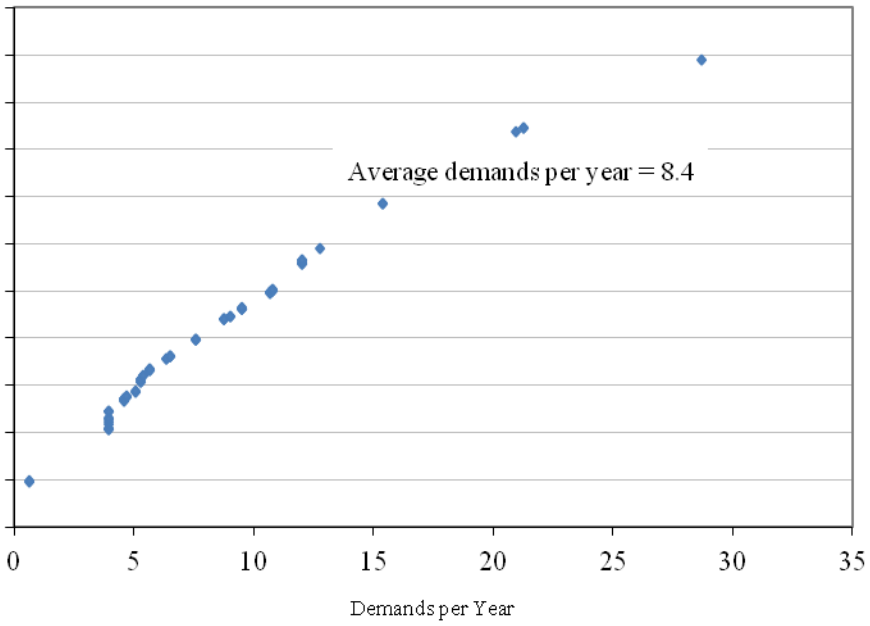

Figure 2-7a. Standby PDP demands per year distribution.

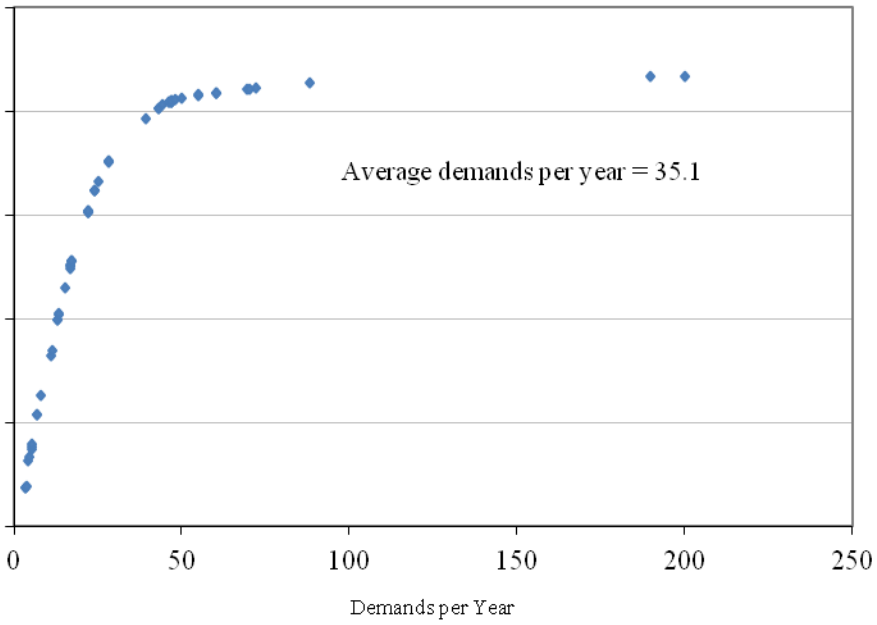

Figure 2-7b. Running/alternating PDP demands per year distribution.

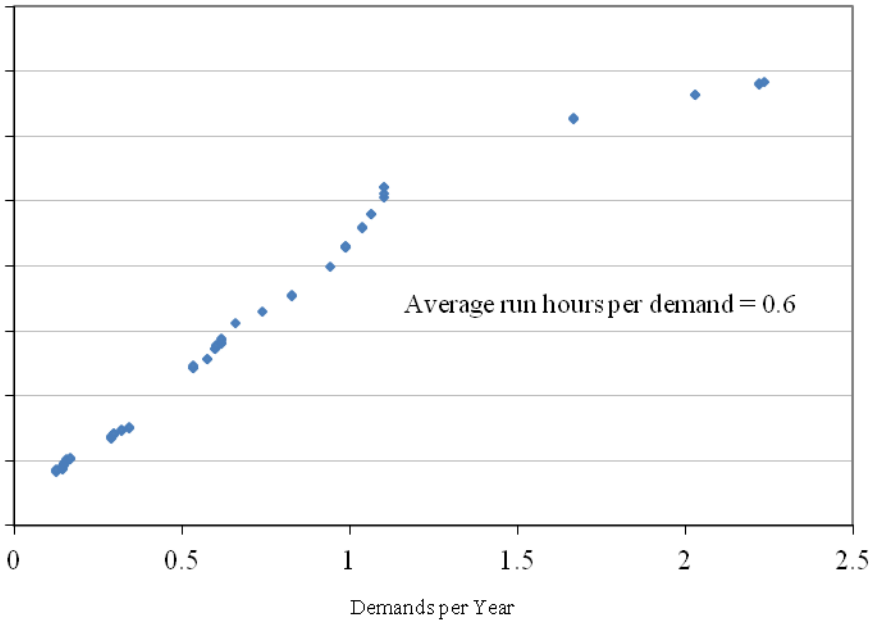

Figure 2-8a. Standby PDP run hours per demand distribution.

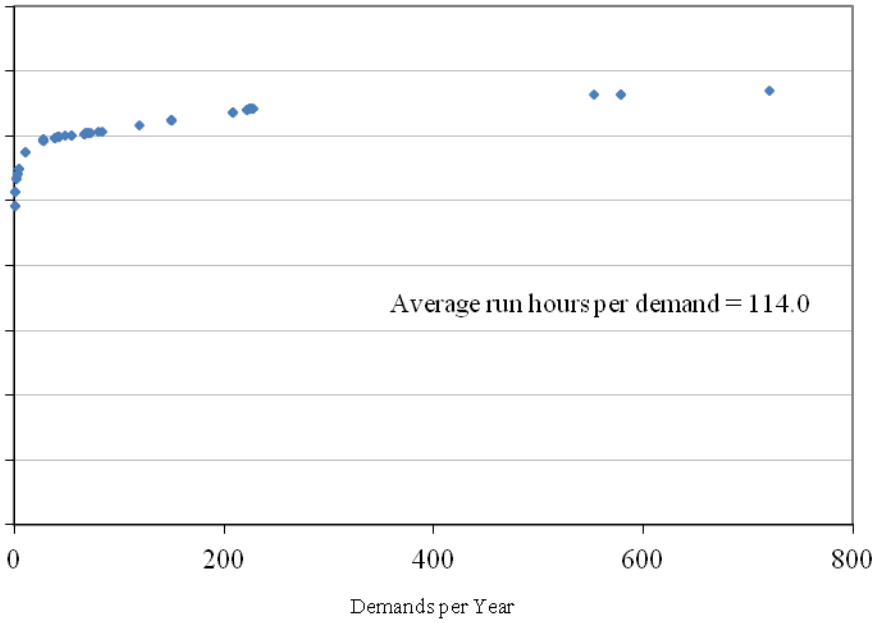

Figure 2-8b. Running/alternating PDP run hours per demand distribution.

2.4.3 Industry-Average Baselines

Table 2-13 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 2-13. Selected industry distributions of p and λ for PDPs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	JNID/IL	1.10E-03	1.75E-03	1.79E-03	2.63E-03	Beta	14.50	8.066E+03
	FTR≤1H	JNID/IL	1.62E-04	6.17E-04	7.09E-04	1.57E-03	Beta	2.50	3.525E+03
	FTR>1H	JNID/IL	4.87E-04	1.85E-03	2.13E-03	4.71E-03	Gamma	2.50	1.175E+03
Running/ Alternating	FTS	EB/PL/KS	1.70E-04	2.20E-03	3.15E-03	9.35E-03	Beta	1.02	3.229E+02
	FTR	EB/PL/KS	1.64E-06	1.68E-05	2.30E-05	6.56E-05	Gamma	1.15	5.006E+04
All	ELS	SCNID/IL	5.07E-10	5.86E-08	1.29E-07	4.95E-07	Gamma	0.500	3.879E+06
	ELL	ELS/EPIX	9.66E-13	2.20E-09	9.02E-09	4.13E-08	Gamma	0.300	3.325E+07

2.5 AFW Pump Volute (PMP)

2.5.1 Component Description

The AFW pump volute (PMP) boundary includes the pump volute portion of AFW EDPs, MDPs, and TDPs. PMP is used only to support the quantification of common-cause failure events across EDPs, MDPs, and TDPs. The failure modes for PMP are listed in Table 2-1.

2.5.2 Data Collection and Review

Data for PMP UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems and operational status included in the PMP data collection are listed in Table 2-14 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤200 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 2-14. PMP systems.

Pooling Group	**System**	**Number of Components**		
		High/ Unknown Demand	**Low Demand**	**Total**
Standby	Auxiliary feedwater (AFW)		203	203
	Grand Total		**203**	**203**

To identify pump volute failures within the AFW EDP, MDP, and TDP failures, the EPIX data was analyzed outside of RADS to determine the failures in the pump volute sub-component. Table 2-15 summarizes the data obtained from the event review and used in the PMP analysis.

Table 2-15. PMP unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
AFW	FTR	7	114233	203	69	3.4%	10.1%

2.5.3 Industry-Average Baselines

Table 2-16 lists the selected industry distributions of p and λ for the PMP failure modes. These industry-average failure rates do not account for any recovery.

Table 2-16. Selected industry distributions of p and λ for PMPs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
AFW	FTR	JNID/IL	3.18E-05	6.28E-05	6.57E-05	1.09E-04	Gamma	7.50	1.14E+05

3 Generators

The generators covered in this data sheet include those within the Class 1E ac electrical power system, the high-pressure core spray (HPCS) systems, and station blackout (SBO) generators.

The failure modes for the generator are listed in Table 3-1.

Table 3-1. Generator failure modes.

Pooling Group	Failure Mode	Parameter	Units	Description
All	FTS	p	-	Failure to start
	FTLR	p	-	Fail to load and run for 1 h
	FTR>1H	λ	1/h	Fail to run beyond 1 h

Table 3-2 shows the breakdown of the generator component data available for calculations. Not all of the generators are provided with demand and run time estimates. The column, "Unknown Demand" shows the generator counts for which, there are no demand and/or run time estimates. The component count is broken down into two categories: Unknown Demand which shows the counts for those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤200 demands per year.

Table 3-2. Generator component counts.

Pooling Group	**System**	**Number of Components**		
		Unknown Demand	**Low Demand**	**Total**
CTG	Emergency power supply (EPS)	2	3	5
	Plant ac power (ACP)	2		2
	CTG Total	**4**	**3**	**7**
EDG	Emergency power supply (EPS)	4	224	228
	Plant ac power (ACP)	1		1
	EDG Total	**5**	**224**	**229**
HPCS	High pressure core spray (HCS)		8	8
	HPCS Total		**8**	**8**
HTG	Emergency power supply (EPS)		2	2
	HTG Total		**2**	**2**
SBO	Emergency power supply (EPS)	4	2	6
	Plant ac power (ACP)	14	2	16
	SBO Total	**18**	**4**	**22**
	Grand Total	**27**	**241**	**268**

3.1 Emergency Diesel Generator (EDG)

3.1.1 Component Description

The emergency diesel generators (EDGs) covered in this data sheet are those within the Class 1E ac electrical power system at U.S. commercial nuclear power plants.

The EDG boundary includes the diesel engine with all components in the exhaust path, electrical generator, generator exciter, output breaker, combustion air, lube oil systems, fuel oil system, and starting compressed air system, and local instrumentation and control circuitry. However, the sequencer is not included. For the service water system providing cooling to the EDGs, only the devices providing control of cooling flow to the EDG heat exchangers are included. Room heating and ventilating is not included. The failure modes for EDG are listed in Table 3-1.

3.1.2 Data Collection and Review

Data for EDG UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems included in the EDG data collection are listed in Table 3-2 with the number of components included with each system.

Table 3-3 summarizes the data obtained from the event review and used in the EDG analysis.

Table 3-3. EDG unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	FTS	161	56695	224	95	49.1%	78.9%
	FTLR	182	49383	224	95	50.4%	73.7%
	FTR	113	106820 h	224	95	40.6%	67.4%

Figure 3-1 shows the range of start demands per year in the EDG data set. Figure 3-2 shows the range of run hours per demand in the EDG data set.

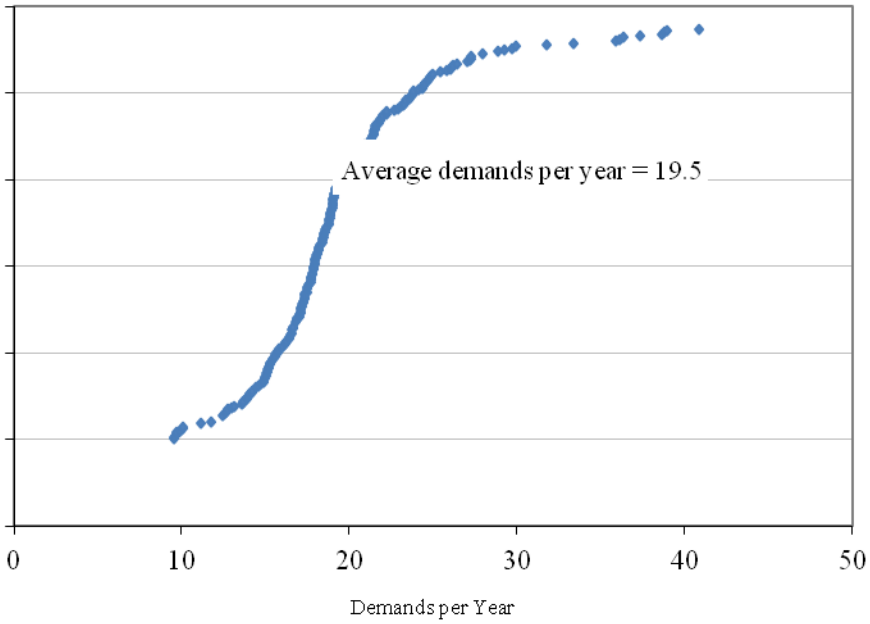

Figure 3-1. EDG demands per year distribution.

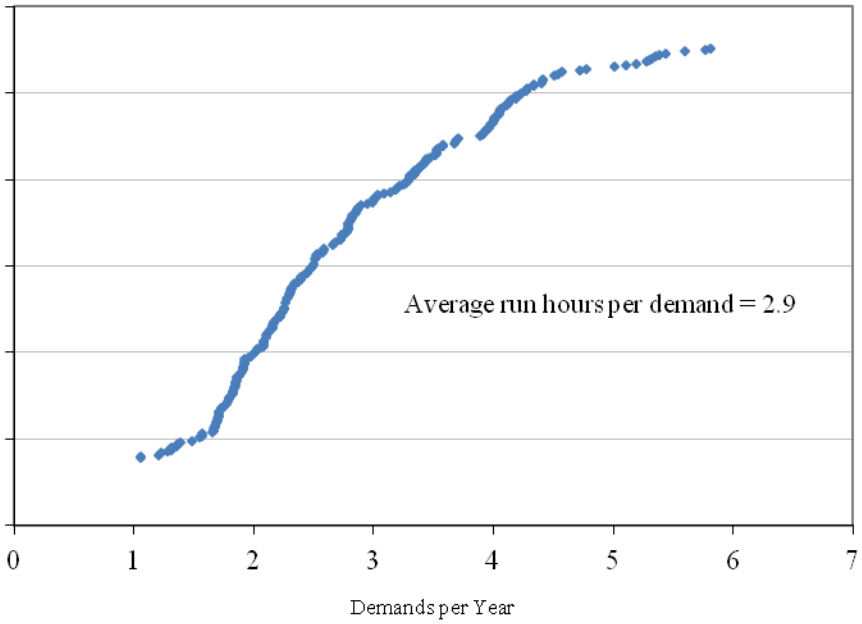

Figure 3-2. EDG run hours per demand distribution.

3.1.3 Industry-Average Baselines

Table 3-4 lists the selected industry distributions of p and λ for the EDG failure modes. These industry-average failure rates do not account for any recovery.

Table 3-4. Selected industry distributions of p and λ for EDGs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTS	EB/PL/KS	1.45E-03	2.77E-03	2.89E-03	4.73E-03	Beta	8.11	2.798E+03
	FTLR	EB/PL/KS	9.61E-04	3.34E-03	3.78E-03	8.10E-03	Beta	2.77	7.311E+02
	FTR	EB/PL/KS	4.04E-04	1.02E-03	1.10E-03	2.06E-03	Gamma	4.49	4.093E+03

3.2 Hydro Turbine Generator (HTG)

3.2.1 Component Description

The hydro turbine generator (HTG) boundary includes the turbine, generator, circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for HTG are listed in Table 3-1.

3.2.2 Data Collection and Review

Data for HTG UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems included in the HTG data collection are listed in Table 3-2 with the number of components included with each system.

Table 3-5 summarizes the data obtained from EPIX and used in the HTG analysis.

Table 3-5. HTG unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	FTS	7	5141	2	1	100.0%	100.0%
	FTLR	6	3087	2	1	50.0%	100.0%
	FTR	1	7449 h	2	1	50.0%	100.0%

3.2.3 Industry-Average Baselines

Table 3-6 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 3-6. Selected industry distributions of p and λ for HTGs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTS	JNID/IL	7.06E-04	1.39E-03	1.46E-03	2.43E-03	Beta	7.50	5.135E+03
	FTLR	JNID/IL	9.55E-04	2.00E-03	2.10E-03	3.62E-03	Beta	6.50	3.081E+03
	FTR	JNID/IL	2.36E-05	1.59E-04	2.01E-04	5.25E-04	Gamma	1.50	7.449E+03

3.3 Combustion Turbine Generator (CTG)

3.3.1 Component Description

The combustion turbine generator (CTG) boundary includes the gas turbine, generator, circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for CTG are listed in Table 3-1.

