Component Reliability Data Sheets

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1 Automatic Bus Transfer Switch (ABT)

1.1 Component Description

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

Table 1-1. ABT failure modes.

Operation	Failure Mode	Parameter	Units	Description
Running	FTOP	*p*	-	Fail to operate

1.2 Data Collection and Review

Data for the ABT UR baseline were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. There are 32 ABTs from eight plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1 in Reference 14) there were 27 components in eight plants. After analyzing the original data, there were no FTOP failures, so the data set was expanded to 1997– 2004 (see Section A.1 in Reference 14). The systems included in the ABT data collection are listed in Table 1-2 with the number of components included with each system.

Table 1-2. ABT systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
Running	ACP	Plant ac power	9	4	0
	DCP	Dc power	5	5	5
	EPS	Emergency power supply	11	11	11
	IPS	Instrument ac power	7	7	7
	Total		32	27	23

The ABT data set obtained from RADS was further reduced to include only those ABTs with ≤ 20 demands/year. See Section A.1 in Reference 14 for a discussion concerning this decision to limit the certain component populations.

The data review process is described in detail in Section A.1 in Reference 14. Table 1-3 summarizes the data obtained from EPIX and used in the ABT analysis.

Table 1-3. ABT unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Running	FTOP	0	163	23	7	0.0%	0.0%

Figure 1-1 shows the range of ABT demands per year in the ABT data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 1.3. The average for the data set is 0.6 demand/year.

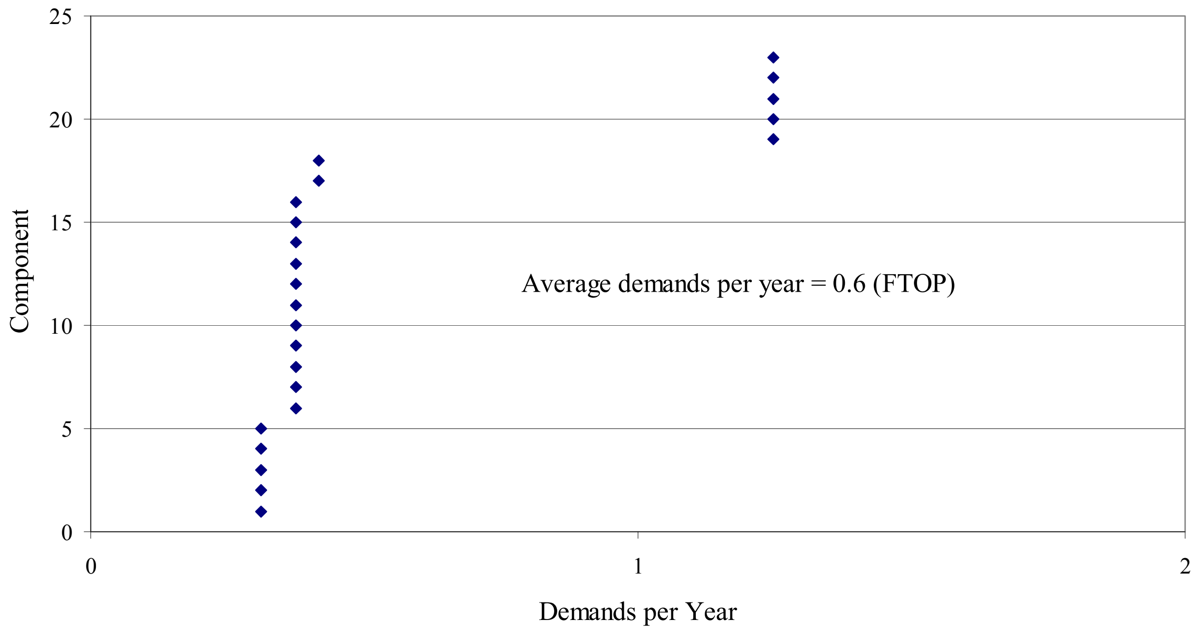

Figure 1-1. ABT demands per year distribution.

1.3 Data Analysis

The ABT data can be examined at the component, plant, or industry level. However, with zero failures, all maximum likelihood estimates (MLEs), which are failures/demands (or hours), are zero. Results for all three levels are presented in Table 1-4.

Table 1-4. Empirical distributions of MLEs for p and λ for ABTs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Running	FTOP	Component	-	-	0.00E+00	-
		Plant	-	-	0.00E+00	-
		Industry	-	-	0.00E+00	-

With no failures, no empirical Bayes analyses were performed. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table 1-5 for ABTs.

Table 1-5. Fitted distributions for p and λ for ABTs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	FTOP	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.20E-05	1.39E-03	3.05E-03	1.17E-02	Beta	0.500	1.636E+02

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

1.4 Industry-Average Baselines

Table 1-6 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 1-6. Selected industry distributions of p and λ for ABTs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	FTOP	SCNID/IL	1.20E-05	1.39E-03	3.05E-03	1.17E-02	Beta	0.500	1.636E+02

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 1-7 shows the rounded value for the ABT failure mode.

Table 1-7. Selected industry distributions of p and λ for ABTs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	FTOP	SCNID/IL	1.2E-05	1.5E-03	3.0E-03	1.2E-02	Beta	0.50	1.67E+02

1.5 Breakdown by System

ABT UR results (Jeffreys means of the system data) are compared by system and failure mode in Table 1-8. With no failures, there are no system results presented.

Table 1-8. ABT p and λ by system.

System	FTOP
DCP	-
EPS	-
IPS	-

2 Air Accumulator (ACC)

2.1 Component Description

The air accumulator (ACC) boundary includes the tank and associated relief valves. The failure modes for ACC are listed in Table 2-1.

Table 2-1. ACC failure modes.

Operation	Failure Mode	Parameter	Units	Description
All	ELS	λ	1/h	External leak small
	ELL	λ	1/h	External leak large

2.2 Data Collection and Review

Data for ACC UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1997–2004. There are 961 ACCs from 92 plants in the data originally gathered from EPIX. The systems and operational status included in the ACC data collection are listed in Table 2-2 with the number of components included with each system.

Table 2-2. ACC systems.

Operation	System	Description	Number of Components
All	CIS	Containment isolation system	26
	EPS	Emergency power supply	604
	ESW	Emergency service water	2
	FWS	Firewater	14
	HCS	High pressure core spray	19
	HPI	High pressure injection	5
	IAS	Instrument air	133
	LPI	Low pressure injection	2
	MFW	Main feedwater	7
	MSS	Main steam	102
	OEP	Offsite electrical power	10
	RCS	Reactor coolant	2
	RGW	Radioactive gaseous waste	10
	RRS	Reactor recirculation	3
	SLC	Standby liquid control	20
	VSS	Vapor suppression	2
	Total		961

Table 2-3 summarizes the data obtained from EPIX and used in the ACC analysis.

Table 2-3. ACC unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	ELS	3	67346880 h	961	92	0.3%	3.3%

2.3 Data Analysis

The ACC data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 2-4. The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 2-3, only 0.3% of the ACCs experienced an ELS over the period 1997–2004, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 99.7% portion of the distribution, and non-zero values above 99.7%.

Table 2-4. Empirical distributions of MLEs for p and λ for ACCs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
All	ELS	Component	0.00E+00	0.00E+00	4.45E-08	0.00E+00
		Plant	0.00E+00	0.00E+00	1.83E-07	0.00E+00
		Industry	-	-	4.45E-08	-

Empirical Bayes analyses were performed at both the component and plant level. At the component level, the empirical Bayes failed to converge but indicated little variation between components. Therefore, the data were considered to be homogeneous and the Jeffreys distribution was calculated. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table 2-5.

Table 2-5. Fitted distributions for p and λ for ACCs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	ELS	JEFF/CL	1.61E-08	4.71E-08	5.20E-08	1.04E-07	Gamma	3.500	6.735E+07
		EB/PL/KS	6.68E-13	8.29E-09	4.94E-08	2.41E-07	Gamma	0.245	4.962E+06
		SCNID/IL	2.04E-10	2.36E-08	5.20E-08	2.00E-07	Gamma	0.500	9.621E+06

Note – JEFF/CL is the posterior distribution at the component level of a Bayesian update of the Jeffreys noninformative prior with industry data, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

2.4 Industry-Average Baselines

Table 2-6 lists the industry-average failure rate distributions. For ELS, the EB/PL/KS result indicated an α parameter lower than 0.3. As explained in Section A.1 in Reference 14, in these cases a lower limit of 0.3 (upper bound on the uncertainty band) was assumed. 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 2-6. Selected industry distributions of p and λ for ACCs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	ELS	EB/PL/KS	5.29E-12	1.20E-08	4.94E-08	2.26E-07	Gamma	0.300	6.072E+06
	ELL	ELS/EPIX	3.70E-13	8.43E-10	3.46E-09	1.58E-08	Gamma	0.300	8.675E+07

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 2-7 shows the rounded values for the ACC failure modes.

Table 2-7. Selected industry distributions of p and λ for ACCs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	ELS	EB/PL/KS	5.0E-12	1.2E-08	5.0E-08	2.5E-07	Gamma	0.30	6.00E+06
	ELL	ELS/EPIX	3.0E-13	7.0E-10	3.0E-09	1.5E-08	Gamma	0.30	1.00E+08

2.5 Breakdown by System

ACC UR results (Jeffreys means of system data) are compared by system and failure mode in Table 2-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 2-8. ACC p and λ by system.

System	ELS
CIS	-
EPS	-
ESW	-
FWS	1.5E-06
HCS	-
HPI	-
IAS	-
LPI	-
MFW	-
MSS	2.1E-07
OEP	-
RCS	-
RGW	-
RRS	7.1E-06
SLC	-
VSS	-

3 Air Dryer Unit (ADU)

3.1 Component Description

The air dryer unit (ADU) boundary includes the air dryer unit. The failure mode for ADU is listed in Table 3-1.

Table 3-1. ADU failure modes.

Operation	Failure Mode	Parameter	Units	Description
Running	FTOP	λ	1/h	Fail to operate

3.2 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.

3.3 Industry-Average Baselines

Table 3-2 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 3-2. Selected industry distributions of p and λ for ADUs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 3-3 shows the rounded value for the ADU failure mode.

Table 3-3. Selected industry distributions of p and λ for ADUs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	FTOP	WSRC	5.0E-10	1.2E-06	5.0E-06	2.5E-05	Gamma	0.30	6.00E+04

4 Air Handling Unit (AHU)

4.1 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 4-1.

Table 4-1. AHU failure modes.

Operation	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

4.2 Data Collection and Review

Data for AHU UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. There are 428 AHUs from 51 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1 in Reference 14) there were 428 components in 51 plants. These data were then further partitioned into standby and running/alternating components. The systems and operational status included in the AHU data collection are listed in Table 4-2 with the number of components included with each system.

Table 4-2. AHU systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 200 Demands per Year
Standby	AFW	Auxiliary feedwater	1	1	1
	CCW	Component cooling water	1	1	1
	CHW	Chilled water system	2	2	2
	EPS	Emergency power supply	55	55	55
	ESW	Emergency service water	6	6	6
	HVC	Heating ventilation and air conditioning	165	165	162
	LPI	Low pressure injection	2	2	2
	Total		232	232	229
Running/ Alternating	CHW	Chilled water system	2	2	2
	DCP	Plant dc power	2	2	2
	EPS	Emergency power supply	6	6	6
	HVC	Heating ventilation and air conditioning	184	184	164
	IAS	Instrument air	2	2	2
	Total		196	196	176

The data review process is described in detail in Section A.1 in Reference 14. Table 4-3 summarizes the data obtained from EPIX and used in the AHU analysis. Note that for the running/alternating AHUs, those components with > 200 demands/year were removed.

Figure 4-1a shows the range of start demands per year in the standby AHU data set. The start demands per year range from approximately 1 to 70. The average for the data set is 19.3 demands/year. Figure 4-1b shows the range of start demands per year in the running AHU data set. The demands per year range from approximately 1 to 80. The average for the data set is 17.5 demands/year.

Table 4-3. AHU unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTS	10	22251	231	39	4.3%	25.6%
	FTR≤1H	4	6965	56	14	1.7%	7.7%
	FTR>1H	5 (0)	146736 h (131445 h)	175	37	1.7%	7.7%
Running/ Alternating	FTS	33	15484	176	32	7.9%	20.5%
	FTR	24	4864939 h	176	32	7.4%	30.8%

Note – The reviewed data entries in parentheses for FTR>1H are after processing to remove events expected to have occurred within 1 h and to remove the first hour of operation. That process is explained in Section A.1 in Reference 14.

Figure 4-2a shows the range of run hours per demand in the standby AHU data set. The run hours per demand range is from approximately 1 hour/demand to 324 hours/demand. The average is 19.3 hours/demand. Figure 4-2b shows the range of run hours per demand in the running AHU data set. The range is from approximately 37 hours/demand to 17,512 hours/demand. The average is 1526.8 hours/demand.

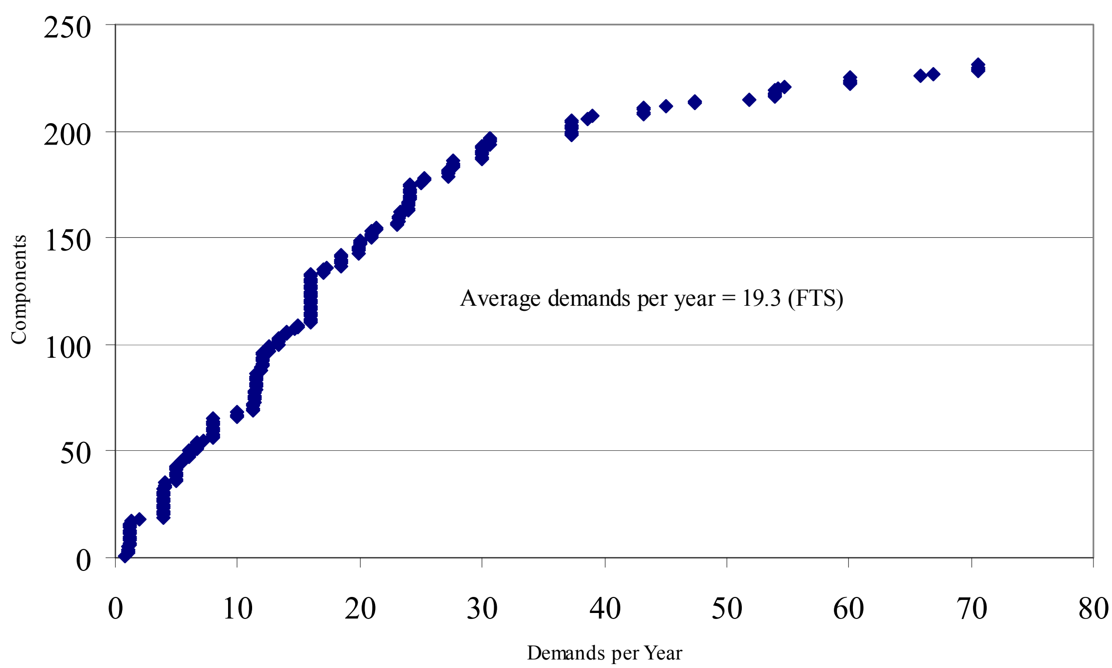

Figure 4-1a. Standby AHU demands per year distribution.

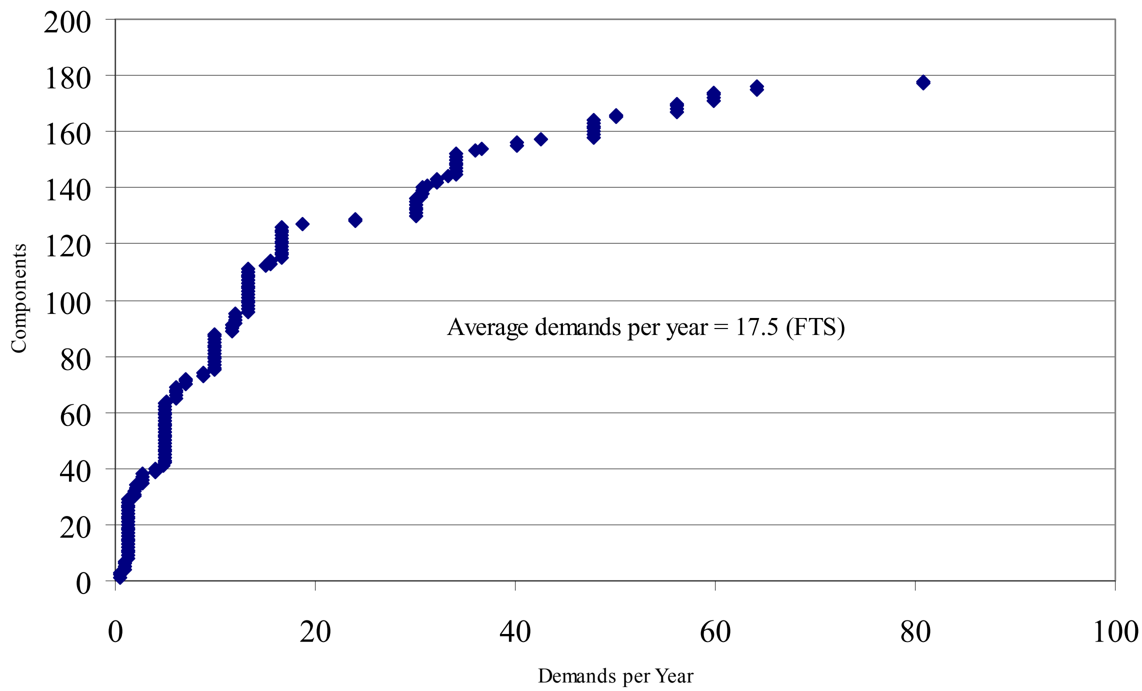

Figure 4-1b. Running/alternating AHU demands per year distribution.

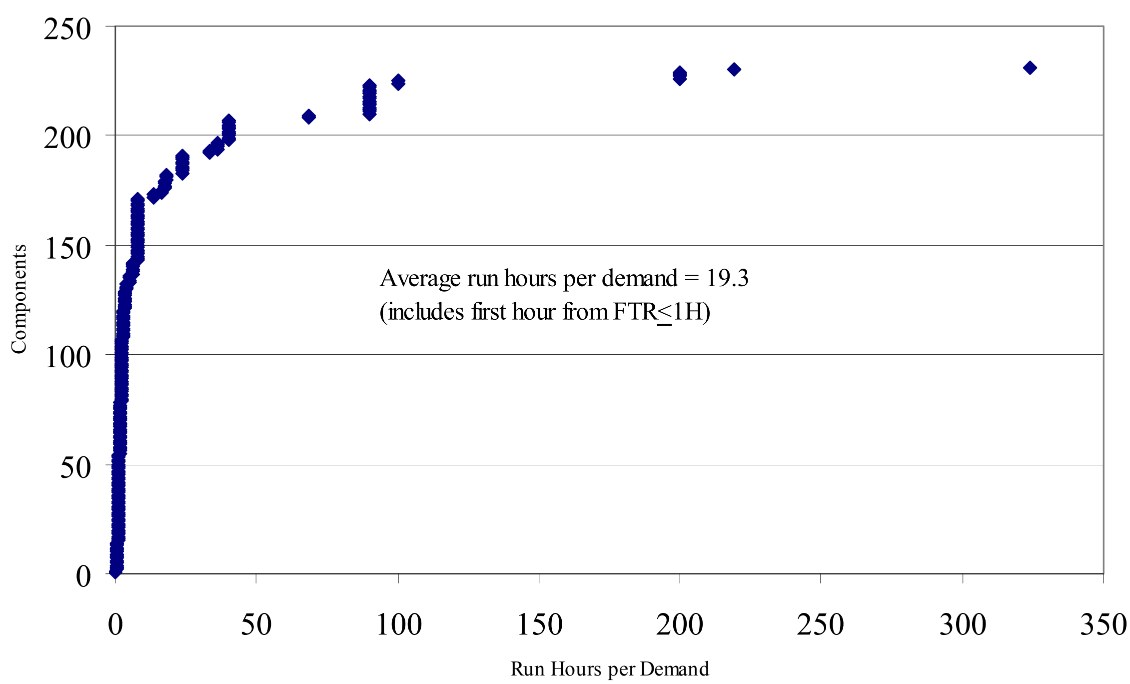

Figure 4-2a. Standby AHU run hours per demand distribution.

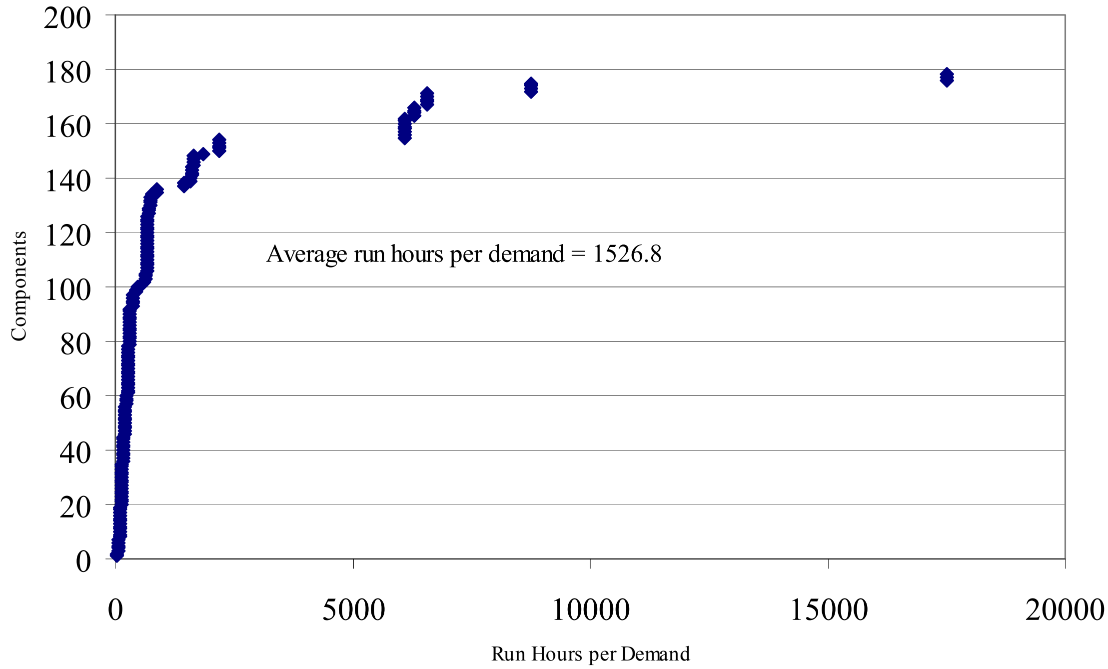

Figure 4-2b. Running/alternating AHU run hours per demand distribution.

4.3 Data Analysis

The AHU data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 4-4.

Table 4-4. Empirical distributions of MLEs for p and λ for AHUs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Standby	FTS	Component	0.00E+00	0.00E+00	8.15E-04	0.00E+00
		Plant	0.00E+00	0.00E+00	2.20E-03	9.07E-03
		Industry	-	-	4.51E-04	-
	FTR≤1H	Component	0.00E+00	0.00E+00	3.92E-03	5.37E-03
		Plant	0.00E+00	0.00E+00	3.31E-03	1.45E-02
		Industry	-	-	5.75E-04	-
	FTR>1H	Component	-	-	-	-
		Plant	-	-	-	-
		Industry	-	-	0.00E+00	-
Running/ Alternating	FTS	Component	0.00E+00	0.00E+00	4.45E-03	2.00E-02
		Plant	0.00E+00	0.00E+00	2.32E-03	8.77E-03
		Industry	-	-	2.13E-03	-
	FTR	Component	0.00E+00	0.00E+00	9.86E-06	4.60E-05
		Plant	0.00E+00	0.00E+00	2.12E-05	1.08E-04
		Industry	-	-	4.93E-06	-

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 4-3, only 4.3% of the AHUs experienced a FTS over the period 1998–2002, so the empirical distribution of MLEs, at the

component level, involves zeros for the 0% to 95.7% portion of the distribution, and non-zero values above 95.7%.

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table 4-5 for AHUs.

Table 4-5. Fitted distributions for p and λ for AHUs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/CL/KS	8.22E-09	8.93E-05	5.16E-04	2.50E-03	Beta	0.249	4.816E+02
		EB/PL/KS	4.10E-07	2.65E-04	8.29E-04	3.57E-03	Beta	0.360	4.346E+02
		SCNID/IL	1.87E-06	2.16E-04	4.74E-04	1.82E-03	Beta	0.500	1.054E+03
	FTR≤1H	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	3.01E-11	1.02E-04	2.28E-03	1.25E-02	Gamma	0.153	6.727E+01
		SCNID/IL	2.54E-06	2.94E-04	6.47E-04	2.48E-03	Gamma	0.500	7.733E+02
	FTR>1H	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.50E-08	1.73E-06	3.80E-06	1.46E-05	Gamma	0.500	1.314E+05
Running/ Alternating	FTS	EB/CL/KS	8.86E-18	6.89E-06	3.58E-03	2.11E-02	Beta	0.084	2.339E+01
		EB/PL/KS	3.40E-09	2.96E-04	2.73E-03	1.40E-02	Beta	0.203	7.420E+01
		SCNID/IL	8.53E-06	9.87E-04	2.16E-03	8.30E-03	Beta	0.500	2.307E+02
	FTR	EB/CL/KS	2.36E-18	3.59E-08	6.75E-06	3.92E-05	Gamma	0.098	1.455E+04
		EB/PL/KS	2.23E-11	1.55E-06	1.37E-05	6.98E-05	Gamma	0.207	1.513E+04
		SCNID/IL	1.98E-08	2.29E-06	5.04E-06	1.93E-05	Gamma	0.500	9.929E+04

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

4.4 Industry-Average Baselines

Table 4-6 lists the industry-average failure rate distributions. For four of the five failure modes, the data sets were sufficient for empirical Bayes analyses to be performed. For these failure modes, the industry-average distributions are based on the empirical Bayes analysis results at the plant level. However, three of the results indicated α parameters lower than 0.3. As explained in Section A.1 in Reference 14, in these cases a lower limit of 0.3 (upper bound on the uncertainty band) was assumed. The industry-average distribution for FTR>1H is not sufficient (Section A.1 in Reference 14) for the empirical Bayes method; therefore a SCNID analysis was performed to provide a failure rate distribution. Note that this distribution is based on zero failures and may be conservatively high. These industry-average failure rates do not account for any recovery.

Table 4-6. Selected industry distributions of p and λ for AHUs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/PL/KS	4.10E-07	2.65E-04	8.29E-04	3.57E-03	Beta	0.360	4.346E+02
	FTR≤1H	EB/PL/KS	2.44E-07	5.55E-04	2.28E-03	1.04E-02	Gamma	0.300	1.317E+02
	FTR>1H	SCNID/IL	1.50E-08	1.73E-06	3.80E-06	1.46E-05	Gamma	0.500	1.314E+05
Running/	FTS	EB/PL/KS	2.93E-07	6.66E-04	2.73E-03	1.24E-02	Beta	0.300	1.101E+02
Alternating	FTR	EB/PL/KS	1.46E-09	3.33E-06	1.37E-05	6.25E-05	Gamma	0.300	2.194E+04

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 4-7 shows the rounded values for the AHU failure modes.

Table 4-7. Selected industry distributions of p and λ for AHUs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/PL/KS	8.0E-07	3.0E-04	8.0E-04	3.0E-03	Beta	0.40	5.00E+02
	FTR≤1H	EB/PL/KS	2.5E-07	6.0E-04	2.5E-03	1.2E-02	Gamma	0.30	1.20E+02
	FTR>1H	SCNID/IL	1.5E-08	2.0E-06	4.0E-06	1.5E-05	Gamma	0.50	1.25E+05
Running/ Alternating	FTS	EB/PL/KS	2.5E-07	6.0E-04	2.5E-03	1.2E-02	Beta	0.30	1.20E+02
	FTR	EB/PL/KS	1.5E-09	4.0E-06	1.5E-05	7.0E-05	Gamma	0.30	2.00E+04

4.5 Breakdown by System

AHU UR results (Jeffreys means of system data) are compared by system and failure mode in Table 4-8. Results are shown only for the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 4-8. AHU p and λ by system.

Operation	System	FTS	FTR≤1H	FTR>1H
Standby	AFW	-	-	-
	CCW	-	-	-
	CHW	1.2E-02	-	-
	EPS	5.0E-04	5.4E-03	-
	ESW	-	-	-
	HVC	4.5E-04	3.9E-04	-
Operation	System	FTS		FTR
Running/ Alternating	CHW	4.2E-02		5.7E-05
	DCP	-		-
	EPS	4.6E-03		-
	HVC	1.7E-03		4.8E-06
	IAS	-		2.6E-05

5 Air-Operated Valve (AOV)

5.1 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. The failure modes for AOV are listed in Table 5-1.

Table 5-1. AOV failure modes.

Operation	Failure Mode	Parameter	Units	Description
Standby	FTO/C	p	-	Failure to open or failure to close
	SO	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

5.2 Data Collection and Review

Most of the data for AOV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. (The AOV external and internal leakage data cover 1997–2004 and were directly extracted from EPIX. EPIX contained a total of 2771 AOVs that were used for the external and internal leakage data.) There are 3443 AOVs from 98 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1 in Reference 14) there were 3363 components in 98 plants. The systems included in the AOV data collection are listed in Table 5-2 with the number of components included with each system.

Table 5-2. AOV systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
Standby	AFW	Auxiliary feedwater	271	251	183
	CCW	Component cooling water	295	280	241
	CDS	Condensate system	7	7	7
	CHW	Chilled water system	5	5	5
	CIS	Containment isolation system	853	846	707
	CRD	Control rod drive	99	98	86
	CSR	Containment spray recirculation	27	27	23
	CVC	Chemical and volume control	397	389	355
	EPS	Emergency power supply	34	34	25
	ESW	Emergency service water	359	357	206
	FWS	Firewater	1	1	1
	HCI	High pressure coolant injection	11	9	7
	HPI	High pressure injection	94	91	67
	HVC	Heating ventilation and air conditioning	189	189	128
	IAS	Instrument air	18	18	18
	ICS	Ice condenser	13	13	13
	ISO	Isolation condenser	6	6	2
	LCI	Low pressure coolant injection	33	31	31
	LCS	Low pressure core spray	14	14	14
	LPI	Low pressure injection	149	131	107
	MFW	Main feedwater	215	215	207
	MSS	Main steam	132	132	122
	NSW	Normal service water	99	99	99
	RCI	Reactor core isolation	6	5	5

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
	RCS	Reactor coolant	37	37	28
	RGW	Radioactive gaseous waste	2	2	1
	RPS	Reactor protection	13	13	13
	RRS	Reactor recirculation	19	18	16
	SLC	Standby liquid control	1	1	1
	TBC	Turbine building cooling water	2	2	1
	VSS	Vapor suppression	42	42	37
	Total		3443	3363	2756

The AOV data set obtained from RADS was further reduced to include only those AOVs with ≤ 20 demands/year. See Section A.1 in Reference 14 for a discussion concerning this decision to limit certain component populations. Table 5-3 summarizes the data used in the AOV analysis. Note that the hours for SO, ELS, and ILS are calendar hours. The FC failure mode is not supported with EPIX data.

Table 5-3. AOV unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
Standby	FTO/C	76	80117	2756	98	2.4%	43.9%
	SO	20	120712800 h	2756	98	0.7%	10.2%
	ELS	2	194191680 h	2771	98	0.1%	2.0%
	ILS	49	194191680 h	2771	98	1.6%	25.5%
Control	FC	-	-	-	-	-	-

Figure 5-1 shows the range of valve demands per year in the AOV data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 20. The average for the data set is 5.8 demands/year.

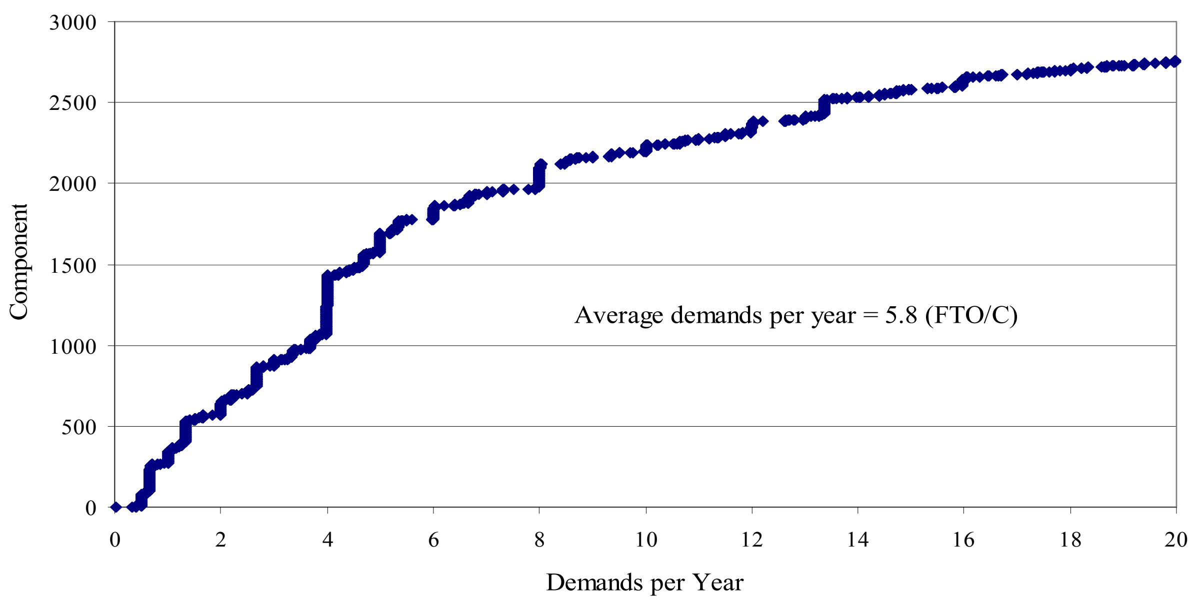

Figure 5-1. AOV demands per year distribution.

5.3 Data Analysis

The AOV data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 5-4. The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 5-3, only 2.4% of the AOVs experienced a FTO/C over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 97.6% portion of the distribution, and non-zero values above 97.6%.

Table 5-4. Empirical distributions of MLEs for p and λ for AOVs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Standby	FTO/C	Component	0.00E+00	0.00E+00	2.18E-03	0.00E+00
		Plant	0.00E+00	0.00E+00	1.67E-03	9.67E-03
		Industry	-	-	9.49E-04	-
	SO	Component	0.00E+00	0.00E+00	1.66E-07	0.00E+00
		Plant	0.00E+00	0.00E+00	1.53E-07	1.09E-06
		Industry	-	-	1.66E-07	-
	ELS	Component	0.00E+00	0.00E+00	1.03E-08	0.00E+00
		Plant	0.00E+00	0.00E+00	1.66E-08	0.00E+00
		Industry	-	-	1.03E-08	-
	ILS	Component	0.00E+00	0.00E+00	2.52E-07	0.00E+00
		Plant	0.00E+00	0.00E+00	2.06E-07	1.06E-06
		Industry	-	-	2.52E-07	-
Control	FC	-	-	-	-	-

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table 5-5.

Table 5-5. Fitted distributions for p and λ for AOVs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTO/C	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	5.75E-05	7.69E-04	1.11E-03	3.31E-03	Beta	1.005	9.075E+02
		SCNID/IL	3.76E-06	4.35E-04	9.55E-04	3.67E-03	Beta	0.500	5.232E+02
	SO	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	5.26E-18	2.40E-09	1.82E-07	1.04E-06	Gamma	0.116	6.356E+05
		SCNID/IL	6.68E-10	7.72E-08	1.70E-07	6.52E-07	Gamma	0.500	2.945E+06
	ELS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	5.06E-11	5.86E-09	1.29E-08	4.94E-08	Gamma	0.500	3.885E+07
	ILS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	3.39E-09	1.36E-07	2.42E-07	8.39E-07	Gamma	0.661	2.737E+06
		SCNID/IL	1.00E-09	1.16E-07	2.55E-07	9.79E-07	Gamma	0.500	1.962E+06
Control	FC	-	-	-	-	-	-	-	-

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

5.4 Industry-Average Baselines

Table 5-6 lists the selected industry distributions of p and λ for the AOV failure modes. For the FTO/C, SO, and ILS failure modes, the data sets were sufficient (see Section A.1 in Reference 14) for empirical Bayes analyses to be performed. Therefore, the industry-average distribution is based on the empirical Bayes analysis results at the plant level for FTO/C, SO, and ILS. However, the industry-average distribution for ELS is not sufficient (Section A.1 in Reference 14) for the empirical Bayes method; therefore, a SCNID analysis was performed to provide a failure rate distribution. For SO, the EB/PL/KS result indicated an α parameter lower than 0.3. As explained in Section A.1 in Reference 14, in these cases a lower limit of 0.3 (upper bound on the uncertainty band) was assumed. 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. The FC failure mode distribution was derived from the Westinghouse Savannah River Company (WSRC) database. That source lists Category 2 data (see Section A.1 in Reference 14) for AOV control valves from sources other than commercial power plants. The selected value from WSRC was used as the mean, with an assumed α of 0.3. These industry-average failure rates do not account for any recovery.

Table 5-6. Selected industry distributions of p and λ for AOVs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTO/C	EB/PL/KS	5.75E-05	7.69E-04	1.11E-03	3.31E-03	Beta	1.005	9.075E+02
	SO	EB/PL/KS	1.95E-11	4.43E-08	1.82E-07	8.31E-07	Gamma	0.300	1.651E+06
	ELS	SCNID/IL	5.06E-11	5.86E-09	1.29E-08	4.94E-08	Gamma	0.500	3.885E+07
	ELL	ELS/EPIX	9.64E-14	2.20E-10	9.01E-10	4.12E-09	Gamma	0.300	3.330E+08
	ILS	EB/PL/KS	3.39E-09	1.36E-07	2.42E-07	8.39E-07	Gamma	0.661	2.737E+06
	ILL	ILS/EPIX	5.17E-13	1.18E-09	4.83E-09	2.21E-08	Gamma	0.300	6.208E+07
Control	FC	WSRC	3.21E-10	7.31E-07	3.00E-06	1.37E-05	Gamma	0.300	1.000E+05

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 5-7 shows the rounded values for the AOV.

Table 5-7. Selected industry distributions of p and λ for AOVs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTO/C	EB/PL/KS	6.0E-05	8.0E-04	1.2E-03	4.0E-03	Beta	1.00	8.33E+02
	SO	EB/PL/KS	2.0E-11	5.0E-08	2.0E-07	9.0E-07	Gamma	0.30	1.50E+06
	ELS	SCNID/IL	5.0E-11	5.0E-09	1.2E-08	5.0E-08	Gamma	0.50	4.17E+07
	ELL	ELS/EPIX	1.0E-13	2.0E-10	9.0E-10	4.0E-09	Gamma	0.30	3.33E+08
	ILS	EB/PL/KS	4.0E-09	1.5E-07	2.5E-07	9.0E-07	Gamma	0.70	2.80E+06
	ILL	ILS/EPIX	5.0E-13	1.2E-09	5.0E-09	2.5E-08	Gamma	0.30	6.00E+07
Control	FC	WSRC	3.0E-10	7.0E-07	3.0E-06	1.5E-05	Gamma	0.30	1.00E+05

5.5 Breakdown by System

AOV UR results (Jeffreys means of system data) are compared by system and failure mode in Table 5-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 5-8. AOV p and λ by system.

System	FTO/C	SO	ELS	ILS
AFW	9.1E-04	4.4E-07	-	-
CCW	9.8E-04	3.3E-07	-	1.5E-07
CDS	-	-	-	-
CHW	-	-	-	-
CIS	8.1E-04	-	-	5.5E-07
CRD	6.3E-04	1.2E-06	-	-
CSR	-	-	-	-
CVC	1.6E-03	4.2E-07	-	1.8E-07
EPS	-	-	-	-
ESW	1.6E-03	-	-	-
FWS	-	-	-	-
HCI	-	-	-	-
HPI	-	-	-	-
HVC	4.5E-04	-	-	2.8E-07
IAS	2.9E-03	-	-	2.8E-06
ICS	-	-	-	2.7E-06
ISO	-	-	-	-
LCI	-	-	-	-
LCS	3.1E-03	-	-	-
LPI	1.5E-03	3.2E-07	2.0E-07	-
MFW	3.4E-03	1.7E-07	1.0E-07	3.1E-07
MSS	2.0E-03	4.7E-07	-	1.8E-07
NSW	-	-	-	-
RCI	-	-	-	-
RCS	-	-	-	7.6E-07
RGW	-	-	-	-
RPS	-	-	-	1.6E-06
RRS	-	-	-	1.3E-06
SLC	-	-	-	-
TBC	-	-	-	-
VSS	-	-	-	5.8E-07

6 Battery (BAT)

6.1 Component Description

The battery (BAT) boundary includes the battery cells. The failure mode for BAT is listed in Table 6-1.

Table 6-1. BAT failure modes.

Operation	Failure Mode	Parameter	Units	Description
Running	FTOP	λ	1/h	Fail to operate

6.2 Data Collection and Review

Data for BAT UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. Failures were identified using the FTOP failure mode, but components were identified using the FTR failure mode. There are 363 BATs from 89 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1 in Reference 14) there were 363 components in 89 plants. The systems included in the BAT data collection are listed in Table 6-2 with the number of components included with each system.

Table 6-2. BAT systems.

Operation	System	Description	Number of Components	
			Initial	After Review
Running	DCP	Plant dc power	363	363
	Total		363	363

The data review process is described in detail in Section A.1 in Reference 14. Table 6-3 summarizes the data obtained from EPIX and used in the BAT analysis.

Table 6-3. BAT unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Running	FTOP	27 (27)	14926799 h (15899400 h)	363	89	6.1%	21.3%

Note: The reviewed data entries in parentheses are after processing to adjust the run hours to the full calendar time. That process is explained in Section A.1 in Reference 14.

6.3 Data Analysis

The BAT data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 6-4.

Table 6-4. Empirical distributions of MLEs for p and λ for BATs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Running	FTOP	Component	0.00E+00	0.00E+00	1.70E-06	2.28E-05
		Plant	0.00E+00	0.00E+00	2.34E-06	1.14E-05
		Industry	-	-	1.70E-06	-

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 6-3, only 6.1% of the BATs experienced a FTOP over the period 1998–2002, so the empirical distribution of MLEs, at the

component level, involves zeros for the 0% to 93.9% portion of the distribution, and non-zero values above 93.9%.

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table 6-5 for BATs.

Table 6-5. Fitted distributions for p and λ for BATs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	FTOP	EB/CL/KS	5.14E-13	1.40E-07	1.70E-06	8.93E-06	Gamma	0.184	1.085E+05
		EB/PL/KS	2.94E-09	7.26E-07	1.86E-06	7.57E-06	Gamma	0.427	2.290E+05
		SCNID/IL	6.80E-09	7.87E-07	1.73E-06	6.65E-06	Gamma	0.500	2.890E+05

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

6.4 Industry-Average Baselines

Table 6-6 lists the industry-average failure rate distribution. The data set was sufficient (Section A.1 in Reference 14) for empirical Bayes analyses to be performed. The industry-average distribution is based on the empirical Bayes analysis results at the plant level. This industry-average failure rate does not account for any recovery.

Table 6-6. Selected industry distributions of p and λ for BATs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	FTOP	EB/PL/KS	2.94E-09	7.26E-07	1.86E-06	7.57E-06	Gamma	0.427	2.290E+05

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 6-7 shows the rounded value for the BAT failure mode.

Table 6-7. Selected industry distributions of p and λ for BATs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	FTOP	EB/PL/KS	2.0E-09	7.0E-07	2.0E-06	8.0E-06	Gamma	0.40	2.00E+05

6.5 Breakdown by System

The BAT component is only in one system, the dc power system.

7 Battery Charger (BCH)

7.1 Component Description

The battery charger (BCH) boundary includes the battery charger and its breakers. The failure mode for BAT is listed in Table 7-1.

Table 7-1. BCH failure modes.

Operation	Failure Mode	Parameter	Units	Description
Running/Alternating	FTOP	λ	1/h	Fail to operate

7.2 Data Collection and Review

Data for BCH UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. Failures were identified using the FTOP failure mode, but components were identified using the FTR failure mode. There are 392 BCHs from 65 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1 in Reference 14) there were 392 components in 65 plants. The systems included in the BCH data collection are listed in Table 7-2 with the number of components included with each system.

Table 7-2. BCH systems.

Operation	System	Description	Number of Components	
			Initial	After Review
Running/ Alternating	DCP	Plant dc power	392	392
	Total		392	392

The data review process is described in detail in Section A.1 in Reference 14. Table 7-3 summarizes the data obtained from EPIX and used in the BCH analysis.

Table 7-3. BCH unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Running/ Alternating	FTOP	80 (80)	14785007 h (17169600 h)	392	65	15.8%	60.0%

Note: The reviewed data entries in parentheses are after processing to adjust the run hours to the full calendar time. That process is explained in Section A.1 in Reference 14.

7.3 Data Analysis

The BCH data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 7-4.

Table 7-4. Empirical distributions of MLEs for p and λ for BCHs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Running/ Alternating	FTOP	Component	0.00E+00	0.00E+00	4.66E-06	2.28E-05
		Plant	0.00E+00	3.81E-06	5.52E-06	1.71E-05
		Industry	-	-	4.66E-06	-

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 7-3, only 15.8% of the BCHs experienced a FTOP over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 84.2% portion of the distribution, and non-zero values above 84.2%.

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table 7-5 for BCHs. These results were used to develop the industry-average distributions for FTOP.

Table 7-5. Fitted distributions for *p* and *λ* for BCHs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	*α*	*β*
Running/ Alternating	FTOP	EB/CL/KS	2.03E-08	2.16E-06	4.66E-06	1.78E-05	Gamma	0.510	1.095E+05
		EB/PL/KS	6.51E-07	4.06E-06	5.08E-06	1.30E-05	Gamma	1.585	3.121E+05
		SCNID/IL	1.84E-08	2.13E-06	4.69E-06	1.80E-05	Gamma	0.500	1.066E+05

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

7.4 Industry-Average Baselines

Table 7-6 lists the industry-average failure rate distribution. The data set was sufficient (Section A.1 in Reference 14) for empirical Bayes analyses to be performed. The industry-average distribution is based on the empirical Bayes analysis results at the plant level. This industry-average failure rate does not account for any recovery.

Table 7-6. Selected industry distributions of *p* and *λ* for BCHs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	*α*	*β*
Running/ Alternating	FTOP	EB/PL/KS	6.51E-07	4.06E-06	5.08E-06	1.30E-05	Gamma	1.585	3.121E+05

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the *α* parameter was rounded. In order to preserve the mean value, the *β* parameter is presented to three significant figures. Table 7-7 shows the rounded value for the BCH failure mode.

Table 7-7. Selected industry distributions of *p* and *λ* for BCHs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	*α*	*β*
Running/ Alternating	FTOP	EB/PL/KS	6.0E-07	4.0E-06	5.0E-06	1.2E-05	Gamma	1.50	3.00E+05

7.5 Breakdown by System

The BCH component is only in one system, the dc power system.

