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Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants

Idaho National Laboratory

**U.S. Nuclear Regulatory Commission
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ABSTRACT

This report characterizes current industry-average performance for components and initiating events at U.S. commercial nuclear power plants. Studies have indicated that industry performance has improved since the 1980s and early 1990s, so the characterization of current industry-average performance is an important step in maintaining up-to-date risk models. Four types of events are covered: component unreliability (e.g., pump fail to start or fail 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 initiating event frequencies. Typically data for 1998–2002 were used to characterize current industry-average performance, although many initiating events required longer periods (ending in 2002) to adequately characterize frequencies. Results (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 (SPAR) models covering U.S. commercial nuclear power plants.

FOREWORD

The U.S. Nuclear Regulatory Commission (NRC) is publishing this report to document updated industry-average component and initiating event parameter estimates representing current industry practices. The report presents the parameter estimation process to estimate component failure probabilities, component failure rates, maintenance unavailabilities, and initiating event frequencies for the Level 1 standardized plant risk analysis (SPAR) models.

NRC's development of the SPAR models for internal events started in 1993. The Idaho National Laboratory (INL) has been developing and improving these models for the NRC. These risk assessment models use fault trees and event trees to model potential core damage accident scenarios at nuclear power plants (NPPs). In recent years, these risk models have an ever-increasing role supporting the Commission's overall policy on the use of probabilistic risk assessment (PRA) in nuclear regulatory activities. The staff uses the SPAR models to (1) perform analyses supporting risk-informed reviews of license amendments, (2) independently verify the Mitigating Systems Performance Index, and (3) support the Reactor Oversight Process, the Accident Sequence Precursor Program, Management Directive (MD) 8.3 evaluations, and the generic safety issue resolution process.

In 2004, the Office of Nuclear Reactor Regulation (NRR) requested that the Office of Nuclear Regulatory Research (RES) update the component failure probabilities in the SPAR models using recent data. RES used data from the Equipment Performance and Information Exchange (EPIX) and from the updated RES risk studies (e.g., Station Blackout Risk Study).

For Level 1 SPAR models, this report documents the results of approximately 50 component types and 150 component type and failure mode combinations when applying the standard estimation methods as documented in NUREG/CR-6823, "Handbook for Parameter Estimation for Probabilistic Risk Assessment." The data span an approximately 5-year period from 1998 through 2002. This report also compares these results with other current sources and historical estimates. The comparisons show that component failure probabilities and failure rates generally have decreased indicating the industry's performance has improved from the 1980s through the early 1990s. Additionally, the report includes component unavailability data, representing test and maintenance basic events.

Initiating event data for 18 of the 24 initiating event categories came from the initiating event database maintained by RES. RES estimated the initiating event frequencies and resulting frequency distributions by determining baseline periods as documented in the Inspection Manual Chapter 0313, Industry Trends Program. The baseline starting dates include 1988 – 1997, depending on the initiating event. Loss of offsite power (LOOP) and large and medium loss of coolant accident frequencies were developed under separate studies (NUREG/CR-6890 and draft NUREG-1829, respectively).

This report distinguishes between standby and alternating/running component basic events and the breakdown of fail to run into (1) fail to run for the first hour and (2) fail to run beyond the first hour for emergency diesel generators, cooling units (e.g., air handling units, fans, and chillers), and selected pumps. This is a fundamental improvement in SPAR model basic event parameter estimation. The staff based these changes on observations that fail to run rates significantly differ for standby versus running/alternating categories for some components. This report also notes significant differences between rates for fail to run for the first hour and fail to run beyond the first hour.

This report has enhanced the determination of uncertainty distributions. In the past, the preferred uncertainty distribution in PRAs has been the lognormal distribution. In this effort, beta (for demand failure probabilities) and gamma (for time-related failure rates) distributions are used to express the uncertainty in SPAR basic events. These uncertainty distributions can be used as prior distributions to obtain updated plant-specific parameter estimates when needed, such as in some Phase 3 Significance Determination Process evaluations, Accident Sequence Precursor analyses, and other risk studies.

Overall, the results of the SPAR model basic event parameter estimation indicate that industry performance has been generally constant over this 5-year period from 1998 – 2002. Therefore, the staff based current baseline performance on this period, and the resultant set of performance estimates represents industry performance during this period. When compared with data previously used in these models (which typically reflected performance at U.S. commercial nuclear plants during the early 1990s, the 1980s, and in some cases, even earlier), current performance is significantly better, in most cases, than it was during these earlier periods. The staff plans to update these parameter estimates on a periodic basis.

Brian W. Sheron, Director
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EXECUTIVE SUMMARY

The U.S. Nuclear Regulatory Commission (NRC) maintains a set of risk models for the 103 operating U.S. commercial nuclear power plants (NPPs), termed the "industry" in this report. 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 Program 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 work performed to generate SPAR model input values such as component unreliabilities and initiating event frequencies that represent current industry performance. Current in this context refers to a period centered about the year 2000 and generally implies 1998–2002.

Prior to this effort, the SPAR model inputs reflected industry performance from the various system and initiating event studies performed by the NRC and from data analyses performed in support of the NUREG-1150 studies. The system studies used data from 1987 through 1993, 1995, or 1997, depending upon the study, so they typically characterized component performance around 1990. For components not covered by these system studies, the data analyses performed in support of the NUREG-1150 studies typically reflected industry performance from the 1970s and early 1980s. However, component performance has improved significantly since the 1970s, as documented in the article "Historical Perspective on Failure Rates for U.S. Commercial Reactor Components" (*Reliability Engineering and System Safety*, 2003). An example of component performance improvement is presented in Figure ES-1. Similar improvements occurred with respect to initiating event (IE) frequencies, as illustrated in Figure ES-2. Therefore, there was a need to update such input values to reflect current industry performance.

Four types of risk model events are addressed 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 pump fail to start (FTS) or fail to run (FTR), valve fail to open or close (FTO/C), 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 the 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.

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.

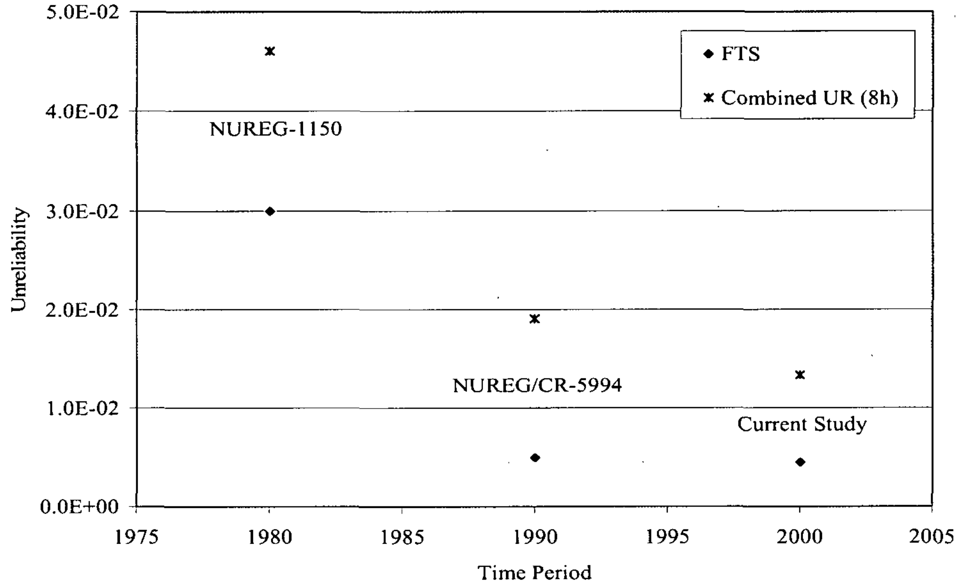

Figure ES-1. Historical trend in emergency diesel generator unreliability performance estimates.[1]

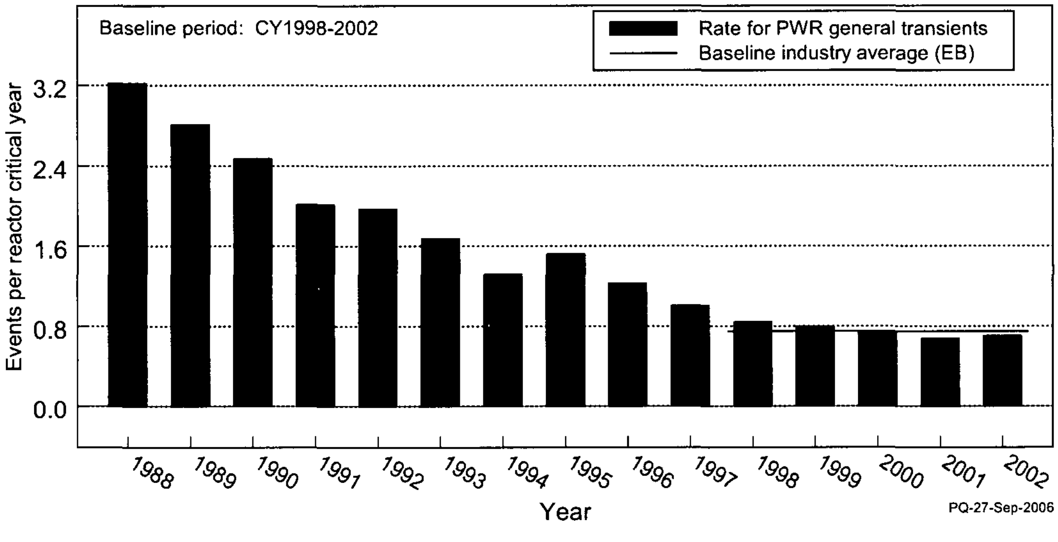

Figure ES-2. Historical trend for pressurized water reactor general transients.[2]

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[1] FTS is fail to start. Combined UR (unreliability) is approximately FTS + FTLR + FTR*7h, or FTS + FTR*8h (if the data source did not list FTLR), where FTLR is fail to load and run for one hour and FTR is fail to run.

[2] CY is calendar year, and EB is empirical Bayes (the analysis procedure used to calculate the baseline frequency distribution).

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. (IEs for shutdown operation are not covered in this report.) The IE frequencies are characterized by gamma distributions.

PRAs of U.S. commercial NPPs have used a variety of statistical distributions to model the uncertainty in both basic events and IE frequencies. Lognormal distributions were used in the *Reactor Safety Study* (WASH-1400, 1975) and have been used in many studies since then. The *PRA Procedures Guide* (NUREG/CR-2300, 1983) presented information on modeling component UR using lognormal, beta, and gamma distributions. In contrast, the *Probabilistic Safety Analysis Procedures Guide* (NUREG/CR-2815, 1985) recommended loguniform distributions for component failure rates listed in that document. Finally, the more recent data analysis studies performed at the Idaho National Laboratory have systematically used beta distributions for probability upon demand data and gamma distributions for time-related data. For the current study, beta and gamma distributions are used exclusively. (However, with the information presented, other distributions can be fitted to the results if desired.) This decision was made based on several factors. The first is the flexibility of such distributions in being able to represent component failure data (similar to the flexibility of the lognormal distribution). In addition, these distributions are natural choices given the assumptions of demand data following the binomial distribution (constant probability of failure per demand) and time-related data following the Poisson distribution (constant occurrence rate with time). The beta distribution is bounded by $(0, 1)$, matching the bounds for probabilities. The gamma distribution is bounded by $(0, \infty)$, matching the bounds for rates. Finally, these distributions are conjugate priors, resulting in simple equations for Bayesian updates using these distributions as industry-average priors.

To identify the types of components and failure modes included in the SPAR models, a master list of basic events (from all of the SPAR models) was constructed. Then that list was examined to ensure that there was consistency in coverage of failure modes between similar component types. From this expanded list, input events were identified that applied to component types and associated failure modes found in the models. The 51 component types include various types of pumps, valves, emergency power sources, and others. These component types contributed 171 component type and failure mode combinations. Failures modes addressed in this effort include fail to start (FTS) and fail to run (FTR) for components that must start upon demand and run for a specified mission time, fail to open or close (FTO/C) for valves and circuit breakers, and others. Table 5-1 presents this master list of components and failure modes and the UR results. The Equipment Performance and Information Exchange (EPIX) database (1998–2002), the preferred data source, was used to generate current estimates of component UR for approximately 85% of these 171 combinations. Information from reactor protection system studies supported most of the remaining 15%.

A fundamental improvement in this report is the distinction between standby and alternating/running component basic events and the breakdown of fail to run into fail to run for the first hour and fail to run beyond the first hour for emergency diesel generators, cooling units, and selected pumps. These changes were made based on observations that failure to run rates are significantly different for standby versus running/alternating categories for some components. Significant differences were also noted between rates for fail to run for the first hour and fail to run beyond the first hour.

Although the UA events are identified by type of component, for the SPAR models they generally apply at the train level. For example, the TDP-TM (HPCI) event covers all components within the high-pressure coolant injection (HPCI) system (a single-train system) that are single failures for the train and can be unavailable while the plant is critical. Therefore, several components could contribute to the train UA. However, experience has shown that in general almost all of the UA for the events listed in Table 6-1 result from the main component listed. The Mitigating Systems Performance Index (MSPI) basis documents were used as the preferred source for updating UA events. These documents provide train data for 2002–2004. MSPI UA data were preferred over Reactor Oversight Process safety system unavailability (SSU) data because the MSPI collection guidelines more closely match those required for the SPAR models. For example, the MSPI includes component overhaul outages while the plant is in critical operation, while the SSU data exclude such outages. Other differences in guidelines also exist, and in all cases the MSPI guidelines more closely fit the SPAR requirements.

Several special events related to system performance are also included in the SPAR models. These events are listed in Table 7-1 and address performance and conditional probability issues related to operation of HPCI, high-pressure core spray (HPCS), and reactor core isolation cooling (RCIC) during unplanned demands. For RCIC, the probability of the turbine-driven pump (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. The updated system study data were used to quantify the special events listed in Table 7-1.

Most IEs included in the SPAR models are listed in Table 8-1. These events represent various categories of unplanned automatic and manual reactor trips within the industry. Several sizes of loss-of-coolant accidents (LOCAs) are included, a variety of transients, and several losses of support systems. The more frequent IEs were quantified using the updated IE database maintained by the NRC. These data come mainly from licensee event reports covering plant unplanned shutdown events. To characterize current industry performance with respect to IEs, baseline periods ending in 2002 were chosen. This end date is the same one used for component unreliability baselines. However, the start dates vary by IE. Resulting data periods used to quantify the IE frequencies range from 1988–2002 to 1998–2002, depending upon the relative frequency and whether a trend exists. For example, the baseline period for pressurized water reactor general transients (Figure ES-2) is 1998–2002. For loss of offsite power (LOOP), the most recent study results were used (NUREG/CR-6890). Finally, LOCA frequencies generally were obtained from the draft report *Estimating Loss-of-Coolant Accident (LOCA) Frequencies through the Elicitation Process* (NUREG-1829, 2005).

Finally, Section 10 presents a comparison of this data collection and evaluation effort with requirements presented in the *Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications* (ASME RA-S-2002 with amendments). Tables 10-1 and 10-2 summarize the results of the comparison. Because the effort documented in the present report addresses industry-average performance rather than plant-specific data collection and analysis, some of the requirements in the ASME standard are not applicable.

The results presented in this report—estimates of current industry-average performance for component unreliability, train unavailability from test or maintenance outages, special event probabilities, and IE frequencies—will be inserted into the SPAR models. However, the results can also be used in plant-specific analyses as prior distributions in Bayesian updates using plant-specific data. Because the results are based on recent U.S. NPP performance, industry may also have use for these results in their own risk models.

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ABBREVIATIONS

A	actual (unplanned demand)
ABT	automatic bus transfer switch
ACC	accumulator
ACP	ac power
ADU	air drier 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
C	clarification or cyclic (every 18 months)
CBK	circuit breaker
CCF	common-cause failure
CCW	component cooling water
CDS	condensate system
CHL	chiller
CHW	chilled water system
CIS	containment isolation system
CKV	check valve
CL	component level
CLN	clean
CNID	constrained noninformative distribution
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
D	demand
DCP	dc power
DDP	diesel-driven pump
DOE	Department of Energy
EB	empirical Bayes

EDG	emergency diesel generator
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
FLT	filter
FRFRST	failure to recover failure to restart
FRFTFR	failure to recover failure to transfer
FRFTRO	failure to recover failure to reopen
FRST	failure to restart
FTC	fail to close
FTCL	fail to close after passing liquid
FTFR	failure to transfer
FTFRI	failure to transfer back to injection mode
FTLR	fail to load and run
FTO	fail to open
FTO/C	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
FTRO	failure to reopen
FTS	fail to start
FWCI	feedwater coolant injection
FWS	firewater system
HCI	high-pressure coolant injection
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
HVAC	heating, ventilating, and air conditioning
HVC	heating, ventilating, and air conditioning
IAS	instrument air system
IC	isolation condenser
ICS	ice condenser
IE	initiating event
IEDB	initiating event database
IL	industry level
ILL	internal leak large

ILS	internal leak small
INL	Idaho National Laboratory
INPO	Institute of Nuclear Power Operations
INV	inverter
IPE	individual plant examination
IPS	instrument ac power
IREP	Interim Reliability Evaluation Program
ISO	isolation condenser
L/S	large leak/small leak
LCI	low-pressure coolant injection
LCS	low-pressure core spray
LER	licensee event report
LL	lower allowable limit
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
LSI	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
ORNL	Oak Ridge National Laboratory
PDP	positive displacement pump
PL	plant level

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
PMINJ	probability of multiple injections
PMP	pump volute
POD	pneumatic-operated damper
PORV	power-operated relief valve
PRA	probabilistic risk assessment
PRST	probability of restart
PWR	pressurized water reactor
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
RGW	radioactive gaseous waste
RHR	residual heat removal
RHRSW	residual heat removal service water
RLY	relay
ROP	Reactor Oversight Process
RPS	reactor protection system
RPV	reactor pressure vessel
RRS	reactor recirculation system
RTB	reactor trip breaker
RUN	running or alternating
RWC	reactor water cleanup
SBO	station blackout
SCNID	simplified constrained noninformative distribution
SD	standard deviation
SDP	Significance Determination Process
SEQ	sequencer
SGT	standby gas treatment
SGTR	steam generator tube rupture
SLC	standby liquid control
SLOCA	small loss-of-coolant accident
SMP	sump
SORV	stuck open relief valve
SOV	solenoid-operated valve
SPAR	standardized plant analysis risk
SRV	safety relief valve
SS	system study
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
T	time (hours or years)
TBC	turbine building cooling water
TDP	turbine-driven pump
TFM	transformer
TM	test or maintenance
TNK	tank
TRAN	transient
TSA	traveling screen assembly
UA	unavailability
UL	upper allowable limit
UR	unreliability
VBV	vacuum breaker valve
VSLOCA	very small loss-of-coolant accident
VSS	vapor suppression system
WSRC	Westinghouse Savannah River Company
XVM	manual-operated valve
ZEBD	Centralized Component Reliability Database

Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants

1. INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) maintains a set of risk models for the 103 operating U.S. commercial nuclear power plants (NPPs), termed the "industry" in this report (Ref. 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 work performed to generate SPAR model inputs that represent current industry performance. Current in this context refers to a period centered about the year 2000 and generally implies 1998–2002.

Prior to this effort, the SPAR models used inputs obtained from the various system studies performed by the NRC (Refs. 2–12) and from data analyses performed in support of the NUREG-1150 studies (Refs. 13, 14). The system studies used data from 1987 through 1993, 1995, or 1997, depending upon the study, so they typically characterized component performance around 1990. For components not covered by these system studies, the data analyses performed in support of the NUREG-1150 studies typically reflected industry performance from the 1970s and early 1980s. However, component performance has improved significantly since the 1970s, as documented in the article "Historical Perspective on Failure Rates for U.S. Commercial Reactor Components" (Ref. 15). Similar improvements occurred with respect to initiating event (IE) frequencies (Ref. 16). Therefore, there was a need to update such inputs to reflect current industry performance.

Four types of risk model events are addressed 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 pump fail to start (FTS) or fail to run (FTR), valve fail to open or close (FTO/C), 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 the 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.

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). (IEs for shutdown operation are not covered in this report.) The IE frequencies are characterized by gamma distributions.

This report documents the philosophy guiding the effort to update the inputs for SPAR, the results, and comparisons with other types of data (where available). In addition, the report identifies potential additional work and periodic updating to continue to monitor industry performance. Finally, appendices present more detailed database information and results.

This update effort does not provide values for sump plugging and interfacing systems loss-of-coolant accident (LOCA) events. Other NRC programs are addressing the sump plugging. The interfacing systems LOCA initiators will be modified by the SPAR model developers as they update their models based on detailed comparisons with licensee plant-specific risk models.

Following a historical review of data collection and analysis efforts in Section 2, Section 3 outlines the database development philosophy and Section 4 discusses parameter distributions. Specific results for component UR, component or train UA, system special event probabilities, and IE frequencies are presented in Sections 5 through 8, respectively. Section 9 presents comparisons of selected component UR and component or train UA results with other sources. Section 10 compares this database development effort with applicable requirements from the American Society of Mechanical Engineers (ASME) Standard for PRAs. Finally, Section 11 summarizes the results, and Section 12 lists the references. In addition, there are seven appendices providing additional detail concerning component UR (Appendix A), component or train UA (Appendix B), system special events (Appendix C), IE frequencies (Appendix D), comparisons with other sources (Appendix E), mathematical relationships between averages obtained from component, plant, industry level data (Appendix F), and responses to comments on the draft report (Appendix G).

2. HISTORICAL DATA COLLECTION AND ANALYSIS EFFORTS

Numerous data collection efforts have been conducted to support risk analyses of NPPs. Selected efforts sponsored by the NRC, U.S. Department of Energy (DOE), and others are discussed in this section. Efforts listed below generally covered a wide variety of components; however, several studies covering a single component are also discussed. Reference 17 also contains a review of data sources with information complementary to that presented below.

NRC sponsored an early data collection effort to support the WASH-1400 study (Ref. 18). Appendix III in that report summarizes data for component UR from 29 different sources covering a wide variety of industries. Components included mechanical categories (pumps, various types of valves, and piping) and electrical categories (motors, transformers, relays, circuit breakers, batteries, instrumentation, and emergency diesel generators or EDGs). The UR data cover pre-1960s to 1973. Failure rate distributions were chosen such that the 5th and 95th percentiles covered the spread in failure rates observed in the 29 data sources. WASH-1400 recommended lognormal distributions, characterized by medians and error factors (95th percentile divided by the 50th percentile or median). Medians were rounded to one or three times the appropriate power of ten. Error factors were rounded to three or ten. In addition, TM UAs were estimated for pumps, valves, EDGs, and instrumentation, based on data from four NPPs for 1972. Finally, frequency estimates were provided for LOCAs and several transient IEs.

In the early 1980s, the Idaho National Laboratory (INL) conducted several component-specific studies for the NRC based on reviews of licensee event reports (LERs). These studies covered various periods within the 1972–1982 range. Reports covered control rod drives (Ref. 19), instrumentation and control (Ref. 20), pumps (Ref. 21), valves (Ref. 22), inverters (Ref. 23), and EDGs (Ref. 24). In these studies, component counts for the U.S. NPPs covered in the LERs were estimated. Demands (for demand-related failure modes) were estimated based on the component counts and knowledge of typical test intervals. Failures included only those reported in LERs.

In 1982, the INL conducted a data workshop to develop a consensus generic component database to support the NRC's Interim and National Reliability Evaluation Programs. The resultant database (Ref. 25) included recommended distributions (nominal value and error factor) for components, IEs, and selected human errors to be used as screening values for initial quantification of NPP risk assessments. Nominal values were typically rounded to one, three, or five times the appropriate power of ten. Error factors were rounded to 3, 10, 30, or 100.

At approximately the same time as the INL studies, Oak Ridge National Laboratory (ORNL) collected and analyzed data from a limited set of U.S. NPPs for several types of components. In contrast to the INL studies that used LERs as the basic source (and therefore covered the entire U.S. commercial NPP industry), the ORNL studies involved detailed reviews of plant maintenance records at selected plants to identify failures. By examining maintenance records, ORNL was able to categorize component "failures" as catastrophic, degraded, or incipient. (Typically only catastrophic failures are reported in LERs and included when calculating failure rates for risk studies. The degraded and incipient events contribute to the maintenance UA.) Data covered six to ten plants (24 to 33 total reactor years) ending in approximately 1980, depending upon the study. Reports were issued covering pumps (Ref. 26), valves (Ref. 27), and electrical components (EDGs, batteries, chargers, and inverters) (Ref. 28). Similar to the INL studies discussed previously, the demands were estimated based on knowledge of typical test intervals. However, in contrast to the INL studies, failures were identified from the maintenance records and the plants supplied component population information.

ORNL also reviewed EDG operating experience based on LERs for 1976–1983 to support development of the station blackout rule. The first study (Ref. 29) covered 1976–1980, while the second

(Ref. 30) covered 1981–1983. Demand estimates were obtained from industry responses to NRC questionnaires. Repair times and TM UA data were also obtained and analyzed. The second report compared EDG failure rates obtained from test data and unplanned demand data.

To support the NUREG-1150 probabilistic risk assessments (PRAs) of five NPPs (Ref. 13), Sandia National Laboratory developed a generic database covering component UR, TM UA, and IE frequency (Ref. 14). Component UR estimates were obtained from a review of 25 sources. Data from these sources covered pre-1970s to approximately 1983. In general, the recommended means and error factors were obtained from the best available source rather than from an aggregation of sources. Lognormal distributions were recommended, means were rounded to one significant figure, and error factors were rounded to three or ten.

During the latter 1980s and early 1990s, the INL developed and maintained a component reliability and human error database termed the Nuclear Computerized Library for Assessing Reactor Reliability or NUCLARR (Ref. 31). Component reliability data and failure rate estimates contained within the database included plant-specific data from PRAs available at that time, data from several foreign sources, and data and/or failure rate estimates from sources such as the INL and ORNL studies discussed previously. Aggregation routines were developed to assemble appropriate UR information for a given component failure mode into a recommended failure rate distribution. Maintenance of this database was discontinued in 1994. Recommended failure rates in Reference 31 include data up through approximately 1990. Results cover a wide variety of components and failure modes.

Also during the early 1990s, Brookhaven National Laboratory performed a study on EDG UR and UA (Ref. 32). This study used industry EDG TM outage data from June 1990 through May 1992 as collected by the NRC regional offices. In addition, failures and demands for 1988–1991 from industry were supplied by the Nuclear Management and Resource Council.

In the latter 1990s, the NRC conducted several component studies based upon failure data in the Nuclear Plant Reliability Database System (NPRDS) (Ref. 33) and LERs. These studies included turbine-driven pumps (TDPs) (Ref. 34), motor-driven pumps (MDPs) (Ref. 35), air-operated valves (AOVs) (Ref. 36), and motor-operated valves (MOVs) (Ref. 37). NPRDS data covered 1987–1995, while LER data covered 1987–1998. (NPRDS was replaced by the Equipment Performance and Information Exchange [EPIX] database (Ref. 38) starting in 1997; 1996 was a transition year, so NPRDS data only up through 1995 were used in these studies.) Because the NPRDS test data overwhelm the LER data (mainly from unplanned demands), the data effectively cover 1987–1995. Component populations and demands associated with the NPRDS failure events were conservatively estimated (to result in conservatively high failure probabilities) based on information in NPRDS supplemented with knowledge of plant-specific testing requirements. Demands associated with the LER failure events were obtained directly from the LERs. These studies analyzed the test demand data (from NPRDS) and the unplanned demand data (from the LERs) and in most cases determined that the two sets of data could be combined. Also, for MDPs and TDPs, FTS and FTR events (typically within the first hour of operation) were combined to obtain failure to operate upon demand probabilities.

Also starting in the latter 1990s and early 2000s, the INL conducted many studies of safety systems at NPPs (Refs. 2–12). Systems included auxiliary feedwater, reactor protection (four different vendor types), high-pressure coolant injection, EDGs, isolation condenser, reactor core isolation cooling, high-pressure core spray, and high-pressure safety injection. These system studies typically identified the various system configurations existing in the U.S. commercial NPP industry, collected LERs concerning these systems, and quantified system reliability based on the performance data in the LERs. (The reactor protection system studies also used NPRDS failure data to support the UR estimates.) Depending upon the particular system, the UR estimates were based solely on unplanned demands, or were based on a combination of unplanned demands and various test demands. Test demands, if used, were estimated based on assumed test intervals. Data collection for the published versions of these studies covered 1987–1993, 1995, or 1997, depending upon the study. Significant development work was also performed to identify or develop state-of-the-art statistical analysis techniques for these studies. These system studies have several unusual features. One is the identification and quantification of recoveries of failures that occurred during unplanned demands. Another is the comparison of unplanned demand performance data with cyclic (approximately every 18 months) and quarterly test data. Finally, for several systems, the unplanned demands provide information concerning actual operational experience such as the restarting of pumps and reopening of injection valves during extended operation (termed system special events in this study). This NRC system study program is ongoing, and yearly updates are now summarized on the NRC public website (Ref. 39).

In addition to NRC data collection efforts, the DOE supported similar projects related to NPP component performance. The DOE Savannah River Site collected and analyzed data from operation of its various production reactors during the 1980s and early 1990s (Refs. 40–42). These reports covered various types of valves and pumps, air compressors, dampers, fans, EDGs, and other electrical equipment.

At approximately the same time, the INL produced two reports related to NPP components to support the risk study of its Advanced Test Reactor. The report *Generic Component Failure Data Base for Light Water and Liquid Sodium Reactor PRAs* (Ref. 43) covers a variety of mechanical systems (water, air/gas, and liquid sodium processing fluids) and electrical components. UR estimates were obtained from the data contained in NUCLARR (discussed previously under NRC efforts) up through February 1990. Data within NUCLARR were divided into a hierarchy of sources: category 1 (plant-specific UR data supporting PRAs involving detailed searches for component failures, demands, and run hours), category 2 (UR data typically involving searches of LERs for failures and estimates for demands or run hours), and category 3 (component UR estimates without supporting data). Component UR estimates were then generated using category 1 data if available. If not available, then category 2 data were used. Finally, if there were no category 1 or 2 data, then category 3 estimates were used. Many component UR estimates in that report were based on category 1 data from U.S. NPPs during the 1980s.

The second report produced by the INL was *Component External Leakage and Rupture Frequency Estimates* (Ref. 44). Component and piping leakage and rupture frequencies listed in that report were obtained from a review of LERs covering 1960–1983. Component counts and piping lengths were estimated using a variety of sources.

In addition, the Savannah River Site produced a component generic database in the early 1990s (Ref. 45). That database covered a wide variety of components in water, chemical process, compressed gas, electrical distribution, and instrumentation and control systems. That effort was essentially an update to the INL report (Ref. 43) but with additional NUCLARR data, Savannah River reactor data, and category 2 sources. These sources included component data up through approximately 1990. When this report was published, it was a comprehensive and up-to-date, publicly available source for component UR estimates for commercial NPPs.

In addition to NRC- and DOE-sponsored data collection efforts, various other organizations have assembled component UR databases applicable to U.S. commercial NPPs. One early and influential effort is documented in the *IEEE Guide to the Collection and Presentation of Electrical, Electronic, Sensing Component, and Mechanical Equipment Reliability Data for Nuclear-Power Generating Stations* (Ref. 46), published in 1984. This report covers the widest range of components of any of the efforts described in this section. Failure rate estimates (low, recommended, and high) were obtained using a Delphi procedure to combine estimates from over 200 data experts within the U.S. Recommended failure rates in this report probably reflect data up through approximately 1980. The report lists as data references the early INL LER surveys (Refs. 19–22) as well as initial results from the ORNL data reviews from selected plants (Ref. 26). Also included in this report are repair times for various components. This data source is no longer supported by the Institute of Electrical and Electronics Engineers.

Although focused on the chemical process industry, *Guidelines for Process Equipment Reliability Data with Data Tables* (Ref. 47), published in 1989, used many of the sources mentioned previously (in addition to data sources from the chemical industry). These include the early 1980s INL and ORNL reports, as well as several foreign databases covering the UR of NPP components. Recommended failure rates in Reference 47 include mean, lower, and upper values.

The Electric Power Research Institute (EPRI) has supported various data collection efforts. One involved EDG UR for 1983–1985 (Ref. 48). EDG data were obtained directly from the industry through the use of surveys. EDG UR results were presented for both all types of demands and only unplanned demands.

In 1992, EPRI developed a component failure database to support the development of advanced reactors (Ref. 49). That report is proprietary and not publicly available. Where possible, recommended failure rates were based on aggregating plant-specific component data obtained from published PRAs. That method is similar to the process used in the INL (Ref. 43) and Savannah River Site (Ref. 45) component reliability databases.

Two notable data collection efforts by risk assessment consulting companies include the Pickard, Lowe, and Garrick, Inc. database (Ref. 50) and the Science Applications International Corporation database (Ref. 51). Both were developed from plant-specific data collected as part of PRAs performed on commercial NPPs by these companies. Both databases are proprietary and not publicly available.

Finally, NPRDS (Ref. 33) and its successor, EPIX (Ref. 38), are the primary databases encompassing component failure data for U.S. commercial NPPs. NPRDS was the main component database for 1974–1996. All operating U.S. plants reported component information (within a specified reportable scope) to this database, which was maintained by The Institute of Nuclear Power Operations (INPO). Information reported to NPRDS included component design, operating characteristics, and performance data. Failures included both catastrophic and degraded events. Reporting of incipient events was optional. Additional information reported to NPRDS included component counts and information concerning operation and testing.

In 1997, the EPIX database replaced NPRDS. EPIX is also maintained by INPO. All operating U.S. commercial NPPs report data to EPIX. Components reported to EPIX generally include those that are within the scope of each plant's Maintenance Rule Program (Ref. 52). Demand and run hour information within EPIX include one-time estimates based on a review of plant experience over at least an 18-month period for all components, and quarterly non-test demands and run hours for a subset of the more important components. Events reported to EPIX include both catastrophic and degraded failures.

Although not considered in this report because the focus is on the performance of components within the U.S. commercial nuclear power industry, various foreign databases have been developed covering NPP component UR. These include the Centralized Component Reliability Database (ZEBD) for German commercial NPPs (and one Dutch and one Swiss plant) (Ref. 53), the Swedish T-Book covering Swedish and Finnish commercial plants (Ref. 54), the Electricité de France database covering French commercial plants (Ref. 55), a Korean effort (Ref. 56), and a Japanese database (Ref. 57).

3. DATABASE DEVELOPMENT PHILOSOPHY

The following concept guided the overall database development effort for SPAR components and IEs:

1. Use data from comprehensive and consistently collected and interpreted sources (containing both failure and demand or run hour information) that are maintained and updated
2. Characterize current industry performance (typically ending in 2002)
3. Structure the characterization of industry-average performance such that results can be updated periodically
4. Allow for efficient yearly comparisons of industry performance with established industry-average baseline performance.

Each of these is discussed below.

Using data from comprehensive existing sources that are maintained and updated minimizes the additional work required to periodically characterize and trend industry performance. In addition, comprehensive sources minimize the need to use backup sources. Finally, use of such data sources minimizes potential inconsistencies in data collection and interpretation.

To characterize current industry performance, data through 2002 were used. For components, data generally covered 1998–2002. The 5-year period for component data is a compromise between two competing effects: longer data periods provide more data and potentially better statistics, but shorter data periods minimize the effects of trends in performance and are therefore more representative of current performance. For system special events and IEs, the data periods all end in 2002, but the starting year varies from 1988 to 1998, depending upon the probability or frequency of the event and whether a trend exists.

Consider a 5-year periodic update as an example of a periodic update to the industry-average performance estimates developed in this report. In that case, the update effort might be performed in 2008, with component data over 2003–2007 being compared with the 1998–2002 results in this report. If no significant differences in component performance were identified, then the baseline estimates in this report might continue to be used. If differences were identified (indicating either improved or degraded performance), then the new estimates (characteristic of the year 2005, rather than 2000), would be used.

Comparisons of industry yearly performance (using data for a given year) with the industry-average baselines developed in this report provide initial information concerning potential trends. These results might be used to identify when the industry-average baselines in this report need to be updated.

For each type of SPAR input, a hierarchy of potential data sources was established. Each results section begins with a description of the applicable hierarchy of data sources. Typically, only the top data source is one that is maintained and updated. These sources may contain data obtained at the component level, plant level, or industry level, or they may contain just recommended probabilities or rates without supporting data. In all cases, the goal was to obtain a mean and distribution for each SPAR input.

Industry-average inputs were generated for the SPAR models. In general, previous inputs to SPAR were also industry averages. In a few cases, the system studies identified significant plant-specific differences. In those cases, the SPAR models used plant-specific values generated in those system studies.

However, a review of more recent data indicated that plants exhibiting the worst performance in those studies (reflecting performance during 1987–1993, 1987–1995, or 1987–1997) generally were no longer outliers in terms of performance. That observation led to a more detailed review of selected component and IE performance for 1997–1999 and 2001–2003, which again indicated that plants with the worst performance during the earlier period were in general nominal performers during the latter period (Ref. 58). In contrast, at the industry level, performance during 1997–2003 was relatively stable. Therefore, industry-average performance inputs were chosen for most uses of the SPAR models. For analyses that require plant-specific performance estimates, the industry-average distributions can be used as priors in Bayesian updates using the plant-specific data as evidence.

Finally, the following two documents helped guide the SPAR basic event and IE update effort:

1. *Handbook of Parameter Estimation for Probabilistic Risk Assessment* (Ref. 17)
2. *Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications* (Ref. 59).

4. PARAMETER DISTRIBUTIONS

PRAs of U.S. commercial NPPs have used a variety of distributions to model the uncertainty in both basic events and IE frequencies. Lognormal distributions were used in the WASH-1400 study (Ref. 18) in the mid 1970s and have been used in many studies since then. The *PRA Procedures Guide* (Ref. 60) presented information on modeling component UR using lognormal, beta, and gamma distributions. In contrast, the *Probabilistic Safety Analysis Procedures Guide* (Ref. 61) recommended loguniform distributions for component failure rates listed in the document. Finally, the more recent data analysis studies performed at the INL have systematically used beta distributions for probability upon demand data and gamma distributions for time-related data. For the current study, beta and gamma distributions are used exclusively. (However, with the information presented, other distributions can be fitted to the results if desired.) This decision was made based on several factors. The first is the flexibility of such distributions in being able to represent component failure data (similar to the flexibility of the lognormal distribution). In addition, these distributions are natural choices given the assumptions of demand data following the binomial distribution (constant probability of failure per demand) and time-related data following the Poisson distribution (constant occurrence rate with time). The beta distribution is bounded by (0, 1), matching the bounds for probabilities. The gamma distribution is bounded by (0, ∞), matching the bounds for rates. Finally, these distributions are conjugate priors, resulting in simple equations for Bayesian updates using these distributions as industry-average priors.

Because the component UR data in this report include a high percentage of components without any failures (often greater than 90%), insufficient data exist to perform detailed studies to clearly identify the most appropriate distribution type (or types) to represent the component failure mode distributions. Attempts to fit distributions to the component UR data provided inconclusive results as to which types of distributions were most appropriate.

Standby component failure modes such as pump FTS and valve FTO/C historically have been modeled as either demand related (failure probability upon demand) or standby time related (failure rate). For example, the NUREG-1150 studies (Ref. 13) expressed such events as probability per demand, while the *Probabilistic Safety Analysis Procedures Guide* (Ref. 61) expressed such events as rates per standby time. The present study follows the more traditional approach of probability per demand presently used in the SPAR models. Also, this same approach was taken for the INL system studies, in which significant effort was expended to develop state-of-the-art analysis methodologies. However, adoption of this approach does not imply that such standby component failure modes are best modeled as demand-related. This decision was made mainly because the available data were typically collected on a per-demand basis. Additional studies would need to be performed to clearly identify whether such standby component failure modes should be expressed as purely demand related, purely standby time related, or a combination of the two models. See Reference 17 for a discussion of this issue.

Beta and gamma distributions model uncertainties in the SPAR industry-average inputs. The beta distribution applies to probability upon demand types of inputs (FTS, FTO/C, etc.), while the gamma distribution applies to time-based rates (FTR, IE frequencies, etc.). The beta distribution function for probability upon demand p is the following:

$$f(p) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} p^{\alpha-1}(1-p)^{\beta-1} \tag{4-1}$$

for $0 \le p \le 1$ and α and $\beta > 0$. The gamma functions in Equation (4-1), $\Gamma(\alpha)$ for example, are defined as

$$\Gamma(\alpha) = \int_0^\infty x^{\alpha-1} e^{-x} dx . \tag{4-2}$$

The beta distribution is denoted beta (α, β). The mean of this distribution is

$$p_{mean} = \frac{\alpha}{\alpha + \beta} \tag{4-3}$$

and the variance is

$$p_{variance} = \frac{\alpha\beta}{(\alpha + \beta)^2(\alpha + \beta + 1)} \tag{4-4}$$

Additional information on the beta distribution is presented in Reference 17.

The gamma probability distribution function for the failure or IE rate λ (units of events/time) is the following:

$$f(\lambda) = \frac{(\beta)^\alpha}{\Gamma(\alpha)} \lambda^{\alpha-1} \exp(-\lambda\beta) \tag{4-5}$$

where λ, α, and $\beta > 0$. The mean of this distribution is

$$\lambda_{mean} = \frac{\alpha}{\beta} \tag{4-6}$$

and the variance is

$$\lambda_{variance} = \frac{\alpha}{\beta^2} \tag{4-7}$$

Additional information on the gamma distribution is also presented in Reference 17. Alternative definitions of the gamma distribution (such as those in the Microsoft Excel software) define β as the inverse of the β used in this report. The β used in this report has units of hours or reactor critical years (depending upon the application).

Details concerning the estimation of α and β are presented in the appendices. In general, if sufficient data were available such that an empirical Bayes analysis (termed parametric empirical Bayes analysis in Chapter 8 of Reference 17 provided results, then α and β estimates from that analysis were used. (The definition of "sufficient" is not clear cut. However, in general if there were only several failure events, the empirical Bayes analysis failed to produce results. Such cases are discussed later in this section.) The empirical Bayes method can be applied at the plant or component level or at the year level. At the plant level, failure data (f_i / d_i) for a given component failure mode (combining data from similar component types at the plant) are considered a group. The beta distribution (parameters α and β) is estimated directly from the data, modeling variation between groups. Each group is assumed to have its own failure probability (p_i), obtained from this beta distribution. Failures (f_i) are assumed to have a binomial distribution governed by p_i. The likelihood function for the data is based on the observed number of failures and successes and on this beta-binomial model. The likelihood function is then maximized based on an iterative search of the parameters α and β. For time-based failures, a similar process is used, based on a gamma-Poisson model. The empirical Bayes method is similar at the component level, except each component's data are considered a group. Finally, at the year level, data for each year are considered a group.

Past industry-average databases have often worked with component data at the plant level. For example, the NUCLARR database discussed in Section 2 typically identified summary component data from each available plant (generally obtained from plant-specific PRAs). For a specific component such as EDGs, data collected for each EDG at a given plant (e.g., FTS events and associated demands over some time period) were combined and only these combined, plant-level results were reported. (Therefore, the component-level results were lost in this aggregation process.) These plant-level data groups were then analyzed to obtain industry-average mean and uncertainty estimates. This approach was also used in other efforts (Refs. 43, 45, 49, and 50). Empirical Bayes analysis results at the plant level were used in this report to determine the beta and gamma distribution parameters α and β. Plant-level results were used rather than component-level results to estimate uncertainties based on several considerations:

1. Because of the limited number of components with failures (see Appendix A for summaries of component data presented at the component, plant, and industry level), data grouped at the component level often result in a high percentage of component groups with no failures. This results in cases where the empirical Bayes analysis fails to generate results. In contrast, at the plant level, significantly fewer plant-level groups have no failures. This results in fewer cases where the empirical Bayes analysis fails to generate results.

2. Because of the limited number of components with failures, empirical Bayes results obtained at the component level do not always appear to be realistic (very low estimates for α can result, leading to extremely low 5th percentile estimates). In contrast, the results obtained at the plant level generally appear to be better behaved.

Appendix F discusses data at the component, plant, and industry level in more detail. An area for possible future study is to examine, in detail, uncertainty analyses performed at the component level to determine under what types of conditions such analyses are considered to be appropriate.

In some cases, the empirical Bayes analyses at the plant level resulted in estimates for α less than 0.3. (The lower the estimate is for α, the wider the uncertainty band.) Both the beta and gamma distributions can result in unrealistically low estimates for the 5th percentiles of the distributions as α decreases. This behavior is illustrated in Table 4-1. In that table, beta and gamma distribution percentiles are tabulated for means of 5E–03 and 5E–06, with α varying from 10 to 0.1. As shown in the table, the 5th percentile drops dramatically as α is reduced from 0.3 to 0.2 and 0.1. For both means, 5E–03 and 5E–06, the 5th percentiles for $\alpha = 0.2$ and 0.1 are considered unrealistic in terms of representing lower bounds on component UR. Therefore, if the empirical Bayes analyses resulted in estimates of α less than 0.3, a lower allowable limit of 0.3 was assumed. In such instances, the β parameter was then recalculated, based on the mean and lower limit α. Cases where this lower limit was applied are identified in Appendix A and in Table 5-1 [the "Distribution (note a)" column] in the next section.

One interesting observation from Table 4-1 is that the beta and gamma distributions are similar in terms of parameters and percentiles for the two mean values listed. However, as the mean value increases above 5E–03, the two distributions start to diverge, especially for lower α's. In addition, the 95th percentiles do not vary dramatically as α varies from 10 to 0.1 (unlike the behavior of the 5th percentiles). The difference between the lowest and highest 95th percentiles is less than a factor of four.

In several cases, even with many failure events (typically greater than five), empirical Bayes analysis results were degenerate, indicating little variation between plants. For these few cases, the assumption of homogeneity in the data resulted in the use of α estimates obtained from the Bayesian update of the Jeffreys noninformative prior. Again, these cases are identified in Appendix A and in Table 5-1.

Table 4-1. Beta and gamma distribution percentiles as a function of the mean and α.

Beta Parameters			Beta Distribution				
Mean	α	β	5th Percentile	Median	Mean	95th Percentile	Error Factor (note a)
5.00E-03	10	1.99E+03	2.72E-03	4.84E-03	5.00E-03	7.84E-03	1.6
5.00E-03	3	5.97E+02	1.37E-03	4.46E-03	5.00E-03	1.05E-02	2.3
5.00E-03	1	1.99E+02	2.58E-04	3.48E-03	5.00E-03	1.49E-02	4.3
5.00E-03	0.5	9.95E+01	1.98E-05	2.29E-03	5.00E-03	1.92E-02	8.4
5.00E-03	0.3	5.97E+01	5.41E-07	1.23E-03	5.00E-03	2.29E-02	18.6
5.00E-03	0.2	3.98E+01	5.18E-09	5.26E-04	5.00E-03	2.58E-02	49.0
5.00E-03	0.1	1.99E+01	3.05E-15	3.05E-05	5.00E-03	2.94E-02	963.7
5.00E-06	10	2.00E+06	2.71E-06	4.83E-06	5.00E-06	7.85E-06	1.6
5.00E-06	3	6.00E+05	1.36E-06	4.46E-06	5.00E-06	1.05E-05	2.4
5.00E-06	1	2.00E+05	2.56E-07	3.47E-06	5.00E-06	1.50E-05	4.3
5.00E-06	0.5	1.00E+05	1.97E-08	2.27E-06	5.00E-06	1.92E-05	8.4
5.00E-06	0.3	6.00E+04	5.35E-10	1.22E-06	5.00E-06	2.29E-05	18.8
5.00E-06	0.2	4.00E+04	5.10E-12	5.19E-07	5.00E-06	2.58E-05	49.7
5.00E-06	0.1	2.00E+04	2.97E-18	2.97E-08	5.00E-06	2.90E-05	978.1
Gamma Parameters			Gamma Distribution				
Mean	α	β	5th Percentile	Median	Mean	95th Percentile	Error Factor
5.00E-03	10	2.00E+03	2.71E-03	4.83E-03	5.00E-03	7.85E-03	1.6
5.00E-03	3	6.00E+02	1.36E-03	4.46E-03	5.00E-03	1.05E-02	2.4
5.00E-03	1	2.00E+02	2.56E-04	3.47E-03	5.00E-03	1.50E-02	4.3
5.00E-03	0.5	1.00E+02	1.97E-05	2.27E-03	5.00E-03	1.92E-02	8.4
5.00E-03	0.3	6.00E+01	5.35E-07	1.22E-03	5.00E-03	2.29E-02	18.8
5.00E-03	0.2	4.00E+01	5.10E-09	5.19E-04	5.00E-03	2.58E-02	49.7
5.00E-03	0.1	2.00E+01	2.97E-15	2.97E-05	5.00E-03	2.90E-02	978.2
5.00E-06	10	2.00E+06	2.71E-06	4.83E-06	5.00E-06	7.85E-06	1.6
5.00E-06	3	6.00E+05	1.36E-06	4.46E-06	5.00E-06	1.05E-05	2.4
5.00E-06	1	2.00E+05	2.56E-07	3.47E-06	5.00E-06	1.50E-05	4.3
5.00E-06	0.5	1.00E+05	1.97E-08	2.27E-06	5.00E-06	1.92E-05	8.4
5.00E-06	0.3	6.00E+04	5.35E-10	1.22E-06	5.00E-06	2.29E-05	18.8
5.00E-06	0.2	4.00E+04	5.10E-12	5.19E-07	5.00E-06	2.58E-05	49.7
5.00E-06	0.1	2.00E+04	2.97E-18	2.97E-08	5.00E-06	2.90E-05	978.2
Note a - The error factor is the 95th percentile divided by the median.							

In all cases, a simplified version of the constrained noninformative distribution (CNID) (Ref. 17) was also generated. However, those results were used only if the empirical Bayes analyses did not produce results. The CNID for gamma distributions uses $\alpha = 0.5$ and the posterior mean of a Bayesian update of the Jeffreys noninformative prior with industry data (Ref. 17) (termed the Jeffreys mean in this report) to calculate β (Equation 4-5). However, the CNID for beta distributions uses an α that is a function of the industry Jeffreys mean and ranges from 0.5 to approximately 0.32. For this report, a simplified CNID (SCNID) was used for beta distributions in which α was always set to 0.5. In cases where the SCNID was used, the Jeffreys mean was used. The industry Jeffreys mean is

$$P_{mean} = \frac{n+0.5}{D+1} \tag{4-8}$$

for beta distributions and

$$\lambda_{mean} = \frac{n+0.5}{T} \tag{4-9}$$

for gamma distributions

where

n = number of industry events

D = number of industry demands

T = number of industry hours or reactor critical years.

Finally, for use in the SPAR models, selected distributions for component UR and UA, system special event probabilities and rates, and IE frequencies were rounded to reflect the precision of the results. The selected mean values were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. This rounding scheme ensures that the largest change resulting from rounding is approximately 15%. This rounding scheme was also applied to α, which is an indication of the spread in the distribution (similar to the error factor, which is defined as the 95th percentile divided by the median). However, β is presented using three significant figures to preserve the mean. Note that rounding is typical for industry-average databases. For example, the WASH-1400 (Ref. 18) authors rounded component failure rate estimates to one or three times the appropriate power of ten. The database supporting the NUREG-1150 studies (Ref. 14) typically rounded estimates to one significant figure. Finally, (Ref. 15) rounded its estimates to one significant figure. Given the amount of data available for this effort and their applicability, rounding to one significant figure was considered to be too gross. For example, if the mean from the data was determined to be 1.49E–03, this would be rounded to 1E–03 using one significant figure. This represents a 33% change because of the rounding scheme. Given that typical cut sets in PRAs contain more than one basic event, this 33% change could be magnified even more and result in significant differences. That is why the intermediate rounded values of 1.2, 1.5, and 2.5 were introduced into the rounding scheme. In contrast, rounding to two significant figures would imply a maximum imprecision of approximately 1% at the upper range of 9.9, which would also be misleading.

5. COMPONENT UNRELIABILITY

To identify the types of components and failure modes included in the SPAR models, a master list of basic events (from all of the SPAR models) was constructed. Then that list was examined to ensure that there was consistency in coverage of failure modes between similar component types. From this expanded list, input events were identified that applied to component types and associated failure modes found in the models. The 51 component types include various types of pumps, valves, emergency power sources, and others. These component types contributed 171 component type and failure mode combinations. Failures modes addressed in this effort include FTS and FTR for components that must start upon demand and run for a specified mission time, FTO/C for valves and circuit breakers, and others. Table 5-1 presents this master list of components and failure modes and the UR results. The following sections explain the various entries in the table.

External leakage and internal leakage failure modes are also addressed in this document. External leakage is subdivided into two modes: small (ELS), covering 1 to 50 gallons per minute (gpm) and large (ELL), covering > 50 gpm (for water systems). These failure modes are applicable to pumps, valves, heat exchanger shells and tubes, tanks, and piping. The definitions for these modes are similar to those used in Reference 44, although in that document ELL was referred to as rupture. Internal leakage applies to valves and is subdivided into small (ILS) (covering events that indicate local leak rate tests resulted in internal leakage greater than allowable limits or involve 1 to 50 gpm [water systems]), and large (ILL) (covering more severe internal leakages or > 50 gpm).

Two changes to SPAR basic events made in this report include the distinction between standby and running/alternating components and the breakdown of FTR into fail to run for the first hour (FTR≤1H) and fail to run beyond the first hour (FTR>1H). These changes were made based on observations from Reference 15. In that article, FTR rates were significantly different for standby versus running/alternating categories for some components. In addition, significant differences were noted between rates for FTR≤1H and FTR>1H. The Mitigating Systems Performance Index (MSPI) Program (Ref. 62) also distinguishes failures that occur during the first hour of operation by placing them into the FTS category.

5.1 Component Boundaries

Appendix A presents details of the boundaries for the components listed in Table 5-1. In general, valves include the valve, valve operator, circuit breaker (if applicable), and local instrumentation and control circuitry (including the local motor control center). Pumps include the pump, pump driver, circuit breaker (if applicable), and local instrument and control circuitry. Room cooling and pump cooling provided by service water systems are not included. Emergency power sources (mainly diesel generators) include the generator, generator driver (typically a diesel engine), output circuit breaker, and local control circuitry. (The sequencer is included in this report as a separate component.) Again, room cooling and cooling water support are not included. These component boundary definitions generally are consistent with those presented in the parameter estimation handbook (Ref. 17), the MSPI Program, and the NRC common-cause failure efforts (Ref. 16). However, the common-cause failure database efforts include the sequencer and the heating, ventilating, and air conditioning within the EDG component boundary.

Table 5-1. Component UR data and results.

Component Failure Mode	Description	Data Source	Data				Industry-average Failure Probability or Rate Distribution (note a)									Comments (see Appendix A for details)
			Failures	Demands or Hours	d or h	Components	Distribution (note b)	Mean	α	β	Error Factor	Rounded Mean (note c)	Rounded α (note c)	β (note d)	Error Factor	
ABT FTOP	Automatic Bus Transfer Switch Fail to Operate	EPIX	0	163	d	23	Beta (Jeffreys, SCNID)	3.05E-03	0.500	1.635E+02	8.4	3.0E-03	0.5	1.66E+02	8.4	0 events for 1998 - 2002, so 1997 - 2004 data used
ACC ELS	Air Accumulator External Leak Small	EPIX	3	67346880	h	961	Gamma (EB/PL/KS, LL)	4.94E-08	0.300	6.073E+06	18.8	5.0E-08	0.3	6.00E+06	18.8	1997 - 2004 data
ACC ELL	Air Accumulator External Leak Large	EPIX			h		Gamma (ELS*0.07, LL)	3.46E-09	0.300	8.676E+07	18.8	3.0E-09	0.3	1.00E+08	18.8	Small leak times 0.07
ADU FTOP	Air Dryer Unit Fail to Operate	WSRC			h		Gamma (WSRC, LL)	5.00E-06	0.300	6.000E+04	18.8	5.0E-06	0.3	6.00E+04	18.8	
AHU RUN FTR	Air Handling Unit (Running) Fail to Run	EPIX	24	4864939	h	176	Gamma (EB/PL/KS, LL)	1.37E-05	0.300	2.190E+04	18.8	1.5E-05	0.3	2.00E+04	18.8	
AHU RUN FTS	Air Handling Unit (Running) Fail to Start	EPIX	31	15484	d	176	Beta (EB/PL/KS, LL)	2.73E-03	0.300	1.096E+02	18.7	2.5E-03	0.3	1.20E+02	18.7	
AHU STBY FTR≤1H	Air Handling Unit (Standby) Fail to Run During First Hour of Operation	EPIX	4	6965	h	56	Gamma (EB/PL/KS, LL)	2.28E-03	0.300	1.316E+02	18.8	2.5E-03	0.3	1.20E+02	18.8	
AHU STBY FTR>1H	Air Handling Unit (Standby) Fail to Run After First Hour of Operation	EPIX	0	131445	h	175	Gamma (Jeffreys, SCNID)	3.80E-06	0.500	1.314E+05	8.4	4.0E-06	0.5	1.25E+05	8.4	
AHU STBY FTS	Air Handling Unit (Standby) Fail to Start	EPIX	10	22251	d	231	Beta (EB/PL/KS, EB/PL/KS)	8.29E-04	0.360	4.339E+02	13.5	8.0E-04	0.4	5.00E+02	11.4	
AOV FC	Air-Operated Valve Fail to Control	WSRC			h		Gamma(WSRC, LL)	3.00E-06	0.300	1.000E+05	18.8	3.0E-06	0.3	1.00E+05	18.8	
AOV FTO/C	Air-Operated Valve Fail to Open or Close	EPIX	76	80117	d	2756	Beta (EB/PL/KS, EB/PL/KS)	1.11E-03	1.005	9.044E+02	4.3	1.2E-03	1.0	8.32E+02	4.3	
AOV SO	Air-Operated Valve Spurious Operation	EPIX	20	120712800	h	2756	Gamma (EB/PL/KS, LL)	1.82E-07	0.300	1.648E+06	18.8	2.0E-07	0.3	1.50E+06	18.8	
AOV ELS	Air-Operated Valve External Leak Small	EPIX	2	194191680	h	2771	Gamma (Jeffreys, SCNID)	1.29E-08	0.500	3.884E+07	8.4	1.2E-08	0.5	4.17E+07	8.4	1 to 50 gpm. 1997 - 2004 data.
AOV ELL	Air-Operated Valve External Leak Large	EPIX			h		Gamma (ELS*0.07, LL)	9.01E-10	0.300	3.329E+08	18.8	9.0E-10	0.3	3.33E+08	18.8	> 50 gpm. Small leak times 0.07.
AOV ILS	Air-Operated Valve Internal Leak Small	EPIX	49	194191680	h	2771	Gamma (EB/PL/KS, EB/PL/KS)	2.42E-07	0.661	2.731E+06	6.2	2.5E-07	0.7	2.80E+06	5.8	1 to 50 gpm. 1997 - 2004 data.
AOV ILL	Air-Operated Valve Internal Leak Large	EPIX			h		Gamma (ILS*0.02, LL)	4.84E-09	0.300	6.198E+07	18.8	5.0E-09	0.3	6.00E+07	18.8	> 50 gpm. Small leak times 0.02
BAT FTOP	Battery (dc) Fail to Operate	EPIX	27	15899400	h	363	Gamma (EB/PL/KS, EB/PL/KS)	1.86E-06	0.427	2.296E+05	10.4	2.0E-06	0.4	2.00E+05	11.5	
BCH FTOP	Battery Charger Fail to Operate	EPIX	80	17169600	h	392	Gamma (EB/PL/KS, EB/PL/KS)	5.08E-06	1.585	3.120E+05	3.2	5.0E-06	1.5	3.00E+05	3.3	
BIS FTOP	Bistable Fail to Operate	RPS SSs	55.0	102094	d		Beta (Jeffreys, SCNID)	5.44E-04	0.500	9.193E+02	8.4	5.0E-04	0.5	1.00E+03	8.4	
BUS FTOP	Bus Fail to Operate	EPIX	3	7183200	h	164	Gamma (EB/PL/KS, EB/PL/KS)	4.34E-07	0.502	1.157E+06	8.4	4.0E-07	0.5	1.25E+06	8.4	
CBK FTO/C	Circuit Breaker Fail to Open or Close	EPIX	83	50226	d	4022	Beta (EB/PL/KS, EB/PL/KS)	2.55E-03	0.698	2.730E+02	5.8	2.5E-03	0.7	2.79E+02	5.8	
CBK SO	Circuit Breaker Spurious Operation	EPIX	28	176163600	h	4022	Gamma (EB/PL/KS, EB/PL/KS)	1.71E-07	1.983	1.160E+07	2.8	1.5E-07	2.0	1.33E+07	2.8	
CHL RUN FTR	Chiller (Running) Fail to Run	EPIX	164	3402465	h	113	Gamma (EB/PL/KS, EB/PL/KS)	9.42E-05	0.489	5.191E+03	8.7	9.0E-05	0.5	5.56E+03	8.4	
CHL RUN FTS	Chiller (Running) Fail to Start	EPIX	66	6483	d	113	Beta (EB/PL/KS, EB/PL/KS)	9.83E-03	0.818	8.240E+01	5.0	1.0E-02	0.8	7.92E+01	5.1	
CHL STBY FTR≤1H	Chiller (Standby) Fail to Run During First Hour of Operation	EPIX	5	2401	h	38	Gamma (Jeffreys, Jeffreys)	2.29E-03	5.500	2.401E+03	1.9	2.5E-03	5.0	2.00E+03	2.0	
CHL STBY FTR>1H	Chiller (Standby) Fail to Run After First Hour of Operation	EPIX	13.7	16427	h	21	Gamma (Jeffreys, SCNID)	8.64E-04	0.500	5.784E+02	8.4	9.0E-04	0.5	5.56E+02	8.4	
CHL STBY FTS	Chiller (Standby) Fail to Start	EPIX	10	5470	d	59	Beta (Jeffreys, SCNID)	1.92E-03	0.500	2.600E+02	8.4	2.0E-03	0.5	2.50E+02	8.4	

Table 5-1. (continued).