3.3.2 Data Collection and Review

Data for CTG UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems included in the CTG data collection are listed in Table 3-2 with the number of components included with each system.

Table 3-7 summarizes the data obtained from the plant and used in the CTG analysis.

Table 3-7. CTG unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	FTS	10	672	3	3	100.0%	100.0%
	FTLR	2	156296	3	3	66.7%	66.7%
	FTR	3	473 h	3	3	100.0%	100.0%

3.3.3 Industry-Average Baselines

Table 3-8 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 3-8. Selected industry distributions of p and λ for CTGs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTS	JNID/IL	8.64E-03	1.51E-02	1.56E-02	2.42E-02	Beta	10.50	6.629E+02
	FTLR	JNID/IL	3.66E-06	1.39E-05	1.60E-05	3.54E-05	Beta	2.50	1.563E+05
	FTR	JNID/IL	2.29E-03	6.70E-03	7.40E-03	1.49E-02	Gamma	3.50	4.732E+02

3.4 High-Pressure Core Spray Generator (HPCS)

3.4.1 Component Description

The high-pressure core spray generator (HPCS) boundary includes the engine, generator, circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for HPCS are listed in Table 3-1.

3.4.2 Data Collection and Review

Data for HPCS UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010.

The systems included in the HPCS data collection are listed in Table 3-2 with the number of components included with each system. Table 3-9 summarizes the data obtained from the plant and used in the CTG analysis.

Table 3-9. HPCS unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	FTS	14	372	4	4	75.0%	75.0%
	FTR	1	1155 h	4	4	25.0%	25.0%

3.4.3 Industry-Average Baselines

Table 3-10 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 3-10. Selected industry distributions of p and λ for HPCSs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTS	EB/PL/KS	2.86E-03	3.18E-02	4.32E-02	1.23E-01	Beta	1.09	2.423E+01
	FTR	JNID/IL	1.52E-04	1.02E-03	1.30E-03	3.38E-03	Gamma	1.50	1.155E+03

3.5 Station Blackout Generator (SBO)

3.5.1 Component Description

The station blackout generator (SBO) boundary includes the engine, exhaust, generator, circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for SBO are listed in Table 3-1.

3.5.2 Data Collection and Review

Data for SBO UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010.

The systems included in the SBO data collection are listed in Table 3-2 with the number of components included with each system. Table 3-11 summarizes the data obtained from the plant and used in the SBO analysis.

Table 3-11. SBO unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	FTS	14	372	4	4	75.0%	75.0%
	FTR	1	1155 h	4	4	25.0%	25.0%

3.5.3 Industry-Average Baselines

Table 3-12 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 3-12. Selected industry distributions of p and λ for SBOs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTS	EB/PL/KS	2.86E-03	3.18E-02	4.32E-02	1.23E-01	Beta	1.09	2.423E+01
	FTR	JNID/IL	1.52E-04	1.02E-03	1.30E-03	3.38E-03	Gamma	1.50	1.155E+03

4 Relief Valves

The relief valves presented in this section include the BWR dual-acting relief valves (SRV), the PWR power-operated relief valves (PORV) that are on the pressurizer and on the steam generators, and the code safety valves (SVV) that are on the pressurizer and on the steam generators. The failure modes for relief valves are listed in Table 4-1.

Table 4-1. Relief valve failure modes.

Pooling Group	Failure Mode	Parameter	Units	Description
All	FTO	p	-	Fail to open
	FTC	p	-	Fail to close
	SOP	λ	1/h	Spurious opening
	FTCL	p	-	Fail to close after passing liquid

4.1 Safety Relief Valve (SRV)

4.1.1 Component Description

The safety relief valve (SRV) component boundary includes the valve, the valve operator, and local instrumentation and control circuitry. The SRV lifts either by system pressure directly acting on the valve operator or by an electronic signal to the pilot valve. These are known as dual acting relief valves. The failure modes for SRV are listed in Table 4-1.

4.1.2 Data Collection and Review

Data for most SRV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010 using RADS. The systems included in the SRV data collection are listed in Table 4-2 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 4-2. SRV systems.

Pooling Group	**System**	**Number of Components**		
		High/ Unknown Demand	**Low Demand**	**Total**
All	Main steam (MSS)	169	409	578
	Grand Total	**169**	**409**	**578**

Table 4-3 summarizes the data used in the SRV analysis. Note that the hours for SOP, ELS, and ILS are reactor-year hours.

Table 4-3. SRV unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO	20	7396	409	33	3.7%	24.2%
	FTC	6	7396	409	33	1.5%	15.2%
	FC	0	62541477 h	577	35	0.0%	0.0%
	SOP	12	62541477 h	577	35	2.1%	25.7%
	ILS	23	62541477 h	577	35	4.0%	40.0%

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
	ELS	1	62541477 h	577	35	0.2%	2.9%

Figure 4-1 shows the range of valve demands per year in the SRV data set (limited to low-demand components only).

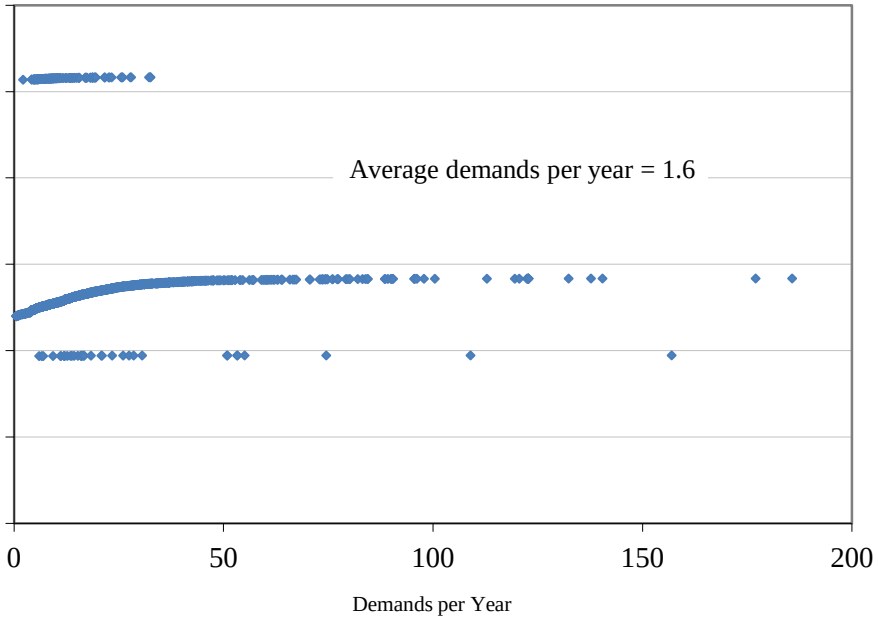

Figure 4-1. SRV demands per year distribution.

4.1.3 Industry-Average Baselines

Table 4-4 lists the selected industry distributions of p and λ for the SRV failure modes. These industry-average failure rates do not account for any recovery.

The FTCL failure mode is not supported by EPIX data. The selected distribution was generated by reviewing the FTC data in WSRC. To approximate the FTCL, the highest 95th percentiles for FTC were identified from that source. The highest values were approximately 1.0E-01. The mean for FTCL was assumed to be 1.0E-01. An α of 0.5 was also assumed.

Table 4-4. Selected industry distributions of p and λ for SRVs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	JNID/IL	1.85E-03	2.73E-03	2.77E-03	3.85E-03	Beta	20.50	7.376E+03
	FTC	EB/PL/KS	3.56E-05	5.74E-04	8.56E-04	2.64E-03	Beta	0.92	1.076E+03
	FC	JNID/IL	3.14E-11	3.64E-09	7.99E-09	3.07E-08	Gamma	0.50	6.254E+07
	SOP	EB/PL/KS	4.81E-10	9.85E-08	2.43E-07	9.75E-07	Gamma	0.44	1.821E+06
	ILS	EB/PL/KS	1.16E-08	2.61E-07	4.15E-07	1.34E-06	Gamma	0.81	1.942E+06
	ILL	EB/PL/KS	8.88E-13	2.02E-09	8.29E-09	3.79E-08	Gamma	0.30	3.617E+07
	ELS	JNID/IL	2.81E-09	1.89E-08	2.40E-08	6.25E-08	Gamma	1.50	6.254E+07
	ELL	JNID/IL	1.80E-13	4.10E-10	1.68E-09	7.69E-09	Gamma	0.30	1.786E+08

4.2 Safety Valve (SVV)

4.2.1 Component Description

The safety valve (SVV) component boundary includes the valve and the valve operator. The SVV is a direct-acting relief valve. These relief valves are also known as 'Code Safeties' since their lift points are the highest and are meant to protect the piping integrity. The failure modes for SVV are listed in Table 4-1.

4.2.2 Data Collection and Review

Data for SVV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010 using RADS. The systems included in the SVV data collection are listed in Table 4-5 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 4-5. SVV systems.

Pooling Group	**System**	**Number of Components**		
		High/ Unknown Demand	**Low Demand**	**Total**
All	Main steam (MSS)	410	804	1214
	Reactor coolant (RCS)	74	147	221
	Grand Total	**484**	**951**	**1435**

The SVV data set obtained from RADS was further reduced to include only those SVVs with ≤ 20 demands/year. See Section A.1 in Reference 14 for a discussion concerning this decision to limit the component populations for valves. Table 4-6 summarizes the data used in the SVV analysis. The FTCL failure mode is not supported with EPIX data. Note that the hours for SOP, ELS, and ILS are reactor-year hours.

Table 4-6. SVV unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
PWR RCS	FTO	1	2048	147	47	0.7%	2.1%
	FTC	1	2048	147	47	0.7%	2.1%
	SOP	9	136514441 h	1198	76	0.8%	5.3%
PWR MSS	FTO	6	14809	760	46	0.8%	10.9%
	FTC	2	14809	760	46	0.3%	2.2%
	SOP	9	136514441 h	1198	76	0.8%	5.3%
All	FTO	7	17320	950	66	0.7%	9.1%
	FTC	3	17320	950	66	0.3%	3.0%
	ILS	14	161355977 h	1416	79	1.0%	12.7%
	ELS	4	161355977 h	1416	79	0.3%	5.1%

Figure 4-2 shows the range of valve demands per year in the SVV data set (limited to low-demand components only).

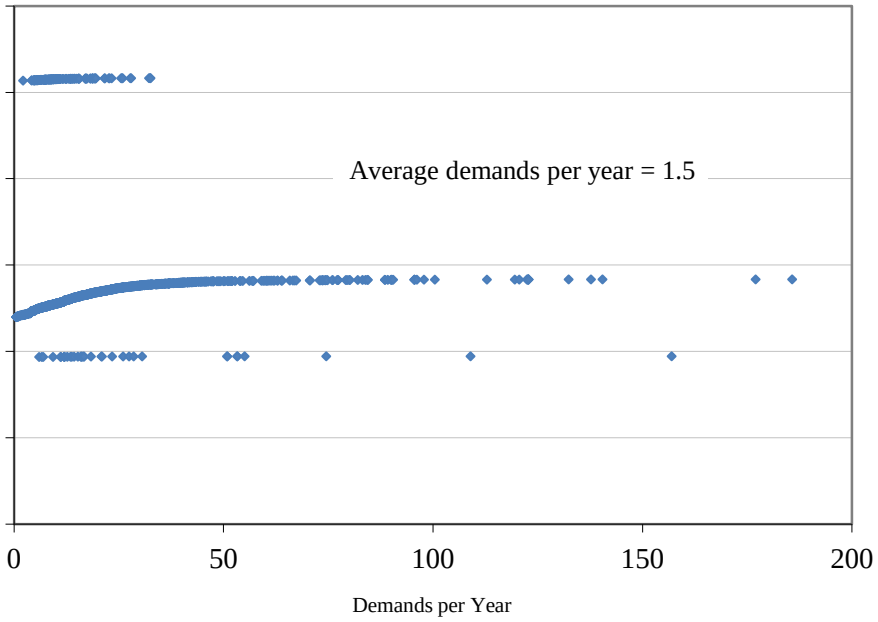

Figure 4-2. SVV demands per year distribution.

4.2.3 Industry-Average Baselines

Table 4-7 lists the selected industry distributions of p and λ for the SVV failure modes. These industry-average failure rates do not account for any recovery.

Table 4-7. Selected industry distributions of p and λ for SVVs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
PWR RCS	FTO	JNID/IL	8.59E-05	5.77E-04	7.32E-04	1.91E-03	Beta	1.50	2.05E+03
	FTC	JNID/IL	8.59E-05	5.77E-04	7.32E-04	1.91E-03	Beta	1.50	2.05E+03
	SOP	JNID/IL	3.71E-08	6.72E-08	6.96E-08	1.10E-07	Gamma	9.50	1.37E+08
PWR MSS	FTO	EB/PL/KS	1.86E-06	2.07E-04	4.51E-04	1.73E-03	Beta	0.50	1.12E+03
	FTC	JNID/IL	3.87E-05	1.47E-04	1.69E-04	3.74E-04	Beta	2.50	1.48E+04
	SOP	JNID/IL	3.71E-08	6.72E-08	6.96E-08	1.10E-07	Gamma	9.50	1.37E+08
All	FTO	EB/PL/KS	2.36E-05	2.97E-04	4.23E-04	1.25E-03	Beta	1.03	2.44E+03
	FTC	JNID/IL	6.26E-05	1.83E-04	2.02E-04	4.06E-04	Beta	3.50	1.73E+04
	ILS	JNID/IL	5.49E-08	8.78E-08	8.99E-08	1.32E-07	Gamma	14.50	1.61E+08
	ILL	JNID/IL	1.92E-13	4.38E-10	1.80E-09	8.22E-09	Gamma	0.30	1.67E+08
	ELS	JNID/IL	1.03E-08	2.59E-08	2.79E-08	5.24E-08	Gamma	4.50	1.61E+08
	ELL	JNID/IL	2.09E-13	4.76E-10	1.95E-09	8.93E-09	Gamma	0.30	1.54E+08

4.3 Power-Operated Relief Valve (PORV)

4.3.1 Component Description

The power-operated relief valve (PORV) component boundary includes the valve, the valve operator, local circuit breaker, and local instrumentation and control circuitry. The failure modes for PORV are listed in Table 4-1.

4.3.2 Data Collection and Review

Data for PORV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010 using RADS. The systems included in the PORV data collection are listed in Table 4-8 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 4-8. PORV systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
All	Main steam (MSS)	169	126	295
	Reactor coolant (RCS)	9	120	129
	Grand Total	**178**	**246**	**424**

Table 4-9 summarizes the data used in the PORV analysis. Note that the hours for FC, SOP, ELS, and ILS are reactor-year hours.

Table 4-9. PORV unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
RCS	FTO	16	4657	120	57	10.0%	19.3%
	FTC	4	4657	120	57	3.3%	7.0%
MSS	FTO	41	8363	126	41	27.0%	53.7%
	FTC	14	8363	126	41	10.3%	22.0%
All	FC	8	31564704 h	277	64	2.9%	6.3%
	SOP	21	46264512 h	406	71	4.2%	18.3%
	ILS	23	46264512 h	406	71	4.7%	19.7%
	ELS	5	46264512 h	406	71	1.2%	7.0%

Figure 4-3 shows the range of valve demands per year in the PORV data set (limited to low-demand components only).

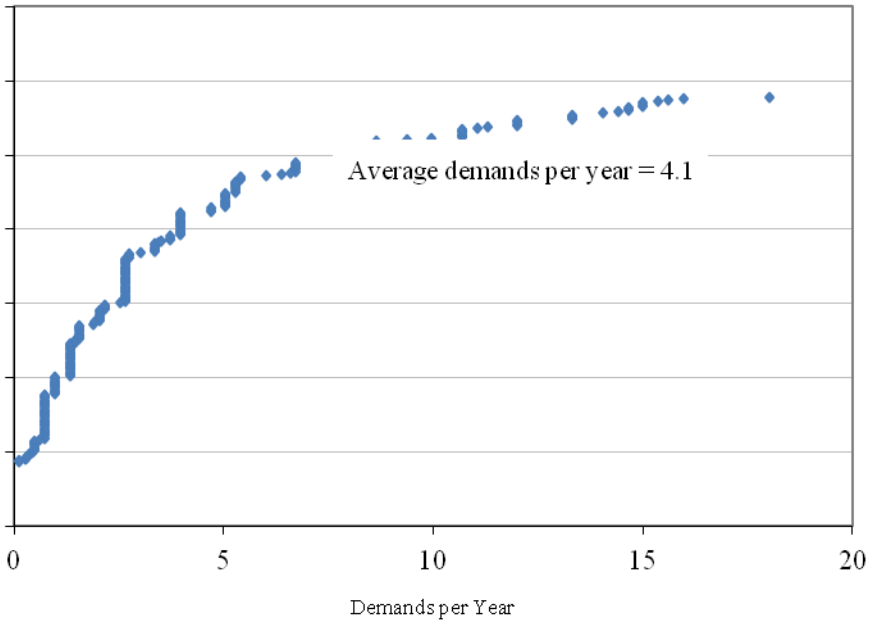

Figure 4-3. PORV demands per year distribution.

4.3.3 Industry-Average Baselines

Table 4-10 lists the selected industry distributions of p and λ for the PORV failure modes. These industry-average failure rates do not account for any recovery.

