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ABSTRACT

This report documents the quantitative results of the current industry-average performance for components and initiating events (IEs) at U.S. commercial nuclear power plants (NPPs). It represents the third update of the original analysis in NUREG/CR-6928 with data through 2020. Continuous characterization and updating of current industry-average performance with the latest industry data available are important steps in maintaining up-to-date risk models. Typically, data from 1998–2002 were used in NUREG/CR-6928, data from 1998–2010 in the first update, data from 1998–2015 in the second update, and data from 2006–2020 in this update, although many IEs required longer periods for adequate characterization of frequencies in all these analyses.

As with NUREG/CR-6928 and previous updates, four types of events are covered in this report: component unreliability (e.g., a pump that fails to start or fails to run), component or train unavailability resulting from test or maintenance outages, special event probabilities covering operational issues (e.g., pump restarts and injection valve re-openings during unplanned demands), and IE frequencies. Results (in the form of beta distributions for failure probabilities upon demand and gamma distributions for rates) are used as inputs to the U.S. Nuclear Regulatory Commission standardized plant analysis risk models covering U.S. commercial NPPs.

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ACRONYMS

ABT	automatic bus transfer switch
ACC	accumulator
ACP	ac power
ADAMS	Agency Document Access & Management System
ADU	air dryer unit
AFW	auxiliary feedwater
AFWS	auxiliary feedwater system
AHU	air handling unit
AOV	air-operated valve
ASME	American Society of Mechanical Engineers
ASP	accident sequence precursor
BAT	battery
BIS	bistable
BME	breaker mechanical
BSN	breaker shunt trip
BUS	bus (electrical)
BUV	breaker undervoltage trip
BWR	boiling water reactor
CCF	common-cause failure
CCP	channel calculator for pressure
CCW	component cooling water
CDS	condensate system
CHL	chiller
CHW	chilled water system
CIS	containment isolation system
CKV	check valve
CLN	clean
CNID	constrained noninformative distribution
CRB	circuit breaker
CRD	control rod drive
CSR	containment spray recirculation
CST	condensate storage tank
CTF	cooling tower fan

CTG	combustion turbine generator
CTS	condensate transfer system
CVC	chemical and volume control
DCP	dc power
DDP	diesel-driven pump
EB	empirical Bayes
EDG	emergency diesel generator
EDP	engine-driven pump
EE	expert elicitation
ELL	external leak, large
ELS	external leak, small
EOV	explosive-operated valve
EPIX	Equipment Performance and Information Exchange
EPRI	Electric Power Research Institute
EPS	emergency power system
ESW	emergency or essential service water
FAN	fan
FC	fail to control
FCV	flow-control valve
FLT	filter
FTC	fail to close
FTCL	fail to close after passing liquid
FTFR	failure to transfer
FTLR	fail to load and run
FTO	fail to open
FTOC	fail to open or close
FTOP	fail to operate
FTR	fail to run
FTR>1H	fail to run after 1 hour of operation
FTR≤1H	fail to run for 1 hour of operation
FTS	fail to start
FWS	feedwater system
HCI	high-pressure coolant injection
HDR	header
HOV	hydraulic-operated valve

HPCI	high-pressure coolant injection
HPCS	high-pressure core spray
HPI	high-pressure safety injection
HPSI	high-pressure safety injection
HTG	hydro-turbine generator
HTX	heat exchanger
HVC	heating, ventilating, and air conditioning
IAS	instrument air system
IC	isolation condenser
ICS	ice condenser
ILL	internal leak large
ILS	internal leak small
INL	Idaho National Laboratory
INPO	Institute of Nuclear Power Operations
INV	inverter
ISO	isolation condenser
JNID	Jefferies non-informative distribution
LCI	low-pressure coolant injection
LCS	low-pressure core spray
LER	licensee event report
LLOCA	large loss-of-coolant accident
LOAC	loss of ac bus
LOCA	loss-of-coolant accident
LOCCW	loss of component cooling water
LOCHS	loss of condenser heat sink
LODC	loss of dc bus
LOIA	loss of instrument air
LOMFW	loss of main feedwater
LOOP	loss of offsite power
LOSWS	loss of service water system
LPI	low-pressure injection
LPSI	low-pressure safety injection
MDC	motor-driven compressor
MDP	motor-driven pump
MFW	main feedwater

MLE	maximum likelihood estimate
MLOCA	medium loss-of-coolant accident
MOOS	maintenance-out-of-service
MOV	motor-operated valve
MSPI	Mitigating Systems Performance Index
MSS	main steam system
MSW	manual switch
NPP	nuclear power plant
NPRDS	Nuclear Plant Reliability Database System
NRC	U.S. Nuclear Regulatory Commission
NREP	National Reliability Evaluation Program
NSW	nuclear or normal service water
NUCLARR	Nuclear Computerized Library for Assessing Reactor Reliability
OEP	offsite electrical power
ORF	orifice
PDP	positive displacement pump
PLDT	process logic delta temperature
PLF	process logic flow
PLG	plug
PLL	process logic level
PLOCCW	partial loss of component cooling water
PLOSWS	partial loss of service water system
PLP	process logic pressure
PMP	pump volute
POD	pneumatic-operated damper
PORV	power-operated relief valve
PRA	probabilistic risk assessment
PWR	pressurized water reactor
PWROG	Pressurized Water Reactor Owners Group
RADS	Reliability and Availability Database System
RCI	reactor core isolation cooling
RCIC	reactor core isolation cooling
rcry	reactor critical year
RCS	reactor coolant system
rcy	reactor calendar year

RHR	residual heat removal
RLY	relay
ROP	Reactor Oversight Process
RPS	reactor protection system
RPV	reactor pressure vessel
RRS	reactor recirculation system
rsy	reactor shutdown year
RTB	reactor trip breaker
RUN	running or alternating
SBO	station blackout
SCNID	simplified constrained noninformative distribution
SD	standard deviation
SDP	Significance Determination Process
SEQ	sequencer
SGTR	steam generator tube rupture
SLC	standby liquid control
SLOCA	small loss-of-coolant accident
SMP	sump
SOP	spurious operation
SORV	stuck open relief valve
SOV	solenoid-operated valve
SPAR	standardized plant analysis risk
SRV	safety relief valve
SSU	safety system unavailability
STF	sensor/transmitter flow
STL	sensor/transmitter level
STP	sensor/transmitter pressure
STR	strainer
STT	sensor/transmitter temperature
SUC	suction
SWS	service water system
TDP	turbine-driven pump
TFM	transformer
TM	test or maintenance
TNK	tank

TRAN	transient
TSA	traveling screen assembly
UA	unavailability
UR	unreliability
VBV	vacuum breaker valve
VSLOCA	very small loss-of-coolant accident
VSS	vapor suppression system
XVM	manual valve

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1. INTRODUCTION

1.1 Background

The U.S. Nuclear Regulatory Commission (NRC) maintains a set of risk models for the operating U.S. commercial nuclear power plants (NPPs), termed the “industry” in this report [1]. These standardized plant analysis risk (SPAR) models are used by the NRC on a day-to-day basis to support risk-informed decision-making. In addition to supporting accident sequence precursor analyses, the SPAR models also support the Significance Determination Process and are used to confirm licensee risk analyses submitted in support of license amendment requests. Therefore, it is important that the SPAR models reflect current plant performance. This report documents the quantitative results of the current industry-average performance for components and initiating events (IEs) at U.S. commercial NPPs. It represents the third update of the original analysis in NUREG/CR-6928 [2] with data through 2020. Continuous characterization and updating of current industry-average performance with the latest industry data available are important steps in maintaining up-to-date risk models. Typically, data for 1998–2002 were used in NUREG/CR-6928, data for 1998–2010 in the first update [3–6], data for 1998–2015 in the second update [7–9], and data for 2006–2020 in this update although many IEs required longer periods for adequate characterization of frequencies in all these analyses. The parameter estimation results are used as inputs to the U.S. NRC SPAR models covering U.S. commercial NPPs.

As with NUREG/CR-6928 and previous updates, four types of risk model events are covered in this report: component unreliability (UR), component or train unavailability (UA), system special event probabilities, and IE frequencies. Each is discussed below:

1. Component UR includes events such as a pump that fails to start (FTS) or fails to run (FTR), valve fail to open or close (FTOC), and electrical component fail to operate (FTOP). Failure modes are characterized by beta distributions for failure upon demand events and gamma distributions for failure to run and other events.

2. Component/train UA is the probability that a component or train is unavailable to perform its safety function because of test or maintenance (TM) outages. Component or train UAs are characterized by beta distributions in NUREG/CR-6928 and by normal distribution since the 2015 update.

3. System special event probabilities address operational issues that might occur during actual unplanned demands. Examples include a pump having to restart (following the initial start) during its response to an unplanned demand, injection valves having to reopen (after the initial opening), and the automatic transfer of an injection system from its tank source to its recirculation source. Typical component UR values obtained mainly from test demands may not be applicable to these special events, so these are covered separately. System special event probabilities are generally characterized by beta distributions.

4. IEs are plant upset conditions that result in a plant trip. In addition, certain IEs also result in functional impacts on safety systems that may be used to transition the plant to a stable shutdown state. IE frequencies in this report are appropriate for plant critical operation and are reported as events per reactor critical year (rcry). Note, however, that IEs for shutdown operation are not covered in this report. The IE frequencies are characterized by gamma distributions.

This report documents the updated quantitative results of the above risk model events with data through 2020. A comparison with the results in NUREG/CR-6928 and previous updates is provided for selected events. The appendices of the report present more detailed information and results. However, the original NUREG/CR-6928 report should be referred for the philosophy that is used to guide the effort to update the inputs for SPAR and the comparisons with historical data such as those in NUREG-1150 [10,11] and individual plant examinations (IPEs) [12]. NUREG/CR-6823 [13] can be referenced for the methodologies that are used to estimate various parameters for probabilistic risk assessment (PRA).

1.2 Evolution of the Updates since NUREG/CR-6928

1.2.1 Prior Updates Before This One

There were two major updates in the reliability data analysis since the original issue of NUREG/CR-6928: the first update was published in September 2012 and generally contained data from 1998–2010, the second update was published in December 2016 and generally contained data from 1998–2015. The detailed results of these updates can be obtained through the NRC Reactor Operational Experience Results and Databases web page for industry average parameter estimates: https://nrcoe.inl.gov/. There have been several major enhancements to the collection and analysis of reliability data in previous updates that are different from those in NUREG/CR-6928. The following is a summary of those changes:

1. Most of the reliability results, included those presented herein, are taken directly from the Reliability and Availability Data System (RADS)[1], https://rads.inl.gov/ [14]. The Institute for Nuclear Power Operation (INPO) Industry Reporting and Information System (IRIS), formerly the INPO Consolidated Events System (ICES) and the Equipment Performance Information Exchange (EPIX), data loaded into RADS has undergone significant review and scrutiny by the staff at the Idaho National Laboratory (INL) to prepare the data to be useful in PRAs. Most IRIS failure data are being updated to reflect the results of the data collection and coding taken at INL. In addition, the demand and run-hour data have been scrutinized before data load to remove or correct suspect data entries.
2. The overall performance of RADS has undergone extensive verification and validation. RADS performs database searches for component failure data. These searches have been independently verified to be accurate for all combinations of search criteria.
3. NUREG/CR-6928 introduced the concepts of high- and low-demand components, as well as standby and normally running equipment. Off-line analysis of data was required to produce segregated results for these component partitions. Currently, the identification of high- and low-demand components, as well as standby and normally running equipment, is taken care of before data are loaded into RADS.

Multiple component and failure mode combinations that were not reported in the original NUREG/CR-6928 have been added since to support SPAR model data needs.

Several minor changes to the component reliability data sheets were made to enhance readability and simplify the product:

1. The tables from each section that compare the maximum likelihood estimators (MLE) and various methods of estimating uncertainty (e.g., using component, plant, or industry level data in analyses) have been removed. Most readers were confused as to which of many possible estimates for reliability were valid and the estimates based on component level data for component variability were never used in parameter estimations in NUREG/CR-6928 other than listed in those tables.

[1] NRC RADS uses data from the INPO IRIS and is only accessible by INPO members under a memorandum between INPO and the NRC.

2. In many places, the text reiterated what was obvious in the figure or the table or described the selection of low-demand data, so that text has been removed.
3. The selected industry distribution table showing the rounded results has been removed. The user may round the data to suit specific needs.
4. The subsections entitled “Breakdown by System” generally provided limited results for systems. Because use of these results without further analysis is problematic, the subsections were deleted.
5. Many results (e.g., leakage, spurious operation) depend on an exposure time that is independent of whether the plant is critical or shutdown. Previously, no allowance was made for whether the plant was operational; now the exposure time is based on reactor years.
6. The first column in the tables has been changed from “Operation” to “Pooling Group.” The pooling group indicates whether any additional refinements (“All” means no refinements) were made to the data search beyond what was discussed in the introduction.

The following statistical adjustments to data in the original NUREG/CR-6928 have been modified :

1. The use of the simplified constrained non-informative distribution (SCNID), which is a simplified version of the constrained non-informative distribution (CNID), has been discontinued. The Jefferies non-informative distribution (JNID) replaces that distribution. The SCNID had the property of producing a result with a highly uncertain distribution, which was intended to enhance the use of the reliability results as the Bayesian prior to a plant-specific update. The primary use of these results is to support SPAR, but the use of highly uncertain distributions lead to excessive uncertainty in the final core damage frequency.
2. A decision was made such that, when the empirical Bayes (EB) analysis (refer to NUREG/CR-6823 [13] for the EB analysis and other methodologies used in nuclear industry parameter estimation) produced a result that have a low (<0.3) alpha parameter to the beta or gamma distribution, then the α parameter would be reset to 0.3 and the β parameter was recalculated based on the same mean value and the revised α parameter. This action was motivated because the EB could produce extremely wide distributions that did not appear credible. This approach has been replaced by an alternative method of obtaining a reasonable distribution. The decision point is now whether the difference between the 5th percentile and the mean is greater than 4 orders of magnitude (this approximates the decision point of α <0.3). When the decision point is reached, instead of creating an arbitrary distribution, the Jeffries distribution is used, which is the same decision that is made when the EB does not return a result.
3. The abbreviations used to describe the distributions in this update are the EB-plant level-Kass-Steffey (EB/PL/KS) and the Jeffries non-informative distribution at the industry level (JNID/IL).

1.2.2 Additional Updates in This Edition

This third update of NUREG/CR-6928 generally uses data from 2006–2020. The main changes in this update are as follows:

1. This update covers data from January 1, 2006 to December 31, 2020, the most recent 15-year period in which the data are available. This differs from previous updates, in which January 1, 1998 was used as the starting date (e.g., January 1, 1998 to December 31, 2015 for the 2015 update, January 1, 1998 to December 31, 2010 for the 2010 update). The new date range (i.e., the latest 15-year period) was selected for this update so that the data analysis results could reflect the most recent industry performance yet still provide sufficient data.
2. This update puts the component UR, component or train UA, system special events, and IE-frequency data-analysis results (including the data, parameter estimates, and the detailed data sheets) together in one report to facilitate easier usage by analysts.

3. The results from an updated relief valve study are used for relief valves (including safety valves, safety relief valves, and power-operated relief valves) fail-to-open and fail-to-reclose failure modes. The updated relief valve study is an update of the previous study on relief valve performance as documented in NUREG/CR-7037 which used data through 2007 only [15]. Unlike NUREG/CR-7037 that used both test data and actual demand data in the analysis, this updated study uses only actual demands so as to better represent the actual in-situ valve performance.
4. The typos, errors, and issues identified by the industry and NRC/INL analysts since the publication of the 2015 update were resolved in this update. Nonetheless, we recognize that there are still a few issues extant in our data analysis efforts. We will work with the industry to get these issues addressed commensurate with their importance as well as the available resources.
5. The Pressurized Water Reactor Owners Group (PWROG) provided the staff with comments and concerns regarding aspects of the NRC long-term operating experience data analysis program in their transmittal, "Component Reliability Data Issues for Discussion with NRC Research (PWROG-18029-NP, Rev. 1" dated August 2020 (Agency Document Access & Management System [ADAMS] Accession No. ML20279A597) [16]. The staff responses to the industry concerns are contained in the enclosure (ML21242A031) to the letter from NRC to the PWROG, Subject: Transmittal of NRC Responses to PWROG Data Issues (ML21242A030), dated August 31, 2021 [17]. In a number of instances the staff agrees with the comments and has made changes to aspects of the data analysis program, which take effect with this edition.

1.3 Report Organization

Sections 1 through 5 present specific results for component UR, component or train UA, system special event probabilities, and IE frequencies, respectively. Section 6 compares the data and results in this update with those in the 2015 update. Section 7 lists the references. In addition, there are three appendices providing additional detail concerning component UR (Appendix A), component or train UA (Appendix B), and IE frequencies (Appendix C).

2. COMPONENT UNRELIABILITY

This section represents the third update to the original set of component UR data and results documented in NUREG/CR-6928. The original set of component availability data sheets were extracted from NUREG/CR-6928 and generally contained data from the date range 2002–2004. The first update to NUREG/CR-6928 generally represents component availability results using a date range 1998–2010 and is often called the 2010 update. The second update generally represents component availability results using a date range 2002–2015 and is often called the 2015 update. This update generally represents component availability results using a date range 2006–2020.

Component UR data and resulting failure probability or rate distributions are summarized in Table 1. More detailed information for each component is presented in Appendix A, "Component Unreliability Data Sheets." IRIS data (obtained through RADS) from 2006–2020 provide the basis for most component type and failure mode combinations. System studies (SSs) covering reactor protection systems (RPSs) [18–21] and the Westinghouse Savannah River Company (WSRC) database [22] that provided historic data (late 1980s and early 1990s) and estimates for a specific component type and failure mode combinations in the original NUREG/CR-6928 were also included for completeness andto provide the basis for those component type and failure mode combinations.

Table 1. Component UR data and results.

Grouping	Component Type	Component Failure Mode	Description	Data Source	Data				Industry-average Failure Probability or Rate Distribution (note a)									Date Range
					Failures	Demands or Hours	d or h	Components	Distribution	Analysis Type	5th	Median	Mean	95th	α	β	Error Factor (note b)	
Valves	Air-Operated Valve (AOV)	AOV-FTO	Air-Operated Valve Fails To Open	EPIX/RADS	50	165,942	d	1755	Beta	JNID/IL	2.37E-04	3.02E-04	3.04E-04	3.78E-04	50.500	1.660E+05	1.3	2006--2020
		AOV-FTC	Air-Operated Valve Fails To Close	EPIX/RADS	27	165,942	d	1755	Beta	EB/PL/KS	2.30E-06	1.04E-04	1.89E-04	6.64E-04	0.638	3.380E+03	6.4	2006--2020
		AOV-FTOC	Air-Operated Valve Fails To Open/Close	EPIX/RADS	83	165,942	d	1755	Beta	EB/PL/KS	1.73E-05	3.57E-04	5.58E-04	1.78E-03	0.832	1.490E+03	5.0	2006--2020
		AOV-FC	Air-Operated Valve Fails To Control	EPIX/RADS	167	1,109,287,000	h	8788	Gamma	EB/PL/KS	1.50E-08	1.32E-07	1.75E-07	4.86E-07	1.260	7.170E+06	3.7	2006--2020
		AOV-SOP	Air-Operated Valve Spurious Operation	EPIX/RADS	61	1,109,287,000	h	8788	Gamma	EB/PL/KS	1.99E-09	3.79E-08	5.83E-08	1.85E-07	0.859	1.470E+07	4.9	2006--2020
		AOV-ILS	Air-Operated Valve Internal Leakage (Small)	EPIX/RADS	35	1,109,287,000	h	8788	Gamma	JNID/IL	2.37E-08	3.17E-08	3.20E-08	4.13E-08	35.500	1.110E+09	1.3	2006--2020
		AOV-ILL	Air-Operated Valve Internal Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	8788	Gamma	JNID/IL	6.85E-14	1.56E-10	6.40E-10	2.93E-09	0.300	4.688E+08	18.8	2006--2020
		AOV-ELS	Air-Operated Valve External Leakage (Small)	EPIX/RADS	35	1,109,287,000	h	8788	Gamma	EB/PL/KS	2.67E-10	1.75E-08	3.43E-08	1.25E-07	0.575	1.680E+07	7.2	2006--2020
		AOV-ELL	Air-Operated Valve External Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	8788	Gamma	EB/PL/KS	2.57E-13	5.85E-10	2.40E-09	1.10E-08	0.300	1.249E+08	18.8	2006--2020
		AOV-SOP-CCW	Component Cooling Water AOV Spurious Operation	EPIX/RADS	10	144,615,200	h	1164	Gamma	JNID/IL	4.00E-08	7.01E-08	7.26E-08	1.13E-07	10.500	1.450E+08	1.6	2006--2020
		AOV-SOP-IAS	Instrument Air System AOV Spurious Operation	EPIX/RADS	0	6,218,450	h	50	Gamma	JNID/IL	3.16E-10	3.66E-08	8.04E-08	3.09E-07	0.500	6.220E+06	8.4	2006--2020
	Motor-Operated Valve (MOV)	MOV-FTO	Motor-Operated Valve Fails To Open	EPIX/RADS	190	593,626	d	7120	Beta	EB/PL/KS	7.80E-05	2.99E-04	3.43E-04	7.62E-04	2.480	7.220E+03	2.6	2006--2020
		MOV-FTC	Motor-Operated Valve Fails To Close	EPIX/RADS	123	593,626	d	7120	Beta	EB/PL/KS	1.09E-05	1.56E-04	2.28E-04	6.90E-04	0.972	4.260E+03	4.4	2006--2020
		MOV-FTOC	Motor-Operated Valve Fails To Open/Close	EPIX/RADS	346	593,626	d	7120	Beta	EB/PL/KS	1.42E-04	5.54E-04	6.40E-04	1.43E-03	2.430	3.800E+03	2.6	2006--2020
		MOV-FC	Motor-Operated Feed Control Valve Fails To Control	EPIX/RADS	59	1,634,537,000	h	13344	Gamma	EB/PL/KS	9.42E-10	2.17E-08	3.47E-08	1.13E-07	0.798	2.300E+07	5.2	2006--2020
		MOV-SOP	Motor-Operated Valve Spurious Operation	EPIX/RADS	41	1,634,537,000	h	13344	Gamma	JNID/IL	1.93E-08	2.53E-08	2.54E-08	3.23E-08	41.500	1.630E+09	1.3	2006--2020
		MOV-ILS	Motor-Operated Valve Internal Leakage (Small)	EPIX/RADS	55	1,634,537,000	h	13344	Gamma	EB/PL/KS	7.97E-11	1.49E-08	3.61E-08	1.44E-07	0.451	1.250E+07	9.7	2006--2020
		MOV-ILL	Motor-Operated Valve Internal Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	13344	Gamma	EB/PL/KS	7.73E-14	1.76E-10	7.22E-10	3.30E-09	0.300	4.155E+08	18.8	2006--2020
		MOV-ELS	Motor-Operated Valve External Leakage (Small)	EPIX/RADS	29	1,634,537,000	h	13344	Gamma	EB/PL/KS	4.85E-11	7.97E-09	1.88E-08	7.43E-08	0.463	2.460E+07	9.3	2006--2020
		MOV-ELL	Motor-Operated Valve External Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	13344	Gamma	EB/PL/KS	1.41E-13	3.21E-10	1.32E-09	6.02E-09	0.300	2.280E+08	18.8	2006--2020
		MOV-FTO-BFV	Butterfly Valve Fails To Open	EPIX/RADS	24	89,399	d	983	Beta	JNID/IL	1.90E-04	2.70E-04	2.74E-04	3.71E-04	24.500	8.940E+04	1.4	2006--2020
		MOV-FTC-BFV	Butterfly Valve Fails To Close	EPIX/RADS	24	89,399	d	983	Beta	EB/PL/KS	2.52E-05	2.18E-04	2.89E-04	7.97E-04	1.270	4.390E+03	3.7	2006--2020
		MOV-FTOC-BFV	Butterfly Valve Fails To Open/Close	EPIX/RADS	54	89,399	d	983	Beta	EB/PL/KS	7.34E-06	4.06E-04	7.69E-04	2.76E-03	0.602	7.830E+02	6.8	2006--2020
		MOV-SOP-CCW	Component Cooling Water MOV Spurious Operation	EPIX/RADS	4	183,661,900	h	1472	Gamma	JNID/IL	9.04E-09	2.27E-08	2.45E-08	4.60E-08	4.500	1.840E+08	2.0	2006--2020
		MOV-SOP-SWS	Standby Service Water Motor-Operated Valve Spurious Operation	EPIX/RADS	0	64,725,970	h	566	Gamma	JNID/IL	3.04E-11	3.52E-09	7.72E-09	2.97E-08	0.500	6.470E+07	8.4	2006--2020
		MOV-BFV-SOP-CCW	Component Cooling Water Butterfly Valve Spurious Operation	EPIX/RADS	2	86,552,190	h	738	Gamma	JNID/IL	6.61E-09	2.51E-08	2.89E-08	6.39E-08	2.500	8.660E+07	2.5	2006--2020
	Hydraulic-Operated Valve (HOV)	HOV-FTOC	Hydraulic-Operated Valve Fails To Open	EPIX/RADS	17	16,401	d	219	Beta	EB/PL/KS	2.23E-06	4.93E-04	1.23E-03	4.97E-03	0.436	3.530E+02	10.1	2006--2020
		HOV-FC	Hydraulic-Operated Valve Fails To Control	EPIX/RADS	21	76,176,020	h	603	Gamma	JNID/IL	1.90E-07	2.78E-07	2.82E-07	3.89E-07	21.500	7.620E+07	1.4	2006--2020
		HOV-SOP	Hydraulic-Operated Valve Spurious Operation	EPIX/RADS	10	76,176,020	h	603	Gamma	EB/PL/KS	6.27E-10	5.84E-08	1.23E-07	4.64E-07	0.526	4.280E+06	7.9	2006--2020
		HOV-ILS	Hydraulic-Operated Valve Internal Leakage (Small)	EPIX/RADS	2	76,176,020	h	603	Gamma	JNID/IL	7.52E-09	2.86E-08	3.28E-08	7.26E-08	2.500	7.620E+07	2.5	2006--2020
		HOV-ILL	Hydraulic-Operated Valve Internal Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	603	Gamma	JNID/IL	7.02E-14	1.60E-10	6.56E-10	3.00E-09	0.300	4.573E+08	18.8	2006--2020
		HOV-ELS	Hydraulic-Operated Valve External Leakage (Small)	EPIX/RADS	7	76,176,020	h	603	Gamma	EB/PL/KS	2.08E-10	3.97E-08	9.66E-08	3.85E-07	0.449	4.650E+06	9.7	2006--2020
		HOV-ELL	Hydraulic-Operated Valve External Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	603	Gamma	EB/PL/KS	7.24E-13	1.65E-09	6.76E-09	3.09E-08	0.300	4.437E+07	18.8	2006--2020
	Solenoid-Operated Valve (SOV)	SOV-FTOC	Solenoid-Operated Valve Fails To Open	EPIX/RADS	13	27,937	d	555	Beta	JNID/IL	2.89E-04	4.72E-04	4.83E-04	7.18E-04	13.500	2.790E+04	1.5	2006--2020
		SOV-FC	Solenoid-Operated Valve Fails To Control	EPIX/RADS	15	115,760,700	h	921	Gamma	EB/PL/KS	1.52E-09	8.08E-08	1.52E-07	5.44E-07	0.609	4.010E+06	6.7	2006--2020
		SOV-SOP	Solenoid-Operated Valve Spurious Operation	EPIX/RADS	9	115,760,700	h	921	Gamma	JNID/IL	4.36E-08	7.90E-08	8.21E-08	1.30E-07	9.500	1.160E+08	1.6	2006--2020

Grouping	Component Type	Component Failure Mode	Description	Data Source	Data				Industry-average Failure Probability or Rate Distribution (note a)									Date Range
					Failures	Demands or Hours	d or h	Components	Distribution	Analysis Type	5th	Median	Mean	95th	α	β	Error Factor (note b)	
		SOV-ILS	Solenoid-Operated Valve Internal Leakage (Small)	EPIX/RADS	8	115,760,700	h	921	Gamma	JNID/IL	3.74E-08	7.04E-08	7.34E-08	1.19E-07	8.500	1.160E+08	1.7	2006--2020
		SOV-ILL	Solenoid-Operated Valve Internal Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	921	Gamma	JNID/IL	1.57E-13	3.58E-10	1.47E-09	6.72E-09	0.300	2.044E+08	18.8	2006--2020
		SOV-ELS	Solenoid-Operated Valve External Leakage (Small)	EPIX/RADS	2	115,760,700	h	921	Gamma	JNID/IL	4.94E-09	1.88E-08	2.16E-08	4.77E-08	2.500	1.160E+08	2.5	2006--2020
		SOV-ELL	Solenoid-Operated Valve External Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	921	Gamma	JNID/IL	1.62E-13	3.69E-10	1.51E-09	6.92E-09	0.300	1.984E+08	18.8	2006--2020
	Explosive-Operated Valve (EOV)	EOV-FTO	Explosive-Operated Valve Fails To Open	EPIX/RADS	3	674	d	59	Beta	EB/PL/KS	2.45E-04	3.23E-03	4.62E-03	1.38E-02	1.010	2.170E+02	4.3	2006--2020
	Vacuum Breaker Valve (VBV)	VBV-FTO	Vacuum Breaker Valve Fails To Open	EPIX/RADS	1	23,202	d	167	Beta	JNID/IL	7.58E-06	5.10E-05	6.46E-05	1.68E-04	1.500	2.320E+04	3.3	2006--2020
		VBV-FTC	Vacuum Breaker Valve Fails To Close	EPIX/RADS	1	23,202	d	167	Beta	JNID/IL	7.58E-06	5.10E-05	6.46E-05	1.68E-04	1.500	2.320E+04	3.3	2006--2020
		VBV-FTOC	Vacuum Breaker Valve Fails To Open/Close	EPIX/RADS	2	23,202	d	167	Beta	JNID/IL	2.47E-05	9.38E-05	1.08E-04	2.39E-04	2.500	2.320E+04	2.5	2006--2020
		VBV-SOP	Vacuum Breaker Valve Spurious Operation	EPIX/RADS	0	43,685,040	h	343	Gamma	JNID/IL	4.50E-11	5.21E-09	1.14E-08	4.40E-08	0.500	4.370E+07	8.4	2006--2020
		VBV-ILS	Vacuum Breaker Valve Internal Leakage (Small)	EPIX/RADS	2	43,685,040	h	343	Gamma	JNID/IL	1.31E-08	4.98E-08	5.72E-08	1.27E-07	2.500	4.370E+07	2.5	2006--2020
		VBV-ILL	Vacuum Breaker Valve Internal Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	343	Gamma	JNID/IL	1.22E-13	2.79E-10	1.14E-09	5.23E-09	0.300	2.622E+08	18.8	2006--2020
	Turbine Bypass Valve (TBV)	TBV-FTO	Turbine Bypass Valve Fails To Open	EPIX/RADS	1	2,367	d	73	Beta	JNID/IL	7.42E-05	4.99E-04	6.33E-04	1.65E-03	1.500	2.370E+03	3.3	2006--2020
		TBV-FTC	Turbine Bypass Valve Fails To Close	EPIX/RADS	0	2,367	d	73	Beta	JNID/IL	8.30E-07	9.60E-05	2.11E-04	8.10E-04	0.500	2.370E+03	8.4	2006--2020
		TBV-FTOC	Turbine Bypass Valve Fails To Open/Close	EPIX/RADS	1	2,367	d	73	Beta	JNID/IL	7.42E-05	4.99E-04	6.33E-04	1.65E-03	1.500	2.370E+03	3.3	2006--2020
		TBV-FC	Turbine Bypass Valve Fails To Control	EPIX/RADS	6	19,263,540	h	153	Gamma	EB/PL/KS	1.29E-09	1.60E-07	3.57E-07	1.38E-06	0.492	1.380E+06	8.6	2006--2020
	Main Steam Isolation Valve (MSV)	MSV-FTOC	Main Steam Isolation Valve Fails To Open/Close	EPIX/RADS	24	32,199	d	425	Beta	JNID/IL	5.27E-04	7.50E-04	7.61E-04	1.03E-03	24.500	3.220E+04	1.4	2006--2020
		MSV-SOP	Main Steam Isolation Valve Spurious Operation	EPIX/RADS	16	65,768,320	h	520	Gamma	EB/PL/KS	9.30E-10	1.07E-07	2.34E-07	8.99E-07	0.501	2.140E+06	8.4	2006--2020
		MSV-ILS	Main Steam Isolation Valve Internal Leakage (Small)	EPIX/RADS	23	65,768,320	h	520	Gamma	JNID/IL	2.45E-07	3.52E-07	3.57E-07	4.86E-07	23.500	6.580E+07	1.4	2006--2020
		MSV-ILL	Main Steam Isolation Valve Internal Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	520	Gamma	JNID/IL	7.64E-13	1.74E-09	7.14E-09	3.27E-08	0.300	4.202E+07	18.8	2006--2020
		MSV-ELS	Main Steam Isolation Valve External Leakage (Small)	EPIX/RADS	1	65,768,320	h	520	Gamma	JNID/IL	2.67E-09	1.80E-08	2.28E-08	5.94E-08	1.500	6.580E+07	3.3	2006--2020
		MSV-ELL	Main Steam Isolation Valve External Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	520	Gamma	JNID/IL	1.71E-13	3.89E-10	1.60E-09	7.30E-09	0.300	1.880E+08	18.8	2006--2020
	Check Valve (CKV)	CKV-FTO	Check Valve Fails To Open	EPIX/RADS	0	44,791	d	489	Beta	JNID/IL	4.39E-08	5.08E-06	1.12E-05	4.29E-05	0.500	4.480E+04	8.4	2006--2020
		CKV-FTC	Check Valve Fails To Close	EPIX/RADS	5	44,791	d	489	Beta	JNID/IL	5.11E-05	1.15E-04	1.23E-04	2.20E-04	5.500	4.480E+04	1.9	2006--2020
		CKV-SOP	Check Valve Spurious Operation	EPIX/RADS	0	806,744,700	h	6379	Gamma	JNID/IL	2.44E-12	2.82E-10	6.20E-10	2.38E-09	0.500	8.070E+08	8.4	2006--2020
		CKV-ILS	Check Valve Internal Leakage (Small)	EPIX/RADS	58	806,744,700	h	6379	Gamma	JNID/IL	5.76E-08	7.21E-08	7.25E-08	8.88E-08	58.500	8.070E+08	1.2	2006--2020
		CKV-ILL	Check Valve Internal Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	6379	Gamma	JNID/IL	1.55E-13	3.53E-10	1.45E-09	6.63E-09	0.300	2.069E+08	18.8	2006--2020
		CKV-ELS	Check Valve External Leakage (Small)	EPIX/RADS	3	806,744,700	h	6379	Gamma	JNID/IL	1.34E-09	3.93E-09	4.34E-09	8.72E-09	3.500	8.070E+08	2.2	2006--2020
		CKV-ELL	Check Valve External Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	6379	Gamma	JNID/IL	3.25E-14	7.41E-11	3.04E-10	1.39E-09	0.300	9.875E+08	18.8	2006--2020
	Manual Valve (XVM)	XVM-FTOC	Manual Valve Fails To Open	EPIX/RADS	1	2,875	d	66	Beta	JNID/IL	6.13E-05	4.12E-04	5.22E-04	1.36E-03	1.500	2.870E+03	3.3	2006--2020
		XVM-SOP	Manual Valve Spurious Operation	EPIX/RADS	2	132,674,000	h	1035	Gamma	JNID/IL	4.31E-09	1.64E-08	1.88E-08	4.16E-08	2.500	1.330E+08	2.5	2006--2020
		XVM-ILS	Manual Valve Internal Leakage (Small)	EPIX/RADS	3	132,674,000	h	1035	Gamma	JNID/IL	8.15E-09	2.39E-08	2.64E-08	5.29E-08	3.500	1.330E+08	2.2	2006--2020
		XVM-ILL	Manual Valve Internal Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	1035	Gamma	JNID/IL	5.65E-14	1.29E-10	5.28E-10	2.42E-09	0.300	5.682E+08	18.8	2006--2020
		XVM-ELS	Manual Valve External Leakage (Small)	EPIX/RADS	11	132,674,000	h	1035	Gamma	JNID/IL	4.92E-08	8.40E-08	8.67E-08	1.32E-07	11.500	1.330E+08	1.6	2006--2020
		XVM-ELL	Manual Valve External Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	1035	Gamma	JNID/IL	6.50E-13	1.48E-09	6.07E-09	2.78E-08	0.300	4.943E+07	18.8	2006--2020
		XVM-SOP-SWS	Standby Service Water Manual Valve Spuriously Transfers	EPIX/RADS	0	18,055,700	h	140	Gamma	JNID/IL	1.09E-10	1.26E-08	2.77E-08	1.06E-07	0.500	1.810E+07	8.4	2006--2020
	Flow Control Valve (FCV)	FCV-FTOC	Flow Control Valve Fails To Open/Close	EPIX/RADS	0	11,345	d	105	Beta	JNID/IL	1.74E-07	2.01E-05	4.41E-05	1.70E-04	0.500	1.130E+04	8.4	2006--2020
		FCV-FC	Flow Control Valve Fails To Control	EPIX/RADS	8	73,637,280	h	595	Gamma	JNID/IL	5.89E-08	1.11E-07	1.15E-07	1.87E-07	8.500	7.360E+07	1.7	2006--2020

Grouping	Component Type	Component Failure Mode	Description	Data Source	Data				Industry-average Failure Probability or Rate Distribution (note a)									Date Range
					Failures	Demands or Hours	d or h	Components	Distribution	Analysis Type	5th	Median	Mean	95th	α	β	Error Factor (note b)	
		FCV-SOP	Flow Control Valve Spurious Operation	EPIX/RADS	2	73,637,280	h	595	Gamma	JNID/IL	7.78E-09	2.96E-08	3.40E-08	7.52E-08	2.500	7.360E+07	2.5	2006--2020
		FRV-FTOP	Feedwater Regulating Valve Fails To Operate	EPIX/RADS	49	27,637,200	h	221	Gamma	EB/PL/KS	2.71E-08	1.06E-06	1.88E-06	6.52E-06	0.666	3.540E+05	6.1	2006--2020
Pumps	Motor-Driven Pump (MDP)	MDP-FTS-NS	Motor-Driven Pump Fails To Start, Normally Standby	EPIX/RADS	227	410,593	d	1311	Beta	EB/PL/KS	1.09E-04	4.96E-04	5.88E-04	1.38E-03	2.070	3.520E+03	2.8	2006--2020
		MDP-FTR<1H	Motor-Driven Pump FTR<1H	EPIX/RADS	31	378,369	h	1305	Gamma	EB/PL/KS	7.34E-07	4.68E-05	9.13E-05	3.33E-04	0.579	6.340E+03	7.1	2006--2020
		MDP-FTR>1H	Motor-Driven Pump FTR>1H	EPIX/RADS	92	19,248,030	h	1311	Gamma	EB/PL/KS	3.58E-08	3.77E-06	8.12E-06	3.10E-05	0.511	6.290E+04	8.2	2006--2020
		MDP-ELS	Motor-Driven Pump External Leakage (Small)	EPIX/RADS	59	288,839,600	h	2351	Gamma	EB/PL/KS	3.16E-09	1.14E-07	1.98E-07	6.80E-07	0.684	3.450E+06	6.0	2006--2020
		MDP-ELL	Motor-Driven Pump External Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	2351	Gamma	EB/PL/KS	1.48E-12	3.38E-09	1.39E-08	6.34E-08	0.300	2.165E+07	18.8	2006--2020
		MDP-FTS-NR	Motor-Driven Pump Fails To Start, Normally Running	EPIX/RADS	89	125,005	d	649	Beta	EB/PL/KS	4.86E-05	5.62E-04	7.86E-04	2.30E-03	1.080	1.370E+03	4.1	2006--2020
		MDP-FTR-NR	Motor-Driven Pump Fails To Run, Normally Running	EPIX/RADS	129	56,750,330	h	650	Gamma	EB/PL/KS	3.94E-07	1.89E-06	2.26E-06	5.38E-06	1.970	8.720E+05	2.8	2006--2020
		MDP-FTS-CCW	Component Cooling Water Motor-Driven Pump Fails To Start	EPIX/RADS	31	80,067	h	288	Beta	EB/PL/KS	1.23E-05	2.86E-04	4.57E-04	1.49E-03	0.796	1.740E+03	5.2	2006--2020
		MDP-FTR-CCW	Component Cooling Water Motor-Driven Pump Fails To Run	EPIX/RADS	31	17,527,790	h	288	Gamma	EB/PL/KS	2.86E-07	1.47E-06	1.77E-06	4.33E-06	1.850	1.040E+06	2.9	2006--2020
		MDP-FTS-SWS	Service Water Motor-Driven Pump Fails To Start	EPIX/RADS	132	225,636	d	529	Beta	EB/PL/KS	2.43E-05	4.80E-04	7.43E-04	2.36E-03	0.848	1.140E+03	4.9	2006--2020
		MDP-FTR-SWS	Service Water Motor-Driven Pump Fails To Run	EPIX/RADS	100	25,635,460	h	529	Gamma	EB/PL/KS	3.09E-07	3.08E-06	4.20E-06	1.19E-05	1.170	2.790E+05	3.9	2006--2020
		MDP-FTR-CWS	Circulating Water Motor-Driven Pump Fails To Run	EPIX/RADS	15	3,116,679	h	31	Gamma	EB/PL/KS	1.81E-06	4.51E-06	4.86E-06	9.09E-06	4.570	9.410E+05	2.0	2006--2020
	Turbine-Driven Pump (TDP)	TDP-FTS-NS	Turbine-Driven Pump Fails To Start (Pooled Systems), Normally Standby	EPIX/RADS	105	22,512	d	133	Beta	EB/PL/KS	4.59E-04	4.02E-03	5.32E-03	1.47E-02	1.260	2.350E+02	3.7	2006--2020
		TDP-FTR<1H	Turbine-Driven Pump Fails To Run (Pooled Systems), Early Term	EPIX/RADS	34	15,530	h	133	Gamma	EB/PL/KS	5.17E-06	1.04E-03	2.56E-03	1.03E-02	0.444	1.730E+02	9.9	2006--2020
		TDP-FTR>1H	Turbine-Driven Pump Fails To Run (Pooled Systems), Late Term	EPIX/RADS	17	4,454	h	133	Gamma	EB/PL/KS	1.23E-05	2.56E-03	6.35E-03	2.55E-02	0.441	6.950E+01	10.0	2006--2020
		TDP-ELS	Turbine-Driven Pump External Leakage (Small)	EPIX/RADS	10	24,190,380	h	191	Gamma	EB/PL/KS	7.42E-08	3.47E-07	4.13E-07	9.75E-07	2.020	4.900E+06	2.8	2006--2020
		TDP-ELL	Turbine Bypass Valve External Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	191	Gamma	EB/PL/KS	3.09E-12	7.05E-09	2.89E-08	1.32E-07	0.300	1.038E+07	18.8	2006--2020
		TDP-FTS-NS-AFW	Auxiliary Feedwater Turbine-Driven Pump Fails To Start, Normally Standby	EPIX/RADS	52	15,672	d	74	Beta	EB/PL/KS	1.17E-04	2.43E-03	3.79E-03	1.21E-02	0.831	2.180E+02	5.0	2006--2020
		TDP-FTR<1H-AFW	Auxiliary Feedwater Turbine-Driven Pump FTR<1H	EPIX/RADS	18	10,670	h	74	Gamma	JNID/IL	1.12E-03	1.70E-03	1.73E-03	2.44E-03	18.500	1.070E+04	1.4	2006--2020
		TDP-FTR>1H-AFW	Auxiliary Feedwater Turbine-Driven Pump FTR>1H	EPIX/RADS	8	3,295	h	74	Gamma	JNID/IL	1.31E-03	2.48E-03	2.58E-03	4.18E-03	8.500	3.300E+03	1.7	2006--2020
		TDP-FTS-NS-HCI-RCI	HCI-RCI Turbine-Driven Pump Fails To Start, Normally Standby	EPIX/RADS	25	4,026	d	31	Beta	EB/PL/KS	6.02E-04	5.07E-03	6.68E-03	1.82E-02	1.290	1.920E+02	3.6	2006--2020
		TDP-FTR<1H-HCI-RCI	HCI Turbine-Driven Pump FTR<1H	EPIX/RADS	16	4,860	h	59	Gamma	EB/PL/KS	6.73E-04	2.86E-03	3.35E-03	7.68E-03	2.220	6.640E+02	2.7	2006--2020
		TDP-FTR>1H-HCI-RCI	HCI-RCI Turbine-Driven Pump FTR>1H	EPIX/RADS	9	1,159	h	59	Gamma	JNID/IL	4.36E-03	7.90E-03	8.20E-03	1.30E-02	9.500	1.160E+03	1.6	2006--2020
		TDP-FTS-NR-MFW	Main Feedwater Turbine-Driven Pump Fails To Start, Normally Running	EPIX/RADS	5	1,147	d	42	Beta	EB/PL/KS	5.45E-05	2.52E-03	4.60E-03	1.62E-02	0.633	1.370E+02	6.4	2006--2020
		TDP-FTR-NR-MFW	Main Feedwater Turbine-Driven Pump Fails To Run, Normally Running	EPIX/RADS	39	4,938,575	h	42	Gamma	EB/PL/KS	2.53E-07	5.37E-06	8.45E-06	2.71E-05	0.824	9.760E+04	5.0	2006--2020
	Engine-Driven Pump (EDP)	EDP-FTS-NS	Engine-Driven Pump Fails To Start, Normally Standby	EPIX/RADS	13	17,773	d	44	Beta	JNID/IL	4.53E-04	7.39E-04	7.60E-04	1.13E-03	13.500	1.780E+04	1.5	2006--2020
		EDP-FTR<1H	Engine-Driven Pump FTR<1H, Normally Standby	EPIX/RADS	6	9,888	h	39	Gamma	JNID/IL	2.98E-04	6.24E-04	6.57E-04	1.13E-03	6.500	9.890E+03	1.8	2006--2020
		EDP-FTR>1H	Engine-Driven Pump FTR>1H, Normally Standby	EPIX/RADS	15	4,754	h	44	Gamma	JNID/IL	2.03E-03	3.19E-03	3.26E-03	4.74E-03	15.500	4.750E+03	1.5	2006--2020
		EDP-ELS	Engine-Driven Pump External Leakage (Small)	EPIX/RADS	6	7,690,189	h	69	Gamma	JNID/IL	3.83E-07	8.02E-07	8.45E-07	1.45E-06	6.500	7.690E+06	1.8	2006--2020
		EDP-ELL	Engine-Driven Pump External Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	69	Gamma	JNID/IL	6.33E-12	1.44E-08	5.92E-08	2.71E-07	0.300	5.072E+06	18.8	2006--2020
		EDP-FTS-AFW	Auxiliary Feedwater Engine-driven pump Fails To Start	EPIX/RADS	1	1,163	d	5	Beta	JNID/IL	1.52E-04	1.02E-03	1.29E-03	3.36E-03	1.500	1.160E+03	3.3	2006--2020
		EDP-FTR<1H-AFW	Auxiliary Feedwater Engine-driven pump Fails To Run <1H	EPIX/RADS	2	759	h	5	Gamma	JNID/IL	7.55E-04	2.87E-03	3.29E-03	7.29E-03	2.500	7.590E+02	2.5	2006--2020

Grouping	Component Type	Component Failure Mode	Description	Data Source	Data				Industry-average Failure Probability or Rate Distribution (note a)									Date Range
					Failures	Demands or Hours	d or h	Components	Distribution	Analysis Type	5th	Median	Mean	95th	α	β	Error Factor (note b)	
		EDP-FTR>1H-AFW	Auxiliary Feedwater Engine-driven pump Fails To Run >1H	EPIX/RADS	2	234	h	5	Gamma	JNID/IL	2.45E-03	9.30E-03	1.07E-02	2.37E-02	2.500	2.340E+02	2.5	2006--2020
	Positive Displacement Pump (PDP)	PDP-FTS-NR	Positive Displacement Pump Fails To Start, Normally Running	EPIX/RADS	53	28,865	d	57	Beta	EB/PL/KS	7.46E-05	1.58E-03	2.47E-03	7.92E-03	0.825	3.330E+02	5.0	2006--2020
		PDP-FTR-NR	Positive Displacement Pump Fails To Run, Normally Running	EPIX/RADS	40	2,353,162	h	54	Gamma	EB/PL/KS	1.81E-06	1.45E-05	1.91E-05	5.17E-05	1.330	6.980E+04	3.6	2006--2020
		PDP-FTS-NS	Positive Displacement Pump Fails To Start, Normally Standby	EPIX/RADS	10	9,064	d	72	Beta	JNID/IL	6.40E-04	1.12E-03	1.16E-03	1.80E-03	10.500	9.050E+03	1.6	2006--2020
		PDP-FTR<1H	Positive Displacement Pump FTR<1H	EPIX/RADS	1	4,045	h	72	Gamma	JNID/IL	4.34E-05	2.92E-04	3.71E-04	9.65E-04	1.500	4.050E+03	3.3	2006--2020
		PDP-FTR>1H	Positive Displacement Pump FTR>1H	EPIX/RADS	0	1,505	h	72	Gamma	JNID/IL	1.31E-06	1.52E-04	3.32E-04	1.28E-03	0.500	1.500E+03	8.4	2006--2020
		PDP-ELS	Positive Displacement Pump External Leakage (Small)	EPIX/RADS	15	21,211,980	h	171	Gamma	JNID/IL	4.55E-07	7.15E-07	7.31E-07	1.06E-06	15.500	2.120E+07	1.5	2006--2020
		PDP-ELL	Positive Displacement Pump External Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	171	Gamma	JNID/IL	5.48E-12	1.25E-08	5.12E-08	2.34E-07	0.300	5.863E+06	18.8	2006--2020
	Pump Volute (PMP)	PMP-Volute	Pump Volute Fails To Run (Driver Independent Centrifugal Pumps)	EPIX/RADS	16	133,247	h	208	Gamma	JNID/IL	7.84E-05	1.22E-04	1.24E-04	1.78E-04	16.500	1.330E+05	1.5	2006--2020
Generators	Emergency Diesel Generator (EDG)	EDG-FTS	Diesel Generator Fails To Start, Normally Standby	EPIX/RADS	136	61,363	d	234	Beta	EB/PL/KS	1.53E-03	2.19E-03	2.22E-03	3.02E-03	23.800	1.070E+04	1.4	2006--2020
		EDG-FTLR	Diesel Generator Fails To Load And Run, Early	EPIX/RADS	172	53,343	h	234	Gamma	EB/PL/KS	1.05E-03	3.01E-03	3.31E-03	6.60E-03	3.610	1.090E+03	2.2	2006--2020
		EDG-FTR	Diesel Generator Fails To Run, Late Term	EPIX/RADS	155	137,584	h	234	Gamma	EB/PL/KS	3.90E-04	1.08E-03	1.18E-03	2.31E-03	3.830	3.250E+03	2.1	2006--2020
	Hydro Turbine Generator (HTG)	HTG-FTS	Hydro Turbine Generator Fails To Start	EPIX/RADS	6	6,362	d	2	Beta	JNID/IL	4.63E-04	9.69E-04	1.02E-03	1.76E-03	6.500	6.360E+03	1.8	2006--2020
		HTG-FTLR	Hydro Turbine Generator Fails To Load And Run, Early	EPIX/RADS	2	4,582	h	2	Gamma	JNID/IL	1.25E-04	4.75E-04	5.46E-04	1.21E-03	2.500	4.580E+03	2.5	2006--2020
		HTG-FTR	Hydro Turbine Generator Fails To Run, Late Term	EPIX/RADS	1	13,874	h	2	Gamma	JNID/IL	1.27E-05	8.51E-05	1.08E-04	2.81E-04	1.500	1.390E+04	3.3	2006--2020
	Combustion Turbine Generator (CTG)	CTG-FTS	Combustion Turbine Generator Fails To Start, Normally Standby	EPIX/RADS	21	419	d	3	Beta	EB/PL/KS	5.81E-03	5.40E-02	7.03E-02	1.90E-01	1.200	1.590E+01	3.5	2006--2020
		CTG-FTLR	Combustion Turbine Generator Fails To Load And Run, Early Term	EPIX/RADS	2	360	d	2	Gamma	JNID/IL	1.59E-03	6.04E-03	6.94E-03	1.54E-02	2.500	3.600E+02	2.5	2006--2020
		CTG-FTR	Combustion Turbine Generator Fails To Run, Late Term	EPIX/RADS	4	959	h	3	Gamma	JNID/IL	1.73E-03	4.35E-03	4.69E-03	8.82E-03	4.500	9.590E+02	2.0	2006--2020
	High-Pressure Core Spray Generator (HPCS)	EDG-FTS-HCS	High-Pressure Core Spray Generator Fails To Start	EPIX/RADS	4	2,114	d	8	Beta	JNID/IL	7.87E-04	1.97E-03	2.13E-03	4.00E-03	4.500	2.110E+03	2.0	2006--2020
		EDG-FTR-HCS	High-Pressure Core Spray Generator Fails To Run	EPIX/RADS	3	4,196	h	8	Gamma	JNID/IL	2.58E-04	7.55E-04	8.34E-04	1.67E-03	3.500	4.200E+03	2.2	2006--2020
	Station Blackout (SBO) Generator	EDG-FTS-SBO	SBO Generator Fails To Start	EPIX/RADS	14	625	d	5	Beta	EB/PL/KS	1.46E-03	2.06E-02	2.94E-02	8.75E-02	0.975	3.220E+01	4.3	2006--2020
		EDG-FTR-SBO	SBO Generator Fails To Run	EPIX/RADS	2	2,204	h	5	Gamma	JNID/IL	2.60E-04	9.89E-04	1.13E-03	2.52E-03	2.500	2.200E+03	2.5	2006--2020
Relief Valves	Safety Relief Valve (SRV)	SRV-FTO	Safety relief valve fails To open	RV Update, Table 26.	7	3,548	d	--	Beta	JNID	1.02E-03	2.02E-03	2.11E-03	3.52E-03	7.500	3.542E+03	1.7	1988--2020
		SRV-FTC	BWR ADS/SRV Fails To Reclose	RV Update, Table 26.	0	3,548	d	--	Beta	CNID	5.54E-07	6.41E-05	1.41E-04	5.41E-04	0.500	3.547E+03	8.4	1988--2020
		SRV-FC	Safety Relief Valve (BWR Only) Fails To Control	EPIX/RADS	0	61,005,550	h	519	Gamma	JNID/IL	3.22E-11	3.73E-09	8.20E-09	3.15E-08	0.500	6.100E+07	8.4	2006--2020
		SRV-SOP	Safety Relief Valve Spurious Operation	EPIX/RADS	4	61,005,550	h	519	Gamma	JNID/IL	2.73E-08	6.84E-08	7.38E-08	1.39E-07	4.500	6.100E+07	2.0	2006--2020
		SRV-ILS	Safety Relief Valve (BWR Only) Internal Leakage (Small)	EPIX/RADS	23	61,005,550	h	519	Gamma	JNID/IL	2.64E-07	3.80E-07	3.85E-07	5.25E-07	23.500	6.100E+07	1.4	2006--2020
		SRV-ILL	Safety Relief Valve (BWR Only) Internal Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	519	Gamma	JNID/IL	8.24E-13	1.88E-09	7.70E-09	3.52E-08	0.300	3.896E+07	18.8	2006--2020
		SRV-ELS	Safety Relief Valve (BWR Only) External Leakage (Small)	EPIX/RADS	0	61,005,550	h	519	Gamma	JNID/IL	3.22E-11	3.73E-09	8.20E-09	3.15E-08	0.500	6.100E+07	8.4	2006--2020
		SRV-ELL	Safety Relief Valve (BWR Only) External Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	519	Gamma	JNID/IL	6.14E-14	1.40E-10	5.74E-10	2.63E-09	0.300	5.226E+08	18.8	2006--2020
	Safety Valve (SVV)	SVV-SOP	Code Safety Valve Spurious Operation	EPIX/RADS	1	171,647,800	h	1380	Gamma	JNID/IL	1.02E-09	6.88E-09	8.74E-09	2.27E-08	1.500	1.720E+08	3.3	2006--2020
		SVV-ILS	Code Safety Valve Internal Leakage (Small)	EPIX/RADS	5	171,647,800	h	1380	Gamma	JNID/IL	1.33E-08	3.01E-08	3.20E-08	5.72E-08	5.500	1.720E+08	1.9	2006--2020
		SVV-ILL	Code Safety Valve Internal Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	1380	Gamma	JNID/IL	6.85E-14	1.56E-10	6.40E-10	2.93E-09	0.300	4.688E+08	18.8	2006--2020