Component Failure Mode	Description	Data Source	Data					Industry-average Failure Probability or Rate Distribution (note a)								Comments (see Appendix A for details)
			Failures	Demands or Hours	d or h	Components	Distribution (note b)	Mean	α	β	Error Factor	Rounded Mean (note c)	Rounded α (note c)	β (note d)	Error Factor	
CKV FTC	Check Valve Fail to Close	EPIX	2	24090	d	729	Beta (Jeffreys, SCNID)	1.04E-04	0.500	4.818E+03	8.4	1.0E-04	0.5	5.00E+03	8.4	
CKV FTO	Check Valve Fail to Open	EPIX	0	38550	d	729	Beta (Jeffreys, SCNID)	1.30E-05	0.500	3.855E+04	8.4	1.2E-05	0.5	4.17E+04	8.4	0 events for 1998 - 2002, so 1997 - 2004 data used
CKV ELS	Check Valve External Leak Small	EPIX	1	51088320	h	729	Gamma (Jeffreys, SCNID)	2.94E-08	0.500	1.703E+07	8.4	3.0E-08	0.5	1.67E+07	8.4	1 to 50 gpm. 1997 - 2004 data.
CKV ELL	Check Valve External Leak Large	EPIX			h		Gamma (ELS*0.07, LL)	2.06E-09	0.300	1.460E+08	18.8	2.0E-09	0.3	1.50E+08	18.8	> 50 gpm. Small leak times 0.07.
CKV ILS	Check Valve Internal Leak Small	EPIX	23	51088320	h	729	Gamma (EB/PL/KS, LL)	1.48E-06	0.300	2.027E+05	18.8	1.5E-06	0.3	2.00E+05	18.8	1 to 50 gpm. 1997 - 2004 data.
CKV ILL	Check Valve Internal Leak Large	EPIX			h		Gamma (ILS*0.02, LL)	2.96E-08	0.300	1.014E+07	18.8	3.0E-08	0.3	1.00E+07	18.8	> 50 gpm. Small leak times 0.02
CRD FTOP	Control Rod Drive Fail to Operate	RPS SSs	2.0	189536	d		Beta (Jeffreys, SCNID)	1.32E-05	0.500	3.791E+04	8.4	1.2E-05	0.5	4.17E+04	8.4	
CTF RUN FTR	Cooling Tower Fan (Running) Fail to Run	EPIX	0	839875	h	34	Gamma (Jeffreys, SCNID)	5.95E-07	0.500	8.399E+05	8.4	6.0E-07	0.5	8.33E+05	8.4	
CTF RUN FTS	Cooling Tower Fan (Running) Fail to Start	EPIX	1	13855	d	34	Beta (Jeffreys, SCNID)	1.08E-04	0.500	4.618E+03	8.4	1.0E-04	0.5	5.00E+03	8.4	
CTF STBY FTR≤1H	Cooling Tower Fan (Standby) Fail to Run During First Hour of Operation	EPIX	2	1515	h	31	Gamma (Jeffreys, SCNID)	1.65E-03	0.500	3.030E+02	8.4	1.5E-03	0.5	3.33E+02	8.4	
CTF STBY FTR>1H	Cooling Tower Fan (Standby) Fail to Run After First Hour of Operation	EPIX	0	11133	h	31	Gamma (Jeffreys, SCNID)	4.49E-05	0.500	1.113E+04	8.4	4.0E-05	0.5	1.25E+04	8.4	
CTF STBY FTS	Cooling Tower Fan (Standby) Fail to Start	EPIX	3	1515	d	31	Beta (Jeffreys, SCNID)	2.31E-03	0.500	2.161E+02	8.4	2.5E-03	0.5	2.00E+02	8.4	
CTG STBY FTLR	Combustion Turbine Generator (Standby) Fail to Load and Run During First Hour of Operation	EPIX	0	267	d	2	Beta (Jeffreys, SCNID)	1.87E-03	0.500	2.680E+02	8.4	2.0E-03	0.5	2.50E+02	8.4	1998 - 3Q2004 data used
CTG STBY FTR>1H	Combustion Turbine Generator (Standby) Fail to Run After First Hour of Operation	EPIX	0	16	h	2	Gamma (EDG FTR, SCNID)	8.48E-04	0.300	3.538E+02	18.8	8.0E-04	0.3	3.75E+02	18.8	1998 - 3Q2004 data used. Data limited so EDG FTR used
CTG STBY FTS	Combustion Turbine Generator (Standby) Fail to Start	EPIX	6	267	d	2	Beta (Jeffreys, SCNID)	2.43E-02	0.500	2.012E+01	8.1	2.5E-02	0.5	1.95E+01	8.1	1998 - 3Q2004 data used
DDP STBY FTR≤1H	Diesel-Driven Pump (Standby) Fail to Run During First Hour of Operation	EPIX	4	3277	h	27	Gamma (EB/PL/KS, LL)	1.58E-03	0.300	1.899E+02	18.8	1.5E-03	0.3	2.00E+02	18.8	
DDP STBY FTR>1H	Diesel-Driven Pump (Standby) Fail to Run After First Hour of Operation	EPIX	No data		h		Gamma (FTR≤1H*0.06, LL)	9.48E-05	0.300	3.165E+03	18.8	9.0E-05	0.3	3.33E+03	18.8	No data. FTR≤1H times 0.06
DDP STBY FTS	Diesel-Driven Pump (Standby) Fail to Start	EPIX	9	5161	d	27	Beta (EB/PL/KS, LL)	3.88E-03	0.300	7.702E+01	18.6	4.0E-03	0.3	7.47E+01	18.6	
DDP ELS	Diesel-Driven Pump External Leak Small	EPIX	0	2032320	h	29	Gamma (Jeffreys, SCNID)	2.46E-07	0.500	2.032E+06	8.4	2.5E-07	0.5	2.00E+06	8.4	1 to 50 gpm. 1997 - 2004 data.
DDP ELL	Diesel-Driven Pump External Leak Large	EPIX			h		Gamma (ELS*0.07, LL)	1.72E-08	0.300	1.742E+07	18.8	1.5E-08	0.3	2.00E+07	18.8	> 50 gpm. Small leak times 0.07.
EDG STBY FTLR	Emergency Diesel Generator (Standby) Fail to Load and Run During First Hour of Operation	EPIX	61	21342	d	225	Beta (EB/PL/KS, EB/PL/KS)	2.90E-03	1.411	4.866E+02	3.4	3.0E-03	1.5	5.00E+02	3.3	
EDG STBY FTR>1H	Emergency Diesel Generator (Standby) Fail to Run After First Hour of Operation	EPIX	50	59875	h	225	Gamma (EB/PL/KS, EB/PL/KS)	8.48E-04	2.010	2.370E+03	2.8	8.0E-04	2.0	2.50E+03	2.8	
EDG STBY FTS	Emergency Diesel Generator (Standby) Fail to Start	EPIX	98	24206	d	225	Beta (EB/PL/KS, EB/PL/KS)	4.53E-03	1.075	2.362E+02	4.1	5.0E-03	1.0	1.99E+02	4.3	
EOV FTO	Explosive-Operated Valve Fail to Open	EPIX	0	468	d	53	Beta (Jeffreys, SCNID)	1.07E-03	0.500	4.685E+02	8.4	1.0E-03	0.5	5.00E+02	8.4	
FAN RUN FTR	Fan (Running) Fail to Run	EPIX	57	6279790	h	234	Gamma (EB/PL/KS, EB/PL/KS)	1.08E-05	0.652	6.037E+04	6.3	1.0E-05	0.7	7.00E+04	5.8	
FAN RUN FTS	Fan (Running) Fail to Start	EPIX	18	24024	d	234	Beta (EB/PL/KS, LL)	1.79E-03	0.300	1.673E+02	18.7	2.0E-03	0.3	1.50E+02	18.7	
FAN STBY FTR≤1H	Fan (Standby) Fail to Run During First Hour of Operation	EPIX	19	17019	h	145	Gamma (EB/PL/KS, EB/PL/KS)	1.91E-03	0.348	1.822E+02	14.3	2.0E-03	0.3	1.50E+02	18.8	
FAN STBY FTR>1H	Fan (Standby) Fail to Run After First Hour of Operation	EPIX	8.0	76434	h	103	Gamma (Jeffreys, SCNID)	1.11E-04	8.500	7.643E+04	1.7	1.2E-04	8.0	6.67E+04	1.7	
FAN STBY FTS	Fan (Standby) Fail to Start	EPIX	33	25099	d	248	Beta (EB/PL/KS, LL)	2.89E-03	0.300	1.035E+02	18.6	3.0E-03	0.3	9.97E+01	18.6	

Table 5-1. (continued).

Component Failure Mode	Description	Data Source	Data				Industry-average Failure Probability or Rate Distribution (note a)									Comments (see Appendix A for details)
			Failures	Demands or Hours	d or h	Components	Distribution (note b)	Mean	α	β	Error Factor	Rounded Mean (note c)	Rounded α (note c)	β (note d)	Error Factor	
FLT PLG (CLEAN)	Filter Plug (Clean Water System)	EPIX	1	15207360	h	217	Gamma (Jeffreys, SCNID)	9.86E-08	0.500	5.069E+06	8.4	1.0E-07	0.5	5.00E+06	8.4	
HOD FTO/C	*Hydraulic-Operated Damper Fail to Open or Close*	EPIX	7	5341	d	113	Beta (EB/PL/KS, LL)	2.61E-03	0.300	1.146E+02	18.7	2.5E-03	0.3	1.20E+02	18.7	
HOD SO	Hydraulic-Operated Damper Spurious Operation	EPIX	1	4949400	h	113	Gamma (Jeffreys, SCNID)	3.03E-07	0.500	1.650E+06	8.4	3.0E-07	0.5	1.67E+06	8.4	
HOV FC	Hydraulic-Operated Valve Fail to Control	WSRC			h		Gamma(WSRC, LL)	3.00E-06	0.300	1.000E+05	18.8	3.0E-06	0.3	1.00E+05	18.8	
HOV FTO/C	Hydraulic-Operated Valve Fail to Open or Close	EPIX	8	11827	d	558	Beta (EB/PL/KS, LL)	1.51E-03	0.300	1.984E+02	18.7	1.5E-03	0.3	2.00E+02	18.7	
HOV SO	Hydraulic-Operated Valve Spurious Operation	EPIX	6	24440400	h	558	Gamma (EB/PL/KS, LL)	3.61E-07	0.300	8.310E+05	18.8	4.0E-07	0.3	7.50E+05	18.8	
HOV ELS	Hydraulic-Operated Valve External Leak Small	EPIX	0	33848640	h	483	Gamma (Jeffreys, SCNID)	1.48E-08	0.500	3.385E+07	8.4	1.5E-08	0.5	3.33E+07	8.4	1 to 50 gpm. 1997 - 2004 data.
HOV ELL	Hydraulic-Operated Valve External Leak Large	EPIX			h		Gamma (ELS*0.07, LL)	1.03E-09	0.300	2.901E+08	18.8	1.0E-09	0.3	3.00E+08	18.8	> 50 gpm. Small leak times 0.07.
HOV ILS	Hydraulic-Operated Valve Internal Leak Small	EPIX	1	39314880	h	561	Gamma (Jeffreys, SCNID)	3.82E-08	0.500	1.310E+07	8.4	4.0E-08	0.5	1.25E+07	8.4	1 to 50 gpm. 1997 - 2004 data.
HOV ILL	Hydraulic-Operated Valve Internal Leak Large	EPIX			h		Gamma (ILS*0.02, LL)	7.63E-10	0.300	3.931E+08	18.8	8.0E-10	0.3	3.75E+08	18.8	> 50 gpm. Small leak times 0.02
HTG STBY FTLR	Hydro Turbine Generator (Standby) Fail to Load and Run During First Hour of Operation	EPIX	7	1767	d	2	Beta (Jeffreys, SCNID)	4.24E-03	0.500	1.179E+02	8.4	4.0E-03	0.5	1.25E+02	8.4	1997 - 2004 data, additional input from plant
HTG STBY FTR>1H	Hydro Turbine Generator (Standby) Fail to Run After First Hour of Operation	EPIX	1	6162	h	2	Gamma (Jeffreys, SCNID)	2.43E-04	0.500	2.054E+03	8.4	2.5E-04	0.5	2.00E+03	8.4	1997 - 2004 data, additional input from plant
HTG STBY FTS	Hydro Turbine Generator (Standby) Fail to Start	EPIX	6	3322	d	2	Beta (Jeffreys, SCNID)	1.96E-03	0.500	2.551E+02	8.4	2.0E-03	0.5	2.50E+02	8.4	1997 - 2004 data, additional input from plant
HTX PLG CCW/RHR	Heat Exchanger Plug/Foul (CCW or RHR)	EPIX	20	31229400	h	713	Gamma(EB/PL/KS, EB/PL/KS)	6.45E-07	1.416	2.195E+06	3.4	6.0E-07	1.5	2.50E+06	3.3	Data limited to CCW and RHR systems
HTX SHELL ELS	Heat Exchanger Shell External Leak Small	EPIX	2	49967040	h	713	Gamma(Jeffreys, SCNID)	5.00E-08	0.500	9.993E+06	8.4	5.0E-08	0.5	1.00E+07	8.4	1 to 50 gpm. 1997 - 2004 data.
HTX SHELL ELL	Heat Exchanger Shell External Leak Large	EPIX			h		Gamma (ELS*0.07, LL)	3.50E-09	0.300	8.566E+07	18.8	4.0E-09	0.3	7.50E+07	18.8	> 50 gpm. Small leak times 0.07.
HTX TUBE ELS	Heat Exchanger Tube External Leak Small	EPIX	10	49967040	h	713	Gamma (EB/PL/KS, LL)	2.32E-07	0.300	1.293E+06	18.8	2.5E-07	0.3	1.20E+06	18.8	1 to 50 gpm. 1997 - 2004 data.
HTX TUBE ELL	Heat Exchanger Tube External Leak Large	EPIX			h		Gamma (ELS*0.15, LL)	3.48E-08	0.300	8.621E+06	18.8	3.0E-08	0.3	1.00E+07	18.8	> 50 gpm. Small leak times 0.15.
INV FTOP	Inverter Fail to Operate	EPIX	153	27944400	h	638	Gamma (EB/PL/KS, EB/PL/KS)	5.28E-06	1.203	2.278E+05	3.8	5.0E-06	1.2	2.40E+05	3.8	
MDC RUN FTR	Motor-Driven Compressor (Running) Fail to Run	EPIX	158	1989420	h	77	Gamma (EB/PL/KS, EB/PL/KS)	9.16E-05	1.423	1.553E+04	3.4	9.0E-05	1.5	1.67E+04	3.3	
MDC RUN FTS	Motor-Driven Compressor (Running) Fail to Start	EPIX	36	8980	d	77	Beta (EB/PL/KS, EB/PL/KS)	1.33E-02	0.364	2.700E+01	12.9	1.2E-02	0.4	3.29E+01	11.2	
MDC STBY FTR≤1H	Motor-Driven Compressor (Standby) Fail to Run During First Hour of Operation	EPIX	3	939	h	5	Gamma (EB/PL/KS, LL)	3.14E-03	0.300	9.554E+01	18.8	3.0E-03	0.3	1.00E+02	18.8	
MDC STBY FTR>1H	Motor-Driven Compressor (Standby) Fail to Run After First Hour of Operation	EPIX	17.9	10999	h	28	Gamma (EB/PL/KS, EB/PL/KS)	2.62E-03	1.696	6.473E+02	3.1	2.5E-03	1.5	6.00E+02	3.3	
MDC STBY FTS	Motor-Driven Compressor (Standby) Fail to Start	EPIX	15	2150	d	33	Beta (EB/PL/KS, EB/PL/KS)	7.13E-03	0.476	6.628E+01	8.9	7.0E-03	0.5	7.09E+01	8.3	
MDP RUN FTR	Motor-Driven Pump (Running) Fail to Run	EPIX	87	19572488	h	758	Gamma (EB/PL/KS, EB/PL/KS)	4.54E-06	1.655	3.645E+05	3.1	5.0E-06	1.5	3.00E+05	3.3	
MDP RUN FTS	Motor-Driven Pump (Running) Fail to Start	EPIX	132	75048	d	758	Beta (EB/PL/KS, EB/PL/KS)	2.23E-03	0.881	3.942E+02	4.8	2.0E-03	0.9	4.49E+02	4.7	
MDP STBY FTR≤1H	Motor-Driven Pump (Standby) Fail to Run During First Hour of Operation	EPIX	12	32495	h	437	Gamma (EB/PL/KS, EB/PL/KS)	3.78E-04	1.703	4.505E+03	3.1	4.0E-04	1.5	3.75E+03	3.3	
MDP STBY FTR>1H	Motor-Driven Pump (Standby) Fail to Run After First Hour of Operation	EPIX	2.8	568826	h	450	Gamma (Jeffreys, SCNID)	5.80E-06	0.500	8.619E+04	8.4	6.0E-06	0.5	8.33E+04	8.4	
MDP STBY FTS	Motor-Driven Pump (Standby) Fail to Start	EPIX	104	82137	d	887	Beta (EB/PL/KS, EB/PL/KS)	1.47E-03	0.909	6.175E+02	4.6	1.5E-03	0.9	5.99E+02	4.7	

Table 5-1. (continued).

Component Failure Mode	Description	Data Source	Data				Industry-average Failure Probability or Rate Distribution (note a)									Comments (see Appendix A for details)
			Failures	Demands or Hours	d or h	Components	Distribution (note b)	Mean	α	β	Error Factor	Rounded Mean (note c)	Rounded α (note c)	β (note d)	Error Factor	
MDP ELS	Motor-Driven Pump External Leak Small	EPIX	15	130629120	h	1864	Gamma (EB/PL/KS, EB/PL/KS)	1.15E-07	0.987	8.583E+06	4.4	1.2E-07	1.0	8.33E+06	4.3	1 to 50 gpm. 1997 - 2004 data.
MDP ELL	Motor-Driven Pump External Leak Large	EPIX			h		Gamma (ELS*0.07, LL)	8.05E-09	0.300	3.727E+07	18.8	8.0E-09	0.3	3.75E+07	18.8	> 50 gpm. Small leak times 0.07.
MOD FTO/C	Motor-Operated Damper Fail to Open or Close	EPIX	1	1320	d	21	Beta (Jeffreys, SCNID)	1.14E-03	0.500	4.398E+02	8.4	1.2E-03	0.5	4.16E+02	8.4	
MOD SO	Motor-Operated Damper Spurious Operation	EPIX	0	1471680	h	21	Gamma (Jeffreys, SCNID)	3.40E-07	0.500	1.472E+06	8.4	3.0E-07	0.5	1.67E+06	8.4	
MOV FC	Motor-Operated Valve Fail to Control	WSRC			h		Gamma(WSRC, LL)	3.00E-06	0.300	1.000E+05	18.8	3.0E-06	0.3	1.00E+05	18.8	
MOV FTO/C	Motor-Operated Valve Fail to Open or Close	EPIX	244	232264	d	7441	Beta (EB/PL/KS, EB/PL/KS)	1.07E-03	1.277	1.192E+03	3.6	1.0E-03	1.2	1.20E+03	3.8	
MOV SO	Motor-Operated Valve Spurious Operation	EPIX	14	325915800	h	7441	Gamma (Jeffreys, SCNID)	4.45E-08	0.500	1.124E+07	8.4	4.0E-08	0.5	1.25E+07	8.4	
MOV ELS	Motor-Operated Valve External Leak Small	EPIX	7	533589120	h	7614	Gamma (Jeffreys, SCNID)	1.41E-08	0.500	3.557E+07	8.4	1.5E-08	0.5	3.33E+07	8.4	1 to 50 gpm. 1997 - 2004 data.
MOV ELL	Motor-Operated Valve External Leak Large	EPIX			h		Gamma (ELS*0.07, LL)	9.84E-10	0.300	3.049E+08	18.8	1.0E-09	0.3	3.00E+08	18.8	> 50 gpm. Small leak times 0.07.
MOV ILS	Motor-Operated Valve Internal Leak Small	EPIX	87.5	528122880	h	7536	Gamma (EB/PL/KS, EB/PL/KS)	1.67E-07	0.434	2.599E+06	10.2	1.5E-07	0.5	3.33E+06	8.4	1 to 50 gpm. 1997 - 2004 data.
MOV ILL	Motor-Operated Valve Internal Leak Large	EPIX			h		Gamma (ILS*0.02, LL)	3.34E-09	0.300	8.982E+07	18.8	3.0E-09	0.3	1.00E+08	18.8	> 50 gpm. Small leak times 0.02
MSW FTO/C	Manual Switch Fail to Open or Close	RPS SSs	2	19789	d		Beta (Jeffreys, SCNID)	1.26E-04	0.500	3.958E+03	8.4	1.2E-04	0.5	4.17E+03	8.4	
ORF PLG	Orifice Plug	WSRC			h		Gamma(WSRC, LL)	1.00E-06	0.300	3.000E+05	18.8	1.0E-06	0.3	3.00E+05	18.8	
PDP RUN FTR	Positive Displacement Pump (Running) Fail to Run	EPIX	12	1456663	h	69	Gamma (EB/PL/KS, LL)	8.32E-06	0.300	3.606E+04	18.8	8.0E-06	0.3	3.75E+04	18.8	
PDP RUN FTS	Positive Displacement Pump (Running) Fail to Start	EPIX	32	9838	d	69	Beta (EB/PL/KS, EB/PL/KS)	3.34E-03	0.519	1.549E+02	8.0	3.0E-03	0.5	1.66E+02	8.4	
PDP STBY FTR≤1H	Positive Displacement Pump (Standby) Fail to Run During First Hour of Operation	EPIX	1	3540	h	66	Gamma (Jeffreys, SCNID)	4.24E-04	0.500	1.180E+03	8.4	4.0E-04	0.5	1.25E+03	8.4	
PDP STBY FTR>1H	Positive Displacement Pump (Standby) Fail to Run After First Hour of Operation	EPIX	No data		h		Gamma (FTR≤1H*0.06, LL)	2.54E-05	0.300	1.180E+04	18.8	2.5E-05	0.3	1.20E+04	18.8	No data. FTR≤1H times 0.06
PDP STBY FTS	Positive Displacement Pump (Standby) Fail to Start	EPIX	9	3171	d	66	Beta (Jeffreys, SCNID)	2.99E-03	0.500	1.664E+02	8.4	3.0E-03	0.5	1.66E+02	8.4	
PDP ELS	Positive Displacement Pump External Leak Small	EPIX	1	11633280	h	166	Gamma (Jeffreys, SCNID)	1.29E-07	0.500	3.878E+06	8.4	1.2E-07	0.5	4.17E+06	8.4	1 to 50 gpm. 1997 - 2004 data.
PDP ELL	Positive Displacement Pump External Leak Large	EPIX			h		Gamma (ELS*0.07, LL)	9.03E-09	0.300	3.324E+07	18.8	9.0E-09	0.3	3.33E+07	18.8	> 50 gpm. Small leak times 0.07.
PIPE SWS ELS	Piping Service Water System External Leak Small	EPIX	8.5	1.306E+10	h-ft		Gamma (Jeffreys, SCNID)	6.89E-10	0.500	7.256E+08	8.4	7.0E-10	0.5	7.14E+08	8.4	1 to 50 gpm. 1997 - 2004 data. Leakage rate is per hour per foot.
PIPE SWS ELL	Piping Service Water System External Leak Large	EPIX			h-ft		Gamma (ELS*0.2, LL)	1.38E-10	0.300	2.177E+09	18.8	1.5E-10	0.3	2.00E+09	18.8	> 50 gpm. Small leak times 0.2. Leakage rate is per hour per foot.
PIPE OTHER ELS	Piping Non-Service Water System External Leak Small	EPIX	3.5	1.583E+10	h-ft		Gamma (Jeffreys, SCNID)	2.53E-10	0.500	1.979E+09	8.4	2.5E-10	0.5	2.00E+09	8.4	1 to 50 gpm. 1997 - 2004 data. Leakage rate is per hour per foot.
PIPE OTHER ELL	Piping Non-Service Water System External Leak Large	EPIX			h-ft		Gamma (ELS*0.1, LL)	2.53E-11	0.300	1.187E+10	18.8	2.5E-11	0.3	1.20E+10	18.8	> 50 gpm. Small leak times 0.1. Leakage rate is per hour per foot.
PLDT FTOP	Process Logic (Delta Temperature) Fail to Operate	RPS SSs	24.3	4887	d		Beta (Jeffreys, SCNID)	5.07E-03	0.500	9.805E+01	8.4	5.0E-03	0.5	9.95E+01	8.4	
PLF FTOP	Process Logic (Flow) Fail to Operate	RPS SSs	No data		d		Beta (PLL, SCNID)	6.25E-04	0.500	7.990E+02	8.4	6.0E-04	0.5	8.33E+02	8.4	No data, so PLL FTOP used
PLL FTOP	Process Logic (Level) Fail to Operate	RPS SSs	3.3	6075	d		Beta (Jeffreys, SCNID)	6.25E-04	0.500	7.990E+02	8.4	6.0E-04	0.5	8.33E+02	8.4	
PLP FTOP	Process Logic (Pressure) Fail to Operate	RPS SSs	5.6	38115	d		Beta (Jeffreys, SCNID)	1.60E-04	0.500	3.124E+03	8.4	1.5E-04	0.5	3.33E+03	8.4	

Table 5-1. (continued).

Component Failure Mode	Description	Data Source	Data				Industry-average Failure Probability or Rate Distribution (note a)									Comments (see Appendix A for details)
			Failures	Demands or Hours	d or h	Components	Distribution (note b)	Mean	α	β	Error Factor	Rounded Mean (note c)	Rounded α (note c)	β (note d)	Error Factor	
PMP FTR	Pump Volute Fail to Run	EPIX	9	74199	h	180	Gamma (EB/PL/KS, EB/PL/KS)	1.35E-04	1.389	1.029E+04	3.5	1.2E-04	1.5	1.25E+04	3.3	
PMP FTS	*Pump Volute Fail to Start*	*EPIX*	*4*	*16776*	*d*	*180*	*Beta (Jeffreys, SCNID)*	*2.68E-04*	*0.500*	*1.864E+03*	*8.4*	*2.5E-04*	*0.5*	*2.00E+03*	*8.4*	
POD FTO/C	Pneumatic-Operated Damper Fail to Open or Close	EPIX	2	2461	d	59	Beta (Jeffreys, SCNID)	1.02E-03	0.500	4.919E+02	8.4	1.0E-03	0.5	5.00E+02	8.4	
POD SO	Pneumatic-Operated Damper Spurious Operation	EPIX	0	4134720	h	59	Gamma (Jeffreys, SCNID)	1.21E-07	0.500	4.135E+06	8.4	1.2E-07	0.5	4.17E+06	8.4	0 events for 1998 - 2002, so 1997 - 2004 data used
PORV FTC	Power-Operated Relief Valve Fail to Close	EPIX	5	5054	d	235	Beta (Jeffreys, SCNID)	1.09E-03	0.500	4.590E+02	8.4	1.0E-03	0.5	5.00E+02	8.4	
PORV FTO	Power-Operated Relief Valve Fail to Open	EPIX	33	5054	d	235	Beta (EB/PL/KS, EB/PL/KS)	7.25E-03	0.435	5.957E+01	10.0	7.0E-03	0.4	5.67E+01	11.3	
PORV SO	Power-Operated Relief Valve Spurious Operation	EPIX	5	10555800	h	241	Gamma (EB/PL/KS, LL)	4.63E-07	0.300	6.479E+05	18.8	5.0E-07	0.5	1.00E+06	8.4	
RLY FTOP	Relay Fail to Operate	RPS SSs	23.7	974417	d		Beta (Jeffreys, SCNID)	2.48E-05	0.500	2.013E+04	8.4	2.5E-05	0.5	2.00E+04	8.4	
RTB (BME) FTO/C	RPS Breaker (Mechanical) Fail to Open or Close	RPS SSs	1.0	97359	d		Beta (Jeffreys, SCNID)	1.54E-05	0.500	3.245E+04	8.4	1.5E-05	0.5	3.33E+04	8.4	
RTB (BSN) FTOP	RPS Breaker (Shunt Trip) Fail to Operate	RPS SSs	14.0	44104	d		Beta (Jeffreys, SCNID)	3.29E-04	0.500	1.520E+03	8.4	3.0E-04	0.5	1.67E+03	8.4	
RTB (BUV) FTOP	RPS Breaker (Undervoltage Trip) Fail to Operate	RPS SSs	23.1	57199	d		Beta (Jeffreys, SCNID)	4.13E-04	0.500	1.211E+03	8.4	4.0E-04	0.5	1.25E+03	8.4	
RTB FTO/C	RPS Breaker (Combined) Fail to Open or Close	RPS SSs			d		Beta (Jeffreys, SCNID)	1.55E-05	0.500	3.217E+04	8.4	1.5E-05	0.5	3.33E+04	8.4	RTB combined failure probability is BME + BSN*BUV
SEQ FTOP	Sequencer Fail to Operate	EPIX	2	750	d	225	Beta (Jeffreys, SCNID)	3.33E-03	0.500	1.497E+02	8.4	3.0E-03	0.5	1.66E+02	8.4	
SOV FC	Solenoid-Operated Valve Fail to Control	WSRC			h		Gamma(WSRC, LL)	3.00E-06	0.300	1.000E+05	18.8	3.0E-06	0.3	1.00E+05	18.8	
SOV FTO/C	Solenoid-Operated Valve Fail to Open or Close	EPIX	25	31813	d	1510	Beta (EB/PL/KS, EB/PL/KS)	9.54E-04	0.471	4.932E+02	9.1	1.0E-03	0.5	5.00E+02	8.4	
SOV SO	Solenoid-Operated Valve Spurious Operation	EPIX	6	66138000	h	1510	Gamma (EB/PL/KS, LL)	9.23E-08	0.300	3.250E+06	18.8	9.0E-08	0.3	3.33E+06	18.8	
SOV ELS	Solenoid-Operated Valve External Leak Small	EPIX	0.5	107152320	h	1529	Gamma (Jeffreys, SCNID)	9.33E-09	0.500	5.358E+07	8.4	9.0E-09	0.5	5.56E+07	8.4	1 to 50 gpm. 1997 - 2004 data.
SOV ELL	Solenoid-Operated Valve External Leak Large	EPIX			h		Gamma (ELS*0.07, LL)	6.53E-10	0.300	4.592E+08	18.8	7.0E-10	0.3	4.29E+08	18.8	> 50 gpm. Small leak times 0.07.
SOV ILS	Solenoid-Operated Valve Internal Leak Small	EPIX	26	107152320	h	1529	Gamma (EB/PL/KS, EB/PL/KS)	2.78E-07	0.357	1.284E+06	13.7	3.0E-07	0.4	1.33E+06	11.5	1 to 50 gpm. 1997 - 2004 data.
SOV ILL	Solenoid-Operated Valve Internal Leak Large	EPIX			h		Gamma (ILS*0.02, LL)	5.56E-09	0.300	5.396E+07	18.8	6.0E-09	0.3	5.00E+07	18.8	> 50 gpm. Small leak times 0.02
SRV FTC	Safety Relief Valve Fail to Close	EPIX	2	3142	d	386	Beta (Jeffreys, SCNID)	7.95E-04	0.500	6.281E+02	8.4	8.0E-04	0.5	6.25E+02	8.4	
SRV FTO	Safety Relief Valve Fail to Open	EPIX	10	3142	d	386	Beta (EB/PL/KS, LL)	7.71E-03	0.300	3.861E+01	18.5	8.0E-03	0.3	3.72E+01	18.4	
SRV SO	Safety Relief Valve Spurious Operation	EPIX	9	16906800	h	386	Gamma (EB/PL/KS, LL)	5.08E-07	0.300	5.906E+05	18.8	5.0E-07	0.3	6.00E+05	18.8	
SRV FTCL	Safety Relief Valve Fail to Close (Passing Liquid)	WSRC			d		Beta (WSRC, SCNID)	1.00E-01	0.500	4.500E+00	7.0	1.0E-01	0.5	4.50E+00	7.0	Average of 95th percentiles of FTC data entries
STF FTOP	Sensor/Transmitter (Flow) Fail to Operate	RPS SSs			d		Beta (STL, SCNID)	8.15E-04	0.500	6.132E+02	8.4	8.0E-04	0.5	6.25E+02	8.4	Level sensor/transmitter results used. Both the beta distribution and the gamma distribution must be used (added). For the RPS, the time-related failures are typically annunciated (or noticed) in the control room, so the detection time and repair time are short (assumed to be 12 hours in the studies).
	Sensor/Transmitter (Flow) Fail to Operate	RPS SSs			h		Gamma (STL, SCNID)	1.02E-07	0.500	4.916E+06	8.4	1.0E-07	0.5	5.00E+06	8.4	

Table 5-1. (continued).

Component Failure Mode	Description	Data Source	Data				Industry-average Failure Probability or Rate Distribution (note a)									Comments (see Appendix A for details)
			Failures	Demands or Hours	d or h	Components	Distribution (note b)	Mean	α	β	Error Factor	Rounded Mean (note c)	Rounded α (note c)	β (note d)	Error Factor	
STL FTOP	Sensor/Transmitter (Level) Fail to Operate	RPS SSs	5.0	6750	d		Beta (Jeffreys, SCNID)	8.15E-04	0.500	6.132E+02	8.4	8.0E-04	0.5	6.25E+02	8.4	Both the beta distribution and the gamma distribution must be used (added). For the *RPS, the time-related failures are typically* annunciated (or noticed) in the control room, so the detection time and repair time are short (assumed to be 12 hours in the studies).
	Sensor/Transmitter (Level) Fail to Operate	RPS SSs	0.5	9831968	h		Gamma (Jeffreys, SCNID)	1.02E-07	0.500	4.916E+06	8.4	1.0E-07	0.5	5.00E+06	8.4	
STP FTOP	Sensor/Transmitter (Pressure) Fail to Operate	RPS SSs	2.3	23960	d		Beta (Jeffreys, SCNID)	1.17E-04	0.500	4.278E+03	8.4	1.2E-04	0.5	4.17E+03	8.4	Both the beta distribution and the gamma distribution must be used (added). For the RPS, the time-related failures are typically annunciated (or noticed) in the control room, so the detection time and repair time are short (assumed to be 12 hours in the studies).
	Sensor/Transmitter (Pressure) Fail to Operate	RPS SSs	35.2	43430451	h		Gamma (Jeffreys, SCNID)	8.22E-07	0.500	6.083E+05	8.4	8.0E-07	0.5	6.25E+05	8.4	
STT FTOP	Sensor/Transmitter (Temperature) Fail to Operate	RPS SSs	17.1	40759	d		Beta (Jeffreys, SCNID)	4.32E-04	0.500	1.157E+03	8.4	4.0E-04	0.5	1.25E+03	8.4	Both the beta distribution and the gamma distribution must be used (added). For the RPS, the time-related failures are typically annunciated (or noticed) in the control room, so the detection time and repair time are short (assumed to be 12 hours in the studies).
	Sensor/Transmitter (Temperature) Fail to Operate	RPS SSs	29.0	35107399	h		Gamma (Jeffreys, SCNID)	8.40E-07	0.500	5.950E+05	8.4	8.0E-07	0.5	6.25E+05	8.4	
STR PLG	Strainer Plug	EPIX	34	5475000	h	125	Gamma (EB/PL/KS, LL)	7.38E-06	0.300	4.065E+04	18.8	7.0E-06	0.3	4.29E+04	18.8	For SWSs with potential for environmental insults
SVV FTC	Safety Valve Fail to Close	EPIX	0	7393	d	997	Beta (Jeffreys, SCNID)	6.76E-05	0.500	7.394E+03	8.4	7.0E-05	0.5	7.14E+03	8.4	
SVV FTO	Safety Valve Fail to Open	EPIX	18	7393	d	997	Beta (EB/PL/KS, LL)	2.47E-03	0.300	1.212E+02	18.7	2.5E-03	0.3	1.20E+02	18.7	
SVV SO	Safety Valve Spurious Operation	EPIX	11	43668600	h	997	Gamma (EB/PL/KS, LL)	2.12E-07	0.300	1.415E+06	18.8	2.0E-07	0.3	1.50E+06	18.8	
SVV FTCL	Safety Valve Fail to Close (Passing Liquid)	EPIX			d		Beta (WSRC, SCNID)	1.00E-01	0.500	4.500E+00	7.0	1.0E-01	0.5	4.50E+00	7.0	Average of 95th percentiles of FTC data entries
TDP RUN FTR	Turbine-Driven Pump (Running) Fail to Run	EPIX	13	2231788	h	55	Gamma (EB/PL/KS, EB/PL/KS)	5.77E-06	3.422	5.931E+05	2.2	6.0E-06	3.0	5.00E+05	2.4	
TDP RUN FTS	Turbine-Driven Pump (Running) Fail to Start	EPIX	11	503	d	55	Beta (EB/PL/KS, EB/PL/KS)	2.22E-02	1.323	5.827E+01	3.5	2.0E-02	1.2	5.88E+01	3.7	
TDP STBY FTR≤1H	Turbine-Driven Pump (Standby) Fail to Run During First Hour of Operation	EPIX	18	7188	h	113	Gamma (EB/PL/KS, EB/PL/KS)	2.64E-03	0.796	3.015E+02	5.2	2.5E-03	0.8	3.20E+02	5.2	
TDP STBY FTR>1H	Turbine-Driven Pump (Standby) Fail to Run After First Hour of Operation	EPIX	0	6803	h	6	Gamma (Jeffreys, SCNID)	7.35E-05	0.500	6.803E+03	8.4	7.0E-05	0.5	7.14E+03	8.4	0 events for 1998 - 2002, so 1997 - 2004 data used
TDP STBY FTS	Turbine-Driven Pump (Standby) Fail to Start	EPIX	46	7627	d	119	Beta (EB/PL/KS, EB/PL/KS)	6.88E-03	0.414	5.976E+01	10.7	7.0E-03	0.4	5.67E+01	11.3	
TDP ELS	Turbine-Driven Pump External Leak Small	EPIX	1	12264000	h	175	Gamma (Jeffreys, SCNID)	1.22E-07	0.500	4.088E+06	8.4	1.2E-07	0.5	4.17E+06	8.4	1 to 50 gpm. 1997 - 2004 data.
TDP ELL	Turbine-Driven Pump External Leak Large	EPIX			h		Gamma (ELS*0.07, LL)	8.56E-09	0.300	3.504E+07	18.8	9.0E-09	0.3	3.33E+07	18.8	> 50 gpm. Small leak times 0.07.
TFM FTOP	Transformer Fail to Operate	EPIX	81	199027200	h	4544	Gamma (EB/PL/KS, EB/PL/KS)	9.04E-07	0.314	3.473E+05	17.2	9.0E-07	0.3	3.33E+05	18.8	
TNK UNPR ELS	Tank Unpressurized External Leak Small	EPIX	1	47023680	h	671	Gamma (Jeffreys, SCNID)	3.19E-08	0.500	1.567E+07	8.4	3.0E-08	0.5	1.67E+07	8.4	1 to 50 gpm. 1997 - 2004 data.
TNK UNPR ELL	Tank Unpressurized External Leak Large	EPIX			h		Gamma (ELS*0.07, LL)	2.23E-09	0.300	1.344E+08	18.8	2.0E-09	0.3	1.50E+08	18.8	> 50 gpm. Small leak times 0.07.
TNK PRES ELS	Tank Pressurized External Leak Small	EPIX	1.5	50948160	h	727	Gamma (Jeffreys, SCNID)	3.93E-08	0.500	1.274E+07	8.4	4.0E-08	0.5	1.25E+07	8.4	1 to 50 gpm. 1997 - 2004 data.
TNK UNPR ELL	Tank Unpressurized External Leak Large	EPIX			h		Gamma (ELS*0.07, LL)	2.75E-09	0.300	1.092E+08	18.8	3.0E-09	0.3	1.00E+08	18.8	> 50 gpm. Small leak times 0.07.

Table 5-1. (continued).

Component Failure Mode	Description	Data Source	Data				Industry-average Failure Probability or Rate Distribution (note a)									Comments (see Appendix A for details)
			Failures	Demands or Hours	d or h	Components	Distribution (note b)	Mean	α	β	Error Factor	Rounded Mean (note c)	Rounded α (note c)	β (note d)	Error Factor	
TSA PLG	Traveling Screen Assembly Plug	EPIX	29	8584800	h	196	Gamma (EB/PL/KS, EB/PL/KS)	4.68E-06	0.502	1.073E+05	8.4	5.0E-06	0.5	1.00E+05	8.4	For SWSs with potential for environmental insults
VBV FTC	*Vacuum Breaker Valve Fail to Close*	*EPIX*	*2*	*7301*	*h*	*139*	*Gamma (Jeffreys, SCNID)*	*3.42E-04*	*0.500*	*1.460E+03*	*8.4*	*3.0E-04*	*0.5*	*1.67E+03*	*8.4*	
VBV FTO	Vacuum Breaker Valve Fail to Open	EPIX	3	7301	h	139	Gamma (Jeffreys, SCNID)	4.79E-04	0.500	1.043E+03	8.4	5.0E-04	0.5	1.00E+03	8.4	
XVM FTO/C	Manual Valve Fail to Open or Close	EPIX	1	2017	d	107	Beta (Jeffreys, SCNID)	7.43E-04	0.500	6.722E+02	8.4	7.0E-04	0.5	7.14E+02	8.4	
XVM PLG	Manual Valve Plug	EPIX	0	78559680	h	1121	Gamma (Jeffreys, SCNID)	6.36E-09	0.500	7.856E+07	8.4	6.0E-09	0.5	8.33E+07	8.4	
XVM ELS	Manual Valve External Leak Small	EPIX	3	78559680	h	1121	Gamma (Jeffreys, SCNID)	4.46E-08	0.500	1.122E+07	8.4	4.0E-08	0.5	1.25E+07	8.4	1 to 50 gpm. 1997 - 2004 data.
XVM ELL	Manual Valve External Leak Large	EPIX			h		Gamma (ELS*0.07, LL)	3.12E-09	0.300	9.620E+07	18.8	3.0E-09	0.3	1.00E+08	18.8	> 50 gpm. Small leak times 0.07.
XVM ILS	Manual Valve Internal Leak Small	EPIX	0	7498560	h	107	Gamma (Jeffreys, SCNID)	6.67E-08	0.500	7.499E+06	8.4	7.0E-08	0.5	7.14E+06	8.4	1 to 50 gpm. 1997 - 2004 data.
XVM ILL	Manual Valve Internal Leak Large	EPIX			h		Gamma (ILS*0.02, LL)	1.33E-09	0.300	2.250E+08	18.8	1.2E-09	0.3	2.50E+08	18.8	> 50 gpm. Small leak times 0.02

Acronyms - BWR (boiling water reactor), EB (empirical Bayes), EPIX (Equipment Performance and Information Exchange), KS (Kass Steffey), LL (lower limit), PL (plant level), PLL (process logic level), PWR (pressurized water reactor), SCNID (simplified constrained noninformative distribution), SS (system study), STL (sensor/transmitter level), SWS (service water system), WSRC (Westinghouse Savannah River Company)

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 Reference 59 and outlined in Section 6.2.3.5 in Reference 17.

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

Note c - The value is rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten.

Note d - The β parameter is determined from the mean and α. The β parameter is presented to three significant figures to preserve the mean of the distribution

5.2 Hierarchy of Data Sources

For component UR data, the following hierarchy of sources was used:

1. EPIX database (Ref. 38), as processed using the Reliability and Availability Database System (RADS) software (Ref. 63)
2. Updated system studies (Ref. 16)
3. *Savannah River Site Generic Data Base Development (U)* (Ref. 45).

Detailed information concerning each of these sources is found in Reference 17. Brief summaries are presented below.

EPIX is the preferred data source for component UR estimates. The EPIX database is an industry-sponsored effort administered by INPO. Over 100 U.S. commercial NPPs report component UR data to EPIX. This database covers U.S. industry performance from 1997 to the present. Component UR data include periodic tests (weekly to quarterly), cyclic tests (every 18 months), operational demands, and unplanned demands. Events reported to EPIX include both failures and degraded performance. The RADS software maps the EPIX failure events to the various failure modes of interest (or to a "no failure" category). The events of interest are those involving failures as defined for PRAs. Events in which a component may be declared inoperable (with respect to technical specifications) but is still functional with respect to its PRA mission are mapped to the "no failure" category. Component demands and run hours (if applicable) in EPIX are estimates from knowledgeable plant personnel of actual demands and run hours over a recent cycle (typically 18 months). In addition, for a subset of components judged to be more risk significant, this information is supplemented by quarterly information on unplanned demands and run hours. The RADS software uses this information to generate estimates for demands and run hours over the period of interest. Finally, all component failures are reported to EPIX, not just those that could not be quickly recovered.

EPIX does not explicitly define component boundaries. Instead, key components are identified, and any event that results in a failure of that key component is reported. Therefore, EPIX failures may include events outside of the component boundary definitions used in this study. As an example, EDG failures in EPIX may include those involving the cooling water supply to the EDG. In the SPAR models, such failures are modeled explicitly rather than implicitly within the EDG basic events. However, a review of EPIX failure events for several components indicated that events outside the component boundaries used in this study represented a small fraction (typically less than 5%) of the overall failures. Therefore, failure events generally were not reviewed to eliminate this small fraction of events.

The EPIX database was chosen as the preferred database for component UR because it contains industry UR information (failures and demands or hours) for a wide range of components included in the SPAR models. In addition, EPIX is the only industry-wide component database that is maintained and updated. EPIX data are available to the U.S. commercial NPP industry and to the NRC under a memorandum of understanding (Ref. 64). However, these data are not publicly available. Typically, analysis results from the use of such data can be published or made available to the public as long as plant-specific results are not listed. This report presents only industry-level analyses.

The EPIX data collection system has sophisticated, automated quality assurance tools that provide direct feedback to the submitter. INPO calls this set of software tools a "Coach." The EPIX "Coach" has greatly improved the quality of the failure and reliability records. In addition, INPO has undertaken a well-organized effort to obtain more complete demand and run hour information from the utilities when these are anomalous or missing. Because of its structure, EPIX can be monitored effectively from a central location and corrective actions promptly taken to address deficiencies in the data. This structure also allows INPO to track reporting by each plant. Tracking records are reported back to the EPIX contact at the plant and also to utility senior managers. These efforts have led to improvements in EPIX over the last 2 or 3 years.

The second data source in the hierarchy is the yearly effort to update results from previously published system studies (Refs. 2–12). An NRC public website (Ref. 16) summarizes yearly updates to these studies (except for those covering the reactor protection system). The system studies use failure information contained in LERs, which are publicly available. Depending upon LER reporting requirements, failure data for systems with multiple trains may be available for unplanned demands only (such as the auxiliary feedwater system [AFWS] and high-pressure safety injection [HPSI]). However, for single train systems such as high-pressure coolant injection (HPCI), high-pressure core spray (HPCS), and reactor core isolation cooling (RCIC), the LERs include failures from both unplanned demands and periodic tests. The unplanned demands are based on counts of actual unplanned demands of the systems. For the periodic tests, the demands are estimates rather than actual counts. These estimates are not considered to be as accurate as the test demands obtained from EPIX because the EPIX test demands are estimated by plant personnel knowledgeable in each plant's testing and operation. Because the system study updates are based on LERs, results from these studies are considered relatively independent from the EPIX data, although both are reports on performance from the same component set.

The system study updates focus on system performance, not component performance. Data are collected for what are termed segments of the system. Segments include pump trains, injection valves, and others. Segments typically include components in addition to the one of interest. For example, a pump train segment may include isolation valves in addition to the pump. The segment approach to collecting data has the potential to include failures outside the component boundaries used in this report. A review of the system study data for segments indicated that almost all segment failures reported were within the component boundaries used in this report. (The other components included in a segment typically did not contribute significantly to the segment failures.) Therefore, the segment data typically provide information applicable to the component level for the purposes of this study.

Updated system study data can be used in two ways: as the primary source of data for the component or event of interest, or as a relatively independent comparison to the EPIX data and results. This study used the updated system study data for both purposes. Section 9 and Appendix E present cases where the updated system study data were compared with parameter estimates in this report.

The third data source in the hierarchy is a component generic database developed for Savannah River. This database development was supported by the Westinghouse Savannah River Company (WSRC), and is referred to as the WSRC database. Although developed for a DOE site, the WSRC database includes component data mainly from U.S. commercial nuclear reactors during the late 1980s. This data source has not been updated since its publication in 1993. At that time, the database represented the state of the art. However, as indicated in Reference 15, component performance has improved since the late 1980s.

5.3 Data Period

A goal of this study was to characterize current industry performance for use in SPAR models. At the time this work started, component data in EPIX covered 1997–2002, updated system study data covered 1988–2002, and component UR estimates in Reference 15 used EPIX data from 1999 through 2001. Although 3 years of data were sufficient to generate failure rates, a longer period is better for the component failure modes with lower failure rates (and fewer failures). In addition, the extra data from a longer period allow for better characterization of failure rate distributions. Therefore, a 5-year period was chosen (1998–2002), and resulting component failure rates represent industry performance centered about the year 2000. Periodic reviews of these results will be performed as additional years of data become available.

A concern with longer periods of data is that a trend may exist within the period chosen. If such trends exist, the earlier data that are not indicative of current performance may bias the results. This would be the case if, for example, data collected for 1990–2002 to characterize industry performance for 2000 had higher component failure rates during the earlier years. The 5-year period chosen is short enough such that trends generally do not exist. In addition, if a trend does exist, centering the period about 2000 results in estimates representative of the year 2000 (higher failure rates from one side of 2000 are balanced by lower failure rates on the other side of 2000).

The leakage rates (ELS, ELL, ILS, and ILL) were generated at the end of this project, using data covering 1997–2004. This longer period was used to better characterize the large leaks (ELL and ILL), which are rare events with few or no occurrences within the shorter period of 1998–2002. In general, there did not appear to be trends in these data over this longer period. Even if there were, the resulting estimate appeared appropriate for the year 2000.

5.4 General Process for Collecting and Analyzing Data

For the majority of component unreliabilities, the preferred source (EPIX) was used. The EPIX database is continually updated. For this study, the EPIX database used was the one submitted by INPO to NRC covering data through December 2004. Initial work involved an EPIX database covering data through December 2003, but this work was revised using the December 2004 database.

The process to obtain and analyze EPIX data is outlined in Table 5-2. General descriptions of some of the steps are provided below. Details of the process for each component are presented in Appendix A.

For each component and failure mode combination listed in Table 5-1, the RADS software was used to identify failures and calculate demands (or run or calendar hours) from EPIX for 1998–2002. These data can be grouped at the individual component level or the plant level. At the component level, each component has its associated failures and demands or hours. At the plant level, data from all of the components of a given component type at a plant are combined. Therefore, grouping data at the plant level results in loss of information on component-to-component variability within the plant. To maximize the use of available information and to better perform a limited quality assurance check, component-level data were the starting point of the analysis (Step 1 in Table 5-2).

Component-level data obtained from EPIX using RADS were loaded into Microsoft Excel for review and additional data analysis. The review of the data involved a review of demands and run hours for individual components to identify potential input errors (Step 2 in Table 5-2). Such errors included run hours exceeding 24 hours/day, run hours for standby components that were a factor of ten too high, EDG load run demands that were greater than the start demands, and others. These errors were corrected. Details concerning this process are presented in Appendix A under each component subsection.

Table 5-2. Process for collecting and analyzing EPIX data.

	Step	Purpose	Methods
1	Obtain the data	To obtain information for estimating a failure rate or probability	• Collect failures and demands or run hours at the component level
2	Perform a sanity/reasonableness check of the data at the component level	To ensure the adequacy of the collected data	• Check consistency of the data (e.g., run hours do not exceed 24 h/d, start demands are greater than load run demands for emergency diesel generators)
3	Calculate the industry maximum likelihood estimate (MLE)	To determine an initial estimate of the industry mean	• Pool all failures and demands (or hours) and divide total failures by total demands (or hours)
4	Examine component level behavior	To determine the behavior at the component level, e.g., check for homogeneity among components	• Obtain the MLEs for each component. • Perform a chi square goodness-of- fit test to check for component differences • Review the distribution of demands • From the chi square results and the distribution of demands, identify outlier components • Obtain population estimates for mean, variance, percentiles using the component MLEs
5	Examine plant level behavior	To determine the behavior at the plant level, e.g., check for homogeneity among plants	• Obtain the MLEs for each plant. • Perform a chi square goodness-of-fit test to check for plant differences • Obtain population estimates for mean, variance, percentiles using the MLEs
6	Compare the component level and plant level dataset statistics	To determine differences in behavior between the component level population and the plant level population	• Compare the means from the different levels of data aggregation • Observe which levels have similar 95th percentiles
7	Estimate the population variability distribution using an appropriate method	Adequately characterize the population variability distribution	• Few failures, use Jeffreys mean of the pooled industry data • More failures, use a more complicated method, estimating parameters of an uncertainty distribution • Choice of model (gamma, beta, lognormal, etc.)
8	Validate the model	Judge the adequacy of the model	• Use techniques contained in Reference 17 • Does the distribution make sense from an engineering perspective?

For a given component failure mode, outliers with respect to demands indicate either faulty input data or components whose operational environment is significantly different from others within the group. Any outlier components based on demand counts were eliminated before further analysis of the data (Step 4 in Table 5-2). Detailed information concerning the data review is presented in Appendix A.

Components that start and run for mission success required special processing of the data. These components include pumps, fans (FANs), air handling units (AHUs), and chillers (CHLs). Such component data generally can be separated into standby and running/alternating categories. The standby components must start and run upon demand, while the running/alternating components may already be running when a demand occurs. Examples of standby pumps include those in safety systems such as AFWS, HPCI, and RCIC. In contrast, pumps in the service water systems and component cooling water systems often are running or alternating. A review of component data from systems with pumps known to be standby indicated that such components typically had run hours (from tests, unplanned demands, and other operational demands) that were up to several percent of the calendar hours. Therefore, to divide components into standby versus running/alternating categories, the components were sorted by run hours. Components with run hours fewer than 10% of calendar hours were placed in the standby category, while those with more run hours were placed in the running/alternating category. Data from each category were then analyzed separately to obtain FTS and FTR rates.

In addition, the FTR failure mode for standby components was subdivided into FTR≤1H and FTR>1H. This was done because the historical perspective on failure rates article (Ref. 15) indicated approximately a factor of 15 difference between the two failure rates for several component types. The process used to separate data into FTR≤1H and FTR>1H categories is approximate because the EPIX failure records rarely indicate how long a component was operating when it experienced an FTR event. The process used is the following:

1. Sort the components by run hours/demand, from lowest to highest.
2. Add cumulative columns to the sorted component list indicating the total component demands and total component hours (up through the component being considered).
3. Identify within this sorted list the component where the cumulative run hours divided by cumulative demands equals 1.0. The subset of components up through this component has an average of 1 hour of run time per demand.
4. Calculate the FTR≤1H rate from the subset of components identified, using their run hours and FTR events.
5. Use the remaining components to calculate FTR>1H. However, the FTR event total from these other components is reduced by the expected number of FTR≤1H events. (The expected number of FTR≤1H events is just the number of demands for this group times the FTR≤1H rate.) Also, the run hours in this group are reduced by the number of demands. In cases where the modified FTR>1H event total was negative, it was assumed that there were no FTR>1H events. Reducing the event total for FTR>1H and the associated number of run hours is an enhancement not included in the results in the historical perspective (Ref. 15).

This process is not possible for the running/alternating components, because there are no components with run hours/demand less than 1.0. Therefore, for the running/alternating components, FTR is used, rather than FTR≤1H and FTR>1H.

For AOVs, hydraulic-operated valves (HOVs), MOVs, solenoid-operated valves (SOVs), manual valves (XVMs), circuit breakers (CBKs), and pneumatic-operated dampers (PODs), the fail to open (FTO), fail to close (FTC), and FTOP failure modes were combined into a single FTO/C failure mode. For these components, EPIX does not distinguish open demands from close demands. In addition, failure events might be classified as FTO, FTC, or FTOP. To simplify the analysis of such components, the combined FTO/C failure mode is used. This approach is also used in the Swedish T-Book database (Ref. 54).

For components and failure modes not covered by the EPIX data, other data sources were used, as indicated in the hierarchy of data sources. These other sources were used to obtain mean failure probabilities or rates. Then either the SCNID α of 0.5 or the lower allowable limit of 0.3 was assumed to describe the distribution. The SCNID value corresponds with an error factor of approximately 8.4, while the lower limit corresponds with an error factor of approximately 19. More details concerning this process are presented in Appendix A.

5.5 Component Unreliability Data and Results

Component UR data and resulting failure probability or rate distributions are summarized in Table 5-1. Two sets of distributions are presented. The first distribution is based on the mean and α parameter obtained from the data (or other source). The second distribution is based on the rounded mean and α parameter. (The SPAR models use the rounded values and associated distribution.) More detailed information for each component is presented in Appendix A. EPIX data from 1998–2002 (or 1997–2004) provide the basis for 144 of the 171 component type and failure mode combinations. System studies covering reactor protection systems provide data (late 1980s and early 1990s) and estimates for 20 component failure modes. The WSRC database (data from the late 1980s) provides the basis for an additional seven component type and failure mode combinations.

In several cases, the EPIX data indicated no failures. In such cases, there is a potential that the Jeffreys means may be conservatively high. For cases with no failures, the data period was expanded to 1997–2004 (for components supported by EPIX data). These cases are indicated in the "Comments" column in Table 5-1. Finally, three cases involved standby components with EPIX data for FTR≤1H but no or limited data for FTR>1H. In two cases (diesel-driven pump [DDP] and positive displacement pump [PDP]), the FTR≤1H failure rate was divided by 0.06 to estimate the FTR>1H rate. (For the nine components with sufficient data [AHU, CHL, CTF, EDG, FAN, HTG, MDC, MDP, and TDP], the geometric average of the ratios is 0.064, which was rounded to 0.06. Because of the wide range, a geometric average provides a more central estimate than an arithmetic average.) The other case (combustion turbine generator CTG) used information from a related component to estimate the FTR>1H rate.