Table 4-10. Selected industry distributions of p and λ for PORVs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
RCS	FTO	JNID/IL	2.24E-03	3.47E-03	3.54E-03	5.09E-03	Beta	16.50	4.64E+03
	FTC	JNID/IL	3.57E-04	8.96E-04	9.66E-04	1.82E-03	Beta	4.50	4.65E+03
MSS	FTO	EB/PL/KS	1.07E-03	4.73E-03	5.56E-03	1.29E-02	Beta	2.12	3.79E+02
	FTC	JNID/IL	1.06E-03	1.69E-03	1.73E-03	2.54E-03	Beta	14.50	8.35E+03
All	FC	JNID/IL	1.37E-07	2.59E-07	2.69E-07	4.37E-07	Gamma	8.50	3.16E+07
	SOP	JNID/IL	3.13E-07	4.58E-07	4.65E-07	6.41E-07	Gamma	21.50	4.63E+07
	ILS	JNID/IL	3.49E-07	5.01E-07	5.08E-07	6.92E-07	Gamma	23.50	4.63E+07
	ILL	JNID/IL	1.09E-12	2.48E-09	1.02E-08	4.65E-08	Gamma	0.30	2.95E+07
	ELS	JNID/IL	4.94E-08	1.12E-07	1.19E-07	2.13E-07	Gamma	5.50	4.63E+07
	ELL	JNID/IL	8.92E-13	2.03E-09	8.33E-09	3.81E-08	Gamma	0.30	3.60E+07
Liquid [a]	FTC	JNID/IL	6.45E-05	2.46E-02	6.25E-02	2.54E-01	Beta	0.39	5.90E+00
Stick Open [a]	FTC	JNID/IL	2.61E-04	1.23E-03	1.46E-03	3.46E-03	Beta	2.01	1.37E+03
LOOP [b]	SO	Point Estimate	-	-	1.48E-01	-		-	-
Transient [b]	SO	Point Estimate	-	-	3.67E-02	-		-	-

Note: a. NUREG/CR-7037 (Reference 15), Table 30
b. NUREG/CR-7037 (Reference 15), Table 13

4.4 Low-Capacity Relief Valve (RVL)

4.4.1 Component Description

The low-capacity relief valve (RVL) component boundary includes the valve, the valve operator,. The failure modes for RVL are listed in Table 4-1.

4.4.2 Data Collection and Review

Data for RVL UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010 using RADS. The systems included in the RVL data collection are listed in Table 4-11 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 4-11. RVL systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
All	Auxiliary feedwater (AFW)	1		1
	Chemical and volume control (CVC)	20	2	22
	Component cooling water (CCW)	21	1	22
	Containment spray recirculation (CSR)	3		3
	High pressure injection (HPI)	1		1
	Low pressure core spray (LCS)		1	1
	Normally operating service water (SWN)	10		10
	Reactor core isolation (RCI)	1		1
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	12	6	18
	Standby liquid control (SLC)	2	3	5
	Standby service water (SWS)	3		3
	Grand Total	**74**	**13**	**87**

Table 4-12 summarizes the data used in the RVL analysis. Note that the hours for SOP, ELS, and ILS are reactor-year hours.

Table 4-12. RVL unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO	1	185	14	9	7.1%	11.1%
	FTC	5	185	14	9	35.7%	33.3%
	SO	1	7520832 h	66	33	1.5%	3.0%
	ILS	15	7520832 h	66	33	22.7%	42.4%
	ELS	3	7520832 h	66	33	4.5%	9.1%

Figure 4-4 shows the range of valve demands per year in the RVL data set (limited to low-demand components only).

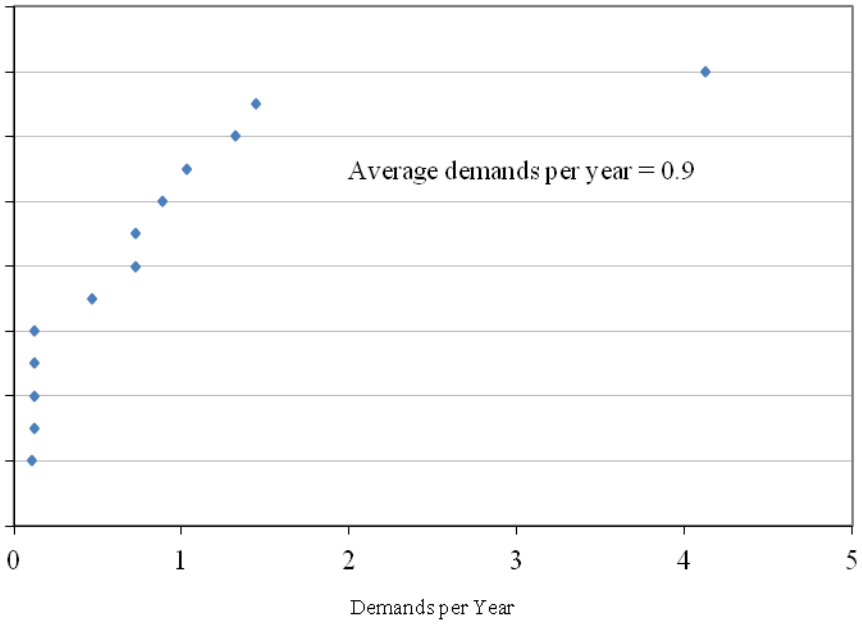

Figure 4-4. RVL demands per year distribution.

4.4.3 Industry-Average Baselines

Table 4-13 lists the selected industry distributions of p and λ for the RVL failure modes. These industry-average failure rates do not account for any recovery.

Table 4-13. Selected industry distributions of p and λ for RVLs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	JNID/IL	9.51E-04	6.38E-03	8.06E-03	2.09E-02	Beta	1.50	1.85E+02
	FTC	JNID/IL	1.24E-02	2.79E-02	2.96E-02	5.24E-02	Beta	5.50	1.81E+02
	SO	JNID/IL	2.34E-08	1.57E-07	1.99E-07	5.20E-07	Gamma	1.50	7.52E+06
	ILS	JNID/IL	1.28E-06	2.02E-06	2.06E-06	2.99E-06	Gamma	15.50	7.52E+06
	ILL	JNID/IL	4.41E-12	1.00E-08	4.12E-08	1.88E-07	Gamma	0.30	7.28E+06
	ELS	JNID/IL	1.44E-07	4.22E-07	4.65E-07	9.35E-07	Gamma	3.50	7.52E+06
	ELL	JNID/IL	3.48E-12	7.93E-09	3.26E-08	1.49E-07	Gamma	0.30	9.22E+06

5 Electrical Equipment

This section provides reliability estimates of various electrical equipment used in probabilistic risk assessment. The failure modes applicable to electrical equipment are listed in Table 5-1.

Table 5-1. Electrical equipment failure modes.

Pooling Group	Failure Mode	Parameter	Units	Description
All	FTO/C	p	-	Failure to open or failure to close
	SOP	λ	1/h	Spurious operation
	FTOP	λ	1/h	Fail to operate
	FF	p	-	Failure to function on demand

5.1 Battery Charger (BCH)

5.1.1 Component Description

The battery charger (BCH) boundary includes the battery charger and its breakers. The failure mode for BCH is listed in Table 5-1.

5.1.2 Data Collection and Review

Data for BCH UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems included in the BCH data collection are listed in Table 5-2 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 5-2. BCH systems.

Pooling Group	**System**	**Number of Components**		
		High/ Unknown Demand	**Low Demand**	**Total**
All	dc power (DCP)	755	11	766
	Emergency power supply (EPS)	10		10
	High pressure core spray (HCS)	1		1
	Main steam (MSS)	2		2
	Offsite electrical power (OEP)	4		4
	Plant ac power (ACP)	55		55
	Uninterruptable instrument power supply (UPS)	7		7
	Grand Total	**834**	**11**	**845**

Table 5-3 summarizes the data obtained from EPIX and used in the BCH analysis.

Table 5-3. BCH unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	FTOP	233	95947373 h	842	99	20.8%	72.7%

5.1.3 Industry-Average Baselines

Table 5-4 lists the industry-average failure rate distribution. This industry-average failure rate does not account for any recovery.

Table 5-4. Selected industry distributions of p and λ for BCHs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTOP	EB/PL/KS	2.39E-07	2.05E-06	2.71E-06	7.44E-06	Gamma	1.28	4.728E+05

5.2 Battery (BAT)

5.2.1 Component Description

The battery (BAT) boundary includes the battery cells. The failure mode for BAT is listed in Table 5-1.

5.2.2 Data Collection and Review

Data for BAT UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems included in the BAT data collection are listed in Table 5-5 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 5-5. BAT systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
All	dc power (DCP)	490	7	497
	Uninterruptable instrument power supply (UPS)	6		6
	Grand Total	**496**	**7**	**503**

Table 5-6 summarizes the data obtained from EPIX and used in the BAT analysis.

Table 5-6. BAT unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	FTOP	33	57203716 h	502	101	6.0%	25.7%

5.2.3 Industry-Average Baselines

Table 5-7 lists the industry-average failure rate distribution. This industry-average failure rate does not account for any recovery.

Table 5-7. Selected industry distributions of p and λ for BATs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTOP	EB/PL/KS	9.64E-08	4.86E-07	5.86E-07	1.42E-06	Gamma	1.88	3.213E+06

5.3 Automatic Bus Transfer Switch (ABT)

5.3.1 Component Description

The automatic bus transfer switch (ABT) boundary includes the ABT component itself. The failure mode for ABT is listed in Table 5-1.

5.3.2 Data Collection and Review

Data for the ABT UR baseline were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems included in the ABT data collection are listed in Table 5-8 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 5-8. ABT systems.

Pooling Group	**System**	**Number of Components**		
		High/ Unknown Demand	**Low Demand**	**Total**
All	dc power (DCP)		5	5
	Emergency power supply (EPS)		11	11
	Plant ac power (ACP)	9		9
	Uninterruptable instrument power supply (UPS)		7	7
	Grand Total	**9**	**23**	**32**

Table 5-9 summarizes the data obtained from EPIX and used in the ABT analysis.

Table 5-9. ABT unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	FF	0	311	23	5	0.0%	0.0%
	SOP	0	3646454 h	32	7	0.0%	0.0%

Figure 5-1 shows the range of ABT demands per year in the ABT data set (limited to low-demand components only).

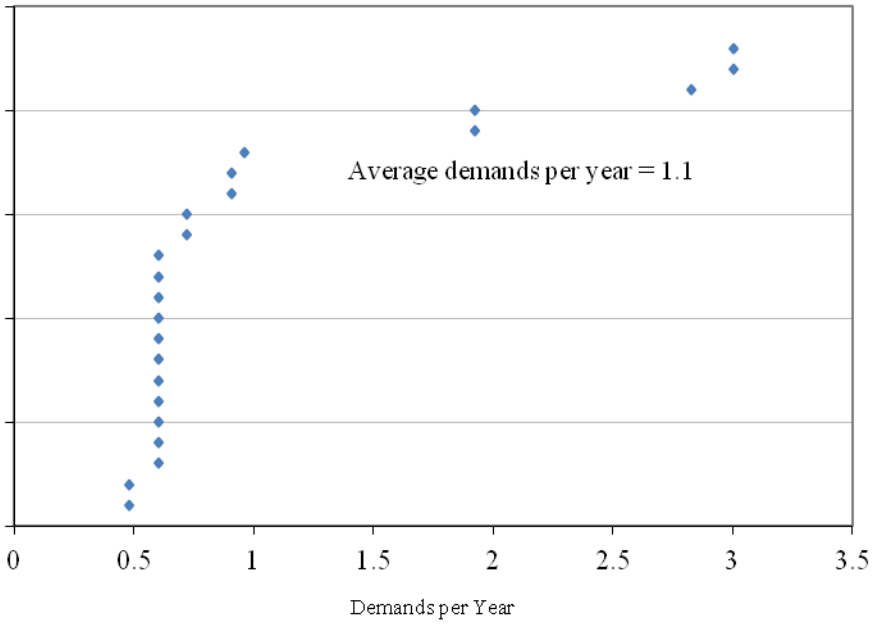

Figure 5-1. ABT demands per year distribution.

5.3.3 Industry-Average Baselines

Table 5-10 lists the industry-average failure rate distribution. Note that this distribution is based on zero failures and few demands and may be conservatively high. This industry-average failure rate does not account for any recovery.

Table 5-10. Selected industry distributions of p and λ for ABTs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FF	JNID/IL	6.31E-06	7.30E-04	1.60E-03	6.15E-03	Beta	0.50	3.12E+02
	SOP	JNID/IL	5.39E-10	6.24E-08	1.37E-07	5.27E-07	Gamma	0.50	3.65E+06

5.4 Circuit Breaker (CBK)

5.4.1 Component Description

The circuit breaker (CBK) is defined as the breaker itself and local instrumentation and control circuitry. The circuit breaker data presented here is limited to circuit breakers used in the distribution of power. Circuit breakers used to supply power to a specific load are included within that components boundary. External equipment used to monitor under voltage, ground faults, differential faults, and other protection schemes for individual breakers are considered part of the breaker. The failure modes for CBK are listed in Table 5-1.

5.4.2 Data Collection and Review

Data for CBK UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010 using RADS. The systems included in the CBK data collection are listed in Table 5-11 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 5-11. CBK systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
13.8Kv	Plant ac power (ACP)	11	118	129
	13.8 Total	**11**	**118**	**129**
480v	dc power (DCP)	135	309	444
	Offsite electrical power (OEP)	1	12	13
	Plant ac power (ACP)	772	2067	2839
	Reactor protection (RPS)	6	95	101
	480 Total	**914**	**2483**	**3397**
4160v	dc power (DCP)		1	1
	Plant ac power (ACP)	159	1086	1245
	4160 Total	**159**	**1087**	**1246**
16Kv	Offsite electrical power (OEP)	31	109	140
	Plant ac power (ACP)	5	30	35
	16Kv Total	**36**	**139**	**175**
DC	dc power (DCP)	133	645	778
	Plant ac power (ACP)	4	22	26
	DC Total	**137**	**667**	**804**
GEN	Emergency power supply (EPS)	70	190	260
	High pressure core spray (HCS)	12	2	14
	Plant ac power (ACP)	1	1	2
	GEN Total	**83**	**193**	**276**
	Grand Total	**1340**	**4687**	**6027**

Table 5-12 summarizes the data used in the CBK analysis. Note that the hours for SOP are reactor-year hours.

Table 5-12. CBK unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
DC	FTO/C	7	13080	667	51	1.0%	13.7%
	SOP	4	91161573 h	800	67	0.5%	6.0%
HV (13.8 and 16 Kv)	FTO/C	39	7964	257	39	12.5%	48.7%
	SOP	23	32248367 h	283	45	7.4%	37.8%
MV (4160 v and 6.9 Kv)	FTO/C	59	43068	1087	84	5.0%	42.9%
	SOP	14	139818814 h	1227	88	0.9%	11.4%
All	FTO/C	179	126213	4494	101	3.6%	60.4%
	SOP	109	645942457 h	5670	101	1.7%	48.5%

Figure 5-2 shows the range of breaker demands per year in the CBK data set (limited to low-demand components only).

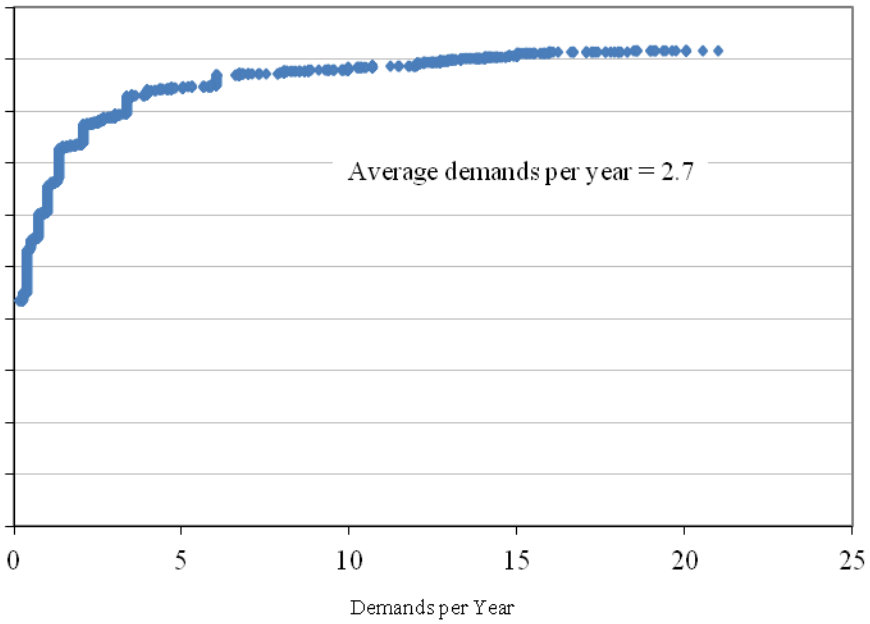

Figure 5-2. CBK demands per year distribution.

5.4.3 Industry-Average Baselines

Table 5-13 lists the selected industry distributions of p and λ for the CBK failure modes. These industry-average failure rates do not account for any recovery.

Table 5-13. Selected industry distributions of p and λ for CBKs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
DC	FTO/C	JNID/IL	2.78E-04	5.48E-04	5.73E-04	9.55E-04	Beta	7.50	1.307E+04
	SOP	JNID/IL	1.82E-08	4.58E-08	4.94E-08	9.28E-08	Gamma	4.50	9.116E+07
HV	FTO/C	EB/PL/KS	4.22E-04	4.79E-03	6.66E-03	1.93E-02	Beta	1.09	1.625E+02
	SOP	EB/PL/KS	8.10E-08	6.22E-07	8.08E-07	2.17E-06	Gamma	1.37	1.696E+06
MV	FTO/C	EB/PL/KS	1.81E-05	1.35E-03	2.70E-03	9.98E-03	Beta	0.56	2.052E+02
	SOP	JNID/IL	6.33E-08	1.01E-07	1.04E-07	1.52E-07	Gamma	14.50	1.398E+08
All	FTO/C	EB/PL/KS	1.09E-04	1.63E-03	2.39E-03	7.27E-03	Beta	0.95	3.983E+02
	SOP	EB/PL/KS	1.52E-08	1.54E-07	2.11E-07	6.02E-07	Gamma	1.16	5.470E+06

5.5 Inverter (INV)

5.5.1 Component Description

The inverter (INV) boundary includes the inverter unit. The failure mode for INV is listed in Table 5-1.

5.5.2 Data Collection and Review

Data for INV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems and operational status included in the INV data collection are listed in Table 5-14 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 5-14. INV systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
All	Auxiliary feedwater (AFW)	2		2
	dc power (DCP)	14		14
	Emergency power supply (EPS)	2		2
	High pressure coolant injection (HCI)	1		1
	Normally operating service water (SWN)	2		2
	Plant ac power (ACP)	23		23
	Reactor core isolation (RCI)	3		3
	Reactor protection (RPS)	21		21
	Uninterruptable instrument power supply (UPS)	154		154
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	6		6
	Grand Total	**228**		**228**

Table 5-15 summarizes the data obtained from EPIX and used in the INV analysis. Note that the hours are reactor-year hours.