8 Bistable (BIS)

8.1 Component Description

The bistable (BIS) boundary includes the bistable unit itself. The failure mode for BIS is listed in Table 8-1.

Table 8-1. BIS failure modes.

Operation	Failure Mode	Parameter	Units	Description
Running	FTOP	*p*	-	Fail to operate

8.2 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 8-2 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 8-2. BIS unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Running	FTOP	55	102094	-	-	-	-

8.3 Industry-Average Baselines

Table 8-3 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 8-3. Selected industry distributions of p and λ for BISs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 8-4 shows the rounded value for the BIS failure mode.

Table 8-4. Selected industry distributions of p and λ for BISs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	FTOP	RPS SS	2.0E-06	2.5E-04	5.0E-04	2.0E-03	Beta	0.50	1.00E+03

9 Bus (BUS)

9.1 Component Description

The bus (BUS) boundary includes the bus component itself. Associated circuit breakers and step-down transformers are not included. The failure mode for BUS is listed in Table 9-1.

Table 9-1. BUS failure modes.

Operation	Failure Mode	Parameter	Units	Description
Running	FTOP	λ	1/h	Fail to operate

9.2 Data Collection and Review

Data for the BUS UR baseline were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. Failures were identified using the FTOP failure mode, but components were identified using the FTR failure mode. There are 164 BUSs from 11 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1 in Reference 14) there were 164 components in 11 plants. The systems included in the BUS data collection are listed in Table 9-2 with the number of components included with each system.

Table 9-2. BUS systems.

Operation	System	Description	Number of Components	
			Initial	After Review
Running	ACP	Plant ac power	117	117
	DCP	Plant dc power	33	33
	EPS	Emergency power supply	9	9
	OEP	Offsite electrical power	4	4
	RPS	Reactor protection	1	1
	Total		164	164

The data review process is described in detail in Section A.1 in Reference 14. Table 9-3 summarizes the data obtained from EPIX and used in the BUS analysis. Note that the hours are calendar hours.

Table 9-3. BUS unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Running	FTOP	3	7183200 h	164	11	1.2%	18.2%

9.3 Data Analysis

The BUS data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 9-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 9-3, only 1.2% of the BUSs experienced a FTOP over the period 1997–2004, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 98.8% portion of the distribution, and non-zero values above 98.8%.

Table 9-4. Empirical distributions of MLEs for p and λ for BUSs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Running	FTOP	Component	0.00E+00	0.00E+00	4.18E-07	0.00E+00
		Plant	0.00E+00	0.00E+00	3.09E-07	9.93E-07
		Industry	-	-	4.18E-07	-

The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table 9-5 for BUSs.

Table 9-5. Fitted distributions for p and λ for BUSs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	FTOP	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	1.74E-09	1.98E-07	4.34E-07	1.67E-06	Gamma	0.502	1.155E+06
		SCNID/IL	1.91E-09	2.22E-07	4.87E-07	1.87E-06	Gamma	0.500	1.027E+06

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

9.4 Industry-Average Baselines

Table 9-6 lists the industry-average failure rate distribution. The data set was sufficient (Section A.1 in Reference 14) for empirical Bayes analyses to be performed. This industry-average failure rate does not account for any recovery.

Table 9-6. Selected industry distributions of p and λ for BUSs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	FTOP	EB/PL/KS	1.74E-09	1.98E-07	4.34E-07	1.67E-06	Gamma	0.502	1.155E+06

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 9-7 shows the rounded value for the BUS failure mode.

Table 9-7. Selected industry distributions of p and λ for BUSs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	FTOP	EB/PL/KS	1.5E-09	2.0E-07	4.0E-07	1.5E-06	Gamma	0.50	1.25E+06

9.5 Breakdown by System

BUS UR results (Jeffreys means of system data) are compared by system and failure mode in Table 9-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 9-8. BUS p and λ by system.

System	FTOP
ACP	6.4E-07
DCP	-
EPS	-
OEP	-
RPS	-

10 Circuit Breaker (CBK)

10.1 Component Description

The circuit breaker (CBK) is defined as the breaker itself and local instrumentation and control circuitry. External equipment used to monitor under voltage, ground faults, differential faults, and other protection schemes for individual breakers are considered part of the breaker. The failure modes for CBK are listed in Table 10-1.

Table 10-1. CBK failure modes.

Operation	Failure Mode	Parameter	Units	Description
All	FTO/C	p	-	Failure to open or failure to close
	SO	λ	1/h	Spurious operation

10.2 Data Collection and Review

Data for CBK UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. The breakers included in the CBK data are those that are used in the power distribution function and do not include load breakers or reactor trip breakers. There are 4211 CBKs from 97 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1 in Reference 14) there were 4050 components in 97 plants. The systems included in the CBK data collection are listed in Table 10-2 with the number of components included with each system.

Table 10-2. CBK systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
All	ACP	Plant ac power	3115	2989	2972
	DCP	Dc power	868	844	839
	EPS	Emergency power supply	110	109	103
	OEP	Offsite electrical power	118	108	108
	Total		4211	4050	4022

The CBK data set obtained from RADS was further reduced to include only those CBKs with ≤ 20 demands/year (≤ 100 demands over 5 years). See Section A.1 in Reference 14 for a discussion concerning this decision to limit certain component populations. Table 10-3 summarizes the data used in the CBK analysis. Note that the hours for SO are calendar hours.

Table 10-3. CBK unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO/C	83	50226	4022	97	1.9%	42.3%
	SO	28	176163600 h	4022	97	0.7%	23.7%

Figure 10-1 shows the range of breaker demands per year in the CBK data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 20. The average for the data set is 2.5 demands/year.

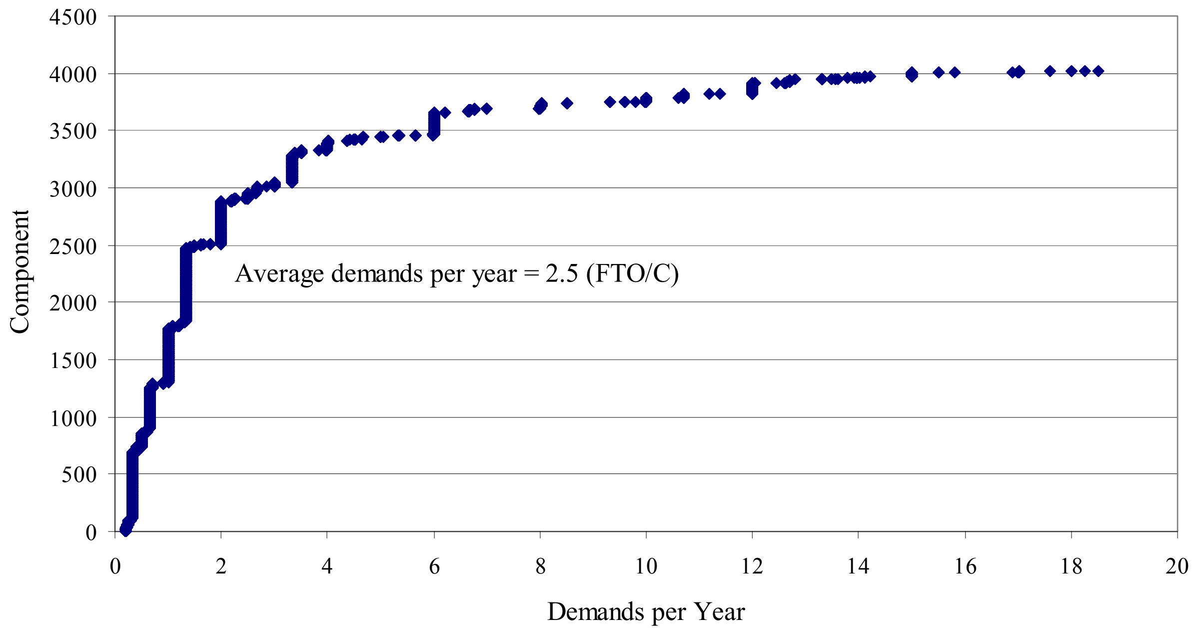

Figure 10-1. CBK demands per year distribution.

10.3 Data Analysis

The CBK data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 10-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 10-3, only 1.9% of the CBKs experienced a FTO/C over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 98.1% portion of the distribution, and non-zero values above 98.1%.

Table 10-4. Empirical distributions of MLEs for p and λ for CBKs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
All	FTO/C	Component	0.00E+00	0.00E+00	4.24E-03	0.00E+00
		Plant	0.00E+00	0.00E+00	5.87E-03	1.93E-02
		Industry	-	-	1.65E-03	-
	SO	Component	0.00E+00	0.00E+00	1.59E-07	0.00E+00
		Plant	0.00E+00	0.00E+00	3.53E-07	1.14E-06
		Industry	-	-	1.59E-07	-

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5.Results from these analyses are presented in Table 10-5.

Table 10-5. Fitted distributions for p and λ for CBKs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO/C	EB/CL/KS	4.30E-27	4.62E-08	2.17E-03	1.19E-02	Beta	0.053	2.414E+01
		EB/PL/KS	4.40E-05	1.49E-03	2.55E-03	8.68E-03	Beta	0.698	2.729E+02
		SCNID/IL	6.55E-06	7.58E-04	1.66E-03	6.38E-03	Beta	0.500	3.003E+02
	SO	JEFF/CL	1.15E-07	1.60E-07	1.62E-07	2.15E-07	Gamma	28.500	1.762E+08
		EB/PL/KS	3.00E-08	1.43E-07	1.71E-07	4.06E-07	Gamma	1.983	1.163E+07
		SCNID/IL	6.36E-10	7.36E-08	1.62E-07	6.22E-07	Gamma	0.500	3.090E+06

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, JEFF/CL is the posterior distribution at the component level of a Bayesian update of the Jeffreys noninformative prior with industry data, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

10.4 Industry-Average Baselines

Table 10-6 lists the selected industry distributions of p and λ for the CBK failure modes. For both the FTO/C and SO failure modes, the data sets were sufficient (see Section A.1 in Reference 14) for empirical Bayes analyses to be performed. Therefore, the industry-average distribution is based on the empirical Bayes analysis results at the plant level for FTO/C and SO. These industry-average failure rates do not account for any recovery.

Table 10-6. Selected industry distributions of p and λ for CBKs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO/C	EB/PL/KS	4.40E-05	1.49E-03	2.55E-03	8.68E-03	Beta	0.698	2.729E+02
	SO	EB/PL/KS	3.00E-08	1.43E-07	1.71E-07	4.06E-07	Gamma	1.983	1.163E+07

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 10-7 shows the rounded values for the CBK failure modes.

Table 10-7. Selected industry distributions of p and λ for CBKs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO/C	EB/PL/KS	4.0E-05	1.5E-03	2.5E-03	9.0E-03	Beta	0.70	2.80E+02
	SO	EB/PL/KS	3.0E-08	1.5E-07	1.5E-07	4.0E-07	Gamma	2.00	1.33E+07

10.5 Breakdown by System

CBK UR results (Jeffreys means of system data) are compared by system and failure mode in Table 10-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 10-8. CBK p and λ by system.

System	FTO/C	SO
ACP	2.0E-03	1.6E-07
DCP	4.6E-04	6.8E-08
EPS	8.4E-04	-
OEP	3.8E-03	1.4E-06

11 Chiller (CHL)

11.1 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 11-1.

Table 11-1. CHL failure modes.

Operation	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

11.2 Data Collection and Review

Data for CHL UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. There are 178 CHLs from 35 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1 in Reference 14) there were 174 components in 31 plants. These data were then further partitioned into standby and running/alternating components. The systems and operational status included in the CHL data collection are listed in Table 11-2 with the number of components included with each system.

Table 11-2. CHL systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 200 Demands per Year
Standby	CHW	Chilled water system	6	6	6
	CIS	Containment isolation system	1	1	1
	HVC	Heating ventilation and air conditioning	54	54	52
	RPS	Reactor protection	2	0	0
	Total		63	61	59
Running/ Alternating	ACP	Plant ac power	30	30	30
	CCW	Component cooling water	3	3	3
	CHW	Chilled water system	13	11	11
	EPS	Emergency power supply	2	2	2
	ESW	Emergency service water	12	12	12
	HVC	Heating ventilation and air conditioning	54	54	54
	OEP	Offsite electrical power	1	1	1
	Total		115	113	113

The data review process is described in detail in Section A.1 in Reference 14. Table 11-3 summarizes the data obtained from EPIX and used in the CHL analysis. Note that components with > 200 demands/year were removed.

Figure 11-1a shows the range of start demands per year in the standby CHL data set. The start demands per year range from approximately 4 to 86. The average for the data set is 18.5 demands/year. Figure 11-1b shows the range of start demands per year in the running CHL data set. The demands per year range from approximately 1 (once per year) to 30. The average for the data set is 11.5 demands/year.

Table 11-3. CHL unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTS	10	5470	59	9	16.9%	44.4%
	FTR≤1H	5	2401 h	38	4	8.5%	33.3%
	FTR>1H	20 (13.7)	19464 h (16427 h)	21	7	22.0%	77.8%
Running/ Alternating	FTS	66	6483	113	22	28.3%	68.2%
	FTR	164	3402465 h	113	22	40.7%	77.3%

Note: The reviewed data entries in parentheses for FTR>1H are after processing to remove events expected to have occurred within 1 h and to remove the first hour of operation. That process is explained in Section A.1 in Reference 14.

Figure 11-2a shows the range of run hours per demand in the standby CHL data set. The run hours per demand range is from approximately 0 hours/demand to 38 hours/demand. The average is 3.7 hours/demand. Figure 11-2b shows the range of run hours per demands in the running CHL data set. The range is from approximately 141 hours/demand to 26,280 hours/demand. The average is 1093.6 hours/demand.

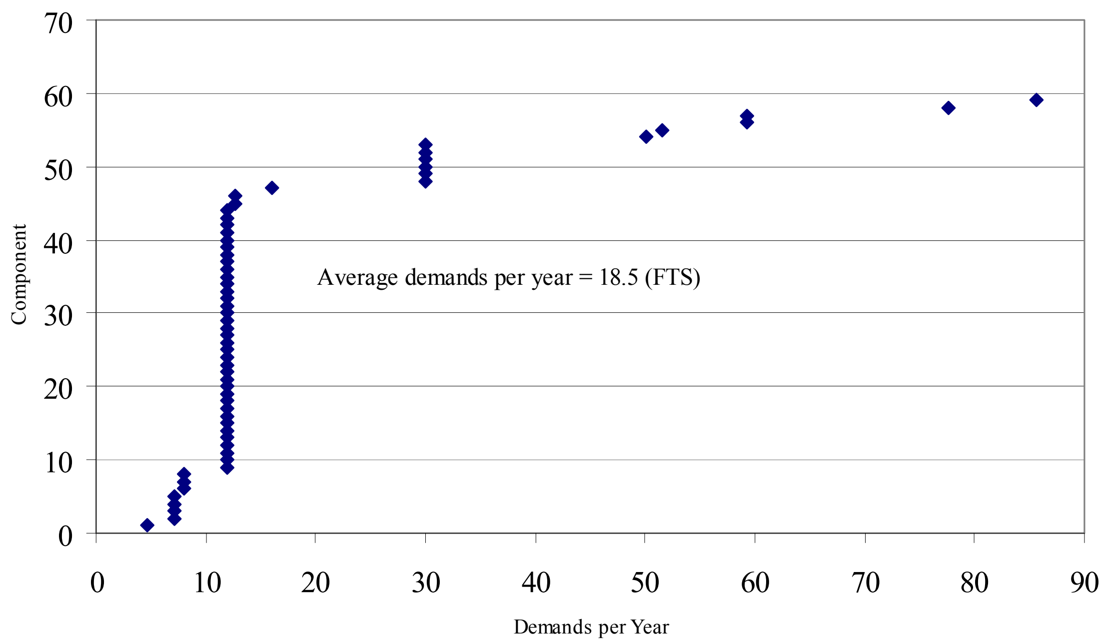

Figure 11-1a. Standby CHL demands per year distribution.

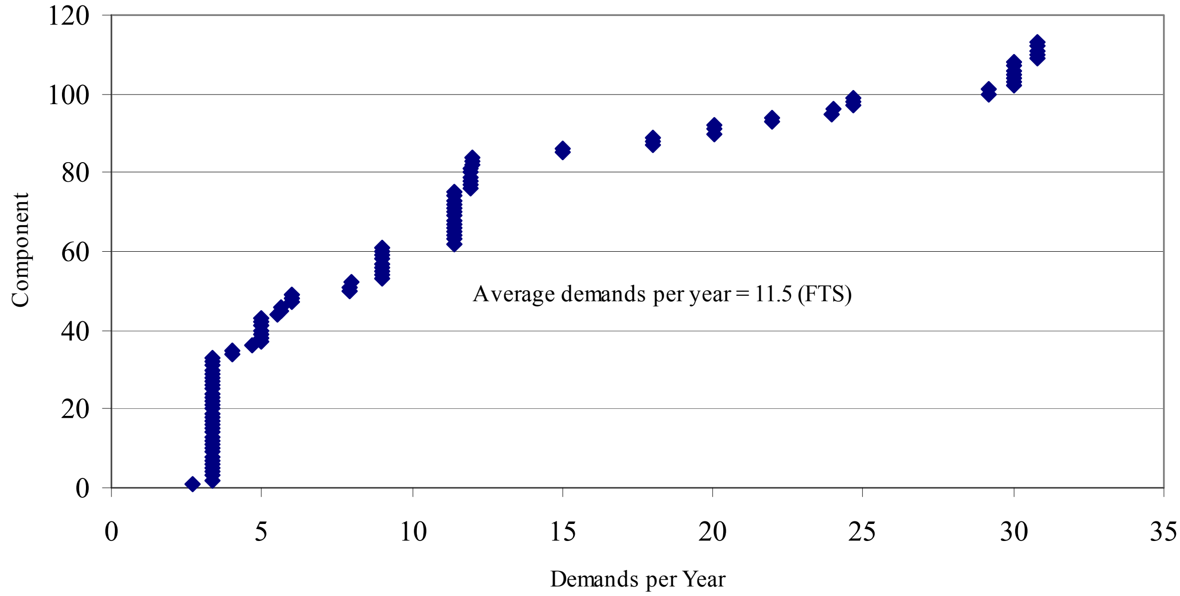

Figure 11-1b. Running/alternating CHL demands per year distribution.

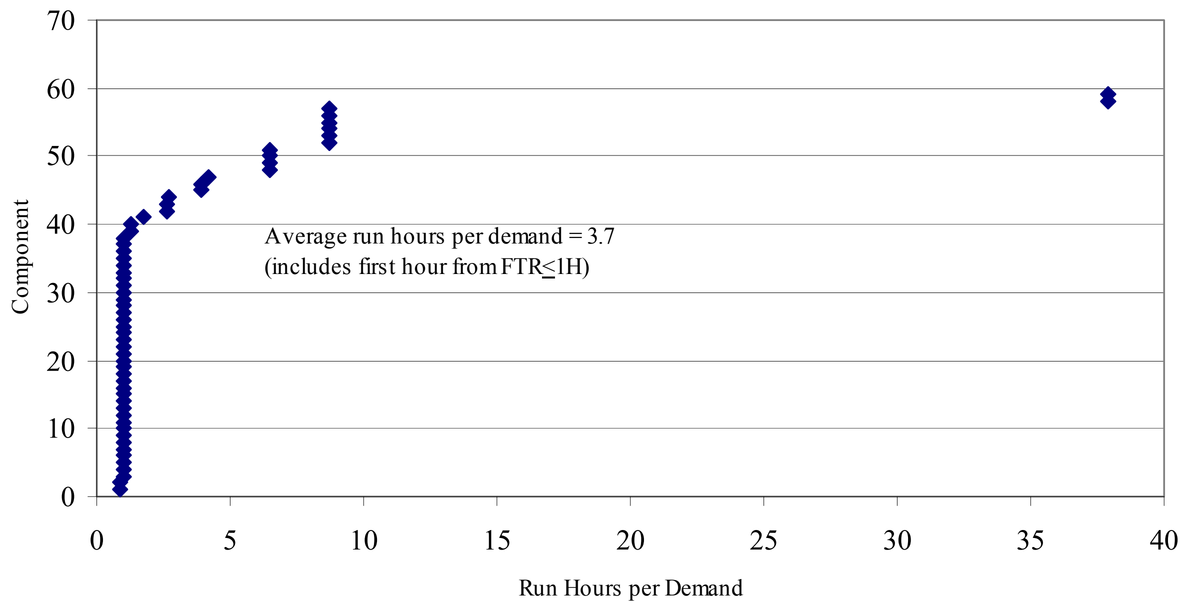

Figure 11-2a. Standby CHL run hours per demand distribution.

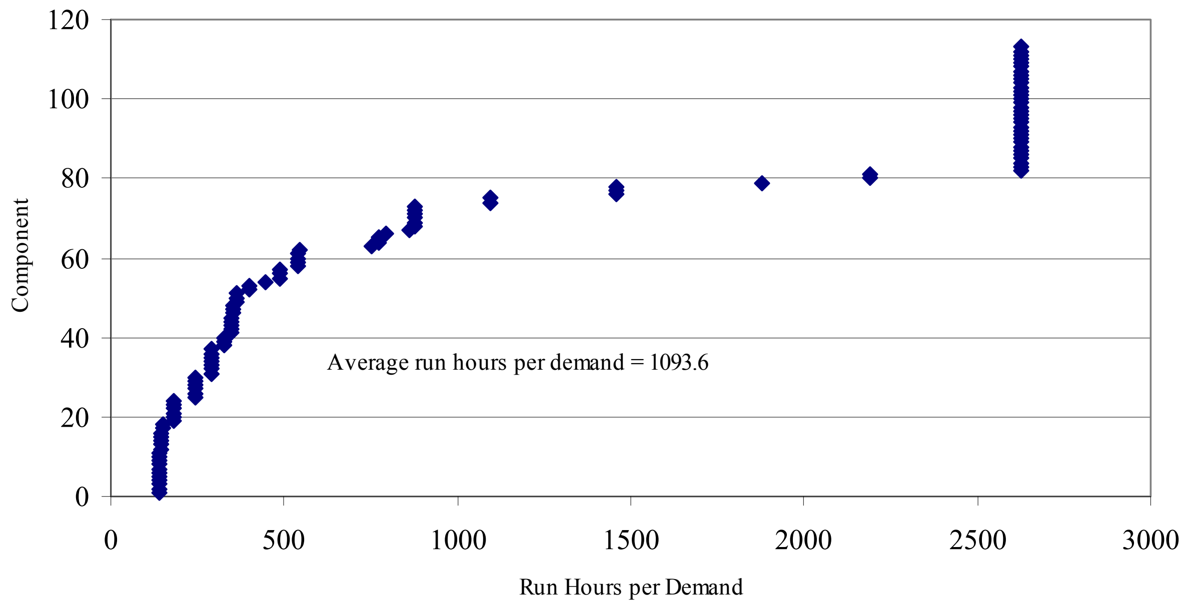

Figure 11-2b. Running/alternating CHL run hours per demand distribution.

11.3 Data Analysis

The CHL data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 11-4.

Table 11-4. Empirical distributions of MLEs for p and λ for CHLs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Standby	FTS	Component	0.00E+00	0.00E+00	2.36E-03	1.67E-02
		Plant	0.00E+00	0.00E+00	3.53E-03	2.78E-02
		Industry	-	-	1.83E-03	-
	FTR≤1H	Component	0.00E+00	0.00E+00	1.87E-03	1.67E-02
		Plant	0.00E+00	1.04E-03	2.01E-03	4.51E-03
		Industry	-	-	2.08E-03	-
	FTR>1H	Component	0.00E+00	5.86E-04	6.84E-03	2.71E-02
		Plant	0.00E+00	3.46E-03	9.00E-03	3.72E-02
		Industry	-	-	8.33E-04	-
Running/ Alternating	FTS	Component	0.00E+00	0.00E+00	1.03E-02	4.00E-02
		Plant	0.00E+00	3.32E-03	1.04E-02	3.34E-02
		Industry	-	-	1.02E-02	-
	FTR	Component	0.00E+00	0.00E+00	7.32E-05	3.20E-04
		Plant	0.00E+00	4.57E-05	9.67E-05	2.77E-04
		Industry	-	-	4.82E-05	-

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 11-3, only 17.5% of the CHLs experienced a FTS over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 82.5% portion of the distribution, and non-zero values above 82.5%.

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5.Results from these analyses are presented in Table 11-5 for CHLs.

Table 11-5. Fitted distributions for p and λ for CHLs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	7.57E-06	8.75E-04	1.92E-03	7.37E-03	Beta	0.500	2.601E+02
	FTR≤1H	JEFF/CL	9.53E-04	2.15E-03	2.29E-03	4.10E-03	Gamma	5.500	2.401E+03
		JEFF/PL	9.53E-04	2.15E-03	2.29E-03	4.10E-03	Gamma	5.500	2.401E+03
		SCNID/IL	9.01E-06	1.04E-03	2.29E-03	8.80E-03	Gamma	0.500	2.182E+02
	FTR>1H	EB/CL/KS	2.83E-06	1.02E-03	2.83E-03	1.18E-02	Gamma	0.398	1.405E+02
		EB/PL/KS	2.54E-05	2.34E-03	4.91E-03	1.85E-02	Gamma	0.527	1.075E+02
		SCNID/IL	3.39E-06	3.93E-04	8.63E-04	3.32E-03	Gamma	0.500	5.794E+02
Running/ Alternating	FTS	EB/CL/KS	3.15E-05	4.64E-03	1.06E-02	4.12E-02	Beta	0.474	4.432E+01
		EB/PL/KS	2.92E-04	6.28E-03	9.83E-03	3.15E-02	Beta	0.818	8.244E+01
		SCNID/IL	4.10E-05	4.73E-03	1.03E-02	3.92E-02	Beta	0.500	4.823E+01
	FTR	EB/CL/KS	6.90E-10	1.09E-05	6.82E-05	3.35E-04	Gamma	0.239	3.502E+03
		EB/PL/KS	3.29E-07	4.20E-05	9.42E-05	3.65E-04	Gamma	0.489	5.188E+03
		SCNID/IL	1.90E-07	2.20E-05	4.84E-05	1.86E-04	Gamma	0.500	1.034E+04

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, JEFF/CL is the posterior distribution at the component level of a Bayesian update of the Jeffreys noninformative prior with industry data, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

11.4 Industry-Average Baselines

Table 11-6 lists the industry-average failure rate distributions. For three of the five failure modes, the data sets were sufficient for empirical Bayes analyses to be performed. For these failure modes, the industry-average distributions are based on the empirical Bayes analysis results at the plant level, except for FTR>1H. The empirical Bayes results (EB/PL/KS) indicate a mean that is six times higher than the SCNID result. Because of this very large difference (resulting in a FTR>1H rate higher than the FTR≤1H rate), the SCNID result is recommended. Note that both cases indicate an α of approximately 0.5. The industry-average distribution for FTS is not sufficient (Section A.1 in Reference 14) for the empirical Bayes method. Therefore, a SCNID analysis was performed to provide a failure rate distribution. Finally, for FTR≤1H, the empirical Bayes analysis did not converge but indicated very little variation. For that case, the distribution was obtained using a Bayesian update of the Jeffreys noninformative prior. These industry-average failure rates do not account for any recovery.

Table 11-6. Selected industry distributions of p and λ for CHLs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	SCNID/IL	7.57E-06	8.75E-04	1.92E-03	7.37E-03	Beta	0.500	2.601E+02
	FTR≤1H	JEFF/PL	9.53E-04	2.15E-03	2.29E-03	4.10E-03	Gamma	5.500	2.401E+03
	FTR>1H	SCNID/IL	3.39E-06	3.93E-04	8.63E-04	3.32E-03	Gamma	0.500	5.794E+02
Running/	FTS	EB/PL/KS	2.92E-04	6.28E-03	9.83E-03	3.15E-02	Beta	0.818	8.244E+01
Alternating	FTR	EB/PL/KS	3.29E-07	4.20E-05	9.42E-05	3.65E-04	Gamma	0.489	5.188E+03

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 11-7 shows the rounded values for the CHL failure modes.

Table 11-7. Selected industry distributions of p and λ for CHLs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	SCNID/IL	8.0E-06	9.0E-04	2.0E-03	8.0E-03	Beta	0.50	2.50E+02
	FTR≤1H	JEFF/PL	1.0E-03	2.5E-03	2.5E-03	4.0E-03	Gamma	6.00	2.40E+03
	FTR>1H	SCNID/IL	3.0E-06	4.0E-04	9.0E-04	3.0E-03	Gamma	0.500	5.80E+02
Running/ Alternating	FTS	EB/PL/KS	2.5E-04	6.0E-03	1.0E-02	3.0E-02	Beta	0.80	8.00E+01
	FTR	EB/PL/KS	4.0E-07	4.0E-05	9.0E-05	3.0E-04	Gamma	0.50	5.56E+03

11.5 Breakdown by System

CHL UR results (Jeffreys means of system data) are compared by system and failure mode in Table 11-8. Results are shown only for the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 11-8. CHL p and λ by system.

Operation	System	FTS	FTR≤1H	FTR>1H
Standby	CHW	6.1E-03	-	-
	CIS	-	-	-
	HVC	1.4E-03	2.3E-03	-

Operation	System	FTS		FTR
Running/ Alternating	ACP	-		-
	CCW	-		-
	CHW	4.0E-03		4.2E-05
	EPS	2.5E-02		5.1E-05
	ESW	6.6E-03		-
	HVC	1.4E-02		1.1E-04
	OEP	1.0E-01		1.5E-04

12 Check Valve (CKV)

12.1 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 12-1.

Table 12-1. CKV failure modes.

Operation	Failure Mode	Parameter	Units	Description
Standby	FTO	*p*	-	Failure to open
	FTC	λ	1/h	Failure to close
	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

12.2 Data Collection and Review

Data for CKV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. (The external and internal leakage data cover 1997–2004.) There are 935 CKVs from 50 plants in the data originally gathered by RADS. After analyzing the original data, there were no FTO failures, so the data set was expanded to 1997– 2004 for FTO failure mode (see Section A.1 in Reference). After removing data without demand information (see Section A.1 in Reference 14) there were 828 components in 50 plants. The systems included in the CKV data collection are listed in Table 12-2 with the number of components included with each system.

Table 12-2. CKV systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
Standby	AFW	Auxiliary feedwater	99	81	54
	CCW	Component cooling water	72	66	47
	CHW	Chilled water system	1	1	1
	CIS	Containment isolation system	55	49	45
	CRD	Control rod drive	2	2	2
	CSR	Containment spray recirculation	63	63	61
	CVC	Chemical and volume control	63	63	56
	EPS	Emergency power supply	29	29	26
	ESW	Emergency service water	51	46	28
	HCI	High pressure coolant injection	10	10	10
	HPI	High pressure injection	181	160	157
	HVC	Heating ventilation and air conditioning	6	4	4
	IAS	Instrument air	2	2	0
	ISO	Isolation condenser	2	1	1
	LCI	Low pressure coolant injection	16	15	14
	LCS	Low pressure core spray	3	3	3
	LPI	Low pressure injection	134	122	120
	MFW	Main feedwater	53	33	27
	MSS	Main steam	27	27	27
	RCI	Reactor core isolation	13	12	12
	RCS	Reactor coolant	8	8	8
	RRS	Reactor recirculation	2	2	2
	SLC	Standby liquid control	8	8	6
	VSS	Vapor suppression	35	21	18
	Total		935	828	729

The CKV data set obtained from RADS was further reduced to include only those CKVs with ≤ 20 demands/year (≤ 100 demands over 5 years). See Section A.1 in Reference 14 for a discussion concerning this decision to limit certain component populations. Table 12-3 summarizes the data used in the CKV analysis. Note that the hours for ELS and ILS are calendar hours.

Table 12-3. CKV unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
Standby	FTO	0	38550	729	50	0.0%	0.0%
	FTC	2	24090	729	50	0.3%	4.0%
	ELS	1	51088320 h	729	50	0.1%	2.0%
	ILS	23	51088320 h	729	50	2.5%	28.0%

Figure 12-1 shows the range of valve demands per year in the CKV data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 20. The average for the data set is 6.6 demands/year.

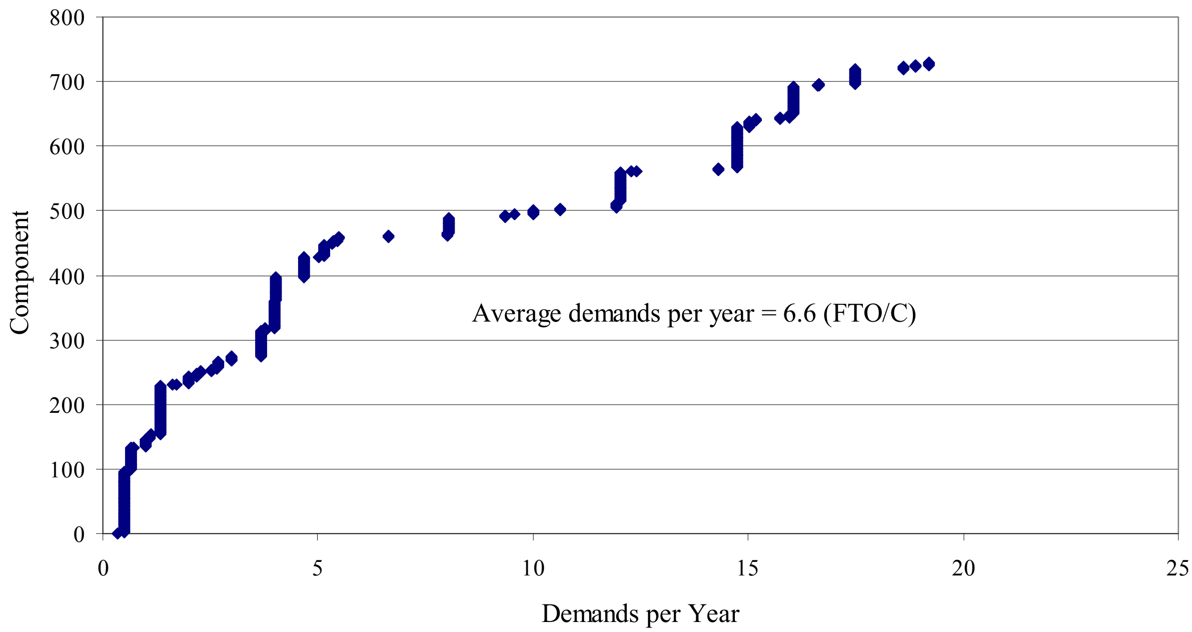

Figure 12-1. CKV demands per year distribution.

12.3 Data Analysis

The CKV data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 12-4. Note that with one failure for FTC, the MLE distributions at the component and plant levels provide no information for either the lower or upper portions of the distribution (other than to indicate zeros). From Table 12-3, only 0.1% of the CKVs experienced a FTC over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 99.9% portion of the distribution, and non-zero values above 99.9%.

Table 12-4. Empirical distributions of MLEs for p and λ for CKVs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Standby	FTO	Component	-	-	-	-
		Plant	-	-	-	-
		Industry	-	-	0.00E+00	-
	FTC	Component	0.00E+00	0.00E+00	3.02E-04	0.00E+00
		Plant	0.00E+00	0.00E+00	4.10E-03	0.00E+00
		Industry	-	-	8.30E-05	-
	ELS	Component	0.00E+00	0.00E+00	1.96E-08	0.00E+00
		Plant	0.00E+00	0.00E+00	6.07E-09	0.00E+00
		Industry	-	-	1.96E-08	-
	ILS	Component	0.00E+00	0.00E+00	4.50E-07	0.00E+00
		Plant	0.00E+00	0.00E+00	2.13E-06	7.13E-06
		Industry	-	-	4.50E-07	-

Because of the limited failures, an empirical Bayes analysis was performed at both the component and plant level only for ILS. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5.Results from these analyses are presented in Table 12-5.

Table 12-5. Fitted distributions for p and λ for CKVs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTO	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	5.10E-08	5.90E-06	1.30E-05	4.98E-05	Beta	0.500	3.855E+04
	FTC	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	4.08E-07	4.72E-05	1.04E-04	3.99E-04	Beta	0.500	4.816E+03
	ELS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.15E-10	1.34E-08	2.94E-08	1.13E-07	Gamma	0.500	1.703E+07
	ILS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	4.49E-13	1.22E-07	1.48E-06	7.76E-06	Gamma	0.184	1.249E+05
		SCNID/IL	1.81E-09	2.09E-07	4.60E-07	1.77E-06	Gamma	0.500	1.087E+06

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

12.4 Industry-Average Baselines

Table 12-6 lists the selected industry distributions of p and λ for the CKV failure modes. The data set was insufficient (see Section A.1 in Reference 14) for empirical Bayes analyses to be performed for FTO, FTC, and ELS failure modes. A SCNID analysis was performed to provide a failure rate distribution. The data set was sufficient to perform the empirical Bayes analysis for the ILS failure mode. However the resulting α was less than 0.3, so a lower limit of 0.3 was assumed. These industry-average failure rates do not account for any recovery. 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 12-6. Selected industry distributions of p and λ for CKVs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution Type	α	β
Standby	FTO	SCNID/IL	5.10E-08	5.90E-06	1.30E-05	4.98E-05	Beta	0.500	3.855E+04
	FTC	SCNID/IL	4.08E-07	4.72E-05	1.04E-04	3.99E-04	Beta	0.500	4.816E+03
	ELS	SCNID/IL	1.15E-10	1.34E-08	2.94E-08	1.13E-07	Gamma	0.500	1.703E+07
	ELL	ELS/EPIX	2.20E-13	5.01E-10	2.06E-09	9.40E-09	Gamma	0.300	1.460E+08
	ILS	EB/PL/KS	1.58E-10	3.60E-07	1.48E-06	6.75E-06	Gamma	0.300	2.034E+05
	ILL	ILS/EPIX	3.16E-12	7.19E-09	2.95E-08	1.35E-07	Gamma	0.300	1.017E+07

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 12-7 shows the rounded values for the CKV failure modes.

Table 12-7. Selected industry distributions of p and λ for CKVs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution Type	α	β
Standby	FTO	SCNID/IL	5.0E-08	5.0E-06	1.2E-05	5.0E-05	Beta	0.50	4.17E+04
	FTC	SCNID/IL	4.0E-07	5.0E-05	1.0E-04	4.0E-04	Beta	0.50	5.00E+03
	ELS	SCNID/IL	1.2E-10	1.5E-08	3.0E-08	1.2E-07	Gamma	0.50	1.67E+07
	ELL	ELS/EPIX	2.0E-13	5.0E-10	2.0E-09	9.0E-09	Gamma	0.30	1.50E+08
	ILS	EB/PL/KS	1.5E-10	4.0E-07	1.5E-06	7.0E-06	Gamma	0.30	2.00E+05
	ILL	ILS/EPIX	3.0E-12	7.0E-09	3.0E-08	1.5E-07	Gamma	0.30	1.00E+07

12.5 Breakdown by System

CKV UR results (Jeffreys means of system data) are compared by system and failure mode in Table 12-8. Results are shown only for systems and failure modes with failures in the data set. Because most system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 12-8. CKV p and λ by system.

System	FTO	FTC	ELS	ILS
AFW	-	-	-	-
CCW	-	-	-	7.6E-07
CHW	-	-	-	2.1E-05
CIS	-	-	-	1.4E-06
CRD	-	-	-	-
CSR	-	-	-	-
CVC	-	-	-	3.8E-07
EPS	-	-	-	-
ESW	-	1.9E-03	-	-
HCI	-	-	-	-
HPI	-	-	-	-
HVC	-	-	-	-

System	FTO	FTC	ELS	ILS
ISO	-	-	-	6.4E-05
LCI	-	-	-	2.5E-06
LCS	-	-	-	-
LPI	-	-	-	-
MFW	-	7.9E-03	-	1.3E-06
MSS	-	-	-	-
RCI	-	-	1.8E-06	4.2E-06
RCS	-	-	-	2.7E-06
RRS	-	-	-	2.5E-05
SLC	-	-	-	-
VSS	-	-	-	-

13 Control Rod Drive (CRD)

13.1 Component Description

The control rod drive (CRD) boundary includes the PWR control rod drive mechanism. The failure mode for CRD is listed in Table 13-1.

Table 13-1. CRD failure modes.

Operation	Failure Mode	Parameter	Units	Description
Standby	FTOP	p	-	Fail to operate

13.2 Data Collection and Review

Data for the CRD UR baseline 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 13-2 summarizes the data obtained from the RPS SSs and used in the CRD analysis. These data are at the industry level. Results at the plant and component levels are not presented in these studies.

Table 13-2. CRD unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	FTOP	2.0	189536	-	-	-	-

13.3 Industry-Average Baselines

Table 13-3 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 α = 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 13-3. Selected industry distributions of p and λ for CRDs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTOP	RPS SS	5.19E-08	6.00E-06	1.32E-05	5.07E-05	Beta	0.500	3.791E+04

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 13-4 shows the rounded value for the CRD failure mode.

Table 13-4. Selected industry distributions of p and λ for CRDs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTOP	RPS SS	5.0E-08	6.0E-06	1.2E-05	5.0E-05	Beta	0.50	4.17E+04

14 Cooling Tower Fan (CTF)

14.1 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 14-1.

Table 14-1. CTF failure modes.

Operation	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

14.2 Data Collection and Review

Data for CTF UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. After analyzing the original data, there were very few failures, so the data set was expanded to 1997– 2004 (see Section A.1 in Reference 14). There are 81 CTFs from five plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1 in Reference 14) there were 81 components in five plants. The individual failure records were reviewed to determine which failure mode applied. For this component, the failure to run events indicated how long after initial start before the failure occurred, so the typical binning process was not needed. The systems included in the CTF data collection are listed in Table 14-2 with the number of components included with each system.

Table 14-2. CTF systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 200 Demands per Year
Standby	CCW	Component cooling water	3	3	3
	ESW	Emergency service water	28	28	28
	Total		31	31	31
Running/ Alternating	CCW	Component cooling water	30	30	14
	ESW	Emergency service water	20	20	20
	Total		50	50	34

The data review process is described in detail in Section A.1 in Reference 14. Table 14-3 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 14-3. CTF unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTS	3	1515	31	4	6.5%	50.0%
	FTR≤1H	2	1515 h	31	4	6.5%	50.0%
	FTR>1H	0	11133 h	31	4	0.0%	0.0%
Running/ Alternating	FTS	1	13855	34	2	2.9%	50.0%
	FTR	0	839875 h	34	2	0.0%	0.0%

Figure 14-1a shows the range of start demands per year in the standby MDP data set. The start demands per year range from approximately 30 to 107. The average for the data set is 6.1 demands/year.

Figure 14-1b shows the range of start demands per year in the running MDP data set. The demands per year range from approximately 20 to 2,660. The average for the data set is 133.6 demands/year.

Figure 14-2a shows the range of run hours per demand in the standby MDP data set. The run hours per demand range is from approximately 0 hours/demand to 12.0 hours/demand. The average is 6.7 hours/demand. Figure 14-2b shows the range of run hours per demands in the running MDP data set. The range is from approximately 12 hours/demand to 3,153 hours/demand. The average is 369.2 hours/demand.

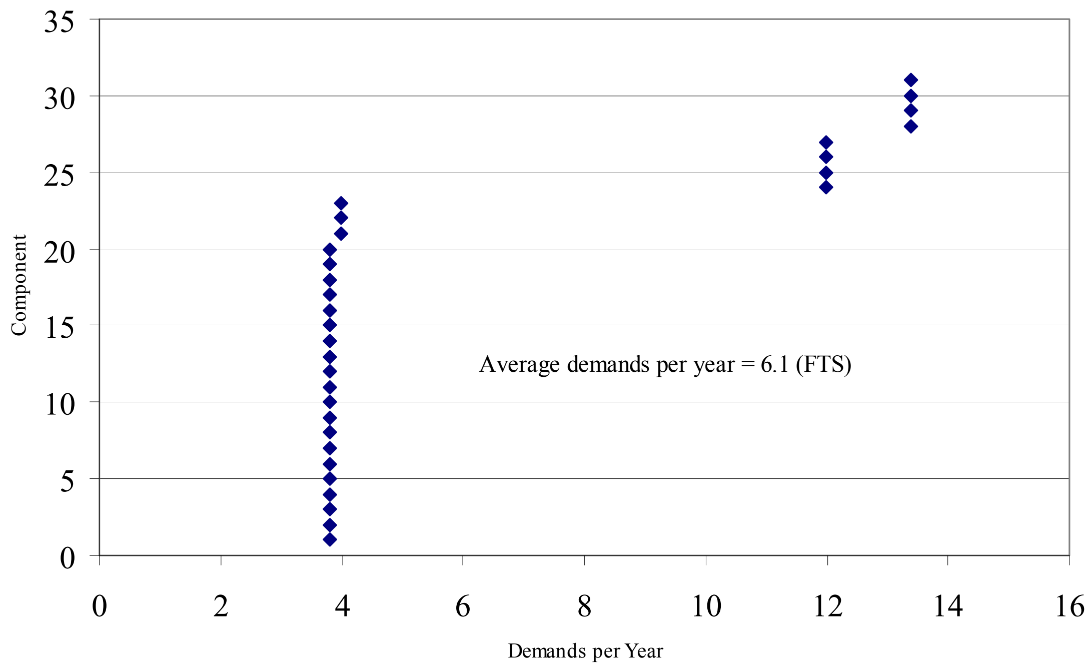

Figure 14-1a. Standby CTF demands per year distribution.

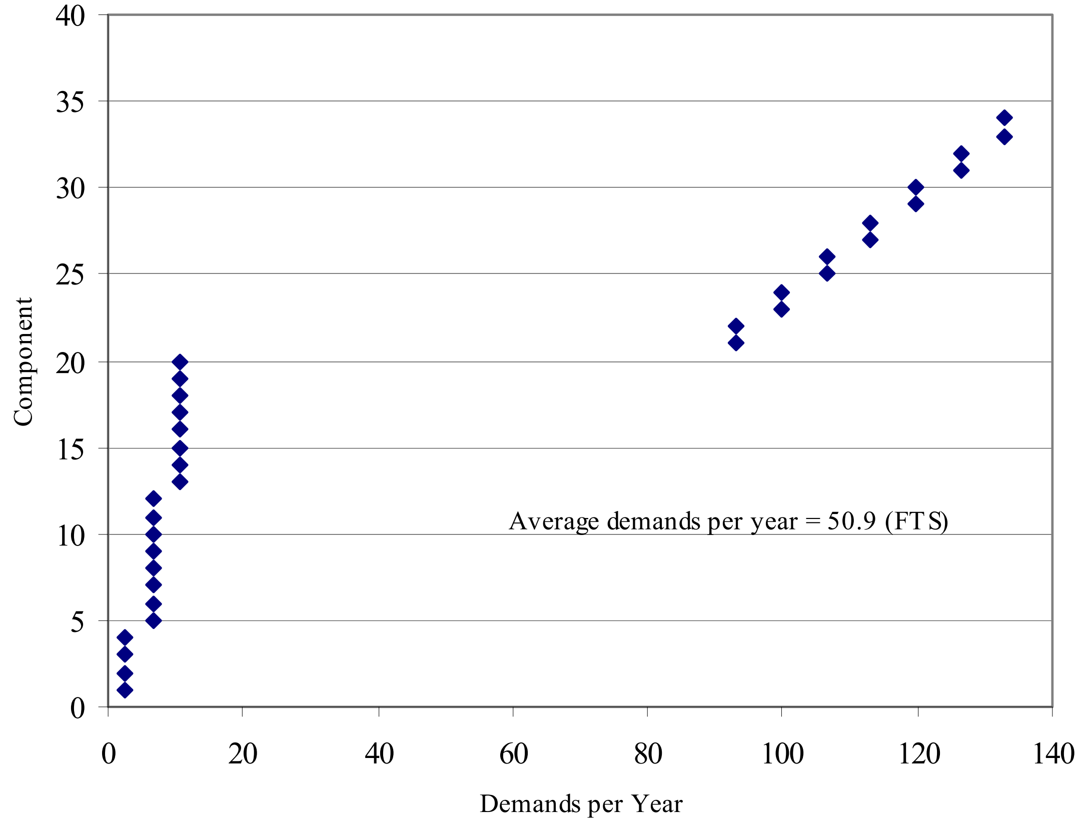

Figure 14-1b. Running/alternating CTF demands per year distribution.