Within component types, component UR can be compared using the results from Table 5-1. For example, among the emergency power sources, the hydro turbine generators (HTGs) have the lowest UR. For a mission of 8 hours, their combined UR is estimated to be

$$UR_{combined} = P_{FTS} + P_{FTLR} + (\lambda_{FTR>1H})(7\,hr) = 7.9E-03 \tag{5-1}$$

where FTLR is fail to load and run. EDGs have an estimated combined UR of 1.3E–02 not including the sequencer and 1.7E–02 including the sequencer, while CTGs have an estimated combined UR of 3.2E–02.

For standby pumps, the combined UR based on a 24-hour mission is estimated to be

$$UR_{combined} = P_{FTS} + (\lambda_{FTR\leq 1H})(1\,hr) + (\lambda_{FTR>1H})(23\,hr) = 2.0E-03 \tag{5-2}$$

for MDPs (centrifugal). PDPs that are motor driven have an estimated combined UR of 4.0E–03. The DDP estimate is 7.6E–03, and the TDP estimate is 1.1E–02.

Standby cooling units also can be compared assuming a 24-hour mission. AHUs have an estimated combined UR of 3.2E–03. The FAN estimate is 7.4E–03, and the CHL result is 2.4E–02.

Component UR results can be examined to determine whether dividing components into standby and running/alternating categories was justified. TDPs indicate a significant difference. The standby TDPs have an FTS probability of 6.9E–03, while the running/alternating TDPs have an FTS of 2.2E–02. If FTR≤1H (2.6E–03/hour) for the standby TDPs is added to FTS to obtain a failure to start and run for 1 hour, the probability is

$$6.9E-03+(2.6E-3/hr)(1\,hr)=9.5E-03 \tag{5-3}$$

The corresponding value for running/alternating TDPs is

$$2.2E-2+(5.8E-6/h)(1\,hr)=2.2E-02 \tag{5-4}$$

In addition, the FTR>1H rates differ by a factor of approximately ten, with the standby TDP FTR>1H rate of 7.4E–05/hour and the running/alternating rate of 5.8E–06/hour. Therefore, for TDPs, the division into standby and running/alternating categories results in different UR estimates.

For MDPs, however, the division is not as useful. The failure to start and run for 1 hour probability for standby MDPs is

$$1.5E-03+(3.8E-04/hr)(1\,hr)=1.9E-03 \tag{5-5}$$

while for running/alternating MDPs the result is

$$2.2E-03+(4.5E-06/hr)(1\,hr)=2.2E-03 \tag{5-6}$$

The FTR>1H rate for standby MDPs is 5.8E–06/hour, while running MDPs is 4.5E–06/hour.

Other components that were divided into standby and running/alternating categories indicate differences not as great as TDPs but greater than MDPs.

Finally, the results indicate that for standby components, the ratio of FTR>1H to FTR≤1H rates ranges from 0.45 to 0.006. The geometric average of the ratios is 0.064. This compares with the estimate of 0.067 from an earlier analysis of EPIX data for 1999–2001 (Ref. 15).

6. COMPONENT OR TRAIN UNAVAILABILITY

Similar to the component UR effort, the SPAR models were reviewed to identify the types of UA events included. These events are termed TM outages. These UA events model the probability that a component or train will be unavailable if demanded because of a TM outage. Table 6-1 lists these events. The following sections explain the various entries in the table.

6.1 Event Boundaries

Although the UA events are identified by type of component, for the SPAR models they generally apply at the train level. For example, the TDP-TM (HPCI) event covers all components within the HPCI system (a single-train system) that are single failures for the train and can be unavailable while the plant is critical. Therefore, several components could contribute to the train UA. However, experience has shown that in general almost all of the UA for the events listed in Table 6-1 result from the main component listed.

6.2 Hierarchy of Data Sources

For train UA data, the following hierarchy of sources was used:

1. MSPI basis document (Ref. 62) data
2. Reactor Oversight Process (ROP) safety system unavailability (SSU) data (Ref. 65)
3. Updated system study (Ref. 16) maintenance-out-of-service (MOOS) or other data
4. Individual plant examination (IPE) TM data (Ref. 66).

Descriptions of each of these sources are presented below.

The MSPI basis documents present baseline UA data covering 2002–2004. These basis documents cover all 103 operating U.S. commercial NPPs. Data include planned and (in most cases) unplanned train outages (hours) while plants were in critical operation, along with the associated critical operation hours. Planned outages include periodic TM activities that are scheduled in advance and that disable a train. Unplanned outages typically involve repair of components that failed during testing or during unplanned demands or exhibited degraded performance such that maintenance was deemed appropriate. MSPI Program guidance for collection of UA data closely matches the requirements for use in PRAs. For example, only train outages during critical operation are considered, overhaul outages during critical operation are considered, and outages resulting from support system UA are not included. (The support system outages are modeled separately within the support systems.)

Train UA data cover four important types of frontline safety systems: emergency power, high-pressure injection, heat removal, and residual heat removal (RHR). For individual plants, these systems include EDGs and HTGs; HPSI, HPCI, HPCS and feedwater (FWR) injection; AFWS, RCIC, and isolation condenser (IC) systems; and pressurized water reactor (PWR) and boiling water reactor (BWR) RHR systems. In addition, train UA data cover selected service water and component cooling water systems. The MSPI basis document data (for 2002–2004) are not in an electronic database. However, starting in July 2006, MSPI train data replaced the reporting of ROP SSU data. The MSPI train UA data under this program cover July 2003 (some plants submitted data starting earlier than this date) through the present and are submitted quarterly to the NRC.

Table 6-1. Train UA data and results.

Train *Unavailability* Event	Train Description	Data *Source*	Data	Industry-average Probability Distribution (note a)								Error	Comments
			MSPI Trains	*Distribution* (note b)	*Mean*	*α*	*β*	*Error* Factor	*Rounded* Mean (note c)	*Rounded* *α* (note c)	*β* (note d)	*Error* Factor	*(see Appendix B for details)*
AHU-TM	Air Handling Unit Test or Maintenance	IPEs		Beta (IPEs, SCNID)	2.48E-03	0.500	2.011E+02	8.4	2.5E-03	0.50	2.00E+02	8.4	
BAC-TM	Bus (ac) Test or Maintenance	IPEs		Beta (IPEs, SCNID)	2.15E-04	0.500	2.325E+03	8.4	2.0E-04	0.50	2.50E+03	8.4	
BCH-TM	Battery Charger Test or Maintenance	IPEs		Beta (IPEs, SCNID)	2.20E-03	0.500	2.268E+02	8.4	2.0E-03	0.50	2.50E+02	8.4	
CHL-TM	Chiller Test or Maintenance	IPEs		Beta (IPEs/2, SCNID)	1.98E-02	0.500	2.482E+01	8.2	2.0E-02	0.50	2.45E+01	8.2	Comparison of IPE UAs versus 2002 - 2004 MSPI UAs and 1998 - 2002 ROP SSU UAs indicates a drop of approximately 50% for IPE UAs > 5.0E-3. IPE value divided by 2.
CTF-TM	Cooling Tower Fan Test or Maintenance	IPEs		Beta (IPEs, SCNID)	1.86E-03	0.500	2.683E+02	8.4	2.0E-03	0.50	2.50E+02	8.4	
CTG-TM	Combustion Turbine Generator Test or Maintenance	IPEs		Beta (IPEs/2, SCNID)	5.00E-02	0.500	9.500E+00	7.7	5.0E-02	0.50	9.50E+00	7.7	Comparison of IPE UAs versus 2002 - 2004 MSPI UAs and 1998 - 2002 ROP SSU UAs indicates a drop of approximately 50% for IPE UAs > 5.0E-3. IPE value divided by 2.
DDP-TM (AFWS)	Diesel-Driven Pump Test or Maintenance (AFWS)	MSPI	5	Beta (MSPI, MSPI)	9.70E-03	10.946	1.118E+03	1.6	1.0E-02	10.00	9.90E+02	1.6	
DDP-TM (SWS)	Diesel-Driven Pump Test or Maintenance (SWS)	MSPI	5	Beta (MSPI, MSPI)	2.95E-02	6.134	2.018E+02	1.8	3.0E-02	6.00	1.94E+02	1.8	
EDG-TM (EPS)	Emergency Diesel Generator Test or Maintenance (EPS)	MSPI	219	Beta (MSPI, MSPI)	1.34E-02	3.586	2.640E+02	2.2	1.2E-02	4.00	3.29E+02	2.1	
EDG-TM (HPCS)	Emergency Diesel Generator Test or Maintenance (HPCS)	MSPI	8	Beta (MSPI, MSPI)	1.33E-02	5.761	4.274E+02	1.9	1.2E-02	6.00	4.94E+02	1.8	
EOV-TM	Explosive-Operated Valve Test or Maintenance	IPEs		Beta (IPEs, SCNID)	5.52E-04	0.500	9.053E+02	8.4	6.0E-04	0.50	8.33E+02	8.4	
FAN-TM	Fan Test or Maintenance	IPEs		Beta (IPEs, SCNID)	2.00E-03	0.500	2.495E+02	8.4	2.0E-03	0.50	2.50E+02	8.4	
FWR-TM	Feedwater Injection Test or Maintenance	MSPI	4	Beta (MSPI, MSPI Ave)	1.60E-02	2.500	1.538E+02	2.5	1.5E-02	2.50	1.64E+02	2.5	Limited data. Average α used.
HDR-TM (ESW)	Piping Header Test or Maintenance (ESW)	MSPI	53	Beta (MSPI, MSPI)	8.65E-03	1.000	1.146E+02	4.3	9.0E-03	1.00	1.10E+02	4.3	Header may include 1 MDP or 2 or more MDPs in parallel
HDR-TM (RHRSW)	Piping Header Test or Maintenance (RHRSW)	MSPI	38	Beta (MSPI, MSPI)	3.63E-03	1.747	4.795E+02	3.0	4.0E-03	1.50	3.74E+02	3.3	Header includes either 1 MDP or 2 MDPs in parallel
HTG-TM	Hydro Turbine Generator Test or Maintenance	SSU		Beta (SSU, MSPI Ave)	8.97E-03	2.500	2.761E+02	2.5	9.0E-03	2.50	2.75E+02	2.5	Limited data. Average α used. MSPI data cover mainly the transmission lines (underground and aboveground from the HTGs to the plants)
HTX-TM (CCW)	Heat Exchanger Test or Maintenance (CCW)	MSPI	73	Beta (MSPI, MSPI)	7.23E-03	1.000	1.373E+02	4.3	7.0E-03	1.00	1.42E+02	4.3	CCW HTX trains may include 1 MDP or 2 MDPs in parallel
HTX-TM (RHR-BWR)	Heat Exchanger Test or Maintenance (RHR-BWR)	MSPI	70	Beta (MSPI, MSPI)	7.62E-03	3.759	4.895E+02	2.2	8.0E-03	4.00	4.96E+02	2.1	RHR-BWR HTX trains include 1 MDP or 2 MDPs in parallel
HTX-TM (RHR-PWR)	Heat Exchanger Test or Maintenance (RHR-PWR)	MSPI	145	Beta (MSPI, MSPI)	5.18E-03	2.748	5.278E+02	2.4	5.0E-03	2.50	4.98E+02	2.5	RHR-PWR HTX trains include 1 MDP or 2 MDPs in parallel
IC-TM	Isolation Condenser Test or Maintenance	MSPI	6	Beta (MSPI, MSPI)	5.86E-03	1.265	2.146E+02	3.6	6.0E-03	1.20	1.99E+02	3.8	
MDC-TM	Motor-Driven Compressor Test or Maintenance	IPEs		Beta (IPEs/2, SCNID)	1.30E-02	0.500	3.796E+01	8.3	1.2E-02	0.50	4.12E+01	8.3	Comparison of IPE UAs versus 2002 - 2004 MSPI UAs and 1998 - 2002 ROP SSU UAs indicates a drop of approximately 50% for IPE UAs > 5.0E-3. IPE value divided by 2.

Table 6-1. (continued).

Train Unavailability Event	Train Description	Data Source	Data	Industry-average Probability Distribution (note a)									Comments (see Appendix B for details)
			MSPI Trains	Distribution (note b)	Mean	α	β	Error Factor	Rounded Mean (note c)	Rounded α (note c)	β (note d)	Error Factor	
MDP-TM (AFWS)	Motor-Driven Pump Test or Maintenance (AFWS)	MSPI	122	Beta (MSPI, MSPI)	3.95E-03	2.387	6.019E+02	2.6	4.0E-03	2.50	6.23E+02	2.5	
MDP-TM (CCW)	Motor-Driven Pump Test or Maintenance (CCW)	MSPI	133	Beta (MSPI, MSPI)	5.91E-03	1.288	2.166E+02	3.6	6.0E-03	1.20	1.99E+02	3.8	
MDP-TM (HPCS)	Motor-Driven Pump Test or Maintenance (HPCS)	MSPI	8	Beta (MSPI, MSPI)	1.31E-02	1.537	1.158E+02	3.2	1.2E-02	1.50	1.24E+02	3.3	
MDP-TM (HPSI)	Motor-Driven Pump Test or Maintenance (HPSI)	MSPI	196	Beta (MSPI, MSPI)	4.12E-03	2.348	5.676E+02	2.6	4.0E-03	2.50	6.23E+02	2.5	
MDP-TM (ESW)	Motor-Driven Pump Test or Maintenance (ESW)	MSPI	223	Beta (MSPI, MSPI)	1.30E-02	1.000	7.592E+01	4.3	1.2E-02	1.00	8.23E+01	4.3	
MDP-TM (NSW)	Motor-Driven Pump Test or Maintenance (NSW)	MSPI	6	Beta (MSPI, MSPI)	1.64E-02	6.278	3.765E+02	1.8	1.5E-02	6.00	3.94E+02	1.8	
MDP-TM (RHRSW)	Motor-Driven Pump Test or Maintenance (RHRSW)	MSPI	8	Beta (MSPI, MSPI)	5.76E-03	1.320	2.278E+02	3.6	6.0E-03	1.20	1.99E+02	3.8	Most RHRSW MDPs are included in header trains with 2 parallel MDPs, rather than reported individually
MDP-TM (Other)	Motor-Driven Pump Test or Maintenance (Other)	MSPI	696	Beta (MSPI, MSPI)	7.51E-03	1.000	1.322E+02	4.3	8.0E-03	1.00	1.24E+02	4.3	Results from all MDP data combined
PDP-TM	Positive Displacement Pump Test or Maintenance	IPEs		Beta (IPEs, SCNID)	3.19E-03	0.500	1.562E+02	8.4	3.0E-03	0.50	1.66E+02	8.4	
SPC-TM	Signal Processing Channel Test or Maintenance	SS		Beta (SS, SCNID)	5.80E-02	0.500	8.121E+00	7.6	6.0E-02	0.50	7.83E+00	7.6	
TDP-TM (AFWS)	Turbine-Driven Pump Test or Maintenance (AFWS)	MSPI	69	Beta (MSPI, MSPI)	5.44E-03	2.177	3.980E+02	2.7	5.0E-03	2.00	3.98E+02	2.8	
TDP-TM (HPCI)	Turbine-Driven Pump Test or Maintenance (HPCI)	MSPI	24	Beta (MSPI, MSPI)	1.30E-02	3.288	2.496E+02	2.3	1.2E-02	3.00	2.47E+02	2.3	
TDP-TM (RCIC)	Turbine-Driven Pump Test or Maintenance (RCIC)	MSPI	30	Beta (MSPI, MSPI)	1.07E-02	4.703	4.348E+02	2.0	1.0E-02	5.00	4.95E+02	2.0	

Acronyms - AFWS (auxiliary feedwater system), BWR (boiling water reactor), CCW (component cooling water), EPS (emergency power system), ESW (emergency or essential service water), HPCI (high-pressure coolant injection), HPCS (high-pressure core spray), IC (isolation condenser), HTX (heat exchanger), IPE (Individual Plant Examination), MDP (motor-driven pump), MSPI (Mitigating Systems Performance Index), NSW (normal service water), PWR (pressurized water reactor), RCIC (reactor core isolation cooling), RHR (residual heat removal), RHRSW (residual heat removal service water), ROP (Reactor Oversight Process), SCNID (simplified constrained noninformative distribution), SS (system study), SSU (Safety System Unavailability), SWS (service water system)

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 Reference 59 and outlined in Section 6.2.3.5 in Reference 17.

Note b - The format for the distributions is the following: distribution type (source for mean, source for α factor). If the source for the mean indicates IPE/2, these are cases in which the IPE value was divided by 2 to reflect more current performance.

Note c - The value is rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten.

Note d - The β factor is determined from the mean and α. The β factor is presented to three significant figures to preserve the mean of the distribution.

The MSPI train UA data covering 2002–2004 were chosen as the preferred source because of the wide coverage of trains and plants, the data collection requirements that closely match PRA requirements, and the continuing collection and reporting. However, these train UA data are not centered about the year 2000.

The ROP SSU data include planned, unplanned, and fault exposure outage (a surrogate for component UR) hours and required hours for trains within the four important types of frontline safety systems listed above. Reporting requirements for the SSU specify that planned component overhaul maintenance performed during plant critical operation is not to be included in the planned outage hours. However, support system outages (supporting the monitored systems) are included in the SSU. SSU data were provided quarterly to the NRC for the 103 operating U.S. commercial NPPs. The ROP SSU program officially started in 2000, but because the SSU indicators require 3 years of outage information, data are available for 1997 through March 2006. These data are no longer being collected because they have been replaced by the MSPI Program data. ROP SSU UA data were used mainly to compare with the MSPI UA data. Only the planned and unplanned outages were used; the fault exposure outages were not included.

Most updated system studies include MOOS data, which indicate actual unplanned demands where a system train was unavailable because of ongoing TM. These data are available for 1988 to the present. Because MOOS data are obtained from LER reviews, this data source is independent of the MSPI UA data. Therefore, the MOOS data can be used in two ways: as the primary source for UA data or as an independent comparison to the MSPI UA results.

Finally, the IPE TM data source (Ref. 66) presents component or train average UA values (and associated error factors if available) obtained from a review of IPEs. IPEs are the plant risk models developed for each of the U.S. commercial NPPs and submitted to NRC in the early 1990s. The UA values in these risk models typically were based on plant-specific component or train data obtained from the late 1980s. This data source has not been updated.

6.3 Data Period

To match the period used for component UR, train UA data for 1998–2002 would have been most appropriate. However, the preferred source—MSPI train UA data—starts with 2002 (in the MSPI basis documents and continuing with the quarterly data submitted to NRC). As a compromise, the MSPI train UA data for 2002–2004 were chosen to represent current performance. This data period is not centered about the year 2000. To observe what differences between these two periods might exist, these results were then compared with ROP SSU UA data for 1998–2002. Similar to concerns for component UR, longer periods provide more UA data. However, if trends exist over these longer periods, then the earlier data are not indicative of current plant performance. The 3-year period was chosen to provide sufficient data close to the year 2000 but to be short enough to minimize concerns about potential trends.

6.4 General Process for Collecting and Analyzing Data

Of the 34 train UA events listed in Table 6-1, the preferred source—MSPI data—was used for 22 events. For each train UA event, planned and unplanned outage hours over 2002–2004 were summed and divided by the train required hours. This resulted in a set of estimated train UAs, with the sets ranging from four trains for the feedwater (FWR) injection to greater than 200 trains. Train UAs were averaged across the industry to obtain the mean value. To characterize the data, beta distributions were then fit to these data, using a maximum likelihood estimate approach. For systems with fewer than five train values, the beta distribution was characterized by the mean of the train values and an average α parameter from other UA beta fits. (This average is approximately 2.5.) Results reflect industry performance centered about the year 2003, rather than 2000.

Unlike the component UR analysis, where data were aggregated at the plant level before determining a distribution, the individual train UA data were not aggregated at the system level within a plant before fitting a distribution. Therefore, the fitted distribution represents the industry variation at the train level, rather than at the system or plant level. This approach was used because non-zero UA values existed for nearly all of the trains. (In contrast, for the component UR often fewer than 10% of the components experienced a failure over the period considered.) Several entries in Table 6-1 were re-analyzed after aggregating the train data at the system level within a plant. The resulting curve fits indicated a similar mean and slightly higher α parameter (e.g., 3.74 rather than 3.59 for EDG trains). This is to be expected; the variability at the train level across the industry should be greater (lower α) than the variability at the system level across the industry.

The SSU UA data (1998–2002) analysis was similar to what was done for the MSPI UA data. For each train, the planned and unplanned hours were summed and divided by the train required hours. Results are centered about the year 2000. The SSU data were used for one train UA event, the HTG-TM. MSPI data were not used for this event because the MSPI train definition is focused on the transmission lines (one underground and one aboveground) connecting the two HTGs to the three Oconee plants. The SSU train definition is focused more on the actual HTGs.

Older IPE data were used for ten train UA events not covered by the SSU or MSPI data. However, these data are representative of plant performance during the late 1980s. A comparison of these data with corresponding MSPI data (2002–2004) and SSU data (1998–2002) indicates that for IPE train UAs greater than 5.0E–03, current industry UAs are approximately half as large. (See Appendix B for the details of this comparison.) Therefore, IPE UAs greater than 5.0E–03 were divided by two to approximate current performance. IPE UAs lower than 5.0E–03 were used without any adjustments. Finally, although Reference 66 indicates error factors for many of the train UAs, based on the variation observed between the various IPEs, these were not judged to be indicative of the variation in current industry performance. For the UA events supported by IPE data, the SCNID ($\alpha = 0.50$) was assumed.

Finally, one UA event was quantified using information from the system study covering the Westinghouse reactor protection system (Ref. 3). That system study did not use MOOS events; rather, the UA event was quantified by assuming a testing interval and duration.

6.5 Train Unavailability Data and Results

Train UA data and resulting probability distributions are summarized in Table 6-1. Two sets of distributions are presented. The first distribution is based on the mean and α parameter obtained from the data (or other source). The second distribution is based on the rounded mean and α parameter. (The SPAR models use the rounded values and associated distribution.) More detailed information is presented in Appendix B. The emergency power source UAs are 9.0E–03 for HTGs, 1.3E–02 for EDGs, and 5.0E–02 for CTGs. For centrifugal MDPs, the UAs range from 4.0E–03 (AFWS) to 1.6E–02 for nuclear or normal service water (NSW). For TDPs, the UAs are 5.4E–03 for AFWS, 1.1E–02 for RCIC, and 1.3E–02 for HPCI. Other train UAs range from 2.2E–04 to 5.8E–02.

The MSPI train UA results covering 2002–2004 were compared with corresponding ROP SSU UA results covering 1998–2002. As explained previously, the reporting requirements for these two programs differ. The MPSI Program includes component overhauls while the plant is in critical operation; the ROP SSU does not include such events. However, the MPSI Program does not include support system UA within frontline safety systems, while the ROP SSU does include these. Therefore, a comparison of the MSPI 2002–2004 results with the ROP SSU 1998–2002 results encompasses not only the time period difference but also reporting requirement differences.

Table 6-2 presents the results of this comparison. The MSPI train UA results for EDGs are approximately 50% higher than the ROP SSU results. This difference is believed to result mainly from the inclusion of EDG planned overhauls during plant critical operation in the MSPI data. However, an additional consideration may be the approvals of longer-allowed outage times for EDGs at selected plants (assuming these longer-allowed outage times lead to some longer EDG outages during critical operation). For several other train UA events, the MSPI values are also higher than the ROP SSU values. The reasons for these differences were not investigated, but the main reason is believed to be the difference in reporting requirements, rather than a difference in actual UA outages for 1998–2002 versus 2002–2004. Finally, results from both data sources and periods agree well for the RHR heat exchanger trains, various system TDPs, and the HPSI and AFWS MDPs.

Table 6-2. Comparison of MSPI 2002–2004 train UA results with ROP SSU 1998–2002 results.

Train Unavailability Event	Train Description	Data Source	MSPI Data (2002 - 2004)				ROP SSU Data (1998 - 2002)				MSPI Mean/ ROP SSU Mean	Comments (see Appendix B for details)
			Mean	α	β	Error Factor	Mean	α	β	Error Factor		
DDP-TM (AFWS)	Diesel-Driven Pump Test or Maintenance (AFWS)	MSPI	9.70E-03	10.946	1.118E+03	1.6	5.05E-03	3.400	6.699E+02	2.2	1.92	ROP SSU data do not identify AFWS pump types, so the result is an average of MDPs, TDPs, and DDPs
DDP-TM (SWS)	Diesel-Driven Pump Test or Maintenance (SWS)	MSPI	2.95E-02	6.134	2.018E+02	1.8						ROP SSU UA data do not cover SWSs or CCW
EDG-TM (EPS)	Emergency Diesel Generator Test or Maintenance (EPS)	MSPI	1.34E-02	3.586	2.640E+02	2.2	9.06E-03	3.600	3.938E+02	2.2	1.48	
EDG-TM (HPCS)	Emergency Diesel Generator Test or Maintenance (HPCS)	MSPI	1.33E-02	5.761	4.274E+02	1.9	7.61E-03	3.800	4.955E+02	2.1	1.75	
FWR-TM	Feedwater Injection Test or Maintenance	MSPI	1.60E-02	2.500	1.538E+02	2.5	9.10E-03	2.500	2.722E+02	2.5	1.76	
HDR-TM (ESW)	Piping Header Test or Maintenance (ESW)	MSPI	8.65E-03	1.000	1.146E+02	4.3						ROP SSU UA data do not cover SWSs or CCW
HDR-TM (RHRSW)	Piping Header Test or Maintenance (RHRSW)	MSPI	3.63E-03	1.747	4.795E+02	3.0						ROP SSU UA data do not cover SWSs or CCW
HTX-TM (CCW)	Heat Exchanger Test or Maintenance (CCW)	MSPI	7.23E-03	1.000	1.373E+02	4.3						ROP SSU UA data do not cover SWSs or CCW
HTX-TM (RHR-BWR)	Heat Exchanger Test or Maintenance (RHR-BWR)	MSPI	7.62E-03	3.759	4.895E+02	2.2	7.71E-03	6.200	7.980E+02	1.8	0.99	
HTX-TM (RHR-PWR)	Heat Exchanger Test or Maintenance (RHR-PWR)	MSPI	5.18E-03	2.748	5.278E+02	2.4	5.98E-03	2.500	4.156E+02	2.5	0.87	
IC-TM	Isolation Condenser Test or Maintenance	MSPI	5.86E-03	1.265	2.146E+02	3.6	7.48E-03	2.500	3.317E+02	2.5	0.78	
MDP-TM (AFWS)	Motor-Driven Pump Test or Maintenance (AFWS)	MSPI	3.95E-03	2.387	6.019E+02	2.6	5.05E-03	3.400	6.699E+02	2.2	0.78	ROP SSU data do not identify AFWS pump types, so the result is an average of MDPs, TDPs, and DDPs
MDP-TM (CCW)	Motor-Driven Pump Test or Maintenance (CCW)	MSPI	5.91E-03	1.288	2.166E+02	3.6						ROP SSU UA data do not cover SWSs or CCW
MDP-TM (HPCS)	Motor-Driven Pump Test or Maintenance (HPCS)	MSPI	1.31E-02	1.537	1.158E+02	3.2	7.20E-03	20.000	2.758E+03	1.4	1.82	
MDP-TM (HPSI)	Motor-Driven Pump Test or Maintenance (HPSI)	MSPI	4.12E-03	2.348	5.676E+02	2.6	4.97E-03	2.200	4.405E+02	2.7	0.83	
MDP-TM (ESW)	Motor-Driven Pump Test or Maintenance (ESW)	MSPI	1.30E-02	1.000	7.592E+01	4.3						ROP SSU UA data do not cover SWSs or CCW
MDP-TM (NSW)	Motor-Driven Pump Test or Maintenance (NSW)	MSPI	1.64E-02	6.278	3.765E+02	1.8						ROP SSU UA data do not cover SWSs or CCW
MDP-TM (RHRSW)	Motor-Driven Pump Test or Maintenance (RHRSW)	MSPI	5.76E-03	1.306	2.254E+02	3.6						ROP SSU UA data do not cover SWSs or CCW
MDP-TM (Other)	Motor-Driven Pump Test or Maintenance (Other)	MSPI	7.51E-03	1.000	1.322E+02	4.3	5.06E-03	2.700	5.309E+02	2.5	1.48	ROP SSU result is combination of AFWS, HPCS, and HPSI data
TDP-TM (AFWS)	Turbine-Driven Pump Test or Maintenance (AFWS)	MSPI	5.44E-03	2.177	3.980E+02	2.7	5.05E-03	3.400	6.699E+02	2.2	1.08	ROP SSU data do not identify AFWS pump types, so the result is an average of MDPs, TDPs, and DDPs
TDP-TM (HPCI)	Turbine-Driven Pump Test or Maintenance (HPCI)	MSPI	1.30E-02	3.288	2.496E+02	2.3	1.15E-02	3.900	3.352E+02	2.1	1.13	
TDP-TM (RCIC)	Turbine-Driven Pump Test or Maintenance (RCIC)	MSPI	1.07E-02	4.703	4.348E+02	2.0	1.29E-02	4.600	3.520E+02	2.0	0.83	

Acronyms - AFWS (auxiliary feedwater system), BWR (boiling water reactor), CCW (component cooling water), DDP (diesel-driven pump), EPS (emergency power system), ESW (emergency or essential service water), HPCI (high-pressure coolant injection), HPCS (high-pressure core spray), HPSI (high-pressure safety injection), IC (isolation condenser), MDP (motor-driven pump), MSPI (Mitigating Systems Performance Index), NSW (normal service water), PWR (pressurized water reactor), RCIC (reactor core isolation cooling), RHR (residual heat removal), RHRSW (residual heat removal service water), ROP (Reactor Oversight Process), SSU (Safety System Unavailability), SWS (service water system), TDP (turbine-driven pump), TM (test or maintenance)

7. SYSTEM SPECIAL EVENTS

Several special events related to system performance are also included in the SPAR models. These events are listed in Table 7-1 and address performance and conditional probability issues related to operation of HPCI, HPCS, and RCIC during unplanned demands. For RCIC, the probability of the 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.

The updated system study data (Ref. 16) were used to quantify the special events listed in Table 7-1. Data from these studies supporting the special events were obtained from a review of unplanned demands described in LERs. These data are updated yearly, and such updates can include changes to previous data. The database used for this study was the one covering 1988 through 2004. However, to match the period used for component UR, data through 2002 were used. In addition, because the unplanned demand data are sparse compared with test demand data, the start date for each special event was optimized. Optimization in this case indicates that yearly data were examined, starting with 2002 and working backward in time, to identify the longest baseline period with the least evidence of a trend. Typically, the system study data indicate more failures in the early years and fewer failures in the latter years, so the early years with poorer performance were not included in the baseline period used to quantify the special events. Statistical tests were used to evaluate whether a trend existed within each potential baseline period. The starting year that resulted in the highest p-value (lowest probability of a trend existing) was then chosen. Additionally, if there were no events or only one event during 1988–2002, then the entire period was chosen as the baseline. Finally, if there were only two events and they occurred during the first 3 year (probability of this is less than 0.05 assuming a constant occurrence rate), then the baseline period started with the first year with no events. This optimization of the period used to characterize current performance resulted in baseline periods with start years of 1988 to 1998, but all ending in 2002.

Empirical Bayes analyses of the system special events were performed at the year level, looking for year-to-year variation. (With so few events, plant-level analyses were not possible.)

Updated system study data and results for the special events are presented in Table 7-1. Two sets of distributions are presented. The first distribution is based on the mean and α parameter obtained from the data. The second distribution is based on the rounded mean and α parameter. (The SPAR models use the rounded values and associated distribution.) More detailed information is provided in Appendix C.

The special events are included in the HPCI, HPCS, and RCIC fault trees in the SPAR models. As an example, for RCIC to start and run for a mission of 24 hours, the TDP must initially start and run. Data for the initial start and run are obtained from the component UR results presented in Section 5. However, operation of RCIC may involve stopping and then restarting the TDP during the mission. This is modeled in the fault tree with three events under an AND gate: probability of the TDP having to restart (TDP-PRST in Table 7-1), failure of the TDP to restart (TDP-FRST), and failure to recover failure of the TDP to restart (TDP-FRFRST). Similarly, the injection valve initially must open, but might close and have to reopen over the 24-hour mission. Data for the initial opening of the valve come from Section 5, while data for events modeling the reopening of the valve are covered in Table 7-1.

Table 7-1. System special event data and results.

Special Event Name	Description	Data Source	Data			Industry-average Probability or Rate Distribution (note a)									Comments (see Appendix C for details)
			Failures	Demands or Hours	d or h	Distribution (note b)	Mean	α	β	Error Factor	Rounded Mean (note c)	Rounded α (note c)	β (note d)	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	1.5E-01	6.0	3.40E+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	8.0E-02	0.5	5.75E+00	7.3	
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	2.5E-01	0.5	1.50E+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	5.0E-01	4.0	4.00E+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	4.0E-02	0.5	1.20E+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	8.0E-01	0.5	1.25E-01	1.0	
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	8.0E-03	0.5	6.20E+01	8.4	Note that this is per hour. Failure occurred 8 min after RCIC initiation.
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	2.5E-01	0.5	1.50E+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	1.5E-01	0.5	2.83E+00	6.2	
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	1.5E-01	0.5	2.83E+00	6.2	
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	8.0E-01	0.5	1.25E-01	1.0	
SUC-FTFR (HPCI)	HPCI failure to transfer	SS	0	1270	d	Beta (Jeffreys, SCNID)	3.93E-04	0.500	1.271E+03	8.4	4.0E-04	0.5	1.25E+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	5.0E-01	0.5	5.00E-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	3.0E-03	0.5	1.66E+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	8.0E-01	0.5	1.25E-01	1.0	

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 Reference 59 and outlined in Section 6.2.3.5 in Reference 17.

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

Note c - The value is rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten.

Note d - The β factor is determined from mean and α. The β factor is presented to three significant figures to preserve the mean of the distribution.

8. INITIATING EVENT FREQUENCY

Most IEs included in the SPAR models are listed in Table 8-1. These events represent various categories of unplanned automatic and manual reactor trips within the industry. Several sizes of LOCAs are included, a variety of transients, and several losses of support systems. The various interfacing systems LOCAs modeled in SPAR are not listed because their modeling and associated frequencies will be addressed in separate SPAR model improvement efforts.

8.1 Initiating Event Descriptions

The IE descriptions generally are those presented in NUREG/CR-5750 (Ref. 67) and are summarized in Appendix D. For all IEs except for the general transient category, the functional impact definitions in Reference 67 apply. As an example, the loss of offsite power (LOOP) category includes (a) events in which the LOOP is the initial plant fault (causes the plant to trip) and (b) events in which other upset conditions cause the plant to trip but a LOOP occurs subsequent to the plant trip.

8.2 Hierarchy of Data Sources

For IE data, the following hierarchy of sources was used:

1. Updated IE database maintained by the NRC (Ref. 16)
2. Updated study of LOOP and station blackout (SBO) (Ref. 68)
3. Draft report on the updating of LOCA frequencies using expert elicitation (Ref. 69).

Similar to the updated system study data maintained by the NRC, the IE data presented in NUREG/CR-5750 (Ref. 67) are updated yearly. Events contained within this database meet all of the following criteria:

- Include an unplanned reactor trip
- Occur when the reactor is critical and at or above the point of adding heat
- Are reported by an LER.

Such events are categorized by both initial plant fault category and functional impact category (if applicable). This database covers 1987 through the present.

The updated LOOP/SBO report (Ref. 68) reviewed LOOP data over 1986–2004. However, the LOOP frequencies in that report for critical operation are based on the more recent 1997–2004 data. In this present report, the overall LOOP category is subdivided into four categories: plant centered, switchyard centered, grid related, and weather related.

Reference 69 is a draft report addressing LOCA frequencies for BWRs and PWRs. Frequencies were estimated using the expert elicitation process. LOCA events include large, medium, and small LOCAs and steam generator tube ruptures.

Table 8-1. Initiating event data and results.

Initiating Event	Description	Data Source	Data		Industry-average Frequency Distribution (note a)									Comments (see Appendix D for details)
			Number of Events	Critical Years (rcry)	Distribution (note b)	Mean	α	β	Error Factor	Rounded Mean (note c)	Rounded α (note c)	β (note d)	Error Factor	
IE-LLOCA (BWR)	Large Loss-of-Coolant Accident (BWRs)	[69]			Gamma (EE, EE)	6.78E-06	0.470	6.932E+04	9.1	7.0E-06	0.5	7.14E+04	8.4	
IE-LLOCA (PWR)	Large Loss-of-Coolant Accident (PWRs)	[69]			Gamma (EE, EE)	1.33E-06	0.420	3.158E+05	10.7	1.2E-06	0.4	3.33E+05	11.5	
IE-LOAC	Loss of Vital AC Bus	IEDB	8	965.8	Gamma (Jeffreys, Jeffreys)	8.80E-03	8.500	9.658E+02	1.7	9.0E-03	8.0	8.89E+02	1.7	Review of events to remove those not applicable based on SPAR modeling
IE-LOCCW	Total Loss of Component Cooling Water	IEDB	0	1282.4	Gamma (Jeffreys, SCNID)	3.90E-04	0.500	1.282E+03	8.4	4.0E-04	0.5	1.25E+03	8.4	No failures (but some ASP events have been close to complete loss of CCW)
IE-LOCHS (BWR)	Total Loss of Condenser Heat Sink (BWRs)	IEDB	41	208.6	Gamma (EB/PL/KS, EB/PL/KS)	1.97E-01	11.080	5.638E+01	1.6	2.0E-01	12.0	6.00E+01	1.6	
IE-LOCHS (PWR)	Total Loss of Condenser Heat Sink (PWRs)	IEDB	38	475.0	Gamma (Jeffreys, Jeffreys)	8.11E-02	38.500	4.750E+02	1.3	8.0E-02	40.0	5.00E+02	1.3	
IE-LODC	Loss of Vital DC Bus	IEDB	1	1282.4	Gamma (Jeffreys, SCNID)	1.17E-03	0.500	4.275E+02	8.4	1.2E-03	0.5	4.17E+02	8.4	Review of events to remove those not applicable based on SPAR modeling
IE-LOIA (BWR)	Total Loss of Instrument Air (BWRs)	IEDB	3	343.3	Gamma (Jeffreys, Jeffreys)	1.02E-02	3.500	3.433E+02	2.2	1.0E-02	3.0	3.00E+02	2.4	Review of events to remove those not applicable based on SPAR modeling
IE-LOIA (PWR)	Total Loss of Instrument Air (PWRs)	IEDB	3	356.9	Gamma (Jeffreys, SCNID)	9.81E-03	0.500	5.099E+01	8.4	1.0E-02	0.5	5.00E+01	8.4	Review of events to remove those not applicable based on SPAR modeling
IE-LOMFW	Total Loss of Main Feedwater	IEDB	84	881.9	Gamma (EB/PL/KS, EB/PL/KS)	9.59E-02	1.326	1.383E+01	3.6	1.0E-01	1.2	1.20E+01	3.8	
IE-LOOP	Total Loss of Offsite Power	[68]			Gamma (Jeffreys, Simulation)	3.59E-02	1.580	4.402E+01	3.2	4.0E-02	1.5	3.75E+01	3.3	
	Plant Centered Contribution to LOOP	IEDB	1	724.3										
	Switchyard Centered Contribution to LOOP	IEDB	7	724.3										
	Grid Related Contribution to LOOP	IEDB	13	724.3										
	Weather Related Contribution to LOOP	IEDB	3	724.3										
IE-LOESW	Total Loss of Emergency Service Water	IEDB	0	1269.4	Gamma (Jeffreys, SCNID)	3.94E-04	0.500	1.269E+03	8.4	4.0E-04	0.5	1.25E+03	8.4	The Harris event in the database involves complete failure of the NSW, not the ESW
IE-MLOCA (BWR)	Medium Loss-of-Coolant Accident (BWRs)	[69]			Gamma (EE, EE)	1.04E-04	0.610	5.865E+03	6.7	1.0E-04	0.6	6.00E+03	6.8	
IE-MLOCA (PWR)	Medium Loss-of-Coolant Accident (PWRs)	[69]			Gamma (EE, EE)	5.10E-04	0.440	8.627E+02	10.0	5.0E-04	0.4	8.00E+02	11.5	
IE-PLOCCW	Partial Loss of Component Cooling Water	IEDB	1	1282.4	Gamma (Jeffreys, SCNID)	1.17E-03	0.500	4.275E+02	8.4	1.2E-03	0.5	4.17E+02	8.4	Review of events to remove those not applicable based on SPAR modeling
IE-PLOESW	Partial Loss of Emergency Service Water	IEDB	2	1282.4	Gamma (Jeffreys, SCNID)	1.95E-03	0.500	2.565E+02	8.4	2.0E-03	0.5	2.50E+02	8.4	Review of events to remove those not applicable based on SPAR modeling
IE-SGTR (PWR)	Steam Generator Tube Rupture (PWRs)	IEDB	2	706.4	Gamma (Jeffreys, SCNID)	3.54E-03	0.500	1.413E+02	8.4	4.0E-03	0.5	1.25E+02	8.4	
IE-SLOCA (BWR)	Small Loss-of-Coolant Accident (BWRs)	[69]			Gamma (EE, EE)	5.00E-04	0.780	1.560E+03	5.3	5.0E-04	0.8	1.60E+03	5.2	
IE-SLOCA (PWR)	Small Loss-of-Coolant Accident (PWRs)	IEDB	0	866.6	Gamma (Jeffreys, SCNID)	5.77E-04	0.500	8.666E+02	8.4	6.0E-04	0.5	8.33E+02	8.4	No failures, but there were events in the early 1980s (RCP seal LOCAs)
IE-SORV (BWR)	Stuck Open Safety/Relief Valve (BWRs)	IEDB	6	291.7	Gamma (Jeffreys, Jeffreys)	2.23E-02	6.500	2.917E+02	1.8	2.0E-02	6.0	3.00E+02	1.9	
IE-SORV (PWR)	Stuck Open Safety/Relief Valve (PWRs)	IEDB	2	866.6	Gamma (Jeffreys, SCNID)	2.88E-03	0.500	1.733E+02	8.4	3.0E-03	0.5	1.67E+02	8.4	

Table 8-1. (continued).

Initiating Event	Description	Data Source	Data		Industry-average Frequency Distribution (note a)									Comments
			Number of Events	Critical Years (rcry)	Distribution (note b)	Mean	*α*	*β*	Error Factor	Rounded Mean (note c)	Rounded *α* (note c)	*β* (note d)	Error Factor	*(see Appendix D for details)*
IE-TRAN (BWR)	General Transient (BWRs)	IEDB	149	180.2	Gamma (Jeffreys, Jeffreys)	8.30E-01	149.500	1.802E+02	1.1	8.0E-01	150.0	1.88E+02	1.1	
IE-TRAN (PWR)	General Transient (PWRs)	IEDB	228	304.0	Gamma (EB/PL/KS, EB/PL/KS)	7.51E-01	17.772	2.366E+01	1.4	8.0E-01	20.0	2.50E+01	1.4	
IE-VSLOCA	Very Small Loss-of-Coolant Accident	IEDB	1	965.8	Gamma (Jeffreys, SCNID)	1.55E-03	0.500	3.219E+02	8.4	1.50E-03	0.5	3.33E+02	8.4	

Acronyms - ASP (accident sequence precursor), BWR (boiling water reactor), CCW (component cooling water), EB (empirical Bayes), EE (expert elicitation), ESW (emergency service water), IE (initiating event), IEDB (initiating events database), KS (Kass-Steffey), LOCA (loss-of-coolant accident), LOOP (loss of offsite power), NSW (normal service water), PL (plant level), PWR (pressurized water reactor), RCP (reactor coolant pump), SCNID (simplified constrained noninformative distribution), SPAR (standardized plant analysis risk)

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 Reference 59 and outlined in Section 6.2.3.5 in Reference 17.

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

Note c - The value is rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten.

Note d - The β factor is determined from the mean and α. The β factor is presented to three significant figures to preserve the mean of the distribution

8.3 Data Period

To characterize current industry performance with respect to IEs, baseline periods ending in 2002 are preferred. This end date is the same one used for component UR baselines. However, similar to the process used for the system special events, the start dates vary by IE. Resulting data periods used to quantify the IE frequencies range from 1988–2002 to 1998–2002, depending upon the relative frequency and whether a trend exists.

8.4 General Process for Collecting and Analyzing Data

Most IE frequencies were quantified using the updated IE database. The IE database is updated on a yearly basis. The database used for this effort was the one covering data up through 2004. However, only data through 2002 were used. The RADS software was used to identify the events and corresponding reactor critical years for each IE category. For each category, a plot of these data over the period 1988–2002 was reviewed to identify potential start years for the baseline period (ending in 2002). The goal was to choose a baseline period that best characterizes industry performance centered about the year 2000. Therefore, the plot was reviewed to identify potential start years that would result in baselines with the most constant performance. Each potential baseline was then analyzed for the existence of a trend, and the one with the least potential for a trend (highest p-value from the trend analysis) was chosen. Additionally, if there were no events or only one event during 1988 – 2002, then the entire period was chosen as the baseline. Finally, if there were only two events and they occurred during the first 3 years (probability of this is less than 0.05 assuming a constant occurrence rate), then the baseline period started with the first year with no events. Note that this procedure is identical to the one used to identify baseline periods for the special events in Section 7. Data from the resulting baseline period were then analyzed to obtain a mean and distribution (empirical Bayes analysis). In cases where the empirical Bayes analysis was degenerate, the SCNID distribution was assumed. In five cases, the empirical Bayes analysis failed to converge but indicated insufficient variation between plants. Therefore, assuming homogeneous data, a Bayesian update of the Jeffreys noninformative prior using the industry data was calculated for these cases.

Six IEs required additional review to ensure that the events identified matched the SPAR modeling assumptions for each initiator. These events were loss of ac bus (LOAC), loss of dc bus (LODC), loss of instrument air for both BWRs and PWRs (LOIA BWR and LOIA PWR), and partial losses of emergency service water or component cooling water (PLOESW and PLOCCW). More detail concerning these additional reviews is presented in Appendix D. Only the events remaining after this review were included in this report to characterize frequencies.

8.5 Initiating Event Data and Results

Initiating event data and resulting frequency distributions are presented in Table 8-1. Two sets of distributions are presented. The first distribution is based on the mean and α parameter obtained from the data (or other source). The second distribution is based on the rounded mean and α parameter. (The SPAR models use the rounded values and associated distribution.) The preferred data source, the updated IE database, was used to characterize the frequency distributions for 18 of the 24 IE categories. Because LOOP was analyzed in detail in a recent NRC study (Ref. 68), the LOOP data were obtained from that source (which used the updated IE database). The data period for the LOOP frequency is 1997–2004, in contrast to the other baselines that end in 2002. Finally, the small (except for PWRs), medium, and large LOCA frequency distributions were obtained from the draft report on expert elicitation for LOCAs (Ref. 69).

9. COMPARISON WITH OTHER SOURCES

Two types of comparisons are presented in this section. The first is a comparison of current results from Sections 5 through 8 with other sources of current data (if available). The second is a comparison of current results with historical estimates.

9.1 Comparison with Other Current Sources

For component UR, several of the current baselines presented in Table 5-1 can be compared with corresponding updated system study data. The system study data cover standby MDPs, standby TDPs, standby DDPs, MOVs, and EDGs. The component UR baselines were derived mainly from EPIX data, which are heavily weighted by test and operational demand data. (Over 95% of the data for most component failure modes are test data and operational demands, with the remaining data coming from unplanned demands.) In contrast, the updated system study data are derived from LERs. Most of these data are from unplanned demands, although several system studies also include cyclic (every cycle or approximately 18 months) and quarterly tests.

To compare the system study results with the component UR baselines, the individual system study data were aggregated to obtain total failures and demands corresponding with the component failure modes covered in this report. For example, the MDP FTS data from the AFWS, HPSI, and HPCS system studies were combined to obtain a single set of data. Similar aggregations were performed for TDPs and MOVs. The system studies do not subdivide FTR data into FTR≤1H and FTR>1H. For this comparison, the system study FTR data were subdivided for comparison purposes. This required a review of the LERs for each FTR event to determine how long the component ran before failing.

Results of the comparison of system study data with the component UR baselines are presented in Table 9-1. Additional information concerning this comparison is presented in Appendix E. Comparisons presented in Table 9-1 assume that the system study data are homogeneous, with no significant plant-to-plant variation. More sophisticated analyses could be performed if the system study were aggregated by plant rather than by year.

Referring to the standby MDP components, the system study data indicate an FTS probability of 6.7E–03 before recovery is considered and 5.7E–03 with recovery considered. Recoveries allowed within the system study are typically simple actions that are performed from the control room. In comparison, the corresponding component UR baseline is 1.5E–03. Statistical tests discussed in Appendix E indicate that there is a significant difference between the system study data and the EPIX data for this failure mode. For FTR≤1H, the system study rate without recovery is 2.6E–03/hour and with recovery is 1.6E–03/hour. The corresponding component UR baseline is 3.8E–04/hour. For this failure mode, the system study data without recovery are significantly different from the EPIX data, but the system study data with recovery are not. Finally, for FTR>1H, the system study data are not significantly different from the EPIX data. Therefore, for standby MDP components, the system study data including recovery do support the component UR baselines obtained from EPIX data except for FTS. However, if recovery is not considered, the system study data lie above the baselines obtained from the EPIX data.

For standby TDP components, the system study data indicate an FTS probability of 5.3E–03 without recovery and 3.2E–03 with recovery. Both of these results lie below the component UR baseline of 6.9E–03 but are not significantly different. However, for FTR≤1H and FTR>1H, the system study results (with or without recovery) are significantly different from the EPIX data.

Table 9-1. Comparison of component UR baseline data with updated system study data.

Component	Failure Mode	Updated System Study Data (note a)					EPIX Data (1998 - 2002) (note b)				Statistical Comparison (note c)
		Failures	Demands or Hours	Probability	Rate (1/h)	Comment	Failures	Demands or Hours	Probability	Rate (1/h)	
MDP STBY	FTS	6	964.0	6.74E-03			104	82137.0	1.47E-03		Significant difference
	FTS not recovered	5	964.0	5.70E-03							Significant difference
	FTR<1H (note d)	2	964.0		2.59E-03		12	32495.0		3.78E-04	Significant difference
	FTR<1H not recovered	1	964.0		1.56E-03						No significant difference
	FTR>1H (note d)	0	2922.6		1.71E-04	No events	2.8	568826.0		5.80E-06	No significant difference
	FTR>1H not recovered	No data				No data					No comparison possible
TDP STBY	FTS	7	1402.0	5.35E-03			46	7627.0	6.88E-03		No significant difference
	FTS not recovered	4	1402.0	3.21E-03							No significant difference
	FTR<1H (note d)	10	1402.0		7.49E-03		18	7188.0		2.64E-03	Significant difference
	FTR<1H not recovered	8	1402.0		6.06E-03						Significant difference
	FTR>1H (note d)	3	2820.4		1.24E-03		0	6803.0		7.35E-05	Significant difference
	FTR>1H not recovered	2	2820.4		8.86E-04						Significant difference
DDP STBY	FTS	1	67.0	2.21E-02			9	5161.0	3.88E-03		Significant difference
	FTS not recovered	0	67.0	7.35E-03		No events					No significant difference
	FTR<1H (note d)	1	36.3		4.13E-02		4	3277.0		1.58E-03	Significant difference
	FTR<1H not recovered	0	36.3		1.38E-02						Limited system study data and no failures
	FTR>1H (note d)	No data					No data				No comparison possible
	FTR>1H not recovered	No data									No comparison possible
MOV	FTO/C	0	305.0	1.63E-03		No events	244	232264.0	1.07E-03		No significant difference
EDG (HPCS) (note e)	FTS	0	138.0	3.60E-03		No events	3	870.9	3.44E-03		No significant difference
	FTS not recovered	No data									No comparison possible
	FTLR	0	138.0	3.60E-03		No events	0	699.4		7.15E-04	Limited system study data and no failures
	FTLR not recovered	No data									No comparison possible
	FTR>1H	2	2304.2		1.08E-03		1	1618.7		9.27E-04	No significant difference
	FTR>1H not recovered	2	2304.2		1.08E-03						No significant difference

Table 9-1. (continued).

Component	Failure Mode	Updated System Study Data (note a)					EPIX Data (1998 - 2002) (note b)				Statistical Comparison (note c)
		Failures	Demands or Hours	Probability	Rate (1/h)	Comment	Failures	Demands or Hours	Probability	Rate (1/h)	
EDG (w/o HPCS) (note f)	FTS	1	162.0	9.20E-03			98	24206.0	4.53E-03		No significant difference
	FTS not recovered	1	162.0	9.20E-03							No significant difference
	FTLR	4	162.0	2.76E-02			61	21342.0		2.90E-03	Significant difference
	FTLR not recovered	2	162.0	1.53E-02							Significant difference
	FTR>1H	3	1286.0		2.72E-03		50	59875.0		8.48E-04	Significant difference
	FTR>1H not recovered	3	1286.0		2.72E-03						Significant difference

Acronyms - DDP (diesel-driven pump), EDG (emergency diesel generator), EPIX (Equipment Performance and Information Exchange), FTLR (fail to load and run for 1 h), FTO/C (fail to open or close), FTR <1H (fail to run for 1 h), FTR>1H (fail to run after 1 h), FTS (fail to start), HPCS (high-pressure core spray), MDP (motor-driven pump), MOV (motor-operated valve), RCIC (reactor core isolation cooling), SPAR (standardized plant analysis risk), TDP (turbine-driven pump)

Note a - See Appendix E for the data collection details. The probability or rate is a Bayesian update of the Jeffreys noninformative prior.

Note b - EPIX results are from Table 5-1. Some mean values are from empirical Bayes analyses and are not Bayesian updates of the Jeffreys noninformative prior.

Note c - See Appendix E for an explanation of the statistical analyses performed.

Note d - The SPAR database divides FTR into FTR (<1h) and FTR (>1h). The system study FTR data were subdivided into these same two categories for this comparison. Each demand was assumed to include 1 h of run time.

Note e - The SPAR database does not include the HPCS EDG. Results presented in this table were obtained from an additional search of EPIX data.

Note f - Updated system study data were obtained from Reference 68. Data cover unplanned demands (bus undervoltage) over 1997 - 2003.

Data for standby DDPs are limited for the system studies. For FTS, the system study results are 2.2E–02 without recovery (based on a single failure) and 7.3E–03 with recovery. The corresponding component UR baseline is 3.9E–03. The system study data without recovery are significantly different from the EPIX data (but include only one failure), while the system study data with recovery (no failures) are not. For FTR≤1H the system study data without recovery (one failure) are significantly different from the EPIX data, while the system study data with recovery (no failures) are considered too limited to perform a comparison.

For MOVs, the system study data indicate an FTO probability of 1.6E–03 (based on no failures), compared with the EPIX baseline of 1.1E–03. There is no significant difference between the two data sets.

Finally, EDGs are separated into two categories for the comparison: HPCS EDGs and non-HPCS EDGs. For HPCS EDGs, the system study FTS result is 3.6E–03 (no failures) and the EPIX data baseline is 3.4E–03 (Appendix A, Section A.2.17), indicating no significant difference. For FTLR, both the system study and the component UR baseline are based on no failures, so a comparison should not be made. However, for FTR>1H, the system study result is 1.1E–03/hour, while the EPIX baseline is 9.3E–04/hour, again indicating no significant difference.

For the non-HPCS EDGs, the system study result for FTS is 9.2E–03 (based on a single failure), while the EPIX baseline is 4.5E–03, indicating no significant difference. However, the system study results for FTLR and FTR>1H are significantly different. The system study result for FTLR is 2.8E–02 and the EPIX baseline is 2.9E–03, while the FTR>1H results are 2.7E–03/hour and 8.5E–04/hour, respectively.

Summarizing, of the 16 component and failure mode combinations listed in Table 9-1, statistical comparisons can be made for 15 if recovery is not considered. Of these 15 comparisons, eight indicate significant differences between the system study data and the EPIX data, while seven indicate no significant differences. If recovery is considered, then statistical comparisons can be made for 11 of the combinations. Of these 11, five indicate significant differences, while six do not. Overall, the comparison of EPIX data with the relatively independent system study data indicates both agreement and disagreement between the two sources. As indicated earlier, more sophisticated comparisons could be performed if the system study data were aggregated by plant. Results of such a comparison might differ from those presented in Table 9-1.

The comparison in Table 9-1 is limited to standby MDPs, standby TDPs, standby DDPs, MOVs, and EDGs, which cover most of the risk significant components in the SPAR models. The system studies typically do not provide data for other types of components.

The system study data can also be compared with the train UA baselines presented in Table 6-1. System study MOOS events are an independent source of information for UA, based on actual train outages from TM that existed when unplanned demands occurred. Table 9-2 presents system study data for ten different component UA combinations. For the MDP (HPCS) MOOS, the system study data (only one event) are significantly higher than the MSPI UA result. In addition, for the EDG (HPCS) MOOS, the system study data (only one event) are significantly higher than the MSPI UA result. For the other eight combinations, the system study MOOS data are not significantly different from the MSPI UA data. Overall, the comparison results indicate that the component UA baselines obtained from the MSPI data are appropriate.

Special events listed in Table 7-1 and IEs listed in Table 8-1 have no independent sources with which to compare.

Table 9-2. Comparison of component UA baseline data with updated system study data.

Component	Failure Mode	Updated System Study Data (note a)					MSPI Data (2002 - 2004) (note b)				Statistical Comparison (note c)
		Failures	Demands or Hours	Probability	Rate (1/h)	Comment	Failures	Demands or Hours	Probability	Rate (1/h)	
MDP STBY	MOOS (AFWS)	2	2243.0	1.11E-03			N/A	N/A	3.95E-03		No significant difference
	MOOS (HPSI)	0	210.0	2.37E-03		No events	N/A	N/A	4.12E-03		No significant difference
	MOOS (HPCS)	1	37.0	3.95E-02			N/A	N/A	1.31E-02		Significant difference
TDP STBY	MOOS (AFWS)	1	625.0	2.40E-03			N/A	N/A	5.44E-03		No significant difference
	MOOS (HPCI)	1	94.0	1.58E-02			N/A	N/A	1.30E-02		No significant difference
	MOOS (RCIC)	1	158.0	9.43E-03			N/A	N/A	1.07E-02		No significant difference
DDP STBY	MOOS (AFWS)	0	67.0	7.35E-03		No events	N/A	N/A	9.70E-03		No significant difference
EDG (HPCS)	MOOS	1	35.0	4.17E-02			N/A	N/A	1.33E-02		Significant difference
EDG (w/o HPCS) (note d)	MOOS	1	95.0	1.56E-02			N/A	N/A	1.34E-02		No significant difference
	MOOS not recovered	0	95.0	5.21E-03		No events					No significant difference

Acronyms - AFWS (auxiliary feedwater system), DDP (diesel-driven pump), EDG (emergency diesel generator), HPCI (high-pressure coolant injection), HPCS (high-pressure core spray), HPSI (high-pressure safety injection), MDP (motor-driven pump), MOOS (maintenance out of service), MSPI (mitigating systems performance index), RCIC (reactor core isolation cooling), TDP (turbine-driven pump)

Note a - See Appendix E for the data collection details. The probability or rate is a Bayesian update of the Jeffreys noninformative prior.

Note b - The MSPI results are from Table 6-1.

Note c - See Appendix E for an explanation of the statistical analyses performed.

Note d - Updated system study data were obtained from Reference 68. Data cover unplanned demands (bus undervoltage) over 1997 - 2003.

