Component Reliability Data Sheets

2015 Update

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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 of 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 2015 directly analyzed using the Reliability and Availability Data System (RADS).

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 Institute for Nuclear Power Operation (INPO) Consolidated Events System (ICES), formerly 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 ICES 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 top 10% increased unreliability estimates.

Section	Rule	Description	Previous Data				Current Data				Delta	Comments
			Failures	Demands /Time	Comp. Count	Mean	Failures	Demands /Time	Comp. Count	Mean		
9.1	HOD-FTOC	Hydraulic Operated Damper Fails To Open/Close	20	35320	95	0.00058	11	6,225 d	39	5.57E-03	860%	The 2015 rule specifies only low-demand components.
2.3	AFW-EDP-FTR>1H	AFW Engine-driven pump Fails to Run >1H	0	231 h	5	0.00216	2	262 h	5	9.53E-03	341%	Two new failures.
6.1	STR-FLT-PG	Strainer Plugging (Dirty water systems)	3	11281248 h	99	3.10E-07	10	9,300,024 h	59	1.13E-06	265%	
10.1	EDC-FS-NS	Engine Driven Compressor Fails To Start, Normally Standby	2	1019	5	0.00245	17	2,121 d	5	8.24E-03	236%	
1.1	XVM-FTOC	Manual Valve Fails To Open	0	2605	76	0.000192	1	3,270 d	66	4.59E-04	139%	
1.3	HOV-ILS	Hydraulic Operated Valve Internal Leakage (Small)	2	87527799 h	771	2.86E-08	4	93,083,360 h	601	4.83E-08	69%	
2.4	PDP-ELS	Positive Displacement Pump External Leakage (Small)	14	19599696 h	172	7.40E-07	28	26,271,740 h	175	1.08E-06	46%	
3.4	EDG-HCS-FTR	HCS Generator Fail to Run	3	3213 h	8	0.0009411	4	3,948 h	8	1.14E-03	21%	
9.2	AHU-NR-FTR	Air Handling/Heating Unit Fails To Run, Normally Running	52	12998080 h	142	5.61E-06	62	17,498,560 h	139	6.65E-06	18%	

Table 2. Summary of top 10% decreased unreliability estimates.

Section	Rule	Description	Previous Data				Current Data				Delta	Comments
			Failures	Demands /Time	Comp. Count	Mean	Failures	Demands /Time	Comp. Count	Mean		
4.2	SVV-FTO	BWR Code Safety Fails To Open	7	17320	950	0.0004234	5	23,800 d	960	2.18E-04	-49%	
1.1	XVM-ILS	Manual Valve Internal Leakage (Small)	13	100961448 h	886	1.34E-07	7	128,295,300 h	866	6.88E-08	-49%	
1.1	XVM-ELS	Manual Valve External Leakage (Small)	26	100961448 h	886	2.62E-07	14	128,295,300 h	866	1.13E-07	-57%	
4.2	SVV-ELS	Code Safety Valve External Leakage (Small)	4	161355977 h	1416	2.79E-08	2	211,426,600 h	1426	1.18E-08	-58%	
9.1	AOD-ILS	Air-Operated Damper Internal Leakage (Small)	12	20625312 h	181	6.06E-07	5	31,342,830 h	209	1.75E-07	-71%	
4.1	SRV-ELS	Safety Relief Valve (BWR Only) External Leakage (Small)	1	62541477 h	577	2.40E-08	0	72,220,220 h	558	6.92E-09	-71%	
4.4	RVL-SO	Low Capacity Relief Valve Spurious Operation	1	7520832 h	66	1.99E-07	0	9,633,048 h	81	5.19E-08	-74%	
1.8	MSV-ELS	Main Steam Isolation External Leakage (Small)	7	55836292 h	490	1.34E-07	2	79,241,950 h	513	3.15E-08	-76%	
10.1	EDC-FR-E	Engine Driven Compressor Fails To Run <1H, Normally Standby	15	5687 h	5	0.003777	0	2,121 h	5	2.36E-04	-94%	

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 4.5.2015.12 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 ICES database, covering 1998–2015 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)	277	211	488
	Chemical and volume control (CVC)	1		1
	Circulating water system (CWS)	12		12
	Component cooling water (CCW)	851	312	1163
	Condensate system (CDS)	88	17	105
	Condensate transfer system (CTS)	1		1
	Containment fan cooling (CFC)	177	26	203
	Containment isolation system (CIS)	7	9	16
	Containment spray recirculation (CSR)	30	36	66
	Control rod drive (CRD)	483	71	554

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
	Emergency power supply (EPS)	319	23	342
	Engineered safety features actuation (ESF)	1		1
	Firewater (FWS)	4	1	5
	Fuel handling (FHS)	2		2
	Heating ventilation and air conditioning (HVC)	731	101	832
	High pressure coolant injection (HCI)	81	7	88
	High pressure core spray (HCS)	33	1	34
	High pressure injection (HPI)	226	77	303
	Instrument air (IAS)	26	21	47
	Isolation condenser (ISO)	12	6	18
	Low pressure core spray (LCS)	47	10	57
	Main feedwater (MFW)	860	141	1001
	Main steam (MSS)	978	110	1088
	Normally operating service water (SWN)	719	309	1028
	Reactor coolant (RCS)	238	55	293
	Reactor core isolation (RCI)	82	7	89
	Reactor protection (RPS)	8	13	21
	Standby liquid control (SLC)	4	1	5
	Standby service water (SWS)	162	20	182
	Vapor suppression (VSS)	13	32	45
	Residual Heat Removal (LCI in BWRs; LPI in PWRs) (RHR)	548	150	698
	Grand Total	**7021**	**1767**	**8788**

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
-	FTO	78	201,146 d	1767	98	3.2%	35.7%
-	FTC	53	201,146 d	1767	98	2.7%	33.7%
-	FTO/C	134	201,146 d	1767	98	5.9%	53.1%
-	FC	279	1,347,257,000 h	8784	104	2.7%	79.8%
-	SOP	132	1,347,257,000 h	8784	104	1.3%	55.8%
-	ILS	104	1,347,257,000 h	8784	104	1.0%	38.5%
-	ILL	104	1,347,257,000 h	8784	104	1.0%	38.5%
-	ELS	60	1,347,257,000 h	8784	104	0.6%	30.8%
-	ELL	60	1,347,257,000 h	8784	104	0.6%	30.8%
CCW	SOP	25	178,863,300 h	1161	100	1.6%	13.0%
IAS	SOP	0	7,056,096 h	45	24	0.0%	0.0%

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

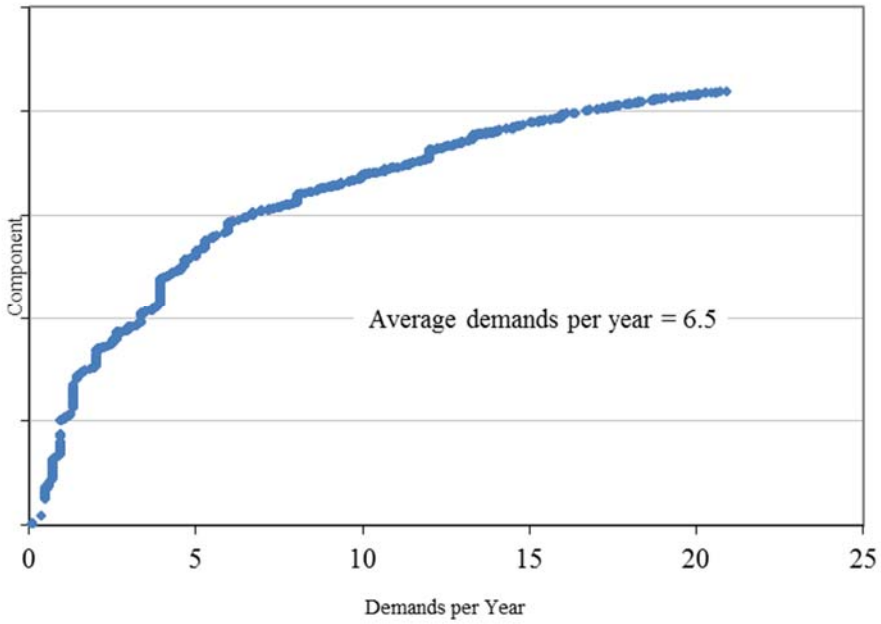

Figure 1-1. AOV demands per year distribution.

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
-	FTO	EB/PL/KS	1.04E-05	2.44E-04	3.91E-04	1.27E-03	Beta	0.79	2.03E+03
-	FTC	EB/PL/KS	2.24E-06	1.78E-04	3.63E-04	1.35E-03	Beta	0.55	1.51E+03
-	FTO/C	EB/PL/KS	4.49E-05	5.49E-04	7.78E-04	2.29E-03	Beta	1.05	1.35E+03
-	FC	EB/PL/KS	2.41E-08	1.77E-07	2.28E-07	6.08E-07	Gamma	1.41	6.17E+06
-	SOP	EB/PL/KS	7.28E-09	7.61E-08	1.05E-07	2.99E-07	Gamma	1.14	1.09E+07
-	ILS	JNID/IL	6.57E-08	7.75E-08	7.76E-08	9.07E-08	Gamma	105.00	1.35E+09
-	ILL	JNID/IL	1.66E-13	3.78E-10	1.55E-09	7.10E-09	Gamma	0.30	1.93E+08
-	ELS	JNID/IL	3.58E-08	4.46E-08	4.49E-08	5.47E-08	Gamma	60.50	1.35E+09
-	ELL	JNID/IL	3.36E-13	7.66E-10	3.14E-09	1.44E-08	Gamma	0.30	9.55E+07
CCW	SOP	JNID/IL	9.94E-08	1.41E-07	1.43E-07	1.92E-07	Gamma	25.50	1.79E+08
IAS	SOP	JNID/IL	2.78E-10	3.22E-08	7.09E-08	2.72E-07	Gamma	0.50	7.06E+06

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 ICES database, covering 1998–2015 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)	258	476	734
	Chemical and volume control (CVC)		13	13
	Circulating water system (CWS)	69	74	143
	Component cooling water (CCW)	760	683	1443
	Condensate system (CDS)	43	1	44
	Condensate transfer system (CTS)		6	6
	Containment fan cooling (CFC)	34	7	41
	Containment isolation system (CIS)	15	18	33
	Containment spray recirculation (CSR)	204	330	534
	Control rod drive (CRD)	74	10	84
	Emergency power supply (EPS)	61	1	62
	Firewater (FWS)	10	8	18
	Heating ventilation and air conditioning (HVC)	189	22	211
	High pressure coolant injection (HCI)	101	262	363
	High pressure core spray (HCS)	46	30	76
	High pressure injection (HPI)	258	1004	1262
	Instrument air (IAS)	16	14	30
	Isolation condenser (ISO)	10	14	24
	Low pressure core spray (LCS)	102	204	306
	Main feedwater (MFW)	877	287	1164
	Main steam (MSS)	707	177	884
	Normally operating service water (SWN)	880	732	1612
	Reactor coolant (RCS)	29	104	133
	Reactor core isolation (RCI)	137	313	450
	Reactor protection (RPS)	10	4	14
	Standby liquid control (SLC)	7	21	28
	Standby service water (SWS)	283	212	495
	Vapor suppression (VSS)	9	14	23

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
	Residual Heat Removal (LCI in BWRs; LPI in PWRs) (RHR)	914	1861	2775
	Grand Total	**6103**	**6902**	**13005**

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
-	FTO	293	740,890 d	6902	104	3.8%	88.5%
-	FTC	234	740,890 d	6902	104	3.0%	76.9%
-	FTO/C	558	740,890 d	6902	104	6.9%	94.2%
-	FC	119	1,983,522,000 h	13001	104	0.8%	55.8%
-	SOP	63	1,983,522,000 h	13001	104	0.5%	33.7%
-	ILS	141	1,983,522,000 h	13001	104	0.9%	56.7%
-	ILL	141	1,983,522,000 h	13001	104	0.9%	56.7%
-	ELS	51	1,983,522,000 h	13001	104	0.3%	29.8%
-	ELL	51	1,983,522,000 h	13001	104	0.3%	29.8%
BFV	FTO	27	109,521 d	961	83	2.2%	20.5%
BFV	FTC	34	109,521 d	961	83	3.4%	28.9%
BFV	FTO/C	65	109,521 d	961	83	5.9%	44.6%
CCW	SOP	6	223,471,400 h	1443	97	0.3%	3.1%
SWS	SOP	3	73,067,170 h	495	41	0.6%	4.9%
BFV—CCW	SOP	6	106,466,800 h	708	72	0.8%	4.2%

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

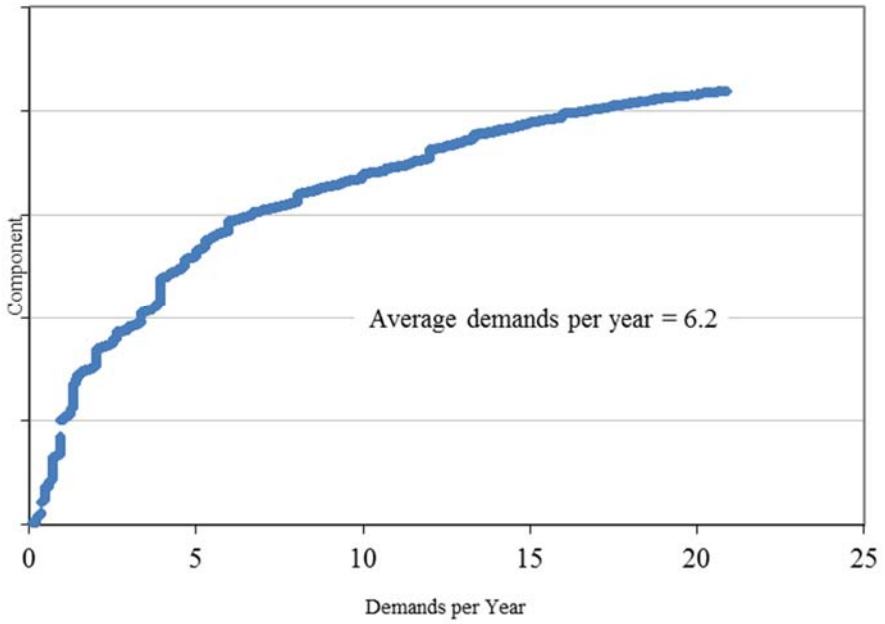

Figure 1-2. MOV demands per year distribution.

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
-	FTO	EB/PL/KS	1.17E-04	3.76E-04	4.21E-04	8.76E-04	Beta	3.08	7.32E+03
-	FTC	EB/PL/KS	5.25E-05	2.76E-04	3.35E-04	8.17E-04	Beta	1.82	5.44E+03
-	FTO/C	EB/PL/KS	2.00E-04	7.20E-04	8.22E-04	1.78E-03	Beta	2.66	3.24E+03
-	FC	EB/PL/KS	7.49E-09	4.69E-08	5.90E-08	1.50E-07	Gamma	1.58	2.69E+07
-	SOP	EB/PL/KS	2.90E-10	1.69E-08	3.24E-08	1.17E-07	Gamma	0.59	1.83E+07
-	ILS	EB/PL/KS	1.66E-09	4.58E-08	7.58E-08	2.52E-07	Gamma	0.75	9.86E+06
-	ILL	EB/PL/KS	1.62E-13	3.70E-10	1.52E-09	6.93E-09	Gamma	0.30	1.98E+08
-	ELS	EB/PL/KS	9.56E-11	1.21E-08	2.71E-08	1.05E-07	Gamma	0.49	1.81E+07
-	ELL	EB/PL/KS	2.03E-13	4.62E-10	1.90E-09	8.68E-09	Gamma	0.30	1.58E+08
BFV	FTO	JNID/IL	1.79E-04	2.49E-04	2.51E-04	3.36E-04	Beta	27.50	1.09E+05
BFV	FTC	EB/PL/KS	2.30E-05	2.45E-04	3.38E-04	9.68E-04	Beta	1.13	3.35E+03
BFV	FTO/C	EB/PL/KS	3.84E-05	4.98E-04	7.14E-04	2.12E-03	Beta	1.02	1.43E+03
CCW	SOP	JNID/IL	1.32E-08	2.77E-08	2.91E-08	5.01E-08	Gamma	6.50	2.23E+08
SWS	SOP	JNID/IL	1.48E-08	4.34E-08	4.79E-08	9.62E-08	Gamma	3.50	7.31E+07
BFV--CCW	SOP	JNID/IL	2.78E-08	5.82E-08	6.11E-08	1.05E-07	Gamma	6.50	1.06E+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 ICES database, covering 1998–2015 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)	46	11	57
	Circulating water system (CWS)	5	3	8
	Component cooling water (CCW)	4		4
	Condensate system (CDS)	3		3
	Containment isolation system (CIS)	3		3
	Emergency power supply (EPS)	5	6	11
	Heating ventilation and air conditioning (HVC)	9	1	10
	High pressure coolant injection (HCI)	21	6	27
	High pressure injection (HPI)		6	6
	Instrument air (IAS)	1		1
	Main feedwater (MFW)	44	73	117
	Main steam (MSS)	192	104	296
	Normally operating service water (SWN)	6	5	11
	Reactor coolant (RCS)		3	3
	Reactor core isolation (RCI)	13	3	16
	Standby service water (SWS)	5	4	9
	Vapor suppression (VSS)		1	1
	Residual Heat Removal (LCI in BWRs; LPI in PWRs) (RHR)	14	4	18
	Grand Total	**371**	**230**	**601**

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
-	FTO/C	26	19,862 d	230	42	9.1%	31.0%
-	FC	42	93,083,360 h	601	80	5.3%	27.5%
-	SOP	17	93,083,360 h	601	80	1.8%	11.3%

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
-	ILS	4	93,083,360 h	601	80	0.7%	5.0%
-	ILL	4	93,083,360 h	601	80	0.7%	5.0%
-	ELS	12	93,083,360 h	601	80	1.2%	8.8%
-	ELL	12	93,083,360 h	601	80	1.2%	8.8%

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

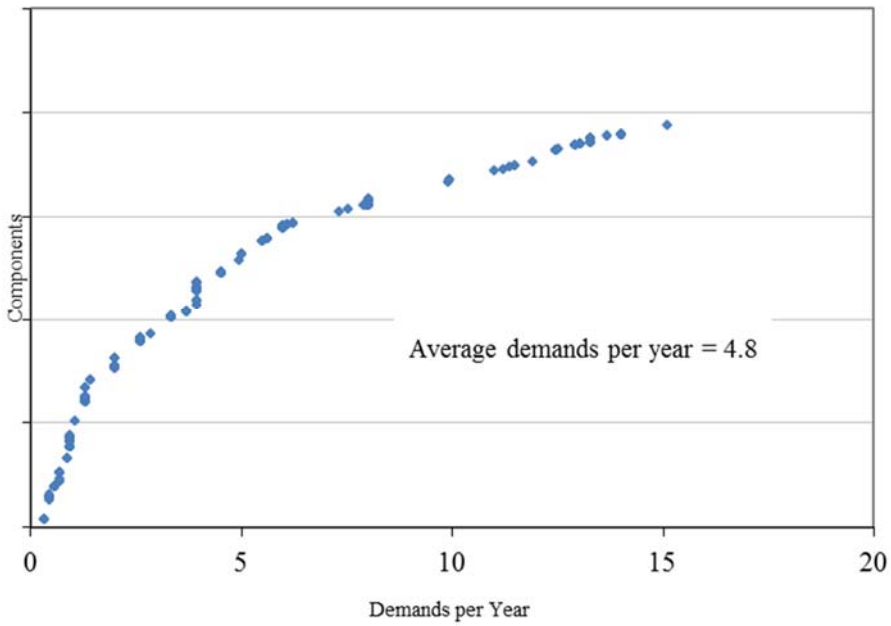

Figure 1-3. HOV demands per year distribution.

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
-	FTO/C	JNID/IL	9.40E-04	1.32E-03	1.33E-03	1.79E-03	Beta	26.50	1.98E+04
-	FC	JNID/IL	3.48E-07	4.53E-07	4.57E-07	5.77E-07	Gamma	42.50	9.31E+07
-	SOP	JNID/IL	1.21E-07	1.84E-07	1.88E-07	2.67E-07	Gamma	17.50	9.31E+07
-	ILS	JNID/IL	1.79E-08	4.48E-08	4.83E-08	9.09E-08	Gamma	4.50	9.31E+07
-	ILL	JNID/IL	1.03E-13	2.35E-10	9.66E-10	4.42E-09	Gamma	0.30	3.11E+08
-	ELS	JNID/IL	7.85E-08	1.31E-07	1.34E-07	2.02E-07	Gamma	12.50	9.31E+07
-	ELL	JNID/IL	1.00E-12	2.29E-09	9.38E-09	4.29E-08	Gamma	0.30	3.20E+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 ICES database, covering 1998–2015 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)	25	31	56
	Chemical and volume control (CVC)		2	2
	Component cooling water (CCW)	10		10
	Condensate system (CDS)	3		3
	Containment fan cooling (CFC)	7		7
	Containment spray recirculation (CSR)	15	11	26
	Control rod drive (CRD)	27	397	424
	Emergency power supply (EPS)	53	23	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)	42	39	81
	Low pressure core spray (LCS)		2	2
	Main feedwater (MFW)	15	6	21
	Main steam (MSS)	29	37	66
	Normally operating service water (SWN)	14	12	26
	Reactor coolant (RCS)	16	87	103
	Reactor core isolation (RCI)	1	2	3
	Reactor protection (RPS)	8	14	22
	Standby service water (SWS)	3		3
	Vapor suppression (VSS)		2	2
	Residual Heat Removal (LCI in BWRs; LPI in PWRs) (RHR)	19	32	51
	Grand Total	**404**	**759**	**1163**

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
-	FTO/C	23	33,316 d	759	54	2.6%	20.4%
-	FC	58	143,582,100 h	1161	87	4.5%	21.8%
-	SOP	9	143,582,100 h	1161	87	0.4%	5.7%
-	ILS	20	143,582,100 h	1161	87	1.7%	13.8%
-	ILL	20	143,582,100 h	1161	87	1.7%	13.8%
-	ELS	3	143,582,100 h	1161	87	0.3%	3.4%
-	ELL	3	143,582,100 h	1161	87	0.3%	3.4%

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

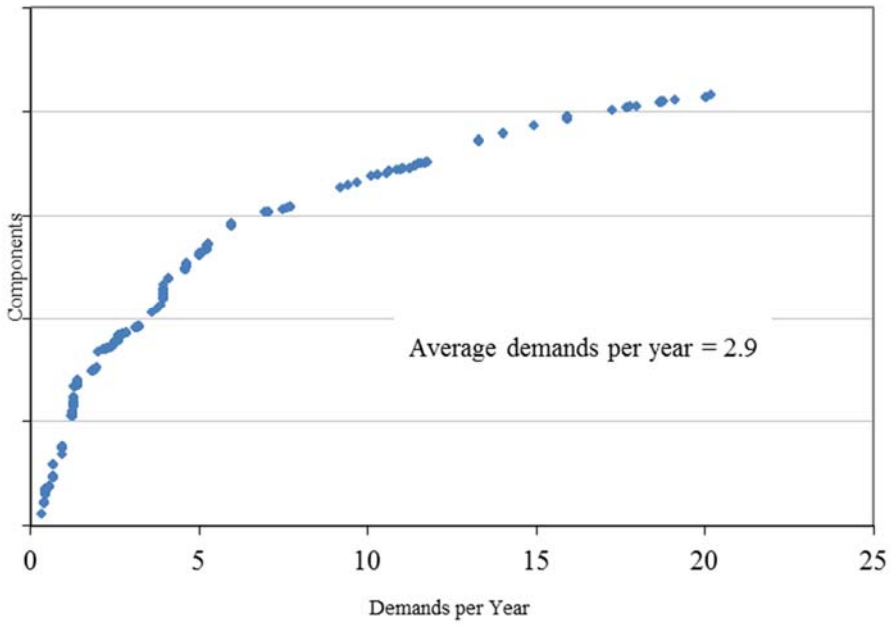

Figure 1-4. SOV demands per year (low demand devices) distribution.