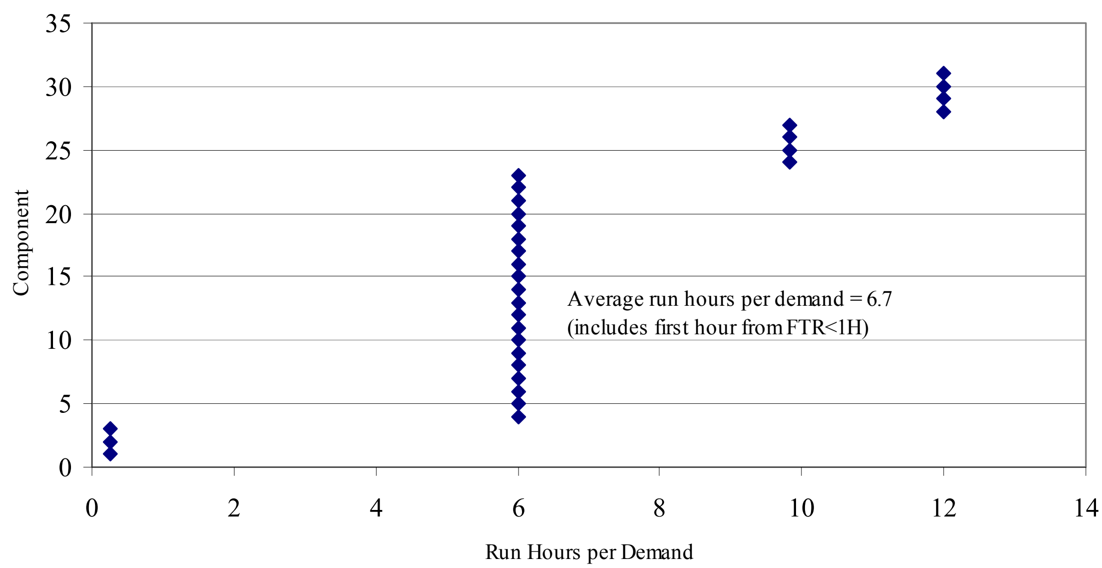

Figure 14-2a. Standby CTF run hours per demand distribution.

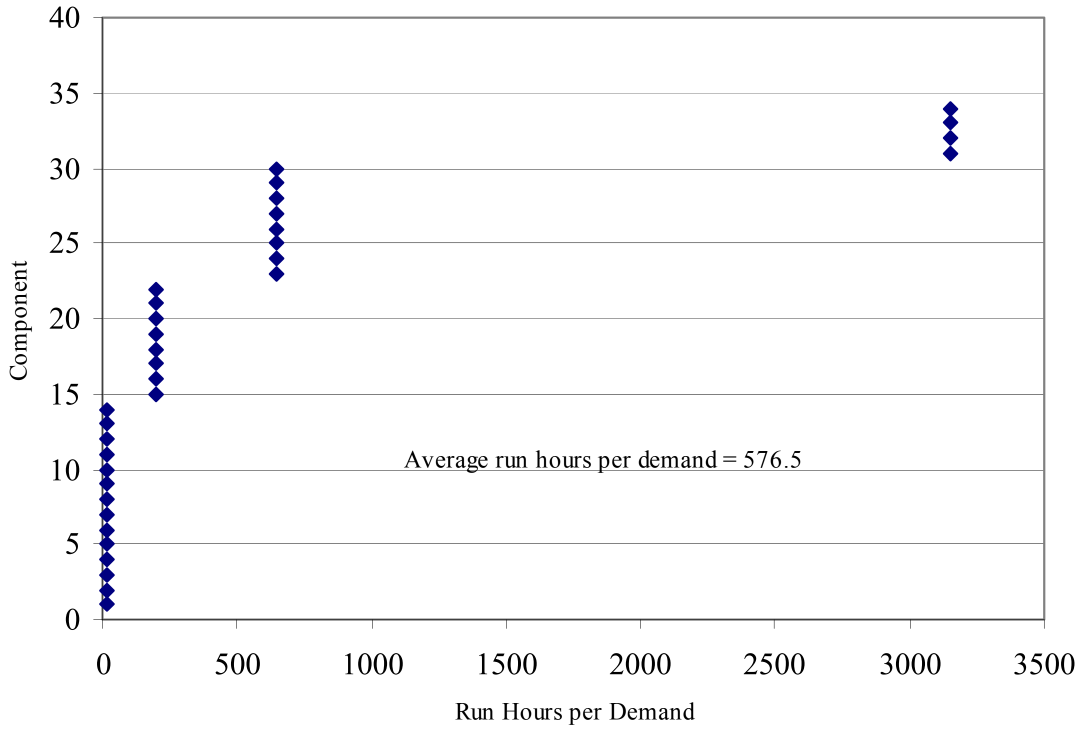

Figure 14-2b. Running/alternating CTF run hours per demand distribution.

14.3 Data Analysis

The CTF data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 14-4.

Table 14-4. Empirical distributions of MLEs for p and λ for CTFs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Standby	FTS	Component	0.00E+00	0.00E+00	9.75E-04	0.00E+00
		Plant	0.00E+00	0.00E+00	1.89E-03	5.22E-03
		Industry	-	-	1.98E-03	-
	FTR≤1H	Component	0.00E+00	0.00E+00	1.35E-03	0.00E+00
		Plant	0.00E+00	0.00E+00	3.26E-03	1.04E-02
		Industry	-	-	1.32E-03	-
	FTR>1H	Component	-	-	-	-
		Plant	-	-	-	-
		Industry	-	-	0.00E+00	-
Running/ Alternating	FTS	Component	0.00E+00	0.00E+00	2.35E-05	0.00E+00
		Plant	0.00E+00	0.00E+00	9.37E-06	1.87E-05
		Industry	-	-	1.87E-05	-
	FTR	Component	-	-	-	-
		Plant	-	-	-	-
		Industry	-	-	0.00E+00	-

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 14-3, only 6.5% of the CTFs experienced a FTR≤1H over the period 1997–2004, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 93.5% portion of the distribution, and non-zero values above 93.5%.

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in
Table 14-5 for CTFs.

Table 14-5. Fitted distributions for p and λ for CTFs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/CL/KS	6.61E-08	3.51E-04	1.73E-03	8.16E-03	Beta	0.270	1.561E+02
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	9.11E-06	1.05E-03	2.31E-03	8.86E-03	Beta	0.500	2.160E+02
	FTR≤1H	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	6.49E-06	7.51E-04	1.65E-03	6.34E-03	Gamma	0.500	3.030E+02
	FTR>1H	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.77E-07	2.04E-05	4.49E-05	1.73E-04	Gamma	0.500	1.113E+04
Running/ Alternating	FTS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	4.25E-07	4.91E-05	1.08E-04	4.15E-04	Beta	0.500	4.629E+03
	FTR	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	2.34E-09	2.71E-07	5.95E-07	2.29E-06	Gamma	0.500	8.403E+05

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

14.4 Industry-Average Baselines

Table 14-6 lists the industry-average failure rate distributions. The industry-average distribution for all of the failure modes is not sufficient (Section A.1 in Reference 14) for the empirical Bayes method; therefore a SCNID analysis was performed to provide a failure rate distribution. Note that this distribution is based on zero or very few failures and may be conservatively high. These industry-average failure rates do not account for any recovery.

Table 14-6. Selected industry distributions of p and λ for CTFs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	SCNID/IL	9.11E-06	1.05E-03	2.31E-03	8.86E-03	Beta	0.500	2.160E+02
	FTR≤1H	SCNID/IL	6.49E-06	7.51E-04	1.65E-03	6.34E-03	Gamma	0.500	3.030E+02
	FTR>1H	SCNID/IL	1.77E-07	2.04E-05	4.49E-05	1.73E-04	Gamma	0.500	1.113E+04
Running/	FTS	SCNID/IL	4.25E-07	4.91E-05	1.08E-04	4.15E-04	Beta	0.500	4.629E+03
Alternating	FTR	SCNID/IL	2.34E-09	2.71E-07	5.95E-07	2.29E-06	Gamma	0.500	8.403E+05

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 14-7 shows the rounded values for the CTF failure modes.

Table 14-7. Selected industry distributions of p and λ for CTFs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	SCNID/IL	1.0E-05	1.2E-03	2.5E-03	1.0E-02	Beta	0.50	2.00E+02
	FTR≤1H	SCNID/IL	6.0E-06	7.0E-04	1.5E-03	6.0E-03	Gamma	0.50	3.33E+02
	FTR>1H	SCNID/IL	1.5E-07	2.0E-05	4.0E-05	1.5E-04	Gamma	0.50	1.25E+04
Running/ Alternating	FTS	SCNID/IL	4.0E-07	5.0E-05	1.0E-04	4.0E-04	Beta	0.50	5.00E+03
	FTR	SCNID/IL	2.0E-09	2.5E-07	6.0E-07	2.5E-06	Gamma	0.50	8.33E+05

14.5 Breakdown by System

CTF UR results (Jeffreys means of system data) are compared by system and failure mode in Table 14-8. Results are shown only for the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 14-8. CTF p and λ by system.

Operation	System	FTS	FTR≤1H	FTR>1H
Standby	CCW	-	1.6E-02	-
	ESW	2.5E-03	1.1E-03	-
Operation	System	FTS		FTR
Running/	CCW	1.2E-04		-
Alternating	ESW	-		-

15 Combustion Turbine Generator (CTG)

15.1 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 15-1.

Table 15-1. CTG failure modes.

Operation	Failure Mode	Parameter	Units	Description
Standby	FTS	*p*	-	Failure to start
	FTLR (FTR≤1H)	*p*	-	Failure to load and run for 1 h
	FTR>1H	λ	1/h	Fail to run beyond 1 h

15.2 Data Collection and Review

Data for CTG UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. There are 2 CTGs from one plant in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1 in Reference 14) there were 2 components in one plant. The systems and operational status included in the CTG data collection are listed in Table 14-2 with the number of components included with each system.

Table 15-2. CTG systems.

Operation	System	Description	Number of Components	
			Initial	After Review
Standby	EPS	Emergency power system	2	2
	Total		2	2

The EPIX data indicated that the CTGs were demanded once per month and all failures were detected during testing. The EPIX database also indicated that the CTGs were running continuously. Because the run hours appeared suspicious, the plant was contacted for clarification. The plant reply provided data from January 1, 1998 to October 1, 2004 which indicated that the CTGs were run approximately 1 h for testing and all failures were detected on demand (start). Table 15-3 summarizes the data obtained from the plant and used in the CTG analysis.

Table 15-3. CTG unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTS	6	267	2	1	100.0%	100.0%
	FTLR	0	267	2	1	0.0%	0.0%
	FTR>1H	0 (0)	283 h (16 h)	2	1	0.0%	0.0%

Note – The reviewed data entries in parentheses for FTR>1H are after processing to remove events expected to have occurred within 1 h and to remove the first hour of operation. That process is explained in Section A.1 in Reference 14.

15.3 Data Analysis

Since there are only two components at two units, the MLE distributions provide little information. In addition, the empirical Bayes analysis cannot be performed. Therefore, only the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table 15-4 for CTGs. The data for FTR>1H, no failures in 16 h, are too limited to estimate the FTR>1H rate.

Table 15-4. Fitted distributions for p and λ for CTGs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	SCNID/IL	9.89E-05	1.14E-02	2.43E-02	9.21E-02	Beta	0.500	2.012E+01
	FTLR	SCNID/IL	7.36E-06	8.51E-04	1.87E-03	7.16E-03	Beta	0.500	2.675E+02
	FTR>1H	-	-	-	-	-	-	-	-

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

15.4 Industry-Average Baselines

Table 15-5 lists the industry-average failure rate distributions. Results for FTS and FTLR are based on EPIX data (modified as discussed). The FTR>1H distribution was assumed to be the same as for EDGs, but with $\alpha = 0.3$. These industry-average failure rates do not account for any recovery.

Table 15-5. Selected industry distributions of p and λ for CTGs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	SCNID/IL	9.89E-05	1.14E-02	2.42E-02	9.21E-02	Beta	0.500	2.012E+01
	FTLR	SCNID/IL	7.36E-06	8.51E-04	1.87E-03	7.16E-03	Beta	0.500	2.675E+02
	FTR>1H	EDGs	9.08E-08	2.07E-04	8.48E-04	3.88E-03	Gamma	0.300	3.538E+02

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 15-6 shows the rounded values for the CTG failure modes.

Table 15-6. Selected industry distributions of p and λ for CTGs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	SCNID/IL	1.0E-04	1.2E-02	2.5E-02	1.0E-01	Beta	0.50	2.00E+01
	FTLR	SCNID/IL	8.0E-06	9.0E-04	2.0E-03	8.0E-03	Beta	0.50	2.50E+02
	FTR>1H	EDGs	9.0E-08	2.0E-04	8.0E-04	4.0E-03	Gamma	0.30	3.75E+02

15.5 Breakdown by System

The CTG is included only in the emergency power system.

16 Diesel-Driven Pump (DDP)

16.1 Component Description

The diesel-driven pump (DDP) 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 16-1.

Table 16-1. DDP failure modes.

Operation	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
All	ELS	λ	1/h	External leak small
	ELL	λ	1/h	External leak large

16.2 Data Collection and Review

Data for DDP UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002, except for the ELS data that cover 1997–2004. There are 27 DDPs from 16 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1 in Reference 14) there were 27 components in 16 plants. Three of these components had run hours that were much higher than others and appeared to be errors. For these three components, an average of 0.9 hours per demand (obtained from the other components) was used. These data were then further partitioned into standby and running/alternating components. (There were no running/alternating components identified.) The systems and operational status included in the DDP data collection are listed in Table 16-2 with the number of components included with each system.

Table 16-2. DDP systems.

Operation	System	Description	Number of Components	
			Initial	After Review
Standby	AFW	Auxiliary feedwater	4	4
	ESW	Emergency service water	3	3
	FWS	Firewater	20	20
	Total		27	27

The data review process is described in detail in Section A.1 in Reference 14. Table 16-3 summarizes the data obtained from EPIX and used in the DDP analysis. Note that the hours for ELS are calendar hours.

Table 16-3. DDP unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTS	9	5161	27	18	18.5%	27.8%
	FTR≤1H	4	3277 h	27	18	14.8%	16.7%
	FTR>1H	0	0 h	0	0	0.0%	0.0%
All	ELS	0	2032320 h	29	21	0.0%	0.0%

Figure 16-1 shows the range of start demands per year in the standby DDP data set. The start demands per year range from approximately 7 to 157. The average for the data set is 38.2 demands/year. Figure 16-2 shows the range of run hours per demand in the standby DDP data set. The run hours per demand range is from approximately 1 hour/demand to 8 hours/demand. The average is 0.9 hour/demand.

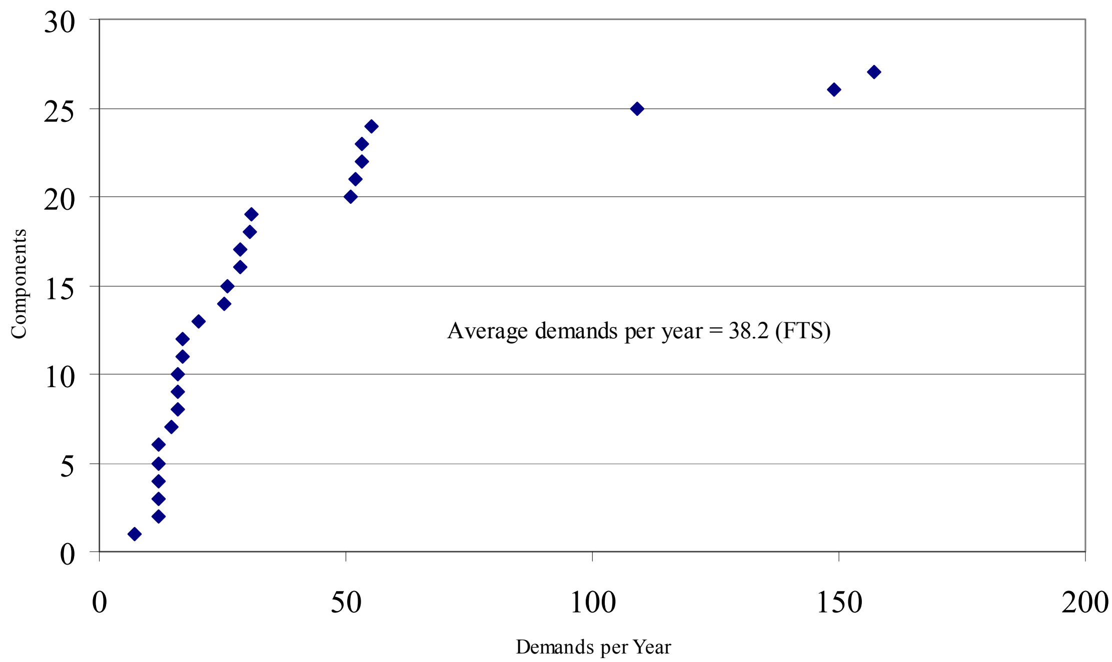

Figure 16-1. Standby DDP demands per year distribution.

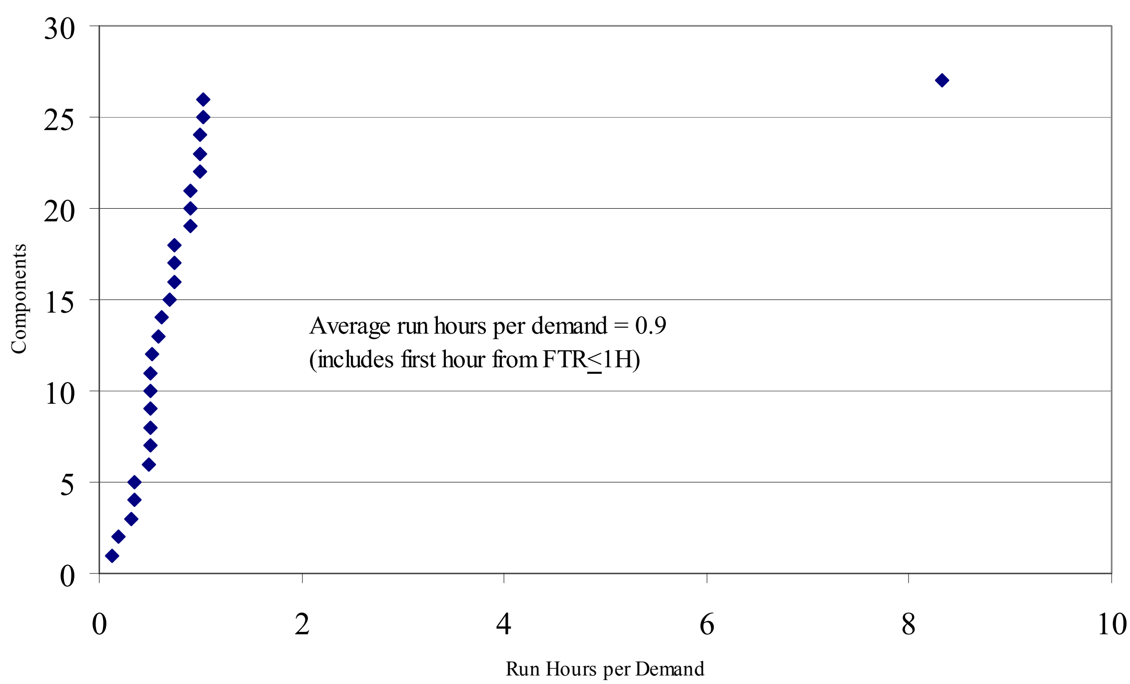

Figure 16-2. Standby DDP run hours per demand distribution.

16.3 Data Analysis

The DDP data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 16-4.

Table 16-4. Empirical distributions of MLEs for p and λ for DDPs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Standby	FTS	Component	0.00E+00	0.00E+00	3.23E-03	2.86E-02
		Plant	0.00E+00	0.00E+00	4.81E-03	2.86E-02
		Industry	-	-	1.74E-03	-
	FTR≤1H	Component	0.00E+00	0.00E+00	1.60E-03	1.20E-02
		Plant	0.00E+00	0.00E+00	1.74E-03	1.20E-02
		Industry	-	-	1.22E-03	-
	FTR>1H	Component	-	-	-	-
		Plant	-	-	-	-
		Industry	-	-	0.00E+00	-
All	ELS	Component	-	-	-	-
		Plant	-	-	-	-
		Industry	-	-	0.00E+00	-

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 16-3, only 20.8% of the DDPs experienced a FTS over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 79.2% portion of the distribution, and non-zero values above 79.2%.

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table 16-5 for DDPs.

Table 16-5. Fitted distributions for p and λ for DDPs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution Type	α	β
Standby	FTS	EB/CL/KS	2.17E-11	1.13E-04	2.77E-03	1.53E-02	Beta	0.149	5.370E+01
		EB/PL/KS	1.83E-10	2.26E-04	3.88E-03	2.10E-02	Beta	0.164	4.214E+01
		SCNID/IL	7.26E-06	8.39E-04	1.84E-03	7.06E-03	Beta	0.500	2.712E+02
	FTR≤1H	JEFF/CL	5.07E-04	1.27E-03	1.37E-03	2.58E-03	Gamma	4.500	3.277E+03
		EB/PL/KS	3.95E-08	2.97E-04	1.58E-03	7.59E-03	Gamma	0.259	1.635E+02
		SCNID/IL	5.40E-06	6.25E-04	1.37E-03	5.27E-03	Gamma	0.500	3.642E+02
	FTR>1H	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	-	-	-	-	-	-	-
All	ELS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	9.67E-10	1.12E-07	2.46E-07	9.45E-07	Gamma	0.500	2.033E+06

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, JEFF/CL is the posterior distribution at the component level of a Bayesian update of the Jeffreys noninformative prior with industry data, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

16.4 Industry-Average Baselines

Table 16-6 lists the selected industry distributions of p and λ for the DDP failure modes. For the FTS and FTR≤1H failure modes, the data sets were sufficient (Section A.1 in Reference 14) for empirical Bayes analyses to be performed. For these failure modes, the industry-average distributions are based on the empirical Bayes analysis results at the plant level. However, both results indicated α values less than 0.3. In both cases, the lower limit of 0.3 was assumed. The FTR>1H data had no failures or demands; therefore the FTR>1H mean is FTR≤1H * 0.06, based on the FTR>1H/ FTR≤1H ratio observed for other similar standby components (Section A.1 in Reference 14). The ELS failure mode also has no failures. Therefore, a SCNID analysis was performed to provide a failure rate distribution. 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. These industry-average failure rates do not account for any recovery.

Table 16-6. Selected industry distributions of p and λ for DDPs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/PL/KS	4.17E-07	9.50E-04	3.88E-03	1.77E-02	Beta	0.300	7.728E+01
	FTR≤1H	EB/PL/KS	1.70E-07	3.86E-04	1.58E-03	7.25E-03	Gamma	0.300	1.893E+02
	FTR>1H	SCNID/IL	1.01E-08	2.31E-05	9.48E-05	4.34E-04	Gamma	0.300	3.165E+03
All	ELS	SCNID/IL	9.67E-10	1.12E-07	2.46E-07	9.45E-07	Gamma	0.500	2.033E+06
	ELL	ELS/EPIX	1.84E-12	4.19E-09	1.72E-08	7.87E-08	Gamma	0.300	1.744E+07

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 16-7 shows the rounded values for the DDP failure modes.

Table 16-7. Selected industry distributions of p and λ for DDPs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/PL/KS	4.0E-07	1.0E-03	4.0E-03	2.0E-02	Beta	0.30	7.50E+01
	FTR≤1H	EB/PL/KS	1.5E-07	4.0E-04	1.5E-03	7.0E-03	Gamma	0.30	2.00E+02
	FTR>1H	SCNID/IL	1.0E-08	2.0E-05	9.0E-05	4.0E-04	Gamma	0.30	3.33E+03
All	ELS	SCNID/IL	1.0E-09	1.2E-07	2.5E-07	1.0E-06	Gamma	0.50	2.00E+06
	ELL	ELS/EPIX	1.5E-12	4.0E-09	1.5E-08	7.0E-08	Gamma	0.30	2.00E+07

16.5 Breakdown by System

DDP UR results (Jeffreys means of system data) are compared by system and failure mode in Table 16-8. Results are shown only the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 16-8. DDP p and λ by system.

Operation	System	FTS	FTR≤1H
Standby	AFW	7.3E-03	-
	ESW	-	-
	FWS	1.5E-03	1.6E-03
Operation	**System**	**ELS**	
All	AFW	-	
	ESW	-	
	FWS	-	

17 Emergency Diesel Generator (EDG)

17.1 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. EDGs supporting the motor-driven pumps in the high-pressure core spray (HPCS) systems and station blackout (SBO) EDGs are not included. However, they are compared with the results for these Class 1E EDGs in Section 17.5.

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 17-1.

Table 17-1. EDG failure modes.

Operation	Failure Mode	Parameter	Units	Description
Standby	FTS	*p*	-	Failure to start
	FTLR (FTR≤1H)	*p*	-	Fail to load and run for 1 h
	FTR>1H	λ	1/h	Fail to run beyond 1 h

17.2 Data Collection and Review

Data for EDG UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. There are 225 EDGs from 95 plants. (There are actually 103 plants, but some multi-plant sites list both plant EDGs under one plant.) The systems included in the EDG data collection are listed in Table 17-2 with the number of components included with each system.

Table 17-2. EDG systems.

Operation	System	Description	Number of Components	
			Initial	After Review
Standby	EPS	Emergency Power System	225	225
	Total		225	225

A review of the data indicated several plants with unreasonably low start and/or load and run demands. Because the start demands should be higher than the load and run demands, a data processing routine was used to modify suspicious data. If the load and run demands were higher than the start demands, then the start demands were set equal to the load and run demands. Then, the load and run demands were compared with the start demands. If the load and run demands were less than 75% of the start demands, the load and run demands were set to 75% of the start demands. In addition, ten of the EDGs appeared to have run hours that were ten times too high (possibly an error in data entry). Those EDG run hours were reduced by a factor of ten. Finally, one plant listed 12 FTR events, while the next highest plant had four FTR events. A review of those failure records indicated that only one of the events was actually a failure. The other 11 events were all similar and involved local instrumentation issues that would not have prevented the EDG from running. Results from this data review are listed in Table 17-3. Overall, the data changes were significant only in terms of the run hours and the number of FTR>1H events.

Table 17-3. EDG unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTS	98	24206	225	95	30.2%	54.7%
	FTLR	61	21342	225	95	21.3%	38.9%
	FTR>1H	50	59875 h	225	95	17.8%	35.8%

Figure 17-1 shows the range of start demands per year in the EDG data set. The demands per year range from approximately 12 to 50. The average for the data set is 21.5 demands/year.

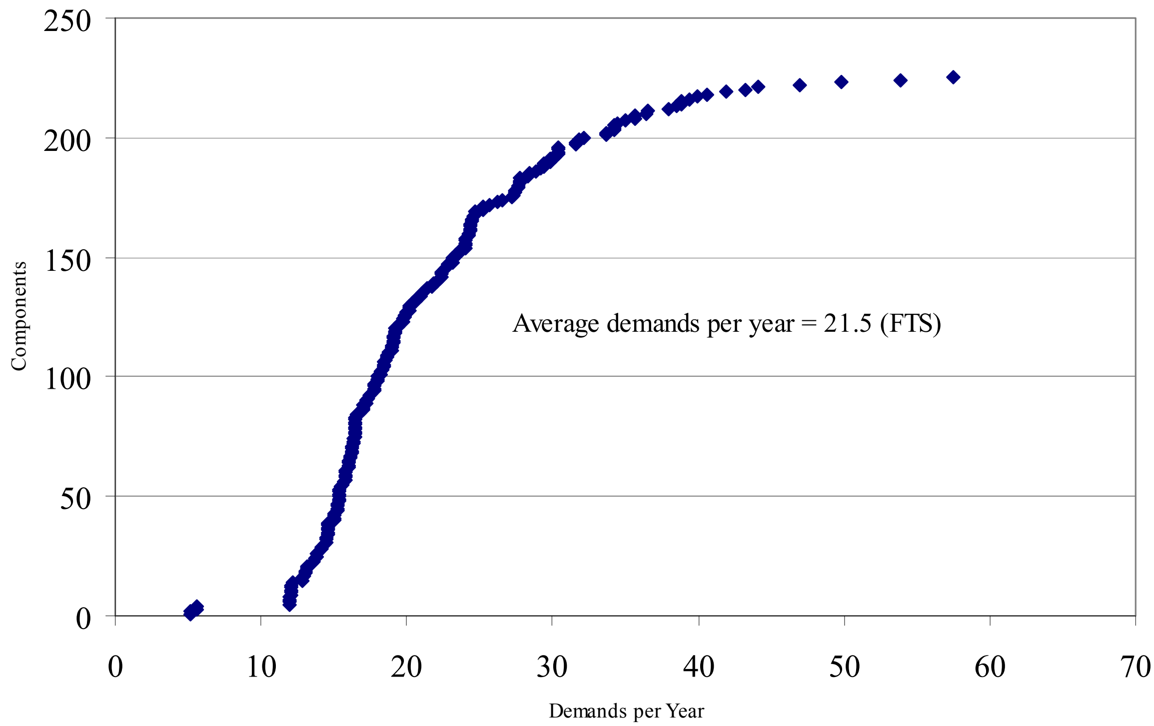

Figure 17-1. EDG demands per year distribution.

Figure 17-2 shows the range of run hours per demand in the EDG data set. The range is from approximately 1 hour/demand to 8 hours/demand. The average is 3.7 hours/demand.

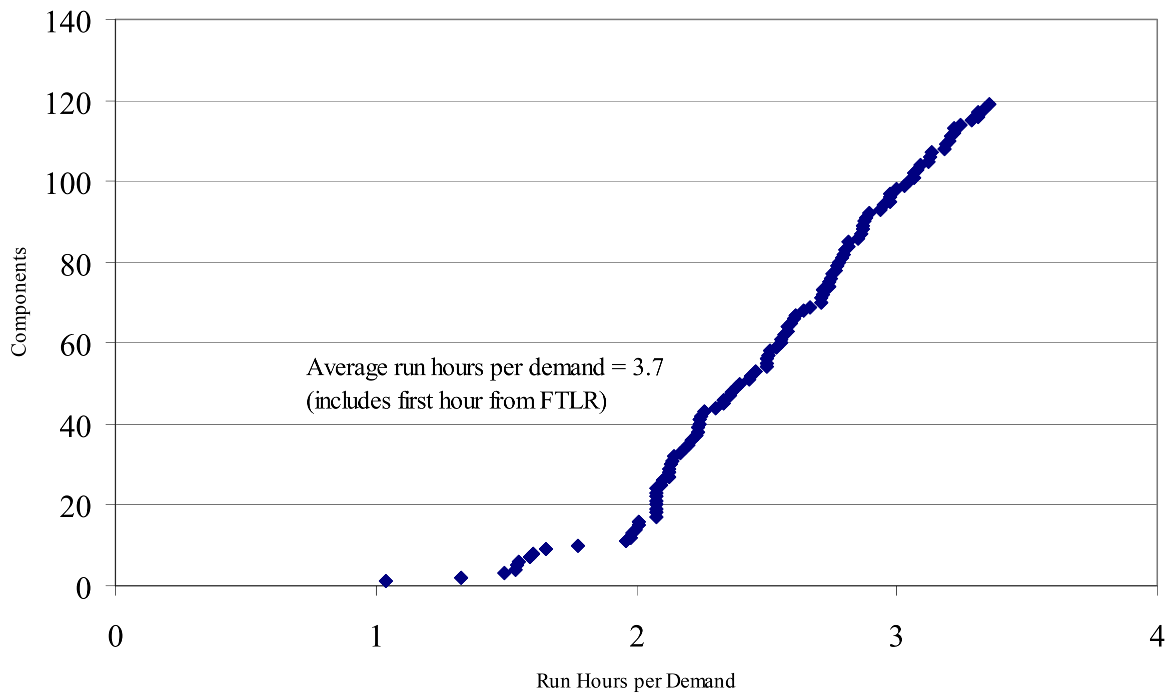

Figure 17-2. EDG run hours per demand distribution.

17.3 Data Analysis

The EDG data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 17-4. The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 17-3, only 30.2% of the EDGs experienced a FTS over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 69.8% portion of the distribution, and non-zero values above 69.8%.

Table 17-4. Empirical distributions of MLEs for p and λ for EDGs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Standby	FTS	Component	0.00E+00	0.00E+00	4.44E-03	2.15E-02
		Plant	0.00E+00	3.77E-03	5.11E-03	1.95E-02
		Industry	-	-	4.05E-03	-
	FTLR	Component	0.00E+00	0.00E+00	3.00E-03	1.45E-02
		Plant	0.00E+00	0.00E+00	2.92E-03	1.23E-02
		Industry	-	-	2.86E-03	-
	FTR>1H	Component	0.00E+00	0.00E+00	9.39E-04	6.25E-03
		Plant	0.00E+00	0.00E+00	9.65E-04	5.60E-03
		Industry	-	-	8.35E-04	-

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table 17-5.

Table 17-5. Fitted distributions for p and λ for EDGs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/CL/KS	1.55E-04	2.76E-03	4.18E-03	1.31E-02	Beta	0.884	2.106E+02
		EB/PL/KS	2.77E-04	3.24E-03	4.53E-03	1.32E-02	Beta	1.075	2.363E+02
		SCNID/IL	1.61E-05	1.86E-03	4.07E-03	1.56E-02	Beta	0.500	1.224E+02
	FTLR	EB/CL/KS	1.48E-04	2.01E-03	2.90E-03	8.69E-03	Beta	0.997	3.425E+02
		EB/PL/KS	3.07E-04	2.25E-03	2.90E-03	7.69E-03	Beta	1.411	4.856E+02
		SCNID/IL	1.14E-05	1.32E-03	2.88E-03	1.11E-02	Beta	0.500	1.730E+02
	FTR>1H	EB/CL/KS	2.27E-05	5.36E-04	8.60E-04	2.80E-03	Gamma	0.790	9.186E+02
		EB/PL/KS	1.52E-04	7.12E-04	8.48E-04	2.01E-03	Gamma	2.010	2.371E+03
		SCNID/IL	3.32E-06	3.84E-04	8.43E-04	3.24E-03	Gamma	0.500	5.928E+02

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

17.4 Industry-Average Baselines

Table 17-6 lists the selected industry distributions of p and λ for the EDG failure modes. For all three failure modes, the data sets were sufficient (Section A.1 in Reference 14) for empirical Bayes analyses to be performed. Therefore, the industry-average distributions are based on the empirical Bayes analysis results at the plant level. These industry-average failure rates do not account for any recovery. However, a limited review of the failures indicates that possibly only 10 to 20% could be easily recovered within minutes.

Table 17-6. Selected industry distributions of p and λ for EDGs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/PL/KS	2.77E-04	3.24E-03	4.53E-03	1.32E-02	Beta	1.075	2.363E+02
	FTLR	EB/PL/KS	3.07E-04	2.25E-03	2.90E-03	7.69E-03	Beta	1.411	4.856E+02
	FTR>1H	EB/PL/KS	1.52E-04	7.12E-04	8.48E-04	2.01E-03	Gamma	2.010	2.371E+03

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 17-7 shows the rounded values for the EDG failure modes.

Table 17-7. Selected industry distributions of p and λ for EDGs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/PL/KS	2.5E-04	3.0E-03	5.0E-03	1.5E-02	Beta	1.00	2.00E+02
	FTLR	EB/PL/KS	4.0E-04	2.5E-03	3.0E-03	8.0E-03	Beta	1.50	5.00E+02
	FTR>1H	EB/PL/KS	1.5E-04	7.0E-04	8.0E-04	2.0E-03	Gamma	2.00	2.50E+03

17.5 Breakdown by System

The EDGs discussed above are within the emergency power system. Additional EDGs not covered in the data discussed above are the HPCS EDGs. EDG UR results (Jeffreys means of system data) are compared with the HPCS EDG results in Table 17-8. There were insufficient data in EPIX to present results for SBO EDGs.

Table 17-8. EDG p and λ by system.

System	EDG Failure Mode Estimate		
	FTS	FTLR	FTR>1H
EPS EDGs	4.5E-3	2.9E-3	8.5E-4
HPCS EDGs	3.4E-3	-	6.2E-4

18 Explosive-Operated Valve (EOV)

18.1 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 18-1.

Table 18-1. EOV failure modes.

Operation	Failure Mode	Parameter	Units	Description
All	FTO	*p*	-	Failure to open

18.2 Data Collection and Review

Data for EOV UR baseline was obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. There are 57 EOVs from 26 plants in the data originally gathered by RADS. After analyzing the original data, there were no FTO failures, so the data set was expanded to 1997– 2004 for FTO failure mode (see Section A.1 in Reference 14). After removing data without demand information (see Section A.1 in Reference 14) there were 55 components in 26 plants. The systems included in the EOV data collection are listed in Table 18-2 with the number of components included with each system.

Table 18-2. EOV systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
All	SLC	Standby liquid control	57	55	53
	Total		57	55	53

The EOV data set obtained from RADS was further reduced to include only those EOVs with ≤ 20 demands/year (≤ 160 demands over 8 y). See Section A.1 in Reference 14 for a discussion concerning this decision to limit certain component populations. Table 18-3 summarizes the data used in the EOV analysis.

Table 18-3. EOV unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO	0	468	53	26	0.0%	0.0%

Figure 18-1 shows the range of valve demands per year in the EOV data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 10. The average for the data set is 1.1 demands/year.

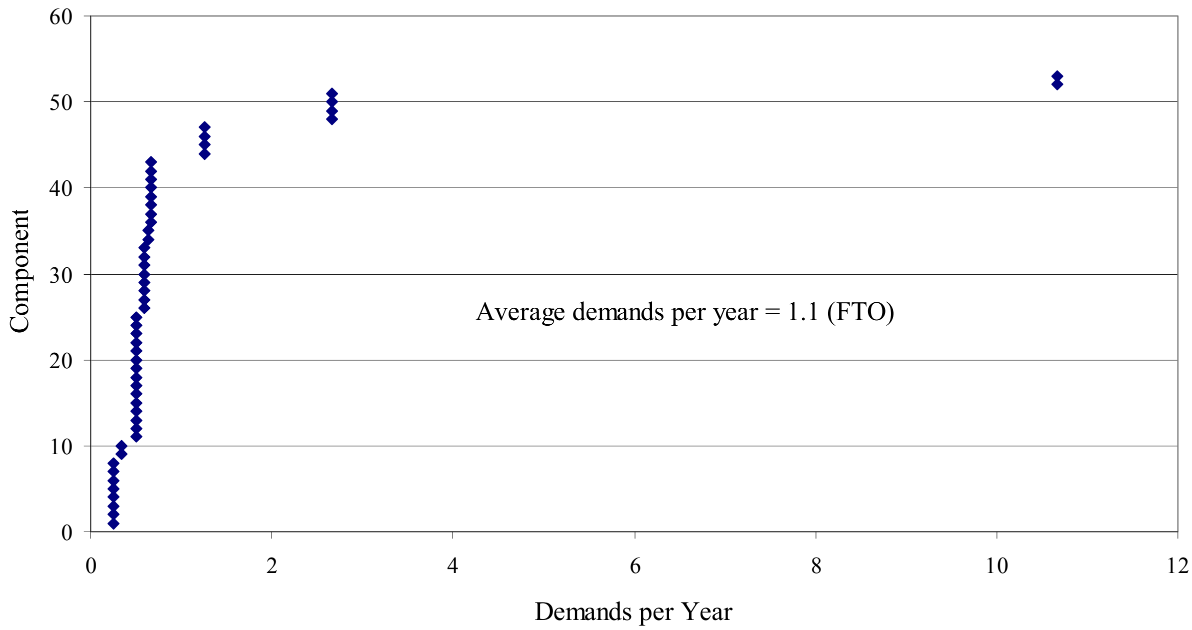

Figure 18-1. EOV demands per year distribution.

18.3 Data Analysis

The EOV data can be examined at the component, plant, or industry level. However, with zero failures, all maximum likelihood estimates (MLEs), which are failures/demands (or hours), are zero. Results for all three levels are presented in Table 18-4.

Table 18-4. Empirical distributions of MLEs for p and λ for EOVs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
All	FTO	Component	-	-	0.00E+00	-
		Plant	-	-	0.00E+00	-
		Industry	-	-	0.00E+00	-

Because of no failures, no empirical Bayes analyses were performed. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table 18-5.

Table 18-5. Fitted distributions for p and λ for EOVs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	4.20E-06	4.86E-04	1.07E-03	4.10E-03	Beta	0.500	4.682E+02

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

18.4 Industry-Average Baselines

Table 18-6 lists the industry-average failure rate distribution for the EOV FTO failure mode. The data set was insufficient (see Section A.1 in Reference 14) for empirical Bayes analyses to be performed. A SCNID analysis was performed to provide a 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 18-6. Selected industry distributions of p and λ for EOVs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	SCNID/IL	4.20E-06	4.86E-04	1.07E-03	4.10E-03	Beta	0.500	4.682E+02

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 18-7 shows the rounded value for EOV FTO.

Table 18-7. Selected industry distributions of p and λ for EOVs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	SCNID/IL	4.0E-06	5.0E-04	1.0E-03	4.0E-03	Beta	0.50	5.00E+02

18.5 Breakdown by System

The EOVs are used only in the SLC system.

19 Fan (FAN)

19.1 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 19-1.

Table 19-1. FAN failure modes.

Operation	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

19.2 Data Collection and Review

Data for FAN UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. There are 520 FANs from 65 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1 in Reference 14) there were 510 components in 64 plants. These data were then further partitioned into standby and running/alternating components. The systems and operational status included in the FAN data collection are listed in Table 19-2 with the number of components included with each system.

Table 19-2. FAN systems.

Operation	System	Description	Number of Components	
			Initial	After Review
Standby	CCW	Component cooling water	2	2
	CIS	Containment isolation system	12	7
	EPS	Emergency power supply	72	72
	HCI	High pressure coolant injection	2	2
	HVC	Heating ventilation and air conditioning	122	121
	IAS	Instrument air	4	4
	MFW	Main feedwater	4	-
	SGT	Standby gas treatment	40	40
	Total		258	248
Running/ Alternating	AFW	Auxiliary feedwater	4	4
	CCW	Component cooling water	7	7
	CIS	Containment isolation system	4	4
	CRD	Control rod drive	2	2
	DCP	Plant dc power	2	2
	EPS	Emergency power supply	8	8
	ESW	Emergency service water	12	12
	HVC	Heating ventilation and air conditioning	206	206
	IAS	Instrument air	10	10
	SGT	Standby gas treatment	7	7
	Total		262	262

The data review process is described in detail in Section A.1 in Reference 14. Table 19-3 summarizes the data obtained from EPIX and used in the FAN analysis.

Table 19-3. FAN unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTS	33	25099	248	46	9.7%	39.1%
	FTR≤1H	19	17019 h	145	32	6.5%	21.7%
	FTR>1H	17 (8.0)	84514 h (76434 h)	103	30	6.5%	28.3%
Running/ Alternating	FTS	18	24024	234	42	7.3%	23.9%
	FTR	57	6279790 h	234	42	14.9%	43.5%

Note – The reviewed data entries in parentheses for FTR>1H are after processing to remove events expected to have occurred within 1 h and to remove the first hour of operation. That process is explained in Section A.1 in Reference 14.

Figure 19-1a shows the range of start demands per year in the standby FAN data set. The start demands per year range from approximately 1 to 104. The average for the data set is 20.2 demands/year. Figure 19-1b shows the range of start demands per year in the running FAN data set. The demands per year range from approximately 1 to 150. The average for the data set is 20.5 demands/year.

Figure 19-2a shows the range of run hours per demand in the standby FAN data set. The run hours per demand range is from approximately 1 hour/demand to 50 hours/demand. The average is 5.9 hours/demand. Figure 19-2b shows the range of run hours per demands in the running FAN data set. The range is from approximately 12 hours/demand to 26,281 hours/demand. The average is 2123.6 hours/demand.

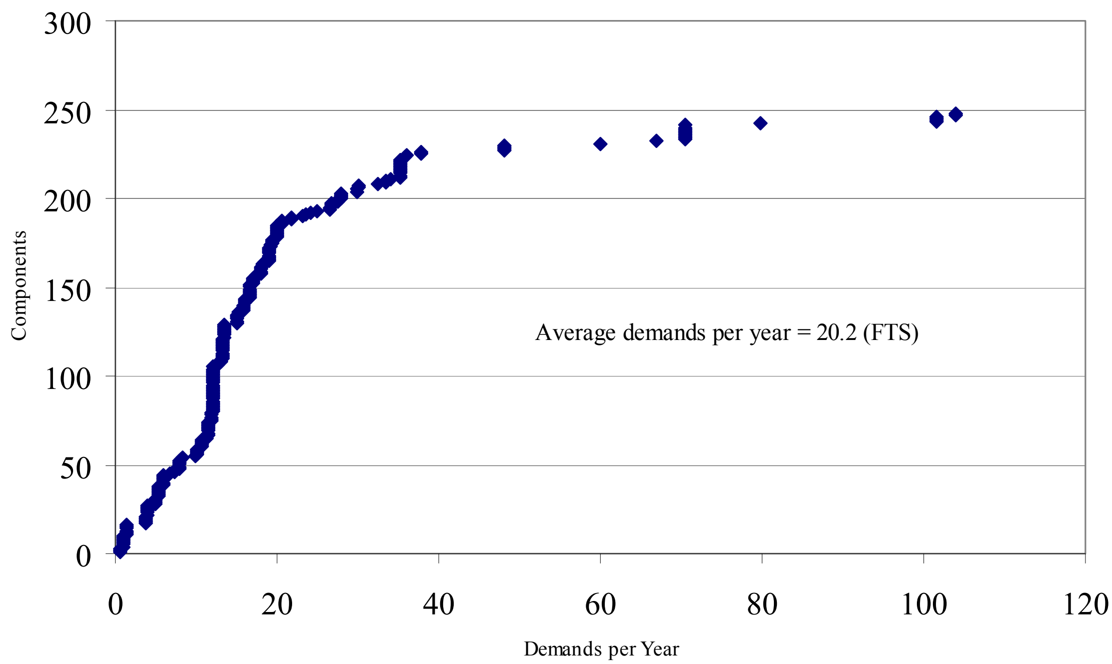

Figure 19-1a. Standby FAN demands per year distribution.