9.2 Comparison of Current Results with Historical Estimates

In general, the component UR baselines presented in this report are lower than historical estimates. Figures 9-1 through 9-5 illustrate the downward trends in UR (improved performance) for EDGs, MDPs, TDPs, DDPs, and MOVs. Historical comparisons can be misleading if the various sources used differing component boundaries, failure definitions, demand or run hour estimation methods, or analysis methods. The comparisons presented in the figures are believed to be consistent, based on a careful review of the source documentation related to these issues.

For the EDG comparison, both FTS and combined UR are presented. For combined UR, an 8-hour mission was used. From Reference 68, unplanned demands for EDGs had average run times of approximately 8 hours. Figure 9-1 indicates that estimates for EDG combined UR (8-hour mission) dropped from 1.0E–01 around 1970 to 1.3E–02 for the current UR baseline. Also, estimates for FTS dropped from 3.8E–02 to 4.5E–03 over the same period. For the other components except for MOVs, a 24-hour mission was used to agree with risk model missions for these types of components. Similar drops in FTS and combined UR are observed for MDPs, TDPs, and DDPs. MOV FTO/C estimates are presented in Figure 9-5. The baseline estimate of 1.1E–03 is approximately three times lower than previous estimates.

Trends in train UA estimates are presented in Figures 9-6 through 9-8 for EDGs, standby MDPs, and standby TDPs. For all of these components, the UA trends start low (NUREG-1150 (Refs. 13, 14) estimates centered around approximately 1980), peak around 1990 with the IPE estimates, and then drop back down with the current UA baselines. The reasons for the NUREG-1150 estimates being so low are unknown. The IPE estimates centered around 1990 are based on actual plant data for that period. Also, the current UA estimates are also based on actual industry data (2002–2004). The current estimates are roughly half of the IPE estimates.

No trends are presented for the special events. The methodology for analyzing the system study data for these events was changed for the present study, so a comparison with previous results would be misleading. Optimizing the baselines for the current estimates has a significant impact on the results, compared with the previous methods of using all of the data available (even if a trend existed) or using only the last half of the period covered.

Finally, trends in IE performance are presented in Appendix E. Of the 18 IEs quantified using the IE database, 12 used a baseline period shorter than 1988–2002 (the period covered by the database), indicating a trend in performance. For the transient category, the current baseline frequencies are less than one-third of the estimates from the late 1980s. Other IEs with trends had changes of this magnitude or less. The other six used the entire period, indicating either no trend or insufficient events to determine whether there is a trend.

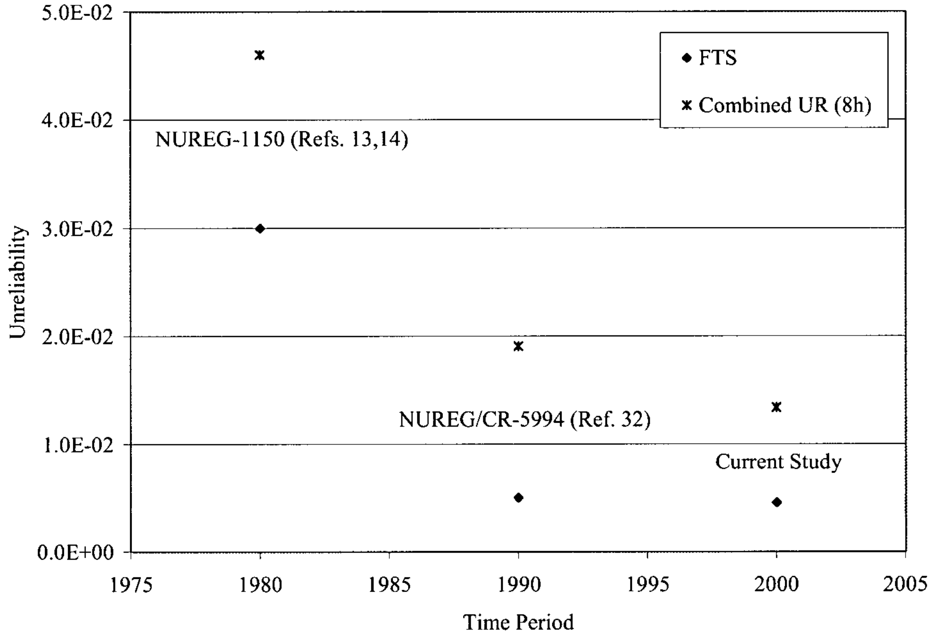

Figure 9-1. Historical trend in EDG UR performance estimates.

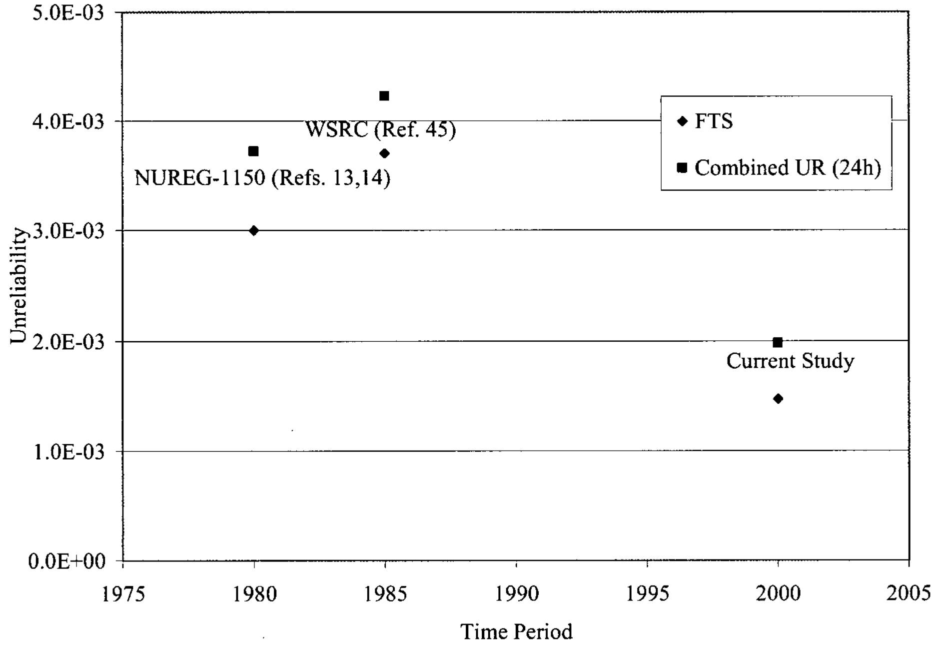

Figure 9-2. Historical trend in MDP standby UR performance estimates.

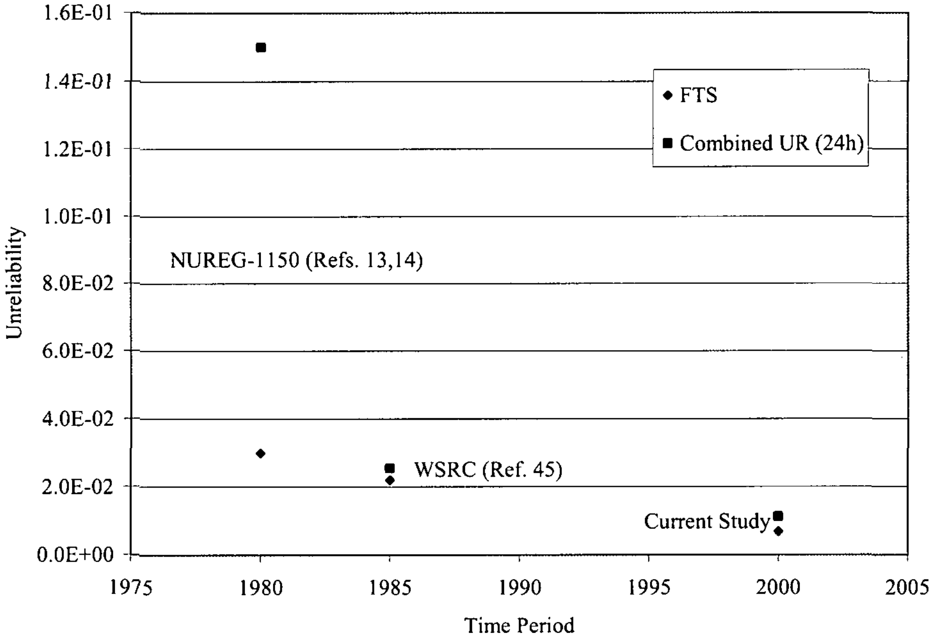

Figure 9-3. Historical trend in TDP standby UR performance estimates.

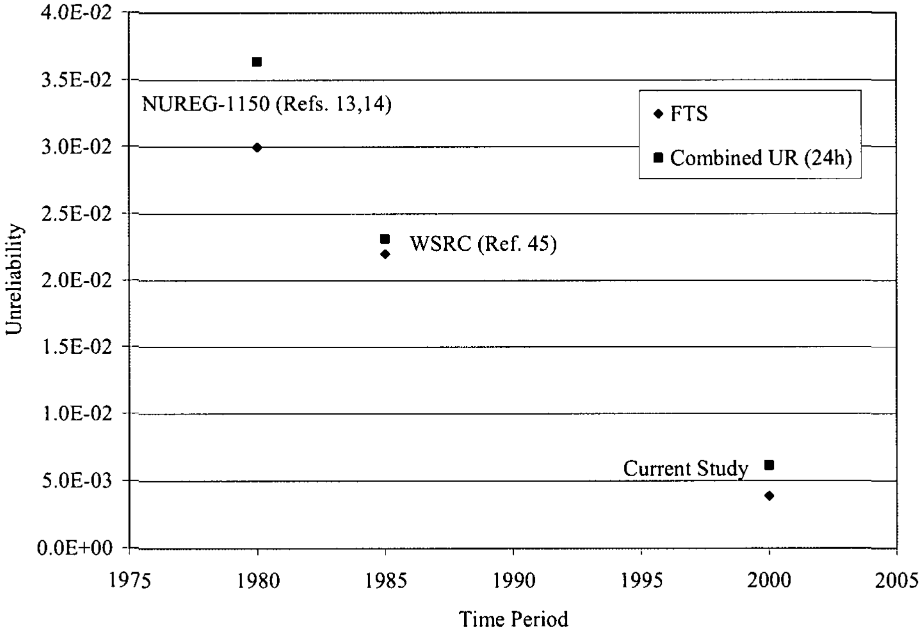

Figure 9-4. Historical trend in DDP standby UR performance estimates.

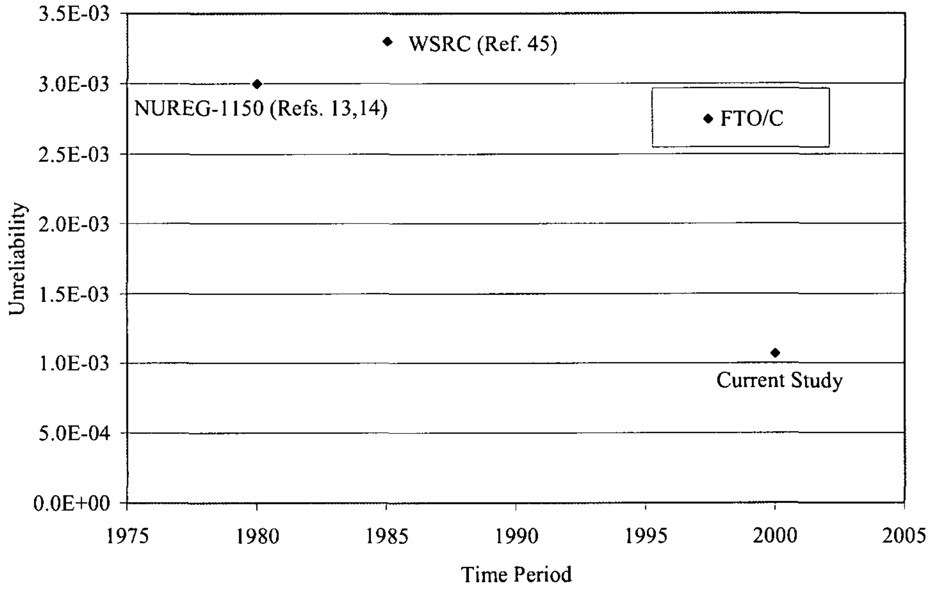

Figure 9-5. Historical trend in MOV FTO/C performance estimates.

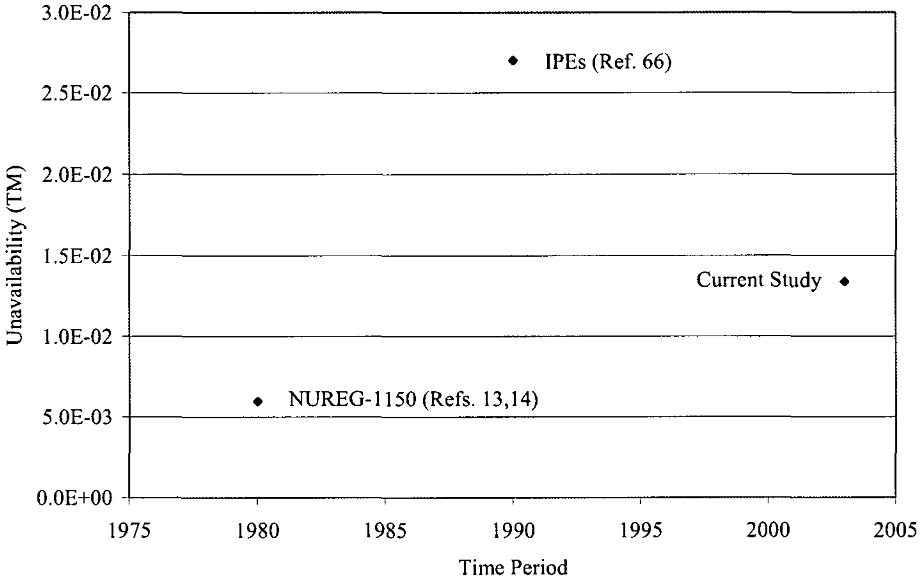

Figure 9-6. Historical trend in EDG UA performance estimates.

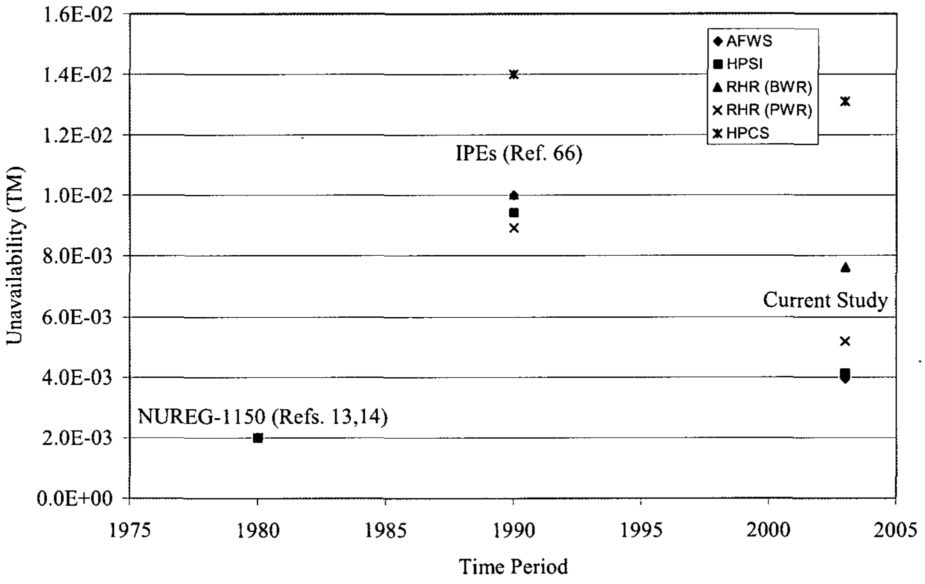

Figure 9-7. Historical trend in MDP UA performance estimates.

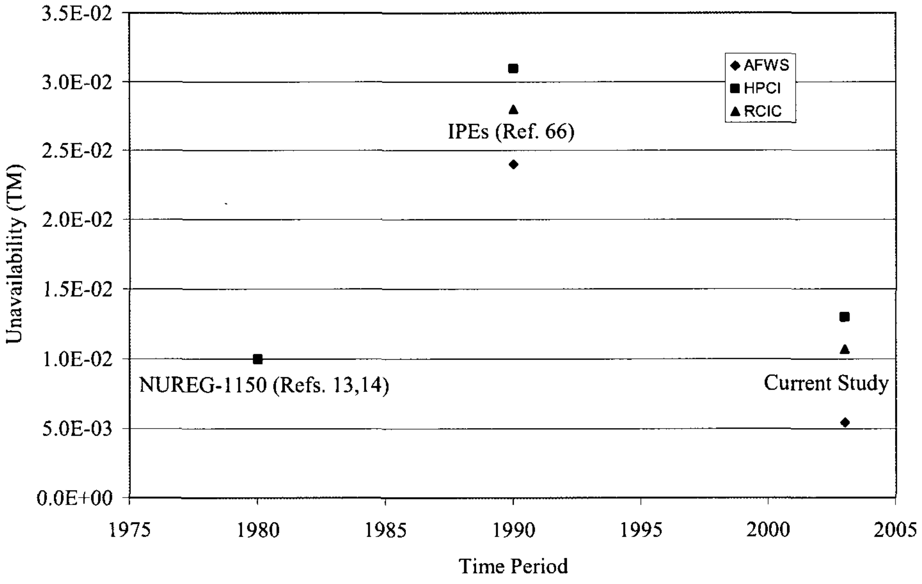

Figure 9-8. Historical trend in TDP UA performance estimates.

10. COMPARISON OF CURRENT BASELINE DATABASE AND ANALYSIS WITH ASME STANDARD

The *Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications* (Ref. 59), or American Society of Mechanical Engineers (ASME) Standard, is focused on the requirements for PRAs to support various applications of PRA results. PRA elements are classified by Capability Categories I, II, and III. Category I indicates the least sophisticated treatment of a PRA element and therefore is appropriate only for a limited number of applications. Category III indicates the most sophisticated treatment of a PRA element with the capability to support a wide variety of applications. The bases for assigning capability categories address three attributes of the PRA element: scope and level of detail, plant specificity, and realism. Although the ASME Standard's focus is a plant-specific PRA, some of the PRA element requirements are relevant to the development of an industry-average database for components and IEs. Those elements include "Data Analysis" and "Initiating Event Analysis." Applicable requirements from the ASME Standard for these elements are discussed below. Summaries of the comparisons are presented in Table 10-1 (Data Analysis) and Table 10-2 (Initiating Event Analysis). Also indicated in these tables are those requirements for which the NRC has indicated a clarification or qualification as documented in Regulatory Guide 1.200 (Ref. 70).

Caution should be used when reviewing results presented in Table 10-1 and Table 10-2. The capability category conclusions indicated in the tables apply only to the industry-average performance database presented in this report. Use of results in this report does not imply that a plant-specific risk model meets the same capability category for each ASME Standard supporting requirement. For example, a plant-specific risk model should collect plant-specific component failure data and IE data. In such cases, the industry-average performance in this report might be used as the prior in a Bayesian update using the plant-specific data. The capability category determination would need to include all applicable elements in this process—the prior, collection and interpretation of plant-specific data, the Bayesian update process, and others.

In Section 4.5.6 ("Data Analysis") of the ASME Standard, all five high-level requirements appear to be applicable:

HLR-DA-A	Clear definitions (basic event boundary, probability model)
HLR-DA-B	Grouping of components
HLR-DA-C	Generic data and data collection
HLR-DA-D	Relevant generic industry evidence
HLR-DA-E	Documentation.

Under HLR-DA-A, several supporting requirements apply. DA-A1 covers the identification of basic events to support the systems analysis. The components and failure modes covered in this current report were identified based mainly on events within the SPAR models. However, that list was expanded based on events covered in other existing generic databases. The final list includes 51 components and 171 component failure mode combinations. DA-A1a addresses boundary definitions for the basic events. Boundary definitions for basic events are summarized in the main body of this report, and more detailed definitions are presented in the appendices. The component boundaries were defined to match the requirements of the SPAR models but should be applicable to most PRAs. DA-A2 requires appropriate probability models to be used, such as binomial distributions for failure upon demand and Poisson distributions for standby and operating failures. The use of beta and gamma distributions to model failure

Table 10-1. Summary of comparison with ASME Standard for data analysis.

ASME Standard Index No. (note a)	RG 1.200 (note b)	Capability Category (notes c,d)	Comments
DA-A1		Met	
DA-A2		Met	Used binomial and Poisson models
DA-A3		Met	Data are summarized in Appendices A, B, and C
DA-B1		II+	Components grouped according to driver and service condition (including in some cases a distinction by demand frequency)
DA-B2		III	Data outliers identified and removed (if applicable)
DA-C1		Met	
DA-C2		Met	
DA-C3		Met	
DA-C4		Met	
DA-C5		Met	
DA-C6		Met	
DA-C7		II/III	EPIX and MSPI UA data based on actual plant experience
DA-C8		II/III	EPIX and MSPI UA data distinguish standby status (where applicable)
DA-C9		I/II or III	EPIX data collection guidelines result in a mixture of I/II or III submittals by plants
DA-C10		II	EDG sequencer treated as a separate component because of different demand counts
DA-C11		Met	MSPI UA data collection guidelines
DA-C12		II/III	MSPI UA data collection guidelines
DA-C13		Not Applicable	Not applicable for an industry-average database
DA-C14	Q	Not Applicable	Not within the scope of this report
DA-C15		Met	Covered in Reference 68
DA-D1		Not Applicable	Not applicable for an industry-average performance database
DA-D2		Not Applicable	Not applicable for an industry-average performance database
DA-D3	Q	III	Industry-average performance characterized by mean and statistical distribution obtained from data analysis
DA-D4		II/III	Cases with no failures analyzed using a Bayesian update of a Jeffreys noninformative prior with industry data
DA-D5		Not Applicable	Common-cause failure modeling not within the scope of this report
DA-D6	C	Not Applicable	Common-cause failure modeling not within the scope of this report
DA-D7		II	Use of current data (generally 1998–2002) to ensure a representative picture of industry-average performance for the year 2000
DA-D8	Q	Not Applicable	Regulatory Guide 1.200 added this index number (not in the ASME Standard) to cover quantification of component repair as a function of time. Not within the scope of this report
DA-E1		Met	
DA-E2		Met	
DA-E3		Met	

Note a - Source: Ref. 59.

Note b - This column indicates where RG 1.200 (Ref. 70) indicates clarifications or qualifications to the ASME Standard. "C" indicates a clarification, and "Q" indicates a qualification.

Note c - Where two or more capability categories are separated by "/", the ASME Standard did make a distinction between categories. "Met" indicates the ASME Standard did not make a distinction between any of the categories. "Not Applicable" indicates the requirement is either not applicable for an industry-average database or is outside the scope of this report.

Note d - The capability categories indicated apply only to the industry-average performance database developed in this report. Use of this database does not imply that a plant-specific risk model would necessarily meet the same capability categories. Categories for the plant-specific risk model would depend upon the collection and interpretation of plant-specific data, methods used to determine means and distributions, and other factors.

Table 10-2. Summary of comparison with ASME Standard for initiating event analysis.

ASME Standard Index No.	RG 1.200 (note a)	Capability Category (notes b,c)	Comments
IE-B1		Met	
IE-B2		Met	
IE-B3		II	Events in six IE categories reviewed to ensure only those applicable to the SPAR modeling of such events were included. (Events excluded were still included in TRAN categories.) Other categories judged appropriate as is
IE-B4		Met	
IE-B5		Met	LOOP analysis in Reference 68 addresses probability of other unit(s) also experiencing a LOOP given a LOOP at one unit
IE-C1	C	Met	Data from entire U.S. commercial nuclear power plant industry reviewed
IE-C2		Not Applicable	Not applicable for an industry-average database
IE-C3		Met	
IE-C4		Not Applicable	IEs already identified in the SPAR program
IE-C5		III	Sophisticated trend analyses performed
IE-C6		Not Applicable	Not within the scope of this report
IE-C7		Not Applicable	Not within the scope of this report
IE-C8		Not Applicable	Not within the scope of this report
IE-C9	C	Not Applicable	Not within the scope of this report
IE-C10		Not Applicable	Not applicable for an industry-average database
IE-C11		I/II or III	I/II for LOESW, PLOESW, LOCCW, and PLOCCW. III for LOCAs (from Ref. 69)
IE-C12		Not Applicable	Not within the scope of this report
IE-C13		III	Industry-average performance characterized by mean and statistical distribution obtained from data analysis
IE-D1		Met	
IE-D2		Met	
IE-D3		Met	

Note a - This column indicates where RG 1.200 indicates clarifications or qualifications to the ASME Standard. "C" indicates a clarification, and "Q" indicates a qualification.
Note b - Where two or more capability categories are separated by "/", the ASME Standard did make a distinction between categories. "Met" indicates the ASME Standard did not make a distinction between any of the categories. "Not Applicable" indicates the requirement is either not applicable for an industry-average database or is outside the scope of this report.
Note c - The capability categories indicated apply only to the industry-average performance database developed in this report. Use of this database does not imply that a plant-specific risk model would necessarily meet the same capability categories. Categories for the plant-specific risk model would depend upon the collection and interpretation of plant-specific data, methods used to determine means and distributions, and other factors.

probabilities and rates in this report is consistent with this requirement. Finally, DA-A3 requires that data used to quantify basic events be collected in an appropriate format. To support the quantification of component UR, the EPIX database as accessed using RADS was used. This resulted in data at the individual component level. Also, train UA data were collected by individual train and quarter. Both data formats are appropriate for development of industry-average performance baselines. None of these supporting requirements include breakdowns based on capability category.

For HLR-DA-B, both supporting requirements apply. DA-B1 addresses the grouping of components for parameter estimation. For example, a Capability Category I PRA (with respect to the "Data Analysis" element) might subdivide valve components by driver (AOV, MOV, etc.). A Capability Category II PRA might further subdivide such components into driver and usage characteristics (such as standby versus control). Finally, a Capability Category III PRA might include additional subdivision to include valve size, demand frequency, etc. The valve breakdown used in this report is by driver and usage characteristics (standby versus control). Additionally, only valves with ≤ 20 demands/year were included in the final populations used for parameter estimation, in order to match the types of valves typically included in the SPAR models. Similarly, pumps are subdivided into driver (DDP, MDP, etc.) and standby or running/alternating. However, further subdivisions are possible (size, system, etc.). This report probably lies between Capability Category II and III for this supporting requirement for component failure modes supported by EPIX/RADS data. With follow-on detailed analysis efforts, the results would clearly be Capability Category III for those components addressed. DA-B2 addresses potential outliers within the data collected. To meet Capability Category III, appropriate hypothesis tests should be used to ensure that data grouped are from compatible populations. For an industry-average performance database, it is not clear that outliers should necessarily be removed. The outliers provide valuable information concerning variability within the industry. For some basic events, hypothesis tests were used to identify outliers. However, a quality assurance procedure was followed for all basic events to ensure that incomplete data records were not used and that potential data entry errors were corrected. Also, for valves and other FTO/C types of component, only components with ≤ 20 demands/year were included. This report may meet Capability Category III for DA-B2, especially in terms of generating an industry-average performance database.

HLR-DA-C has many supporting requirements, all dealing with the use of relevant and applicable data. DA-C4 addresses failure definitions and event reviews based on these definitions. For the EPIX data, the RADS software uses a mapping routine to categorize events by failure mode or discard them as not applicable to the PRA failure modes considered. For several components and failure modes, individual event records were reviewed for applicability. DA-C6 and DA-C7 address the counting of demands. For the EPIX data, the demand counts meet the requirements. DA-C8 and DA-C9 address the counting of standby time and run time. Again, the EPIX data meet the requirements. DA-C10 deals with whether all subcomponents within the component boundary are demanded during tests. The example given is the sequencer associated with an EDG. The sequencer is typically demanded only during the cyclic (every 18 months) tests and unplanned demands involving loss of power to the safety bus. This report models the sequencer as a component separate from the EDG because of this concern. DA-C11, DA-C11a, and DA-C12 deal with collection of appropriate UA data. The MSPI UA data used in this report meet these requirements. DA-C13 covers the identification of coincident UA for redundant trains. The present report does not address this issue. Such events should be addressed in the collection of plant-specific UA data to support a plant-specific PRA. DA-C14 addresses the issue of repair or recovery of components. This report does not address repair times for components. Also, the recovery of component failures is not specifically addressed. However, a review of failure events for several components indicated that no more than possibly 10 to 20% of the component failures in EPIX could have been repaired or recovered within minutes. Therefore, this report suggests that no short-term recovery of component failures be modeled given the use of component failure probabilities and rates in this report. Finally, DA-C15 addresses LOOP and recovery of offsite power. This report references the recently published study on LOOP and station blackout (Ref. 68) for guidance concerning industry-average LOOP frequencies and offsite power recovery probabilities. Also, that report provides repair time information for EDGs.

With respect to HLR-DA-D, two supporting requirements apply. DA-D3 addresses the determination of mean values and uncertainty intervals. The statistical approaches used in this report are considered state of the art and are therefore Capability Category III for those component failure modes supported by EPIX data. DA-D7 addresses conditions (design changes or procedures changes) that might result in past performance not being applicable. The data used for this report typically cover 1998–2002, and resulting failure estimates are considered to be representative of the industry for the year 2000.

Finally, HLR-DA-E addresses documentation. DA-E1 requires the data analysis to be documented to support PRA applications, upgrades, and peer review. DA-E2 covers the processes used in the data collection and analysis. DA-E3 addresses key assumptions and sources of uncertainty. The structure and detail of this report fulfill all of these requirements as they apply to the generation of industry-average performance estimates.

In Section 4.5.1 ("Initiating Event Analysis") of the ASME Standard, three of the four high level requirements appear to be applicable:

- HLR-IE-B Grouping
- HLR-IE-C Frequency estimation
- HLR-IE-D Documentation.

The high-level requirement HLR-IE-A covering the identification of IEs is not applicable. The scope of this report was to provide updated frequency information for the IEs included in the SPAR models. Therefore, the IEs were already identified.

HLR-IE-B has several supporting requirements, mainly addressing the grouping of individual IEs into groups for event tree development. This report generally uses the IE descriptions and groupings presented in Reference 67. The IE database (Ref. 16) is continually updated based on a review of LERs, and event classification follows the guidelines in Reference 67. However, as explained in Section 8.4, six IEs in Reference 16 were reviewed to eliminate events not matching the SPAR assumptions in the associated event trees. This is essentially a redefinition of these IEs. The IE categories used in this report are applicable to the SPAR models. Other risk studies that use the results from this study might need to review the groupings to ensure they are applicable.

HLR-IE-C addresses frequency estimation. Support requirement IE-C1a indicates that the most recent applicable data should be used. This report uses sophisticated trending analyses to determine IE category baseline periods (ending in 2002) to ensure that the results represent current industry performance. IE-C1b addresses recovery actions. IEs were not reviewed as part of this report to identify potential or actual recoveries (and their timings) from such events. However, this report references the recent LOOP and station blackout report (Ref. 68) for LOOP frequencies and associated recovery information. In general, the SPAR models do not allow for recovery of equipment that resulted in the IE, except for LOOP. IE-C3 indicates that frequencies should reflect the typical or expected fraction of time a plant is at power. The frequencies in this report are reported on a reactor critical year basis. Risk results from the SPAR models (core damage frequency on a per reactor critical year basis) can then be adjusted for the fraction of time a plant is at power. IE-C5 addresses time trend analyses. As stated previously, this report includes sophisticated time trend analyses, resulting in Capability Category III for this requirement. IE-C6 through IE-C9 cover the use of IE fault trees. The LOESW and LOCCW initiators in this study have industry-average frequencies. Sophisticated risk studies would not use these frequencies but would instead develop IE fault trees to better model plant-specific designs and environmental influences. IE-C11 addresses rare and extremely rare events. This study uses the results from the draft report on expert elicitation of LOCA frequencies (Ref. 69) for SLOCA (except for PWRs), MLOCA and LLOCA. Finally, IE-C13 addresses mean values and associated uncertainties. This report uses state-of-the-art methods to determine the mean values and associated uncertainty distributions.

HLR-IE-D addresses documentation for the IEs and is similar to the documentation requirements for the data analysis element discussed previously. The structure and detail of this report fulfill all of these requirements as they apply to the generation of industry-average frequencies.

11. Summary and Conclusions

This report presents updated estimates of U.S. commercial NPP performance for component UR, train UA (from TM outages), system special event probability or rate (events such as RCIC TDP restart during a mission, HPCI injection valve re-opening during a mission, and others), and IE frequencies. Component UR distributions (beta for demand type failure modes and gamma for rate type failure modes) include 51 component types and 171 component and failure mode combinations. Train UA distributions (beta distributions) cover 34 different train types. System special event distributions (beta or gamma distributions) cover 15 system events. Finally, 24 IE frequencies (gamma distributions) are included. All of these events were updated to provide current estimates for the SPAR models.

To update inputs to the SPAR models, a hierarchy of data sources was identified. For component UR, the EPIX database is the preferred source. EPIX data supported quantification of approximately 85% of the 171 component and failure mode combinations. For train UA, the preferred source is the MSPI UA data. MSPI UA data supported quantification of approximately 65% of the train UAs. All of the 15 system special events were quantified using NRC updated system study data obtained from LER reviews. Finally, 18 of 24 IE frequencies were characterized using the NRC IE database (based on LER reviews), while the other six were characterized based on recent NRC reports on LOOP and LOCA frequencies.

The current baselines presented in this report for component UR, train UA, system special event probability or rate, and IE frequency represent industry-average performance centered about the year 2000. For component UR, the baselines generally were determined using data from 1998–2002. Special events and IEs used baseline periods ending in 2002 but starting anywhere from 1988 to 1998, depending whether the data exhibited trends. Finally, train UA baselines cover 2002–2004.

In general, the current baselines indicate an improvement in industry performance from the 1980s and early 1990s. This is true for all four types of events covered in this report.

The results presented in this report—estimates of current industry-average performance for component UR, train UA from TM outages, special event probabilities, and IE frequencies—will be inserted into the SPAR models. However, the results can also be used in plant-specific analyses as prior distributions in Bayesian updates using plant-specific data. Because the results are based on recent U.S. NPP performance, industry may also have use for these results in their own risk models.

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Appendix A

Component Unreliability Summaries

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Appendix A

Component Unreliability Summaries

A.1 Data Review Process

A.1.1 Introduction

This appendix provides supporting information and additional detail concerning the component unreliability (UR) baselines presented in Section 5. These estimates reflect industry-average performance for component UR, where U.S. commercial nuclear power plants are defined as the industry. A component can fail because of failure to fulfill its mission (defined as UR in this report) or unavailability resulting from test or maintenance outage (defined as UA). Total UR for a component includes both UR and UA. For example, for a standby pump that must start upon demand and run for 24 h, total UR is

$$UR_{Total} = P_{FTS} + (\lambda_{FTR\leq 1H})(1h) + (\lambda_{FTR>1H})(23h) + P_{UA}$$

for cases where each of the individual contributors is small. In this example, the fail to start (FTS) baseline parameters are the industry-average mean probability of failing to start (P) and the beta distribution parameters α and β. The fail to run (FTR≤1H and FTR>1H) baseline parameters are the mean failure rates per hour (λ) and the gamma distribution parameters α and β. (As explained in Section 4, failure modes characterized by probability of failure upon demand are modeled with beta distributions, and failure modes related to run or calendar hours are modeled with gamma distributions.)

Component failure mode parameter estimates were obtained from a hierarchy of sources, as explained in Section 5. The preferred source is the Equipment Performance and Information Exchange (EPIX) database (Ref. A-1), as accessed using the Reliability and Availability Database System (RADS) (Ref. A-2). Most component failure mode parameter estimates were obtained from this source. Other sources include the reactor protection system (RPS) system studies (SSs) performed for the U.S. Nuclear Regulatory Commission (Refs. A-3 through A-6), and the Westinghouse Savannah River Company database (WSRC, Ref. A-7). This appendix explains in detail how data from each of these sources were used to obtain industry-average UR parameter estimates.

A.1.2 Parameter Estimation Using EPIX Data

The EPIX database and the RADS software are described in Section 5. EPIX provides component UR data at the component level. The RADS software was used to search the EPIX database for specific component failure mode information and process that information. EPIX reportable events for a component can include a variety of types, including UA, incipient or degraded performance, or catastrophic or functional failures as defined in risk assessments. RADS includes a routine that maps component events into risk assessment failure modes (e.g., FTS or FTR), UA (test or maintenance) events, or events that are not applicable. In addition, RADS processes EPIX data related to demands or run hours to determine total demands or run hours over the period specified.

For a specific component type, the failure modes of interest were identified. For valves, these failure modes are typically failure to open or close (FTO/C), spurious operation (SO), external leakage small (ELS), external leakage large (ELL), internal leakage small (ILS), internal leakage large (ILL), and failure to control (FC) for the subset of control valves. For pumps, these failure modes are FTS, FTR (or FTR≤1H and FTR>1H), ELS, and ELL. For components in Section A.2, the component failure modes are listed in the first table of each subsection. For example, for air-operated valves or AOVs (Section A.2.5), the failure modes are presented in Table A.2.5-1. For a specific component failure mode, the RADS software was used to identify at the component level the number of failures and demands (or run or calendar hours) for the period specified. In most cases this period was 1998–2002, centered about the year

2000. However, this period was expanded to 1997–2004 for component failure modes with no failures during 1998–2002, for component external and internal leakages, and for a few components with limited data. (The expanded period for leakages was used in order to obtain information related to the ratio of large leaks to small leaks, because the large leaks are rare.) The resulting component information from RADS includes the component identifier, system, failures, and demands (or hours). For components that were not subdivided into standby and running/alternating categories, this information was used directly to identify the number of components within each system (e.g., Table A.2.5-2 in Section A.2.5).

For components such as pumps, chillers, and others that can be standby or running/alternating, the component data from RADS were processed to identify which operational status applied. This was accomplished by sorting the component data by run hours (low to high). Standby components were defined to have run hours that were less than 10% of the calendar hours. (Calendar hours were defined as 8760*5 = 43800 hours for 1998–2002.) Components with runs hours greater than 10% of the calendar hours were categorized as running/alternating. The 10% cutoff was chosen based on a review of run hours for components in systems known to have only standby components. (The highest result among such systems was approximately 8%, with most system results less than 3%.) After this subdivision, the number of components within each system was tabulated separately for standby and running/alternating operation.

For standby components, the FTR failure mode was subdivided into FTR≤1H and FTR>1H failure modes. This was done because a previous review of component UR (Ref. A-8) indicated that the failure rates for these two subdivisions were different by approximately a factor of 15 (with the FTR>1H rate being lower). Also, the Mitigating Systems Performance Index (MSPI) program distinguishes failures occurring during the first hour of operation from those occurring after the first hour (Ref. A-9). The process used to separate data into FTR≤1H and FTR>1H categories is approximate because the EPIX failure records rarely indicate how long a component was operating when it experienced a FTR event. The process used was the following:

1. Sort the components by run hours/demand, from lowest to highest.
2. Add cumulative columns to the sorted component list indicating the total component demands and total component hours (up through the component being considered).
3. Identify within this sorted list the component where the cumulative run hours divided by cumulative demands equals 1.0. The subset of components up through this component has an average of one hour of run time per demand.
4. Calculate the FTR≤1H rate from the subset of components identified, using their run hours and FTR events.
5. Use the remaining components to calculate FTR>1H. However, the FTR event total from these other components is reduced by the expected number of FTR≤1H events. (The expected number of FTR≤1H events is just the number of demands for this group times the FTR≤1H rate.) Also, the run hours in this group are reduced by the number of demands. In cases where the modified FTR>1H event total was negative, it was assumed that there were no FTR>1H events.

This process was not possible for the running/alternating components, because there are no components with run hours/demand less than 1.0. Therefore, for the running/alternating components, FTR was used, rather than FTR≤1H and FTR>1H.

In addition, a limited review of the component data was performed to identify components with incomplete data (no demands or no run hours, if applicable). Such components were removed. Additional data checks included run hours exceeding calendar hours (corrected to calendar hours), run hours for standby components that appeared to be a factor of ten too high (reduced by a factor of ten), emergency diesel generator (EDG) load and run demands that were higher than start demands (see Section A.2.17 for details concerning this issue), and others. Data reviews specific to certain components are discussed within each component subsection.

For valves, circuit breakers, dampers, and automatic bus transfer switches, only components with ≤ 20 demands/year were used to generate failure rates applicable to most components included in the standardized plant analysis risk (SPAR) models. (Depending upon the demand/year range chosen, some of these component failure probabilities can vary by a factor of ten or more, so matching the data to the operational environment of components in SPAR is important.) In such cases, the table listing component numbers by systems (e.g., Table A.2.5-2 in Section A.2.5) indicates how many components were removed by limiting the component to those with ≤ 20 demands/year. For other component types such as pumps, heating or ventilating devices, compressors, and EDGs, a limitation of ≤ 200 demands/year was applied. For most of these components, the subdivision into standby versus running/alternating was also used to match operational environments with components modeled in SPAR.

To identify data for several specific component failure modes, the EPIX event records were reviewed. This was done because of several reasons: EPIX did not specifically address such a component or failure mode, the EPIX failure mode definition did not match the one used in this report, or other reasons. For example, EPIX does not identify the EDG sequencer as a separate key component. Therefore, in order to identify the sequencer failure events, the EDG failure event records were reviewed to identify those involving the sequencer. In addition, the EPIX external leakage events were reviewed to identify small leaks (1 to 50 gallons per minute or gpm), large leaks (> 50 gpm), and leaks too small to be of interest in this study (< 1 gpm). Finally, the EPIX internal leakage events were reviewed to identify small leaks (leaks exceeding the local leak rate test allowable limits or 1 to 50 gpm), large leaks (typically resulting from component internal degradations greater than just pitting or wearing or > 50 gpm), and negligible leaks (less than the local leak rate test limits or < 1 gpm). These cases where EPIX failure records were reviewed are discussed in the applicable subsections in Section A.2.

Finally, for component failure modes such as SO, ELS, ELL, ILS, ILL, and selected failure to operate (FTOP), calendar hours were used.

The final data for each component failure mode are listed in a table (e.g., Table A.2.5-3 in Section A.2.5). As mentioned previously, these data cover 1998–2002, except for failure modes with no events (expanded to 1997–2004), external and internal leakages (also 1997–2004), and a few components with very limited failures (expanded to 1997–2004). Also presented in these tables are the percentage of components that experienced one or more failures and the percentage of plants that experienced one or more failures.

Given UR data at the component level, a maximum likelihood estimate (MLE) can be calculated for each component failure mode. The MLE is simply the number of failures divided by the demands (or run or calendar hours). The component MLEs can then be ordered (low to high) to identify percentiles (and the mean) of this distribution. This process can also be performed at the plant level and the industry level. However, at the industry level the data include only the total failures and total demands (or run or calendar hours). At that level, an empirical distribution does not exist because there is only a single MLE. These distributions of MLEs at the component, plant, and industry level are summarized in the individual subsections (e.g., Table A.2.5-4 in Section A.2.5). Properties of these MLE distributions are summarized in Appendix F.

Empirical Bayes statistical analyses including a Kass-Steffey adjustment (Ref. A-10) were performed on the data to characterize uncertainty distributions for the component failure modes. These analyses were performed on the component-level data and on data aggregated at the plant level. Results from these analyses are summarized in a table (e.g., Table A.2.5-5 in Section A.2.5). Included are the beta or gamma distribution parameters α and β, the mean, and distribution percentiles (5th, median, and 95th).

In some cases (component failure modes with few failures or little variation between components) the empirical Bayes analyses did not converge and provided no information.

In addition to the empirical Bayes analysis results, a constrained noninformative distribution (CNID, Ref. A-10) is also presented in the table. For a gamma distribution, the CNID is characterized by the mean and an α of 0.5. This distribution has an error factor (95^{th} percentile/median) of approximately 8.4. The mean used for the CNID is the posterior mean of a Bayesian update of the Jeffreys noninformative prior (Ref. A-10) with industry data. This mean is termed the Jeffreys mean in this report.

For beta distributions, the CNID is also characterized by the mean. However, the α parameter ranges from 0.5 to 0.32, depending upon the mean. For mean failure probabilities less than 0.01 (larger than almost all of the component failure probabilities in this report), α ranges from 0.5 to 0.483. With such a limited range for α, a simplified CNID (SCNID) was defined for beta distributions. The SCNID is characterized by the mean and an α of 0.5, similar to the gamma distribution. In this report, the SCNID is used when referring to both beta and gamma distributions, although strictly speaking the SCNID for a gamma distribution is actually the CNID without any simplification.

Finally, if the empirical Bayes analysis did not converge but indicated little variation between plants, then the data were assumed to be homogeneous. In that case, the Jeffreys distribution was assumed. For this distribution, the mean is the Jeffreys mean discussed previously and the α parameter is the number of failures plus 0.5.

An additional table presents the selected distribution for each component failure mode. The selected distribution comes from the empirical Bayes analysis of data aggregated at the plant level (if such results are available). Plant-level results were used rather than component-level results to estimate uncertainties based on several considerations:

1. Because of the limited number of components with failures, data grouped at the component level often result in a high percentage of components with no failures. This results in cases in which the empirical Bayes analysis fails to generate results. In contrast, at the plant level, significantly fewer plant-level groups have no failures. This results in fewer cases in which the empirical Bayes analysis fails to generate results.
2. Because of the limited number of components with failures, empirical Bayes results obtained at the component level do not always appear to be realistic (very low estimates for α can result, leading to extremely low 5^{th} percentile estimates). In contrast, the results obtained at the plant level generally appear to be better behaved.

The empirical Bayes analyses sometimes resulted in α estimates less than 0.3. The error factor corresponding to this value is approximately 19. As explained in Section 4, when the α estimate from the empirical Bayes analysis was smaller than 0.3, a lower limit of 0.3 was assumed. In such cases, the mean from the empirical Bayes analysis was used with $\alpha = 0.3$ to redefine the beta or gamma distribution.

If the empirical Bayes analysis did not converge but indicated little variation between plants, then the Jeffreys distribution was used. However, if the empirical Bayes analysis did not provide any results, the SCNID distribution was used for the selected distribution. The SCNID assumes $\alpha = 0.5$. This value for α is appropriate because a geometric average of the α's obtained from empirical Bayes analyses of component failure modes (before applying the lower limit on α) is approximately 0.5.

Several special cases exist for the selected distributions. One case involves the ELL and ILL failure modes. For the ELL failure mode, the selected distribution was determined by defining its mean to be the ELS mean multiplied by 0.07, 0.1, 0.15, or 0.2, depending upon the component type. For the ILL failure mode, the mean is the ILS mean multiplied by 0.02. In both cases, the lower limit of 0.3 was assumed for α. Because ELL and ILL events are rare, good estimates for ELL and ILL cannot be obtained using data from only one component. Table A.1.2-1 presents the ELS, ELL, ILS, and ILL events obtained from

EPIX for 1997–2004. For pumps, valves, tanks, and heat exchanger shells, there were two ELL events and 35 ELS events. The Jeffreys mean for the ratio ELL/ELS is 0.069, which was rounded to 0.07. Similar results are presented in the table for other types of components and for the valve ILL/ILS ratio.

Also presented in the table are ELL/ELS estimates from the report *Component External Leakage and Rupture Frequency Estimates* (Ref. A-11). The ELL/ELS estimates in that report are from a search of licensee event reports (LERs) from 1960–1983. For all of the components listed, the new ELL/ELS ratios are higher than those listed in Reference A-11. The reasons for this are not clear.

Other special cases apply to individual component failure modes, and these are explained in the individual subsections in Section A.2.

A.1.3 Parameter Estimation Using RPS SS Data

The RPS SSs provide industry level data for component failure modes. These data were obtained from reviews of the Nuclear Plant Reliability Database System (NPRDS) (Ref. A-12) from 1984 – 1995. Data are not available from these reports at the plant or component level, in contrast to the EPIX data. (The NPRDS data could be reanalyzed to obtain data at the plant level, but that would require significant additional effort. For the purposes of this report, that additional effort was not considered worthwhile.) Therefore, the data analysis associated with component failure modes supported by RPS SS data is simplified. In contrast to the EPIX results, there is no breakdown of the data by system or component. Also, there is no presentation of component or plant level MLE distributions, and no empirical Bayes analyses can be performed. The selected distribution from RPS SS data is SCNID, with the Jeffreys mean of the industry data and $\alpha = 0.5$. The RPS SS data are not as current as the EPIX data (1998–2002) and component performance has generally improved since the late 1980s (Ref. A-8). Therefore, the use of the SCNID with its relatively broad distribution (error factor of approximately 8.4) is appropriate for component failure modes supported by RPS SS data.

A.1.4 Parameter Estimation Using WSRC Data

The WSRC database contains recommended failure probability or rate distributions for a wide variety of components. Data contained in the WSRC typically reflect component performance characteristic of the 1980s; none of the data sources extend beyond approximately 1990. Recommended distributions are often based on supporting data from nuclear power plants or other industries. However, in some cases the recommended distributions were also influenced by data from other types of components or from other industries.

The WSRC database grouped data sources into three categories:

1. Category 1 sources – sources with actual failure data obtained from a detailed review of failure events and a detailed review of component populations and demands (or hours). Such sources were typically plant-specific data collected as part of risk assessment development efforts by the plants.
2. Category 2 sources – sources with actual failure data, but which have an added uncertainty compared with Category 1 data. This uncertainty typically results from data collection efforts where the component population and demands had to be estimated.
3. Category 3 sources – sources that list only failure rate estimates, with little indication of the amount of actual failure data supporting the estimates.

For component failure modes in Section A.2 supported by WSRC, the quality of the data supporting the selected distribution is indicated (e.g., supported by Category 1 data from commercial nuclear power plants). The selected distributions based on WSRC were derived from the recommended mean from WSRC and $\alpha = 0.3$. Use of the lower limit of 0.3 for α reflects greater uncertainty in using WSRC results to characterize current component performance.

Table A.1.2-1. EPIX ELS, ELL, ILS, and ILL events.

Component Type (non-RCS)	Component	ELL Events (note a)	ELS Events (note a)	Components	ILL Events	ILS Events	Components	EGG-SSRE-9639 (Ref. A-11)	Comment
Pump	DDP	0.0	0.0	29					
	MDP	1.0	15.0	1864					ELL event resulted in 862 gal release
	TDP	0.0	1.0	175					
	PDP	0.0	1.0	166					
Valve	AOV	0.0	2.0	2771	1	49	2771		
	CKV	0.0	1.0	729	1	23	729		
	HOV	0.0	0.0	561	0	1	561		
	MOV	0.0	7.0	7614	0	87.5	7536		
	SOV	0.0	0.5	1509	1	25	1509		
	XVM	1.0	3.0	1121	0	0	107		ELL event involved catastrophic failure of valve body
Tank	Unpressurized	0.0	1.0	671					
	Pressurized	0.0	1.5	727					
Heat Exchanger	Shell	0.0	2.0	713					
All except piping and tubes	Many	2.0	35.0		3	185.5			
	Ratio (ELL/ELS)(note b)		0.069	Ratio (ILL/ILS)(note b)		0.019		0.04 (ELL/ELS)	
	Rounded		0.07	Rounded		0.02			
Heat Exchanger	Tube	1.0	10.0	713					
	Ratio (ELL/ELS)(note b)		0.136					0.04 (ELL/ELS)	
	Rounded		0.15						
Piping	Non-ESW	0.0	3.5	225818					
	Ratio (ELL/ELS)(note b)		0.111					0.04 (ELL/ELS)	
	Rounded		0.10						
	ESW	1.5	8.5	186332					Both ELL events in piping < 2-in diameter
	Ratio (ELL/ELS)(note b)		0.211					0.04 (ELL/ELS)	
	Rounded		0.20						

Acronyms - AOV (air-operated valve), CKV (check valve), DDP (diesel-driven pump), ELL (external leak large), ELS (external leak small), ESW (emergency service water), HOV (hydraulic-operated valve), ILL (internal leak large), ILS (internal leak small), MDP (motor-driven pump), MOV (motor-operated valve), PDP (positive displacement pump), RCS (reactor coolant system), SOV (solenoid-operated valve), TDP (turbine-driven pump), XVM (manual valve)

Note a - Uncertain events were assigned 0.5 weights.

Note b - The ratio is a Jeffreys mean.

A.2 Component Unreliability Data Sheets

A.2.1 Automatic Bus Transfer Switch (ABT) Data Sheet

A.2.1.1 Component Description

The automatic bus transfer switch (ABT) boundary includes the ABT component itself. The failure mode for ABT is listed in Table A.2.1-1.

Table A.2.1-1. ABT failure modes.

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

A.2.1.2 Data Collection and Review

Data for the ABT UR baseline were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. There are 32 ABTs from eight plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1) there were 27 components in eight plants. After analyzing the original data, there were no FTOP failures, so the data set was expanded to 1997–2004 (see Section A.1). The systems included in the ABT data collection are listed in Table A.2.1-2 with the number of components included with each system.

Table A.2.1-2. ABT systems.

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

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

The data review process is described in detail in Section A.1. Table A.2.1-3 summarizes the data obtained from EPIX and used in the ABT analysis.

Table A.2.1-3. ABT unreliability data.

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

Figure A.2.1-1 shows the range of ABT demands per year in the ABT data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 1.3. The average for the data set is 0.6 demand/year.

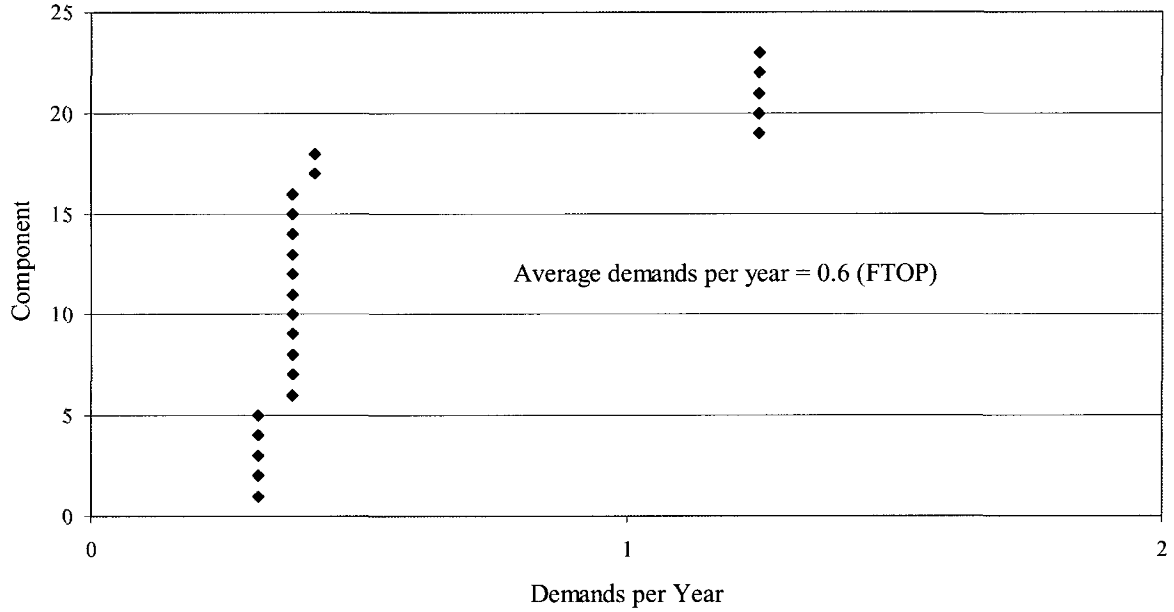

Figure A.2.1-1. ABT demands per year distribution.

A.2.1.3 Data Analysis

The ABT data can be examined at the component, plant, or industry level. However, with zero failures, all maximum likelihood estimates (MLEs), which are failures/demands (or hours), are zero. Results for all three levels are presented in Table A.2.1-4.

Table A.2.1-4. Empirical distributions of MLEs for p and λ for ABTs.

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

With no failures, no empirical Bayes analyses were performed. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.1-5 for ABTs.

Table A.2.1-5. Fitted distributions for p and λ for ABTs.

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

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

A.2.1.4 Industry-Average Baselines

Table A.2.1-6 lists the industry-average failure rate distribution. Note that this distribution is based on zero failures and few demands and may be conservatively high. This industry-average failure rate does not account for any recovery.

Table A.2.1-6. Selected industry distributions of p and λ for ABTs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.1-7 shows the rounded value for the ABT failure mode.

Table A.2.1-7. Selected industry distributions of p and λ for ABTs (after rounding).

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

A.2.1.5 Breakdown by System

ABT UR results (Jeffreys means of the system data) are compared by system and failure mode in Table A.2.1-8. With no failures, there are no system results presented.

Table A.2.1-8. ABT p and λ by system.

System	FTOP
DCP	-
EPS	-
IPS	-

A.2.2 Air Accumulator (ACC) Data Sheet

A.2.2.1 Component Description

The air accumulator (ACC) boundary includes the tank and associated relief valves. The failure modes for ACC are listed in Table A.2.2-1.

Table A.2.2-1. ACC failure modes.

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

A.2.2.2 Data Collection and Review

Data for ACC UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1997–2004. There are 961 ACCs from 92 plants in the data originally gathered from EPIX. The systems and operational status included in the ACC data collection are listed in Table A.2.2-2 with the number of components included with each system.

Table A.2.2-2. ACC systems.

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

Table A.2.2-3 summarizes the data obtained from EPIX and used in the ACC analysis.

Table A.2.2-3. ACC unreliability data.

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

A.2.2.3 Data Analysis

The ACC data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.2-4. The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.2-3, only 0.3% of the ACCs experienced an ELS over the period 1997–2004, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 99.7% portion of the distribution, and non-zero values above 99.7%.

Table A.2.2-4. Empirical distributions of MLEs for p and λ for ACCs.

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

Empirical Bayes analyses were performed at both the component and plant level. At the component level, the empirical Bayes failed to converge but indicated little variation between components. Therefore, the data were considered to be homogeneous and the Jeffreys distribution was calculated. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.2-5.

Table A.2.2-5. Fitted distributions for p and λ for ACCs.

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

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

A.2.2.4 Industry-Average Baselines

Table A.2.2-6 lists the industry-average failure rate distributions. For ELS, the EB/PL/KS result indicated an α parameter lower than 0.3. As explained in Section A.1, in these cases a lower limit of 0.3 (upper bound on the uncertainty band) was assumed. The selected ELL mean is the ELS mean multiplied by 0.07, with an assumed α of 0.3. The 0.07 multiplier is based on limited EPIX data for large leaks as explained in Section A.1.

Table A.2.2-6. Selected industry distributions of p and λ for ACCs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.2-7 shows the rounded values for the ACC failure modes.

Table A.2.2-7. Selected industry distributions of p and λ for ACCs (after rounding).

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

A.2.2.5 Breakdown by System

ACC UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.2-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.2-8. ACC p and λ by system.

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

A.2.3 Air Dryer Unit (ADU) Data Sheet

A.2.3.1 Component Description

The air dryer unit (ADU) boundary includes the air dryer unit. The failure mode for ADU is listed in Table A.2.3-1.

Table A.2.3-1. ADU failure modes.

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

A.2.3.2 Data Collection and Review

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

A.2.3.3 Industry-Average Baselines

Table A.2.3-2 lists the industry-average failure rate distribution. The FTOP failure mode is not supported by EPIX data. The mean is from WSRC, and the α parameter of 0.30 is assumed.

Table A.2.3-2. Selected industry distributions of p and λ for ADUs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.3-3 shows the rounded value for the ADU failure mode.

Table A.2.3-3. Selected industry distributions of p and λ for ADUs (after rounding).

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

A.2.4 Air Handling Unit (AHU) Data Sheet

A.2.4.1 Component Description

The air handling unit (AHU) boundary includes the fan, heat exchanger, valves, control circuitry, and breakers. The failure modes for AHU are listed in Table A.2.4-1.