Grouping	Component Type	Component Failure Mode	Description	Data Source	Data				Industry-average Failure Probability or Rate Distribution (note a)									Date Range
					Failures	Demands or Hours	d or h	Components	Distribution	Analysis Type	5th	Median	Mean	95th	α	β	Error Factor (note b)	
		SVV-ELS	Code Safety Valve External Leakage (Small)	EPIX/RADS	1	171,647,800	h	1380	Gamma	JNID/IL	1.02E-09	6.88E-09	8.74E-09	2.27E-08	1.500	1.720E+08	3.3	2006--2020
		SVV-ELL	Code Safety Valve External Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	1380	Gamma	JNID/IL	6.55E-14	1.49E-10	6.12E-10	2.80E-09	0.300	4.904E+08	18.8	2006--2020
		SVV-FTO-PWR-MSS	Safety Valve Fails To Open+D174 PWRs)	RV Update, Table 24.	0	745	d	--	Beta	CNID	2.61E-06	3.05E-04	6.70E-04	2.58E-03	0.499	7.440E+02	8.5	1988--2020
		SVV-FTC-PWR-MSS	Safety Valve Fails To Close (Main Steam System, PWRs)	RV Update, Table 24.	4	745	d	--	Beta	JNID	2.23E-03	5.60E-03	6.03E-03	1.13E-02	4.500	7.415E+02	2.0	1988--2020
		SVV-SOP-PWR-MSS	Safety Valve Spurious Operation (Main Steam System, PWRs)	EPIX/RADS	0	140,068,800	h	1109	Gamma	JNID/IL	1.40E-11	1.62E-09	3.57E-09	1.37E-08	0.500	1.400E+08	8.4	2006--2020
		SVV-FTO-PWR-RCS	Safety Valve Fails To Open (Reactor Coolant System, PWRs)	RV Update, Table 25.	0	4	d	--	Beta	Bayes	2.58E-06	3.01E-04	6.63E-04	2.55E-03	0.499	7.520E+02	8.5	1988--2020
		SVV-FTC-PWR-RCS	Safety Valve Fails To Close (Reactor Coolant System, PWRs)	RV Update, Table 25.	2	4	d	--	Beta	Bayes	9.65E-03	3.63E-02	4.13E-02	9.01E-02	2.487	5.769E+01	2.5	1988--2020
		SVV-SOP-PWR-RCS	Safety Valve Spurious Operation (Reactor Coolant System, PWRs)	EPIX/RADS	1	23,893,310	h	207	Gamma	JNID/IL	7.36E-09	4.95E-08	6.28E-08	1.63E-07	1.500	2.390E+07	3.3	2006--2020
	Power-Operated Relief Valve (PORV)	PORV-FTO-RCS	Power-Operated Relief Valve Fails To Open (Reactor Coolant System, PWRs)	RV Update, Table 23.	4	377	d	--	Beta	JNID	4.42E-03	1.11E-02	1.19E-02	2.23E-02	4.500	3.735E+02	2.0	1988--2020
		PORV-FTC-RCS	Power-Operated Relief Valve Fails To Close (Reactor Coolant System, PWRs)	RV Update, Table 23.	1	377	d	--	Beta	CNID	1.47E-05	1.79E-03	3.97E-03	1.53E-02	0.494	1.240E+02	8.5	1988--2020
		PORV-FTO-MSS	Power-Operated Relief Valve Fails To Open (Main Steam System, PWRs)	RV Update, Table 22.	25	1,580	d	--	Beta	JNID	1.13E-02	1.59E-02	1.61E-02	2.17E-02	25.500	1.556E+03	1.4	1988--2020
		PORV-FTC-MSS	Power-Operated Relief Fails To Close (Main Steam System, PWRs)	RV Update, Table 22.	7	1,580	d	--	Beta	EB	2.54E-04	3.08E-03	4.35E-03	1.28E-02	1.053	2.412E+02	4.1	1988--2020
		PORV-FC-MSS	Power-Operated Relief Fails To Control (Cooldown) (Main Steam System, PWRs)	RV Update, Table 22.	7	278	d	--	Beta	JNID	1.31E-02	2.58E-02	2.69E-02	4.45E-02	7.500	2.715E+02	1.7	1988--2020
		PORV-SOP	Power Operated Relief Spurious Operation	EPIX/RADS	13	57,223,460	h	454	Gamma	JNID/IL	1.41E-07	2.30E-07	2.36E-07	3.51E-07	13.500	5.720E+07	1.5	2006--2020
		PORV-ILS	Power-Operated Relief Valve Internal Leakage (Small)	EPIX/RADS	3	57,223,460	h	454	Gamma	JNID/IL	1.89E-08	5.55E-08	6.12E-08	1.23E-07	3.500	5.720E+07	2.2	2006--2020
		PORV-ILL	Power-Operated Relief Valve Internal Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	454	Gamma	JNID/IL	1.31E-13	2.98E-10	1.22E-09	5.60E-09	0.300	2.451E+08	18.8	2006--2020
		PORV-ELS	Power-Operated Relief Valve External Leakage (Small)	EPIX/RADS	0	57,223,460	h	454	Gamma	JNID/IL	3.44E-11	3.98E-09	8.74E-09	3.36E-08	0.500	5.720E+07	8.4	2006--2020
		PORV-ELL	Power-Operated Relief Valve External Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	454	Gamma	JNID/IL	6.55E-14	1.49E-10	6.12E-10	2.80E-09	0.300	4.904E+08	18.8	2006--2020
		PORV-LOOP	Power-Operated Relief Valves Open During LOOP (Reactor Coolant System, PWRs)	RV Update, Table 13	--	--	d	--	Point Estimate	Point Estimate	--	--	9.23E-02	--	--	--	--	1988--2020
		PORV-Transient	Power-Operated Relief Valves Open During Transient (Reactor Coolant System, PWRs)	RV Update, Table 13	--	--	d	--	Point Estimate	Point Estimate	--	--	2.28E-02	--	--	--	--	1988--2018
	Low-Capacity Relief Valve (RVL)	RVL-FTO	Low Capacity Relief Valve Fails To Open	EPIX/RADS	0	65	d	12	Beta	JNID/IL	3.02E-05	3.49E-03	7.59E-03	2.91E-02	0.500	6.540E+01	8.3	2006--2020
		RVL-FTC	Low Capacity Relief Valve Fails To Close	EPIX/RADS	0	65	d	12	Beta	JNID/IL	3.02E-05	3.49E-03	7.59E-03	2.91E-02	0.500	6.540E+01	8.3	2006--2020
		RVL-SOP	Low Capacity Relief Valve Spurious Operation	EPIX/RADS	0	9,165,162	h	79	Gamma	JNID/IL	2.14E-10	2.48E-08	5.46E-08	2.09E-07	0.500	9.170E+06	8.4	2006--2020
		RVL-ILS	Low Capacity Relief Valve Internal Leakage (Small)	EPIX/RADS	3	9,165,162	h	79	Gamma	JNID/IL	1.18E-07	3.46E-07	3.82E-07	7.67E-07	3.500	9.170E+06	2.2	2006--2020
		RVL-ILL	Low Capacity Relief Valve Internal Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	79	Gamma	JNID/IL	8.18E-13	1.86E-09	7.64E-09	3.49E-08	0.300	3.927E+07	18.8	2006--2020
		RVL-ELS	Low Capacity Relief Valve External Leakage (Small)	EPIX/RADS	3	9,165,162	h	79	Gamma	JNID/IL	1.18E-07	3.46E-07	3.82E-07	7.67E-07	3.500	9.170E+06	2.2	2006--2020
		RVL-ELL	Low Capacity Relief Valve External Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	79	Gamma	JNID/IL	2.86E-12	6.52E-09	2.67E-08	1.22E-07	0.300	1.122E+07	18.8	2006--2020
Electrical Equipment	Battery Charger (BCH)	BCH-FTOP	Battery Charger Fails To Operate	EPIX/RADS	161	99,754,050	h	781	Gamma	EB/PL/KS	1.09E-07	1.26E-06	1.76E-06	5.15E-06	1.080	6.120E+05	4.1	2006--2020
	Battery (BAT)	BAT-FTOP	Battery Fails To Operate	EPIX/RADS	21	52,018,730	h	412	Gamma	EB/PL/KS	4.79E-09	2.21E-07	4.05E-07	1.42E-06	0.634	1.570E+06	6.5	2006--2020
	Automatic Bus Transfer Switch (ABT)	ABT-FF	Automatic Power Transfer Switch Fails To Transfer	EPIX/RADS	4	3,377	d	27	Beta	JNID/IL	4.93E-04	1.24E-03	1.33E-03	2.51E-03	4.500	3.370E+03	2.0	2006--2020
		ABT-SOP	Automatic Power Transfer Switch Spurious Operation	EPIX/RADS	0	4,010,342	h	32	Gamma	JNID/IL	4.90E-10	5.67E-08	1.25E-07	4.79E-07	0.500	4.010E+06	8.4	2006--2020
	Circuit Breaker (CRB)	CRB-FTOC	Circuit Breaker Fails To Open/Close	EPIX/RADS	102	119,027	d	3461	Beta	EB/PL/KS	4.23E-05	9.91E-04	1.59E-03	5.16E-03	0.793	4.990E+02	5.2	2006--2020

Grouping	Component Type	Component Failure Mode	Description	Data Source	Data				Industry-average Failure Probability or Rate Distribution (note a)									Date Range
					Failures	Demands or Hours	d or h	Components	Distribution	Analysis Type	5th	Median	Mean	95th	α	β	Error Factor (note b)	
		CRB-SOP	Circuit Breaker (All Voltages) Spurious Operation	EPIX/RADS	57	552,883,300	h	4620	Gamma	EB/PL/KS	4.58E-10	7.38E-08	1.73E-07	6.84E-07	0.465	2.680E+06	9.3	2006--2020
		CRBHV-FTOC	High Voltage (13.8 and 16 kV) Circuit Breaker Fails To Open/Close	EPIX/RADS	17	9,198	d	244	Beta	JNID/IL	1.22E-03	1.87E-03	1.90E-03	2.71E-03	17.500	9.180E+03	1.4	2006--2020
		CRBHV-SOP	High Voltage (13.8 and 16 Kv) Circuit Breaker Spurious Operation	EPIX/RADS	14	37,600,840	h	300	Gamma	JNID/IL	2.35E-07	3.77E-07	3.86E-07	5.66E-07	14.500	3.760E+07	1.5	2006--2020
		CRBMV-FTOC	Medium Voltage (4160 V and 6.9 kV) Circuit Breaker Fails To Open/Close	EPIX/RADS	57	50,897	d	1080	Beta	EB/PL/KS	7.09E-06	1.13E-03	2.64E-03	1.04E-02	0.466	1.760E+02	9.2	2006--2020
		CRBMV-SOP	Medium Voltage (4160 v and 6.9 Kv) Circuit Breaker Spurious Operation	EPIX/RADS	15	149,457,800	h	1240	Gamma	JNID/IL	6.47E-08	1.02E-07	1.04E-07	1.51E-07	15.500	1.490E+08	1.5	2006--2020
		CRB-FTOC-480	Low Voltage (480 V) Circuit Breaker Fails To Open/Close	EPIX/RADS	25	46,176	d	1752	Beta	EB/PL/KS	3.27E-06	3.89E-04	8.57E-04	3.30E-03	0.497	5.790E+02	8.5	2006--2020
		CRB-SOP-480	Low Voltage (480 V) Circuit Breaker Spurious Operation	EPIX/RADS	27	310,690,800	h	2630	Gamma	JNID/IL	6.26E-08	8.74E-08	8.85E-08	1.18E-07	27.500	3.110E+08	1.3	2006--2020
		CRBDC-FTOC	DC Circuit Breaker Fails To Open/Close	EPIX/RADS	5	17,566	d	602	Beta	JNID/IL	1.30E-04	2.94E-04	3.13E-04	5.59E-04	5.500	1.760E+04	1.9	2006--2020
		CRBDC-SOP	DC Circuit Breaker Spurious Operation	EPIX/RADS	0	34,938,600	h	270	Gamma	JNID/IL	5.63E-11	6.52E-09	1.43E-08	5.50E-08	0.500	3.490E+07	8.4	2006--2020
	Inverter (INV)	INV-FTOP	Inverter Fails To Operate	EPIX/RADS	52	24,269,470	h	199	Gamma	EB/PL/KS	1.73E-07	2.41E-06	3.49E-06	1.05E-05	0.986	2.820E+05	4.4	2006--2020
	Bus (BUS)	BUS-FTOP-AC	AC Bus Fails To Operate	EPIX/RADS	76	160,545,900	h	1296	Gamma	EB/PL/KS	2.91E-08	4.05E-07	5.88E-07	1.77E-06	0.986	1.680E+06	4.4	2006--2020
		BUS-FTOP-DC	DC Bus Fails To Operate	EPIX/RADS	1	2,103,936	h	16	Gamma	JNID/IL	8.38E-08	5.63E-07	7.13E-07	1.86E-06	1.500	2.100E+06	3.3	2006--2020
	Motor Control Center (MCC)	MCC-FTOP	Motor Control Center Fails To Operate	EPIX/RADS	7	28,535,130	h	217	Gamma	EB/PL/KS	1.31E-08	1.70E-07	2.43E-07	7.24E-07	1.020	4.190E+06	4.3	2006--2020
	Transformer (TFM)	TFM-FTOP	Transformer Fails To Operate	EPIX/RADS	110	60,181,620	h	512	Gamma	EB/PL/KS	2.58E-07	1.55E-06	1.93E-06	4.88E-06	1.630	8.470E+05	3.1	2006--2020
	Sequencer (SEQ)	SEQ-FTOP	Sequencer fails To operate (as a Sub Component of the EDG)	EPIX/RADS	6	61,363	d	234	Beta	JNID/IL	4.80E-05	1.00E-04	1.06E-04	1.82E-04	6.500	6.140E+04	1.8	2006--2020
	Fuse	FUS-SOP	Fuse Spurious Operation	EPIX/RADS	1	169,366,800	h	1288	Gamma	JNID/IL	1.04E-09	7.00E-09	8.86E-09	2.31E-08	1.500	1.690E+08	3.3	2006--2020
Strainers/Filters	**Filter (FLT)**	STR-FLT-RAW-PG	Strainer Plugging (Dirty water systems)	EPIX/RADS	6	7,922,615	h	62	Gamma	JNID/IL	3.72E-07	7.79E-07	8.20E-07	1.41E-06	6.500	7.920E+06	1.8	2006--2020
		STR-FLT-ELS	Filter External Leakage (Small) All Systems	EPIX/RADS	1	28,097,240	h	223	Gamma	JNID/IL	6.26E-09	4.21E-08	5.34E-08	1.39E-07	1.500	2.810E+07	3.3	2006--2020
		STR-FLT-ELL	Filter External Leakage (Small) All Systems	NUREG/CR-6928	(note c)	--	h	223	Gamma	JNID/IL	4.00E-13	9.11E-10	3.74E-09	1.71E-08	0.300	8.026E+07	18.8	2006--2020
		STR-FLT-CLEAN-PG	Filter Plugging, Clean Systems	EPIX/RADS	1	8,161,140	h	68	Gamma	JNID/IL	2.16E-08	1.45E-07	1.84E-07	4.79E-07	1.500	8.160E+06	3.3	2006--2020
		STR-FLT-CLEAN-BYP	Clean Systems Passive Filter Bypass	EPIX/RADS	0	8,161,140	h	68	Gamma	JNID/IL	2.41E-10	2.79E-08	6.13E-08	2.35E-07	0.500	8.160E+06	8.4	2006--2020
		FLT-PG-IAS	Instrument Air System Filter Plugs	EPIX/RADS	0	210,384	h	2	Gamma	JNID/IL	9.36E-09	1.08E-06	2.38E-06	9.15E-06	0.500	2.100E+05	8.4	2006--2020
	Self-Cleaning Strainer (FLTSC)	STR-FLTSC-PG	Self Cleaning Filter Plugging	EPIX/RADS	32	21,560,060	h	167	Gamma	JNID/IL	1.10E-06	1.49E-06	1.51E-06	1.96E-06	32.500	2.160E+07	1.3	2006--2020
		STR-FLTSC-BYP	Self Cleaning Filter Bypass	EPIX/RADS	0	21,560,060	h	167	Gamma	JNID/IL	9.10E-11	1.05E-08	2.32E-08	8.89E-08	0.500	2.160E+07	8.4	2006--2020
		STR-FLTSC-FTOP	Self Cleaning Filter Fails To Operate	EPIX/RADS	53	21,560,060	h	167	Gamma	JNID/IL	1.95E-06	2.46E-06	2.48E-06	3.06E-06	53.500	2.160E+07	1.2	2006--2020
		STR-FLTSC-ELS	Self Cleaning Filter External Leakage (Small)	EPIX/RADS	2	21,560,060	h	167	Gamma	JNID/IL	2.65E-08	1.01E-07	1.16E-07	2.56E-07	2.500	2.160E+07	2.5	2006--2020
		STR-FLTSC-ELL	Self Cleaning Filter External Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	167	Gamma	JNID/IL	8.69E-13	1.98E-09	8.12E-09	3.71E-08	0.300	3.695E+07	18.8	2006--2020
		STR-FLTSC-PG-SWN	Normally Running Service Water Strainer Plugs	EPIX/RADS	19	13,235,010	h	103	Gamma	JNID/IL	9.73E-07	1.45E-06	1.47E-06	2.07E-06	19.500	1.320E+07	1.4	2006--2020
		STR-FLTSC-PG-SSW	Standby Service Water Strainer Plugs	EPIX/RADS	13	7,799,060	h	60	Gamma	JNID/IL	1.04E-06	1.69E-06	1.73E-06	2.57E-06	13.500	7.800E+06	1.5	2006--2020
		STR-FLTSC-PG-EE-SSW	Standby Service Water Strainer Plugging, Environmental	EPIX/RADS	1	7,799,060	h	60	Gamma	JNID/IL	2.26E-08	1.52E-07	1.92E-07	5.01E-07	1.500	7.800E+06	3.3	2006--2020
	Sump Strainer (SMP)	STR-PG-SUMP-BWR	Containment Sump Plugging (BWRs, suppression pool strainers)	EPIX/RADS	0	5,522,832	h	42	Gamma	JNID/IL	3.56E-10	4.12E-08	9.05E-08	3.48E-07	0.500	5.520E+06	8.4	2006--2020
		STR-PG-SUMP-PWR	Containment Sump Plugging (PWRs)	EPIX/RADS	1	3,528,454	h	29	Gamma	JNID/IL	4.98E-08	3.35E-07	4.25E-07	1.11E-06	1.500	3.530E+06	3.3	2006--2020
	Traveling Screen Assembly (TSA)	TSA-PG	Traveling Screen Plugging	EPIX/RADS	37	25,155,920	h	205	Gamma	JNID/IL	1.11E-06	1.47E-06	1.49E-06	1.91E-06	37.500	2.520E+07	1.3	2006--2020
		TSA-BYP	Traveling Screen Bypass	EPIX/RADS	2	25,155,920	h	205	Gamma	JNID/IL	2.27E-08	8.63E-08	9.94E-08	2.20E-07	2.500	2.520E+07	2.5	2006--2020
		TSA-FTOP	Traveling Screen Fails To Operate	EPIX/RADS	45	25,155,920	h	205	Gamma	EB/PL/KS	1.30E-08	1.04E-06	2.12E-06	7.86E-06	0.547	2.590E+05	7.6	2006--2020

Grouping	Component Type	Component Failure Mode	Description	Data Source	Data				Industry-average Failure Probability or Rate Distribution (note a)									Date Range
					Failures	Demands or Hours	d or h	Components	Distribution	Analysis Type	5th	Median	Mean	95th	α	β	Error Factor (note b)	
		TSA-PG-SSW	Standby Service Water Traveling Screen Plugs	EPIX/RADS	0	1,972,440	h	15	Gamma	JNID/IL	9.98E-10	1.15E-07	2.53E-07	9.75E-07	0.500	1.970E+06	8.4	2006--2020
	Trash Rack (TRK)	TRK-PG	Trash Rack Plugging	EPIX/RADS	0	1,314,960	h	10	Gamma	JNID/IL	1.50E-09	1.74E-07	3.80E-07	1.47E-06	0.500	1.310E+06	8.4	2006--2020
RPS	**Bistable (BIS)**	BIS-FTOP	Bistable Fails To Operate	RPS SSs	55	102,094	d	--	Beta	JNID/IL	2.14E-06	2.47E-04	5.44E-04	2.09E-03	0.500	9.193E+02	8.4	--
	Process Logic Components	PLF-FTOP	Process Logic (Flow) Fails To Operate	RPS SSs	(note d)	6,075	d	--	Beta	JNID/IL	2.46E-06	2.85E-04	6.25E-04	2.40E-03	0.500	7.990E+02	8.4	--
		PLL-FTOP	Process Logic (Level) Fails To Operate	RPS SSs	3	6,075	d	--	Beta	JNID/IL	2.46E-06	2.85E-04	6.25E-04	2.40E-03	0.500	7.990E+02	8.4	--
		PLP-FTOP	Process Logic (Pressure) Fails To Operate	RPS SSs	6	38,115	d	--	Beta	JNID/IL	6.29E-07	7.28E-05	1.60E-04	6.15E-04	0.500	3.124E+03	8.4	--
		PLDT-FTOP	Process Logic (Delta Temperature) Fails To Operate	RPS SSs	24	4,887	d	--	Beta	JNID/IL	2.01E-05	2.32E-03	5.07E-03	1.94E-02	0.500	9.805E+01	8.4	--
	Sensor/Transmitter Components	STF-FTOP-D	Sensor/Transmitter (Flow) Fails To Operate on Demand	RPS SSs	(note d)	6,750	d	--	Beta	JNID/IL	3.21E-06	3.71E-04	8.15E-04	3.13E-03	0.500	6.132E+02	8.4	--
		STF-FTOP-R	Sensor/Transmitter (Flow) Fails To Operate per Hour	RPS SSs	(note d)	9,831,970	h	--	Gamma	JNID/IL	4.00E-10	4.63E-08	1.02E-07	3.91E-07	0.500	4.916E+06	8.4	--
		STL-FTOP-D	Sensor/Transmitter (Level) Fails To Operate on Demand	RPS SSs	5	6,750	d	--	Beta	JNID/IL	3.21E-06	3.71E-04	8.15E-04	3.13E-03	0.500	6.132E+02	8.4	--
		STL-FTOP-R	Sensor/Transmitter (Level) Fails To Operate per Hour	RPS SSs	0	9,831,970	h	--	Gamma	JNID/IL	4.00E-10	4.63E-08	1.02E-07	3.91E-07	0.500	4.916E+06	8.4	--
		STP-FTOP-D	Sensor/Transmitter (Pressure) Fails To Operate on Demand	RPS SSs	2	23,960	d	--	Beta	JNID/IL	4.60E-07	5.32E-05	1.17E-04	4.49E-04	0.500	4.278E+03	8.4	--
		STP-FTOP-R	Sensor/Transmitter (Pressure) Fails To Operate per Hour	RPS SSs	35	43,430,500	h	--	Gamma	JNID/IL	3.23E-09	3.74E-07	8.22E-07	3.16E-06	0.500	6.083E+05	8.4	--
		STT-FTOP-D	Sensor/Transmitter (Temperature) Fails To Operate on Demand	RPS SSs	17	40,759	d	--	Beta	JNID/IL	1.70E-06	1.97E-04	4.32E-04	1.66E-03	0.500	1.157E+03	8.4	--
		STT-FTOP-R	Sensor/Transmitter (Temperature) Fails To Operate per Hour	RPS SSs	29	35,107,400	h	--	Gamma	JNID/IL	3.30E-09	3.82E-07	8.40E-07	3.23E-06	0.500	5.950E+05	8.4	--
	Reactor Trip Breaker (RTB)	RTB-FTOC-BME	RPS Breaker (Mechanical) Fails To Open/Close	RPS SSs	1	97,359	d	--	Beta	JNID/IL	6.06E-08	7.01E-06	1.54E-05	5.92E-05	0.500	3.245E+04	8.4	--
		RTB-FTOP-BSN	RPS Breaker (Shunt Trip) Fails To Operate	RPS SSs	14	44,104	d	--	Beta	JNID/IL	1.29E-06	1.50E-04	3.29E-04	1.26E-03	0.500	1.520E+03	8.4	--
		RTB-FTOP-BUV	RPS Breaker (Undervoltage Trip) Fails To Operate	RPS SSs	23	57,199	d	--	Beta	JNID/IL	1.62E-06	1.88E-04	4.13E-04	1.58E-03	0.500	1.211E+03	8.4	--
		RTB-FTOC	RPS Breaker (Combined) Fails To Open/Close	RPS SSs	--	--	d	--	Beta	JNID/IL	6.11E-08	7.07E-06	1.55E-05	5.97E-05	0.500	3.217E+04	8.4	--
	Manual Switch (MSW)	MSW-FTOC	Manual Switch Fails To Open/Close	RPS SSs	2	19,789	d	--	Beta	JNID/IL	4.97E-07	5.75E-05	1.26E-04	4.85E-04	0.500	3.958E+03	8.4	--
	Relay (RLY)	RLY-FTOP	Relay Fails To Operate	RPS SSs	24	974,417	d	--	Beta	JNID/IL	9.77E-08	1.13E-05	2.48E-05	9.54E-05	0.500	2.013E+04	8.4	--
Control Rods	**Control Rod Drive (CRD)**	CRD-FTOP	Control Rod Drive Fails To Insert Rod	EPIX/RADS	19	145,016,900	d	1198	Gamma	EB/PL/KS	1.16E-09	8.38E-08	1.68E-07	6.18E-07	0.560	3.340E+06	7.4	2006--2020
		CRD-SOP	Control Rod Drive Spurious Operation	EPIX/RADS	23	145,016,900	h	1198	Gamma	JNID/IL	1.11E-07	1.60E-07	1.62E-07	2.21E-07	23.500	1.450E+08	1.4	2006--2020
	Control Rod (ROD)	ROD-FTOP	Control Rod Fails To Operate/ Insert Rod	EPIX/RADS	10	110,389,200	d	844	Gamma	JNID/IL	5.27E-08	9.24E-08	9.51E-08	1.49E-07	10.500	1.100E+08	1.6	2006--2020
		ROD-SOP	Control Rod Spurious Operation	EPIX/RADS	11	110,389,200	h	844	Gamma	JNID/IL	5.95E-08	1.02E-07	1.04E-07	1.60E-07	11.500	1.100E+08	1.6	2006--2020
	Hydraulic Control Unit (HCU)	HCU-FTI	Hydraulic Control Unit Components Fail	RPS SSs	--	--	d	--	Lognormal	--	1.05E-09	2.10E-08	1.10E-07	4.19E-07	20.000	--	20.0	--
		HCU-FTOP	Hydraulic Control Unit Fails To Operate	EPIX/RADS	19	1,347,114,000	h	10425	Gamma	JNID/IL	9.52E-09	1.42E-08	1.45E-08	2.02E-08	19.500	1.350E+09	1.4	2006--2020
		HCU-SOP	Hydraulic Control Unit Spurious Operation	EPIX/RADS	27	1,347,114,000	h	10425	Gamma	EB/PL/KS	7.14E-09	1.84E-08	1.99E-08	3.79E-08	4.300	2.160E+08	2.1	2006--2020
Heating & Ventilation	**Air Damper (DMP)**	AOD-FTOC	Air-Operated Damper Fails To Open/Close	EPIX/RADS	0	6,602	d	50	Beta	JNID/IL	2.98E-07	3.45E-05	7.57E-05	2.91E-04	0.500	6.600E+03	8.4	2006--2020
		AOD-SOP	Air-Operated Damper Spurious Operation	EPIX/RADS	4	24,287,000	h	207	Gamma	EB/PL/KS	1.29E-09	8.25E-08	1.61E-07	5.86E-07	0.579	3.600E+06	7.1	2006--2020
		AOD-ILS	Air-Operated Damper Internal Leakage (Small)	EPIX/RADS	3	24,287,000	h	207	Gamma	JNID/IL	4.46E-08	1.31E-07	1.44E-07	2.89E-07	3.500	2.430E+07	2.2	2006--2020
		AOD-ILL	Air-Operated Damper Internal Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	207	Gamma	JNID/IL	3.08E-13	7.02E-10	2.88E-09	1.32E-08	0.300	1.042E+08	18.8	2006--2020
		HOD-FTOC	Hydraulic-Operated Damper Fails To Open/Close	EPIX/RADS	4	6,113	d	42	Beta	JNID/IL	2.72E-04	6.82E-04	7.36E-04	1.38E-03	4.500	6.110E+03	2.0	2006--2020
		HOD-SOP	Hydraulic-Operated Damper Spurious Operation	EPIX/RADS	2	16,454,520	h	126	Gamma	JNID/IL	3.47E-08	1.32E-07	1.52E-07	3.35E-07	2.500	1.650E+07	2.5	2006--2020
		HOD-ILS	Hydraulic-Operated Damper Internal Leakage (Small)	EPIX/RADS	0	16,454,520	h	126	Gamma	JNID/IL	1.19E-10	1.38E-08	3.04E-08	1.16E-07	0.500	1.650E+07	8.4	2006--2020
		HOD-ILL	Hydraulic-Operated Damper Internal Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	126	Gamma	JNID/IL	6.51E-14	1.48E-10	6.08E-10	2.78E-09	0.300	4.934E+08	18.8	2006--2020

Grouping	Component Type	Component Failure Mode	Description	Data Source	Data				Industry-average Failure Probability or Rate Distribution (note a)									Date Range
					Failures	Demands or Hours	d or h	Components	Distribution	Analysis Type	5th	Median	Mean	95th	α	β	Error Factor (note b)	
		MOD-FTOC	Motor-Operated Damper Fails To Open	EPIX/RADS	11	28,949	d	52	Beta	EB/PL/KS	1.74E-05	2.44E-04	3.56E-04	1.07E-03	0.981	2.760E+03	4.4	2006--2020
		MOD-SOP	Motor-Operated Damper Spurious Operation	EPIX/RADS	0	14,134,270	h	109	Gamma	JNID/IL	1.39E-10	1.61E-08	3.54E-08	1.36E-07	0.500	1.410E+07	8.4	2006--2020
		MOD-ILS	Motor-Operated Damper Internal Leakage (Small)	EPIX/RADS	0	14,134,270	d	109	Gamma	JNID/IL	1.39E-10	1.61E-08	3.54E-08	1.36E-07	0.500	1.410E+07	8.4	2006--2020
		MOD-ILL	Motor-Operated Damper Internal Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	109	Gamma	JNID/IL	7.58E-14	1.73E-10	7.08E-10	3.24E-09	0.300	4.237E+08	18.8	2006--2020
	Air Handling	AHU-FTS-NR	Air Handling Unit Fails To Start, Normally Running	EPIX/RADS	23	15,981	d	145	Beta	JNID/IL	1.01E-03	1.45E-03	1.47E-03	2.00E-03	23.500	1.600E+04	1.4	2006--2020
	Air Handling	AHU-FTR-NR	Air Handling Unit Fails To Run, Normally Running	EPIX/RADS	39	15,131,330	h	145	Gamma	JNID/IL	1.97E-06	2.59E-06	2.61E-06	3.34E-06	39.500	1.510E+07	1.3	2006--2020
	Air Handling	AHU-FTS-NS	Air Handling Unit Fails To Start, Normally Standby	EPIX/RADS	33	158,866	d	403	Beta	JNID/IL	1.55E-04	2.09E-04	2.11E-04	2.74E-04	33.500	1.590E+05	1.3	2006--2020
	Air Handling	AHU-FTR<1H	Air Handling Unit Fails To Run <1H, Normally Standby	EPIX/RADS	0	147,963	h	395	Gamma	JNID/IL	1.33E-08	1.54E-06	3.38E-06	1.30E-05	0.500	1.480E+05	8.4	2006--2020
	Air Handling	AHU-FTR>1H	Air Handling Unit Fails To Run >1H, Normally Standby	EPIX/RADS	27	9,928,068	h	403	Gamma	JNID/IL	1.96E-06	2.74E-06	2.77E-06	3.69E-06	27.500	9.930E+06	1.3	2006--2020
	Chiller (CHL)	CHL-FTS-NR	Chiller Unit Fails To Start, Normally Running	EPIX/RADS	66	21,137	d	92	Beta	EB/PL/KS	9.52E-06	2.05E-03	5.09E-03	2.05E-02	0.438	8.560E+01	10.0	2006--2020
	Chiller (CHL)	CHL-FTR-NR	Chiller Unit Fails To Run, Normally Running	EPIX/RADS	179	7,250,769	h	92	Gamma	EB/PL/KS	1.94E-07	1.84E-05	3.87E-05	1.47E-04	0.524	1.350E+04	8.0	2006--2020
	Chiller (CHL)	CHL-FTS-NS	Chiller Unit Fails To Start, Normally Standby	EPIX/RADS	0	18,006	d	64	Beta	JNID/IL	1.09E-07	1.26E-05	2.78E-05	1.07E-04	0.500	1.800E+04	8.4	2006--2020
	Chiller (CHL)	CHL-FTR<1H	Chiller Unit Fails To Run <1H, Normally Standby	EPIX/RADS	34	233,781	h	64	Gamma	JNID/IL	1.09E-04	1.46E-04	1.48E-04	1.91E-04	34.500	2.340E+05	1.3	2006--2020
	Chiller (CHL)	CHL-FTR>1H	Chiller Unit Fails To Run >1H, Normally Standby	EPIX/RADS	34	233,781	h	64	Gamma	JNID/IL	1.09E-04	1.46E-04	1.48E-04	1.91E-04	34.500	2.340E+05	1.3	2006--2020
	Fan (FAN)	FAN-FTS-NS	HVC Fan Fails To Start, Normally Standby	EPIX/RADS	17	63,511	d	154	Beta	JNID/IL	1.77E-04	2.70E-04	2.76E-04	3.92E-04	17.500	6.350E+04	1.5	2006--2020
	Fan (FAN)	FAN-FTR<1H	HVC Fan FTR<1H, Normally Standby	EPIX/RADS	17	39,405	h	133	Gamma	JNID/IL	2.85E-04	4.36E-04	4.44E-04	6.32E-04	17.500	3.940E+04	1.5	2006--2020
	Fan (FAN)	FAN-FTR>1H	HVC Fan FTR>1H, Normally Standby	EPIX/RADS	3	120,200	h	154	Gamma	JNID/IL	9.03E-06	2.64E-05	2.91E-05	5.86E-05	3.500	1.200E+05	2.2	2006--2020
	Fan (FAN)	FAN-FTS-NR	HVC Fan Fails To Start, Normally Running	EPIX/RADS	28	87,323	d	233	Beta	EB/PL/KS	1.69E-06	2.99E-04	7.15E-04	2.84E-03	0.456	6.360E+02	9.5	2006--2020
	Fan (FAN)	FAN-FTR-NR	HVC Fan Fails To Run, Normally Running	EPIX/RADS	50	16,050,850	h	233	Gamma	EB/PL/KS	4.87E-08	1.83E-06	3.23E-06	1.11E-05	0.674	2.090E+05	6.1	2006--2020
Miscellaneous Equipment	Air Compressor (CMP)	MDC-FTS-NR	Motor-Driven Compressor Fails To Start, Normally Running	EPIX/RADS	52	7,855	d	65	Beta	EB/PL/KS	3.28E-05	5.78E-03	1.36E-02	5.36E-02	0.456	3.310E+01	9.3	2006--2020
Miscellaneous Equipment	Air Compressor (CMP)	MDC-FTR-NR	Motor-Driven Compressor Fails To Run	EPIX/RADS	173	4,802,083	h	65	Gamma	EB/PL/KS	9.92E-06	3.54E-05	4.03E-05	8.72E-05	2.690	6.680E+04	2.5	2006--2020
Miscellaneous Equipment	Air Compressor (CMP)	MDC-FTS-NS	Motor-Driven Compressor Fails To Start, Normally Standby	EPIX/RADS	34	21,074	d	57	Beta	EB/PL/KS	9.56E-05	1.89E-03	2.93E-03	9.27E-03	0.847	2.890E+02	4.9	2006--2020
Miscellaneous Equipment	Air Compressor (CMP)	MDC-FTR<1H	Motor-Driven Compressor Fails To Run (0 To 1 Hour)	EPIX/RADS	1	20,248	h	54	Gamma	JNID/IL	8.71E-06	5.86E-05	7.41E-05	1.93E-04	1.500	2.020E+04	3.3	2006--2020
Miscellaneous Equipment	Air Compressor (CMP)	MDC-FTR>1H	Motor-Driven Compressor Fails To Run (> 1 Hour)	EPIX/RADS	90	1,573,366	h	57	Gamma	JNID/IL	4.81E-05	5.74E-05	5.75E-05	6.80E-05	90.500	1.570E+06	1.2	2006--2020
Miscellaneous Equipment	Air Compressor (CMP)	EDC-FTS-NS	Engine-Driven Compressor Fails To Start, Normally Standby	EPIX/RADS	14	1,459	d	4	Beta	JNID/IL	6.06E-03	9.68E-03	9.93E-03	1.45E-02	14.500	1.450E+03	1.5	2006--2020
Miscellaneous Equipment	Air Compressor (CMP)	EDC-FTR<1H	Engine-Driven Compressor Fails To Run <1H, Normally Standby	EPIX/RADS	1	1,459	h	4	Gamma	JNID/IL	1.20E-04	8.10E-04	1.03E-03	2.68E-03	1.500	1.460E+03	3.3	2006--2020
Miscellaneous Equipment	Air Compressor (CMP)	EDC-FTR>1H	Engine-Driven Compressor Fails To Run >1H, Normally Standby	EPIX/RADS	12	1,609	h	4	Gamma	JNID/IL	4.54E-03	7.56E-03	7.77E-03	1.17E-02	12.500	1.610E+03	1.5	2006--2020
Miscellaneous Equipment	Air Compressor (CMP)	EDC-FTR-NR	Engine-Driven Compressor Fails To Run, Normally Running	EPIX/RADS	10	163,321	d	3	Gamma	JNID/IL	3.56E-05	6.24E-05	6.43E-05	1.00E-04	10.500	1.630E+05	1.6	2006--2020
Miscellaneous Equipment	Air Compressor (CMP)	MDC-FTR-IAS	Instrument Air System Motor-Driven Compressor Fails To Run	EPIX/RADS	117	2,376,803	h	36	Gamma	EB/PL/KS	2.41E-05	4.73E-05	4.93E-05	8.22E-05	7.620	1.540E+05	1.7	2006--2020
Miscellaneous Equipment	Air Compressor (CMP)	MDC-FTR-CIA	Containment Instrument Air Motor-Driven Compressor Fails To Run	EPIX/RADS	0	98,561	h	2	Gamma	JNID/IL	1.99E-08	2.31E-06	5.07E-06	1.95E-05	0.500	9.860E+04	8.4	2006--2020
Miscellaneous Equipment	Air Dryer Unit (ADU)	ADU-FTOP	Air dryer unit fails To operate	WSRC	--	--	h	0	Gamma	JNID/IL	5.35E-10	1.22E-06	5.00E-06	2.29E-05	0.300	6.000E+04	18.8	--
Miscellaneous Equipment	Accumulator (ACC)	ACC-FTOP	Accumulator Fails To Operate	EPIX/RADS	11	79,315,180	h	617	Gamma	JNID/IL	8.25E-08	1.41E-07	1.45E-07	2.22E-07	11.500	7.930E+07	1.6	2006--2020
Miscellaneous Equipment	Accumulator (ACC)	ACC-ELS	Accumulator External Leakage (Small)	EPIX/RADS	8	79,315,180	h	617	Gamma	JNID/IL	5.47E-08	1.03E-07	1.07E-07	1.74E-07	8.500	7.930E+07	1.7	2006--2020
Miscellaneous Equipment	Accumulator (ACC)	ACC-ELL	Accumulator External Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	617	Gamma	JNID/IL	8.02E-13	1.83E-09	7.49E-09	3.43E-08	0.300	4.005E+07	18.8	2006--2020

Grouping	Component Type	Component Failure Mode	Description	Data Source	Data				Industry-average Failure Probability or Rate Distribution (note a)									Date Range
					Failures	Demands or Hours	d or h	Components	Distribution	Analysis Type	5th	Median	Mean	95th	α	β	Error Factor (note b)	
	Cooling Tower Fan (CTF)	CTF-FTS-NS	Cooling Tower Fan Fails To Start (Standby)	EPIX/RADS	14	37,307	d	55	Beta	JNID/IL	2.37E-04	3.80E-04	3.89E-04	5.70E-04	14.500	3.730E+04	1.5	2006--2020
		CTF-FTR<1H	Cooling Tower Fan Fails To Run <1H (Standby)	EPIX/RADS	0	37,231	h	54	Gamma	JNID/IL	5.29E-08	6.11E-06	1.34E-05	5.16E-05	0.500	3.720E+04	8.4	2006--2020
		CTF--FTR>1H	Cooling Tower Fan Fails To Run >1H (Standby)	EPIX/RADS	0	895,323	h	55	Gamma	JNID/IL	2.20E-09	2.54E-07	5.58E-07	2.15E-06	0.500	8.950E+05	8.4	2006--2020
		CTF-FTS-NR	Cooling Tower Fan Fails To Start	EPIX/RADS	1	2,239	d	20	Beta	JNID/IL	7.85E-05	5.28E-04	6.70E-04	1.74E-03	1.500	2.240E+03	3.3	2006--2020
		CTF-FTR-NR	Cooling Tower Fan Fails To Run	EPIX/RADS	6	1,253,930	h	20	Gamma	JNID/IL	2.36E-06	4.94E-06	5.18E-06	8.94E-06	6.500	1.250E+06	1.8	2006--2020
	Tank (TNK)	TNK-FC	Tank Rupture	EPIX/RADS	16	46,469,300	h	383	Gamma	EB/PL/KS	5.99E-10	1.61E-07	4.18E-07	1.72E-06	0.420	1.000E+06	10.7	2006--2020
		TNK-PRESS-LIQ-ELS	Pressurized Liquid Tank Small Leakage External Leakage (Small)	EPIX/RADS	5	19,535,510	h	156	Gamma	EB/PL/KS	8.76E-10	1.12E-07	2.51E-07	9.71E-07	0.489	1.950E+06	8.7	2006--2020
		TNK-PRESS-LIQ-ELL	Pressurized Liquid Tank Small Leakage External Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	156	Gamma	EB/PL/KS	1.88E-12	4.28E-09	1.76E-08	8.04E-08	0.300	1.707E+07	18.8	2006--2020
		TNK-UNPRESS-LIQ-ELS	Unpressurized Liquid Tank Small Leakage External Leakage (Small)	EPIX/RADS	4	22,725,910	h	195	Gamma	JNID/IL	7.32E-08	1.84E-07	1.98E-07	3.73E-07	4.500	2.270E+07	2.0	2006--2020
		TNK-UNPRESS-LIQ-ELL	Unpressurized Liquid Tank Small Leakage External Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	195	Gamma	JNID/IL	1.48E-12	3.38E-09	1.39E-08	6.34E-08	0.300	2.165E+07	18.8	2006--2020
		TNK-FC-IAS	Instrument Air System Tank Fails To Control	EPIX/RADS	0	3,287,400	h	25	Gamma	JNID/IL	5.98E-10	6.91E-08	1.52E-07	5.84E-07	0.500	3.290E+06	8.4	2006--2020
		TNK-FC-SWS	Standby Service Water Tank Fails To Control	EPIX/RADS	0	880,966	h	7	Gamma	JNID/IL	2.23E-09	2.58E-07	5.68E-07	2.18E-06	0.500	8.810E+05	8.4	2006--2020
		TNK-GAS-ELS	Gas Tank Small Leakage External Leakage (Small)	EPIX/RADS	0	4,207,872	h	32	Gamma	JNID/IL	4.67E-10	5.40E-08	1.19E-07	4.56E-07	0.500	4.210E+06	8.4	2006--2020
		TNK-GAS-ELL	Gas Tank Small Leakage External Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	32	Gamma	JNID/IL	8.92E-13	2.03E-09	8.33E-09	3.81E-08	0.300	3.601E+07	18.8	2006--2020
	Orifice (ORF)	ORF-PG	Orifice Plugging	WSRC	--	--	h	0	Gamma	JNID/IL	1.07E-10	2.44E-07	1.00E-06	4.57E-06	0.300	3.000E+05	18.8	--
	Pipe (PIPE)	PIPE-OTHER-ELS	Piping Non-Service Water System External Leak Small	EPIX	5	15,830,000,000	h-ft	0	Gamma	JNID/IL	9.94E-13	1.15E-10	2.53E-10	9.71E-10	0.500	1.979E+09	8.4	--
		PIPE-OTHER-ELL	Piping Non-Service Water System External Leak Large	NUREG/CR-6928	(note c)	15,830,000,000	h-ft	0	Gamma	JNID/IL	2.70E-15	6.16E-12	2.53E-11	1.16E-10	0.300	1.187E+10	18.8	--
		PIPE-SWS-ELS	Piping Service Water System External Leak Small	EPIX	9	13,060,000,000	h-ft	0	Gamma	JNID/IL	2.71E-12	3.14E-10	6.89E-10	2.65E-09	0.500	7.256E+08	8.4	--
		PIPE-SWS-ELL	Piping Service Water System External Leak Large	NUREG/CR-6928	(note c)	13,060,000,000	h-ft	0	Gamma	JNID/IL	1.48E-14	3.36E-11	1.38E-10	6.30E-10	0.300	2.177E+09	18.8	--
	Heat Exchanger (HTX)	HTX-LOHT	Heat Exchanger Plugging/Loss of Heat Transfer	EPIX/RADS	67	222,831,700	h	1750	Gamma	EB/PL/KS	1.11E-09	1.50E-07	3.39E-07	1.32E-06	0.483	1.420E+06	8.8	2006--2020
		HTX-ILS	Heat Exchanger Internal Leakage (Small)	EPIX/RADS	61	222,831,700	h	1750	Gamma	JNID/IL	2.21E-07	2.74E-07	2.76E-07	3.36E-07	61.500	2.230E+08	1.2	2006--2020
		HTX-ILL	Heat Exchanger Internal Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	1750	Gamma	JNID/IL	5.91E-13	1.35E-09	5.52E-09	2.53E-08	0.300	5.435E+07	18.8	2006--2020
		HTX-ELS	Heat Exchanger External Leakage (Small)	EPIX/RADS	38	222,831,700	h	1750	Gamma	EB/PL/KS	5.71E-09	1.21E-07	1.90E-07	6.08E-07	0.825	4.350E+06	5.0	2006--2020
		HTX-ELL	Heat Exchanger External Leakage (Rupture)	NUREG/CR-6928	(note c)	--	h	1750	Gamma	EB/PL/KS	3.05E-12	6.95E-09	2.85E-08	1.30E-07	0.300	1.053E+07	18.8	2006--2020
		HTX-PG-CCW	Heat Exchanger Plugging Non Standby	EPIX/RADS	8	28,273,230	h	223	Gamma	JNID/IL	1.53E-07	2.89E-07	3.01E-07	4.87E-07	8.500	2.830E+07	1.7	2006--2020
		HTX-PG-NE-CCW	Component Cooling Water Heat Exchanger Plugging Non-ExEE (hr-1)	EPIX/RADS	3	28,273,230	h	223	Gamma	JNID/IL	3.83E-08	1.12E-07	1.24E-07	2.49E-07	3.500	2.830E+07	2.2	2006--2020

Acronyms - ABT (automatic bus transfer switch), ACC (accumulator), ADU (air dryer unit), AFW (auxiliary feedwater), AHU (air handling unit), AOD (air-operated damper), AOV (air-operated valve), BAT (battery), BCH (battery charger), BFV (butterfly valve), BWR (boiling water reactor), CCW (component cooling water), CHL (chiller), CIA (containment instrument air), CKV (check valve), CMP (air compressor), CRB (circuit breaker), CRD (control rod drive), CTF (cooling Tower fan), CTG (combustion turbine generator), CWS (circulating water system), EB/PL/KS (empirical Bayes/plant level/Kass Steffey), EDC (engine-driven compressor), EDG (diesel generator), EDP (engine-driven pump), ELL (external large leakage), ELS (external small leakage), EOV (explosive-operated valve), EPIX (Equipment Performance and Information Exchange), FC (fail To control), FTC (fail To close), FCV (flow control valve), FRV (feedwater regulating valve), FTLR (fail To load and run), FTO (fail To open), FTOC (fail To open or close), FTOP (fail To operate), FTR (fail To run), FTS (fail To start), HCS (high-pressure core spray), HCU (hydraulic control unit), HOD (hydraulic-operated damper), HOV (hydraulic-operated valve), HTG (hydro turbine generator), HTX (heat exchanger), HVC (heating, ventilating, and air conditioning), IAS (instrument air system), ILL (internal large leakage), ILS (internal small leakage), JNID/IL (Jeffreys noninformative distribution/industry level), LIQ (liquid), LL (lower limit), LOHT (loss of heat transfer), MDC (motor-driven compressor), MDP (motor-driven pump), MFW (main feedwater), MOD (motor-driven damper), MOV (motor-operated valve), MSS (main steam system), MSV (main steam isolation valve), NR (normally running), NS (normally standby), ORF (orifice), PDP (positive displacement pump), PLL (process logic level), PMP (pump volute), PORV (power-operated relief valve), PWR (pressurized water reactor), PZR (pressurizer), RADS (Reliability and Availability Database System), RCS (reactor coolant system), ROD (control rod), RPS (reactor protection system), RVL (low capacity relief valve), SBO (station blackout), SOV (solenoid-operated valve), SRV (safety relief valve), SS (system study), STBY (standby), SVV (code safety valve), SWS (service water system), TDP (turbine-driven pump), TNK (tank), VBV (vacuum breaker valve), WSRC (Westinghouse Savannah River Company), XVM (manual valve)

Note a - If these distributions are To be used as priors in Bayesian updates using plant-specific data, then a check for consistency between the prior and the data should be performed first, as suggested in supporting requirement DA-D4c in ASME/ANS RA-Sa-2009 and outlined in Section 6.2.3.5 of NUREG/CR-6823.

Note b - The error factor is from an empirical Bayes analysis at the plant level, with Kass-Steffey adjustment. The error factor is the 95th percentile divided by the median.

Note c - External and internal large leakage (ELL and ILL) events are defined as greater than 50 gpm. Because ELL and ILL events are rare, good estimates for ELL and ILL cannot be obtained using data from only one component. The NUREG/CR-6928 study (Table A.1.2-1) shows the mean of ELL is the ELS mean multiplied by 0.07 for pump, valves, tanks, and heat exchanger shells, multiplied by 0.2 for Emergency Service Water (ESW) pipe, multiplied by 0.1 for non-ESW pipe, and multiplied by 0.15 for heat exchanger tubes. The ILL mean is the ILS mean multiplied by 0.02.

Note d - The flow process logic (PLF) reliability was estimated by using the level process logic (PLL) data. The flow sensor/transmitter (STF) reliability was estimated by using the level sensor/transmitter (STL) data.

3. COMPONENT OR TRAIN UNAVAILABILITY

This section represents the third update to the original set of component availability data and results documented in NUREG/CR-6928. Train UA data and resulting probability distributions are summarized in Table 2. More detailed information is presented in Appendix B, Component/Train Unavailability Data Sheets.

The Mitigating Systems Performance Index (MSPI) [23] train UA data covering 2006–2020 were used to update the train UA estimates for MSPI systems and components and trains. For non-MSPI systems, the UA results from the original NUREG/CR-6928 continue to be used.

Table 2. Train UA data and results.

Section	Sub Section	Train Unavailability Event	Train Description	Data Source	Analysis	Data: MSPI Trains	Industry-average Probability Distribution (note a): Distribution (note b)	5th	Median	Mean	95th	α	β	Std Dev	Error Factor	Date Range	Comments
Generators	1E EDG	EDG-EPS	Diesel Generator Test or Maintenance	EPIX/RADS	CurveFit/Train	258	Normal	3.48E-03	1.51E-02	1.51E-02	2.67E-02	--	--	7.04E-03	1.8	2006--2020	
	Combustion Turbine	CTG	Combustion Turbine Generator Test or Maintenance	IPEs	SCNID (IPEs/2)	--	Beta	2.12E-04	2.43E-02	5.00E-02	1.87E-01	0.500	9.5000	--	7.7	--	(Note c)
	HPCS	EDG-HCS	HPCS Diesel Generator Test or Maintenance	EPIX/RADS	CurveFit/Train	8	Normal	7.13E-03	1.33E-02	1.33E-02	1.94E-02	--	--	3.74E-03	1.5	2006--2020	
	Generator Service Water	EDG-SW	Service Water for Emergency Diesel Generator Test or Maintenance	EPIX/RADS	CurveFit/Train	6	Normal	-4.49E-04	1.11E-02	1.11E-02	2.27E-02	--	--	7.04E-03	2.0	2006--2020	
		HCS-SW	Service Water for High Pressure Core Spray Generator Test or Maintenance	EPIX/RADS	CurveFit/Train	7	Normal	4.91E-03	7.32E-03	7.32E-03	9.72E-03	--	--	1.46E-03	1.3	2006--2020	
Pumps	Motor Driven	MDP-ALL	Motor-Driven Pump Test or Maintenance (All Clean Systems)	EPIX/RADS	CurveFit/Train	1061	Normal	-8.39E-03	6.56E-03	6.56E-03	2.15E-02	--	--	9.09E-03	3.3	2006--2020	
		MDP-AFW	Motor-Driven Pump Test or Maintenance (AFW)	EPIX/RADS	CurveFit/Train	124	Normal	-2.01E-04	3.14E-03	3.14E-03	6.49E-03	--	--	2.03E-03	2.1	2006--2020	
		MDP-CCW	Motor-Driven Pump Test or Maintenance (CCW)	EPIX/RADS	CurveFit/Train	142	Normal	-5.58E-03	4.82E-03	4.82E-03	1.52E-02	--	--	6.32E-03	3.2	2006--2020	
		MDP-ESW	Motor-Driven Pump Test or Maintenance (ESW)	EPIX/RADS	CurveFit/Train	305	Normal	-1.12E-02	1.24E-02	1.24E-02	3.61E-02	--	--	1.44E-02	2.9	2006--2020	
		MDP-FWS	Feed Water System Motor-Driven Pumps Test or Maintenance	EPIX/RADS	CurveFit/Train	4	Normal	6.43E-03	7.68E-03	7.68E-03	8.93E-03	--	--	7.61E-04	1.2	2006--2020	
		MDP-HCS	Motor-Driven Pump Test or Maintenance (HCS)	EPIX/RADS	CurveFit/Train	8	Normal	4.22E-03	7.68E-03	7.68E-03	1.11E-02	--	--	2.10E-03	1.5	2006--2020	
		MDP-HPI	Motor-Driven Pump Test or Maintenance (HPI)	EPIX/RADS	CurveFit/Train	199	Normal	-4.32E-04	2.99E-03	2.99E-03	6.40E-03	--	--	2.08E-03	2.1	2006--2020	
		MDP-RHR	Motor-Driven Pump Test or Maintenance (RHR)	EPIX/RADS	CurveFit/Train	225	Normal	3.91E-04	5.09E-03	5.09E-03	9.79E-03	--	--	2.86E-03	1.9	2006--2020	
		MDP-RHR-BWR	Motor-Driven Pump Test or Maintenance (RHR-BWR)	EPIX/RADS	CurveFit/Train	80	Normal	1.84E-03	5.92E-03	5.92E-03	1.00E-02	--	--	2.48E-03	1.7	2006--2020	
		MDP-RHR-PWR	Motor-Driven Pump Test or Maintenance (RHR-PWR)	EPIX/RADS	CurveFit/Train	145	Normal	-2.28E-04	4.63E-03	4.63E-03	9.50E-03	--	--	2.96E-03	2.0	2006--2020	
		MDP-RHRSW	Motor-Driven Pump Test or Maintenance (RHR Service Water)	EPIX/RADS	CurveFit/Train	54	Normal	4.43E-04	4.91E-03	4.91E-03	9.38E-03	--	--	2.72E-03	1.9	2006--2020	
		PDP	Positive Displacement Pump Test or Maintenance	IPEs	SCNID (IPEs)	--	Beta	1.26E-05	1.46E-03	3.19E-03	1.23E-02	0.500	156.0000	--	8.4	--	(Note c)
		MDP-CLEAN	Motor-Driven Pump Test or Maintenance (Clean System)	EPIX/RADS	CurveFit/Train	702	Normal	-1.97E-03	4.14E-03	4.14E-03	1.02E-02	--	--	3.71E-03	2.5	2006--2020	
		MDP-NR-CLEAN	Motor-Driven Pump Test & Maintenance (Normally Running System, Clean)	EPIX/RADS	CurveFit/Train	146	Normal	-5.39E-03	4.90E-03	4.90E-03	1.52E-02	--	--	6.25E-03	3.1	2006--2020	
		MDP-NS-CLEAN	Motor-Driven Pump Test or Maintenance (Normally Standby System, Clean)	EPIX/RADS	CurveFit/Train	556	Normal	-4.17E-04	3.94E-03	3.94E-03	8.30E-03	--	--	2.65E-03	2.1	2006--2020	
		MDP-NR-DIRTY	Motor-Driven Pump Test or Maintenance (Normally Running System, Dirty)	EPIX/RADS	CurveFit/Train	305	Normal	-1.12E-02	1.24E-02	1.24E-02	3.61E-02	--	--	1.44E-02	2.9	2006--2020	
		MDP-NS-DIRTY	Motor-Driven Pump Test or Maintenance (Normally Standby System, Dirty)	EPIX/RADS	CurveFit/Train	359	Normal	-1.10E-02	1.13E-02	1.13E-02	3.36E-02	--	--	1.35E-02	3.0	2006--2020	
	Turbine Driven	TDP-ALL	Turbine-Driven Pump Test or Maintenance (AFW, HPCI, and RCIC combined)	EPIX/RADS	CurveFit/Train	120	Normal	1.16E-05	7.30E-03	7.30E-03	1.46E-02	--	--	4.43E-03	2.0	2006--2020	
		TDP-AFW	Turbine-Driven Pump Test or Maintenance (AFW)	EPIX/RADS	CurveFit/Train	66	Normal	-2.71E-04	4.64E-03	4.64E-03	9.55E-03	--	--	2.99E-03	2.1	2006--2020	
		TDP-HCI	Turbine-Driven Pump Test or Maintenance (HPCI)	EPIX/RADS	CurveFit/Train	24	Normal	6.57E-03	1.11E-02	1.11E-02	1.57E-02	--	--	2.77E-03	1.4	2006--2020	
		TDP-RCI	Turbine-Driven Pump Test or Maintenance (RCIC)	EPIX/RADS	CurveFit/Train	30	Normal	3.07E-03	1.01E-02	1.01E-02	1.71E-02	--	--	4.26E-03	1.7	2006--2020	
		TDP-HCI-RCI	Turbine-Driven Pump Test or Maintenance (HPCI and RCIC combined)	EPIX/RADS	CurveFit/Train	24	Normal	6.57E-03	1.11E-02	1.11E-02	1.57E-02	--	--	2.77E-03	1.4	2006--2020	
	Engine Driven	EDP	Engine-Driven Pump Test or Maintenance	EPIX/RADS	CurveFit/Train	15	Normal	-2.87E-03	2.27E-02	2.27E-02	4.83E-02	--	--	1.56E-02	2.1	2006--2020	
		EDP-AFW	Engine-Driven Pump Test or Maintenance	EPIX/RADS	CurveFit/Train	5	Normal	2.10E-03	5.47E-03	5.47E-03	8.85E-03	--	--	2.05E-03	1.6	2006--2020	
		EDP-ESW	Engine-Driven Pump Test or Maintenance	EPIX/RADS	CurveFit/Train	10	Normal	1.29E-02	3.14E-02	3.14E-02	4.99E-02	--	--	1.13E-02	1.6	2006--2020	
Heat Exchangers	Pooled	HTX	Heat Exchanger Test or Maintenance	EPIX/RADS	CurveFit/Train	98	Normal	-7.13E-03	7.63E-03	7.63E-03	2.24E-02	--	--	8.97E-03	2.9	2006--2020	
	CCW	HTX-CCW	Heat Exchanger Test or Maintenance (CCW)	EPIX/RADS	CurveFit/Train	86	Normal	-7.43E-03	7.73E-03	7.73E-03	2.29E-02	--	--	9.22E-03	3.0	2006--2020	
	Service Water	HTX-ESW	Heat Exchanger Test or Maintenance (ESW)	EPIX/RADS	CurveFit/Train	4	Normal	9.74E-03	1.61E-02	1.61E-02	2.24E-02	--	--	3.84E-03	1.4	2006--2020	

Section	Sub Section	Train Unavailability Event	Train Description	Data Source	Analysis	Data	Industry-average Probability Distribution (note a)									Date Range	Comments
						MSPI Trains	Distribution (note b)	5th	Median	Mean	95th	α	β	Std Dev	Error Factor		
	Residual Heat Removal	HTX-RHR-BWR	Heat Exchanger and Pump Train Test or Maintenance (RHR-BWR)	EPIX/RADS	CurveFit/Train	6	Normal	-4.47E-04	3.05E-03	3.05E-03	6.55E-03	--	--	2.13E-03	2.1	2006--2020	
		HTX-RHR-PWR	Heat Exchanger and Pump Train Test or Maintenance (RHR-BWR)	EPIX/RADS	CurveFit/Year	15	Normal	-4.97E-04	2.09E-04	2.09E-04	9.15E-04	--	--	4.29E-04	4.4	2006--2020	
Electrical	**Breaker**	CRB	Circuit Breaker Test or Maintenance	Unknown	CurveFit	--	Beta	--	--	5.00E-01	--	0.500	--	--	--	--	
	Bus	BDC	Bus (DC) Test or Maintenance	IPEs	SCNID (IPEs)	--	Beta	7.87E-07	9.10E-05	2.00E-04	7.68E-04	0.500	2499.5000	--	8.4	--	(Note c)
		BAC	Bus (AC) Test or Maintenance	IPEs	IPEs	--	Beta	7.87E-07	9.10E-05	2.00E-04	7.68E-04	0.500	2499.5000	--	8.4	--	(Note c)
	Battery	BAT	Battery Test or Maintenance	Letter	CurveFit	--	Lognormal	2.80E-06	1.48E-04	2.72E-03	7.84E-03	--		--	52.9	--	
		BCH	Battery Charger Test or Maintenance	IPEs	SCNID (IPEs)	--	Beta	7.89E-06	9.12E-04	2.00E-03	7.68E-03	0.500	249.5000	--	8.4	--	(Note c)
	Transformer	TFM	Startup Transformer Test or Maintenance	Letter	CurveFit	--	Lognormal	4.55E-07	4.11E-05	1.75E-03	3.72E-03	--	--	--	90.5	--	(Note d)
	RPS	CCP-RPS	RPS Channel A Test or Maintenance	RPS SS	NUREG/CR-5500	--	Beta	4.14E-05	4.78E-03	5.00E-03	3.96E-02	0.500	47.7600	--	8.3	--	(Note e)
Other	**Ventilation**	AHU	Air Handling Unit Test or Maintenance	IPEs	SCNID (IPEs)	--	Beta	9.87E-06	1.14E-03	2.50E-03	9.59E-03	0.500	199.5000	--	8.4	--	(Note c)
		CHL	Chiller Test or Maintenance	IPEs	SCNID (IPEs/2)	--	Beta	8.11E-05	9.34E-03	2.00E-02	7.61E-02	0.500	24.5000	--	8.2	--	(Note c)
	Compressor	MDC	Motor-Driven Compressor Test or Maintenance	IPEs	SCNID (IPEs/2)	--	Beta	4.80E-05	5.54E-03	1.20E-02	4.59E-02	0.500	41.1667	--	8.3	--	(Note c)
		DDC	Diesel-Driven Compressor Test or Maintenance	Existing SPAR	JNID/IL	--	Beta	4.80E-05	5.54E-03	1.20E-02	4.59E-02	0.500	41.1667	--	8.3	--	From MDC
		EDC	Engine-Driven Compressor Test or Maintenance	IPEs	SCNID (IPEs/2)	--	Beta	4.80E-05	5.54E-03	1.20E-02	4.59E-02	0.500	41.1667	--	8.3	--	(Note c)
	Fan	FAN	Fan Test or Maintenance	IPEs	SCNID (IPEs)	--	Beta	7.89E-06	9.12E-04	2.00E-03	7.68E-03	0.500	249.5000	--	8.4	--	(Note c)
		CTF	Cooling Tower Fan Test or Maintenance	IPEs	SCNID (IPEs)	--	Beta	7.89E-06	9.12E-04	2.00E-03	7.68E-03	0.500	249.5000	--	8.4	--	(Note c)
	Explosive Valve	EPV	Explosive-Operated (SQUIBB) Valve Test or Maintenance	IPEs	SCNID (IPEs)	--	Beta	2.36E-06	2.73E-04	6.00E-04	2.30E-03	0.500	832.8330	--	8.4	--	(Note c)
Headers	**Clean Water**	HDR-AFW	AFW Header Test or Maintenance	EPIX/RADS	CurveFit/Train	16	Normal	-1.07E-03	7.70E-04	7.70E-04	2.61E-03	--	--	1.12E-03	3.4	2006--2020	
		HDR-CCW	CCW Header Test or Maintenance	EPIX/RADS	CurveFit/Train	6	Normal	-4.16E-04	2.42E-04	2.42E-04	9.00E-04	--	--	4.00E-04	3.7	2006--2020	
		HDR-HPI	HPSI Header Test or Maintenance	EPIX/RADS	CurveFit/Train	45	Normal	-2.68E-04	1.36E-04	1.36E-04	5.41E-04	--	--	2.46E-04	4.0	2006--2020	
		HDR-ISO	ISO Header Test or Maintenance	EPIX/RADS	CurveFit/Train	6	Normal	7.24E-04	2.62E-03	2.62E-03	4.52E-03	--	--	1.15E-03	1.7	2006--2020	
		HDR-RHR	RHR Header Test or Maintenance	EPIX/RADS	CurveFit/Train	16	Normal	-1.39E-03	7.21E-04	7.21E-04	2.83E-03	--	--	1.28E-03	3.9	2006--2020	
	Service Water	HDR-ESW	ESW Header Test or Maintenance	EPIX/RADS	CurveFit/Train	123	Normal	-2.34E-02	4.61E-03	4.61E-03	3.26E-02	--	--	1.70E-02	7.1	2006--2020	
		HDR-RHRSW	RHRSW Header Test or Maintenance	EPIX/RADS	CurveFit/Train	8	Normal	-2.96E-03	2.81E-03	2.81E-03	8.57E-03	--	--	3.50E-03	3.1	2006--2020	

Acronyms - ACX or AHU (air handling unit), AFW (auxiliary feedwater system), BAC (ac bus), BAT (battery), BCH (battery charger), BDC (dc bus), BWR (boiling water reactor), CCP (channel calculator for pressure), CCW (component cooling water), CHL (chiller), CRB (circuit breaker), CTF (cooling tower fan), CTG (combustion turbine generator), DDC (diesel-driven compressor), EDG (emergency diesel generator), EDP (engine-driven pump), EPIX (Equipment Performance and Information Exchange), EPS (emergency power system), EPV (explosive-operated valve), ESW (emergency or essential service water), FWS (feed water system), HDR (header), HPCI or HCI (high-pressure coolant injection), HPCS or HCS (high-pressure core spray), HPSI or HPI (high pressure safety injection), HTX (heat exchanger), IPE (individual plant examination), ISO (isolation condenser), MDC (motor-driven compressor), MDP (motor-driven pump), MOV (motor-operated valve), NR(normally running), NS (normally standby), PDP (positive displacement pump), PWR (pressurized water reactor), RADS (Reliability and Availability Database System), RCIC or RCI (reactor core isolation cooling), RHR (residual heat removal), RPS (reactor protection system), SCNID (simplified constrained noninformative distribution), SS (system study), SW (service water), TDP (turbine-driven pump), TFM (transformer), YL (year level)

Note a - If these distributions are to be used as priors in Bayesian updates using plant-specific data, then a check for consistency between the prior and the data should be performed first, as suggested in supporting requirement DA-D4c in ASME/ANS RA-Sa-2009 and outlined in Section 6.2.3.5 of NUREG/CR-6823.