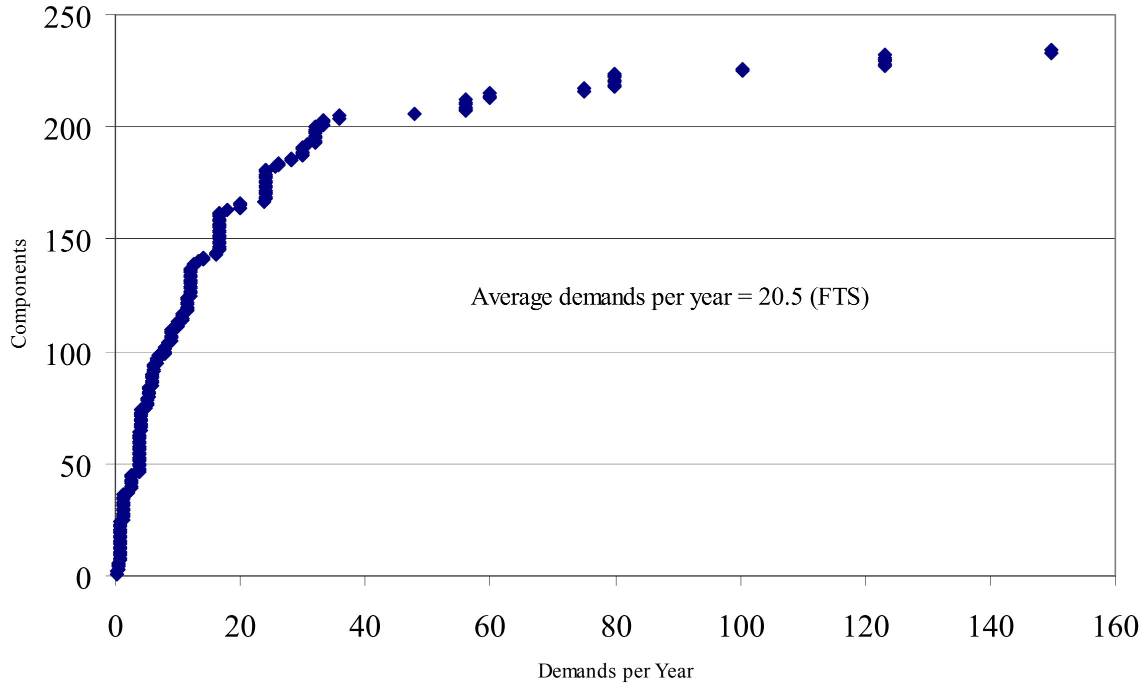

Figure 19-1b. Running/alternating FAN demands per year distribution.

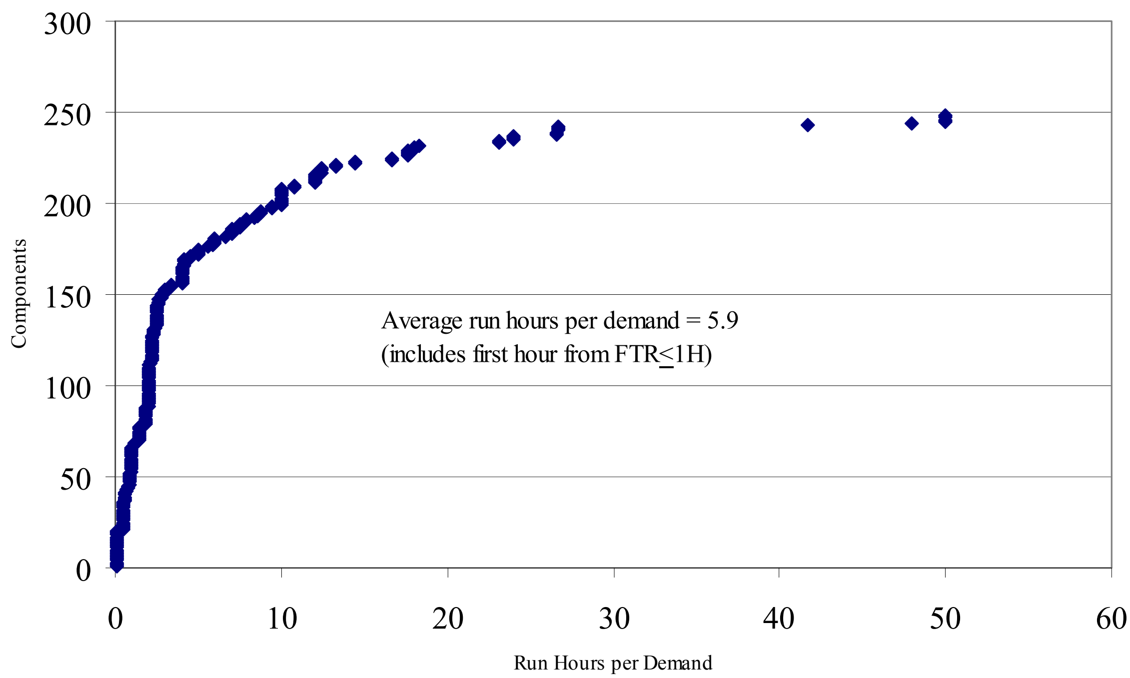

Figure 19-2a. Standby FAN run hours per demand distribution.

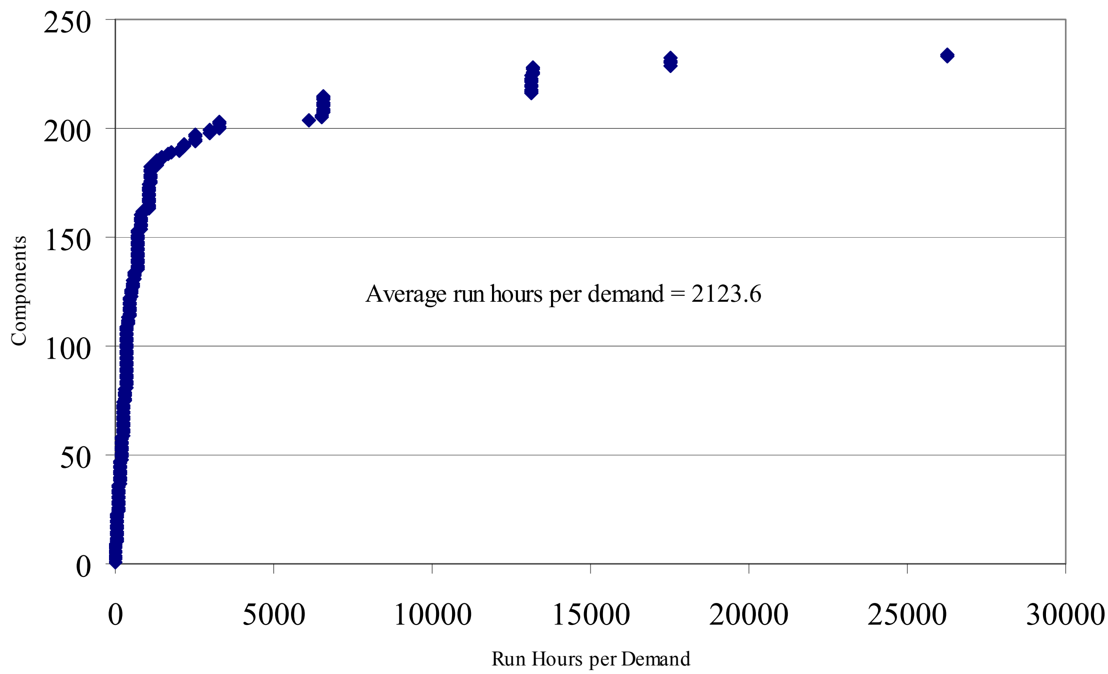

Figure 19-2b. Running/alternating FAN run hours per demand distribution.

19.3 Data Analysis

The FAN data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 19-4.

Table 19-4. Empirical distributions of MLEs for p and λ for FANs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Standby	FTS	Component	0.00E+00	0.00E+00	5.18E-03	1.67E-02
		Plant	0.00E+00	0.00E+00	2.02E-02	2.51E-02
		Industry	-	-	1.31E-03	-
	FTR≤1H	Component	0.00E+00	0.00E+00	1.57E-03	1.50E-02
		Plant	0.00E+00	0.00E+00	2.40E-03	7.05E-03
		Industry	-	-	1.12E-03	-
	FTR>1H	Component	0.00E+00	0.00E+00	1.98E-04	8.72E-04
		Plant	0.00E+00	0.00E+00	2.47E-04	5.06E-04
		Industry	-	-	1.04E-04	-
Running/ Alternating	FTS	Component	0.00E+00	0.00E+00	2.16E-03	1.60E-02
		Plant	0.00E+00	0.00E+00	1.94E-03	8.33E-03
		Industry	-	-	7.49E-04	-
	FTR	Component	0.00E+00	0.00E+00	9.70E-06	6.86E-05
		Plant	0.00E+00	0.00E+00	1.08E-05	4.58E-05
		Industry	-	-	9.08E-06	-

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 19-3, only 9.7% of the FANs experienced a FTS over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 90.3% portion of the distribution, and non-zero values above 90.3%.

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in
Table 19-5 for FANs.

Table 19-5. Fitted distributions for p and λ for FANs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/CL/KS	5.01E-16	1.06E-05	2.14E-03	1.25E-02	Beta	0.097	4.514E+01
		EB/PL/KS	2.19E-07	6.65E-04	2.89E-03	1.34E-02	Beta	0.289	9.975E+01
		SCNID/IL	5.26E-06	6.08E-04	1.34E-03	5.13E-03	Beta	0.500	3.740E+02
	FTR≤1H	EB/CL/KS	3.52E-07	3.73E-04	1.30E-03	5.74E-03	Gamma	0.334	2.570E+02
		EB/PL/KS	7.15E-07	5.81E-04	1.91E-03	8.33E-03	Gamma	0.348	1.818E+02
		SCNID/IL	4.51E-06	5.21E-04	1.15E-03	4.40E-03	Gamma	0.500	4.363E+02
	FTR>1H	JEFF/CL	5.65E-05	1.07E-04	1.11E-04	1.80E-04	Gamma	8.480	7.643E+04
		JEFF/PL	5.65E-05	1.07E-04	1.11E-04	1.80E-04	Gamma	8.480	7.643E+04
		SCNID/IL	4.36E-07	5.05E-05	1.11E-04	4.26E-04	Gamma	0.500	4.509E+03
Running/ Alternating	FTS	EB/CL/KS	9.00E-12	5.26E-05	1.33E-03	7.36E-03	Beta	0.148	1.109E+02
		EB/PL/KS	4.37E-08	3.36E-04	1.79E-03	8.58E-03	Beta	0.258	1.442E+02
		SCNID/IL	3.03E-06	3.51E-04	7.70E-04	2.96E-03	Beta	0.500	6.489E+02
	FTR	EB/CL/KS	1.28E-10	1.61E-06	9.66E-06	4.70E-05	Gamma	0.245	2.535E+04
		EB/PL/KS	1.43E-07	5.99E-06	1.08E-05	3.76E-05	Gamma	0.652	6.063E+04
		SCNID/IL	3.60E-08	4.17E-06	9.16E-06	3.52E-05	Gamma	0.500	5.461E+04

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, JEFF/CL is the posterior distribution at the component level of a Bayesian update of the Jeffreys noninformative prior with industry data, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

19.4 Industry-Average Baselines

Table 19-6 lists the industry-average failure rate distributions. For four of the five failure modes, the data sets were sufficient (Section A.1 in Reference 14) for empirical Bayes analyses to be performed. For these failure modes, the industry-average distributions are based on the empirical Bayes analysis results at the plant level. However, two of the results indicated values for α less than 0.3. In those cases a lower bound value of 0.3 was used (see Section A.1 in Reference 14). For FTR>1H, the empirical Bayes did not converge but indicated little variation between plants. For that failure mode, a Bayesian update of the Jeffreys noninformative prior is recommended. These industry-average failure rates do not account for any recovery.

Table 19-6. Selected industry distributions of p and λ for FANs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/PL/KS	3.10E-07	7.06E-04	2.89E-03	1.32E-02	Beta	0.300	1.039E+02
	FTR≤1H	EB/PL/KS	7.15E-07	5.81E-04	1.91E-03	8.33E-03	Gamma	0.348	1.818E+02
	FTR>1H	JEFF/PL	5.65E-05	1.07E-04	1.11E-04	1.80E-04	Gamma	8.500	7.643E+04
Running/	FTS	EB/PL/KS	1.92E-07	4.37E-04	1.79E-03	8.17E-03	Beta	0.300	1.676E+02
Alternating	FTR	EB/PL/KS	1.43E-07	5.99E-06	1.08E-05	3.76E-05	Gamma	0.652	6.063E+04

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 19-7 shows the rounded values for the FAN failure modes.

Table 19-7. Selected industry distributions of p and λ for FANs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/PL/KS	3.0E-07	7.0E-04	3.0E-03	1.5E-02	Beta	0.30	1.00E+02
	FTR≤1H	EB/PL/KS	2.0E-07	5.0E-04	2.0E-03	9.0E-03	Gamma	0.30	1.50E+02
	FTR>1H	JEFF/PL	6.0E-05	1.2E-04	1.2E-04	2.0E-04	Gamma	8.00	6.67E+04
Running/ Alternating	FTS	EB/PL/KS	2.0E-07	5.0E-04	2.0E-03	9.0E-03	Beta	0.30	1.50E+02
	FTR	EB/PL/KS	1.5E-07	6.0E-06	1.0E-05	3.0E-05	Gamma	0.70	7.00E+04

19.5 Breakdown by System

FAN UR results (Jeffreys means of system data) are compared by system and failure mode in Table 19-8. Results are shown only for the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 19-8. FAN p and λ by system.

Operation	System	FTS	FTR≤1H	FTR>1H
Standby	CCW	-	-	-
	CIS	3.4E-02	1.9E-02	-
	EPS	7.8E-04	5.8E-04	-
	HCI	-	1.8E-02	-
	HVC	1.4E-03	2.0E-03	-
	IAS	9.9E-03	-	-
	SGT	1.1E-03	-	-
Operation	System	FTS		FTR
Running/ Alternating	CIS	-		1.2E-05
	CRD	-		-
	DCP	-		-
	EPS	-		-
	ESW	5.4E-04		1.0E-05
	HVC	9.1E-04		8.6E-06
	IAS	1.4E-03		5.4E-05
	SGT	6.2E-04		-

20 Filter (FLT)

20.1 Component Description

The filter (FLT) boundary includes the filter. The failure mode for the FLT is listed in Table 20-1.

Table 20-1. FLT failure modes.

Operation	Failure Mode	Parameter	Units	Description
All	PG	λ	1/h	Plug

20.2 Data Collection and Review

Data for FLT UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1997–2004. Systems covered in the data search were chosen to ensure that filters were in clean water systems. There are 217 FLTs from 23 plants in the data originally gathered from EPIX. The systems and operational status included in the FLT data collection are listed in Table 20-2 with the number of components included with each system.

Table 20-2. FLT systems.

Operation	System	Description	Number of Components
Clean	CCW	Component cooling water	61
	CRD	Control rod drive	55
	CSR	Containment spray recirculation	36
	HPI	High pressure injection	12
	LCI	Low pressure coolant injection	33
	LCS	Low pressure core spray	7
	LPI	Low pressure injection	13
	Total		217

The data review process is described in detail in Section A.1 in Reference 14. Table 20-3 summarizes the data obtained from EPIX and used in the FLT analysis.

Table 20-3. FLT unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Clean	PG	1	15207360 h	217	23	0.5%	4.3%

20.3 Data Analysis

The FLT data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 20-4.

Table 20-4. Empirical distributions of MLEs for p and λ for FLTs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Clean	PG	Component	0.00E+00	0.00E+00	6.58E-08	0.00E+00
		Plant	0.00E+00	0.00E+00	6.20E-07	0.00E+00
		Industry	-	-	6.58E-08	-

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 20-3, only 0.5% of the FLTs experienced a PG over the period 1997–2004, so the empirical distribution of MLEs, at the

component level, involves zeros for the 0% to 99.5% portion of the distribution, and non-zero values above 99.5%.

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table 20-5 for FLTs.

Table 20-5. Fitted distributions for p and λ for FLTs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Clean	PG	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	3.88E-10	4.49E-08	9.86E-08	3.79E-07	Gamma	0.500	5.069E+06

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

20.4 Industry-Average Baselines

Table 20-6 lists the industry-average failure rate distribution.

Table 20-6. Selected industry distributions of p and λ for FLTs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Clean	PG	SCNID/IL	3.88E-10	4.49E-08	9.86E-08	3.79E-07	Gamma	0.500	5.069E+06

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 20-7 shows the rounded values for the FLT failure mode.

Table 20-7. Selected industry distributions of p and λ for FLTs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Clean	PG	SCNID/IL	4.0E-10	5.0E-08	1.0E-07	4.0E-07	Gamma	0.50	5.00E+06

20.5 Breakdown by System

FLT UR results (Jeffreys means of system data) are compared by system and failure mode in Table 20-8. Results are shown only for the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 20-8. FLT p and λ by system.

Operation	System	PG
Clean	CCW	-
	CRD	3.9E-07
	CSR	-
	HPI	-
	LCI	-
	LCS	-
	LPI	-

21 Hydraulic-Operated Damper (HOD)

21.1 Component Description

The hydraulic-operated damper (HOD) component boundary includes the valve, the valve operator, and local instrumentation and control circuitry. The failure modes for HOD are listed in Table 21-1.

Table 21-1. HOD failure modes.

Operation	Failure Mode	Parameter	Units	Description
All	FTO/C	p	-	Failure to open or failure to close
	SO	λ	1/h	Spurious operation

21.2 Data Collection and Review

Data for HOD UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. There are 159 HODs from nine plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1 in Reference 14) there were 159 components in nine plants. The systems included in the HOD data collection are listed in Table 21-2 with the number of components included with each system.

Table 21-2. HOD systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
All	EPS	Emergency power supply	16	16	8
	HVC	Heating ventilation and air conditioning	125	125	87
	SGT	Standby gas treatment	18	18	18
	Total		159	159	113

The HOD data set obtained from RADS was further reduced to include only those HODs with ≤ 20 demands/year. See Section A.1 in Reference 14 for a discussion concerning this decision to limit certain component populations. Table 21-3 summarizes the data used in the HOD analysis. Note that SO hours are calendar hours.

Table 21-3. HOD unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO/C	7	5341	113	6	6.2%	33.3%
	SO	1	4949400 h	113	6	0.9%	16.7%

Figure 21-1 shows the range of valve demands per year in the HOD data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 17. The average for the data set is 9.5. demands/year.

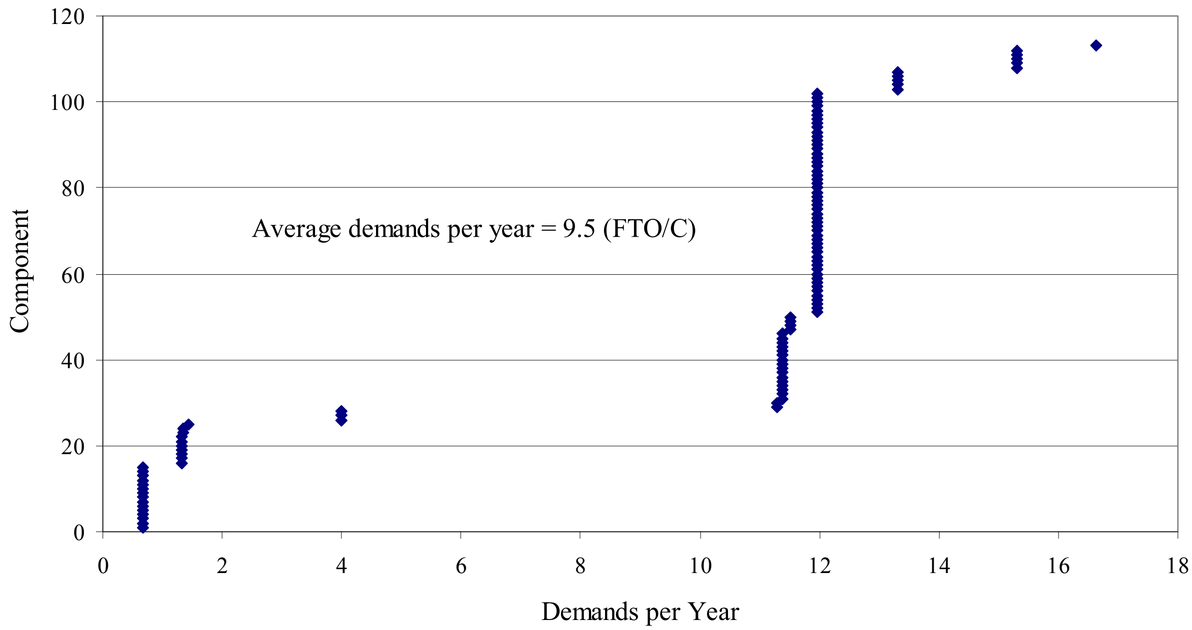

Figure 21-1. HOD demands per year distribution.

21.3 Data Analysis

The HOD data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 21-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 21-3, only 6.2% of the HODs experienced a FTO/C over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 93.8% portion of the distribution, and non-zero values above 93.8%.

Table 21-4. Empirical distributions of MLEs for p and λ for HODs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
All	FTO/C	Component	0.00E+00	0.00E+00	8.50E-03	1.20E-02
		Plant	0.00E+00	0.00E+00	2.97E-03	1.67E-02
		Industry	-	-	1.31E-03	-
	SO	Component	0.00E+00	0.00E+00	2.02E-07	0.00E+00
		Plant	0.00E+00	0.00E+00	5.28E-08	3.17E-07
		Industry	-	-	2.02E-07	-

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table 21-5.

Table 21-5. Fitted distributions for p and λ for HODs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO/C	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	3.77E-09	2.91E-04	2.61E-03	1.34E-02	Beta	0.205	7.824E+01
		SCNID/IL	5.53E-06	6.40E-04	1.40E-03	5.39E-03	Beta	0.500	3.556E+02
	SO	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.19E-09	1.38E-07	3.03E-07	1.16E-06	Gamma	0.500	1.650E+06

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

21.4 Industry-Average Baselines

Table 21-6 lists the selected industry distributions of p and λ for the HOD failure modes. For the FTO/C failure mode, the data set was sufficient (Section A.1 in Reference 14) for empirical Bayes analyses to be performed. For this failure mode, the industry-average distribution is based on the empirical Bayes analysis results at the plant level. However, the result indicated an α value less than 0.3. The lower limit of 0.3 was assumed (see Section A.1 in Reference 14). The industry-average distributions for the SO failure mode are not sufficient for the empirical Bayes method; therefore a SCNID analysis was performed to provide a failure rate distribution. These industry-average failure rates do not account for any recovery.

Table 21-6. Selected industry distributions of p and λ for HODs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO/C	EB/PL/KS	2.80E-07	6.39E-04	2.61E-03	1.19E-02	Beta	0.300	1.148E+02
	SO	SCNID/IL	1.19E-09	1.38E-07	3.03E-07	1.16E-06	Gamma	0.500	1.650E+06

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 21-7 shows the rounded values for the HOD failure modes.

Table 21-7. Selected industry distributions of p and λ for HODs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO/C	EB/PL/KS	2.5E-07	6.0E-04	2.5E-03	1.2E-02	Beta	0.30	1.20E+02
	SO	SCNID/IL	1.2E-09	1.5E-07	3.0E-07	1.2E-06	Gamma	0.50	1.67E+06

21.5 Breakdown by System

HOD UR results (Jeffreys means of system data) are compared by system and failure mode in Table 21-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 21-8. HOD p and λ by system.

System	FTO/C	SO
EPS	6.6E-03	-
HVC	1.2E-03	3.9E-07
SGT	-	-

22 Hydraulic-Operated Valve (HOV)

22.1 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 22-1.

Table 22-1. HOV failure modes.

Operation	Failure Mode	Parameter	Units	Description
Standby	FTO/C	p	-	Failure to open or failure to close
	SO	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

22.2 Data Collection and Review

Most of the data for HOV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. The ELS and ILS data are from RADS, covering 1997–2004. There are 607 HOVs from 60 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1 in Reference 14) there were 606 components in 60 plants. The systems included in the HOV data collection are listed in Table 22-2 with the number of components included with each system.

Table 22-2. HOV systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
Standby	AFW	Auxiliary feedwater	33	32	21
	CCW	Component cooling water	4	4	0
	CIS	Containment isolation system	25	25	25
	CRD	Control rod drive	178	178	178
	CVC	Chemical and volume control	2	2	2
	ESW	Emergency service water	10	10	7
	HCI	High pressure coolant injection	15	15	5
	HPI	High pressure injection	8	8	8
	HVC	Heating ventilation and air conditioning	11	11	1
	LPI	Low pressure injection	10	10	10
	MFW	Main feedwater	97	97	93
	MSS	Main steam	188	188	188
	NSW	Normal service water	3	3	3
	RCI	Reactor core isolation	5	5	5
	RCS	Reactor coolant	3	3	3
	SGT	Standby gas treatment	14	14	8
	VSS	Vapor suppression	1	1	1
	Total		607	606	558

The HOV data set obtained from RADS was further reduced to include only those HOVs with ≤ 20 demands/year. See Section A.1 in Reference 14 for a discussion concerning this decision to limit certain component populations. Table 22-3 summarizes the data used in the HOV analysis. Note that the hours for SO, ELS, and ILS are calendar hours. The FC failure mode is not supported by EPIX data.

Table 22-3. HOV unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
Standby	FTO/C	8	11827	558	57	1.4%	10.5%
	SO	6	24440400 h	558	57	1.1%	7.0%
	ELS	0	33848640 h	483	56	0.0%	0.0%
	ILS	1	39314880 h	561	57	0.2%	1.8%
Control	FC	-	-	-	-	-	-

Figure 22-1 shows the range of valve demands per year in the HOV data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 20. The average for the data set is 4.2. demands/year.

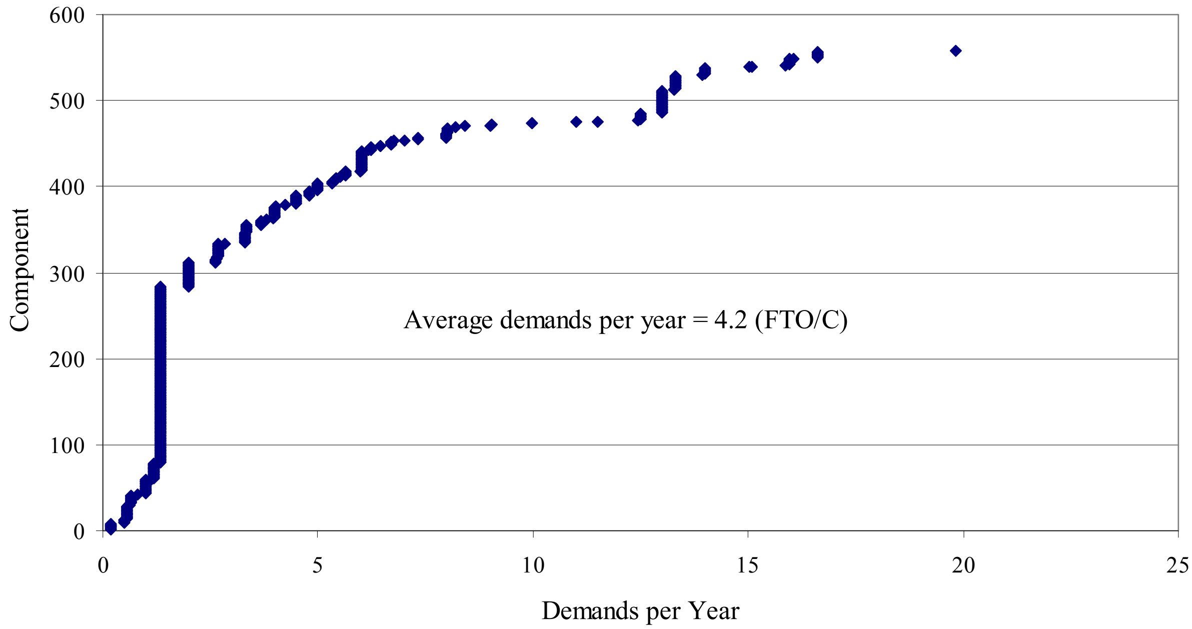

Figure 22-1. HOV demands per year distribution.

22.3 Data Analysis

The HOV data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 22-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 22-3, only 1.4% of the HOVs experienced a FTO/C over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 98.6% portion of the distribution, and non-zero values above 98.6%.

Table 22-4. Empirical distributions of MLEs for p and λ for HOVs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Standby	FTO/C	Component	0.00E+00	0.00E+00	6.75E-04	0.00E+00
		Plant	0.00E+00	0.00E+00	1.65E-03	1.25E-02
		Industry	-	-	6.76E-04	-
	SO	Component	0.00E+00	0.00E+00	2.45E-07	0.00E+00
		Plant	0.00E+00	0.00E+00	3.31E-07	2.28E-06
		Industry	-	-	2.45E-07	-
	ELS	Component	-	-	-	-
		Plant	-	-	-	-
		Industry	-	-	0.00E+00	-
	ILS	Component	0.00E+00	0.00E+00	2.54E-08	0.00E+00
		Plant	0.00E+00	0.00E+00	2.50E-08	0.00E+00
		Industry	-	-	2.54E-08	-
Control	FC	Industry	-	-	-	-

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table 22-5.

Table 22-5. Fitted distributions for p and λ for HOVs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTO/C	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	1.59E-16	6.30E-06	1.51E-03	8.83E-03	Beta	0.094	6.236E+01
		SCNID/IL	2.83E-06	3.27E-04	7.19E-04	2.76E-03	Beta	0.500	6.953E+02
	SO	JEFF/CL	1.21E-07	2.52E-07	2.66E-07	4.57E-07	Gamma	6.500	2.444E+07
		EB/PL/KS	9.52E-20	1.81E-09	3.61E-07	2.10E-06	Gamma	0.097	2.692E+05
		SCNID/IL	1.05E-09	1.21E-07	2.66E-07	1.02E-06	Gamma	0.500	1.880E+06
	ELS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	5.81E-11	6.72E-09	1.48E-08	5.67E-08	Gamma	0.500	3.385E+07
	ILS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.50E-10	1.74E-08	3.82E-08	1.47E-07	Gamma	0.500	1.311E+07
Control	FC	WSRC	-	-	-	-	-	-	-

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, JEFF/CL is the posterior distribution at the component level of a Bayesian update of the Jeffreys noninformative prior with industry data, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

22.4 Industry-Average Baselines

Table 22-6 lists the selected industry distributions of p and λ for the HOV failure modes. For the FTO/C and SO failure modes, the data set was sufficient (see Section A.1 in Reference 14) for empirical Bayes analyses to be performed. Therefore, the industry-average distribution is based on the empirical Bayes analysis results at the plant level for FTO/C and SO. However, the FTO/C and SO analyses resulted in α values less than 0.3. Therefore, the lower bound of 0.3 was assumed (see Section A.1 in Reference 14). The industry-average distributions for ILS and ELS are not sufficient (Section A.1 in Reference 14) for the empirical Bayes method; therefore a SCNID analysis was performed to provide a failure rate distribution. These industry-average failure rates do not account for any recovery. 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.

The FC failure mode distribution was derived from the Westinghouse Savannah River Company (WSRC) database. That source lists Category 2 data (see Section A.1 in Reference 14) for AOV control valves from sources other than commercial power plants. The recommended value from WSRC was used as the mean, with an assumed α of 0.3.

Table 22-6. Selected industry distributions of p and λ for HOVs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTO/C	EB/PL/KS	1.62E-07	3.69E-04	1.51E-03	6.90E-03	Beta	0.300	1.986E+02
	SO	EB/PL/KS	3.87E-11	8.81E-08	3.61E-07	1.65E-06	Gamma	0.300	8.303E+05
	ELS	SCNID/IL	5.81E-11	6.72E-09	1.48E-08	5.67E-08	Gamma	0.500	3.385E+07
	ELL	ELS/EPIX	1.11E-13	2.52E-10	1.03E-09	4.73E-09	Gamma	0.300	2.902E+08
	ILS	SCNID/IL	1.50E-10	1.74E-08	3.82E-08	1.47E-07	Gamma	0.500	1.311E+07
	ILL	ILS/EPIX	8.17E-14	1.86E-10	7.63E-10	3.49E-09	Gamma	0.300	3.932E+08
Control	FC	WSRC	3.21E-10	7.31E-07	3.00E-06	1.37E-05	Gamma	0.300	1.000E+05

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 22-7 shows the rounded values for the HOV.

Table 22-7. Selected industry distributions of p and λ for HOVs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTO/C	EB/PL/KS	1.5E-07	4.0E-04	1.5E-03	7.0E-03	Beta	0.30	2.00E+02
	SO	EB/PL/KS	4.0E-11	1.0E-07	4.0E-07	2.0E-06	Gamma	0.30	7.50E+05
	ELS	SCNID/IL	6.0E-11	7.0E-09	1.5E-08	6.0E-08	Gamma	0.50	3.33E+07
	ELL	ELS/EPIX	1.0E-13	2.5E-10	1.0E-09	5.0E-09	Gamma	0.30	3.00E+08
	ILS	SCNID/IL	1.5E-10	2.0E-08	4.0E-08	1.5E-07	Gamma	0.50	1.25E+07
	ILL	ILS/EPIX	9.0E-14	2.0E-10	8.0E-10	4.0E-09	Gamma	0.30	3.75E+08
Control	FC	WSRC	3.0E-10	7.0E-07	3.0E-06	1.5E-05	Gamma	0.30	1.00E+05

22.5 Breakdown by System

HOV UR results (Jeffreys means of system data) are compared by system and failure mode in Table 22-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 22-8. HOV p and λ by system.

System	FTO/C	SO	ELS	ILS
AFW	-	1.6E-06	-	-
CIS	2.4E-03	-	-	8.6E-07
CRD	-	-	-	-
CVC	-	-	-	-
ESW	-	-	-	-
HCI	-	-	-	-
HPI	-	-	-	-
HVC	-	-	-	-

System	FTO/C	SO	ELS	ILS
LPI	1.2E-02	-	-	-
MFW	2.3E-03	3.7E-07	-	-
MSS	4.4E-04	5.5E-07	-	-
NSW	-	-	-	-
RCI	-	-	-	-
RCS	-	-	-	-
SGT	-	-	-	-
VSS	-	-	-	-

23 Hydro Turbine Generator (HTG)

23.1 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 23-1.

Table 23-1. HTG failure modes.

Operation	Failure Mode	Parameter	Units	Description
Standby	FTS	*P*	-	Failure to start
	FTLR (FTR≤1H)	*P*	-	Failure to load and run for 1 h
	FTR>1H	λ	1/h	Fail to run beyond 1 h

23.2 Data Collection and Review

Data for HTG UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1997–2004. The extended data period was chosen since there are so few components in RADS. In addition, the Oconee plant identified HTG failures during this period that had not yet been entered into EPIX. There are 2 HTGs from one plant in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1 in Reference 14) there were 2 components in one plant. The systems and operational status included in the HTG data collection are listed in Table 23-2 with the number of components included with each system.

Table 23-2. HTG systems.

Operation	System	Description	Number of Components	
			Initial	After Review
Standby	EPS	Emergency power system	2	2
	Total		2	2

The data review process is described in detail in Section A.1 in Reference 14. Table 23-3 summarizes the data obtained from EPIX and used in the HTG analysis.

Table 23-3. HTG unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTS	6	3322	2	1	100.0%	100.0%
	FTLR	7	1767	2	1	100.0%	100.0%
	FTR>1H	1	6162 h	2	1	50.0%	100.0%

23.3 Data Analysis

Since there are only two components at two units, the MLE distributions provide little information. In addition, the empirical Bayes analysis cannot be performed. Therefore, only the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table 23-4 for HTGs. These results were used to develop the industry-average distributions.

Table 23-4. Fitted distributions for p and λ for HTGs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	SCNID/IL	7.71E-06	8.92E-04	1.96E-03	7.51E-03	Beta	0.500	2.551E+02
	FTLR	SCNID/IL	1.68E-05	1.94E-03	4.24E-03	1.63E-02	Beta	0.500	1.174E+02
	FTR>1H	SCNID/IL	9.57E-07	1.11E-04	2.43E-04	9.35E-04	Gamma	0.500	2.054E+03

Note –SCNID/IL is a simplified constrained noninformative distribution at the industry level.

23.4 Industry-Average Baselines

Table 23-5 lists the industry-average failure rate distributions. The industry-average distribution for all of the failure modes is not sufficient (Section A.1 in Reference 14) for the empirical Bayes method; therefore a SCNID analysis was performed to provide a failure rate distribution. These industry-average failure rates do not account for any recovery.

Table 23-5. Selected industry distributions of p and λ for HTGs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	SCNID/IL	7.71E-06	8.92E-04	1.96E-03	7.51E-03	Beta	0.500	2.551E+02
	FTLR	SCNID/IL	1.68E-05	1.94E-03	4.24E-03	1.63E-02	Beta	0.500	1.174E+02
	FTR>1H	SCNID/IL	9.57E-07	1.11E-04	2.43E-04	9.35E-04	Gamma	0.500	2.054E+03

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 23-6 shows the rounded values for the HTG failure modes.

Table 23-6. Selected industry distributions of p and λ for HTGs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	SCNID/IL	8.0E-06	9.0E-04	2.0E-03	8.0E-03	Beta	0.50	2.50E+02
	FTLR	SCNID/IL	1.5E-05	2.0E-03	4.0E-03	1.5E-02	Beta	0.50	1.25E+02
	FTR>1H	SCNID/IL	1.0E-06	1.2E-04	2.5E-04	1.0E-03	Gamma	0.50	2.00E+03

23.5 Breakdown by System

The HTG is included only in the emergency power system.

24 Heat Exchanger (HTX)

24.1 Component Description

The heat exchanger (HTX) boundary includes the heat exchanger shell and tubes. The failure modes for HTX are listed in Table 24-1.

Table 24-1. HTX failure modes.

Operation	Failure Mode	Parameter	Units	Description
All	PG	λ	1/h	Plug
	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

24.2 Data Collection and Review

Data for HTX UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. (ELS data cover 1997–2004.) Only HTXs in the component cooling water (CCW) and residual heat removal systems were included in the data search. There are 713 HTXs from 102 plants in the data originally gathered from EPIX. The systems and operational status included in the HTX data collection are listed in Table 24-2 with the number of components included with each system.

Table 24-2. HTX systems.

Operation	System	Description	Number of Components
All	CCW	Component cooling water	421
	LCI	Low pressure coolant injection	168
	LPI	Low pressure injection	124
	Total		713

The data review process is described in detail in Section A.1 in Reference 14. Table 24-3 summarizes the data obtained from EPIX and used in the HTX analysis.

Table 24-3. HTX unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	PG	20	31229400 h	713	102	2.8%	15.7%
	ELS (tube)	10	49967040 h	713	102	1.4%	7.8%
	ELS (shell)	2	49967040 h	713	102	0.4%	2.9%

24.3 Data Analysis

The HTX data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 24-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 24-3, only 15.7% of the HTXs experienced a PG over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 84.3% portion of the distribution, and non-zero values above 84.3%.

Table 24-4. Empirical distributions of MLEs for p and λ for HTXs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
All	PG	Component	0.00E+00	0.00E+00	6.40E-07	0.00E+00
		Plant	0.00E+00	0.00E+00	5.99E-07	5.71E-06
		Industry	-	-	6.40E-07	-
	ELS (tube)	Component	0.00E+00	0.00E+00	2.00E-07	0.00E+00
		Plant	0.00E+00	0.00E+00	2.32E-07	2.04E-06
		Industry	-	-	2.00E-07	-
	ELS (shell)	Component	0.00E+00	0.00E+00	4.00E-08	0.00E+00
		Plant	0.00E+00	0.00E+00	2.33E-08	0.00E+00
		Industry	-	-	4.00E-08	-

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table 24-5.

Table 24-5. Fitted distributions for p and λ for HTXs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	PG	JEFF/CL	4.37E-07	6.46E-07	6.56E-07	9.12E-07	Gamma	20.500	3.123E+07
		EB/PL/KS	6.86E-08	5.01E-07	6.45E-07	1.71E-06	Gamma	1.416	2.195E+06
		SCNID/IL	2.58E-09	2.99E-07	6.56E-07	2.52E-06	Gamma	0.500	7.617E+05
	ELS (tube)	JEFF/CL	1.16E-07	2.04E-07	2.10E-07	3.27E-07	Gamma	10.500	4.997E+07
		EB/PL/KS	3.85E-14	1.70E-08	2.32E-07	1.23E-06	Gamma	0.177	7.639E+05
		SCNID/IL	8.26E-10	9.56E-08	2.10E-07	8.07E-07	Gamma	0.500	2.380E+06
	ELS (shell)	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.97E-10	2.28E-08	5.00E-08	1.92E-07	Gamma	0.500	9.994E+06

Note – JEFF/CL is the posterior distribution at the component level of a Bayesian update of the Jeffreys noninformative prior with industry data, EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

24.4 Industry-Average Baselines

Table 24-6 lists the selected industry distributions of p and λ for the HTX failure modes. For the PG and ELS (tube) failure modes, the data sets were sufficient (see Section A.1 in Reference 14) for empirical Bayes analyses to be performed. Therefore, the industry-average distributions are based on the empirical Bayes analysis results at the plant level for PG and ELS (tube). However, the industry-average distribution for ELS (shell) is not sufficient (Section A.1 in Reference 14) for the empirical Bayes method; therefore, a SCNID analysis was performed to provide a failure rate distribution.

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 24-6. Selected industry distributions of p and λ for HTXs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	PG	EB/PL/KS	6.86E-08	5.01E-07	6.45E-07	1.71E-06	Gamma	1.416	2.195E+06
	ELS (tube)	EB/PL/KS	2.48E-11	5.66E-08	2.32E-07	1.06E-06	Gamma	0.300	1.293E+06
	ELS (shell)	ELS(tube)	1.97E-10	2.28E-08	5.00E-08	1.92E-07	Gamma	0.500	9.994E+06
	ELL (tube)	SCNID/IL	3.73E-12	8.48E-09	3.48E-08	1.59E-07	Gamma	0.300	8.619E+06
	ELL (shell)	ELS(shell)	3.75E-13	8.53E-10	3.50E-09	1.60E-08	Gamma	0.300	8.571E+07

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 24-7 shows the rounded values for the HTX failure modes.

Table 24-7. Selected industry distributions of p and λ for HTXs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	PG	EB/PL/KS	7.0E-08	5.0E-07	6.0E-07	1.5E-06	Gamma	1.50	2.50E+06
	ELS (tube)	EB/PL/KS	2.5E-11	6.0E-08	2.5E-07	1.2E-06	Gamma	0.30	1.20E+06
	ELS (shell)	ELS (tube)	2.0E-10	2.5E-08	5.0E-08	2.0E-07	Gamma	0.50	1.00E+07
	ELL (tube)	SCNID/IL	3.0E-12	7.0E-09	3.0E-08	1.5E-07	Gamma	0.30	1.00E+07
	ELL (shell)	ELS (shell)	3.0E-13	7.0E-10	3.0E-09	1.5E-08	Gamma	0.30	1.00E+08

24.5 Breakdown by System

HTX UR results (Jeffreys means of system data) are compared by system and failure mode in Table 24-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 24-8. HTX p and λ by system.

System	PG	ELS (tube)	ELS (shell)
CCW	6.2E-07	2.5E-07	8.5E-08
LCI	4.6E-07	2.9E-07	-
LPI	1.0E-06	1.3E-07	-

25 Inverter (INV)

25.1 Component Description

The inverter (INV) boundary includes the inverter unit. The failure mode for INV is listed in Table 25-1.

Table 25-1. INV failure modes.

Operation	Failure Mode	Parameter	Units	Description
Running	FTOP	λ	1/h	Fail to operate

25.2 Data Collection and Review

Data for INV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. There are 638 INVs from 98 plants in the data originally gathered from EPIX. The systems and operational status included in the INV data collection are listed in Table 25-2 with the number of components included with each system.

Table 25-2. INV systems.

Operation	System	Description	Number of Components
All	ACP	Plant ac power	64
	AFW	Auxiliary feedwater	4
	CIS	Containment isolation system	18
	CRD	Control rod drive	2
	DCP	Plant dc power	21
	EPS	Emergency power supply	3
	HCI	High pressure coolant injection	7
	HVC	Heating ventilation and air conditioning	1
	IPS	Instrument ac power	465
	LCS	Low pressure core spray	5
	LPI	Low pressure injection	6
	MFW	Main feedwater	8
	MSS	Main steam	2
	RCI	Reactor core isolation	18
	RPS	Reactor protection	14
	Total		638

Table 25-3 summarizes the data obtained from EPIX and used in the INV analysis. Note that the hours are calendar hours.

Table 25-3. INV unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
Running	FTOP	153	27944400 h	638	98	17.6%	58.2%

25.3 Data Analysis

The INV data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 25-4. The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 25-3, only 0.3% of the INVs experienced a FTOP over the period 1997–2004, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 99.7% portion of the distribution, and non-zero values above 99.7%.

Table 25-4. Empirical distributions of MLEs for p and λ for INVs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Running	FTOP	Component	0.00E+00	0.00E+00	5.48E-06	2.28E-05
		Plant	0.00E+00	3.26E-06	5.07E-06	1.76E-05
		Industry	-	-	5.48E-06	-

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table 25-5.

Table 25-5. Fitted distributions for p and λ for INVs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	FTOP	EB/CL/KS	1.47E-08	2.34E-06	5.48E-06	2.16E-05	Gamma	0.466	8.516E+04
		EB/PL/KS	4.12E-07	3.91E-06	5.28E-06	1.48E-05	Gamma	1.203	2.278E+05
		SCNID/IL	2.16E-08	2.50E-06	5.49E-06	2.11E-05	Gamma	0.500	9.102E+04

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

25.4 Industry-Average Baselines

Table 25-6 lists the industry-average failure rate distributions.

Table 25-6. Selected industry distributions of p and λ for INVs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	FTOP	EB/PL/KS	4.12E-07	3.91E-06	5.28E-06	1.48E-05	Gamma	1.203	2.278E+05

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 25-7 shows the rounded values for the INV failure mode.