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
-	FTO/C	JNID/IL	4.84E-04	6.95E-04	7.05E-04	9.60E-04	Beta	23.50	3.33E+04
-	FC	JNID/IL	3.23E-07	4.04E-07	4.07E-07	4.97E-07	Gamma	58.50	1.44E+08
-	SOP	JNID/IL	3.51E-08	6.37E-08	6.62E-08	1.05E-07	Gamma	9.50	1.44E+08
-	ILS	JNID/IL	9.49E-08	1.40E-07	1.43E-07	1.98E-07	Gamma	20.50	1.44E+08
-	ILL	JNID/IL	3.06E-13	6.97E-10	2.86E-09	1.31E-08	Gamma	0.30	1.05E+08

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
-	ELS	JNID/IL	7.53E-09	2.20E-08	2.44E-08	4.88E-08	Gamma	3.50	1.44E+08
-	ELL	JNID/IL	1.83E-13	4.16E-10	1.71E-09	7.81E-09	Gamma	0.30	1.76E+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 ICES database, covering 1998–2015 using RADS. The systems included in the EOV data collection are listed in Table 1-14with 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)	16	57	73
	Grand Total	**16**	**57**	**73**

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
-	FTO	3	713 d	57	27	5.3%	11.1%

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

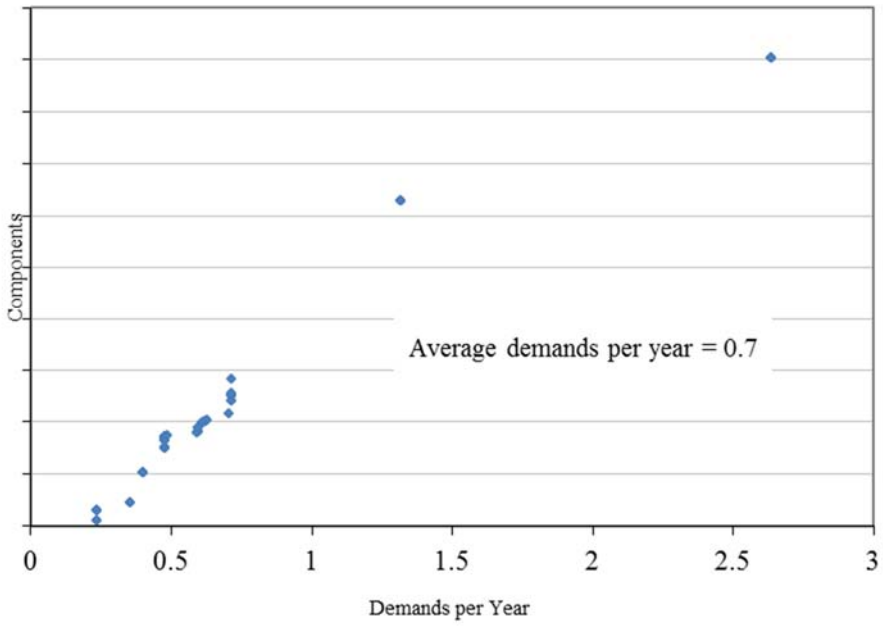

Figure 1-5. EOV demands per year distribution.

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
-	FTO	JNID/IL	1.52E-03	4.44E-03	4.90E-03	9.83E-03	Beta	3.50	7.11E+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 ICES database, covering 1998–2015 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	Main steam (MSS)	10	4	14
	Vapor suppression (VSS)	165	163	328
	Grand Total	**175**	**167**	**342**

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
-	FTO	2	27,842 d	167	17	1.2%	11.8%
-	FTC	6	27,842 d	167	17	3.6%	23.5%
-	FTO/C	8	27,842 d	167	17	4.8%	35.3%
-	SOP	1	52,796,540 h	342	30	0.3%	3.3%
-	ILS	15	52,796,540 h	342	30	4.4%	10.0%
-	ILL	15	52,796,540 h	342	30	4.4%	10.0%

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

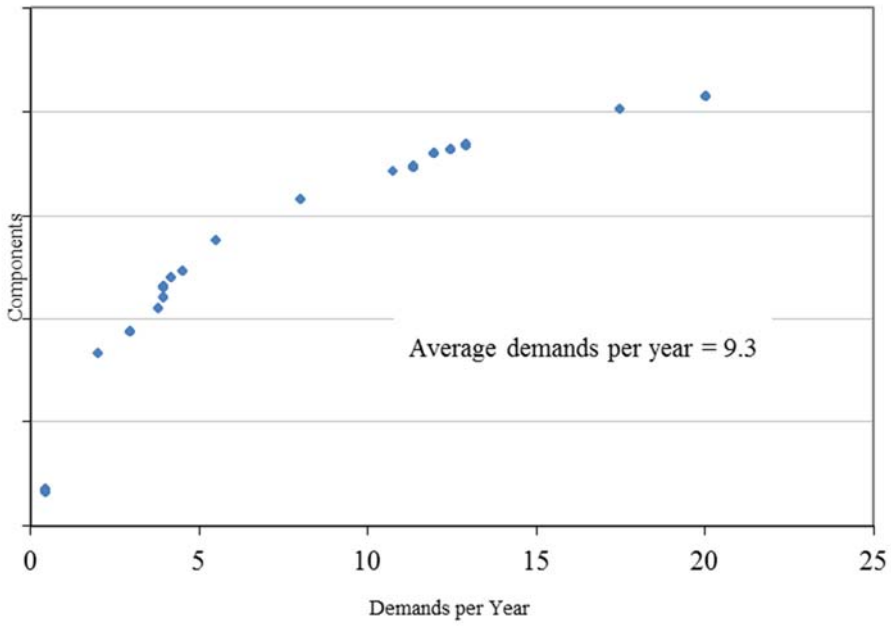

Figure 1-6. VBV demands per year (low demand devices) distribution.

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
-	FTO	JNID/IL	2.06E-05	7.83E-05	8.98E-05	1.99E-04	Beta	2.50	2.78E+04
-	FTC	EB/PL/KS	4.03E-06	1.27E-04	2.15E-04	7.25E-04	Beta	0.72	3.33E+03
-	FTO/C	EB/PL/KS	5.55E-06	1.94E-04	3.37E-04	1.15E-03	Beta	0.69	2.05E+03
-	SOP	JNID/IL	3.33E-09	2.24E-08	2.84E-08	7.40E-08	Gamma	1.50	5.28E+07
-	ILS	JNID/IL	1.83E-07	2.87E-07	2.94E-07	4.26E-07	Gamma	15.50	5.28E+07
-	ILL	JNID/IL	6.29E-13	1.43E-09	5.88E-09	2.69E-08	Gamma	0.30	5.10E+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 ICES database, covering 1998–2015 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)	83	73	156
	Grand Total	**83**	**73**	**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
-	FTO	8	2,725 d	73	15	8.2%	20.0%
-	FTC	0	2,725 d	73	15	0.0%	0.0%
-	FTO/C	8	2,725 d	73	15	8.2%	20.0%
-	FC	14	23,964,260 h	156	27	5.8%	25.9%

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

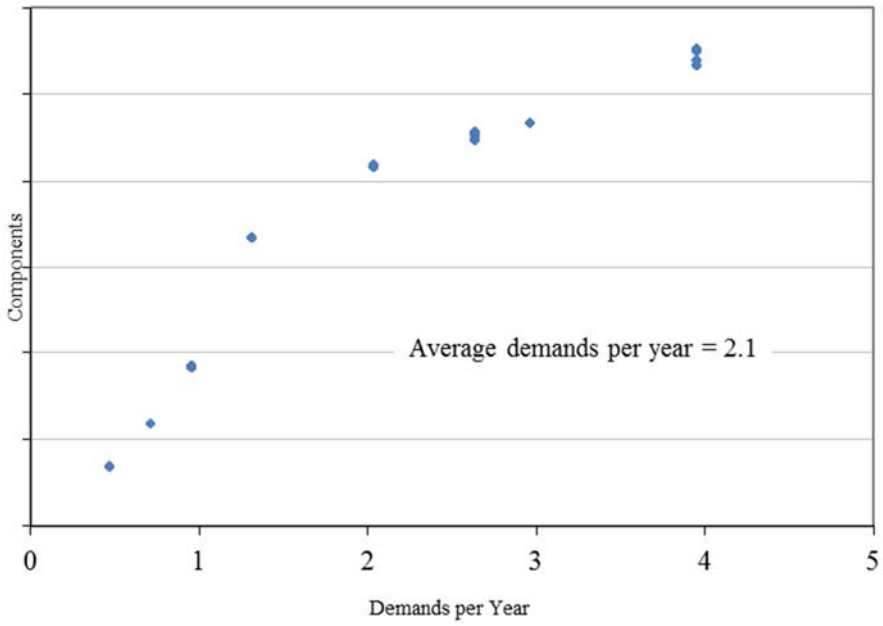

Figure 1-7. TBV demands per year distribution.

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
-	FTO	JNID/IL	1.59E-03	2.99E-03	3.12E-03	5.05E-03	Beta	8.50	2.72E+03
-	FTC	JNID/IL	7.20E-07	8.33E-05	1.83E-04	7.03E-04	Beta	0.50	2.73E+03
-	FTO/C	JNID/IL	1.59E-03	2.99E-03	3.12E-03	5.05E-03	Beta	8.50	2.72E+03
-	FC	JNID/IL	3.69E-07	5.90E-07	6.05E-07	8.87E-07	Gamma	14.50	2.40E+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 ICES database, covering 1998–2015 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)	94	419	513
	Grand Total	**94**	**419**	**513**

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
-	FTO/C	34	38,629 d	419	83	6.4%	24.1%
-	SOP	25	79,241,950 h	513	104	4.3%	17.3%
-	ILS	63	79,241,950 h	513	104	10.1%	20.2%
-	ILL	63	79,241,950 h	513	104	10.1%	20.2%
-	ELS	2	79,241,950 h	513	104	0.4%	1.9%
-	ELL	2	79,241,950 h	513	104	0.4%	1.9%

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

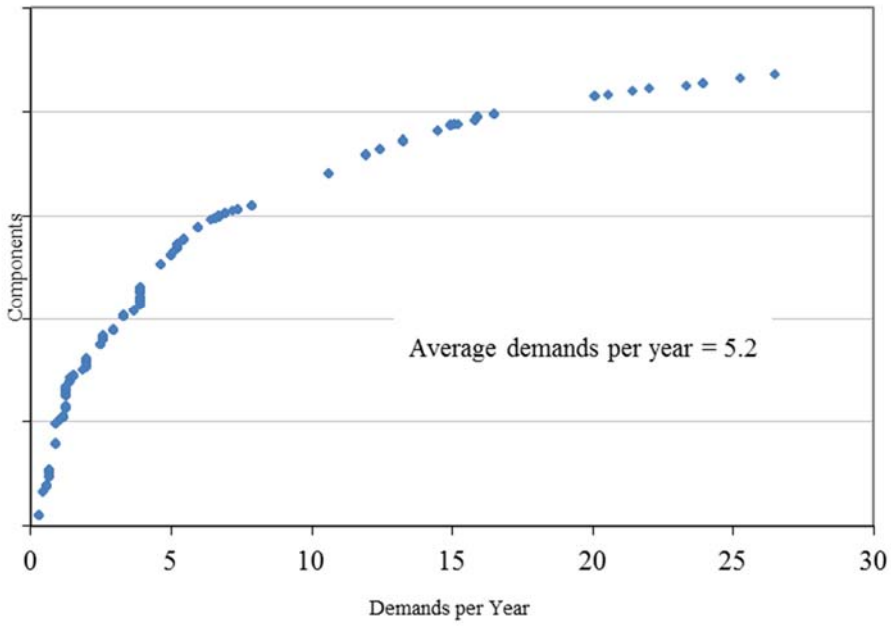

Figure 1-8. MSV demands per year distribution.

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
-	FTO/C	JNID/IL	6.59E-04	8.84E-04	8.93E-04	1.16E-03	Beta	34.50	3.86E+04
-	SOP	EB/PL/KS	1.44E-09	1.45E-07	3.10E-07	1.18E-06	Gamma	0.52	1.66E+06
-	ILS	JNID/IL	6.44E-07	7.98E-07	8.01E-07	9.74E-07	Gamma	63.50	7.92E+07
-	ILL	JNID/IL	1.71E-12	3.91E-09	1.60E-08	7.33E-08	Gamma	0.30	1.87E+07
-	ELS	JNID/IL	7.23E-09	2.75E-08	3.15E-08	6.99E-08	Gamma	2.50	7.92E+07
-	ELL	JNID/IL	2.36E-13	5.38E-10	2.21E-09	1.01E-08	Gamma	0.30	1.36E+08

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 ICES database, covering 1998–2015 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)	857	53	910
	Circulating water system (CWS)	7		7
	Component cooling water (CCW)	441	34	475
	Condensate system (CDS)	81		81
	Condensate transfer system (CTS)	3		3
	Containment fan cooling (CFC)	2	1	3
	Containment isolation system (CIS)		1	1
	Containment spray recirculation (CSR)	301	54	355
	Control rod drive (CRD)	30	3	33
	Emergency power supply (EPS)	314	21	335
	Engineered safety features actuation (ESF)	2		2
	Firewater (FWS)	32		32
	Fuel handling (FHS)	29		29
	Heating ventilation and air conditioning (HVC)	2	4	6
	High pressure coolant injection (HCI)	157	10	167
	High pressure core spray (HCS)	48		48
	High pressure injection (HPI)	861	125	986
	Instrument air (IAS)	126		126
	Isolation condenser (ISO)		1	1
	Low pressure core spray (LCS)	125	5	130
	Main feedwater (MFW)	229	27	256
	Main steam (MSS)	188	23	211
	Normally operating service water (SWN)	509	10	519
	Reactor coolant (RCS)	188	7	195
	Reactor core isolation (RCI)	138	10	148
	Reactor recirculation (RRS)		1	1
	Standby liquid control (SLC)	15		15
	Standby service water (SWS)	178	9	187
	Vapor suppression (VSS)	5	4	9

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
	Residual Heat Removal (LCI in BWRs; LPI in PWRs) (RHR)	967	93	1060
	Grand Total	**5835**	**496**	**6331**

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
-	FTO	0	54,125 d	496	45	0.0%	0.0%
-	FTC	8	54,125 d	496	45	1.4%	11.1%
-	SO	2	977,258,600 h	6331	103	0.0%	1.9%
-	SC	5	977,258,600 h	6331	103	0.0%	1.0%
-	ILS	143	977,258,600 h	6331	103	2.0%	54.4%
-	ILL	143	977,258,600 h	6331	103	2.0%	54.4%
-	ELS	7	977,258,600 h	6331	103	0.1%	5.8%
-	ELL	7	977,258,600 h	6331	103	0.1%	5.8%

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

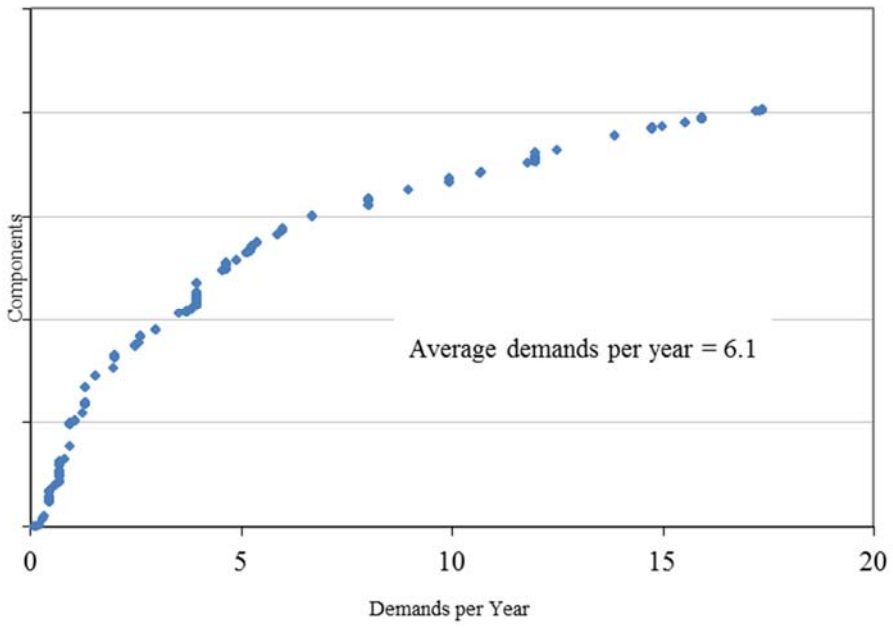

Figure 1-9. CKV demands per year distribution.

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
-	FTO	JNID/IL	3.63E-08	4.20E-06	9.24E-06	3.55E-05	Beta	0.50	5.41E+04
-	FTC	JNID/IL	8.01E-05	1.51E-04	1.57E-04	2.55E-04	Beta	8.50	5.41E+04
-	SO	JNID/IL	5.86E-10	2.23E-09	2.56E-09	5.67E-09	Gamma	2.50	9.77E+08
-	SC	JNID/IL	2.34E-09	5.29E-09	5.63E-09	1.01E-08	Gamma	5.50	9.77E+08
-	ILS	EB/PL/KS	1.14E-09	1.00E-07	2.08E-07	7.80E-07	Gamma	0.53	2.57E+06
-	ILL	EB/PL/KS	4.45E-13	1.01E-09	4.16E-09	1.90E-08	Gamma	0.30	7.21E+07
-	ELS	JNID/IL	3.72E-09	7.34E-09	7.67E-09	1.28E-08	Gamma	7.50	9.77E+08
-	ELL	JNID/IL	5.75E-14	1.31E-10	5.37E-10	2.46E-09	Gamma	0.30	5.59E+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 ICES 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)	96	5	101
	Circulating water system (CWS)	6		6
	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)	28	1	29
	Instrument air (IAS)	5		5
	Isolation condenser (ISO)	24		24
	Low pressure core spray (LCS)	12		12
	Main feedwater (MFW)	6	1	7
	Main steam (MSS)	21	6	27
	Normally operating service water (SWN)	53	6	59
	Reactor coolant (RCS)	9		9
	Reactor core isolation (RCI)	13		13
	Reactor protection (RPS)	2		2
	Standby liquid control (SLC)	8	4	12
	Standby service water (SWS)	113	8	121
	Unknown (UKN)	1		1
	Residual Heat Removal (LCI in BWRs; LPI in PWRs) (RHR)	126	14	140
	Grand Total	**801**	**66**	**867**

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
-	FTO/C	1	3,270 d	66	9	1.5%	11.1%
-	SOP	6	128,295,300 h	866	78	0.7%	7.7%
-	ILS	7	128,295,300 h	866	78	0.8%	9.0%
-	ILL	7	128,295,300 h	866	78	0.8%	9.0%
-	ELS	14	128,295,300 h	866	78	1.5%	12.8%
-	ELL	14	128,295,300 h	866	78	1.5%	12.8%
SWS	SOP	2	18,346,180 h	121	11	1.7%	18.2%

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

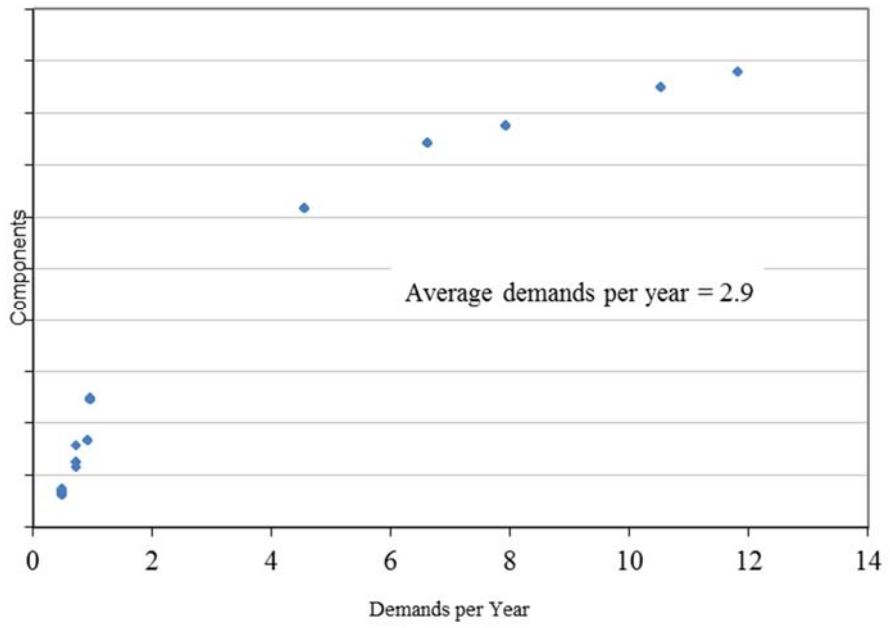

Figure 1-10. XVM demands per year distribution.

1.10.3 Industry-Average Baselines

Table 1-30 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
-	FTO/C	JNID/IL	5.38E-05	3.62E-04	4.59E-04	1.19E-03	Beta	1.50	3.27E+03
-	SOP	JNID/IL	2.30E-08	4.82E-08	5.07E-08	8.74E-08	Gamma	6.50	1.28E+08
-	ILS	EB/PL/KS	9.97E-10	3.89E-08	6.88E-08	2.38E-07	Gamma	0.67	9.70E+06
-	ILL	EB/PL/KS	1.47E-13	3.35E-10	1.38E-09	6.29E-09	Gamma	0.30	2.18E+08
-	ELS	JNID/IL	6.92E-08	1.11E-07	1.13E-07	1.66E-07	Gamma	14.50	1.28E+08
-	ELL	JNID/IL	8.47E-13	1.93E-09	7.91E-09	3.62E-08	Gamma	0.30	3.79E+07
SWS	SOP	JNID/IL	3.13E-08	1.19E-07	1.36E-07	3.02E-07	Gamma	2.50	1.83E+07

1.11 Flow Control Valve (FCV)

1.11.1 Component Description

The Flow Control Valve (FCV) component boundary includes the valve and valve operator. Motor-operated and air-operated valves are included in this group. The failure modes for FCV are listed in Table 1-1.