Note b - For the ROP UAs using the MSPI data and assessed through RADS, the mean is the average of individual train UAs. Each train UA is the total number of planned and unplanned outage hours divided by total number of plant critical hours. The percentiles were obtained from the ordered set of train UAs. The error factor is the 95th percentile divided by the median.

Note c - The UA results are from NUREG/CR-6928 and supported by IPE data. For IPE data with UA estimates > 0.005, the IPE mean was divided by two. For IPE data with UA estimates <0.005, the IPE result was used directly. See Appendix B in NUREG/CR-6928 for details.

Note d - The UA results are from the INL Letter: Generic Test and Maintenance Unavailability Values, JCN W6467 - MBS-02-99.

Note e - The UA results are supported by the RPS system study (NUREG/CR-5500, Vol 2,3,10, and 11).

4. SYSTEM SPECIAL EVENTS

Several special events related to system performance are included in the SPAR models and provided in NUREG/CR-6928. These events address performance and conditional probability issues related to operation of HPCI, HPCS, and RCIC during unplanned demands. For RCIC, the probability of TDP having to restart during the mission time, failure of the TDP to restart, and failure to recover restart failures are addressed. Information on such events must be obtained from unplanned demand data, rather than test data. Additional RCIC events address cycling of the injection valve and failure to automatically switch from pump recirculation mode to injection mode. HPCI events address cycling of the injection valve and failure to switch the suction source. Finally, HPCS events address failure to switch the suction source. All of the system special events covered in this section apply only to BWRs.

These special events have not been updated since NUREG/CR-6928. The data and results listed in Table 3 are the same as those in NUREG/CR-6928, the 2010 update, and the 2015 update. They are included in this report for completeness. More detailed information can be found at Section C-3 and Appendix C of NUREG/CR-6928.

Table 3. System special event data and results.

Special Event Name	Description	Data Source	Data		d or h	Industry-average Probability or Rate Distribution (note a)					Comments
			Failures	Demands or Hours		Distribution (note b)	Mean	α	β	Error Factor	
TDP-PRST (RCIC)	RCIC TDP probability of restart	SS	6	47	d	Beta (Jeffreys, Jeffreys)	1.35E-01	6.500	4.150E+01	1.7	
TDP-FRST (RCIC)	RCIC TDP restart failure per event	SS	1	17	d	Beta (Jeffreys, SCNID)	8.33E-02	0.500	5.500E+00	7.2	
TDP-FRFRST (RCIC)	RCIC failure to recover TDP restart failure	SS	0	1	d	Beta (Jeffreys, SCNID)	2.50E-01	0.500	1.500E+00	4.7	
MOV-PMINJ (RCIC)	RCIC injection valve probability of multiple injections	SS	14	28	d	Beta (EB/YL/KS, EB/YL/KS)	5.03E-01	4.180	4.130E+00	1.5	
MOV-FTRO (RCIC)	RCIC injection valve fails to reopen	SS	1	38	d	Beta (Jeffreys, SCNID)	3.85E-02	0.500	1.250E+01	7.9	
MOV-FRFTRO (RCIC)	RCIC failure to recover injection valve failure to reopen	SS	1	1	d	Beta (Jeffreys, SCNID)	7.50E-01	0.500	1.667E-01	1.1	
SUC-FTFRI (RCIC)	RCIC failure to transfer back to injection mode (pump recirculation valve)	SS	1	198	h	Gamma (Jeffreys, SCNID)	7.58E-03	0.500	6.598E+01	8.4	(note c)
SUC-FRFTFR (RCIC)	RCIC failure to recover transfer failure	SS	0	1	d	Beta (Jeffreys, SCNID)	2.50E-01	0.500	1.500E+00	4.7	
MOV-PMINJ (HPCI)	HPCI injection valve probability of multiple injections	SS	2	17	d	Beta (Jeffreys, SCNID)	1.39E-01	0.500	3.100E+00	6.4	
MOV-FTRO (HPCI)	HPCI injection valve fails to reopen	SS	1	8	d	Beta (Jeffreys, SCNID)	1.67E-01	0.500	2.500E+00	6.0	
MOV-FRFTRO (HPCI)	HPCI failure to recover injection valve failure to reopen	SS	1	1	d	Beta (Jeffreys, SCNID)	7.50E-01	0.500	1.667E-01	1.1	
SUC-FTFR (HPCI)	HPCI failure to transfer	SS	0	1270	d	Beta (Jeffreys, SCNID)	3.93E-04	0.500	1.271E+03	8.4	
SUC-FRFTFR (HPCI)	HPCI failure to recover transfer failure	SS	0	0	d	Beta (Jeffreys, SCNID)	5.00E-01	0.500	5.000E-01	2.0	
SUC-FTFR (HPCS)	HPCS failure to transfer	SS	1	478	d	Beta (Jeffreys, SCNID)	3.13E-03	0.500	1.592E+02	8.4	
SUC-FRFTFR (HPCS)	HPCS failure to recover transfer failure	SS	1	1	d	Beta (Jeffreys, SCNID)	7.50E-01	0.500	1.667E-01	1.1	

Acronyms - EB (empirical Bayes), HPCI (high-pressure coolant injection), HPCS (high-pressure core spray), KS (Kass-Steffey), MOV (motor-operated valve), RCIC (reactor core isolation cooling), SCNID (simplified constrained noninformative distribution), SUC (suction), SS (updated system study), TDP (turbine-driven pump), YL (year level)

Note a - If these distributions are to be used as priors in Bayesian updates using plant-specific data, then a check for consistency between the prior and the data should be performed first, as suggested in supporting requirement DA-D4c in ASME/ANS RA-Sa-2009 and outlined in Section 6.2.3.5 in NUREG/CR-6823.

Note b - The format for the distributions is the following: distribution type (source for mean, source for α factor).

Note c - Note that this is per hour. Failure occurred 8 min after RCIC initiation.

5. INITIATING EVENT FREQUENCY

This section presents the third update to the original set of IE data and results documented in NUREG/CR-6928. The updated IE data and resulting frequency distributions are presented in Table 4. These events represent various categories of unplanned automatic and manual reactor trips within the industry. These estimates reflect industry-average frequencies for IEs, where U.S. commercial NPPs are defined as the industry. Only those IEs occurring while plants are critical are covered. Low-power and shutdown IEs are not addressed, other than the shutdown loss-of-offsite-power (LOOP) IEs.

For the baseline period used to quantify the IE frequencies, Section D.1.2 of NUREG/CR-6928 describes the original process while Section 2 of INL/EXT-21-63577 [24] presents the process used in the 2020 IE analysis and the results that were used in this section. One significant change made in this update is that for “not sparse” IE groups including loss of feedwater, BWR general transients, BWR loss of condenser heat sink, PWR general transients, and PWR loss of condenser heat sink, the most recent 10-year period (i.e., 2011—2020) and the most recent 15-year period (i.e., 2006–2020) were included in the considerations in order to respond to the industry request, discussed previously, to provide shorter periods than in previous updates (e.g., use of 1997 or 1998 as the fixed starting year for parameter estimations) in order to reflect more recent industry performance. Note that for SPAR model input, the staff intends to use the 15-year timeframe, when feasible.

IE frequency estimates were obtained from a hierarchy of sources, as explained in Section 8 of NUREG/CR-6928. The preferred sources are the NRC IE database and the LOOP database, as accessed using the RADS website https://rads.inl.gov/. The IE database uses IE definitions presented in NUREG/CR-5750 [25]. Most IE parameter estimates were obtained from the IE database and LOOP database. Other sources used include NUREG/CR-6890 [26] (and its updates) and NUREG-1829 [27]. LOOP has been analyzed in detail annually in NRC LOOP studies after NUREG/CR-6890, and LOOP data were obtained from the most recent 2020 LOOP update INL/EXT-21-64151 [28]. The data period for the LOOP frequency is 2006–2020. The small, medium, and large LOCA frequency distributions were obtained from the approach described in [29]. The excessive LOCA (or vessel rupture) rate estimate was obtained from WASH-1285 [30]. The IE data sheets in Appendix C explainhow data from each of these sources were used to obtain industry-average IE parameter estimates.

This update uses the same hierarchy of the 2015 update in terms of IE categories and subcategories. A few IEs that have been added to the 2015 update were analyzed in this update to support more detailed SPAR models:

1. All of the high-energy line break events
2. Two or more stuck open relief valves
3. Calculated loss of multiple alternating current (AC) or direct current (DC) busses
4. Interfacing system Loss of Coolant Accident (LOCA)
5. Reactor coolant pump seal LOCA (RCPLOCA)
6. LOOP in power operations and in shutdown.

Table 4. Initiating event data and results.

Cat.	Sub-Category	Initiating Event	Description	Data			Industry-average Frequency Distribution (note a)									Baseline Period
				Source	Number of Events	Critical Years (rcry)	Distribution	Analysis Type	5th	Median	Mean	95th	α	β	Error Factor	
Primary/Secondary Inventory Control	High Energy Line Breaks	FWLB BWR FI	Feedwater Line Break (BWR)	RADS	0	989.4	Gamma	JNID/IL	1.99E-06	2.30E-04	5.05E-04	1.94E-03	0.5	9.89E+02	8.4	1988--2020
		FWLB PWR FI	Feedwater Line Break (PWR)	RADS	2	1962.4	Gamma	JNID/IL	2.92E-04	1.11E-03	1.27E-03	2.82E-03	2.5	1.96E+03	2.5	1988--2020
		SLBIC PWR FI	Steam Line Break Inside Containment (PWR)	RADS	0	1962.4	Gamma	JNID/IL	1.00E-06	1.16E-04	2.55E-04	9.80E-04	0.5	1.96E+03	8.4	1988--2020
		SLBOC BWR FI	Steam Line Break Outside Containment (BWR)	RADS	2	989.4	Gamma	JNID/IL	5.79E-04	2.20E-03	2.53E-03	5.60E-03	2.5	9.89E+02	2.5	1988--2020
		SLBOC PWR FI	Steam Line Break Outside Containment (PWR)	RADS	10	1962.4	Gamma	JNID/IL	2.96E-03	5.19E-03	5.35E-03	8.33E-03	10.5	1.96E+03	1.6	1988--2020
	Steam Generator Tube Rupture	SGTR	Steam Generator Tube Rupture	RADS	3	1962.4	Gamma	JNID/IL	5.53E-04	1.62E-03	1.78E-03	3.59E-03	3.5	1.96E+03	2.2	1988--2020
	Loss of Coolant Accidents	LLOCA BWR	Large Loss-of-Coolant Accident (BWR)	RADS & NUREG-1829	0	573.8	Gamma	(note b)	1.25E-09	2.86E-06	1.17E-05	5.36E-05	0.3	2.56E+04	18.8	2003--2020
		LLOCA PWR	Large Loss-of-Coolant Accident (PWR)	RADS & NUREG-1829	0	1096.5	Gamma	(note b)	6.28E-10	1.43E-06	5.87E-06	2.69E-05	0.3	5.11E+04	18.8	2003--2020
		MLOCA BWR	Medium Loss-of-Coolant Accident (BWR)	RADS & NUREG-1829	0	573.8	Gamma	(note b)	9.07E-08	3.17E-05	8.75E-05	3.64E-04	0.4	4.57E+03	11.5	2003--2020
		MLOCA PWR	Medium Loss-of-Coolant Accident (PWR)	RADS & NUREG-1829	0	1096.5	Gamma	(note b)	1.40E-08	3.18E-05	1.31E-04	5.97E-04	0.3	2.30E+03	18.8	2003--2020
		SLOCA BWR	Small Loss-of-Coolant Accident (BWR)	RADS & NUREG-1829	0	573.8	Gamma	(note b)	3.34E-07	1.17E-04	3.22E-04	1.34E-03	0.4	1.24E+03	11.5	2003--2020
		SLOCA PWR	Small Loss-of-Coolant Accident (PWR)	RADS & NUREG-1829	0	1096.5	Gamma	(note b)	3.19E-07	1.12E-04	3.09E-04	1.28E-03	0.4	1.30E+03	11.5	2003--2020
		VSLOCA BWR FI	Very Small Loss-of-Coolant Accident (BWR)	RADS	2	890.6	Gamma	JNID/IL	6.43E-04	2.44E-03	2.81E-03	6.21E-03	2.5	8.91E+02	2.5	1992--2020
		VSLOCA PWR FI	Very Small Loss-of-Coolant Accident (PWR)	RADS	0	1744.8	Gamma	JNID/IL	1.13E-06	1.31E-04	2.87E-04	1.10E-03	0.5	1.74E+03	8.4	1992--2020
		SORV1 BWR FI	Stuck Open Safety/Relief Valve (BWR)	RADS	7	838.6	Gamma	EB/PL/KS	1.30E-03	6.85E-03	8.32E-03	2.03E-02	1.8	2.19E+02	3.0	1994--2020
		SORV2 BWR FI	Stuck Open Relief Valve >2 (BWR)	RADS	0	838.6	Gamma	JNID/IL	2.34E-06	2.71E-04	5.96E-04	2.29E-03	0.5	8.39E+02	8.4	1994--2020
		SORV1 PWR FI	Stuck Open Safety/Relief Valve (PWR)	RADS	2	1962.4	Gamma	JNID/IL	2.92E-04	1.11E-03	1.27E-03	2.82E-03	2.5	1.96E+03	2.5	1988--2020
		SORV2 PWR FI	Stuck Open Relief Valve >2 (PWR)	RADS	0	1962.4	Gamma	JNID/IL	1.00E-06	1.16E-04	2.55E-04	9.80E-04	0.5	1.96E+03	8.4	1988--2020
		ISLOCA BWR FI	Interfacing System Loss-of-Coolant Accident (BWR)	RADS	0	989.4	Gamma	JNID/IL	1.99E-06	2.30E-04	5.05E-04	1.94E-03	0.5	9.89E+02	8.4	1988--2020
		ISLOCA PWR FI	Interfacing System Loss-of-Coolant Accident (PWR)	RADS	0	1962.4	Gamma	JNID/IL	1.00E-06	1.16E-04	2.55E-04	9.80E-04	0.5	1.96E+03	8.4	1988--2020
		RCPLOCA	Reactor Coolant Pump Seal Loss-of-Coolant Accident (PWR)	RADS	0	1962.4	Gamma	JNID/IL	1.00E-06	1.16E-04	2.55E-04	9.80E-04	0.5	1.96E+03	8.4	1988--2020
		XLOCA	Excessive Loss-of-Coolant Accident (Vessel Rupture)	WASH-1285	--	--	Gamma	Geo Mean Aggregate	1.07E-11	2.44E-08	1.00E-07	4.57E-07	0.3	3.00E+06	18.8	--

Cat.	Sub-Category	Initiating Event	Description	Data			Industry-average Frequency Distribution (note a)									Baseline Period
				Source	Number of Events	Critical Years (rcry)	Distribution	Analysis Type	5th	Median	Mean	95th	α	β	Error Factor	
Transients	General Transient	TRANS BWR	Transient Initiating Event (BWR)	RADS	173	316.7	Gamma	EB/PL/KS	7.98E-02	4.52E-01	5.55E-01	1.38E+00	1.7	3.08E+00	3.1	2011--2020
		TRANS PWR	Transient Initiating Event (PWR)	RADS	300	596.5	Gamma	EB/PL/KS	1.39E-01	4.60E-01	5.18E-01	1.09E+00	2.9	5.68E+00	2.4	2011--2020
	Loss of Condenser Heat Sink	LOCHS BWR FI	Loss of Condenser Heat Sink (BWR)	RADS	16	381.9	Gamma	EB/PL/KS	1.77E-02	3.93E-02	4.19E-02	7.41E-02	5.7	1.36E+02	1.9	2009--2020
		LOCHS PWR FI	Loss of Condenser Heat Sink (PWR)	RADS	23	909.8	Gamma	EB/PL/KS	1.04E-02	2.38E-02	2.53E-02	4.57E-02	5.4	2.11E+02	1.9	2006--2020
	Loss of Feedwater	LOMFW	Loss of Main Feedwater	RADS	20	913.2	Gamma	EB/PL/KS	1.18E-03	1.53E-02	2.19E-02	6.51E-02	1.0	4.66E+01	4.3	2011--2020
Loss of Support Systems	Loss of Safety-Related Cooling Water	LOSWS	Loss of Safety Related Cooling Water (Open System)	RADS	1	2951.7	Gamma	JNID/IL	5.96E-05	4.01E-04	5.08E-04	1.32E-03	1.5	2.95E+03	3.3	1988--2020
		PLOSWS FI	Partial Loss of SWS Initiating Event	RADS	4	2951.7	Gamma	JNID/IL	5.64E-04	1.41E-03	1.52E-03	2.87E-03	4.5	2.95E+03	2.0	1988--2020
		LOCCW FI	Loss of Safety Related Cooling Water (Closed System)	RADS	1	2951.7	Gamma	JNID/IL	5.96E-05	4.01E-04	5.08E-04	1.32E-03	1.5	2.95E+03	3.3	1988--2020
		PLOCCW FI	Partial Loss of CCW Initiating Event	RADS	4	2951.7	Gamma	JNID/IL	5.64E-04	1.41E-03	1.52E-03	2.87E-03	4.5	2.95E+03	2.0	1988--2020
	Loss of Instrument Control Air	LOIA BWR	Loss of Instrument Air (BWR)	RADS	6	916.9	Gamma	EB/PL/KS	1.02E-04	3.74E-03	6.55E-03	2.25E-02	0.7	1.04E+02	6.0	1991--2020
		LOIA PWR	Loss of Instrument Air (PWR)	RADS	10	1453.3	Gamma	JNID/IL	4.00E-03	7.01E-03	7.23E-03	1.13E-02	10.5	1.45E+03	1.6	1997--2020
Loss of Offsite Power	Loss of Offsite Power, Power Operations	PO.LOOP	Loss-of-Offsite-Power, All Categories, Power Operations, per rcry	LOOP	35	1388.9	Gamma	EB/PL/KS	2.39E-03	1.92E-02	2.52E-02	6.83E-02	1.3	5.28E+01	3.6	2006--2020
		PO.LOOP-GR	Loss-of-Offsite-Power, Grid-Related, Power Operations, per rcry	LOOP	7	1388.9	Gamma	JNID/IL	2.61E-03	5.16E-03	5.40E-03	8.99E-03	7.5	1.39E+03	1.7	2006--2020
		PO.LOOP-PC	Loss-of-Offsite-Power, Plant-Centered, Power Operations, per rcry	LOOP	6	1388.9	Gamma	JNID/IL	2.12E-03	4.44E-03	4.68E-03	8.04E-03	6.5	1.39E+03	1.8	2006--2020
		PO.LOOP-SC	Loss-of-Offsite-Power, Switchyard-Centered, Power Operations, per rcry	LOOP	12	1388.9	Gamma	JNID/IL	5.26E-03	8.75E-03	9.00E-03	1.35E-02	12.5	1.39E+03	1.5	2006--2020
		PO.LOOP-WR	Loss-of-Offsite-Power, Weather-Related, Power Operations, per rcry	LOOP	10	1388.9	Gamma	EB/PL/KS	1.34E-04	4.25E-03	7.21E-03	2.44E-02	0.7	9.88E+01	5.7	2006--2020
	Loss of Offsite Power, Shutdown Operations	SD.LOOP	Loss-of-Offsite-Power, All Categories, Shutdown Operations, per rsy	RADS	17	127.2	Gamma	JNID/IL	8.84E-02	1.35E-01	1.38E-01	1.96E-01	17.5	1.27E+02	1.5	2006--2020
		SD.LOOP-GR	Loss-of-Offsite-Power, Grid-Related, Shutdown Operations, per rsy	RADS	2	127.2	Gamma	JNID/IL	4.51E-03	1.71E-02	1.97E-02	4.36E-02	2.5	1.27E+02	2.5	2006--2020
		SD.LOOP-PC	Loss-of-Offsite-Power, Plant-Centered, Shutdown Operations, per rsy	RADS	3	127.2	Gamma	JNID/IL	8.53E-03	2.50E-02	2.75E-02	5.54E-02	3.5	1.27E+02	2.2	2006--2020

Cat.	Sub-Category	Initiating Event	Description	Data			Industry-average Frequency Distribution (note a)									Baseline Period
				Source	Number of Events	Critical Years (rcry)	Distribution	Analysis Type	5th	Median	Mean	95th	α	β	Error Factor	
		SD.LOOP-SC	Loss-of-Offsite-Power, Switchyard-Centered, Shutdown Operations, per rsy	RADS	8	127.2	Gamma	JNID/IL	3.41E-02	6.43E-02	6.68E-02	1.09E-01	8.5	1.27E+02	1.7	2006--2020
		SD.LOOP-WR	Loss-of-Offsite-Power, Weather-Related, Shutdown Operations, per rsy	RADS	4	127.2	Gamma	JNID/IL	1.31E-02	3.28E-02	3.54E-02	6.66E-02	4.5	1.27E+02	2.0	2006--2020
Electrical Power	Loss of AC Electrical Bus	LOAC	Loss of Vital AC Bus	RADS	16	2635.4	Gamma	JNID/IL	3.95E-03	6.12E-03	6.26E-03	8.98E-03	16.5	2.64E+03	1.5	1992--2020
		LOAC 4160V FI	Loss of Vital AC Bus (4160 Volt)	RADS	11	2635.4	Gamma	EB/PL/KS	3.34E-04	3.10E-03	4.16E-03	1.16E-02	1.2	2.93E+02	3.8	1992--2020
		LOAC LOWV FI	Loss of Vital AC Bus (Low Voltage)	RADS	5	2635.4	Gamma	JNID/IL	8.66E-04	1.96E-03	2.09E-03	3.73E-03	5.5	2.64E+03	1.9	1992--2020
		LOACB2	Loss of Vital AC Bus Event (2 Buses modeled as IEs)	RADS Adjusted	(note c)	--	Gamma	JNID/IL	3.15E-07	7.17E-04	2.94E-03	1.34E-02	0.3	1.02E+02	18.8	1992--2020
	Loss of DC Electrical Bus	LODC	Loss of Vital DC Bus	RADS	2	2951.7	Gamma	JNID/IL	1.94E-04	7.38E-04	8.47E-04	1.88E-03	2.5	2.95E+03	2.5	1988--2020
		LODCB2	Loss of Vital DC Bus Event (2 Buses modeled as IEs)	RADS Adjusted	(note c)	--	Gamma	JNID/IL	4.53E-08	1.03E-04	4.24E-04	1.94E-03	0.3	7.08E+02	18.8	1988--2020

Acronyms - BWR (boiling water reactor), CCW (component cooling water), EB (empirical Bayes), EE (expert elicitation), FI (functional impact), FWLB (feedwater line break), GR (grid-related), IE (initiating event), IEDB (initiating events database - https://nrcoe.inl.gov), IL (industry level), ISLOCA (interfacing system loss-of-coolant accident), KS (Kass-Steffey), JNID (Jeffreys noninformative distribution), LOCCW (loss of component cooling water), LLOCA (large loss-of-coolant event), LOAC (loss of vital ac bus), LOCHS (loss of condenser heat sink), LODC (loss of vital dc bus), LOIA (loss of instrument air), LOMFW (loss of main feedwater), LOOP (loss-of-offsite-power), LOSWS (loss of emergency service water), MLOCA (medium loss-of-accident accident), PC (plant-centered), PL (plant level), PLOCCW (partial loss of component cooling water), PLOSWS (partial loss of emergency service water), PO (power operations), PWR (pressurized water reactor), RADS (Reliability and Availability Database System), rcry (reactor critical year), RCPLOCA (reactor coolant pump seal loss-of-coolant accident), rsy (reactor shutdown year), SC (switchyard-centered), SD (shutdown operations), SGTR (steam generator tube rupture), SLBIC (steam line break inside containment), SLBOC (steam line break outside containment), SLOCA (small loss-of-coolant accident), SORV (stuck open safety/relief valve), TRANS (transient), VSLOCA (very small loss-of-coolant accident), WR (weather-related), XLOCA (excessive loss-of-coolant accident)

Note a - If these distributions are to be used as priors in Bayesian updates using plant-specific data, then a check for consistency between the prior and the data should be performed first, as suggested in supporting requirement DA-D4c in ASME/ANS RA-Sa-2009 and outlined in Section 6.2.3.5 of NUREG/CR-6823.

Note b - The NUREG-1829 results are used as the prior to Bayesian update the newer observed data.

Note c – The mean value of the loss of two AC (or DC) buses frequency are calculated by dividing the mean value of the loss of one vital AC (or DC) bus.

6. COMPARISON WITH PREVIOUS RESULTS

This section compares the data and results in this update with those in the 2015 update. Table 5 provides a comparison of current component UR results with those in the 2015 update (only component failure mode templates with 50% increase or decrease are listed). Table 6 presents a comparison of train UA results with those in the 2015 update. Table 7 presents a comparison of initiating event results with those in the 2015 update.

With the UR data from 2006–2020 used in this update, older data from 1998–2005, which represent nearly half of the data represented in the 2015 update (from 1998–2015), were excluded from the analysis, and thus the results in this update could be significantly different from the values in the 2015 update. Of about 300 UR templates, there are 20 templates that have a 50% or more increase from the 2015 update values (red highlighted in Table 5), and there are 60 templates that have a 50% or more decrease from the 2015 update values (blue highlighted in Table 5). For the top seven most increased (four times or bigger) UR templates,

- Four of them (PORV-FC-MSS, SVV-FTC-PWR-RCS, SVV-FTC-PWR-MSS, PORV-FTC-RCS) are related to the updated RV study that uses actual demand data only instead of both demand and testing data in the original NUREG/CR-7037 study (which was used as the basis for the 2015 values).
- For MDP-FTR-SWS-NE that is used for SPAR template ZT-IE-SWS-MDP-FR-NE, the mean hourly failure rate increases from 1.5E-7 in the 2015 update to 4.2E-6 in this update. This is due to the changes in the associated RADS rule that estimate the parameter. The 2015 RADS rule (named MDP-FE-SWS) erroneously included standby service water MDP FTR failure mode, which led to 2 failures in 16,692,670 hours and a mean failure rate of 1.5E-7 per hour. This was found to be incorrect since standby pumps should use FTR<1H and FTR>1H failure modes while normally running pumps should use the FTR failure mode. After discussion with the SPAR modeler, the rule was revised so that both normally running and standby service water MDPs use both FTR<1H and FTR>1H failure modes. This rule change led to 100 failures in 25,635,460 hours and the mean failure rate of 4.2E-06 per hour listed above.
- The other two templates EDC-FTR>1H and MDC-FTR<1H have much different results as a result of re-running the associated RADS reliability rule: 19 failures in 1,735 hours instead of 0 failure in 1,735 hours in the 2015 update documentation for EDC-FTR>1H; 0 failure in 24,111 hours instead of 22 failures in 1,683,943 hours in the 2015 update documentation for MDC-FTR<1H. It is believed that errors may have occurred when developing or running the associated RADS rules during the 2015 update.

The differences in UA results are smaller as this update used data from 2006–2020 and the 2015 update used data from 2002–2015. Of the 40 updated UA templates, 12 templates have a 10% or more increase from the 2015 update (red highlighted in Table 6), and 9 templates have a 10% or more decrease (blue highlighted in Table 6).

Of the 49 initiating events, six categories (loss of safety related cooling water – open system, loss of safety related cooling water – closed system, plant-centered loss-of-offsite-power during power operations, plant-centered loss-of-offsite-power during shutdown operations, weather-related loss-of-offsite-power during power operations, and loss of vital AC bus – 4160 volt) have a 10% or more increase from the 2015 update (red highlighted in Table 7). Thirty-four categories have a 10% or more decrease from the 2015 update (blue highlighted in Table 7).

Table 5. Comparison of component UR data and results with 2015 update.

Component Failure Mode	Description	2015 Update (1998–2015)			2020 Update (2006–2020)			
		Failures	Demands or Hours	Mean	Failures	Demands or Hours	Mean	Δ of Mean
PORV-FC-MSS	Power-Operated Relief Fails To Control (Cooldown) (Main Steam System, PWRs)	13	49,398,360	2.57E-07	7	278	2.69E-02	1.0E+05
SVV-FTC-PWR-RCS	Safety Valve Fails To Close (Reactor Coolant System, PWRs)	1	2,907	5.16E-04	2	4	4.13E-02	79.0
SVV-FTC-PWR-MSS	Safety Valve Fails To Close (Main Steam System, PWRs)	2	20,243	1.23E-04	4	745	6.03E-03	48.0
MDP-FTR-SWS-NE	Service Water Motor-Driven Pump Fails To Run Non-ExEE	2	16,692,670	1.50E-07	100	25,635,460	4.2E-06	27.0
EDC-FTR>1H	Engine-Driven Compressor Fails To Run >1H, Normally Standby	0	1,735	2.88E-04	12	1,609	7.77E-03	26.0
MDC-FTR<1H	Motor-Driven Compressor Fails To Run (0 To 1 Hour)	22	1,683,943	1.34E-05	1	20,248	7.41E-05	4.5
PORV-FTC-RCS	Power-Operated Relief Valve Fails To Close (Reactor Coolant System, PWRs)	4	6,130	7.34E-04	1	377	3.97E-03	4.4
EDC-FTR<1H	Engine-Driven Compressor Fails To Run <1H, Normally Standby	0	2,122	2.36E-04	1	1,459	1.03E-03	3.4
MDC-FTR>1H	Motor-Driven Compressor Fails To Run (> 1 Hour)	22	1,683,943	1.34E-05	90	1,573,366	5.75E-05	3.3
PORV-FTO-RCS	Power-Operated Relief Valve Fails To Open (Reactor Coolant System, PWRs)	16	6,130	3.24E-03	4	377	1.19E-02	2.7
BUS-FTOP-DC	DC Bus Fails To Operate	0	2,305,320	2.17E-07	1	2,103,936	7.13E-07	2.3
PORV-FTO-MSS	Power-Operated Relief Valve Fails To Open (Main Steam System, PWRs)	42	10,401	4.91E-03	25	1,580	1.61E-02	2.3
TDP-FTR>1H	Turbine-Driven Pump Fails To Run (Pooled Systems), Late Term	23	11,205	2.10E-03	17	4,454	6.35E-03	2.0
SVV-FTO-PWR-MSS	Safety Valve Fails To Open+D174 PWRs)	4	20,243	2.22E-04	0	745	6.70E-04	2.0
EDG-FTS-HCS	High-Pressure Core Spray Generator Fails To Start	2	2,654	9.42E-04	4	2,114	2.13E-03	1.3
CTF-FTR-NR	Cooling Tower Fan Fails To Run	3	1,504,717	2.33E-06	6	1,253,930	5.18E-06	1.2
PORV-FTC-MSS	Power-Operated Relief Fails To Close (Main Steam System, PWRs)	19	10,401	2.21E-03	7	1,580	4.35E-03	96.8%

Component Failure Mode	Description	2015 Update (1998–2015)			2020 Update (2006–2020)			
		Failures	Demands or Hours	Mean	Failures	Demands or Hours	Mean	Δ of Mean
TDP-FTR>1H-AFW	Auxiliary Feedwater Turbine-Driven Pump FTR>1H	13	9,283	1.45E-03	8	3,295	2.58E-03	77.9%
EDP-FTR>1H	Engine-Driven Pump FTR>1H, Normally Standby	11	5,820	1.98E-03	15	4,754	3.26E-03	64.6%
TNK-FC	Tank Rupture	15	59,350,270	2.61E-07	16	46,469,300	4.18E-07	60.2%
MOD-FTOC	Motor-Operated Damper Fails To Open	7	33,254	2.26E-04	11	28,949	3.56E-04	57.5%
MOV-ILS	Motor-Operated Valve Internal Leakage (Small)	141	1,983,522,000	7.58E-08	--	1,634,537,000	3.61E-08	-52.4%
MOV-ILL	Motor-Operated Valve Internal Leakage (Rupture)	141	1,983,522,000	1.52E-09	--	--	7.22E-10	-52.5%
MOV-BFV-SOP-CCW	Component Cooling Water Butterfly Valve Spurious Operation	6	106,466,800	6.11E-08	--	86,552,190	2.89E-08	-52.7%
TDP-FTR<1H-AFW	Auxiliary Feedwater Turbine-Driven Pump FTR<1H	40	12,076	3.67E-03	--	10,670	1.73E-03	-52.9%
EDP-FTS-AFW	Auxiliary Feedwater Engine-driven pump Fails To Start	3	1,275	2.74E-03	--	1,163	1.29E-03	-52.9%
SVV-ILL	Code Safety Valve Internal Leakage (Rupture)	14	211,426,600	1.37E-09	--	--	6.40E-10	-53.3%
SVV-ILS	Code Safety Valve Internal Leakage (Small)	14	211,426,600	6.86E-08	--	171,647,800	3.20E-08	-53.4%
MSV-ILL	Main Steam Isolation Valve Internal Leakage (Rupture)	63	79,241,950	1.60E-08	--	--	7.14E-09	-55.4%
MSV-ILS	Main Steam Isolation Valve Internal Leakage (Small)	63	79,241,950	8.01E-07	--	65,768,320	3.57E-07	-55.4%
FAN-FTS-NS	HVC Fan Fails To Start, Normally Standby	37	57,512	6.52E-04	--	63,511	2.76E-04	-57.7%
AOV-ILL	Air-Operated Valve Internal Leakage (Rupture)	104	1,347,257,000	1.55E-09	--	--	6.40E-10	-58.7%
AOV-ILS	Air-Operated Valve Internal Leakage (Small)	104	1,347,257,000	7.76E-08	--	1,109,287,000	3.20E-08	-58.8%
MOD-ILS	Motor-Operated Damper Internal Leakage (Small)	1	17,147,900	8.75E-08	--	14,134,270	3.54E-08	-59.5%
MOD-ILL	Motor-Operated Damper Internal Leakage (Rupture)	1	17,147,900	1.75E-09	--	--	7.08E-10	-59.5%
CRBDC-SOP	DC Circuit Breaker Spurious Operation	1	42,345,960	3.54E-08	--	34,938,600	1.43E-08	-59.6%
VBV-SOP	Vacuum Breaker Valve Spurious Operation	1	52,796,540	2.84E-08	--	43,685,040	1.14E-08	-59.9%
MDC-FTS-NR	Motor-Driven Compressor Fails To Start, Normally Running	109	9,197	3.41E-02	--	7,855	1.36E-02	-60.1%
STR-FLTSC-BYP	Self Cleaning Filter Bypass	1	25,738,850	5.83E-08	--	21,560,060	2.32E-08	-60.2%
AHU-FTR-NR	Air Handling Unit Fails To Run, Normally Running	62	17,498,560	6.65E-06	--	15,131,330	2.61E-06	-60.8%
XVM-ILS	Manual Valve Internal Leakage (Small)	7	128,295,300	6.88E-08	--	132,674,000	2.64E-08	-61.6%
XVM-ILL	Manual Valve Internal Leakage (Rupture)	7	128,295,300	1.38E-09	--	--	5.28E-10	-61.7%

Component Failure Mode	Description	2015 Update (1998–2015)			2020 Update (2006–2020)			
		Failures	Demands or Hours	Mean	Failures	Demands or Hours	Mean	Δ of Mean
AHU-FTS-NS	Air Handling Unit Fails To Start, Normally Standby	55	149,242	5.57E-04	--	158,866	2.11E-04	-62.1%
SOV-FC	Solenoid-Operated Valve Fails To Control	58	143,582,100	4.07E-07	--	115,760,700	1.52E-07	-62.7%
XVM-SOP	Manual Valve Spurious Operation	6	128,295,300	5.07E-08	--	132,674,000	1.88E-08	-62.9%
TSA-BYP	Traveling Screen Bypass	8	30,417,290	2.79E-07	--	25,155,920	9.94E-08	-64.4%
EDP-FTS-NS	Engine-Driven Pump Fails To Start, Normally Standby	26	17,988	2.17E-03	--	17,773	7.60E-04	-65.0%
CKV-ILS	Check Valve Internal Leakage (Small)	143	977,258,600	2.08E-07	--	806,744,700	7.25E-08	-65.1%
CKV-ILL	Check Valve Internal Leakage (Rupture)	143	977,258,600	4.16E-09	--	--	1.45E-09	-65.1%
HOD-SOP	Hydraulic-Operated Damper Spurious Operation	8	19,397,950	4.38E-07	--	16,454,520	1.52E-07	-65.3%
HTG-FTLR	Hydro Turbine Generator Fails To Load And Run, Early	7	4,629	1.62E-03	--	4,582	5.46E-04	-66.3%
RVL-ILS	Low Capacity Relief Valve Internal Leakage (Small)	11	9,633,048	1.19E-06	--	9,165,162	3.82E-07	-67.9%
RVL-ILL	Low Capacity Relief Valve Internal Leakage (Rupture)	11	9,633,048	2.38E-08	--	--	7.64E-09	-67.9%
VBV-FTOC	Vacuum Breaker Valve Fails To Open/Close	8	27,842	3.37E-04	--	23,202	1.08E-04	-68.0%
VBV-FTC	Vacuum Breaker Valve Fails To Close	6	27,842	2.15E-04	--	23,202	6.46E-05	-70.0%
FCV-SOP	Flow Control Valve Spurious Operation	10	88,861,090	1.18E-07	--	73,637,280	3.40E-08	-71.2%
CKV-SOP	Check Valve Spurious Operation	2	977,258,600	2.56E-09	--	806,744,700	6.20E-10	-75.8%
TNK-GAS-ELS	Gas Tank Small Leakage External Leakage (Small)	2	5,048,832	4.95E-07	--	4,207,872	1.19E-07	-76.0%
TNK-GAS-ELL	Gas Tank Small Leakage External Leakage (Rupture)	2	5,048,832	3.47E-08	--	--	8.33E-09	-76.0%
CTF--FTR>1H	Cooling Tower Fan Fails To Run >1H (Standby)	2	1,073,115	2.33E-06	--	895,323	5.58E-07	-76.1%
AOD-FTOC	Air-Operated Damper Fails To Open/Close	2	7,799	3.21E-04	--	6,602	7.57E-05	-76.4%
PORV-ILS	Power-Operated Relief Valve Internal Leakage (Small)	18	69,470,980	2.66E-07	--	57,223,460	6.12E-08	-77.0%
PORV-ILL	Power-Operated Relief Valve Internal Leakage (Rupture)	18	69,470,980	5.32E-09	--	--	1.22E-09	-77.1%
PDP-FTR>1H	Positive Displacement Pump FTR>1H	2	1,710	1.46E-03	--	1,505	3.32E-04	-77.3%
STR-FLTSC-ELL	Self Cleaning Filter External Leakage (Rupture)	14	25,738,850	3.94E-08	--	--	8.12E-09	-79.4%
STR-FLTSC-ELS	Self Cleaning Filter External Leakage (Small)	14	25,738,850	5.63E-07	--	21,560,060	1.16E-07	-79.4%
XVM-SOP-SWS	Standby Service Water Manual Valve Spuriously Transfers	2	18,346,180	1.36E-07	--	18,055,700	2.77E-08	-79.6%

Component Failure Mode	Description	2015 Update (1998–2015)			2020 Update (2006–2020)			
		Failures	Demands or Hours	Mean	Failures	Demands or Hours	Mean	Δ of Mean
TBV-FTO	Turbine Bypass Valve Fails To Open	8	2,725	3.12E-03	--	2,367	6.33E-04	-79.7%
TBV-FTOC	Turbine Bypass Valve Fails To Open/Close	8	2,725	3.12E-03	--	2,367	6.33E-04	-79.7%
VBV-ILS	Vacuum Breaker Valve Internal Leakage (Small)	15	52,796,540	2.94E-07	--	43,685,040	5.72E-08	-80.5%
VBV-ILL	Vacuum Breaker Valve Internal Leakage (Rupture)	15	52,796,540	5.88E-09	--	--	1.14E-09	-80.6%
MDC-FTR-CIA	Containment Instrument Air Motor-Driven Compressor Fails To Run	3	118,273	2.96E-05	0	98,561	5.07E-06	-82.9%
TRK-PG	Trash Rack Plugging	3	1,577,760	2.23E-06	0	1,314,960	3.80E-07	-83.0%
MOV-SOP-SWS	Standby Service Water Motor-Operated Valve Spurious Operation	3	73,067,170	4.79E-08	0	64,725,970	7.72E-09	-83.9%
SVV-SOP	Code Safety Valve Spurious Operation	11	211,426,600	5.44E-08	1	171,647,800	8.74E-09	-83.9%
SRV-FTC	BWR ADS/SRV Fails To Reclose	8	9,720	8.86E-04	0	3,548	1.41E-04	-84.1%
FAN-FTR>1H	HVC Fan FTR>1H, Normally Standby	27	137,892	1.99E-04	3	120,200	2.91E-05	-85.4%
HOD-FTOC	Hydraulic-Operated Damper Fails To Open/Close	11	6,225	5.57E-03	4	6,113	7.36E-04	-86.8%
FCV-FTOC	Flow Control Valve Fails To Open/Close	5	12,488	4.40E-04	0	11,345	4.41E-05	-90.0%
SVV-SOP-PWR-MSS	Safety Valve Spurious Operation (Main Steam System, PWRs)	8	172,245,500	4.93E-08	0	140,068,800	3.57E-09	-92.8%
RVL-FTO	Low Capacity Relief Valve Fails To Open	5	78	1.07E-01	0	65	7.59E-03	-92.9%

Note: refer to Table 1 for acronyms used in this table.

Table 6. Comparison of train UA data and results with 2015 update.

Train Unavailability Event	Train Description	2015 Update		2020 Update		
		Mean	Date Range	Mean	Date Range	Δ of Mean
HDR-RHRSW	RHRSW Header Test or Maintenance	1.20E-03	2002--2015	2.81E-03	2006--2020	134.2%
EDP	Engine-Driven Pump Test or Maintenance	1.64E-02	2002--2015	2.27E-02	2006--2020	38.4%
HDR-AFW	AFW Header Test or Maintenance	5.61E-04	2002--2015	7.70E-04	2006--2020	37.3%
HCS-SW	Service Water for High Pressure Core Spray Generator Test or Maintenance	5.54E-03	2002--2015	7.32E-03	2006--2020	32.1%
MDP-ESW	Motor-Driven Pump Test or Maintenance (ESW)	9.66E-03	2002--2015	1.24E-02	2006--2020	28.4%
MDP-NR-DIRTY	Motor-Driven Pump Test or Maintenance (Normally Running System, Dirty)	9.66E-03	2002--2015	1.24E-02	2006--2020	28.4%
EDG-SW	Service Water for Emergency Diesel Generator Test or Maintenance	9.17E-03	2002--2015	1.11E-02	2006--2020	21.0%
MDP-NS-DIRTY	Motor-Driven Pump Test or Maintenance (Normally Standby System, Dirty)	9.34E-03	2002--2015	1.13E-02	2006--2020	21.0%
HTX-RHR-BWR	Heat Exchanger and Pump Train Test or Maintenance (RHR-BWR)	2.55E-03	2002--2015	3.05E-03	2006--2020	19.6%
EDG-HCS	HPCS Diesel Generator Test or Maintenance	1.17E-02	2002--2015	1.33E-02	2006--2020	13.7%
HDR-RHR	RHR Header Test or Maintenance	6.36E-04	2002--2015	7.21E-04	2006--2020	13.4%
HTX	Heat Exchanger Test or Maintenance	6.93E-03	2002--2015	7.63E-03	2006--2020	10.1%
EDP-ESW	Engine-Driven Pump Test or Maintenance	2.89E-02	2002--2015	3.14E-02	2006--2020	8.7%
MDP-CCW	Motor-Driven Pump Test or Maintenance (CCW)	4.46E-03	2002--2015	4.82E-03	2006--2020	8.1%
MDP-RHRSW	Motor-Driven Pump Test or Maintenance (RHR Service Water)	4.55E-03	2002--2015	4.91E-03	2006--2020	7.9%
MDP-NR-CLEAN	Motor-Driven Pump Test & Maintenance (Normally Running System, Clean)	4.56E-03	2002--2015	4.90E-03	2006--2020	7.5%
HTX-ESW	Heat Exchanger Test or Maintenance (ESW)	1.50E-02	2002--2015	1.61E-02	2006--2020	7.3%
HTX-CCW	Heat Exchanger Test or Maintenance (CCW)	7.31E-03	2002--2015	7.73E-03	2006--2020	5.7%
MDP-ALL	Motor-Driven Pump Test or Maintenance (All Clean Systems)	6.21E-03	2002--2015	6.56E-03	2006--2020	5.6%
MDP-HCS	Motor-Driven Pump Test or Maintenance (HCS)	7.35E-03	2002--2015	7.68E-03	2006--2020	4.5%
EDG-EPS	Diesel Generator Test or Maintenance	1.48E-02	2002--2015	1.51E-02	2006--2020	2.0%
TDP-ALL	Turbine-Driven Pump Test or Maintenance (AFW, HPCI, and RCIC combined)	7.25E-03	2002--2015	7.30E-03	2006--2020	0.7%
MDP-RHR-BWR	Motor-Driven Pump Test or Maintenance (RHR-BWR)	5.95E-03	2002--2015	5.92E-03	2006--2020	-0.5%
MDP-RHR	Motor-Driven Pump Test or Maintenance (RHR)	5.18E-03	2002--2015	5.09E-03	2006--2020	-1.7%
MDP-CLEAN	Motor-Driven Pump Test or Maintenance (Clean System)	4.22E-03	2002--2015	4.14E-03	2006--2020	-1.9%
TDP-RCI	Turbine-Driven Pump Test or Maintenance (RCIC)	1.04E-02	2002--2015	1.01E-02	2006--2020	-2.9%
MDP-RHR-PWR	Motor-Driven Pump Test or Maintenance (RHR-PWR)	4.81E-03	2002--2015	4.63E-03	2006--2020	-3.7%
TDP-HCI	Turbine-Driven Pump Test or Maintenance (HPCI)	1.17E-02	2002--2015	1.11E-02	2006--2020	-5.1%
TDP-HCI-RCI	Turbine-Driven Pump Test or Maintenance (HPCI and RCIC combined)	1.17E-02	2002--2015	1.11E-02	2006--2020	-5.1%

Train Unavailability Event	Train Description	2015 Update		2020 Update		
		Mean	Date Range	Mean	Date Range	Δ of Mean
MDP-AFW	Motor-Driven Pump Test or Maintenance (AFW)	3.34E-03	2002--2015	3.14E-03	2006--2020	-6.0%
MDP-HPI	Motor-Driven Pump Test or Maintenance (HPI)	3.32E-03	2002--2015	2.99E-03	2006--2020	-9.9%
TDP-AFW	Turbine-Driven Pump Test or Maintenance (AFW)	5.24E-03	2002--2015	4.64E-03	2006--2020	-11.5%
HTX-RHR-PWR	Heat Exchanger and Pump Train Test or Maintenance (RHR-BWR)	2.42E-04	2002--2015	2.09E-04	2006--2020	-13.6%
MDP-NS-CLEAN	Motor-Driven Pump Test or Maintenance (Normally Standby System, Clean)	4.60E-03	2002--2015	3.94E-03	2006--2020	-14.3%
EDP-AFW	Engine-Driven Pump Test or Maintenance	6.44E-03	2002--2015	5.47E-03	2006--2020	-15.1%
MDP-FWS	Feed Water System Motor-Driven Pumps Test or Maintenance	9.44E-03	2002--2015	7.68E-03	2006--2020	-18.6%
HDR-CCW	CCW Header Test or Maintenance	3.17E-04	2002--2015	2.42E-04	2006--2020	-23.7%
HDR-ISO	ISO Header Test or Maintenance	4.01E-03	2002--2015	2.62E-03	2006--2020	-34.7%
HDR-HPI	HPSI Header Test or Maintenance	2.21E-04	2002--2015	1.36E-04	2006--2020	-38.5%
HDR-ESW	ESW Header Test or Maintenance	8.95E-03	2002--2015	4.61E-03	2006--2020	-48.5%

Note: refer to Table 2 for acronyms used in this table

Table 7. Comparison of initiating event data and results with 2015 update.

Initiating Event	Description	2015 Update				2020 Update				
		Number of Events	Critical Years (rcry)	Mean	Baseline Period	Number of Events	Critical Years (rcry)	Mean	Baseline Period	Δ of Mean
LOSWS	Loss of Safety Related Cooling Water (Open System)	0	2496.3	2.00E-04	1988--2015	1	2951.7	5.08E-04	1988--2020	154.0%
LOCCW FI	Loss of Safety Related Cooling Water (Closed System)	0	2496.3	2.00E-04	1988--2015	1	2951.7	5.08E-04	1988--2020	154.0%
PO.LOOP-PC	Loss-of-Offsite-Power, Plant-Centered, Power Operations, per rcry	3	1751.7	2.00E-03	1997--2015	6	1388.9	4.68E-03	2006--2020	134.0%
SD.LOOP-PC	Loss-of-Offsite-Power, Plant-Centered, Shutdown Operations, per rsy	7	213.4	2.11E-02	1997--2015	3	127.2	2.75E-02	2006--2020	30.3%
LOAC 4160V FI	Loss of Vital AC Bus (4160 Volt)	7	2179.9	3.44E-03	1992--2015	11	2635.4	4.16E-03	1992--2020	20.9%
PO.LOOP-WR	Loss-of-Offsite-Power, Weather-Related, Power Operations, per rcry	10	1751.7	5.99E-03	1997--2015	10	1388.9	7.21E-03	2006--2020	20.4%
LOAC	Loss of Vital AC Bus	12	2179.9	5.73E-03	1992--2015	16	2635.4	6.26E-03	1992--2020	9.2%
SGTR	Steam Generator Tube Rupture	2	1502.7	1.66E-03	1991--2015	3	1962.4	1.78E-03	1988--2020	7.2%
SD.LOOP-GR	Loss-of-Offsite-Power, Grid-Related, Shutdown Operations, per rsy	4	213.4	1.90E-02	1997--2015	2	127.2	1.97E-02	2006--2020	3.7%
LOACB2	Loss of Vital AC Bus Event (2 Buses modeled as IEs)	12	2179.9	2.87E-03	1992--2015	--	--	2.94E-03	1992--2020	2.4%
XLOCA	Excessive Loss-of-Coolant Accident (Vessel Rupture)	--	--	1.00E-07	--	--	--	1.00E-07	--	0.0%
LLOCA PWR	Large Loss-of-Coolant Accident (PWR)	--	--	5.91E-06	--	0	1096.5	5.87E-06	2003--2020	-0.7%
LLOCA BWR	Large Loss-of-Coolant Accident (BWR)	--	--	1.18E-05	--	0	573.8	1.17E-05	2003--2020	-0.8%
MLOCA BWR	Medium Loss-of-Coolant Accident (BWR)	--	--	9.05E-05	--	0	573.8	8.75E-05	2003--2020	-3.3%
LOIA BWR	Loss of Instrument Air (BWR)	5	761.2	7.23E-03	1991--2015	6	916.9	6.55E-03	1991--2020	-9.4%
SD.LOOP-WR	Loss-of-Offsite-Power, Weather-Related, Shutdown Operations, per rsy	8	213.4	3.98E-02	1997--2015	4	127.2	3.54E-02	2006--2020	-11.1%
LOIA PWR	Loss of Instrument Air (PWR)	9	1153.5	8.24E-03	1997--2015	10	1453.3	7.23E-03	1997--2020	-12.3%
MLOCA PWR	Medium Loss-of-Coolant Accident (PWR)	--	--	1.50E-04	--	0	1096.5	1.31E-04	2003--2020	-12.7%
SLOCA BWR	Small Loss-of-Coolant Accident (BWR)	1	418	3.69E-04	--	0	573.8	3.22E-04	2003--2020	-12.7%
LODCB2	Loss of Vital DC Bus Event (2 Buses modeled as IEs)	2	2496.3	5.00E-04	1988--2015	--	--	4.24E-04	1988--2020	-15.2%
SLBIC PWR FI	Steam Line Break Inside Containment (PWR)	0	1662.6	3.01E-04	1988--2015	0	1962.4	2.55E-04	1988--2020	-15.3%

Initiating Event	Description	2015 Update				2020 Update				
		Number of Events	Critical Years (rcry)	Mean	Baseline Period	Number of Events	Critical Years (rcry)	Mean	Baseline Period	Δ of Mean
LODC	Loss of Vital DC Bus	2	2496.3	1.00E-03	1988--2015	2	2951.7	8.47E-04	1988--2020	-15.3%
FWLB PWR FI	Feedwater Line Break (PWR)	2	1662.6	1.50E-03	1988--2015	2	1962.4	1.27E-03	1988--2020	-15.3%
SORV1 PWR FI	Stuck Open Safety/Relief Valve (PWR)	2	1662.6	1.50E-03	1988--2015	2	1962.4	1.27E-03	1988--2020	-15.3%
SLBOC PWR FI	Steam Line Break Outside Containment (PWR)	10	1662.6	6.32E-03	1988--2015	10	1962.4	5.35E-03	1988--2020	-15.3%
SORV2 BWR FI	Stuck Open Relief Valve >2 (BWR)	0	709.7	7.05E-04	1993--2015	0	838.6	5.96E-04	1994--2020	-15.5%
PLOSWS FI	Partial Loss of SWS Initiating Event	4	2496.3	1.80E-03	1988--2015	4	2951.7	1.52E-03	1988--2020	-15.6%
PLOCCW FI	Partial Loss of CCW Initiating Event	4	2496.3	1.80E-03	1988--2015	4	2951.7	1.52E-03	1988--2020	-15.6%
SLBOC BWR FI	Steam Line Break Outside Containment (BWR)	2	833.7	3.00E-03	1988--2015	2	989.4	2.53E-03	1988--2020	-15.7%
FWLB BWR FI	Feedwater Line Break (BWR)	0	833.7	6.00E-04	1988--2015	0	989.4	5.05E-04	1988--2020	-15.8%
VSLOCA PWR FI	Very Small Loss-of-Coolant Accident (PWR)	0	1445	3.46E-04	1992--2015	0	1744.8	2.87E-04	1992--2020	-17.1%
LOAC LOWV FI	Loss of Vital AC Bus (Low Voltage)	5	2179.9	2.52E-03	1992--2015	5	2635.4	2.09E-03	1992--2020	-17.1%
VSLOCA BWR FI	Very Small Loss-of-Coolant Accident (BWR)	2	734.9	3.40E-03	1992--2015	2	890.6	2.81E-03	1992--2020	-17.4%
SD.LOOP	Loss-of-Offsite-Power, All Categories, Shutdown Operations, per rsy	36	213.4	1.69E-01	1997--2015	17	127.2	1.38E-01	2006--2020	-18.3%
SD.LOOP-SC	Loss-of-Offsite-Power, Switchyard-Centered, Shutdown Operations, per rsy	17	213.5	8.20E-02	1997--2015	8	127.2	6.68E-02	2006--2020	-18.5%
PO.LOOP	Loss-of-Offsite-Power, All Categories, Power Operations, per rcry	54	1751.7	3.11E-02	1997--2015	35	1388.9	2.52E-02	2006--2020	-19.0%
SLOCA PWR	Small Loss-of-Coolant Accident (PWR)	0	797	4.01E-04		0	1096.5	3.09E-04	2003--2020	-22.9%
TRANS PWR	Transient Initiating Event (PWR)	743	1100.6	6.76E-01	1998--2015	300	596.5	5.18E-01	2011--2020	-23.4%
TRANS BWR	Transient Initiating Event (BWR)	441	598.2	7.40E-01	1997--2015	173	316.7	5.55E-01	2011--2020	-25.0%
PO.LOOP-SC	Loss-of-Offsite-Power, Switchyard-Centered, Power Operations, per rcry	23	1751.7	1.34E-02	1997--2015	12	1388.9	9.00E-03	2006--2020	-32.8%
SORV1 BWR FI	Stuck Open Safety/Relief Valve (BWR)	9	709.7	1.26E-02	1993--2015	7	838.6	8.32E-03	1994--2020	-34.0%
SORV2 PWR FI	Stuck Open Relief Valve >2 (PWR)	0	1100.6	4.54E-04	1998--2015	0	1962.4	2.55E-04	1988--2020	-43.8%
LOCHS PWR FI	Loss of Condenser Heat Sink (PWR)	61	1271.4	4.82E-02	1995--2015	23	909.8	2.53E-02	2006--2020	-47.5%
PO.LOOP-GR	Loss-of-Offsite-Power, Grid-Related, Power Operations, per rcry	18	1751.7	1.10E-02	1997--2015	7	1388.9	5.40E-03	2006--2020	-50.9%

Initiating Event	Description	2015 Update				2020 Update				
		Number of Events	Critical Years (rcry)	Mean	Baseline Period	Number of Events	Critical Years (rcry)	Mean	Baseline Period	Δ of Mean
LOCHS BWR FI	Loss of Condenser Heat Sink (BWR)	69	626.6	1.10E-01	1996--2015	16	381.9	4.19E-02	2009--2020	-61.9%
LOMFW	Loss of Main Feedwater	124	2096.3	5.94E-02	1993--2015	20	913.2	2.19E-02	2011--2020	-63.1%
ISLOCA BWR FI	Interfacing System Loss-of-Coolant Accident (BWR)	0	323.4	1.55E-03	2006--2015	0	989.4	5.05E-04	1988--2020	-67.4%
ISLOCA PWR FI	Interfacing System Loss-of-Coolant Accident (PWR)	0	610	8.20E-04	2006--2015	0	1962.4	2.55E-04	1988--2020	-68.9%
RCPLOCA	Reactor Coolant Pump Seal Loss-of-Coolant Accident (PWR)	0	610	8.20E-04	2006--2015	0	1962.4	2.55E-04	1988--2020	-68.9%

Note: refer to Table 4 for acronyms used in this table

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Appendix A

Component Unreliability Data Sheets 2020 Update

A-1. VALVES

The valve component boundary includes the valve, the valve operator, local circuit breaker, and local instrumentation and control circuitry. The failure modes for valves are listed in Table 8.