Table 25-7. Selected industry distributions of p and λ for INVs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	FTOP	EB/PL/KS	4.0E-07	4.0E-06	5.0E-06	1.5E-05	Gamma	1.20	2.40E+05

25.5 Breakdown by System

INV UR results (Jeffreys means of system data) are compared by system and failure mode in Table 25-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 25-8. INV p and λ by system.

System	FTOP
ACP	8.7E-06
AFW	1.4E-05
CIS	7.0E-06
CRD	-
DCP	8.2E-06
EPS	1.9E-05
HCI	-
HVC	3.4E-05
IPS	5.1E-06
LCS	-
LPI	1.3E-05
MFW	-
MSS	-
MSS	-
RCI	1.9E-06
RPS	9.0E-06

26 Motor-Driven Compressor (MDC)

26.1 Component Description

The motor-driven compressor (MDC) boundary includes the compressor, motor, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for MDC are listed in Table 26-1.

Table 26-1. MDC failure modes.

Operation	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

26.2 Data Collection and Review

Data for MDC UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. There are 143 MDCs from 46 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1 in Reference 14) there were 132 components in 46 plants. These data were then further partitioned into standby and running/alternating components. The systems and operational status included in the MDC data collection are listed in Table 26-2 with the number of components included with each system.

Table 26-2. MDC systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 200 Demands per Year
Standby	CIS	Containment isolation system	6	4	2
	HVC	Heating ventilation and air conditioning	6	4	4
	IAS	Instrument air	32	27	27
	Total		44	35	33
Running/ Alternating	CIS	Containment isolation system	5	5	3
	HVC	Heating ventilation and air conditioning	3	3	3
	IAS	Instrument air	91	89	71
	Total		99	97	77

The data review process is described in detail in Section A.1 in Reference 14. Table 26-3 summarizes the data obtained from EPIX and used in the MDC analysis. Note that components with > 200 demands/year were removed.

Table 26-3. MDC unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTS	15	2150	33	17	21.2%	29.4%
	FTR≤1H	3	939 h	5	5	3.0%	5.9%
	FTR>1H	20 (17.9)	12205 h (10999 h)	28	15	45.5%	70.6%
Running/ Alternating	FTS	36	8980	77	34	35.1%	64.7%
	FTR	158	1989420 h	77	34	67.5%	85.3%

Note – The reviewed data entries in parentheses for FTR>1H are after processing to remove events expected to have occurred within 1 h and to remove the first hour of operation. That process is explained in Section A.1 in Reference 14.

Figure 26-1a shows the range of start demands per year in the standby MDC data set. The start demands per year range from approximately 1 to 102. The average for the data set is 13.0 demands/year. Figure 26-1b shows the range of start demands per year in the running MDC data set. The demands per year range from approximately 1 to 120. The average for the data set is 23.3 demands/year.

Figure 26-2a shows the range of run hours per demand in the standby MDC data set. The run hours per demand range is from approximately 1 hour/demand to 167 hours/demand. The average is 19.8 hours/demand. Figure 26-2b shows the range of run hours per demands in the running MDC data set. The range is from approximately 29 hours/demand to 17,527 hours/demand. The average is 797.0 hours/demand.

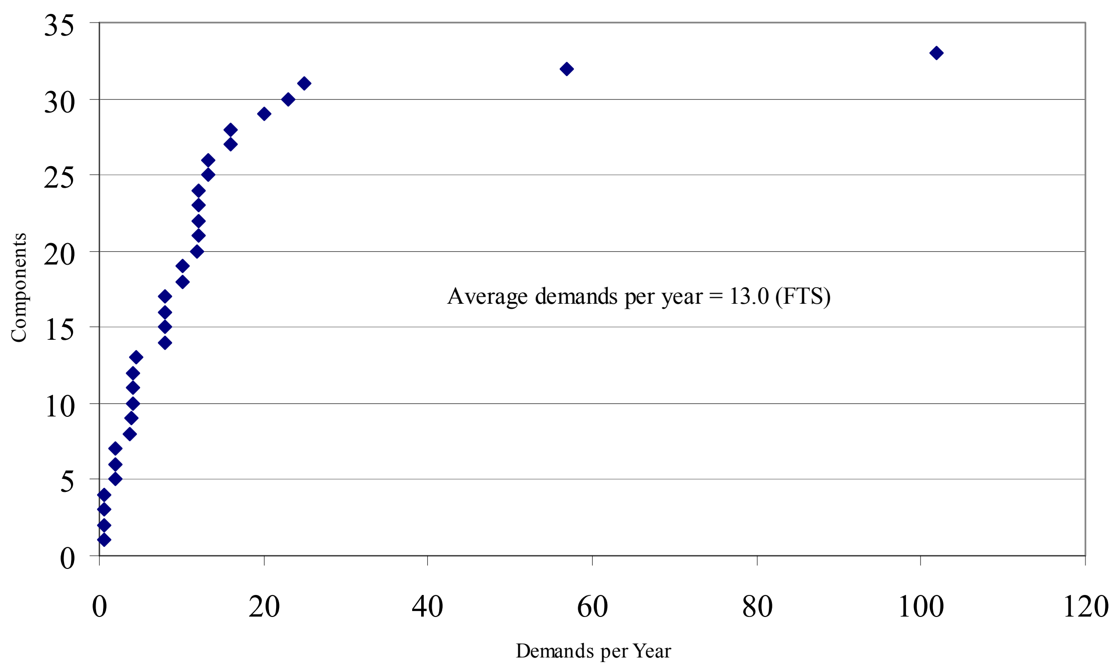

Figure 26-1a. Standby MDC demands per year distribution.

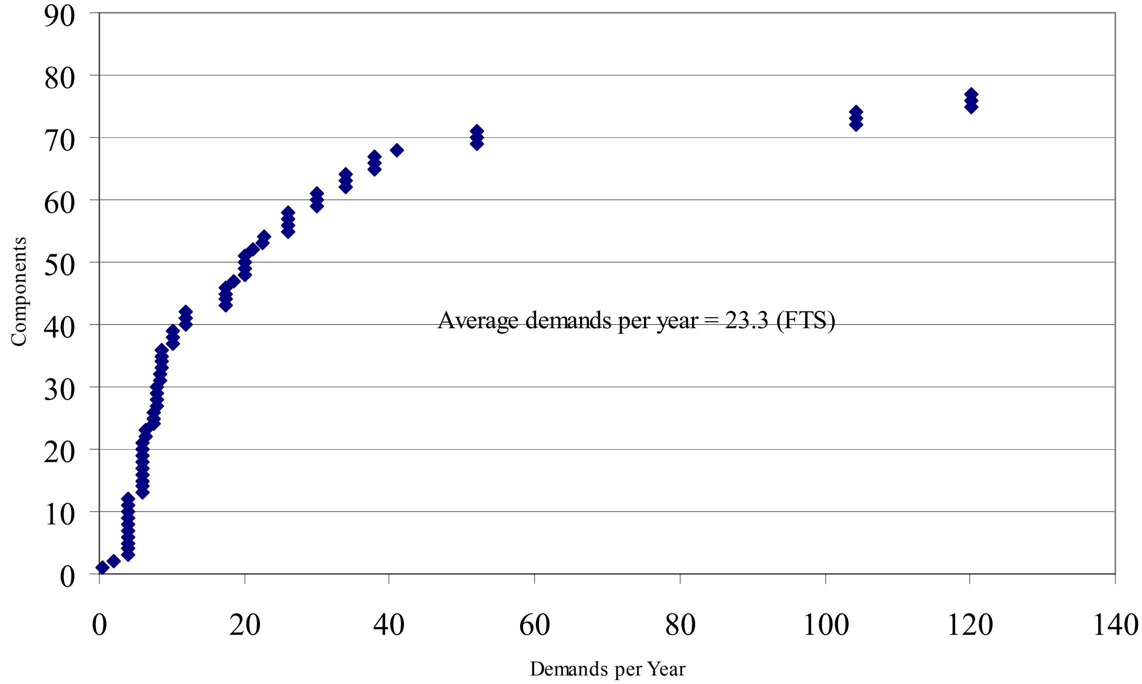

Figure 26-1b. Running/alternating MDC demands per year distribution.

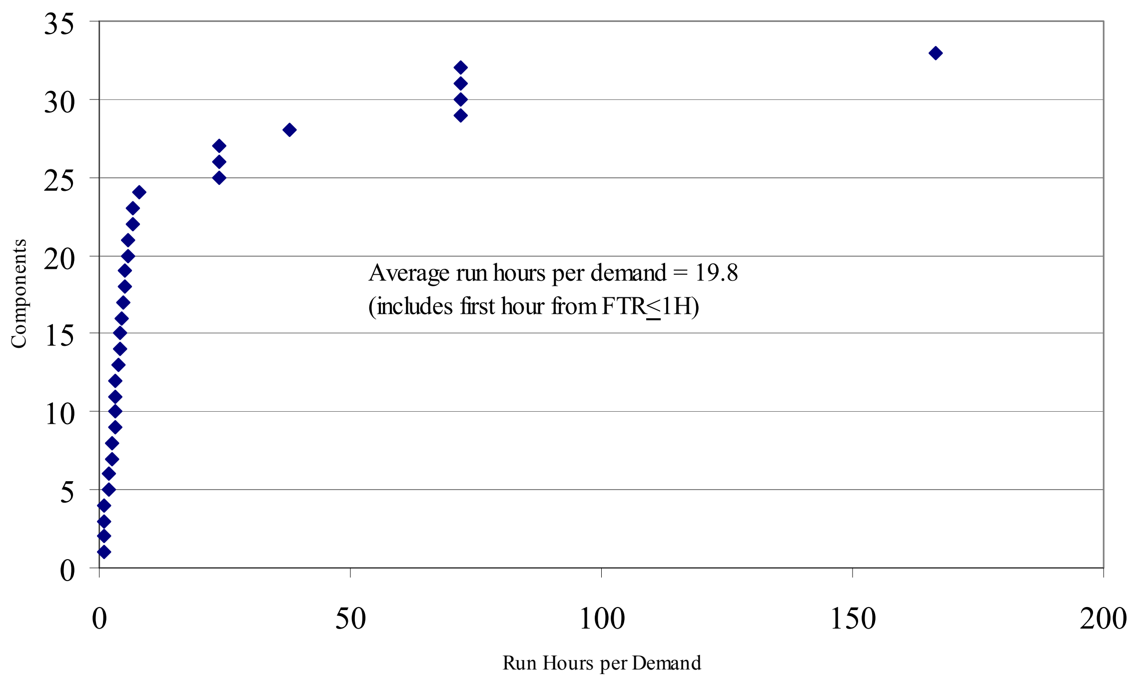

Figure 26-2a. Standby MDC run hours per demand distribution.

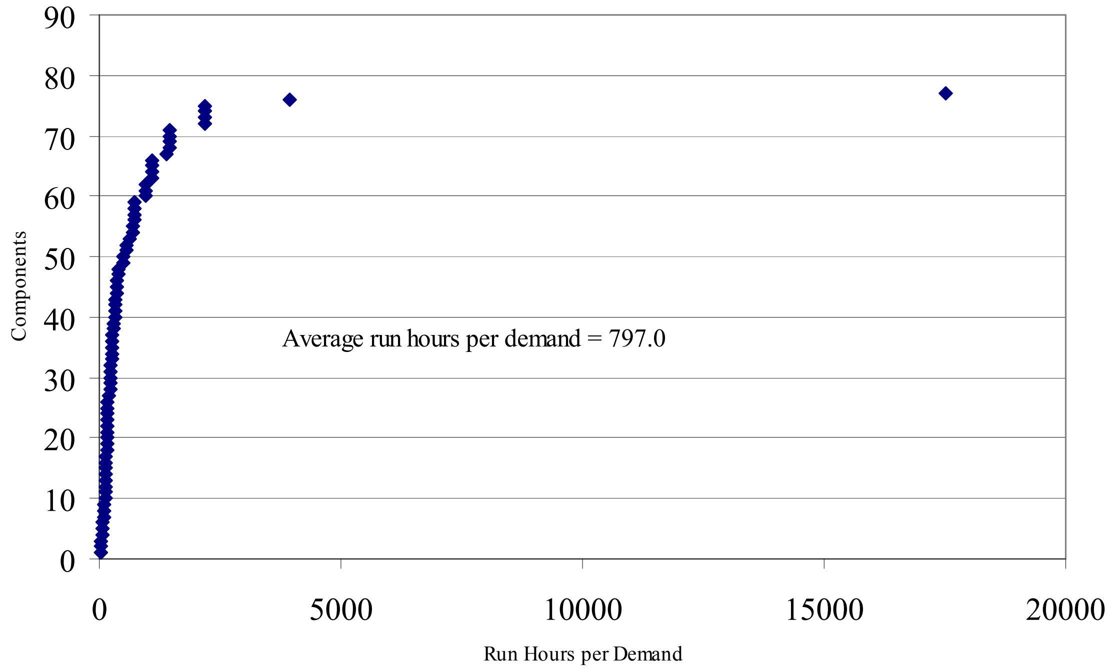

Figure 26-2b. Running/alternating MDC run hours per demand distribution.

26.3 Data Analysis

The MDC data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 26-4.

Table 26-4. Empirical distributions of MLEs for p and λ for MDCs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Standby	FTS	Component	0.00E+00	0.00E+00	1.68E-02	4.45E-02
		Plant	0.00E+00	0.00E+00	1.15E-02	4.45E-02
		Industry	-	-	6.98E-03	-
	FTR≤1H	Component	0.00E+00	0.00E+00	2.11E-03	1.06E-02
		Plant	0.00E+00	0.00E+00	2.11E-03	1.06E-02
		Industry	-	-	3.20E-03	-
	FTR>1H	Component	0.00E+00	2.42E-04	5.42E-03	1.28E-02
		Plant	0.00E+00	1.54E-03	7.87E-03	6.31E-03
		Industry	-	-	1.63E-03	-
Running/ Alternating	FTS	Component	0.00E+00	0.00E+00	2.80E-02	6.15E-02
		Plant	0.00E+00	3.85E-03	5.26E-02	6.66E-02
		Industry	-	-	4.01E-03	-
	FTR	Component	0.00E+00	5.00E-05	9.70E-05	2.75E-04
		Plant	0.00E+00	9.35E-05	9.52E-05	2.05E-04
		Industry	-	-	7.94E-05	-

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 26-3, only 21.2% of the MDCs experienced a FTS over the period 1998–2002, so the empirical distribution of MLEs, at the

component level, involves zeros for the 0% to 78.8% portion of the distribution, and non-zero values above 78.8%.

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table 26-5 for MDCs.

Table 26-5. Fitted distributions for p and λ for MDCs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/CL/KS	1.30E-05	3.00E-03	7.51E-03	3.03E-02	Beta	0.432	5.716E+01
		EB/PL/KS	2.16E-05	3.13E-03	7.13E-03	2.78E-02	Beta	0.476	6.621E+01
		SCNID/IL	2.86E-05	3.31E-03	7.21E-03	2.76E-02	Beta	0.500	6.888E+01
	FTR≤1H	EB/CL/KS	3.77E-08	5.15E-04	3.14E-03	1.53E-02	Gamma	0.243	7.729E+01
		EB/PL/KS	3.77E-08	5.15E-04	3.14E-03	1.53E-02	Gamma	0.243	7.729E+01
		SCNID/IL	1.47E-05	1.70E-03	3.73E-03	1.43E-02	Gamma	0.500	1.341E+02
	FTR>1H	EB/CL/KS	2.65E-04	2.14E-03	2.80E-03	7.59E-03	Gamma	1.329	4.748E+02
		EB/PL/KS	3.72E-04	2.13E-03	2.62E-03	6.56E-03	Gamma	1.696	6.471E+02
		SCNID/IL	6.59E-06	7.62E-04	1.67E-03	6.43E-03	Gamma	0.500	2.985E+02
Running/ Alternating	FTS	EB/CL/KS	3.96E-07	1.89E-03	8.95E-03	4.22E-02	Beta	0.273	3.024E+01
		EB/PL/KS	7.24E-06	4.40E-03	1.33E-02	5.69E-02	Beta	0.364	2.699E+01
		SCNID/IL	1.61E-05	1.86E-03	4.06E-03	1.56E-02	Beta	0.500	1.225E+02
	FTR	EB/CL/KS	5.46E-06	6.18E-05	8.62E-05	2.50E-04	Gamma	1.092	1.267E+04
		EB/PL/KS	9.82E-06	7.12E-05	9.16E-05	2.43E-04	Gamma	1.423	1.554E+04
		SCNID/IL	3.13E-07	3.62E-05	7.97E-05	3.06E-04	Gamma	0.500	6.276E+03

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

26.4 Industry-Average Baselines

Table 26-6 lists the industry-average failure rate distributions. For all five failure modes, the data sets were sufficient (Section A.1 in Reference 14) for empirical Bayes analyses to be performed. For these failure modes, the industry-average distributions are based on the empirical Bayes analysis results at the plant level. However, because the standby FTR≤1H result indicated an α value less than 0.3, the lower bound of 0.3 was assumed (see Section A.1 in Reference 14). These industry-average failure rates do not account for any recovery.

Table 26-6. Selected industry distributions of p and λ for MDCs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/PL/KS	2.16E-05	3.13E-03	7.13E-03	2.78E-02	Beta	0.476	6.621E+01
	FTR≤1H	EB/PL/KS	3.36E-07	7.65E-04	3.14E-03	1.44E-02	Gamma	0.300	9.557E+01
	FTR>1H	EB/PL/KS	3.72E-04	2.13E-03	2.62E-03	6.56E-03	Gamma	1.696	6.471E+02
Running/ Alternating	FTS	EB/PL/KS	7.24E-06	4.40E-03	1.33E-02	5.69E-02	Beta	0.364	2.699E+01
	FTR	EB/PL/KS	9.82E-06	7.12E-05	9.16E-05	2.43E-04	Gamma	1.423	1.554E+04

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 26-7 shows the rounded values for the MDC failure modes.

Table 26-7. Selected industry distributions of p and λ for MDCs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/PL/KS	3.0E-05	3.0E-03	7.0E-03	2.5E-02	Beta	0.50	7.14E+01
	FTR≤1H	EB/PL/KS	3.0E-07	7.0E-04	3.0E-03	1.5E-02	Gamma	0.30	1.00E+02
	FTR>1H	EB/PL/KS	3.0E-04	2.0E-03	2.5E-03	7.0E-03	Gamma	1.50	6.00E+02
Running/ Alternating	FTS	EB/PL/KS	1.2E-05	4.0E-03	1.2E-02	5.0E-02	Beta	0.40	3.33E+01
	FTR	EB/PL/KS	1.0E-05	7.0E-05	9.0E-05	2.5E-04	Gamma	1.50	1.67E+04

26.5 Breakdown by System

MDC UR results (Jeffreys means of system data) are compared by system and failure mode in Table 26-8. Results are shown only the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 26-8. MDC p and λ by system.

Operation	System	FTS	FTR≤1H	FTR>1H
Standby	CIS	-	-	-
	HVC	7.1E-03	-	-
	IAS	7.9E-03	4.0E-03	-
Operation	System	FTS		FTR
Running/ Alternating	CIS	5.8E-03		8.4E-05
	HVC	8.3E-03		4.0E-05
	IAS	4.0E-03		8.1E-05

27 Motor-Driven Pump (MDP)

27.1 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 failure modes for MDP are listed in Table 27-1.

Table 27-1. MDP failure modes.

Operation	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

27.2 Data Collection and Review

Data for MDP UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002, except for the ELS data that cover 1997–2004. There are 1689 MDPs from 103 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1 in Reference 14) there were 1660 components in 103 plants. These data were then further partitioned into standby and running/alternating components. The systems and operational status included in the MDP data collection are listed in Table 27-2 with the number of components included with each system.

Table 27-2. MDP systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤200 Demands per Year
Standby	AFW	Auxiliary feedwater	114	114	113
	CCW	Component cooling water	29	24	24
	CDS	Condensate system	16	0	0
	CRD	Control rod drive	3	3	3
	CSR	Containment spray recirculation	143	143	143
	CVC	Chemical and volume control	4	4	4
	ESW	Emergency service water	151	145	143
	HCS	High pressure core spray	9	9	9
	HPI	High pressure injection	117	117	117
	LCI	Low pressure coolant injection	120	120	116
	LCS	Low pressure core spray	64	63	63
	LPI	Low pressure injection	134	134	134
	MFW	Main feedwater	18	18	18
	Total		922	894	887
Running/ Alternating	CCW	Component cooling water	213	213	211
	CDS	Condensate system	121	121	121
	CRD	Control rod drive	43	43	43
	CVC	Chemical and volume control	41	41	41
	ESW	Emergency service water	257	256	250
	HPI	High pressure injection	41	41	41
	LCI	Low pressure coolant injection	4	4	4
	LPI	Low pressure injection	9	9	9
	MFW	Main feedwater	33	33	33

Operation	System	Description	Number of Components		
			Initial	After Review	≤200 Demands per Year
	NSW	Normal service water	3	3	3
	TBC	Turbine building cooling water	2	2	2
	Total		767	766	758

The data review process is described in detail in Section A.1 in Reference 14. Components with > 200 demands/year were removed. Table 27-3 summarizes the data obtained from EPIX and used in the MDP analysis. Note that the hours for ELS are calendar hours.

Table 27-3. MDP unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTS	104	82137	887	103	10.3%	52.4%
	FTR≤1H	12	32495 h	437	98	1.2%	10.7%
	FTR>1H	21 (2.8)	618130 h (568826 h)	450	100	1.9%	14.6%
Running/ Alternating	FTS	132	75048	758	96	13.9%	59.4%
	FTR	87	19572488 h	758	96	9.8%	47.9%
All	ELS	15	130629120 h	1864	103	0.8%	12.6%

Note – The reviewed data entries in parentheses for FTR>1H are after processing to remove events expected to have occurred within 1 h and to remove the first hour of operation. That process is explained in Section A.1 in Reference 14.

Figure 27-1a shows the range of start demands per year in the standby MDP data set. The start demands per year range from approximately 1 to 160. The average for the data set is 18.5 demands/year. Figure 27-1b shows the range of start demands per year in the running MDP data set. The demands per year range from approximately 1 (once per year) to 150. The average for the data set is 19.8 demands/year.

Figure 27-2a shows the range of run hours per demand in the standby MDP data set. The run hours per demand range is from approximately 0 hours/demand to 360 hours/demand. The average is 12.1 hours/demand. Figure 27-2b shows the range of run hours per demands in the running MDP data set. The range is from approximately 8 hours/demand to 12,165 hours/demand. The average is 1039.1 hours/demand.

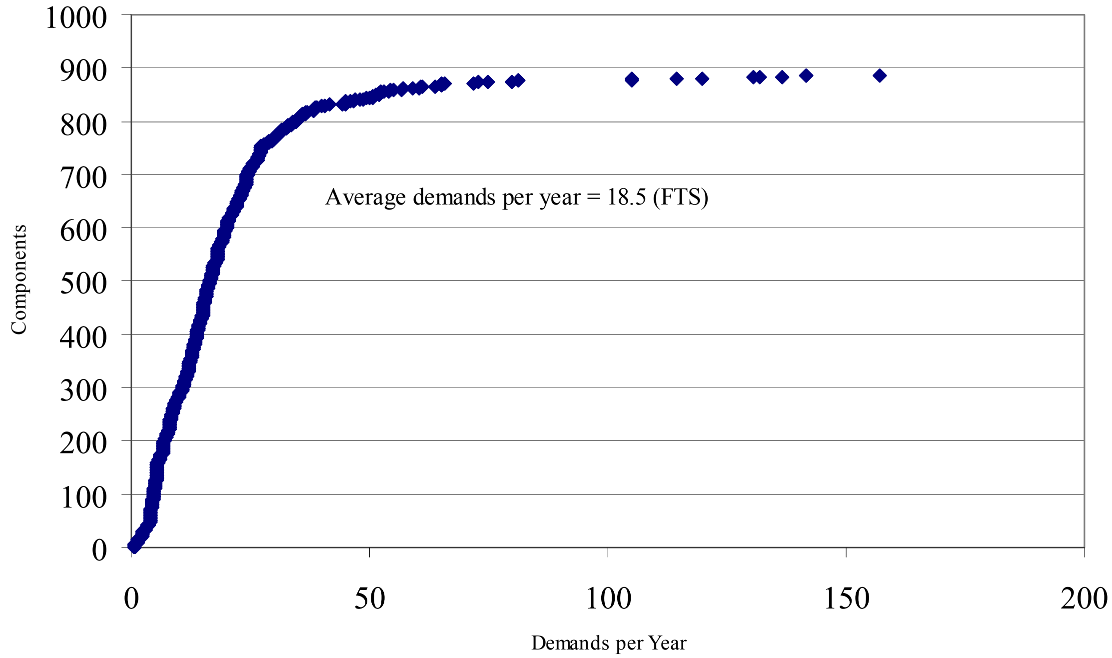

Figure 27-1a. Standby MDP demands per year distribution.

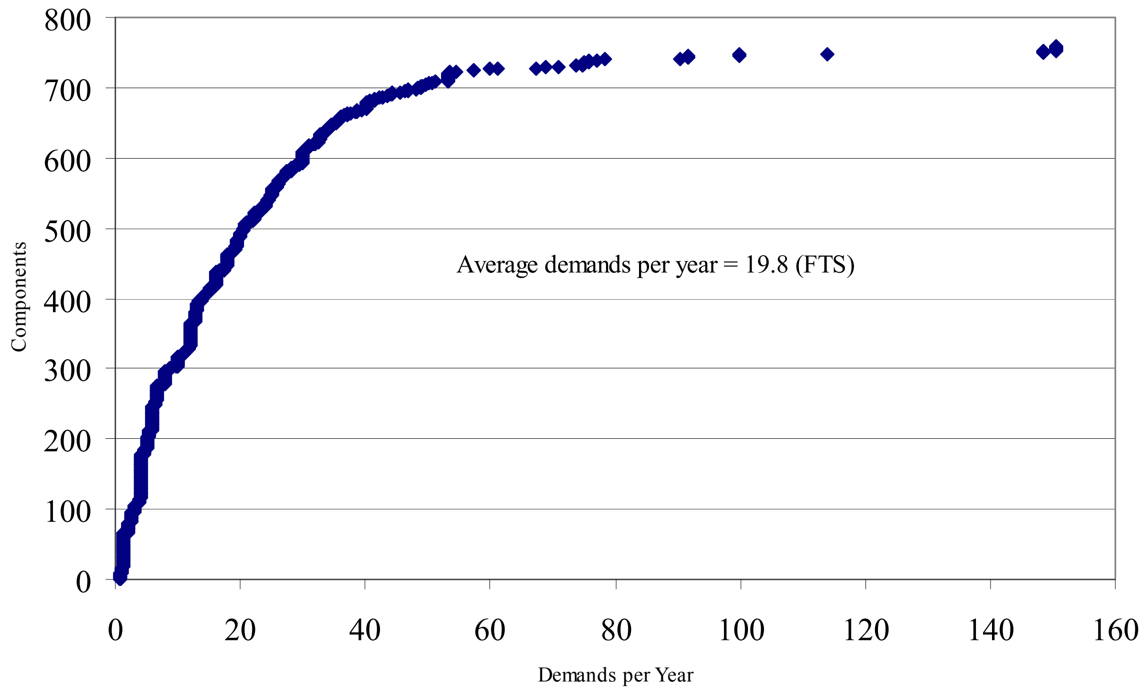

Figure 27-1b. Running/alternating MDP demands per year distribution.

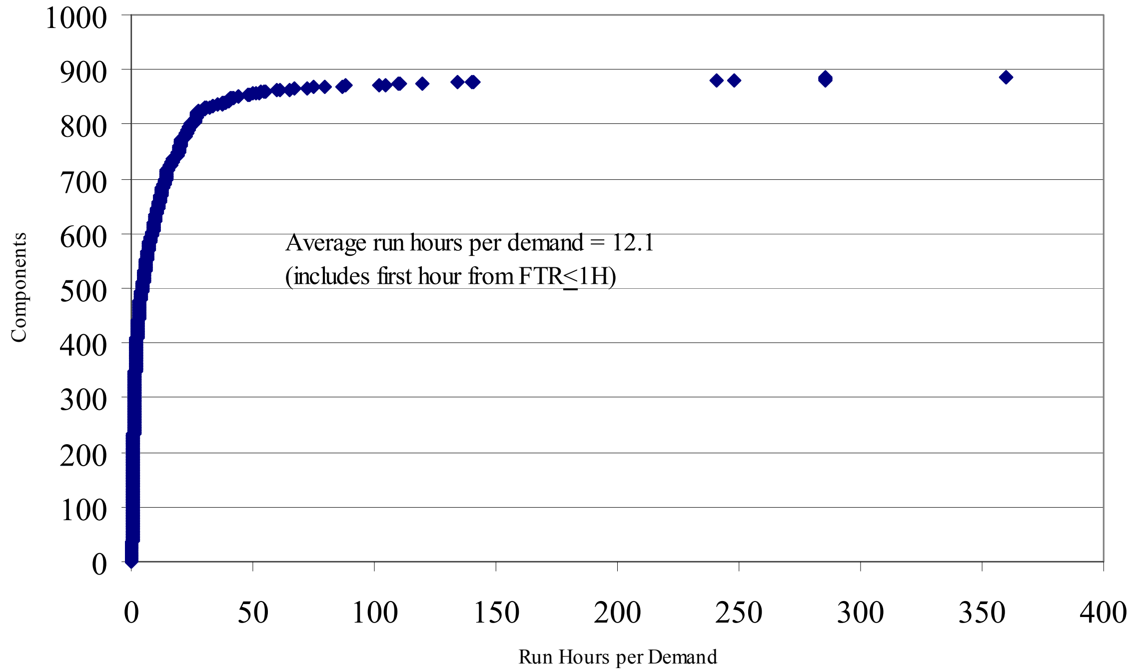

Figure 27-2a. Standby MDP run hours per demand distribution.

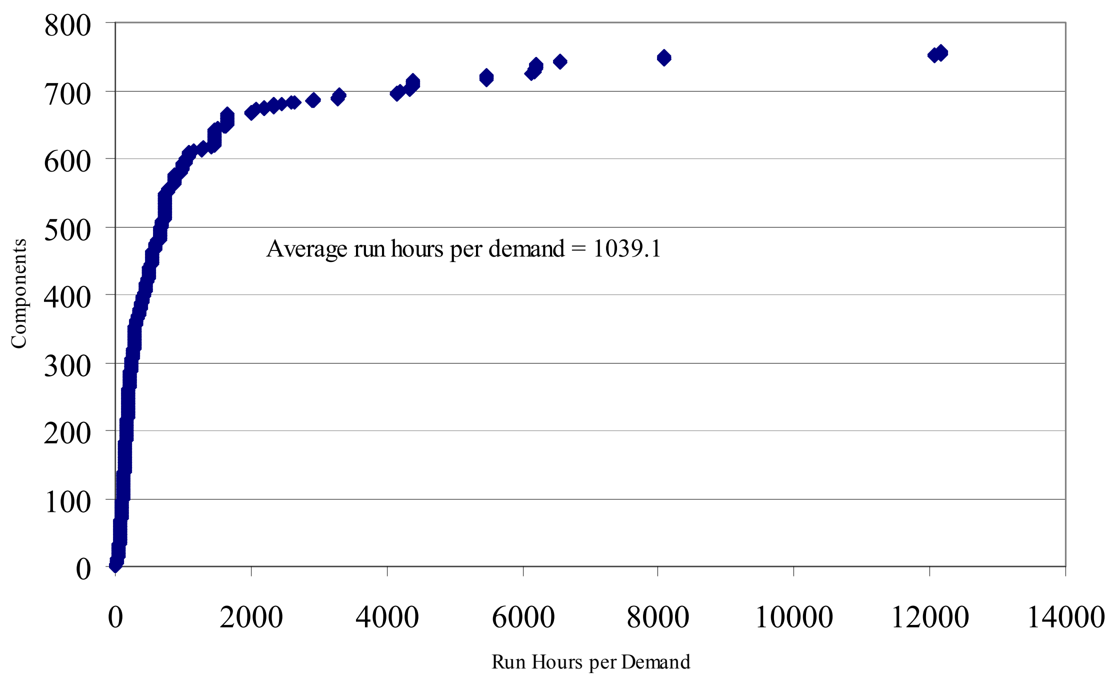

Figure 27-2b. Running/alternating MDP run hours per demand distribution.

27.3 Data Analysis

The MDP data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 27-4.

Table 27-4. Empirical distributions of MLEs for p and λ for MDPs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Standby	FTS	Component	0.00E+00	0.00E+00	2.47E-03	1.41E-02
		Plant	0.00E+00	5.67E-04	1.60E-03	6.35E-03
		Industry	-	-	1.27E-03	-
	FTR≤1H	Component	0.00E+00	0.00E+00	2.06E-03	0.00E+00
		Plant	0.00E+00	0.00E+00	7.06E-04	2.24E-03
		Industry	-	-	3.69E-04	-
	FTR>1H	Component	0.00E+00	0.00E+00	6.98E-06	0.00E+00
		Plant	0.00E+00	0.00E+00	7.15E-06	4.96E-05
		Industry	-	-	4.91E-06	-
Running/ Alternating	FTS	Component	0.00E+00	0.00E+00	4.16E-03	1.67E-02
		Plant	0.00E+00	9.61E-04	2.33E-03	7.15E-03
		Industry	-	-	1.76E-03	-
	FTR	Component	0.00E+00	0.00E+00	4.96E-06	4.57E-05
		Plant	0.00E+00	0.00E+00	4.34E-06	1.45E-05
		Industry	-	-	4.45E-06	-
All	ELS	Component	0.00E+00	0.00E+00	1.15E-07	0.00E+00
		Plant	0.00E+00	0.00E+00	1.21E-07	1.02E-06
		Industry	-	-	1.15E-07	-

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 27-3, only 10.2% of the MDPs experienced a FTS over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 89.8% portion of the distribution, and non-zero values above 89.8%.

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table 27-5 for MDPs. These results were used to develop the industry-average distributions.

Table 27-5. Fitted distributions for p and λ for MDPs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/CL/KS	3.15E-07	4.10E-04	1.49E-03	6.64E-03	Beta	0.324	2.174E+02
		EB/PL/KS	5.87E-05	9.77E-04	1.47E-03	4.54E-03	Beta	0.909	6.198E+02
		SCNID/IL	5.01E-06	5.80E-04	1.27E-03	4.88E-03	Beta	0.500	3.926E+02
	FTR≤1H	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	5.40E-05	3.07E-04	3.78E-04	9.43E-04	Gamma	1.703	4.509E+03
		SCNID/IL	1.51E-06	1.75E-04	3.85E-04	1.48E-03	Gamma	0.500	1.300E+03
	FTR>1H	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	2.28E-08	2.63E-06	5.79E-06	2.22E-05	Gamma	0.500	8.640E+04
Running/ Alternating	FTS	EB/CL/KS	1.65E-06	7.42E-04	2.15E-03	9.05E-03	Beta	0.383	1.779E+02
		EB/PL/KS	8.18E-05	1.47E-03	2.23E-03	6.98E-03	Beta	0.881	3.942E+02
		SCNID/IL	6.96E-06	8.05E-04	1.77E-03	6.78E-03	Beta	0.500	2.826E+02
	FTR	EB/CL/KS	1.02E-08	1.88E-06	4.55E-06	1.81E-05	Gamma	0.452	9.944E+04
		EB/PL/KS	6.21E-07	3.66E-06	4.54E-06	1.14E-05	Gamma	1.655	3.649E+05
		SCNID/IL	1.76E-08	2.03E-06	4.47E-06	1.72E-05	Gamma	0.500	1.118E+05
All	ELS	JEFF/CL	7.38E-08	1.16E-07	1.19E-07	1.72E-07	Gamma	15.500	1.306E+08
		EB/PL/KS	5.72E-09	7.94E-08	1.15E-07	3.47E-07	Gamma	0.987	8.574E+06
		SCNID/IL	4.67E-10	5.40E-08	1.19E-07	4.56E-07	Gamma	0.500	4.212E+06

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, JEFF/CL is the posterior distribution at the component level of a Bayesian update of the Jeffreys noninformative prior with industry data, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

27.4 Industry-Average Baselines

Table 27-6 lists the selected industry distributions of p and λ for the MDP failure modes. For five of the seven failure modes, the data sets were sufficient for empirical Bayes analyses to be performed. For these failure modes, the industry-average distributions are based on the empirical Bayes analysis results at the plant level. However, the industry-average distribution for FTR>1H is not sufficient (Section A.1 in Reference 14) for the empirical Bayes method; therefore a SCNID analysis was performed to provide a failure rate distribution. 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. These industry-average failure rates do not account for any recovery.

Table 27-6. Selected industry distributions of p and λ for MDPs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/PL/KS	5.87E-05	9.77E-04	1.47E-03	4.54E-03	Beta	0.909	6.198E+02
	FTR≤1H	EB/PL/KS	5.40E-05	3.07E-04	3.78E-04	9.43E-04	Gamma	1.703	4.509E+03
	FTR>1H	SCNID/IL	2.28E-08	2.63E-06	5.79E-06	2.22E-05	Gamma	0.500	8.640E+04
Running/ Alternating	FTS	EB/PL/KS	8.18E-05	1.47E-03	2.23E-03	6.98E-03	Beta	0.881	3.942E+02
	FTR	EB/PL/KS	6.21E-07	3.66E-06	4.54E-06	1.14E-05	Gamma	1.655	3.649E+05
All	ELS	EB/PL/KS	5.72E-09	7.94E-08	1.15E-07	3.47E-07	Gamma	0.987	8.574E+06
	ELL	ELS/EPIX	8.63E-13	1.97E-09	8.06E-09	3.69E-08	Gamma	0.300	3.721E+07

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 27-7 shows the rounded values for the MDP failure modes.

Table 27-7. Selected industry distributions of p and λ for MDPs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/PL/KS	6.0E-05	1.0E-03	1.5E-03	5.0E-03	Beta	0.90	6.00E+02
	FTR≤1H	EB/PL/KS	5.0E-05	3.0E-04	4.0E-04	1.0E-03	Gamma	1.50	3.75E+03
	FTR>1H	SCNID/IL	2.5E-08	2.5E-06	6.0E-06	2.5E-05	Gamma	0.50	8.33E+04
Running/ Alternating	FTS	EB/PL/KS	8.0E-05	1.2E-03	2.0E-03	6.0E-03	Beta	0.90	4.50E+02
	FTR	EB/PL/KS	6.0E-07	4.0E-06	5.0E-06	1.2E-05	Gamma	1.50	3.00E+05
All	ELS	EB/PL/KS	6.0E-09	8.0E-08	1.2E-07	4.0E-07	Gamma	1.00	8.33E+06
	ELL	ELS/EPIX	9.0E-13	2.0E-09	8.0E-09	4.0E-08	Gamma	0.30	3.75E+07

27.5 Breakdown by System

MDP UR results (Jeffreys means of system data) are compared by system and failure mode in Table 27-8. Results are shown only for the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 27-8. MDP p and λ by system.

Operation	System	FTS	FTR≤1H
Standby	AFW	1.6E-03	1.0E-03
	CCW	2.4E-03	-
	CRD	8.9E-03	-
	CSR	9.5E-04	6.2E-04
	CVC	-	-
	ESW	1.3E-03	-
	HCS	2.8E-03	-
	HPI	1.4E-03	1.9E-04
	LCI	1.0E-03	-
	LCS	1.7E-03	7.6E-04
	LPI	1.1E-03	-
	MFW	2.4E-03	3.7E-03

Operation	System	FTS	FTR
Running/ Alternating	CCW	1.1E-03	2.8E-06
	CDS	2.7E-03	3.6E-06
	CRD	8.2E-03	8.6E-06
	CVC	2.1E-03	5.8E-06
	ESW	1.8E-03	5.1E-06
	HPI	2.2E-03	7.5E-06
	LCI	1.6E-03	-
	LPI	-	-

Operation	System	FTS	FTR
	MFW	2.2E-03	7.8E-06
	NSW	-	1.7E-05
	TBC	-	-

Operation	System	ELS
All	AFW	-
	CCW	-
	CDS	3.6E-07
	CRD	-
	CSR	2.5E-07
	CVC	-
	ESW	-
	HCS	-
	HPI	-
	LCI	1.7E-07
	LCS	-
	LPI	3.5E-07
	MFW	1.5E-06
	MSS	-
	NSW	-
	SLC	-
	TBC	5.4E-06

28 Motor-Operated Damper (MOD)

28.1 Component Description

The motor-operated damper (MOD) component boundary includes the valve, the valve operator, local circuit breaker, and local instrumentation and control circuitry. The failure modes for MOD are listed in Table 28-1.

Table 28-1. MOD failure modes.

Operation	Failure Mode	Parameter	Units	Description
All	FTO/C	p	-	Failure to open or failure to close
	SO	λ	1/h	Spurious operation

28.2 Data Collection and Review

Data for MOD UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. There are 48 MODs from eight plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1 in Reference 14) there were 48 components in eight plants. After analyzing the original data, there were no SO failures, so the data set was expanded to 1997– 2004 for the SO failure mode (see Section A.1 in Reference 14). The systems included in the MOD data collection are listed in Table 28-2 with the number of components included with each system.

Table 28-2. MOD systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
All	EPS	Emergency power supply	17	17	15
	ESF	Engineered safety features actuation	2	2	2
	ESW	Emergency service water	6	6	-
	HVC	Heating ventilation and air conditioning	23	23	4
	Total		48	48	21

The MOD data set obtained from RADS was further reduced to include only those MODs with ≤ 20 demands/year. See Section A.1 in Reference 14 for a discussion concerning this decision to limit certain component populations. Table 28-3 summarizes the data used in the MOD analysis. Note that the hours for SO are calendar hours.

Table 28-3. MOD unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO/C	1	1320	21	4	4.8%	25.0%
	SO	0	1471680 h	21	4	0.0%	0.0%

Figure 28-1 shows the range of valve demands per year in the MOD data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 20. The average for the data set is 12.6. demands/year.

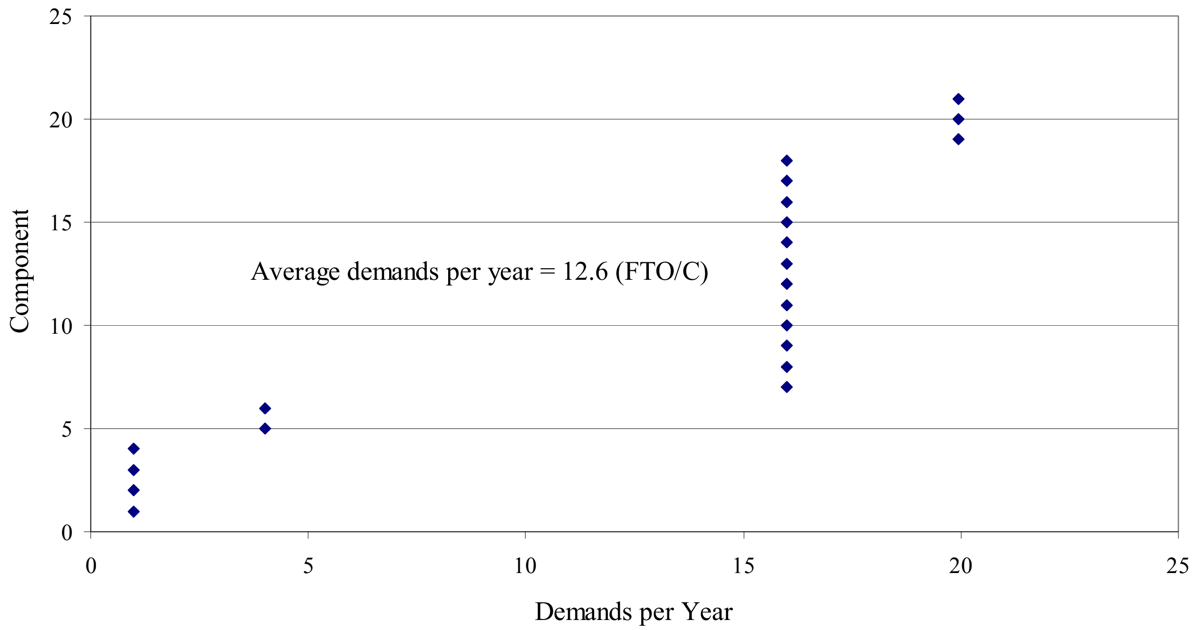

Figure 28-1. MOD demands per year distribution.

28.3 Data Analysis

The MOD data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 28-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 28-4, only 4.8% of the MODs experienced a FTO/C over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 95.2% portion of the distribution, and non-zero values above 95.2%.

Table 28-4. Empirical distributions of MLEs for p and λ for MODs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
All	FTO/C	Component	0.00E+00	0.00E+00	2.38E-03	0.00E+00
		Plant	0.00E+00	0.00E+00	6.25E-03	2.50E-02
		Industry	-	-	7.58E-04	-
	SO	Component	-	-	-	-
		Plant	-	-	-	-
		Industry	-	-	0.00E+00	-

With only one failure for FTO/C and no failures for SO, no empirical Bayes analyses were performed. However, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table 28-5.

Table 28-5. Fitted distributions for p and λ for MODs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO/C	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	4.47E-06	5.18E-04	1.14E-03	4.36E-03	Beta	0.500	4.396E+02
	SO	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.34E-09	1.55E-07	3.40E-07	1.30E-06	Gamma	0.500	1.472E+06

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

28.4 Industry-Average Baselines

Table 28-6 lists the selected industry distributions of p and λ for the MOD failure modes. The industry-average distributions for the FTO/C and SO failure modes are not sufficient (Section A.1 in Reference 14) for the empirical Bayes method; therefore a SCNID analysis was performed to provide a failure rate distribution. These industry-average failure rates do not account for any recovery.

Table 28-6. Selected industry distributions of p and λ for MODs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO/C	SCNID/IL	4.47E-06	5.18E-04	1.14E-03	4.36E-03	Beta	0.500	4.396E+02
	SO	SCNID/IL	1.34E-09	1.55E-07	3.40E-07	1.30E-06	Gamma	0.500	1.472E+06

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 36-7 shows the rounded values for the MOD failure modes.

Table 28-7. Selected industry distributions of p and λ for MODs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO/C	SCNID/IL	5.0E-06	5.0E-04	1.2E-03	5.0E-03	Beta	0.50	4.17E+02
	SO	SCNID/IL	1.2E-09	1.5E-07	3.0E-07	1.2E-06	Gamma	0.50	1.67E+06

28.5 Breakdown by System

MOD UR results (Jeffreys means of system data) are compared by system and failure mode in Table 36-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 28-8. MOD p and λ by system.

System	FTO/C	SO
EPS	-	-
ESF	3.7E-02	-
HVC	-	-

29 Motor-Operated Valve (MOV)

29.1 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 29-1.

Table 29-1. MOV failure modes.