Table 5-15. INV unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTOP	95	25981056 h	228	42	28.1%	78.6%

5.5.3 Industry-Average Baselines

Table 5-16 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 5-16. Selected industry distributions of p and λ for INVs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTOP	EB/PL/KS	4.22E-07	4.13E-06	5.60E-06	1.58E-05	Gamma	1.18	2.114E+05

5.6 Bus (BUS)

5.6.1 Component Description

The bus (BUS) boundary includes the bus component itself, which includes the bus bar, fuses, and control circuitry. Associated circuit breakers and step-down transformers are not included. The failure mode for BUS is listed in Table 5-1.

5.6.2 Data Collection and Review

Data for the BUS UR baseline were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems included in the BUS data collection are listed in Table 5-17 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 5-17. BUS systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	**Low Demand**	**Total**
AC	Plant ac power (ACP)	1225	92	1317
	AC Total	**1225**	**92**	**1317**
DC	dc power (DCP)	56		56
	DC Total	**56**		**56**
	Grand Total	**1281**	**92**	**1373**

Table 5-18 summarizes the data obtained from EPIX and used in the BUS analysis. Note that the hours are reactor-year hours.

Table 5-18. BUS unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
AC	FTOP	101	146884096 h	1289	83	7.1%	61.4%
DC	FTOP	1	6381312 h	56	15	1.8%	6.7%

5.6.3 Industry-Average Baselines

Table 5-19 lists the industry-average failure rate distribution. This industry-average failure rate does not account for any recovery.

Table 5-19. Selected industry distributions of p and λ for BUSs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
AC	FTOP	EB/PL/KS	2.45E-08	8.10E-07	1.39E-06	4.72E-06	Gamma	0.70	5.065E+05
DC	FTOP	JNID/IL	2.76E-08	1.85E-07	2.35E-07	6.12E-07	Gamma	1.50	6.381E+06

5.7 Motor Control Center (MCC)

5.7.1 Component Description

The motor control center (MCC) component boundary includes the MCC cabinet, the bus bars, fuses, and protection equipment. The failure modes for MCC are listed in Table 5-1.

5.7.2 Data Collection and Review

The data for MCC UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010 using RADS. The systems included in the MCC data collection are listed in Table 1-5 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 5-20. MCC systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
All	Component cooling water (CCW)	1		1
	dc power (DCP)	13		13
	Emergency power supply (EPS)	16		16
	Plant ac power (ACP)	170	3	173
	Uninterruptable instrument power supply (UPS)	12	2	14
	Grand Total	**212**	**5**	**217**

Table 5-21 summarizes the data used in the MCC analysis.

Table 5-21. MCC unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTOP	6	24727584 h	217	18	2.8%	22.2%

5.7.3 Industry-Average Baselines

Table 5-22 lists the selected industry distributions of p and λ for the MCC failure modes. These industry-average failure rates do not account for any recovery.

Table 5-22. Selected industry distributions of p and λ for MCCs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTOP	EB/PL/KS	8.42E-09	1.68E-07	2.61E-07	8.31E-07	Gamma	0.84	3.230E+06

5.8 Transformer (TFM)

5.8.1 Component Description

The transformer (TFM) boundary includes the transformer unit, which includes the wiring, cooling, and protection equipment. The failure mode for TFM is listed in Table 5-1.

5.8.2 Data Collection and Review

Data for TFM UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems included in the TFM data collection are listed in Table 5-23 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 5-23. TFM systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
All	Control rod drive (CRD)	6		6
	dc power (DCP)	412	2	414
	Emergency power supply (EPS)	1		1
	Offsite electrical power (OEP)	8		8
	Plant ac power (ACP)	4793	42	4835
	Grand Total	**5220**	**44**	**5264**

Table 5-24 summarizes the data obtained from EPIX and used in the TFM analysis. Note that the hours are reactor-year hours.

Table 5-24. TFM unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	FTOP	267	599615105 h	5262	103	3.6%	79.6%

5.8.3 Industry-Average Baselines

Table 5-25 lists the industry-average failure rate distributions. This industry-average failure rate does not account for any recovery.

Table 5-25. Selected industry distributions of p and λ for TFMs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTOP	EB/PL/KS	4.33E-08	6.43E-07	9.44E-07	2.87E-06	Gamma	0.96	1.014E+06

5.9 Sequencer (SEQ)

5.9.1 Component Description

The sequencer (SEQ) boundary includes the relays, logic modules, etc that comprise the sequencer function of the emergency diesel generator (EDG) load process. The failure mode for SEQ is listed in Table 5-1.

5.9.2 Data Collection and Review

Data for the SEQ UR baseline were obtained from EPIX data from 1998 to 2010. The EPIX data was analyzed outside of RADS to determine the failures in the sequencer sub-component. The demand data are based on assuming a full test of the sequencer every fuel cycle (18 months) for each EDG. Table 5-26 summarizes the data obtained from EPIX and used in the SEQ analysis.

Table 5-26. SEQ unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	FTOP	3	1967	227	95	1.3%	3.2%

5.9.3 Industry-Average Baselines

Table 5-27 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 5-27. Selected industry distributions of p and λ for SEQs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTOP	JNID/IL	5.46E-04	1.60E-03	1.76E-03	3.54E-03	Beta	3.50	1.98E+03

6 Strainers

This section contains reliability results for various strainer-like components used in PRAs. The strainers include passive filters (FLT), self-cleaning filters (FLTSC), travelling screens (TSA), and trash racks (TRK).

The failure modes for the strainer are listed in Table 6-1.

Table 6-1. Strainer failure modes.

Pooling Group	Failure Mode	Parameter	Units	Description
All	PG	λ	1/h	Plug
	ELS	λ	1/h	External leak small
	ELL	λ	1/h	External leak large
	BYP	λ	1/h	Bypass
	ILL	λ	1/h	Internal leak large
Self Cleaning and Travelling Screen	FTOP	λ	1/h	Failure to operate

The systems and operational status included in the strainer data collection are listed in Table 6-2 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 6-2. Strainer systems and component counts.

Pooling Group	**System**	**Number of Components**		
		High/ Unknown Demand	**Low Demand**	**Total**
FLT	Auxiliary feedwater (AFW)	5	10	15
	Chemical and volume control (CVC)	20		20
	Circulating water system (CWS)	15		15
	Component cooling water (CCW)	24		24
	Condensate system (CDS)	10		10
	Containment spray recirculation (CSR)	13		13
	Control rod drive (CRD)	21		21
	Emergency power supply (EPS)	35		35
	Firewater (FWS)	10		10
	Heating ventilation and air conditioning (HVC)	3		3
	High pressure core spray (HCS)	3		3
	Instrument air (IAS)	2		2
	Low pressure core spray (LCS)	1		1
	Main feedwater (MFW)	6		6
	Main steam (MSS)	1		1
	Normally operating service water (SWN)	3		3
	Reactor core isolation (RCI)	2		2
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	5		5
	Standby service water (SWS)	29	2	31
	FLT Total	**208**	**12**	**220**
FLTSC	Normally operating service water (SWN)	104	2	106
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	4		4

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
	Standby service water (SWS)	59		59
	FLTSC Total	**167**	**2**	**169**
Sump	Chemical and volume control (CVC)	7		7
	Containment spray recirculation (CSR)	7		7
	Control rod drive (CRD)	17		17
	High pressure coolant injection (HCI)	3		3
	High pressure core spray (HCS)	5		5
	Low pressure core spray (LCS)	5		5
	Reactor core isolation (RCI)	8		8
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	43		43
	Sump Total	**95**		**95**
TRK	Circulating water system (CWS)	10		10
	TRK Total	**10**		**10**
TSA	Circulating water system (CWS)	163		163
	Normally operating service water (SWN)	34		34
	Standby service water (SWS)	15		15
	TSA Total	**212**		**212**
	Grand Total	**692**	**14**	**706**

6.1 Filter (FLT)

6.1.1 Component Description

The filter (FLT) boundary includes the filter. The failure mode for the FLT is listed in Table 6-1. The systems available in the FLT data collection are listed in Table 6-2 with the number of components included with each system. The FLT data analysis uses only data from components installed in "clean" systems (e.g., not service water).

6.1.2 Data Collection and Review

Data for FLT UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1997–2004. Table 6-3 summarizes the data obtained from EPIX and used in the FLT analysis. Note that PG hours are reactor-year hours.

Table 6-3. FLT unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
FLT	PG	3	11281248 h	99	23	2.0%	8.7%
	ELS	3	24955463 h	219	44	0.9%	4.5%

6.1.3 Industry-Average Baselines

Table 6-4 lists the industry-average failure rate distribution. These industry-average failure rates do not account for any recovery.

Table 6-4. Selected industry distributions of p and λ for FLTs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
FLT	PG	JNID/IL	9.61E-08	2.81E-07	3.10E-07	6.23E-07	Gamma	3.50	1.128E+07
	ELS	JNID/IL	4.34E-08	1.27E-07	1.40E-07	2.82E-07	Gamma	3.50	2.496E+07
	ELL	JNID/IL	1.05E-12	2.39E-09	9.80E-09	4.48E-08	Gamma	0.30	3.061E+07

6.2 Self-Cleaning Strainer (FLTSC)

6.2.1 Component Description

The strainer (FLTSC) component boundary includes the strainer, the rotating assembly, backwash valves, and control circuitry. The failure mode for FLTSC is listed in Table 6-1.

6.2.2 Data Collection and Review

Data for the FLTSC UR baseline were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems included in the FLTSC data collection are listed in Table 6-2 with the number of components included with each system.

Table 6-5 summarizes the data used in the FLTSC analysis. Note that FTOP, BYP, ELS, and PG hours are reactor-year hours.

Table 6-5. FLTSC unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
Self-Cleaning	PG	44	19143936 h	168	46	16.7%	37.0%
	BYP	1	19143936 h	168	46	0.6%	2.2%
	FTOP	76	19143936 h	168	46	23.2%	37.0%
	ELS	16	19143936 h	168	46	6.5%	13.0%

6.2.3 Industry-Average Baselines

Table 6-6 lists the industry-average failure rate distribution for the FLTSC component. These industry-average failure rates do not account for any recovery.

Table 6-6. Selected industry distributions of p and λ for FLTSCs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Self-Cleaning	PG	JNID/IL	1.78E-06	2.31E-06	2.32E-06	2.93E-06	Gamma	44.50	1.914E+07
	BYP	JNID/IL	9.19E-09	6.18E-08	7.84E-08	2.04E-07	Gamma	1.50	1.914E+07
	FTOP	JNID/IL	3.28E-06	3.98E-06	4.00E-06	4.78E-06	Gamma	76.50	1.914E+07
	ELS	JNID/IL	5.45E-07	8.45E-07	8.62E-07	1.24E-06	Gamma	16.50	1.914E+07
	ELL	JNID/IL	1.78E-06	2.31E-06	2.32E-06	2.93E-06	Gamma	44.50	1.914E+07

6.3 Sump Strainer (SMP)

6.3.1 Component Description

The sum strainer (SMP) component boundary includes the strainer. The failure mode for SMP is listed in Table 6-1.

6.3.2 Data Collection and Review

Data for the SMP UR baseline were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems included in the SMP data collection are listed in Table 6-2 with the number of components included with each system.

Table 6-7 summarizes the data used in the SMP analysis. Note that PG hours are reactor-year hours.

Table 6-7. SMP unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
Sump	PG	5	10825440 h	95	26	5.3%	15.4%

6.3.3 Industry-Average Baselines

Table 6-8 lists the industry-average failure rate distribution for the SMP component. These industry-average failure rates do not account for any recovery.

Table 6-8. Selected industry distributions of p and λ for SMPs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Sump	PG	JNID/IL	2.11E-07	4.78E-07	5.08E-07	9.09E-07	Gamma	5.50	1.083E+07

6.4 Traveling Screen Assembly (TSA)

6.4.1 Component Description

The traveling screen (TSA) component boundary includes the traveling screen, motor, and drive mechanism. The failure mode for TSA is listed in Table 6-1.

6.4.2 Data Collection and Review

Data for the TSA UR baseline were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems included in the TSA data collection are listed in Table 6-2 with the number of components included with each system.

Table 6-9 summarizes the data used in the TSA analysis. Note that FTOP, BYP, and PG hours are reactor-year hours.

Table 6-9. TSA unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
TSA	PG	64	23929916 h	210	48	22.4%	47.9%
	BYP	7	23929916 h	210	48	2.4%	6.3%
	FTOP	85	23929916 h	210	48	27.1%	58.3%

6.4.3 Industry-Average Baselines

Table 6-10 lists the industry-average failure rate distribution for the TSA component. These industry-average failure rates do not account for any recovery.

Table 6-10. Selected industry distributions of p and λ for TSAs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
TSA	PG	EB/PL/KS	1.51E-08	1.45E-06	3.07E-06	1.16E-05	Gamma	0.52	1.699E+05
	BYP	JNID/IL	1.52E-07	3.00E-07	3.13E-07	5.22E-07	Gamma	7.50	2.393E+07
	FTOP	EB/PL/KS	3.88E-08	2.21E-06	4.21E-06	1.52E-05	Gamma	0.60	1.419E+05

6.5 Trash Rack (TRK)

6.5.1 Component Description

The trash rack (TRK) component boundary includes the traveling screen, motor, and drive mechanism. The failure mode for TRK is listed in Table 6-1.

6.5.2 Data Collection and Review

Data for the TRK UR baseline were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems included in the TRK data collection are listed in Table 6-2 with the number of components included with each system.

Table 6-11 summarizes the data used in the TRK analysis. Note that PG hours are reactor-year hours.

Table 6-11. TRK unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
TRK	PG	4	1139520 h	10	5	30.0%	40.0%

6.5.3 Industry-Average Baselines

Table 6-12 lists the industry-average failure rate distribution for the TRK component. These industry-average failure rates do not account for any recovery.

Table 6-12. Selected industry distributions of p and λ for TRKs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
TRK	PG	JNID/IL	1.46E-06	3.66E-06	3.95E-06	7.42E-06	Gamma	4.50	1.140E+06

7 Reactor Protection

This section presents reliability data pertaining to the reactor protection system (RPS). The failure modes for reactor protection components are listed in Table 7-1.

Table 7-1. Reactor protection equipment failure modes.

Pooling Group	Failure Mode	Parameter	Units	Description
All	FTOP	*p*	-	Fail to operate

7.1 Bistable (BIS)

7.1.1 Component Description

The bistable (BIS) boundary includes the bistable unit itself. The failure mode for BIS is listed in Table 7-1.

7.1.2 Data Collection and Review

Data for the BIS UR baseline were obtained from the reactor protection system (RPS) system studies (SSs). The RPS SSs contain data from 1984 to 1995. Table 7-2 summarizes the data obtained from the RPS SSs and used in the BIS analysis. These data are at the industry level. Results at the plant and component levels are not presented in these studies.

Table 7-2. BIS unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	FTOP	55	102094	-	-	-	-

7.1.3 Industry-Average Baselines

Table 7-3 lists the industry-average failure rate distribution. The FTOP failure mode is not supported by EPIX data. The selected FTOP distribution has a mean based on the Jeffreys mean of industry data and $\alpha = 0.5$. For all distributions based on RPS SS data, an α of 0.5 is assumed (see Section A.1 in Reference 14).

Table 7-3. Selected industry distributions of p and λ for BISs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTOP	RPS SS	2.14E-06	2.47E-04	5.44E-04	2.09E-03	Beta	0.500	9.198E+02

7.2 Process Logic Components (PLDT, PLF, PLL, PLP)

7.2.1 Component Description

The process logic delta temperature (PLDT), process logic flow (PLF), process logic level (PLL), and process logic pressure (PLP boundary includes the logic components. The failure mode for these components is listed in Table 7-1.

7.2.2 Data Collection and Review

Data for process logic component UR baselines were obtained from the reactor protection system (RPS) system studies (SSs). The RPS SSs contain data from 1984 to 1995. Table 7-4 summarizes the data obtained from the RPS SSs and used in the process logic component analysis. These data are at the industry level. Results at the plant and component levels are not presented in these studies.

Table 7-4. Process logic component unreliability data.

Pooling Group	Component Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	PLDT FTOP	24.3	4887	-	-	-	-
	PLF FTOP	-	-	-	-	-	-
	PLL FTOP	3.3	6075	-	-	-	-
	PLP FTOP	5.6	38115	-	-	-	-

7.2.3 Industry-Average Baselines

Table 7-5 lists the industry-average failure rate distributions. The FTOP failure mode is not supported by EPIX data. The selected FTOP distributions have means based on the Jeffreys mean of industry data and $\alpha = 0.5$. For all distributions based on RPS SS data, an α of 0.5 is assumed (see Section A.1 in Reference 14). Because PLF has no data, the PLL result was used for the PLL mean.

Table 7-5. Selected industry distributions of p and λ for process logic components.

Pooling Group	Component Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	PLDT FTOP	RPS SS	2.01E-05	2.32E-03	5.07E-03	1.94E-02	Beta	0.500	9.805E+01
	PLF FTOP	PLL	2.46E-06	2.85E-04	6.25E-04	2.40E-03	Beta	0.500	7.990E+02
	PLL FTOP	RPS SS	2.46E-06	2.85E-04	6.25E-04	2.40E-03	Beta	0.500	7.990E+02
	PLP FTOP	RPS SS	6.29E-07	7.28E-05	1.60E-04	6.15E-04	Beta	0.500	3.124E+03

7.3 Sensor/Transmitter Components (STF, STL, STP, STT)

7.3.1 Component Description

The sensor/transmitter flow (STF), sensor/transmitter level (STL), sensor/transmitter pressure (STP), and sensor/transmitter temperature (STT) boundaries includes the sensor and transmitter. The failure mode for sensor/transmitter is listed in Table 7-1.

7.3.2 Data Collection and Review

Data for the sensor/transmitter UR baseline were obtained from the reactor protection system (RPS) system studies (SSs). The RPS SSs contain data from 1984 to 1995. Table 7-6 summarizes the data obtained from the RPS SSs and used in the sensor/transmitter analysis. These data are at the industry level. Results at the plant and component levels are not presented in these studies. Unlike other component failure modes, each component FTOP has both a demand and a calendar time contribution.