The selected external leakage, large (ELL) mean is the external leak, small (ELS) mean multiplied by 0.07, with an assumed α of 0.3. The selected internal leak, large (ILL) mean is the internal leak, small (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 NUREG/CR-6928 [A-1].

Table 8. Valve failure modes.

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

A-1.1 Air-Operated Valve (AOV)

A-1.1.1 Component Description

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

A-1.1.2 Data Collection and Review

The data for AOV UR baselines were obtained from the IRIS database (formerly the ICES and EPIX [A-2]), covering 2006–2020 using RADS [A-3]. The systems included in the AOV data collection are listed in Table 9, with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component-demand information use all components, regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 9. AOV systems.

		Number of Components		
Pooling Group	System	High/ Unknown Demand	Low Demand	Total
All	Auxiliary feedwater (AFW)	272	213	485
	Chemical and volume control (CVC)	1384	352	1736
	Circulating water system (CWS)	10	2	12

Pooling Group	System	Number of Components High/ Unknown Demand	Low Demand	Total
	Component cooling water (CCW)	855	305	1160
	Condensate system (CDS)	86	19	105
	Condensate transfer system (CTS)	1		1
	Containment fan cooling (CFC)	176	26	202
	Containment isolation system (CIS)	7	9	16
	Containment spray recirculation (CSR)	36	32	68
	Control rod drive (CRD)	468	86	554
	Emergency power supply (EPS)	329	25	354
	Engineered safety features actuation (ESF)	1		1
	Firewater system (FWS)	4	1	5
	Fuel handling system (FHS)	2		2
	Heating ventilation and air conditioning (HVC)	739	108	847
	High pressure coolant injection (HPCI or HCI)	80	8	88
	High pressure core spray (HPCS or HCS)	33		33
	High pressure injection (HPI)	235	75	310
	Instrument air system (IAS)	26	21	47
	Isolation condenser (ISO)	12	6	18
	Low pressure core spray (LCS)	45	12	57
	Main feedwater (MFW)	830	174	1004
	Main steam system (MSS)	979	106	1085
	Normally operating service water (SWN)	709	330	1039
	Reactor coolant system (RCS)	238	56	294
	Reactor core isolation (RCIC or RCI)	82	7	89
	Reactor protection system (RPS)	8	15	23
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	538	163	701
	Standby liquid control (SLC)	4	1	5
	Standby service water (SSW)	159	22	181
	Vapor suppression (VSS)	12	33	45
	Grand Total	**8360**	**2207**	**10567**

Table 10 summarizes the data used in the AOV analysis. Note that the hours for FC, spurious operations (SOP), ELS, and ILS are reactor-year hours.

Table 10. AOV unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent with Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
--	FTO	50	165,942 d	1,755	98	2.3%	23.5%
--	FTC	27	165,942 d	1,755	98	1.5%	20.4%
--	FTOC	83	165,942 d	1,755	98	4.0%	41.8%
--	FC	167	1,109,287,000 h	8,788	105	1.7%	67.6%
--	SOP	61	1,109,287,000 h	8,788	105	0.6%	35.2%
--	ILS	35	1,109,287,000 h	8,788	105	0.4%	15.2%
--	ILL	--	--	8,788	105	--	--
--	ELS	35	1,109,287,000 h	8,788	105	0.4%	23.8%
--	ELL	--	--	8,788	105	--	--
CCW	SOP	10	144,615,200 h	1,164	100	0.6%	6.0%
IAS	SOP	0	6,218,450	50	27	0.0%	0.0%

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

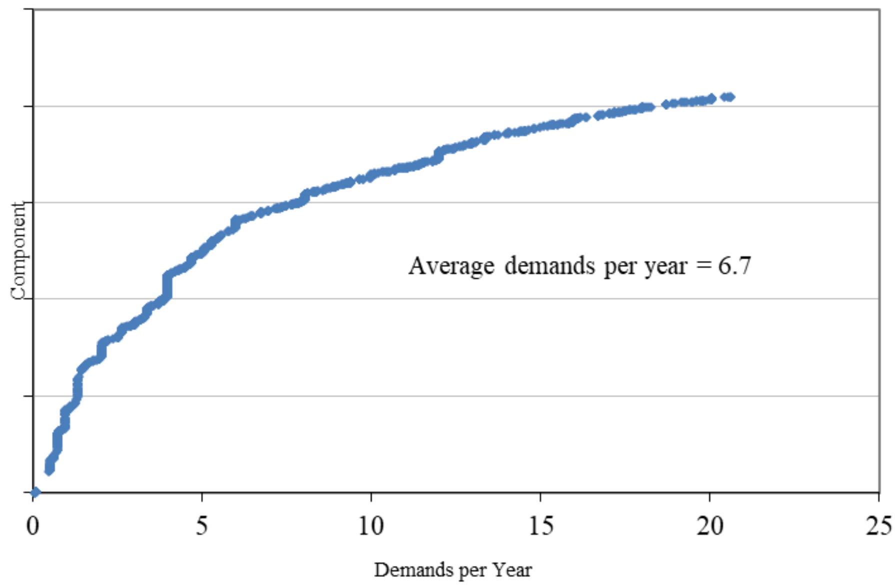


Figure 1. AOV demands per year distribution.

A-1.1.3 Industry-Average Baselines

Table 11 lists the selected industry distributions of *p* and *λ* for the AOV failure modes. These industry-average failure rates do not account for any recovery.

Table 11. Selected industry distributions of p and λ for AOVs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
--	FTO	JNID/IL	2.37E-04	3.02E-04	3.04E-04	3.78E-04	Beta	50.50	1.66E+05
--	FTC	EB/PL/KS	2.30E-06	1.04E-04	1.89E-04	6.64E-04	Beta	0.64	3.38E+03
--	FTOC	EB/PL/KS	1.73E-05	3.57E-04	5.58E-04	1.78E-03	Beta	0.83	1.49E+03
--	FC	EB/PL/KS	1.50E-08	1.32E-07	1.75E-07	4.86E-07	Gamma	1.26	7.17E+06
--	SOP	EB/PL/KS	1.99E-09	3.79E-08	5.83E-08	1.85E-07	Gamma	0.86	1.47E+07
--	ILS	JNID/IL	2.37E-08	3.17E-08	3.20E-08	4.13E-08	Gamma	35.50	1.11E+09
--	ILL	--	6.85E-14	1.56E-10	6.40E-10	2.93E-09	Gamma	0.30	4.69E+08
--	ELS	EB/PL/KS	2.67E-10	1.75E-08	3.43E-08	1.25E-07	Gamma	0.58	1.68E+07
--	ELL	--	2.57E-13	5.85E-10	2.40E-09	1.10E-08	Gamma	0.30	1.25E+08
CCW	SOP	JNID/IL	4.00E-08	7.01E-08	7.26E-08	1.13E-07	Gamma	10.50	1.45E+08
IAS	SOP	JNID/IL	3.16E-10	3.66E-08	8.04E-08	3.09E-07	Gamma	0.50	6.22E+06

A-1.2 Motor-Operated Valve (MOV)

A-1.2.1 Component Description

The motor-operated valve (MOV) component boundary includes the valve, the valve operator, local circuit breaker, and local instrumentation and control circuitry. The failure modes for MOV are listed in Table 8.

A-1.2.2 Data Collection and Review

The data for MOV UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the MOV data collection are listed in Table 12 with the number of components included for each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 12. MOV systems.

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

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

Table 13 summarizes the data used in the MOV analysis. Note that the hours for fail to control (FC), SOP, ELS, and ILS are reactor-year hours.

Table 13. MOV unreliability data.

Pooling Group	Failure Mode	Data Events	Demands or Hours	Counts Components	Plants	Percent with Failures Components	Plants
--	FTO	190	593,626 d	7,120	105	2.5%	78.1%
--	FTC	123	593,626 d	7,120	105	1.6%	56.2%
--	FTOC	346	593,626 d	7,120	105	4.3%	90.5%
--	FC	59	1,634,537,000 h	13,344	105	0.4%	31.4%
--	SOP	41	1,634,537,000 h	13,344	105	0.3%	21.9%
--	ILS	55	1,634,537,000 h	13,344	105	0.4%	30.5%
--	ILL	--	--	13,344	105	0.4%	30.5%
--	ELS	29	1,634,537,000 h	13,344	105	0.2%	20.0%
--	ELL	--	--	13,344	105	0.2%	20.0%
BFV	FTO	24	89,399 d	983	85	2.0%	18.8%
BFV	FTC	24	89,399 d	983	85	2.2%	22.4%
BFV	FTOC	54	89,399 d	983	85	4.6%	35.3%
CCW	SOP	4	183,661,900 h	1,472	98	0.1%	1.0%
SWS	SOP	0	64,725,970 h	566	47	0.0%	0.0%
BFV--CCW	SOP	2	86,552,190 h	738	75	0.1%	1.3%

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

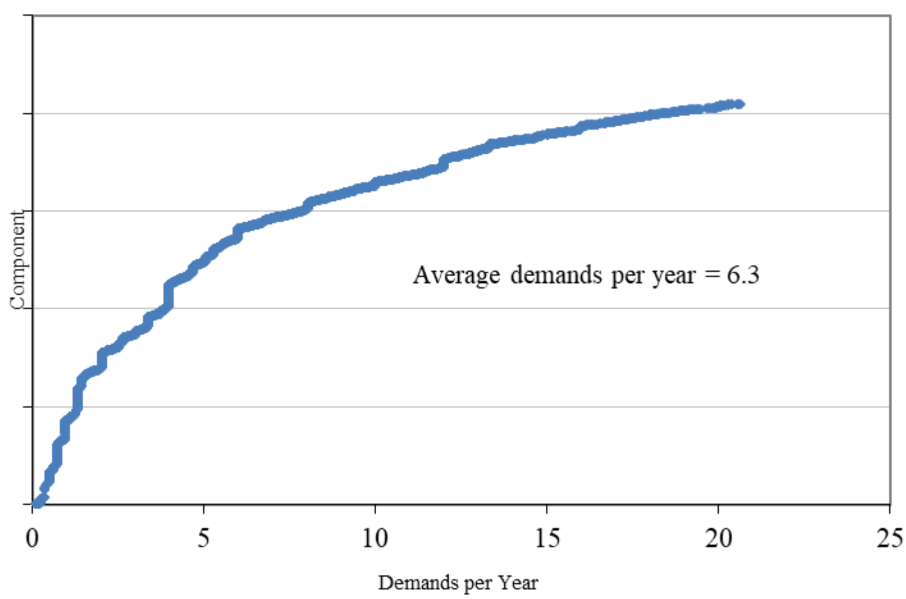


Figure 2. MOV demands per year distribution.

A-1.2.3 Industry-Average Baselines

Table 14 lists the selected industry distributions of *p* and *λ* for the MOV failure modes. These industry-average failure rates do not account for any recovery.

Table 14. Selected industry distributions of p and λ for MOVs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
--	FTO	EB/PL/KS	7.80E-05	2.99E-04	3.43E-04	7.62E-04	Beta	2.48	7.22E+03
--	FTC	EB/PL/KS	1.09E-05	1.56E-04	2.28E-04	6.90E-04	Beta	0.97	4.26E+03
--	FTOC	EB/PL/KS	1.42E-04	5.54E-04	6.40E-04	1.43E-03	Beta	2.43	3.80E+03
--	FC	EB/PL/KS	9.42E-10	2.17E-08	3.47E-08	1.13E-07	Gamma	0.80	2.30E+07
--	SOP	JNID/IL	1.93E-08	2.53E-08	2.54E-08	3.23E-08	Gamma	41.50	1.63E+09
--	ILS	EB/PL/KS	7.97E-11	1.49E-08	3.61E-08	1.44E-07	Gamma	0.45	1.25E+07
--	ILL	--	7.73E-14	1.76E-10	7.22E-10	3.30E-09	Gamma	0.30	4.16E+08
--	ELS	EB/PL/KS	4.85E-11	7.97E-09	1.88E-08	7.43E-08	Gamma	0.46	2.46E+07
--	ELL	--	1.41E-13	3.21E-10	1.32E-09	6.02E-09	Gamma	0.30	2.28E+08
BFV	FTO	JNID/IL	1.90E-04	2.70E-04	2.74E-04	3.71E-04	Beta	24.50	8.94E+04
BFV	FTC	EB/PL/KS	2.52E-05	2.18E-04	2.89E-04	7.97E-04	Beta	1.27	4.39E+03
BFV	FTOC	EB/PL/KS	7.34E-06	4.06E-04	7.69E-04	2.76E-03	Beta	0.60	7.83E+02
CCW	SOP	JNID/IL	9.04E-09	2.27E-08	2.45E-08	4.60E-08	Gamma	4.50	1.84E+08
SWS	SOP	JNID/IL	3.04E-11	3.52E-09	7.72E-09	2.97E-08	Gamma	0.50	6.47E+07
BFV--CCW	SOP	JNID/IL	6.61E-09	2.51E-08	2.89E-08	6.39E-08	Gamma	2.50	8.66E+07

A-1.3 Hydraulic-Operated Valve (HOV)

A-1.3.1 Component Description

The hydraulic-operated valve (HOV) component boundary includes the valve, the valve operator, and local instrumentation and control circuitry. The failure modes for HOV are listed in Table 8.

A-1.3.2 Data Collection and Review

The data for HOV UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the HOV data collection are listed in Table 15 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 15. HOV systems.

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

Table 16 summarizes the data used in the HOV analysis. Note that the hours for FC, SOP, ELS, and ILS are reactor-year hours.

Table 16. HOV unreliability data.

Pooling Group	Failure Mode	Data Events	Demands or Hours	Counts Components	Plants	Percent with Failures Components	Plants
--	FTOC	17	16,401 d	219	42	7.3%	23.8%

Pooling Group	Failure Mode	Events	Data Demands or Hours	Counts Components	Plants	Percent with Failures Components	Plants
--	FC	21	76,176,020 h	603	80	3.3%	20.0%
--	SOP	10	76,176,020 h	603	80	1.2%	8.8%
--	ILS	2	76,176,020 h	603	80	0.3%	2.5%
--	ILL	--	--	603	80	0.3%	2.5%
--	ELS	7	76,176,020 h	603	80	1.0%	7.5%
--	ELL	--	--	603	80	1.0%	7.5%

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

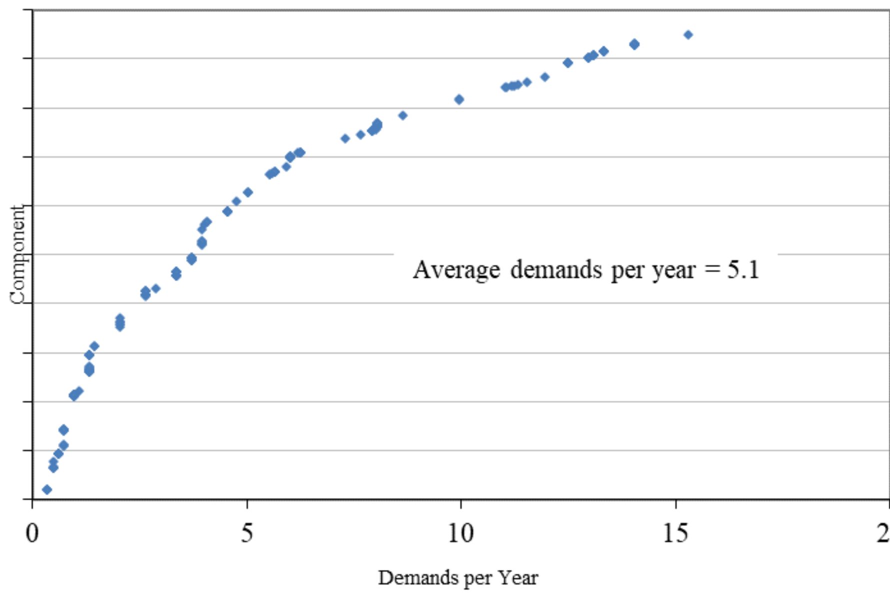


Figure 3. HOV demands per year distribution.

A-1.3.3 Industry-Average Baselines

Table 17 lists the selected industry distributions of *p* and *λ* for the HOV failure modes. These industry-average failure rates do not account for any recovery.

Table 17. Selected industry distributions of p and λ for HOVs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
--	FTOC	EB/PL/KS	2.23E-06	4.93E-04	1.23E-03	4.97E-03	Beta	0.44	3.53E+02
--	FC	JNID/IL	1.90E-07	2.78E-07	2.82E-07	3.89E-07	Gamma	21.50	7.62E+07
--	SOP	EB/PL/KS	6.27E-10	5.84E-08	1.23E-07	4.64E-07	Gamma	0.53	4.28E+06
--	ILS	JNID/IL	7.52E-09	2.86E-08	3.28E-08	7.26E-08	Gamma	2.50	7.62E+07
--	ILL	--	7.02E-14	1.60E-10	6.56E-10	3.00E-09	Gamma	0.30	4.57E+08
--	ELS	EB/PL/KS	2.08E-10	3.97E-08	9.66E-08	3.85E-07	Gamma	0.45	4.65E+06
--	ELL	--	7.24E-13	1.65E-09	6.76E-09	3.09E-08	Gamma	0.30	4.44E+07

A-1.4 Solenoid-Operated Valve (SOV)

A-1.4.1 Component Description

The solenoid-operated valve (SOV) component boundary includes the valve, the valve operator, and local instrumentation and control circuitry. The failure modes for SOV are listed in Table 8.

A-1.4.2 Data Collection and Review

The data for SOV UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the SOV data collection are listed in Table 18 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 18. SOV systems.

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

Table 19 summarizes the data used in the SOV analysis.

Table 19. SOV unreliability data.

Pooling Group	Failure Mode	Events	Data Demands or Hours	Counts Components	Counts Plants	Percent with Failures Components	Percent with Failures Plants
--	FTOC	13	27,937 d	555	54	2.0%	14.8%
--	FC	15	115,760,700 h	921	86	1.6%	12.8%
--	SOP	9	115,760,700 h	921	86	0.4%	4.7%
--	ILS	8	115,760,700 h	921	86	0.9%	5.8%
--	ILL	--	--	921	86	--	--
--	ELS	2	115,760,700 h	921	86	0.2%	2.3%
--	ELL	--	--	921	86	--	--

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

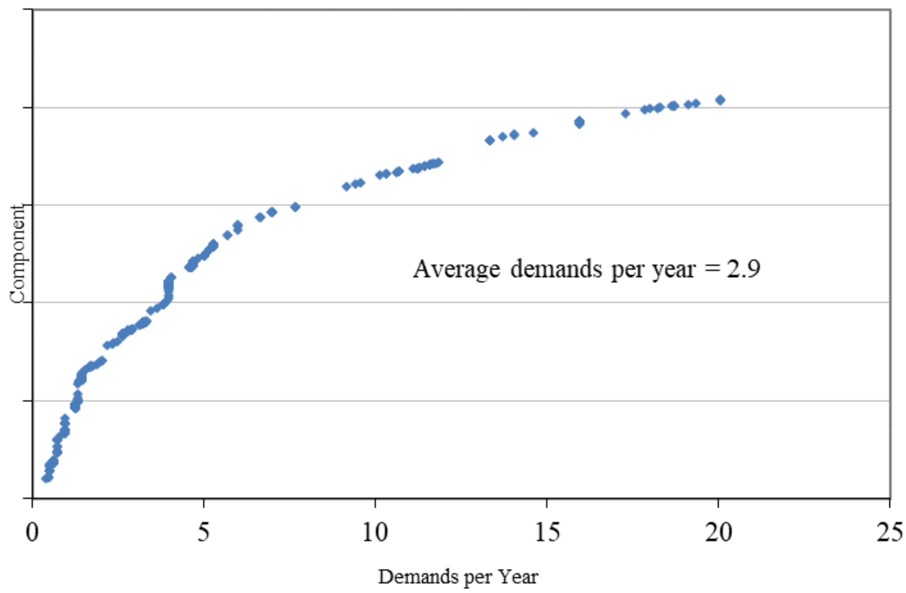


Figure 4. SOV demands per year distribution.

A-1.4.3 Industry-Average Baselines

Table 20 lists the selected industry distributions of *p* and *λ* for the SOV failure modes. These industry-average failure rates do not account for any recovery.

Table 20. Selected industry distributions of p and λ for SOVs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
--	FTOC	JNID/IL	2.89E-04	4.72E-04	4.83E-04	7.18E-04	Beta	13.50	2.79E+04
--	FC	EB/PL/KS	1.52E-09	8.08E-08	1.52E-07	5.44E-07	Gamma	0.61	4.01E+06
--	SOP	JNID/IL	4.36E-08	7.90E-08	8.21E-08	1.30E-07	Gamma	9.50	1.16E+08
--	ILS	JNID/IL	3.74E-08	7.04E-08	7.34E-08	1.19E-07	Gamma	8.50	1.16E+08
--	ILL	--	1.57E-13	3.58E-10	1.47E-09	6.72E-09	Gamma	0.30	2.04E+08
--	ELS	JNID/IL	4.94E-09	1.88E-08	2.16E-08	4.77E-08	Gamma	2.50	1.16E+08
--	ELL	--	1.62E-13	3.69E-10	1.51E-09	6.92E-09	Gamma	0.30	1.98E+08

A-1.5 Explosive-Operated Valve (EOV)

A-1.5.1 Component Description

The explosive-operated valve (EOV) component boundary includes the valve and local instrumentation and control circuitry. The failure modes for EOV are listed in Table 8.

A-1.5.2 Data Collection and Review

Data for EOV UR baseline was obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the EOV data collection are listed in Table 21 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 21. EOV systems.

		Number of Components		
Pooling Group	**System**	**High/ Unknown Demand**	**Low Demand**	**Total**
All	Standby liquid control (SLC)	13	60	73
	Grand Total	13	60	73

Table 22 summarizes the data used in the EOV analysis.

Table 22. EOV unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Events**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
--	FTO	3	674 d	59	28	5.1%	10.7%

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

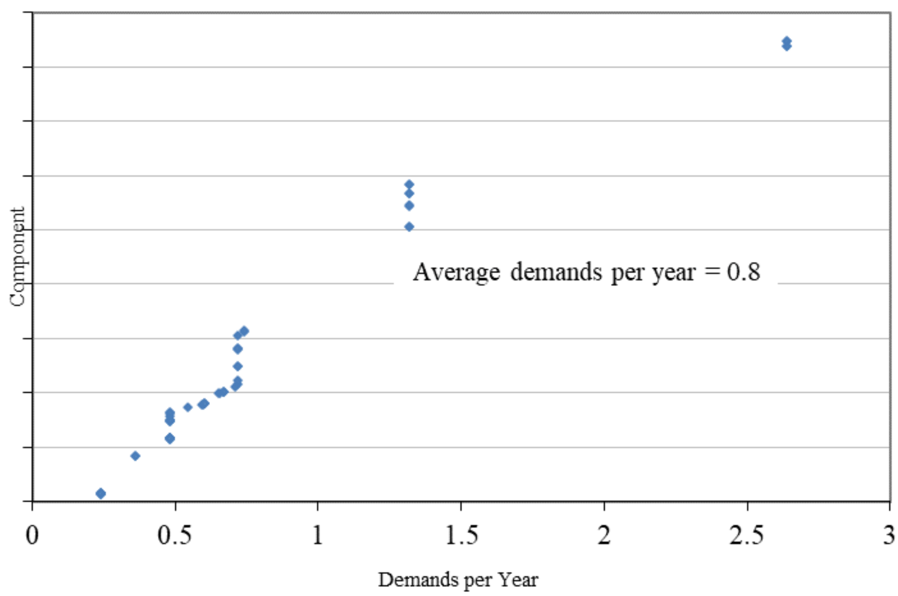


Figure 5. EOV demands per year distribution.

A-1.5.3 Industry-Average Baselines

Table 23 lists the industry-average failure rate distribution for the EOV FTO failure mode. This industry-average failure rate does not account for any recovery.

Table 23. Selected industry distributions of p and λ for EOVs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
--	FTO	EB/PL/KS	2.45E-04	3.23E-03	4.62E-03	1.38E-02	Beta	1.01	2.17E+02

A-1.6 Vacuum Breaker Valve (VBV)

A-1.6.1 Component Description

The vacuum breaker valve (VBV) component boundary includes the valve, the valve operator, local circuit breaker, and local instrumentation and control circuitry. The failure modes for VBV are listed in Table 8.

A-1.6.2 Data Collection and Review

Data for VBV UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the VBV data collection are listed in Table 24 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 24. VBV systems.

		Number of Components		
Pooling Group	**System**	**High/ Unknown Demand**	**Low Demand**	**Total**
All	Vapor suppression (VSS)	174	167	341
	Grand Total	**174**	**167**	**34**

Table 25 summarizes the data used in the VBV analysis.

Table 25. VBV unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Events**	**Demands or Hours**	**Component s**	**Plants**	**Components**	**Plants**
--	FTO	1	23,202 d	167	17	0.6%	5.9%
--	FTC	1	23,202 d	167	17	0.6%	5.9%
--	FTOC	2	23,202 d	167	17	1.2%	11.8%
--	SOP	0	43,685,040 h	343	30	0.0%	0.0%
--	ILS	2	43,685,040 h	343	30	0.6%	6.7%
--	ILL	--	--	343	30	--	--

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

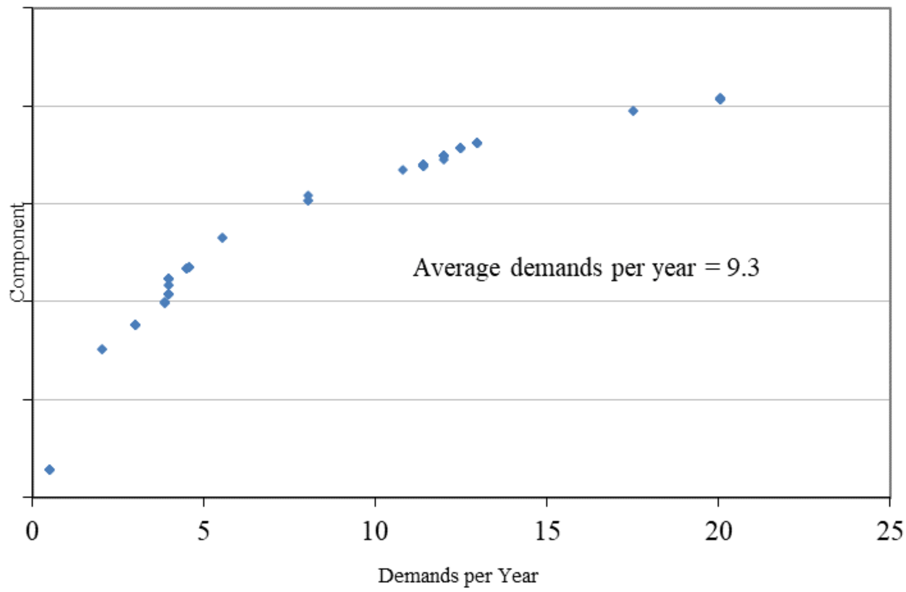


Figure 6. VBV demands per year distribution.

A-1.6.3 Industry-Average Baselines

Table 26 lists the selected industry distributions of *p* and λ for the VBV failure modes. These industry-average failure rates do not account for any recovery.

Table 26. Selected industry distributions of p and λ for VBVs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
--	FTO	JNID/IL	7.58E-06	5.10E-05	6.46E-05	1.68E-04	Beta	1.50	2.32E+04
--	FTC	JNID/IL	7.58E-06	5.10E-05	6.46E-05	1.68E-04	Beta	1.50	2.32E+04
--	FTOC	JNID/IL	2.47E-05	9.38E-05	1.08E-04	2.39E-04	Beta	2.50	2.32E+04
--	SOP	JNID/IL	4.50E-11	5.21E-09	1.14E-08	4.40E-08	Gamma	0.50	4.37E+07
--	ILS	JNID/IL	1.31E-08	4.98E-08	5.72E-08	1.27E-07	Gamma	2.50	4.37E+07
--	ILL	--	1.22E-13	2.79E-10	1.14E-09	5.23E-09	Gamma	0.30	2.62E+08

A-1.7 Turbine Bypass Valve (TBV)

A-1.7.1 Component Description

The turbine bypass valve (TBV) component boundary includes the valve, the valve operator (including the associated solenoid operated valves), local circuit breaker, and local instrumentation and control circuitry. The failure modes for TBV are listed in Table 8.

A-1.7.2 Data Collection and Review

The data for TBV UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the TBV data collection are listed in Table 27 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 27. TBV systems.

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

Table 28 summarizes the data used in the AOV analysis. Note that the hours for FC are reactor-year hours.

Table 28. TBV unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	Failure Mode	Events	Demands or Hours	Components	Plants	Components	Plants
--	FTO	1	2,367 d	73	15	1.4%	6.7%
--	FTC	0	2,367 d	73	15	0.0%	0.0%
--	FTOC	1	2,367 d	73	15	1.4%	6.7%
--	FC	6	19,263,540 h	153	27	3.3%	18.5%

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

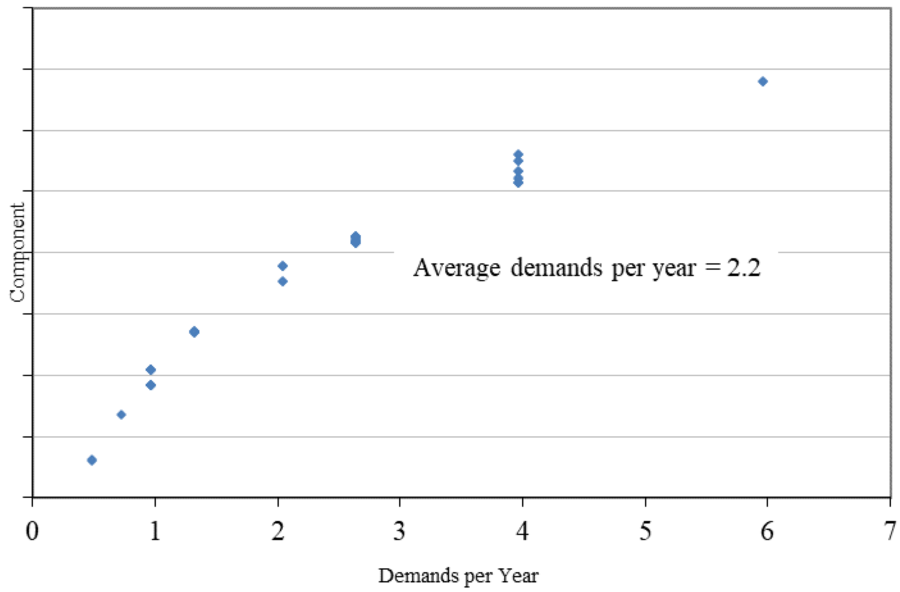


Figure 7. TBV demands per year distribution.

A-1.7.3 Industry-Average Baselines

Table 29 lists the selected industry distributions of *p* and *λ* for the TBV failure modes. These industry-average failure rates do not account for any recovery.

Table 29. Selected industry distributions of p and λ for TBVs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
--	FTO	JNID/IL	7.42E-05	4.99E-04	6.33E-04	1.65E-03	Beta	1.50	2.37E+03
--	FTC	JNID/IL	8.30E-07	9.60E-05	2.11E-04	8.10E-04	Beta	0.50	2.37E+03
--	FTOC	JNID/IL	7.42E-05	4.99E-04	6.33E-04	1.65E-03	Beta	1.50	2.37E+03
--	FC	EB/PL/KS	1.29E-09	1.60E-07	3.57E-07	1.38E-06	Gamma	0.49	1.38E+06

A-1.8 Main Steam Isolation Valve (MSV)

A-1.8.1 Component Description

The motor-operated valve (MSV) component boundary includes the valve, the valve operator, local circuit breaker, and local instrumentation and control circuitry. The failure modes for MSV are listed in Table 8.

A-1.8.2 Data Collection and Review

The data for MSV UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the MOV data collection are listed in Table 30 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 30. MSV systems.

		Number of Components		
Pooling Group	**System**	**High/ Unknown Demand**	**Low Demand**	**Total**
All	Main steam (MSS)	95	425	520
	Grand Total	**95**	**425**	**520**

Table 31 summarizes the data used in the MSV analysis. Note that the hours for SOP, ELS, and ILS are reactor-year hours.

Table 31. MSV unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Events**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
--	FTOC	24	32,199 d	425	84	4.9%	19.0%
--	SOP	16	65,768,320 h	520	105	2.9%	11.4%
--	ILS	23	65,768,320 h	520	105	4.0%	12.4%
--	ILL	--	--	520	105	--	--
--	ELS	1	65,768,320 h	520	105	0.2%	1.0%
--	ELL	--	--	520	105	--	--

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

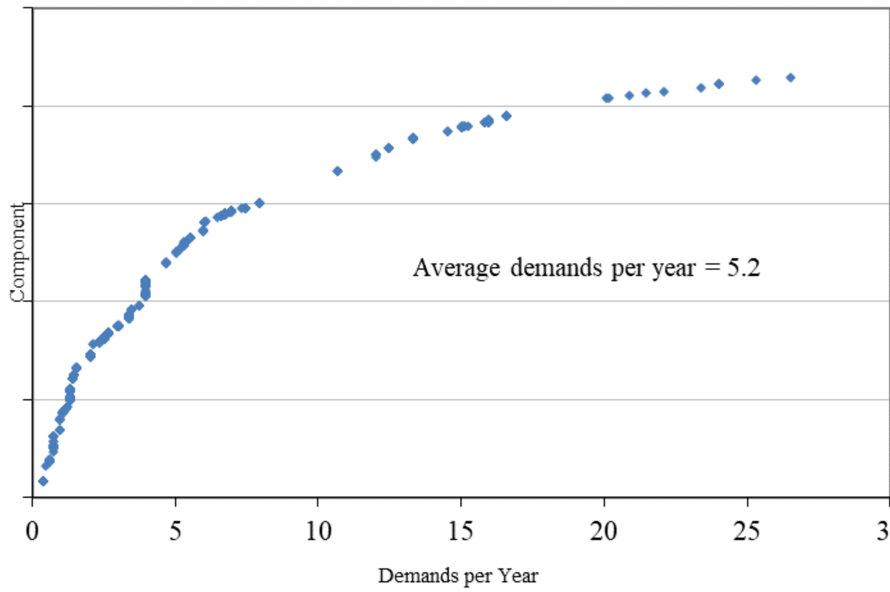


Figure 8. MSV demands per year distribution.

A-1.8.3 Industry-Average Baselines

Table 32 lists the selected industry distributions of *p* and *λ* for the MSV failure modes. These industry-average failure rates do not account for any recovery.

Table 32. Selected industry distributions of p and λ for MSVs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
--	FTOC	JNID/IL	5.27E-04	7.50E-04	7.61E-04	1.03E-03	Beta	24.50	3.22E+04
--	SOP	EB/PL/KS	9.30E-10	1.07E-07	2.34E-07	8.99E-07	Gamma	0.50	2.14E+06
--	ILS	JNID/IL	2.45E-07	3.52E-07	3.57E-07	4.86E-07	Gamma	23.50	6.58E+07
--	ILL	--	7.64E-13	1.74E-09	7.14E-09	3.27E-08	Gamma	0.30	4.20E+07
--	ELS	JNID/IL	2.67E-09	1.80E-08	2.28E-08	5.94E-08	Gamma	1.50	6.58E+07
--	ELL	--	1.71E-13	3.89E-10	1.60E-09	7.30E-09	Gamma	0.30	1.88E+08

A-1.9 Check Valve (CKV)

A-1.9.1 Component Description

The check valve (CKV) component boundary includes the valve and no other supporting components. The failure modes for CKV are listed in Table 8.

A-1.9.2 Data Collection and Review

Data for CKV UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the CKV data collection are listed in Table 33 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 33. CKV systems.

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

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

Table 34 summarizes the data used in the CKV analysis. Note that the hours for SOP, ELS, and ILS are reactor-year hours.

Table 34. CKV unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent with Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
-	FTO	0	44,791 d	489	44	0.0%	0.0%
-	FTC	5	44,791 d	489	44	1.0%	9.1%
-	SOP	0	806,744,700 h	6,379	104	0.0%	0.0%
-	ILS	58	806,744,700 h	6,379	104	0.9%	28.8%
-	ILL	--	--	6,379	104	--	--
-	ELS	3	806,744,700 h	6,379	104	0.0%	2.9%
-	ELL	--	--	6,379	104	--	--

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

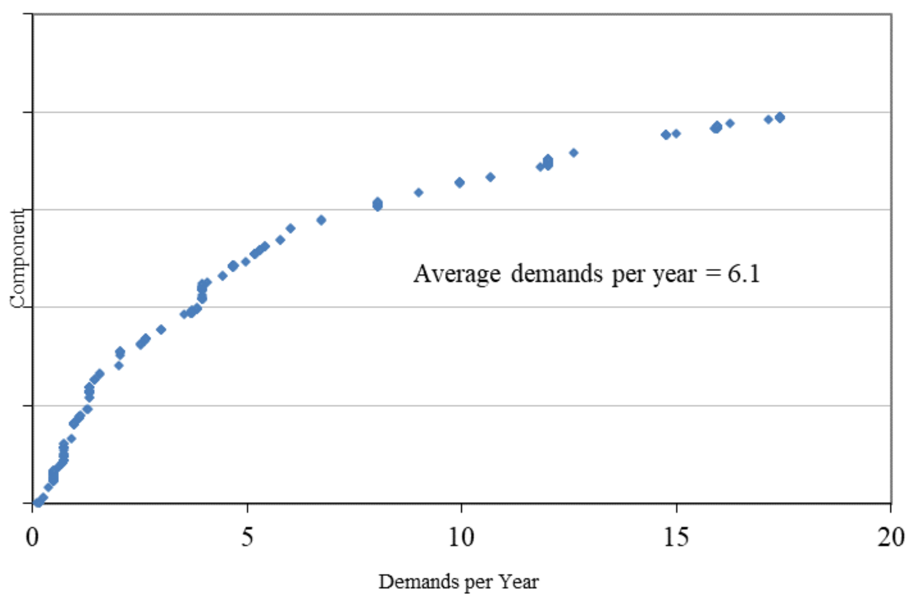


Figure 9. CKV demands per year distribution.

A-1.9.3 Industry-Average Baselines

Table 35lists the selected industry distributions of p and λ for the CKV failure modes. These industry-average failure rates do not account for any recovery.

Table 35. Selected industry distributions of p and λ for CKVs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
-	FTO	JNID/IL	4.39E-08	5.08E-06	1.12E-05	4.29E-05	Beta	0.50	4.48E+04
-	FTC	JNID/IL	5.11E-05	1.15E-04	1.23E-04	2.20E-04	Beta	5.50	4.48E+04
-	SOP	JNID/IL	2.44E-12	2.82E-10	6.20E-10	2.38E-09	Gamma	0.50	8.07E+08
-	ILS	JNID/IL	5.76E-08	7.21E-08	7.25E-08	8.88E-08	Gamma	58.50	8.07E+08
-	ILL	--	1.55E-13	3.53E-10	1.45E-09	6.63E-09	Gamma	0.30	2.07E+08
-	ELS	JNID/IL	1.34E-09	3.93E-09	4.34E-09	8.72E-09	Gamma	3.50	8.07E+08
-	ELL	--	3.25E-14	7.41E-11	3.04E-10	1.39E-09	Gamma	0.30	9.87E+08

A-1.10 Manual Valve (XVM)

A-1.10.1 Component Description

The manual valve (XVM) component boundary includes the valve and valve operator. The failure modes for XVM are listed in Table 8.

A-1.10.2 Data Collection and Review

Data for XVM UR baselines were obtained from the IRIS database, covering 1997–2004 using RADS. The systems included in the XVM data collection are listed in Table 36 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 36. XVM systems.

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

Table 37 summarizes the data used in the XVM analysis. Note that the hours for SOP, ELS, and ILS are reactor-year hours.

Table 37. XVM unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent with Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
--	FTOC	1	2,875 d	66	9	1.5%	11.1%
--	SOP	2	132,674,000 h	1,035	83	0.2%	2.4%
--	ILS	3	132,674,000 h	1,035	83	0.3%	3.6%
--	ILL	--	--	1,035	83	--	--
--	ELS	11	132,674,000 h	1,035	83	1.1%	9.6%
--	ELL	--	--	1,035	83	--	--
SWS	SOP	0	18,055,700 h	140	20	0.0%	0.0%

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

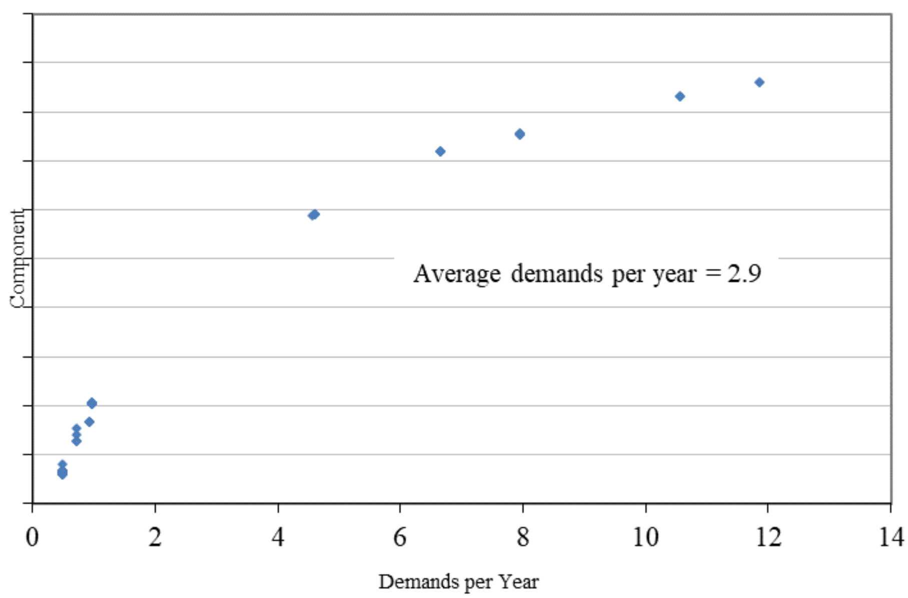


Figure 10. XVM demands per year distribution.

A-1.10.3 Industry-Average Baselines

Table 38 lists the selected industry distributions of p and λ for the XVM failure modes. These industry-average failure rates do not account for any recovery.

Table 38. Selected industry distributions of p and λ for XVMs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
--	FTOC	JNID/IL	6.13E-05	4.12E-04	5.22E-04	1.36E-03	Beta	1.50	2.87E+03
--	SOP	JNID/IL	4.31E-09	1.64E-08	1.88E-08	4.16E-08	Gamma	2.50	1.33E+08
--	ILS	JNID/IL	8.15E-09	2.39E-08	2.64E-08	5.29E-08	Gamma	3.50	1.33E+08
--	ILL	--	5.65E-14	1.29E-10	5.28E-10	2.42E-09	Gamma	0.30	5.68E+08
--	ELS	JNID/IL	4.92E-08	8.40E-08	8.67E-08	1.32E-07	Gamma	11.50	1.33E+08
--	ELL	--	6.50E-13	1.48E-09	6.07E-09	2.78E-08	Gamma	0.30	4.94E+07
SWS	SOP	JNID/IL	1.09E-10	1.26E-08	2.77E-08	1.06E-07	Gamma	0.50	1.81E+07

A-1.11 Flow Control Valve (FCV)

A-1.11.1 Component Description

The Flow Control Valve (FCV) component boundary includes the valve and valve operator. Motor-operated and air-operated valves are included in this group. The failure modes for FCV are listed in Table 8.

A-1.11.2 Data Collection and Review

Data for FCV UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the FCV data collection are listed in Table 39 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 39. FCV systems.

Pooling Group	System	Number of Components: High/ Unknown Demand	Low Demand	Total
FCV	Auxiliary feedwater (AFW)		6	6
	Chemical and volume control (CVC)	2		2
	Component cooling water (CCW)	413	103	516
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	3	4	7
	FCV Total	**418**	**113**	**531**
FRV	Main feedwater (MFW)	175	41	216
	FRV Total	**175**	**41**	**216**
	Grand Total	**593**	**154**	**747**

Table 40 summarizes the data used in the FCV analysis. Note that the hours for SOP, ELS, and ILS are reactor-year hours.

Table 40. FCV unreliability data.

Pooling Group	Failure Mode	Data: Events	Data: Demands or Hours	Counts: Components	Counts: Plants	Percent with Failures: Components	Percent with Failures: Plants
FCV	FTOC	0	11,345 d	105	15	0.0%	0.0%
FCV	FC	8	73,637,280 h	595	84	1.2%	8.3%
FCV	SOP	2	73,637,280 h	595	84	0.3%	2.4%
FRV	FTOP	49	27,637,200 h	221	77	18.1%	36.4%

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

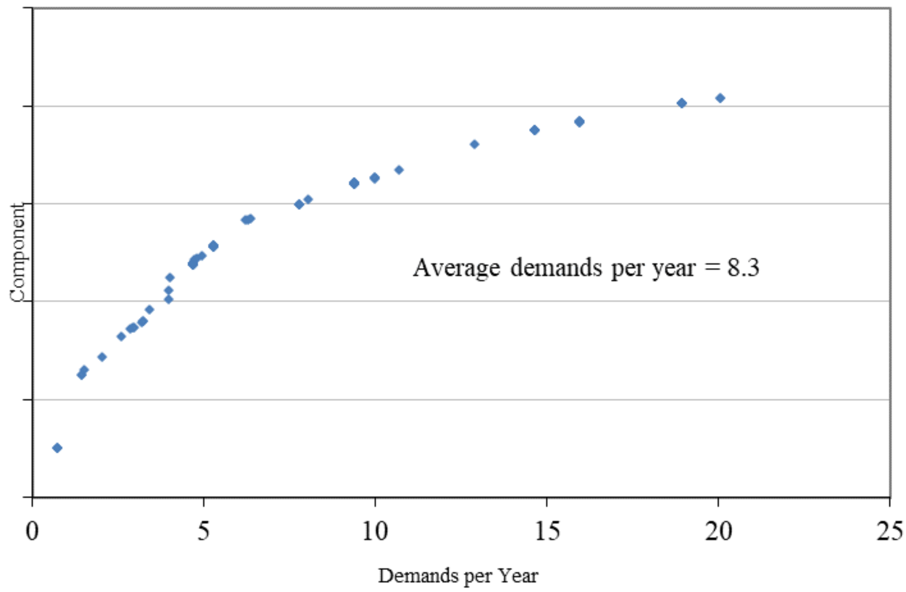


Figure 11. FCV demands per year distribution.

A-1.11.3 Industry-Average Baselines

Table 41 lists the selected industry distributions of *p* and *λ* for the FCV failure modes. These industry-average failure rates do not account for any recovery.

Table 41. Selected industry distributions of p and λ for FCVs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	Distribution α	Distribution β
FCV	FTOC	JNID/IL	1.74E-07	2.01E-05	4.41E-05	1.70E-04	Beta	0.50	1.13E+04
FCV	FC	JNID/IL	5.89E-08	1.11E-07	1.15E-07	1.87E-07	Gamma	8.50	7.36E+07
FCV	SOP	JNID/IL	7.78E-09	2.96E-08	3.40E-08	7.52E-08	Gamma	2.50	7.36E+07
FRV	FTOP	EB/PL/KS	2.71E-08	1.06E-06	1.88E-06	6.52E-06	Gamma	0.67	3.54E+05

A-2. PUMPS

The pump boundary includes the pump, driver, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for pumps are listed in Table 42.

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 NUREG/CR-6928.

Table 42. Pump failure modes.

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

A-2.1 Motor-Driven Pump (MDP)

A-2.1.1 Component Description

The motor-driven pump (MDP) boundary includes the pump, motor, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The MDP component data in this section include only centrifugal type pumps. Component data for positive displacement which are also motor-driven, are presented in Section A-1.1. The failure modes for MDP are listed in Table 42.

A-2.1.2 Data Collection and Review

Data for MDP UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems and operational status included in the MDP data collection are listed in Table 43 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤200 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 43. MDP systems.

Pooling Group	System	Number of Components: High/ Unknown Demand	Low Demand	Total
Normally Running	Chemical and volume control (CVC)	1	62	63
	Chilled water system (CHW)	1	2	3
	Circulating water system (CWS)	104	32	136
	Component cooling water (CCW)	98	281	379
	Condensate system (CDS)	5	142	147
	Condensate transfer system (CTS)	3		3
	Containment spray recirculation (CSR)	25		25

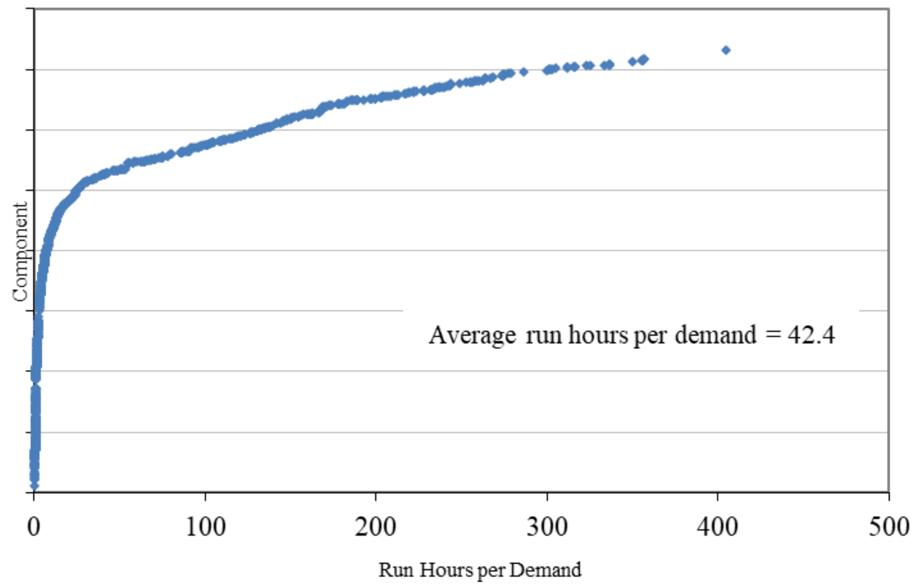
Pooling Group	System	Number of Components: High/ Unknown Demand	Low Demand	Total
	Control rod drive (CRD)	5	41	46
	Emergency power supply (EPS)	2		2
	Firewater (FWS)	2		2
	Fuel Oil Transfer (FOT)	16		16
	Heating ventilation and air conditioning (HVC)	2		2
	High pressure injection (HPI)	2	5	7
	Low pressure core spray (LCS)	14	5	19
	Main feedwater (MFW)	5	41	46
	Normally operating service water (SWN)	50	88	138
	Reactor protection (RPS)	2		2
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	2		2
	Standby service water (SSW)	24	15	39
	Chemical and volume control (CVC)	**363**	**714**	**1077**
	Normally Running Total		124	124
Standby	Auxiliary feedwater (AFW)		152	152
	Containment spray recirculation (CSR)		9	9
	Control rod drive (CRD)		14	14
	Emergency power supply (EPS)		1	1
	Firewater (FWS)		18	18
	Fuel Oil Transfer (FOT)		9	9
	High pressure core spray (HCS)		168	168
	High pressure injection (HPI)		67	67
	Low pressure core spray (LCS)		216	216
	Normally operating service water (SWN)		308	308
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	2	211	213
	Standby service water (SSW)			
	Standby Total	**2**	**1297**	**1299**
	Grand Total	**365**	**2011**	**2376**

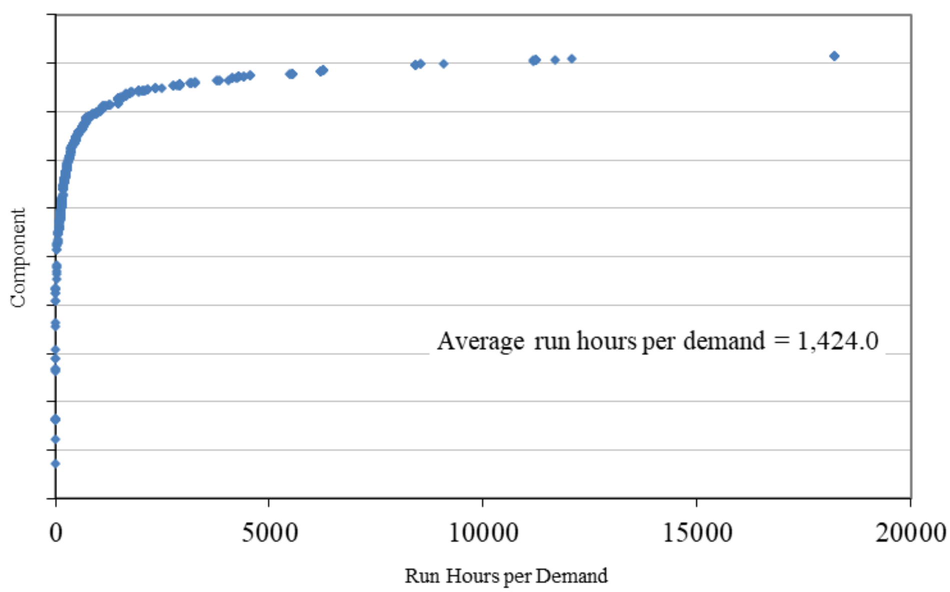
Table 44 summarizes the data obtained from EPIX and used in the MDP analysis. Note that the hours for ELS are reactor-year hours.

Table 44. MDP unreliability data.

Pooling Group	Failure Mode	Data: Failures	Data: Demands or Hours	Counts: Components	Counts: Plants	Percent with Failures: Components	Percent with Failures: Plants
STBY	FTS	227	410,593 d	1,311	107	14.3%	75.7%
STBY	FTR<1H	31	378,369 h	1,305	107	2.1%	22.4%
STBY	FTR>1H	92	19,248,030 h	1,311	107	6.0%	47.7%
--	ELS	59	288,839,600 h	2,351	105	2.2%	32.4%
--	ELL	--	--	2,351	105	--	--
NR	FTS	89	125,005 d	649	102	11.4%	46.1%
NR	FTR	129	56,750,330 h	650	102	15.2%	50.0%
CCW	FTS	31	80,067 d	288	86	9.4%	27.9%
CCW	FTR	31	17,527,790 h	288	86	9.0%	26.7%
SWS	FTS	132	225,636 d	529	100	19.7%	57.0%
SWS	FTR	100	25,635,460 h	529	100	14.7%	51.0%
CWS	FTR	15	3,116,679 h	31	12	38.7%	58.3%

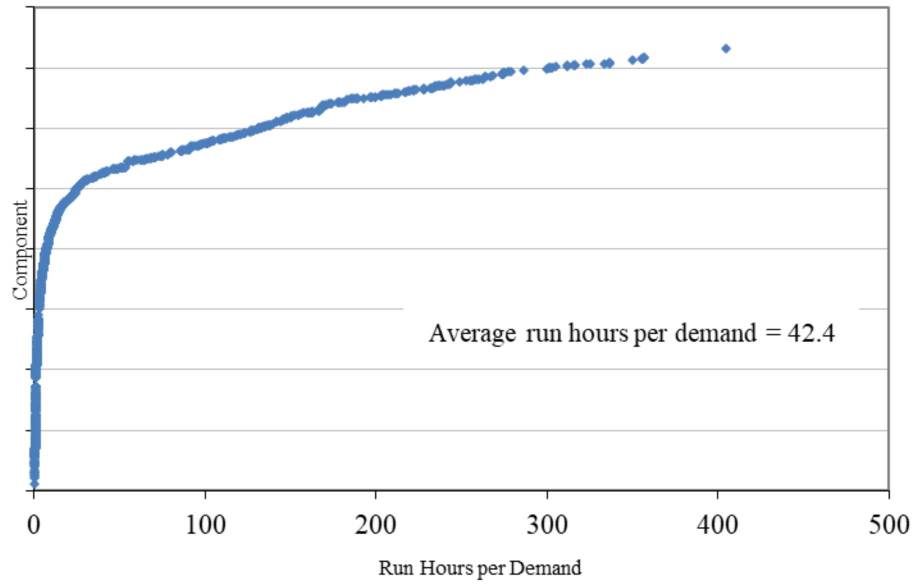
Figure 12(a) shows the range of start demands per year in the standby MDP data set. Figure 12(b) shows the range of start demands per year in the running MDP data set. a.

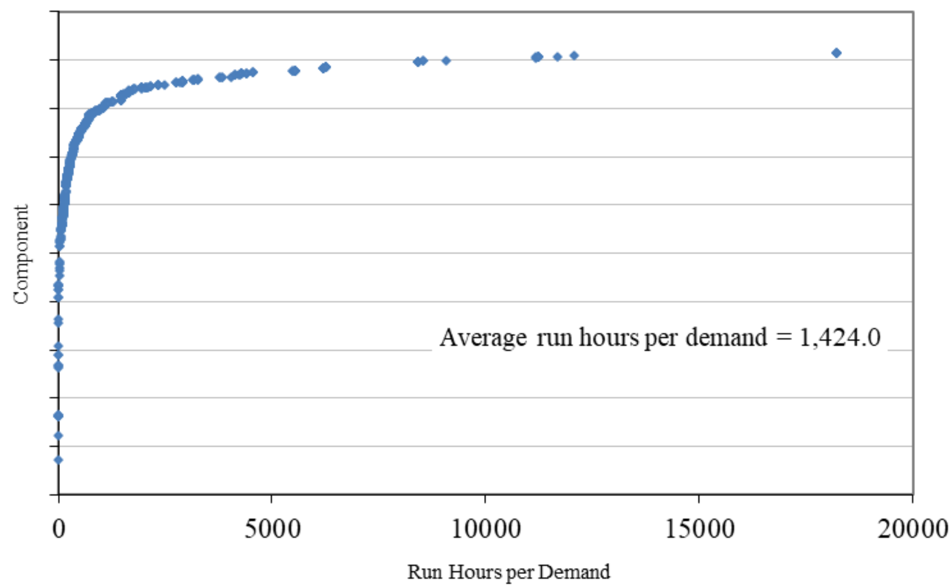




b.