Table A.2.4-1. AHU failure modes.

Operation	Failure Mode	Parameter	Units	Description
Standby	FTS	p	-	Failure to start
	FTR≤1H	λ	1/h	Failure to run for 1 h
	FTR>1H	λ	1/h	Fail to run beyond 1 h
Running/Alternating	FTS	p	-	Failure to start
	FTR	λ	1/h	Fail to run

A.2.4.2 Data Collection and Review

Data for AHU UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. There are 428 AHUs from 51 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1) there were 428 components in 51 plants. These data were then further partitioned into standby and running/alternating components. The systems and operational status included in the AHU data collection are listed in Table A.2.4-2 with the number of components included with each system.

Table A.2.4-2. AHU systems.

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

The data review process is described in detail in Section A.1. Table A.2.4-3 summarizes the data obtained from EPIX and used in the AHU analysis. Note that for the running/alternating AHUs, those components with > 200 demands/year were removed.

Figure A.2.4-1a shows the range of start demands per year in the standby AHU data set. The start demands per year range from approximately 1 to 70. The average for the data set is 19.3 demands/year. Figure A.2.4-1b shows the range of start demands per year in the running AHU data set. The demands per year range from approximately 1 to 80. The average for the data set is 17.5 demands/year.

Table A.2.4-3. AHU unreliability data.

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

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

Figure A.2.4-2a shows the range of run hours per demand in the standby AHU data set. The run hours per demand range is from approximately 1 hour/demand to 324 hours/demand. The average is 19.3 hours/demand. Figure A.2.4-2b shows the range of run hours per demand in the running AHU data set. The range is from approximately 37 hours/demand to 17,512 hours/demand. The average is 1526.8 hours/demand.

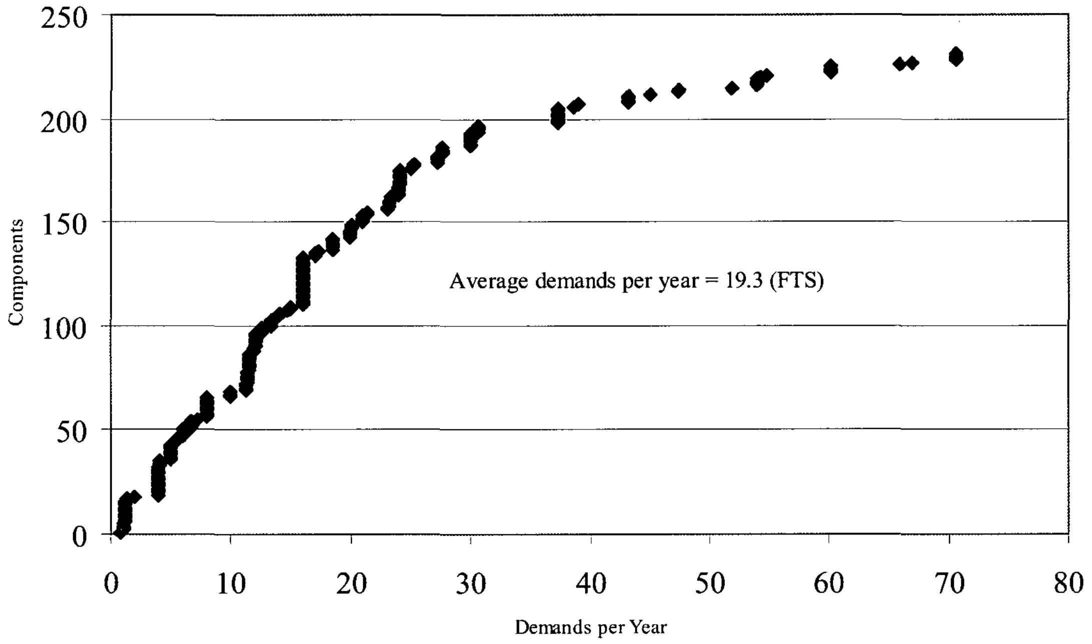

Figure A.2.4-1a. Standby AHU demands per year distribution.

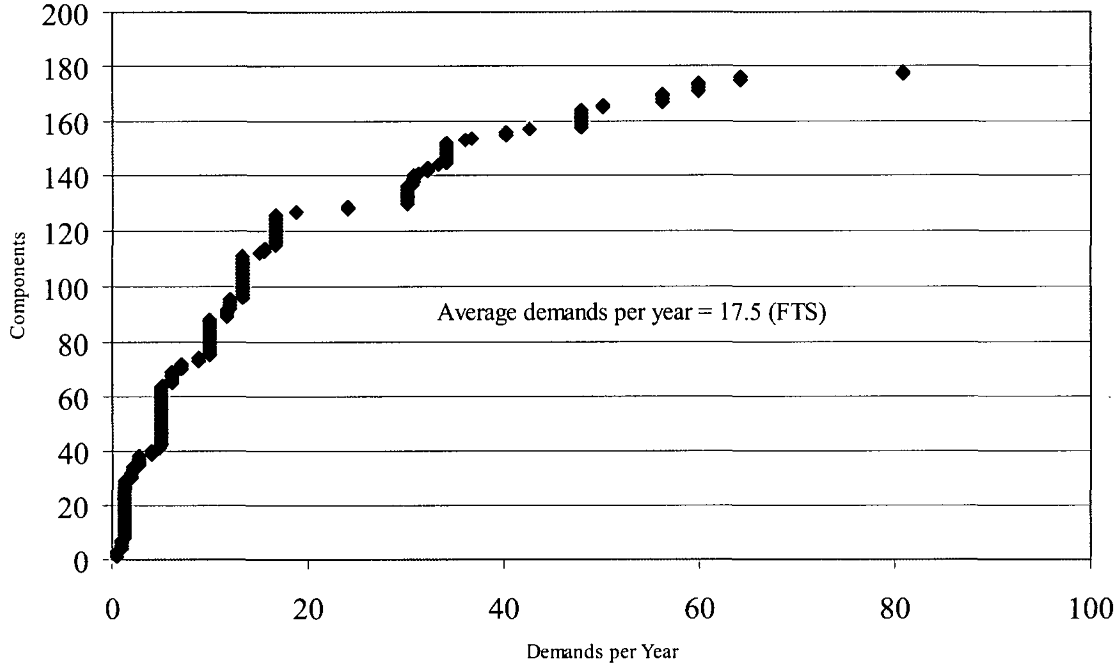

Figure A.2.4-1b. Running/alternating AHU demands per year distribution.

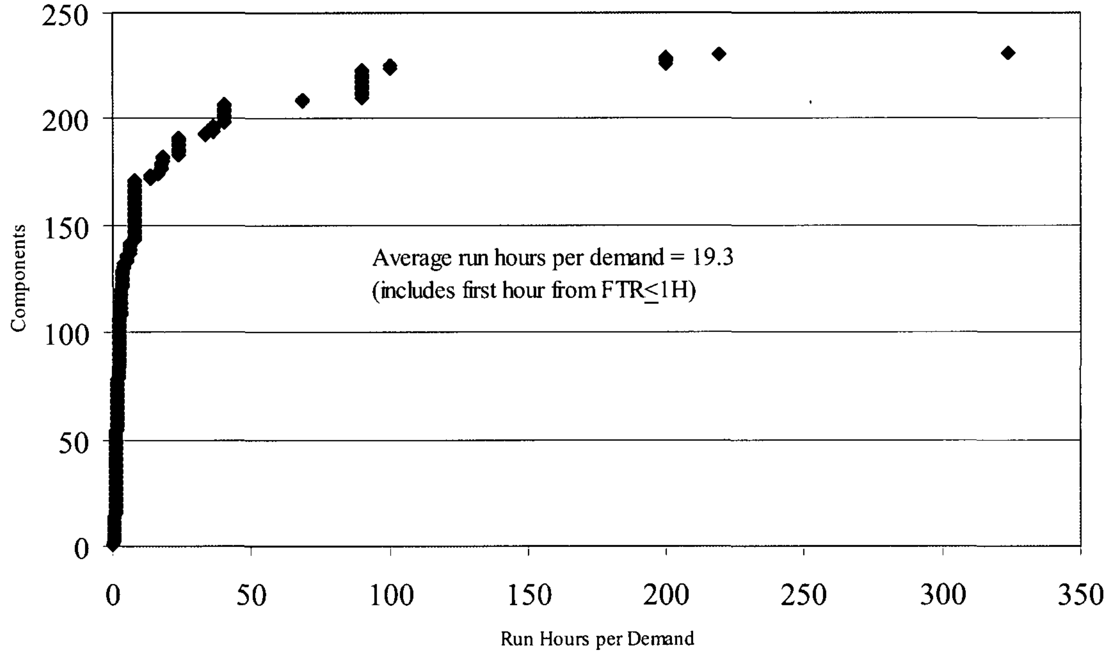

Figure A.2.4-2a. Standby AHU run hours per demand distribution.

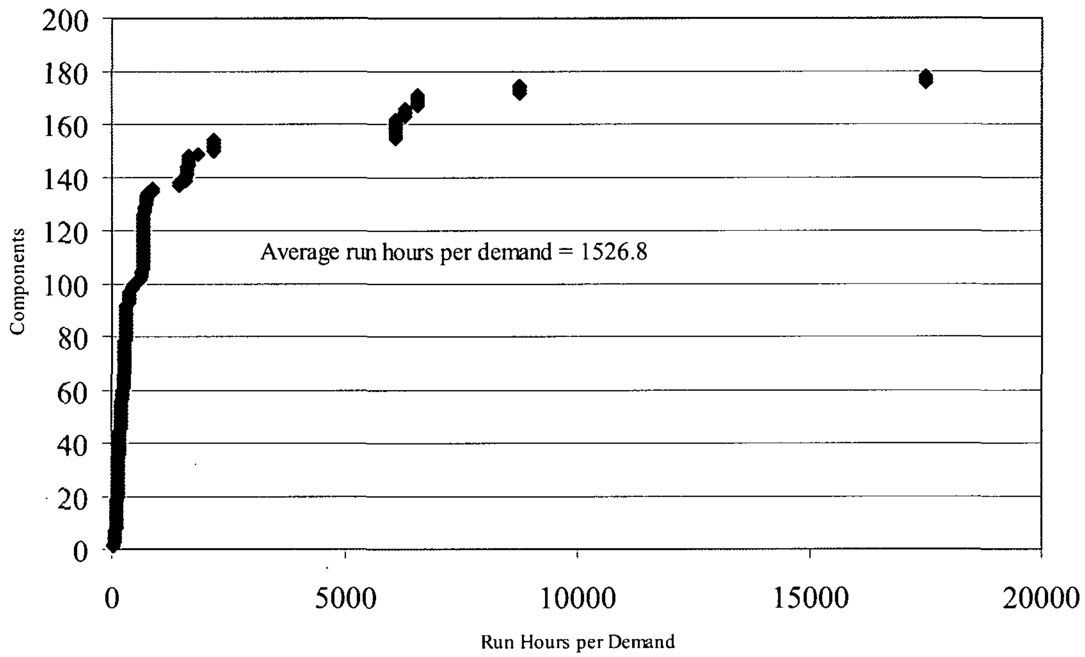

Figure A.2.4-2b. Running/alternating AHU run hours per demand distribution.

A.2.4.3 Data Analysis

The AHU data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.4-4.

Table A.2.4-4. Empirical distributions of MLEs for p and λ for AHUs.

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

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.4-3, only

4.3% of the AHUs experienced a FTS over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 95.7% portion of the distribution, and non-zero values above 95.7%.

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.4-5 for AHUs.

Table A.2.4-5. Fitted distributions for p and λ for AHUs.

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

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

A.2.4.4 Industry-Average Baselines

Table A.2.4-6 lists the industry-average failure rate distributions. For four of the five failure modes, the data sets were sufficient for empirical Bayes analyses to be performed. For these failure modes, the industry-average distributions are based on the empirical Bayes analysis results at the plant level. However, three of the results indicated α parameters lower than 0.3. As explained in Section A.1, in these cases a lower limit of 0.3 (upper bound on the uncertainty band) was assumed. The industry-average distribution for FTR>1H is not sufficient (Section A.1) for the empirical Bayes method; therefore a SCNID analysis was performed to provide a failure rate distribution. Note that this distribution is based on zero failures and may be conservatively high. These industry-average failure rates do not account for any recovery.

Table A.2.4-6. Selected industry distributions of p and λ for AHUs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.4-7 shows the rounded values for the AHU failure modes.

Table A.2.4-7. Selected industry distributions of p and λ for AHUs (after rounding).

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

A.2.4.5 Breakdown by System

AHU UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.4-8. Results are shown only for the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.4-8. AHU p and λ by system.

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

A.2.5 Air-Operated Valve (AOV) Data Sheet

A.2.5.1 Component Description

The air-operated valve (AOV) component boundary includes the valve, the valve operator (including the associated solenoid operated valves), local circuit breaker, and local instrumentation and control circuitry. The failure modes for AOV are listed in Table A.2.5-1.

Table A.2.5-1. AOV failure modes.

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

A.2.5.2 Data Collection and Review

Most of the data for AOV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. (The AOV external and internal leakage data cover 1997–2004 and were directly extracted from EPIX. EPIX contained a total of 2771 AOVs that were used for the external and internal leakage data.) There are 3443 AOVs from 98 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1) there were 3363 components in 98 plants. The systems included in the AOV data collection are listed in Table A.2.5-2 with the number of components included with each system.

Table A.2.5-2. AOV systems.

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

Operation	System	Description	Number of Components Initial	 After Review	 ≤ 20 Demands per Year
	NSW	Normal service water	99	99	99
	RCI	Reactor core isolation	6	5	5
	RCS	Reactor coolant	37	37	28
	RGW	Radioactive gaseous waste	2	2	1
	RPS	Reactor protection	13	13	13
	RRS	Reactor recirculation	19	18	16
	SLC	Standby liquid control	1	1	1
	TBC	Turbine building cooling water	2	2	1
	VSS	Vapor suppression	42	42	37
	Total		3443	3363	2756

The AOV data set obtained from RADS was further reduced to include only those AOVs with ≤ 20 demands/year. See Section A.1 for a discussion concerning this decision to limit certain component populations. Table A.2.5-3 summarizes the data used in the AOV analysis. Note that the hours for SO, ELS, and ILS are calendar hours. The FC failure mode is not supported with EPIX data.

Table A.2.5-3. AOV unreliability data.

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

Figure A.2.5-1 shows the range of valve demands per year in the AOV data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 20. The average for the data set is 5.8 demands/year.

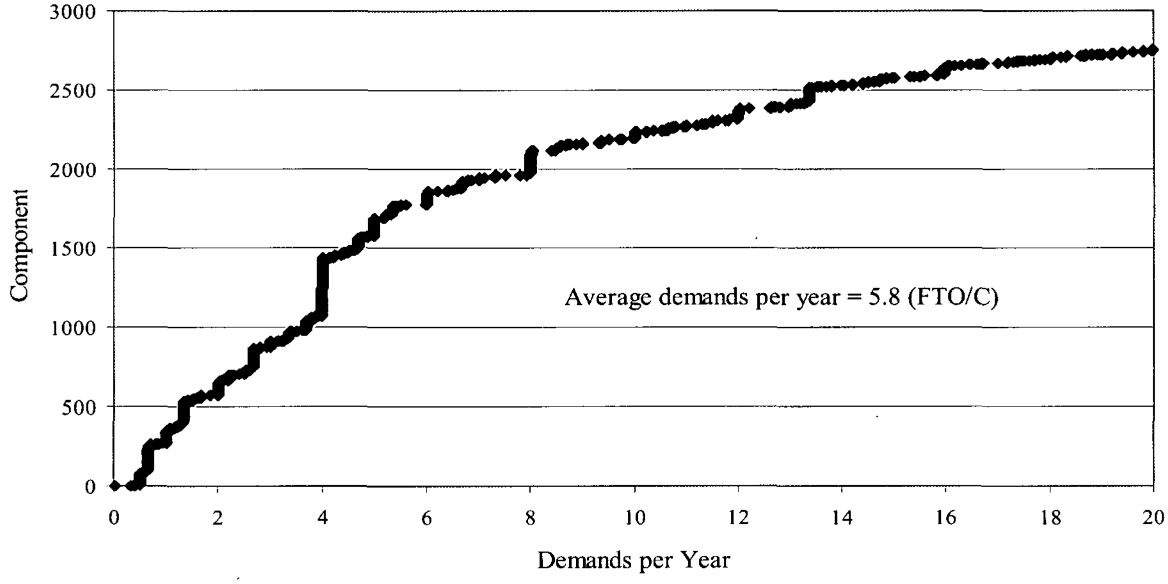

Figure A.2.5-1. AOV demands per year distribution.

A.2.5.3 Data Analysis

The AOV data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.5-4. The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.5-3, only 2.4% of the AOVs experienced a FTO/C over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 97.6% portion of the distribution, and non-zero values above 97.6%.

Table A.2.5-4. Empirical distributions of MLEs for p and λ for AOVs.

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

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.5-5.

Table A.2.5-5. Fitted distributions for p and λ for AOVs.

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

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

A.2.5.4 Industry-Average Baselines

Table A.2.5-6 lists the selected industry distributions of p and λ for the AOV failure modes. For the FTO/C, SO, and ILS failure modes, the data sets were sufficient (see Section A.1) for empirical Bayes analyses to be performed. Therefore, the industry-average distribution is based on the empirical Bayes analysis results at the plant level for FTO/C, SO, and ILS. However, the industry-average distribution for ELS is not sufficient (Section A.1) for the empirical Bayes method; therefore, a SCNID analysis was performed to provide a failure rate distribution. For SO, the EB/PL/KS result indicated an α parameter lower than 0.3. As explained in Section A.1, in these cases a lower limit of 0.3 (upper bound on the uncertainty band) was assumed. The selected ELL mean is the ELS mean multiplied by 0.07, with an assumed α of 0.3. The selected ILL mean is the ILS mean multiplied by 0.02, with an assumed α of 0.3. The 0.07 and 0.02 multipliers are based on limited EPIX data for large leaks as explained in Section A.1. The FC failure mode distribution was derived from the Westinghouse Savannah River Company (WSRC) database. That source lists Category 2 data (see Section A.1) for AOV control valves from sources other than commercial power plants. The selected value from WSRC was used as the mean, with an assumed α of 0.3. These industry-average failure rates do not account for any recovery.

Table A.2.5-6. Selected industry distributions of p and λ for AOVs (before rounding).

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

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

Table A.2.5-7. Selected industry distributions of p and λ for AOVs (after rounding).

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

A.2.5.5 Breakdown by System

AOV UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.5-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.5-8. AOV p and λ by system.

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

A.2.6 Battery (BAT) Data Sheet

A.2.6.1 Component Description

The battery (BAT) boundary includes the battery cells. The failure mode for BAT is listed in Table A.2.6-1.

Table A.2.6-1. BAT failure modes.

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

A.2.6.2 Data Collection and Review

Data for BAT UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. Failures were identified using the FTOP failure mode, but components were identified using the FTR failure mode. There are 363 BATs from 89 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1) there were 363 components in 89 plants. The systems included in the BAT data collection are listed in Table A.2.6-2 with the number of components included with each system.

Table A.2.6-2. BAT systems.

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

The data review process is described in detail in Section A.1. Table A.2.6-3 summarizes the data obtained from EPIX and used in the BAT analysis.

Table A.2.6-3. BAT unreliability data.

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

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

A.2.6.3 Data Analysis

The BAT data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.6-4.

Table A.2.6-4. Empirical distributions of MLEs for p and λ for BATs.

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

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.6-3, only 6.1% of the BATs experienced a FTOP over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 93.9% portion of the distribution, and non-zero values above 93.9%.

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table A.2.6-5 for BATs.

Table A.2.6-5. Fitted distributions for p and λ for BATs.

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

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

A.2.6.4 Industry-Average Baselines

Table A.2.6-6 lists the industry-average failure rate distribution. The data set was sufficient (Section A.1) for empirical Bayes analyses to be performed. The industry-average distribution is based on the empirical Bayes analysis results at the plant level. This industry-average failure rate does not account for any recovery.

Table A.2.6-6. Selected industry distributions of p and λ for BATs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.6-7 shows the rounded value for the BAT failure mode.

Table A.2.6-7. Selected industry distributions of p and λ for BATs (after rounding).

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

A.2.6.5 Breakdown by System

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

A.2.7 Battery Charger (BCH) Data Sheet

A.2.7.1 Component Description

The battery charger (BCH) boundary includes the battery charger and its breakers. The failure mode for BAT is listed in Table A.2.7-1.

Table A.2.7-1. BCH failure modes.

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

A.2.7.2 Data Collection and Review

Data for BCH UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. Failures were identified using the FTOP failure mode, but components were identified using the FTR failure mode. There are 392 BCHs from 65 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1) there were 392 components in 65 plants. The systems included in the BCH data collection are listed in Table A.2.7-2 with the number of components included with each system.

Table A.2.7-2. BCH systems.

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

The data review process is described in detail in Section A.1. Table A.2.7-3 summarizes the data obtained from EPIX and used in the BCH analysis.

Table A.2.7-3. BCH unreliability data.

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

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

A.2.7.3 Data Analysis

The BCH data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.7-4.

Table A.2.7-4. Empirical distributions of MLEs for p and λ for BCHs.

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

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.7-3, only 15.8% of the BCHs experienced a FTOP over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 84.2% portion of the distribution, and non-zero values above 84.2%.

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table A.2.7-5 for BCHs. These results were used to develop the industry-average distributions for FTOP.

Table A.2.7-5. Fitted distributions for *p* and *λ* for BCHs.

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

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

A.2.7.4 Industry-Average Baselines

Table A.2.7-6 lists the industry-average failure rate distribution. The data set was sufficient (Section A.1) for empirical Bayes analyses to be performed. The industry-average distribution is based on the empirical Bayes analysis results at the plant level. This industry-average failure rate does not account for any recovery.

Table A.2.7-6. Selected industry distributions of *p* and *λ* for BCHs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the *α* parameter was rounded. In order to preserve the mean value, the *β* parameter is presented to three significant figures. Table A.2.7-7 shows the rounded value for the BCH failure mode.

Table A.2.7-7. Selected industry distributions of *p* and *λ* for BCHs (after rounding).

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

A.2.7.5 Breakdown by System

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

A.2.8 Bistable (BIS) Data Sheet

A.2.8.1 Component Description

The bistable (BIS) boundary includes the bistable unit itself. The failure mode for BIS is listed in Table A.2.8-1.

Table A.2.8-1. BIS failure modes.

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

A.2.8.2 Data Collection and Review

Data for the BIS UR baseline were obtained from the reactor protection system (RPS) system studies (SSs). The RPS SSs contain data from 1984 to 1995. Table A.2.8-2 summarizes the data obtained from the RPS SSs and used in the BIS analysis. These data are at the industry level. Results at the plant and component levels are not presented in these studies.

Table A.2.8-2. BIS unreliability data.

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

A.2.8.3 Industry-Average Baselines

Table A.2.8-3 lists the industry-average failure rate distribution. The FTOP failure mode is not supported by EPIX data. The selected FTOP distribution has a mean based on the Jeffreys mean of industry data and $\alpha = 0.5$. For all distributions based on RPS SS data, an α of 0.5 is assumed (see Section A.1).

Table A.2.8-3. Selected industry distributions of p and λ for BISs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.8-4 shows the rounded value for the BIS failure mode.

Table A.2.8-4. Selected industry distributions of p and λ for BISs (after rounding).

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

A.2.9 Bus (BUS) Data Sheet

A.2.9.1 Component Description

The bus (BUS) boundary includes the bus component itself. Associated circuit breakers and step-down transformers are not included. The failure mode for BUS is listed in Table A.2.9-1.

Table A.2.9-1. BUS failure modes.

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

A.2.9.2 Data Collection and Review

Data for the BUS UR baseline were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. Failures were identified using the FTOP failure mode, but components were identified using the FTR failure mode. There are 164 BUSs from 11 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1) there were 164 components in 11 plants. The systems included in the BUS data collection are listed in Table A.2.9-2 with the number of components included with each system.

Table A.2.9-2. BUS systems.

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

The data review process is described in detail in Section A.1. Table A.2.9-3 summarizes the data obtained from EPIX and used in the BUS analysis. Note that the hours are calendar hours.

Table A.2.9-3. BUS unreliability data.

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

A.2.9.3 Data Analysis

The BUS data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.9-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.9-3, only 1.2% of the BUSs experienced a FTOP over the period 1997–2004, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 98.8% portion of the distribution, and non-zero values above 98.8%.

Table A.2.9-4. Empirical distributions of MLEs for p and λ for BUSs.

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

The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.9-5 for BUSs.

Table A.2.9-5. Fitted distributions for p and λ for BUSs.

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

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

A.2.9.4 Industry-Average Baselines

Table A.2.9-6 lists the industry-average failure rate distribution. The data set was sufficient (Section A.1) for empirical Bayes analyses to be performed. This industry-average failure rate does not account for any recovery.

Table A.2.9-6. Selected industry distributions of p and λ for BUSs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.9-7 shows the rounded value for the BUS failure mode.

Table A.2.9-7. Selected industry distributions of p and λ for BUSs (after rounding).

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

A.2.9.5 Breakdown by System

BUS UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.9-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.9-8. BUS p and λ by system.

System	FTOP
ACP	6.4E-07
DCP	-
EPS	-

System	FTOP
OEP	-
RPS	-

A.2.10 Circuit Breaker (CBK) Data Sheet

A.2.10.1 Component Description

The circuit breaker (CBK) is defined as the breaker itself and local instrumentation and control circuitry. External equipment used to monitor under voltage, ground faults, differential faults, and other protection schemes for individual breakers are considered part of the breaker. The failure modes for CBK are listed in Table A.2.10-1.

Table A.2.10-1. CBK failure modes.

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

A.2.10.2 Data Collection and Review

Data for CBK UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. The breakers included in the CBK data are those that are used in the power distribution function and do not include load breakers or reactor trip breakers. There are 4211 CBKs from 97 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1) there were 4050 components in 97 plants. The systems included in the CBK data collection are listed in Table A.2.10-2 with the number of components included with each system.

Table A.2.10-2. CBK systems.

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

The CBK data set obtained from RADS was further reduced to include only those CBKs with ≤ 20 demands/year (≤ 100 demands over 5 years). See Section A.1 for a discussion concerning this decision to limit certain component populations. Table A.2.10-3 summarizes the data used in the CBK analysis. Note that the hours for SO are calendar hours.

Table A.2.10-3. CBK unreliability data.

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

Figure A.2.10-1 shows the range of breaker demands per year in the CBK data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 20. The average for the data set is 2.5 demands/year.

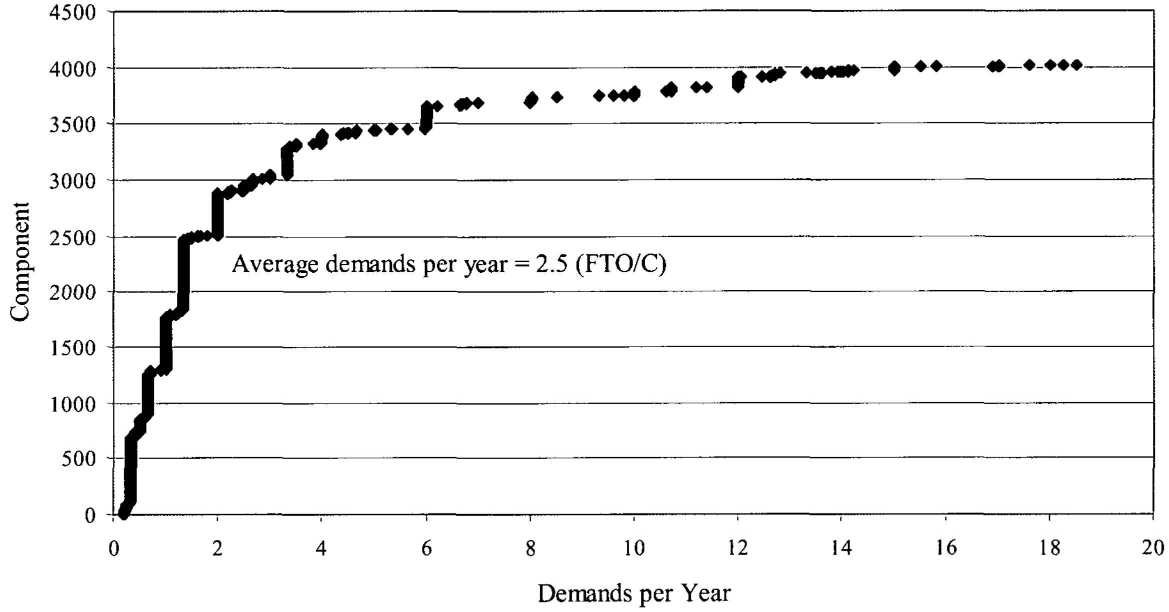

Figure A.2.10-1. CBK demands per year distribution.

A.2.10.3 Data Analysis

The CBK data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.10-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.10-3, only 1.9% of the CBKs experienced a FTO/C over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 98.1% portion of the distribution, and non-zero values above 98.1%.

Table A.2.10-4. Empirical distributions of MLEs for p and λ for CBKs.

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

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$.Results from these analyses are presented in Table A.2.10-5.

Table A.2.10-5. Fitted distributions for p and λ for CBKs.

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

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

A.2.10.4 Industry-Average Baselines

Table A.2.10-6 lists the selected industry distributions of p and λ for the CBK failure modes. For both the FTO/C and SO failure modes, the data sets were sufficient (see Section A.1) for empirical Bayes analyses to be performed. Therefore, the industry-average distribution is based on the empirical Bayes analysis results at the plant level for FTO/C and SO. These industry-average failure rates do not account for any recovery.

Table A.2.10-6. Selected industry distributions of p and λ for CBKs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.10-7 shows the rounded values for the CBK failure modes.

Table A.2.10-7. Selected industry distributions of p and λ for CBKs (after rounding).

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

A.2.10.5 Breakdown by System

CBK UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.10-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.10-8. CBK p and λ by system.

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

A.2.11 Chiller (CHL) Data Sheet

A.2.11.1 Component Description

The chiller (CHL) boundary includes the compressor, motor, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for CHL are listed in Table A.2.11-1.

Table A.2.11-1. CHL failure modes.

Operation	Failure Mode	Parameter	Units	Description
Standby	FTS	p	-	Failure to start
	FTR≤1H	λ	1/h	Failure to run for 1 h
	FTR>1H	λ	1/h	Fail to run beyond 1 h
Running/Alternating	FTS	p	-	Failure to start
	FTR	λ	1/h	Fail to run

A.2.11.2 Data Collection and Review

Data for CHL UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. There are 178 CHLs from 35 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1) there were 174 components in 31 plants. These data were then further partitioned into standby and running/alternating components. The systems and operational status included in the CHL data collection are listed in Table A.2.11-2 with the number of components included with each system.

Table A.2.11-2. CHL systems.

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

The data review process is described in detail in Section A.1. Table A.2.11-3 summarizes the data obtained from EPIX and used in the CHL analysis. Note that components with > 200 demands/year were removed.

Figure A.2.11-1a shows the range of start demands per year in the standby CHL data set. The start demands per year range from approximately 4 to 86. The average for the data set is 18.5 demands/year. Figure A.2.11-1b shows the range of start demands per year in the running CHL data set. The demands per year range from approximately 1 (once per year) to 30. The average for the data set is 11.5 demands/year.

Table A.2.11-3. CHL unreliability data.

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

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

Figure A.2.11-2a shows the range of run hours per demand in the standby CHL data set. The run hours per demand range is from approximately 0 hours/demand to 38 hours/demand. The average is 3.7 hours/demand. Figure A.2.11-2b shows the range of run hours per demands in the running CHL data set. The range is from approximately 141 hours/demand to 26,280 hours/demand. The average is 1093.6 hours/demand.

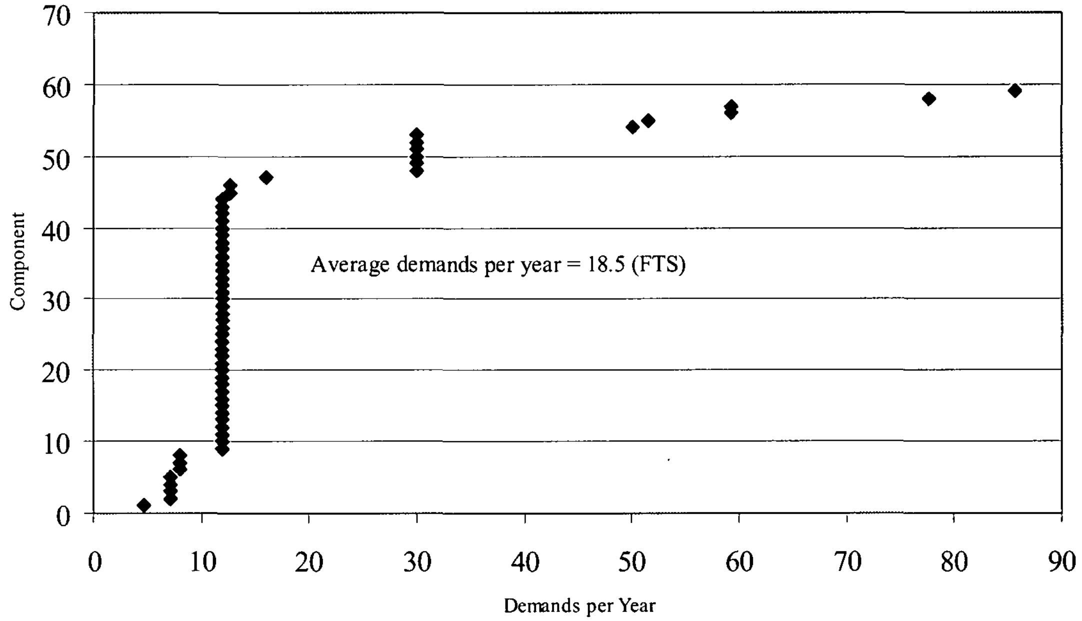

Figure A.2.11-1a. Standby CHL demands per year distribution.

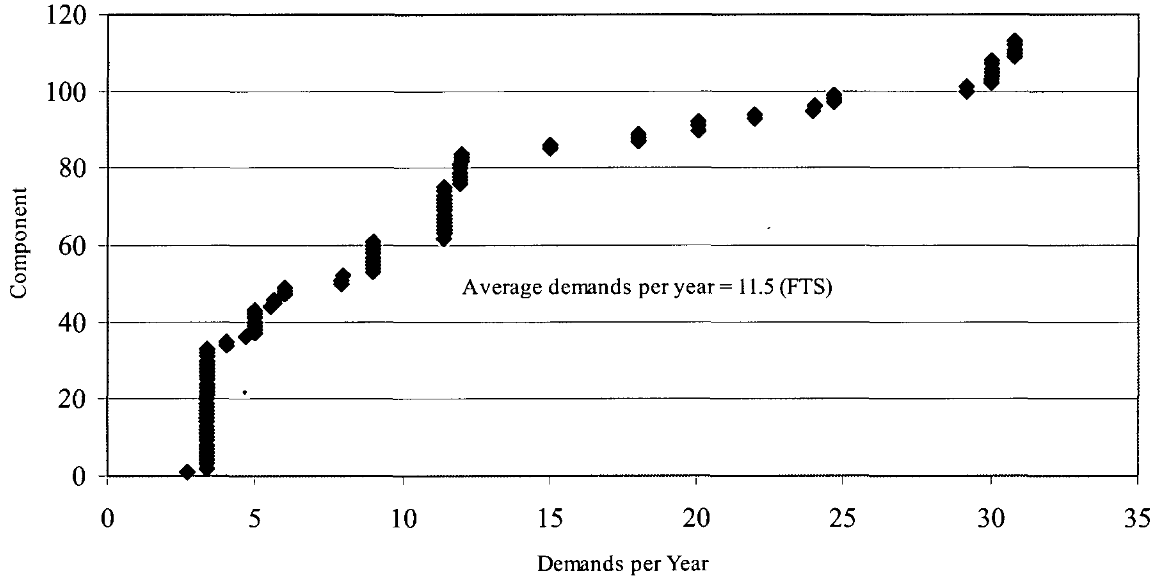

Figure A.2.11-1b. Running/alternating CHL demands per year distribution.

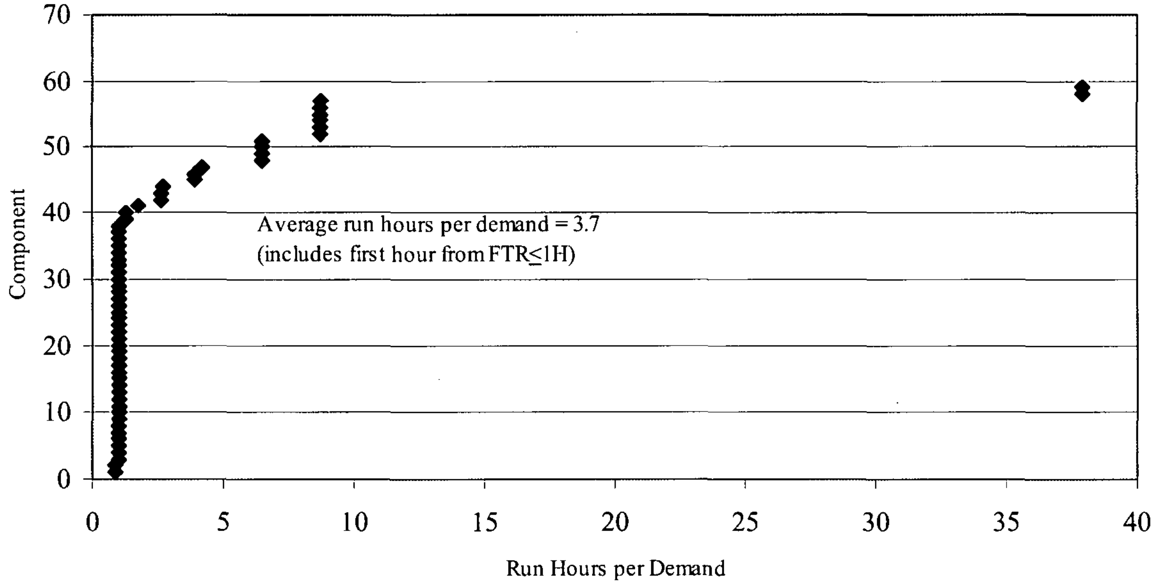

Figure A.2.11-2a. Standby CHL run hours per demand distribution.

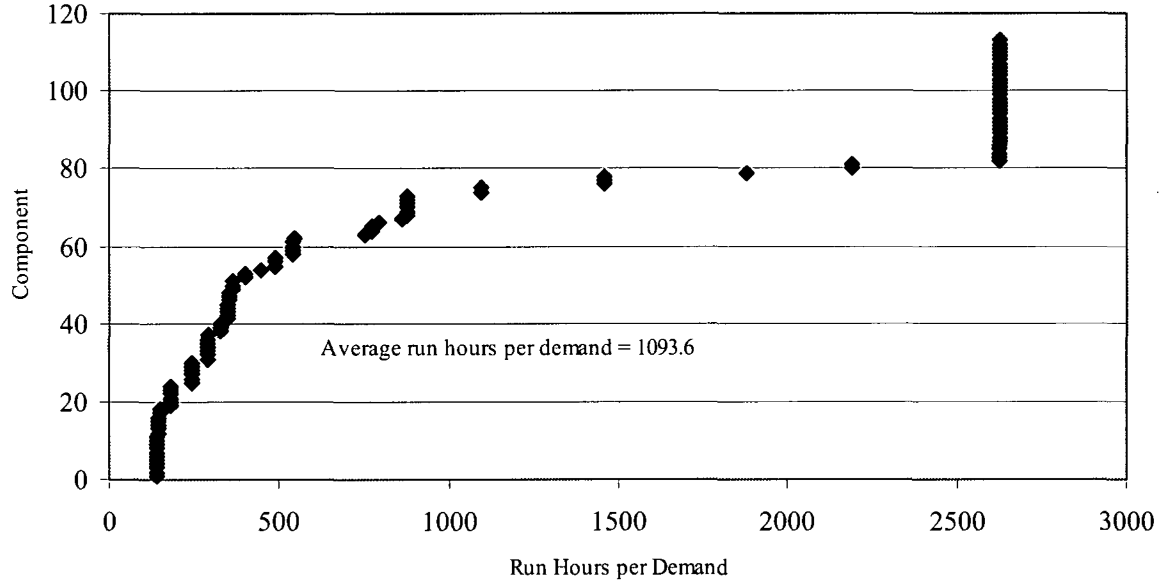

Figure A.2.11-2b. Running/alternating CHL run hours per demand distribution.

A.2.11.3 Data Analysis

The CHL data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.11-4.

Table A.2.11-4. Empirical distributions of MLEs for p and λ for CHLs.

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

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.11-3, only 17.5% of the CHLs experienced a FTS over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 82.5% portion of the distribution, and non-zero values above 82.5%.

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$.Results from these analyses are presented in Table A.2.11-5 for CHLs.

Table A.2.11-5. Fitted distributions for p and λ for CHLs.

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

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

A.2.11.4 Industry-Average Baselines

Table A.2.11-6 lists the industry-average failure rate distributions. For three of the five failure modes, the data sets were sufficient for empirical Bayes analyses to be performed. For these failure modes, the industry-average distributions are based on the empirical Bayes analysis results at the plant level, except for FTR>1H. The empirical Bayes results (EB/PL/KS) indicate a mean that is six times higher than the SCNID result. Because of this very large difference (resulting in a FTR>1H rate higher than the FTR≤1H rate), the SCNID result is recommended. Note that both cases indicate an α of approximately 0.5. The industry-average distribution for FTS is not sufficient (Section A.1) for the empirical Bayes method. Therefore, a SCNID analysis was performed to provide a failure rate distribution. Finally, for FTR≤1H, the empirical Bayes analysis did not converge but indicated very little variation. For that case, the distribution was obtained using a Bayesian update of the Jeffreys noninformative prior. These industry-average failure rates do not account for any recovery.

Table A.2.11-6. Selected industry distributions of p and λ for CHLs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.11-7 shows the rounded values for the CHL failure modes.

Table A.2.11-7. Selected industry distributions of p and λ for CHLs (after rounding).

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

A.2.11.5 Breakdown by System

CHL UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.11-8. Results are shown only for the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.11-8. CHL p and λ by system.

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

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

A.2.12 Check Valve (CKV) Data Sheet

A.2.12.1 Component Description

The check valve (CKV) component boundary includes the valve and no other supporting components. The failure modes for CKV are listed in Table A.2.12-1.

Table A.2.12-1. CKV failure modes.

Operation	Failure Mode	Parameter	Units	Description
Standby	FTO	p	-	Failure to open
	FTC	λ	1/h	Failure to close
	ELS	λ	1/h	External leak small
	ELL	λ	1/h	External leak large
	ILS	λ	1/h	Internal leak small
	ILL	λ	1/h	Internal leak large

A.2.12.2 Data Collection and Review

Data for CKV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. (The external and internal leakage data cover 1997–2004.) There are 935 CKVs from 50 plants in the data originally gathered by RADS. After analyzing the original data, there were no FTO failures, so the data set was expanded to 1997– 2004 for FTO failure mode (see Section A.1). After removing data without demand information (see Section A.1) there were 828 components in 50 plants. The systems included in the CKV data collection are listed in Table A.2.12-2 with the number of components included with each system.

Table A.2.12-2. CKV systems.

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

The CKV data set obtained from RADS was further reduced to include only those CKVs with ≤ 20 demands/year (≤ 100 demands over 5 years). See Section A.1 for a discussion concerning this decision to limit certain component populations. Table A.2.12-3 summarizes the data used in the CKV analysis. Note that the hours for ELS and ILS are calendar hours.

Table A.2.12-3. CKV unreliability data.

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

Figure A.2.12-1 shows the range of valve demands per year in the CKV data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 20. The average for the data set is 6.6 demands/year.

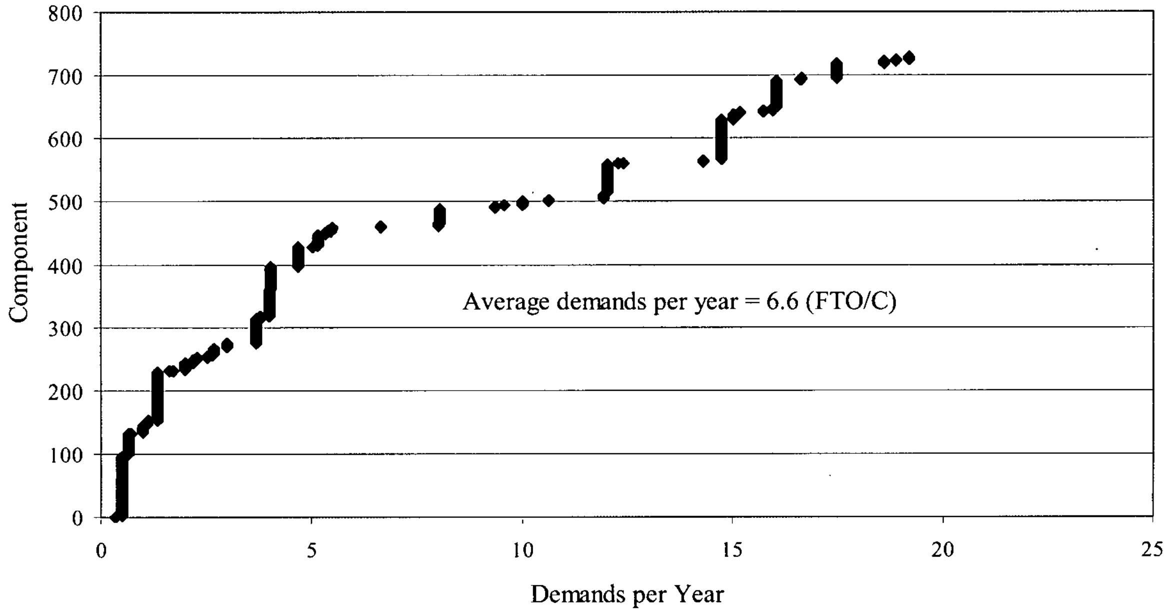

Figure A.2.12-1. CKV demands per year distribution.

A.2.12.3 Data Analysis

The CKV data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.12-4. Note that with one failure for FTC, the MLE distributions at the component and plant levels provide no information for either the lower or upper portions of the distribution (other than to indicate zeros). From Table A.2.12-3, only 0.1% of the CKVs experienced a FTC over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 99.9% portion of the distribution, and non-zero values above 99.9%.

Table A.2.12-4. Empirical distributions of MLEs for p and λ for CKVs.

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

Because of the limited failures, an empirical Bayes analysis was performed at both the component and plant level only for ILS. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$.Results from these analyses are presented in Table A.2.12-5.

Table A.2.12-5. Fitted distributions for p and λ for CKVs.

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

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

A.2.12.4 Industry-Average Baselines

Table A.2.12-6 lists the selected industry distributions of p and λ for the CKV failure modes. The data set was insufficient (see Section A.1) for empirical Bayes analyses to be performed for FTO, FTC, and ELS failure modes. A SCNID analysis was performed to provide a failure rate distribution. The data set was sufficient to perform the empirical Bayes analysis for the ILS failure mode. However the resulting α was less than 0.3, so a lower limit of 0.3 was assumed. These industry-average failure rates do not account for any recovery. The selected ELL mean is the ELS mean multiplied by 0.07, with an assumed α of 0.3. The selected ILL mean is the ILS mean multiplied by 0.02, with an assumed α of 0.3. The 0.07 and 0.02 multipliers are based on limited EPIX data for large leaks as explained in Section A.1.

Table A.2.12-6. Selected industry distributions of p and λ for CKVs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.12-7 shows the rounded values for the CKV failure modes.

Table A.2.12-7. Selected industry distributions of p and λ for CKVs (after rounding).

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

A.2.12.5 Breakdown by System

CKV UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.12-8. Results are shown only for systems and failure modes with failures in the data set. Because most system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.12-8. CKV p and λ by system.

System	FTO	FTC	ELS	ILS
AFW	-	-	-	-
CCW	-	-	-	7.6E-07
CHW	-	-	-	2.1E-05
CIS	-	-	-	1.4E-06
CRD	-	-	-	-
CSR	-	-	-	-
CVC	-	-	-	3.8E-07
EPS	-	-	-	-
ESW	-	1.9E-03	-	-
HCI	-	-	-	-
HPI	-	-	-	-
HVC	-	-	-	-
ISO	-	-	-	6.4E-05
LCI	-	-	-	2.5E-06
LCS	-	-	-	-
LPI	-	-	-	-
MFW	-	7.9E-03	-	1.3E-06
MSS	-	-	-	-
RCI	-	-	1.8E-06	4.2E-06
RCS	-	-	-	2.7E-06
RRS	-	-	-	2.5E-05
SLC	-	-	-	-
VSS	-	-	-	-

A.2.13 Control Rod Drive (CRD) Data Sheet

A.2.13.1 Component Description

The control rod drive (CRD) boundary includes the PWR control rod drive mechanism. The failure mode for CRD is listed in Table A.2.13-1.

Table A.2.13-1. CRD failure modes.

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

A.2.13.2 Data Collection and Review

Data for the CRD UR baseline were obtained from the pressurized water reactor (PWR) reactor protection system (RPS) system studies (SSs). The RPS SSs contain data from 1984 to 1995. Table A.2.13-2 summarizes the data obtained from the RPS SSs and used in the CRD analysis. These data are at the industry level. Results at the plant and component levels are not presented in these studies.

Table A.2.13-2. CRD unreliability data.

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

A.2.13.3 Industry-Average Baselines

Table A.2.13-3 lists the industry-average failure rate distribution. The FTOP failure mode is not supported by EPIX data. The selected FTOP distribution has a mean based on the Jeffreys mean of industry data and $\alpha = 0.5$. For all distributions based on RPS SS data, an α of 0.5 is assumed (see Section A.1).

Table A.2.13-3. Selected industry distributions of p and λ for CRDs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.13-4 shows the rounded value for the CRD failure mode.

Table A.2.13-4. Selected industry distributions of p and λ for CRDs (after rounding).

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

A.2.14 Cooling Tower Fan (CTF) Data Sheet

A.2.14.1 Component Description

The cooling tower fan (CTF) boundary includes the fan, motor, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for CTF are listed in Table A.2.14-1.

Table A.2.14-1. CTF failure modes.

Operation	Failure Mode	Parameter	Units	Description
Standby	FTS	P	-	Failure to start
	FTR≤1H	λ	1/h	Failure to run for 1 h
	FTR>1H	λ	1/h	Fail to run beyond 1 h
Running/Alternating	FTS	P	-	Failure to start
	FTR	λ	1/h	Fail to run

A.2.14.2 Data Collection and Review

Data for CTF UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. After analyzing the original data, there were very few failures, so the data set was expanded to 1997– 2004 (see Section A.1). There are 81 CTFs from five plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1) there were 81 components in five plants. The individual failure records were reviewed to determine which failure mode applied. For this component, the failure to run events indicated how long after initial start before the failure occurred, so the typical binning process was not needed. The systems included in the CTF data collection are listed in Table A.2.14-2 with the number of components included with each system.

Table A.2.14-2. CTF systems.

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

The data review process is described in detail in Section A.1. Table A.2.14-3 summarizes the data obtained from EPIX and used in the CTF analysis. Note that for the running/alternating CTFs, those components with > 200 demands/year were removed.

Table A.2.14-3. CTF unreliability data.

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

Figure A.2.14-1a shows the range of start demands per year in the standby MDP data set. The start demands per year range from approximately 30 to 107. The average for the data set is 6.1 demands/year. Figure A.2.14-1b shows the range of start demands per year in the running MDP data set. The demands per year range from approximately 20 to 2,660. The average for the data set is 133.6 demands/year.

Figure A.2.14-2a shows the range of run hours per demand in the standby MDP data set. The run hours per demand range is from approximately 0 hours/demand to 12.0 hours/demand. The average is 6.7 hours/demand. Figure A.2.14-2b shows the range of run hours per demands in the running MDP data set. The range is from approximately 12 hours/demand to 3,153 hours/demand. The average is 369.2 hours/demand.

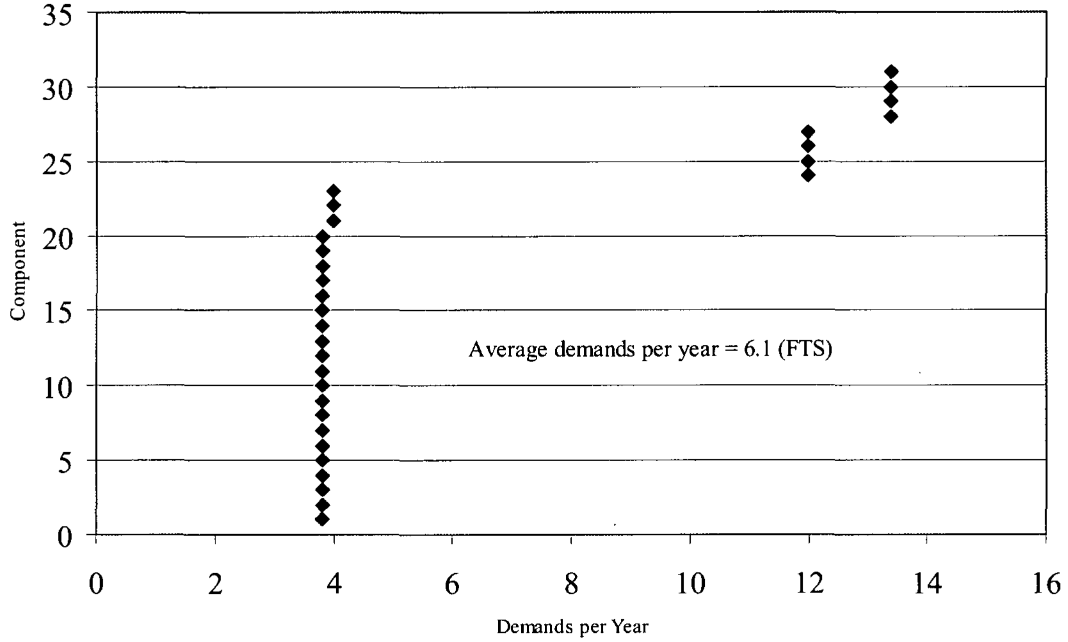

Figure A.2.14-1a. Standby CTF demands per year distribution.

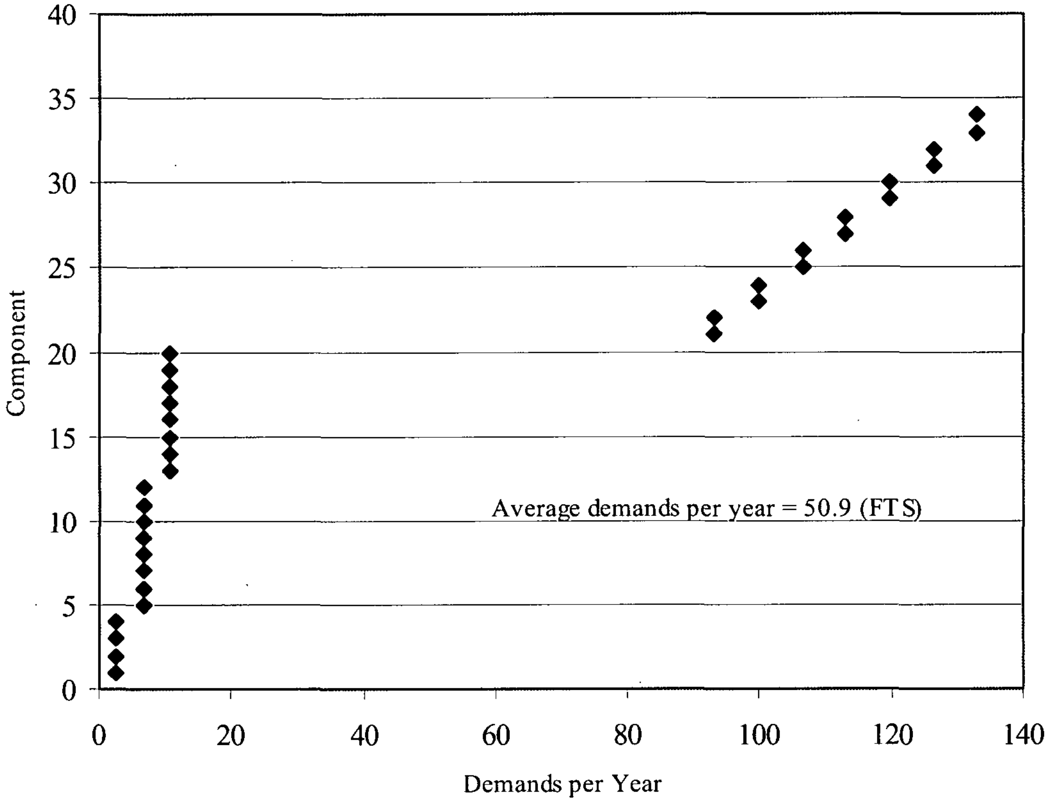

Figure A.2.14-1b. Running/alternating CTF demands per year distribution.

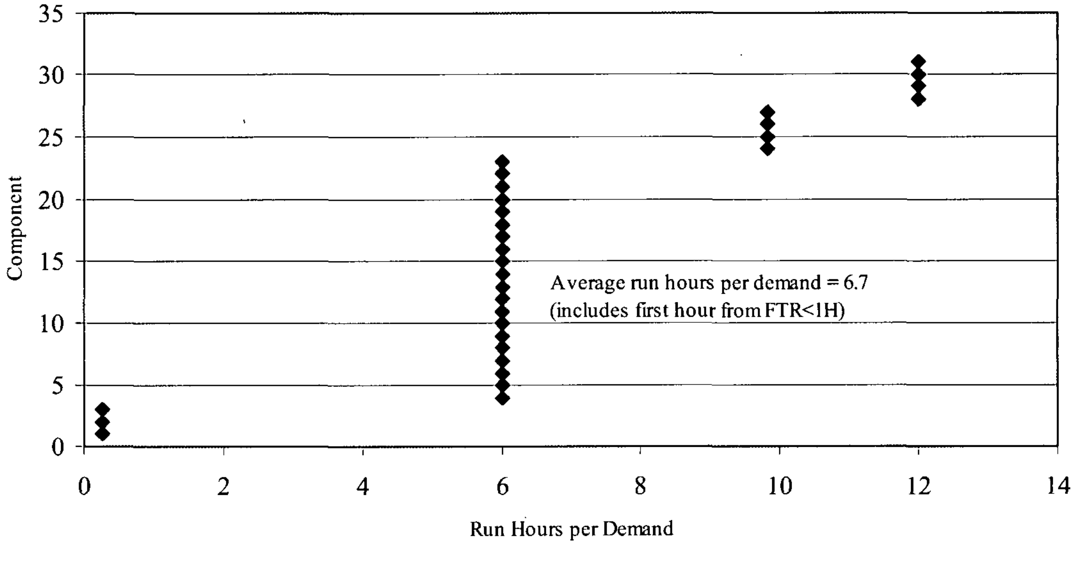

Figure A.2.14-2a. Standby CTF run hours per demand distribution.