1.11.2 Data Collection and Review

Data for FCV UR baselines were obtained from the ICES database, covering 1997–2004 using RADS. The systems included in the FCV data collection are listed in Table 1-32 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 1-32. FCV systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
FCV	Auxiliary feedwater (AFW)	2	6	8
	Component cooling water (CCW)	425	87	512
	Condensate system (CDS)	18		18
	Main feedwater (MFW)	7		7
	Residual Heat Removal (LCI in BWRs; LPI in PWRs) (RHR)	26	3	29
	FCV Total	**478**	**96**	**574**
FWR	Main feedwater (MFW)	196	20	216
	FWR Total	**196**	**20**	**216**
	Grand Total	**674**	**116**	**790**

Table 1-33 summarizes the data used in the FCV analysis. Note that the hours for SOP, ELS, and ILS are reactor-year hours.

Table 1-33. FCV unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
FCV	FTO/C	5	12,487 d	96	14	4.2%	21.4%
FCV	FC	16	88,861,090 h	574	84	2.3%	10.7%
FCV	SOP	10	88,861,090 h	574	84	1.0%	6.0%
FRV	FF	72	33,730,380 h	216	76	26.4%	50.0%

Figure 1-11 shows the range of valve demands per year in the XVM data set (limited to low-demand components only).

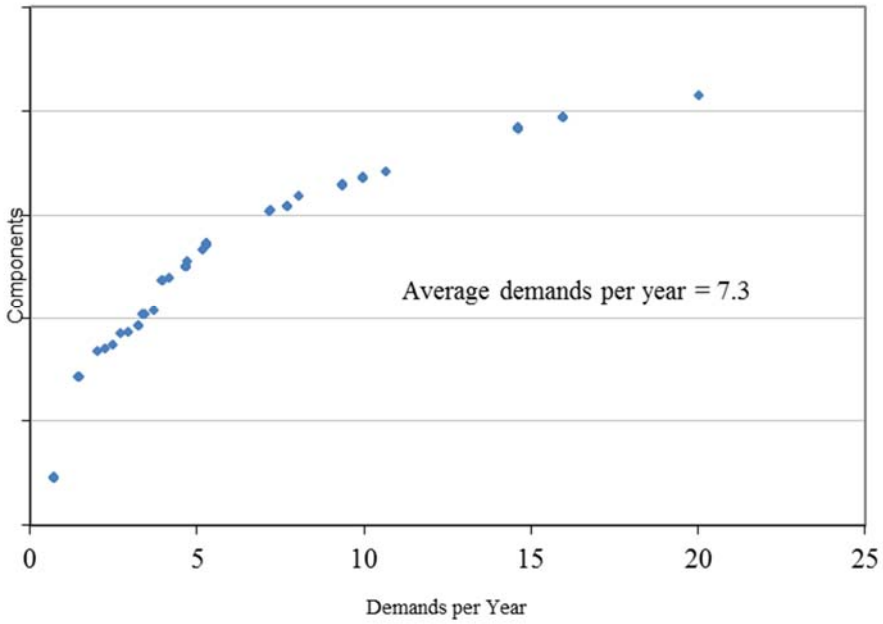

Figure 1-11. FCV demands per year distribution.

1.11.3 Industry-Average Baselines

Table 1-34 lists the selected industry distributions of p and λ for the FCV failure modes. These industry-average failure rates do not account for any recovery.

Table 1-34. Selected industry distributions of p and λ for FCVs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
FCV	FTO/C	JNID/IL	1.83E-04	4.13E-04	4.40E-04	7.87E-04	Beta	5.50	1.25E+04
FCV	FC	JNID/IL	1.17E-07	1.82E-07	1.86E-07	2.67E-07	Gamma	16.50	8.89E+07
FCV	SOP	JNID/IL	6.52E-08	1.14E-07	1.18E-07	1.84E-07	Gamma	10.50	8.89E+07
FRV	FF	EB/PL/KS	3.08E-07	1.72E-06	2.10E-06	5.23E-06	Gamma	1.73	8.22E+05

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 ICES database, covering 1998–2015. 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)		8	8
	Chilled water system (CHW)	1	2	3
	Circulating water system (CWS)	113	32	145
	Component cooling water (CCW)	98	291	389
	Condensate system (CDS)	9	143	152
	Condensate transfer system (CTS)	1		1

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
	Containment spray recirculation (CSR)	25		25
	Control rod drive (CRD)	3	43	46
	Emergency power supply (EPS)	2		2
	Firewater (FWS)	5		5
	Fuel Oil Transfer (FOT)	17		17
	Heating ventilation and air conditioning (HVC)	2		2
	High pressure injection (HPI)	1	5	6
	Low pressure core spray (LCS)	15	4	19
	Main feedwater (MFW)	2	44	46
	Normally operating service water (SWN)	38	105	143
	Reactor protection (RPS)	2		2
	Standby service water (SWS)	27	2	29
	Residual Heat Removal (LCI in BWRs; LPI in PWRs) (RHR)	1		1
Normally Running Total		**362**	**679**	**1041**
Standby	Auxiliary feedwater (AFW)		128	128
	Containment spray recirculation (CSR)		157	157
	Control rod drive (CRD)		9	9
	Emergency power supply (EPS)		14	14
	Firewater (FWS)		1	1
	Fuel Oil Transfer (FOT)		20	20
	High pressure core spray (HCS)		9	9
	High pressure injection (HPI)		168	168
	Low pressure core spray (LCS)		70	70
	Standby service water (SWS)	2	442	444
	Residual Heat Removal (LCI in BWRs; LPI in PWRs) (RHR)		293	293
Standby Total		**2**	**1311**	**1313**
Grand Total		**364**	**1990**	**2354**

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	351	482,205 d	1311	106	20.6%	86.8%
Standby	FTR<1H	48	437,647 h	1311	106	3.4%	32.1%
Standby	FTR>1H	143	20,062,180 h	1311	106	9.3%	59.4%
-	ELS	105	347,850,600 h	2344	104	3.5%	47.1%
-	ELL	105	347,850,600 h	2344	104	3.5%	47.1%
Normally Running	FTS	147	138,318 d	670	101	16.7%	63.4%
Normally Running	FTR	225	59,582,350 h	664	101	25.0%	69.3%
CCW	FTS	69	88,692 h	291	85	16.5%	45.9%

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
CCW	FTR	53	19,648,220 h	291	85	15.5%	38.8%
SWS	FTS	149	249,956 h	446	97	24.0%	63.9%
SWS	FTS	180	264,383 d	549	100	24.2%	66.0%
SWS	FTR	64	10,443,960 h	106	37	34.9%	67.6%
SWS	FTR	2	16,692,670 h	446	97	0.4%	2.1%
NSW	FTR	64	10,256,170 h	104	37	35.6%	67.6%
SWS-NE	FTS	179	264,383 d	549	100	24.0%	66.0%
SWS-NE	FTR	151	26,944,240 h	548	100	20.4%	61.0%
CSW	FTR	25	3,654,539 h	32	12	59.4%	66.7%

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.

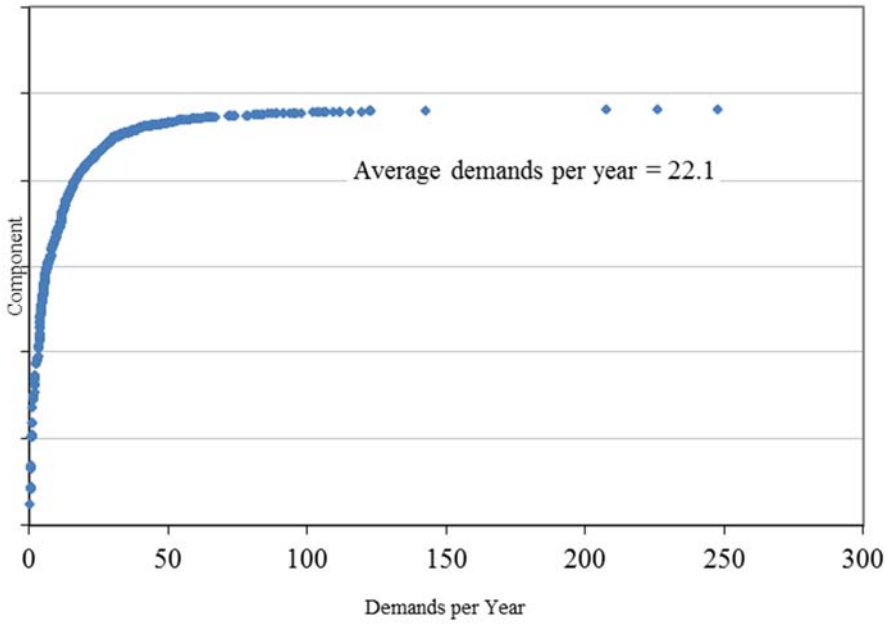

Figure 2-1a. Standby MDP demands per year distribution.

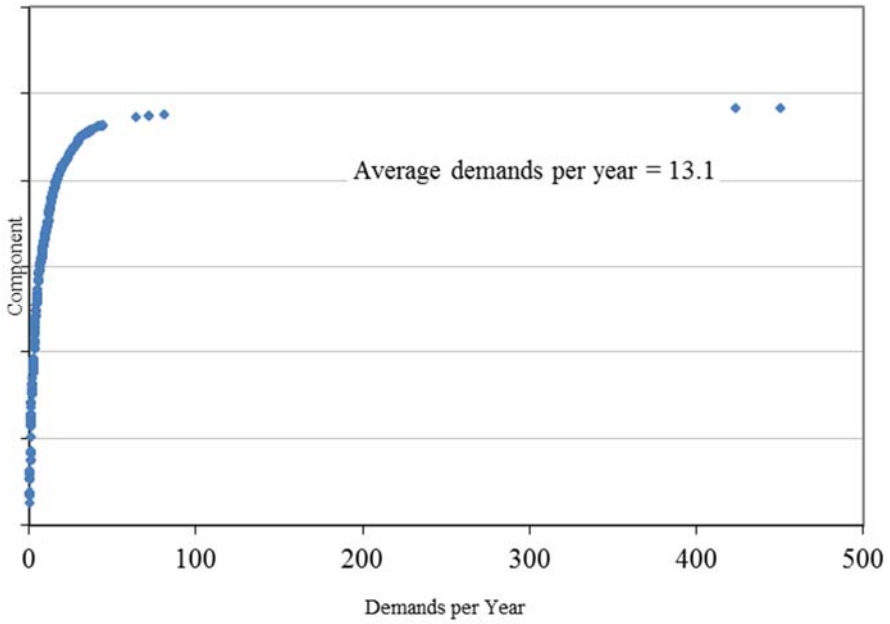

Figure 2-1b. Running/alternating MDP demands per year distribution.

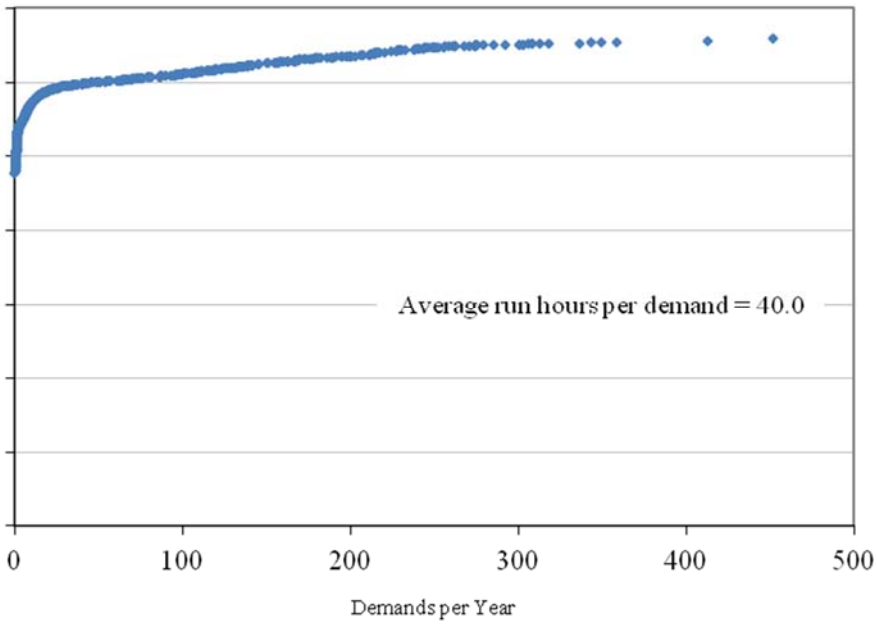

Figure 2-2a. Standby MDP run hours per demand distribution.

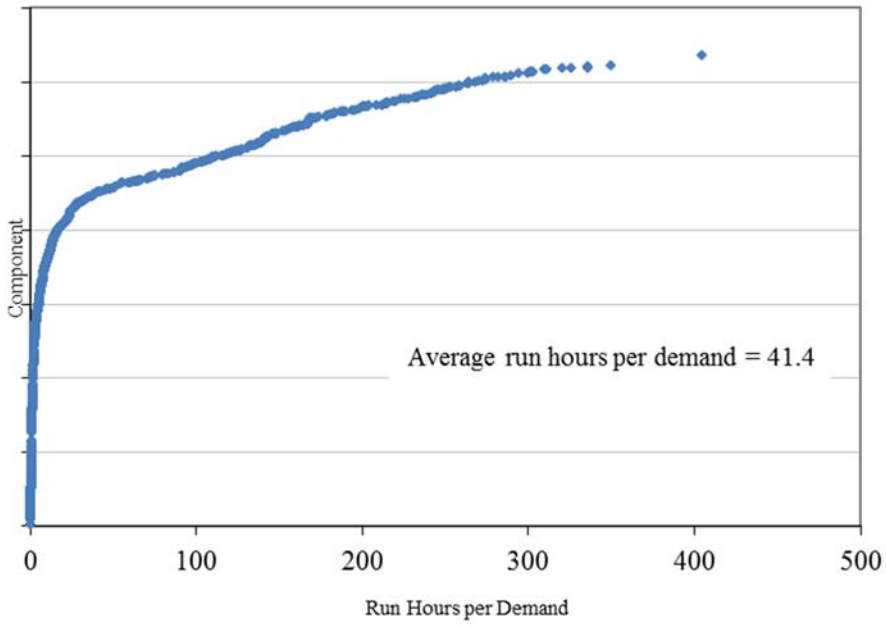

Figure 2-2b. Running/alternating MDP run hours per demand distribution.

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	1.59E-04	6.78E-04	7.94E-04	1.83E-03	Beta	2.21	2.78E+03
Standby	FTR<1H	EB/PL/KS	3.94E-06	7.86E-05	1.22E-04	3.89E-04	Gamma	0.84	6.91E+03
Standby	FTR>1H	EB/PL/KS	1.35E-07	6.28E-06	1.15E-05	4.07E-05	Gamma	0.63	5.49E+04
-	ELS	EB/PL/KS	9.46E-09	1.87E-07	2.91E-07	9.22E-07	Gamma	0.85	2.92E+06
-	ELL	EB/PL/KS	2.18E-12	4.97E-09	2.04E-08	9.32E-08	Gamma	0.30	1.47E+07
Normally Running	FTS	EB/PL/KS	2.61E-04	9.52E-04	1.08E-03	2.37E-03	Beta	2.62	2.41E+03
Normally Running	FTR	EB/PL/KS	1.15E-06	3.43E-06	3.79E-06	7.68E-06	Gamma	3.42	9.01E+05
CCW	FTS	EB/PL/KS	5.86E-05	6.32E-04	8.78E-04	2.52E-03	Beta	1.12	1.28E+03
CCW	FTR	EB/PL/KS	2.87E-07	2.13E-06	2.76E-06	7.33E-06	Gamma	1.40	5.09E+05
SWS	FTS	EB/PL/KS	5.67E-05	5.56E-04	7.55E-04	2.14E-03	Beta	1.18	1.56E+03
SWS	FTS	EB/PL/KS	6.20E-05	6.17E-04	8.41E-04	2.38E-03	Beta	1.17	1.39E+03
SWS	FTR	EB/PL/KS	4.14E-07	4.70E-06	6.56E-06	1.91E-05	Gamma	1.09	1.66E+05
SWS	FTR	JNID/IL	3.43E-08	1.30E-07	1.50E-07	3.31E-07	Gamma	2.50	1.67E+07
NSW	FTR	EB/PL/KS	4.34E-07	4.85E-06	6.72E-06	1.96E-05	Gamma	1.10	1.63E+05
SWS-NE	FTS	EB/PL/KS	6.39E-05	6.18E-04	8.36E-04	2.36E-03	Beta	1.19	1.42E+03
SWS-NE	FTR	EB/PL/KS	8.93E-07	4.69E-06	5.67E-06	1.39E-05	Gamma	1.82	3.20E+05
CSW	FTR	JNID/IL	4.88E-06	6.90E-06	6.98E-06	9.41E-06	Gamma	25.50	3.65E+06

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 ICES database, covering 1998–2015. 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)	10	43	53
Normally Running Total		**10**	**43**	**53**
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		**10**	**176**	**186**

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	146	26,557 d	133	98	54.9%	60.2%
Standby	FTR<1H	61	18,025 h	133	98	31.6%	38.8%
Standby	FTR>1H	23	11,204 h	133	98	16.5%	22.4%
Normally Running	FTS	12	1,395 d	43	20	20.9%	40.0%
Normally Running	FTR	62	5,984,882 h	43	20	60.5%	85.0%
-	ELS	15	28,788,990 h	186	102	5.9%	10.8%
-	ELL	15	28,788,990 h	186	102	5.9%	10.8%

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
AFW	FTS	72	18,053 d	74	65	41.9%	47.7%
AFW	FTR<1H	40	12,075 h	74	65	32.4%	36.9%
AFW	FTR>1H	13	9,282 h	74	65	17.6%	20.0%
HCI-RCI	FTS	41	4,929 d	31	31	71.0%	71.0%
HCI-RCI	FTR<1H	21	5,949 h	59	33	30.5%	42.4%
HCI-RCI	FTR>1H	10	1,922 h	59	33	15.3%	27.3%
MFW	FTS	62	5,984,882 d	43	20	60.5%	85.0%
MFW	FTR	62	5,984,882 h	43	20	60.5%	85.0%

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.

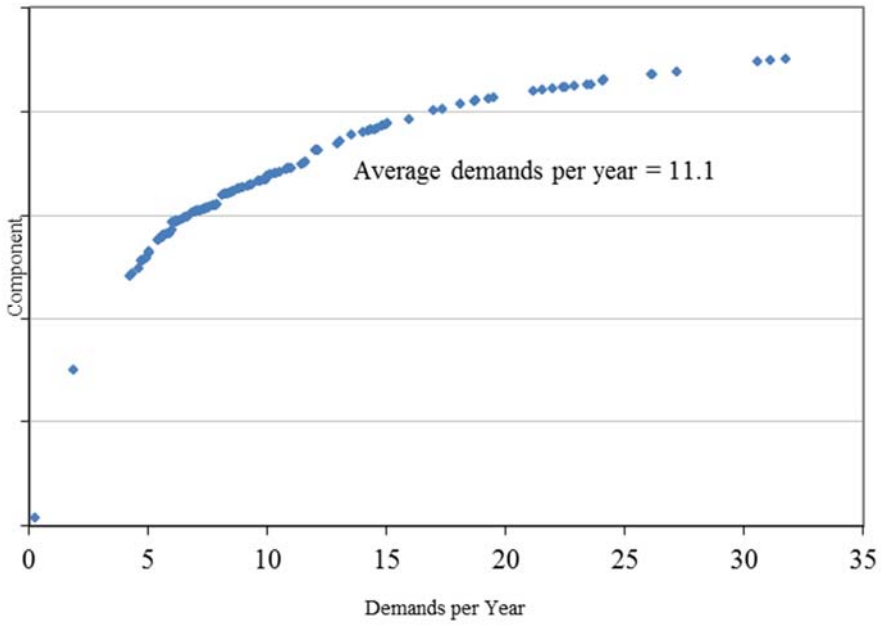

Figure 2-3a. Standby TDP demands per year distribution.

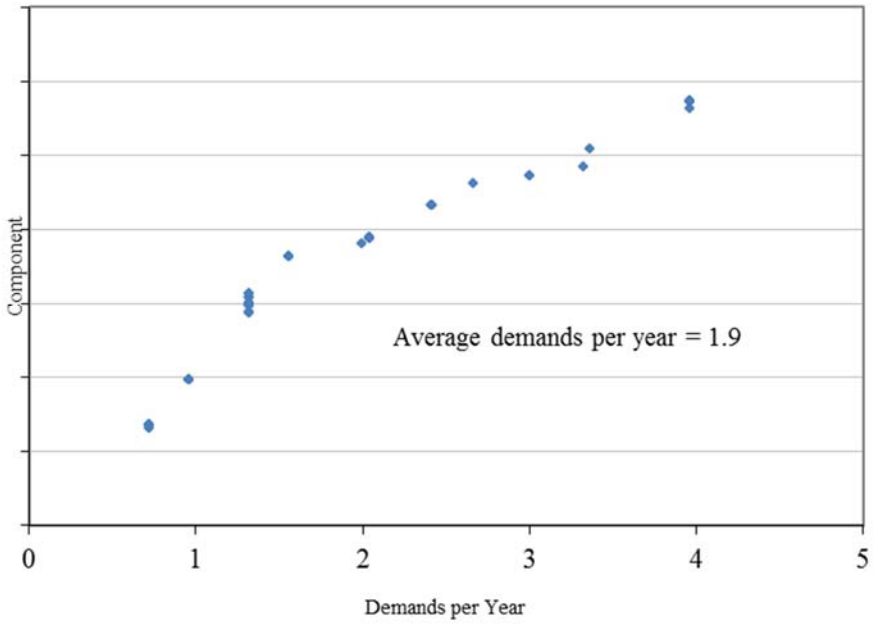

Figure 2-3b. Running/alternating TDP demands per year distribution.

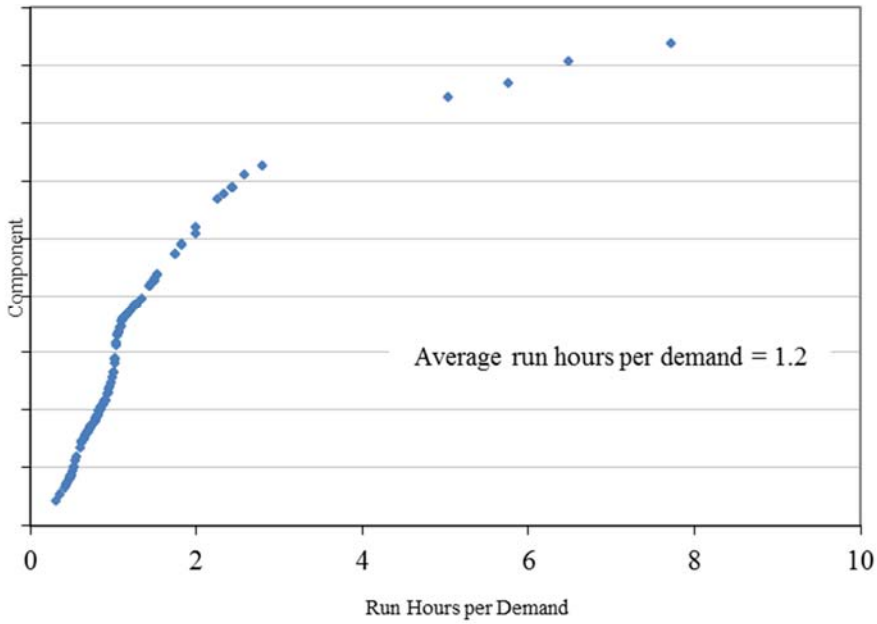

Figure 2-4a. Standby TDP run hours per demand distribution.