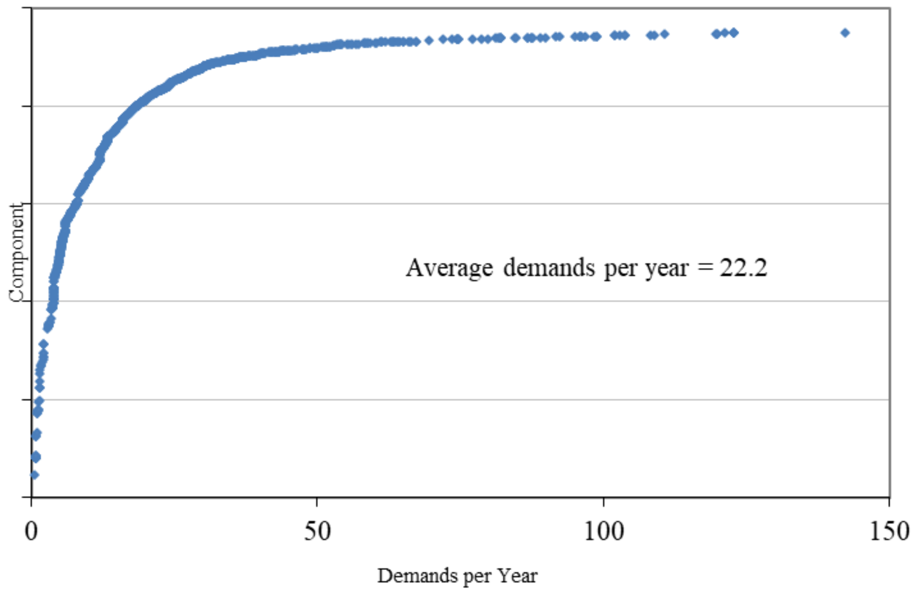
Figure 13(a) shows the range of run hours per demand in the standby MDP data set. a.



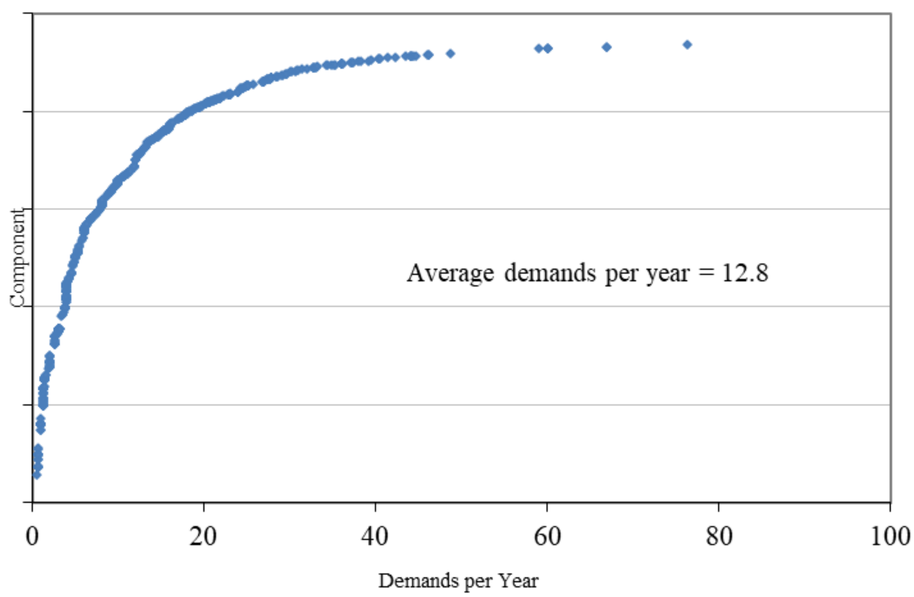


b.

Figure 13(b) shows the range of run hours per demands in the running MDP data set.

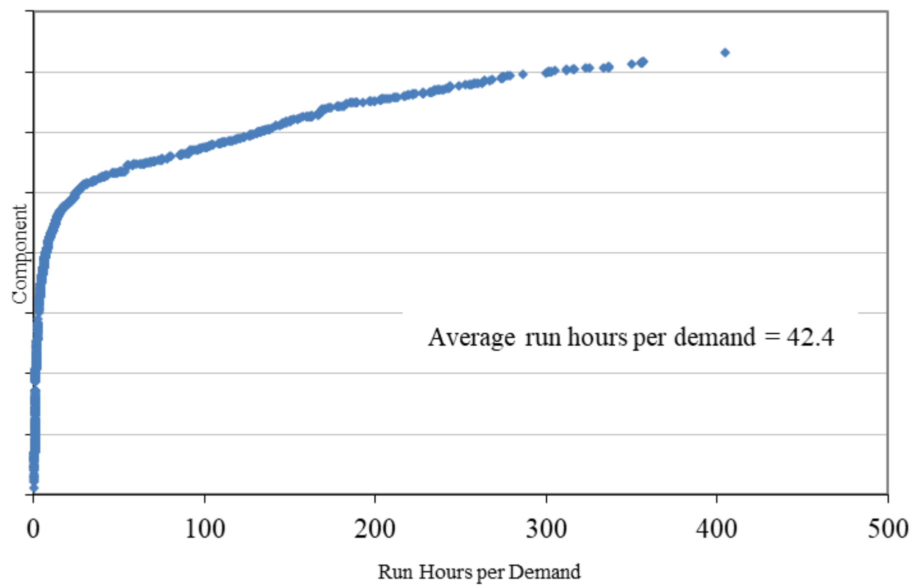


a.

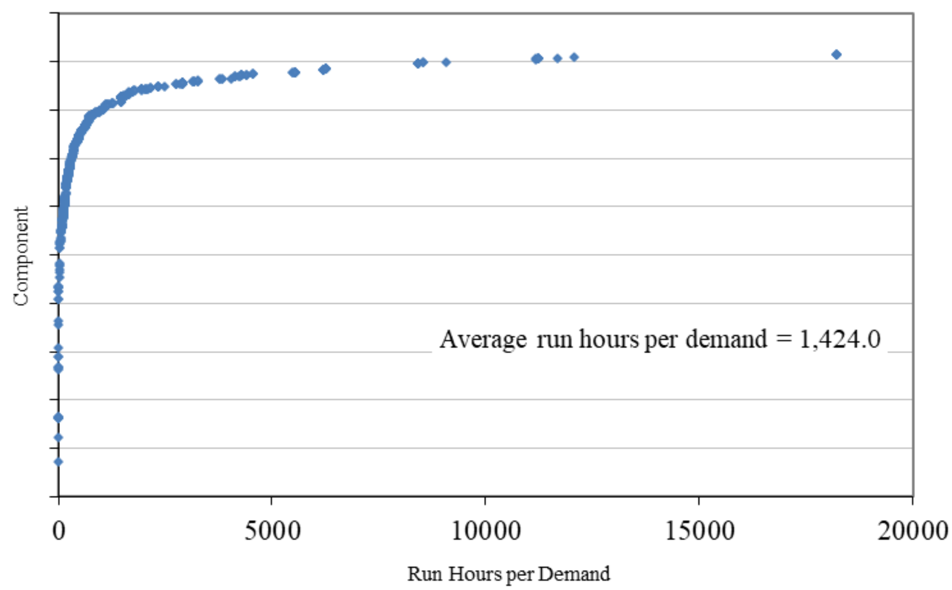


b.

Figure 12. a. Standby MDP demands per year distribution. b. Running/alternating MDP demands per year distribution.



a.



b.

Figure 13. a. Standby MDP run hours per demand distribution. b. Running/alternating MDP run hours per demand distribution.

A-2.1.3 Industry-Average Baselines

Table 45 lists the selected industry distributions of *p* and *λ* for the MDP failure modes. These industry-average failure rates do not account for any recovery.

Table 45. Selected industry distributions of p and λ for MDPs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
STBY	FTS	EB/PL/KS	1.09E-04	4.96E-04	5.88E-04	1.38E-03	Beta	2.07	3.52E+03
STBY	FTR<1H	EB/PL/KS	7.34E-07	4.68E-05	9.13E-05	3.33E-04	Gamma	0.58	6.34E+03
STBY	FTR>1H	EB/PL/KS	3.58E-08	3.77E-06	8.12E-06	3.10E-05	Gamma	0.51	6.29E+04
--	ELS	EB/PL/KS	3.16E-09	1.14E-07	1.98E-07	6.80E-07	Gamma	0.68	3.45E+06
--	ELL	--	1.48E-12	3.38E-09	1.39E-08	6.34E-08	Gamma	0.30	2.16E+07
NR	FTS	EB/PL/KS	4.86E-05	5.62E-04	7.86E-04	2.30E-03	Beta	1.08	1.37E+03
NR	FTR	EB/PL/KS	3.94E-07	1.89E-06	2.26E-06	5.38E-06	Gamma	1.97	8.72E+05
CCW	FTS	EB/PL/KS	1.23E-05	2.86E-04	4.57E-04	1.49E-03	Beta	0.80	1.74E+03
CCW	FTR	EB/PL/KS	2.86E-07	1.47E-06	1.77E-06	4.33E-06	Gamma	1.85	1.04E+06
SWS	FTS	EB/PL/KS	2.43E-05	4.80E-04	7.43E-04	2.36E-03	Beta	0.85	1.14E+03
SWS	FTR	EB/PL/KS	3.09E-07	3.08E-06	4.20E-06	1.19E-05	Gamma	1.17	2.79E+05
CWS	FTR	EB/PL/KS	1.81E-06	4.51E-06	4.86E-06	9.09E-06	Gamma	4.57	9.41E+05

A-2.2 Turbine-Driven Pump (TDP)

A-2.2.1 Component Description

The TDP boundary includes the pump, turbine, governor control, steam emission valve, local lubrication or cooling systems, and local instrumentation and controls. The failure modes for TDP are listed in Table 42.

A-2.2.2 Data Collection and Review

Data for TDP UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems and operational status included in the TDP data collection are listed in Table 46 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤200 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 46. TDP systems.

		Number of Components		
Pooling Group	**System**	**High/ Unknown Demand**	**Low Demand**	**Total**
Normally Running	Main feedwater (MFW)	4	42	46
	Normally Running Total	**4**	**42**	**46**
Standby	Auxiliary feedwater (AFW)		74	74
	High pressure coolant injection (HCI)		28	28
	Reactor core isolation (RCI)		31	31
	Standby Total		**133**	**133**
	Grand Total	**4**	**175**	**179**

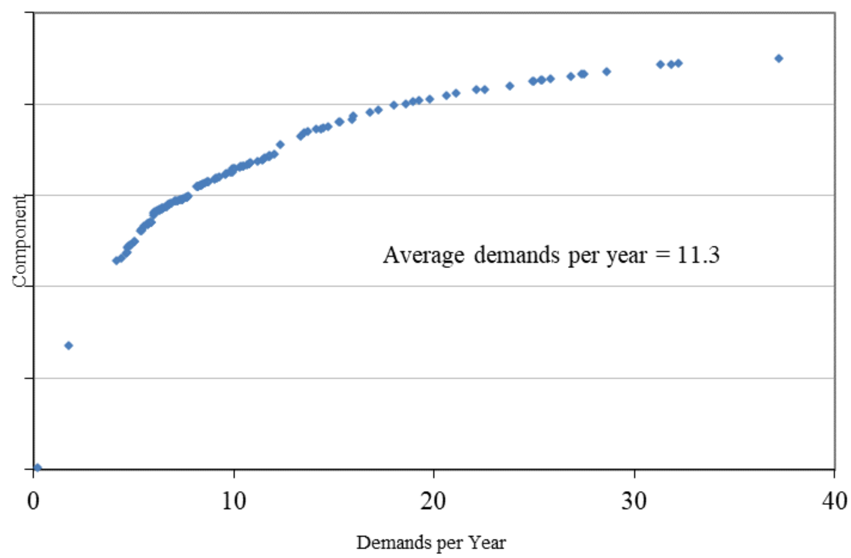
Table 47 summarizes the data obtained from EPIX and used in the TDP analysis. Note that the hours for ELS are reactor-year hours.

Table 47. TDP unreliability data.

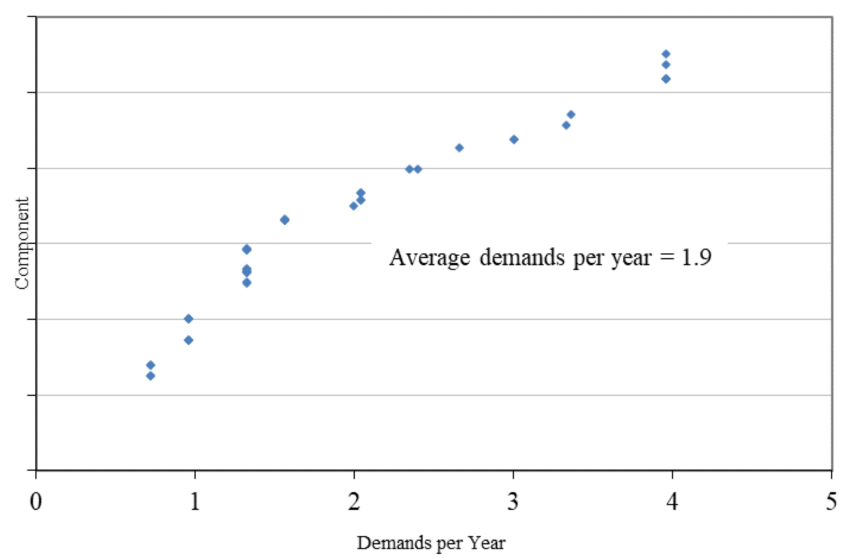
		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Failures**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
STBY	FTS	105	22,512 d	133	99	48.1%	55.6%
STBY	FTR<1H	34	15,530 h	133	99	19.5%	23.2%
STBY	FTR>1H	17	4,454 h	133	99	12.0%	16.2%
NR	FTS	5	1,147 d	42	20	11.9%	20.0%
NR	FTR	39	4,938,575 h	42	20	47.6%	60.0%
-	ELS	10	24,190,380 h	191	103	4.7%	8.7%
-	ELL	--	--	191	103	--	--
AFW	FTS	52	15,672 d	74	66	39.2%	43.9%
AFW	FTR<1H	18	10,670 h	74	66	14.9%	16.7%
AFW	FTR>1H	8	3,295 h	74	66	10.8%	12.1%
HCI-RCI	FTS	25	4,026 d	31	31	48.4%	48.4%
HCI-RCI	FTR<1H	16	4,860 h	59	33	25.4%	36.4%
HCI-RCI	FTR>1H	9	1,159 h	59	33	13.6%	24.2%

Pooling Group	Failure Mode	Data		Counts		Percent with Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
MFW	FTS	5	1,147 d	42	20	11.9%	20.0%
MFW	FTR	39	4,938,575 h	42	20	47.6%	60.0%

Figure 14(a) shows the range of start demands per year in the standby TDP data set. Figure 14(b) shows the range of start demands per year in the running/alternating TDP data set. Figure 15(a) shows the range of run hours per demand in the standby TDP data set. Figure 15(b) shows the range of run hours per demands in the running TDP data set.

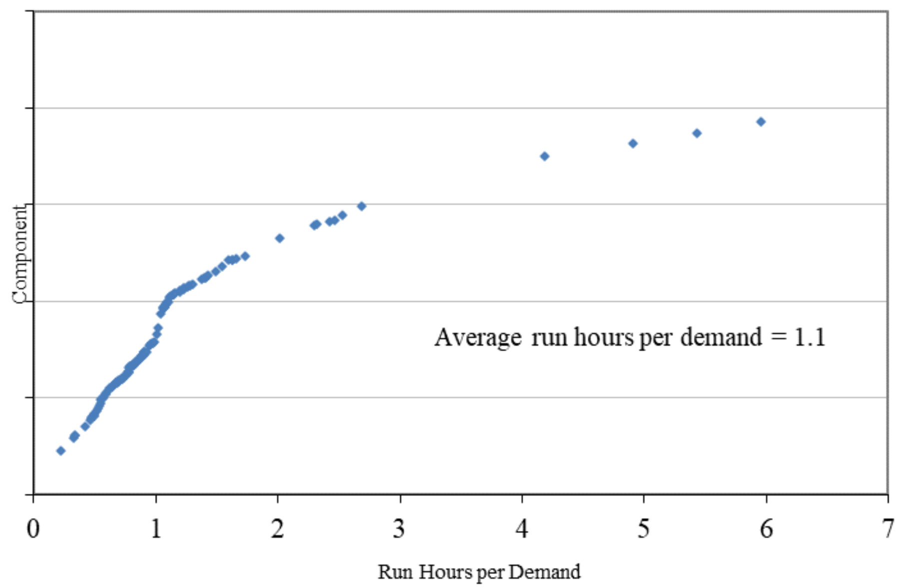


a.

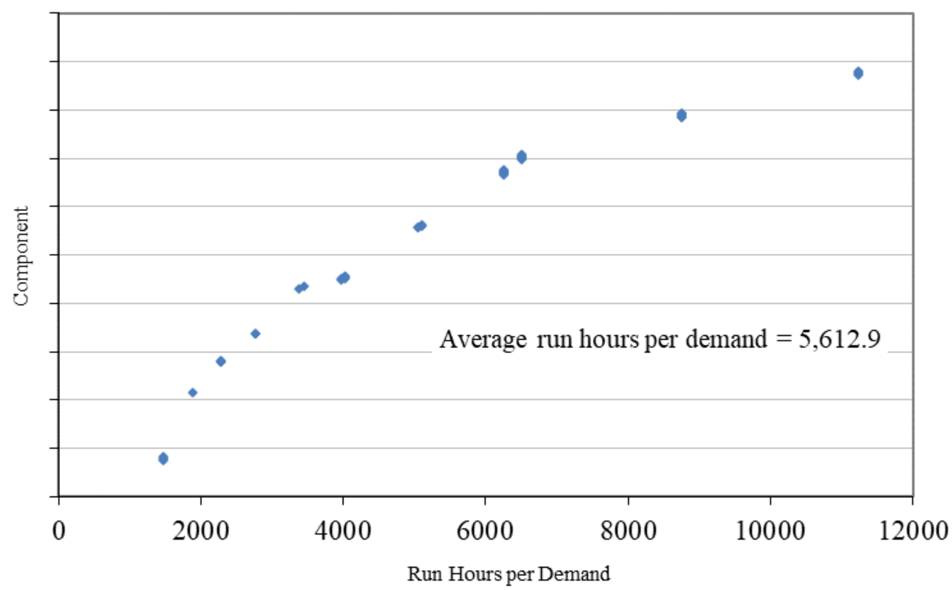


b.

Figure 14. a. Standby TDP demands per year distribution. b. Running/alternating TDP demands per year distribution.



a.



b.

Figure 15. a. Standby TDP run hours per demand distribution. b. Running/alternating TDP run hours per demand distribution.

A-2.2.3 Industry-Average Baselines

Table 48 lists the selected industry distributions of *p* and *λ* for the TDP failure modes. These industry-average failure rates do not account for any recovery.

Table 48. Selected industry distributions of p and λ for TDPs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
STBY	FTS	EB/PL/KS	4.59E-04	4.02E-03	5.32E-03	1.47E-02	Beta	1.26	2.35E+02
STBY	FTR<1H	EB/PL/KS	5.17E-06	1.04E-03	2.56E-03	1.03E-02	Gamma	0.44	1.73E+02
STBY	FTR>1H	EB/PL/KS	1.23E-05	2.56E-03	6.35E-03	2.55E-02	Gamma	0.44	6.95E+01
NR	FTS	EB/PL/KS	5.45E-05	2.52E-03	4.60E-03	1.62E-02	Beta	0.63	1.37E+02
NR	FTR	EB/PL/KS	2.53E-07	5.37E-06	8.45E-06	2.71E-05	Gamma	0.82	9.76E+04
--	ELS	EB/PL/KS	7.42E-08	3.47E-07	4.13E-07	9.75E-07	Gamma	2.02	4.90E+06
--	ELL	--	3.09E-12	7.05E-09	2.89E-08	1.32E-07	Gamma	0.30	1.04E+07
AFW	FTS	EB/PL/KS	1.17E-04	2.43E-03	3.79E-03	1.21E-02	Beta	0.83	2.18E+02
AFW	FTR<1H	JNID/IL	1.12E-03	1.70E-03	1.73E-03	2.44E-03	Gamma	18.50	1.07E+04
AFW	FTR>1H	JNID/IL	1.31E-03	2.48E-03	2.58E-03	4.18E-03	Gamma	8.50	3.30E+03
HCI-RCI	FTS	EB/PL/KS	6.02E-04	5.07E-03	6.68E-03	1.82E-02	Beta	1.29	1.92E+02
HCI-RCI	FTR<1H	EB/PL/KS	6.73E-04	2.86E-03	3.35E-03	7.68E-03	Gamma	2.22	6.64E+02
HCI-RCI	FTR>1H	JNID/IL	4.36E-03	7.90E-03	8.20E-03	1.30E-02	Gamma	9.50	1.16E+03
MFW	FTS	EB/PL/KS	5.45E-05	2.52E-03	4.60E-03	1.62E-02	Beta	0.63	1.37E+02
MFW	FTR	EB/PL/KS	2.53E-07	5.37E-06	8.45E-06	2.71E-05	Gamma	0.82	9.76E+04

A-2.4 Engine-Driven Pump (EDP)

A-2.4.1 Component Description

The diesel-driven pump (EDP) boundary includes the pump, diesel engine, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for EDPs are listed in Table 42.

A-2.4.2 Data Collection and Review

Data for EDP UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems and operational status included in the EDP data collection are listed in Table 49 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤200 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 49. EDP systems.

		Number of Components		
Pooling Group	**System**	**High/ Unknown Demand**	**Low Demand**	**Total**
Normally Running	Auxiliary feedwater (AFW)	1		1
	Firewater (FWS)	18	5	23
	Main feedwater (MFW)	1		1
	Standby service water (SSW)	3		3
	Normally Running Total	**23**	**5**	**28**
Standby	Auxiliary feedwater (AFW)		5	5
	Emergency power supply (EPS)		1	1
	Firewater (FWS)		20	20
	Standby service water (SSW)		10	10
	Standby Total		**36**	**36**
	Grand Total	**23**	**41**	**64**

Table 50 summarizes the data obtained from EPIX and used in the EDP analysis.

Table 50. EDP unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Failures**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
STBY	FTS	13	17,773 d	44	27	20.5%	29.6%
STBY	FTR<1H	6	9,888 h	39	25	12.8%	20.0%
STBY	FTR>1H	15	4,754 h	44	27	18.2%	25.9%
--	ELS	6	7,690,189 h	69	40	8.7%	15.0%
--	ELL	--	--	69	40	--	--
AFW	FTS	1	1,163 d	5	5	20.0%	20.0%
AFW	FTR<1H	2	759 h	5	5	40.0%	40.0%
AFW	FTR>1H	2	234 h	5	5	40.0%	40.0%

Figure 16 shows the range of start demands per year in the standby EDP data set. Figure 17 shows the range of run hours per demand in the standby EDP data set.

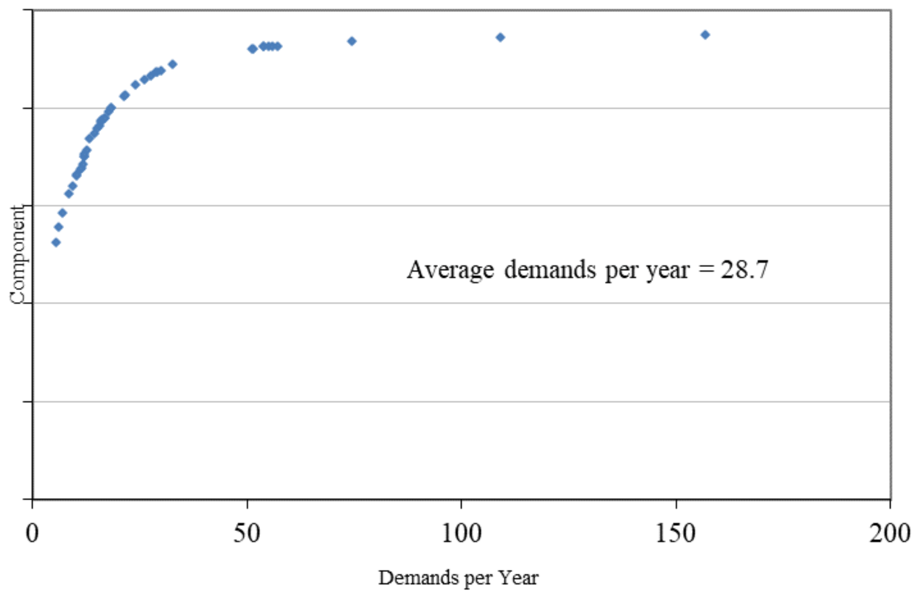


Figure 16. Standby EDP demands per year distribution.

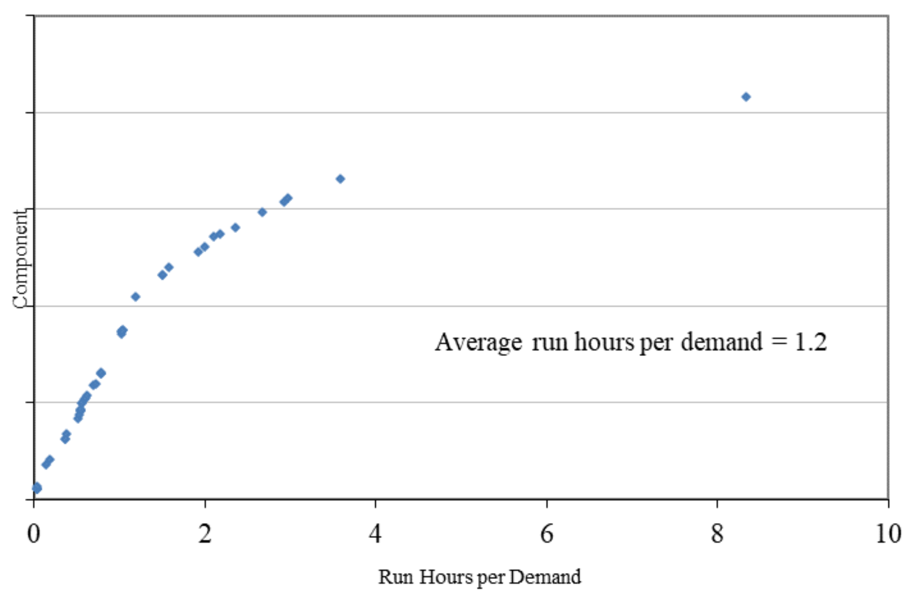


Figure 17. Standby EDP run hours per demand distribution.

A-2.4.3 Industry-Average Baselines

Table 51 lists the selected industry distributions of p and λ for the EDP failure modes. These industry-average failure rates do not account for any recovery.

Table 51. Selected industry distributions of p and λ for EDPs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
STBY	FTS	JNID/IL	4.53E-04	7.39E-04	7.60E-04	1.13E-03	Beta	13.50	1.78E+04
STBY	FTR<1H	JNID/IL	2.98E-04	6.24E-04	6.57E-04	1.13E-03	Gamma	6.50	9.89E+03
STBY	FTR>1H	JNID/IL	2.03E-03	3.19E-03	3.26E-03	4.74E-03	Gamma	15.50	4.75E+03
--	ELS	JNID/IL	3.83E-07	8.02E-07	8.45E-07	1.45E-06	Gamma	6.50	7.69E+06
--	ELL	--	6.33E-12	1.44E-08	5.92E-08	2.71E-07	Gamma	0.30	5.07E+06
AFW	FTS	JNID/IL	1.52E-04	1.02E-03	1.29E-03	3.36E-03	Beta	1.50	1.16E+03
AFW	FTR<1H	JNID/IL	7.55E-04	2.87E-03	3.29E-03	7.29E-03	Gamma	2.50	7.59E+02
AFW	FTR>1H	JNID/IL	2.45E-03	9.30E-03	1.07E-02	2.37E-02	Gamma	2.50	2.34E+02

A-2.5 Positive Displacement Pump (PDP)

A-2.5.1 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 42.

A-2.5.2 Data Collection and Review

Data for PDP UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems and operational status included in the PDP data collection are listed in Table 52 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤200 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 52. PDP systems.

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

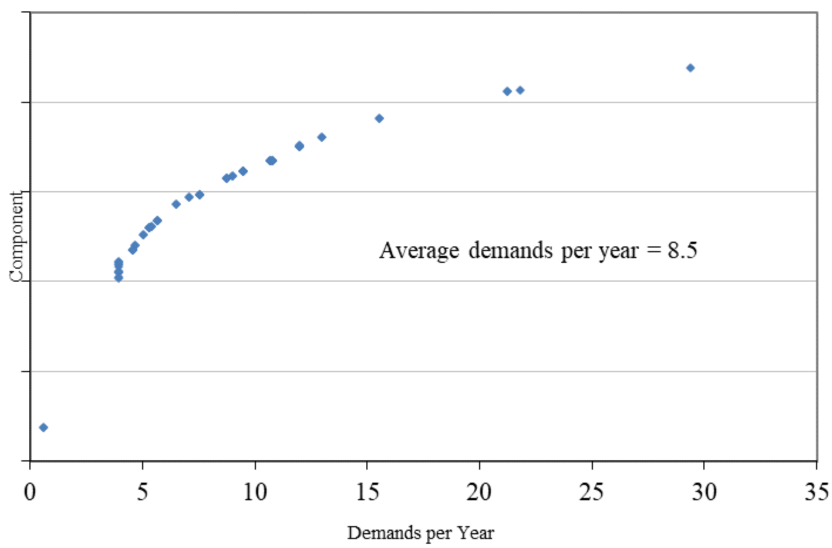
Table 53summarizes the data obtained from EPIX and used in the PDP analysis. Note that the hours for ELS are reactor-year hours.

Table 53. PDP unreliability data.

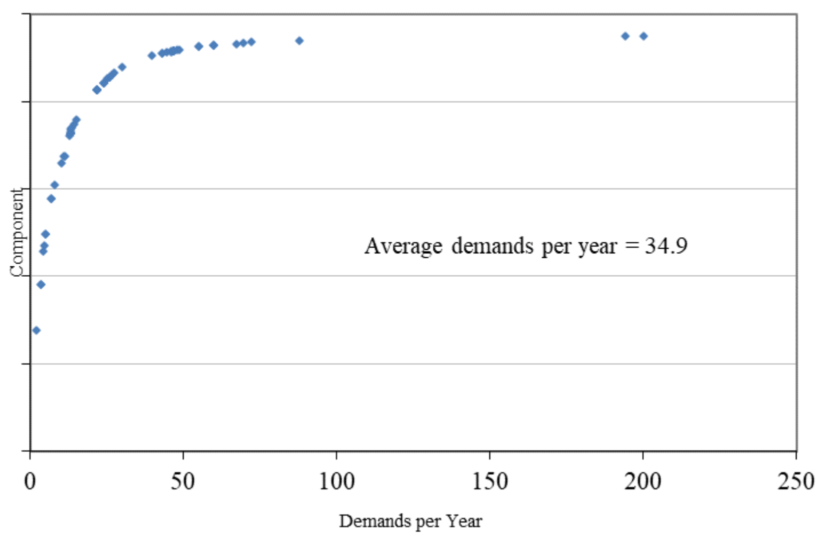
		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Failures**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
NR	FTS	53	28,865 d	57	25	50.9%	64.0%
NR	FTR	40	2,353,162 h	54	24	38.9%	54.2%
STBY	FTS	10	9,064 d	72	34	13.9%	26.5%
STBY	FTR<1H	1	4,045 h	72	34	1.4%	2.9%
STBY	FTR>1H	0	1,505 h	72	34	0.0%	0.0%

Pooling Group	Failure Mode	Failures	Data Demands or Hours	Counts Components	Plants	Percent with Failures Components	Plants
--	ELS	15	21,211,980 h	171	73	6.4%	12.3%
--	ELL	--	--	171	73	--	--

Figure 18a shows the range of start demands per year in the standby PDP data set. Figure 18b shows the range of start demands per year in the running PDP data set. Figure 19a shows the range of run hours per demand in the standby PDP data set. Figure 19b shows the range of run hours per demands in the running PDP data set.

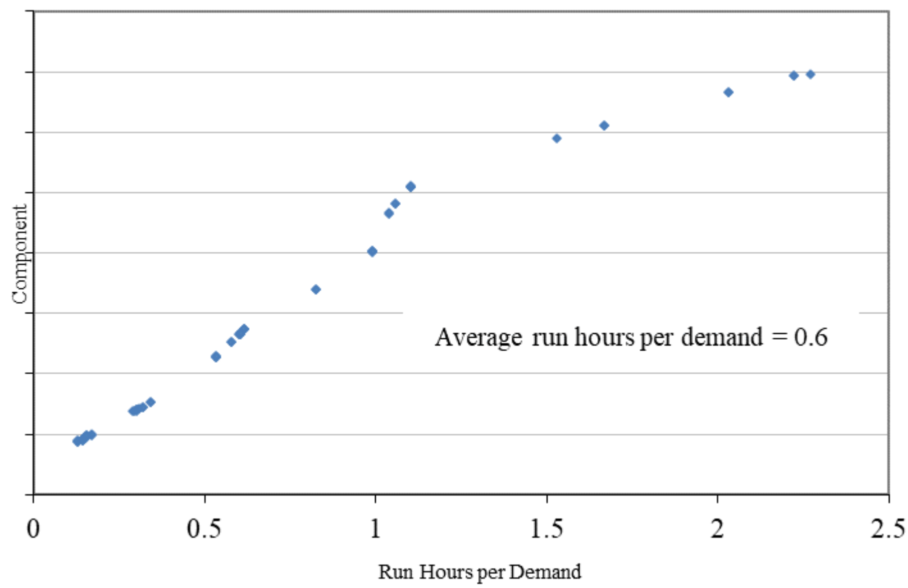


a.

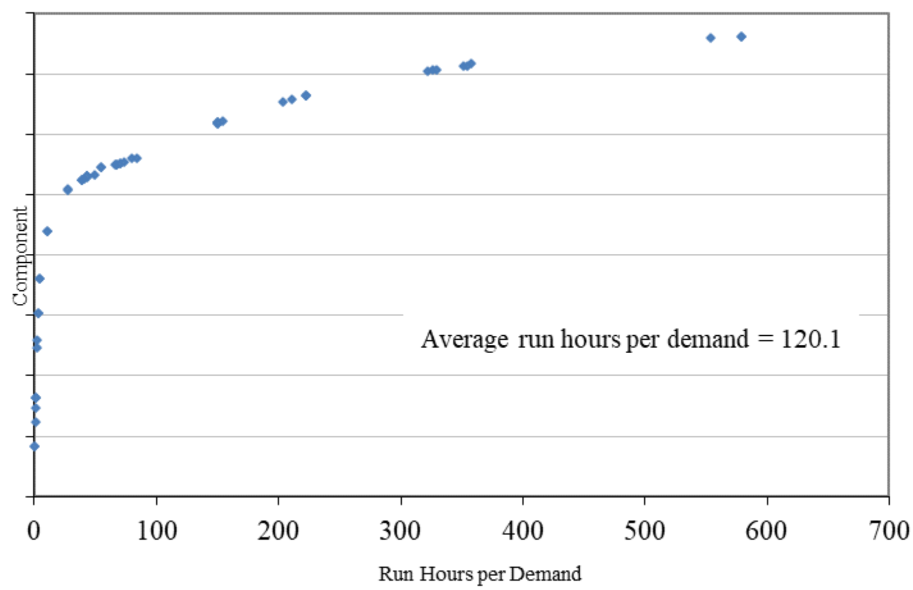


b.

Figure 18. a. Standby PDP demands per year distribution. b. Running/alternating PDP demands per year distribution.



a.



b.

Figure 19. a. Standby PDP run hours per demand distribution. b. Running/alternating PDP run hours per demand distribution.

A-2.5.3 Industry-Average Baselines

Table 54 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 54. Selected industry distributions of p and λ for PDPs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
NR	FTS	EB/PL/KS	7.46E-05	1.58E-03	2.47E-03	7.92E-03	Beta	0.83	3.33E+02
NR	FTR	EB/PL/KS	1.81E-06	1.45E-05	1.91E-05	5.17E-05	Gamma	1.33	6.98E+04
STBY	FTS	JNID/IL	6.40E-04	1.12E-03	1.16E-03	1.80E-03	Beta	10.50	9.05E+03
STBY	FTR<1H	JNID/IL	4.34E-05	2.92E-04	3.71E-04	9.65E-04	Gamma	1.50	4.05E+03
STBY	FTR>1H	JNID/IL	1.31E-06	1.52E-04	3.32E-04	1.28E-03	Gamma	0.50	1.50E+03
--	ELS	JNID/IL	4.55E-07	7.15E-07	7.31E-07	1.06E-06	Gamma	15.50	2.12E+07
--	ELL	--	5.48E-12	1.25E-08	5.12E-08	2.34E-07	Gamma	0.30	5.86E+06

A-2.6 AFW Pump Volute (PMP)

A-2.6.1 Component Description

The AFW pump volute (PMP) boundary includes the pump volute portion of AFW EDPs, MDPs, and TDPs. PMP is used only to support the quantification of common-cause failure events across EDPs, MDPs, and TDPs. The failure modes for PMP are listed in Table 42.

A-2.6.2 Data Collection and Review

Data for PMP UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems and operational status included in the PMP data collection are listed in Table 55 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤200 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 55. PMP systems.

Pooling Group	System	Number of Components High/ Unknown Demand	Low Demand	Total
Standby	Auxiliary feedwater (AFW)	1	203	204
Standby Total			**203**	**204**
Grand Total		**1**	**203**	**204**

To identify PMP failures within the AFW EDP, MDP, and TDP failures, EPIX data was analyzed outside of RADS to determine the failures in the PMP subcomponent. Table 56 summarizes the data obtained from the event review and used in the PMP analysis.

Table 56. PMP unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent with Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
STBY	FTR	16	133,247 h	208	70	7.7%	22.9%

A-2.6.3 Industry-Average Baselines

Table 57 lists the selected industry distributions of p and λ for the PMP failure modes. These industry-average failure rates do not account for any recovery.

Table 57. Selected industry distributions of p and λ for PMPs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
STBY	FTR	JNID/IL	7.84E-05	1.22E-04	1.24E-04	1.78E-04	Gamma	16.50	1.33E+05

A-3. GENERATORS

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

The failure modes for the generator are listed in Table 58.

Table 58. Generator failure modes.

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

Table 59 shows the breakdown of the generator component data available for calculations. Not all of the generators are provided with demand and run time estimates. The column, “Unknown Demand” shows the generator counts for which there are no demand and/or run time estimates. The component count is divided into two categories: Unknown Demand which shows the counts for those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤200 demands per year.

Table 59. Generator component counts.

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

A-3.1 Emergency Diesel Generators (EDG)

A-3.1.1 Component Description

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

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 are not included. The failure modes for EDG are listed in Table 58.

A-3.1.2 Data Collection and Review

Data for EDG UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the EDG data collection are listed in Table 60, with the number of components included with each system.

Table 60 summarizes the data obtained from the event review and used in the EDG analysis.

Table 60. EDG unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	Failure Mode	Failures	Demands or Hours	Components	Plants	Components	Plants
EDG	FTS	136	61,363 d	234	95	41.9%	70.5%
EDG	FTLR	172	53,343 h	234	95	49.6%	81.1%
EDG	FTR	155	137,584 h	234	95	46.2%	75.8%

Figure 20 shows the range of start demands per year in the EDG data set. Figure 21 shows the range of run hours per demand in the EDG data set.

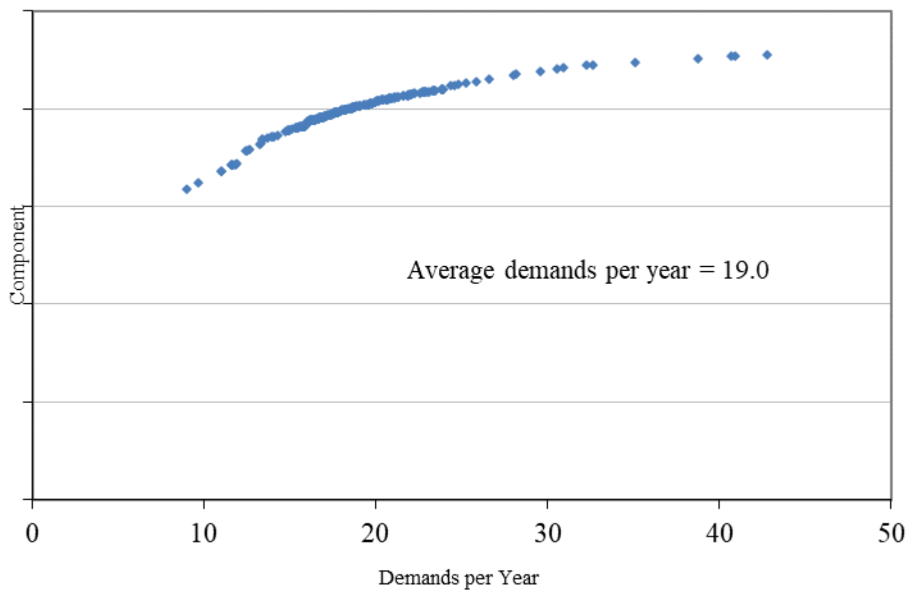


Figure 20. EDG demands per year distribution.

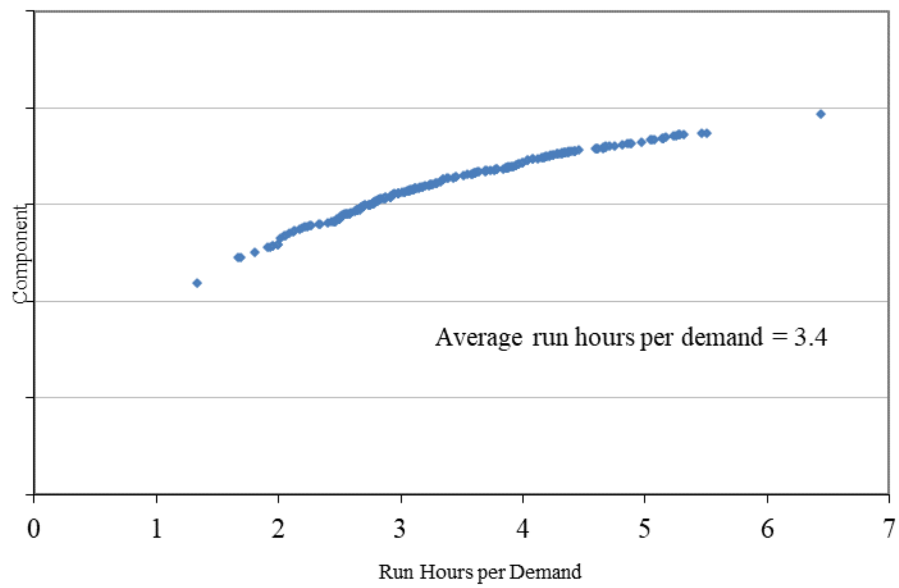


Figure 21. EDG run hours per demand distribution.

A-3.1.3 Industry-Average Baselines

Table 61 lists the selected industry distributions of *p* and *λ* for the EDG failure modes. These industry-average failure rates do not account for any recovery.

Table 61. Selected industry distributions of p and λ for EDGs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
EDG	FTS	EB/PL/KS	1.53E-03	2.19E-03	2.22E-03	3.02E-03	Beta	23.80	1.07E+04
EDG	FTLR	EB/PL/KS	1.05E-03	3.01E-03	3.31E-03	6.60E-03	Gamma	3.61	1.09E+03
EDG	FTR	EB/PL/KS	3.90E-04	1.08E-03	1.18E-03	2.31E-03	Gamma	3.83	3.25E+03

A-3.2 Hydro Turbine Generator (HTG)

A-3.2.1 Component Description

The hydro turbine generator (HTG) boundary includes the turbine, generator, circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for HTG are listed in Table 58.

A-3.2.2 Data Collection and Review

Data for HTG UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the HTG data collection are listed in Table 62, with the number of components included with each system.

Table 62 summarizes the data obtained from EPIX and used in the HTG analysis.

Table 62. HTG unreliability data.

Pooling Group	Failure Mode	Data: Failures	Data: Demands or Hours	Counts: Components	Counts: Plants	Percent with Failures: Components	Percent with Failures: Plants
HTG	FTS	6	6,362 d	2	1	100.0%	100.0%
HTG	FTLR	2	4,582 h	2	1	50.0%	100.0%
HTG	FTR	1	13,874 h	2	1	50.0%	100.0%

A-3.2.3 Industry-Average Baselines

Table 63 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 63. Selected industry distributions of p and λ for HTGs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution: Type	Distribution: α	Distribution: β
HTG	FTS	JNID/IL	4.63E-04	9.69E-04	1.02E-03	1.76E-03	Beta	6.50	6.36E+03
HTG	FTLR	JNID/IL	1.25E-04	4.75E-04	5.46E-04	1.21E-03	Gamma	2.50	4.58E+03
HTG	FTR	JNID/IL	1.27E-05	8.51E-05	1.08E-04	2.81E-04	Gamma	1.50	1.39E+04

A-3.3 Combustion Turbine Generator (CTG)

A-3.3.1 Component Description

The combustion turbine generator (CTG) boundary includes the gas turbine, generator, circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for CTG are listed in Table 58.

A-3.3.2 Data Collection and Review

Data for CTG UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the CTG data collection are listed in Table 64, with the number of components included with each system.

Table 64 summarizes the data obtained from the plant and used in the CTG analysis.

Table 64. CTG unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Failures**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
CTG	FTS	21	419 d	3	3	100.0%	100.0%
CTG	FTLR	2	360 h	2	2	100.0%	100.0%
CTG	FTR	4	959 h	3	3	100.0%	100.0%

A-3.3.3 Industry-Average Baselines

Table 65 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 65. Selected industry distributions of p and λ for CTGs.

							Distribution		
Pooling Group	**Failure Mode**	**Analysis Type / Source**	**5%**	**Median**	**Mean**	**95%**	**Type**	α	β
CTG	FTS	EB/PL/KS	5.81E-03	5.40E-02	7.03E-02	1.90E-01	Beta	1.20	1.59E+01
CTG	FTLR	JNID/IL	1.59E-03	6.04E-03	6.94E-03	1.54E-02	Gamma	2.50	3.60E+02
CTG	FTR	JNID/IL	1.73E-03	4.35E-03	4.69E-03	8.82E-03	Gamma	4.50	9.59E+02

A-3.4 High-Pressure Core Spray Generator (HPCS)

A-3.4.1 Component Description

The high-pressure core spray generator (HPCS or HCS) boundary includes the engine, generator, circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for HPCS are listed in Table 58.

A-3.4.2 Data Collection and Review

Data for HPCS UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS.

The systems included in the HPCS data collection are listed in Table 66 with the number of components included with each system. Table 66 summarizes the data obtained from the plant and used in the HPCS analysis.

Table 66. HPCS unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Failures**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
HCS	FTS	4	2,114 d	8	8	37.5%	37.5%
HCS	FTR	3	4,196 h	8	8	37.5%	37.5%

A-3.4.3 Industry-Average Baselines

Table 67 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 67. Selected industry distributions of p and λ for HPCSs.

							Distribution		
Pooling Group	**Failure Mode**	**Analysis Type / Source**	**5%**	**Median**	**Mean**	**95%**	**Type**	**α**	**β**
HCS	FTS	JNID/IL	7.87E-04	1.97E-03	2.13E-03	4.00E-03	Beta	4.50	2.11E+03
HCS	FTR	JNID/IL	2.58E-04	7.55E-04	8.34E-04	1.67E-03	Gamma	3.50	4.20E+03

A-3.5 Station Blackout Generator (SBO)

A-3.5.1 Component Description

The station blackout generator (SBO) boundary includes the engine, exhaust, generator, circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for SBO are listed in Table 58.

A-3.5.2 Data Collection and Review

Data for SBO UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS.

The systems included in the SBO data collection are listed in Table 68, with the number of components included with each system. Table 68 summarizes the data obtained from the plant and used in the SBO analysis.

Table 68. SBO unreliability data.

		Data		**Counts**		**Percent with Failures**	
Pooling Group	**Failure Mode**	**Failures**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
SBO	FTS	14	625 d	5	5	80.0%	80.0%
SBO	FTR	2	2,204 h	5	5	40.0%	40.0%

A-3.5.3 Industry-Average Baselines

Table 69 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 69. Selected industry distributions of p and λ for SBOs.

							Distribution		
Pooling Group	**Failure Mode**	**Analysis Type / Source**	**5%**	**Median**	**Mean**	**95%**	**Type**	α	β
SBO	FTS	EB/PL/KS	1.46E-03	2.06E-02	2.94E-02	8.75E-02	Beta	0.98	3.22E+01
SBO	FTR	JNID/IL	2.60E-04	9.89E-04	1.13E-03	2.52E-03	Gamma	2.50	2.20E+03

A-4. RELIEF VALVES

The relief valves (RVs) presented in this section include the boiling-water reactor dual-acting relief valves (SRVs), the PWR power-operated relief valves (PORV) that are on the pressurizer and on the steam generators, and the code safety valves (SVV) that are on both the pressurizer and the steam generators. The failure modes for relief valves are listed in Table 70.

Table 70. Relief valve failure modes.

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

A-4.1 Safety Relief Valve (SRV)

A-4.1.1 Component Description

The safety relief valve (SRV) component boundary includes the valve, the valve operator, and local instrumentation and control circuitry. The SRV lifts either by system pressure directly acting on the valve operator or by an electronic signal to the pilot valve. These are known as dual acting relief valves. The failure modes for SRV are listed in Table 70.

A-4.1.2 Data Collection and Review

Data for most SRV UR baselines were obtained either from the updated RV report for NUREG/CR-7037 [A-4] for the FTO and FTC failure modes, or from IRIS database, covering 2006–2020 using RADS, for the spurious operation and leakage failure modes. The systems included in the SRV data collection are listed in Table 71 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 71. SRV systems.

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

Table 72 summarizes the data used in the SRV analysis. Note that the hours for SOP, ELS, and ILS are reactor-year hours.

Table 72. SRV unreliability data.

Pooling Group	Failure Mode	Data Events	 Demands or Hours	Counts Components	 Plants	Percent with Failures Components	 Plants
-	FTO	7	3,548 d	--	--	--	--
-	FTC	0	3,548 d	--	--	--	--
-	FC	0	61,005,550 h	519	34	0.0%	0.0%

Pooling Group	Failure Mode	Events	Data Demands or Hours	Counts Components	Plants	Percent with Failures Components	Plants
-	SOP	4	61,005,550 h	519	34	0.8%	8.8%
-	ILS	23	61,005,550 h	519	34	3.9%	32.4%
-	ILL	--	--	519	34	--	--
-	ELS	0	61,005,550 h	519	34	0.0%	0.0%
-	ELL	--	--	519	34	--	--

A-4.1.3 Industry-Average Baselines

Table 73 lists the selected industry distributions of *p* and *λ* for the SRV failure modes. These industry-average failure rates do not account for any recovery.

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

Table 73. Selected industry distributions of p and λ for SRVs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	*α*	*β*
-	FTO	JNID	1.02E-03	2.02E-03	2.11E-03	3.52E-03	Beta	JNID	1.02E-03
-	FTC	CNID	5.54E-07	6.41E-05	1.41E-04	5.41E-04	Beta	CNID	5.54E-07
-	FC	JNID/IL	3.22E-11	3.73E-09	8.20E-09	3.15E-08	Gamma	JNID/IL	3.22E-11
-	SOP	JNID/IL	2.73E-08	6.84E-08	7.38E-08	1.39E-07	Gamma	JNID/IL	2.73E-08
-	ILS	JNID/IL	2.64E-07	3.80E-07	3.85E-07	5.25E-07	Gamma	JNID/IL	2.64E-07
-	ILL	--	8.24E-13	1.88E-09	7.70E-09	3.52E-08	Gamma	--	8.24E-13
-	ELS	JNID/IL	3.22E-11	3.73E-09	8.20E-09	3.15E-08	Gamma	JNID/IL	3.22E-11
-	ELL	--	6.14E-14	1.40E-10	5.74E-10	2.63E-09	Gamma	--	6.14E-14

A-4.2 Safety Valve (SVV)

A-4.2.1 Component Description

The safety valve (SVV) component boundary includes the valve and the valve operator. The SVV is a direct-acting relief valve. These relief valves are also known as 'Code Safeties' since their lift points are the highest and are meant to protect the piping integrity. The failure modes for SVV are listed in Table 70.

A-4.2.2 Data Collection and Review

Data for SVV UR baselines were obtained either from the updated RV report for NUREG/CR-7037 for the FTO and FTC failure modes, or from IRIS database, covering 2006–2020 using RADS, for the spurious operation and leakage failure modes. The systems included in the SVV data collection are listed in Table 74 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 74. SVV systems.

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

The SVV data set obtained from RADS was further reduced to include only those SVVs with 20 or fewer demands/year. See Section A.1 in NUREG/CR-6928 for a discussion concerning this decision to limit the component populations for valves. Table 75 summarizes the data used in the SVV analysis. The FTCL failure mode is not supported with EPIX data. Note that the hours for SOP, ELS, and ILS are reactor-year hours.

Table 75. SVV unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Events**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
--	SOP	1	171,647,800 h	1,380	81	0.1%	1.2%
--	ILS	5	171,647,800 h	1,380	81	0.4%	6.2%
--	ILL	--	--	1,380	81	--	--
--	ELS	1	171,647,800 h	1,380	81	0.1%	1.2%
--	ELL	--	--	1,380	81	--	--
PWR MSS	FTO	0	745 d	--	--	--	--
PWR MSS	FTC	4	745 d	--	--	--	--
PWR MSS	SOP	0	140,068,800 h	1,109	66	0.0%	0.0%
PWR RCS	FTO	0	4 d	--	--	--	--
PWR RCS	FTC	2	4 d	--	--	--	--
PWR RCS	SOP	1	23,893,310 h	207	70	0.5%	1.4%

A-4.2.3 Industry-Average Baselines

Table 76 lists the selected industry distributions of *p* and *λ* for the SVV failure modes. These industry-average failure rates do not account for any recovery.

Table 76. Selected industry distributions of p and λ for SVVs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
--	SOP	JNID/IL	1.02E-09	6.88E-09	8.74E-09	2.27E-08	Gamma	1.50	1.72E+08
--	ILS	JNID/IL	1.33E-08	3.01E-08	3.20E-08	5.72E-08	Gamma	5.50	1.72E+08
--	ILL	--	6.85E-14	1.56E-10	6.40E-10	2.93E-09	Gamma	0.30	4.69E+08
--	ELS	JNID/IL	1.02E-09	6.88E-09	8.74E-09	2.27E-08	Gamma	1.50	1.72E+08
--	ELL	--	6.55E-14	1.49E-10	6.12E-10	2.80E-09	Gamma	0.30	4.90E+08
PWR MSS	FTO	CNID	2.61E-06	3.05E-04	6.70E-04	2.58E-03	Beta	0.50	7.44E+02
PWR MSS	FTC	JNID	2.23E-03	5.60E-03	6.03E-03	1.13E-02	Beta	4.50	7.42E+02
PWR MSS	SOP	JNID/IL	1.40E-11	1.62E-09	3.57E-09	1.37E-08	Gamma	0.50	1.40E+08
PWR RCS	FTO	Bayes	2.58E-06	3.01E-04	6.63E-04	2.55E-03	Beta	0.50	7.52E+02
PWR RCS	FTC	Bayes	9.65E-03	3.63E-02	4.13E-02	9.01E-02	Beta	2.49	5.77E+01
PWR RCS	SOP	JNID/IL	7.36E-09	4.95E-08	6.28E-08	1.63E-07	Gamma	1.50	2.39E+07

A-4.3 Power-Operated Relief Valve (PORV)

A-4.3.1 Component Description

The power-operated relief valve (PORV) component boundary includes the valve, the valve operator, local circuit breaker, and local instrumentation and control circuitry. The failure modes for PORV are listed in Table 70.

A-4.3.2 Data Collection and Review

Data for PORV UR baselines were obtained either from the updated RV report for NUREG/CR-7037 for the FTO and FTC failure modes, or from IRIS database, covering 2006–2020 using RADS, for the spurious operation and leakage failure modes. The systems included in the PORV data collection are listed in Table 78 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 77. PORV systems.

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

Table 78 summarizes the data used in the PORV analysis. Note that the hours for FC, SOP, ELS, and ILS are reactor-year hours.

Table 78. PORV unreliability data.

Pooling Group	Failure Mode	Data Events	Demands or Hours	Counts Components	Plants	Percent with Failures Components	Plants
RCS	FTO	4	377 d	--	--	--	--
RCS	FTC	1	377 d	--	--	--	--
MSS	FTO	25	1,580 d	--	--	--	--
MSS	FTC	7	1,580 d	--	--	--	--
MSS	FC	7	278 d	--	--	--	--
--	SOP	13	57,223,460 h	454	72	2.4%	13.9%
--	ILS	3	57,223,460 h	454	72	0.7%	4.2%
--	ILL	--	--	454	72	--	--
--	ELS	0	57,223,460 h	454	72	0.0%	0.0%
--	ELL	--	--	454	72	--	--

A-4.3.3 Industry-Average Baselines

Table 79 lists the selected industry distributions of p and λ for the PORV failure modes. These industry-average failure rates do not account for any recovery.

Table 79. Selected industry distributions of p and λ for PORVs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
RCS	FTO	JNID	4.42E-03	1.11E-02	1.19E-02	2.23E-02	Beta	4.50	3.74E+02
RCS	FTC	CNID	1.47E-05	1.79E-03	3.97E-03	1.53E-02	Beta	0.49	1.24E+02
MSS	FTO	JNID	1.13E-02	1.59E-02	1.61E-02	2.17E-02	Beta	25.50	1.56E+03
MSS	FTC	EB	2.54E-04	3.08E-03	4.35E-03	1.28E-02	Beta	1.05	2.41E+02
MSS	FC	JNID	1.31E-02	2.58E-02	2.69E-02	4.45E-02	Beta	7.50	2.72E+02
--	SOP	JNID/IL	1.41E-07	2.30E-07	2.36E-07	3.51E-07	Gamma	13.50	5.72E+07
	ILS	JNID/IL	1.89E-08	5.55E-08	6.12E-08	1.23E-07	Gamma	3.50	5.72E+07
--	ILL	--	1.31E-13	2.98E-10	1.22E-09	5.60E-09	Gamma	0.30	2.45E+08
--	ELS	JNID/IL	3.44E-11	3.98E-09	8.74E-09	3.36E-08	Gamma	0.50	5.72E+07
--	ELL	--	6.55E-14	1.49E-10	6.12E-10	2.80E-09	Gamma	0.30	4.90E+08
LOOP [a]		Point Estimate	-	-	9.23E-02	-		-	-
Transient [a]		Point Estimate	-	-	2.28E-02	-		-	-

a. Updated RV Report, Table 13.

A-4.4 Low-Capacity Relief Valve (RVL)

A-4.4.1 Component Description

The low-capacity relief valve (RVL) component boundary includes the valve, and the valve operator. The failure modes for RVLs are listed in Table 70.

A-4.4.2 Data Collection and Review

Data for RVL UR baselines were obtained either from the updated RV report for NUREG/CR-7037 for the FTO and FTC failure modes, or from IRIS database, covering 2006–2020 using RADS, for the spurious operation and leakage failure modes. The systems included in the RVL data collection are listed in Table 80 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 80. RVL systems.

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

Table 81 summarizes the data used in the RVL analysis. Note that the hours for SOP, ELS, and ILS are reactor-year hours.

Table 81. RVL unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Events**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
-	FTO	0	65 d	12	6	0.0%	0.0%
-	FTC	0	65 d	12	6	0.0%	0.0%
-	SOP	0	9,165,162 h	79	30	0.0%	0.0%
-	ILS	3	9,165,162 h	79	30	3.8%	10.0%
-	ILL	--	--	79	30	--	--
-	ELS	3	9,165,162 h	79	30	3.8%	10.0%
-	ELL	--	--	79	30	--	--

A-4.4.3 Industry-Average Baselines

Table 82 lists the selected industry distributions of p and λ for the RVL failure modes. These industry-average failure rates do not account for any recovery.