Operation	Failure Mode	Parameter	Units	Description
Standby	FTO/C	p	-	Failure to open or failure to close
	SO	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

29.2 Data Collection and Review

Most of the data for MOV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. (The external and internal leakage data cover 1997–2004.) There are 8661 MOVs from 103 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1 in Reference 14) there were 8516 components in 103 plants. The systems included in the MOV data collection are listed in Table 29-2 with the number of components included with each system.

Table 29-2. MOV systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
All	AFW	Auxiliary feedwater	525	516	451
	CCW	Component cooling water	685	681	555
	CDS	Condensate system	3	1	1
	CHW	Chilled water system	46	46	46
	CIS	Containment isolation system	455	444	401
	CRD	Control rod drive	17	17	16
	CSR	Containment spray recirculation	345	343	333
	CTS	Condensate transfer system	6	6	6
	CVC	Chemical and volume control	558	555	510
	EPS	Emergency power supply	2	2	2
	ESW	Emergency service water	1187	1168	889
	FWS	Firewater	8	8	8
	HCI	High pressure coolant injection	241	235	214
	HCS	High pressure core spray	45	43	34
	HPI	High pressure injection	1043	983	889
	HVC	Heating ventilation and air conditioning	42	38	24
	IAS	Instrument air	14	14	14
	ISO	Isolation condenser	20	20	20
	LCI	Low pressure coolant injection	935	926	689
	LCS	Low pressure core spray	230	230	204
	LPI	Low pressure injection	1124	1116	1059
	MFW	Main feedwater	345	343	339
	MSS	Main steam	179	179	176
	RCI	Reactor core isolation	288	286	263
	RCS	Reactor coolant	166	164	158

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
	RGW	Radioactive gaseous waste	1	1	1
	RPS	Reactor protection	4	4	4
	RRS	Reactor recirculation	68	68	68
	RWC	Reactor water cleanup	13	13	13
	SGT	Standby gas treatment	20	20	10
	SLC	Standby liquid control	23	23	23
	TBC	Turbine building cooling water	2	2	2
	VSS	Vapor suppression	21	21	19
	Total		8661	8516	7441

The MOV data set obtained from RADS was further reduced to include only those MOVs with ≤ 20 demands/year (≤ 100 demands over 5 years). See Section A.1 in Reference 14 for a discussion concerning this decision to limit certain component populations. Table 29-3 summarizes the data used in the MOV analysis. Note that the hours for SO, ELS, and ILS are calendar hours. The FC failure mode is not supported by EPIX data.

Table 29-3. MOV unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
Standby	FTO/C	244	232264	7441	103	3.1%	69.9%
	SO	14	325915800 h	7441	103	0.2%	10.7%
	ELS	7	535536736 h	7614	103	0.1%	6.8%
	ILS	87.5	528122880 h	7536	103	1.0%	35.0%
Control	FC	-	-	-	-	-	-

Figure 29-1 shows the range of valve demands per year in the MOV data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 20. The average for the data set is 4.6 demands/year.

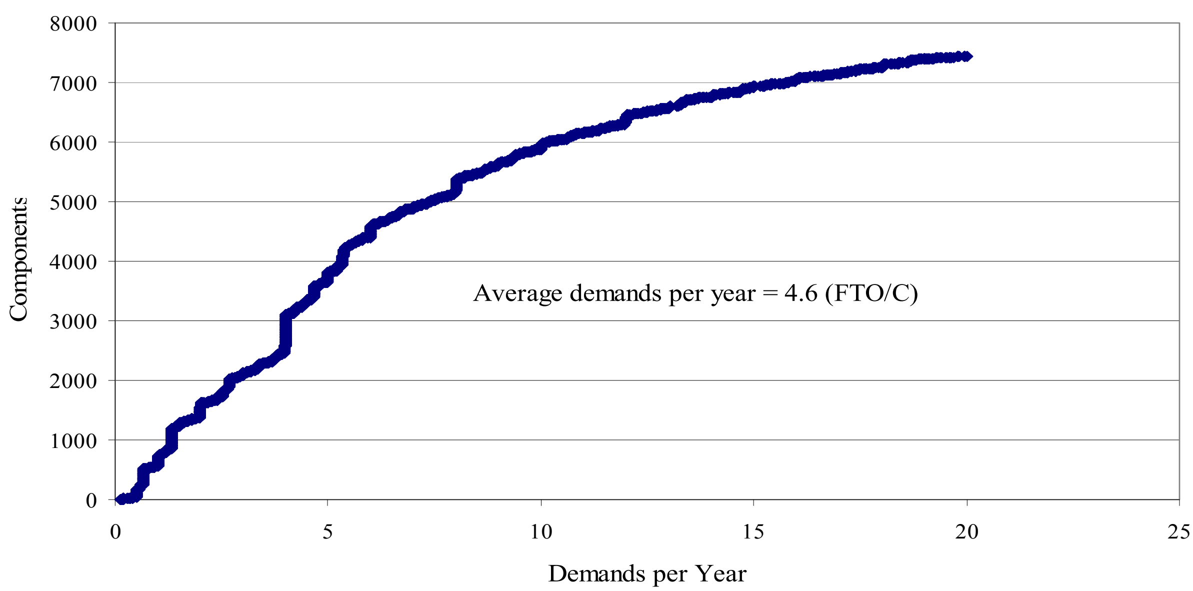

Figure 29-1. MOV demands per year distribution.

29.3 Data Analysis

The MOV data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 29-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 29-3, only 3.1% of the MOVs experienced a FTO/C over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 96.9% portion of the distribution, and non-zero values above 96.9%.

Table 29-4. Empirical distributions of MLEs for p and λ for MOVs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Standby	FTO/C	Component	0.00E+00	0.00E+00	1.90E-03	0.00E+00
		Plant	0.00E+00	6.64E-04	1.08E-03	4.09E-03
		Industry	-	-	1.05E-03	-
	SO	Component	0.00E+00	0.00E+00	4.30E-08	0.00E+00
		Plant	0.00E+00	0.00E+00	4.08E-08	2.26E-07
		Industry	-	-	4.30E-08	-
	ELS	Component	0.00E+00	0.00E+00	1.31E-08	0.00E+00
		Plant	0.00E+00	0.00E+00	1.04E-08	9.71E-08
		Industry	-	-	1.31E-08	-
	ILS	Component	0.00E+00	0.00E+00	1.66E-07	0.00E+00
		Plant	0.00E+00	0.00E+00	1.63E-07	8.39E-07
		Industry	-	-	1.66E-07	-
Control	FC	-	-	-	-	-

Empirical Bayes analyses were performed at both the component and plant level. For these analyses, the five uncertain events for ILS (weights of 0.5) were assumed to be certain. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table 29-5. These results were used to develop the industry-average distributions for FTO/C and SO.

Table 29-5. Fitted distributions for p and λ for MOVs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTO/C	EB/CL/KS	1.88E-09	1.28E-04	1.12E-03	5.72E-03	Beta	0.207	1.849E+02
		EB/PL/KS	9.42E-05	8.08E-04	1.07E-03	2.94E-03	Beta	1.277	1.192E+03
		SCNID/IL	4.13E-06	4.78E-04	1.05E-03	4.03E-03	Beta	0.500	4.757E+02
	SO	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.75E-10	2.02E-08	4.45E-08	1.71E-07	Gamma	0.500	1.124E+07
	ELS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	5.54E-11	6.41E-09	1.41E-08	5.42E-08	Gamma	0.500	3.546E+07
	ILS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	2.94E-10	6.64E-08	1.67E-07	6.75E-07	Gamma	0.434	2.599E+06
		SCNID/IL	6.57E-10	7.60E-08	1.67E-07	6.42E-07	Gamma	0.500	2.994E+06
Control	FC	EB/CL/KS	-	-	-	-	-	-	-

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

29.4 Industry-Average Baselines

Table 29-6 lists the selected industry distributions of p and λ for the MOV failure modes. For the FTO/C and ILS, the data sets were sufficient (see Section A.1 in Reference 14) for empirical Bayes analyses to be performed. Therefore, the industry-average distributions are based on the empirical Bayes analysis results at the plant level for FTO/C and ILS. However, the industry-average distributions for SO, ELS, and ELL are not sufficient (Section A.1 in Reference 14) for the Empirical Bayes method; therefore, a SCNID analysis was performed to provide a failure rate distribution. 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.

The FC failure mode distribution was derived from the Westinghouse Savannah River Company (WSRC) database. That source lists Category 2 data (see Section A.1 in Reference 14) for AOV control valves from sources other than commercial power plants. The recommended value from WSRC was used as the mean, with an assumed α of 0.3. These industry-average failure rates do not account for any recovery.

Table 29-6. Selected industry distributions of p and λ for MOVs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTO/C	EB/PL/KS	9.42E-05	8.08E-04	1.07E-03	2.94E-03	Beta	1.277	1.192E+03
	SO	SCNID/IL	1.75E-10	2.02E-08	4.45E-08	1.71E-07	Gamma	0.500	1.124E+07
	ELS	SCNID/IL	5.54E-11	6.41E-09	1.41E-08	5.42E-08	Gamma	0.500	3.546E+07
	ELL	ELS/EPIX	1.06E-13	2.41E-10	9.87E-10	4.52E-09	Gamma	0.300	3.040E+08
	ILS	EB/PL/KS	2.94E-10	6.64E-08	1.67E-07	6.75E-07	Gamma	0.434	2.599E+06
	ILL	ILS/EPIX	3.58E-13	8.15E-10	3.34E-09	1.53E-08	Gamma	0.300	8.982E+07
Control	FC	WSRC	3.21E-10	7.31E-07	3.00E-06	1.37E-05	Gamma	0.300	1.000E+05

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 29-7 shows the rounded values for the MOV.

Table 29-7. Selected industry distributions of p and λ for MOVs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTO/C	EB/PL/KS	8.0E-05	7.0E-04	1.0E-03	3.0E-03	Beta	1.20	1.20E+03
	SO	SCNID/IL	1.5E-10	2.0E-08	4.0E-08	1.5E-07	Gamma	0.50	1.25E+07
	ELS	SCNID/IL	6.0E-11	7.0E-09	1.5E-08	6.0E-08	Gamma	0.50	3.33E+07
	ELL	ELS/EPIX	1.0E-13	2.5E-10	1.0E-09	5.0E-09	Gamma	0.30	3.00E+08
	ILS	EB/PL/KS	1.5E-10	5.0E-08	1.5E-07	6.0E-07	Gamma	0.40	2.67E+06
	ILL	ILS/EPIX	3.0E-13	7.0E-10	3.0E-09	1.5E-08	Gamma	0.30	1.00E+08
Control	FC	WSRC	3.0E-10	7.0E-07	3.0E-06	1.5E-05	Gamma	0.30	1.00E+05

29.5 Breakdown by System

The MOVs discussed above are in multiple systems. MOV UR results (Jeffreys means of system data) are compared by system and failure mode in Table 29-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 29-8. MOV p and λ by system.

System	FTO/C	SO	ELS	ILS
AFW	1.1E-03	1.3E-07	-	4.7E-08
CCW	7.1E-04	1.0E-07	-	1.7E-07
CDS	-	-	-	-
CHW	1.6E-03	-	-	-
CIS	1.4E-03	8.5E-08	-	5.9E-07
CRD	4.6E-03	-	-	-
CSR	5.0E-04	1.0E-07	-	1.5E-07
CTS	1.2E-02	-	-	-
CVC	1.0E-03	6.7E-08	-	-
EPS	-	-	-	-
ESW	1.6E-03	3.9E-08	-	1.7E-07
FWS	9.8E-03	-	-	-
HCI	1.5E-03	-	1.3E-07	3.6E-07
HCS	-	-	-	-
HPI	7.4E-04	-	-	4.0E-08
HVC	1.4E-03	-	-	8.9E-07
IAS	-	-	-	-
ISO	5.7E-03	-	-	1.1E-06

System	FTO/C	SO	ELS	ILS
LCI	6.3E-04	1.2E-07	-	2.8E-07
LCS	2.0E-03	-	-	1.7E-07
LPI	1.1E-03	-	1.3E-08	3.3E-08
MFW	2.9E-04	-	-	-
MSS	9.5E-04	-	2.4E-07	1.6E-06
RCI	1.3E-03	2.2E-07	1.7E-07	4.2E-07
RCS	4.0E-04	-	-	-
RGW	-	-	-	-
RPS	-	-	-	5.4E-06
RRS	2.2E-03	-	-	-
RWC	1.6E-02	2.6E-06	-	-
SGT	-	-	-	-
SLC	-	-	-	-
TBC	-	-	-	-
VSS	2.5E-03	-	-	-

30 Manual Switch (MSW)

30.1 Component Description

The manual switch (MSW) boundary includes the switch itself. The failure mode for MSW is listed in Table 30-1.

Table 30-1. MSW failure modes.

Operation	Failure Mode	Parameter	Units	Description
Running	FTO/C	*p*	-	Fail to open or close

30.2 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 30-2 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 30-2. MSW unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Running	FTO/C	2	19789	-	-	-	-

30.3 Industry-Average Baselines

Table 30-3 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 α = 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 30-3. Selected industry distributions of *p* and *λ* for MSWs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the *α* parameter was rounded. In order to preserve the mean value, the *β* parameter is presented to three significant figures. Table 30-4 shows the rounded values for the MSW failure mode.

Table 30-4. Selected industry distributions of *p* and *λ* for MSWs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	*α*	*β*
Running	FTO/C	RPS SS	5.0E-07	6.0E-05	1.2E-04	5.0E-04	Beta	0.50	4.17E+03

31 Orifice (ORF)

31.1 Component Description

The orifice (ORF) boundary includes the orifice. The failure mode for ORF is listed in Table 31-1.

Table 31-1. ORF failure modes.

Operation	Failure Mode	Parameter	Units	Description
Running	PG	λ	1/h	Plugged

31.2 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.

31.3 Industry-Average Baselines

Table 31-2 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 31-2. Selected industry distributions of p and λ for ORFs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 31-3 shows the rounded values for the ORF failure mode.

Table 31-3. Selected industry distributions of p and λ for ORFs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	PG	WSRC	1.0E-10	2.5E-07	1.0E-06	5.0E-06	Gamma	0.30	3.00E+05

32 Positive Displacement Pump (PDP)

32.1 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 32-1.

Table 32-1. PDP failure modes.

Operation	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

32.2 Data Collection and Review

Data for PDP UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002, except for the ELS data that cover 1997 - 2004. There are 153 PDPs from 63 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1 in Reference) there were 153 components in 63 plants. These data were then further partitioned into standby and running/alternating components. The systems and operational status included in the PDP data collection are listed in Table 32-2 with the number of components included with each system.

Table 32-2. PDP systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 200 Demands per Year
Standby	CVC	Chemical and volume control	12	12	12
	HPI	High pressure injection	2	2	2
	SLC	Standby liquid control	52	52	52
	Total		66	66	66
Running/ Alternating	CVC	Chemical and volume control	55	55	43
	LCS	Low pressure core spray	1	1	1
	MFW	Main feedwater	1	1	1
	MSS	Main steam	22	22	16
	SLC	Standby liquid control	8	8	8
	Total		87	87	69

The data review process is described in detail in Section A.1 in Reference 14. Table 32-3 summarizes the data obtained from EPIX and used in the PDP analysis. Note that the hours for ELS are calendar hours. In addition, the single ELS event was identified by reviewing events that had originally been classified as “no failure” events.

Figure 32-1a shows the range of start demands per year in the standby PDP data set. The start demands per year range from approximately 1 to 70. The average for the data set is 9.6 demands/year. Figure 32-1b shows the range of start demands per year in the running PDP data set. The demands per year range from approximately 1 to 90. The average for the data set is 28.5 demands/year.

Table 32-3. PDP unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTS	9	3171	66	34	13.6%	20.6%
	FTR≤1H	1	3540 h	66	34	1.5%	2.9%
	FTR>1H	0	0 h	0	0	0.0%	0.0%
Running/ Alternating	FTS	32	9838	69	29	26.1%	37.9%
	FTR	12	1456663 h	69	29	13.0%	20.7%
All	ELS	1	11633280 h	166	63	1.4%	3.4%

Note – The reviewed data entries in parentheses for FTR>1H are after processing to remove events expected to have occurred within 1 h and to remove the first hour of operation. That process is explained in Section A.1 in Reference 14.

Figure 32-2a shows the range of run hours per demand in the standby PDP data set. The run hours per demand range is from approximately 1 hour/demand to 11 hours/demand. The average is 1.1 hours/demand. Figure 32-2b shows the range of run hours per demands in the running PDP data set. The range is from approximately 24 hours/demand to 3,300 hours/demand. The average is 509.2 hours/demand.

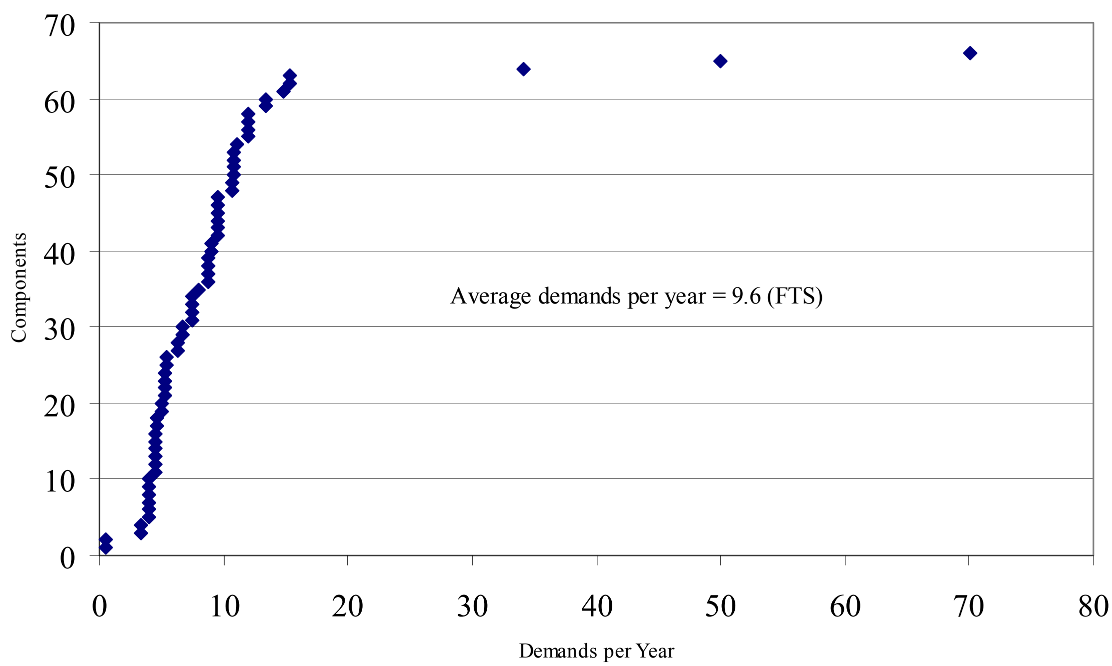

Figure 32-1a. Standby PDP demands per year distribution.

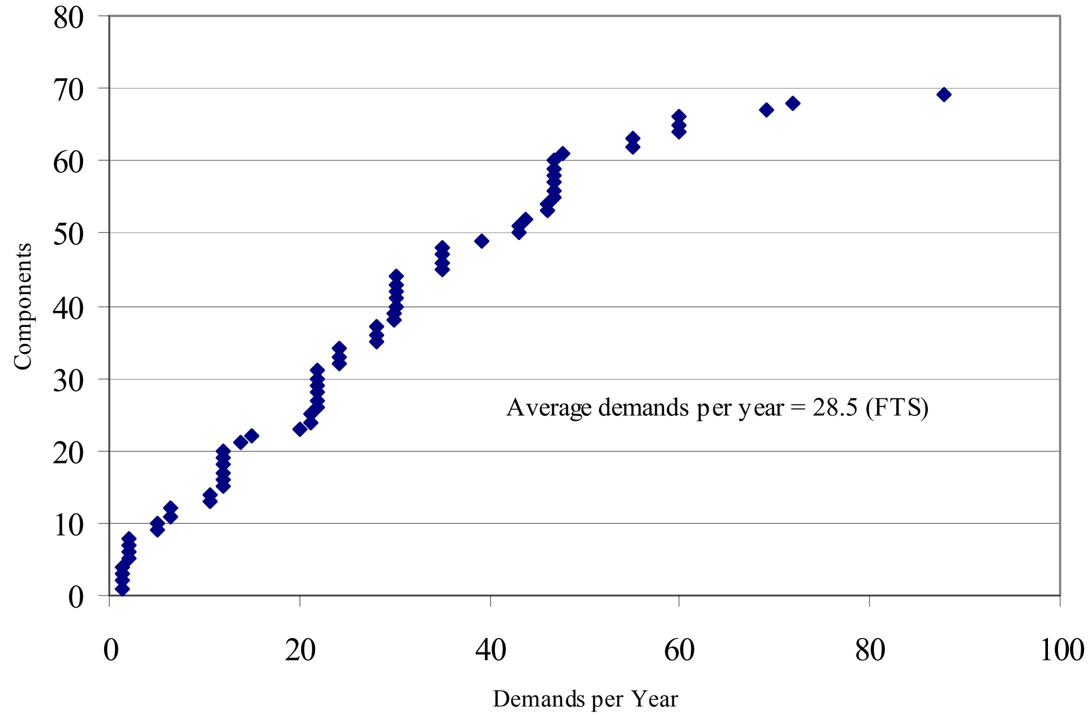

Figure 32-1b. Running/alternating PDP demands per year distribution.

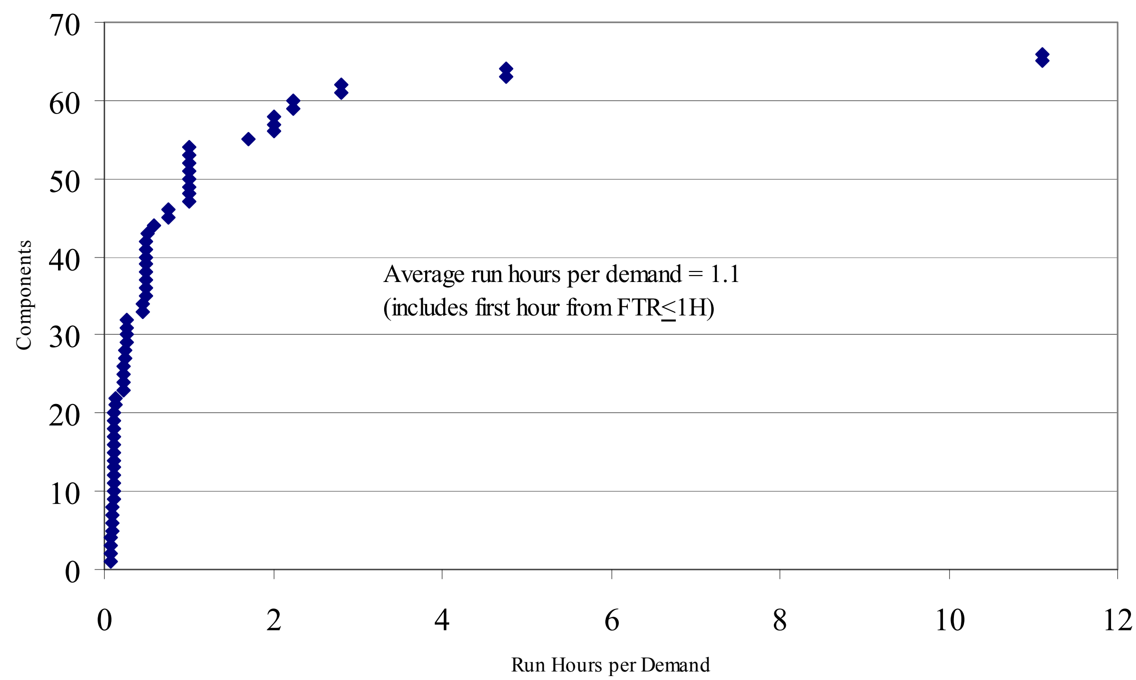

Figure 32-2a. Standby PDP run hours per demand distribution.

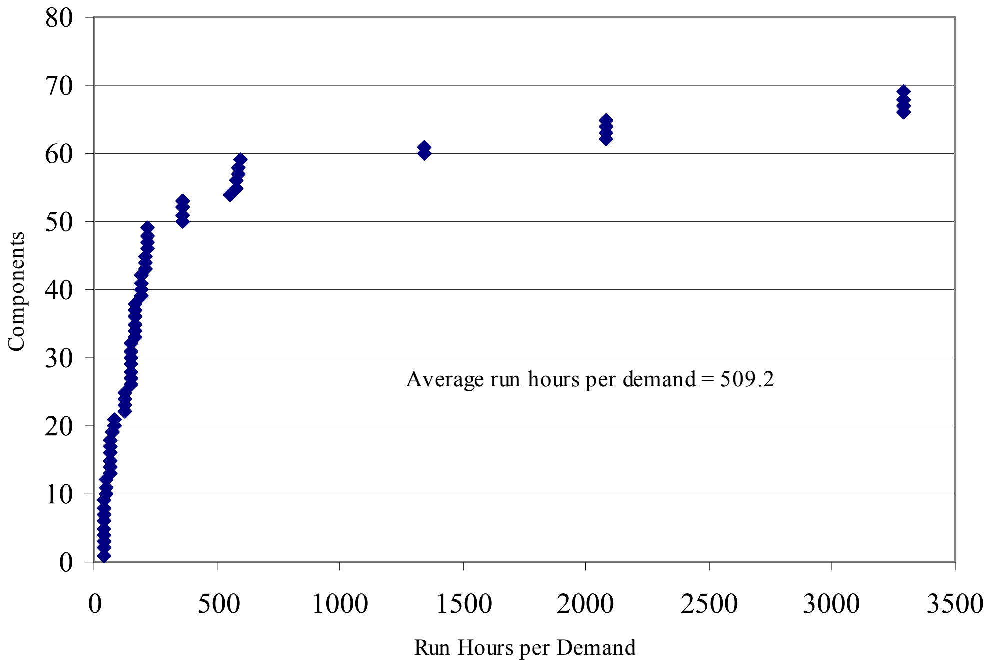

Figure 32-2b. Running/alternating PDP run hours per demand distribution.

32.3 Data Analysis

The PDP data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 32-4.

Table 32-4. Empirical distributions of MLEs for p and λ for PDPs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Standby	FTS	Component	0.00E+00	0.00E+00	3.18E-03	2.67E-02
		Plant	0.00E+00	0.00E+00	2.72E-03	1.81E-02
		Industry	-	-	2.84E-03	-
	FTR≤1H	Component	0.00E+00	0.00E+00	2.52E-05	0.00E+00
		Plant	0.00E+00	0.00E+00	2.67E-05	0.00E+00
		Industry	-	-	2.82E-04	-
	FTR>1H	Component	-	-	-	-
		Plant	-	-	-	-
		Industry	-	-	0.00E+00	-
Running/ Alternating	FTS	Component	0.00E+00	0.00E+00	4.20E-03	1.71E-02
		Plant	0.00E+00	0.00E+00	3.98E-03	1.42E-02
		Industry	-	-	3.25E-03	-
	FTR	Component	0.00E+00	0.00E+00	1.10E-05	9.97E-05
		Plant	0.00E+00	0.00E+00	8.48E-06	7.34E-05
		Industry	-	-	8.24E-06	-
All	ELS	Component	0.00E+00	0.00E+00	8.60E-08	0.00E+00
		Plant	0.00E+00	0.00E+00	7.55E-08	0.00E+00
		Industry	-	-	8.60E-08	-

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 32-3, 27.3% of the running/alternating PDPs experienced a FTS over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 72.7% portion of the distribution, and non-zero values above 72.7%.

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table 32-5 for PDPs. These results were used to develop the industry-average distributions.

Table 32-5. Fitted distributions for p and λ for PDPs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.18E-05	1.37E-03	2.99E-03	1.15E-02	Beta	0.500	1.664E+02
	FTR≤1H	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.67E-06	1.93E-04	4.24E-04	1.63E-03	Gamma	0.500	1.180E+03
	FTR>1H	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	-	-	-	-	-	-	-
Running/ Alternating	FTS	EB/CL/KS	7.32E-06	1.42E-03	3.46E-03	1.38E-02	Beta	0.447	1.288E+02
		EB/PL/KS	1.60E-05	1.57E-03	3.34E-03	1.26E-02	Beta	0.519	1.550E+02
		SCNID/IL	1.31E-05	1.51E-03	3.30E-03	1.27E-02	Beta	0.500	1.509E+02
	FTR	EB/CL/KS	3.23E-11	1.21E-06	9.25E-06	4.65E-05	Gamma	0.219	2.368E+04
		EB/PL/KS	9.14E-11	1.34E-06	8.32E-06	4.07E-05	Gamma	0.241	2.893E+04
		SCNID/IL	3.37E-08	3.90E-06	8.58E-06	3.30E-05	Gamma	0.500	5.827E+04
All	ELS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	5.07E-10	5.86E-08	1.29E-07	4.95E-07	Gamma	0.500	3.879E+06

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

32.4 Industry-Average Baselines

Table 32-6 lists the industry-average failure rate distributions. For the running/alternating FTS and FTR failure modes, the data sets were sufficient (Section A.1 in Reference 14) for empirical Bayes analyses to be performed. For these failure modes, the industry-average distributions are based on the empirical Bayes analysis results at the plant level. However, the FTR α estimate was below the lower bound of 0.3. In that case, the lower bound of 0.3 was assumed (see Section A.1 in Reference 14). The industry-average distributions for the three failure modes for standby components and the external leakage failure modes are not sufficient (Section A.1 in Reference 14) for the empirical Bayes method; therefore SCNID analyses were performed to provide failure rate distributions. The FTR>1H data had no failures or demands; therefore the FTR>1H mean is FTR≤1H * 0.06, based on the FTR>1H/ FTR≤1H ratio observed for other similar standby components (Section A.1 in Reference 14). The α parameter is 0.3 for this case.

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. These industry-average failure rates do not account for any recovery.

Table 32-6. Selected industry distributions of p and λ for PDPs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	SCNID/IL	1.18E-05	1.37E-03	2.99E-03	1.15E-02	Beta	0.500	1.664E+02
	FTR≤1H	SCNID/IL	1.67E-06	1.93E-04	4.24E-04	1.63E-03	Gamma	0.500	1.180E+03
	FTR>1H	SCNID/IL	2.72E-09	6.19E-06	2.54E-05	1.16E-04	Gamma	0.300	1.181E+04
Running/ Alternating	FTS	EB/PL/KS	1.60E-05	1.57E-03	3.34E-03	1.26E-02	Beta	0.519	1.550E+02
	FTR	EB/PL/KS	8.91E-10	2.03E-06	8.32E-06	3.81E-05	Gamma	0.300	3.605E+04
All	ELS	SCNID/IL	5.07E-10	5.86E-08	1.29E-07	4.95E-07	Gamma	0.500	3.879E+06
	ELL	ELS/EPIX	9.66E-13	2.20E-09	9.02E-09	4.13E-08	Gamma	0.300	3.325E+07

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 32-7 shows the rounded values for the PDP failure modes.

Table 32-7. Selected industry distributions of p and λ for PDPs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	SCNID/IL	1.2E-05	1.5E-03	3.0E-03	1.2E-02	Beta	0.50	1.67E+02
	FTR≤1H	SCNID/IL	1.5E-06	2.0E-04	4.0E-04	1.5E-03	Gamma	0.50	1.25E+03
	FTR>1H	SCNID/IL	1.0E-07	1.2E-05	2.5E-05	1.0E-04	Gamma	0.50	2.00E+04
Running/ Alternating	FTS	EB/PL/KS	1.2E-05	1.5E-03	3.0E-03	1.2E-02	Beta	0.50	1.67E+02
	FTR	EB/PL/KS	9.0E-10	2.0E-06	8.0E-06	4.0E-05	Gamma	0.30	3.75E+04
All	ELS	SCNID/IL	5.0E-10	5.0E-08	1.2E-07	5.0E-07	Gamma	0.50	4.17E+06
	ELL	ELS/EPIX	1.0E-12	2.0E-09	9.0E-09	4.0E-08	Gamma	0.30	3.33E+07

32.5 Breakdown by System

PDP UR results (Jeffreys means of system data) are compared by system and failure mode in Table 32-8. Results are shown only the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 32-8. PDP p and λ by system.

Operation	System	FTS	FTR≤1H	FTR>1H
Standby	CVC	4.6E-03	5.6E-04	-
	HPI	6.1E-03	-	-
	SLC	2.3E-03	-	-
Operation	System	FTS		FTR
Running/ Alternating	CVC	3.7E-03		1.5E-05
	LCS	-		-
	MFW	-		-
	MSS	9.9E-04		-
	SLC	2.0E-03		-
Operation	System	ELS		
All	CVC	3.1E-07		
	HPI	-		
	LCS	-		
	MFW	-		
	MSS	-		
	SLC	-		

33 Pipe (PIPE)

33.1 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 33-1.

Table 33-1. PIPE failure modes.

Operation	Failure Mode	Parameter	Units	Description
All	ELS	λ	1/h-ft	External leak small
	ELL	λ	1/h-ft	External leak large

33.2 Data Collection and Review

Data for PIPE UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1997–2004. There are 10,330 PIPE components in 112 systems from 96 plants in the data originally gathered from EPIX. EPIX reporting requirements allow great flexibility in defining PIPE components. Within a given system, one plant may report one PIPE component covering the entire system, while another may subdivide the piping into many smaller segments. The systems included in the PIPE data collection are listed in Table 33-2 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 33-2.

Table 33-2. 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 33-3 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 calendar hours.

Table 33-3. PIPE unreliability data.

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

33.3 Industry-Average Baselines

Table 33-4 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 33-4. Selected industry distributions of λ for PIPEs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 33-5 shows the rounded values for the PIPE failure modes.

Table 33-5. Selected industry distributions of λ for PIPEs (after rounding).

System	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
ESW	ELS	SCNID/IL	2.5E-12	3.0E-10	7.0E-10	2.5E-09	Gamma	0.50	7.14E+08
	ELL	ELS/EPIX	1.5E-14	3.0E-11	1.5E-10	6.0E-10	Gamma	0.30	2.00E+09
Non-ESW	ELS	SCNID/IL	1.0E-12	1.2E-10	2.5E-10	1.0E-09	Gamma	0.50	2.00E+09
	ELL	ELS/EPIX	2.5E-15	6.0E-12	2.5E-11	1.2E-10	Gamma	0.30	1.20E+10

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

34.1 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 34-1.

Table 34-1. Process logic component failure modes.

Operation	Failure Mode	Parameter	Units	Description
Running	FTOP	*p*	-	Fail to operate

34.2 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 34-2 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 34-2. Process logic component unreliability data.

Component Operation	Component Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Running	PLDT FTOP	24.3	4887	-	-	-	-
	PLF FTOP	-	-	-	-	-	-
	PLL FTOP	3.3	6075	-	-	-	-
	PLP FTOP	5.6	38115	-	-	-	-

34.3 Industry-Average Baselines

Table 34-3 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 α = 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 34-3. Selected industry distributions of *p* and *λ* for process logic components (before rounding).

Operation	Component Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	*α*	*β*
Running	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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the *α* parameter was rounded. In order to preserve the mean value, the *β* parameter is presented to three significant figures. Table 34-4 shows the rounded values for the process logic component failure modes.

Table 34-4. Selected industry distributions of *p* and *λ* for process logic components (after rounding).

Operation	Component Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	*α*	*β*
Running	PLDT FTOP	RPS SS	2.0E-05	2.5E-03	5.0E-03	2.0E-02	Beta	0.50	1.00E+02
	PLF FTOP	PLL	2.5E-06	3.0E-04	6.0E-04	2.5E-03	Beta	0.50	8.33E+02
	PLL FTOP	RPS SS	2.5E-06	3.0E-04	6.0E-04	2.5E-03	Beta	0.50	8.33E+02
	PLP FTOP	RPS SS	6.0E-07	7.0E-05	1.5E-04	6.0E-04	Beta	0.50	3.33E+03

35 Pump Volute (PMP)

35.1 Component Description

The pump volute (PMP) boundary includes the pump volute portion of AFW DDPs, MDPs, and TDPs. PMP is used only to support the quantification of common-cause failure events across DDPs, MDPs, and TDPs. The failure modes for PMP are listed in Table 35-1. Unlike other standby pump components, the PMP FTR is not divided into FTR≤1H and FTR>1H because the common-cause failure parameters do not distinguish these two failure modes.

Table 35-1. PMP failure modes.

Operation	Failure Mode	Parameter	Units	Description
Standby	FTS	p	-	Failure to start
	FTR	λ	1/h	Failure to run

35.2 Data Collection and Review

Data for PMP UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. There are 180 PMPs from 64 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1 in Reference 14) there were 180 components in 64 plants. The systems and operational status included in the PMP data collection are listed in Table 35-2 with the number of components included with each system.

Table 35-2. PMP systems.

Operation	System	Description	Number of Components	
			Initial	After Review
Standby	AFW	Auxiliary feedwater	180	180
	Total		180	180

To identify pump volute failures within the AFW DDP, MDP, and TDP failures, the failure descriptions were reviewed. (EPIX does not identify pump volute events as a separate category.) Table 35-3 summarizes the data obtained from the EPIX event review and used in the PMP analysis.

Table 35-3. PMP unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTS	4	16776	180	64	2.2%	4.7%
	FTR	9	74199 h	180	64	5.0%	14.1%

Figure 35-1 shows the range of start demands per year in the standby PMP data set. The start demands per year range from approximately 3 to 50. The average for the data set is 18.6 demands/year. Figure 35-2 shows the range of run hours per demand in the standby PMP data set. The run hours per demand range is from approximately 1 hour/demand to 37 hours/demand. The average is 4.1 hours/demand.

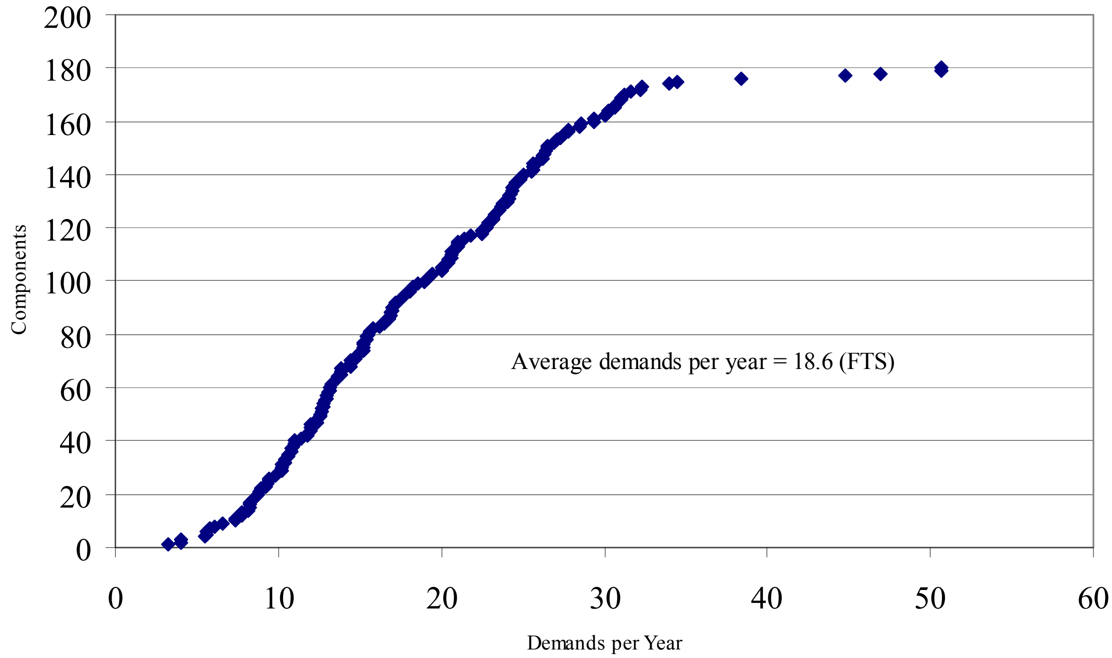

Figure 35-1. Standby PMP demands per year distribution.

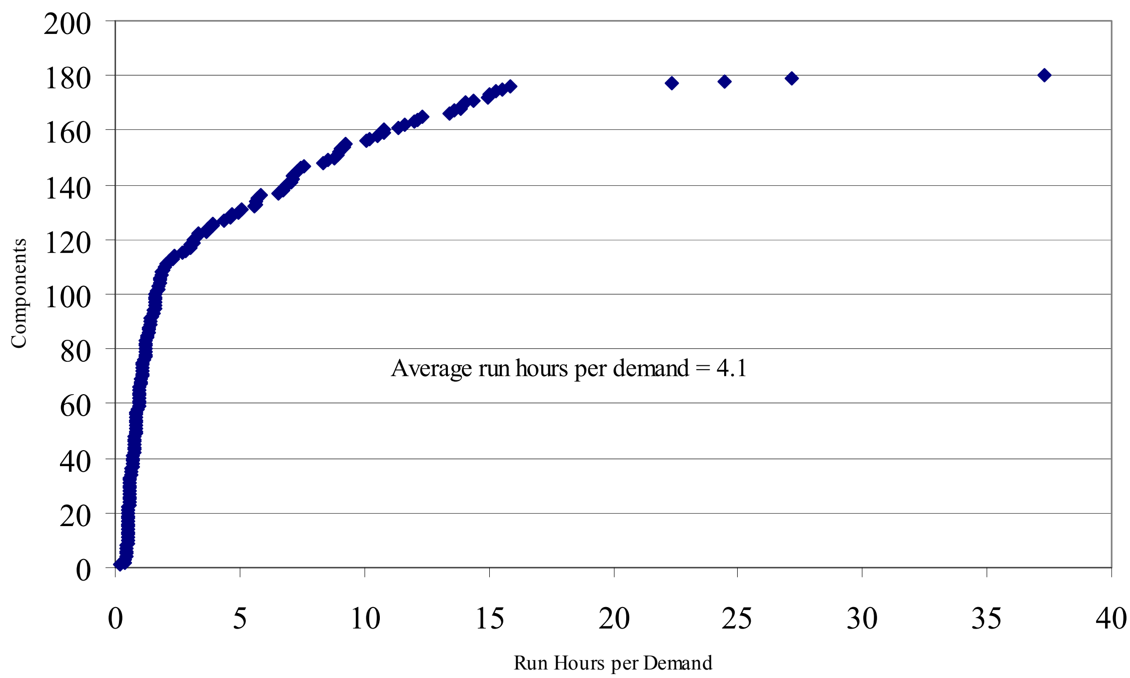

Figure 35-2. Standby PMP run hours per demand distribution.

35.3 Data Analysis

The PMP data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 35-4.

Table 35-4. Empirical distributions of MLEs for p and λ for PMPs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Standby	FTS	Component	0.00E+00	0.00E+00	5.05E-04	0.00E+00
		Plant	0.00E+00	0.00E+00	4.46E-04	0.00E+00
		Industry	-	-	2.38E-04	-
	FTR	Component	0.00E+00	0.00E+00	8.44E-04	0.00E+00
		Plant	0.00E+00	0.00E+00	7.20E-04	5.84E-03
		Industry	-	-	1.21E-04	-

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 35-3, only 5.0% of the PMPs experienced a FTR over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 95.0% portion of the distribution, and non-zero values above 95.0%.

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table 35-5 for PMPs.

Table 35-5. Fitted distributions for p and λ for PMPs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/CL/KS	5.14E-25	2.70E-08	2.96E-04	1.66E-03	Beta	0.060	2.022E+02
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.06E-06	1.22E-04	2.68E-04	1.03E-03	Beta	0.500	1.864E+03
	FTR	EB/CL/KS	8.23E-09	3.37E-05	1.57E-04	7.35E-04	Gamma	0.278	1.775E+03
		EB/PL/KS	1.39E-05	1.04E-04	1.35E-04	3.60E-04	Gamma	1.389	1.030E+04
		SCNID/IL	5.03E-07	5.82E-05	1.28E-04	4.92E-04	Gamma	0.500	3.906E+03

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

35.4 Industry-Average Baselines

Table 35-6 lists the selected industry distributions of p and λ for the PMP failure modes. For the FTR failure mode, the data set was sufficient for empirical Bayes analyses to be performed. For this failure mode, the industry-average distribution is based on the empirical Bayes analysis results at the plant level. However, the industry-average distribution for FTS is not sufficient (Section A.1 in Reference 14) for the empirical Bayes method; therefore, a SCNID analysis was performed to provide a failure rate distribution. These industry-average failure rates do not account for any recovery.

Table 35-6. Selected industry distributions of p and λ for PMPs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	SCNID/IL	1.06E-06	1.22E-04	2.68E-04	1.03E-03	Beta	0.500	1.864E+03
	FTR	EB/PL/KS	1.39E-05	1.04E-04	1.35E-04	3.60E-04	Gamma	1.389	1.030E+04

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 35-7 shows the rounded values for the MDP failure modes.

Table 35-7. Selected industry distributions of p and λ for PMPs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	SCNID/IL	1.0E-06	1.2E-04	2.5E-04	1.0E-03	Beta	0.50	2.00E+03
	FTR	EB/PL/KS	1.5E-05	9.0E-05	1.2E-04	3.0E-04	Gamma	1.50	1.25E+04

35.5 Breakdown by System

The pumps discussed above are all in the AFW system.

36 Pneumatic-Operated Damper (POD)

36.1 Component Description

The pneumatic-operated damper (POD) component boundary includes the damper, the damper operator, any associated solenoid operated valves, and local instrumentation and control circuitry. The failure modes for POD are listed in Table 36-1.

Table 36-1. POD failure modes.

Operation	Failure Mode	Parameter	Units	Description
All	FTO/C	p	-	Failure to open or failure to close
	SO	λ	1/h	Spurious operation

36.2 Data Collection and Review

Data for POD UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. There are 101 PODs from 12 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1 in Reference 14) there were 101 components in 12 plants. After analyzing the original data, there were no SO failures, so the data set was expanded to 1997– 2004 for SO failure mode (see Section A.1 in Reference 14). The systems included in the POD data collection are listed in Table 36-2 with the number of components included with each system.

Table 36-2. POD systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
All	CIS	Containment isolation system	1	1	1
	CVC	Chemical and volume control	1	1	1
	HVC	Heating ventilation and air conditioning	79	79	37
	SGT	Standby gas treatment	20	20	20
	Total		101	101	59

The POD data set obtained from RADS was further reduced to include only those PODs 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 36-3 summarizes the data used in the POD analysis. Note that the hours for SO are calendar hours.

Table 36-3. POD unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO/C	2	2461	59	10	3.4%	10.0%
	SO	0	4134720 h	59	10	0.0%	0.0%

Figure 36-1 shows the range of valve demands per year in the POD data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 16. The average for the data set is 8.3. demands/year.