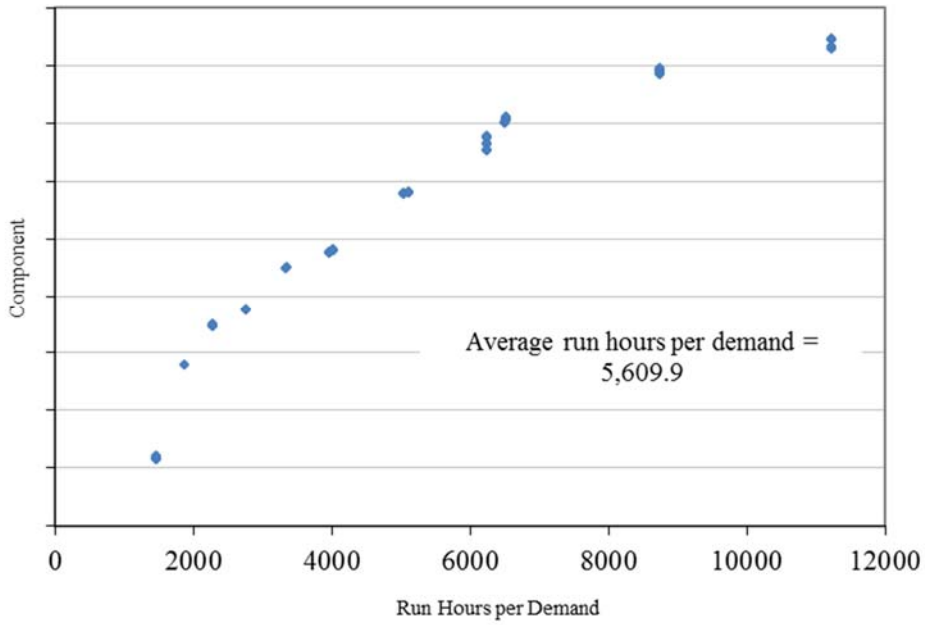

Figure 2-4b. Running/alternating TDP run hours per demand distribution.

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	4.70E-04	4.47E-03	6.01E-03	1.69E-02	Beta	1.20	1.98E+02
Standby	FTR<1H	EB/PL/KS	1.34E-04	2.43E-03	3.70E-03	1.16E-02	Gamma	0.88	2.37E+02
Standby	FTR>1H	JNID/IL	1.44E-03	2.07E-03	2.10E-03	2.86E-03	Gamma	23.50	1.12E+04
Normally Running	FTS	EB/PL/KS	4.04E-04	6.25E-03	9.17E-03	2.81E-02	Beta	0.94	1.01E+02
Normally Running	FTR	EB/PL/KS	1.43E-06	8.73E-06	1.09E-05	2.77E-05	Gamma	1.61	1.48E+05
-	ELS	JNID/IL	3.35E-07	5.27E-07	5.38E-07	7.81E-07	Gamma	15.50	2.88E+07
-	ELL	JNID/IL	4.03E-12	9.18E-09	3.77E-08	1.72E-07	Gamma	0.30	7.97E+06
AFW	FTS	EB/PL/KS	9.44E-05	2.62E-03	4.33E-03	1.43E-02	Beta	0.75	1.72E+02
AFW	FTR<1H	EB/PL/KS	9.03E-05	2.26E-03	3.67E-03	1.20E-02	Gamma	0.77	2.11E+02
AFW	FTR>1H	JNID/IL	8.70E-04	1.42E-03	1.45E-03	2.16E-03	Gamma	13.50	9.28E+03
HCI-RCI	FTS	EB/PL/KS	2.52E-03	7.90E-03	8.78E-03	1.81E-02	Beta	3.16	3.56E+02
HCI-RCI	FTR<1H	EB/PL/KS	2.36E-04	2.68E-03	3.75E-03	1.09E-02	Gamma	1.09	2.91E+02
HCI-RCI	FTR>1H	EB/PL/KS	1.04E-03	4.67E-03	5.52E-03	1.29E-02	Gamma	2.10	3.81E+02
MFW	FTS	EB/PL/KS	1.43E-06	8.73E-06	1.09E-05	2.77E-05	Gamma	1.61	1.48E+05
MFW	FTR	EB/PL/KS	1.43E-06	8.73E-06	1.09E-05	2.77E-05	Gamma	1.61	1.48E+05

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 ICES database, covering 1998–2015. 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)	23	6	29
	Fuel Oil Transfer (FOT)	2		2
	Standby service water (SWS)	3		3
Normally Running Total		**29**	**6**	**35**
Standby	Auxiliary feedwater (AFW)		5	5
	Emergency power supply (EPS)		1	1
	Firewater (FWS)		21	21
	Standby service water (SWS)		10	10
Standby Total			**37**	**37**
Grand Total		**29**	**43**	**72**

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
-	FTS	26	17,987 d	37	24	37.8%	50.0%
-	FTR<1H	10	10,716 h	37	24	18.9%	29.2%
-	FTR>1H	11	5,820 h	37	24	21.6%	29.2%
-	ELS	8	9,129,089 h	69	40	11.6%	17.5%
-	ELL	8	9,129,089 h	69	40	11.6%	17.5%
AFW	FTS	3	1,274 d	5	5	40.0%	40.0%

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
AFW	FTR<1H	4	739 h	5	5	60.0%	60.0%
AFW	FTR>1H	2	262 h	5	5	40.0%	40.0%

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.

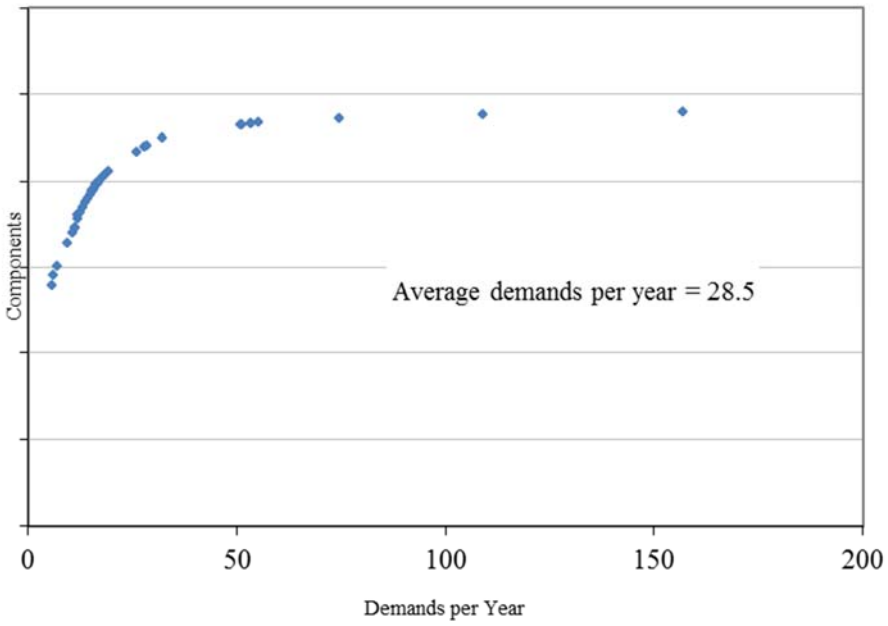

Figure 2-5. Standby EDP demands per year distribution.

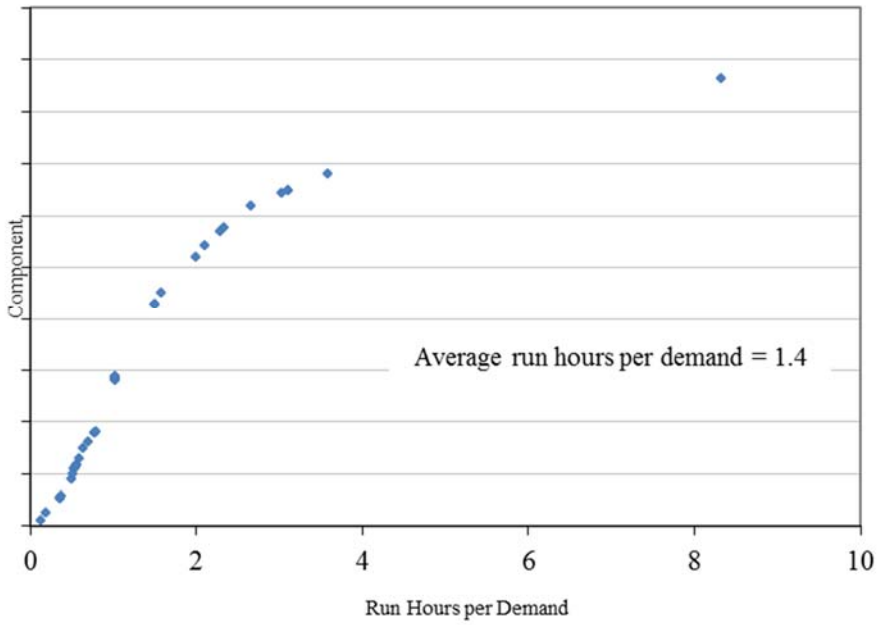

Figure 2-6. Standby EDP run hours per demand distribution.

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
-	FTS	EB/PL/KS	2.52E-05	1.19E-03	2.17E-03	7.68E-03	Beta	0.63	2.89E+02
-	FTR<1H	JNID/IL	5.42E-04	9.50E-04	9.80E-04	1.53E-03	Gamma	10.50	1.07E+04
-	FTR>1H	JNID/IL	1.12E-03	1.92E-03	1.98E-03	3.02E-03	Gamma	11.50	5.82E+03
-	ELS	EB/PL/KS	5.15E-08	6.42E-07	9.12E-07	2.70E-06	Gamma	1.04	1.14E+06
-	ELL	EB/PL/KS	6.83E-12	1.56E-08	6.38E-08	2.92E-07	Gamma	0.30	4.70E+06
AFW	FTS	JNID/IL	8.52E-04	2.49E-03	2.74E-03	5.52E-03	Beta	3.50	1.27E+03
AFW	FTR<1H	JNID/IL	2.25E-03	5.64E-03	6.09E-03	1.14E-02	Gamma	4.50	7.39E+02
AFW	FTR>1H	JNID/IL	2.19E-03	8.30E-03	9.53E-03	2.11E-02	Gamma	2.50	2.62E+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 ICES database, covering 1998–2015. 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)	26	63	89
	Containment spray recirculation (CSR)	6		6
	Emergency power supply (EPS)	3		3
	Fuel Oil Transfer (FOT)	3		3
	Instrument air (IAS)	1		1
	Standby liquid control (SLC)	1		1
Normally Running Total		**40**	**63**	**103**
Standby	Emergency power supply (EPS)		2	2
	Standby liquid control (SLC)		70	70
Standby Total			**72**	**72**
Grand Total		**40**	**135**	**175**

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
Normally Running	FTS	78	35,863 d	63	26	63.5%	73.1%
Normally Running	FTR	71	2,905,081 h	60	25	53.3%	64.0%
Standby	FTS	16	10,798 d	72	34	19.4%	38.2%

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTR<1H	2	4,699 h	72	34	2.8%	5.9%
Standby	FTR>1H	2	1,709 h	72	34	2.8%	5.9%
-	ELS	28	26,271,740 h	175	74	10.9%	18.9%
-	ELL	28	26,271,740 h	175	74	10.9%	18.9%

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.

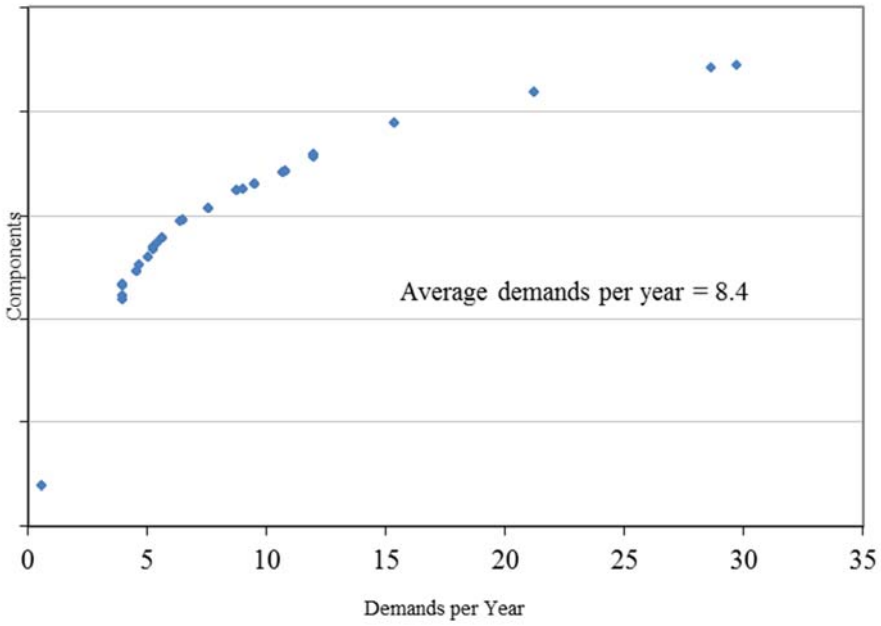

Figure 2-7a. Standby PDP demands per year distribution.

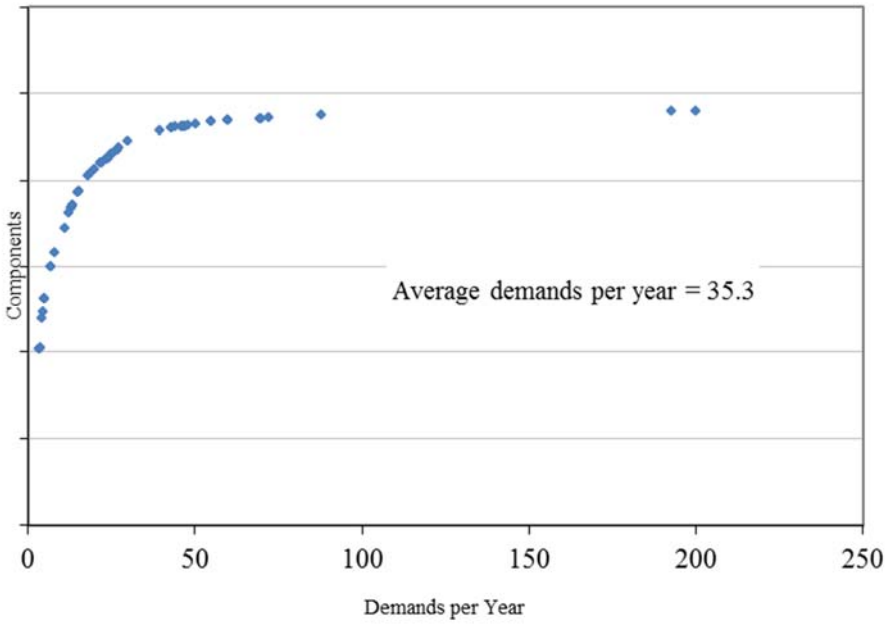

Figure 2-7b. Running/alternating PDP demands per year distribution.

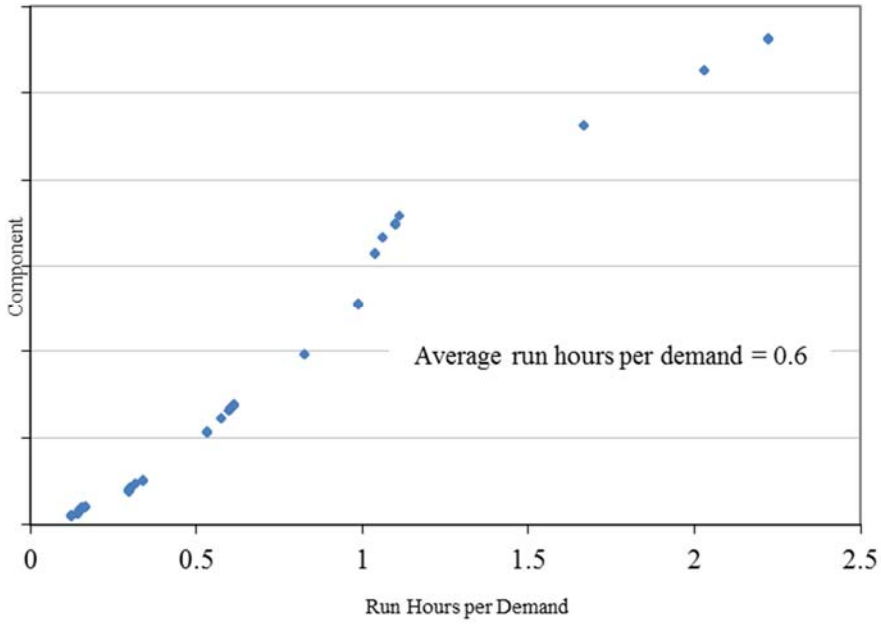

Figure 2-8a. Standby PDP run hours per demand distribution.

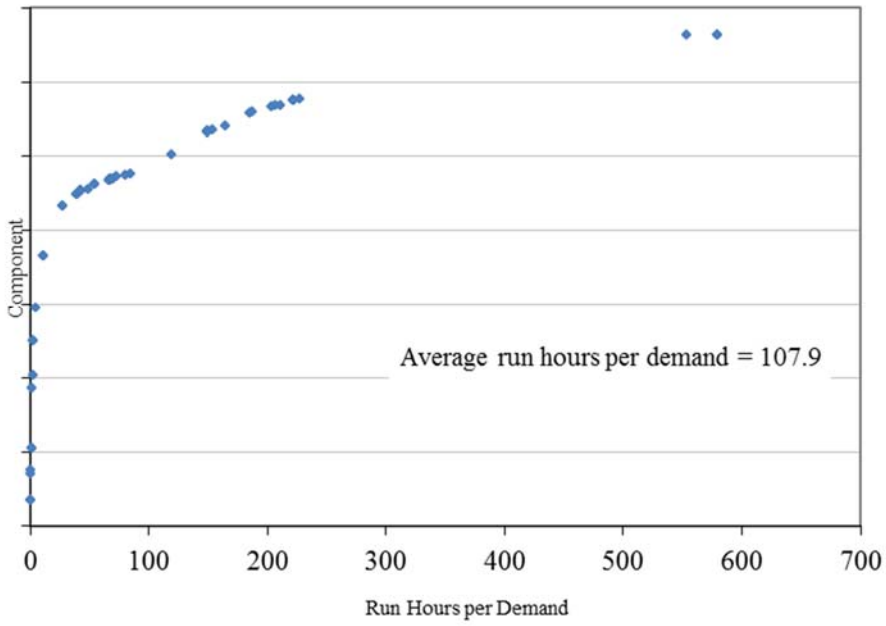

Figure 2-8b. Running/alternating PDP run hours per demand distribution.

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
Normally Running	FTS	EB/PL/KS	3.63E-04	2.13E-03	2.63E-03	6.63E-03	Beta	1.66	6.28E+02
Normally Running	FTR	EB/PL/KS	1.43E-06	2.49E-05	3.77E-05	1.17E-04	Gamma	0.89	2.37E+04
Standby	FTS	JNID/IL	9.65E-04	1.49E-03	1.53E-03	2.19E-03	Beta	16.50	1.08E+04
Standby	FTR<1H	JNID/IL	1.22E-04	4.63E-04	5.32E-04	1.18E-03	Gamma	2.50	4.70E+03
Standby	FTR>1H	JNID/IL	3.35E-04	1.27E-03	1.46E-03	3.24E-03	Gamma	2.50	1.71E+03
-	ELS	JNID/IL	7.73E-07	1.07E-06	1.08E-06	1.44E-06	Gamma	28.50	2.63E+07
-	ELL	JNID/IL	8.09E-12	1.84E-08	7.56E-08	3.46E-07	Gamma	0.30	3.97E+06

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 ICES database, covering 1998–2015. 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)		207	207
Standby Total			**207**	**207**
Grand Total		**1**	**207**	**208**

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
Standby	FTR	25	158,885 h	207	69	12.1%	34.8%

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
Standby	FTR	JNID/IL	1.12E-04	1.58E-04	1.60E-04	2.16E-04	Gamma	25.50	1.59E+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)	1	3	4
	Plant ac power (ACP)	2		2
CTG Total		**3**	**3**	**6**
EDG	Emergency power supply (EPS)	4	232	236
	Plant ac power (ACP)	1		1
EDG Total		**5**	**232**	**237**
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)	6	2	8
	Plant ac power (ACP)	14	2	16
SBO Total		**20**	**4**	**24**
Grand Total		**28**	**249**	**277**

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 ICES database, covering 1998–2015. 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
EDG	FTS	214	75,451 d	232	95	55.2%	86.3%
EDG	FTLR	239	65,993 h	232	95	60.8%	82.1%
EDG	FTR	184	133,975 h	232	95	51.7%	77.9%

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.

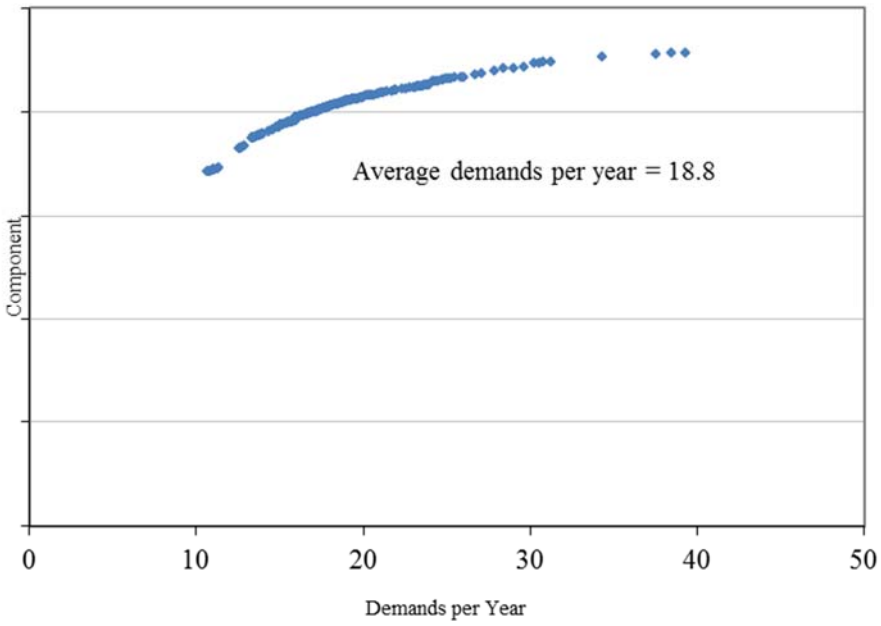

Figure 3-1. EDG demands per year distribution.