Table 82. Selected industry distributions of p and λ for RVLs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
-	FTO	JNID/IL	3.02E-05	3.49E-03	7.59E-03	2.91E-02	Beta	0.50	6.54E+01
-	FTC	JNID/IL	3.02E-05	3.49E-03	7.59E-03	2.91E-02	Beta	0.50	6.54E+01
-	SOP	JNID/IL	2.14E-10	2.48E-08	5.46E-08	2.09E-07	Gamma	0.50	9.17E+06
-	ILS	JNID/IL	1.18E-07	3.46E-07	3.82E-07	7.67E-07	Gamma	3.50	9.17E+06
-	ILL	--	8.18E-13	1.86E-09	7.64E-09	3.49E-08	Gamma	0.30	3.93E+07
-	ELS	JNID/IL	1.18E-07	3.46E-07	3.82E-07	7.67E-07	Gamma	3.50	9.17E+06
-	ELL	--	2.86E-12	6.52E-09	2.67E-08	1.22E-07	Gamma	0.30	1.12E+07

A-5. ELECTRICAL EQUIPMENT

This section provides reliability estimates of various electrical equipment used in probabilistic risk assessment. The failure modes applicable to electrical equipment are listed in Table 83.

Table 83. Electrical equipment failure modes.

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

A-5.1 Battery Charger (BCH)

A-5.1.1 Component Description

The battery charger (BCH) boundary includes the battery charger and its breakers. The failure modes for BCHs are listed in Table 83.

A-5.1.2 Data Collection and Review

Data for BCH UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the BCH data collection are listed in Table 84 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 84. BCH systems.

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

Table 85 summarizes the data obtained from EPIX and used in the BCH analysis.

Table 85. BCH unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Failures**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
-	FTOP	161	99,754,050 h	781	100	16.1%	63.0%

A-5.1.3 Industry-Average Baselines

Table 86 lists the industry-average failure rate distribution. This industry-average failure rate does not account for any recovery.

Table 86. Selected industry distributions of p and λ for BCHs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
-	FTOP	EB/PL/KS	1.09E-07	1.26E-06	1.76E-06	5.15E-06	Gamma	1.08	6.12E+05

A-5.2 Battery (BAT)

A-5.2.1 Component Description

The battery (BAT) boundary includes the battery cells. The failure modes for BAT are listed in Table 83.

A-5.2.2 Data Collection and Review

Data for BAT UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the BAT data collection are listed in Table 87 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 87. BAT systems.

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

Table 88 summarizes the data obtained from EPIX and used in the BAT analysis.

Table 88. BAT unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent with Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
-	FTOP	21	52,018,730 h	412	99	4.9%	16.2%

A-5.2.3 Industry-Average Baselines

Table 89 lists the industry-average failure rate distribution. This industry-average failure rate does not account for any recovery.

Table 89. Selected industry distributions of p and λ for BATs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
-	FTOP	EB/PL/KS	4.79E-09	2.21E-07	4.05E-07	1.42E-06	Gamma	0.63	1.57E+06

A-5.3 Automatic Bus Transfer Switch (ABT)

A-5.3.1 Component Description

The automatic bus transfer switch (ABT) boundary includes the ABT component itself. The failure modes for ABT are listed in Table 83.

A-5.3.2 Data Collection and Review

Data for the ABT UR baseline were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the ABT data collection are listed in Table 90 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 90. ABT systems.

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

Table 91 summarizes the data obtained from EPIX and used in the ABT analysis.

Table 91. ABT unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Failures**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
-	FF	4	3,377 d	27	7	11.1%	28.6%
-	SOP	0	4,010,342 h	32	7	0.0%	0.0%

Figure 22 shows the range of ABT demands per year in the ABT data set (limited to low-demand components only).

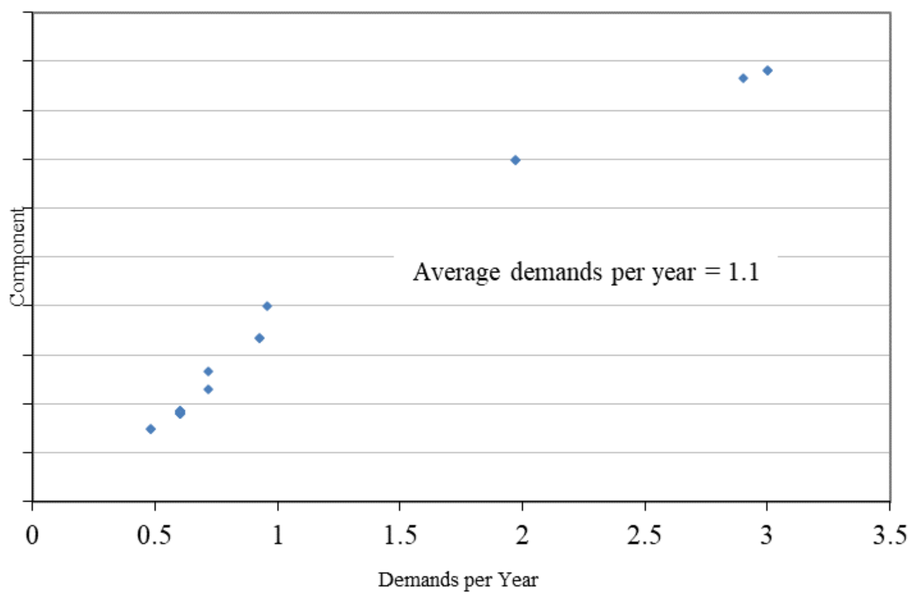


Figure 22. ABT demands per year distribution.

A-5.3.3 Industry-Average Baselines

Table 92 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 92. Selected industry distributions of p and λ for ABTs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
-	FF	JNID/IL	4.93E-04	1.24E-03	1.33E-03	2.51E-03	Beta	4.50	3.37E+03
-	SOP	JNID/IL	4.90E-10	5.67E-08	1.25E-07	4.79E-07	Gamma	0.50	4.01E+06

A-5.4 Circuit Breaker (CRB)

A-5.4.1 Component Description

The circuit breaker (CRB) is defined as the breaker itself and local instrumentation and control circuitry. The circuit breaker data presented here is limited to circuit breakers used in the distribution of power. Circuit breakers used to supply power to a specific load are included within that components boundary. External equipment used to monitor under voltage, ground faults, differential faults, and other protection schemes for individual breakers are considered part of the breaker. The failure modes for CRB are listed in Table 83.

A-5.4.2 Data Collection and Review

Data for CRB UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the CRB data collection are listed in Table 93 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 93. CRB systems.

Pooling Group	System	Number of Components High/ Unknown Demand	 Low Demand	 Total
ALL	dc power (DCP)	278	961	1239
	Emergency power supply (EPS)	70	190	260
	High pressure core spray (HCS)	12	2	14
	Offsite electrical power (OEP)	32	121	153
	Plant ac power (ACP)	952	3324	4276
	Reactor protection (RPS)	133	223	356
	Grand Total	**1477**	**4821**	**6298**

Table 94 summarizes the data used in the CRB analysis. Note that the hours for SOP are reactor-year hours.

Table 94. CRB unreliability data.

Pooling Group	Failure Mode	Events	Data Demands or Hours	Counts Components	 Plants	Percent with Failures Components	 Plants
--	FTOC	102	119,027 d	3,461	102	2.6%	53.9%
--	SOP	57	552,883,300 h	4,620	102	1.1%	37.3%
HV (13.8 and 16 kV)	FTOC	17	9,198 d	244	40	5.3%	25.0%
HV (13.8 and 16 kV)	SOP	14	37,600,840 h	300	58	4.3%	20.7%
MV (4.16 and 6.9 kV)	FTOC	57	50,897 d	1,080	85	4.6%	44.7%
MV (4.16 and 6.9 kV)	SOP	15	149,457,800 h	1,240	91	1.0%	13.2%
LV (480 V)	FTOC	25	46,176 d	1,752	81	1.4%	22.2%

Pooling Group	Failure Mode	Events	Data Demands or Hours	Counts Components	Counts Plants	Percent with Failures Components	Percent with Failures Plants
LV (480 V)	SOP	27	310,690,800 h	2,630	91	1.0%	23.1%
DC	FTOC	5	17,566 d	602	47	0.8%	8.5%
DC	SOP	0	34,938,600 h	270	31	0.0%	0.0%

Figure 23 shows the range of breaker demands per year in the CRB data set (limited to low-demand components only).

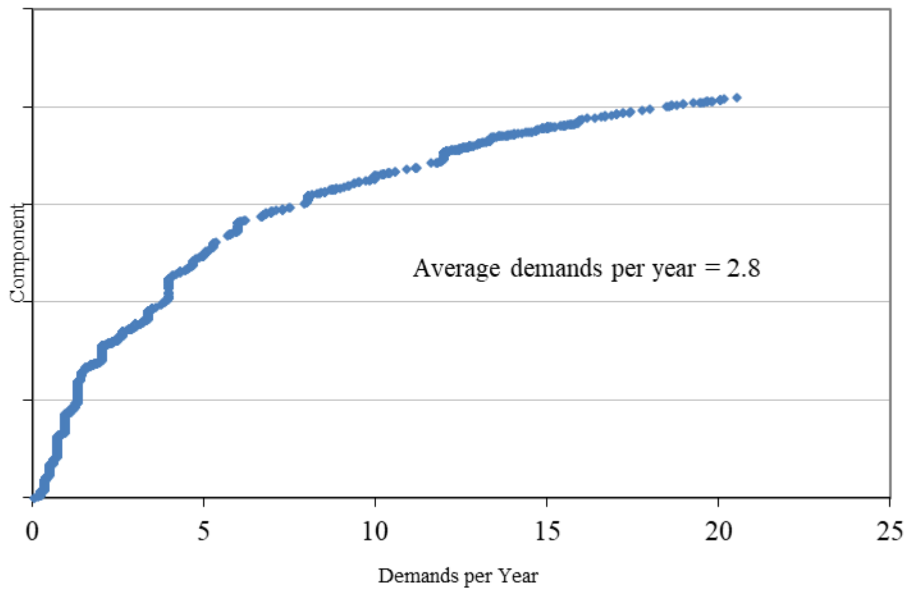


Figure 23. CRB demands per year distribution.

A-5.4.3 Industry-Average Baselines

Table 95 lists the selected industry distributions of *p* and λ for the CRB failure modes. These industry-average failure rates do not account for any recovery.

Table 95. Selected industry distributions of p and λ for CRBs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
--	FTOC	EB/PL/KS	4.23E-05	9.91E-04	1.59E-03	5.16E-03	Beta	0.79	4.99E+02
--	SOP	EB/PL/KS	4.58E-10	7.38E-08	1.73E-07	6.84E-07	Gamma	0.47	2.68E+06
HV (13.8 and 16 kV)	FTOC	JNID/IL	1.22E-03	1.87E-03	1.90E-03	2.71E-03	Beta	17.50	9.18E+03
HV (13.8 and 16 kV)	SOP	JNID/IL	2.35E-07	3.77E-07	3.86E-07	5.66E-07	Gamma	14.50	3.76E+07
MV (4.16 and 6.9 kV)	FTOC	EB/PL/KS	7.09E-06	1.13E-03	2.64E-03	1.04E-02	Beta	0.47	1.76E+02
MV (4.16 and 6.9 kV)	SOP	JNID/IL	6.47E-08	1.02E-07	1.04E-07	1.51E-07	Gamma	15.50	1.49E+08
LV (480V)	FTOC	EB/PL/KS	3.27E-06	3.89E-04	8.57E-04	3.30E-03	Beta	0.50	5.79E+02

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
LV (480V)	SOP	JNID/IL	6.26E-08	8.74E-08	8.85E-08	1.18E-07	Gamma	27.50	3.11E+08
DC	FTOC	JNID/IL	1.30E-04	2.94E-04	3.13E-04	5.59E-04	Beta	5.50	1.76E+04
DC	SOP	JNID/IL	5.63E-11	6.52E-09	1.43E-08	5.50E-08	Gamma	0.50	3.49E+07

A-5.5 Inverter (INV)

A-5.5.1 Component Description

The inverter (INV) boundary includes the inverter unit. The failure modes for INV are listed in Table 83.

A-5.5.2 Data Collection and Review

Data for INV UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems and operational status included in the INV data collection are listed in Table 96 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 96. INV systems.

		Number of Components		
Pooling Group	**System**	**High/ Unknown Demand**	**Low Demand**	**Total**
All	Auxiliary feedwater (AFW)	2		2
	dc power (DCP)	14		14
	Emergency power supply (EPS)	2		2
	High pressure coolant injection (HCI)	1		1
	Normally operating service water (SWN)	2		2
	Plant ac power (ACP)	22		22
	Reactor core isolation (RCI)	3		3
	Reactor protection (RPS)	22		22
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	6		6
	Uninterruptable instrument power supply (UPS)	154		154
	Grand Total	**228**		**228**

Table 97 summarizes the data obtained from EPIX and used in the INV analysis. Note that the hours are reactor-year hours.

Table 97. INV unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Events**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
-	FTOP	52	24,269,470 h	199	37	17.6%	67.6%

A-5.5.3 Industry-Average Baselines

Table 98 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 98. Selected industry distributions of p and λ for INVs.

							Distribution		
Pooling Group	**Failure Mode**	**Analysis Type / Source**	**5%**	**Median**	**Mean**	**95%**	**Type**	α	β
-	FTOP	EB/PL/KS	1.73E-07	2.41E-06	3.49E-06	1.05E-05	Gamma	0.99	2.82E+05

A-5.6 Bus (BUS)

A-5.6.1 Component Description

The bus (BUS) boundary includes the bus component itself, which includes the bus bar, fuses, and control circuitry. Associated circuit breakers and step-down transformers are not included. The failure modes for BUS are listed in Table 83.

A-5.6.2 Data Collection and Review

Data for the BUS UR baseline were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the BUS data collection are listed in Table 99 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether SOP (e.g., leakage, spurious operation, and operation).

Table 99. BUS systems.

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

Table 100 summarizes the data obtained from EPIX and used in the BUS analysis. Note that the hours are reactor-year hours.

Table 100. BUS unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Failures**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
AC	FTOP	76	160,545,900 h	1,296	87	5.2%	43.7%
DC	FTOP	1	2,103,936 h	16	6	6.3%	16.7%

A-5.6.3 Industry-Average Baselines

Table 101 lists the industry-average failure rate distribution. This industry-average failure rate does not account for any recovery.

Table 101. Selected industry distributions of p and λ for BUSs.

							Distribution		
Pooling Group	**Failure Mode**	**Analysis Type / Source**	**5%**	**Median**	**Mean**	**95%**	**Type**	α	β
AC	FTOP	EB/PL/KS	2.91E-08	4.05E-07	5.88E-07	1.77E-06	Gamma	0.99	1.68E+06
DC	FTOP	JNID/IL	8.38E-08	5.63E-07	7.13E-07	1.86E-06	Gamma	1.50	2.10E+06

A-5.7 Motor Control Center (MCC)

A-5.7.1 Component Description

The motor control center (MCC) component boundary includes the MCC cabinet, the bus bars, fuses, and protection equipment. The failure modes for MCC are listed in Table 83.

A-5.7.2 Data Collection and Review

The data for MCC UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the MCC data collection are listed in Table 102 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 102. MCC systems.

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

Table 103 summarizes the data used in the MCC analysis.

Table 103. MCC unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Events**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
-	FTOP	7	28,535,130 h	217	18	2.3%	22.2%

A-5.7.3 Industry-Average Baselines

Table 104 lists the selected industry distributions of p and λ for the MCC failure modes. These industry-average failure rates do not account for any recovery.

Table 104. Selected industry distributions of p and λ for MCCs.

							Distribution		
Pooling Group	**Failure Mode**	**Analysis Type / Source**	**5%**	**Median**	**Mean**	**95%**	**Type**	α	β
-	FTOP	EB/PL/KS	1.31E-08	1.70E-07	2.43E-07	7.24E-07	Gamma	1.02	4.19E+06

A-5.8 Transformer (TFM)

A-5.8.1 Component Description

The transformer (TFM) boundary includes the transformer unit, which includes the wiring, cooling, and protection equipment. The failure modes for TFM are listed in Table 83.

A-5.8.2 Data Collection and Review

Data for TFM UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the TFM data collection are listed in Table 105 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 105. TFM systems.

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

Table 106 summarizes the data obtained from EPIX and used in the TFM analysis. Note that the hours are reactor-year hours.

Table 106. TFM unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Failures**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
>15kV	FTOP	110	60,181,620 h	512	99	17.2%	53.5%

A-5.8.3 Industry-Average Baselines

Table 107 lists the industry-average failure rate distributions. This industry-average failure rate does not account for any recovery.

Table 107. Selected industry distributions of p and λ for TFMs.

							Distribution		
Pooling Group	**Failure Mode**	**Analysis Type / Source**	**5%**	**Median**	**Mean**	**95%**	**Type**	**α**	**β**
>15kV	FTOP	EB/PL/KS	2.58E-07	1.55E-06	1.93E-06	4.88E-06	Gamma	1.63	8.47E+05

A-5.9 Sequencer (SEQ)

A-5.9.1 Component Description

The sequencer (SEQ) boundary includes the relays, logic modules, etc. that comprise the sequencer function of the emergency diesel generator (EDG) load process. The failure modes for SEQ are listed in Table 83.

A-5.9.2 Data Collection and Review

Data for the SEQ UR baseline were obtained from the IRIS database, covering 2006–2020 using RADS. The EPIX data was analyzed outside of RADS to determine the failures in the sequencer sub-component. The demand data are based on assuming a full test of the sequencer every fuel cycle (18 months) for each EDG. Table 108 summarizes the data obtained from EPIX and used in the SEQ analysis.

Table 108. SEQ unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	Failure Mode	Failures	Demands or Hours	Components	Plants	Components	Plants
-	FTOP	6	61,363 d	234	95	2.6%	6.3%

A-5.9.3 Industry-Average Baselines

Table 109 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 109. Selected industry distributions of p and λ for SEQs.

							Distribution		
Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Type	α	β
-	FTOP	JNID/IL	4.80E-05	1.00E-04	1.06E-04	1.82E-04	Beta	6.50	6.14E+04

A-5.10 Fuse (FUS)

A-5.10.1 Component Description

The fuse (FUS) boundary includes the transformer unit, which includes the wiring, cooling, and protection equipment. The failure modes for FUS are listed in Table 83.

A-5.10.2 Data Collection and Review

Data for FUS UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the FUS data collection are listed in Table 110 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 110. FUS systems.

		Number of Components		
Pooling Group	**System**	**High/ Unknown Demand**	**Low Demand**	**Total**
All	Auxiliary feedwater (AFW)	8		8
	Circulating water system (CWS)	14		14
	Component cooling water (CCW)	4		4
	Containment fan cooling (CFC)	6		6
	Containment isolation system (CIS)	5		5
	Control rod drive (CRD)	8		8
	dc power (DCP)	369		369
	Emergency power supply (EPS)	26		26
	Heating ventilation and air conditioning (HVC)	48		48
	Instrument air (IAS)	2		2
	Main steam (MSS)	24		24
	Plant ac power (ACP)	310		310
	Reactor coolant (RCS)	23		23
	Grand Total	**847**		**847**

Table 111 summarizes the data obtained from EPIX and used in the FUS analysis. Note that the hours are reactor-year hours.

Table 111. FUS unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Failures**	**Demands or Hours**	**Component s**	**Plants**	**Components**	**Plants**
-	SOP	1	169,366,800 h	1,288	5	0.1%	20.0%

A-5.10.3 Industry-Average Baselines

Table 112 lists the industry-average failure rate distributions. This industry-average failure rate does not account for any recovery.

Table 112. Selected industry distributions of p and λ for FUS.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
-	SOP	JNID/IL	1.04E-09	7.00E-09	8.86E-09	2.31E-08	Gamma	1.50	1.69E+08

A-6. STRAINERS

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

The failure modes for the strainer are listed in Table 113.

Table 113. Strainer failure modes.

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

The systems and operational status included in the strainer data collection are listed in Table 114 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 114. Strainer systems and component counts.

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

Pooling Group	System	Number of Components High/ Unknown Demand	Low Demand	Total
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	4		4
	Standby service water (SSW)	59		59
	FLTSC Total	**167**	**2**	**169**
Sump	Chemical and volume control (CVC)	7		7
	Containment spray recirculation (CSR)	7		7
	Control rod drive (CRD)	17		17
	High pressure coolant injection (HCI)	3		3
	High pressure core spray (HCS)	5		5
	Low pressure core spray (LCS)	5		5
	Reactor core isolation (RCI)	8		8
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	43		43
	Sump Total	**95**		**95**
TRK	Circulating water system (CWS)	10		10
	TRK Total	**10**		**10**
TSA	Circulating water system (CWS)	163		163
	Normally operating service water (SWN)	34		34
	Standby service water (SSW)	15		15
	TSA Total	**212**		**212**
	Grand Total	**692**	**14**	**706**

A-6.1 Filter (FLT)

A-6.1.1 Component Description

The filter (FLT) boundary includes the filter. The failure modes for the FLT are listed in Table 113. The systems available in the FLT data collection are listed in Table 115 with the number of components included with each system. The FLT data analysis uses only data from components installed in “clean” systems (e.g., not service water).

A-6.1.2 Data Collection and Review

Data for FLT UR baselines were obtained from the IRIS database, covering 1997–2004. Table 115 summarizes the data obtained from EPIX and used in the FLT analysis. Note that PG hours are reactor-year hours.

Table 115. FLT unreliability data.

Pooling Group	Failure Mode	Data: Failures	Data: Demands or Hours	Counts: Components	Counts: Plants	Percent with Failures: Components	Percent with Failures: Plants
FLT	PG	6	7,922,615 h	62	20	8.1%	20.0%
FLT	ELS	1	28,097,240 h	223	47	0.4%	2.1%
FLT	ELL	--	--	223	47	--	--
FLT-Clean	PG	1	8,161,140 h	68	19	1.5%	5.3%
FLT-Clean	BYP	0	8,161,140 h	68	19	0.0%	0.0%
FLT-IAS	PG	0	210,384 h	2	1	0.0%	0.0%

A-6.1.3 Industry-Average Baselines

Table 116 lists the industry-average failure rate distribution. These industry-average failure rates do not account for any recovery.

Table 116. Selected industry distributions of p and λ for FLTs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
FLT	PG	JNID/IL	3.72E-07	7.79E-07	8.20E-07	1.41E-06	Gamma	6.50	7.92E+06
FLT	ELS	JNID/IL	6.26E-09	4.21E-08	5.34E-08	1.39E-07	Gamma	1.50	2.81E+07
FLT	ELL	--	4.00E-13	9.11E-10	3.74E-09	1.71E-08	Gamma	0.30	8.03E+07
FLT-Clean	PG	JNID/IL	2.16E-08	1.45E-07	1.84E-07	4.79E-07	Gamma	1.50	8.16E+06
FLT-Clean	BYP	JNID/IL	2.41E-10	2.79E-08	6.13E-08	2.35E-07	Gamma	0.50	8.16E+06
FLT-IAS	PG	JNID/IL	9.36E-09	1.08E-06	2.38E-06	9.15E-06	Gamma	0.50	2.10E+05

A-6.2 Self-Cleaning Strainer (FLTSC)

A-6.2.1 Component Description

The strainer (FLTSC) component boundary includes the strainer, the rotating assembly, backwash valves, and control circuitry. The failure modes for FLTSC are listed in Table 113.

A-6.2.2 Data Collection and Review

Data for the FLTSC UR baseline were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the FLTSC data collection are listed in Table 117 with the number of components included with each system.

Table 117 summarizes the data used in the FLTSC analysis. Note that FTOP, BYP, ELS, and PG hours are reactor-year hours.

Table 117. FLTSC unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Events**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
FLTSC	PG	32	21,560,060 h	167	47	9.0%	21.3%
FLTSC	BYP	0	21,560,060 h	167	47	0.0%	0.0%
FLTSC	FTOP	53	21,560,060 h	167	47	16.2%	31.9%
FLTSC	ELS	2	21,560,060 h	167	47	1.2%	4.3%
FLTSC	ELL	--	--	167	47	--	--
FLTSC-SWN	PG	19	13,235,010 h	103	33	7.8%	15.2%
FLTSC-SSW	PG	13	7,799,060 h	60	26	11.7%	19.2%
FLTSC-SSW-EE	PG	1	7,799,060 h	60	26	1.7%	3.8%
FLTSC-SSW-NE	PG	10	7,799,060 h	60	26	10.0%	15.4%

A-6.2.3 Industry-Average Baselines

Table 118 lists the industry-average failure rate distribution for the FLTSC component. These industry-average failure rates do not account for any recovery.

Table 118. Selected industry distributions of p and λ for FLTSCs.

							Distribution		
Pooling Group	**Failure Mode**	**Analysis Type / Source**	**5%**	**Median**	**Mean**	**95%**	**Type**	**α**	**β**
FLTSC	PG	JNID/IL	1.10E-06	1.49E-06	1.51E-06	1.96E-06	Gamma	32.50	2.16E+07
FLTSC	BYP	JNID/IL	9.10E-11	1.05E-08	2.32E-08	8.89E-08	Gamma	0.50	2.16E+07
FLTSC	FTOP	JNID/IL	1.95E-06	2.46E-06	2.48E-06	3.06E-06	Gamma	53.50	2.16E+07
FLTSC	ELS	JNID/IL	2.65E-08	1.01E-07	1.16E-07	2.56E-07	Gamma	2.50	2.16E+07
FLTSC	ELL	--	8.69E-13	1.98E-09	8.12E-09	3.71E-08	Gamma	0.30	3.69E+07
FLTSC-SWN	PG	JNID/IL	9.73E-07	1.45E-06	1.47E-06	2.07E-06	Gamma	19.50	1.32E+07
FLTSC-SSW	PG	JNID/IL	1.04E-06	1.69E-06	1.73E-06	2.57E-06	Gamma	13.50	7.80E+06
FLTSC-SSW-EE	PG	JNID/IL	2.26E-08	1.52E-07	1.92E-07	5.01E-07	Gamma	1.50	7.80E+06
FLTSC-SSW-NE	PG	JNID/IL	7.43E-07	1.30E-06	1.35E-06	2.09E-06	Gamma	10.50	7.80E+06

A-6.3 Sump Strainer (SMP)

A-6.3.1 Component Description

The sum strainer (SMP) component boundary includes the strainer. The failure modes for SMP are listed in Table 113.

A-6.3.2 Data Collection and Review

Data for the SMP UR baseline were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the SMP data collection are listed in Table 119 with the number of components included with each system.

Table 119 summarizes the data used in the SMP analysis. Note that PG hours are reactor-year hours.

Table 119. SMP unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent with Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
Sump PWR	PG	1	3,528,454 h	29	14	3.4%	7.1%
Sump BWR	PG	0	5,522,832 h	42	7	0.0%	0.0%

A-6.3.3 Industry-Average Baselines

Table 120 lists the industry-average failure rate distribution for the SMP component. These industry-average failure rates do not account for any recovery.

Table 120. Selected industry distributions of p and λ for SMPs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Sump PWR	PG	JNID/IL	4.98E-08	3.35E-07	4.25E-07	1.11E-06	Gamma	1.50	3.53E+06
Sump BWR	PG	JNID/IL	3.56E-10	4.12E-08	9.05E-08	3.48E-07	Gamma	0.50	5.52E+06

A-6.4 Traveling Screen Assembly (TSA)

A-6.4.1 Component Description

The traveling screen (TSA) component boundary includes the traveling screen, motor, and drive mechanism. The failure modes for TSA are listed in Table 113.

A-6.4.2 Data Collection and Review

Data for the TSA UR baseline were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the TSA data collection are listed in Table 121 with the number of components included with each system.

Table 121 summarizes the data used in the TSA analysis. Note that FTOP, BYP, and PG hours are reactor-year hours.

Table 121. TSA unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Events**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
TSA	PG	37	25,155,920 h	205	48	11.2%	29.2%
TSA	BYP	2	25,155,920 h	205	48	1.0%	4.2%
TSA	FTOP	45	25,155,920 h	205	48	16.6%	43.8%
TSA-SSW	PG	0	1,972,440 h	15	5	0.0%	0.0%
TSA-SSW-NE	PG	0	1,972,440 h	15	5	0.0%	0.0%

A-6.4.3 Industry-Average Baselines

Table 122 lists the industry-average failure rate distribution for the TSA component. These industry-average failure rates do not account for any recovery.

Table 122. Selected industry distributions of p and λ for TSAs.

							Distribution		
Pooling Group	**Failure Mode**	**Analysis Type / Source**	**5%**	**Median**	**Mean**	**95%**	**Type**	α	β
TSA	PG	JNID/IL	1.11E-06	1.47E-06	1.49E-06	1.91E-06	Gamma	37.50	2.52E+07
TSA	BYP	JNID/IL	2.27E-08	8.63E-08	9.94E-08	2.20E-07	Gamma	2.50	2.52E+07
TSA	FTOP	EB/PL/KS	1.30E-08	1.04E-06	2.12E-06	7.86E-06	Gamma	0.55	2.59E+05
TSA-SSW	PG	JNID/IL	9.98E-10	1.15E-07	2.53E-07	9.75E-07	Gamma	0.50	1.97E+06
TSA-SSW-NE	PG	JNID/IL	9.98E-10	1.15E-07	2.53E-07	9.75E-07	Gamma	0.50	1.97E+06

A-6.5 Trash Rack (TRK)

A-6.5.1 Component Description

The trash rack (TRK) component boundary includes the traveling screen, motor, and drive mechanism. The failure modes for TRK are listed in Table 113.

A-6.5.2 Data Collection and Review

Data for the TRK UR baseline were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the TRK data collection are listed in Table 123 with the number of components included with each system.

Table 123 summarizes the data used in the TRK analysis. Note that PG hours are reactor-year hours.

Table 123. TRK unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Events**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
TRK	PG	0	1,314,960 h	10	5	0.0%	0.0%

A-6.5.3 Industry-Average Baselines

Table 124 lists the industry-average failure rate distribution for the TRK component. These industry-average failure rates do not account for any recovery.

Table 124. Selected industry distributions of p and λ for TRKs.

							Distribution		
Pooling Group	**Failure Mode**	**Analysis Type / Source**	**5%**	**Median**	**Mean**	**95%**	**Type**	**α**	**β**
TRK	PG	JNID/IL	1.50E-09	1.74E-07	3.80E-07	1.47E-06	Gamma	0.50	1.31E+06

A-7. REACTOR PROTECTION

This section presents reliability data pertaining to the reactor protection system (RPS). The failure modes for reactor protection components are listed in Table 125.

Table 125. Reactor protection equipment failure modes.

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

A-7.1 Bistable (BIS)

A-7.1.1 Component Description

The bistable (BIS) boundary includes the bistable unit itself. The failure mode for BIS is listed in Table 125.

A-7.1.2 Data Collection and Review

Data for the BIS UR baseline were obtained from the reactor protection system (RPS) system studies (SSs) [A-5, A-6, A-7, A-8]. The RPS SSs contain data from 1984 to 1995. Table 126 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 126. BIS unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	Failure Mode	Failures	Demands or Hours	Components	Plants	Components	Plants
All	FTOP	55	102,094 d	-	-	-	-

A-7.1.3 Industry-Average Baselines

Table 127 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 NUREG/CR-6928).

Table 127. Selected industry distributions of p and λ for BISs.

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

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

A-7.2.1 Component Description

The process logic delta temperature (PLDT), process logic flow (PLF), process logic level (PLL), and process logic pressure (PLP boundary includes the logic components. The failure modes for these components are listed in Table 125.

A-7.2.2 Data Collection and Review

Data for process logic component UR baselines were obtained from the reactor protection system (RPS) system studies (SSs). The RPS SSs contain data from 1984 to 1995. Table 128 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 128. Process logic component unreliability data.

Pooling Group	Component Failure Mode	Data		Counts		Percent with Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	PLDT FTOP	24	4,887 d	-	-	-	-
	PLF FTOP	-	-	-	-	-	-
	PLL FTOP	3	6,075 d	-	-	-	-
	PLP FTOP	6	38,115 d	-	-	-	-

A-7.2.3 Industry-Average Baselines

Table 129 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 NUREG/CR-6928). Because PLF has no data, the PLL result was used for the PLL mean.

Table 129. Selected industry distributions of p and λ for process logic components.

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

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

A-7.3.1 Component Description

The sensor/transmitter flow (STF), sensor/transmitter level (STL), sensor/transmitter pressure (STP), and sensor/transmitter temperature (STT) boundaries includes the sensor and transmitter. The failure modes for sensor/transmitter are listed in Table 125.

A-7.3.2 Data Collection and Review

Data for the sensor/transmitter UR baseline were obtained from the reactor protection system (RPS) system studies (SSs). The RPS SSs contain data from 1984 to 1995. Table 130 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 130. Sensor/transmitter unreliability data.

Pooling Group	Component Failure Mode	Data		Counts		Percent with Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
All	STF FTOP	-	-	-	-	-	-
	STF FTOP	-	-	-	-	-	-
	STL FTOP	5	6,750 d	-	-	-	-
	STL FTOP	0	9,831,968 h	-	-	-	-
	STP FTOP	2	23,960 d	-	-	-	-
	STP FTOP	35	43,430,451 h	-	-	-	-
	STT FTOP	17	40,759 d	-	-	-	-
	STT FTOP	29	35,107,399 h	-	-	-	-

A-7.3.3 Industry-Average Baselines

Table 131 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 NUREG/CR-6928). Because there were no data for STF FTOP, the results for STL FTOP were used.

Table 131. Selected industry distributions of p and λ for sensor/transmitters.

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

A-7.4 Reactor Trip Breaker (RTB)

A-7.4.1 Component Description

The reactor trip breaker (RTB) boundary includes the entire trip breaker. The RTB has been broken up into three subcomponents for use in modeling the failure of the RTB to open on demand. These three subcomponents are the mechanical portion of the breaker (BME), the breaker shunt trip (BSN), and the breaker undervoltage trip (BUV). The component and subcomponent failure modes for RTB are listed in Table 125.

Table 132. RTB failure modes.

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

A-7.4.2 Data Collection and Review

Data for RTB UR baselines were obtained from the pressurized water reactor (PWR) reactor protection system (RPS) system studies (SSs). The RPS SSs contain data from 1984 to 1995. Table 133summarizes 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 133. RTB unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	Failure Mode	Failures	Demands or Hours	Components	Plants	Components	Plants
All	BME FTOP	1	97,359 d	-	-	-	-
	BSN FTOP	14	44,104 d	-	-	-	-
	BUV FTOP	23	57,199 d	-	-	-	-
	RTB FTOP	-	-	-	-	-	-

A-7.4.3 Industry-Average Baselines

Table 134 lists the industry-average failure rate distributions. The selected FTOP distributions have means based on the Jeffreys mean of industry data and $\alpha = 0.5$. For all distributions based on RPS SS data, an α of 0.5 is assumed (see Section A.1 in NUREG/CR-6928). 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 134. Selected industry distributions of p and λ for RTBs.

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

A-7.5 Manual Switch (MSW)

A-7.5.1 Component Description

The manual switch (MSW) boundary includes the switch itself. The failure mode for MSW is listed in Table 125.

A-7.5.2 Data Collection and Review

Data for the MSW UR baseline were obtained from the reactor protection system (RPS) system studies (SSs). The RPS SSs contain data from 1984 to 1995. Table 135 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 135. MSW unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Failures**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
All	FTOC	2	19,789 d	-	-	-	-

A-7.5.3 Industry-Average Baselines

Table 136 lists the industry-average failure rate distributions. The FTOC failure mode is not supported by EPIX data. The selected FTOC 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 NUREG/CR-6928).

Table 136. Selected industry distributions of p and λ for MSWs.

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

A-7.6 Relay (RLY)

A-7.6.1 Component Description

The relay (RLY) boundary includes the relay unit itself. The failure mode for RLY is listed in Table 125.

A-7.6.2 Data Collection and Review

Data for the RLY UR baseline were obtained from the reactor protection system (RPS) system studies (SSs). The RPS SSs contain data from 1984 to 1995. Table 137 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 137. RLY unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Failures**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
-	FTOP	24	974,417 d	-	-	-	-

A-7.6.3 Industry-Average Baselines

Table 138 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 NUREG/CR-6928).

Table 138. Selected industry distributions of p and λ for RLYs.

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

A-8. CONTROL RODS

The control rod equipment includes the control rod drives (CRDs) and rods (RODs) for PWRs and the hydraulic control units (HCUs) for BWRs. The failure modes for control rod components are listed in Table 139.

Table 139. ROD equipment failure modes.

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

Data for control rod UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the control rod data collection are listed in Table 140 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 140. Control rod systems.

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

A-8.1 Control Rod Drive (CRD)

A-8.1.1 Component Description

The control rod drive (CRD) boundary includes the PWR control rod drive mechanism. The failure modes for CRD are listed in Table 139.

A-8.1.2 Data Collection and Review

Data for CRD UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. Table 141 summarizes the data from EPIX and used in the CRD analysis.

Table 141. CRD unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Failures**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
CRDM	FTOP	19	145,016,900 h	1,198	30	1.6%	36.7%

Pooling Group	Failure Mode	Data		Counts		Percent with Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
CRDM	SOP	23	145,016,900 h	1,198	30	1.6%	30.0%

A-8.1.3 Industry-Average Baselines

Table 142 lists the industry-average failure rate distribution. These industry-average failure rates do not account for any recovery.

Table 142. Selected industry distributions of p and λ for CRDs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
CRDM	FTOP	EB/PL/KS	1.16E-09	8.38E-08	1.68E-07	6.18E-07	Gamma	0.56	3.34E+06
CRDM	SOP	JNID/IL	1.11E-07	1.60E-07	1.62E-07	2.21E-07	Gamma	23.50	1.45E+08

A-8.2 Control Rod (ROD)

A-8.2.1 Component Description

The control rod (ROD) boundary includes the PWR control rod excluding the drive mechanism. The failure modes for ROD are listed in Table 139.

A-8.2.2 Data Collection and Review

Data for ROD UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. Table 143 summarizes the data obtained from EPIX and used in the ROD analysis.

Table 143. ROD unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Failures**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
Control Rod	FTOP	10	110,389,200 h	844	39	1.2%	15.4%
Control Rod	SOP	11	110,389,200 h	844	39	1.2%	12.8%

A-8.2.3 Industry-Average Baselines

Table 144 lists the industry-average failure rate distribution. These industry-average failure rates do not account for any recovery.

Table 144. Selected industry distributions of p and λ for RODs.

							Distribution		
Pooling Group	**Failure Mode**	**Analysis Type / Source**	**5%**	**Median**	**Mean**	**95%**	**Type**	**α**	**β**
Control Rod	FTOP	JNID/IL	5.27E-08	9.24E-08	9.51E-08	1.49E-07	Gamma	10.50	1.10E+08
Control Rod	SOP	JNID/IL	5.95E-08	1.02E-07	1.04E-07	1.60E-07	Gamma	11.50	1.10E+08

A-8.3 Hydraulic Control Unit (HCU)

A-8.3.1 Component Description

The hydraulic control unit (HCU) boundary includes the PWR control rod drive mechanism. The failure modes for HCU are listed in Table 139.

A-8.3.2 Data Collection and Review

Data for HCU UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. Table 145 summarizes the data obtained from EPIX and used in the HCU analysis.

Table 145. HCU unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	Failure Mode	Failures	Demands or Hours	Components	Plants	Components	Plants
HCU	FTI	-	-	-	-	-	-
HCU	FTOP	19	1,347,114,000 h	10,425	35	0.2%	42.9%
HCU	SOP	27	1,347,114,000 h	10,425	35	0.3%	51.4%

A-8.3.3 Industry-Average Baselines

Table 146 lists the industry-average failure rate distribution. These industry-average failure rates do not account for any recovery.

Table 146. Selected industry distributions of p and λ for HCUs.

							Distribution		
Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Type	α	β
HCU	FTI	RPS SS	1.05E-09	2.10E-08	1.10E-07	4.19E-07	Lognormal	20.00	-
HCU	FTOP	JNID/IL	9.52E-09	1.42E-08	1.45E-08	2.02E-08	Gamma	19.50	1.35E+09
HCU	SOP	EB/PL/KS	7.14E-09	1.84E-08	1.99E-08	3.79E-08	Gamma	4.30	2.16E+08

A-9. HEATING AND VENTILATION

The heating and ventilating (HVC) equipment included in this section includes dampers, air-handling units, chillers, and fans. The failure modes for HVC equipment are listed in Table 147.

Table 147. Heating and ventilation equipment failure modes.

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

A-9.1 Damper (DMP)

A-9.1.1 Component Description

The damper (DMP) component boundary includes the valve, the valve operator, and local instrumentation and control circuitry. The failure modes for dampers are listed in Table 147. This section presents results for dampers with pneumatic -operators (AOD), hydraulic-operators (HOD), and motor-operators (MOD).

A-9.1.2 Data Collection and Review

Data for DMP UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the DMP data collection are listed in Table 148 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 148. Damper systems.

		Number of Components		
Pooling Group	**Description**	**High/ Unknown Demand**	**Low Demand**	**Total**
AIR	Chemical and volume control (CVC)		1	1
	Containment fan cooling (CFC)	2	22	24
	Emergency power supply (EPS)	1		1
	Heating ventilation and air conditioning (HVC)	114	59	173
	High pressure injection (HPI)	1		1
	Instrument air (IAS)	4		4
	Plant ac power (ACP)	1		1
AIR Total		**123**	**82**	**205**
HYD	Containment fan cooling (CFC)		4	4
	dc power (DCP)	1		1
	Emergency power supply (EPS)	16	8	24

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

Table 149 summarizes the data used in the DMP analysis. Note that SOP and ILS hours are reactor-year hours.

Table 149. DMP unreliability data.

Pooling Group	Failure Mode	Data Events	Data Demands or Hours	Counts Components	Counts Plants	Percent with Failures Components	Percent with Failures Plants
Pneumatic	FTOC	0	6,602 d	50	10	0.0%	0.0%
Pneumatic	SOP	4	24,287,000 h	207	37	1.9%	8.1%
Pneumatic	ILS	3	24,287,000 h	207	37	1.4%	5.4%
Pneumatic	ILL	--	--	207	37	--	--
Hydraulic	FTOC	4	6,113 d	42	5	9.5%	60.0%
Hydraulic	SOP	2	16,454,520 h	126	15	1.6%	6.7%
Hydraulic	ILS	0	16,454,520 h	126	15	0.0%	0.0%
Hydraulic	ILL	--	--	126	15	--	--
Motor	FTOC	11	28,949 d	52	10	11.5%	30.0%
Motor	SOP	0	14,134,270 h	109	22	0.0%	0.0%
Motor	ILS	0	14,134,270 h	109	22	0.0%	0.0%
Motor	ILL	--	--	109	22	--	--

Figure 24 shows the range of valve demands per year in the DMP data set (limited to low-demand components only).

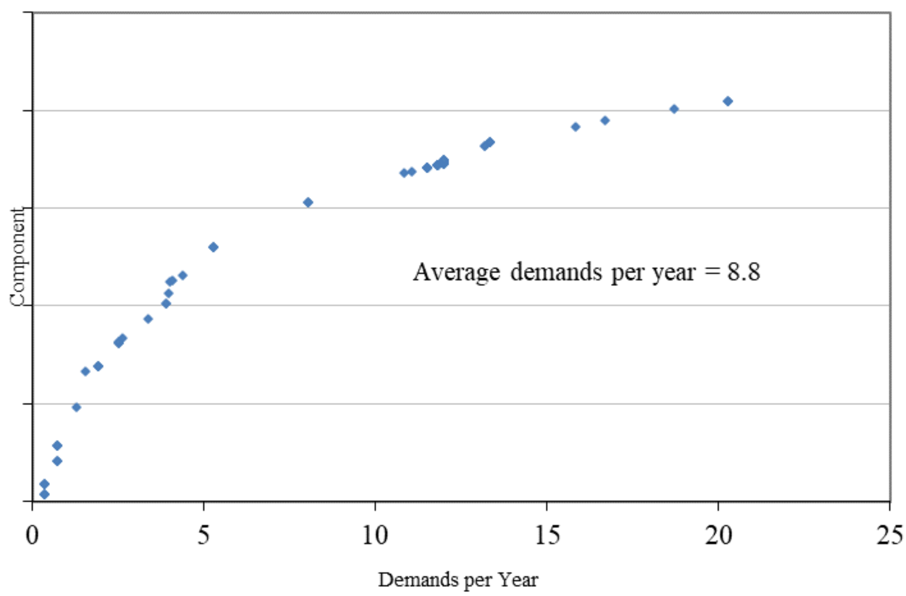


Figure 24. DMP demands per year distribution.

A-9.1.3 Industry-Average Baselines

Table 150 lists the selected industry distributions of *p* and *λ* for the DMP failure modes. These industry-average failure rates do not account for any recovery.

Table 150. Selected industry distributions of p and λ for DMPs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
Pneumatic	FTOC	JNID/IL	2.98E-07	3.45E-05	7.57E-05	2.91E-04	Beta	0.50	6.60E+03
Pneumatic	SOP	EB/PL/KS	1.29E-09	8.25E-08	1.61E-07	5.86E-07	Gamma	0.58	3.60E+06
Pneumatic	ILS	JNID/IL	4.46E-08	1.31E-07	1.44E-07	2.89E-07	Gamma	3.50	2.43E+07
Pneumatic	ILL	--	3.08E-13	7.02E-10	2.88E-09	1.32E-08	Gamma	0.30	1.04E+08
Hydraulic	FTOC	JNID/IL	2.72E-04	6.82E-04	7.36E-04	1.38E-03	Beta	4.50	6.11E+03
Hydraulic	SOP	JNID/IL	3.47E-08	1.32E-07	1.52E-07	3.35E-07	Gamma	2.50	1.65E+07
Hydraulic	ILS	JNID/IL	1.19E-10	1.38E-08	3.04E-08	1.16E-07	Gamma	0.50	1.65E+07
Hydraulic	ILL	--	6.51E-14	1.48E-10	6.08E-10	2.78E-09	Gamma	0.30	4.93E+08
Motor	FTOC	EB/PL/KS	1.74E-05	2.44E-04	3.56E-04	1.07E-03	Beta	0.98	2.76E+03
Motor	SOP	JNID/IL	1.39E-10	1.61E-08	3.54E-08	1.36E-07	Gamma	0.50	1.41E+07
Motor	ILS	JNID/IL	1.39E-10	1.61E-08	3.54E-08	1.36E-07	Gamma	0.50	1.41E+07
Motor	ILL	--	7.58E-14	1.73E-10	7.08E-10	3.24E-09	Gamma	0.30	4.24E+08

A-9.2 Air Handling Unit (AHU)

A-9.2.1 Component Description

The air-handling unit (AHU) boundary includes the fan, heat exchanger, valves, control circuitry, and breakers. The failure modes for AHU are listed in Table 147.

A-9.2.2 Data Collection and Review

Data for AHU UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems and operational status included in the AHU data collection are listed in Table 151 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤200 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data (e.g., leakage, SOP, and operation) are available.

Table 151. AHU systems.

		Number of Components		
Pooling Group	**System**	**High/ Unknown Demand**	**Low Demand**	**Total**
Normally Running	Auxiliary feedwater (AFW)	3	1	4
	Circulating water system (CWS)	3		3
	Component cooling water (CCW)	37	2	39
	Condensate system (CDS)	10		10
	Containment fan cooling (CFC)	113	58	171
	Containment isolation system (CIS)	4		4
	Control rod drive (CRD)	14		14
	dc power (DCP)	1	2	3
	Emergency power supply (EPS)	95	5	100
	Fuel handling (FHS)	4		4
	Heating ventilation and air conditioning (HVC)	1048	78	1126
	High pressure coolant injection (HCI)	1		1
	High pressure injection (HPI)	1		1
	Instrument air (IAS)	6	2	8
	Main feedwater (MFW)	4		4
	Main steam (MSS)	107		107
	Plant ac power (ACP)	13		13
	Reactor coolant (RCS)	16		16
	Reactor protection (RPS)	10		10
	Standby service water (SSW)	8		8
	Uninterruptable instrument power supply (UPS)	10		10
	Normally Running Total	**1508**	**148**	**1656**
Standby	Chemical and volume control (CVC)		2	2
	Component cooling water (CCW)		1	1
	Containment fan cooling (CFC)	1	60	61
	Containment spray recirculation (CSR)		2	2
	Emergency power supply (EPS)		57	57
	Heating ventilation and air conditioning (HVC)	3	240	243
	High pressure injection (HPI)		2	2

Pooling Group	System	Number of Components High/ Unknown Demand	Low Demand	Total
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)		4	4
	Standby service water (SSW)		6	6
	Standby Total	**4**	**374**	**378**
	Grand Total	**1512**	**522**	**2034**

Table 152 summarizes the data obtained from EPIX and used in the AHU analysis.

Table 152. AHU unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Failures**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
NR	FTS	23	15,981 d	145	35	12.4%	22.9%
NR	FTR	39	15,131,330 h	145	35	17.2%	51.4%
STBY	FTS	33	158,866 d	403	51	7.2%	31.4%
STBY	FTR<1H	0	147,963 h	395	51	0.0%	0.0%
STBY	FTR>1H	27	9,928,068 h	403	51	5.7%	25.5%

Figure 25 shows the range of start demands per year in the standby AHU data set. Figure 26 shows the range of run hours per demand in the standby AHU data set. Figure 26 shows the range of run hours per demand in the running AHU data set.

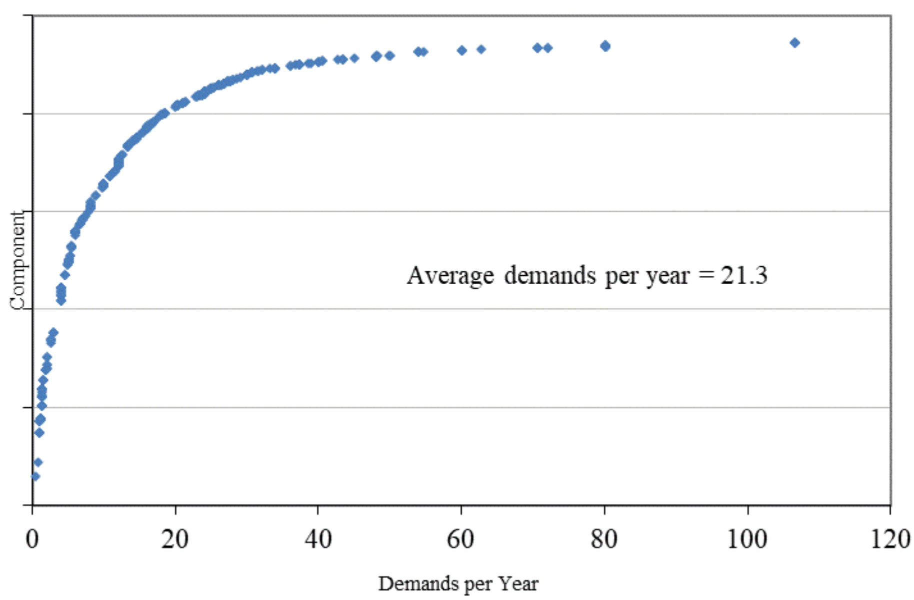


Figure 25. AHU demands per year distribution.

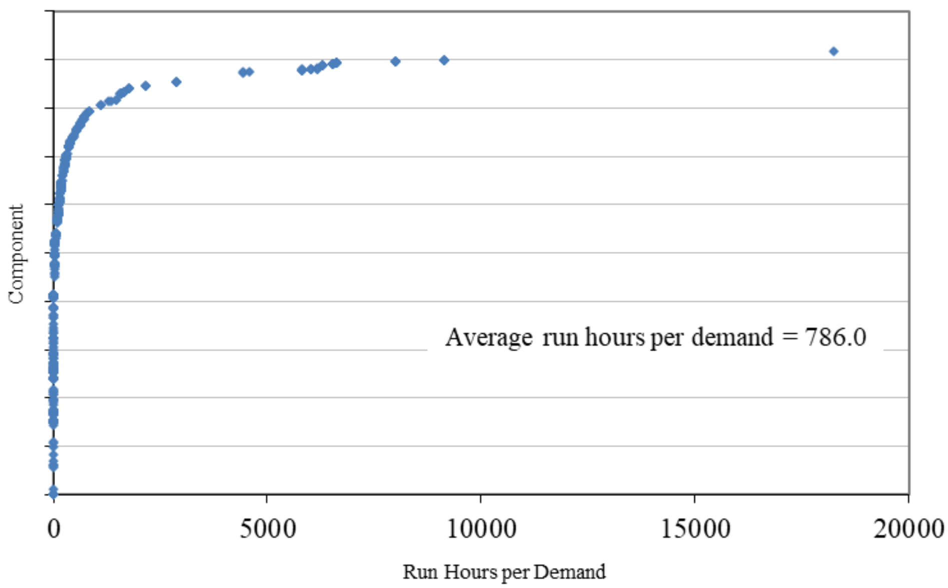


Figure 26. AHU run hours per demand distribution.

A-9.2.3 Industry-Average Baselines

Table 153 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 153. Selected industry distributions of p and λ for AHUs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
NR	FTS	JNID/IL	1.01E-03	1.45E-03	1.47E-03	2.00E-03	Beta	23.50	1.60E+04
NR	FTR	JNID/IL	1.97E-06	2.59E-06	2.61E-06	3.34E-06	Gamma	39.50	1.51E+07
STBY	FTS	JNID/IL	1.55E-04	2.09E-04	2.11E-04	2.74E-04	Beta	33.50	1.59E+05
STBY	FTR<1H	JNID/IL	1.33E-08	1.54E-06	3.38E-06	1.30E-05	Gamma	0.50	1.48E+05
STBY	FTR>1H	JNID/IL	1.96E-06	2.74E-06	2.77E-06	3.69E-06	Gamma	27.50	9.93E+06

A-9.3 Chiller (CHL)

A-9.3.1 Component Description

The chiller (CHL) boundary includes the compressor, motor, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for CHL are listed in Table 147.

A-9.3.2 Data Collection and Review

Data for CHL UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems and operational status included in the CHL data collection are listed in Table 154 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤200 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 154. CHL systems.

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

Table 155 summarizes the data obtained from EPIX and used in the CHL analysis.

Table 155. CHL unreliability data.

Pooling Group	Failure Mode	Failures	Data Demands or Hours	Counts Components	Counts Plants	Percent with Failures Components	Percent with Failures Plants
NR	FTS	66	21,137 d	92	23	30.4%	60.9%
NR	FTR	179	7,250,769 h	92	23	42.4%	78.3%
STBY	FTS	0	18,006 d	64	11	0.0%	0.0%
STBY	FTR<1H	34	233,781 h	64	11	23.4%	81.8%
STBY	FTR>1H	34	233,781 h	64	11	23.4%	81.8%

Figure 27 shows the range of start demands per year in the standby CHL data set. Figure 28 shows the range of run hours per demand in the standby CHL data set.

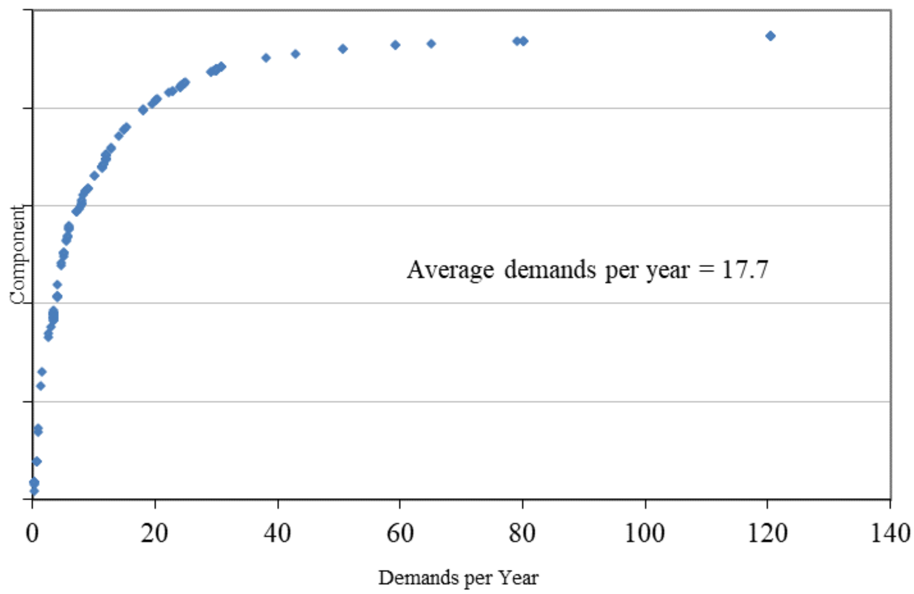


Figure 27. CHL demands per year distribution.

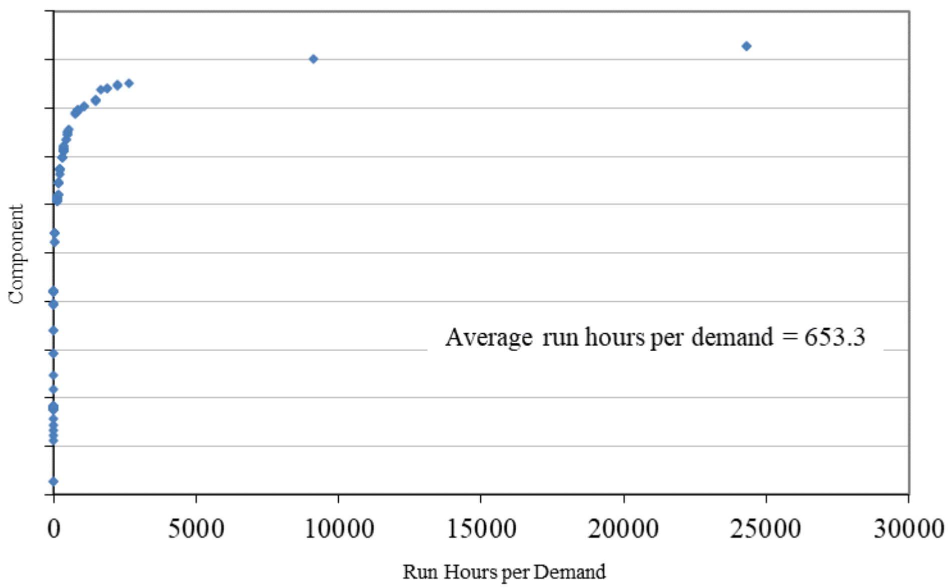


Figure 28. CHL run hours per demand distribution.

A-9.3.3 Industry-Average Baselines

Table 156 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 156. Selected industry distributions of p and λ for CHLs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
NR	FTS	EB/PL/KS	9.52E-06	2.05E-03	5.09E-03	2.05E-02	Beta	0.44	8.56E+01
NR	FTR	EB/PL/KS	1.94E-07	1.84E-05	3.87E-05	1.47E-04	Gamma	0.52	1.35E+04
STBY	FTS	JNID/IL	1.09E-07	1.26E-05	2.78E-05	1.07E-04	Beta	0.50	1.80E+04
STBY	FTR<1H	JNID/IL	1.09E-04	1.46E-04	1.48E-04	1.91E-04	Gamma	34.50	2.34E+05
STBY	FTR>1H	JNID/IL	1.09E-04	1.46E-04	1.48E-04	1.91E-04	Gamma	34.50	2.34E+05

A-9.4 Fan (FAN)

A-9.4.1 Component Description

The fan (FAN) boundary includes the fan, motor, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for FAN are listed in Table 147.

A-9.4.2 Data Collection and Review

Data for FAN UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems and operational status included in the FAN data collection are listed in Table 157 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤200 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 157. FAN systems.