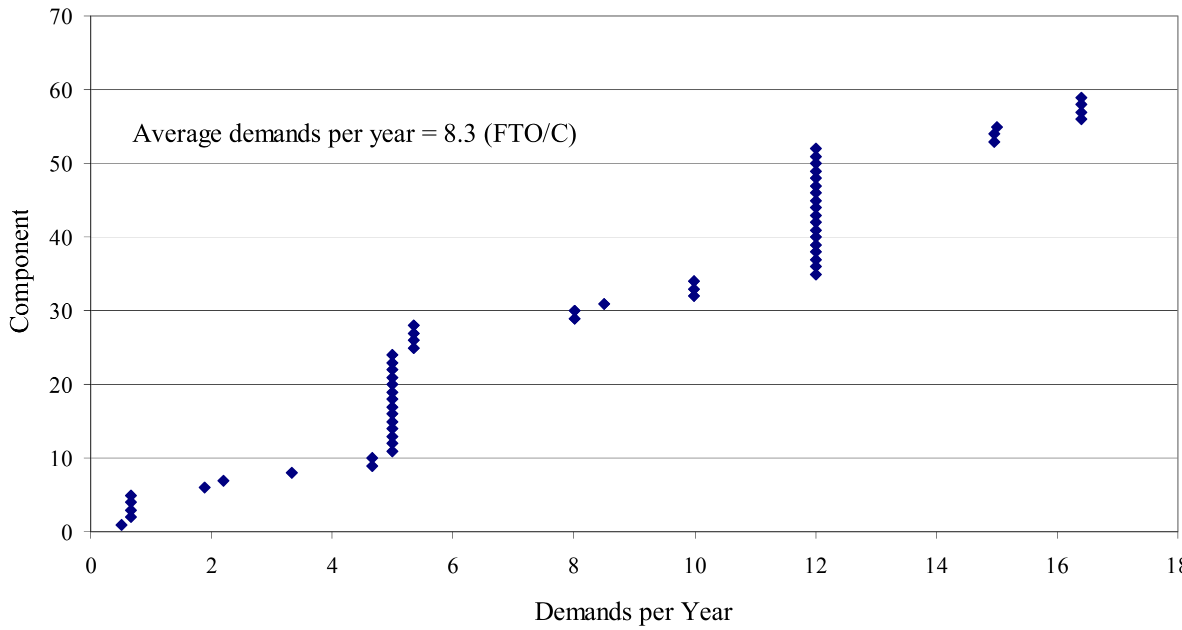

Figure 36-1. POD demands per year distribution.

36.3 Data Analysis

The POD data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 29-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 36-3, only 3.4% of the PODs experienced a FTO/C over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 97.6% portion of the distribution, and non-zero values above 97.6%.

Table 36-4. Empirical distributions of MLEs for p and λ for PODs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
All	FTO/C	Component	0.00E+00	0.00E+00	1.36E-03	0.00E+00
		Plant	0.00E+00	0.00E+00	2.36E-04	2.36E-03
		Industry	-	-	8.13E-04	-
	SO	Component	-	-	0.00E+00	-
		Plant	-	-	0.00E+00	-
		Industry	-	-	0.00E+00	-

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table 36-5.

Table 36-5. Fitted distributions for p and λ for PODs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO/C	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	4.00E-06	4.62E-04	1.01E-03	3.90E-03	Beta	0.500	4.921E+02
	SO	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	4.75E-10	5.50E-08	1.21E-07	4.64E-07	Gamma	0.500	4.136E+06

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

36.4 Industry-Average Baselines

Table 36-6 lists the selected industry distributions of p and λ for the POD failure modes. The industry-average distributions for the FTO/C and SO failure modes are not sufficient (Section A.1 in Reference 14) for the empirical Bayes method; therefore, SCNID analyses were performed to provide failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 36-6. Selected industry distributions of p and λ for PODs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO/C	SCNID/IL	4.00E-06	4.62E-04	1.01E-03	3.90E-03	Beta	0.500	4.921E+02
	SO	SCNID/IL	4.75E-10	5.50E-08	1.21E-07	4.64E-07	Gamma	0.500	4.136E+06

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 36-7 shows the rounded values for the POD failure modes.

Table 36-7. Selected industry distributions of p and λ for PODs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO/C	SCNID/IL	4.0E-06	5.0E-04	1.0E-03	4.0E-03	Beta	0.50	5.00E+02
	SO	SCNID/IL	5.0E-10	5.0E-08	1.2E-07	5.0E-07	Gamma	0.50	4.17E+06

36.5 Breakdown by System

POD UR results (Jeffreys means of system data) are compared by system and failure mode in Table 36-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 36-8. POD p and λ by system.

System	FTO/C	SO
CIS	-	-
CVC	-	-
HVC	2.1E-03	-
SGT	-	-

37 Power-Operated Relief Valve (PORV)

37.1 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 37-1.

Table 37-1. PORV failure modes.

Operation	Failure Mode	Parameter	Units	Description
All	FTO	*p*	-	Failure to open
	FTC	*p*	-	Failure to close
	SO	λ	1/h	Spurious operation

37.2 Data Collection and Review

Data for PORV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. There are 243 PORVs from 65 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1 in Reference 14) there were 241 components in 65 plants. The systems included in the PORV data collection are listed in Table 37-2 with the number of components included with each system.

Table 37-2. PORV systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
All	MSS	Main steam	127	127	121
	RCS	Reactor coolant	116	114	114
	Total		243	241	235

The PORV data set obtained from RADS was further reduced to include only those PORVs 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 37-3 summarizes the data used in the PORV analysis. Note that SO hours are calendar hours.

Table 37-3. PORV unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO	33	5054	235	65	11.9%	24.6%
	FTC	5	5054	235	65	2.1%	7.7%
	SO	5	10555800 h	241	65	2.1%	6.2%

Figure 37-1 shows the range of valve demands per year in the PORV data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 20. The average for the data set is 4.3 demands/year.

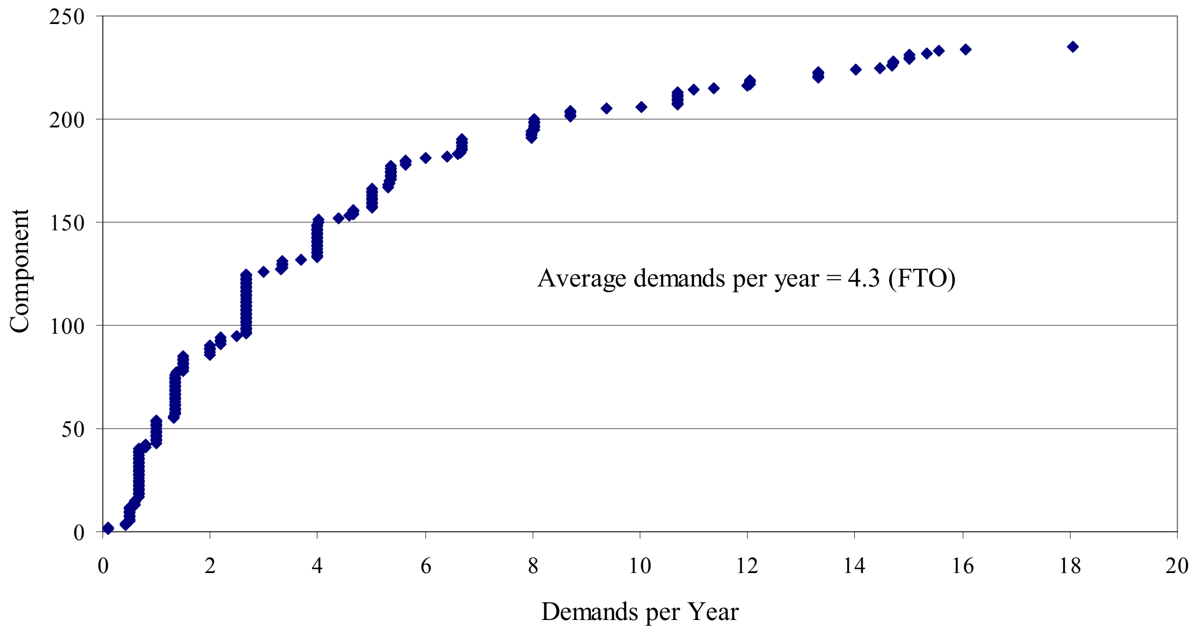

Figure 37-1. PORV demands per year distribution.

37.3 Data Analysis

The PORV data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 37-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 37-3, 11.9% of the PORVs experienced a FTO over the period 1998–2002, so the distribution of MLEs, at the component level, involves zeros for the 0% to 88.1% portion of the distribution, and non-zero values above 88.1%.

Table 37-4. Empirical distributions of MLEs for p and λ for PORVs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
All	FTO	Component	0.00E+00	0.00E+00	1.27E-02	5.44E-02
		Plant	0.00E+00	0.00E+00	9.96E-03	5.98E-02
		Industry	-	-	6.53E-03	-
	FTC	Component	0.00E+00	0.00E+00	1.88E-03	0.00E+00
		Plant	0.00E+00	0.00E+00	3.64E-03	9.77E-03
		Industry	-	-	9.89E-04	-
	SO	Component	0.00E+00	0.00E+00	4.74E-07	0.00E+00
		Plant	0.00E+00	0.00E+00	3.57E-07	3.81E-06
		Industry	-	-	4.74E-07	-

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table 37-5.

Table 37-5. Fitted distributions for p and λ for PORVs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	EB/CL/KS	1.59E-05	3.03E-03	7.30E-03	2.91E-02	Beta	0.449	6.103E+01
		EB/PL/KS	1.30E-05	2.91E-03	7.25E-03	2.92E-02	Beta	0.435	5.955E+01
		SCNID/IL	2.63E-05	3.04E-03	6.63E-03	2.54E-02	Beta	0.500	7.495E+01
	FTC	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	4.29E-06	4.96E-04	1.09E-03	4.18E-03	Beta	0.500	4.591E+02
	SO	JEFF/CL	2.17E-07	4.90E-07	5.21E-07	9.32E-07	Gamma	5.500	1.056E+07
		EB/PL/KS	1.28E-11	8.84E-08	4.63E-07	2.21E-06	Gamma	0.262	5.650E+05
		SCNID/IL	2.05E-09	2.37E-07	5.21E-07	2.00E-06	Gamma	0.500	9.597E+05

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

37.4 Industry-Average Baselines

Table 37-6 lists the selected industry distributions of p and λ for the PORV failure modes. For the FTO and SO failure modes, the data sets were sufficient (see Section A.1 in Reference 14) for empirical Bayes analyses to be performed. Therefore, the industry-average distribution is based on the empirical Bayes analysis results at the plant level for FTO and SO. However, the industry-average distribution for FTC is not sufficient (Section A.1 in Reference 14) for the empirical Bayes method; therefore, a SCNID analysis was performed to provide a failure rate distribution. These industry-average failure rates do not account for any recovery.

Table 37-6. Selected industry distributions of p and λ for PORVs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	EB/PL/KS	1.30E-05	2.91E-03	7.25E-03	2.92E-02	Beta	0.435	5.955E+01
	FTC	SCNID/IL	4.29E-06	4.96E-04	1.09E-03	4.18E-03	Beta	0.500	4.591E+02
	SO	EB/PL/KS	4.95E-11	1.13E-07	4.63E-07	2.12E-06	Gamma	0.300	6.481E+05

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 37-7 shows the rounded values for the PORV failure modes.

Table 37-7. Selected industry distributions of p and λ for PORVs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	EB/PL/KS	7.0E-06	2.5E-03	7.0E-03	3.0E-02	Beta	0.40	5.71E+01
	FTC	SCNID/IL	4.0E-06	5.0E-04	1.0E-03	4.0E-03	Beta	0.50	5.00E+02
	SO	EB/PL/KS	5.0E-11	1.2E-07	5.0E-07	2.5E-06	Gamma	0.30	6.00E+05

37.5 Breakdown by System

PORV UR results (Jeffreys means of system data) are compared by system and failure mode in Table 37-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 37-8. PORV p and λ by system.

System	FTO	FTC	SO
MSS	7.6E-03	7.8E-04	8.1E-07
RCS	5.2E-03	1.9E-03	3.0E-07

38 Relay (RLY)

38.1 Component Description

The relay (RLY) boundary includes the relay unit itself. The failure mode for RLY is listed in Table 38-1.

Table 38-1. RLY failure modes.

Operation	Failure Mode	Parameter	Units	Description
Running	FTOP	*p*	-	Fail to operate

38.2 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 38-2 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 38-2. RLY unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Running	FTOP	23.7	974417	-	-	-	-

38.3 Industry-Average Baselines

Table 38-3 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 α = 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 38-3. Selected industry distributions of p and λ for RLYs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 39-4 shows the rounded value for the RLY failure mode.

Table 38-4. Selected industry distributions of p and λ for RLYs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	FTOP	RPS SS	1.0E-07	1.2E-05	2.5E-05	1.0E-04	Beta	0.50	2.00E+04

39 Reactor Trip Breaker (RTB)

39.1 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 39-1.

Table 39-1. RTB failure modes.

Operation	Failure Mode	Parameter	Units	Description
Standby	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

39.2 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 39-2 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 39-2. RTB unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	BME FTOP	1	97359	-	-	-	-
	BSN FTOP	14	44104	-	-	-	-
	BUV FTOP	23.1	57199	-	-	-	-
	RTB FTOP	-	-	-	-	-	-

39.3 Industry-Average Baselines

Table 39-3 lists the industry-average failure rate distributions. The selected FTOP distributions have means based on the Jeffreys mean of industry data and α = 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 39-3. Selected industry distributions of p and λ for RTBs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 39-4 shows the rounded values for the RTB failure modes.

Table 39-4. Selected industry distributions of p and λ for RTBs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	BME FTOP	RPS SS	6.0E-08	7.0E-06	1.5E-05	6.0E-05	Beta	0.50	3.33E+04
	BSN FTOP	RPS SS	1.2E-06	1.5E-04	3.0E-04	1.2E-03	Beta	0.50	1.67E+03
	BUV FTOP	RPS SS	1.5E-06	2.0E-04	4.0E-04	1.5E-03	Beta	0.50	1.25E+03
	RTB FTOP	RPS SS	6.0E-08	7.0E-06	1.5E-05	6.0E-05	Beta	0.50	3.33E+04

40 Sequencer (SEQ)

40.1 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 40-1.

Table 40-1. SEQ failure modes.

Operation	Failure Mode	Parameter	Units	Description
Standby	FTOP	*p*	-	Fail to operate

40.2 Data Collection and Review

Data for the SEQ UR baseline were obtained from EPIX data from 1998 to 2002. The sequencer is not treated separately from the EDG output circuit breaker in EPIX. The EDG failure events were read to obtain sequencer-only failure data. The demand data are based on assuming a full test of the sequencer every fuel cycle (18 months) for each EDG. Table 40-2 summarizes the data obtained from EPIX and used in the SEQ analysis.

Table 40-2. SEQ unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTOP	2	750	225	95	0.99%	2.1%

40.3 Industry-Average Baselines

Table 40-3 lists the industry-average failure rate distributions. The selected FTOP distribution has a mean based on the Jeffreys mean of industry data and α = 0.5. An *α* of 0.5 is assumed.

Table 40-3. Selected industry distributions of *p* and *λ* for SEQs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	*α*	*β*
Standby	FTOP	SCNID	1.31E-05	1.52E-03	3.33E-03	1.27E-02	Beta	0.500	1.502E+02

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the *α* parameter was rounded. In order to preserve the mean value, the *β* parameter is presented to three significant figures. Table 40-4 shows the rounded values for the SEQ failure mode.

Table 40-4. Selected industry distributions of *p* and *λ* for SEQs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	*α*	*β*
Standby	FTOP	SCNID	1.2E-05	1.5E-03	3.0E-03	1.2E-02	Beta	0.50	1.67E+02

41 Solenoid-Operated Valve (SOV)

41.1 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 41-1.

Table 41-1. SOV failure modes.

Operation	Failure Mode	Parameter	Units	Description
Standby	FTO/C	p	-	Failure to open or failure to close
	SO	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

41.2 Data Collection and Review

Most of the data for SOV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS, except for the ILS and ELS data that cover 1997–2004. There are 1748 SOVs from 77 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1 in Reference 14) there were 1722 components in 77 plants. The systems included in the SOV data collection are listed in Table 41-2 with the number of components included with each system.

Table 41-2. SOV systems.

			Number of Components		
Operation	System	Description	Initial	After Review	≤ 20 Demands per Year
All	AFW	Auxiliary feedwater	39	39	21
	CIS	Containment isolation system	832	814	680
	CRD	Control rod drive	414	410	402
	CSR	Containment spray recirculation	6	6	6
	CVC	Chemical and volume control	30	26	20
	EPS	Emergency power supply	33	33	21
	ESW	Emergency service water	17	17	14
	FWS	Firewater	4	4	4
	HCI	High pressure coolant injection	8	8	8
	HPI	High pressure injection	6	6	6
	HVC	Heating ventilation and air conditioning	78	78	60
	IAS	Instrument air	39	39	39
	LCI	Low pressure coolant injection	24	24	21
	LCS	Low pressure core spray	2	2	2
	LPI	Low pressure injection	13	13	13
	MFW	Main feedwater	4	4	4
	MSS	Main steam	58	58	54
	RCI	Reactor core isolation	2	2	2
	RCS	Reactor coolant	78	78	78
	RPS	Reactor protection	14	14	14
	RRS	Reactor recirculation	35	35	35
	SGT	Standby gas treatment	10	10	4
	VSS	Vapor suppression	2	2	2
	Total		1748	1722	1510

The SOV data set obtained from RADS was further reduced to include only those SOVs with ≤ 20 demands/year. See Section A.1 in Reference 14 for a discussion concerning this decision to limit certain component populations. Table 41-3 summarizes the data used in the SOV analysis. Note that the hours for SO, ELS, and ILS are calendar hours. The FC failure mode is not supported by EPIX data.

Table 41-3. SOV unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
Standby	FTO/C	25	31813	1510	71	1.5%	19.7%
	SO	6	66138000 h	1510	71	0.3%	5.6%
	ELS	0.5	108253200 h	1529	71	0.1%	1.4%
	ILS	26	107152320 h	1529	71	1.7%	16.9%
Control	FC	-	-	-	-	-	-

Figure 41-1 shows the range of valve demands per year in the SOV data set (limited to ≤ 20 demands/year). The demands per year range from approximately 1 to 20. The average for the data set is 4.2 demands/year.

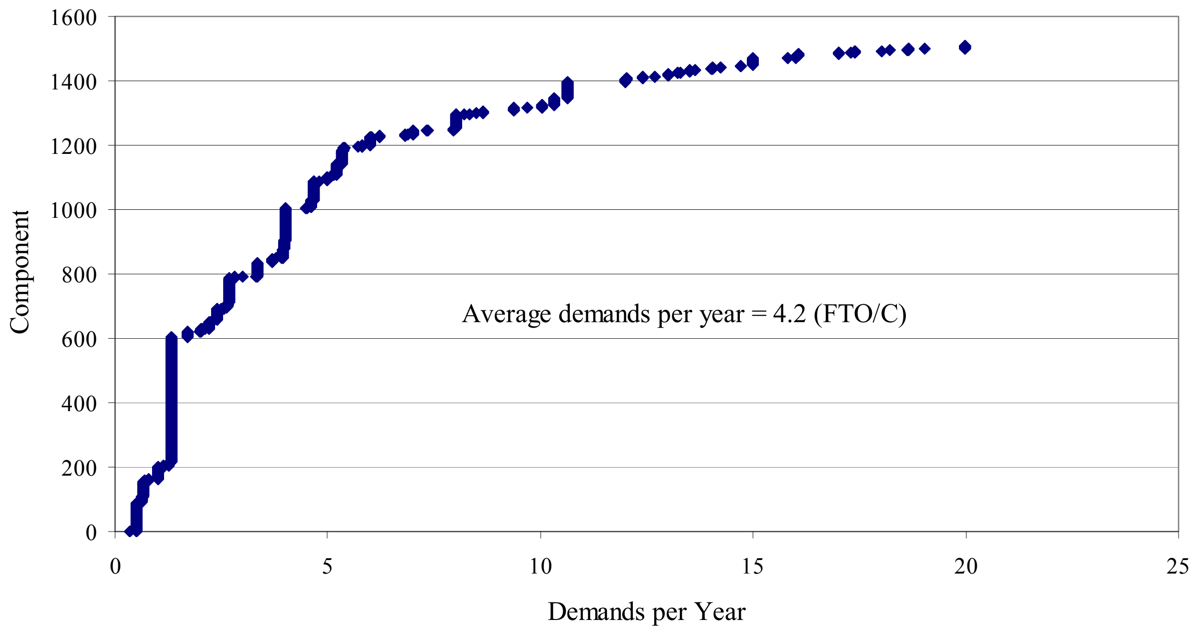

Figure 41-1. SOV demands per year distribution.

41.3 Data Analysis

The SOV data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 41-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 41-3, only 1.5% of the SOVs experienced a FTO/C over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 98.5% portion of the distribution, and non-zero values above 98.5%.

Table 41-4. Empirical distributions of MLEs for p and λ for SOVs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Standby	FTO/C	Component	0.00E+00	0.00E+00	1.15E-03	0.00E+00
		Plant	0.00E+00	0.00E+00	1.10E-03	2.98E-03
		Industry	-	-	7.86E-04	-
	SO	Component	0.00E+00	0.00E+00	9.07E-08	0.00E+00
		Plant	0.00E+00	0.00E+00	4.45E-08	0.00E+00
		Industry	-	-	9.07E-08	-
	ELS	Component	0.00E+00	0.00E+00	4.67E-09	0.00E+00
		Plant	0.00E+00	0.00E+00	3.98E-09	0.00E+00
		Industry	-	-	4.67E-09	-
	ILS	Component	0.00E+00	0.00E+00	2.43E-07	0.00E+00
		Plant	0.00E+00	0.00E+00	1.85E-07	1.15E-06
		Industry	-	-	2.43E-07	-
Control	FC	-	-	-	-	-

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table 41-5.

Table 41-5. Fitted distributions for p and λ for SOVs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTO/C	EB/CL/KS	1.78E-18	1.51E-06	8.17E-04	4.77E-03	Beta	0.084	1.025E+02
		EB/PL/KS	2.70E-06	4.11E-04	9.54E-04	3.74E-03	Beta	0.471	4.931E+02
		SCNID/IL	3.16E-06	3.65E-04	8.02E-04	3.08E-03	Beta	0.500	6.233E+02
	SO	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	4.46E-12	1.95E-08	9.23E-08	4.33E-07	Gamma	0.276	2.992E+06
		SCNID/IL	3.86E-10	4.47E-08	9.83E-08	3.78E-07	Gamma	0.500	5.088E+06
	ELS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	3.67E-11	4.24E-09	9.33E-09	3.58E-08	Gamma	0.500	5.359E+07
	ILS	EB/CL/KS	8.11E-12	4.80E-08	2.43E-07	1.15E-06	Gamma	0.266	1.098E+06
		EB/PL/KS	1.28E-10	8.76E-08	2.78E-07	1.20E-06	Gamma	0.357	1.283E+06
		SCNID/IL	9.72E-10	1.13E-07	2.47E-07	9.50E-07	Gamma	0.500	2.022E+06
Control	FC	-	-	-	-	-	-	-	-

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

41.4 Industry-Average Baselines

Table 41-6 lists the selected industry distributions of p and λ for the SOV failure modes. For the FTO/C, SO, and ILS failure modes, the data sets were sufficient (see Section A.1 in Reference 14) for empirical Bayes analyses to be performed. Therefore, the industry-average distribution is based on the empirical Bayes analysis results at the plant level. However, the empirical Bayes results for SO indicated an α less than 0.3. In that case, the lower limit of 0.3 was assumed (see Section A.1 in Reference 14). The industry-average distribution for ELS is not sufficient (Section A.1 in Reference 14) for the empirical Bayes method; therefore, a SCNID analysis was performed to provide a failure rate distribution. 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. These industry-average failure rates do not account for any recovery.

Table 41-6. Selected industry distributions of p and λ for SOVs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTO/C	EB/PL/KS	2.70E-06	4.11E-04	9.54E-04	3.74E-03	Beta	0.471	4.931E+02
	SO	EB/PL/KS	9.88E-12	2.25E-08	9.23E-08	4.22E-07	Gamma	0.300	3.251E+06
	ELS	SCNID/IL	3.67E-11	4.24E-09	9.33E-09	3.58E-08	Gamma	0.500	5.359E+07
	ELL	ELS/EPIX	6.99E-14	1.59E-10	6.53E-10	2.99E-09	Gamma	0.300	4.594E+08
	ILS	EB/PL/KS	1.28E-10	8.76E-08	2.78E-07	1.20E-06	Gamma	0.357	1.283E+06
	ILL	ILS/EPIX	5.96E-13	1.36E-09	5.56E-09	2.55E-08	Gamma	0.300	5.392E+07
Control	FC	WSRC	3.21E-10	7.31E-07	3.00E-06	1.37E-05	Gamma	0.300	1.000E+05

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 41-7 shows the rounded values for the SOV failure modes.

Table 41-7. Selected industry distributions of p and λ for SOVs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTO/C	EB/PL/KS	4.0E-06	5.0E-04	1.0E-03	4.0E-03	Beta	0.50	5.00E+02
	SO	EB/PL/KS	1.0E-11	2.0E-08	9.0E-08	4.0E-07	Gamma	0.30	3.33E+06
	ELS	SCNID/IL	4.0E-11	4.0E-09	9.0E-09	3.0E-08	Gamma	0.50	3.33E+07
	ELL	ELS/EPIX	7.0E-14	1.5E-10	7.0E-10	3.0E-09	Gamma	0.30	4.29E+08
	ILS	EB/PL/KS	3.0E-10	1.0E-07	3.0E-07	1.2E-06	Gamma	0.40	1.33E+06
	ILL	ILS/EPIX	6.0E-13	1.5E-09	6.0E-09	2.5E-08	Gamma	0.30	5.00E+07
Control	FC	WSRC	3.0E-10	7.0E-07	3.0E-06	1.5E-05	Gamma	0.30	1.00E+05

41.5 Breakdown by System

SOV UR results (Jeffreys means of system data) are compared by system and failure mode in Table 41-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 41-8. SOV p and λ by system.

System	FTO/C	SO	ELS	ILS
AFW	1.54E-03	-	-	-
CIS	6.04E-04	1.51E-07	3.04E-08	4.61E-07
CRD	5.51E-04	-	-	-
CSR	-	-	-	-
CVC	6.51E-03	-	-	-
EPS	-	-	-	-
ESW	2.00E-03	-	-	-
FWS	-	-	-	-
HCI	-	-	-	-
HPI	3.08E-02	-	-	-
HVC	1.16E-03	5.71E-07	-	-
IAS	-	-	-	-

System	FTO/C	SO	ELS	ILS
LCI	8.71E-03	-	-	-
LCS	-	-	-	-
LPI	-	-	-	-
MFW	-	-	-	-
MSS	-	6.34E-07	-	-
RCI	-	-	-	-
RCS	-	-	-	8.23E-07
RPS	-	-	-	-
RRS	-	-	-	-
SGT	-	-	-	-
VSS	-	-	-	-

42 Safety Relief Valve (SRV)

42.1 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 42-1.

Table 42-1. SRV failure modes.

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

42.2 Data Collection and Review

Data for most SRV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. There are 404 SRVs from 31 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1 in Reference 14) there were 404 components in 31 plants. The systems included in the SRV data collection are listed in Table 42-2 with the number of components included with each system.

Table 42-2. SRV systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
All	MSS	Main steam	404	387	386
	Total		404	387	386

The SRV data set obtained from RADS was further reduced to include only those SRVs 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 42-3 summarizes the data used in the SRV analysis. The FTCL failure mode is not supported with EPIX data. Note that SO hours are calendar hours.

Table 42-3. SRV unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO	10	3142	386	31	2.6%	12.9%
	FTC	2	3142	386	31	0.5%	6.5%
	SO	9	16906800 h	386	31	2.3%	12.9%
	FTCL	-	-	-	-	-	-

Figure 42-1 shows the range of valve demands per year in the SRV data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 20. The average for the data set is 1.6 demands/year.

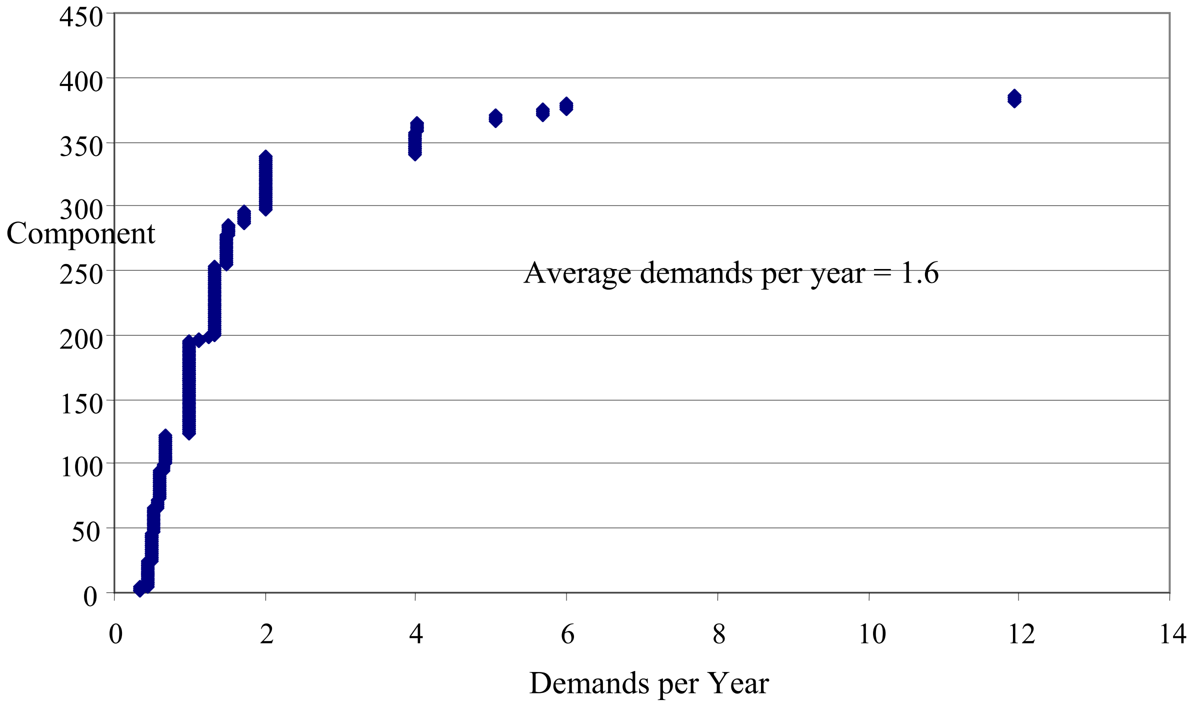

Figure 42-1. SRV demands per year distribution.

42.3 Data Analysis

The SRV data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 42-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 42-3, 2.3% of the SRVs experienced a SO over the period 1998–2002, so the distribution of MLEs, at the component level, involves zeros for the 0% to 97.7% portion of the distribution, and non-zero values above 97.7%.

Table 42-4. Empirical distributions of MLEs for p and λ for SRVs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
All	FTO	Component	0.00E+00	0.00E+00	5.91E-03	0.00E+00
		Plant	0.00E+00	0.00E+00	9.20E-03	2.22E-02
		Industry	-	-	3.18E-03	-
	FTC	Component	0.00E+00	0.00E+00	1.29E-03	0.00E+00
		Plant	0.00E+00	0.00E+00	9.64E-04	0.00E+00
		Industry	-	-	6.36E-04	-
	SO	Component	0.00E+00	0.00E+00	5.32E-07	0.00E+00
		Plant	0.00E+00	0.00E+00	4.52E-07	1.76E-06
		Industry	-	-	5.32E-07	-
	FTCL	-	-	-	-	-

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table 42-5.

Table 42-5. Fitted distributions for p and λ for SRVs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution Type	α	β
All	FTO	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	7.82E-26	2.44E-07	7.71E-03	4.44E-02	Beta	0.054	6.958E+00
		SCNID/IL	1.32E-05	1.53E-03	3.34E-03	1.28E-02	Beta	0.500	1.492E+02
	FTC	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	3.13E-06	3.62E-04	7.95E-04	3.05E-03	Beta	0.500	6.282E+02
	SO	JEFF/CL	2.99E-07	5.42E-07	5.62E-07	8.91E-07	Gamma	9.500	1.691E+07
		EB/PL/KS	2.14E-16	1.15E-08	5.08E-07	2.87E-06	Gamma	0.129	2.545E+05
		SCNID/IL	2.21E-09	2.56E-07	5.62E-07	2.16E-06	Gamma	0.500	8.898E+05
	FTCL	-	-	-	-	-	-	-	-

Note – JEFF/CL is the posterior distribution at the component level of a Bayesian update of the Jeffreys noninformative prior with industry data, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

42.4 Industry-Average Baselines

Table 42-6 lists the selected industry distributions of p and λ for the SRV failure modes. For the FTO and SO failure modes, the data set was sufficient (see Section A.1 in Reference 14) for empirical Bayes analyses to be performed. Therefore, the industry-average distribution is based on the empirical Bayes analysis results at the plant level for FTO and SO. The FTO and SO analyses resulted in α less than the lower bound of 0.3. In these cases, 0.3 was assumed (see Section A.1 in Reference 14). However, the industry-average distribution for FTC is not sufficient (Section A.1 in Reference 14) for the empirical Bayes method; therefore a SCNID analysis was performed to provide a failure rate distribution. 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 42-6. Selected industry distributions of p and λ for SRVs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution Type	α	β
All	FTO	EB/PL/KS	8.33E-07	1.89E-03	7.71E-03	3.50E-02	Beta	0.300	3.891E+01
	FTC	SCNID/IL	3.13E-06	3.62E-04	7.95E-04	3.05E-03	Beta	0.500	6.282E+02
	SO	EB/PL/KS	5.44E-11	1.24E-07	5.08E-07	2.33E-06	Gamma	0.300	5.900E+05
	FTCL	WSRC	4.62E-04	5.20E-02	1.00E-01	3.62E-01	Beta	0.500	4.500E+00

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 42-7 shows the rounded values for the SRV failure modes.

Table 42-7. Selected industry distributions of p and λ for SRVs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution Type	α	β
All	FTO	EB/PL/KS	9.0E-07	2.0E-03	8.0E-03	4.0E-02	Beta	0.30	3.75E+01
	FTC	SCNID/IL	3.0E-06	4.0E-04	8.0E-04	3.0E-03	Beta	0.50	6.25E+02
	SO	EB/PL/KS	5.0E-11	1.2E-07	5.0E-07	2.5E-06	Gamma	0.30	6.00E+05
	FTCL	WSRC	5.0E-04	5.0E-02	1.0E-01	4.0E-01	Beta	0.50	4.50E+00

42.5 Breakdown by System

The SRV is included only in the main stem system of BWRs.

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

43.1 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 43-1.

Table 43-1. Sensor/transmitter failure modes.

Operation	Failure Mode	Parameter	Units	Description
Running	FTOP	λ	1/h	Fail to operate
Running	FTOP	p	-	Fail to operate

43.2 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 43-2 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 43-2. Sensor/transmitter unreliability data.

Component Operation	Component Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Running	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	-	-	-	-

43.3 Industry-Average Baselines

Table 43-3 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 43-3. Selected industry distributions of p and λ for sensor/transmitters (before rounding).

Operation	Component Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 43-4 shows the rounded values for the sensor/transmitter failure modes.

Table 43-4. Selected industry distributions of p and λ for sensor/transmitters (after rounding).

Operation	Component Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	STF FTOP	STL	3.0E-06	4.0E-04	8.0E-04	3.0E-03	Beta	0.50	6.25E+02
	STF FTOP	STL	4.0E-10	5.0E-08	1.0E-07	4.0E-07	Gamma	0.50	5.00E+06
	STL FTOP	RPS SS	3.0E-06	4.0E-04	8.0E-04	3.0E-03	Beta	0.50	6.25E+02
	STL FTOP	RPS SS	4.0E-10	5.0E-08	1.0E-07	4.0E-07	Gamma	0.50	5.00E+06
	STP FTOP	RPS SS	5.0E-07	5.0E-05	1.2E-04	4.0E-04	Beta	0.50	4.17E+03
	STP FTOP	RPS SS	3.0E-09	4.0E-07	8.0E-07	3.0E-06	Gamma	0.50	6.25E+05
	STT FTOP	RPS SS	1.5E-06	2.0E-04	4.0E-04	1.5E-03	Beta	0.50	1.25E+03
	STT FTOP	RPS SS	3.0E-09	4.0E-07	8.0E-07	3.0E-06	Gamma	0.50	6.25E+05

44 Strainer (STR)

44.1 Component Description

The strainer (STR) component boundary includes the strainer. The failure mode for STR is listed in Table 44-1.

Table 44-1. STR failure modes.

Operation	Failure Mode	Parameter	Units	Description
All	PG	λ	1/h	Plugging

44.2 Data Collection and Review

Data for the STR UR baseline were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. Note that the data search was limited to emergency service water systems. There are 125 STRs from 35 plants in the data The systems included in the STR data collection are listed in Table 44-2 with the number of components included with each system.

Table 44-2. STR systems.

Operation	System	Description	Number of Components	
			Initial	After Review
All	ESW	Emergency cooling water	125	125
	Total		125	125

Table 44-3 summarizes the data used in the STR analysis. Note that PG hours are calendar hours.

Table 44-3. STR unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	PG	34	5475000 h	125	35	15.2%	34.3%

44.3 Data Analysis

The STR data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 44-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 44-3, 15.2% of the STRs experienced a PG over the period 1998–2002, so the distribution of MLEs, at the component level, involves zeros for the 0% to 84.8% portion of the distribution, and non-zero values above 84.8%.

Table 44-4. Empirical distributions of MLEs for p and λ for STRs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
All	PG	Component	0.00E+00	0.00E+00	6.21E-06	4.57E-05
		Plant	0.00E+00	0.00E+00	8.18E-06	3.04E-05
		Industry	-	-	6.21E-06	-

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table 44-5.

Table 44-5. Fitted distributions for p and λ for STRs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	PG	EB/CL/KS	1.36E-12	4.81E-07	6.21E-06	3.28E-05	Gamma	0.180	2.905E+04
		EB/PL/KS	2.51E-10	1.46E-06	7.38E-06	3.50E-05	Gamma	0.267	3.617E+04
		SCNID/IL	2.48E-08	2.87E-06	6.30E-06	2.42E-05	Gamma	0.500	7.935E+04

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

44.4 Industry-Average Baselines

Table 44-6 lists the industry-average failure rate distribution for the STR component. For the PG failure mode, the data set was sufficient (see Section A.1 in Reference 14) for empirical Bayes analyses to be performed. Therefore, the industry-average distribution is based on the empirical Bayes analysis results at the plant level for PG. The PG analysis resulted in α less than the lower bound of 0.3. In this case, 0.3 was assumed (see Section A.1 in Reference 14).

Table 44-6. Selected industry distributions of p and λ for STRs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	PG	EB/PL/KS	7.89E-10	1.80E-06	7.38E-06	3.37E-05	Gamma	0.300	4.067E+04

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 44-7 shows the rounded values for the STR failure mode.

Table 44-7. Selected industry distributions of p and λ for STRs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	PG	EB/PL/KS	7.0E-10	1.5E-06	7.0E-06	3.0E-05	Gamma	0.30	4.29E+04

44.5 Breakdown by System

The STR data were limited to the ESW system.

45 Safety Valve (SVV)

45.1 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 45-1.

Table 45-1. SVV failure modes.

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

45.2 Data Collection and Review

Data for most SVV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. There are 1060 SVVs from 68 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1 in Reference 14) there were 998 components in 68 plants. The systems included in the SVV data collection are listed in Table 45-2 with the number of components included with each system.

Table 45-2. SVV systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
All	MSS	Main steam	900	846	845
	RCS	Reactor coolant	160	152	152
	Total		1060	998	997

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 45-3 summarizes the data used in the SVV analysis. The FTCL failure mode is not supported with EPIX data. Note that SO hours are calendar hours.

Table 45-3. SVV unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO	18	7393	997	68	1.8%	10.3%
	FTC	0	7393	997	68	0.0%	0.0%
	SO	11	43668600 h	997	68	1.1%	8.8%
	FTCL	-	-	-	-	-	-

Figure 45-1 shows the range of valve demands per year in the SVV data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 20. The average for the data set is 1.5 demands/year.

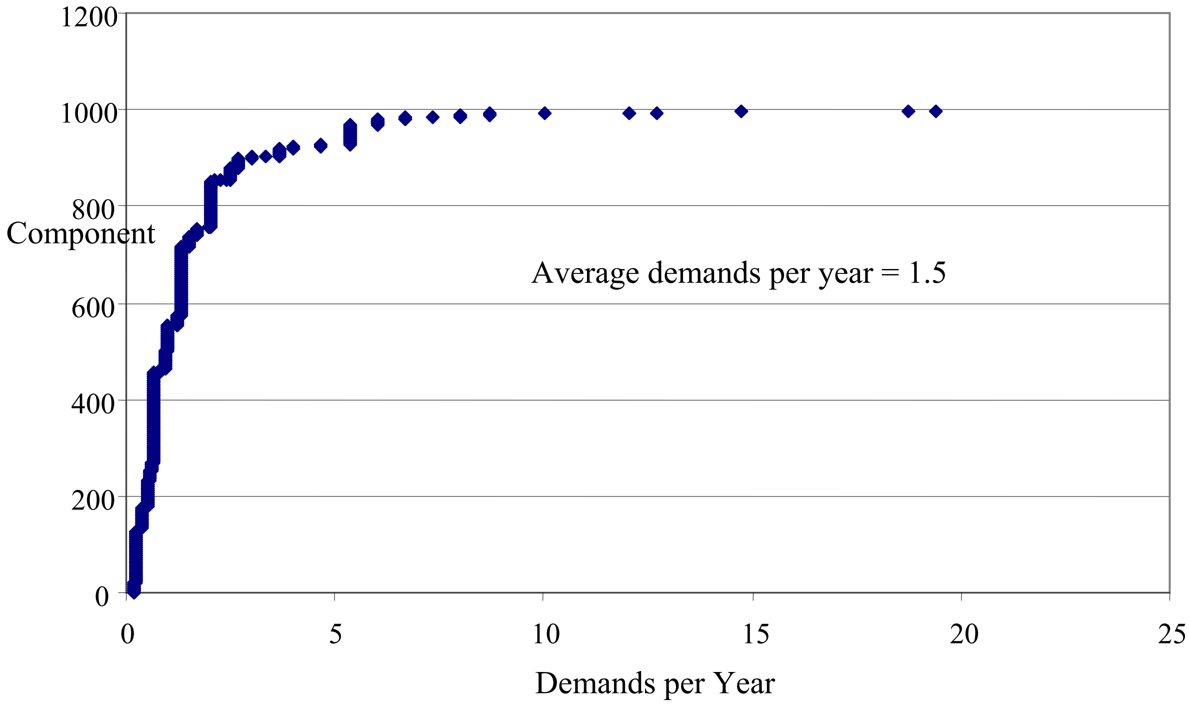

Figure 45-1. SVV demands per year distribution.

45.3 Data Analysis

The SVV data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 45-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 45-3, 1.1% of the SVVs experienced a SO over the period 1998–2002, so the distribution of MLEs, at the component level, involves zeros for the 0% to 98.9% portion of the distribution, and non-zero values above 98.9%.

Table 45-4. Empirical distributions of MLEs for p and λ for SVVs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
All	FTO	Component	0.00E+00	0.00E+00	3.19E-03	0.00E+00
		Plant	0.00E+00	0.00E+00	1.91E-03	1.50E-02
		Industry	-	-	2.43E-03	-
	FTC	Component	-	-	-	-
		Plant	-	-	-	-
		Industry	-	-	0.00E+00	-
	SO	Component	0.00E+00	0.00E+00	2.52E-07	0.00E+00
		Plant	0.00E+00	0.00E+00	1.46E-07	9.93E-07
		Industry	-	-	2.52E-07	-
	FTCL	-	-	-	-	-

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table 45-5.

Table 45-5. Fitted distributions for p and λ for SVVs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	6.50E-13	5.14E-05	2.47E-03	1.41E-02	Beta	0.127	5.106E+01
		SCNID/IL	9.88E-06	1.14E-03	2.50E-03	9.60E-03	Beta	0.500	1.993E+02
	FTC	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	2.66E-07	3.08E-05	6.76E-05	2.60E-04	Beta	0.500	7.394E+03
	SO	JEFF/CL	1.50E-07	2.56E-07	2.63E-07	4.03E-07	Gamma	11.500	4.367E+07
		EB/PL/KS	4.18E-14	1.61E-08	2.12E-07	1.12E-06	Gamma	0.179	8.445E+05
		SCNID/IL	1.04E-09	1.20E-07	2.63E-07	1.01E-06	Gamma	0.500	1.899E+06
	FTCL	-	-	-	-	-	-	-	-

Note – EB/CL/KS is am empirical Bayes analysis at the component level with the Kass-Steffey adjustment, JEFF/CL is the posterior distribution at the component level of a Bayesian update of the Jeffreys noninformative prior with industry data, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

45.4 Industry-Average Baselines

Table 45-6 lists the selected industry distributions of p and λ for the SVV failure modes. For the FTO and SO failure modes, the data set was sufficient (see Section A.1 in Reference 14) for empirical Bayes analyses to be performed. Therefore, the industry-average distribution is based on the empirical Bayes analysis results at the plant level for FTO and SO. The FTO and SO analyses resulted in α less than the lower limit of 0.3. In these cases, 0.3 was assumed (see Section A.1 in Reference 14). However, the industry-average distribution for FTC is not sufficient (Section A.1 in Reference 14) for the empirical Bayes method; therefore a SCNID analysis was performed to provide a failure rate distribution. 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 45-6. Selected industry distributions of p and λ for SVVs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	EB/PL/KS	2.66E-07	6.05E-04	2.47E-03	1.13E-02	Beta	0.300	1.213E+02
	FTC	SCNID/IL	2.66E-07	3.08E-05	6.76E-05	2.60E-04	Beta	0.500	7.394E+03
	SO	EB/PL/KS	2.27E-11	5.17E-08	2.12E-07	9.71E-07	Gamma	0.300	1.414E+06
	FTCL	WSRC	4.62E-04	5.20E-02	1.00E-01	3.62E-01	Beta	0.500	4.500E+00

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 45-7 shows the rounded values for the SVV failure modes.

Table 45-7. Selected industry distributions of p and λ for SVVs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	EB/PL/KS	2.5E-07	6.0E-04	2.5E-03	1.2E-02	Beta	0.30	1.20E+02
	FTC	SCNID/IL	3.0E-07	3.0E-05	7.0E-05	2.5E-04	Beta	0.50	7.14E+03
	SO	EB/PL/KS	2.0E-11	5.0E-08	2.0E-07	9.0E-07	Gamma	0.30	1.50E+06
	FTCL	WSRC	5.0E-04	5.0E-02	1.0E-01	4.0E-01	Beta	0.50	4.50E+00

45.5 Breakdown by System

SVV UR results (Jeffreys means of system data) are compared by system and failure mode in Table 45-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 45-8. SVV *p* and λ by system.

System	FTO	FTC	SO	FTCL
MSS	2.3E-03	-	2.3E-07	-
RCS	4.6E-03	-	5.3E-07	-

46 Turbine-Driven Pump (TDP)

46.1 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 46-1.