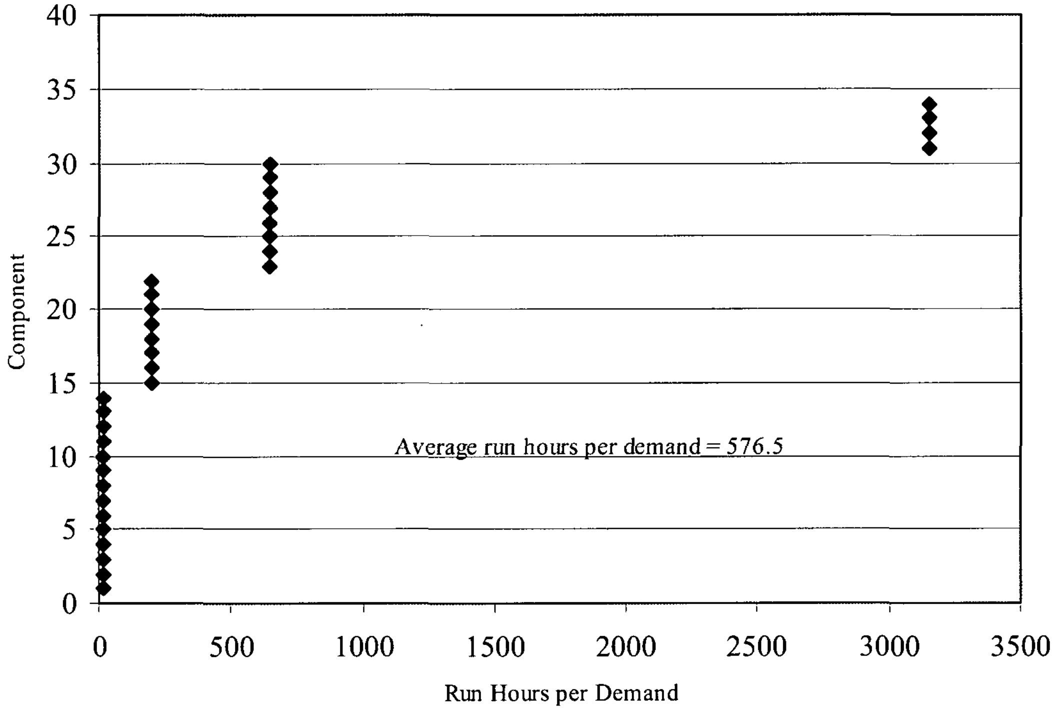

Figure A.2.14-2b. Running/alternating CTF run hours per demand distribution.

A.2.14.3 Data Analysis

The CTF data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.14-4.

Table A.2.14-4. Empirical distributions of MLEs for p and λ for CTFs.

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

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.14-3, only 6.5% of the CTFs experienced a FTR≤1H over the period 1997–2004, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 93.5% portion of the distribution, and non-zero values above 93.5%.

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.14-5 for CTFs.

Table A.2.14-5. Fitted distributions for p and λ for CTFs.

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

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

A.2.14.4 Industry-Average Baselines

Table A.2.14-6 lists the industry-average failure rate distributions. The industry-average distribution for all of the failure modes is not sufficient (Section A.1) for the empirical Bayes method; therefore a SCNID analysis was performed to provide a failure rate distribution. Note that this distribution is based on zero or very few failures and may be conservatively high. These industry-average failure rates do not account for any recovery.

Table A.2.14-6. Selected industry distributions of p and λ for CTFs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.14-7 shows the rounded values for the CTF failure modes.

Table A.2.14-7. Selected industry distributions of p and λ for CTFs (after rounding).

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

A.2.14.5 Breakdown by System

CTF UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.14-8. Results are shown only for the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.14-8. CTF p and λ by system.

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

A.2.15 Combustion Turbine Generator (CTG) Data Sheet

A.2.15.1 Component Description

The combustion turbine generator (CTG) boundary includes the gas turbine, generator, circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for CTG are listed in Table A.2.15-1.

Table A.2.15-1. CTG failure modes.

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

A.2.15.2 Data Collection and Review

Data for CTG UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. There are 2 CTGs from one plant in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1) there were 2 components in one plant. The systems and operational status included in the CTG data collection are listed in Table A.2.14-2 with the number of components included with each system.

Table A.2.15-2. CTG systems.

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

The EPIX data indicated that the CTGs were demanded once per month and all failures were detected during testing. The EPIX database also indicated that the CTGs were running continuously. Because the run hours appeared suspicious, the plant was contacted for clarification. The plant reply provided data from January 1, 1998 to October 1, 2004 which indicated that the CTGs were run approximately 1 h for testing and all failures were detected on demand (start). Table A.2.15-3 summarizes the data obtained from the plant and used in the CTG analysis.

Table A.2.15-3. CTG unreliability data.

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

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

A.2.15.3 Data Analysis

Since there are only two components at two units, the MLE distributions provide little information. In addition, the empirical Bayes analysis cannot be performed. Therefore, only the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha =$

0.5. Results from these analyses are presented in Table A.2.15-4 for CTGs. The data for FTR>1H, no failures in 16 h, are too limited to estimate the FTR>1H rate.

Table A.2.15-4. Fitted distributions for p and λ for CTGs.

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

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

A.2.15.4 Industry-Average Baselines

Table A.2.15-5 lists the industry-average failure rate distributions. Results for FTS and FTLR are based on EPIX data (modified as discussed). The FTR>1H distribution was assumed to be the same as for EDGs, but with $\alpha = 0.3$. These industry-average failure rates do not account for any recovery.

Table A.2.15-5. Selected industry distributions of p and λ for CTGs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.15-6 shows the rounded values for the CTG failure modes.

Table A.2.15-6. Selected industry distributions of p and λ for CTGs (after rounding).

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

A.2.15.5 Breakdown by System

The CTG is included only in the emergency power system.

A.2.16 Diesel-Driven Pump (DDP) Data Sheet

A.2.16.1 Component Description

The diesel-driven pump (DDP) boundary includes the pump, diesel engine, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for DDP are listed in Table A.2.16-1.

Table A.2.16-1. DDP failure modes.

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

A.2.16.2 Data Collection and Review

Data for DDP UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002, except for the ELS data that cover 1997–2004. There are 27 DDPs from 16 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1) there were 27 components in 16 plants. Three of these components had run hours that were much higher than others and appeared to be errors. For these three components, an average of 0.9 hours per demand (obtained from the other components) was used. These data were then further partitioned into standby and running/alternating components. (There were no running/alternating components identified.) The systems and operational status included in the DDP data collection are listed in Table A.2.16-2 with the number of components included with each system.

Table A.2.16-2. DDP systems.

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

The data review process is described in detail in Section A.1. Table A.2.16-3 summarizes the data obtained from EPIX and used in the DDP analysis. Note that the hours for ELS are calendar hours.

Table A.2.16-3. DDP unreliability data.

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

Figure A.2.16-1 shows the range of start demands per year in the standby DDP data set. The start demands per year range from approximately 7 to 157. The average for the data set is 38.2 demands/year. Figure A.2.16-2 shows the range of run hours per demand in the standby DDP data set. The run hours per demand range is from approximately 1 hour/demand to 8 hours/demand. The average is 0.9 hour/demand.

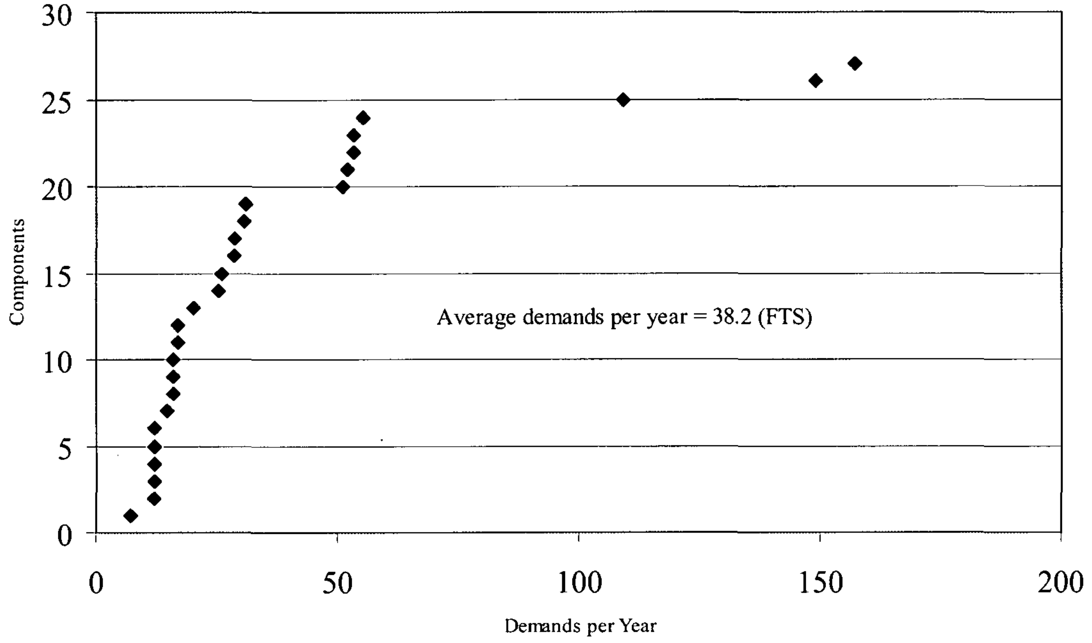

Figure A.2.16-1. Standby DDP demands per year distribution.

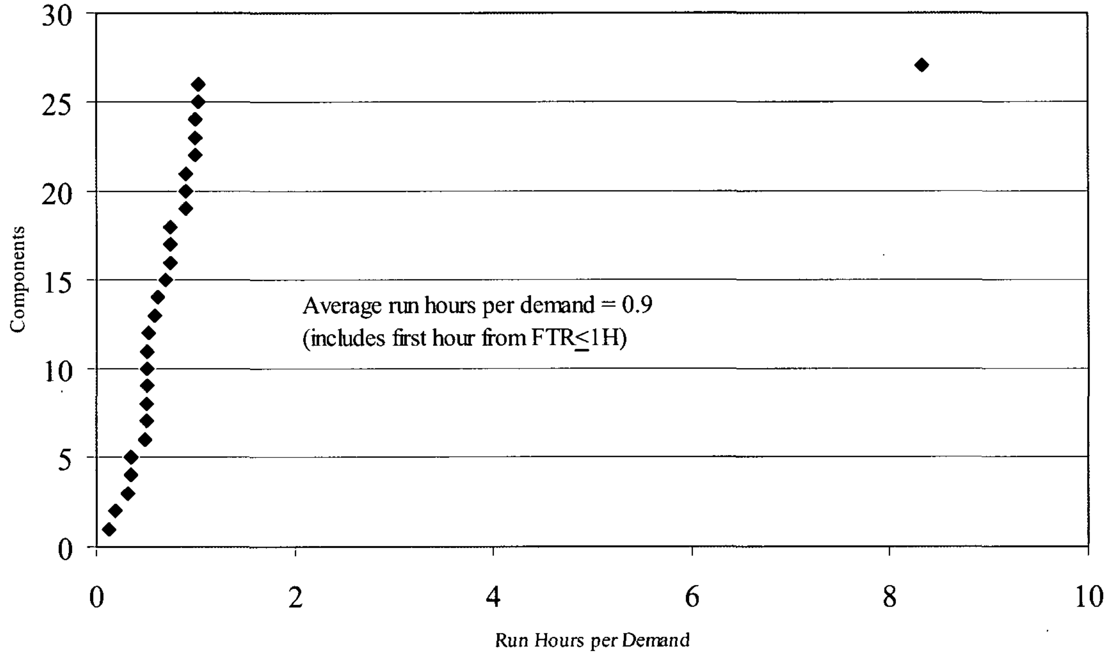

Figure A.2.16-2. Standby DDP run hours per demand distribution.

A.2.16.3 Data Analysis

The DDP data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.16-4.

Table A.2.16-4. Empirical distributions of MLEs for p and λ for DDPs.

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

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.16-3, only 20.8% of the DDPs experienced a FTS over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 79.2% portion of the distribution, and non-zero values above 79.2%.

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table A.2.16-5 for DDPs.

Table A.2.16-5. Fitted distributions for p and λ for DDPs.

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

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

A.2.16.4 Industry-Average Baselines

Table A.2.16-6 lists the selected industry distributions of p and λ for the DDP failure modes. For the FTS and FTR≤1H failure modes, the data sets were sufficient (Section A.1) for empirical Bayes analyses to be performed. For these failure modes, the industry-average distributions are based on the empirical Bayes analysis results at the plant level. However, both results indicated α values less than 0.3. In both cases, the lower limit of 0.3 was assumed. The FTR>1H data had no failures or demands; therefore the FTR>1H mean is FTR≤1H * 0.06, based on the FTR>1H/ FTR≤1H ratio observed for other similar standby components (Section A.1). The ELS failure mode also has no failures. Therefore, a SCNID analysis was performed to provide a failure rate distribution. The selected ELL mean is the ELS mean multiplied by 0.07, with an assumed α of 0.3. The 0.07 multiplier is based on limited EPIX data for large leaks as explained in Section A.1. These industry-average failure rates do not account for any recovery.

Table A.2.16-6. Selected industry distributions of p and λ for DDPs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.16-7 shows the rounded values for the DDP failure modes.

Table A.2.16-7. Selected industry distributions of p and λ for DDPs (after rounding).

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

A.2.16.5 Breakdown by System

DDP UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.16-8. Results are shown only the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.16-8. DDP p and λ by system.

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

A.2.17 Emergency Diesel Generator (EDG) Data Sheet

A.2.17.1 Component Description

The emergency diesel generators (EDGs) covered in this data sheet are those within the Class 1E ac electrical power system at U.S. commercial nuclear power plants. EDGs supporting the motor-driven pumps in the high-pressure core spray (HPCS) systems and station blackout (SBO) EDGs are not included. However, they are compared with the results for these Class 1E EDGs in Section A.2.17.5.

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

The failure modes for EDG are listed in Table A.2.17-1.

Table A.2.17-1. EDG failure modes.

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

A.2.17.2 Data Collection and Review

Data for EDG UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. There are 225 EDGs from 95 plants. (There are actually 103 plants, but some multi-plant sites list both plant EDGs under one plant.) The systems included in the EDG data collection are listed in Table A.2.17-2 with the number of components included with each system.

Table A.2.17-2. EDG systems.

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

A review of the data indicated several plants with unreasonably low start and/or load and run demands. Because the start demands should be higher than the load and run demands, a data processing routine was used to modify suspicious data. If the load and run demands were higher than the start demands, then the start demands were set equal to the load and run demands. Then, the load and run demands were compared with the start demands. If the load and run demands were less than 75% of the start demands, the load and run demands were set to 75% of the start demands. In addition, ten of the EDGs appeared to have run hours that were ten times too high (possibly an error in data entry). Those EDG run hours were reduced by a factor of ten. Finally, one plant listed 12 FTR events, while the next highest plant had four FTR events. A review of those failure records indicated that only one of the events was actually a failure. The other 11 events were all similar and involved local instrumentation issues that would not have prevented the EDG from running. Results from this data review are listed in Table A.2.17-3. Overall, the data changes were significant only in terms of the run hours and the number of FTR>1H events.

Table A.2.17-3. EDG unreliability data.

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

Figure A.2.17-1 shows the range of start demands per year in the EDG data set. The demands per year range from approximately 12 to 50. The average for the data set is 21.5 demands/year.

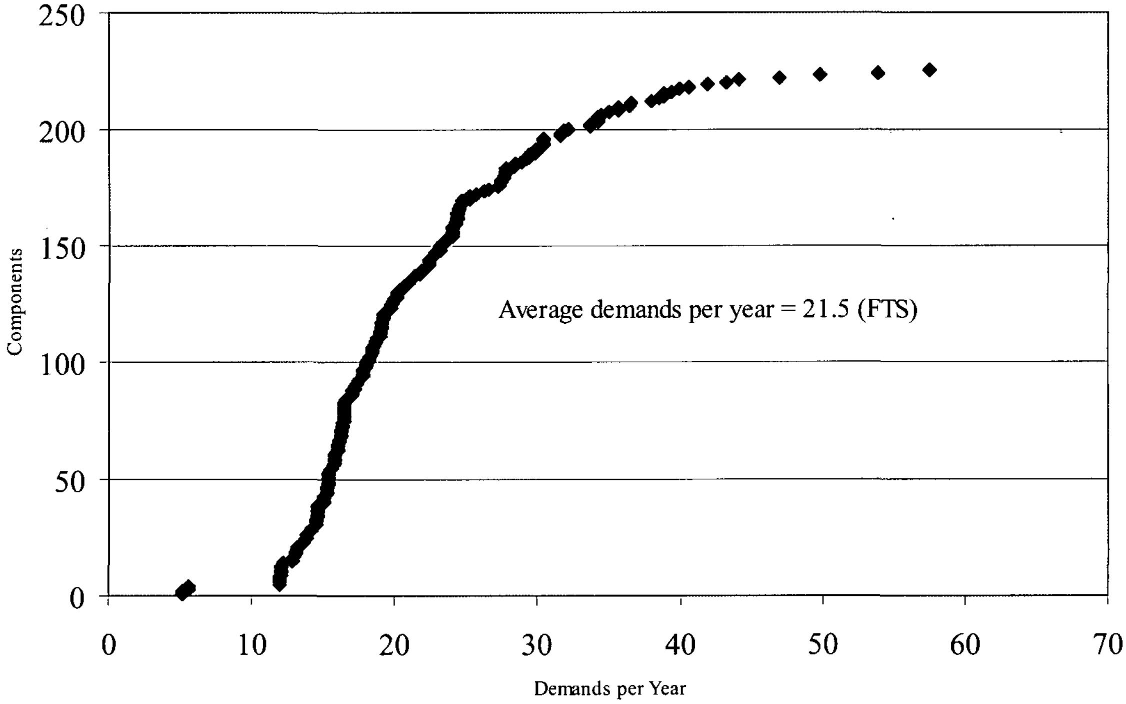

Figure A.2.17-1. EDG demands per year distribution.

Figure A.2.17-2 shows the range of run hours per demand in the EDG data set. The range is from approximately 1 hour/demand to 8 hours/demand. The average is 3.7 hours/demand.

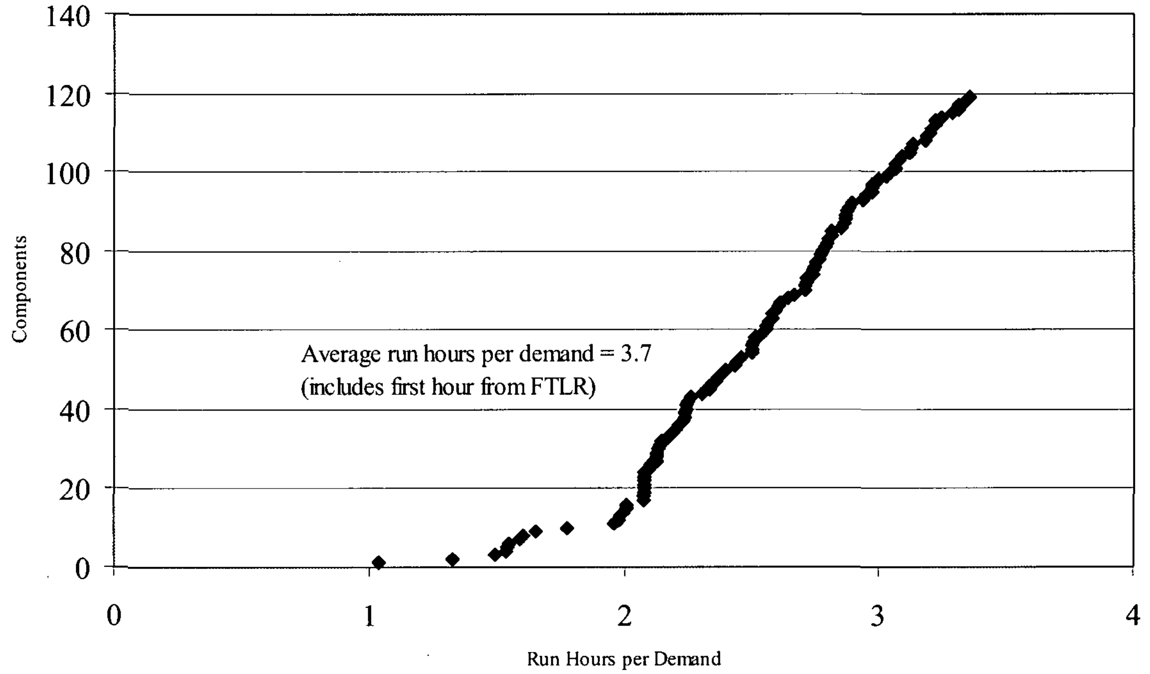

Figure A.2.17-2. EDG run hours per demand distribution.

A.2.17.3 Data Analysis

The EDG data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.17-4. The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.17-3, only 30.2% of the EDGs experienced a FTS over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 69.8% portion of the distribution, and non-zero values above 69.8%.

Table A.2.17-4. Empirical distributions of MLEs for p and λ for EDGs.

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

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in
Table A.2.17-5.

Table A.2.17-5. Fitted distributions for p and λ for EDGs.

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

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

A.2.17.4 Industry-Average Baselines

Table A.2.17-6 lists the selected industry distributions of p and λ for the EDG failure modes. For all three failure modes, the data sets were sufficient (Section A.1) for empirical Bayes analyses to be performed. Therefore, the industry-average distributions are based on the empirical Bayes analysis results at the plant level. These industry-average failure rates do not account for any recovery. However, a limited review of the failures indicates that possibly only 10 to 20% could be easily recovered within minutes.

Table A.2.17-6. Selected industry distributions of p and λ for EDGs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.17-7 shows the rounded values for the EDG failure modes.

Table A.2.17-7. Selected industry distributions of p and λ for EDGs (after rounding).

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

A.2.17.5 Breakdown by System

The EDGs discussed above are within the emergency power system. Additional EDGs not covered in the data discussed above are the HPCS EDGs. EDG UR results (Jeffreys means of system data) are compared with the HPCS EDG results in Table A.2.17-8. There were insufficient data in EPIX to present results for SBO EDGs.

Table A.2.17-8. EDG p and λ by system.

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

A.2.18 Explosive-Operated Valve (EOV) Data Sheet

A.2.18.1 Component Description

The explosive-operated valve (EOV) component boundary includes the valve and local instrumentation and control circuitry. The failure mode for EOV is listed in Table A.2.18-1.

Table A.2.18-1. EOV failure modes.

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

A.2.18.2 Data Collection and Review

Data for EOV UR baseline was obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. There are 57 EOVs from 26 plants in the data originally gathered by RADS. After analyzing the original data, there were no FTO failures, so the data set was expanded to 1997– 2004 for FTO failure mode (see Section A.1). After removing data without demand information (see Section A.1) there were 55 components in 26 plants. The systems included in the EOV data collection are listed in Table A.2.18-2 with the number of components included with each system.

Table A.2.18-2. EOV systems.

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

The EOV data set obtained from RADS was further reduced to include only those EOVs with ≤ 20 demands/year (≤ 160 demands over 8 y). See Section A.1 for a discussion concerning this decision to limit certain component populations. Table A.2.18-3 summarizes the data used in the EOV analysis.

Table A.2.18-3. EOV unreliability data.

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

Figure A.2.18-1 shows the range of valve demands per year in the EOV data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 10. The average for the data set is 1.1 demands/year.

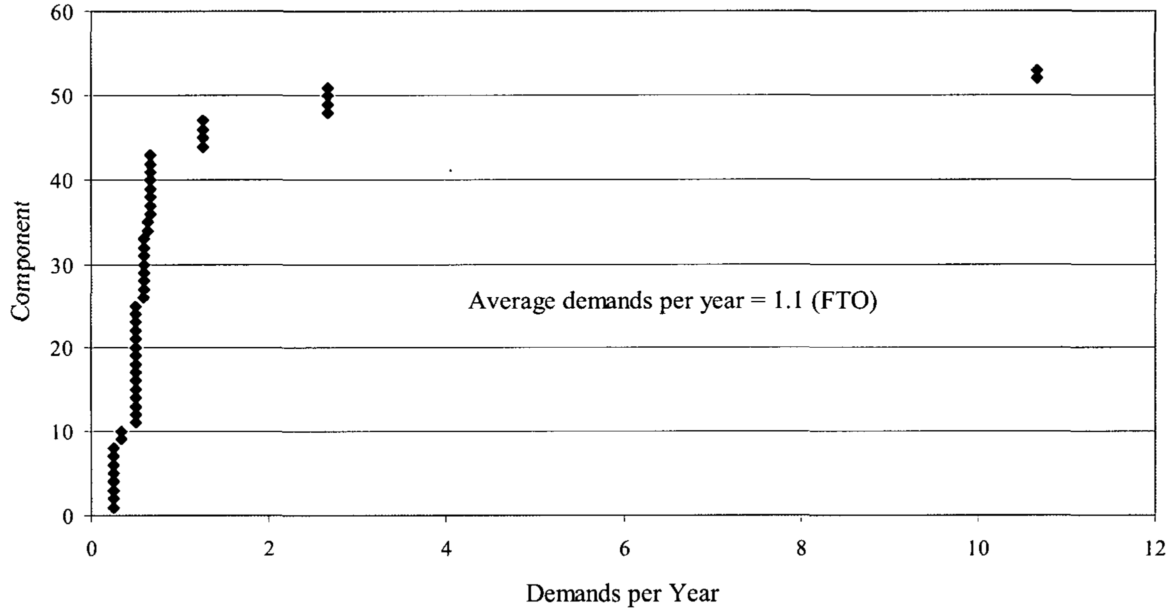

Figure A.2.18-1. EOV demands per year distribution.

A.2.18.3 Data Analysis

The EOV data can be examined at the component, plant, or industry level. However, with zero failures, all maximum likelihood estimates (MLEs), which are failures/demands (or hours), are zero. Results for all three levels are presented in Table A.2.18-4.

Table A.2.18-4. Empirical distributions of MLEs for p and λ for EOVs.

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

Because of no failures, no empirical Bayes analyses were performed. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table A.2.18-5.

Table A.2.18-5. Fitted distributions for p and λ for EOVs.

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

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

A.2.18.4 Industry-Average Baselines

Table A.2.18-6 lists the industry-average failure rate distribution for the EOV FTO failure mode. The data set was insufficient (see Section A.1) for empirical Bayes analyses to be performed. A SCNID analysis was performed to provide a failure rate distribution. Note that this distribution is based on zero failures and few demands and may be conservatively high. This industry-average failure rate does not account for any recovery.

Table A.2.18-6. Selected industry distributions of p and λ for EOVs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.18-7 shows the rounded value for EOV FTO.

Table A.2.18-7. Selected industry distributions of p and λ for EOVs (after rounding).

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

A.2.18.5 Breakdown by System

The EOVs are used only in the SLC system.

A.2.19 Fan (FAN) Data Sheet

A.2.19.1 Component Description

The fan (FAN) boundary includes the fan, motor, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for FAN are listed in Table A.2.19-1.

Table A.2.19-1. FAN failure modes.

Operation	Failure Mode	Parameter	Units	Description
Standby	FTS	p	-	Failure to start
	FTR≤1H	λ	1/h	Failure to run for 1 h
	FTR>1H	λ	1/h	Fail to run beyond 1 h
Running/Alternating	FTS	p	-	Failure to start
	FTR	λ	1/h	Fail to run

A.2.19.2 Data Collection and Review

Data for FAN UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. There are 520 FANs from 65 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1) there were 510 components in 64 plants. These data were then further partitioned into standby and running/alternating components. The systems and operational status included in the FAN data collection are listed in Table A.2.19-2 with the number of components included with each system.

Table A.2.19-2. FAN systems.

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

The data review process is described in detail in Section A.1. Table A.2.19-3 summarizes the data obtained from EPIX and used in the FAN analysis.

Table A.2.19-3. FAN unreliability data.

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

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

Figure A.2.19-1a shows the range of start demands per year in the standby FAN data set. The start demands per year range from approximately 1 to 104. The average for the data set is 20.2 demands/year. Figure A.2.19-1b shows the range of start demands per year in the running FAN data set. The demands per year range from approximately 1 to 150. The average for the data set is 20.5 demands/year.

Figure A.2.19-2a shows the range of run hours per demand in the standby FAN data set. The run hours per demand range is from approximately 1 hour/demand to 50 hours/demand. The average is 5.9 hours/demand. Figure A.2.19-2b shows the range of run hours per demands in the running FAN data set. The range is from approximately 12 hours/demand to 26,281 hours/demand. The average is 2123.6 hours/demand.

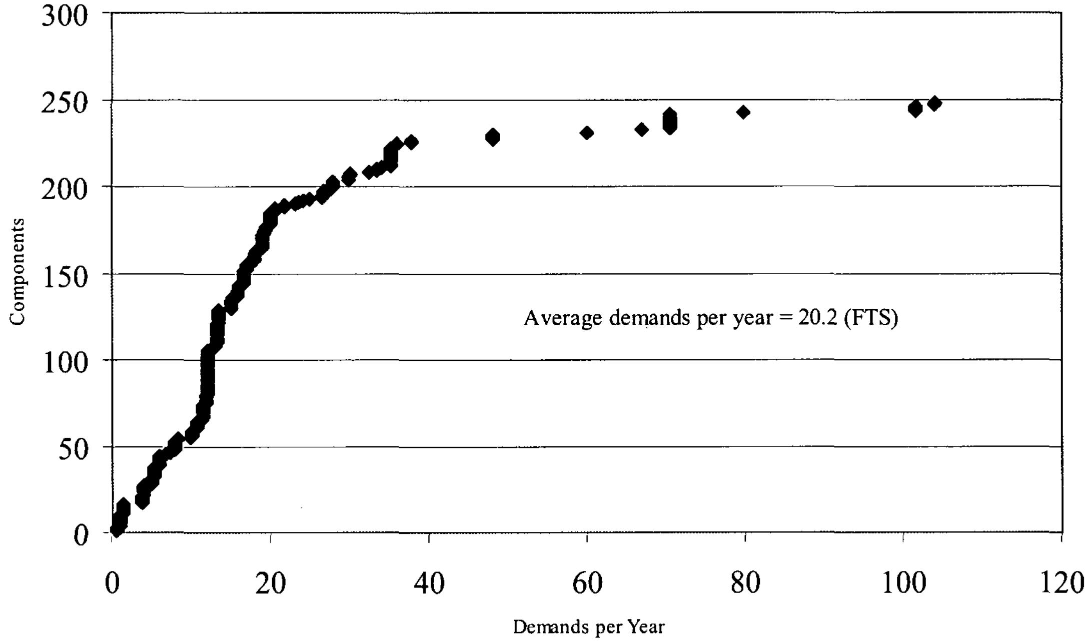

Figure A.2.19-1a. Standby FAN demands per year distribution.

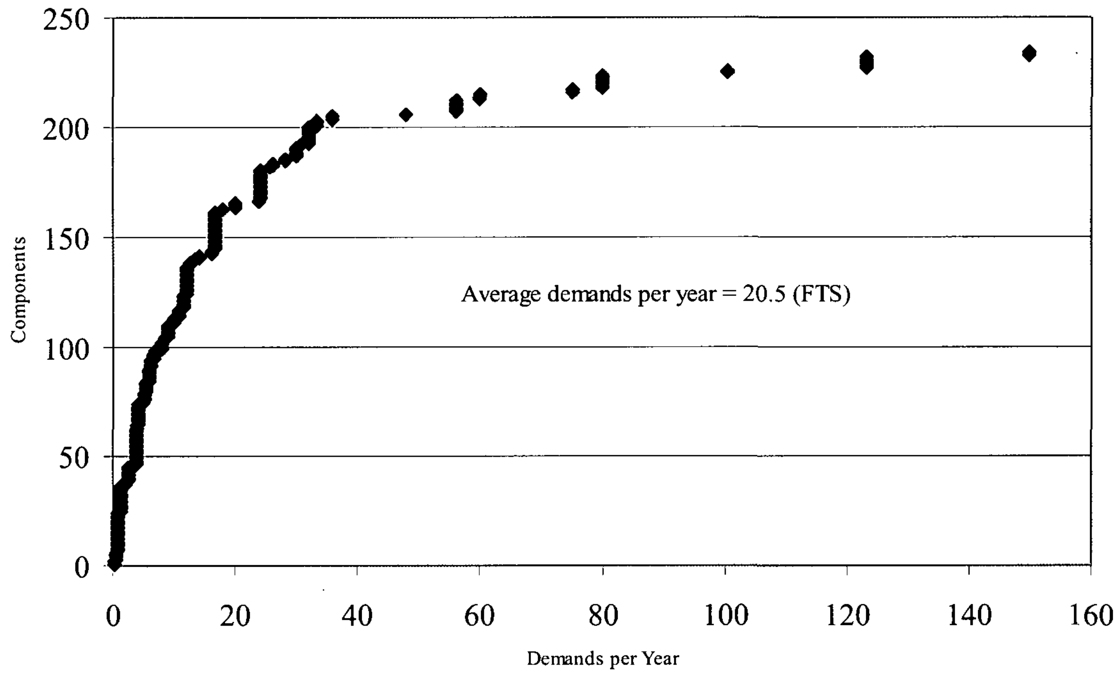

Figure A.2.19-1b. Running/alternating FAN demands per year distribution.

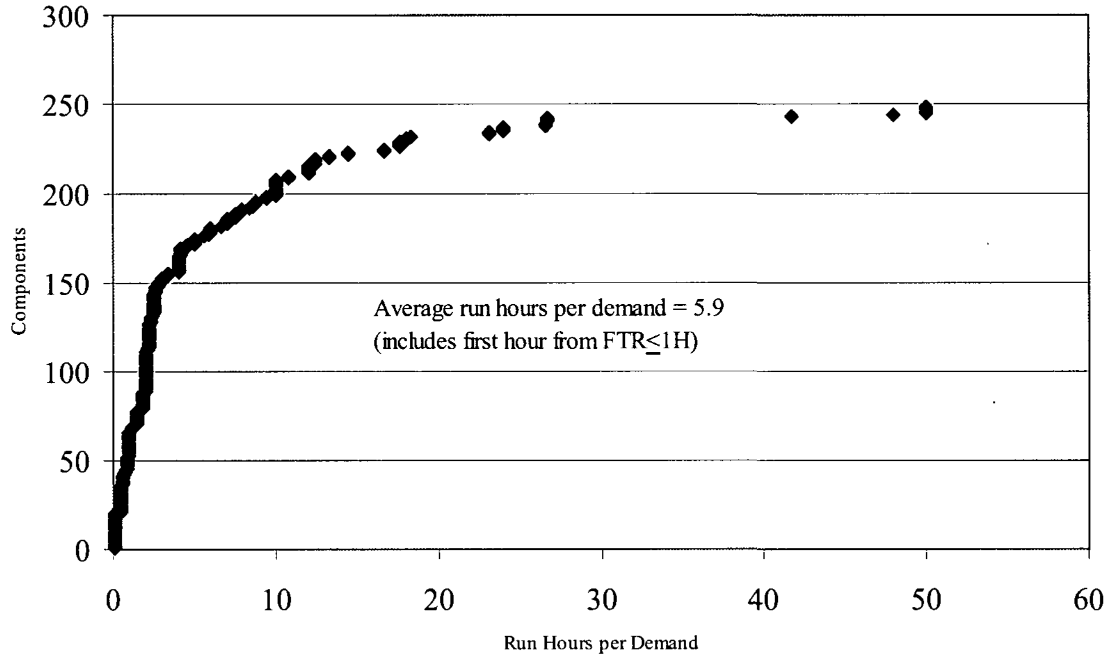

Figure A.2.19-2a. Standby FAN run hours per demand distribution.

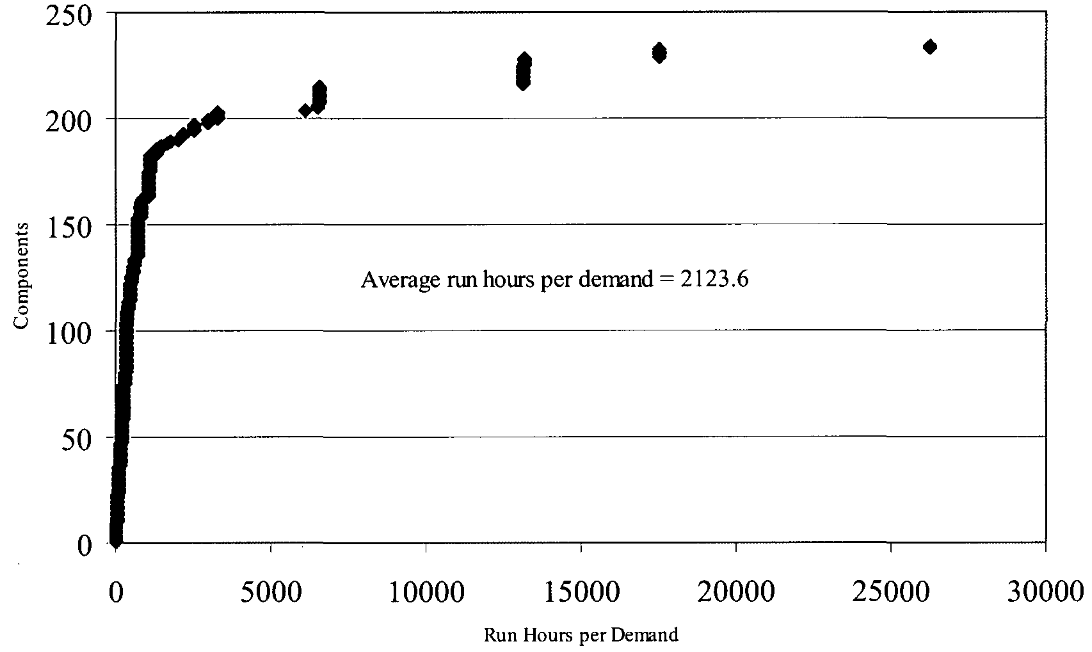

Figure A.2.19-2b. Running/alternating FAN run hours per demand distribution.

A.2.19.3 Data Analysis

The FAN data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.19-4.

Table A.2.19-4. Empirical distributions of MLEs for p and λ for FANs.

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

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.19-3, only 9.7% of the FANs experienced a FTS over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 90.3% portion of the distribution, and non-zero values above 90.3%.

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.19-5 for FANs.

Table A.2.19-5. Fitted distributions for p and λ for FANs.

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

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

A.2.19.4 Industry-Average Baselines

Table A.2.19-6 lists the industry-average failure rate distributions. For four of the five failure modes, the data sets were sufficient (Section A.1) for empirical Bayes analyses to be performed. For these failure modes, the industry-average distributions are based on the empirical Bayes analysis results at the plant level. However, two of the results indicated values for α less than 0.3. In those cases a lower bound value of 0.3 was used (see Section A.1). For FTR>1H, the empirical Bayes did not converge but indicated little variation between plants. For that failure mode, a Bayesian update of the Jeffreys noninformative prior is recommended. These industry-average failure rates do not account for any recovery.

Table A.2.19-6. Selected industry distributions of p and λ for FANs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.19-7 shows the rounded values for the FAN failure modes.

Table A.2.19-7. Selected industry distributions of p and λ for FANs (after rounding).

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

A.2.19.5 Breakdown by System

FAN UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.19-8. Results are shown only for the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.19-8. FAN p and λ by system.

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

A.2.20 Filter (FLT) Data Sheet

A.2.20.1 Component Description

The filter (FLT) boundary includes the filter. The failure mode for the FLT is listed in Table A.2.20-1.

Table A.2.20-1. FLT failure modes.

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

A.2.20.2 Data Collection and Review

Data for FLT UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1997–2004. Systems covered in the data search were chosen to ensure that filters were in clean water systems. There are 217 FLTs from 23 plants in the data originally gathered from EPIX. The systems and operational status included in the FLT data collection are listed in Table A.2.20-2 with the number of components included with each system.

Table A.2.20-2. FLT systems.

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

The data review process is described in detail in Section A.1. Table A.2.20-3 summarizes the data obtained from EPIX and used in the FLT analysis.

Table A.2.20-3. FLT unreliability data.

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

A.2.20.3 Data Analysis

The FLT data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.20-4.

Table A.2.20-4. Empirical distributions of MLEs for p and λ for FLTs.

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

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.20-3, only 0.5% of the FLTs experienced a PG over the period 1997–2004, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 99.5% portion of the distribution, and non-zero values above 99.5%.

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.20-5 for FLTs.

Table A.2.20-5. Fitted distributions for p and λ for FLTs.

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

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

A.2.20.4 Industry-Average Baselines

Table A.2.20-6 lists the industry-average failure rate distribution.

Table A.2.20-6. Selected industry distributions of p and λ for FLTs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.20-7 shows the rounded values for the FLT failure mode.

Table A.2.20-7. Selected industry distributions of p and λ for FLTs (after rounding).

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

A.2.20.5 Breakdown by System

FLT UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.20-8. Results are shown only for the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.20-8. FLT p and λ by system.

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

A.2.21 Hydraulic-Operated Damper (HOD) Data Sheet

A.2.21.1 Component Description

The hydraulic-operated damper (HOD) component boundary includes the valve, the valve operator, and local instrumentation and control circuitry. The failure modes for HOD are listed in Table A.2.21-1.

Table A.2.21-1. HOD failure modes.

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

A.2.21.2 Data Collection and Review

Data for HOD UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. There are 159 HODs from nine plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1) there were 159 components in nine plants. The systems included in the HOD data collection are listed in Table A.2.21-2 with the number of components included with each system.

Table A.2.21-2. HOD systems.

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

The HOD data set obtained from RADS was further reduced to include only those HODs with ≤ 20 demands/year. See Section A.1 for a discussion concerning this decision to limit certain component populations. Table A.2.21-3 summarizes the data used in the HOD analysis. Note that SO hours are calendar hours.

Table A.2.21-3. HOD unreliability data.

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

Figure A.2.21-1 shows the range of valve demands per year in the HOD data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 17. The average for the data set is 9.5. demands/year.

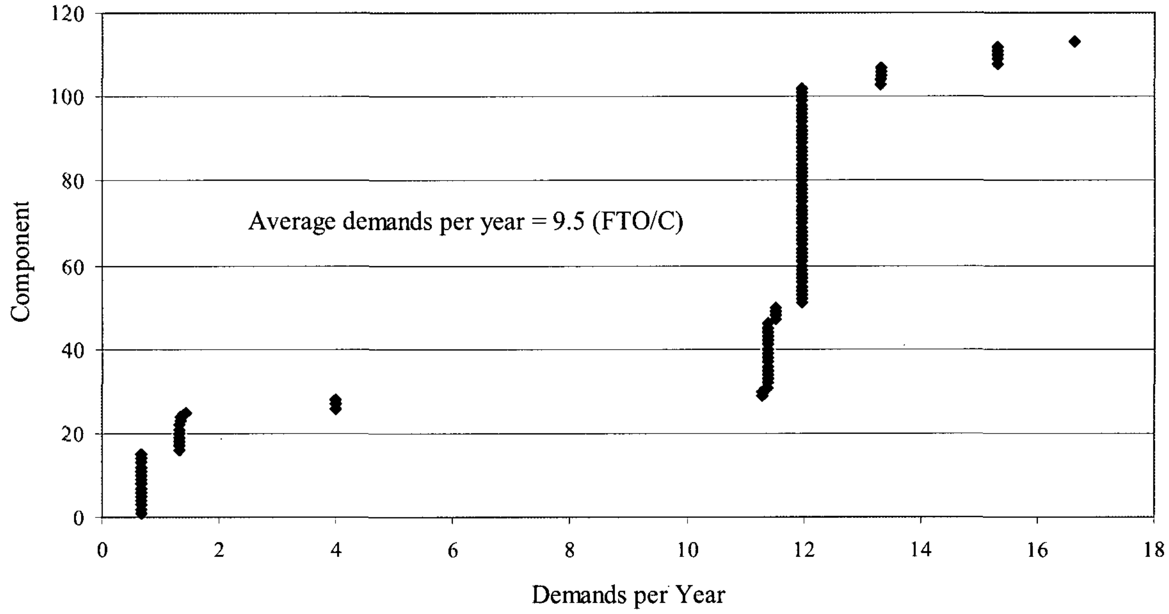

Figure A.2.21-1. HOD demands per year distribution.

A.2.21.3 Data Analysis

The HOD data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.21-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.21-3, only 6.2% of the HODs experienced a FTO/C over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 93.8% portion of the distribution, and non-zero values above 93.8%.

Table A.2.21-4. Empirical distributions of MLEs for p and λ for HODs.

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

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table A.2.21-5.

Table A.2.21-5. Fitted distributions for p and λ for HODs.

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

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

A.2.21.4 Industry-Average Baselines

Table A.2.21-6 lists the selected industry distributions of p and λ for the HOD failure modes. For the FTO/C failure mode, the data set was sufficient (Section A.1) for empirical Bayes analyses to be performed. For this failure mode, the industry-average distribution is based on the empirical Bayes analysis results at the plant level. However, the result indicated an α value less than 0.3. The lower limit of 0.3 was assumed (see Section A.1). The industry-average distributions for the SO failure mode are not sufficient for the empirical Bayes method; therefore a SCNID analysis was performed to provide a failure rate distribution. These industry-average failure rates do not account for any recovery.

Table A.2.21-6. Selected industry distributions of p and λ for HODs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.21-7 shows the rounded values for the HOD failure modes.

Table A.2.21-7. Selected industry distributions of p and λ for HODs (after rounding).

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

A.2.21.5 Breakdown by System

HOD UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.21-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.21-8. HOD p and λ by system.

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

A.2.22 Hydraulic-Operated Valve (HOV) Data Sheet

A.2.22.1 Component Description

The hydraulic-operated valve (HOV) component boundary includes the valve, the valve operator, and local instrumentation and control circuitry. The failure modes for HOV are listed in Table A.2.22-1.

Table A.2.22-1. HOV failure modes.

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

A.2.22.2 Data Collection and Review

Most of the data for HOV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. The ELS and ILS data are from RADS, covering 1997–2004. There are 607 HOVs from 60 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1) there were 606 components in 60 plants. The systems included in the HOV data collection are listed in Table A.2.22-2 with the number of components included with each system.

Table A.2.22-2. HOV systems.

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

The HOV data set obtained from RADS was further reduced to include only those HOVs with ≤ 20 demands/year. See Section A.1 for a discussion concerning this decision to limit certain component populations. Table A.2.22-3 summarizes the data used in the HOV analysis. Note that the hours for SO, ELS, and ILS are calendar hours. The FC failure mode is not supported by EPIX data.

Table A.2.22-3. HOV unreliability data.

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

Figure A.2.22-1 shows the range of valve demands per year in the HOV data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 20. The average for the data set is 4.2. demands/year.

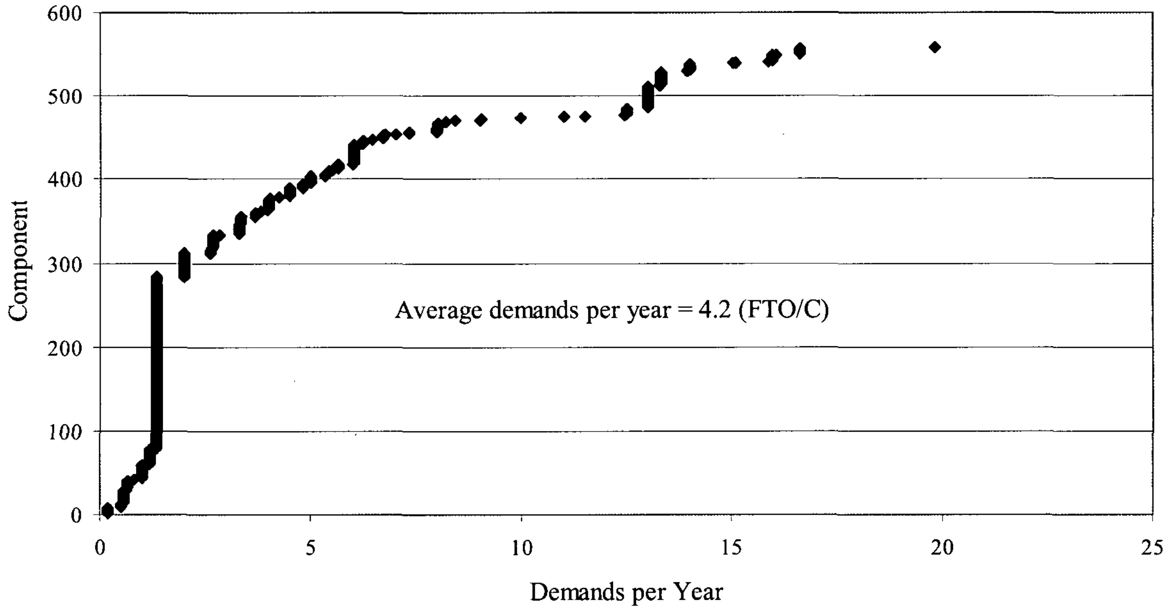

Figure A.2.22-1. HOV demands per year distribution.

A.2.22.3 Data Analysis

The HOV data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.22-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.22-3, only 1.4% of the HOVs experienced a FTO/C over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 98.6% portion of the distribution, and non-zero values above 98.6%.

Table A.2.22-4. Empirical distributions of MLEs for p and λ for HOVs.

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

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table A.2.22-5.

Table A.2.22-5. *Fitted distributions for p and λ for HOVs.*

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

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

A.2.22.4 Industry-Average Baselines

Table A.2.22-6 lists the selected industry distributions of p and λ for the HOV failure modes. For the FTO/C and SO failure modes, the data set was sufficient (see Section A.1) for empirical Bayes analyses to be performed. Therefore, the industry-average distribution is based on the empirical Bayes analysis results at the plant level for FTO/C and SO. However, the FTO/C and SO analyses resulted in α values less than 0.3. Therefore, the lower bound of 0.3 was assumed (see Section A.1). The industry-average distributions for ILS and ELS are not sufficient (Section A.1) for the empirical Bayes method; therefore a SCNID analysis was performed to provide a failure rate distribution. These industry-average failure rates do not account for any recovery. The selected ELL mean is the ELS mean multiplied by 0.07, with an assumed α of 0.3. The selected ILL mean is the ILS mean multiplied by 0.02, with an assumed α of 0.3. The 0.07 and 0.02 multipliers are based on limited EPIX data for large leaks as explained in Section A.1.

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

Table A.2.22-6. Selected industry distributions of p and λ for HOVs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.22-7 shows the rounded values for the HOV.

Table A.2.22-7. Selected industry distributions of p and λ for HOVs (after rounding).

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

A.2.22.5 Breakdown by System

HOV UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.22-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.22-8. HOV p and λ by system.

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

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

A.2.23 Hydro Turbine Generator (HTG) Data Sheet

A.2.23.1 Component Description

The hydro turbine generator (HTG) boundary includes the turbine, generator, circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for HTG are listed in Table A.2.23-1.

Table A.2.23-1. HTG failure modes.

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

A.2.23.2 Data Collection and Review

Data for HTG UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1997–2004. The extended data period was chosen since there are so few components in RADS. In addition, the Oconee plant identified HTG failures during this period that had not yet been entered into EPIX. There are 2 HTGs from one plant in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1) there were 2 components in one plant. The systems and operational status included in the HTG data collection are listed in Table A.2.23-2 with the number of components included with each system.

Table A.2.23-2. HTG systems.

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

The data review process is described in detail in Section A.1. Table A.2.23-3 summarizes the data obtained from EPIX and used in the HTG analysis.

Table A.2.23-3. HTG unreliability data.

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

A.2.23.3 Data Analysis

Since there are only two components at two units, the MLE distributions provide little information. In addition, the empirical Bayes analysis cannot be performed. Therefore, only the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table A.2.23-4 for HTGs. These results were used to develop the industry-average distributions.

Table A.2.23-4. Fitted distributions for p and λ for HTGs.

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

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

A.2.23.4 Industry-Average Baselines

Table A.2.23-5 lists the industry-average failure rate distributions. The industry-average distribution for all of the failure modes is not sufficient (Section A.1) for the empirical Bayes method; therefore a SCNID analysis was performed to provide a failure rate distribution. These industry-average failure rates do not account for any recovery.

Table A.2.23-5. Selected industry distributions of p and λ for HTGs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.23-6 shows the rounded values for the HTG failure modes.

Table A.2.23-6. Selected industry distributions of p and λ for HTGs (after rounding).

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

A.2.23.5 Breakdown by System

The HTG is included only in the emergency power system.

A.2.24 Heat Exchanger (HTX) Data Sheet

A.2.24.1 Component Description

The heat exchanger (HTX) boundary includes the heat exchanger shell and tubes. The failure modes for HTX are listed in Table A.2.24-1.

Table A.2.24-1. HTX failure modes.

Operation	Failure Mode	Parameter	Units	Description
All	PG	λ	1/h	Plug
	ELS (tube)	λ	1/h	External leak of the heat exchanger tube side
	ELS (shell)	λ	1/h	External leak of the heat exchanger shell side

A.2.24.2 Data Collection and Review

Data for HTX UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. (ELS data cover 1997–2004.) Only HTXs in the component cooling water (CCW) and residual heat removal systems were included in the data search. There are 713 HTXs from 102 plants in the data originally gathered from EPIX. The systems and operational status included in the HTX data collection are listed in Table A.2.24-2 with the number of components included with each system.

Table A.2.24-2. HTX systems.

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

The data review process is described in detail in Section A.1. Table A.2.24-3 summarizes the data obtained from EPIX and used in the HTX analysis.

Table A.2.24-3. HTX unreliability data.

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

A.2.24.3 Data Analysis

The HTX data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.24-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.24-3, only 15.7% of the HTXs experienced a PG over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 84.3% portion of the distribution, and non-zero values above 84.3%.

Table A.2.24-4. Empirical distributions of MLEs for p and λ for HTXs.

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

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.24-5.

Table A.2.24-5. Fitted distributions for p and λ for HTXs.

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

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

A.2.24.4 Industry-Average Baselines

Table A.2.24-6 lists the selected industry distributions of p and λ for the HTX failure modes. For the PG and ELS (tube) failure modes, the data sets were sufficient (see Section A.1) for empirical Bayes analyses to be performed. Therefore, the industry-average distributions are based on the empirical Bayes analysis results at the plant level for PG and ELS (tube). However, the industry-average distribution for ELS (shell) is not sufficient (Section A.1) for the empirical Bayes method; therefore, a SCNID analysis was performed to provide a failure rate distribution.

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

Table A.2.24-6. Selected industry distributions of p and λ for HTXs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.24-7 shows the rounded values for the HTX failure modes.

Table A.2.24-7. Selected industry distributions of p and λ for HTXs (after rounding).

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

A.2.24.5 Breakdown by System

HTX UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.24-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.24-8. HTX p and λ by system.

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

A.2.25 Inverter (INV) Data Sheet

A.2.25.1 Component Description

The inverter (INV) boundary includes the inverter unit. The failure mode for INV is listed in Table A.2.25-1.

Table A.2.25-1. INV failure modes.

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

A.2.25.2 Data Collection and Review

Data for INV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. There are 638 INVs from 98 plants in the data originally gathered from EPIX. The systems and operational status included in the INV data collection are listed in Table A.2.25-2 with the number of components included with each system.

Table A.2.25-2. INV systems.

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

Table A.2.25-3 summarizes the data obtained from EPIX and used in the INV analysis. Note that the hours are calendar hours.

Table A.2.25-3. INV unreliability data.

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

A.2.25.3 Data Analysis

The INV data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.25-4. The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.25-3, only 0.3% of the INVs experienced a FTOP over the period 1997–2004, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 99.7% portion of the distribution, and non-zero values above 99.7%.

Table A.2.25-4. Empirical distributions of MLEs for p and λ for INVs.

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

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.25-5.

Table A.2.25-5. Fitted distributions for p and λ for INVs.

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

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

A.2.25.4 Industry-Average Baselines

Table A.2.25-6 lists the industry-average failure rate distributions.

Table A.2.25-6. Selected industry distributions of p and λ for INVs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.25-7 shows the rounded values for the INV failure mode.

Table A.2.25-7. Selected industry distributions of p and λ for INVs (after rounding).

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

A.2.25.5 Breakdown by System

INV UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.25-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.25-8. INV p and λ by system.

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

A.2.26 Motor-Driven Compressor (MDC) Data Sheet

A.2.26.1 Component Description

The motor-driven compressor (MDC) boundary includes the compressor, motor, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for MDC are listed in Table A.2.26-1.

Table A.2.26-1. MDC failure modes.

Operation	Failure Mode	Parameter	Units	Description
Standby	FTS	p	-	Failure to start
	FTR≤1H	λ	1/h	Failure to run for 1 h
	FTR>1H	λ	1/h	Fail to run beyond 1 h
Running/Alternating	FTS	p	-	Failure to start
	FTR	λ	1/h	Fail to run

A.2.26.2 Data Collection and Review

Data for MDC UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. There are 143 MDCs from 46 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1) there were 132 components in 46 plants. These data were then further partitioned into standby and running/alternating components. The systems and operational status included in the MDC data collection are listed in Table A.2.26-2 with the number of components included with each system.

Table A.2.26-2. MDC systems.

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

The data review process is described in detail in Section A.1. Table A.2.26-3 summarizes the data obtained from EPIX and used in the MDC analysis. Note that components with > 200 demands/year were removed.

Table A.2.26-3. MDC unreliability data.

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

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

Figure A.2.26-1a shows the range of start demands per year in the standby MDC data set. The start demands per year range from approximately 1 to 102. The average for the data set is 13.0 demands/year. Figure A.2.26-1b shows the range of start demands per year in the running MDC data set. The demands per year range from approximately 1 to 120. The average for the data set is 23.3 demands/year.

Figure A.2.26-2a shows the range of run hours per demand in the standby MDC data set. The run hours per demand range is from approximately 1 hour/demand to 167 hours/demand. The average is 19.8 hours/demand. Figure A.2.26-2b shows the range of run hours per demands in the running MDC data set. The range is from approximately 29 hours/demand to 17,527 hours/demand. The average is 797.0 hours/demand.

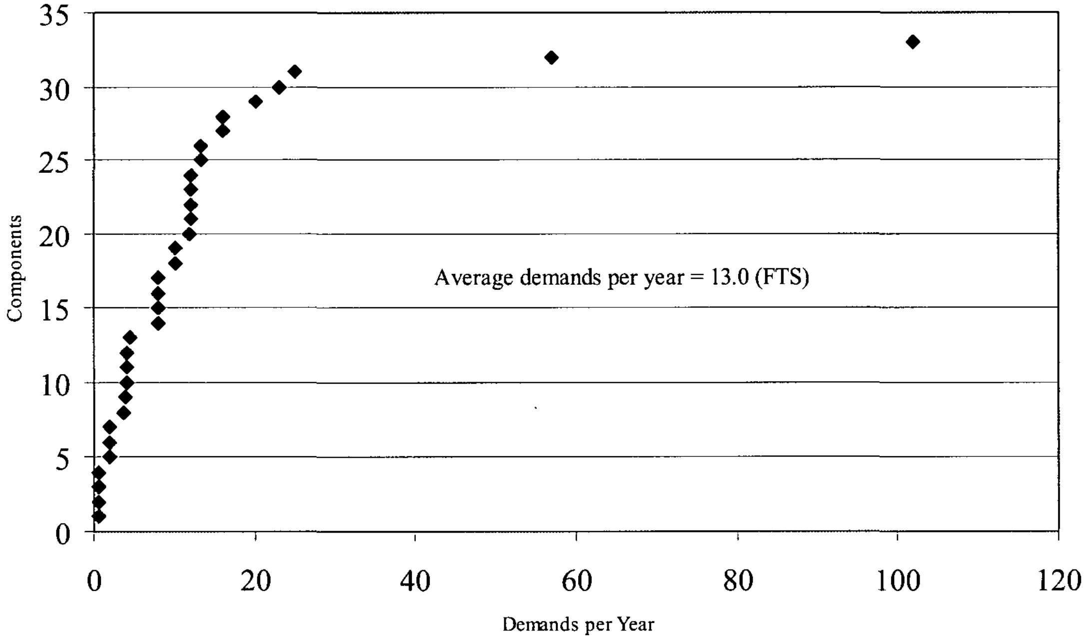

Figure A.2.26-1a. Standby MDC demands per year distribution.