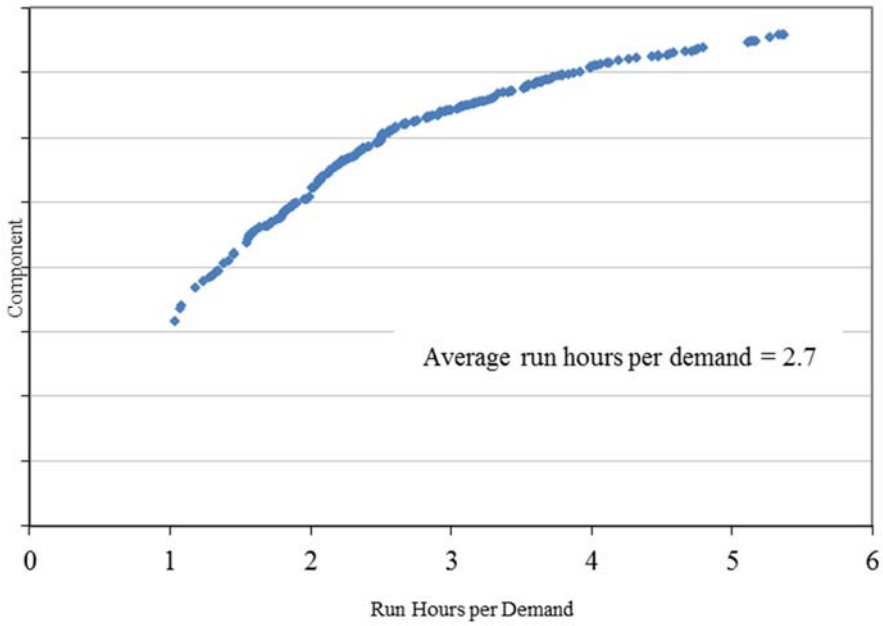

Figure 3-2. EDG run hours per demand distribution.

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
EDG	FTS	EB/PL/KS	1.52E-03	2.78E-03	2.88E-03	4.60E-03	Beta	9.19	3.18E+03
EDG	FTLR	EB/PL/KS	1.14E-03	3.37E-03	3.72E-03	7.49E-03	Gamma	3.47	9.33E+02
EDG	FTR	EB/PL/KS	3.53E-04	1.33E-03	1.52E-03	3.36E-03	Gamma	2.53	1.66E+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 ICES database, covering 1998–2015. 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
HTG	FTS	11	7,270 d	2	1	100.0%	100.0%
HTG	FTLR	7	4,629 h	2	1	50.0%	100.0%
HTG	FTR	1	10,678 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
HTG	FTS	JNID/IL	9.00E-04	1.54E-03	1.58E-03	2.42E-03	Beta	11.50	7.26E+03
HTG	FTLR	JNID/IL	7.84E-04	1.55E-03	1.62E-03	2.70E-03	Gamma	7.50	4.63E+03
HTG	FTR	JNID/IL	1.64E-05	1.11E-04	1.40E-04	3.65E-04	Gamma	1.50	1.07E+04

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 ICES database, covering 1998–2015. 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
CTG	FTS	18	503 d	3	3	100.0%	100.0%
CTG	FTLR	2	432 d	2	2	100.0%	100.0%
CTG	FTR	5	648 h	2	2	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
CTG	FTS	EB/PL/KS	2.98E-03	3.73E-02	5.12E-02	1.48E-01	Beta	1.03	1.90E+01
CTG	FTLR	JNID/IL	1.33E-03	5.04E-03	5.79E-03	1.28E-02	Gamma	2.50	4.32E+02
CTG	FTR	JNID/IL	3.53E-03	7.98E-03	8.49E-03	1.52E-02	Gamma	5.50	6.48E+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 ICES database, covering 1998–2015.

The systems included in the HPCS data collection are listed in **Error! Reference source not found.** 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
HCS	FTS	2	2,653 d	8	8	25.0%	25.0%
HCS	FTR	4	3,948 h	8	8	37.5%	37.5%

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
HCS	FTS	JNID/IL	2.16E-04	8.20E-04	9.42E-04	2.09E-03	Beta	2.50	2.65E+03
HCS	FTR	JNID/IL	4.21E-04	1.06E-03	1.14E-03	2.14E-03	Gamma	4.50	3.95E+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 ICES database, covering 1998–2015.

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
SBO	FTS	12	419 d	4	4	50.0%	50.0%
SBO	FTR	2	1,667 h	4	4	50.0%	50.0%

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
SBO	FTS	JNID/IL	1.75E-02	2.90E-02	2.98E-02	4.45E-02	Beta	12.50	4.08E+02
SBO	FTR	JNID/IL	3.43E-04	1.30E-03	1.50E-03	3.31E-03	Gamma	2.50	1.67E+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 ICES database, covering 1998–2015 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)	118	440	558
	Grand Total	**118**	**440**	**558**

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
-	FTO	23	9,719 d	440	33	3.6%	27.3%
-	FTC	8	9,719 d	440	33	1.8%	21.2%
-	FC	0	72,220,220 h	558	34	0.0%	0.0%
-	SOP	9	72,220,220 h	558	34	1.6%	23.5%

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
-	SOP	9	72,220,220 h	558	34	1.6%	23.5%
-	ILS	25	72,220,220 h	558	34	4.1%	38.2%
-	ILL	25	72,220,220 h	558	34	4.1%	38.2%
-	ELS	0	72,220,220 h	558	34	0.0%	0.0%

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

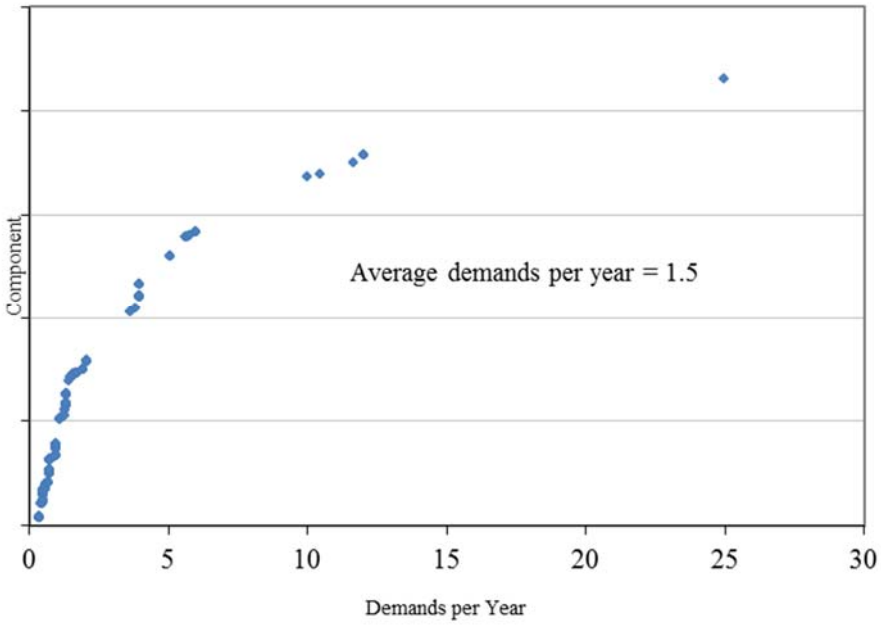

Figure 4-1. SRV demands per year distribution.

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
-	FTO	JNID/IL	1.66E-03	2.38E-03	2.42E-03	3.29E-03	Beta	23.50	9.70E+03
-	FTC	EB/PL/KS	9.42E-05	6.85E-04	8.86E-04	2.34E-03	Beta	1.42	1.61E+03
-	FC	JNID/IL	2.72E-11	3.15E-09	6.92E-09	2.66E-08	Gamma	0.50	7.22E+07
-	SOP	EB/PL/KS	6.03E-09	9.44E-08	1.40E-07	4.29E-07	Gamma	0.94	6.68E+06
-	ILS	EB/PL/KS	1.16E-09	1.76E-07	4.09E-07	1.61E-06	Gamma	0.47	1.15E+06
-	ILL	EB/PL/KS	8.76E-13	1.99E-09	8.18E-09	3.74E-08	Gamma	0.30	3.67E+07
-	ELS	JNID/IL	2.72E-11	3.15E-09	6.92E-09	2.66E-08	Gamma	0.50	7.22E+07

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
-	ELL	JNID/IL	5.18E-14	1.18E-10	4.84E-10	2.22E-09	Gamma	0.30	6.19E+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 ICES database, covering 1998–2015 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
BWR	Main steam (MSS)	22	43	65
PWR	Main steam (MSS)	375	762	1137
	Reactor coolant (RCS)	69	155	224
	Grand Total	**466**	**960**	**1426**

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
-	FTO	5	23,800 d	960	66	0.5%	6.1%
-	FTC	3	23,800 d	960	66	0.3%	3.0%
-	SOP	11	211,426,600 h	1426	79	0.8%	7.6%
-	ILS	14	211,426,600 h	1426	79	1.0%	13.9%
-	ILL	14	211,426,600 h	1426	79	1.0%	13.9%
-	ELS	2	211,426,600 h	1426	79	0.1%	2.5%
-	ELL	2	211,426,600 h	1426	79	0.1%	2.5%
PWR MSS	FTO	4	20,242 d	762	46	0.5%	6.5%
PWR MSS	FTC	2	20,242 d	762	46	0.3%	2.2%
PWR MSS	SOP	8	172,245,500 h	1137	66	0.7%	4.5%
PWR RCS	FTO	1	2,906 d	155	48	0.6%	2.1%
PWR RCS	FTC	1	2,906 d	155	48	0.6%	2.1%
PWR RCS	SOP	3	29,547,930 h	224	69	1.3%	4.3%

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

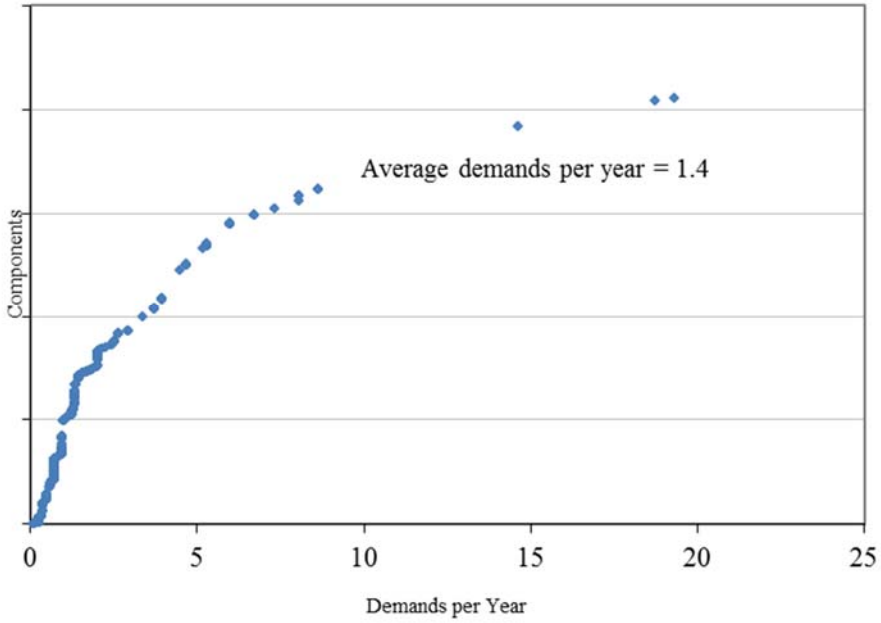

Figure 4-2. SVV demands per year distribution.

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
-	FTO	EB/PL/KS	4.04E-07	8.73E-05	2.18E-04	8.77E-04	Beta	0.44	2.01E+03
-	FTC	JNID/IL	4.55E-05	1.33E-04	1.47E-04	2.95E-04	Beta	3.50	2.38E+04
-	SOP	JNID/IL	3.10E-08	5.29E-08	5.44E-08	8.33E-08	Gamma	11.50	2.11E+08
-	ILS	JNID/IL	4.20E-08	6.71E-08	6.86E-08	1.01E-07	Gamma	14.50	2.11E+08
-	ILL	JNID/IL	1.47E-13	3.34E-10	1.37E-09	6.28E-09	Gamma	0.30	2.19E+08
-	ELS	JNID/IL	2.71E-09	1.03E-08	1.18E-08	2.62E-08	Gamma	2.50	2.11E+08
-	ELL	JNID/IL	8.84E-14	2.01E-10	8.26E-10	3.78E-09	Gamma	0.30	3.63E+08
PWR MSS	FTO	JNID/IL	8.23E-05	2.06E-04	2.22E-04	4.19E-04	Beta	4.50	2.02E+04
PWR MSS	FTC	JNID/IL	2.84E-05	1.08E-04	1.23E-04	2.74E-04	Beta	2.50	2.02E+04
PWR MSS	SOP	JNID/IL	2.52E-08	4.75E-08	4.93E-08	8.02E-08	Gamma	8.50	1.72E+08
PWR RCS	FTO	JNID/IL	6.04E-05	4.06E-04	5.16E-04	1.34E-03	Beta	1.50	2.91E+03
PWR RCS	FTC	JNID/IL	6.04E-05	4.06E-04	5.16E-04	1.34E-03	Beta	1.50	2.91E+03
PWR RCS	SOP	JNID/IL	3.67E-08	1.08E-07	1.18E-07	2.38E-07	Gamma	3.50	2.95E+07

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 ICES database, covering 1998–2015 using RADS. The systems included in the PORV data collection are listed in Table 4-9 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 ≤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)	206	111	317
	Reactor coolant (RCS)	17	114	131
	Grand Total	**223**	**225**	**448**

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
PPR	FTO	16	6,129 d	114	54	11.4%	22.2%
PPR	FTC	4	6,129 d	114	54	3.5%	7.4%
RCS	FTC	16	6,129 d	114	54	11.4%	22.2%
MSS	FTO	19	10,401 d	111	36	14.4%	30.6%
MSS	FTO	42	10,401 d	111	36	29.7%	55.6%
MSS	FTC	19	10,401 d	111	36	14.4%	30.6%
MSS	FC	42	10,401 d	111	36	29.7%	55.6%
MSS	FC	13	49,398,360 d	317	64	3.5%	14.1%
-	FC	13	49,398,360 d	317	64	3.5%	14.1%
-	SOP	24	69,470,980 h	448	70	4.7%	22.9%
-	ILS	18	69,470,980 h	448	70	3.6%	17.1%
-	ILL	18	69,470,980 h	448	70	3.6%	17.1%
-	ELS	0	69,470,980 h	448	70	0.0%	0.0%
-	ELL	0	69,470,980 h	448	70	0.0%	0.0%

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

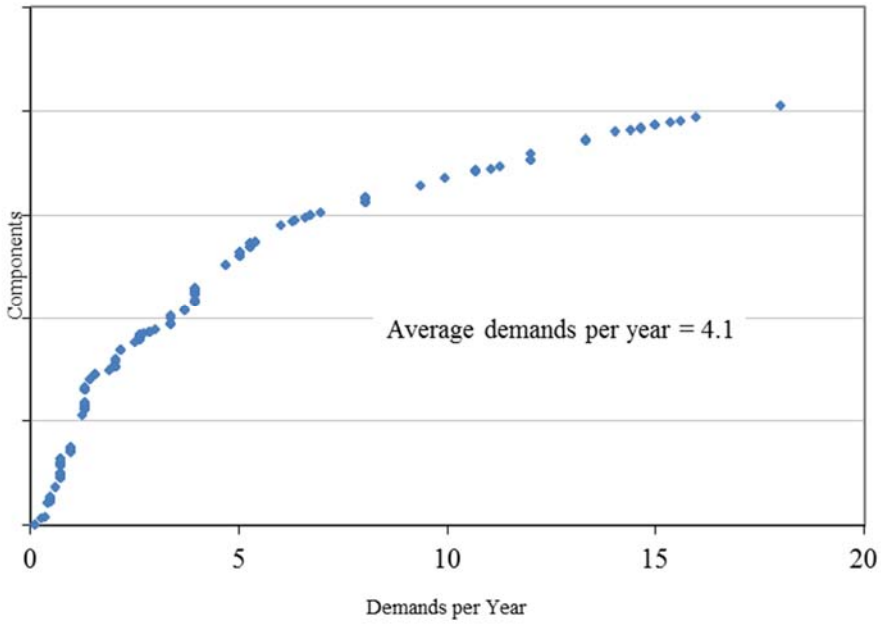

Figure 4-3. PORV demands per year distribution.

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
PPR	FTO	EB/PL/KS	2.05E-05	1.60E-03	3.24E-03	1.20E-02	Beta	0.55	1.70E+02
PPR	FTC	JNID/IL	2.71E-04	6.80E-04	7.34E-04	1.38E-03	Beta	4.50	6.13E+03
RCS	FTC	EB/PL/KS	2.05E-05	1.60E-03	3.24E-03	1.20E-02	Beta	0.55	1.70E+02
MSS	FTO	EB/PL/KS	8.60E-06	1.00E-03	2.21E-03	8.46E-03	Beta	0.50	2.26E+02
MSS	FTO	EB/PL/KS	4.08E-04	3.67E-03	4.91E-03	1.36E-02	Beta	1.24	2.52E+02
MSS	FTC	EB/PL/KS	8.60E-06	1.00E-03	2.21E-03	8.46E-03	Beta	0.50	2.26E+02
MSS	FC	EB/PL/KS	4.91E-10	1.04E-07	2.57E-07	1.03E-06	Gamma	0.44	1.71E+06
MSS	FC	EB/PL/KS	4.08E-04	3.67E-03	4.91E-03	1.36E-02	Beta	1.24	2.52E+02
-	FC	EB/PL/KS	4.91E-10	1.04E-07	2.57E-07	1.03E-06	Gamma	0.44	1.71E+06
-	SOP	JNID/IL	2.44E-07	3.48E-07	3.53E-07	4.77E-07	Gamma	24.50	6.95E+07
-	ILS	JNID/IL	1.73E-07	2.61E-07	2.66E-07	3.75E-07	Gamma	18.50	6.95E+07
-	ILL	JNID/IL	5.69E-13	1.30E-09	5.32E-09	2.43E-08	Gamma	0.30	5.64E+07
-	ELS	JNID/IL	2.83E-11	3.27E-09	7.20E-09	2.76E-08	Gamma	0.50	6.95E+07
-	ELL	JNID/IL	5.39E-14	1.23E-10	5.04E-10	2.31E-09	Gamma	0.30	5.95E+08
Liquid [a]	FTC	JNID/IL	6.45E-05	2.46E-02	6.25E-02	2.54E-01	Beta	0.39	5.90E+00
Stick	FTC	JNID/IL	2.61E-04	1.23E-03	1.46E-03	3.46E-03	Beta	2.01	1.37E+03
Open [a] LOOP [b]	SO	Point Estimate	-	-	1.48E-01	-		-	-
Transient [b]	SO	Point Estimate	-	-	3.55E-02	-		-	-

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 ICES database, covering 1998–2015 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
	Component cooling water (CCW)	21	1	22
	Containment spray recirculation (CSR)	3		3
	High pressure coolant injection (HCI)	1		1
	High pressure injection (HPI)	4		4
	Low pressure core spray (LCS)		2	2
	Main feedwater (MFW)	1		1
	Normally operating service water (SWN)	10		10
	Reactor core isolation (RCI)	1		1
	Standby liquid control (SLC)	4	3	7
	Standby service water (SWS)	5		5
	Generic water system for relief valves (WAT)	1		1
	Residual Heat Removal (LCI in BWRs; LPI in PWRs) (RHR)	17	6	23
	Grand Total	**69**	**12**	**81**

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
-	FTO	5	77 d	12	6	41.7%	50.0%
-	FTC	0	77 d	12	6	0.0%	0.0%
-	SO	0	9,633,048 h	81	31	0.0%	0.0%
-	ILS	11	9,633,048 h	81	31	13.6%	29.0%
-	ILL	11	9,633,048 h	81	31	13.6%	29.0%
-	ELS	2	9,633,048 h	81	31	2.5%	6.5%
-	ELL	2	9,633,048 h	81	31	2.5%	6.5%

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

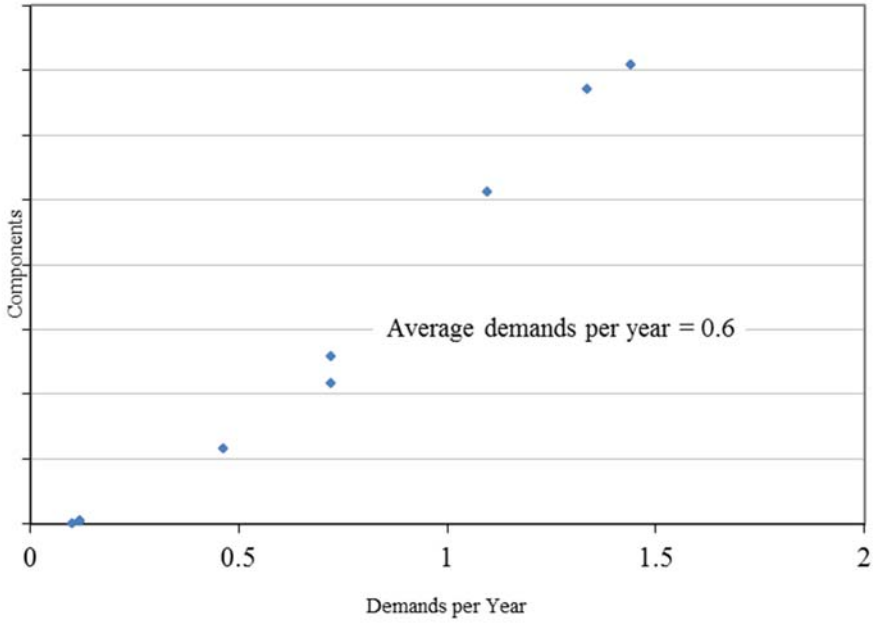

Figure 4-4. RVL demands per year distribution.