Table 7-6. Sensor/transmitter unreliability data.

Pooling Group	Component Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	STF FTOP	-	-	-	-	-	-
	STF FTOP	-	-	-	-	-	-
	STL FTOP	5.0	6750	-	-	-	-
	STL FTOP	0.5	9831968 h	-	-	-	-
	STP FTOP	2.3	23960	-	-	-	-
	STP FTOP	35.2	43430451 h	-	-	-	-
	STT FTOP	17.1	40759	-	-	-	-
	STT FTOP	29.0	35107399 h	-	-	-	-

7.3.3 Industry-Average Baselines

Table 7-7 lists the industry-average failure rate distributions. The FTOP failure mode is not supported by EPIX data. The selected FTOP distributions have means based on the Jeffreys mean of industry data and $\alpha = 0.5$. For all distributions based on RPS SS data, an α of 0.5 is assumed (see Section A.1 in Reference 14). Because there were no data for STF FTOP, the results for STL FTOP were used.

Table 7-7. Selected industry distributions of p and λ for sensor/transmitters.

Pooling Group	Component Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	STF FTOP	STL	3.21E-06	3.71E-04	8.15E-04	3.13E-03	Beta	0.500	6.132E+02
	STF FTOP	STL	4.00E-10	4.63E-08	1.02E-07	3.91E-07	Gamma	0.500	4.916E+06
	STL FTOP	RPS SS	3.21E-06	3.71E-04	8.15E-04	3.13E-03	Beta	0.500	6.132E+02
	STL FTOP	RPS SS	4.00E-10	4.63E-08	1.02E-07	3.91E-07	Gamma	0.500	4.916E+06
	STP FTOP	RPS SS	4.60E-07	5.32E-05	1.17E-04	4.49E-04	Beta	0.500	4.278E+03
	STP FTOP	RPS SS	3.23E-09	3.74E-07	8.22E-07	3.16E-06	Gamma	0.500	6.083E+05
	STT FTOP	RPS SS	1.70E-06	1.97E-04	4.32E-04	1.66E-03	Beta	0.500	1.157E+03
	STT FTOP	RPS SS	3.30E-09	3.82E-07	8.40E-07	3.23E-06	Gamma	0.500	5.950E+05

7.4 Reactor Trip Breaker (RTB)

7.4.1 Component Description

The reactor trip breaker (RTB) boundary includes the entire trip breaker. The RTB has been broken up into three subcomponents for use in modeling the failure of the RTB to open on demand. These three subcomponents are the mechanical portion of the breaker (BME), the breaker shunt trip (BSN), and the breaker undervoltage trip (BUV). The component and subcomponent failure modes for RTB are listed in Table 7-8.

Table 7-8. RTB failure modes.

Pooling Group	Failure Mode	Parameter	Units	Description
All	BME FTOP	*p*	-	BME fail to operate
	BSN FTOP	*p*	-	BSN fail to operate
	BUV FTOP	*p*	-	BUV fail to operate
	RTB FTOP	*p*	-	RTB fail to operate

7.4.2 Data Collection and Review

Data for RTB UR baselines were obtained from the pressurized water reactor (PWR) reactor protection system (RPS) system studies (SSs). The RPS SSs contain data from 1984 to 1995. Table 7-9 summarizes the data obtained from the RPS SSs and used in the RTB analysis. These data are at the industry level. Results at the plant and component levels are not presented in these studies.

Table 7-9. RTB unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	BME FTOP	1	97359	-	-	-	-
	BSN FTOP	14	44104	-	-	-	-
	BUV FTOP	23.1	57199	-	-	-	-
	RTB FTOP	-	-	-	-	-	-

7.4.3 Industry-Average Baselines

Table 7-10 lists the industry-average failure rate distributions. The selected FTOP distributions have means based on the Jeffreys mean of industry data and $\alpha = 0.5$. For all distributions based on RPS SS data, an α of 0.5 is assumed (see Section A.1 in Reference 14). The RTB FTOP is calculated using a Boolean expression for the RTB failure involving either the BME failure or the combination of BSN and BUV failures.

Table 7-10. Selected industry distributions of p and λ for RTBs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	BME FTOP	RPS SS	6.06E-08	7.01E-06	1.54E-05	5.92E-05	Beta	0.500	3.245E+04
	BSN FTOP	RPS SS	1.29E-06	1.50E-04	3.29E-04	1.26E-03	Beta	0.500	1.521E+03
	BUV FTOP	RPS SS	1.62E-06	1.88E-04	4.13E-04	1.58E-03	Beta	0.500	1.212E+03
	RTB FTOP	RPS SS	6.11E-08	7.07E-06	1.55E-05	5.97E-05	Beta	0.500	3.217E+04

7.5 Manual Switch (MSW)

7.5.1 Component Description

The manual switch (MSW) boundary includes the switch itself. The failure mode for MSW is listed in Table 7-1.

7.5.2 Data Collection and Review

Data for the MSW UR baseline were obtained from the reactor protection system (RPS) system studies (SSs). The RPS SSs contain data from 1984 to 1995. Table 7-11 summarizes the data obtained from the RPS SSs and used in the MSW analysis. These data are at the industry level. Results at the plant and component levels are not presented in these studies.

Table 7-11. MSW unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	FTO/C	2	19789	-	-	-	-

7.5.3 Industry-Average Baselines

Table 7-12 lists the industry-average failure rate distributions. The FTO/C failure mode is not supported by EPIX data. The selected FTO/C distribution has a mean based on the Jeffreys mean of industry data and $\alpha = 0.5$. For all distributions based on RPS SS data, an α of 0.5 is assumed (see Section A.1 in Reference 14).

Table 7-12. Selected industry distributions of p and λ for MSWs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO/C	RPS SS	4.97E-07	5.75E-05	1.26E-04	4.85E-04	Beta	0.500	3.958E+03

7.6 Relay (RLY)

7.6.1 Component Description

The relay (RLY) boundary includes the relay unit itself. The failure mode for RLY is listed in Table 7-1.

7.6.2 Data Collection and Review

Data for the RLY UR baseline were obtained from the reactor protection system (RPS) system studies (SSs). The RPS SSs contain data from 1984 to 1995. Table 7-13 summarizes the data obtained from the RPS SSs and used in the RLY analysis. These data are at the industry level. Results at the plant and component levels are not presented in these studies.

Table 7-13. RLY unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	FTOP	23.7	974417	-	-	-	-

7.6.3 Industry-Average Baselines

Table 7-14 lists the industry-average failure rate distribution. The FTOP failure mode is not supported by EPIX data. The selected FTOP distribution has a mean based on the Jeffreys mean of industry data and $\alpha = 0.5$. For all distributions based on RPS SS data, an α of 0.5 is assumed (see Section A.1 in Reference 14).

Table 7-14. Selected industry distributions of p and λ for RLYs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTOP	RPS SS	9.77E-08	1.13E-05	2.48E-05	9.54E-05	Beta	0.500	2.013E+04

8 Control Rods

The control rod equipment includes the control rod drives and rods for PWRs and the hydraulic control units for BWRs. The failure modes for control rod components are listed in Table 8-1.

Table 8-1. Control rod equipment failure modes.

Pooling Group	Failure Mode	Parameter	Units	Description
All	FTOP	λ	1/h	Fail to operate
	SOP	λ	1/h	Spurious operation
HCU	FTI	p	-	Failure to Insert

Data for control rod UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010 using RADS. The systems included in the control rod data collection are listed in Table 8-2 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 8-2. Control rod systems.

Pooling Group	**Description**	**Number of Components**		
		High/ Unknown Demand	**Low Demand**	**Total**
CRD	Control rod drive (CRD)	1199		1199
	CRD Total	**1199**		**1199**
HCU	Control rod drive (CRD)	6012	370	6382
	Reactor protection (RPS)	177		177
	HCU Total	**6189**	**370**	**6559**
ROD	Control rod drive (CRD)	742		742
	Reactor coolant (RCS)	106		106
	ROD Total	**848**		**848**
	Grand Total	**8236**	**370**	**8606**

8.1 Control Rod Drive (CRD)

8.1.1 Component Description

The control rod drive (CRD) boundary includes the PWR control rod drive mechanism. The failure modes for CRD are listed in Table 8-1.

8.1.2 Data Collection and Review

Data for CRD UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1997–2004. Table 8-3 summarizes the data from EPIX and used in the CRD analysis.

Table 8-3. CRD unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
CRD	FTOP	13	136286592 h	1196	27	1.1%	14.8%
	SOP	26	136286592 h	1196	27	2.0%	33.3%

8.1.3 Industry-Average Baselines

Table 8-4 lists the industry-average failure rate distribution. These industry-average failure rates do not account for any recovery.

Table 8-4. Selected industry distributions of p and λ for CRDs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
CRD	FTOP	JNID/IL	5.93E-08	9.66E-08	9.91E-08	1.47E-07	Gamma	13.50	1.363E+08
	SOP	JNID/IL	1.37E-07	1.92E-07	1.94E-07	2.60E-07	Gamma	26.50	1.363E+08

8.2 Control Rod (ROD)

8.2.1 Component Description

The control rod (ROD) boundary includes the PWR control rod excluding the drive mechanism. The failure modes for ROD are listed in Table 8-1.

8.2.2 Data Collection and Review

Data for ROD UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1997–2004. Table 8-5 summarizes the data obtained from EPIX and used in the ROD analysis.

Table 8-5. ROD unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
ROD	FTOP	28	95605727 h	839	39	3.1%	35.9%
	SOP	18	95605727 h	839	39	2.1%	15.4%

8.2.3 Industry-Average Baselines

Table 8-6 lists the industry-average failure rate distribution. These industry-average failure rates do not account for any recovery.

Table 8-6. Selected industry distributions of p and λ for RODs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
ROD	FTOP	JNID/IL	2.13E-07	2.95E-07	2.98E-07	3.96E-07	Gamma	28.50	9.561E+07
	SOP	JNID/IL	1.26E-07	1.90E-07	1.94E-07	2.73E-07	Gamma	18.50	9.561E+07

8.3 Hydraulic Control Unit (HCU)

8.3.1 Component Description

The hydraulic control unit (HCU) boundary includes the PWR control rod drive mechanism. The failure mode for HCU is listed in Table 8-1.

8.3.2 Data Collection and Review

Data for HCU UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1997–2004. Table 8-7 summarizes the data obtained from EPIX and used in the HCU analysis.

Table 8-7. HCU unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
HCU	FTI	2	269552	370	1	0.5%	100.0%
	FTOP	22	747292641 h	6558	27	0.3%	44.4%
	SOP	14	747292641 h	6558	27	0.2%	40.7%

8.3.3 Industry-Average Baselines

Table 8-8 lists the industry-average failure rate distribution. These industry-average failure rates do not account for any recovery.

Table 8-8. Selected industry distributions of p and λ for HCUs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
HCU	FTI	JNID/IL	2.12E-06	8.07E-06	9.27E-06	2.05E-05	Beta	2.50	2.696E+05
	FTOP	EB/PL/KS	3.85E-10	1.79E-08	3.28E-08	1.16E-07	Gamma	0.63	1.931E+07
	SOP	JNID/IL	1.18E-08	1.90E-08	1.94E-08	2.85E-08	Gamma	14.50	7.473E+08

9 Heating and Ventilation

The heating and ventilating (HVC) equipment included in this section includes: dampers, air-handling units, chillers, and fans. The failure modes for HVC equipment are listed in Table 9-1.

Table 9-1. Heating and ventilation equipment failure modes.

Pooling Group	Failure Mode	Parameter	Units	Description
All	FTO/C	p	-	Failure to open or failure to close
	SOP	λ	1/h	Spurious operation
	ILS	λ	1/h	Internal leak small
	ILL	λ	1/h	Internal leak large
	FTOP	λ	1/h	Fail to operate
Running	FTS	p	-	Failure to start
	FTR	λ	1/h	Fail to run
Standby	FTS	p	-	Failure to start
	FTR≤1H	λ	1/h	Failure to run for 1 h
	FTR>1H	λ	1/h	Fail to run beyond 1 h

9.1 Damper (DMP)

9.1.1 Component Description

The damper (DMP) component boundary includes the valve, the valve operator, and local instrumentation and control circuitry. The failure modes for dampers are listed in Table 9-1. This section presents results for dampers with pneumatic -operators (AOD), hydraulic-operators (HOD), and motor-operators (MOD).

9.1.2 Data Collection and Review

Data for DMP UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010 using RADS. The systems included in the DMP data collection are listed in Table 9-2 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 9-2. Damper systems.

Pooling Group	**Description**	**Number of Components**		
		High/ Unknown Demand	**Low Demand**	**Total**
Pneumatic -Operator	Chemical and volume control (CVC)		1	1
	Containment fan cooling (CFC)		22	22
	Emergency power supply (EPS)	1		1
	Heating ventilation and air conditioning (HVC)	48	58	106
	Total	**49**	**81**	**130**
Hydraulic -Operator	Containment fan cooling (CFC)		4	4
	Emergency power supply (EPS)	14	8	22
	Heating ventilation and air conditioning (HVC)	34	41	75
	Total	**48**	**53**	**101**
Motor-Operator	Containment fan cooling (CFC)		3	3
	Emergency power supply (EPS)	4	16	20

Pooling Group	Description	Number of Components		
		High/ Unknown Demand	Low Demand	Total
	Engineered safety features actuation (ESF)		1	1
	Heating ventilation and air conditioning (HVC)	37	3	40
	Standby service water (SWS)	6		6
	Total	**47**	**23**	**70**

Table 9-3 summarizes the data used in the DMP analysis. Note that SOP and ILS hours are reactor-year hours.

Table 9-3. DMP unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
Pneumatic-Operator	FTO/C	10	28725	126	15	4.8%	20.0%
	SOP	1	20625312 h	181	32	0.6%	3.1%
	ILS	2	20625312 h	181	32	1.1%	6.3%
Hydraulic-Operator	FTO/C	20	35320	95	7	16.8%	57.1%
	SOP	8	13902144 h	122	12	6.6%	33.3%
	ILS	0	13902144 h	122	12	0.0%	0.0%
Motor-Operator	FTO/C	7	28537	64	13	7.8%	23.1%
	SOP	0	10825440 h	95	18	0.0%	0.0%
	ILS	1	10825440 h	95	18	1.1%	5.6%

Figure 9-1 shows the range of valve demands per year in the DMP data set (limited to low-demand components only).

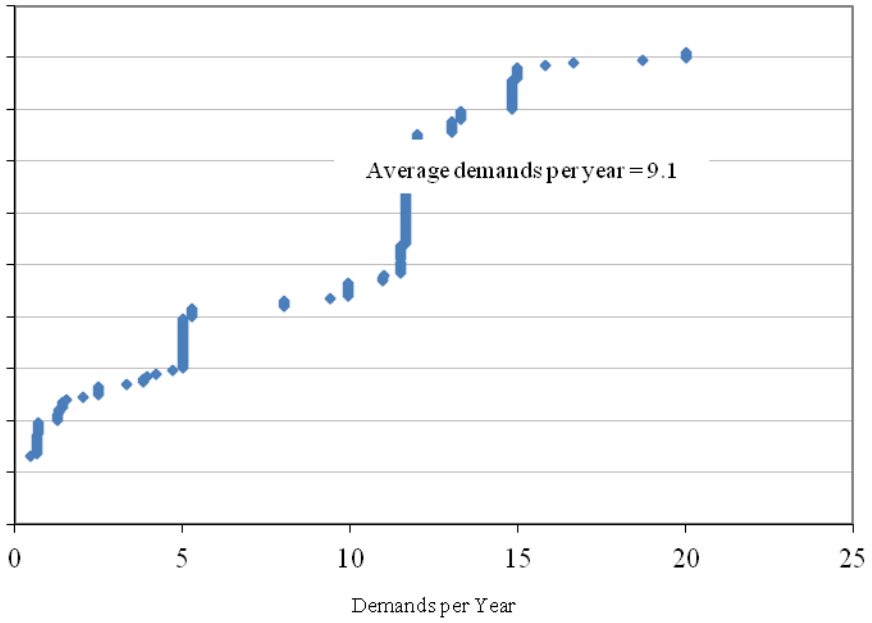

Figure 9-1. DMP demands per year distribution.

9.1.3 Industry-Average Baselines

Table 9-4 lists the selected industry distributions of p and λ for the DMP failure modes. These industry-average failure rates do not account for any recovery.

Table 9-4. Selected industry distributions of p and λ for DMPs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Pneumatic-Operator	FTO/C	JNID/IL	2.02E-04	3.54E-04	3.66E-04	5.69E-04	Beta	10.500	2.872E+04
	SOP	JNID/IL	8.53E-09	5.74E-08	7.27E-08	1.89E-07	Gamma	1.500	2.063E+07
	ILS	EB/PL/KS	3.52E-09	6.67E-08	1.03E-07	3.24E-07	Gamma	0.862	8.394E+06
	ILL	EB/PL/KS	2.20E-13	5.01E-10	2.05E-09	9.40E-09	Gamma	0.300	1.461E+08
Hydraulic-Operator	FTO/C	JNID/IL	3.87E-04	5.71E-04	5.80E-04	8.06E-04	Beta	20.500	3.530E+04
	SOP	JNID/IL	3.12E-07	5.88E-07	6.11E-07	9.92E-07	Gamma	8.500	1.390E+07
	ILS	JNID/IL	1.41E-10	1.64E-08	3.60E-08	1.38E-07	Gamma	0.500	1.390E+07
	ILL	JNID/IL	7.71E-14	1.76E-10	7.20E-10	3.29E-09	Gamma	0.300	4.167E+08
Motor-Operator	FTO/C	EB/PL/KS	2.87E-05	1.85E-04	2.33E-04	6.01E-04	Beta	1.546	6.634E+03
	SOP	JNID/IL	1.82E-10	2.10E-08	4.62E-08	1.77E-07	Gamma	0.500	1.083E+07
	ILS	JNID/IL	1.63E-08	1.09E-07	1.39E-07	3.61E-07	Gamma	1.500	1.083E+07
	ILL	JNID/IL	2.98E-13	6.78E-10	2.78E-09	1.27E-08	Gamma	0.300	1.079E+08

9.2 Air Handling Unit (AHU)

9.2.1 Component Description

The air-handling unit (AHU) boundary includes the fan, heat exchanger, valves, control circuitry, and breakers. The failure modes for AHU are listed in Table 9-1.