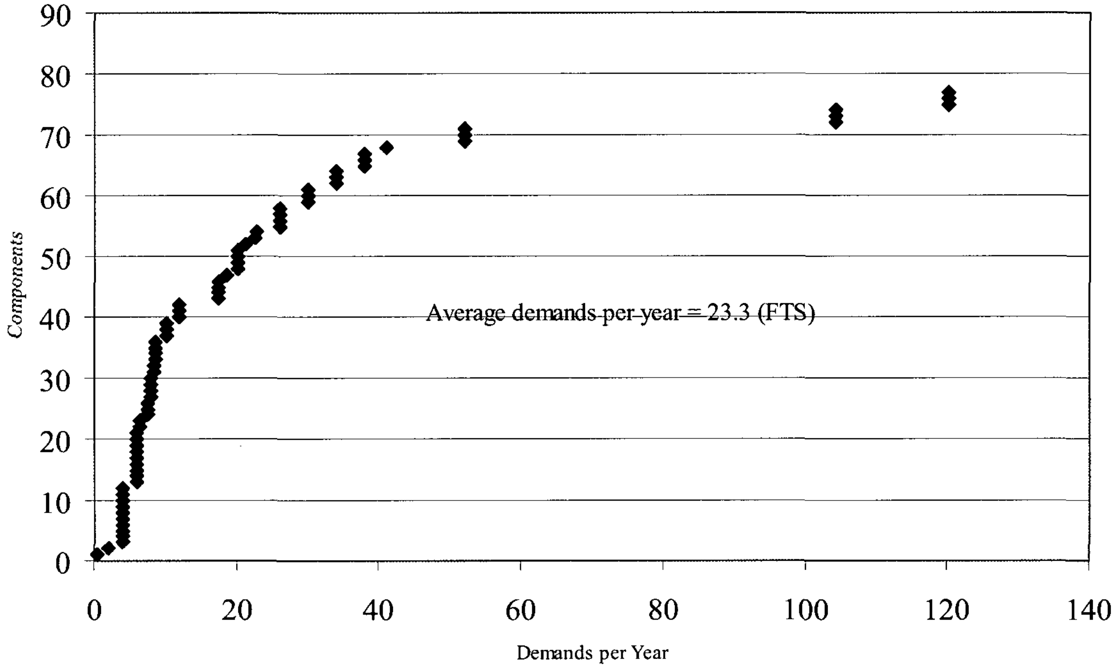

Figure A.2.26-1b. Running/alternating MDC demands per year distribution.

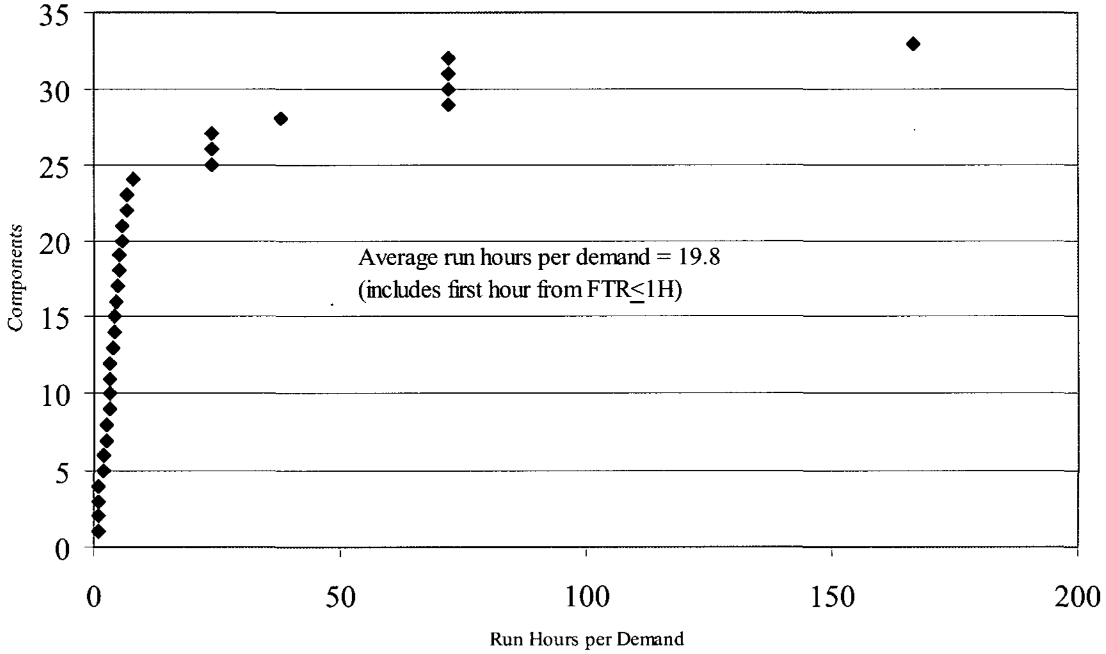

Figure A.2.26-2a. Standby MDC run hours per demand distribution.

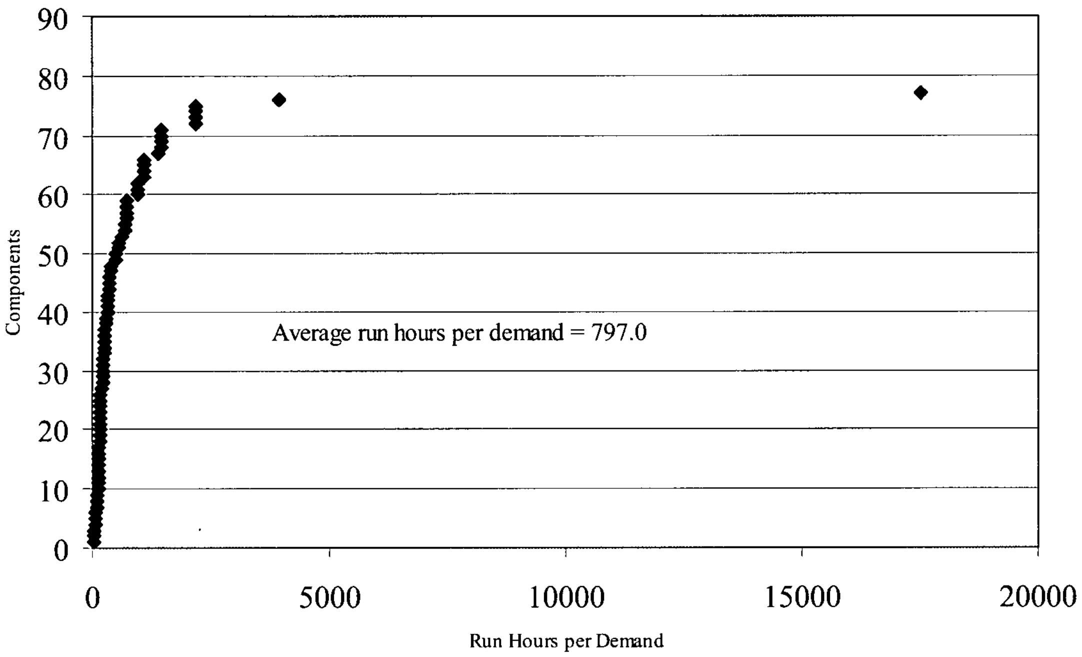

Figure A.2.26-2b. Running/alternating MDC run hours per demand distribution.

A.2.26.3 Data Analysis

The MDC data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.26-4.

Table A.2.26-4. Empirical distributions of MLEs for p and λ for MDCs.

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

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.26-3, only

21.2% of the MDCs experienced a FTS over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 78.8% portion of the distribution, and non-zero values above 78.8%.

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.26-5 for MDCs.

Table A.2.26-5. Fitted distributions for p and λ for MDCs.

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

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

A.2.26.4 Industry-Average Baselines

Table A.2.26-6 lists the industry-average failure rate distributions. For all five failure modes, the data sets were sufficient (Section A.1) for empirical Bayes analyses to be performed. For these failure modes, the industry-average distributions are based on the empirical Bayes analysis results at the plant level. However, because the standby FTR≤1H result indicated an α value less than 0.3, the lower bound of 0.3 was assumed (see Section A.1). These industry-average failure rates do not account for any recovery.

Table A.2.26-6. Selected industry distributions of p and λ for MDCs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.26-7 shows the rounded values for the MDC failure modes.

Table A.2.26-7. Selected industry distributions of p and λ for MDCs (after rounding).

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

A.2.26.5 Breakdown by System

MDC UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.26-8. Results are shown only the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.26-8. MDC p and λ by system.

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

A.2.27 Motor-Driven Pump (MDP) Data Sheet

A.2.27.1 Component Description

The motor-driven pump (MDP) boundary includes the pump, motor, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for MDP are listed in Table A.2.27-1.

Table A.2.27-1. MDP failure modes.

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

A.2.27.2 Data Collection and Review

Data for MDP UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002, except for the ELS data that cover 1997–2004. There are 1689 MDPs from 103 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1) there were 1660 components in 103 plants. These data were then further partitioned into standby and running/alternating components. The systems and operational status included in the MDP data collection are listed in Table A.2.27-2 with the number of components included with each system.

Table A.2.27-2. MDP systems.

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

Operation	System	Description	Number of Components		
			Initial	After Review	≤200 Demands per Year
	LPI	Low pressure injection	9	9	9
	MFW	Main feedwater	33	33	33
	NSW	Normal service water	3	3	3
	TBC	Turbine building cooling water	2	2	2
	Total		767	766	758

The data review process is described in detail in Section A.1. Components with > 200 demands/year were removed. Table A.2.27-3 summarizes the data obtained from EPIX and used in the MDP analysis. Note that the hours for ELS are calendar hours.

Table A.2.27-3. MDP unreliability data.

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

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

Figure A.2.27-1a shows the range of start demands per year in the standby MDP data set. The start demands per year range from approximately 1 to 160. The average for the data set is 18.5 demands/year. Figure A.2.27-1b shows the range of start demands per year in the running MDP data set. The demands per year range from approximately 1 (once per year) to 150. The average for the data set is 19.8 demands/year.

Figure A.2.27-2a shows the range of run hours per demand in the standby MDP data set. The run hours per demand range is from approximately 0 hours/demand to 360 hours/demand. The average is 12.1 hours/demand. Figure A.2.27-2b shows the range of run hours per demands in the running MDP data set. The range is from approximately 8 hours/demand to 12,165 hours/demand. The average is 1039.1 hours/demand.

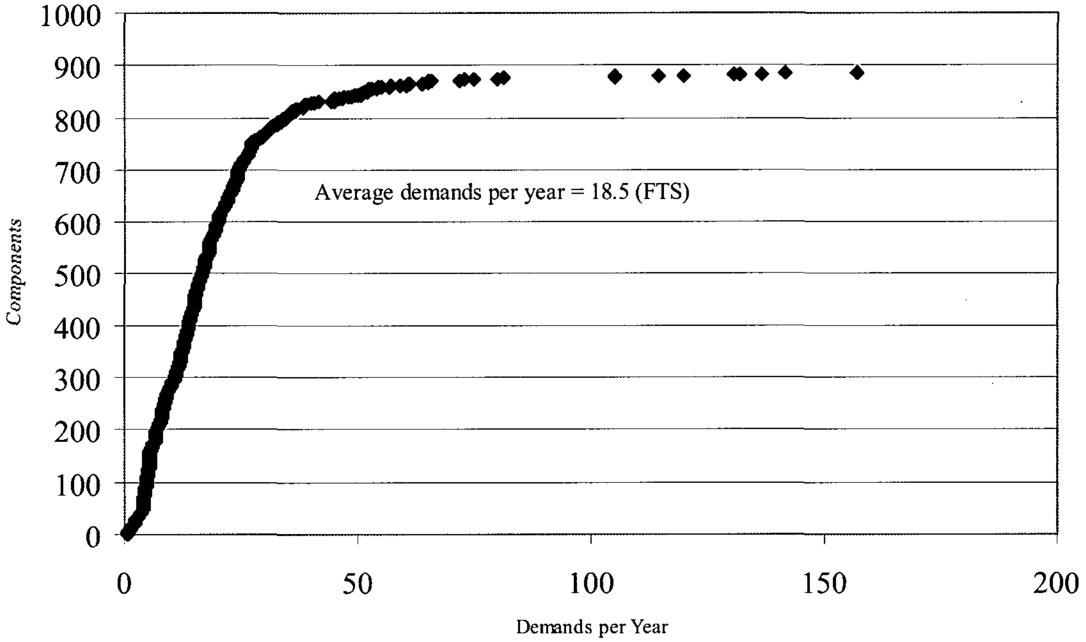

Figure A.2.27-1a. Standby MDP demands per year distribution.

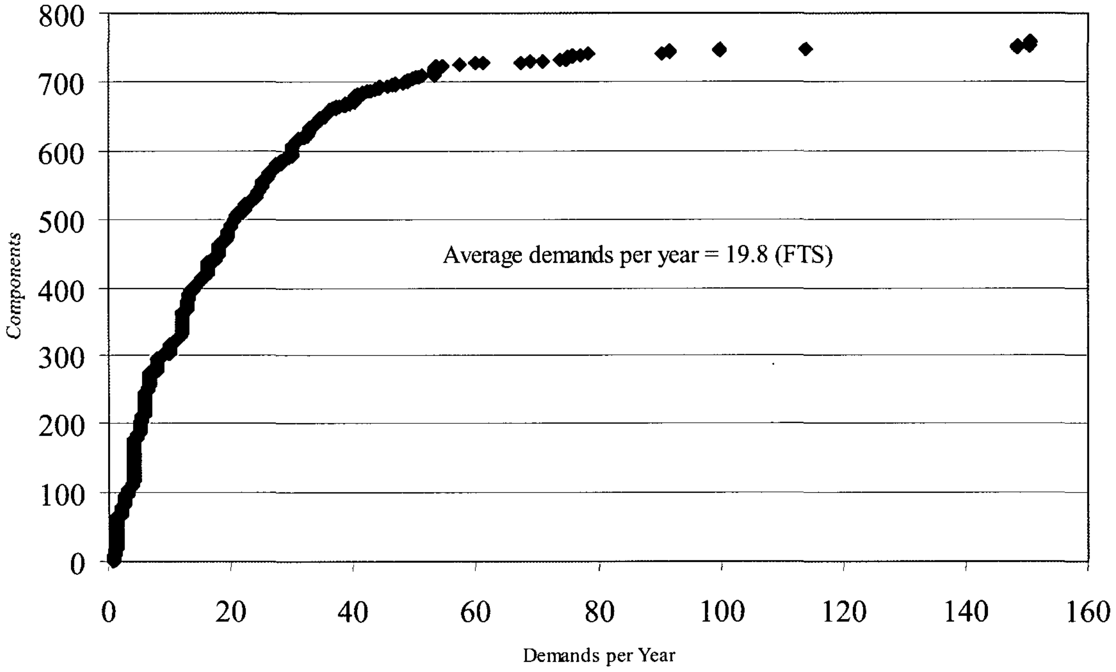

Figure A.2.27-1b. Running/alternating MDP demands per year distribution.

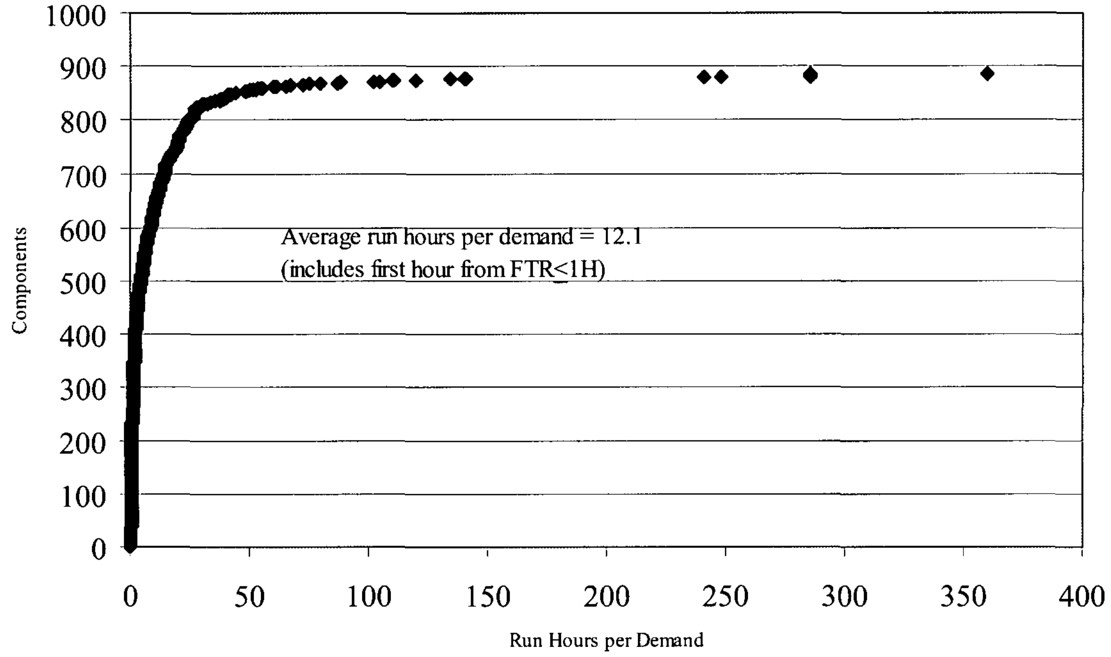

Figure A.2.27-2a. Standby MDP run hours per demand distribution.

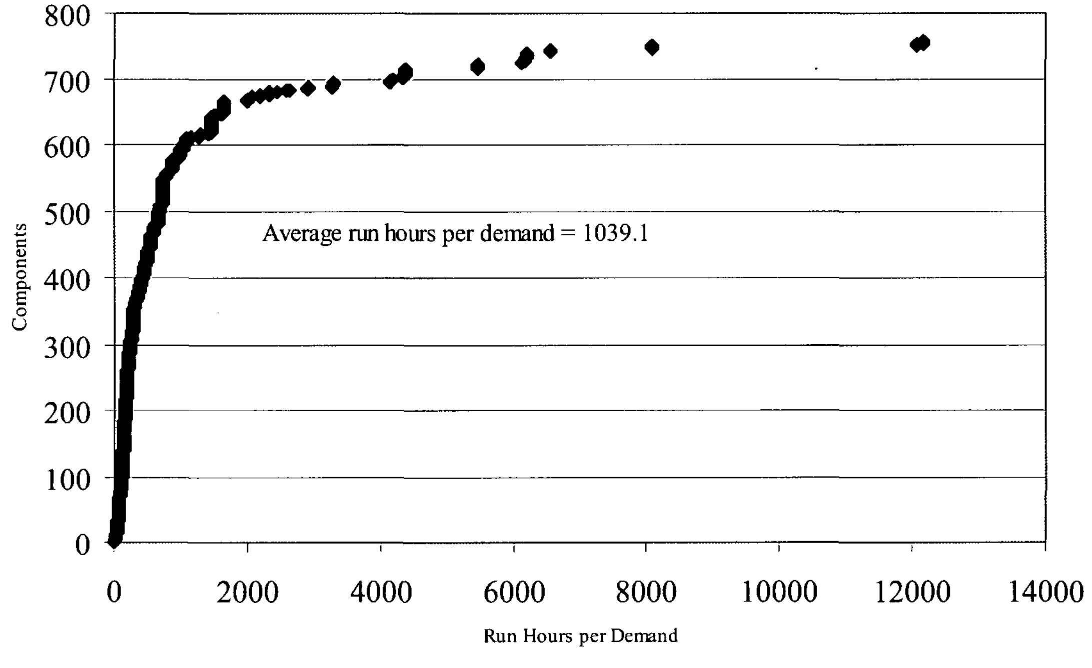

Figure A.2.27-2b. Running/alternating MDP run hours per demand distribution.

A.2.27.3 Data Analysis

The MDP data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.27-4.

Table A.2.27-4. Empirical distributions of MLEs for p and λ for MDPs.

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

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.27-3, only 10.2% of the MDPs experienced a FTS over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 89.8% portion of the distribution, and non-zero values above 89.8%.

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.27-5 for MDPs. These results were used to develop the industry-average distributions.

Table A.2.27-5. Fitted distributions for p and λ for MDPs.

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

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

A.2.27.4 Industry-Average Baselines

Table A.2.27-6 lists the selected industry distributions of p and λ for the MDP failure modes. For five of the seven failure modes, the data sets were sufficient for empirical Bayes analyses to be performed. For these failure modes, the industry-average distributions are based on the empirical Bayes analysis results at the plant level. However, the industry-average distribution for FTR>1H is not sufficient (Section A.1) for the empirical Bayes method; therefore a SCNID analysis was performed to provide a failure rate distribution. The selected ELL mean is the ELS mean multiplied by 0.07, with an assumed α of 0.3. The 0.07 multiplier is based on limited EPIX data for large leaks as explained in Section A.1. These industry-average failure rates do not account for any recovery.

Table A.2.27-6. Selected industry distributions of p and λ for MDPs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.27-7 shows the rounded values for the MDP failure modes.

Table A.2.27-7. Selected industry distributions of p and λ for MDPs (after rounding).

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

A.2.27.5 Breakdown by System

MDP UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.27-8. Results are shown only for the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.27-8. MDP p and λ by system.

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

Operation	System	FTS	FTR
Running/ Alternating	CCW	1.1E-03	2.8E-06
	CDS	2.7E-03	3.6E-06
	CRD	8.2E-03	8.6E-06
	CVC	2.1E-03	5.8E-06
	ESW	1.8E-03	5.1E-06
	HPI	2.2E-03	7.5E-06
	LCI	1.6E-03	-
	LPI	-	-
	MFW	2.2E-03	7.8E-06
	NSW	-	1.7E-05
	TBC	-	-

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

A.2.28 Motor-Operated Damper (MOD) Data Sheet

A.2.28.1 Component Description

The motor-operated damper (MOD) component boundary includes the valve, the valve operator, local circuit breaker, and local instrumentation and control circuitry. The failure modes for MOD are listed in Table A.2.28-1.

Table A.2.28-1. MOD failure modes.

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

A.2.28.2 Data Collection and Review

Data for MOD UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. There are 48 MODs from eight plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1) there were 48 components in eight plants. After analyzing the original data, there were no SO failures, so the data set was expanded to 1997– 2004 for the SO failure mode (see Section A.1). The systems included in the MOD data collection are listed in Table A.2.28-2 with the number of components included with each system.

Table A.2.28-2. MOD systems.

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

The MOD data set obtained from RADS was further reduced to include only those MODs with ≤ 20 demands/year. See Section A.1 for a discussion concerning this decision to limit certain component populations. Table A.2.28-3 summarizes the data used in the MOD analysis. Note that the hours for SO are calendar hours.

Table A.2.28-3. MOD unreliability data.

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

Figure A.2.28-1 shows the range of valve demands per year in the MOD data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 20. The average for the data set is 12.6. demands/year.

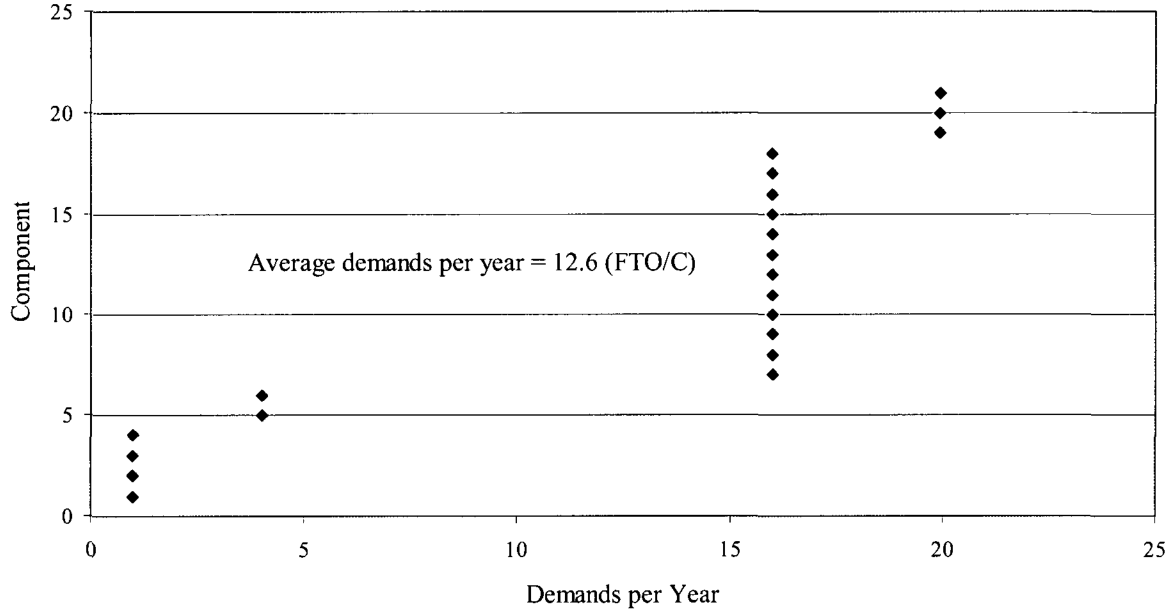

Figure A.2.28-1. MOD demands per year distribution.

A.2.28.3 Data Analysis

The MOD data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.28-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.28-4, only 4.8% of the MODs experienced a FTO/C over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 95.2% portion of the distribution, and non-zero values above 95.2%.

Table A.2.28-4. Empirical distributions of MLEs for p and λ for MODs.

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

With only one failure for FTO/C and no failures for SO, no empirical Bayes analyses were performed. However, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.28-5.

Table A.2.28-5. Fitted distributions for p and λ for MODs.

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

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

A.2.28.4 Industry-Average Baselines

Table A.2.28-6 lists the selected industry distributions of p and λ for the MOD failure modes. The industry-average distributions for the FTO/C and SO failure modes are not sufficient (Section A.1) for the empirical Bayes method; therefore a SCNID analysis was performed to provide a failure rate distribution. These industry-average failure rates do not account for any recovery.

Table A.2.28-6. Selected industry distributions of p and λ for MODs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.36-7 shows the rounded values for the MOD failure modes.

Table A.2.28-7. Selected industry distributions of p and λ for MODs (after rounding).

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

A.2.28.5 Breakdown by System

MOD UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.36-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.28-8. MOD p and λ by system.

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

A.2.29 Motor-Operated Valve (MOV) Data Sheet

A.2.29.1 Component Description

The motor-operated valve (MOV) component boundary includes the valve, the valve operator, local circuit breaker, and local instrumentation and control circuitry. The failure modes for MOV are listed in Table A.2.29-1.

Table A.2.29-1. MOV failure modes.

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

A.2.29.2 Data Collection and Review

Most of the data for MOV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. (The external and internal leakage data cover 1997–2004.) There are 8661 MOVs from 103 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1) there were 8516 components in 103 plants. The systems included in the MOV data collection are listed in Table A.2.29-2 with the number of components included with each system.

Table A.2.29-2. MOV systems.

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

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
	RCS	Reactor coolant	166	164	158
	RGW	Radioactive gaseous waste	1	1	1
	RPS	Reactor protection	4	4	4
	RRS	Reactor recirculation	68	68	68
	RWC	Reactor water cleanup	13	13	13
	SGT	Standby gas treatment	20	20	10
	SLC	Standby liquid control	23	23	23
	TBC	Turbine building cooling water	2	2	2
	VSS	Vapor suppression	21	21	19
	Total		8661	8516	7441

The MOV data set obtained from RADS was further reduced to include only those MOVs with ≤ 20 demands/year (≤ 100 demands over 5 years). See Section A.1 for a discussion concerning this decision to limit certain component populations. Table A.2.29-3 summarizes the data used in the MOV analysis. Note that the hours for SO, ELS, and ILS are calendar hours. The FC failure mode is not supported by EPIX data.

Table A.2.29-3. MOV unreliability data.

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

Figure A.2.29-1 shows the range of valve demands per year in the MOV data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 20. The average for the data set is 4.6 demands/year.

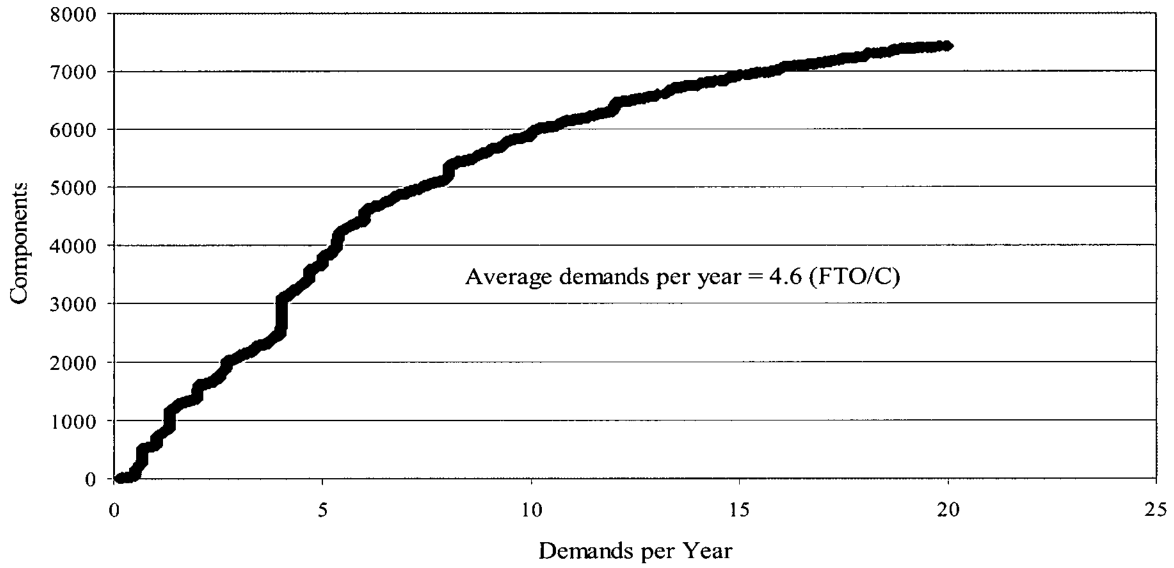

Figure A.2.29-1. MOV demands per year distribution.

A.2.29.3 Data Analysis

The MOV data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.29-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.29-3, only 3.1% of the MOVs experienced a FTO/C over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 96.9% portion of the distribution, and non-zero values above 96.9%.

Table A.2.29-4. Empirical distributions of MLEs for p and λ for MOVs.

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

Empirical Bayes analyses were performed at both the component and plant level. For these analyses, the five uncertain events for ILS (weights of 0.5) were assumed to be certain. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.29-5. These results were used to develop the industry-average distributions for FTO/C and SO.

Table A.2.29-5. Fitted distributions for p and λ for MOVs.

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

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

A.2.29.4 Industry-Average Baselines

Table A.2.29-6 lists the selected industry distributions of p and λ for the MOV failure modes. For the FTO/C and ILS, the data sets were sufficient (see Section A.1) for empirical Bayes analyses to be performed. Therefore, the industry-average distributions are based on the empirical Bayes analysis results at the plant level for FTO/C and ILS. However, the industry-average distributions for SO, ELS, and ELL are not sufficient (Section A.1) for the Empirical Bayes method; therefore, a SCNID analysis was performed to provide a failure rate distribution. The selected ELL mean is the ELS mean multiplied by 0.07, with an assumed α of 0.3. The selected ILL mean is the ILS mean multiplied by 0.02, with an assumed α of 0.3. The 0.07 and 0.02 multipliers are based on limited EPIX data for large leaks as explained in Section A.1.

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

Table A.2.29-6. Selected industry distributions of p and λ for MOVs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.29-7 shows the rounded values for the MOV.

Table A.2.29-7. Selected industry distributions of p and λ for MOVs (after rounding).

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

A.2.29.5 Breakdown by System

The MOVs discussed above are in multiple systems. MOV UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.29-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.29-8. MOV p and λ by system.

System	FTO/C	SO	ELS	ILS
AFW	1.1E-03	1.3E-07	-	4.7E-08
CCW	7.1E-04	1.0E-07	-	1.7E-07
CDS	-	-	-	-
CHW	1.6E-03	-	-	-
CIS	1.4E-03	8.5E-08	-	5.9E-07
CRD	4.6E-03	-	-	-
CSR	5.0E-04	1.0E-07	-	1.5E-07
CTS	1.2E-02	-	-	-
CVC	1.0E-03	6.7E-08	-	-
EPS	-	-	-	-
ESW	1.6E-03	3.9E-08	-	1.7E-07
FWS	9.8E-03	-	-	-
HCI	1.5E-03	-	1.3E-07	3.6E-07
HCS	-	-	-	-
HPI	7.4E-04	-	-	4.0E-08
HVC	1.4E-03	-	-	8.9E-07
IAS	-	-	-	-
ISO	5.7E-03	-	-	1.1E-06
LCI	6.3E-04	1.2E-07	-	2.8E-07
LCS	2.0E-03	-	-	1.7E-07
LPI	1.1E-03	-	1.3E-08	3.3E-08
MFW	2.9E-04	-	-	-
MSS	9.5E-04	-	2.4E-07	1.6E-06
RCI	1.3E-03	2.2E-07	1.7E-07	4.2E-07
RCS	4.0E-04	-	-	-
RGW	-	-	-	-
RPS	-	-	-	5.4E-06
RRS	2.2E-03	-	-	-
RWC	1.6E-02	2.6E-06	-	-
SGT	-	-	-	-
SLC	-	-	-	-
TBC	-	-	-	-
VSS	2.5E-03	-	-	-

A.2.30 Manual Switch (MSW) Data Sheet

A.2.30.1 Component Description

The manual switch (MSW) boundary includes the switch itself. The failure mode for MSW is listed in Table A.2.30-1.

Table A.2.30-1. MSW failure modes.

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

A.2.30.2 Data Collection and Review

Data for the MSW UR baseline were obtained from the reactor protection system (RPS) system studies (SSs). The RPS SSs contain data from 1984 to 1995. Table A.2.30-2 summarizes the data obtained from the RPS SSs and used in the MSW analysis. These data are at the industry level. Results at the plant and component levels are not presented in these studies.

Table A.2.30-2. MSW unreliability data.

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

A.2.30.3 Industry-Average Baselines

Table A.2.30-3 lists the industry-average failure rate distributions. The FTO/C failure mode is not supported by EPIX data. The selected FTO/C distribution has a mean based on the Jeffreys mean of industry data and α = 0.5. For all distributions based on RPS SS data, an *α* of 0.5 is assumed (see Section A.1).

Table A.2.30-3. Selected industry distributions of *p* and *λ* for MSWs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the *α* parameter was rounded. In order to preserve the mean value, the *β* parameter is presented to three significant figures. Table A.2.30-4 shows the rounded values for the MSW failure mode.

Table A.2.30-4. Selected industry distributions of *p* and *λ* for MSWs (after rounding).

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

A.2.31 Orifice (ORF) Data Sheet

A.2.31.1 Component Description

The orifice (ORF) boundary includes the orifice. The failure mode for ORF is listed in Table A.2.31-1.

Table A.2.31-1. ORF failure modes.

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

A.2.31.2 Data Collection and Review

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

A.2.31.3 Industry-Average Baselines

Table A.2.31-2 lists the industry-average failure rate distributions. The FTOP failure mode is not supported by EPIX data. The mean is from WSRC, and the α parameter of 0.30 is assumed.

Table A.2.31-2. Selected industry distributions of p and λ for ORFs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.31-3 shows the rounded values for the ORF failure mode.

Table A.2.31-3. Selected industry distributions of p and λ for ORFs (after rounding).

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

A.2.32 Positive Displacement Pump (PDP) Data Sheet

A.2.32.1 Component Description

The positive displacement pump (PDP) boundary includes the pump, motor, local circuit breaker, local lubrication or cooling systems, and local instrumentation and control circuitry. The failure modes for PDP are listed in Table A.2.32-1.

Table A.2.32-1. PDP failure modes.

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

A.2.32.2 Data Collection and Review

Data for PDP UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002, except for the ELS data that cover 1997 - 2004. There are 153 PDPs from 63 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1) there were 153 components in 63 plants. These data were then further partitioned into standby and running/alternating components. The systems and operational status included in the PDP data collection are listed in Table A.2.32-2 with the number of components included with each system.

Table A.2.32-2. PDP systems.

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

The data review process is described in detail in Section A.1. Table A.2.32-3 summarizes the data obtained from EPIX and used in the PDP analysis. Note that the hours for ELS are calendar hours. In addition, the single ELS event was identified by reviewing events that had originally been classified as "no failure" events.

Figure A.2.32-1a shows the range of start demands per year in the standby PDP data set. The start demands per year range from approximately 1 to 70. The average for the data set is 9.6 demands/year. Figure A.2.32-1b shows the range of start demands per year in the running PDP data set. The demands per year range from approximately 1 to 90. The average for the data set is 28.5 demands/year.

Table A.2.32-3. PDP unreliability data.

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

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

Figure A.2.32-2a shows the range of run hours per demand in the standby PDP data set. The run hours per demand range is from approximately 1 hour/demand to 11 hours/demand. The average is 1.1 hours/demand. Figure A.2.32-2b shows the range of run hours per demands in the running PDP data set. The range is from approximately 24 hours/demand to 3,300 hours/demand. The average is 509.2 hours/demand.

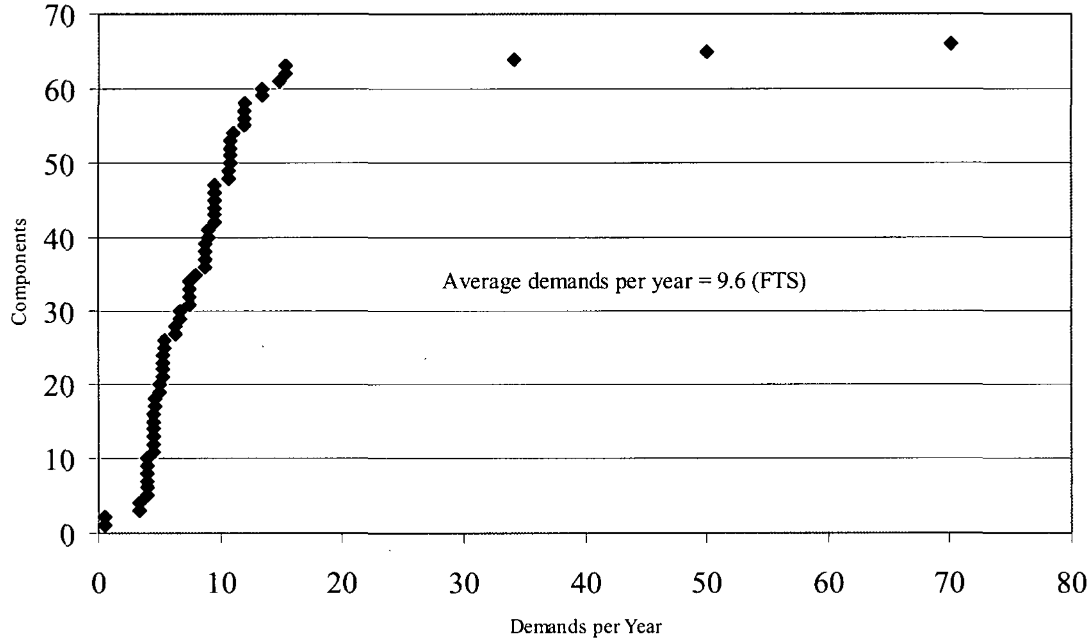

Figure A.2.32-1a. Standby PDP demands per year distribution.

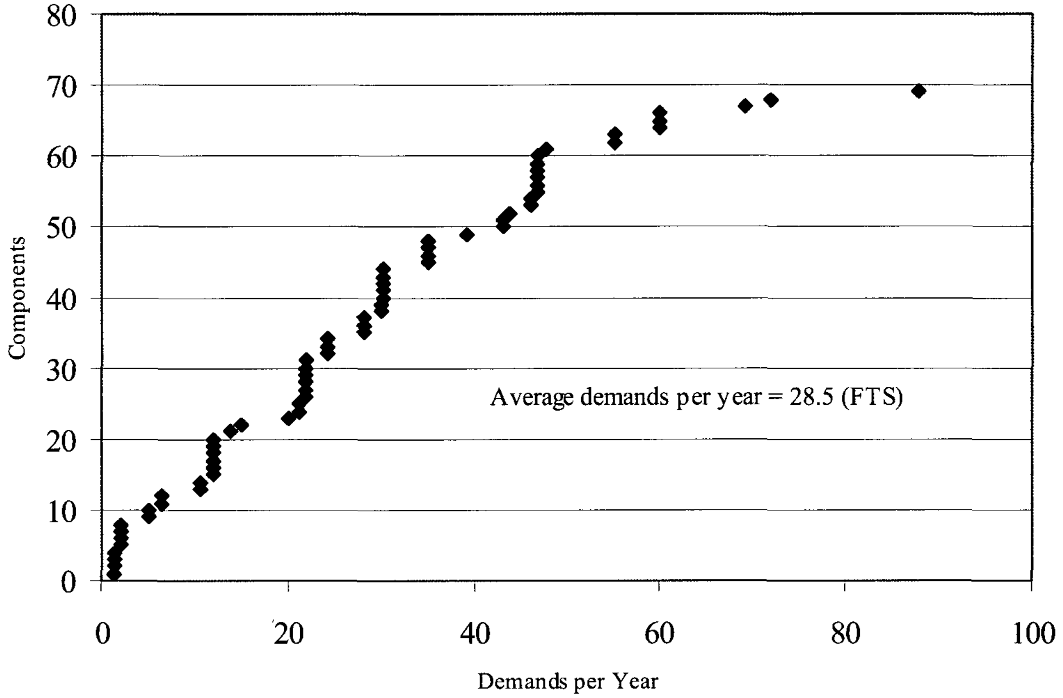

Figure A.2.32-1b. Running/alternating PDP demands per year distribution.

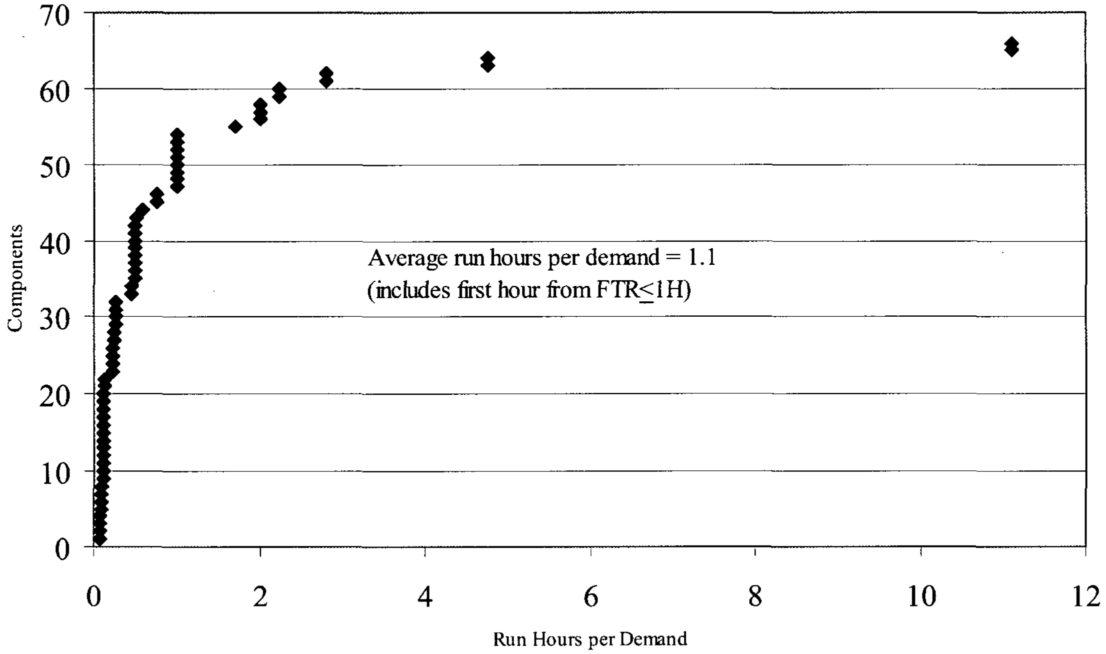

Figure A.2.32-2a. Standby PDP run hours per demand distribution.

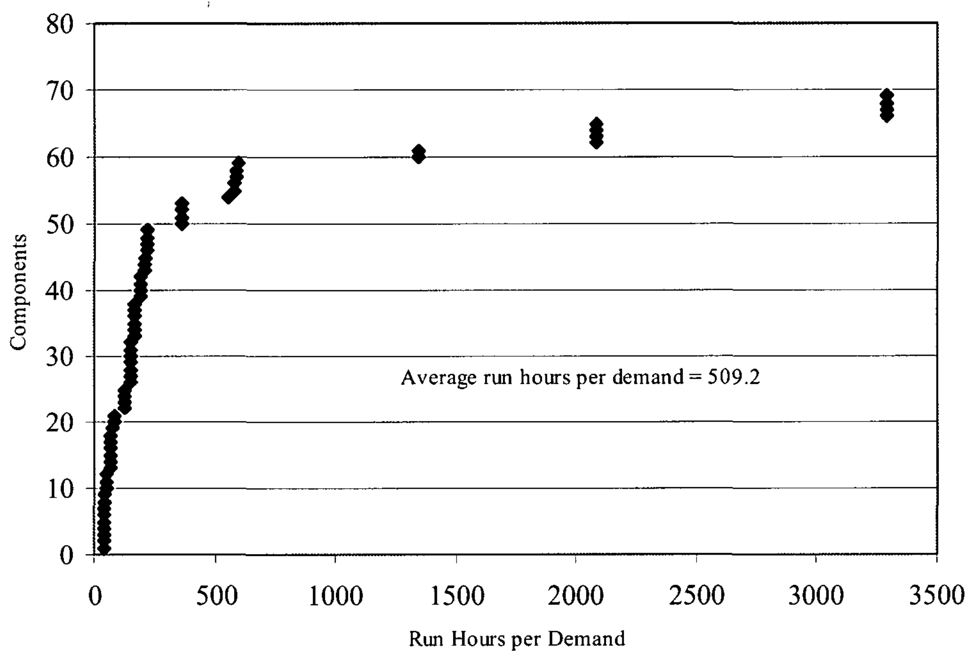

Figure A.2.32-2b. Running/alternating PDP run hours per demand distribution.

A.2.32.3 Data Analysis

The PDP data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.32-4.

Table A.2.32-4. Empirical distributions of MLEs for p and λ for PDPs.

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

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.32-3, 27.3% of the running/alternating PDPs experienced a FTS over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 72.7% portion of the distribution, and non-zero values above 72.7%.

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.32-5 for PDPs. These results were used to develop the industry-average distributions.

Table A.2.32-5. Fitted distributions for p and λ for PDPs.

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

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

A.2.32.4 Industry-Average Baselines

Table A.2.32-6 lists the industry-average failure rate distributions. For the running/alternating FTS and FTR failure modes, the data sets were sufficient (Section A.1) for empirical Bayes analyses to be performed. For these failure modes, the industry-average distributions are based on the empirical Bayes analysis results at the plant level. However, the FTR α estimate was below the lower bound of 0.3. In that case, the lower bound of 0.3 was assumed (see Section A.1). The industry-average distributions for the three failure modes for standby components and the external leakage failure modes are not sufficient (Section A.1) for the empirical Bayes method; therefore SCNID analyses were performed to provide failure rate distributions. The FTR>1H data had no failures or demands; therefore the FTR>1H mean is FTR≤1H * 0.06, based on the FTR>1H/ FTR≤1H ratio observed for other similar standby components (Section A.1). The α parameter is 0.3 for this case.

The selected ELL mean is the ELS mean multiplied by 0.07, with an assumed α of 0.3. The 0.07 multiplier is based on limited EPIX data for large leaks as explained in Section A.1. These industry-average failure rates do not account for any recovery.

Table A.2.32-6. Selected industry distributions of p and λ for PDPs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.32-7 shows the rounded values for the PDP failure modes.

Table A.2.32-7. Selected industry distributions of p and λ for PDPs (after rounding).

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

A.2.32.5 Breakdown by System

PDP UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.32-8. Results are shown only the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.32-8. PDP p and λ by system.

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

A.2.33 Pipe (PIPE) Data Sheet

A.2.33.1 Component Description

The pipe (PIPE) boundary includes piping and pipe welds in each system. The flanges connecting piping segments are not included in the pipe component. The failure modes for PIPE are listed in Table A.2.33-1.

Table A.2.33-1. PIPE failure modes.

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

A.2.33.2 Data Collection and Review

Data for PIPE UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1997–2004. There are 10,330 PIPE components in 112 systems from 96 plants in the data originally gathered from EPIX. EPIX reporting requirements allow great flexibility in defining PIPE components. Within a given system, one plant may report one PIPE component covering the entire system, while another may subdivide the piping into many smaller segments. The systems included in the PIPE data collection are listed in Table A.2.33-2 with the number of plants reporting information for each system. Note that the number of PIPE components per system is not a meaningful number given the flexibility in reporting requirements. However, the number of plants per system is useful, given the system footage information presented in Table A.2.33-2.

Table A.2.33-2. PIPE systems.

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

a. This entry is the number of plants reporting piping data to EPIX for the system indicated.

b. Estimates are from NUREG/CR-4407, *Pipe Break Frequency Estimation for Nuclear Power Plants* (Ref. A-13). Estimates are for piping with 2-inch or larger diameter.

Table A.2.33-3 summarizes the data obtained from EPIX and used in the PIPE analysis. Piping ELS events are those with external leakage rates from 1 to 50 gpm. Events that were uncertain were counted as 0.5 events. Note that the hours for ELS are calendar hours.

Table A.2.33-3. PIPE unreliability data.

Operation	System	Failure Mode	Events (1997 - 2004)	Total Foot-Hours (1997 - 2004)
All	ESW	ELS	8.5	1.306E+10
	CCW	ELS	0.5	3.321E+09
	AFW	ELS	0.0	6.122E+08
	CSR	ELS	0.0	1.445E+09
	HCS	ELS	0.0	2.041E+08
	HCI	ELS	0.0	1.429E+09
	LCS	ELS	0.0	1.867E+08
	RCI	ELS	0.0	1.458E+08
	LCI	ELS	0.0	1.315E+09
	LPI	ELS	0.5	1.708E+09
	HPI	ELS	1.0	1.096E+09
	CVC	ELS	1.5	4.362E+09
	All but ESW	ELS	3.5	1.583E+10

A.2.33.3 Industry-Average Baselines

Table A.2.33-4 lists the industry-average failure rate distributions. For ESW piping, the selected ELL mean is the ELS mean multiplied by 0.2, with an assumed α of 0.3. For non-ESW piping, the ELL mean is multiplied by 0.1. These multipliers are based on limited EPIX data for large leaks as explained in Section A.1.

Table A.2.33-4. Selected industry distributions of λ for PIPEs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.33-5 shows the rounded values for the PIPE failure modes.

Table A.2.33-5. Selected industry distributions of λ for PIPEs (after rounding).

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

A.2.34 Process Logic Components (PLDT, PLF, PLL, PLP) Data Sheet

A.2.34.1 Component Description

The process logic delta temperature (PLDT), process logic flow (PLF), process logic level (PLL), and process logic pressure (PLP boundary includes the logic components. The failure mode for these components is listed in Table A.2.34-1.

Table A.2.34-1. Process logic component failure modes.

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

A.2.34.2 Data Collection and Review

Data for process logic component UR baselines were obtained from the reactor protection system (RPS) system studies (SSs). The RPS SSs contain data from 1984 to 1995. Table A.2.34-2 summarizes the data obtained from the RPS SSs and used in the process logic component analysis. These data are at the industry level. Results at the plant and component levels are not presented in these studies.

Table A.2.34-2. Process logic component unreliability data.

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

A.2.34.3 Industry-Average Baselines

Table A.2.34-3 lists the industry-average failure rate distributions. The FTOP failure mode is not supported by EPIX data. The selected FTOP distributions have means based on the Jeffreys mean of industry data and $\alpha = 0.5$. For all distributions based on RPS SS data, an α of 0.5 is assumed (see Section A.1). Because PLF has no data, the PLL result was used for the PLL mean.

Table A.2.34-3. Selected industry distributions of p and λ for process logic components (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.34-4 shows the rounded values for the process logic component failure modes.

Table A.2.34-4. Selected industry distributions of p and λ for process logic components (after rounding).

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

A.2.35 Pump Volute (PMP) Data Sheet

A.2.35.1 Component Description

The pump volute (PMP) boundary includes the pump volute portion of AFW DDPs, MDPs, and TDPs. PMP is used only to support the quantification of common-cause failure events across DDPs, MDPs, and TDPs. The failure modes for PMP are listed in Table A.2.35-1. Unlike other standby pump components, the PMP FTR is not divided into FTR≤1H and FTR>1H because the common-cause failure parameters do not distinguish these two failure modes.

Table A.2.35-1. PMP failure modes.

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

A.2.35.2 Data Collection and Review

Data for PMP UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. There are 180 PMPs from 64 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1) there were 180 components in 64 plants. The systems and operational status included in the PMP data collection are listed in Table A.2.35-2 with the number of components included with each system.

Table A.2.35-2. PMP systems.

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

To identify pump volute failures within the AFW DDP, MDP, and TDP failures, the failure descriptions were reviewed. (EPIX does not identify pump volute events as a separate category.) Table A.2.35-3 summarizes the data obtained from the EPIX event review and used in the PMP analysis.

Table A.2.35-3. PMP unreliability data.

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

Figure A.2.35-1 shows the range of start demands per year in the standby PMP data set. The start demands per year range from approximately 3 to 50. The average for the data set is 18.6 demands/year. Figure A.2.35-2 shows the range of run hours per demand in the standby PMP data set. The run hours per demand range is from approximately 1 hour/demand to 37 hours/demand. The average is 4.1 hours/demand.

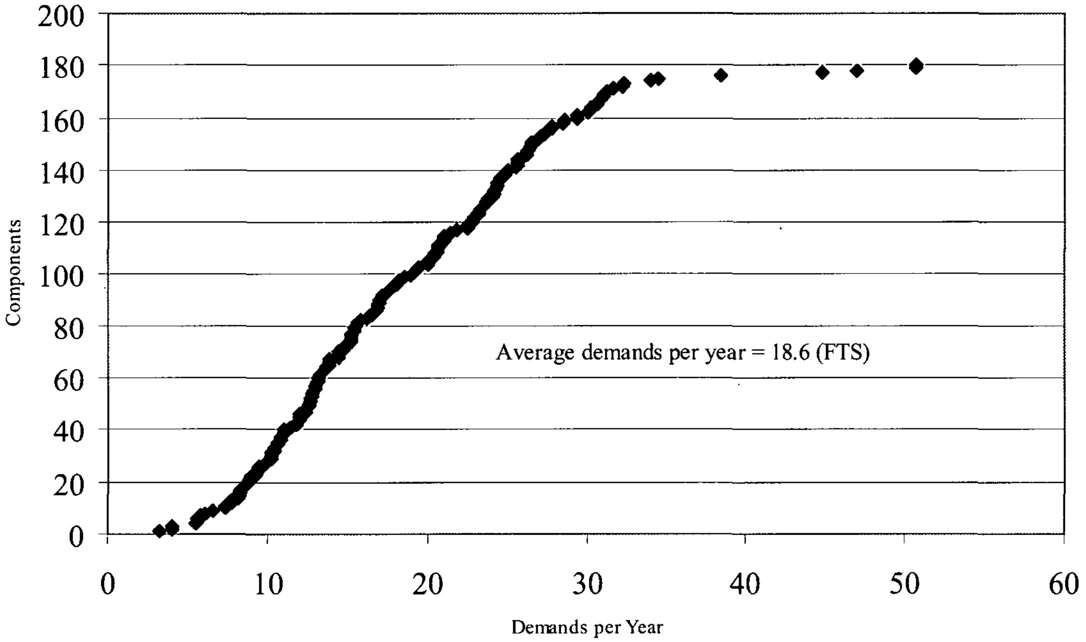

Figure A.2.35-1. Standby PMP demands per year distribution.

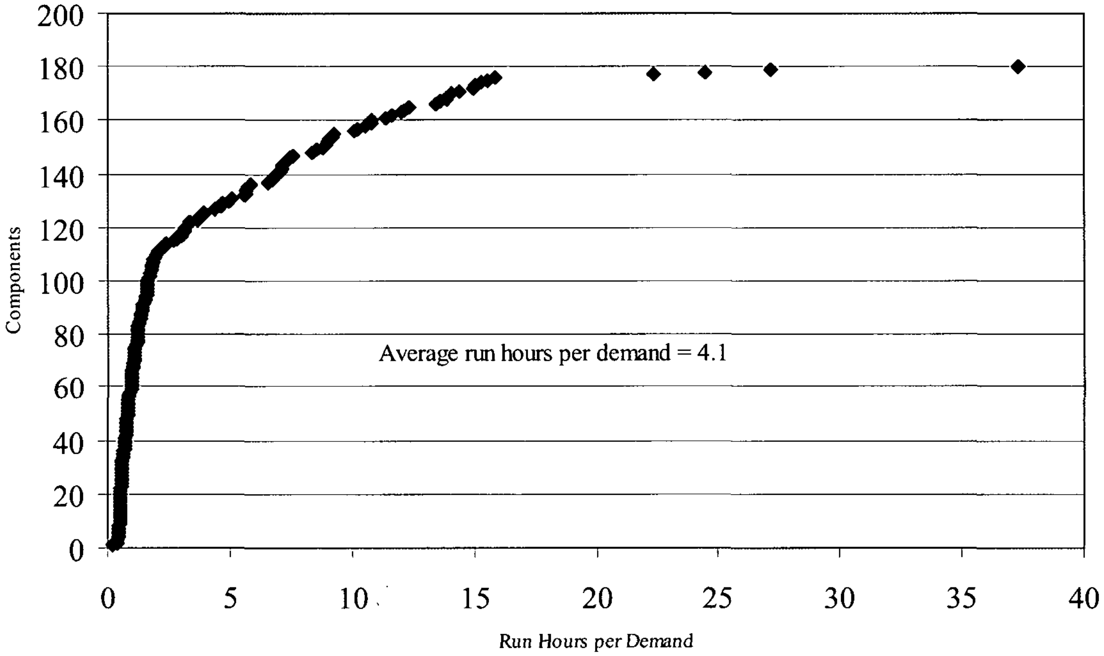

Figure A.2.35-2. Standby PMP run hours per demand distribution.

A.2.35.3 Data Analysis

The PMP data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.35-4.

Table A.2.35-4. Empirical distributions of MLEs for p and λ for PMPs.

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

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.35-3, only 5.0% of the PMPs experienced a FTR over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 95.0% portion of the distribution, and non-zero values above 95.0%.

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.35-5 for PMPs.

Table A.2.35-5. Fitted distributions for p and λ for PMPs.

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

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

A.2.35.4 Industry-Average Baselines

Table A.2.35-6 lists the selected industry distributions of p and λ for the PMP failure modes. For the FTR failure mode, the data set was sufficient for empirical Bayes analyses to be performed. For this failure mode, the industry-average distribution is based on the empirical Bayes analysis results at the plant level. However, the industry-average distribution for FTS is not sufficient (Section A.1) for the empirical Bayes method; therefore, a SCNID analysis was performed to provide a failure rate distribution. These industry-average failure rates do not account for any recovery.

Table A.2.35-6. Selected industry distributions of p and λ for PMPs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.35-7 shows the rounded values for the MDP failure modes.

Table A.2.35-7. Selected industry distributions of p and λ for PMPs (after rounding).

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

A.2.35.5 Breakdown by System

The pumps discussed above are all in the AFW system.

A.2.36 Pneumatic-Operated Damper (POD) Data Sheet

A.2.36.1 Component Description

The pneumatic-operated damper (POD) component boundary includes the damper, the damper operator, any associated solenoid operated valves, and local instrumentation and control circuitry. The failure modes for POD are listed in Table A.2.36-1.

Table A.2.36-1. POD failure modes.

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

A.2.36.2 Data Collection and Review

Data for POD UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. There are 101 PODs from 12 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1) there were 101 components in 12 plants. After analyzing the original data, there were no SO failures, so the data set was expanded to 1997– 2004 for SO failure mode (see Section A.1). The systems included in the POD data collection are listed in Table A.2.36-2 with the number of components included with each system.

Table A.2.36-2. POD systems.