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
-	FTO	EB/PL/KS	1.67E-04	4.78E-02	1.07E-01	4.14E-01	Beta	0.41	3.45E+00
-	FTC	JNID/IL	2.52E-05	2.91E-03	6.34E-03	2.43E-02	Beta	0.50	7.84E+01
-	SO	JNID/IL	2.04E-10	2.36E-08	5.19E-08	1.99E-07	Gamma	0.50	9.63E+06
-	ILS	JNID/IL	6.80E-07	1.16E-06	1.19E-06	1.83E-06	Gamma	11.50	9.63E+06
-	ILL	JNID/IL	2.55E-12	5.80E-09	2.38E-08	1.09E-07	Gamma	0.30	1.26E+07
-	ELS	JNID/IL	5.95E-08	2.26E-07	2.60E-07	5.75E-07	Gamma	2.50	9.63E+06
-	ELL	JNID/IL	1.95E-12	4.44E-09	1.82E-08	8.33E-08	Gamma	0.30	1.65E+07

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 ICES database, covering 1998–2015. 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)	758	2	760
	Emergency power supply (EPS)	8		8
	High pressure core spray (HCS)	1		1
	Main steam (MSS)	2		2
	Offsite electrical power (OEP)	4		4
	Plant ac power (ACP)	9		9
	Uninterruptable instrument power supply (UPS)	7		7
	Grand Total	**789**	**2**	**791**

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
-	FTOP	294	120,676,300 h	790	100	25.8%	76.0%

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
-	FTOP	EB/PL/KS	2.67E-07	2.00E-06	2.59E-06	6.93E-06	Gamma	1.39	5.36E+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 ICES database, covering 1998–2015. 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)	408	1	409
	Uninterruptable instrument power supply (UPS)	6		6
	Grand Total	**414**	**1**	**415**

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
-	FTOP	23	63,157,740 h	415	99	5.5%	20.2%

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
-	FTOP	JNID/IL	2.55E-07	3.67E-07	3.72E-07	5.06E-07	Gamma	23.50	6.32E+07

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 ICES database, covering 1998–2015. 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
-	FF	4	3,976 d	27	7	14.8%	28.6%
-	SOP	0	5,048,822 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).

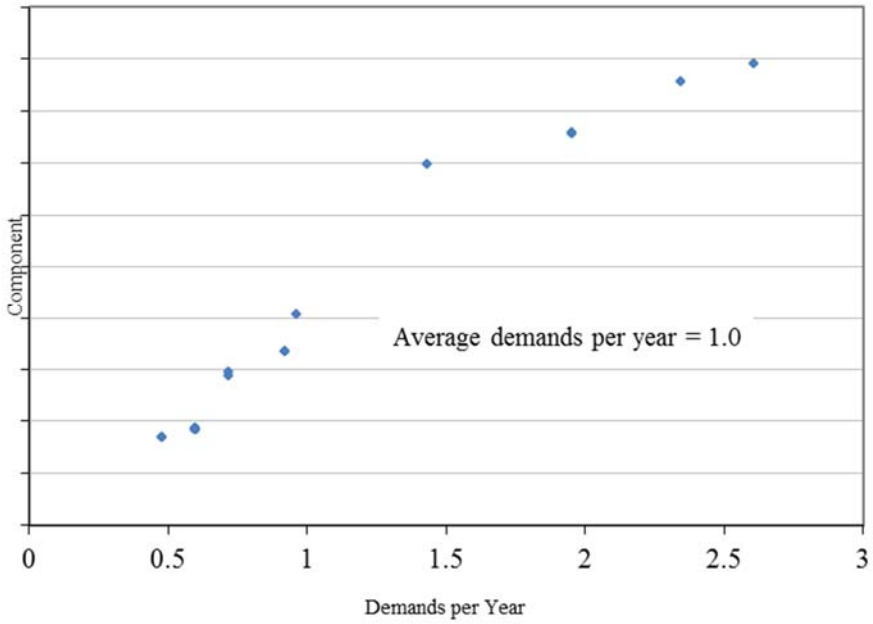

Figure 5-1. ABT demands per year distribution.

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
-	FF	JNID/IL	4.19E-04	1.05E-03	1.13E-03	2.13E-03	Beta	4.50	3.97E+03
-	SOP	JNID/IL	3.89E-10	4.50E-08	9.90E-08	3.80E-07	Gamma	0.50	5.05E+06

5.4 Circuit Breaker (CRB)

5.4.1 Component Description

The circuit breaker (CRB) 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 CRB are listed in Table 5-1.

5.4.2 Data Collection and Review

Data for CRB UR baselines were obtained from the ICES database, covering 1998–2015 using RADS. The systems included in the CRB 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. CRB systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
13.8	Plant ac power (ACP)	12	118	130
13.8 Total		**12**	**118**	**130**
250	dc power (DCP)	52	385	437
250 Total		**52**	**385**	**437**
480	dc power (DCP)	92	21	113
	Emergency power supply (EPS)	1	2	3
	Offsite electrical power (OEP)	1	12	13
	Plant ac power (ACP)	762	1741	2503
480 Total		**856**	**1776**	**2632**
4160	Plant ac power (ACP)	152	1093	1245
4160 Total		**152**	**1093**	**1245**
16Kv	Offsite electrical power (OEP)	30	108	138
	Plant ac power (ACP)	8	32	40
16Kv Total		**38**	**140**	**178**
DC	dc power (DCP)	50	195	245
	Plant ac power (ACP)	4	22	26
DC Total		**54**	**217**	**271**
Grand Total		**1164**	**3729**	**4893**

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

Table 5-12. CRB unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
-	FTO/C	154	141,621 d	3512	101	4.0%	59.4%
-	SOP	77	690,765,200 h	4609	101	1.6%	41.6%
HV (13.8 and 16 Kv)	FTO/C	21	11,066 d	258	39	7.0%	35.9%
HV (13.8 and 16 Kv)	SOP	17	43,105,710 h	298	50	5.7%	24.0%
MV (4160v and 6.9kV)	FTO/C	72	60,179 d	1093	84	5.9%	51.2%
MV (4160v and 6.9kV)	SOP	19	184,867,300 h	1245	89	1.4%	16.9%
LV (480v)	FTO/C	56	55,060 d	1776	80	2.9%	32.5%
LV (480v)	SOP	39	396,295,000 h	2629	85	1.4%	28.2%
DC	FTO/C	2	5,777 d	217	19	0.9%	10.5%
DC	SOP	1	42,345,960 h	271	31	0.4%	3.2%

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

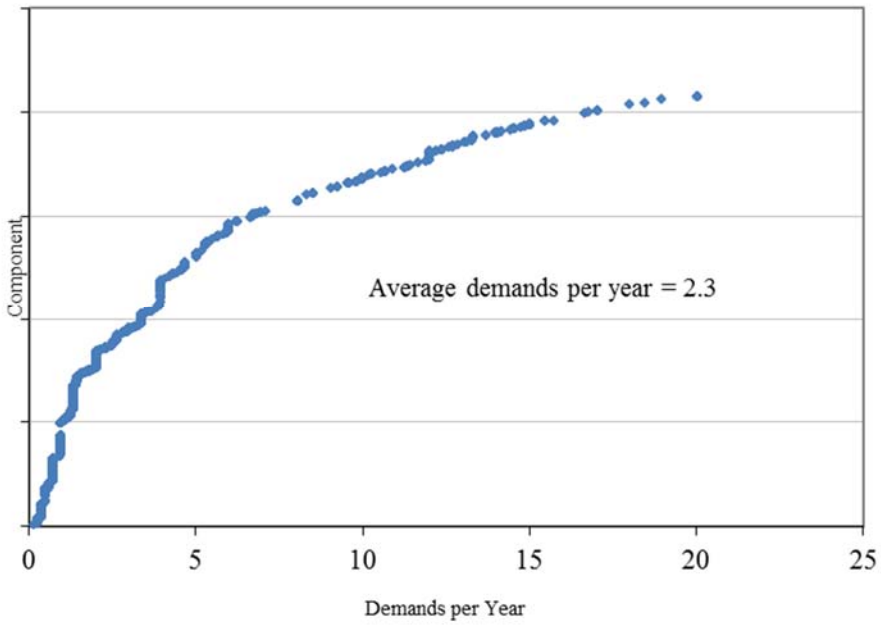

Figure 5-2. CRB demands per year distribution.

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 CRBs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
-	FTO/C	EB/PL/KS	4.77E-05	1.26E-03	2.07E-03	6.85E-03	Beta	0.76	3.65E+02
-	SOP	EB/PL/KS	2.06E-09	9.01E-08	1.63E-07	5.72E-07	Gamma	0.64	3.95E+06
HV (13.8 and 16 Kv)	FTO/C	EB/PL/KS	3.93E-05	1.59E-03	2.83E-03	9.84E-03	Beta	0.66	2.32E+02
HV (13.8 and 16 Kv)	SOP	EB/PL/KS	1.67E-09	2.15E-07	4.83E-07	1.87E-06	Gamma	0.49	1.01E+06
MV (4160v and 6.9kV)	FTO/C	EB/PL/KS	3.15E-05	1.38E-03	2.49E-03	8.72E-03	Beta	0.64	2.58E+02
MV (4160v and 6.9kV)	SOP	EB/PL/KS	2.80E-10	4.81E-08	1.15E-07	4.53E-07	Gamma	0.46	4.01E+06
LV (480v)	FTO/C	JNID/IL	8.13E-04	1.02E-03	1.03E-03	1.26E-03	Beta	56.50	5.50E+04
LV (480v)	SOP	JNID/IL	7.52E-08	9.89E-08	9.97E-08	1.27E-07	Gamma	39.50	3.96E+08
DC	FTO/C	JNID/IL	9.91E-05	3.76E-04	4.33E-04	9.57E-04	Beta	2.50	5.78E+03
DC	SOP	JNID/IL	4.16E-09	2.80E-08	3.54E-08	9.24E-08	Gamma	1.50	4.23E+07

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 ICES database, covering 1998–2015. 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	dc power (DCP)	15		15
	Plant ac power (ACP)	23		23
	Reactor protection (RPS)	18		18
	Uninterruptable instrument power supply (UPS)	154		154
	Grand Total	**210**		**210**

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
-	FTOP	92	30,051,790 h	210	37	27.6%	78.4%

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
-	FTOP	EB/PL/KS	3.40E-07	3.61E-06	4.97E-06	1.43E-05	Gamma	1.13	2.27E+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 ICES database, covering 1998–2015. 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)	1221	92	1313
DC	dc power (DCP)	56		56
	Grand Total	**1277**	**92**	**1369**

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	129	198,241,600 h	1352	85	8.4%	63.5%
DC	FTOP	0	2,305,320 h	15	5	0.0%	0.0%

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	6.10E-08	6.81E-07	9.55E-07	2.75E-06	Gamma	1.10	1.16E+06
DC	FTOP	JNID/IL	8.51E-10	9.85E-08	2.17E-07	8.31E-07	Gamma	0.50	2.31E+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 ICES database, covering 1998–2015 using RADS. The systems included in the MCC data collection are listed in Table 5-20 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 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
-	FTOP	6	34,080,880 h	217	18	2.8%	27.8%

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
-	FTOP	JNID/IL	8.64E-08	1.81E-07	1.91E-07	3.28E-07	Gamma	6.50	3.41E+07

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 ICES database, covering 1998–2015. 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
TFM >15kV	dc power (DCP)	12	2	14
	Emergency power supply (EPS)	1		1
	Offsite electrical power (OEP)	8		8
	Plant ac power (ACP)	474	9	483
	TFM >15kV Total	**495**	**11**	**506**
TFM 3kV to 15kV	dc power (DCP)	2		2
	Plant ac power (ACP)	1262	22	1284
	TFM 3kV to 15kV Total	**1264**	**22**	**1286**
TFM <3kV	Control rod drive (CRD)	6		6
	dc power (DCP)	9		9
	Plant ac power (ACP)	670		670
	TFM <3kV Total	**685**		**685**
Grand Total		**2444**	**33**	**2477**

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
>15kV	FTOP	185	71,234,060 h	506	97	25.5%	73.2%

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
-	FTOP	EB/PL/KS	6.33E-07	2.50E-06	2.89E-06	6.47E-06	Gamma	2.40	8.32E+05

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 2015. 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
-	FTOP	8	65,993 d	232	95	3.4%	7.4%

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
-	FTOP	EB/PL/KS	1.37E-06	6.51E-05	1.20E-04	4.24E-04	Gamma	0.63	5.24E+03

5.10 Fuse (FUS)

5.10.1 Component Description

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

5.10.2 Data Collection and Review

Data for FUS UR baselines were obtained from the ICES database, covering 1998–2015. The systems included in the FUS data collection are listed in Table 5-28 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 5-28. FUS systems.

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
All	Auxiliary feedwater (AFW)	8		8
	Circulating water system (CWS)	14		14
	Component cooling water (CCW)	4		4
	Containment fan cooling (CFC)	6		6
	Containment isolation system (CIS)	5		5
	Control rod drive (CRD)	8		8
	dc power (DCP)	369		369
	Emergency power supply (EPS)	26		26
	Heating ventilation and air conditioning (HVC)	48		48
	Instrument air (IAS)	2		2
	Main steam (MSS)	24		24
	Plant ac power (ACP)	752		752
	Reactor coolant (RCS)	23		23
	Grand Total	**1289**		**1289**

Table 5-29 summarizes the data obtained from EPIX and used in the FUS analysis. Note that the hours are reactor-year hours.

Table 5-29. FUS unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
-	SOP	2	203,224,300 h	1289	5	0.2%	40.0%

5.10.3 Industry-Average Baselines

Table 5-30 lists the industry-average failure rate distributions. This industry-average failure rate does not account for any recovery.

Table 5-30. Selected industry distributions of p and λ for FUS.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
-	SOP	JNID/IL	2.82E-09	1.07E-08	1.23E-08	2.73E-08	Gamma	2.50	2.03E+08

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)	23		23
	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)	2		2
	Normally operating service water (SWN)	2		2
	Reactor core isolation (RCI)	2		2
	Standby service water (SWS)	30	2	32
	Residual Heat Removal (LCI in BWRs; LPI in PWRs) (RHR)	5		5
FLT Total		**208**	**12**	**220**
FLTSC	Normally operating service water (SWN)	101	2	103
	Standby service water (SWS)	59		59

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
	Residual Heat Removal (LCI in BWRs; LPI in PWRs) (RHR)	4		4
FLTSC Total		**164**	**2**	**166**
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		**689**	**14**	**703**

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 ICES 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	10	9,300,024 h	59	18	10.2%	27.8%
FLT	ELS	3	33,686,420 h	220	45	0.9%	4.4%
FLT	ELL	3	33,686,420 h	220	45	0.9%	4.4%
FLT-Clean	PG	2	10,115,010 h	68	19	1.5%	5.3%
FLT-Clean	BYP	0	10,115,010 h	68	19	0.0%	0.0%
IAS-FLT	PG	0	122,688 h	2	1	0.0%	0.0%

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	6.23E-07	1.09E-06	1.13E-06	1.76E-06	Gamma	10.50	9.30E+06
FLT-Clean	BYP	JNID/IL	1.95E-10	2.25E-08	4.94E-08	1.90E-07	Gamma	0.50	1.01E+07
FLT	ELS	JNID/IL	3.22E-08	9.42E-08	1.04E-07	2.09E-07	Gamma	3.50	3.37E+07
FLT	ELL	JNID/IL	7.79E-13	1.77E-09	7.28E-09	3.33E-08	Gamma	0.30	4.12E+07
IAS-FLT	PG	JNID/IL	1.60E-08	1.85E-06	4.08E-06	1.56E-05	Gamma	0.50	1.23E+05
IAS-FLT	FC	JNID/IL	1.60E-08	1.85E-06	4.08E-06	1.56E-05	Gamma	0.50	1.23E+05

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 ICES database, covering 1998–2015. 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
FLTSC	PG	55	25,738,850 h	166	46	16.9%	34.8%
FLTSC	BYP	1	25,738,850 h	166	46	0.6%	2.2%
FLTSC	FTOP	91	25,738,850 h	166	46	24.1%	41.3%
FLTSC	ELS	14	25,738,850 h	166	46	5.4%	13.0%
FLTSC	ELL	14	25,738,850 h	166	46	5.4%	13.0%
FLTSC SWS-NE	PG	35	25,738,850 h	166	46	11.4%	23.9%
FLTSC NSW	PG	42	15,944,260 h	103	33	20.4%	36.4%
FLTSC SWS	PG	13	9,198,527 h	59	25	11.9%	20.0%
FLTSC SWS-PE	PG	1	9,198,527 h	59	25	1.7%	4.0%

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
FLTSC	PG	JNID/IL	1.71E-06	2.15E-06	2.16E-06	2.66E-06	Gamma	55.50	2.57E+07
FLTSC	BYP	JNID/IL	6.85E-09	4.60E-08	5.83E-08	1.52E-07	Gamma	1.50	2.57E+07
FLTSC	FTOP	JNID/IL	2.97E-06	3.55E-06	3.55E-06	4.19E-06	Gamma	91.50	2.57E+07
FLTSC	ELS	JNID/IL	3.45E-07	5.51E-07	5.63E-07	8.28E-07	Gamma	14.50	2.57E+07
FLTSC	ELL	JNID/IL	4.22E-12	9.61E-09	3.94E-08	1.80E-07	Gamma	0.30	7.61E+06
FLTSC SWS-NE	PG	JNID/IL	1.02E-06	1.37E-06	1.38E-06	1.78E-06	Gamma	35.50	2.57E+07
FLTSC NSW	PG	JNID/IL	2.04E-06	2.65E-06	2.67E-06	3.38E-06	Gamma	42.50	1.59E+07
FLTSC SWS	PG	JNID/IL	8.78E-07	1.43E-06	1.47E-06	2.18E-06	Gamma	13.50	9.20E+06
FLTSC SWS-PE	PG	JNID/IL	1.91E-08	1.29E-07	1.63E-07	4.25E-07	Gamma	1.50	9.20E+06

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 ICES database, covering 1998–2015. 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	4	14,682,020 h	95	26	4.2%	15.4%
Sump	PG	1	14,682,020 h	95	26	1.1%	3.8%
Sump BWR	PG	0	6,565,272 h	42	7	0.0%	0.0%
Sump PWR	PG	1	4,382,688 h	29	14	3.4%	7.1%

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	1.13E-07	2.84E-07	3.06E-07	5.75E-07	Gamma	4.50	1.47E+07
Sump	PG	JNID/IL	1.20E-08	8.05E-08	1.02E-07	2.66E-07	Gamma	1.50	1.47E+07
Sump BWR	PG	JNID/IL	2.99E-10	3.46E-08	7.62E-08	2.92E-07	Gamma	0.50	6.57E+06
Sump PWR	PG	JNID/IL	4.02E-08	2.70E-07	3.42E-07	8.92E-07	Gamma	1.50	4.38E+06

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 ICES database, covering 1998–2015. 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	68	30,417,290 h	212	48	22.6%	47.9%
TSA	FTS	97	30,417,290 d	212	48	29.7%	60.4%
TSA	BYP	8	30,417,290 h	212	48	2.8%	8.3%
TSA	FTR	97	30,417,290 h	212	48	29.7%	60.4%
TSA	FTOP	97	30,417,290 h	212	48	29.7%	60.4%
TSA-SWS-NE	PG	0	2,331,600 h	15	5	0.0%	0.0%
TSA-SWS	PG	0	2,331,600 h	15	5	0.0%	0.0%

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	6.77E-09	1.08E-06	2.53E-06	9.98E-06	Gamma	0.47	1.84E+05
TSA	FTS	EB/PL/KS	3.30E-08	1.92E-06	3.67E-06	1.32E-05	Gamma	0.59	1.62E+05
TSA	BYP	JNID/IL	1.43E-07	2.69E-07	2.79E-07	4.54E-07	Gamma	8.50	3.04E+07
TSA	FTR	EB/PL/KS	3.30E-08	1.92E-06	3.67E-06	1.32E-05	Gamma	0.59	1.62E+05
TSA	FTOP	EB/PL/KS	3.30E-08	1.92E-06	3.67E-06	1.32E-05	Gamma	0.59	1.62E+05
TSA-SWS-NE	PG	JNID/IL	8.44E-10	9.76E-08	2.14E-07	8.24E-07	Gamma	0.50	2.33E+06
TSA-SWS	PG	JNID/IL	8.44E-10	9.76E-08	2.14E-07	8.24E-07	Gamma	0.50	2.33E+06

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 ICES database, covering 1998–2015. 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	3	1,577,760 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	EB/PL/KS	2.05E-08	1.17E-06	2.23E-06	8.03E-06	Gamma	0.60	2.68E+05

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
-	FTOP	24	974,417 d	-	-	-	-

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 ICES database, covering 1998–2015 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 ICES database, covering 1997–2015. 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
CRDM	FTOP	18	183,267,700 d	1,201	30	1.5%	30.0%
CRDM	SOP	34	183,267,700 h	1,201	30	2.5%	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
CRDM	FTOP	EB/PL/KS	1.62E-10	4.40E-08	1.15E-07	4.71E-07	Gamma	0.42	3.64E+06
CRDM	SOP	JNID/IL	1.39E-07	1.87E-07	1.88E-07	2.44E-07	Gamma	34.50	1.83E+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 ICES database, covering 1997–2015. 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
Control Rod	FTOP	20	132,832,800 d	846	39	2.1%	23.1%
Control Rod	SOP	20	132,832,800 h	846	39	2.2%	17.9%

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
Control Rod	FTOP	JNID/IL	1.03E-07	1.52E-07	1.54E-07	2.14E-07	Gamma	20.50	1.33E+08
Control Rod	SOP	JNID/IL	1.03E-07	1.52E-07	1.54E-07	2.14E-07	Gamma	20.50	1.33E+08

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 ICES database, covering 1997–2015. 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	29	1,625,902,000 d	10,436	35	0.3%	45.7%
HCU	FTOP	29	1,625,902,000 h	10,436	35	0.3%	45.7%
HCU	SOP	35	1,625,902,000 h	10,436	35	0.3%	57.1%

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	EB/PL/KS	1.16E-09	1.30E-08	1.81E-08	5.23E-08	Gamma	1.10	6.09E+07
HCU	FTOP	EB/PL/KS	1.16E-09	1.30E-08	1.81E-08	5.23E-08	Gamma	1.10	6.09E+07
HCU	SOP	EB/PL/KS	6.01E-09	1.93E-08	2.16E-08	4.49E-08	Gamma	3.08	1.43E+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 ICES database, covering 1998–2015 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**
AIR	Chemical and volume control (CVC)		1	1
	Containment fan cooling (CFC)	2	22	24
	Emergency power supply (EPS)	1		1
	Heating ventilation and air conditioning (HVC)	114	59	173
	High pressure injection (HPI)	1		1
	Instrument air (IAS)	4		4
	Plant ac power (ACP)	1		1
AIR Total		**123**	**82**	**205**

Pooling Group	Description	Number of Components		
		High/ Unknown Demand	Low Demand	Total
HYD	Containment fan cooling (CFC)		4	4
	dc power (DCP)	1		1
	Emergency power supply (EPS)	16	8	24
	Heating ventilation and air conditioning (HVC)	55	41	96
HYD Total		**72**	**53**	**125**
MOT	Containment fan cooling (CFC)		3	3
	Emergency power supply (EPS)	6	16	22
	Engineered safety features actuation (ESF)		1	1
	Heating ventilation and air conditioning (HVC)	60	3	63
	Standby service water (SWS)	6		6
MOT Total		**72**	**23**	**95**
Grand Total		**267**	**158**	**425**

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	FTO/C	2	7,799 d	49	10	2.0%	10.0%
Pneumatic	SOP	3	31,342,830 h	209	37	1.4%	8.1%
Pneumatic	ILS	5	31,342,830 h	209	37	2.4%	8.1%
Pneumatic	ILL	5	31,342,830 h	209	37	2.4%	8.1%
Hydraulic	FTO/C	11	6,225 d	39	6	25.6%	100.0%
Hydraulic	SOP	8	19,397,950 h	128	15	6.3%	26.7%
Hydraulic	ILS	0	19,397,950 h	128	15	0.0%	0.0%
Hydraulic	ILL	0	19,397,950 h	128	15	0.0%	0.0%
Motor	FTO/C	7	33,254 d	45	9	8.9%	22.2%
Motor	SOP	0	17,147,900 h	111	23	0.0%	0.0%
Motor	ILS	1	17,147,900 d	111	23	0.9%	4.3%
Motor	ILL	1	17,147,900 h	111	23	0.9%	4.3%

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

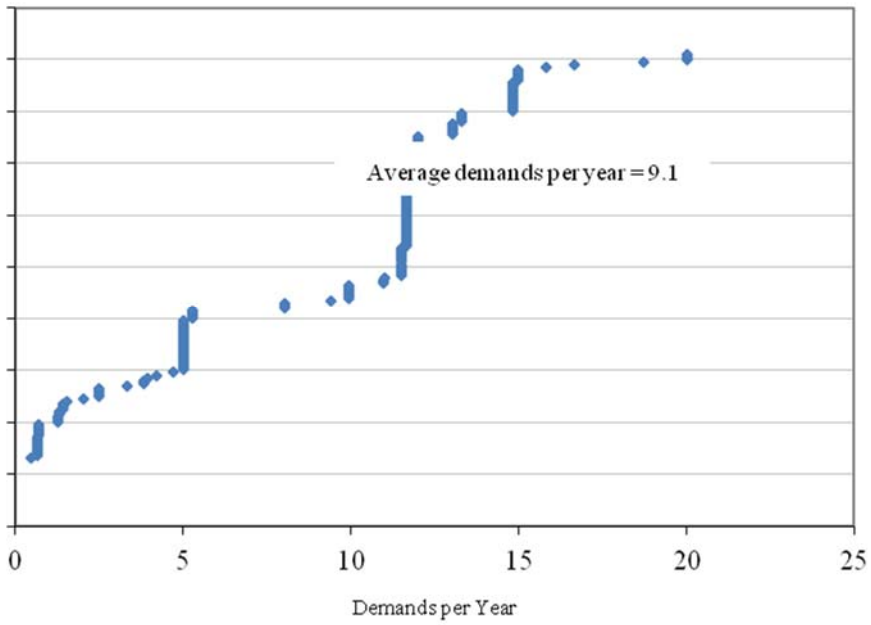

Figure 9-1. DMP demands per year distribution.