9.2.2 Data Collection and Review

Data for AHU UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems and operational status included in the AHU data collection are listed in Table 9-5 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤200 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 9-5. AHU systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
All	Auxiliary feedwater (AFW)	3	1	4
	Chemical and volume control (CVC)		2	2
	Circulating water system (CWS)	3		3
	Component cooling water (CCW)	37	3	40
	Condensate system (CDS)	10		10
	Containment fan cooling (CFC)	114	118	232
	Containment isolation system (CIS)	4		4
	Containment spray recirculation (CSR)		2	2
	Control rod drive (CRD)	14		14
	dc power (DCP)	1	2	3
	Emergency power supply (EPS)	95	62	157
	Fuel handling (FHS)	4		4
	Heating ventilation and air conditioning (HVC)	1051	318	1369
	High pressure coolant injection (HCI)	1		1
	High pressure injection (HPI)	1	2	3
	Instrument air (IAS)	6	2	8
	Main feedwater (MFW)	4		4
	Main steam (MSS)	107		107
	Plant ac power (ACP)	13		13
	Reactor coolant (RCS)	16		16
	Reactor protection (RPS)	10		10
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)		4	4
	Standby service water (SWS)	8	6	14
	Uninterruptable instrument power supply (UPS)	10		10
	Grand Total	**1512**	**522**	**2034**

Table 9-6 summarizes the data obtained from EPIX and used in the AHU analysis.

Table 9-6. AHU unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	FTS	44	12566	142	35	17.6%	40.0%
	FTR	52	12998080 h	142	35	24.6%	62.9%

Figure 9-2a shows the range of start demands per year in the standby AHU data set. Figure 9-3 shows the range of run hours per demand in the standby AHU data set. Figure 9-3 shows the range of run hours per demand in the running AHU data set.

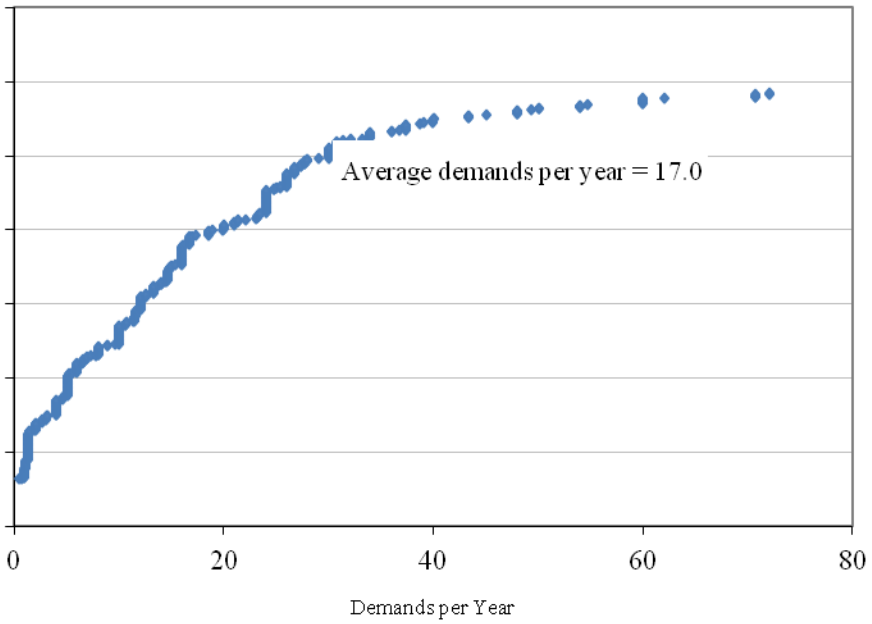

Figure 9-2. AHU demands per year distribution.

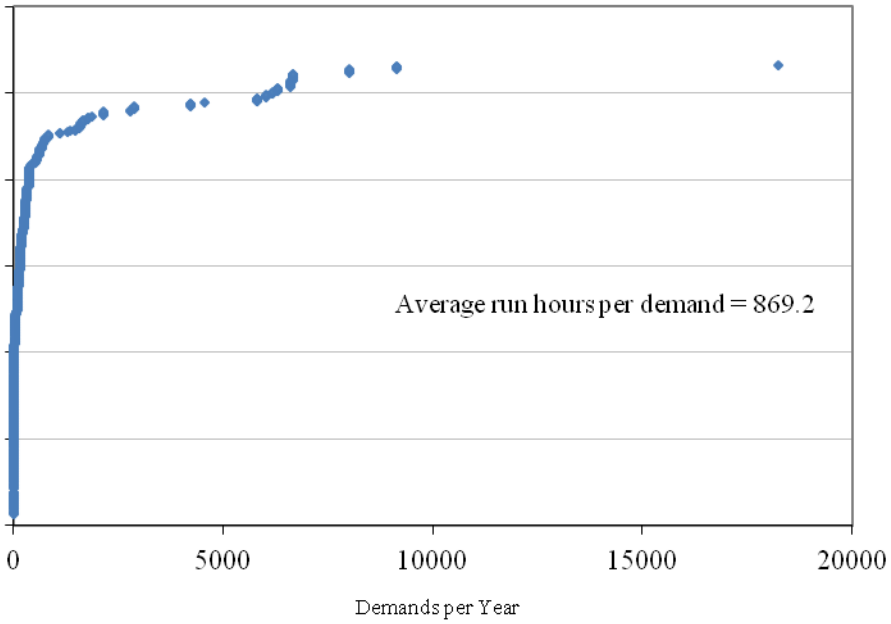

Figure 9-3. AHU run hours per demand distribution.

9.2.3 Industry-Average Baselines

Table 9-7 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 9-7. Selected industry distributions of p and λ for AHUs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTS	EB/PL/KS	9.74E-06	1.64E-03	3.86E-03	1.52E-02	Beta	0.461	1.189E+02
	FTR	EB/PL/KS	1.38E-07	3.46E-06	5.61E-06	1.84E-05	Gamma	0.774	1.379E+05

9.3 Chiller (CHL)

9.3.1 Component Description

The chiller (CHL) boundary includes the compressor, motor, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for CHL are listed in Table 9-1.

9.3.2 Data Collection and Review

Data for CHL UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems and operational status included in the CHL data collection are listed in Table 9-8 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤200 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 9-8. CHL systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
All	Chemical and volume control (CVC)	1		1
	Chilled water system (CHW)		1	1
	Component cooling water (CCW)	14		14
	Containment spray recirculation (CSR)	31		31
	Emergency power supply (EPS)	58	2	60
	Heating ventilation and air conditioning (HVC)	87	84	171
	High pressure core spray (HCS)	1		1
	Instrument air (IAS)		3	3
	Main steam (MSS)	3		3
	Normally operating service water (SWN)	10		10
	Plant ac power (ACP)	19	31	50
	Standby service water (SWS)	48	12	60
	Grand Total	**272**	**133**	**405**

Table 9-9 summarizes the data obtained from EPIX and used in the CHL analysis.

Table 9-9. CHL unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	FTS	84	19071	135	22	25.2%	81.8%
	FTR	180	5913615 h	131	20	35.1%	90.0%

Figure 9-4 shows the range of start demands per year in the standby CHL data set. Figure 9-5 shows the range of run hours per demand in the standby CHL data set.

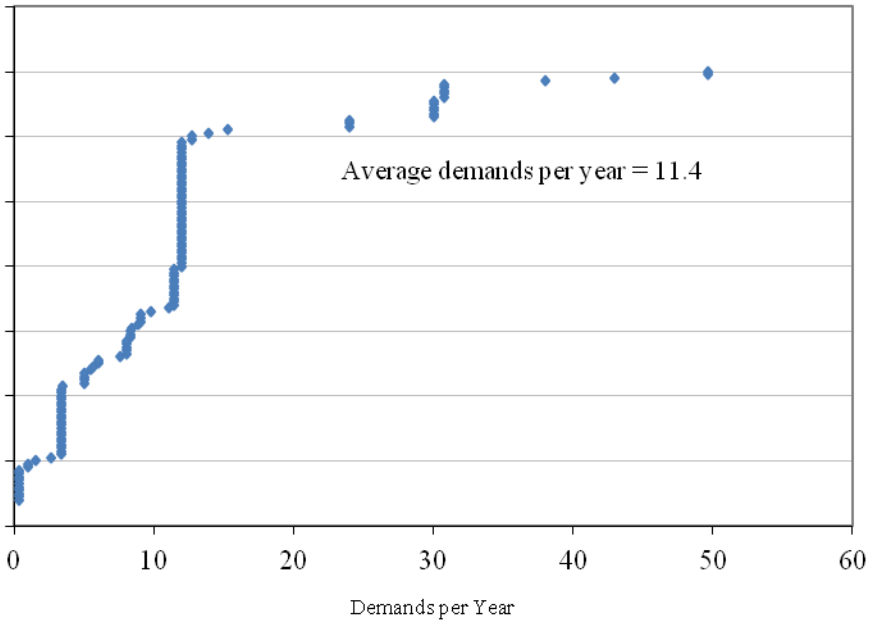

Figure 9-4. CHL demands per year distribution.

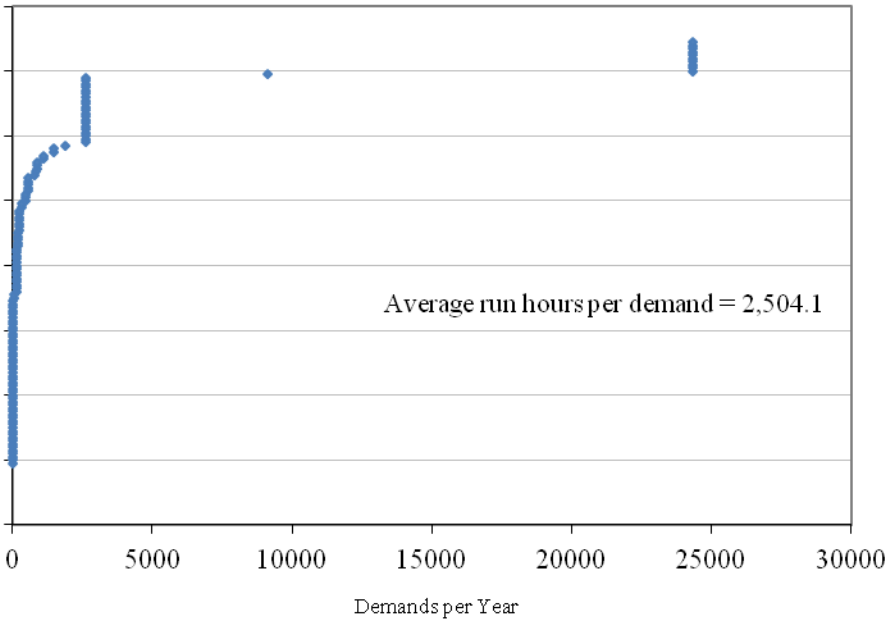

Figure 9-5. CHL run hours per demand distribution.

9.3.3 Industry-Average Baselines

Table 9-10 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 9-10. Selected industry distributions of p and λ for CHLs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTS	EB/PL/KS	1.08E-04	6.79E-03	1.30E-02	4.71E-02	Beta	0.58	4.408E+01
	FTR	JNID/IL	2.69E-05	3.05E-05	3.05E-05	3.44E-05	Gamma	180.50	5.914E+06

9.4 Fan (FAN)

9.4.1 Component Description

The fan (FAN) boundary includes the fan, motor, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for FAN are listed in Table 9-1.

9.4.2 Data Collection and Review

Data for FAN UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems and operational status included in the FAN data collection are listed in Table 9-11 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤200 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 9-11. FAN systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
Normally Running	Circulating water system (CWS)	3		3
	Component cooling water (CCW)	3		3
	Condensate system (CDS)	2		2
	Containment fan cooling (CFC)	47	43	90
	Containment isolation system (CIS)	1		1
	Containment spray recirculation (CSR)	3		3
	Control rod drive (CRD)	14	2	16
	dc power (DCP)	1	2	3
	Emergency power supply (EPS)	98	30	128
	Engineered safety features actuation (ESF)		1	1
	Heating ventilation and air conditioning (HVC)	551	141	692
	High pressure coolant injection (HCI)	20		20
	Instrument air (IAS)	10	11	21
	Main feedwater (MFW)	2		2
	Main steam (MSS)	10		10
	Normally operating service water (SWN)		8	8
	Plant ac power (ACP)	8		8
	Reactor coolant (RCS)	2		2
	Reactor protection (RPS)	8		8
	Standby service water (SWS)		3	3
	Vapor suppression (VSS)	1		1
	Normally Running Total	**784**	**241**	**1025**
Standby	Component cooling water (CCW)	7	2	9
	Containment fan cooling (CFC)		1	1
	Emergency power supply (EPS)		72	72
	Heating ventilation and air conditioning (HVC)		44	44
	High pressure coolant injection (HCI)		2	2
	Instrument air (IAS)		4	4

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
	Normally operating service water (SWN)		1	1
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)		1	1
	Standby Total	**7**	**127**	**134**
	Grand Total	**791**	**368**	**1159**

Table 9-12 summarizes the data obtained from EPIX and used in the FAN analysis.

Table 9-12. FAN unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTS	34	40959	127	31	15.7%	45.2%
	FTR≤1H	33	31278 h	127	31	17.3%	48.4%
	FTR>1H	4	99174 h	127	31	1.6%	3.2%
Running/ Alternating	FTS	42	59920	219	31	13.2%	45.2%
	FTR	59	12619800 h	219	31	17.8%	58.1%

Figure 9-6a shows the range of start demands per year in the standby FAN data set. Figure 9-6b shows the range of start demands per year in the running FAN data set. Figure 9-7a shows the range of run hours per demand in the standby FAN data set. Figure 9-7b shows the range of run hours per demands in the running FAN data set.

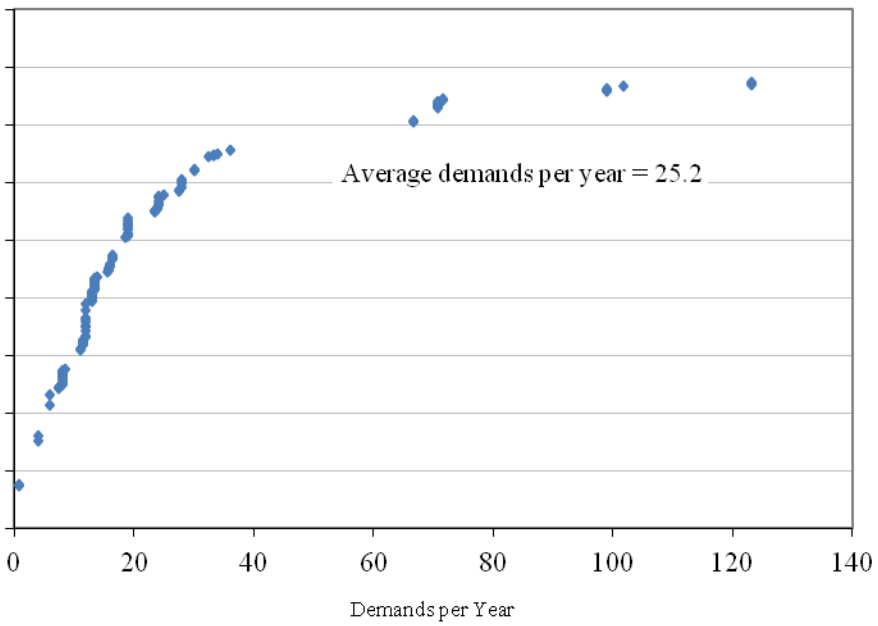

Figure 9-6a. Standby FAN demands per year distribution.

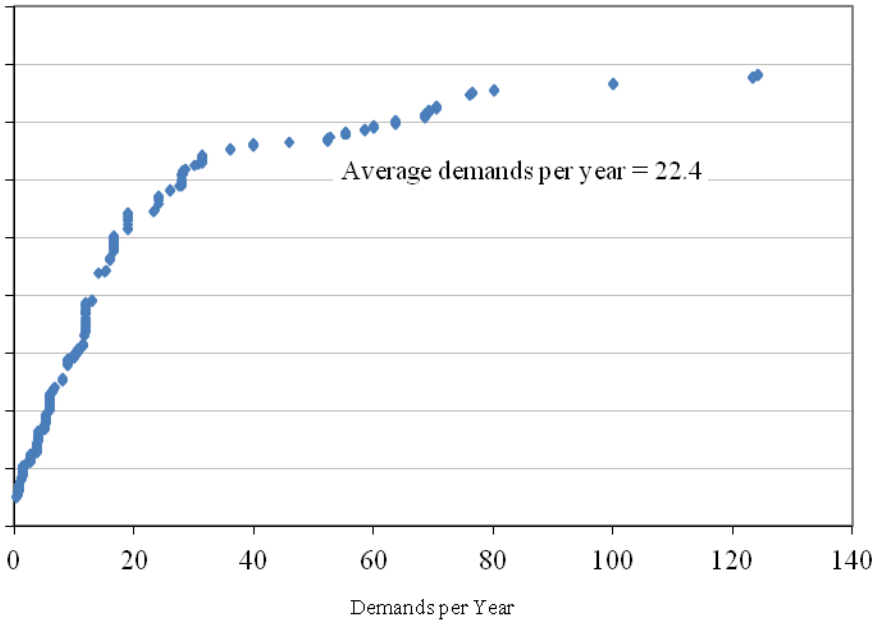

Figure 9-6b. Running/alternating FAN demands per year distribution.