Table 46-1. TDP failure modes.

Operation	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

46.2 Data Collection and Review

Data for TDP UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002, except for the ELS data, which cover 1997–2004. After analyzing the original data, there were no standby FTR>1H failures, so the data set was expanded to 1997– 2004 for the standby FTR>1H failure mode (see Section A.1 in Reference 14). There are 175 TDPs from 97 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1 in Reference 14) there were 174 components in 97 plants. These data were then further partitioned into standby and running/alternating components. The systems and operational status included in the TDP data collection are listed in Table 46-2 with the number of components included with each system.

Table 46-2. TDP systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 200 Demands per Year
Standby	AFW	Auxiliary feedwater	62	62	62
	HCI	High pressure coolant injection	24	24	24
	MFW	Main feedwater	4	4	4
	RCI	Reactor core isolation	30	29	29
	Total		120	119	119
Running/ Alternating	MFW	Main feedwater	55	55	55
	Total		55	55	55

The data review process is described in detail in Section A.1 in Reference 14. Table 46-3 summarizes the data obtained from EPIX and used in the TDP analysis. Note that the hours for ELS are calendar hours.

Figure 46-1a shows the range of start demands per year in the standby TDP data set. The start demands per year range from approximately 2 to 34. The average for the data set is 12.8 demands/year. Figure 46-1b shows the range of start demands per year in the running/alternating TDP data set. The demands per year range from approximately 0 to 4. The average for the data set is 1.8 demands/year. Figure 46-2a shows the range of run hours per demand in the standby TDP data set. The run hours per demand range is from approximately 0 hours/demand to 22 hours/demand. The average is 1.5 hours/demand. Figure 46-2b shows the range of run hours per demands in the running TDP data set. The range is from approximately 1460 hours/demand to 12,165 hours/demand. The average is 5539.4 hours/demand.

Table 46-3. TDP unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTS	46	7627	119	93	26.1%	29.0%
	FTR≤1H	18	7188	113	87	12.6%	16.1%
	FTR>1H	0	6803 h	6	6	0.0%	0.0%
Running/ Alternating	FTS	11	503	55	25	8.4%	8.6%
	FTR	13	2231788 h	55	25	10.1%	9.7%
All	ELS	1	12264000 h	175	141	0.8%	1.1%

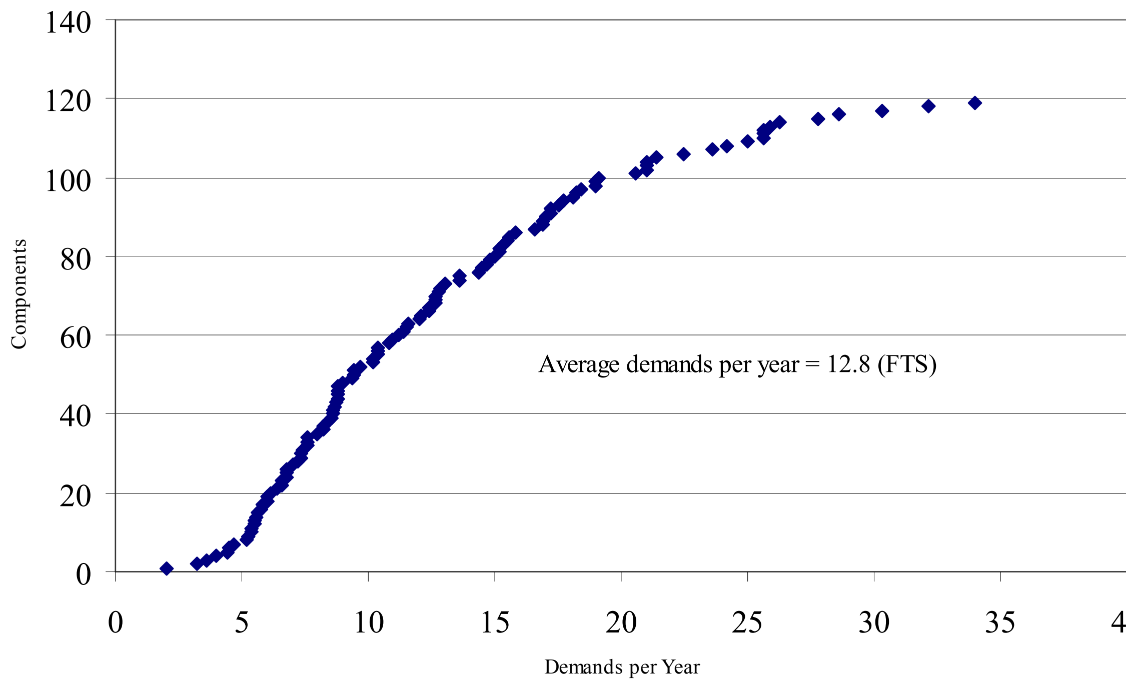

Figure 46-1a. Standby TDP demands per year distribution.

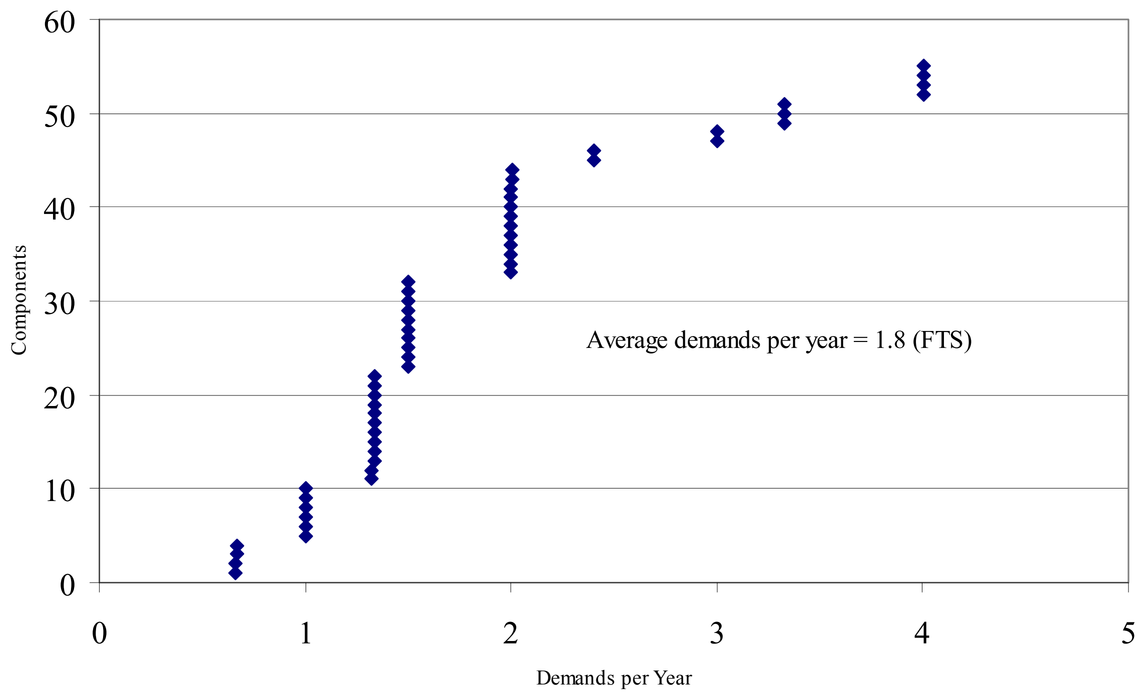

Figure 46-1b. Running/alternating TDP demands per year distribution.

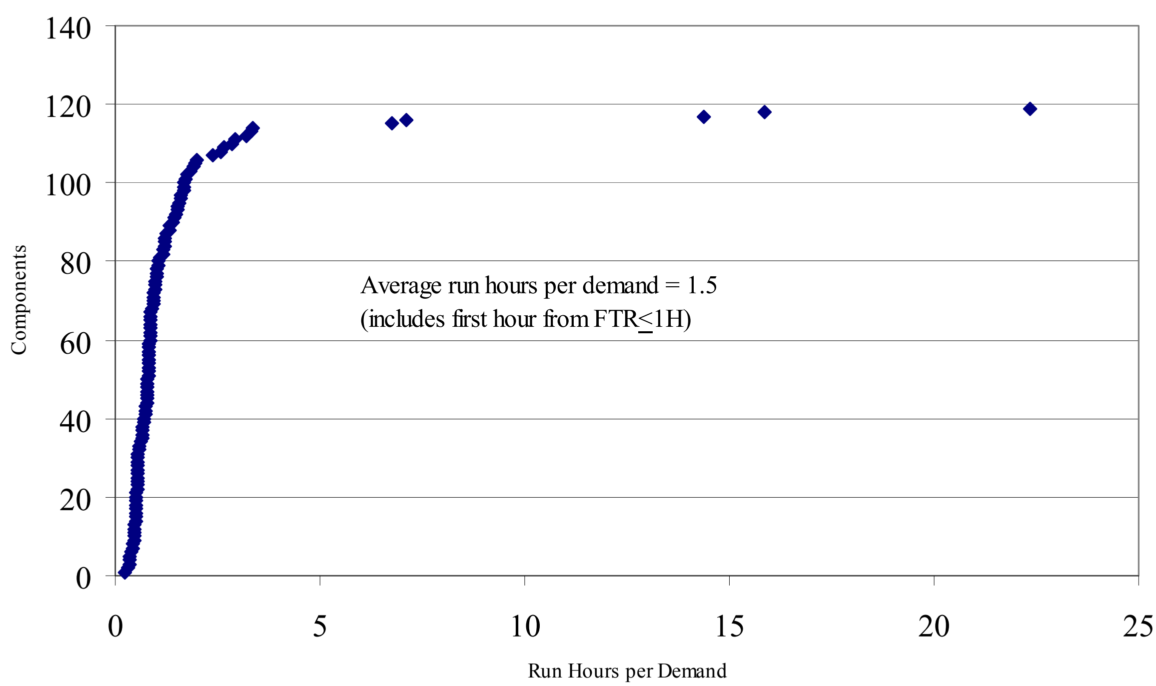

Figure 46-2a. Standby TDP run hours per demand distribution.

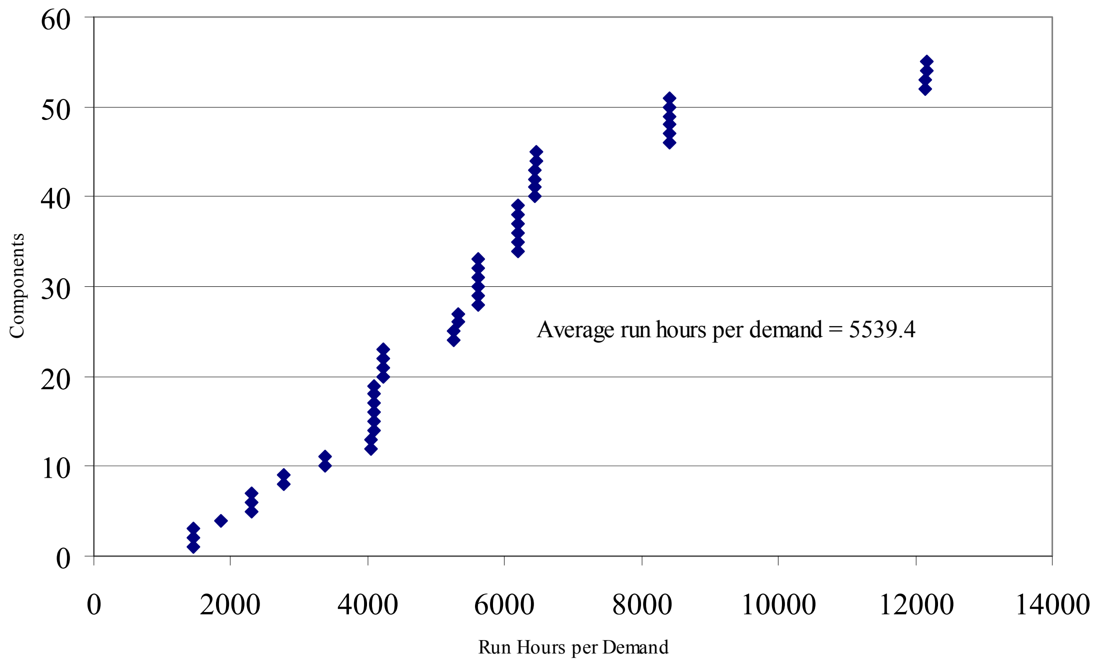

Figure 46-2b. Running/alternating TDP run hours per demand distribution.

46.3 Data Analysis

The TDP data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 46-4.

Table 46-4. Empirical distributions of MLEs for p and λ for TDPs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Standby	FTS	Component	0.00E+00	0.00E+00	9.27E-03	3.70E-02
		Plant	0.00E+00	0.00E+00	8.03E-03	3.79E-02
		Industry	-	-	6.03E-03	-
	FTR≤1H	Component	0.00E+00	0.00E+00	2.86E-03	2.63E-02
		Plant	0.00E+00	0.00E+00	2.99E-03	2.14E-02
		Industry	-	-	2.50E-03	-
	FTR>1H	Component	-	-	0.00E+00	-
		Plant	-	-	0.00E+00	-
		Industry	-	-	0.00E+00	-
Running/ Alternating	FTS	Component	0.00E+00	0.00E+00	1.90E-02	1.00E-01
		Plant	0.00E+00	0.00E+00	2.15E-02	8.31E-02
		Industry	-	-	2.19E-02	-
	FTR	Component	0.00E+00	0.00E+00	5.71E-06	2.44E-05
		Plant	0.00E+00	0.00E+00	5.16E-06	1.62E-05
		Industry	-	-	5.82E-06	-
All	ELS	Component	0.00E+00	0.00E+00	8.15E-08	0.00E+00
		Plant	0.00E+00	0.00E+00	1.01E-07	0.00E+00
		Industry	-	-	8.15E-08	-

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 46-3, 26.1% of the TDPs experienced a FTS over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 73.9% portion of the distribution, and non-zero values above 73.9%.

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table 46-5 for TDPs.

Table 46-5. Fitted distributions for p and λ for TDPs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/CL/KS	9.22E-06	2.68E-03	7.04E-03	2.89E-02	Beta	0.414	5.831E+01
		EB/PL/KS	9.01E-06	2.62E-03	6.88E-03	2.82E-02	Beta	0.414	5.973E+01
		SCNID/IL	2.42E-05	2.79E-03	6.10E-03	2.34E-02	Beta	0.500	8.152E+01
	FTR≤1H	EB/CL/KS	4.74E-05	1.51E-03	2.56E-03	8.66E-03	Gamma	0.712	2.781E+02
		EB/PL/KS	7.12E-05	1.65E-03	2.64E-03	8.58E-03	Gamma	0.796	3.017E+02
		SCNID/IL	1.01E-05	1.17E-03	2.57E-03	9.89E-03	Gamma	0.500	1.943E+02
	FTR>1H	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	2.89E-07	3.34E-05	7.35E-05	2.82E-04	Gamma	0.500	6.803E+03
Running/ Alternating	FTS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	2.12E-03	1.71E-02	2.22E-02	5.96E-02	Beta	1.323	5.836E+01
		SCNID/IL	9.30E-05	1.07E-02	2.28E-02	8.68E-02	Beta	0.500	2.139E+01
	FTR	JEFF/CL	3.62E-06	5.90E-06	6.05E-06	8.99E-06	Gamma	13.500	2.232E+06
		EB/PL/KS	1.76E-06	5.22E-06	5.77E-06	1.17E-05	Gamma	3.422	5.929E+05
		SCNID/IL	2.38E-08	2.75E-06	6.05E-06	2.32E-05	Gamma	0.500	8.266E+04
All	ELS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	4.81E-10	5.56E-08	1.22E-07	4.70E-07	Gamma	0.500	4.088E+06

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, JEFF/CL is the posterior distribution at the component level of a Bayesian update of the Jeffreys noninformative prior with industry data, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

46.4 Industry-Average Baselines

Table 46-6 lists the selected industry distributions of p and λ for the TDP failure modes. For Standby FTS and FTR≤1H and Running/Alternating FTS and FTR failure modes, the data sets were sufficient for empirical Bayes analyses to be performed. For these failure modes, the industry-average distributions are based on the empirical Bayes analysis results at the plant level. However, the industry-average distributions for FTR>1H and ELS are not sufficient (Section A.1 in Reference 14) for the empirical Bayes method; therefore, a SCNID analysis was performed to provide a failure rate distribution. However, the data for FTR>1H are limited (a larger data set was obtained to improve the estimate) and contain no failures.

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. These industry-average failure rates do not account for any recovery.

Table 46-6. Selected industry distributions of p and λ for TDPs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/PL/KS	9.01E-06	2.62E-03	6.88E-03	2.82E-02	Beta	0.414	5.973E+01
	FTR≤1H	EB/PL/KS	7.12E-05	1.65E-03	2.64E-03	8.58E-03	Gamma	0.796	3.017E+02
	FTR>1H	SCNID/IL	2.89E-07	3.34E-05	7.35E-05	2.82E-04	Gamma	0.500	6.803E+03
Running/ Alternating	FTS	EB/PL/KS	2.12E-03	1.71E-02	2.22E-02	5.96E-02	Beta	1.323	5.836E+01
	FTR	EB/PL/KS	1.76E-06	5.22E-06	5.77E-06	1.17E-05	Gamma	3.422	5.929E+05
All	ELS	SCNID/IL	4.81E-10	5.56E-08	1.22E-07	4.70E-07	Gamma	0.500	4.088E+06
	ELL	ELS/EPIX	9.16E-13	2.09E-09	8.56E-09	3.92E-08	Gamma	0.300	3.504E+07

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 46-7 shows the rounded values for the TDP failure modes.

Table 46-7. Selected industry distributions of p and λ for TDPs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/PL/KS	7.0E-06	2.5E-03	7.0E-03	3.0E-02	Beta	0.40	5.71E+01
	FTR≤1H	EB/PL/KS	7.0E-05	1.5E-03	2.5E-03	8.0E-03	Gamma	0.80	3.20E+02
	FTR>1H	SCNID/IL	3.0E-07	3.0E-05	7.0E-05	2.5E-04	Gamma	0.50	7.14E+03
Running/ Alternating	FTS	EB/PL/KS	1.5E-03	1.5E-02	2.0E-02	6.0E-02	Beta	1.20	6.00E+01
	FTR	EB/PL/KS	1.5E-06	5.0E-06	6.0E-06	1.2E-05	Gamma	3.00	5.00E+05
All	ELS	SCNID/IL	5.0E-10	5.0E-08	1.2E-07	5.0E-07	Gamma	0.50	4.17E+06
	ELL	ELS/EPIX	1.0E-12	2.0E-09	9.0E-09	4.0E-08	Gamma	0.30	3.33E+07

46.5 Breakdown by System

TDP UR results (Jeffreys means of system data) are compared by system and failure mode in Table 46-8. Results are shown only the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 46-8. TDP p and λ by system.

Operation	System	FTS	FTR≤1H	FTR>1H
Standby	AFW	4.8E-03	2.5E-03	-
	HCI	1.3E-02	2.8E-03	-
	RCI	7.5E-03	4.1E-03	-
	MFW	5.5E-03	-	-
Operation	System	FTS		FTR
Running/ Alternating	MFW	2.3E-02		6.0E-06
Operation	System	ELS		
All	AFW	3.5E-07		
	HCI	-		
	RCI	-		
	MFW	-		

47 Transformer (TFM)

47.1 Component Description

The transformer (TFM) boundary includes the transformer unit. The failure mode for TFM is listed in Table 47-1.

Table 47-1. TFM failure modes.

Operation	Failure Mode	Parameter	Units	Description
Running	FTOP	λ	1/h	Fail to operate

47.2 Data Collection and Review

Data for TFM UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. Failures were identified using the FTOP failure mode. There are 4544 TFMs from 98 plants in the EPIX data. The systems included in the TFM data collection are listed in Table 47-2 with the number of components included with each system.

Table 47-2. TFM systems.

Operation	System	Description	Number of Components
Running	ACP	Plant ac power	4544
	Total		4544

The data review process is described in detail in Section A.1 in Reference 14. Table 47-3 summarizes the data obtained from EPIX and used in the TFM analysis. Note that the hours are calendar hours.

Table 47-3. TFM unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Running	FTOP	81	199027200 h	4544	98	1.3%	35.7%

47.3 Data Analysis

The TFM data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 47-4.

Table 47-4. Empirical distributions of MLEs for p and λ for TFMs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Running	FTOP	Component	0.00E+00	0.00E+00	4.07E-07	0.00E+00
		Plant	0.00E+00	0.00E+00	1.01E-06	3.81E-06
		Industry	-	-	4.07E-07	-

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 47-3, only 1.3% of the TFMs experienced a FTOP over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 98.7% portion of the distribution, and non-zero values above 98.7%.

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table 47-5 for TFMs.

Table 47-5. Fitted distributions for p and λ for TFMs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	FTOP	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	1.44E-10	2.36E-07	9.04E-07	4.08E-06	Gamma	0.314	3.468E+05
		SCNID/IL	1.61E-09	1.86E-07	4.09E-07	1.57E-06	Gamma	0.500	1.221E+06

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

47.4 Industry-Average Baselines

Table 47-6 lists the industry-average failure rate distributions. The data set was sufficient (Section A.1 in Reference 14) for empirical Bayes analyses to be performed. The industry-average distribution is based on the empirical Bayes analysis results at the plant level. This industry-average failure rate does not account for any recovery.

Table 47-6. Selected industry distributions of p and λ for TFMs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	FTOP	EB/PL/KS	1.44E-10	2.36E-07	9.04E-07	4.08E-06	Gamma	0.314	3.468E+05

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 47-7 shows the rounded values for the TFM FTOP failure mode.

Table 47-7. Selected industry distributions of p and λ for TFMs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	FTOP	EB/PL/KS	1.0E-10	2.0E-07	9.0E-07	4.0E-06	Gamma	0.30	3.33E+05

47.5 Breakdown by System

The TFM component is only in one system, the ac power system.

48 Tank (TNK)

48.1 Component Description

The tank (TNK) boundary includes the tank. The failure modes for TNK are listed in Table 48-1.

Table 48-1. TNK failure modes.

Operation	Failure Mode	Parameter	Units	Description
All	ELS	λ	1/h	External leak small
	ELL	λ	1/h	External leak large

48.2 Data Collection and Review

Data for TNK UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1997–2004. There are 1398 TNKs from 101 plants in the data originally gathered from EPIX. 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 48-2 with the number of components included with each system.

Table 48-2. TNK systems.

Operation	System	Description	Number of Components
All (Pressurized)	CCW	Component cooling water	76
	CDS	Condensate system	4
	CHW	Chilled water system	8
	CIS	Containment isolation system	11
	CRD	Control rod drive	10
	CSR	Containment spray recirculation	15
	CTS	Condensate transfer system	3
	CVC	Chemical and volume control	156
	EPS	Emergency power supply	33
	ESW	Emergency service water	7
	HCS	High pressure core spray	5
	HPI	High pressure injection	76
	HVC	Heating ventilation and air conditioning	2
	LPI	Low pressure injection	165
	MFW	Main feedwater	6
	MSS	Main steam	87
	Other	Other	18
	RCI	Reactor core isolation	3
	RCS	Reactor coolant	6
	RRS	Reactor recirculation	1
	SLC	Standby liquid control	29
	TBC	Turbine building cooling water	6
	Total		727
All (Unpressurized)	AFW	Auxiliary feedwater	4
	CCW	Component cooling water	127
	CDS	Condensate system	24
	CHW	Chilled water system	6
	CIS	Containment isolation system	24
	CSR	Containment spray recirculation	42
	CTS	Condensate transfer system	21
	CVC	Chemical and volume control	64
	EPS	Emergency power supply	139
	ESW	Emergency service water	12
	FWS	Firewater	6

Operation	System	Description	Number of Components
	HCI	High pressure coolant injection	12
	HCS	High pressure core spray	12
	HPI	High pressure injection	32
	IAS	Instrument air	3
	ICS	Ice condenser	5
	LCS	Low pressure core spray	2
	LPI	Low pressure injection	38
	MFW	Main feedwater	4
	MSS	Main steam	20
	Other	Other	19
	RCI	Reactor core isolation	11
	SLC	Standby liquid control	43
	TBC	Turbine building cooling water	1
	Total		671

The data review process is described in detail in Section A.1 in Reference 14. Table 48-3 summarizes the data obtained from EPIX and used in the TNK analysis. Note that the hours for ELS are calendar hours.

Table 48-3. TNK unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Pressurized	ELS	1.5	50948160 h	727	96	0.3%	2.1%
Unpressurized	ELS	1	47023680 h	671	101	0.3%	2.0%

48.3 Data Analysis

The TNK data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 48-4.

Table 48-4. Empirical distributions of MLEs for p and λ for TNKs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Pressurized	ELS	Component	0.00E+00	0.00E+00	2.94E-08	0.00E+00
		Plant	0.00E+00	0.00E+00	1.34E-07	0.00E+00
		Industry	-	-	2.94E-08	-
Unpressurized	ELS	Component	0.00E+00	0.00E+00	2.13E-08	0.00E+00
		Plant	0.00E+00	0.00E+00	2.02E-08	0.00E+00
		Industry	-	-	2.13E-08	-

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 48-3, 0.3% of the TNKs experienced a ELS over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 99.7% portion of the distribution, and non-zero values above 99.7%.

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table 48-5 for TNKs.

Table 48-5. Fitted distributions for p and λ for TNKs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Pressurized	ELS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.55E-10	1.79E-08	3.93E-08	1.51E-07	Gamma	0.500	1.272E+07
Unpressurized	ELS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.25E-10	1.45E-08	3.19E-08	1.23E-07	Gamma	0.500	1.567E+07

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

48.4 Industry-Average Baselines

Table 48-6 lists the industry-average failure rate distributions. For ELS, the EB/PL/KS result indicated and α parameter lower than 0.3. As explained in Section A.1 in Reference 14, in these cases a lower limit of 0.3 (upper bound on the uncertainty band) was assumed. 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 48-6. Selected industry distributions of p and λ for TNKs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Pressurized	ELS	SCNID/IL	1.55E-10	1.79E-08	3.93E-08	1.51E-07	Gamma	0.500	1.272E+07
	ELL	ELS/EPIX	2.94E-13	6.70E-10	2.75E-09	1.26E-08	Gamma	0.300	1.091E+08
Unpressurized	ELS	SCNID/IL	1.25E-10	1.45E-08	3.19E-08	1.23E-07	Gamma	0.500	1.567E+07
	ELL	ELS/EPIX	2.39E-13	5.44E-10	2.23E-09	1.02E-08	Gamma	0.300	1.343E+08

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 48-7 shows the rounded values for the TNK failure modes.

Table 48-7. Selected industry distributions of p and λ for TNKs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Pressurized	ELS	SCNID/IL	1.5E-10	2.0E-08	4.0E-08	1.5E-07	Gamma	0.50	1.00E+07
	ELL	ELS/EPIX	3.0E-13	7.0E-10	3.0E-09	1.5E-08	Gamma	0.30	1.00E+08
Unpressurized	ELS	SCNID/IL	1.2E-10	1.5E-08	3.0E-08	1.2E-07	Gamma	0.50	1.67E+07
	ELL	ELS/EPIX	2.0E-13	5.0E-10	2.0E-09	9.0E-09	Gamma	0.30	1.50E+08

48.5 Breakdown by System

TNK UR results (Jeffreys means of system data) are compared by system and failure mode in Table 48-8. Results are shown only the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 48-8. TNK *p* and *λ* by system.

		Pressurized	Un-pressurized
Operation	System	ELS	ELS
All	AFW	-	-
	CCW	-	-
	CDS	-	-
	CHW	-	-
	CIS	-	-
	CSR	-	-
	CTS	-	-
	CVC	-	-
	EPS	-	-
	ESW	-	-
	FWS	-	-
	HCI	-	-
	HCS	-	-
	HPI	2.8E-07	-
	IAS	-	-
	ICS	-	-
	LCS	-	-
	LPI	-	-
	MFW	-	-
	MSS	2.5E-07	-
	Other	-	1.1E-06
	RCI	-	-
	SLC	-	-
	TBC	-	-

49 Traveling Screen Assembly (TSA)

49.1 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 49-1.

Table 49-1. TSA failure modes.

Operation	Failure Mode	Parameter	Units	Description
All	PG	λ	1/h	Plugging

49.2 Data Collection and Review

Data for the TSA UR baseline were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. There are 125 TSAs from 35 plants in the data. After removing data without demand information (see Section A.1 in Reference 14) there were 125 components in 35 plants. The systems included in the TSA data collection are listed in Table 49-2 with the number of components included with each system.

Table 49-2. TSA systems.

Operation	System	Description	Number of Components	
			Initial	After Review
All	CWS	Circulating water system	125	125
	ESW	Emergency cooling water	71	71
	Total		196	196

Table 49-3 summarizes the data used in the TSA analysis. Note that the PG hours are calendar hours. Also, TSA PG events that were caused by problems with the screen wash system were included.

Table 49-3. TSA unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	PG	29	8584800 h	196	36	13.8%	38.9%

49.3 Data Analysis

The TSA data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 42-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 49-3, 13.8% of the TSAs experienced a PG over the period 1998–2002, so the distribution of MLEs, at the component level, involves zeros for the 0% to 86.2% portion of the distribution, and non-zero values above 86.2%.

Table 49-4. Empirical distributions of MLEs for p and λ for TSAs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
All	PG	Component	0.00E+00	0.00E+00	3.38E-06	2.28E-05
		Plant	0.00E+00	0.00E+00	5.03E-06	2.28E-05
		Industry	-	-	3.38E-06	-

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table 49-5.

Table 49-5. Fitted distributions for p and λ for TSAs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	PG	JEFF/CL	2.47E-06	3.40E-06	3.44E-06	4.54E-06	Gamma	29.500	8.585E+06
		EB/PL/KS	1.87E-08	2.14E-06	4.68E-06	1.80E-05	Gamma	0.502	1.072E+05
		SCNID/IL	1.35E-08	1.56E-06	3.44E-06	1.32E-05	Gamma	0.500	1.455E+05

Note – JEFF/CL is the posterior distribution at the component level of a Bayesian update of the Jeffreys noninformative prior with industry data, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

49.4 Industry-Average Baselines

Table 49-6 lists the industry-average failure rate distribution for the TSA component. For the PG failure mode, the data set was sufficient (see Section A.1 in Reference 14) for empirical Bayes analyses to be performed. Therefore, the industry-average distribution is based on the empirical Bayes analysis results at the plant level for PG.

Table 49-6. Selected industry distributions of p and λ for TSAs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	PG	EB/PL/KS	1.87E-08	2.14E-06	4.68E-06	1.80E-05	Gamma	0.502	1.072E+05

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 49-7 shows the rounded values for the TSA failure mode.

Table 49-7. Selected industry distributions of p and λ for TSAs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	PG	EB/PL/KS	2.0E-08	2.5E-06	5.0E-06	2.0E-05	Gamma	0.50	1.00E+05

49.5 Breakdown by System

TSA UR results (Jeffreys means of system data) are compared by system and failure mode in Table 46-8. Results are shown only the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 49-8. TSA p and λ by system.

Operation	System	PG
Standby	ESW	6.9E-06
	CWS	1.6E-06

50 Vacuum Breaker Valve (VBV)

50.1 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 50-1.

Table 50-1. VBV failure modes.

Operation	Failure Mode	Parameter	Units	Description
All	FTO	*p*	-	Failure to open
	FTC	*p*	-	Failure to close

50.2 Data Collection and Review

Data for VBV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. There are 168 VBVs from 20 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1 in Reference 14) there were 160 components in 19 plants. The systems included in the VBV data collection are listed in Table 50-2 with the number of components included with each system.

Table 50-2. VBV systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
All	CIS	Containment isolation system	47	45	43
	VSS	Vapor suppression	121	115	96
	Total		168	160	139

The VBV data set obtained from RADS was further reduced to include only those VBVs 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 50-3 summarizes the data used in the VBV analysis.

Table 50-3. VBV unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO	3	7301	139	16	2.2%	18.8%
	FTC	2	7301	139	16	1.4%	12.5%

Figure 50-1 shows the range of valve demands per year in the VBV data set (limited to ≤ 20 demands/year). The demands per year range from approximately 3.8 to 20. The average for the data set is 10.5 demands/year.

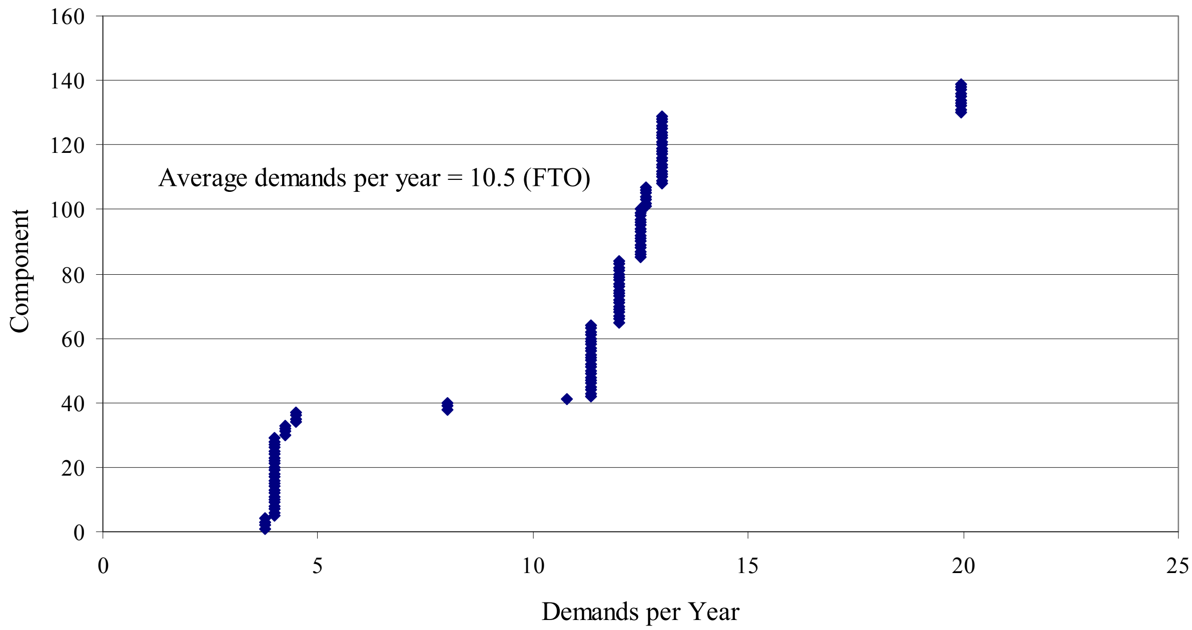

Figure 50-1. VBV demands per year distribution.

50.3 Data Analysis

The VBV data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 50-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 50-3, the VBVs experienced 3 FTOs over the period 1998–2002, so the distribution of MLEs, at the component level, involves zeros for the 0% to 97.8% portion of the distribution, and non-zero values above 97.8%.

Table 50-4. Empirical distributions of MLEs for p and λ for VBVs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
All	FTO	Component	0.00E+00	0.00E+00	5.86E-04	0.00E+00
		Plant	0.00E+00	0.00E+00	1.31E-03	1.39E-03
		Industry	-	-	4.11E-04	-
	FTC	Component	0.00E+00	0.00E+00	2.91E-04	0.00E+00
		Plant	0.00E+00	0.00E+00	5.96E-04	1.21E-03
		Industry	-	-	2.74E-04	-

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table 50-5. These results were used to develop the industry-average distributions for FTO and FTC.

Table 50-5. Fitted distributions for p and λ for VBVs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.89E-06	2.18E-04	4.79E-04	1.84E-03	Beta	0.500	1.043E+03
	FTC	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.35E-06	1.56E-04	3.42E-04	1.32E-03	Beta	0.500	1.460E+03

Note – EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

50.4 Industry-Average Baselines

Table 50-6 lists the selected industry distributions of p and λ for the VBV failure modes. The data set was not sufficient for either failure mode (see Section A.1 in Reference 14) for empirical Bayes analyses to be performed. Therefore, SCNID analyses were performed to provide failure rate distributions for FTO and FTC. These industry-average failure rates do not account for any recovery.

Table 50-6. Selected industry distributions of p and λ for VBVs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	SCNID/IL	1.89E-06	2.18E-04	4.79E-04	1.84E-03	Beta	0.500	1.043E+03
	FTC	SCNID/IL	1.35E-06	1.56E-04	3.42E-04	1.32E-03	Beta	0.500	1.460E+03

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 50-7 shows the rounded values for the VBV failure modes.

Table 50-7. Selected industry distributions of p and λ for VBVs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	SCNID/IL	2.0E-06	2.5E-04	5.0E-04	2.0E-03	Beta	0.50	1.00E+03
	FTC	SCNID/IL	1.2E-06	1.5E-04	3.0E-04	1.2E-03	Beta	0.50	1.67E+03

50.5 Breakdown by System

VBV UR results (Jeffreys means of system data) are compared by system and failure mode in Table 50-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 50-8. VBV p and λ by system.

System	FTO	FTC
CIS	-	-
VSS	6.1E-04	4.3E-04

51 Manual Valve (XVM)

51.1 Component Description

The manual valve (XVM) component boundary includes the valve and valve operator. The failure modes for XVM are listed in Table 41-1.

Table 51-1. XVM failure modes.

Operation	Failure Mode	Parameter	Units	Description
Standby	FTO/C	*p*	-	Failure to open or failure to close
	PLG	λ	1/h	Plug
	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

51.2 Data Collection and Review

Data for XVM UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1997–2004 using RADS. There are 119 XVMs from 13 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1 in Reference 14) there were 109 components in 13 plants. The systems included in the XVM data collection are listed in Table 51-2 with the number of components included with each system.

Table 51-2. XVM systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
Standby	AFW	Auxiliary feedwater	5	5	5
	CCW	Component cooling water	24	19	19
	CHW	Chilled water system	1	1	-
	CIS	Containment isolation system	27	27	27
	CSR	Containment spray recirculation	2	2	2
	CVC	Chemical and volume control	11	10	10
	ESW	Emergency service water	16	15	14
	HPI	High pressure injection	6	5	5
	LCI	Low pressure coolant injection	6	4	4
	LPI	Low pressure injection	10	10	10
	MFW	Main feedwater	1	1	1
	MSS	Main steam	6	6	6
	SLC	Standby liquid control	4	4	4
	Total		119	109	107

The XVM data set obtained from RADS was further reduced to include only those XVMs with ≤ 20 demands/year. See Section A.1 in Reference 14 for a discussion concerning this decision to limit certain component populations. The XVM population in RADS is significantly larger than 107. However, most of these components do not have an entry showing hours or demands. It was decided to use the larger population (1121) for the PLG and ELS failure mode calculations, since only calendar time is required for the exposure. Table 51-3 summarizes the data used in the XVM analysis. Note that the hours for PLG, ELS, and ILS are calendar hours.

Table 51-3. XVM unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
Standby	FTO/C	1	2017	107	12	0.9%	8.3%
	PLG	0	78559680 h	1121	81	0.0%	0.0%
	ELS	3	78559680 h	1121	81	2.8%	25.0%
	ILS	0	7498560 h	107	12	0.0%	0.0%

Figure 51-1 shows the range of valve demands per year in the XVM data set (limited to ≤ 20 demands/year). The demands per year range from approximately 1 to 12. The average for the data set is 2.4 demands/year.

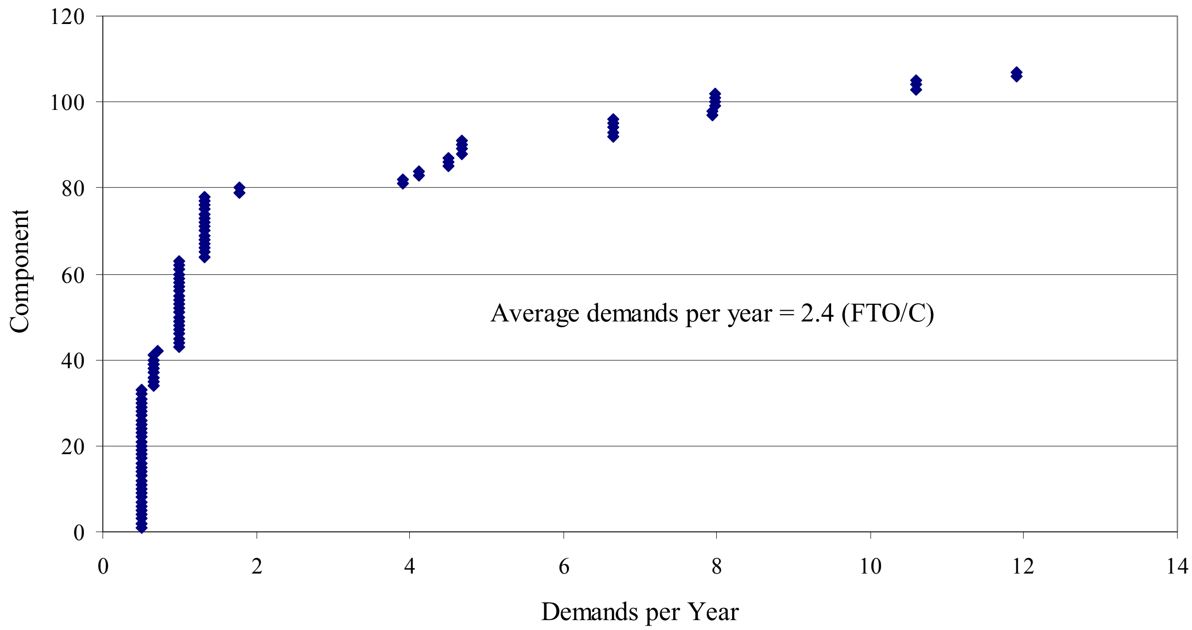

Figure 51-1. XVM demands per year distribution.

51.3 Data Analysis

The XVM data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table 51-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 51-3, only 0.9% of the XVMs experienced a FTO/C over the period 1997–2004, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 99.1% portion of the distribution, and non-zero values above 99.1%.

Table 51-4. Empirical distributions of MLEs for p and λ for XVMs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Standby	FTO/C	Component	0.00E+00	0.00E+00	1.75E-03	0.00E+00
		Plant	0.00E+00	0.00E+00	1.56E-02	0.00E+00
		Industry	-	-	4.96E-04	-
	PLG	Component	-	-	-	-
		Plant	-	-	-	-
		Industry	-	-	0.00E+00	-
	ELS	Component	0.00E+00	0.00E+00	3.82E-08	0.00E+00
		Plant	0.00E+00	0.00E+00	3.23E-07	0.00E+00
		Industry	-	-	3.82E-08	-
	ILS	Component	-	-	-	-
		Plant	-	-	-	-
		Industry	-	-	0.00E+00	-

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table 51-5.

Table 51-5. Fitted distributions for p and λ for XVMs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTO/C	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	2.93E-06	3.39E-04	7.43E-04	2.86E-03	Beta	0.500	6.720E+02
	PG	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	2.50E-11	2.90E-09	6.36E-09	2.45E-08	Gamma	0.500	7.855E+07
	ELS	JEFF/CL	1.38E-08	4.04E-08	4.46E-08	8.95E-08	Gamma	3.500	7.856E+07
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.75E-10	2.03E-08	4.45E-08	1.71E-07	Gamma	0.500	1.122E+07
	ILS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	2.62E-10	3.03E-08	6.67E-08	2.56E-07	Gamma	0.500	7.499E+06

Note – JEFF/CL is the posterior distribution at the component level of a Bayesian update of the Jeffreys noninformative prior with industry data, EB/CL/KS is an empirical Bayes analysis at the component level with the Kass-Steffey adjustment, EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level.

51.4 Industry-Average Baselines

Table 51-6 lists the selected industry distributions of p and λ for the XVM failure modes. The industry-average distributions for FTO/C, ILS, and ELS are not sufficient (Section A.1 in Reference 14) for the empirical Bayes method; therefore, a SCNID analysis was performed to provide failure rate distributions. 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. These industry-average failure rates do not account for any recovery.

Table 51-6. Selected industry distributions of p and λ for XVMs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTO/C	SCNID/IL	2.93E-06	3.39E-04	7.43E-04	2.86E-03	Beta	0.500	6.720E+02
	PG	SCNID/IL	2.50E-11	2.90E-09	6.36E-09	2.45E-08	Gamma	0.500	7.855E+07
	ELS	SCNID/IL	1.75E-10	2.03E-08	4.45E-08	1.71E-07	Gamma	0.500	1.122E+07
	ELL	ELS/EPIX	3.34E-13	7.60E-10	3.12E-09	1.43E-08	Gamma	0.300	9.620E+07
	ILS	SCNID/IL	2.62E-10	3.03E-08	6.67E-08	2.56E-07	Gamma	0.500	7.499E+06
	ILL	ILS/EPIX	1.43E-13	3.25E-10	1.33E-09	6.10E-09	Gamma	0.300	2.250E+08

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 51-7 shows the rounded values for the XVM failure modes.

Table 51-7. Selected industry distributions of p and λ for XVMs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTO/C	SCNID/IL	3.0E-06	3.0E-04	7.0E-04	2.5E-03	Beta	0.50	7.14E+02
	PG	SCNID/IL	2.5E-11	2.5E-09	6.0E-09	2.5E-08	Gamma	0.50	8.33E+07
	ELS	SCNID/IL	1.5E-10	2.0E-08	4.0E-08	1.5E-07	Gamma	0.50	1.25E+07
	ELL	ELS/EPIX	3.0E-13	7.0E-10	3.0E-09	1.5E-08	Gamma	0.30	1.00E+08
	ILS	SCNID/IL	3.0E-10	3.0E-08	7.0E-08	2.5E-07	Gamma	0.50	7.14E+06
	ILL	ILS/EPIX	1.2E-13	3.0E-10	1.2E-09	5.0E-09	Gamma	0.30	2.50E+08

51.5 Breakdown by System

XVM UR results (Jeffreys means of system data) are compared by system and failure mode in Table 51-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table 51-8. XVM p and λ by system.

System	FTO/C	PG	ELS	ILS
AFW	-	-	-	-
CCW	-	-	-	-
CDS	-	-	-	-
CHW	-	-	2.1E-07	-
CIS	-	-	-	-
CRD	-	-	-	-
CSR	-	-	-	-
CTS	-	-	-	-
CVC	-	-	2.4E-07	-
CWS	-	-	-	-
EPS	-	-	-	-
ESW	2.3E-03	-	-	-
FWS	-	-	-	-
HCI	-	-	-	-
HCS	-	-	-	-
HPI	-	-	5.9E-07	-

System	FTO/C	PG	ELS	ILS
IAS	-	-	-	-
IPS	-	-	-	-
LCI	-	-	-	-
LCS	-	-	-	-
LPI	-	-	-	-
MFW	-	-	-	-
MSS	-	-	-	-
NSW	-	-	-	-
RCI	-	-	-	-
RCS	-	-	-	-
RPS	-	-	-	-
RRS	-	-	-	-
SGT	-	-	-	-
SLC	-	-	-	-
TBC	-	-	-	-

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