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

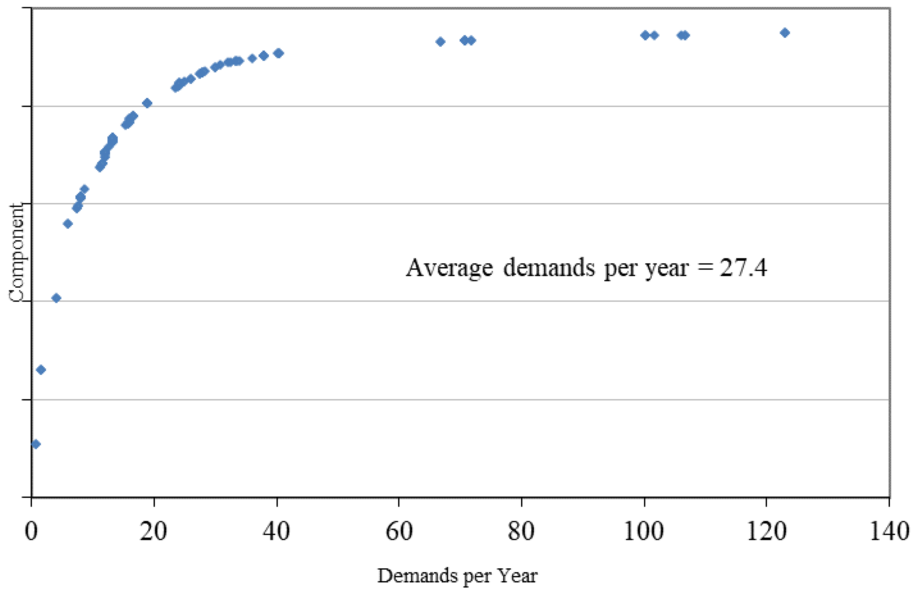
Pooling Group	System	Number of Components High/ Unknown Demand	Low Demand	Total
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)		1	1
	Standby Total	**7**	**127**	**134**
	Grand Total	**791**	**368**	**1159**

Table 158 summarizes the data obtained from EPIX and used in the FAN analysis.

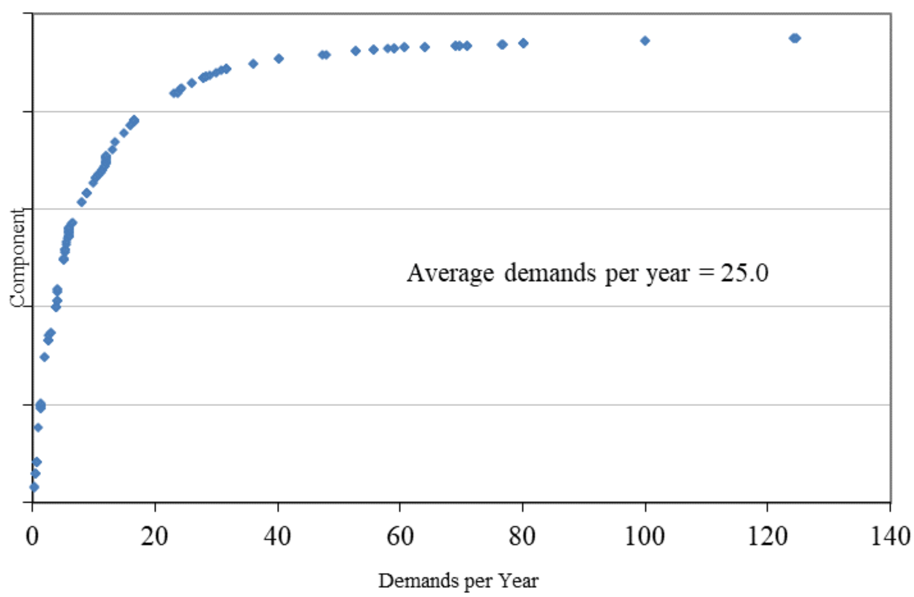
Table 158. FAN unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent with Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
NR	FTS	28	87,323 d	233	34	8.6%	38.2%
NR	FTR	50	16,050,850 h	233	34	15.5%	47.1%
STBY	FTS	17	63,511 d	154	37	9.1%	29.7%
STBY	FTR<1H	17	39,405 h	133	33	6.8%	18.2%
STBY	FTR>1H	3	120,200 h	154	37	1.9%	5.4%

Figure 29a shows the range of start demands per year in the standby FAN data set. Figure 29b shows the range of start demands per year in the running FAN data set. Figure 30a shows the range of run hours per demand in the standby FAN data set. Figure 30b shows the range of run hours per demands in the running FAN data set.

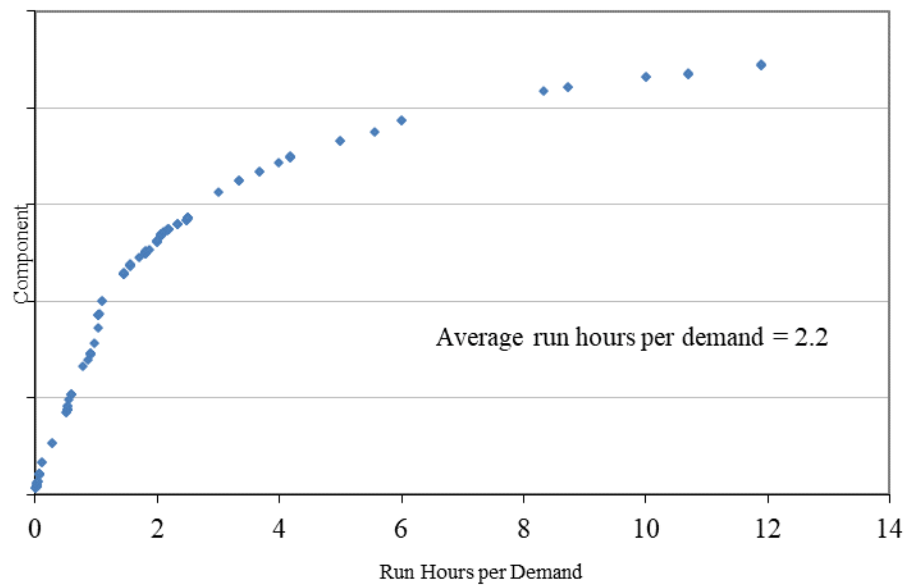


a.

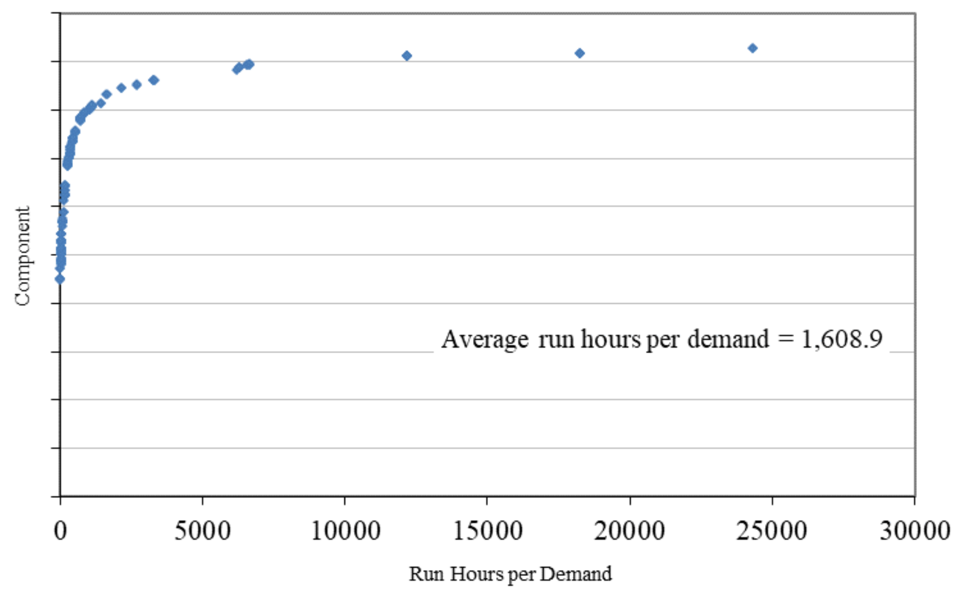


b.

Figure 29. a. Standby FAN demands per year distribution. b. Running/alternating FAN demands per year distribution.



(a)



(b)

Figure 30. a. Standby FAN run hours per demand distribution. b. Running/alternating FAN run hours per demand distribution.

A-9.4.3 Industry-Average Baselines

Table 159 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 159. Selected industry distributions of p and λ for FANs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
NR	FTS	EB/PL/KS	1.69E-06	2.99E-04	7.15E-04	2.84E-03	Beta	0.46	6.36E+02
NR	FTR	EB/PL/KS	4.87E-08	1.83E-06	3.23E-06	1.11E-05	Gamma	0.67	2.09E+05
STBY	FTS	JNID/IL	1.77E-04	2.70E-04	2.76E-04	3.92E-04	Beta	17.50	6.35E+04
STBY	FTR<1H	JNID/IL	2.85E-04	4.36E-04	4.44E-04	6.32E-04	Gamma	17.50	3.94E+04
STBY	FTR>1H	JNID/IL	9.03E-06	2.64E-05	2.91E-05	5.86E-05	Gamma	3.50	1.20E+05

A-10. MISCELLANEOUS EQUIPMENT

This section presents reliability data on equipment that does not fall under the other major groupings. The failure modes applicable to these equipment are listed in Table 160.

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 NUREG/CR-6928.

Table 160. Failure modes applicable to miscellaneous equipment.

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

A-10.1 Air Compressor (CMP)

A-10.1.1 Component Description

The air compressor (CMP) boundary includes the compressor, driver, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for CMP are listed in Table 160. This section presents results for both the motor-driven (MDC) and engine-driven (EDC) air compressors.

A-10.1.2 Data Collection and Review

Data for CMP UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems and operational status included in the compressor data collection are listed in Table 161 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be 200 or fewer demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 161. CMP systems.

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

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

Table 162 summarizes the data obtained from EPIX and used in the CMP analysis.

Table 162. CMP unreliability data.

		Data		Counts		Percent with Failures	
Pooling Group	**Failure Mode**	**Failures**	**Demands or Hours**	**Components**	**Plants**	**Components**	**Plants**
MDC-NR	FTS	52	7,855 d	65	28	43.1%	64.3%
MDC-NR	FTR	173	4,802,083 h	65	28	80.0%	100.0%
MDC-STBY	FTS	34	21,074 d	57	20	43.9%	80.0%
MDC-STBY	FTR<1H	1	20,248 h	54	20	1.9%	5.0%
MDC-STBY	FTR>1H	90	1,573,366 h	57	20	61.4%	90.0%
EDC-STBY	FTS	14	1,459 d	4	4	50.0%	50.0%
EDC-STBY	FTR<1H	1	1,459 h	4	4	25.0%	25.0%
EDC-STBY	FTR>1H	12	1,609 h	4	4	75.0%	75.0%
EDC-NR	FTR	10	163,321 h	3	3	100.0%	100.0%
MDC-IAS	FTR	117	2,376,803 h	36	15	88.9%	100.0%
MDC-CIA	FTR	0	98,561 h	2	1	0.0%	0.0%

Figure 31 shows the range of start demands per year in the CMP data set. Figure 32 shows the range of run hours per demand in the CMP data set.

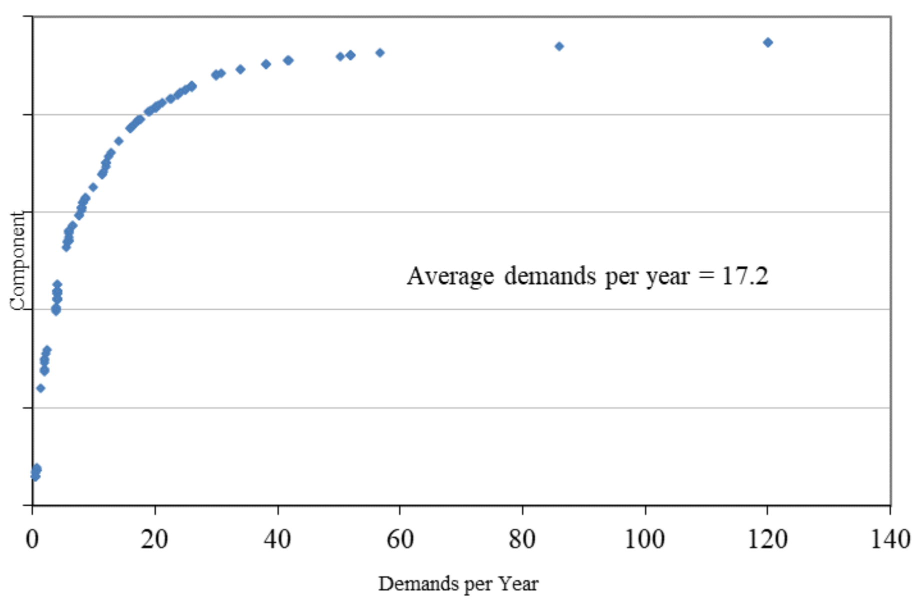


Figure 31. CMP demands per year distribution.

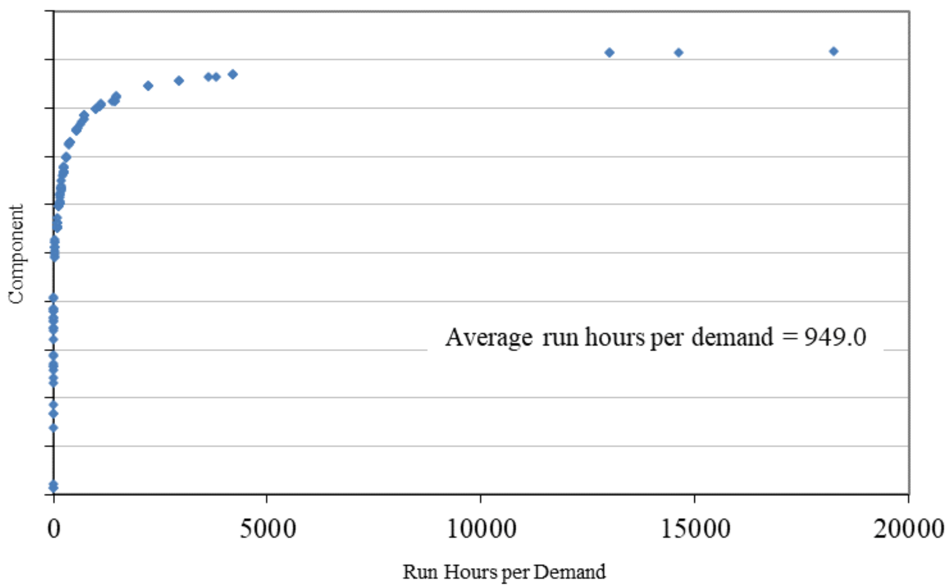


Figure 32. CMP run hours per demand distribution.

A-10.1.3 Industry-Average Baselines

Table 163 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 163. Selected industry distributions of p and λ for CMPs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
MDC-NR	FTS	EB/PL/KS	3.28E-05	5.78E-03	1.36E-02	5.36E-02	Beta	0.46	3.31E+01
MDC-NR	FTR	EB/PL/KS	9.92E-06	3.54E-05	4.03E-05	8.72E-05	Gamma	2.69	6.68E+04
MDC-STBY	FTS	EB/PL/KS	9.56E-05	1.89E-03	2.93E-03	9.27E-03	Beta	0.85	2.89E+02
MDC-STBY	FTR<1H	JNID/IL	8.71E-06	5.86E-05	7.41E-05	1.93E-04	Gamma	1.50	2.02E+04
MDC-STBY	FTR>1H	JNID/IL	4.81E-05	5.74E-05	5.75E-05	6.80E-05	Gamma	90.50	1.57E+06
EDC-STBY	FTS	JNID/IL	6.06E-03	9.68E-03	9.93E-03	1.45E-02	Beta	14.50	1.45E+03
EDC-STBY	FTR<1H	JNID/IL	1.20E-04	8.10E-04	1.03E-03	2.68E-03	Gamma	1.50	1.46E+03
EDC-STBY	FTR>1H	JNID/IL	4.54E-03	7.56E-03	7.77E-03	1.17E-02	Gamma	12.50	1.61E+03
EDC-NR	FTR	JNID/IL	3.56E-05	6.24E-05	6.43E-05	1.00E-04	Gamma	10.50	1.63E+05
MDC-IAS	FTR	EB/PL/KS	2.41E-05	4.73E-05	4.93E-05	8.22E-05	Gamma	7.62	1.54E+05
MDC-CIA	FTR	JNID/IL	1.99E-08	2.31E-06	5.07E-06	1.95E-05	Gamma	0.50	9.86E+04

A-10.2 Air Dryer Unit (ADU)

A-10.2.1 Component Description

The air dryer unit (ADU) boundary includes the air dryer unit. The failure mode for ADU is listed in Table 160.

A-10.2.2 Data Collection and Review

Data for the ADU UR baseline were obtained from the Westinghouse Savannah River Company (WSRC) database. None of the data sources used in WSRC are newer than approximately 1990. WSRC presents Category 1 data (see Section A.1 in NUREG/CR-6928) from compressed gas systems for ADUs in commercial NPPs.

A-10.2.3 Industry-Average Baselines

Table 164 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 164. Selected industry distributions of p and λ for ADUs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
IAS	FTOP	WSRC	5.35E-10	1.22E-06	5.00E-06	2.29E-05	Gamma	0.30	6.00E+04

A-10.3 Accumulator (ACC)

A-10.3.1 Component Description

The air accumulator (ACC) boundary includes the tank and associated relief valves. The failure modes for ACC are listed in Table 160.

A-10.3.2 Data Collection and Review

Data for ACC UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems and operational status included in the ACC data collection are listed in Table 165 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 165. ACC systems.

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

Table 166 summarizes the data obtained from EPIX and used in the ACC analysis.

Table 166. ACC unreliability data.

Pooling Group	Failure Mode	Data		Counts		Percent with Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
-	FTOP	11	79,315,180 h	617	79	1.8%	11.4%
-	ELS	8	79,315,180 h	617	79	1.3%	7.6%
-	ELL	--	--	617	79	--	--

A-10.3.3 Industry-Average Baselines

Table 167 lists the industry-average failure rate distributions. The selected ELL mean is the ELS mean multiplied by 0.07, with an assumed α of 0.3. The 0.07 multiplier is based on limited EPIX data for large leaks as explained in Section A.1 in NUREG/CR-6928.

Table 167. Selected industry distributions of p and λ for ACCs.

Pooling Group	Failure Mode	Analysis Type/Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
-	FTOP	JNID/IL	8.25E-08	1.41E-07	1.45E-07	2.22E-07	Gamma	11.50	7.93E+07
-	ELS	JNID/IL	5.47E-08	1.03E-07	1.07E-07	1.74E-07	Gamma	8.50	7.93E+07
-	ELL	--	8.02E-13	1.83E-09	7.49E-09	3.43E-08	Gamma	0.30	4.01E+07

A-10.4 COOLING TOWER FAN (CTF)

A-10.4.1 Component Description

The cooling tower fan (CTF) boundary includes the fan, motor, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for CTF are listed in Table 160.

A-10.4.2 Data Collection and Review

Data for CTF UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems included in the CTF data collection are listed in Table 168 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤200 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 168. CTF systems.

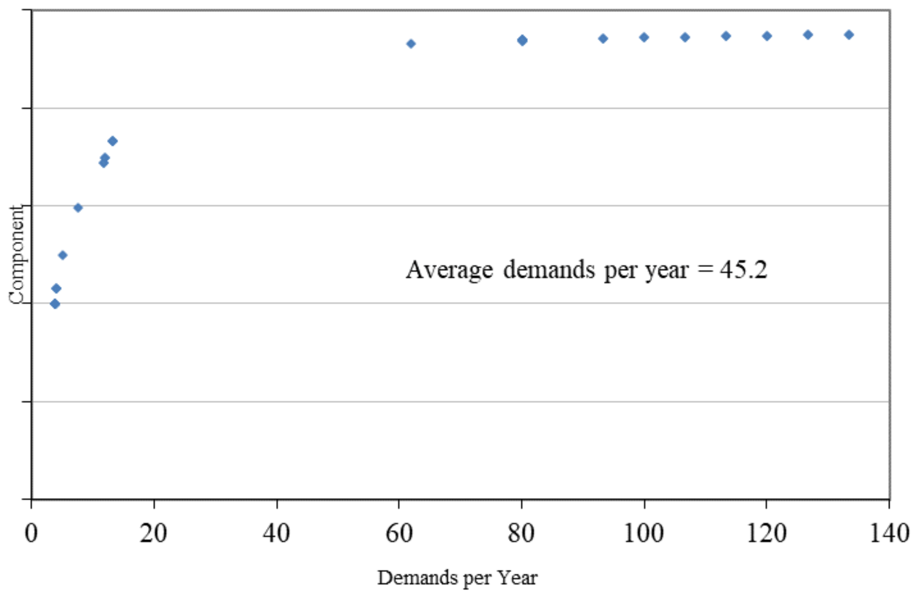
Pooling Group	System	Number of Components: High/ Unknown Demand	Low Demand	Total
Normally Running	Circulating water system (CWS)	1		1
	Normally operating service water (SWN)		16	16
	Standby service water (SSW)	10	5	15
	Normally Running Total	**11**	**21**	**32**
Standby	Circulating water system (CWS)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

Table 169 summarizes the data obtained from EPIX and used in the CTF analysis. Note that for the running/alternating CTFs, those components with fewer than 200 demands/year were removed.

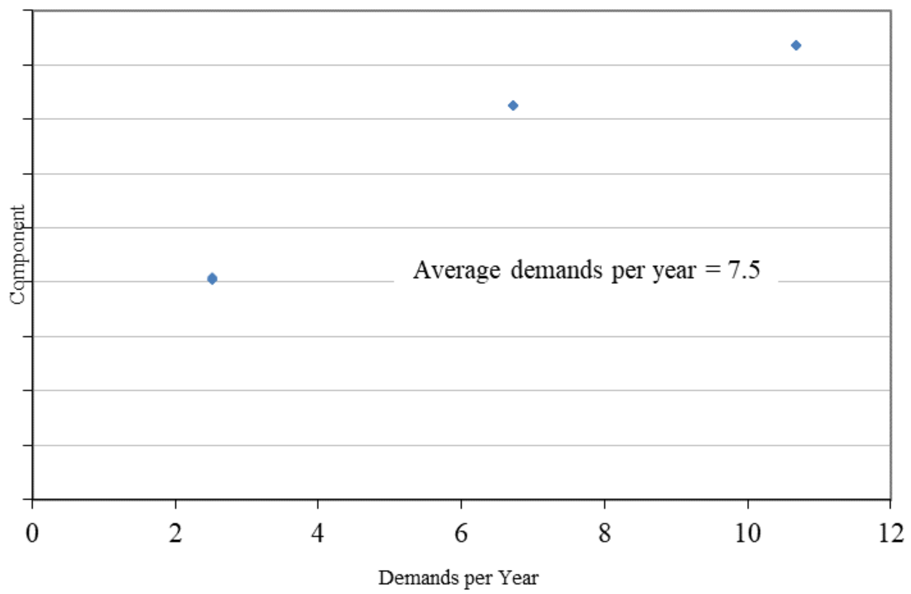
Table 169. CTF unreliability data.

Pooling Group	Failure Mode	Data: Failures	Data: Demands or Hours	Counts: Components	Counts: Plants	Percent with Failures: Components	Percent with Failures: Plants
STBY	FTS	14	37,307 d	55	6	21.8%	66.7%
STBY	FTR<1H	0	37,231 h	54	6	0.0%	0.0%
STBY	FTR>1H	0	895,323 h	55	6	0.0%	0.0%
NR	FTS	1	2,239 d	20	2	5.0%	50.0%
NR	FTR	6	1,253,930 h	20	2	25.0%	100.0%

Figure 33a shows the range of start demands per year in the standby CTF data set. Figure 33b shows the range of start demands per year in the running CTF data set. Figure 34a shows the range of run hours per demand in the standby CTF data set. Figure 34b shows the range of run hours per demands in the running CTF data set.

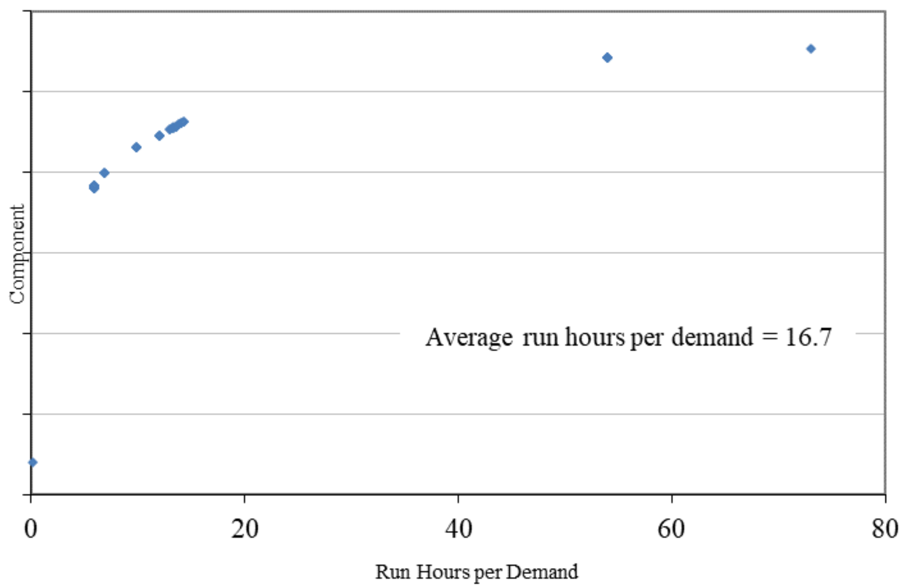


a.

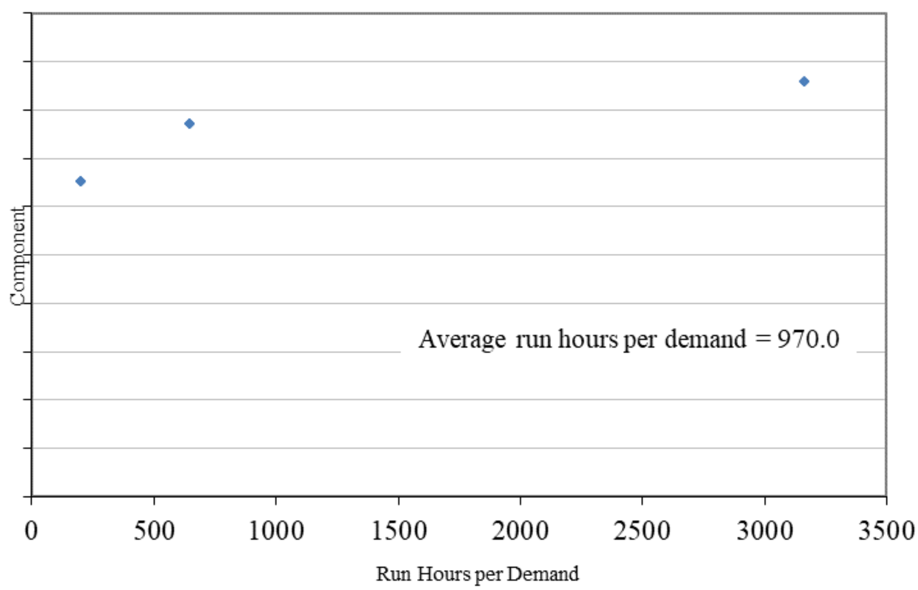


b.

Figure 33. a. Standby CTF demands per year distribution. b. Running/alternating CTF demands per year distribution.



a.



b.

Figure 34. a. Standby CTF run hours per demand distribution. b. Running/alternating CTF run hours per demand distribution.

A-10.4.3 Industry-Average Baselines

Table 170 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 170. Selected industry distributions of p and λ for CTFs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
STBY	FTS	JNID/IL	2.37E-04	3.80E-04	3.89E-04	5.70E-04	Beta	14.50	3.73E+04
STBY	FTR<1H	JNID/IL	5.29E-08	6.11E-06	1.34E-05	5.16E-05	Gamma	0.50	3.72E+04
STBY	FTR>1H	JNID/IL	2.20E-09	2.54E-07	5.58E-07	2.15E-06	Gamma	0.50	8.95E+05
NR	FTS	JNID/IL	7.85E-05	5.28E-04	6.70E-04	1.74E-03	Beta	1.50	2.24E+03
NR	FTR	JNID/IL	2.36E-06	4.94E-06	5.18E-06	8.94E-06	Gamma	6.50	1.25E+06

A-10.5 Tank (TNK)

A-10.5.1 Component Description

The tank (TNK) boundary includes the tank. The tank component has been further divided into tanks that hold pressurized liquid, unpressurized liquid, and gas. The failure modes for TNK are listed in Table 160.

A-10.5.2 Data Collection and Review

Data for TNK UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. 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 171 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be 20 or fewer demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 171. TNK systems.

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

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

Table 172 summarizes the data obtained from EPIX and used in the TNK analysis.

Table 172. TNK unreliability data.

Pooling Group	Failure Mode	Data Failures	Demands or Hours	Counts Components	Plants	Percent with Failures Components	Plants
--	FC	16	46,469,300 h	383	77	3.7%	16.9%
Liquid, Pressurized	ELS	5	19,535,510 h	156	45	3.2%	8.9%
Liquid, Pressurized	ELL	--	--	156	45	--	--
Liquid, Unpressurized	ELS	4	22,725,910 h	195	68	2.1%	5.9%
Liquid, Unpressurized	ELL	--	--	195	68	--	--
IAS	FC	0	3,287,400 h	25	4	0.0%	0.0%
SWS	FC	0	880,966 h	7	4	0.0%	0.0%
Gas	ELS	0	4,207,872 h	32	7	0.0%	0.0%
Gas	ELL	--	--	32	7	--	--

A-10.5.3 Industry-Average Baselines

Table 173 lists the industry-average failure rate distributions. These industry-average failure rates do not account for any recovery.

Table 173. Selected industry distributions of p and λ for TNKs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
--	FC	EB/PL/KS	5.99E-10	1.61E-07	4.18E-07	1.72E-06	Gamma	0.42	1.00E+06
Liquid, Pressurized	ELS	EB/PL/KS	8.76E-10	1.12E-07	2.51E-07	9.71E-07	Gamma	0.49	1.95E+06
Liquid, Pressurized	ELL	--	1.88E-12	4.28E-09	1.76E-08	8.04E-08	Gamma	0.30	1.71E+07
Liquid, Unpressurized	ELS	JNID/IL	7.32E-08	1.84E-07	1.98E-07	3.73E-07	Gamma	4.50	2.27E+07
Liquid, Unpressurized	ELL	--	1.48E-12	3.38E-09	1.39E-08	6.34E-08	Gamma	0.30	2.16E+07
IAS	FC	JNID/IL	5.98E-10	6.91E-08	1.52E-07	5.84E-07	Gamma	0.50	3.29E+06
SSW	FC	JNID/IL	2.23E-09	2.58E-07	5.68E-07	2.18E-06	Gamma	0.50	8.81E+05

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution Type	α	β
Gas	ELS	JNID/IL	4.67E-10	5.40E-08	1.19E-07	4.56E-07	Gamma	0.50	4.21E+06
Gas	ELL	--	8.92E-13	2.03E-09	8.33E-09	3.81E-08	Gamma	0.30	3.60E+07

A-10.6 Orifice (ORF)

A-10.6.1 Component Description

The orifice (ORF) boundary includes the orifice. The failure mode for ORF is listed in Table 160.

A-10.6.1.1 Data Collection and Review

Data for ORF UR baselines were obtained from the Westinghouse Savannah River Company (WSRC) database [A-9]. None of the data sources used in WSRC are newer than approximately 1990. WSRC presents Category 3 data (see Section A.1 in NUREG/CR-6928) for ORFs in water systems.

A-10.6.1.2 Industry-Average Baselines

Table 174 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 174. Selected industry distributions of p and λ for ORFs.

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

A-10.7 PIPE (PIPE)

A-10.7.1 Component Description

The pipe (PIPE) boundary includes piping and pipe welds in each system. The flanges connecting piping segments are not included in the pipe component. The failure modes for PIPE are listed in Table 160.

A-10.7.2 Data Collection and Review

The data and results for PIPE UR baselines were obtained from NUREG/CR-6928 which used the data from the 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 175 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 175.

Table 175. 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 176 summarizes the data obtained from EPIX and used in the PIPE analysis. Piping ELS events are those with external leakage rates from 1 to 50 gpm. Events that were uncertain were counted as 0.5 events. Note that the hours for ELS are reactor-year hours.

Table 176. PIPE unreliability data.

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

A-10.7.3 Industry-Average Baselines

Table 177 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 NUREG/CR-6928.

Table 177. Selected industry distributions of λ for PIPEs.

System	Failure Mode	Analysis Type / 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

A-10.8 Heat Exchanger (HTX)

A-10.8.1 Component Description

The heat exchanger (HTX) boundary includes the heat exchanger shell and tubes. The failure modes for HTX are listed in Table 178.

Table 178. HTX failure modes.

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

A-10.8.2 Data Collection and Review

Data for HTX UR baselines were obtained from the IRIS database, covering 2006–2020 using RADS. The systems and operational status included in the HTX data collection are listed in Table 179 with the number of components included with each system. The component count is divided into two categories: High/Unknown Demand, which shows the counts for either high-demand components or those components that do not have demand information available, and Low-Demand, which shows the counts for those components that are known to be ≤20 demands per year. The reliability estimates that do not require specific component demand information use all components regardless of whether demand data are available (e.g., leakage, spurious operation, and operation).

Table 179. HTX systems.

		Number of Components		
Pooling Group	**System**	**High/ Unknown Demand**	**Low Demand**	**Total**
All	Auxiliary feedwater (AFW)	9		9
	Chemical and volume control (CVC)	105		105
	Circulating water system (CWS)	2		2
	Component cooling water (CCW)	273	8	281
	Condensate system (CDS)	341		341
	Containment fan cooling (CFC)	206	1	207
	Containment spray recirculation (CSR)	30	4	34
	Control rod drive (CRD)	2		2
	Emergency power supply (EPS)	189		189
	Firewater (FWS)	1		1
	Heating ventilation and air conditioning (HVC)	104	1	105
	High pressure coolant injection (HCI)	4		4
	High pressure core spray (HCS)	3		3
	High pressure injection (HPI)	11		11
	Instrument air (IAS)	33		33
	Isolation condenser (ISO)	11		11
	Low pressure core spray (LCS)	2		2
	Main feedwater (MFW)	120		120
	Main steam (MSS)	40		40
	Normally operating service water (SWN)	22		22
	Plant ac power (ACP)	5		5
	Reactor coolant (RCS)	151		151
	Reactor core isolation (RCI)	7		7
	Residual Heat Removal (LCI in BWRs, LPI in PWRs) (RHR)	251		251

Pooling Group	System	Number of Components High/ Unknown Demand	Low Demand	Total
	Standby service water (SSW)	21		21
	Grand Total	**1943**	**14**	**1957**

Table 180 summarizes the data obtained from EPIX and used in the HTX analysis.

Table 180. HTX unreliability data.

Pooling Group	Failure Mode	Data: Failures	Data: Demands or Hours	Counts: Components	Counts: Plants	Percent with Failures: Components	Percent with Failures: Plants
--	LOHT	67	222,831,700 h	1,750	104	3.1%	30.8%
--	ILS	61	222,831,700 h	1,750	104	2.4%	22.1%
--	ILL	--	--	1,750	104	--	--
--	ELS	38	222,831,700 h	1,750	104	2.0%	25.0%
--	ELL	--	--	1,750	104	--	--
CCW	PG	8	28,273,230 h	223	82	3.1%	8.5%
CCW-NE	PG	3	28,273,230 h	223	82	1.3%	3.7%

A-10.8.3 Industry-Average Baselines

Table 181 lists the selected industry distributions of p and λ for the HTX failure modes. These industry-average failure rates do not account for any recovery.

The selected ELL (shell) mean is the ELS mean multiplied by 0.07, with an assumed α of 0.3. The selected ELL (tube) mean is the ELS (tube) mean multiplied by 0.15, with an assumed α of 0.3. The 0.07 and 0.15 multipliers are based on limited EPIX data for large leaks as explained in Section A.1 in NUREG/CR-6928.

Table 181. Selected industry distributions of p and λ for HTXs.

Pooling Group	Failure Mode	Analysis Type / Source	5%	Median	Mean	95%	Distribution: Type	α	β
--	LOHT	EB/PL/KS	1.11E-09	1.50E-07	3.39E-07	1.32E-06	Gamma	0.48	1.42E+06
--	ILS	JNID/IL	2.21E-07	2.74E-07	2.76E-07	3.36E-07	Gamma	61.50	2.23E+08
--	ILL	--	5.91E-13	1.35E-09	5.52E-09	2.53E-08	Gamma	0.30	5.43E+07
--	ELS	EB/PL/KS	5.71E-09	1.21E-07	1.90E-07	6.08E-07	Gamma	0.83	4.35E+06
--	ELL	--	3.05E-12	6.95E-09	2.85E-08	1.30E-07	Gamma	0.30	1.05E+07
CCW	PG	JNID/IL	1.53E-07	2.89E-07	3.01E-07	4.87E-07	Gamma	8.50	2.83E+07
CCW-NE	PG	JNID/IL	3.83E-08	1.12E-07	1.24E-07	2.49E-07	Gamma	3.50	2.83E+07

A-11. REFERENCES

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Appendix B

Component/Train Unavailability Data Sheets 2020 Update

UPDATE NOTES

This appendix represents the third update to the original set of component availability data sheets documented in NUREG/CR-6928 [B-1]. The original set of component availability data sheets were extracted from NUREG/CR-6928 and generally contained data during the date range from 2002 to 2004. The first update to NUREG/CR-6928 generally represents component availability results using a date range from 2002 to 2010 and is often called the 2010 update. The second update generally represents component availability results using the date range from 2002 to 2015 and is often called the 2015update. This update generally represents component availability results using a date range from 2006 to 2020.

The curve fitting of the MSPI [B-2] UA data follows the approach in the 2015 update by using a Normal distribution, which was based on recommendations from statisticians during the 2015 update.

B-1. MSPI UNAVAILABILITY DATA

Table 182. MSPI unavailability data and fitted distributions.

EDG-EPS (258 Trains, 2006--2020)		
Statistic	Plant Data	Normal Distribution
Mean	1.51E-02	1.51E-02
SD	7.03E-03	7.04E-03
95%	2.72E-02	2.67E-02
Median	1.40E-02	1.51E-02
5%	4.10E-03	3.48E-03
EF	1.94	1.77
μ	--	1.51E-02
σ	--	7.04E-03

EDG-HCS (8 Trains, 2006--2020)		
Statistic	Plant Data	Normal Distribution
Mean	1.33E-02	1.33E-02
SD	3.50E-03	3.74E-03
95%	1.84E-02	1.94E-02
Median	1.28E-02	1.33E-02
5%	9.07E-03	7.13E-03
EF	1.44	1.46
μ	--	1.33E-02
σ	--	3.74E-03

EDG-SW (6 Trains, 2006--2020)		
Statistic	Plant Data	Normal Distribution
Mean	1.11E-02	1.11E-02
SD	6.42E-03	7.04E-03
95%	1.83E-02	2.27E-02
Median	1.31E-02	1.11E-02
5%	2.56E-03	-4.49E-04
EF	1.40	2.05
μ	--	1.11E-02
σ	--	7.04E-03

HCS-SW (7 Trains, 2006--2020)		
Statistic	Plant Data	Normal Distribution
Mean	7.32E-03	7.32E-03
SD	1.35E-03	1.46E-03
95%	8.58E-03	9.72E-03
Median	7.91E-03	7.32E-03
5%	5.25E-03	4.91E-03
EF	1.08	1.33
μ	--	7.32E-03
σ	--	1.46E-03

EDP-AFW (5 Trains, 2006--2020)		
Statistic	Plant Data	Normal Distribution
Mean	5.47E-03	5.47E-03
SD	1.83E-03	2.05E-03
95%	8.02E-03	8.85E-03
Median	5.48E-03	5.47E-03
5%	3.45E-03	2.10E-03
EF	1.46	1.62
μ	--	5.47E-03
σ	--	2.05E-03

EDP-ESW (10 Trains, 2006--2020)		
Statistic	Plant Data	Normal Distribution
Mean	3.14E-02	3.14E-02
SD	1.07E-02	1.13E-02
95%	5.07E-02	4.99E-02
Median	2.57E-02	3.14E-02
5%	2.16E-02	1.29E-02
EF	1.97	1.59
μ	--	3.14E-02
σ	--	1.13E-02

HDR-AFW (16 Trains, 2006--2020)		
Statistic	Plant Data	Normal Distribution
Mean	7.70E-04	7.70E-04
SD	1.09E-03	1.12E-03
95%	3.08E-03	2.61E-03
Median	0.00E+00	7.70E-04
5%	0.00E+00	-1.07E-03
EF		3.39
μ	--	7.70E-04
σ	--	1.12E-03

HDR-CCW (6 Trains, 2006--2020)		
Statistic	Plant Data	Normal Distribution
Mean	2.42E-04	2.42E-04
SD	3.65E-04	4.00E-04
95%	8.45E-04	9.00E-04
Median	2.26E-05	2.42E-04
5%	0.00E+00	-4.16E-04
EF	37.39	3.72
μ	--	2.42E-04
σ	--	4.00E-04

HDR-ESW (123 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	4.61E-03	4.61E-03
SD	1.69E-02	1.70E-02
95%	1.58E-02	3.26E-02
Median	1.49E-04	4.61E-03
5%	0.00E+00	-2.34E-02
EF	106.04	7.07
μ	--	4.61E-03
σ	--	1.70E-02

HDR-HPI (45 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	1.36E-04	1.36E-04
SD	2.43E-04	2.46E-04
95%	6.60E-04	5.41E-04
Median	4.39E-05	1.36E-04
5%	0.00E+00	-2.68E-04
EF	15.03	3.98
μ	--	1.36E-04
σ	--	2.46E-04

HDR-ISO (6 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	2.62E-03	2.62E-03
SD	1.05E-03	1.15E-03
95%	4.00E-03	4.52E-03
Median	2.57E-03	2.62E-03
5%	1.26E-03	7.24E-04
EF	1.56	1.73
μ	--	2.62E-03
σ	--	1.15E-03

HDR-RHR (16 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	7.21E-04	7.21E-04
SD	1.24E-03	1.28E-03
95%	3.78E-03	2.83E-03
Median	2.26E-05	7.21E-04
5%	0.00E+00	-1.39E-03
EF	167.26	3.93
μ	--	7.21E-04
σ	--	1.28E-03

HDR-RHRSW (8 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	2.81E-03	2.81E-03
SD	3.28E-03	3.50E-03
95%	8.20E-03	8.57E-03
Median	1.90E-03	2.81E-03
5%	6.13E-05	-2.96E-03
EF	4.32	3.05
μ	--	2.81E-03
σ	--	3.50E-03

HTX-CCW (86 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	7.73E-03	7.73E-03
SD	9.16E-03	9.22E-03
95%	3.58E-02	2.29E-02
Median	4.24E-03	7.73E-03
5%	1.83E-04	-7.43E-03
EF	8.44	2.96
μ	--	7.73E-03
σ	--	9.22E-03

HTX-ESW (4 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	1.61E-02	1.61E-02
SD	3.32E-03	3.84E-03
95%	1.97E-02	2.24E-02
Median	1.59E-02	1.61E-02
5%	1.26E-02	9.74E-03
EF	1.24	1.39
μ	--	1.61E-02
σ	--	3.84E-03

HTX-RHR-BWR (6 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	3.05E-03	3.05E-03
SD	1.94E-03	2.13E-03
95%	4.83E-03	6.55E-03
Median	3.99E-03	3.05E-03
5%	3.43E-04	-4.47E-04
EF	1.21	2.15
μ	--	3.05E-03
σ	--	2.13E-03

HTX-RHR-PWR (15 Years, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	2.09E-04	2.09E-04
SD	4.15E-04	4.29E-04
95%	1.09E-03	9.15E-04
Median	0.00E+00	2.09E-04
5%	0.00E+00	-4.97E-04
EF		4.38
μ	--	2.09E-04
σ	--	4.29E-04

MDP-ALL (1061 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	6.56E-03	6.56E-03
SD	9.08E-03	9.09E-03
95%	2.02E-02	2.15E-02
Median	4.08E-03	6.56E-03
5%	6.48E-04	-8.39E-03
EF	4.95	3.28
μ	--	6.56E-03
σ	--	9.09E-03

MDP-AFW (124 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	3.14E-03	3.14E-03
SD	2.02E-03	2.03E-03
95%	7.02E-03	6.49E-03
Median	2.50E-03	3.14E-03
5%	5.40E-04	-2.01E-04
EF	2.81	2.07
μ	--	3.14E-03
σ	--	2.03E-03

MDP-CCW (142 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	4.82E-03	4.82E-03
SD	6.30E-03	6.32E-03
95%	1.58E-02	1.52E-02
Median	3.36E-03	4.82E-03
5%	4.60E-04	-5.58E-03
EF	4.70	3.15
μ	--	4.82E-03
σ	--	6.32E-03

MDP-ESW (305 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	1.24E-02	1.24E-02
SD	1.43E-02	1.44E-02
95%	4.55E-02	3.61E-02
Median	6.87E-03	1.24E-02
5%	5.10E-04	-1.12E-02
EF	6.62	2.91
μ	--	1.24E-02
σ	--	1.44E-02

MDP-FWS (4 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	7.68E-03	7.68E-03
SD	6.59E-04	7.61E-04
95%	8.55E-03	8.93E-03
Median	7.54E-03	7.68E-03
5%	7.00E-03	6.43E-03
EF	1.13	1.16
μ	--	7.68E-03
σ	--	7.61E-04

MDP-HCS (8 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	7.68E-03	7.68E-03
SD	1.97E-03	2.10E-03
95%	1.02E-02	1.11E-02
Median	7.67E-03	7.68E-03
5%	4.75E-03	4.22E-03
EF	1.33	1.45
μ	--	7.68E-03
σ	--	2.10E-03

MDP-HPI (199 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	2.99E-03	2.99E-03
SD	2.07E-03	2.08E-03
95%	5.79E-03	6.40E-03
Median	2.69E-03	2.99E-03
5%	7.39E-04	-4.32E-04
EF	2.15	2.14
μ	--	2.99E-03
σ	--	2.08E-03

MDP-RHR (225 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	5.09E-03	5.09E-03
SD	2.85E-03	2.86E-03
95%	1.04E-02	9.79E-03
Median	4.92E-03	5.09E-03
5%	1.44E-03	3.91E-04
EF	2.11	1.92
μ	--	5.09E-03
σ	--	2.86E-03

MDP-RHR-BWR (80 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	5.92E-03	5.92E-03
SD	2.47E-03	2.48E-03
95%	1.02E-02	1.00E-02
Median	5.73E-03	5.92E-03
5%	2.12E-03	1.84E-03
EF	1.78	1.69
μ	--	5.92E-03
σ	--	2.48E-03

MDP-RHR-PWR (145 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	4.63E-03	4.63E-03
SD	2.95E-03	2.96E-03
95%	1.03E-02	9.50E-03
Median	4.06E-03	4.63E-03
5%	1.07E-03	-2.28E-04
EF	2.54	2.05
μ	--	4.63E-03
σ	--	2.96E-03

MDP-RHRSW (54 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	4.91E-03	4.91E-03
SD	2.69E-03	2.72E-03
95%	8.54E-03	9.38E-03
Median	4.57E-03	4.91E-03
5%	1.67E-03	4.43E-04
EF	1.87	1.91
μ	--	4.91E-03
σ	--	2.72E-03

TDP-AFW (66 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	4.64E-03	4.64E-03
SD	2.96E-03	2.99E-03
95%	1.06E-02	9.55E-03
Median	4.16E-03	4.64E-03
5%	1.15E-03	-2.71E-04
EF	2.55	2.06
μ	--	4.64E-03
σ	--	2.99E-03

TDP-HCI (24 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	1.11E-02	1.11E-02
SD	2.71E-03	2.77E-03
95%	1.51E-02	1.57E-02
Median	1.14E-02	1.11E-02
5%	7.08E-03	6.57E-03
EF	1.32	1.41
μ	--	1.11E-02
σ	--	2.77E-03

TDP-RCI (30 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	1.01E-02	1.01E-02
SD	4.19E-03	4.26E-03
95%	1.92E-02	1.71E-02
Median	9.23E-03	1.01E-02
5%	5.28E-03	3.07E-03
EF	2.08	1.69
μ	--	1.01E-02
σ	--	4.26E-03

TDP-ALL (120 Trains, 2006--2020)

Statistic	Plant Data	Normal Distribution
Mean	7.30E-03	7.30E-03
SD	4.41E-03	4.43E-03
95%	1.53E-02	1.46E-02
Median	7.02E-03	7.30E-03
5%	1.43E-03	1.16E-05
EF	2.18	2.00
μ	--	7.30E-03
σ	--	4.43E-03

Acronyms - AFW (auxiliary feedwater), BWR (boiling water reactor), CCW (component cooling water), EDG (emergency diesel generator), EDGSW (EDG service water), EDP (engine driven pump), EPS (emergency power system), ESW (emergency service water), FWS (feedwater system), HDR (header), HCI (high pressure coolant injection), HCS (high pressure core spray), HPSI (high pressure safety injection), HTX (heat exchanger), IC (isolation condenser), MDP (motor driven pump), PWR (pressurized water reactor), RCI (reactor core isolation cooling), RHR (residual heat removal), RHRSW (RHR service water), TDP (turbine driven pump), UA (unavailability)

B-2. OTHER UNAVAILABILITY ESTIMATES

Table 183. Other source unavailability estimates.

Train Unavailability Event	Description	Data: Source	Data: Reference	Recommended Probability Distribution: Distribution	Mean	α	β	Error Factor
AHU-TM	Air Handling Unit Test Or Maintenance	IPEs	NUREG/CR-6928 Appendix B, Section B.4	Beta	2.50E-03	0.50	199.5	8.4
BAC-TM	AC Bus In Test Or Maintenance	IPEs	NUREG/CR-6928 Appendix B, Section B.4	Beta	2.00E-04	0.50	2499.5	8.4
BAT-TM	Battery Test or Maintenance	IPEs	Letter: Generic Test and Maintenance Unavailability Values, JCN W6467 - MBS-02-99	Lognormal	2.72E-03	52.90	--	8.4
BCH-TM	Battery Charger Test & Maintenance	IPEs	NUREG/CR-6928 Appendix B, Section B.4	Beta	2.00E-03	0.50	249.5	8.4
BDC-TM	DC Bus Test & Maintenance	IPEs	NUREG/CR-6928 Appendix B, Section B.4	Beta	2.00E-04	0.50	2499.5	8.4
CCP-TM-RPS	RPS Channel-A IN T&M	IPEs	RPS Study NUREGs; NUREG/CR-5500, Vol 2,3,10, and 11	Beta	5.00E-03	0.24	47.8	30.2
CHL-TM	Chiller Unit In Test Or Maintenance	IPEs	NUREG/CR-6928 Appendix B, Section B.4	Beta	2.00E-02	0.50	24.5	8.2
CRB-TM	Circuit Breaker Test Or Maintenance	IPEs	Letter: Generic Test and Maintenance Unavailability Values, JCN W6467 - MBS-02-99	Lognormal	5.00E-01	0.50	--	2.0
CTF-TM	Cooling Tower Fan Test Or Maintenance	IPEs	NUREG/CR-6928 Appendix B, Section B.4	Beta	2.00E-03	0.50	249.5	8.4
CTG-TM	Gas Turbine Generator Test & Maintenance	IPEs	NUREG/CR-6928 Appendix B, Section B.4	Beta	5.00E-02	0.50	9.5	7.7
DDC-TM	Diesel Driven Compressor Fails Due To T&M	IPEs	NUREG/CR-6928 Appendix B, Section B.4	Beta	1.20E-02	0.50	41.2	8.3
EDC-TM	Engine-Driven Compressor Test or Maintenance	IPEs	NUREG/CR-6928 Appendix B, Section B.4	Beta	1.20E-02	0.50	41.2	8.3
EOV-TM	Explosive-Operated (SQUIBB) Valve Test or Maintenance	IPEs	NUREG/CR-6928 Appendix B, B.4	Beta	6.00E-04	0.50	832.8	8.4

Train Unavailability Event	Description	Data Source	Data Reference	Recommended Probability Distribution: Distribution	Mean	α	β	Error Factor
FAN-TM	HVC Fan In Test Or Maintenance	IPEs	NUREG/CR-6928 Appendix B, Section B.4	Beta	2.00E-03	0.50	249.5	8.4
HTX-TM	Heat Exchanger In Test Or Maintenance	IPEs	SPAR (IPEs)	Beta	2.50E-03	0.30	119.7	18.7
MDC-TM	Motor-Driven Compressor Test or Maintenance	IPEs	NUREG/CR-6928 Appendix B, Section B.4	Beta	1.20E-02	0.50	41.2	8.3
PDP-TM	Positive Displacement Pump Test Or Maintenance	IPEs	NUREG/CR-6928 Appendix B, Section B.4	Beta	3.00E-03	0.50	166.2	8.4
TFM-TM	Startup Transformer Test or Maintenance	IPEs	Letter: Generic Test and Maintenance Unavailability Values, JCN W6467 - MBS-02-99 [B-3]	Lognormal	1.75E-03	90.50	--	8.4

B-3. REFERENCES

B-1. S.A. Eide et al., Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants, U.S. Nuclear Regulatory Commission, NUREG/CR-6928, January 2007.

B-2. U.S. Nuclear Regulatory Commission, "Mitigating Systems Performance Index (MSPI)," http://nrc.gov/NRR/OVERSIGHT/ASSESS/mspi.html.

B-3. M.S. DeHaan et al., "Generic Test and Maintenance Unavailabilities Based on Data from the IPEs," September 1999, attached to letter from M.B. Sattison, Idaho National Laboratory, to E.G. Rodrick, U.S. Nuclear Regulatory Commission, MBS-02-99, September 20, 1999.

Appendix C

Initiating Event Data Sheets 2020 Update

UPDATE NOTES

This appendix presents the third update to the original set of IE data and results documented in NUREG/CR-6928 [C-1]. NUREG/CR-6928 was completed in February 2007 and generally contained data ranging from 1988 to 2002. The first update to NUREG/CR-6928 generally represents results from 1988 to 2010, often called the 2010 update. The second update generally represents results from 1988 to 2015; it is often called the 2015 update. This update generally represents results using a date range of 1988 to 2020.

The IE data sheets in this appendix provide supporting information and additional detail on the IE parameter estimates. These estimates reflect industry-average frequencies for IEs where U.S. commercial NPPs define the industry. Only those IEs occurring while plants are critical are covered. Low-power and shutdown IEs are not addressed, other than the shutdown LOOP IEs.

For the baseline period used to quantify the IE frequencies, Section D.1.2 of NUREG/CR-6928 describes the original process while Section 2 of INL/EXT-20-59192 [C-2] presents the process used in the 2020 IE analysis and the results that were used in this section. One change made in this 2020 Update is that for “not sparse” IE groups—including loss of feedwater, BWR general transients, BWR loss of condenser heat sink, PWR general transients, and PWR loss of condenser heat sink—the most recent 10-year period (i.e., 2011—2020) and the most recent 15-year period (i.e., 2006–2020) were included in the considerations in order to respond to an industry request to use a shorter period than the approach used in previous updates (e.g., using 1997 or 1998 as the fixed starting year for parameter estimations) to reflect the more-recent industry performance.

IE frequency estimates were obtained from a hierarchy of sources, as explained in Section 8 of NUREG/CR-6928. The preferred source is the NRC IE database [C-3], as accessed using the RADS website https://rads.inl.gov/ [C-4]. Most IE parameter estimates were obtained from this source. The IE database uses IE definitions presented in NUREG/CR-5750 [C-5]. Other sources used include NUREG/CR-6890 [C-6] and NUREG-1829 [C-7]. LOOP was analyzed in detail annually in the NRC LOOP study and the LOOP data were obtained from the most recent LOOP analysis [C-8]. The data period for the LOOP frequency is 1997–2020. The small, medium, and large LOCA frequency distributions were obtained from the approach described in [C-9]. The excessive LOCA (or vessel rupture) used the estimate from WASH-1285 [C-10]. This appendix explains in detail how data from each of these sources were used to obtain industry-average IE parameter estimates.

This update uses the same hierarchy of the 2015 Update with IE categories and subcategories. A few IEs that have been added to the 2015 update continued to be analyzed in this update to support more-detailed SPAR models:

1. All of the high-energy line break events
2. Two or more stuck open relief valves
3. Calculated loss of multiple AC or DC busses
4. Interfacing system Loss of Coolant Accident (ISLOCA)
5. Reactor Coolant Pump Seal LOCA (RCPLOCA)
6. LOOP in power operations and in shutdown.

C-1. PRIMARY/SECONDARY INVENTORY CONTROL

This category includes line breaks from both the primary and secondary systems.

C-1.1 High Energy Line Breaks

This category includes breaks of steam and feedwater lines greater than one inch in diameter. It does not have to be a complete break. Included are actuations or failure of rupture disks, splits, cracks, and failed welds.

C-1.1.1 Feedwater Line Break at Boiling Water Reactors (FWLB(BWR))

C-1.1.1.1 Initiating Event Description

From NUREG/CR-5750, the Feedwater Line Break at BWRs (FWLB[BWR]) initiating event is a break of a one-inch equivalent diameter or more in a feedwater or condensate line that contains main turbine working fluid at or above atmospheric saturation conditions. Examples include breeches of a pipe caused by a split, crack, weld failure, or circumferential break.

C-1.1.1.2 Data Collection and Review

Data for the FWLB (BWR) baseline, 1988–2020, were obtained from the IEDB, as accessed using the RADS database. The data include total number of FWLB events and total reactor critical years (rcrys) for the U.S. BWRs. Table 184 summarizes the data obtained from RADS and used in the FWLB (BWR) analysis.

Table 184. FWLB (BWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
0	989	1988–2020	37	0.0%

C-1.1.1.3 Industry-Average Baselines

Table 185 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 185. Selected industry distribution of λ for FWLB (BWR).

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
JNID/IL	1.99E-06	5.05E-04	1.94E-03	Gamma	0.50	9.89E+02

Note: JNID/IL is a Jeffrey's noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-1.1.2 Feedwater Line Break at Pressurized Water Reactors (FWLB(PWR))

C-1.1.2.1 Initiating Event Description

From NUREG/CR-5750, the Feedwater Line Break at PWRs (FWLB[PWR]) initiating event is a break of a one-inch equivalent diameter or more in a feedwater or condensate line that contains main turbine working fluid at or above atmospheric saturation conditions. Examples include breeches of a pipe caused by a split, crack, weld failure, or circumferential break.

C-1.1.2.2 Data Collection and Review

Data for the FWLB (PWR) baseline, 1988–2020, were obtained from the IEDB, as accessed using the RADS database. The data include total number of FWLB events and total reactor critical years (rcrys) for the U.S. PWRs. Table 186 summarizes the data obtained from RADS and used in the FWLB (PWR) analysis.

Table 186. FWLB (PWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
2	1,962	1988–2020	78	2.6%

C-1.1.2.3 Industry-Average Baselines

Table 187 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 187. Selected industry distribution of λ for FWLB (PWR).

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
JNID/IL	2.92E-04	1.27E-03	2.82E-03	Gamma	2.50	1.96E+03

Note: JNID/IL is a Jeffrey's noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-1.1.3 Steam Line Break Inside Containment at Pressurized Water Reactors (SLBIC(PWR))

C-1.1.3.1 Initiating Event Description

From NUREG/CR-5750, the Steam Line Break inside Containment at PWRs (SLBIC[PWR]) initiating event is a break of one-inch equivalent diameter or more in a steam line located inside the primary containment that contains main turbine working fluid at or above atmospheric saturation conditions.

This category applies to PWRs only. Examples include breeches of a pipe caused by a split, crack, weld failure, or circumferential break.

C-1.1.3.2 Data Collection and Review

Data for the SLBIC (PWR) baseline, 1988–2020, were obtained from the IEDB, as accessed using the RADS database. The data include total number of SLBIC events and total reactor critical years (rcrys) for the U.S. PWRs. Table 188 summarizes the data obtained from RADS and used in the SLBIC (PWR) analysis.

Table 188. SLBIC (PWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
0	1,962	1988–2020	78	0.0%

C-1.1.3.3 Industry-Average Baselines

Table 189 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 189. Selected industry distribution of λ for SLBIC (PWR).