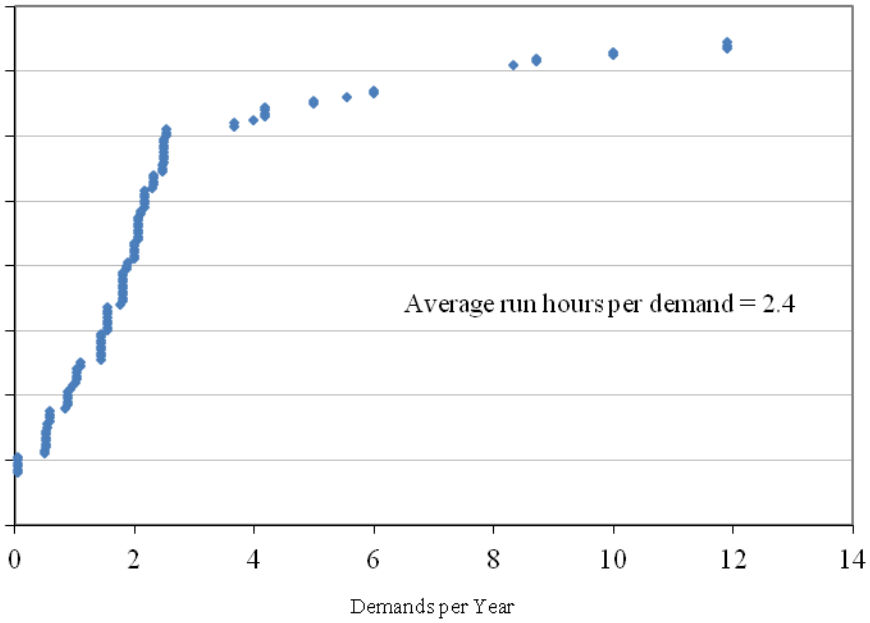

Figure 9-7a. Standby FAN run hours per demand distribution.

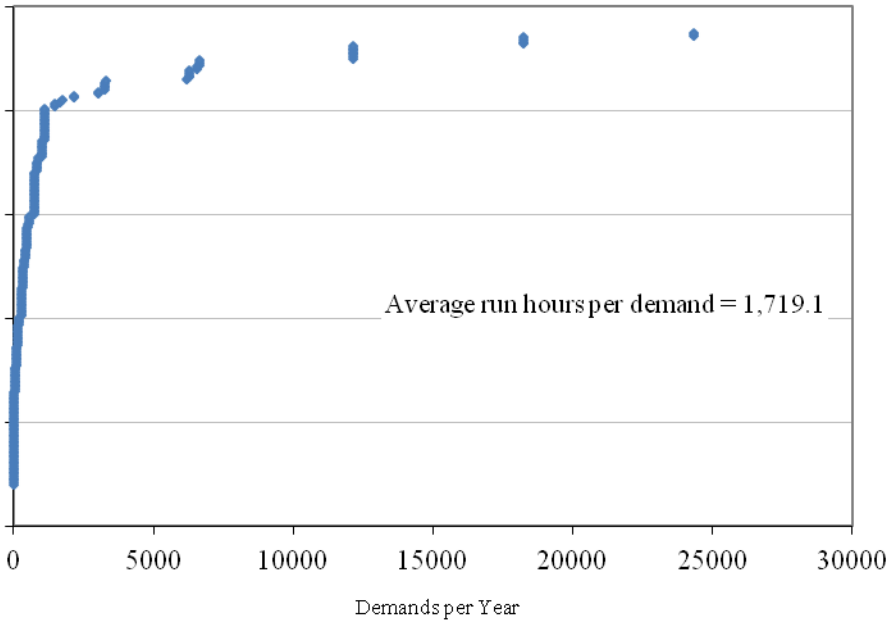

Figure 9-7b. Running/alternating FAN run hours per demand distribution.

9.4.3 Industry-Average Baselines

Table 9-13 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 9-13. Selected industry distributions of p and λ for FANs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	JNID/IL	6.21E-04	8.34E-04	8.42E-04	1.09E-03	Beta	34.50	4.093E+04
	FTR≤1H	JNID/IL	7.86E-04	1.06E-03	1.07E-03	1.39E-03	Beta	33.50	3.125E+04
	FTR>1H	JNID/IL	1.68E-05	4.21E-05	4.54E-05	8.53E-05	Gamma	4.50	9.917E+04
Running/ Alternating	FTS	JNID/IL	5.40E-04	7.04E-04	7.09E-04	8.97E-04	Beta	42.50	5.988E+04
	FTR	EB/PL/KS	3.11E-08	2.81E-06	5.88E-06	2.21E-05	Gamma	0.53	9.019E+04

10 Miscellaneous Equipment

This section presents reliability data on equipment that does not fall under the other major groupings. The failure modes applicable to these equipment are listed in Table 10-1.

The selected ELL mean is the ELS mean multiplied by 0.07, with an assumed α of 0.3. The selected ILL mean is the ILS mean multiplied by 0.02, with an assumed α of 0.3. The 0.07 and 0.02 multipliers are based on limited EPIX data for large leaks as explained in Section A.1 in Reference 14.

Table 10-1. Failure modes applicable to miscellaneous equipment.

Pooling Group	Failure Mode	Parameter	Units	Description
All	FTO/C	p	-	Failure to open or failure to close
	SOP	λ	1/h	Spurious operation
	ILS	λ	1/h	Internal leak small
	ILL	λ	1/h	Internal leak large
	ELS	λ	1/h	External leak small
	ELL	λ	1/h	External leak large
	FTOP	λ	1/h	Fail to operate
Running	FTS	p	-	Failure to start
	FTR	λ	1/h	Fail to run
Standby	FTS	p	-	Failure to start
	FTR≤1H	λ	1/h	Failure to run for 1 h
	FTR>1H	λ	1/h	Fail to run beyond 1 h

10.1 Air Compressor (CMP)

10.1.1 Component Description

The air compressor (CMP) boundary includes the compressor, driver, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for CMP are listed in Table 10-1. This section presents results for both the motor-driven (MDC) and engine-driven (EDC) air compressors.

10.1.2 Data Collection and Review

Data for CMP UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems and operational status included in the compressor data collection are listed in Table 10-2 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤200 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 10-2. CMP systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	**Low Demand**	**Total**
Motor-Driven	Containment Instrument Air (CIA)	9		9
	Instrument air (IAS)	58	92	150
	Service Air System (SAS)	22	36	58
	MOTOR Total	**89**	**128**	**217**

Pooling Group	System	Number of Components		
		High/ Unknown Demand	**Low Demand**	**Total**
Engine-Driven	Instrument air (IAS)	4	3	7
	Service Air System (SAS)	2	2	4
	ENGINE Total	**6**	**5**	**11**
	Grand Total	**95**	**133**	**228**

Table 10-3 summarizes the data obtained from EPIX and used in the CMP analysis.

Table 10-3. CMP unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Engine-Driven	FTS	2	1019	5	4	20.0%	25.0%
	FTR	15	5687 h	5	4	60.0%	75.0%
Motor-Driven	FTS	152	24466	128	42	54.7%	85.7%
	FTR	389	5540316 h	128	42	77.3%	95.2%

Figure 10-1 shows the range of start demands per year in the CMP data set. Figure 10-2 shows the range of run hours per demand in the CMP data set.

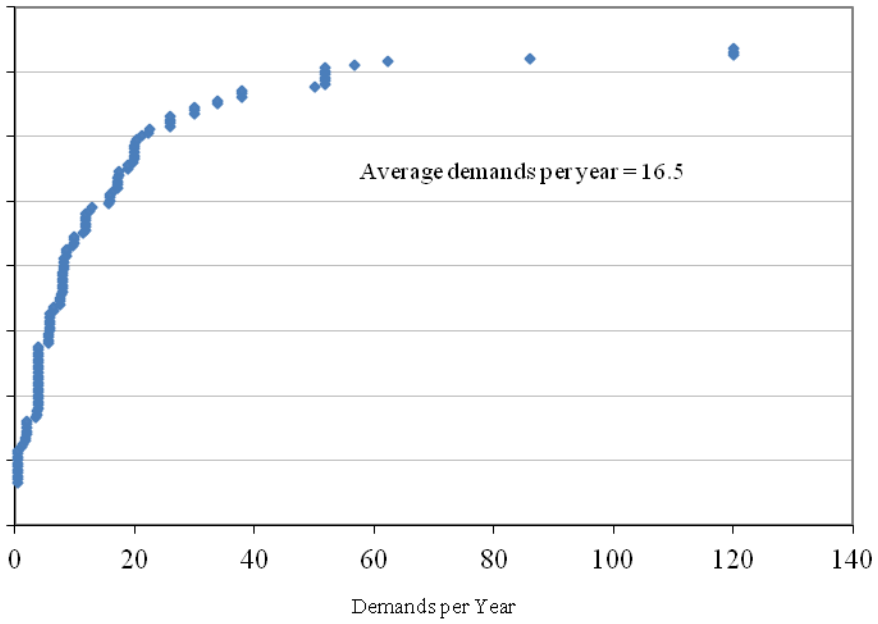

Figure 10-1. CMP demands per year distribution.

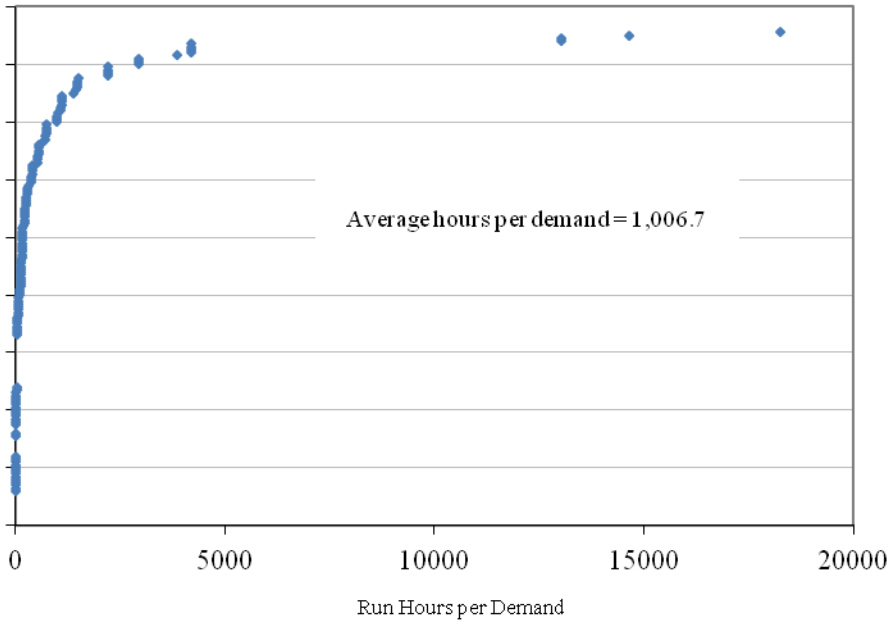

Figure 10-2. CMP run hours per demand distribution.

10.1.3 Industry-Average Baselines

Table 10-4 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 10-4. Selected industry distributions of p and λ for CMPs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Engine-driven	FTS	JNID/IL	5.63E-04	2.14E-03	2.45E-03	5.42E-03	Beta	2.500	1.017E+03
	FTR	EB/PL/KS	4.46E-05	2.06E-03	3.78E-03	1.33E-02	Gamma	0.633	1.676E+02
Motor-driven	FTS	EB/PL/KS	1.49E-04	9.01E-03	1.71E-02	6.15E-02	Beta	0.586	3.372E+01
	FTR	EB/PL/KS	1.51E-05	7.13E-05	8.50E-05	2.01E-04	Gamma	2.003	2.357E+04

10.2 Air Dryer Unit (ADU)

10.2.1 Component Description

The air dryer unit (ADU) boundary includes the air dryer unit. The failure mode for ADU is listed in Table 10-1.

10.2.2 Data Collection and Review

Data for the ADU UR baseline were obtained from the Westinghouse Savannah River Company (WSRC) database. None of the data sources used in WSRC are newer than approximately 1990. WSRC presents Category 1 data (see Section A.1 in Reference 14) from compressed gas systems for ADUs in commercial nuclear power plants.

10.2.3 Industry-Average Baselines

Table 10-5 lists the industry-average failure rate distribution. The FTOP failure mode is not supported by EPIX data. The mean is from WSRC, and the α parameter of 0.30 is assumed.

Table 10-5. Selected industry distributions of p and λ for ADUs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	FTOP	WSRC	5.35E-10	1.22E-06	5.00E-06	2.29E-05	Gamma	0.300	6.000E+04

10.3 Accumulator (ACC)

10.3.1 Component Description

The air accumulator (ACC) boundary includes the tank and associated relief valves. The failure modes for ACC are listed in Table 10-1.

10.3.2 Data Collection and Review

Data for ACC UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems and operational status included in the ACC data collection are listed in Table 10-6 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 10-6. ACC systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
All	Auxiliary feedwater (AFW)	4		4
	Chemical and volume control (CVC)	60		60
	Component cooling water (CCW)	46		46
	Condensate system (CDS)	10		10
	Condensate transfer system (CTS)	3		3
	Containment spray recirculation (CSR)	23		23
	Control rod drive (CRD)	5		5
	Emergency power supply (EPS)	184		184
	Firewater (FWS)	11		11
	Fuel handling (FHS)	18		18
	Heating ventilation and air conditioning (HVC)	3		3
	High pressure coolant injection (HCI)	4		4
	High pressure core spray (HCS)	1		1
	High pressure injection (HPI)	54		54
	Instrument air (IAS)	95		95
	Main steam (MSS)	43		43
	Plant ac power (ACP)	1		1
	Reactor coolant (RCS)	2		2
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	71		71
	Standby liquid control (SLC)	33		33
	Standby service water (SWS)	4		4
	Vapor suppression (VSS)	2		2
	Grand Total	**677**		**677**

Table 10-7 summarizes the data obtained from EPIX and used in the ACC analysis.

Table 10-7. ACC unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTOP	12	76505917 h	675	80	1.8%	12.5%
	ELS	8	76505917 h	675	80	1.2%	6.3%

10.3.3 Industry-Average Baselines

Table 10-8 lists the industry-average failure rate distributions. The selected ELL mean is the ELS mean multiplied by 0.07, with an assumed α of 0.3. The 0.07 multiplier is based on limited EPIX data for large leaks as explained in Section A.1 in Reference 14.

Table 10-8. Selected industry distributions of p and λ for ACCs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTOP	EB/PL/KS	1.49E-09	8.67E-08	1.66E-07	6.00E-07	Gamma	0.593	3.573E+06
	ELS	JNID/IL	5.67E-08	1.07E-07	1.11E-07	1.80E-07	Gamma	8.500	7.651E+07
	ELL	JNID/IL	8.32E-13	1.89E-09	7.77E-09	3.55E-08	Gamma	0.300	3.861E+07

10.4 Cooling Tower Fan (CTF)

10.4.1 Component Description

The cooling tower fan (CTF) boundary includes the fan, motor, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for CTF are listed in Table 10-1.

10.4.2 Data Collection and Review

Data for CTF UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems included in the CTF data collection are listed in Table 10-9 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤200 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 10-9. CTF systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	**Low Demand**	**Total**
Normally Running	Circulating water system (CWS)	1		1
	Normally operating service water (SWN)		16	16
	Standby service water (SWS)	10	5	15
	Normally Running Total	**11**	**21**	**32**
Standby	Circulating water system (CWS)		1	1
	Component cooling water (CCW)	16	17	33
	Normally operating service water (SWN)		4	4
	Standby service water (SWS)		24	24
	Standby Total	**16**	**46**	**62**
	Grand Total	**27**	**67**	**94**

Table 10-10 summarizes the data obtained from EPIX and used in the CTF analysis. Note that for the running/alternating CTFs, those components with > 200 demands/year were removed.

Table 10-10. CTF unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTS	18	23885	46	6	34.8%	83.3%
	FTR≤1H	9	334665 h	46	6	15.2%	83.3%
	FTR>1H	9	334665 h	46	6	15.2%	83.3%
Running/ Alternating	FTS	1	1941	20	2	5.0%	50.0%
	FTR	2	1086740 h	20	2	10.0%	100.0%

Figure 10-3a shows the range of start demands per year in the standby CTF data set. Figure 10-3b shows the range of start demands per year in the running CTF data set. Figure 10-4a shows the range of run hours per demand in the standby CTF data set. Figure 10-4b shows the range of run hours per demands in the running CTF data set.

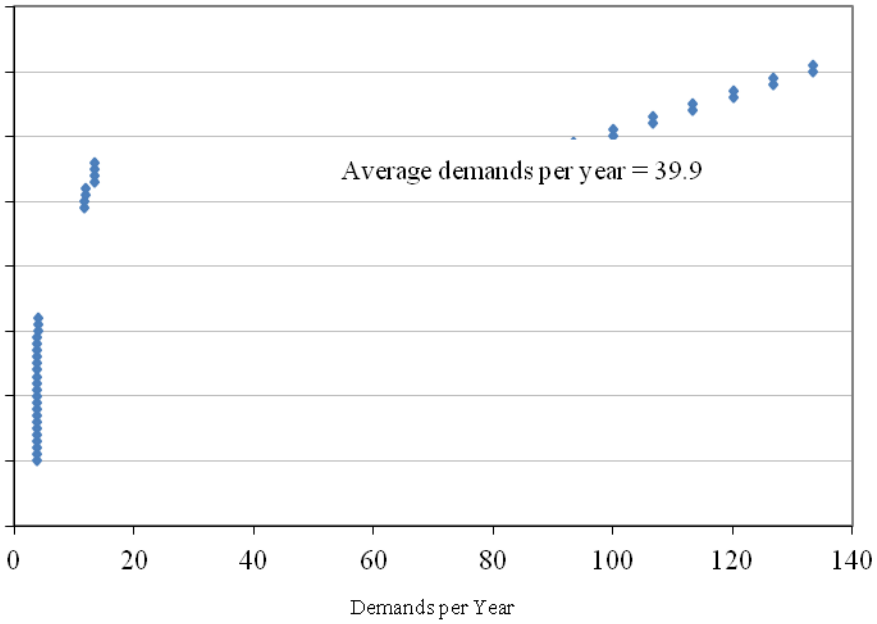

Figure 10-3a. Standby CTF demands per year distribution.