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	FTO/C	JNID/IL	7.34E-05	2.79E-04	3.21E-04	7.09E-04	Beta	2.50	7.80E+03
Pneumatic	SOP	JNID/IL	3.46E-08	1.01E-07	1.12E-07	2.25E-07	Gamma	3.50	3.13E+07
Pneumatic	ILS	JNID/IL	7.31E-08	1.65E-07	1.75E-07	3.14E-07	Gamma	5.50	3.13E+07
Pneumatic	ILL	JNID/IL	3.75E-13	8.53E-10	3.50E-09	1.60E-08	Gamma	0.30	8.57E+07
Hydraulic	FTO/C	EB/PL/KS	3.41E-05	2.74E-03	5.57E-03	2.07E-02	Beta	0.55	9.73E+01
Hydraulic	SOP	JNID/IL	2.23E-07	4.21E-07	4.38E-07	7.11E-07	Gamma	8.50	1.94E+07
Hydraulic	ILS	JNID/IL	1.01E-10	1.17E-08	2.58E-08	9.90E-08	Gamma	0.50	1.94E+07
Hydraulic	ILL	JNID/IL	5.52E-14	1.26E-10	5.16E-10	2.36E-09	Gamma	0.30	5.81E+08
Motor	FTO/C	JNID/IL	1.09E-04	2.16E-04	2.26E-04	3.76E-04	Beta	7.50	3.32E+04
Motor	SOP	JNID/IL	1.15E-10	1.33E-08	2.92E-08	1.12E-07	Gamma	0.50	1.71E+07
Motor	ILS	JNID/IL	1.03E-08	6.92E-08	8.75E-08	2.29E-07	Gamma	1.50	1.71E+07
Motor	ILL	JNID/IL	1.87E-13	4.27E-10	1.75E-09	8.01E-09	Gamma	0.30	1.71E+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 ICES database, covering 1998–2015. 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
Normally Running	Auxiliary feedwater (AFW)	3	1	4
	Circulating water system (CWS)	3		3
	Component cooling water (CCW)	37		37
	Condensate system (CDS)	10		10
	Containment fan cooling (CFC)	113	55	168
	Containment isolation system (CIS)	4		4
	Control rod drive (CRD)	14		14
	dc power (DCP)	1	2	3
	Emergency power supply (EPS)	91	5	96
	Fuel handling (FHS)	4		4
	Heating ventilation and air conditioning (HVC)	1001	121	1122
	High pressure coolant injection (HCI)	1		1
	High pressure injection (HPI)	1		1
	Instrument air (IAS)	1	8	9
	Main feedwater (MFW)	4		4
	Main steam (MSS)	107		107
	Plant ac power (ACP)	13		13
	Reactor coolant (RCS)	16		16
	Reactor protection (RPS)	9	1	10
	Standby service water (SWS)	8		8
	Uninterruptable instrument power supply (UPS)	9		9
	Normally Running Total	**1450**	**193**	**1643**
Standby	Chemical and volume control (CVC)		2	2
	Component cooling water (CCW)		3	3
	Containment fan cooling (CFC)		64	64
	Containment spray recirculation (CSR)		2	2
	Emergency power supply (EPS)		57	57
	Heating ventilation and air conditioning (HVC)	3	243	246
	High pressure injection (HPI)		2	2
	Standby service water (SWS)		6	6

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
	Residual Heat Removal (LCI in BWRs; LPI in PWRs) (RHR)		4	4
	Standby Total	**3**	**383**	**386**
	Grand Total	**1453**	**576**	**2029**

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
NR	FTS	45	17,336 d	139	34	19.4%	38.2%
NR	FTR	62	17,498,560 h	139	34	25.2%	64.7%

Figure 9-2 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.

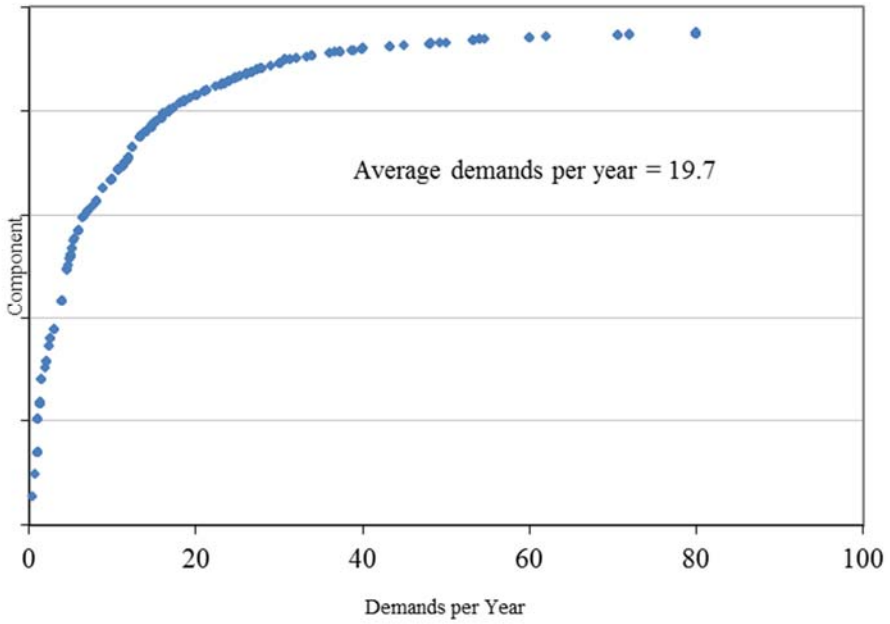

Figure 9-2. AHU demands per year distribution.

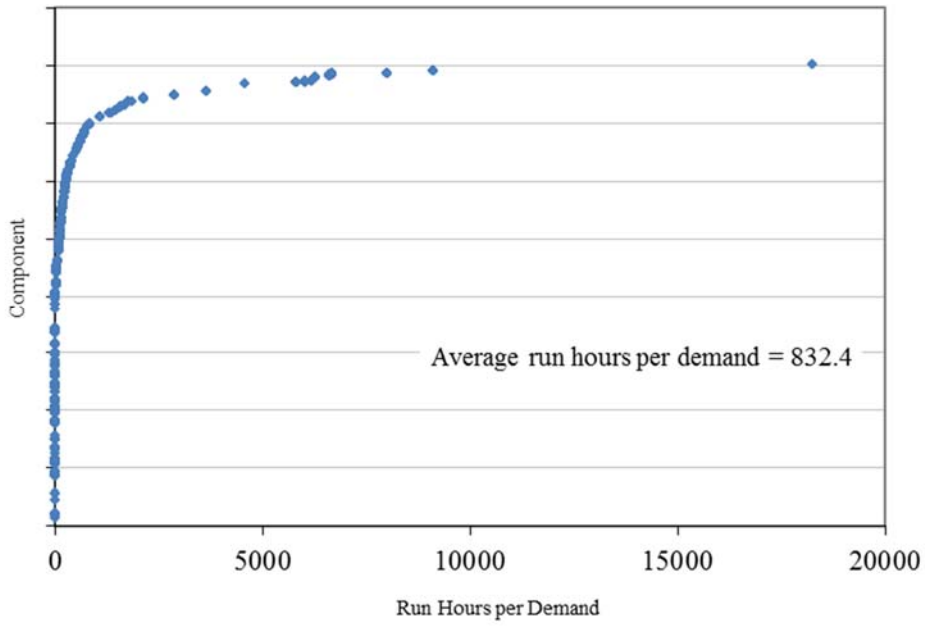

Figure 9-3. AHU run hours per demand distribution.

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
NR	FTS	EB/PL/KS	7.32E-06	1.18E-03	2.76E-03	1.09E-02	Beta	0.47	1.68E+02
NR	FTR	EB/PL/KS	2.64E-08	3.03E-06	6.65E-06	2.55E-05	Gamma	0.50	7.53E+04

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 ICES database, covering 1998–2015. 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
Normally Running	Chilled water system (CHW)	115	25	140
	Component cooling water (CCW)	23	3	26
	Containment isolation system (CIS)	6	1	7
	Containment spray recirculation (CSR)	31		31
	Emergency power supply (EPS)	58	3	61
	Heating ventilation and air conditioning (HVC)	93	56	149
	High pressure core spray (HCS)	1		1
	Instrument air (IAS)		2	2
	Main steam (MSS)	3		3
	Normally operating service water (SWN)	10	6	16
	Offsite electrical power (OEP)		1	1
	Plant ac power (ACP)	19	31	50
	Reactor protection (RPS)	2		2
	Standby service water (SWS)	48	20	68
	Residual Heat Removal (LCI in BWRs; LPI in PWRs) (RHR)	1		1
	Normally Running Total	**410**	**148**	**558**
Standby	Chilled water system (CHW)		5	5
	Heating ventilation and air conditioning (HVC)	2	57	59
	Instrument air (IAS)		1	1
	Standby Total	**2**	**63**	**65**
	Grand Total	**412**	**211**	**623**

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

Table 9-9. CHL unreliability data.

Pooling	Failure	Data	Counts	Percent With Failures

Group	Mode	Failures	Demands or Hours	Components	Plants	Components	Plants
NR	FTS	121	18,215 d	80	22	50.0%	77.3%
NR	FTR	349	6,464,949 h	80	22	72.5%	100.0%
STBY	FTS	0	20,433 d	63	10	0.0%	0.0%
STBY	FTR<1H	61	279,348 h	63	10	36.5%	90.0%
STBY	FTR>1H	61	279,348 h	63	10	36.5%	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.

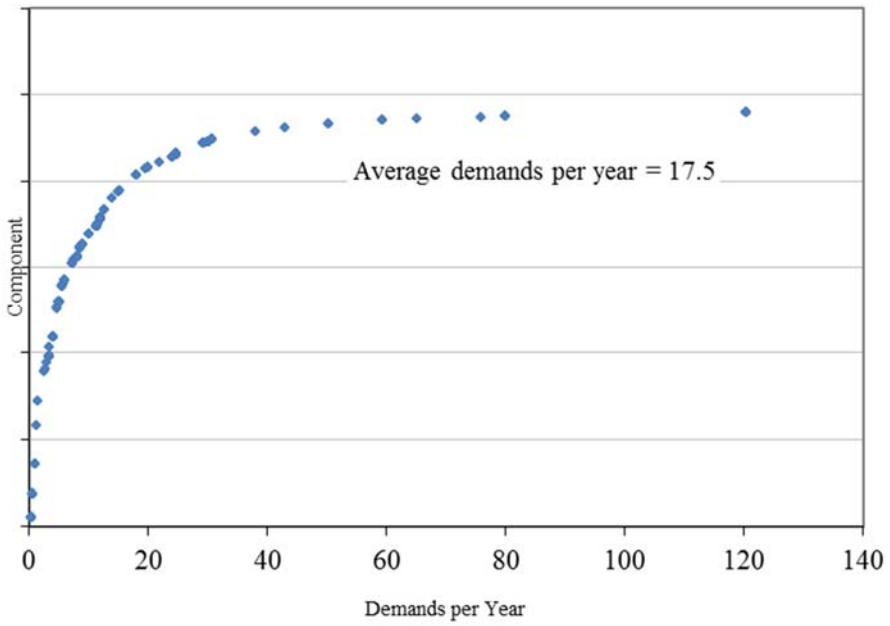

Figure 9-4. CHL demands per year distribution.

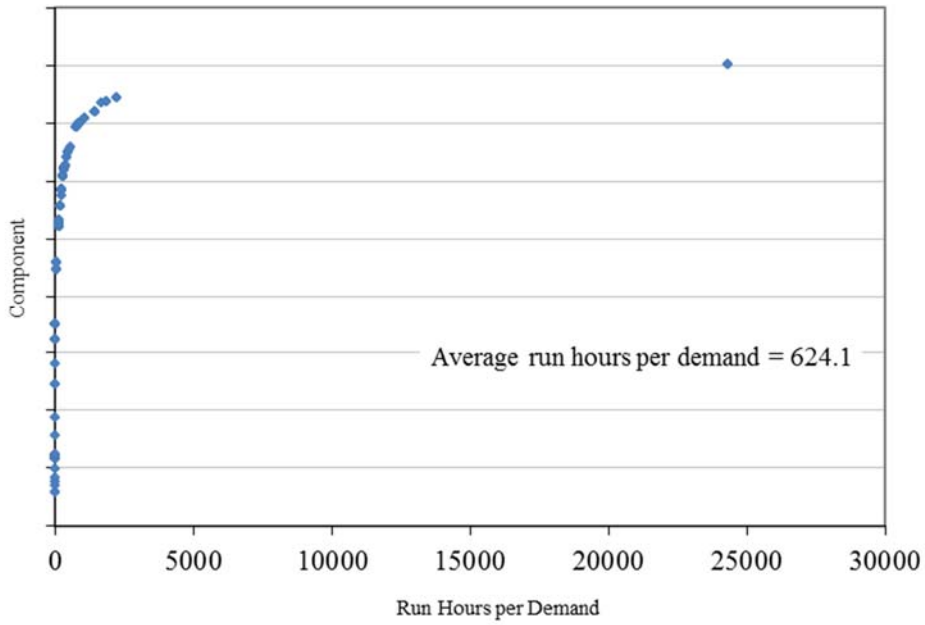

Figure 9-5. CHL run hours per demand distribution.

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
NR	FTS	EB/PL/KS	1.35E-04	5.25E-03	9.21E-03	3.17E-02	Beta	0.67	7.18E+01
NR	FTR	EB/PL/KS	4.19E-06	4.94E-05	6.93E-05	2.03E-04	Gamma	1.07	1.54E+04
STBY	FTS	JNID/IL	9.64E-08	1.12E-05	2.45E-05	9.42E-05	Beta	0.50	2.04E+04
STBY	FTR<1H	JNID/IL	1.76E-04	2.19E-04	2.20E-04	2.69E-04	Gamma	61.50	2.79E+05
STBY	FTR>1H	JNID/IL	1.76E-04	2.19E-04	2.20E-04	2.69E-04	Gamma	61.50	2.79E+05

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 ICES database, covering 1998–2015. 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
	Normally operating service water (SWN)		1	1

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
	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	37	57,511 d	130	33	16.9%	45.5%
Standby	FTR<1H	16	43,743 h	130	33	8.5%	27.3%
Standby	FTR>1H	27	137,892 h	130	33	13.8%	33.3%
Normally Running	FTS	46	85,577 d	218	31	14.2%	45.2%
Normally Running	FTR	67	17,511,120 h	218	31	19.3%	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.

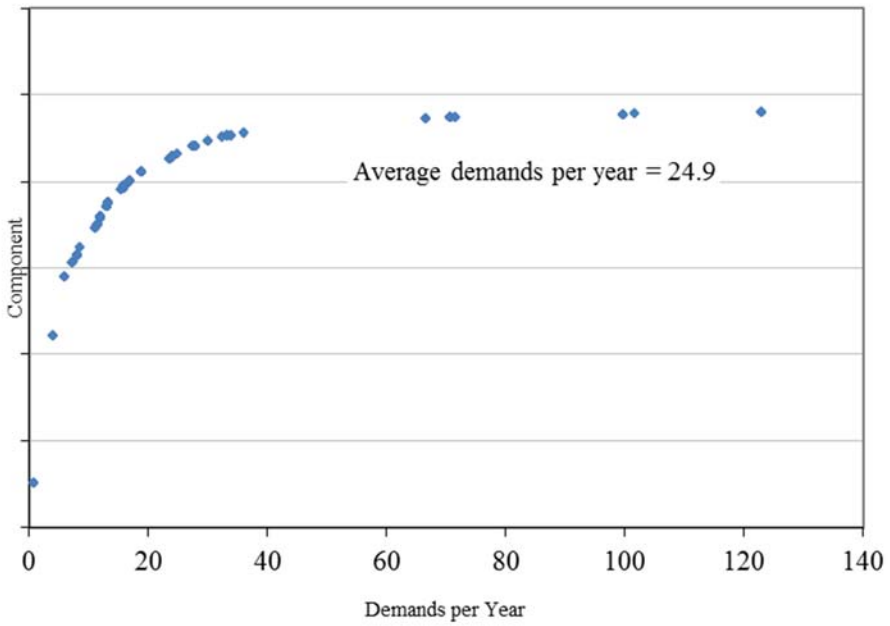

Figure 9-6a. Standby FAN demands per year distribution.

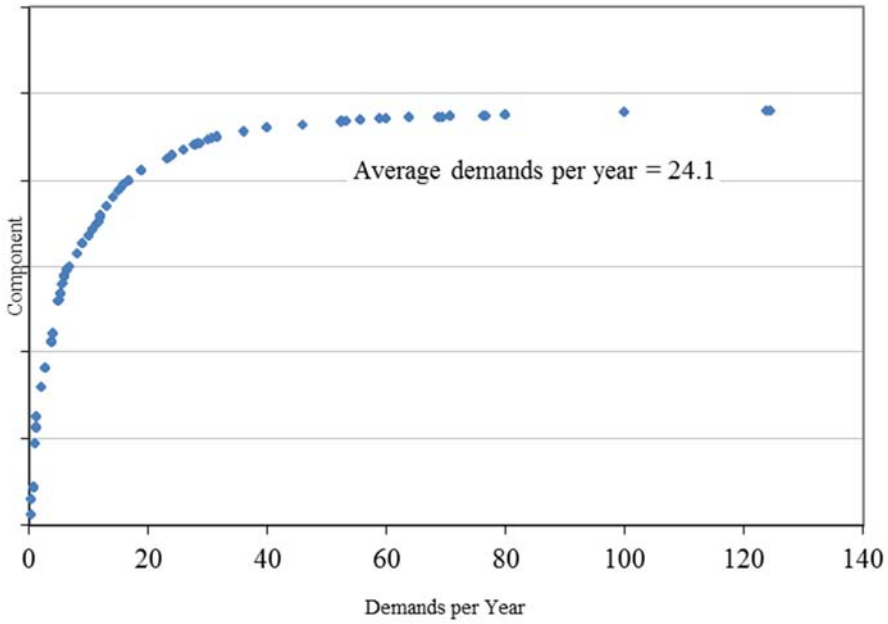

Figure 9-6b. Running/alternating FAN demands per year distribution.

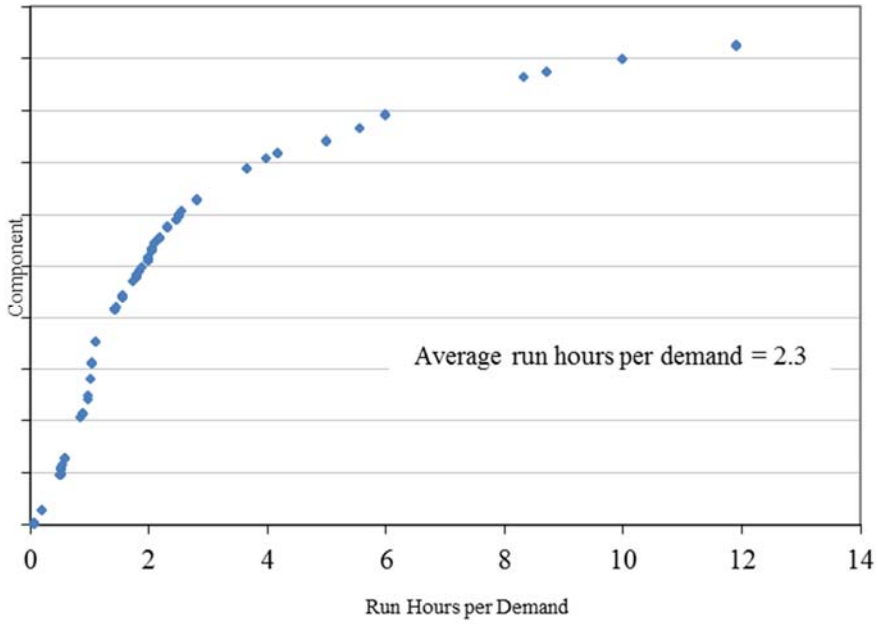

Figure 9-7a. Standby FAN run hours per demand distribution.