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
JNID/IL	1.00E-06	2.55E-04	9.80E-04	Gamma	0.50	1.96E+03

Note: JNID/IL is a Jeffrey's noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-1.1.4 Steam Line Break Outside Containment at Boiling Water Reactors (SLBOC(BWR))

C-1.1.4.1 Initiating Event Description

From NUREG/CR-5750, the Steam Line Break outside Containment at BWRs (SLBOC[BWR]) initiating event is a break of one-inch equivalent diameter or more in a steam line located outside the primary containment that contains main turbine working fluid at or above atmospheric saturation conditions.

Examples include operation of rupture disks; and breeches of a pipe caused by a split, crack, weld failure, or circumferential break.

C-1.1.4.2 Data Collection and Review

Data for the SLBOC (BWR) baseline, 1988–2020, were obtained from the IEDB, as accessed using the RADS database. The data include total number of SLBOC events and total reactor critical years (rcrys) for the U.S. BWRs. Table 190 summarizes the data obtained from RADS and used in the SLBOC (BWR) analysis.

Table 190. SLBOC (BWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
2	989	1988–2020	37	5.4%

C-1.1.4.3 Industry-Average Baselines

Table 191 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 191. Selected industry distribution of λ for SLBOC (BWR).

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
JNID/IL	5.79E-04	2.53E-03	5.60E-03	Gamma	2.50	9.89E+02

Note: JNID/IL is a Jeffrey's noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry

C-1.1.5 Steam Line Break Outside Containment at Pressurized Water Reactors (SLBOC(PWR))

C-1.1.5.1 Initiating Event Description

From NUREG/CR-5750, the Steam Line Break outside Containment at PWRs (SLBOC[PWR]) initiating event is a break of one-inch equivalent diameter or more in a steam line located outside the primary containment that contains main turbine working fluid at or above atmospheric saturation conditions.

Examples include operation of rupture disks and breeches of a pipe caused by a split, crack, weld failure, or circumferential break.

C-1.1.5.2 Data Collection and Review

Data for the SLBOC (PWR) baseline, 1988–2020, were obtained from the IEDB, as accessed using the RADS database. The data include total number of SLBOC events and total reactor critical years (rcrys) for the U.S. PWRs. Table 192 summarizes the data obtained from RADS and used in the SLBOC (PWR) analysis.

Table 192. SLBOC (PWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
10	1,962	1988–2020	78	12.8%

C-1.1.5.3 Industry-Average Baselines

Table 193 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 193. Selected industry distribution of λ for SLBOC (PWR).

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
JNID/IL	2.96E-03	5.35E-03	8.33E-03	Gamma	10.50	1.96E+03

Note: JNID/IL is a Jeffrey's noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry

C-1.2 Steam Generator Tube Rupture (SGTR)

C-1.2.1 Initiating Event Description

From NUREG/CR-5750, the Steam Generator Tube Rupture (STGR) initiating event is a rupture of one or more steam generator tubes that results in a loss of primary coolant to the secondary side of the steam generator at a rate greater than or equal to 100 gpm. An SGTR can occur as the initial plant fault, such as a tube rupture caused by high cycle fatigue or loose parts, or as a consequence of another IE. The latter case would be classified as a functional impact. This category applies to PWRs only. This category includes excessive leakage caused by the failure of a previous SGTR repair (i.e., leakage past a plug).

C-1.2.2 Data Collection and Review

Two methodologies are summarized in this section. For one approach, information for the SGTR baseline was obtained from NUREG-1829, "Estimating Loss-of-Coolant Accident (LOCA) Frequencies through the Elicitation Process" [C-7]. In that document, the SGTR frequency was estimated based on an expert elicitation process ". . . to consolidate service history data and PFM [probabilistic fracture mechanics] studies with knowledge of plant design, operation, and material performance."

From Table 7.3 in NUREG-1829, the mean frequency for SGTR of less than 100 gpm is 3.4E-3/reactor calendar year (rcy). To convert this to reactor critical years (rcrys), it was assumed that reactors are critical 90% of each year. Converting to rcrys, the result is

(3.40E-4/rcy)(1 rcy/0.9 rcry) = 3.78E-3/rcry

The associated error factor (95th percentile divided by median) associated with the SGTR category from NUREG-1829 is

(8.2E-3/rcy)/(2.6E-3/rcy) = 3.2

which converts to an α of 1.6.

For the other approach, data for the SGTR baseline, 1988–2020, were obtained from the IEDB, as accessed using the RADS database. Results include total number of events and total rcrys for the U.S. commercial NPPs. Table 194 summarizes the data obtained from RADS and used in the SGTR analysis.

Table 194. STGR frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
3	1,962	1988-2020	78	3.8%

C-1.2.3 Industry-Average Baselines

Table 195 lists the industry-average frequency distribution which used the IEDB results. This industry-average frequency does not account for any recovery.

Table 195. Selected industry distribution of λ for SGTR.

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
JNID/IL	5.53E-04	1.78E-03	3.59E-03	Gamma	3.50	1.96E+03

Note: JNID/IL is a Jeffrey's noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-1.3 Loss of Coolant Accidents

Although no actual small LOCA or larger events have been recorded in U.S. operating experience data collected through 2020, numerous instances of reactor coolant leakage events—e.g., break flow within the capacity of normal makeup systems—were recorded. Failures of smaller pressure-boundary pipes—i.e., less than 2 inches—have not exceed the capacity of normal makeup systems. In general, most aging management and inspection programs focus on medium and large diameter piping (i.e., >4 inches in diameter). Such programs are more effective for larger diameter piping systems because these pipes are most likely to experiences leaks that can be detected and mitigated before component failure occurs. These factors lead to uncertainty in the small break LOCA frequency estimates, which are principally related to failure of smaller diameter piping (i.e., 2–4 inches diameter). It is therefore important that plant operators are cognizant of the reduced failure margins associated with small diameter piping and that they have aging management programs—including attributes related to inspection, monitoring, and mitigation—specifically targeted to provide reasonable assurance that failure will not occur in these systems.

C-1.3.1 Large Loss-of-Coolant Accident at Boiling Water Reactors (LLOCA(BWR))

C-1.3.1.1 Initiating Event Description

The Large Loss-of-Coolant Accident at BWRs (LLOCA [BWR]) initiating event is defined as a break size greater than 6-inch inside diameter pipe equivalent for liquid and steam in the reactor coolant system pressure boundary.

C-1.3.1.2 Data Collection and Review

Information for the LLOCA (BWR) baseline was obtained from NUREG-1829, "Estimating Loss-of-Coolant Accident (LOCA) Frequencies through the Elicitation Process" [C-7]. The LLOCA frequency was estimated based on an expert elicitation process ". . . to consolidate service history data and PFM [probabilistic fracture mechanics] studies with knowledge of plant design, operation, and material performance."

Table 7.17 in NUREG-1829 presents frequencies for LOCAs exceeding various sizes by gallon per minute break flow and effective pipe size break. Six different sizes are listed, ranging from 0.5-inch diameter (>100 gpm) to 41-inch diameter (>500,000 gpm). The frequencies presented for each size indicate the frequency of LOCAs of that size or greater occurring. In addition, frequencies for each size are presented for 25 years of fleet operation, and for end-of-life conditions (40 years of operation). Because much of the reactor fleet now has over 35 to 40 years of operation, 40-year average fleet conditions were used.

Reference C-9 provides details for determining the break sizes for use in the SPAR models and for obtaining the related frequency information from NUREG-1829. The LLOCA break threshold for the SPAR models is 6 inches which requires interpolation between rows in Table 7.17. The LLOCA frequency is provided in reactor calendar years (rcys). To convert this to reactor critical years (rcrys), it was assumed that reactors are critical 90% of each year. Converting to rcrys and rounding using the NUREG/CR-6928 round off scheme results provided in Table 1-13.

Table 7.17 in NUREG-1829 includes excessive LOCA data (>41.0 inch break diameter) which should be removed from the LLOCA result, but the frequency is so small as to be negligible, and the interpolated result was used without removing the contribution from excessive LOCA.

NUREG-1829 provided an evaluation of industry conditions up to 2002. Additional operating experience has been recorded since then, and the NUREG-1829 result has been updated with no recorded events over 574 rcry of fleet operation for the date range from 2003 to 2020. The updated frequency is provided in the second row of Table 197. The Bayes update row is the recommended value for the SPAR models.

Table 196. LLOCA (BWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
0	574	2003-2020	35	0.0%

C-1.3.1.3 Industry-Average Baselines

Table 197 lists the industry-average frequency distribution.

Table 197. Selected industry distribution of λ for LLOCA (BWR).

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	B
Ref. 7	1.28E-09	1.20E-05	5.49E-05	Gamma	0.30	2.50E+04
Bayes Update	1.25E-09	1.17E-05	5.36E-05	Gamma	0.30	2.56E+04

Note: The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-1.3.2 Large Loss-of-Coolant Accident at Pressurized Water Reactors (LLOCA(PWR))

C-1.3.2.1 Initiating Event Description

The Large Loss-of-Coolant Accident at PWRs (LLOCA [PWR]) initiating event is defined as a break in the primary system boundary with an equivalent inside pipe diameter greater than 6 inches.

C-1.3.2.2 Data Collection and Review

Information for the LLOCA (PWR) baseline was obtained from NUREG-1829, "Estimating Loss-of-Coolant Accident (LOCA) Frequencies through the Elicitation Process" [C-7]. The LLOCA frequency was estimated based on an expert elicitation process ". . . to consolidate service history data and PFM [probabilistic fracture mechanics] studies with knowledge of plant design, operation, and material performance."

Table 7.19 of NUREG-1829 presents frequencies for PWR LOCAs exceeding various sizes by gallon per minute break flow and effective pipe size break **without SGTR contributions**. Six different sizes are listed, ranging from 0.5-inch diameter (>100 gpm) to 31-inch (>500,000 gpm). The frequencies presented for each size indicate the frequency of LOCAs of that size or greater. In addition, frequencies for each size are presented for an average of 25 years of operation, and for end-of-life conditions (40 years of operation). Because much of the reactor fleet now has over 35 to 40 years of operation, 40-year average fleet conditions were used.

Reference C-9 provides details for determining the break sizes for use in the SPAR models and for obtaining the related frequency information from NUREG-1829. The LLOCA break threshold for the SPAR models is 6 inches, which requires interpolation between rows in Table 7.19. The LLOCA frequency is provided in reactor calendar years (rcys). To convert this to reactor critical years (rcrys), it was assumed that reactors are critical 90% of each year. Converting to rcrys and rounding using the NUREG/CR-6928 round off scheme results provided in Table 198.

Table 7.19 of NUREG-1829 includes excessive LOCA data (>31.0 inch equivalent break diameter) which should be removed from the LLOCA result, but the frequency is so small as to be negligible, and the interpolated result was used without removing the contribution from excessive LOCA.

NUREG-1829 was an evaluation of industry conditions up to 2002. Additional operating experience has been recorded since then, and the NUREG-1829 result has been updated with no recorded events over 1,097 rcry of fleet operation for the date range between 2003 and 2020. The updated frequency is provided in Table 199. The Bayes update row is the recommended value for the SPAR models.

Table 198. LLOCA (PWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
0	1,097	2003-2020	70	0.0%

C-1.3.2.3 Industry-Average Baselines

Table 199 lists the industry-average frequency distribution.

Table 199. Selected industry distribution of λ for LLOCA (PWR).

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	B
Ref. 7	6.42E-10	6.00E-06	2.74E-05	Gamma	0.30	5.00E+04
Bayes Update	6.28E-10	5.87E-06	2.69E-05	Gamma	0.30	5.11E+04

Note: The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-1.3.3 Medium Loss-of-Coolant Accident at Boiling Water Reactors (MLOCA(BWR))

C-1.3.3.1 Initiating Event Description

The Medium Loss-of-Coolant Accident at BWRs (MLOCA [BWR]) initiating event is defined as a break in the reactor coolant system boundary with size between 2- and 6-inch inside diameter pipe equivalent.

C-1.3.3.2 Data Collection and Review

Information for the MLOCA (BWR) baseline was obtained from NUREG-1829, "Estimating Loss-of-Coolant Accident (LOCA) Frequencies Through the Elicitation Process" [C-7]. The MLOCA frequency was estimated based on an expert elicitation process ". . . to consolidate service history data and PFM [probabilistic fracture mechanics] studies with knowledge of plant design, operation, and material performance."

Table 7.17 in NUREG-1829 presents frequencies for LOCAs exceeding various sizes indicated by gallon per minute break flow and effective pipe size break. Six different sizes are listed, ranging from 0.5-inch diameter (>100 gpm) to 41-inch diameter (>500,000 gpm). The frequencies presented for each size indicate the frequency of LOCAs of that size or greater occurring. In addition, frequencies for each size are presented for current conditions (assuming an average of 25 years of fleet operation) and for end-of-life conditions (40 years of operation). For this estimate, frequencies appropriate for 40 years of fleet operation were used.

Reference C-9 provides details for determining the break sizes for use in the SPAR models and for obtaining related frequency information from NUREG-1829. The SPAR model break range is not provided in Table 7.17 of NUREG-1829 and must worked out by interpolation between the provided rows. Subtraction of the means from the interpolated results for 2- and 6-inch breaks gives the mean MLOCA frequency. The uncertainty distribution parameters are obtained from the difference in variances assuming lognormally-distributed difference in the means. A lognormal distribution with the resulting mean and variance is converted to an equivalent gamma distribution by setting means and error factors equal. Finally, the result is converted to reactor critical years (rcrys) assuming that reactors are critical 90% of each year and rounded using the round off scheme provided in NUREG/CR-6928. The resulting MLOCA frequency is provided in Table 201.

NUREG-1829 was an evaluation of industry conditions up to 2002. Additional operating experience has been recorded since then, and the NUREG-1829 result has been updated with no recorded events over 574 rcry of fleet operation for the date range 2003 to 2020 (see Table 200). The updated frequency is provided in the second row of Table 201. The Bayes Update row is the recommended value for the SPAR models.

Table 200. MLOCA (BWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
0	574	2003-2020	35	0.0%

C-1.3.3.3 Industry-Average Baselines

Table 201 lists the industry-average frequency distribution.

Table 201. Selected industry distribution of λ for MLOCA (BWR).

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
Ref. 7	1.04E-07	1.00E-04	4.15E-04	Gamma	0.40	4.00E+03
Bayes Update	9.07E-08	8.75E-05	3.64E-04	Gamma	0.40	4.57E+03

Note: The percentiles and the mean of the distribution have units of events/rcry. The units for *β* are rcry.

C-1.3.4 Medium Loss-of-Coolant Accident at Pressurized Water Reactors (MLOCA(PWR))

C-1.3.4.1 Initiating Event Description

The Medium Loss-of-Coolant Accident at PWRs (MLOCA [PWR]) initiating event is defined as a pipe break in the primary system boundary with an inside diameter between 2 and 6 inches.

C-1.3.4.2 Data Collection and Review

Information for the MLOCA (PWR) baseline was obtained from NUREG-1829, "Estimating Loss-of-Coolant Accident (LOCA) Frequencies Through the Elicitation Process" [C-7]. The MLOCA frequency was estimated based on an expert elicitation process ". . . to consolidate service history data and PFM [probabilistic fracture mechanics] studies with knowledge of plant design, operation, and material performance."

Table 7.19 in NUREG-1829 presents frequencies for PWR LOCAs exceeding various sizes indicated by gallon per minute break flow and effective pipe size break **without SGTR contributions**. Six different sizes are listed, ranging from 0.5-inch diameter (>100 gpm) to 31-inch diameter (>500,000 gpm). The frequencies presented for each size indicate the frequency of LOCAs of that size or greater occurring. In addition, frequencies for each size are presented for current conditions (assuming an average of 25 years of operation) and for end-of-life conditions (40 years of operation). For this estimate, frequencies for 40 years of operation were used.

Reference C-9 provides details for determining the break sizes for use in the SPAR models and for obtaining the related frequency information from NUREG-1829. The SPAR-model break range is not provided in Table 7.19 and must be worked out by interpolation between the provided rows. Subtraction of the means from the interpolated results for 2- and 6-inch breaks gives the mean MLOCA frequency. The uncertainty distribution parameters are obtained from the difference in variances assuming lognormally distributed difference in the means. The resulting lognormal distribution is converted to an equivalent gamma distribution by setting means and error factors equal. Finally, the result is converted to reactor critical years (rcrys) assuming that reactors are critical 90% of each year and rounded using the round off scheme provided in NUREG/CR-6928. The resulting MLOCA frequency is provided in Table 203.

NUREG-1829 was an evaluation of industry conditions up to 2002. Additional operating experience has been recorded since then, and the NUREG-1829 result has been updated with no recorded events over 1,097 rcry of fleet operation for the date range between 2003 and 2020 (see Table 202). The updated frequency is provided in the second row of Table 203. The Bayes update row is the recommended value for the SPAR models.

Table 202. MLOCA (PWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
0	1,097	2003-2020	70	0.0%

C-1.3.4.3 Industry-Average Baselines

Table 203 lists the industry-average frequency distribution.

Table 203. Selected industry distribution of λ for MLOCA (PWR).

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
Ref. C-7	2.68E-08	2.50E-04	1.14E-03	Gamma	0.30	1.20E+03
Bayes Update	1.40E-08	1.31E-04	5.97E-04	Gamma	0.30	2.30E+03

Note: The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-1.3.5 Small Loss-of-Coolant Accident at Boiling Water Reactors (SLOCA(BWR))

C-1.3.5.1 Initiating Event Description

The Small Loss-of-Coolant Accident at BWRs (SLOCA[BWR]) initiating event is defined as a break size between 0.5-inch inside diameter pipe equivalent and 2-inch inside diameter pipe equivalent in the reactor coolant system pressure boundary.

C-1.3.5.2 Data Collection and Review

Information for the SLOCA (BWR) baseline was obtained from NUREG-1829, "Estimating Loss-of-Coolant Accident (LOCA) Frequencies Through the Elicitation Process" [C-7]. The LOCA frequency was estimated based on an expert elicitation process ". . . to consolidate service history data and PFM [probabilistic fracture mechanics] studies with knowledge of plant design, operation, and material performance."

Table 7.17 of NUREG-1829 presents frequencies for LOCAs exceeding various sizes indicated by gallon per minute break flow and effective pipe size break. Six different sizes are listed, ranging from 0.5-inch diameter (>100 gpm) to 41-inch diameter (> 500,000 gpm). The frequencies presented for each size indicate the frequency of LOCAs of that size or greater occurring. In addition, frequencies for each size are presented for current day conditions (assuming an average of 25 years of fleet operation) and for end-of-life conditions (40 years of operation). For this estimate frequencies for 40 years of fleet operation were used.

Reference C-9 provides details for determining the break sizes for use in the SPAR models and for obtaining the related frequency information from NUREG-1829. The SPAR model break range is not provided in Table 7.17 of NUREG-1829 and must worked out by interpolation between the provided rows. Subtraction of the means from 0.5-inch break and the interpolated 2-inch break gives the mean SLOCA frequency. The uncertainty distribution parameters are obtained from the difference in variances assuming lognormally-distributed difference in the means. A lognormal distribution with the resulting mean and variance is converted to an equivalent gamma distribution by setting means and error factors equal. Finally, the result is converted to reactor critical years (rcrys) assuming that reactors are critical 90% of each year and rounded using the round off scheme provided in NUREG/CR-6928. The resulting SLOCA frequency is provided in Table 205.

NUREG-1829 was an evaluation of industry conditions up to 2002. Additional operating experience has been recorded since then, and the NUREG-1829 result has been updated with no recorded event and 574 rcry of fleet operation for the date range 2003 to 2020 (see Table 204). The updated frequency is provided in the second row of Table 205. The Bayes update row is the recommended value for the SPAR models.

Table 204. SLOCA (BWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
0	574	2003-2020	35	0.0%

C-1.3.5.3 Industry-Average Baselines

Table 205 lists the industry-average frequency distribution.

Table 205. Selected industry distribution of λ for SLOCA (BWR).

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	B
Ref. C-7	6.22E-07	6.00E-04	2.49E-03	Gamma	0.40	6.67E+02
Bayes Update	3.34E-07	3.22E-04	1.34E-03	Gamma	0.40	1.24E+03

Note: The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-1.3.6 Small Loss-of-Coolant Accident at Pressurized Water Reactors (SLOCA(PWR))

C-1.3.6.1 Initiating Event Description

The Small Loss-of-Coolant Accident at PWRs (SLOCA[PWR]) initiating event is defined as a break in the primary system pressure boundary with an equivalent inside pipe diameter between 0.5 and 2 inches.

C-1.3.6.2 Data Collection and Review

Information for the SLOCA (PWR) baseline was obtained from NUREG-1829, "Estimating Loss-of-Coolant Accident (LOCA) Frequencies Through the Elicitation Process" [C-7]. The LOCA frequency was estimated based on an expert elicitation process ". . . to consolidate service history data and PFM [probabilistic fracture mechanics] studies with knowledge of plant design, operation, and material performance."

Table 7.19 of NUREG-1829 presents frequencies for PWR LOCAs exceeding various sizes indicated by gallon per minute break flow and effective pipe size break **without SGTR contributions**. Six different sizes are listed, ranging from 0.5-inch diameter (>100 gpm) to 31-inch diameter (>500,000 gpm). The frequencies presented for each size indicate the frequency of LOCAs of that size or greater occurring. In addition, frequencies for each size are presented for current day conditions (assuming an average of 25 years of fleet operation) and for end-of-life conditions (40 years of operation). For this estimate, frequencies for 40 years of fleet operation were used.

Reference C-9 provides details for determining the break sizes for use in the SPAR models and for obtaining the related frequency information from NUREG-1829. The SPAR model break range is not provided in Table 7.19 and must be worked out by interpolation between the provided rows. Subtraction of the means from 0.5-inch break and the interpolated 2-inch break gives the mean SLOCA frequency. The uncertainty distribution parameters are obtained from the difference in variances assuming lognormally-distributed difference in the means. A lognormal distribution with the resulting mean and variance is converted to an equivalent gamma distribution by setting means and error factors equal. Finally, the result is converted to reactor critical years (rcrys) assuming that reactors are critical 90% of each year, and rounded using the round off scheme provided in NUREG/CR-6928. The resulting SLOCA frequency is provided in Table 207.

NUREG-1829 was an evaluation of industry conditions up to 2002. Additional operating experience has been recorded since then, and the NUREG-1829 result has been updated with no recorded events over 1,097 rcry of fleet operation for the date range 2003 to 2020 (see Table 206). The updated frequency is provided in the second row (labeled as "Bayes Update") of Table 207.

Table 206. SLOCA (PWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
0	1,097	2003-2020	70	0.0%

C-1.3.6.3 Industry-Average Baselines

Table 207 lists the industry-average frequency distribution.

Table 207. Selected industry distribution of λ for SLOCA (PWR).

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
Ref. C-7	2.07E-06	2.00E-03	8.16E-03	Gamma	0.40	2.00E+02
Bayes Update	3.19E-07	3.09E-04	1.28E-03	Gamma	0.40	1.30E+03

Note: JNID/IL is a Jeffrey's noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-1.3.7 Very Small Loss-of-Coolant Accident at Boiling Water Reactors (VSLOCA(BWR))

C-1.3.7.1 Initiating Event Description

From NUREG/CR-5750, the Very Small Loss of Coolant Accident at BWRs (VSLOCA[BWR]) initiating event is a pipe break or component failure that results in a loss of primary coolant between 10 and 100 gpm, but does not require the automatic or manual actuation of high-pressure injection systems. Examples include PWR reactor coolant pump or BWR recirculating pump seal failures, valve packing failures, steam generator tube leaks, and instrument line fitting failures.

C-1.3.7.2 Data Collection and Review

Data for the VSLOCA (BWR) baseline, 1992–2020, were obtained from the IEDB, as accessed using the RADS database. The data include total number of events and total reactor critical years (rcrys) for the U.S. commercial NPPs. Table 208 summarizes the data obtained from RADS and used in the VSLOCA (BWR) analysis.

Table 208. VSLOCA (BWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
2	891	1992--2020	37	5.4%

C-1.3.7.3 Industry-Average Baselines

Table 209 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 209. Selected industry distribution of λ for VSLOCA (BWR).

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
JNID/IL	6.43E-04	2.81E-03	6.21E-03	Gamma	2.50	8.91E+02

Note: JNID/IL is a Jeffrey's noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-1.3.8 Very Small Loss-of-Coolant Accident at Pressurized Water Reactors (VSLOCA(PWR))

C-1.3.8.1 Initiating Event Description

From NUREG/CR-5750, the Very Small Loss of Coolant Accident at PWRs (VSLOCA[PWR]) initiating event is a pipe break or component failure that results in a loss of primary coolant between 10 to 100 gpm, but does not require the automatic or manual actuation of high-pressure injection systems. Examples include the PWR reactor coolant pumps or BWR recirculating pump seal failures, valve packing failures, steam generator tube leaks, and instrument line fitting failures.

C-1.3.8.2 Data Collection and Review

Data for the VSLOCA baseline, 1992–2020, were obtained from the IEDB, as accessed using the RADS database. The data include total number of events and total reactor critical years (rcrys) for the U.S. commercial NPPs. Table 210 summarizes the data obtained from RADS and used in the VSLOCA (PWR) analysis.

Table 210. VSLOCA (PWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
0	1,745	1992-2020	76	0.0%

C-1.3.8.3 Industry-Average Baselines

Table 211 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 211. Selected industry distribution of λ for VSLOCA (PWR).

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
JNID/IL	1.13E-06	2.87E-04	1.10E-03	Gamma	0.50	1.74E+03

Note: JNID/IL is a Jeffrey's noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-1.3.9 Stuck Open Relief Valve at Boiling Water Reactors (SORV(BWR))

C-1.3.9.1 Initiating Event Description

From NUREG/CR-5750, the Stuck Open Relief Valve at BWRs (SORV [BWR]) initiating event is a failure of one primary system safety and/or relief valve (SRV) to fully close, resulting in the loss of primary coolant. The valves included in this category are BWR main steam line safety valves and automatic depressurization system relief valves. The stuck open SRV may or may not cause the automatic or manual actuation of high-pressure injection systems.

This category includes a stuck open valve that cannot be subsequently closed upon manual demand or does not subsequently close on its own immediately after the reactor trip. The mechanism that opens the valve is not a defining factor. The different mechanisms than can open an SRV are transient-induced opening, manual opening during valve testing, and spurious opening.

C-1.3.9.2 Data Collection and Review

Data for the SORV (BWR) baseline, 1994–2020, were obtained from the IEDB, as accessed using the RADS database. The data include total number of events and total reactor critical years (rcrys) for the U.S. commercial NPPs. The SPAR models use two SORV initiating events in the models: a single SORV (SORV1) and two or more SORVs (SORV2). Table 212 summarizes the data obtained from RADS and used in the SORV (BWR) analysis.

Table 212. SORV (BWR) frequency data for baseline period.

Event Type	Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
	Events	Reactor Critical Years (rcry)			
SORV1	7	839	1994-2020	37	16.2%
SORV2	0	809	1994-2020	37	0.0%

C-1.3.9.3 Industry-Average Baselines

Table 213 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 213. Selected industry distribution of λ for SORV (BWR).

Event Type	Analysis Type / Source	5%	Mean	95%	Distribution		
					Type	α	β
SORV1	EB/PL/KS	1.30E-03	8.32E-03	2.03E-02	Gamma	1.82	2.19E+02
SORV2	JNID/IL	2.34E-06	5.96E-04	2.29E-03	Gamma	0.50	8.39E+02

Note: EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment. JNID/IL is a Jeffrey's noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-1.3.10 Stuck Open Relief Valve at Pressurized Water Reactors (SORV(PWR))

C-1.3.10.1 Initiating Event Description

From NUREG/CR-5750, the Stuck Open Relief Valve at PWRs (SORV [PWR]) initiating event is a failure of one primary system safety and/or relief valve to fully close, resulting in the loss of primary coolant. The valves included in this category are PWR pressurizer code safety valves (SVVs). The stuck open SVV may or may not cause the automatic or manual actuation of high-pressure injection systems.

C-1.3.10.2 Data Collection and Review

Data for the SORV (PWR) baseline, 1988–2020, were obtained from the IEDB, as accessed using the RADS database. The data include total number of events and total reactor critical years (rcrys) for the U.S. commercial NPPs. Results are shown for two SORV IEs: a single SORV (SORV1) and two or more SORVs (SORV2). Table 214 summarizes the data obtained from RADS and used in the SORV (PWR) analysis.

Table 214. SORV (PWR) frequency data for baseline period.

Event Type	Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
	Events	Reactor Critical Years (rcry)			
SORV1	2	1,962	1988–2020	78	2.6%
SORV2	0	1,962	1988–2020	78	0.0%

C-1.3.10.3 Industry-Average Baselines

Table 215 lists the industry-average frequency distribution. With only two events, an empirical Bayes analysis could not be performed. Therefore, the SCNID analysis results were used. This industry-average frequency does not account for any recovery.

Table 215. Selected industry distribution of λ for SORV (PWR).

Event Type	Analysis Type / Source	5%	Mean	95%	Distribution		
					Type	α	β
SORV1	JNID/IL	2.92E-04	1.27E-03	2.82E-03	Gamma	2.50	1.96E+03
SORV2	JNID/IL	1.00E-06	2.55E-04	9.80E-04	Gamma	0.50	1.96E+03

Note: JNID/IL is a Jeffrey's noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-1.3.11 Interfacing System Loss-of-Coolant Accident at Boiling Water Reactors (ISLOCA(BWR))

C-1.3.11.1 Initiating Event Description

From NUREG/CR-5750, the Interfacing System LOCA (ISLOCA) initiating event is a backflow of high-pressure coolant from the primary system through low-pressure system piping that results in the breach of the pipe or component.

C-1.3.11.2 Data Collection and Review

Data for the ISLOCA (BWR) baseline, 1988–2020, were obtained from the IEDB accessed using the RADS database. The data include total number of events and total reactor critical years (rcrys) for the U.S. commercial NPPs. Table 216 summarizes the data obtained from RADS and used in the ISLOCA (BWR) analysis.

Table 216. ISLOCA (BWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
0	989	1988–2020	37	0.0%

C-1.3.11.3 Industry-Average Baselines

Table 217 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 217. Selected industry distribution of λ for ISLOCA (BWR).

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
JNID/IL	1.99E-06	5.05E-04	1.94E-03	Gamma	0.50	9.89E+02

Note: JNID/IL is a Jeffrey's noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-1.3.12 Interfacing System Loss-of-Coolant Accident at Pressurized Water Reactors (ISLOCA(PWR))

C-1.3.12.1 Initiating Event Description

From NUREG/CR-5750, the Interfacing System LOCA (ISLOCA) initiating event is a backflow of high-pressure coolant from the primary system through low-pressure system piping that results in the breach of the pipe or component.

C-1.3.12.2 Data Collection and Review

Data for the ISLOCA (PWR) baseline, 1988–2020, were obtained from the IEDB, as accessed using the RADS database. The data include total number of events and total reactor critical years (rcrys) for the U.S. commercial NPPs. Table 218 summarizes the data obtained from RADS and used in the ISLOCA (PWR) analysis.

Table 218. ISLOCA (PWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
0	1,962	1988–2020	78	0.0%

C-1.3.12.3 Industry-Average Baselines

Table 219 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 219. Selected industry distribution of λ for ISLOCA (PWR).

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
JNID/IL	1.00E-06	2.55E-04	9.80E-04	Gamma	0.50	1.96E+03

Note: JNID/IL is a Jeffrey's noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-1.3.13 Reactor Coolant Pump Seal LOCA (RCPLOCA)

C-1.3.13.1 Initiating Event Description

From NUREG/CR-5750, the Reactor Coolant Pump Seal LOCA (RCPLOCA) initiating event is a catastrophic failure the reactor coolant pump seal assembly that results in a primary coolant leak into the primary containment at a rate greater than 100 gpm. This category applies to PWRs only.

C-1.3.13.2 Data Collection and Review

Data for the RCPLOCA baseline, 1988–2020, were obtained from the IEDB, as accessed using the RADS database. The data include total number of events and total reactor critical years (rcrys) for the U.S. commercial NPPs. Table 220 summarizes the data obtained from RADS and used in the RCPLOCA analysis.

Table 220. RCPLOCA frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
0	1,962	1988–2020	78	0.0%

C-1.3.13.3 Industry-Average Baselines

Table 221 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 221. Selected industry distribution of λ for RCPLOCA.

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
JNID/IL	1.00E-06	2.55E-04	9.80E-04	Gamma	0.50	1.96E+03

Note: JNID/IL is a Jeffrey's noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-1.3.14 Excessive Loss of Coolant Event (Vessel Rupture) (XLOCA)

C-1.3.14.1 Initiating Event Description

Excessive Loss of Coolant Event (Vessel Rupture) (XLOCA) represents a LOCA of such size as to be beyond the capacity of safety systems to protect the reactor core. This is considered to be a break of equivalent pipe diameter of greater than 41 inches for BWRs and 31 inches for PWRs.

C-1.3.14.2 Data Collection and Review

WASH-1285, *The Integrity of Reactor Vessels for Light-Water Power Reactors* [C-10] provided the 1.0E-7 per rcry estimate currently used in the SPAR models. A more current estimate is provided by NUREG-1829, "Estimating Loss-of-Coolant Accident (LOCA) Frequencies Through the Elicitation Process" [C-7]. The LOCA frequency was estimated based on an expert elicitation process ". . . to consolidate service history data and PFM [probabilistic fracture mechanics] studies with knowledge of plant design, operation, and material performance."

Tables 7.17 and 7.19 of NUREG-1829 present frequencies for LOCAs exceeding various sizes indicated by gallon per minute break flow and effective pipe size break. XLOCA is represented by the last entry in the tables, 41-inch breaks for BWRs and 31-inch diameter for PWRs. The frequencies are presented both for current conditions (assuming an average of 25 years of fleet operation) and for end-of-life conditions (40 years of operation). For this estimate, frequencies for 40 years of fleet operation were used. The frequencies are provided in reactor calendar years (rcy) and are converted to reactor critical years (rcry) assuming that reactors are critical 90% of each year, and rounded using the round off scheme provided in NUREG/CR-6928. The resulting XLOCA frequencies are provided in Table 222.

The WASH-1285 [C-10] result is still the recommended value. The other values are provided for reference.

C-1.3.14.3 Industry-Average Baselines

Table 222 lists the industry-average frequency distribution.

Table 222. Selected industry distribution of λ for XLOCA.

Analysis Type / Source	Plant Type	5%	Mean	95%	Distribution		
					Type	α	β
Ref. 7	BWR	1.02E-14	1.00E-08	5.15E-08	Gamma	0.20	2.00E+07
Ref. 7	PWR	8.16E-14	8.00E-08	4.12E-07	Gamma	0.20	2.50E+06
Ref. 10	ALL	1.07E-11	1.00E-07	4.57E-07	Gamma	0.30	3.00E+06

Note: The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-2. TRANSIENTS

The general transient categories result in automatic or manual reactor trips but do not degrade safety system response.

C-2.1 General Transient

C-2.1.1 General Transient at Boiling Water Reactors (TRANS(BWR))

C-2.1.1.1 Initiating Event Description

From NUREG/CR-5750, the General Transient at BWRs (TRANS [BWR]initiating event is a general transient that results in automatic or manual reactor trips but does not degrade safety system response.

C-2.1.1.2 Data Collection and Review

Data for the TRAN (BWR) baseline, 2011–2020, were obtained from the IEDB, accessed using the RADS database. Only initial plant fault events, as defined in NUREG/CR-5750, were used. The data include total number of events and total reactor critical years (rcrys) for the U.S. commercial NPPs. These results also include the individual plant results for the same period. Table 223 summarizes the data obtained from RADS and used in the TRANS (BWR) analysis.

Table 223. TRANS (BWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
173	317	2011--2020	35	88.6%

C-2.1.1.3 Industry-Average Baselines

Table 224 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 224. Selected industry distribution of λ for TRANS (BWR).

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
EB/PL/KS	7.98E-02	5.55E-01	1.38E+00	Gamma	1.71	3.08E+00

Note: EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-2.1.2 General Transient at Pressurized Water Reactors (TRANS(PWR))

C-2.1.2.1 Initiating Event Description

From NUREG/CR-5750, the General Transient at PWRs (TRANS [PWR]) initiating event is a general transient that results in automatic or manual reactor trips but does not degrade safety system response.

C-2.1.2.2 Data Collection and Review

Data for the TRANS (PWR) baseline, 2011–2020, were obtained from the IEDB, as accessed using the RADS database. Only initial plant fault events, as defined in Reference C-3, were used. The data include total number of events and total reactor critical years (rcrys) for the U.S. commercial NPPs. These results also include the individual plant results for the same period. Table 225 summarizes the data obtained from RADS and used in the TRANS (PWR) analysis.

Table 225. TRANS (PWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
300	597	2011--2020	69	91.3%

C-2.1.2.3 Industry-Average Baselines

Table 226 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 226. Selected industry distribution of λ for TRANS (PWR).

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
EB/PL/KS	1.39E-01	5.18E-01	1.09E+00	Gamma	2.94	5.68E+00

Note: EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-2.2 Loss of Condenser Heat Sink

C-2.2.1 Loss of Condenser Heat Sink at Boiling Water Reactors (LOCHS(BWR))

C-2.2.1.1 Initiating Event Description

From NUREG/CR-5750, the Loss of Condenser Heat Sink at BWRs (LOCHS [BWR]) initiating event is defined as at least one of the following:

- A complete closure of at least one main steam isolation valve in each main steam line.
- A decrease in condenser vacuum that leads to an automatic or manual reactor trip, or manual turbine trip; or a complete loss of condenser vacuum that prevents the condenser from removing decay heat after a reactor trip. In addition, reactor trips that are the indirect result of a low condenser vacuum, such as a loss of feedwater caused by condensate pumps tripping on high condensate temperature because of loss of vacuum, are counted.
- The failure of one or more turbine bypass valves to maintain the reactor pressure and temperature at the desired operating condition.

C-2.2.1.2 Data Collection and Review

Data for the LOCHS (BWR) baseline, 2009–2020, were obtained from the IEDB, accessed using the RADS database. The data include total number of events and total reactor critical years (rcrys) for the U.S. commercial NPPs. Table 227 summarizes the data obtained from RADS and used in the LOCHS (BWR) analysis.

Table 227. LOCHS (BWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
16	382	2009--2020	35	34.3%

C-2.2.1.3 Industry-Average Baselines

Table 228 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 228. Selected industry distribution of λ for LOCHS (BWR).

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
EB/PL/KS	1.77E-02	4.19E-02	7.41E-02	Gamma	5.68	1.36E+02

Note: EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-2.2.2 Loss of Condenser Heat Sink at Pressurized Water Reactors (LOCHS(PWR))

C-2.2.2.1 Initiating Event Description

From NUREG/CR-5750, the Loss of Condenser Heat Sink at PWRs (LOCHS [PWR]) initiating event is defined as at least one of the following:

- A complete closure of at least one main steam isolation valve in each main steam line.
- A decrease in condenser vacuum that leads to an automatic or manual reactor trip, or manual turbine trip; or a complete loss of condenser vacuum that prevents the condenser from removing decay heat after a reactor trip. In addition, reactor trips that are the indirect result of a low condenser vacuum, such as a loss of feedwater caused by condensate pumps tripping on high condensate temperature because of loss of vacuum, are counted.
- The failure of one or more turbine bypass valves to maintain the reactor pressure and temperature at the desired operating condition.

C-2.2.2.2 Data Collection and Review

Data for the LOCHS (PWR), 2006–2020, baseline were obtained from the IEDB, as accessed using the RADS database. The data include total number of events and total reactor critical years (rcrys) for the U.S. commercial NPPs. Table 229 summarizes the data obtained from RADS and used in the LOCHS (PWR) analysis.

Table 229. LOCHS (PWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
23	910	2006-2020	70	27.1%

C-2.2.2.3 Industry-Average Baselines

Table 230 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 230. Selected industry distribution of λ for LOCHS (PWR).

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
EB/PL/KS	1.04E-02	2.53E-02	4.57E-02	Gamma	5.35	2.11E+02

Note: EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-2.3 Loss of Main Feedwater (LOMFW)

C-2.3.1 Initiating Event Description

From NUREG/CR-5750, the Loss of Main Feedwater (LOMFW) initiating event is a complete loss of all main feedwater flow. Examples include the following: trip of the only operating feedwater pump while operating at reduced power; loss of a startup or an auxiliary feedwater pump normally used during plant startup; loss of all operating feed pumps due to trips caused by low suction pressure, loss of seal water, or high water level (BWR vessel level or PWR steam generator level); anticipatory reactor trip due to loss of all operating feed pumps; and manual reactor trip in response to feed problems characteristic of a total loss of feedwater flow, but prior to automatic reactor protection system signals. This category also includes the inadvertent isolation or closure of all feedwater control valves prior to the reactor trip; however, a main feedwater isolation caused by valid automatic system response after a reactor trip is not included. This category does not include the total loss of feedwater caused by the loss of offsite power.

C-2.3.2 Data Collection and Review

Data for the LOMFW baseline, 2011–2020, were obtained from the IEDB, as accessed using the RADS database. The data include total number of events and total reactor critical years (rcrys) for the U.S. commercial NPPs. Table 231 summarizes the data obtained from RADS and used in the LOMFW analysis.

Table 231. LOMFW frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
20	913	2011-2020	104	16.3%

C-2.3.3 Industry-Average Baselines

Table 232 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 232. Selected industry distribution of λ for LOMFW.

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
EB/PL/KS	1.18E-03	2.19E-02	6.51E-02	Gamma	1.02	4.66E+01

Note: EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-3. LOSS OF SUPPORT SYSTEMS

C-3.1 Loss of Safety-Related Cooling Water

C-3.1.1 Loss of Standby (Emergency) Service Water (LOSWS)

C-3.1.1.1 Initiating Event Description

From NUREG/CR-5750, the Loss of Service Water System (LOSWS) initiating event is a total loss of service water flow. The service water system (SWS) can be an open-cycle or a closed-cycle cooling water system. An open-cycle SWS takes suction from the plant's ultimate heat sink (e.g., the ocean, bay, lake, pond or cooling towers), removes heat from safety-related systems and components, and discharges the water back to the ultimate heat sink. A closed-cycle or intermediate SWS removes heat from safety-related equipment and discharges the heat through a heat exchanger to an open-cycle service water system.

For this report, the definition was specialized to include only emergency service water (ESW) systems. Therefore, the initiating event is Loss of Emergency Service Water (LOESW).

C-3.1.1.2 Data Collection and Review

Data for the LOESW baseline, 1988–2020, were obtained from the IEDB, accessed using the RADS database. The data include total number of events and total reactor critical years (rcrys) for the U.S. commercial NPPs. These results also include the individual plant results for the same period. Table 233 summarizes the data obtained from RADS and used in the LOESW analysis.

Table 233. LOESW frequency data.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
1	2,952	1988–2020	115	0.9%

C-3.1.1.3 Industry-Average Baselines

Table 234 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 234. Selected industry distribution of λ for LOESW.

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
JNID/IL	5.96E-05	5.08E-04	1.32E-03	Gamma	1.50	2.95E+03

Note: JNID/IL is a Jeffrey's noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-3.1.2 Partial Loss of Standby (Emergency) Service Water (PLOSWS)

C-3.1.2.1 Initiating Event Description

From NUREG/CR-5750, the partial loss of service water system (PLOSWS) initiating event is a loss of one train of a multiple train system or partial loss of a single train system that impairs the ability of the system to perform its function. Examples include pump cavitation, strainer fouling, and piping rupture.

This category does not include loss of a redundant component in a SWS as long as the remaining, similar components provide the required level of performance. For example, a loss of a single SWS pump is not classified as a PLOSWS as long as the remaining operating or standby pumps can provide the required level of performance. A loss of service water to a single component in another system because of a blockage or incorrect line-up that does not affect the cooling to other components serviced by the train is not included under this category, but is instead classified as a failure of the system that the single component serves.

For this report, the definition was specialized to include only emergency service water (ESW) systems; therefore, the initiating event is Partial Loss of Emergency Service Water (PLOESW).

C-3.1.2.2 Data Collection and Review

Data for the PLOESW baseline, 1988–2020, were obtained from the IEDB, as accessed using the RADS database. The data include total number of events and total reactor critical years (rcrys) for the U.S. commercial NPPs. These results also include the individual plant results for the same period. Table 235 summarizes the data obtained from RADS and used in the PLOESW analysis.

Table 235. PLOESW frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
4	2,952	1988–2020	115	3.5%

C-3.1.2.3 Industry-Average Baselines

Table 236 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 236. Selected industry distribution of λ for PLOESW.

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
JNID/IL	5.64E-04	1.52E-03	2.87E-03	Gamma	4.50	2.95E+03

Note: JNID/IL is a Jeffrey’s noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-3.1.3 Loss of Component Cooling Water (LOCCW)

C-3.1.3.1 Initiating Event Description

From NUREG/CR-5750, the Loss of Component Cooling Water (LOCCW) initiating event is a complete loss of the CCW system. CCW is a closed-cycle cooling water system that removes heat from safety-related equipment and discharges the heat through a heat exchanger to an open-cycle service water system.

C-3.1.3.2 Data Collection and Review

Data for LOCCW baselines, 1988–2020, were obtained from the IEDB, as accessed using the RADS database. The data include total number of events and total reactor critical years (rcrys) for the U.S. commercial NPPs. These results also include the individual plant results for the same period. Table 237 summarizes the data obtained from RADS and used in the LOCCW analysis.

Table 237. LOCCW frequency data.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
1	2,952	1988–2020	115	0.9%

C-3.1.3.3 Industry-Average Baselines

Table 238 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 238. Selected industry distribution of λ for LOCCW.

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
JNID/IL	5.96E-05	5.08E-04	1.32E-03	Gamma	1.50	2.95E+03

Note: JNID/IL is a Jeffrey's noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-3.1.4 Partial Loss of Component Cooling Water System (PLOCCW)

C-3.1.4.1 Initiating Event Description

From NUREG/CR-5750, the partial loss of component cooling water system (PLOCCW) initiating event is a loss of one train of a multiple train system or partial loss of a single train system that impairs the ability of the system to perform its function. Examples include pump cavitation, filter fouling, and piping rupture. The CCW is a closed-cycle cooling water system that removes heat from safety-related equipment and discharges the heat through a heat exchanger to an open-cycle service water system.

These categories do not include a loss of a redundant component in a CCW as long as the remaining, similar components provide the required level of performance. For example, a loss of a single CCW pump is not classified as a partial loss of a CCW as long as the remaining operating or standby pumps can provide the required level of performance. A loss of CCW to a single component in another system because of a blockage or incorrect line-up that does not affect the cooling to other components serviced by the train is not included under this category, but is instead classified as a failure of the system that the single component serves.

C-3.1.4.2 Data Collection and Review

Data for the PLOCCW baseline, 1988–2020, were obtained from the IEDB, as accessed using the RADS database. The data include total number of events and total reactor critical years (rcrys) for the U.S. commercial NPPs. These results also include the individual plant results for the same period. Table 239 summarizes the data obtained from RADS and used in the PLOCCW analysis.

Table 239. PLOCCW frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
4	2,952	1988–2020	115	3.5%

C-3.1.4.3 Industry-Average Baselines

Table 240 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 240. Selected industry distribution of λ for PLOCCW.

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
JNID/IL	5.64E-04	1.52E-03	2.87E-03	Gamma	4.50	2.95E+03

Note: JNID/IL is a Jeffrey’s noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-3.2 LOSS OF INSTRUMENT CONTROL AIR

C-3.2.1 Loss of Instrument Air at Boiling Water Reactors (LOIA(BWR))

C-3.2.1.1 Initiating Event Description

From NUREG/CR-5750, the loss of instrument air at Boiling Water Reactors (LOIA [BWR]) initiating event is a total or partial loss of an instrument or control air system that leads to a reactor trip or occurs shortly after the reactor trip. Examples include ruptured air headers, damaged air compressors with insufficient backup capability, losses of power to air compressors, line fitting failures, improper system line-ups, and undesired operations of pneumatic devices in other systems caused by low air header pressure.

C-3.2.1.2 Data Collection and Review

Data for the LOIA (BWR) baseline, 1991–2020, were obtained from the IEDB, as accessed using the RADS database. The data include total number of events and total reactor critical years (rcrys) for the U.S. commercial NPPs. These results also include the individual plant results for the same period. Table 241 summarizes the data obtained from RADS and used in the LOIA (BWR) analysis.

Table 241. LOIA (BWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
6	917	1991-2020	37	13.5%

C-3.2.1.3 Industry-Average Baselines

Table 242 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 242. Selected industry distribution of λ for LOIA (BWR).

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
EB/PL/KS	1.02E-04	6.55E-03	2.25E-02	Gamma	0.68	1.04E+02

Note: JNID/IL is a Jeffrey’s noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-3.2.2 Loss of Instrument Air at Pressurized Water Reactors (LOIA(PWR))

C-3.2.2.1 Initiating Event Description

From NUREG/CR-5750, the loss of instrument air at PWRs (LOIA [PWR]) initiating event is a total or partial loss of an instrument or control air system that leads to a reactor trip or occurs shortly after the reactor trip. Examples include ruptured air headers, damaged air compressors with insufficient backup capability, losses of power to air compressors, line fitting failures, improper system line-ups, and undesired operations of pneumatic devices in other systems caused by low air header pressure.

C-3.2.2.2 Data Collection and Review

Data for the LOIA (PWR) baseline, 1997–2020, were obtained from the IEDB, as accessed using the RADS database. The data include total number of events and total reactor critical years (rcrys) for the U.S. commercial NPPs. These results also include the individual plant results for the same period. Table 243 summarizes the data obtained from RADS and used in the LOIA (PWR) analysis.

Table 243. LOIA (PWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
10	1,453	1997-2020	71	11.3%

C-3.2.2.3 Industry-Average Baselines

Table 244 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 244. Selected industry distribution of λ for LOIA (PWR).

Analysis Type / Source	5%	Mean	95%	Distribution		
				Type	α	β
JNID/IL	4.00E-03	7.23E-03	1.13E-02	Gamma	10.50	1.45E+03

Note: JNID/IL is a Jeffrey's noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-4. LOSS OF OFFSITE POWER

C-4.1 Loss of Offsite Power, Power Operations (LOOP.PO)

C-4.1.1 Initiating Event Description

From NUREG/CR-5750, the loss of offsite power, power operations (LOOP.PO) initiating event is a simultaneous loss of electrical power to all safety-related buses that causes emergency power generators to start and supply power to the safety-related buses. The offsite power boundary extends from the offsite electrical power grid to the output breaker (inclusive) of the step-down transformer that feeds the first safety-related bus with an emergency power generator. The plant switchyard and service-type transformers are included within the offsite power boundary. This category includes the momentary or prolonged degradation of grid voltage that causes all emergency power generators to start (if operable) and load onto their associated safety-related buses (if available).

This category does not include a LOOP event that occurs while the plant is shutdown. In addition, it does not include any momentary undervoltage event that results in the automatic start of all emergency power generators, but in which the generators do not tie on to their respective buses due to the short duration of the undervoltage.

C-4.1.2 Data Collection and Review

Data for the LOOP.PO baseline, 2006–2020, were obtained from the IEDB, as accessed using the RADS database. The data include total number of events and total reactor critical years (rcrys) for the U.S. commercial NPPs. The data also include the results for the four LOOP categories during the same period: grid-related (GR), plant-centered (PC), switchyard-centered (SC), and weather-related (WR) LOOPs. Table 245 summarizes the data obtained from RADS and used in the LOOP.PO analysis.

Table 245. LOOP frequency data for baseline period.

LOOP Category	Data After Review		Baseline Period	Counts Number of Plants	Percent of Plants with Events
	Events	Reactor Critical Years (rcry)			
PO.LOOP	35	1,389	2006-2020	105	25.7%
PO.LOOP-GR	7	1,389	2006-2020	105	5.7%
PO.LOOP-PC	6	1,389	2006-2020	105	5.7%
PO.LOOP-SC	12	1,389	2006-2020	105	11.4%
PO.LOOP-WR	10	1,389	2006-2020	105	8.6%

C-4.1.3 Industry-Average Baselines

Table 246 lists the industry-average frequency distributions for the four LOOP categories and total LOOP. These industry-average frequencies do not account for any recovery.

Table 246. Selected industry distributions of λ for LOOP.

Event	Analysis Type / Source	5%	Mean	95%	Distribution		
					Type	α	β
PO.LOOP	EB/PL/KS	2.39E-03	2.52E-02	6.83E-02	Gamma	1.33	5.28E+01
PO.LOOP-GR	JNID/IL	2.61E-03	5.40E-03	8.99E-03	Gamma	7.50	1.39E+03
PO.LOOP-PC	JNID/IL	2.12E-03	4.68E-03	8.04E-03	Gamma	6.50	1.39E+03
PO.LOOP-SC	JNID/IL	5.26E-03	9.00E-03	1.35E-02	Gamma	12.50	1.39E+03
PO.LOOP-WR	EB/PL/KS	1.34E-04	7.21E-03	2.44E-02	Gamma	0.71	9.88E+01

Note: EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment. JNID/IL is a Jeffrey's noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-4.2 Loss of Offsite Power, Shutdown Operations (LOOP.SD)

C-4.2.1 Initiating Event Description

From NUREG/CR-5750, the loss of offsite power, shutdown operations (LOOP.SD) initiating event is a simultaneous loss of electrical power to all safety-related buses that causes emergency power generators to start and supply power to the safety-related buses. The offsite power boundary extends from the offsite electrical power grid to the output breaker (inclusive) of the step-down transformer that feeds the first safety-related bus with an emergency power generator. The plant switchyard and service-type transformers are included within the offsite power boundary. This category includes the momentary or prolonged degradation of grid voltage that causes all emergency power generators to start (if operable) and load onto their associated safety-related buses (if available).

This category does not include a LOOP event that occurs while the plant is at power. In addition, it does not include any momentary under-voltage event that results in the automatic start of all emergency power generators, but in which the generators do not tie on to their respective buses due to the short duration of the under-voltage.

C-4.2.2 Data Collection and Review

Data for the LOOP.SD baseline, 1997–2020, were obtained from the IEDB, as accessed using the RADS database. The data include total number of events and total reactor shutdown years for the U.S. commercial NPPs. The data also include the results for the four LOOP categories during the same period: grid-related (GR), plant-centered (PC), switchyard-centered (SC), and weather-related (WR) LOOPs. Table 247 summarizes the data obtained from RADS and used in the LOOP.SD analysis.

Table 247. LOOP.SD frequency data for baseline period.

LOOP Category	Data After Review		Baseline Period	Counts Number of Plants	Percent of Plants with Events
	Events	Reactor Shutdown Years			
SD.LOOP	17	127	2006-2020	105	13.3%
SD.LOOP-GR	2	127	2006-2020	105	1.9%
SD.LOOP-PC	3	127	2006-2020	105	1.9%
SD.LOOP-SC	8	127	2006-2020	105	6.7%
SD.LOOP-WR	4	127	2006-2020	105	3.8%

C-4.2.3 Industry-Average Baselines

Table 248 lists the industry-average frequency distributions for the four LOOP.SD categories and total LOOP.SD. These industry-average frequencies do not account for any recovery.

Table 248. Selected industry distributions of λ for LOOP.SD.

Event	Analysis Type / Source	5%	Mean	95%	Distribution		
					Type	α	β
SD.LOOP	JNID/IL	8.84E-02	1.38E-01	1.96E-01	Gamma	17.50	1.27E+02
SD.LOOP-GR	JNID/IL	4.51E-03	1.97E-02	4.36E-02	Gamma	2.50	1.27E+02
SD.LOOP-PC	JNID/IL	8.53E-03	2.75E-02	5.54E-02	Gamma	3.50	1.27E+02
SD.LOOP-SC	JNID/IL	3.41E-02	6.68E-02	1.09E-01	Gamma	8.50	1.27E+02
SD.LOOP-WR	JNID/IL	1.31E-02	3.54E-02	6.66E-02	Gamma	4.50	1.27E+02

Note: EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment. JNID/IL is a Jeffrey's noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-5. ELECTRICAL POWER

C-5.1 Loss of Safety-Related AC Bus

C-5.1.1 Loss of Vital AC Bus (LOAC)

C-5.1.1.1 Initiating Event Description

From NUREG/CR-5750, the Loss of Vital AC Bus (LOAC) initiating event is any sustained de-energization of a safety-related bus due to the inability to connect to any of the normal or alternative electrical power supplies. It includes loss of vital medium voltage AC bus (LOAC 4160V) and loss of vital low voltage AC bus (LOAC LOWV). The bus must be damaged or its power source unavailable for reasons beyond an open, remotely-operated feeder-breaker from a live power source. Examples include supply cable grounds, failed insulators, damaged disconnects, transformer deluge actuations, and improper uses of grounding devices.

C-5.1.1.2 Data Collection and Review

Data for the LOAC baseline, 1992–2020, were obtained from the IEDB, as accessed using the RADS database. The data include total number of events and total reactor critical years (rcrys) for the U.S. commercial NPPs. Table 249 summarizes the baseline data obtained from RADS and used in the LOAC analysis.

The LOAC results shown here in Table 249 and Table 250 include a calculated value to adjust the LOAC frequency to use in PRA models where the LOAC initiator can be caused by more than a single AC bus. The calculated value (LOAC2) consists of dividing the mean by two and recalculating the uncertainty using an alpha parameter of 0.3.

Table 249. LOAC frequency data for baseline period.

IE	Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
	Events	Reactor Critical Years (rcry)			
LOAC	16	2,635	1992-2020	113	13.3%
LOAC 4160V FI	11	2,635	1992-2020	113	8.8%
LOAC LOWV FI	5	2,635	1992-2020	113	4.4%

C-5.1.1.3 Industry-Average Baselines

Table 250 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 250. Selected industry distribution of λ for LOAC.

IE	Analysis Type / Source	5%	Mean	95%	Distribution		
					Type	α	β
LOAC	JNID/IL	3.95E-03	6.26E-03	8.98E-03	Gamma	16.50	2.64E+03
LOAC 4160V FI	EB/PL/KS	3.34E-04	4.16E-03	1.16E-02	Gamma	1.22	2.93E+02
LOAC LOWV FI	JNID/IL	8.66E-04	2.09E-03	3.73E-03	Gamma	5.50	2.64E+03
LOACB2	Adjusted	3.15E-07	2.94E-03	1.34E-02	Gamma	0.30	1.02E+02

Note: JNID/IL is a Jeffrey's noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-5.1.2 Loss of Vital DC Bus (LODC)

C-5.1.2.1 Initiating Event Description

From NUREG/CR-5750, the Loss of Vital DC Bus (LODC) initiating event is any sustained de-energization of a safety-related bus due to the inability to connect to any of the normal or alternative electrical power supplies. The bus must be damaged or have its power source unavailable for reasons beyond an open, remotely-operated feeder-breaker from a live power source. Examples include supply cable grounds, failed insulators, damaged disconnects, transformer deluge actuations, and improper uses of grounding devices.

C-5.1.2.2 Data Collection and Review

Data for the LODC baseline, 1988–2020, were obtained from the IEDB, as accessed using the RADS database. The data include total number of events and total reactor critical years (rcrys) for the U.S. commercial NPPs. Table 251 summarizes the data obtained from RADS and used in the LODC analysis.

The LODC results shown here in Table 251 and Table 252 include a calculated value to adjust the LODC frequency used in PRA models where the LODC initiator can be caused by more than a single DC bus. The calculated value (LODC2) consists of dividing the mean by two and recalculating the uncertainty using an alpha parameter of 0.3.

Table 251. LODC frequency data for baseline period.

IE	Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
	Events	Reactor Critical Years (rcry)			
LODC	2	2,952	1988–2020	115	1.7%

C-5.1.2.3 Industry-Average Baselines

Table 252 lists the industry-average frequency distribution. This industry-average frequency does not account for any recovery.

Table 252. Selected industry distribution of λ for LODC.

IE	Analysis Type / Source	5%	Mean	95%	Distribution		
					Type	α	β
LODC	JNID/IL	1.94E-04	8.47E-04	1.88E-03	Gamma	2.50	2.95E+03
LODCB2	Adjusted	4.53E-08	4.24E-04	1.94E-03	Gamma	0.30	7.08E+02

Note: JNID/IL is a Jeffrey's noninformative distribution at the industry level. The percentiles and the mean of the distribution have units of events/rcry. The units for β are rcry.

C-6. REFERENCES

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