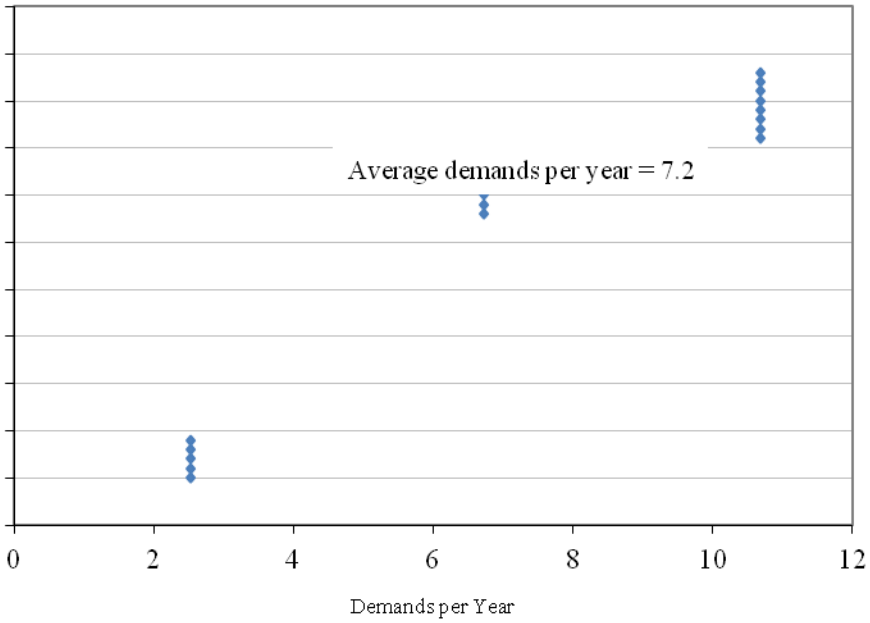

Figure 10-3b. Running/alternating CTF demands per year distribution.

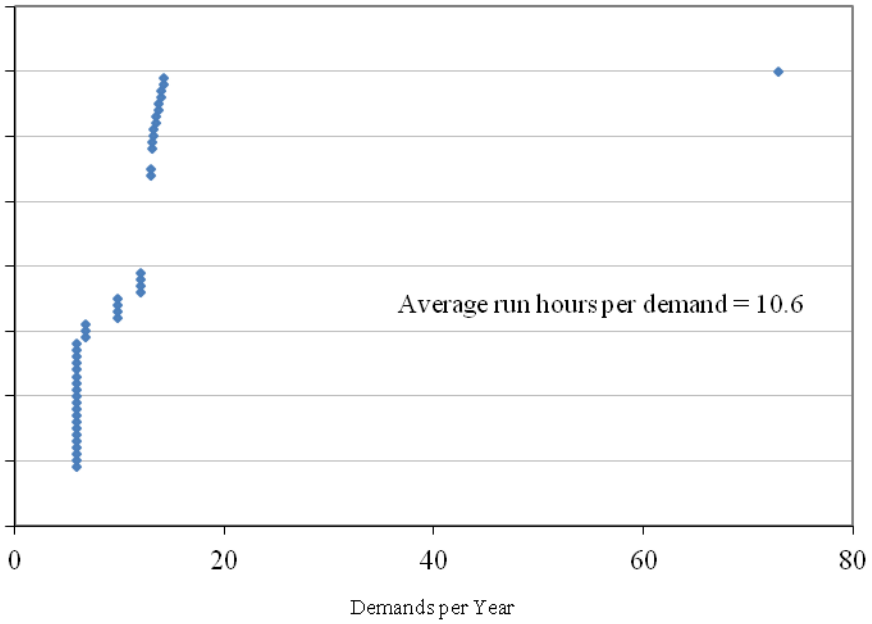

Figure 10-4a. Standby CTF run hours per demand distribution.

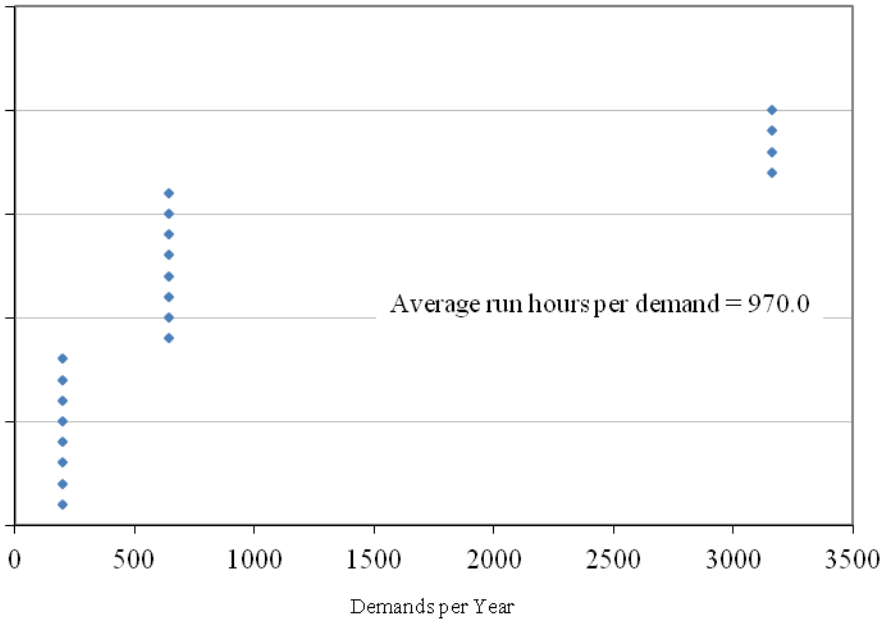

Figure 10-4b. Running/alternating CTF run hours per demand distribution.

10.4.3 Industry-Average Baselines

Table 10-11 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 10-11. Selected industry distributions of p and λ for CTFs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/PL/KS	2.84E-05	1.82E-03	3.54E-03	1.29E-02	Beta	0.58	1.625E+02
	FTR≤1H	JNID/IL	1.51E-05	2.74E-05	2.84E-05	4.50E-05	Gamma	9.50	3.347E+05
	FTR>1H	JNID/IL	1.51E-05	2.74E-05	2.84E-05	4.50E-05	Gamma	9.50	3.347E+05
Running/ Alternating	FTS	JNID/IL	9.07E-05	6.09E-04	7.73E-04	2.01E-03	Beta	1.50	1.940E+03
	FTR	JNID/IL	5.27E-07	2.00E-06	2.30E-06	5.09E-06	Gamma	2.50	1.087E+06

10.5 Tank (TNK)

10.5.1 Component Description

The tank (TNK) boundary includes the tank. The tank component has been further broken down into tanks that hold pressurized liquid, unpressurized liquid, and gas. The failure modes for TNK are listed in Table 10-1.

10.5.2 Data Collection and Review

Data for TNK UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1997–2004. These data were then further partitioned into pressurized and unpressurized components. The systems and operational status included in the TNK data collection are listed in Table 10-12 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 10-12. TNK systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
Liquid, Unpressurized	Auxiliary feedwater (AFW)	16		16
	Chemical and volume control (CVC)	29		29
	Component cooling water (CCW)	30		30
	Condensate system (CDS)	16		16
	Condensate transfer system (CTS)	15		15
	Containment spray recirculation (CSR)	12		12
	Emergency power supply (EPS)	42		42
	Firewater (FWS)	3		3
	Fuel handling (FHS)	6		6
	High pressure core spray (HCS)	2		2
	High pressure injection (HPI)	13		13
	Main feedwater (MFW)	2		2
	Main steam (MSS)	1		1
	Reactor core isolation (RCI)	3		3
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	15		15
	Standby liquid control (SLC)	11		11
	Standby service water (SWS)	5		5
	Liquid, Unpressurized Total	**221**		**221**
Liquid, Pressurized	Chemical and volume control (CVC)	19		19
	Component cooling water (CCW)	11		11
	Condensate system (CDS)	10		10
	Condensate transfer system (CTS)	3		3
	Containment spray recirculation (CSR)	5		5
	Emergency power supply (EPS)	10		10
	Firewater (FWS)	7		7
	Fuel handling (FHS)	1		1
	High pressure injection (HPI)	20		20
	Instrument air (IAS)	2		2

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
	Main steam (MSS)	1		1
	Reactor coolant (RCS)	11		11
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	75		75
	Standby service water (SWS)	2		2
	Liquid, Pressurized Total	**177**		**177**
Gas	Emergency power supply (EPS)	5		5
	Firewater (FWS)	2		2
	Instrument air (IAS)	25		25
	Gas Total	**32**		**32**
	Grand Total	**430**		**430**

Table 10-13 summarizes the data obtained from EPIX and used in the TNK analysis.

Table 10-13. TNK unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Liquid, Pressurized	ELS	6	19941600 h	175	49	2.9%	8.2%
Liquid, Unpressurized	ELS	6	24955440 h	219	73	2.7%	8.2%
Gas	ELS	2	3646464 h	32	7	6.3%	14.3%

10.5.3 Industry-Average Baselines

Table 10-14 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 10-14. Selected industry distributions of p and λ for TNKs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Liquid, Pressurized	ELS	JNID/IL	1.48E-07	3.09E-07	3.26E-07	5.61E-07	Gamma	6.50	1.99E+07
	ELL	JNID/IL	2.44E-12	5.56E-09	2.28E-08	1.04E-07	Gamma	0.30	1.31E+07
Liquid, Unpressurized	ELS	JNID/IL	1.18E-07	2.47E-07	2.60E-07	4.48E-07	Gamma	6.50	2.50E+07
	ELL	JNID/IL	1.95E-12	4.44E-09	1.82E-08	8.33E-08	Gamma	0.30	1.65E+07
Gas	ELS	JNID/IL	1.57E-07	5.97E-07	6.86E-07	1.52E-06	Gamma	2.50	3.65E+06
	ELL	JNID/IL	5.14E-12	1.17E-08	4.80E-08	2.20E-07	Gamma	0.30	6.25E+06

10.6 Orifice (ORF)

10.6.1 Component Description

The orifice (ORF) boundary includes the orifice. The failure mode for ORF is listed in Table 10-1.

10.6.2 Data Collection and Review

Data for ORF UR baselines were obtained from the Westinghouse Savannah River Company (WSRC) database. None of the data sources used in WSRC are newer than approximately 1990. WSRC presents Category 3 data (see Section A.1 in Reference 14) for ORFs in water systems.

10.6.3 Industry-Average Baselines

Table 10-15 lists the industry-average failure rate distributions. The FTOP failure mode is not supported by EPIX data. The mean is from WSRC, and the α parameter of 0.30 is assumed.

Table 10-15. Selected industry distributions of p and λ for ORFs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	PG	WSRC	1.07E-10	2.44E-07	1.00E-06	4.57E-06	Gamma	0.300	3.000E+05

10.7 Pipe (PIPE)

10.7.1 Component Description

The pipe (PIPE) boundary includes piping and pipe welds in each system. The flanges connecting piping segments are not included in the pipe component. The failure modes for PIPE are listed in Table 10-1.

10.7.2 Data Collection and Review

Data for PIPE UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1997–2004. There are 10,330 PIPE components in 112 systems from 96 plants in the data originally gathered from EPIX. EPIX reporting requirements allow great flexibility in defining PIPE components. Within a given system, one plant may report one PIPE component covering the entire system, while another may subdivide the piping into many smaller segments. The systems included in the PIPE data collection are listed in Table 10-16 with the number of plants reporting information for each system. Note that the number of PIPE components per system is not a meaningful number given the flexibility in reporting requirements. However, the number of plants per system is useful, given the system footage information presented in Table 10-16.

Table 10-16. PIPE systems.

System	Description	Count of Plants (note a)	PWR System Footage per Plant (note b)	BWR System Footage per Plant (note b)	Comment
ESW	Emergency service water	37	5036		PWR estimate used for average footage
CCW	Component cooling water	13	4008	2920	CCW footage for BWRs is RBCCW
AFW	Auxiliary feedwater	14	624		
CSR	Containment spray recirculation	11	1875		RHR (PWR) estimate used for CSS footage
HCS	High pressure core spray	1		2912	HPCI estimate used for HPCS footage
HCI	High pressure coolant injection	7		2912	
LCS	Low pressure core spray	4		666	
RCI	Reactor core isolation	4		520	
LCI	Low pressure coolant injection	7		2681	
LPI	Low pressure injection	13	1875		
HPI	High pressure injection	11	1422		
CVC	Chemical and volume control	19	3276		

a. This entry is the number of plants reporting piping data to EPIX for the system indicated.
b. Estimates are from NUREG/CR-4407, *Pipe Break Frequency Estimation for Nuclear Power Plants* (Ref. A-13). Estimates are for piping with 2-inch or larger diameter.

Table 10-17 summarizes the data obtained from EPIX and used in the PIPE analysis. Piping ELS events are those with external leakage rates from 1 to 50 gpm. Events that were uncertain were counted as 0.5 events. Note that the hours for ELS are reactor-year hours.

Table 10-17. PIPE unreliability data.

Pooling Group	System	Failure Mode	Events (1997 - 2004)	Total Foot-Hours (1997 - 2004)
All	ESW	ELS	8.5	1.306E+10
	CCW	ELS	0.5	3.321E+09
	AFW	ELS	0.0	6.122E+08

Pooling Group	System	Failure Mode	Events (1997 - 2004)	Total Foot-Hours (1997 - 2004)
	CSR	ELS	0.0	1.445E+09
	HCS	ELS	0.0	2.041E+08
	HCI	ELS	0.0	1.429E+09
	LCS	ELS	0.0	1.867E+08
	RCI	ELS	0.0	1.458E+08
	LCI	ELS	0.0	1.315E+09
	LPI	ELS	0.5	1.708E+09
	HPI	ELS	1.0	1.096E+09
	CVC	ELS	1.5	4.362E+09
	All but ESW	ELS	3.5	1.583E+10

10.7.3 Industry-Average Baselines

Table 10-18 lists the industry-average failure rate distributions. For ESW piping, the selected ELL mean is the ELS mean multiplied by 0.2, with an assumed α of 0.3. For non-ESW piping, the ELL mean is multiplied by 0.1. These multipliers are based on limited EPIX data for large leaks as explained in Section A.1 in Reference 14.

Table 10-18. Selected industry distributions of λ for PIPEs.

System	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
ESW	ELS	SCNID/IL	2.71E-12	3.14E-10	6.89E-10	2.65E-09	Gamma	0.500	7.255E+08
	ELL	ELS/EPIX	1.48E-14	3.36E-11	1.38E-10	6.31E-10	Gamma	0.300	2.176E+09
Non-ESW	ELS	SCNID/IL	9.94E-13	1.15E-10	2.53E-10	9.71E-10	Gamma	0.500	1.978E+09
	ELL	ELS/EPIX	2.71E-15	6.16E-12	2.53E-11	1.16E-10	Gamma	0.300	1.187E+10

10.8 Heat Exchanger (HTX)

10.8.1 Component Description

The heat exchanger (HTX) boundary includes the heat exchanger shell and tubes. The failure modes for HTX are listed in Table 10-19.

Table 10-19. HTX failure modes.

Pooling Group	Failure Mode	Parameter	Units	Description
All	LOHT	λ	1/h	Loss of heat transfer
	ELS (tube)	λ	1/h	External leak of the heat exchanger tube side
	ELS (shell)	λ	1/h	External leak of the heat exchanger shell side

10.8.2 Data Collection and Review

Data for HTX UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2010. The systems and operational status included in the HTX data collection are listed in Table 10-20 with the number of components included with each system. The component count is broken down into two categories: High/Unknown Demand which shows the counts for either high-demand components or those components that do not have demand information available, Low-Demand which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether there are demand data available (e.g., leakage, spurious operation, and operation).

Table 10-20. HTX systems.

Pooling Group	**System**	**Number of Components**		
		High/ Unknown Demand	**Low Demand**	**Total**
All	Auxiliary feedwater (AFW)	9		9
	Chemical and volume control (CVC)	104		104
	Circulating water system (CWS)	2		2
	Component cooling water (CCW)	266	8	274
	Condensate system (CDS)	341		341
	Containment fan cooling (CFC)	203	1	204
	Containment spray recirculation (CSR)	30	4	34
	Control rod drive (CRD)	2		2
	Emergency power supply (EPS)	189		189
	Firewater (FWS)	1		1
	Heating ventilation and air conditioning (HVC)	104	1	105
	High pressure coolant injection (HCI)	4		4
	High pressure core spray (HCS)	3		3
	High pressure injection (HPI)	11		11
	Instrument air (IAS)	33		33
	Isolation condenser (ISO)	8		8
	Low pressure core spray (LCS)	2		2
	Main feedwater (MFW)	120		120
	Main steam (MSS)	40		40
	Normally operating service water (SWN)	22		22
	Plant ac power (ACP)	5		5
	Reactor coolant (RCS)	143		143
	Reactor core isolation (RCI)	7		7

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
	Standby service water (SWS)	21		21
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	251		251
		1921	**14**	**1935**

Table 10-21 summarizes the data obtained from EPIX and used in the HTX analysis.

Table 10-21. HTX unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	LOHT	82	222547790 h	1953	101	3.2%	39.6%
	ELS (tube)	78	222547790 h	1953	101	3.1%	31.7%
	ELS (shell)	60	222547790 h	1953	101	2.6%	35.6%
CCW	LOHT	16	31564654 h	277	80	5.1%	15.0%

10.8.3 Industry-Average Baselines

Table 10-22 lists the selected industry distributions of p and λ for the HTX failure modes. These industry-average failure rates do not account for any recovery.

The selected ELL (shell) mean is the ELS mean multiplied by 0.07, with an assumed α of 0.3. The selected ELL (tube) mean is the ELS (tube) mean multiplied by 0.15, with an assumed α of 0.3. The 0.07 and 0.15 multipliers are based on limited EPIX data for large leaks as explained in Section A.1 in Reference 14.

Table 10-22. Selected industry distributions of p and λ for HTXs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	LOHT	EB/PL/KS	2.51E-09	2.20E-07	4.57E-07	1.71E-06	Gamma	0.53	1.170E+06
	ELS (tube)	EB/PL/KS	6.23E-10	1.49E-07	3.79E-07	1.54E-06	Gamma	0.43	1.133E+06
	ELL (tube)	EB/PL/KS	8.11E-13	1.85E-09	7.58E-09	3.47E-08	Gamma	0.30	3.958E+07
	ELS (shell)	EB/PL/KS	3.52E-09	1.79E-07	3.34E-07	1.19E-06	Gamma	0.62	1.842E+06
	ELL (shell)	EB/PL/KS	2.50E-12	5.70E-09	2.34E-08	1.07E-07	Gamma	0.30	1.282E+07
CCW	LOHT	JNID/IL	3.31E-07	5.12E-07	5.23E-07	7.51E-07	Gamma	16.50	3.156E+07

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