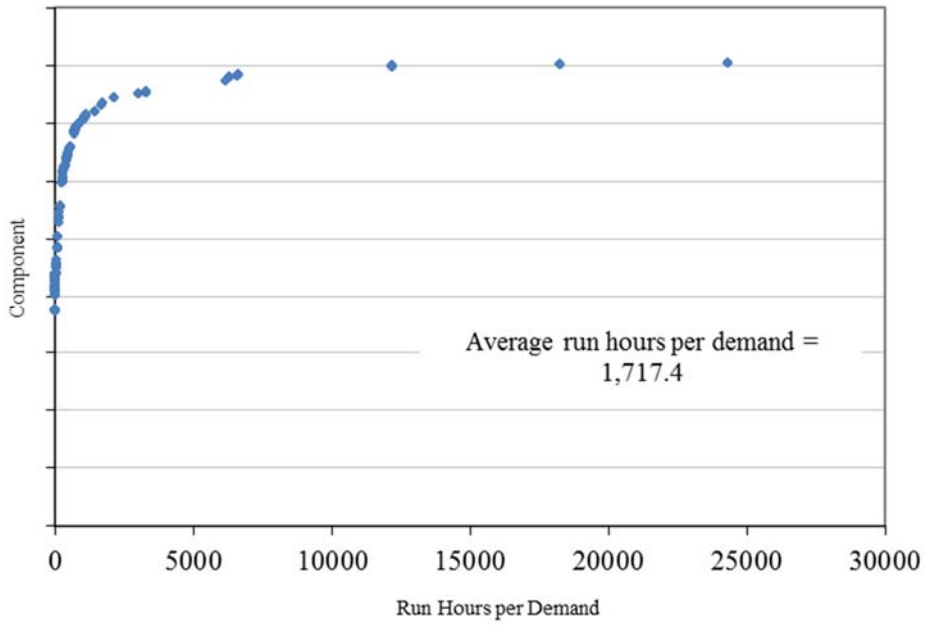

Figure 9-7b. Running/alternating FAN run hours per demand distribution.

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	4.87E-04	6.46E-04	6.52E-04	8.36E-04	Beta	37.50	5.75E+04
Standby	FTR<1H	JNID/IL	2.39E-04	3.70E-04	3.77E-04	5.42E-04	Gamma	16.50	4.37E+04
Standby	FTR>1H	JNID/IL	1.41E-04	1.97E-04	1.99E-04	2.66E-04	Gamma	27.50	1.38E+05
Normally Running	FTS	JNID/IL	4.19E-04	5.40E-04	5.43E-04	6.81E-04	Beta	46.50	8.55E+04
Normally Running	FTR	EB/PL/KS	3.07E-08	2.21E-06	4.41E-06	1.63E-05	Gamma	0.56	1.27E+05

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 ICES database, covering 1998–2015. 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
Motor-driven NR	FTS	109	9,196 d	70	29	65.7%	93.1%
Motor-driven NR	FTR	307	5,595,966 h	70	29	87.1%	96.6%
Motor-driven STBY	FTS	61	23,363 d	58	21	58.6%	85.7%
Motor-driven STBY	FTR<1H	22	1,683,943 h	58	21	15.5%	33.3%
Motor-driven STBY	FTR>1H	22	1,683,943 h	58	21	15.5%	33.3%
Engine-driven	FTS	17	2,121 d	5	4	40.0%	50.0%
Engine-driven	FTR<1H	0	2,121 h	5	4	0.0%	0.0%
Engine-driven	FTR>1H	0	1,735 h	5	4	0.0%	0.0%
IAS-Motor	FTR	186	2,680,601 h	41	16	92.7%	100.0%
PCA-Motor	FTR	3	118,273 h	2	1	100.0%	100.0%

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.

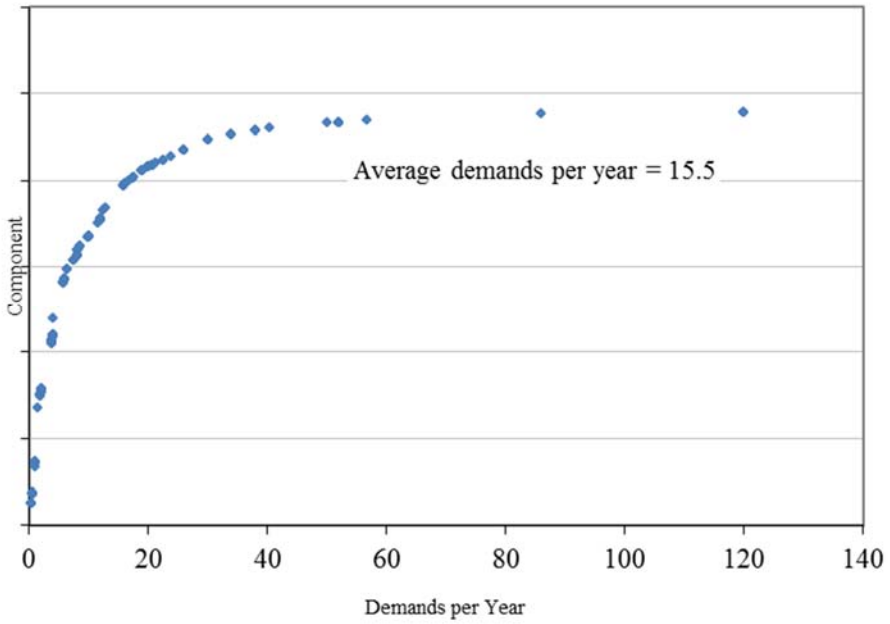

Figure 10-1. CMP demands per year distribution.

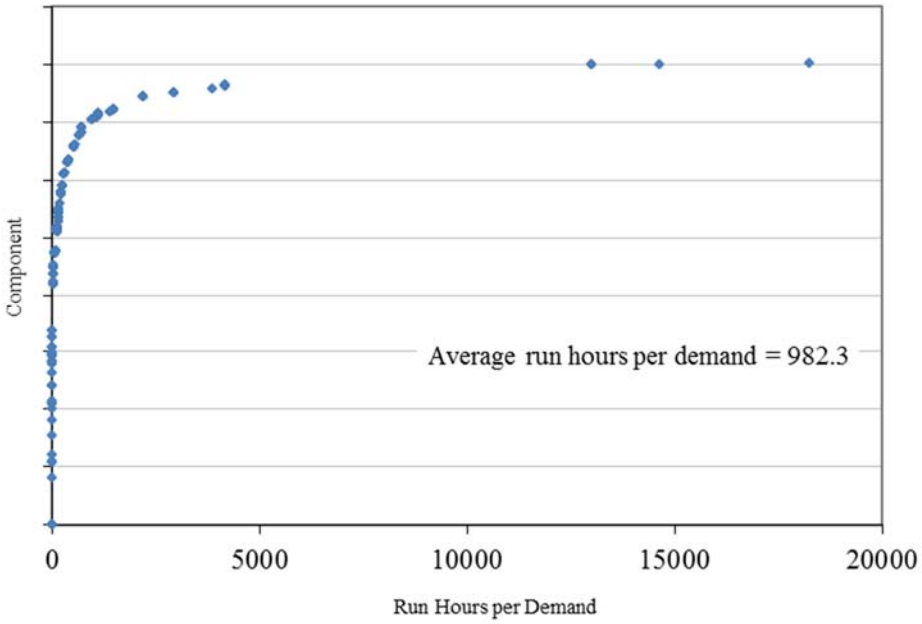

Figure 10-2. CMP run hours per demand distribution.

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
Motor-driven NR	FTS	EB/PL/KS	2.06E-04	1.72E-02	3.41E-02	1.25E-01	Beta	0.54	1.53E+01
Motor-driven NR	FTR	EB/PL/KS	1.20E-05	5.50E-05	6.51E-05	1.53E-04	Gamma	2.06	3.16E+04
Motor-driven STBY	FTS	EB/PL/KS	3.58E-04	3.14E-03	4.16E-03	1.15E-02	Beta	1.26	3.01E+02
Motor-driven STBY	FTR<1H	JNID/IL	9.11E-06	1.32E-05	1.34E-05	1.84E-05	Gamma	22.50	1.68E+06
Motor-driven STBY	FTR>1H	JNID/IL	9.11E-06	1.32E-05	1.34E-05	1.84E-05	Gamma	22.50	1.68E+06
Engine-driven	FTS	JNID/IL	5.29E-03	8.07E-03	8.24E-03	1.17E-02	Beta	17.50	2.11E+03
Engine-driven	FTR<1H	JNID/IL	9.27E-07	1.07E-04	2.36E-04	9.06E-04	Gamma	0.50	2.12E+03
Engine-driven	FTR>1H	JNID/IL	1.13E-06	1.31E-04	2.88E-04	1.10E-03	Gamma	0.50	1.74E+03
IAS-Motor	FTR	EB/PL/KS	1.95E-05	6.64E-05	7.50E-05	1.60E-04	Gamma	2.85	3.80E+04
PCA-Motor	FTR	JNID/IL	9.18E-06	2.69E-05	2.96E-05	5.96E-05	Gamma	3.50	1.18E+05

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
IAS	FTOP	JNID/IL	5.35E-10	1.22E-06	5.00E-06	2.29E-05	Gamma	0.30	6.00E+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 ICES database, covering 1998–2015. 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
-	FTOP	18	96,227,420 h	617	79	2.8%	17.7%
-	ELS	11	96,227,420 h	617	79	1.8%	8.9%
-	ELL	11	96,227,420 h	617	79	1.8%	8.9%

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
-	FTOP	JNID/IL	1.25E-07	1.89E-07	1.92E-07	2.71E-07	Gamma	18.50	9.62E+07
-	ELS	JNID/IL	6.80E-08	1.16E-07	1.20E-07	1.83E-07	Gamma	11.50	9.62E+07
-	ELL	JNID/IL	8.99E-13	2.05E-09	8.40E-09	3.84E-08	Gamma	0.30	3.57E+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 ICES database, covering 1998–2015. 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
STBY	FTS	16	44,600 d	54	6	25.9%	66.7%
STBY	FTR<1H	0	44,487 h	54	6	0.0%	0.0%
STBY	FTR>1H	2	1,073,115 h	54	6	3.7%	33.3%
NR	FTS	1	2,687 d	20	2	5.0%	50.0%
NR	FTR	3	1,504,717 h	20	2	15.0%	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.

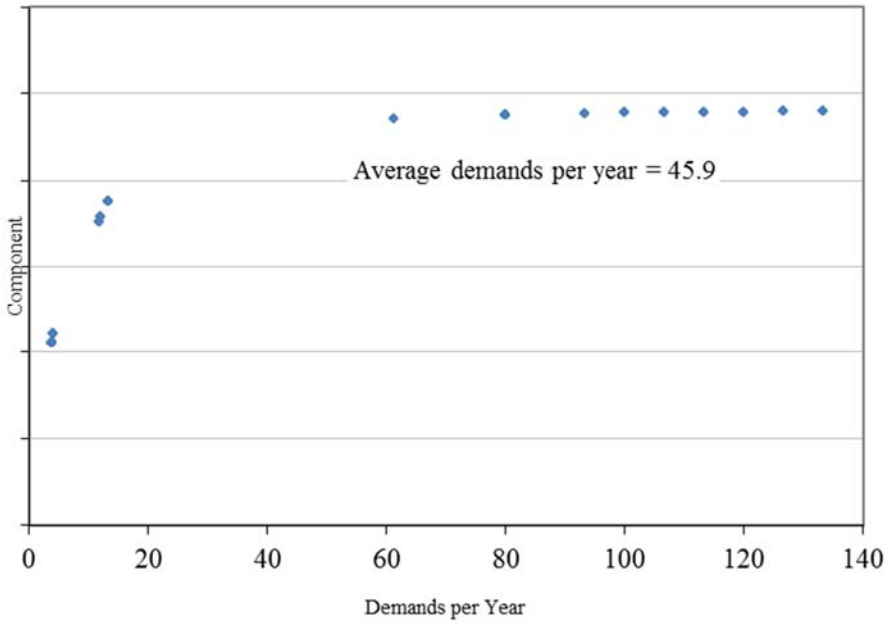

Figure 10-3a. Standby CTF demands per year distribution.

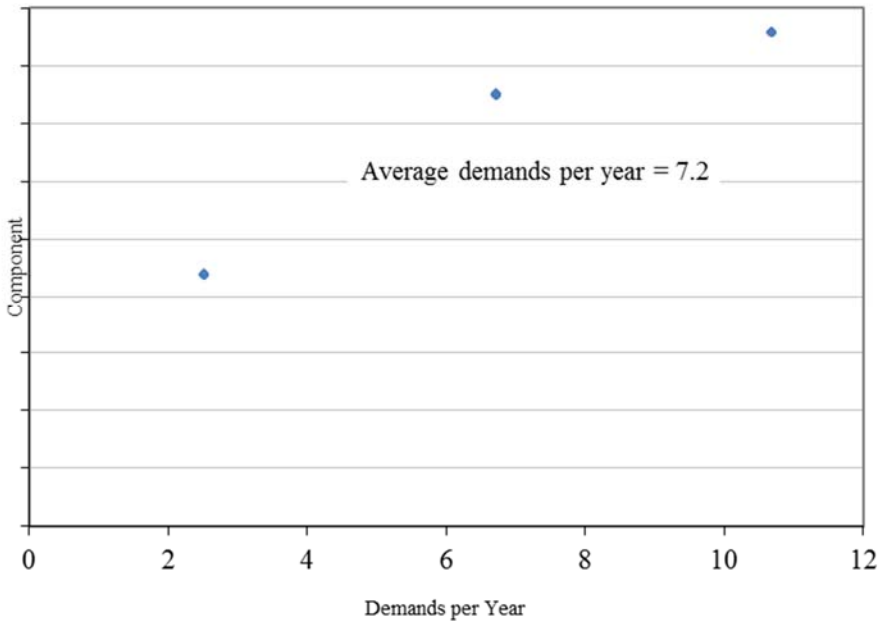

Figure 10-3b. Running/alternating CTF demands per year distribution.

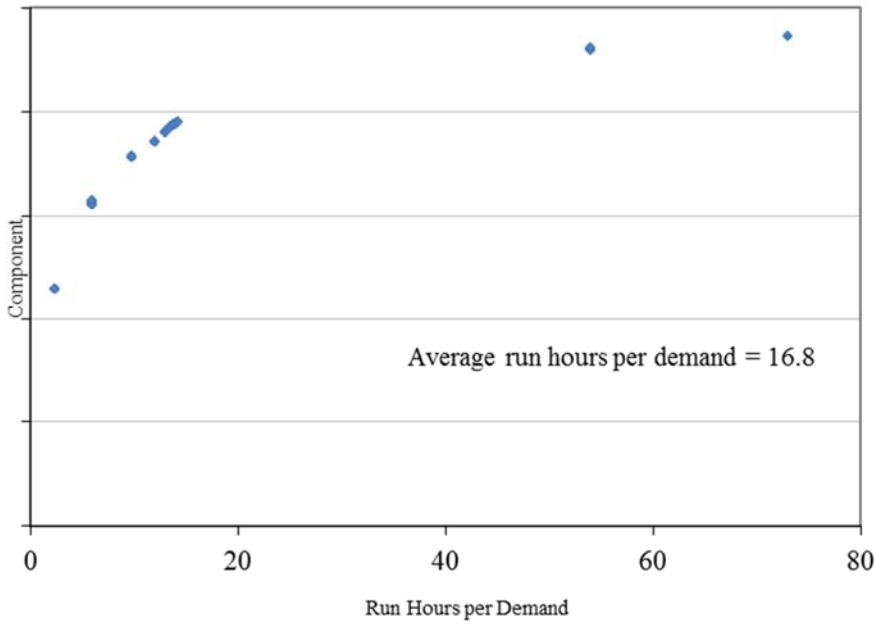

Figure 10-4a. Standby CTF run hours per demand distribution.

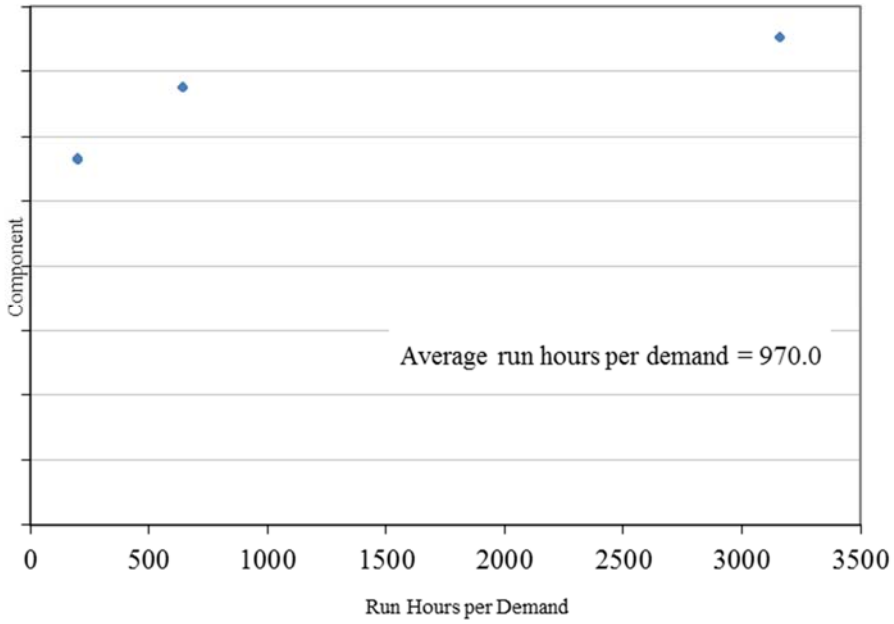

Figure 10-4b. Running/alternating CTF run hours per demand distribution.

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
STBY	FTS	JNID/IL	2.34E-04	3.62E-04	3.70E-04	5.31E-04	Beta	16.50	4.46E+04
STBY	FTR<1H	JNID/IL	4.42E-08	5.11E-06	1.12E-05	4.32E-05	Gamma	0.50	4.45E+04
STBY	FTR>1H	JNID/IL	5.35E-07	2.03E-06	2.33E-06	5.17E-06	Gamma	2.50	1.07E+06
NR	FTS	JNID/IL	6.54E-05	4.40E-04	5.58E-04	1.45E-03	Beta	1.50	2.69E+03
NR	FTR	JNID/IL	7.22E-07	2.12E-06	2.33E-06	4.69E-06	Gamma	3.50	1.50E+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 ICES 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
-	FC	15	59,350,270 h	379	76	3.7%	15.8%
Liquid, Pressurized	ELS	8	24,349,940 h	156	45	5.1%	13.3%
Liquid, Pressurized	ELL	8	24,349,940 h	156	45	5.1%	13.3%
Liquid, Unpressurized	ELS	7	29,235,430 h	191	67	3.7%	10.4%
Liquid, Unpressurized	ELL	7	29,235,430 h	191	67	3.7%	10.4%
IAS	FC	0	3,944,400 h	25	4	0.0%	0.0%
SWS	FC	0	1,086,910 h	7	4	0.0%	0.0%
Gas	ELS	2	5,048,832 h	32	7	6.3%	14.3%
Gas	ELL	2	5,048,832 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
-	FC	JNID/IL	1.62E-07	2.55E-07	2.61E-07	3.79E-07	Gamma	15.50	5.94E+07
Liquid, Pressurized	ELS	EB/PL/KS	1.22E-09	1.49E-07	3.31E-07	1.28E-06	Gamma	0.49	1.49E+06
Liquid, Pressurized	ELL	EB/PL/KS	2.48E-12	5.65E-09	2.32E-08	1.06E-07	Gamma	0.30	1.29E+07
Liquid, Unpressurized	ELS	JNID/IL	1.24E-07	2.46E-07	2.57E-07	4.28E-07	Gamma	7.50	2.92E+07
Liquid, Unpressurized	ELL	JNID/IL	1.93E-12	4.39E-09	1.80E-08	8.23E-08	Gamma	0.30	1.67E+07
IAS	FC	JNID/IL	4.99E-10	5.77E-08	1.27E-07	4.87E-07	Gamma	0.50	3.94E+06
SWS	FC	JNID/IL	1.80E-09	2.09E-07	4.60E-07	1.76E-06	Gamma	0.50	1.09E+06
Gas	ELS	JNID/IL	1.13E-07	4.31E-07	4.95E-07	1.10E-06	Gamma	2.50	5.05E+06

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Gas	ELL	JNID/IL	3.71E-12	8.45E-09	3.47E-08	1.59E-07	Gamma	0.30	8.66E+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
-	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 ICES 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

Pooling Group	System	Failure Mode	Events (1997 - 2004)	Total Foot-Hours (1997 - 2004)
	AFW	ELS	0.0	6.122E+08
	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 ICES database, covering 1998–2015. 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)	105		105
	Circulating water system (CWS)	2		2
	Component cooling water (CCW)	273	8	281
	Condensate system (CDS)	341		341
	Containment fan cooling (CFC)	206	1	207
	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)	11		11
	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)	151		151
	Reactor core isolation (RCI)	7		7

Pooling Group	System	Number of Components		
		High/ Unknown Demand	Low Demand	Total
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	251		251
	Standby service water (SWS)	21		21
	Grand Total	**1943**	**14**	**1957**

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
-	LOHT	87	269,796,800 h	1,770	102	3.6%	39.2%
-	ILS	98	269,796,800 h	1,770	102	3.8%	33.3%
-	ILL	98	269,796,800 h	1,770	102	3.8%	33.3%
-	ELS	65	269,796,800 h	1,770	102	3.3%	36.3%
-	ELL	65	269,796,800 h	1,770	102	3.3%	36.3%
CCW	LOHT	17	34,265,020 h	227	80	6.6%	16.3%
CCW	PG	17	34,265,020 h	227	80	6.6%	16.3%
CCW	FC	17	34,265,020 h	227	80	6.6%	16.3%
CCW-NE	PG	7	34,265,020 h	227	80	3.1%	7.5%

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
-	LOHT	EB/PL/KS	2.32E-09	1.88E-07	3.85E-07	1.44E-06	Gamma	0.54	1.41E+06
-	ILS	EB/PL/KS	5.03E-10	1.42E-07	3.73E-07	1.54E-06	Gamma	0.42	1.11E+06
-	ILL	EB/PL/KS	7.98E-13	1.82E-09	7.46E-09	3.41E-08	Gamma	0.30	4.02E+07
-	ELS	EB/PL/KS	9.77E-09	1.82E-07	2.79E-07	8.81E-07	Gamma	0.87	3.10E+06
-	ELL	EB/PL/KS	4.48E-12	1.02E-08	4.19E-08	1.91E-07	Gamma	0.30	7.17E+06
CCW	LOHT	EB/PL/KS	5.34E-10	1.92E-07	5.33E-07	2.22E-06	Gamma	0.40	7.47E+05
CCW	PG	EB/PL/KS	5.34E-10	1.92E-07	5.33E-07	2.22E-06	Gamma	0.40	7.47E+05
CCW	FC	EB/PL/KS	5.34E-10	1.92E-07	5.33E-07	2.22E-06	Gamma	0.40	7.47E+05
CCW-NE	PG	EB/PL/KS	2.32E-10	7.56E-08	2.06E-07	8.51E-07	Gamma	0.41	1.97E+06

10.9 Instrumentation (INS)

10.9.1 Component Description

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

10.9.2 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.

10.9.3 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 10-23. Selected industry distributions of p and λ for INSs.

Pooling Group	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
ICC	FA	NUCLARR	6.89E-04	1.52E-03	1.70E-03	3.33E-03	Lognormal	2.20	-
ICC	FC	NUCLARR	6.89E-04	1.52E-03	1.70E-03	3.33E-03	Lognormal	2.20	-
ACT	FC	NUCLARR	6.89E-04	1.52E-03	1.70E-03	3.33E-03	Lognormal	2.20	-

11 References

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