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

The POD data set obtained from RADS was further reduced to include only those PODs with ≤ 20 demands/year. See Section A.1 for a discussion concerning this decision to limit the component populations for valves. Table A.2.36-3 summarizes the data used in the POD analysis. Note that the hours for SO are calendar hours.

Table A.2.36-3. POD unreliability data.

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

Figure A.2.36-1 shows the range of valve demands per year in the POD data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 16. The average for the data set is 8.3. demands/year.

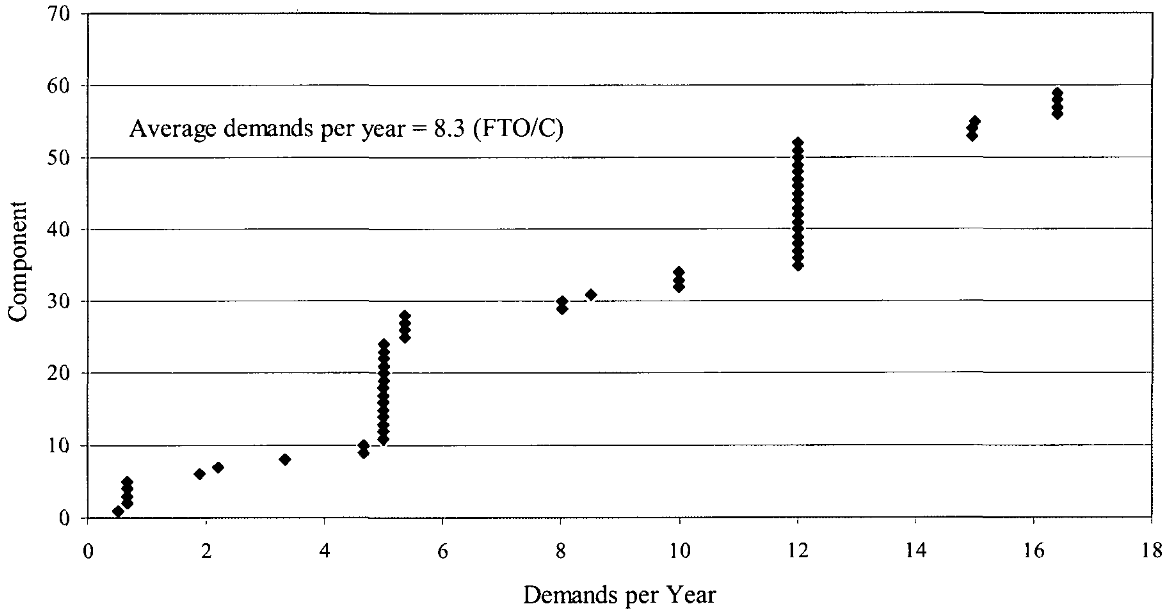

Figure A.2.36-1. POD demands per year distribution.

A.2.36.3 Data Analysis

The POD data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.29-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.36-3, only 3.4% of the PODs experienced a FTO/C over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 97.6% portion of the distribution, and non-zero values above 97.6%.

Table A.2.36-4. Empirical distributions of MLEs for p and λ for PODs.

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

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table A.2.36-5.

Table A.2.36-5. Fitted distributions for p and λ for PODs.

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

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

A.2.36.4 Industry-Average Baselines

Table A.2.36-6 lists the selected industry distributions of p and λ for the POD failure modes. The industry-average distributions for the FTO/C and SO failure modes are not sufficient (Section A.1) for the empirical Bayes method; therefore, SCNID analyses were performed to provide failure rate distributions. These industry-average failure rates do not account for any recovery.

Table A.2.36-6. Selected industry distributions of p and λ for PODs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.36-7 shows the rounded values for the POD failure modes.

Table A.2.36-7. Selected industry distributions of p and λ for PODs (after rounding).

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

A.2.36.5 Breakdown by System

POD UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.36-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.36-8. POD p and λ by system.

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

A.2.37 Power-Operated Relief Valve (PORV) Data Sheet

A.2.37.1 Component Description

The power-operated relief valve (PORV) component boundary includes the valve, the valve operator, local circuit breaker, and local instrumentation and control circuitry. The failure modes for PORV are listed in Table A.2.37-1.

Table A.2.37-1. PORV failure modes.

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

A.2.37.2 Data Collection and Review

Data for PORV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. There are 243 PORVs from 65 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1) there were 241 components in 65 plants. The systems included in the PORV data collection are listed in Table A.2.37-2 with the number of components included with each system.

Table A.2.37-2. PORV systems.

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

The PORV data set obtained from RADS was further reduced to include only those PORVs with ≤ 20 demands/year. See Section A.1 for a discussion concerning this decision to limit the component populations for valves. Table A.2.37-3 summarizes the data used in the PORV analysis. Note that SO hours are calendar hours.

Table A.2.37-3. PORV unreliability data.

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

Figure A.2.37-1 shows the range of valve demands per year in the PORV data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 20. The average for the data set is 4.3 demands/year.

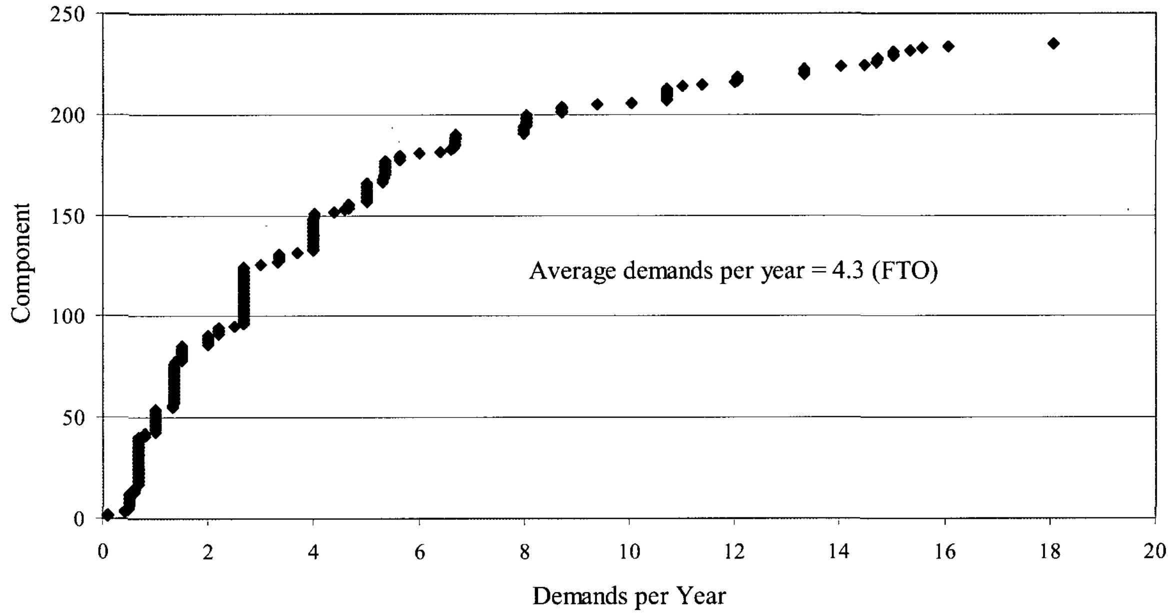

Figure A.2.37-1. PORV demands per year distribution.

A.2.37.3 Data Analysis

The PORV data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.37-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.37-3, 11.9% of the PORVs experienced a FTO over the period 1998–2002, so the distribution of MLEs, at the component level, involves zeros for the 0% to 88.1% portion of the distribution, and non-zero values above 88.1%.

Table A.2.37-4. Empirical distributions of MLEs for p and λ for PORVs.

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

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table A.2.37-5.

Table A.2.37-5. Fitted distributions for p and λ for PORVs.

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

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

A.2.37.4 Industry-Average Baselines

Table A.2.37-6 lists the selected industry distributions of p and λ for the PORV failure modes. For the FTO and SO failure modes, the data sets were sufficient (see Section A.1) for empirical Bayes analyses to be performed. Therefore, the industry-average distribution is based on the empirical Bayes analysis results at the plant level for FTO and SO. However, the industry-average distribution for FTC is not sufficient (Section A.1) for the empirical Bayes method; therefore, a SCNID analysis was performed to provide a failure rate distribution. These industry-average failure rates do not account for any recovery.

Table A.2.37-6. Selected industry distributions of p and λ for PORVs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.37-7 shows the rounded values for the PORV failure modes.

Table A.2.37-7. Selected industry distributions of p and λ for PORVs (after rounding).

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

A.2.37.5 Breakdown by System

PORV UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.37-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.37-8. PORV p and λ by system.

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

A.2.38 Relay (RLY) Data Sheet

A.2.38.1 Component Description

The relay (RLY) boundary includes the relay unit itself. The failure mode for RLY is listed in Table A.2.38-1.

Table A.2.38-1. RLY failure modes.

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

A.2.38.2 Data Collection and Review

Data for the RLY UR baseline were obtained from the reactor protection system (RPS) system studies (SSs). The RPS SSs contain data from 1984 to 1995. Table A.2.38-2 summarizes the data obtained from the RPS SSs and used in the RLY analysis. These data are at the industry level. Results at the plant and component levels are not presented in these studies.

Table A.2.38-2. RLY unreliability data.

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

A.2.38.3 Industry-Average Baselines

Table A.2.38-3 lists the industry-average failure rate distribution. The FTOP failure mode is not supported by EPIX data. The selected FTOP distribution has a mean based on the Jeffreys mean of industry data and $\alpha = 0.5$. For all distributions based on RPS SS data, an α of 0.5 is assumed (see Section A.1).

Table A.2.38-3. Selected industry distributions of p and λ for RLYs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.39-4 shows the rounded value for the RLY failure mode.

Table A.2.38-4. Selected industry distributions of p and λ for RLYs (after rounding).

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

A.2.39 Reactor Trip Breaker (RTB) Data Sheet

A.2.39.1 Component Description

The reactor trip breaker (RTB) boundary includes the entire trip breaker. The RTB has been broken up into three subcomponents for use in modeling the failure of the RTB to open on demand. These three subcomponents are the mechanical portion of the breaker (BME), the breaker shunt trip (BSN), and the breaker undervoltage trip (BUV). The component and subcomponent failure modes for RTB are listed in Table A.2.39-1.

Table A.2.39-1. RTB failure modes.

Operation	Failure Mode	Parameter	Units	Description
Standby	BME FTOP	p	-	BME fail to operate
	BSN FTOP	p	-	BSN fail to operate
	BUV FTOP	p	-	BUV fail to operate
	RTB FTOP	p	-	RTB fail to operate

A.2.39.2 Data Collection and Review

Data for RTB UR baselines were obtained from the pressurized water reactor (PWR) reactor protection system (RPS) system studies (SSs). The RPS SSs contain data from 1984 to 1995. Table A.2.39-2 summarizes the data obtained from the RPS SSs and used in the RTB analysis. These data are at the industry level. Results at the plant and component levels are not presented in these studies.

Table A.2.39-2. RTB unreliability data.

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

A.2.39.3 Industry-Average Baselines

Table A.2.39-3 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). 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 A.2.39-3. Selected industry distributions of p and λ for RTBs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.39-4 shows the rounded values for the RTB failure modes.

Table A.2.39-4. Selected industry distributions of p and λ for RTBs (after rounding).

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

A.2.40 Sequencer (SEQ) Data Sheet

A.2.40.1 Component Description

The sequencer (SEQ) boundary includes the relays, logic modules, etc that comprise the sequencer function of the emergency diesel generator (EDG) load process. The failure mode for SEQ is listed in Table A.2.40-1.

Table A.2.40-1. SEQ failure modes.

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

A.2.40.2 Data Collection and Review

Data for the SEQ UR baseline were obtained from EPIX data from 1998 to 2002. The sequencer is not treated separately from the EDG output circuit breaker in EPIX. The EDG failure events were read to obtain sequencer-only failure data. The demand data are based on assuming a full test of the sequencer every fuel cycle (18 months) for each EDG. Table A.2.40-2 summarizes the data obtained from EPIX and used in the SEQ analysis.

Table A.2.40-2. SEQ unreliability data.

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

A.2.40.3 Industry-Average Baselines

Table A.2.40-3 lists the industry-average failure rate distributions. The selected FTOP distribution has a mean based on the Jeffreys mean of industry data and $\alpha = 0.5$. An α of 0.5 is assumed.

Table A.2.40-3. Selected industry distributions of p and λ for SEQs (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.40-4 shows the rounded values for the SEQ failure mode.

Table A.2.40-4. Selected industry distributions of p and λ for SEQs (after rounding).

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

A.2.41 Solenoid-Operated Valve (SOV) Data Sheet

A.2.41.1 Component Description

The solenoid-operated valve (SOV) component boundary includes the valve, the valve operator, and local instrumentation and control circuitry. The failure modes for SOV are listed in Table A.2.41-1.

Table A.2.41-1. SOV failure modes.

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

A.2.41.2 Data Collection and Review

Most of the data for SOV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS, except for the ILS and ELS data that cover 1997–2004. There are 1748 SOVs from 77 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1) there were 1722 components in 77 plants. The systems included in the SOV data collection are listed in Table A.2.41-2 with the number of components included with each system.

Table A.2.41-2. SOV systems.

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

The SOV data set obtained from RADS was further reduced to include only those SOVs with ≤ 20 demands/year. See Section A.1 for a discussion concerning this decision to limit certain component populations. Table A.2.41-3 summarizes the data used in the SOV analysis. Note that the hours for SO, ELS, and ILS are calendar hours. The FC failure mode is not supported by EPIX data.

Table A.2.41-3. SOV unreliability data.

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

Figure A.2.41-1 shows the range of valve demands per year in the SOV data set (limited to ≤ 20 demands/year). The demands per year range from approximately 1 to 20. The average for the data set is 4.2 demands/year.

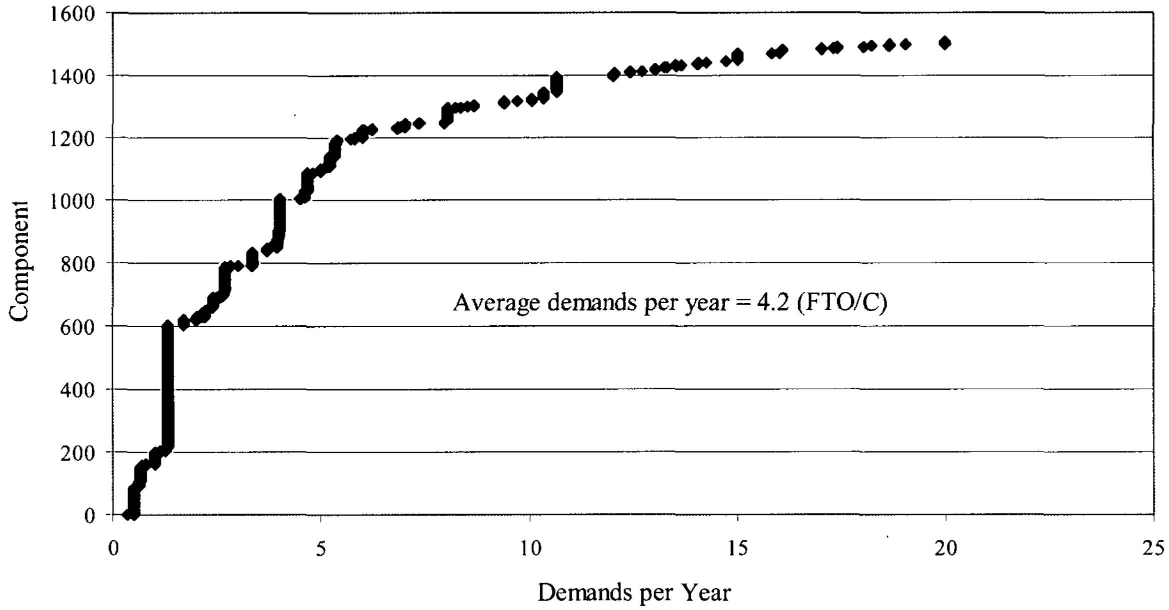

Figure A.2.41-1. SOV demands per year distribution.

A.2.41.3 Data Analysis

The SOV data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.41-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.41-3, only 1.5% of the SOVs experienced a FTO/C over the period 1998–2002, so the empirical distribution of

MLEs, at the component level, involves zeros for the 0% to 98.5% portion of the distribution, and non-zero values above 98.5%.

Table A.2.41-4. Empirical distributions of MLEs for p and λ for SOVs.

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

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.41-5.

Table A.2.41-5. Fitted distributions for p and λ for SOVs.

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

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

A.2.41.4 Industry-Average Baselines

Table A.2.41-6 lists the selected industry distributions of p and λ for the SOV failure modes. For the FTO/C, SO, and ILS failure modes, the data sets were sufficient (see Section A.1) for empirical Bayes analyses to be performed. Therefore, the industry-average distribution is based on the empirical Bayes analysis results at the plant level. However, the empirical Bayes results for SO indicated an α less than 0.3. In that case, the lower limit of 0.3 was assumed (see Section A.1). The industry-average distribution for ELS is not sufficient (Section A.1) for the empirical Bayes method; therefore, a SCNID analysis was performed to provide a failure rate distribution. The selected ELL mean is the ELS mean multiplied by 0.07, with an assumed α of 0.3. The selected ILL mean is the ILS mean multiplied by 0.02, with an assumed α of 0.3. The 0.07 and 0.02 multipliers are based on limited EPIX data for large leaks as explained in Section A.1. These industry-average failure rates do not account for any recovery.

Table A.2.41-6. Selected industry distributions of p and λ for SOVs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution Type	α	β
Standby	FTO/C	EB/PL/KS	2.70E-06	4.11E-04	9.54E-04	3.74E-03	Beta	0.471	4.931E+02
	SO	EB/PL/KS	9.88E-12	2.25E-08	9.23E-08	4.22E-07	Gamma	0.300	3.251E+06
	ELS	SCNID/IL	3.67E-11	4.24E-09	9.33E-09	3.58E-08	Gamma	0.500	5.359E+07
	ELL	ELS/EPIX	6.99E-14	1.59E-10	6.53E-10	2.99E-09	Gamma	0.300	4.594E+08
	ILS	EB/PL/KS	1.28E-10	8.76E-08	2.78E-07	1.20E-06	Gamma	0.357	1.283E+06
	ILL	ILS/EPIX	5.96E-13	1.36E-09	5.56E-09	2.55E-08	Gamma	0.300	5.392E+07
Control	FC	WSRC	3.21E-10	7.31E-07	3.00E-06	1.37E-05	Gamma	0.300	1.000E+05

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.41-7 shows the rounded values for the SOV failure modes.

Table A.2.41-7. Selected industry distributions of p and λ for SOVs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution Type	α	β
Standby	FTO/C	EB/PL/KS	4.0E-06	5.0E-04	1.0E-03	4.0E-03	Beta	0.50	5.00E+02
	SO	EB/PL/KS	1.0E-11	2.0E-08	9.0E-08	4.0E-07	Gamma	0.30	3.33E+06
	ELS	SCNID/IL	4.0E-11	4.0E-09	9.0E-09	3.0E-08	Gamma	0.50	3.33E+07
	ELL	ELS/EPIX	7.0E-14	1.5E-10	7.0E-10	3.0E-09	Gamma	0.30	4.29E+08
	ILS	EB/PL/KS	3.0E-10	1.0E-07	3.0E-07	1.2E-06	Gamma	0.40	1.33E+06
	ILL	ILS/EPIX	6.0E-13	1.5E-09	6.0E-09	2.5E-08	Gamma	0.30	5.00E+07
Control	FC	WSRC	3.0E-10	7.0E-07	3.0E-06	1.5E-05	Gamma	0.30	1.00E+05

A.2.41.5 Breakdown by System

SOV UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.41-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.41-8. SOV p and λ by system.

System	FTO/C	SO	ELS	ILS
AFW	1.54E-03	-	-	-
CIS	6.04E-04	1.51E-07	3.04E-08	4.61E-07
CRD	5.51E-04	-	-	-
CSR	-	-	-	-
CVC	6.51E-03	-	-	-
EPS	-	-	-	-
ESW	2.00E-03	-	-	-
FWS	-	-	-	-
HCI	-	-	-	-
HPI	3.08E-02	-	-	-
HVC	1.16E-03	5.71E-07	-	-
IAS	-	-	-	-
LCI	8.71E-03	-	-	-
LCS	-	-	-	-
LPI	-	-	-	-
MFW	-	-	-	-
MSS	-	6.34E-07	-	-
RCI	-	-	-	-
RCS	-	-	-	8.23E-07
RPS	-	-	-	-
RRS	-	-	-	-
SGT	-	-	-	-
VSS	-	-	-	-

A.2.42 Safety Relief Valve (SRV) Data Sheet

A.2.42.1 Component Description

The safety relief valve (SRV) component boundary includes the valve, the valve operator, and local instrumentation and control circuitry. The SRV lifts either by system pressure directly acting on the valve operator or by an electronic signal to the pilot valve. These are known as dual acting relief valves. The failure modes for SRV are listed in Table A.2.42-1.

Table A.2.42-1. SRV failure modes.

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

A.2.42.2 Data Collection and Review

Data for most SRV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. There are 404 SRVs from 31 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1) there were 404 components in 31 plants. The systems included in the SRV data collection are listed in Table A.2.42-2 with the number of components included with each system.

Table A.2.42-2. SRV systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
All	MSS	Main steam	404	387	386
	Total		404	387	386

The SRV data set obtained from RADS was further reduced to include only those SRVs with ≤ 20 demands/year. See Section A.1 for a discussion concerning this decision to limit the component populations for valves. Table A.2.42-3 summarizes the data used in the SRV analysis. The FTCL failure mode is not supported with EPIX data. Note that SO hours are calendar hours.

Table A.2.42-3. SRV unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO	10	3142	386	31	2.6%	12.9%
	FTC	2	3142	386	31	0.5%	6.5%
	SO	9	16906800 h	386	31	2.3%	12.9%
	FTCL	-	-	-	-	-	-

Figure A.2.42-1 shows the range of valve demands per year in the SRV data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 20. The average for the data set is 1.6 demands/year.

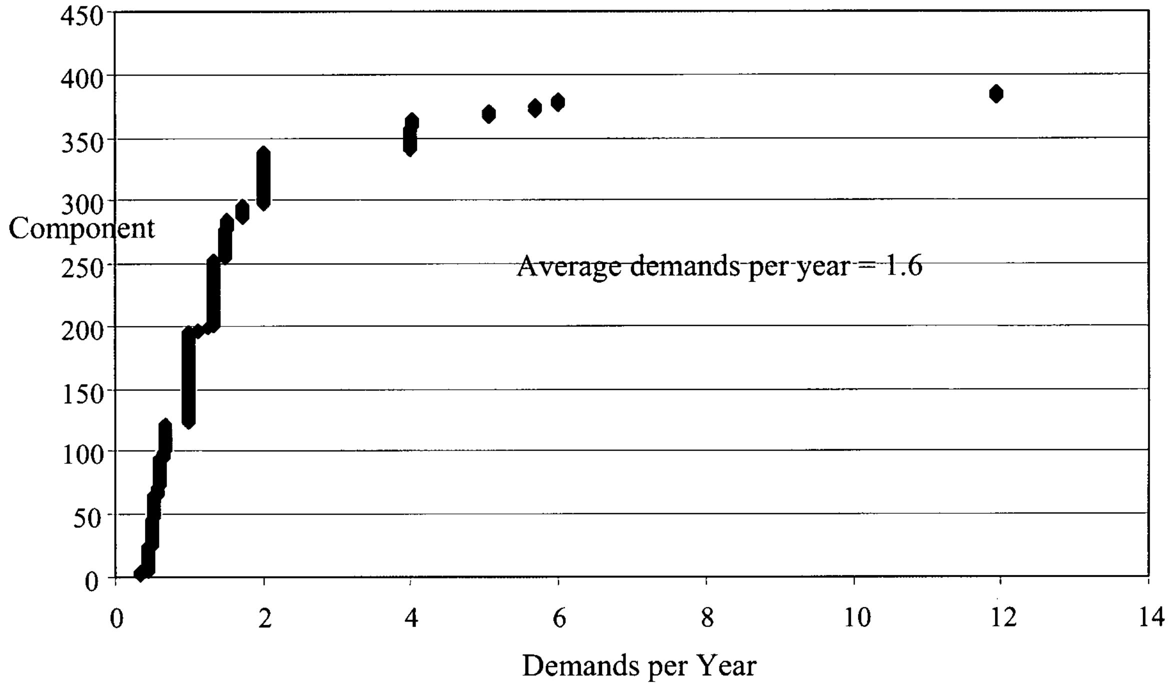

Figure A.2.42-1. SRV demands per year distribution.

A.2.42.3 Data Analysis

The SRV data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.42-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.42-3, 2.3% of the SRVs experienced a SO over the period 1998–2002, so the distribution of MLEs, at the component level, involves zeros for the 0% to 97.7% portion of the distribution, and non-zero values above 97.7%.

Table A.2.42-4. Empirical distributions of MLEs for p and λ for SRVs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
All	FTO	Component	0.00E+00	0.00E+00	5.91E-03	0.00E+00
		Plant	0.00E+00	0.00E+00	9.20E-03	2.22E-02
		Industry	-	-	3.18E-03	-
	FTC	Component	0.00E+00	0.00E+00	1.29E-03	0.00E+00
		Plant	0.00E+00	0.00E+00	9.64E-04	0.00E+00
		Industry	-	-	6.36E-04	-
	SO	Component	0.00E+00	0.00E+00	5.32E-07	0.00E+00
		Plant	0.00E+00	0.00E+00	4.52E-07	1.76E-06
		Industry	-	-	5.32E-07	-
	FTCL	-	-	-	-	-

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.42-5.

Table A.2.42-5. Fitted distributions for p and λ for SRVs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	7.82E-26	2.44E-07	7.71E-03	4.44E-02	Beta	0.054	6.958E+00
		SCNID/IL	1.32E-05	1.53E-03	3.34E-03	1.28E-02	Beta	0.500	1.492E+02
	FTC	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	3.13E-06	3.62E-04	7.95E-04	3.05E-03	Beta	0.500	6.282E+02
	SO	JEFF/CL	2.99E-07	5.42E-07	5.62E-07	8.91E-07	Gamma	9.500	1.691E+07
		EB/PL/KS	2.14E-16	1.15E-08	5.08E-07	2.87E-06	Gamma	0.129	2.545E+05
		SCNID/IL	2.21E-09	2.56E-07	5.62E-07	2.16E-06	Gamma	0.500	8.898E+05
	FTCL	-	-	-	-	-	-	-	-

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

A.2.42.4 Industry-Average Baselines

Table A.2.42-6 lists the selected industry distributions of p and λ for the SRV failure modes. For the FTO and SO failure modes, the data set was sufficient (see Section A.1) for empirical Bayes analyses to be performed. Therefore, the industry-average distribution is based on the empirical Bayes analysis results at the plant level for FTO and SO. The FTO and SO analyses resulted in α less than the lower bound of 0.3. In these cases, 0.3 was assumed (see Section A.1). However, the industry-average distribution for FTC is not sufficient (Section A.1) for the empirical Bayes method; therefore a SCNID analysis was performed to provide a failure rate distribution. These industry-average failure rates do not account for any recovery.

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

Table A.2.42-6. Selected industry distributions of p and λ for SRVs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	EB/PL/KS	8.33E-07	1.89E-03	7.71E-03	3.50E-02	Beta	0.300	3.891E+01
	FTC	SCNID/IL	3.13E-06	3.62E-04	7.95E-04	3.05E-03	Beta	0.500	6.282E+02
	SO	EB/PL/KS	5.44E-11	1.24E-07	5.08E-07	2.33E-06	Gamma	0.300	5.900E+05
	FTCL	WSRC	4.62E-04	5.20E-02	1.00E-01	3.62E-01	Beta	0.500	4.500E+00

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.42-7 shows the rounded values for the SRV failure modes.

Table A.2.42-7. Selected industry distributions of p and λ for SRVs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	EB/PL/KS	9.0E-07	2.0E-03	8.0E-03	4.0E-02	Beta	0.30	3.75E+01
	FTC	SCNID/IL	3.0E-06	4.0E-04	8.0E-04	3.0E-03	Beta	0.50	6.25E+02
	SO	EB/PL/KS	5.0E-11	1.2E-07	5.0E-07	2.5E-06	Gamma	0.30	6.00E+05
	FTCL	WSRC	5.0E-04	5.0E-02	1.0E-01	4.0E-01	Beta	0.50	4.50E+00

A.2.42.5 Breakdown by System

The SRV is included only in the main stem system of BWRs.

A.2.43 Sensor/Transmitter Components (STF, STL, STP, STT) Data Sheet

A.2.43.1 Component Description

The sensor/transmitter flow (STF), sensor/transmitter level (STL), sensor/transmitter pressure (STP), and sensor/transmitter temperature (STT) boundaries includes the sensor and transmitter. The failure mode for sensor/transmitter is listed in Table A.2.43-1.

Table A.2.43-1. Sensor/transmitter failure modes.

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

A.2.43.2 Data Collection and Review

Data for the sensor/transmitter UR baseline were obtained from the reactor protection system (RPS) system studies (SSs). The RPS SSs contain data from 1984 to 1995. Table A.2.43-2 summarizes the data obtained from the RPS SSs and used in the sensor/transmitter analysis. These data are at the industry level. Results at the plant and component levels are not presented in these studies. Unlike other component failure modes, each component FTOP has both a demand and a calendar time contribution.

Table A.2.43-2. Sensor/transmitter unreliability data.

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

A.2.43.3 Industry-Average Baselines

Table A.2.43-3 lists the industry-average failure rate distributions. The FTOP failure mode is not supported by EPIX data. The selected FTOP distributions have means based on the Jeffreys mean of industry data and α = 0.5. For all distributions based on RPS SS data, an α of 0.5 is assumed (see Section A.1). Because there were no data for STF FTOP, the results for STL FTOP were used.

Table A.2.43-3. Selected industry distributions of p and λ for sensor/transmitters (before rounding).

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

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.43-4 shows the rounded values for the sensor/transmitter failure modes.

Table A.2.43-4. Selected industry distributions of p and λ for sensor/transmitters (after rounding).

Operation	Component Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Running	STF FTOP	STL	3.0E-06	4.0E-04	8.0E-04	3.0E-03	Beta	0.50	6.25E+02
	STF FTOP	STL	4.0E-10	5.0E-08	1.0E-07	4.0E-07	Gamma	0.50	5.00E+06
	STL FTOP	RPS SS	3.0E-06	4.0E-04	8.0E-04	3.0E-03	Beta	0.50	6.25E+02
	STL FTOP	RPS SS	4.0E-10	5.0E-08	1.0E-07	4.0E-07	Gamma	0.50	5.00E+06
	STP FTOP	RPS SS	5.0E-07	5.0E-05	1.2E-04	4.0E-04	Beta	0.50	4.17E+03
	STP FTOP	RPS SS	3.0E-09	4.0E-07	8.0E-07	3.0E-06	Gamma	0.50	6.25E+05
	STT FTOP	RPS SS	1.5E-06	2.0E-04	4.0E-04	1.5E-03	Beta	0.50	1.25E+03
	STT FTOP	RPS SS	3.0E-09	4.0E-07	8.0E-07	3.0E-06	Gamma	0.50	6.25E+05

A.2.44 Strainer (STR) Data Sheet

A.2.44.1 Component Description

The strainer (STR) component boundary includes the strainer. The failure mode for STR is listed in Table A.2.44-1.

Table A.2.44-1. STR failure modes.

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

A.2.44.2 Data Collection and Review

Data for the STR UR baseline were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. Note that the data search was limited to emergency service water systems. There are 125 STRs from 35 plants in the data The systems included in the STR data collection are listed in Table A.2.44-2 with the number of components included with each system.

Table A.2.44-2. STR systems.

Operation	System	Description	Number of Components	
			Initial	After Review
All	ESW	Emergency cooling water	125	125
	Total		125	125

Table A.2.44-3 summarizes the data used in the STR analysis. Note that PG hours are calendar hours.

Table A.2.44-3. STR unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	PG	34	5475000 h	125	35	15.2%	34.3%

A.2.44.3 Data Analysis

The STR data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.44-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.44-3, 15.2% of the STRs experienced a PG over the period 1998–2002, so the distribution of MLEs, at the component level, involves zeros for the 0% to 84.8% portion of the distribution, and non-zero values above 84.8%.

Table A.2.44-4. Empirical distributions of MLEs for p and λ for STRs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
All	PG	Component	0.00E+00	0.00E+00	6.21E-06	4.57E-05
		Plant	0.00E+00	0.00E+00	8.18E-06	3.04E-05
		Industry	-	-	6.21E-06	-

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.44-5.

Table A.2.44-5. Fitted distributions for p and λ for STRs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	PG	EB/CL/KS	1.36E-12	4.81E-07	6.21E-06	3.28E-05	Gamma	0.180	2.905E+04
		EB/PL/KS	2.51E-10	1.46E-06	7.38E-06	3.50E-05	Gamma	0.267	3.617E+04
		SCNID/IL	2.48E-08	2.87E-06	6.30E-06	2.42E-05	Gamma	0.500	7.935E+04

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

A.2.44.4 Industry-Average Baselines

Table A.2.44-6 lists the industry-average failure rate distribution for the STR component. For the PG failure mode, the data set was sufficient (see Section A.1) for empirical Bayes analyses to be performed. Therefore, the industry-average distribution is based on the empirical Bayes analysis results at the plant level for PG. The PG analysis resulted in α less than the lower bound of 0.3. In this case, 0.3 was assumed (see Section A.1).

Table A.2.44-6. Selected industry distributions of p and λ for STRs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	PG	EB/PL/KS	7.89E-10	1.80E-06	7.38E-06	3.37E-05	Gamma	0.300	4.067E+04

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.44-7 shows the rounded values for the STR failure mode.

Table A.2.44-7. Selected industry distributions of p and λ for STRs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	PG	EB/PL/KS	7.0E-10	1.5E-06	7.0E-06	3.0E-05	Gamma	0.30	4.29E+04

A.2.44.5 Breakdown by System

The STR data were limited to the ESW system.

A.2.45 Safety Valve (SVV) Data Sheet

A.2.45.1 Component Description

The safety valve (SVV) component boundary includes the valve and the valve operator. The SVV is a direct-acting relief valve. These relief valves are also known as 'Code Safeties' since their lift points are the highest and are meant to protect the piping integrity. The failure modes for SVV are listed in Table A.2.45-1.

Table A.2.45-1. SVV failure modes.

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

A.2.45.2 Data Collection and Review

Data for most SVV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. There are 1060 SVVs from 68 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1) there were 998 components in 68 plants. The systems included in the SVV data collection are listed in Table A.2.45-2 with the number of components included with each system.

Table A.2.45-2. SVV systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
All	MSS	Main steam	900	846	845
	RCS	Reactor coolant	160	152	152
	Total		1060	998	997

The SVV data set obtained from RADS was further reduced to include only those SVVs with ≤ 20 demands/year. See Section A.1 for a discussion concerning this decision to limit the component populations for valves. Table A.2.45-3 summarizes the data used in the SVV analysis. The FTCL failure mode is not supported with EPIX data. Note that SO hours are calendar hours.

Table A.2.45-3. SVV unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO	18	7393	997	68	1.8%	10.3%
	FTC	0	7393	997	68	0.0%	0.0%
	SO	11	43668600 h	997	68	1.1%	8.8%
	FTCL	-	-	-	-	-	-

Figure A.2.45-1 shows the range of valve demands per year in the SVV data set (limited to ≤ 20 demands/year). The demands per year range from approximately 0.1 to 20. The average for the data set is 1.5 demands/year.

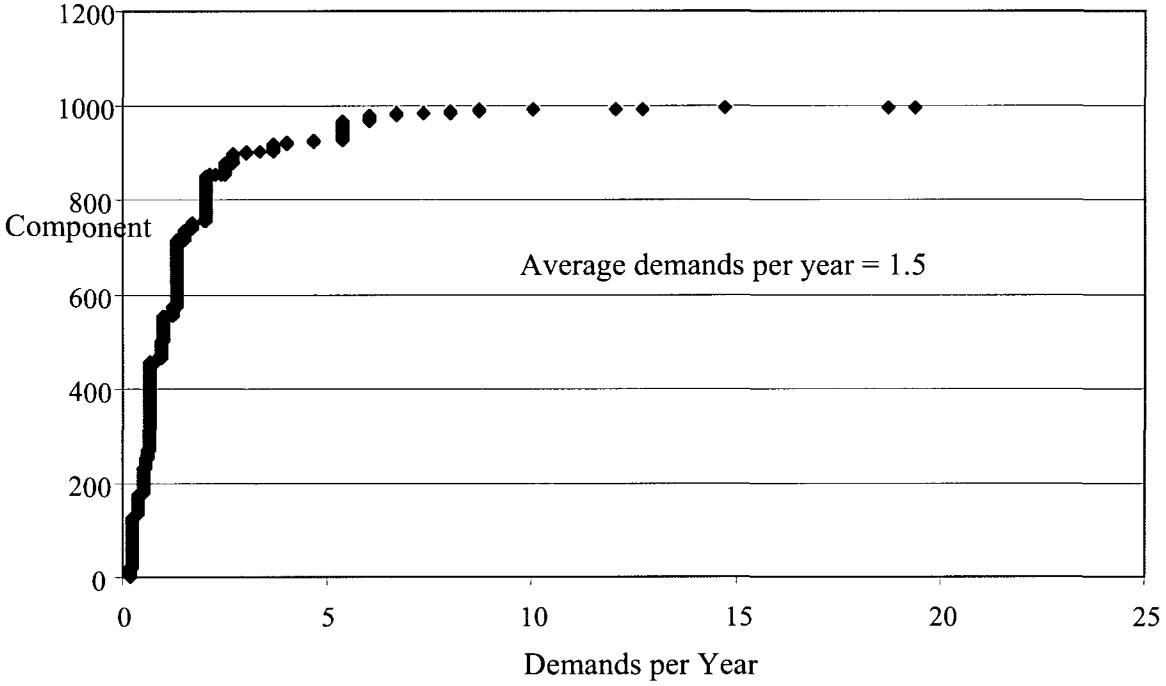

Figure A.2.45-1. SVV demands per year distribution.

A.2.45.3 Data Analysis

The SVV data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.45-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.45-3, 1.1% of the SVVs experienced a SO over the period 1998–2002, so the distribution of MLEs, at the component level, involves zeros for the 0% to 98.9% portion of the distribution, and non-zero values above 98.9%.

Table A.2.45-4. Empirical distributions of MLEs for p and λ for SVVs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
All	FTO	Component	0.00E+00	0.00E+00	3.19E-03	0.00E+00
		Plant	0.00E+00	0.00E+00	1.91E-03	1.50E-02
		Industry	-	-	2.43E-03	-
	FTC	Component	-	-	-	-
		Plant	-	-	-	-
		Industry	-	-	0.00E+00	-
	SO	Component	0.00E+00	0.00E+00	2.52E-07	0.00E+00
		Plant	0.00E+00	0.00E+00	1.46E-07	9.93E-07
		Industry	-	-	2.52E-07	-
	FTCL	-	-	-	-	-

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.45-5.

Table A.2.45-5. Fitted distributions for p and λ for SVVs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	6.50E-13	5.14E-05	2.47E-03	1.41E-02	Beta	0.127	5.106E+01
		SCNID/IL	9.88E-06	1.14E-03	2.50E-03	9.60E-03	Beta	0.500	1.993E+02
	FTC	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	2.66E-07	3.08E-05	6.76E-05	2.60E-04	Beta	0.500	7.394E+03
	SO	JEFF/CL	1.50E-07	2.56E-07	2.63E-07	4.03E-07	Gamma	11.500	4.367E+07
		EB/PL/KS	4.18E-14	1.61E-08	2.12E-07	1.12E-06	Gamma	0.179	8.445E+05
		SCNID/IL	1.04E-09	1.20E-07	2.63E-07	1.01E-06	Gamma	0.500	1.899E+06
	FTCL	-	-	-	-	-	-	-	-

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

A.2.45.4 Industry-Average Baselines

Table A.2.45-6 lists the selected industry distributions of p and λ for the SVV failure modes. For the FTO and SO failure modes, the data set was sufficient (see Section A.1) for empirical Bayes analyses to be performed. Therefore, the industry-average distribution is based on the empirical Bayes analysis results at the plant level for FTO and SO. The FTO and SO analyses resulted in α less than the lower limit of 0.3. In these cases, 0.3 was assumed (see Section A.1). However, the industry-average distribution for FTC is not sufficient (Section A.1) for the empirical Bayes method; therefore a SCNID analysis was performed to provide a failure rate distribution. These industry-average failure rates do not account for any recovery.

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

Table A.2.45-6. Selected industry distributions of p and λ for SVVs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	EB/PL/KS	2.66E-07	6.05E-04	2.47E-03	1.13E-02	Beta	0.300	1.213E+02
	FTC	SCNID/IL	2.66E-07	3.08E-05	6.76E-05	2.60E-04	Beta	0.500	7.394E+03
	SO	EB/PL/KS	2.27E-11	5.17E-08	2.12E-07	9.71E-07	Gamma	0.300	1.414E+06
	FTCL	WSRC	4.62E-04	5.20E-02	1.00E-01	3.62E-01	Beta	0.500	4.500E+00

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.45-7 shows the rounded values for the SVV failure modes.

Table A.2.45-7. Selected industry distributions of p and λ for SVVs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	EB/PL/KS	2.5E-07	6.0E-04	2.5E-03	1.2E-02	Beta	0.30	1.20E+02
	FTC	SCNID/IL	3.0E-07	3.0E-05	7.0E-05	2.5E-04	Beta	0.50	7.14E+03
	SO	EB/PL/KS	2.0E-11	5.0E-08	2.0E-07	9.0E-07	Gamma	0.30	1.50E+06
	FTCL	WSRC	5.0E-04	5.0E-02	1.0E-01	4.0E-01	Beta	0.50	4.50E+00

A.2.45.5 Breakdown by System

SVV UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.45-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.45-8. SVV p and λ by system.

System	FTO	FTC	SO	FTCL
MSS	2.3E-03	-	2.3E-07	-
RCS	4.6E-03	-	5.3E-07	-

A.2.46 Turbine-Driven Pump (TDP) Data Sheet

A.2.46.1 Component Description

The TDP boundary includes the pump, turbine, governor control, steam emission valve, local lubrication or cooling systems, and local instrumentation and controls. The failure modes for TDP are listed in Table A.2.46-1.

Table A.2.46-1. TDP failure modes.

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

A.2.46.2 Data Collection and Review

Data for TDP UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002, except for the ELS data, which cover 1997–2004. After analyzing the original data, there were no standby FTR>1H failures, so the data set was expanded to 1997– 2004 for the standby FTR>1H failure mode (see Section A.1). There are 175 TDPs from 97 plants in the data originally gathered by RADS. After removing data without demand or run hour information (see Section A.1) there were 174 components in 97 plants. These data were then further partitioned into standby and running/alternating components. The systems and operational status included in the TDP data collection are listed in Table A.2.46-2 with the number of components included with each system.

Table A.2.46-2. TDP systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 200 Demands per Year
Standby	AFW	Auxiliary feedwater	62	62	62
	HCI	High pressure coolant injection	24	24	24
	MFW	Main feedwater	4	4	4
	RCI	Reactor core isolation	30	29	29
	Total		120	119	119
Running/Alternating	MFW	Main feedwater	55	55	55
	Total		55	55	55

The data review process is described in detail in Section A.1. Table A.2.46-3 summarizes the data obtained from EPIX and used in the TDP analysis. Note that the hours for ELS are calendar hours.

Figure A.2.46-1a shows the range of start demands per year in the standby TDP data set. The start demands per year range from approximately 2 to 34. The average for the data set is 12.8 demands/year. Figure A.2.46-1b shows the range of start demands per year in the running/alternating TDP data set. The demands per year range from approximately 0 to 4. The average for the data set is 1.8 demands/year. Figure A.2.46-2a shows the range of run hours per demand in the standby TDP data set. The run hours per demand range is from approximately 0 hours/demand to 22 hours/demand. The average is 1.5 hours/demand. Figure A.2.46-2b shows the range of run hours per demands in the running TDP data set. The range is from approximately 1460 hours/demand to 12,165 hours/demand. The average is 5539.4 hours/demand.

Table A.2.46-3. TDP unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Standby	FTS	46	7627	119	93	26.1%	29.0%
	FTR≤1H	18	7188	113	87	12.6%	16.1%
	FTR>1H	0	6803 h	6	6	0.0%	0.0%
Running/ Alternating	FTS	11	503	55	25	8.4%	8.6%
	FTR	13	2231788 h	55	25	10.1%	9.7%
All	ELS	1	12264000 h	175	141	0.8%	1.1%

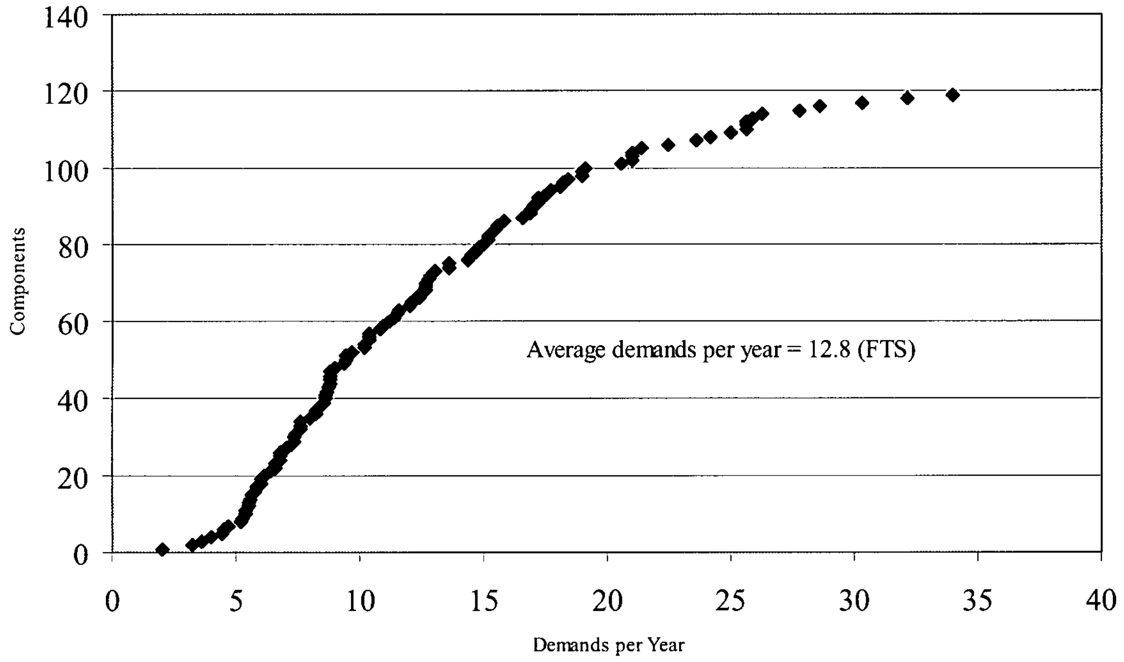

Figure A.2.46-1a. Standby TDP demands per year distribution.

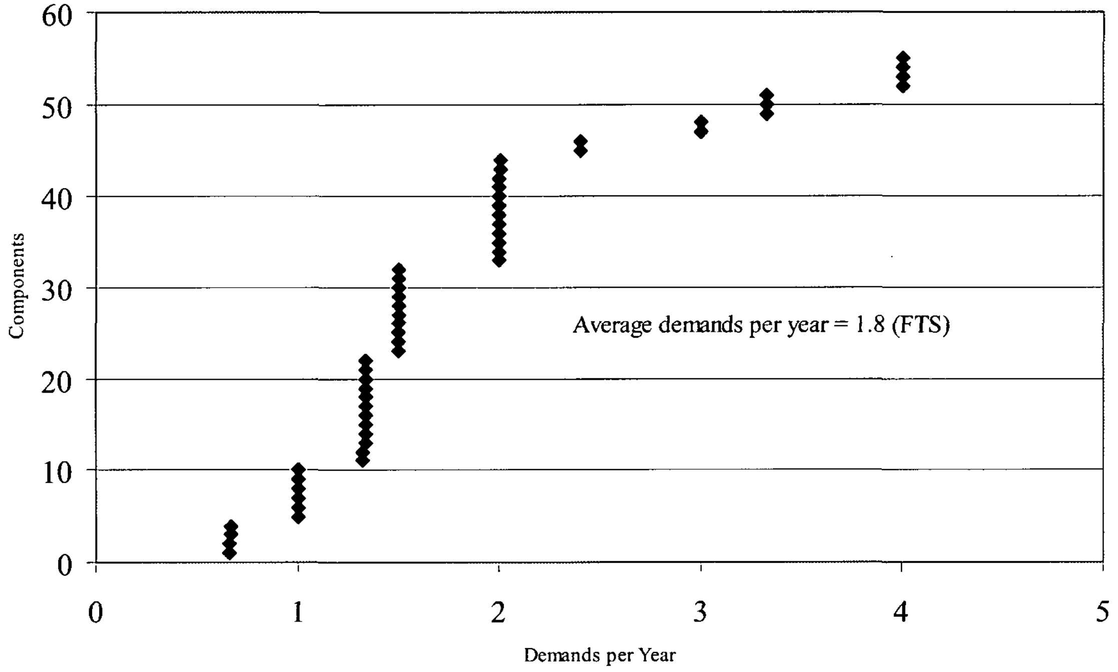

Figure A.2.46-1b. Running/alternating TDP demands per year distribution.

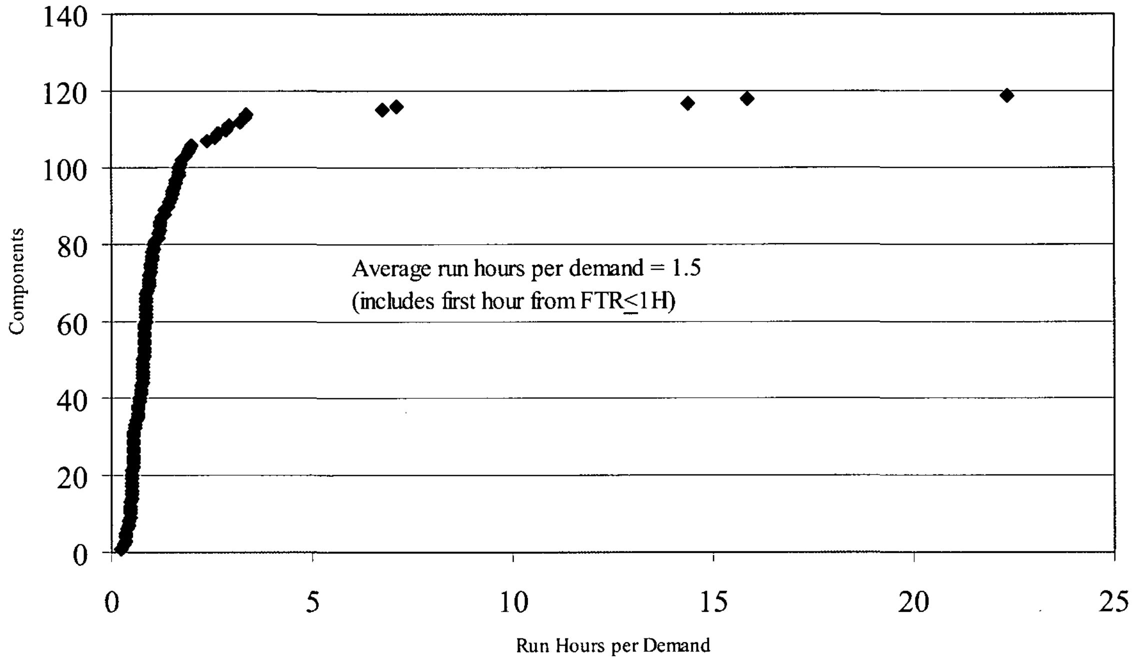

Figure A.2.46-2a. Standby TDP run hours per demand distribution.

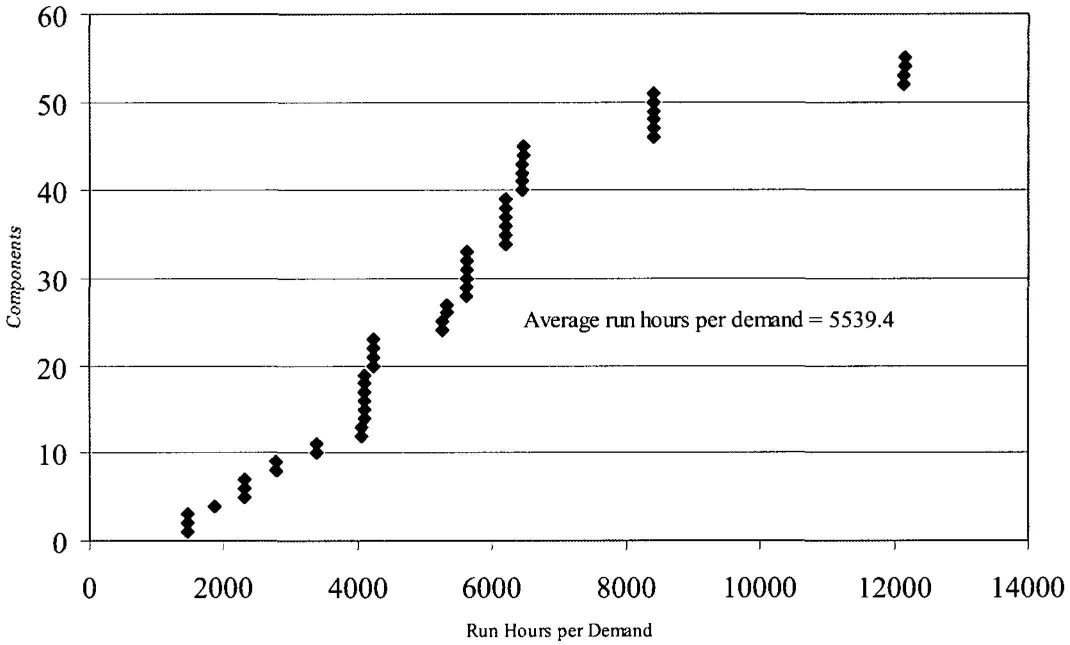

Figure A.2.46-2b. Running/alternating TDP run hours per demand distribution.

A.2.46.3 Data Analysis

The TDP data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.46-4.

Table A.2.46-4. Empirical distributions of MLEs for p and λ for TDPs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Standby	FTS	Component	0.00E+00	0.00E+00	9.27E-03	3.70E-02
		Plant	0.00E+00	0.00E+00	8.03E-03	3.79E-02
		Industry	-	-	6.03E-03	-
	FTR≤1H	Component	0.00E+00	0.00E+00	2.86E-03	2.63E-02
		Plant	0.00E+00	0.00E+00	2.99E-03	2.14E-02
		Industry	-	-	2.50E-03	-
	FTR>1H	Component	-	-	0.00E+00	-
		Plant	-	-	0.00E+00	-
		Industry	-	-	0.00E+00	-
Running/ Alternating	FTS	Component	0.00E+00	0.00E+00	1.90E-02	1.00E-01
		Plant	0.00E+00	0.00E+00	2.15E-02	8.31E-02
		Industry	-	-	2.19E-02	-
	FTR	Component	0.00E+00	0.00E+00	5.71E-06	2.44E-05
		Plant	0.00E+00	0.00E+00	5.16E-06	1.62E-05
		Industry	-	-	5.82E-06	-
All	ELS	Component	0.00E+00	0.00E+00	8.15E-08	0.00E+00
		Plant	0.00E+00	0.00E+00	1.01E-07	0.00E+00
		Industry	-	-	8.15E-08	-

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.46-3, 26.1% of the TDPs experienced a FTS over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 73.9% portion of the distribution, and non-zero values above 73.9%.

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.46-5 for TDPs.

Table A.2.46-5. Fitted distributions for p and λ for TDPs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/CL/KS	9.22E-06	2.68E-03	7.04E-03	2.89E-02	Beta	0.414	5.831E+01
		EB/PL/KS	9.01E-06	2.62E-03	6.88E-03	2.82E-02	Beta	0.414	5.973E+01
		SCNID/IL	2.42E-05	2.79E-03	6.10E-03	2.34E-02	Beta	0.500	8.152E+01
	FTR≤1H	EB/CL/KS	4.74E-05	1.51E-03	2.56E-03	8.66E-03	Gamma	0.712	2.781E+02
		EB/PL/KS	7.12E-05	1.65E-03	2.64E-03	8.58E-03	Gamma	0.796	3.017E+02
		SCNID/IL	1.01E-05	1.17E-03	2.57E-03	9.89E-03	Gamma	0.500	1.943E+02
	FTR>1H	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	2.89E-07	3.34E-05	7.35E-05	2.82E-04	Gamma	0.500	6.803E+03
Running/ Alternating	FTS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	2.12E-03	1.71E-02	2.22E-02	5.96E-02	Beta	1.323	5.836E+01
		SCNID/IL	9.30E-05	1.07E-02	2.28E-02	8.68E-02	Beta	0.500	2.139E+01
	FTR	JEFF/CL	3.62E-06	5.90E-06	6.05E-06	8.99E-06	Gamma	13.500	2.232E+06
		EB/PL/KS	1.76E-06	5.22E-06	5.77E-06	1.17E-05	Gamma	3.422	5.929E+05
		SCNID/IL	2.38E-08	2.75E-06	6.05E-06	2.32E-05	Gamma	0.500	8.266E+04
All	ELS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	4.81E-10	5.56E-08	1.22E-07	4.70E-07	Gamma	0.500	4.088E+06

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

A.2.46.4 Industry-Average Baselines

Table A.2.46-6 lists the selected industry distributions of p and λ for the TDP failure modes. For Standby FTS and FTR≤1H and Running/Alternating FTS and FTR failure modes, the data sets were sufficient for empirical Bayes analyses to be performed. For these failure modes, the industry-average distributions are based on the empirical Bayes analysis results at the plant level. However, the industry-average distributions for FTR>1H and ELS are not sufficient (Section A.1) for the empirical Bayes method; therefore, a SCNID analysis was performed to provide a failure rate distribution. However, the data for FTR>1H are limited (a larger data set was obtained to improve the estimate) and contain no failures.

The selected ELL mean is the ELS mean multiplied by 0.07, with an assumed α of 0.3. The 0.07 multiplier is based on limited EPIX data for large leaks as explained in Section A.1. These industry-average failure rates do not account for any recovery.

Table A.2.46-6. Selected industry distributions of p and λ for TDPs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/PL/KS	9.01E-06	2.62E-03	6.88E-03	2.82E-02	Beta	0.414	5.973E+01
	FTR≤1H	EB/PL/KS	7.12E-05	1.65E-03	2.64E-03	8.58E-03	Gamma	0.796	3.017E+02
	FTR>1H	SCNID/IL	2.89E-07	3.34E-05	7.35E-05	2.82E-04	Gamma	0.500	6.803E+03
Running/ Alternating	FTS	EB/PL/KS	2.12E-03	1.71E-02	2.22E-02	5.96E-02	Beta	1.323	5.836E+01
	FTR	EB/PL/KS	1.76E-06	5.22E-06	5.77E-06	1.17E-05	Gamma	3.422	5.929E+05
All	ELS	SCNID/IL	4.81E-10	5.56E-08	1.22E-07	4.70E-07	Gamma	0.500	4.088E+06
	ELL	ELS/EPIX	9.16E-13	2.09E-09	8.56E-09	3.92E-08	Gamma	0.300	3.504E+07

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.46-7 shows the rounded values for the TDP failure modes.

Table A.2.46-7. Selected industry distributions of p and λ for TDPs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTS	EB/PL/KS	7.0E-06	2.5E-03	7.0E-03	3.0E-02	Beta	0.40	5.71E+01
	FTR≤1H	EB/PL/KS	7.0E-05	1.5E-03	2.5E-03	8.0E-03	Gamma	0.80	3.20E+02
	FTR>1H	SCNID/IL	3.0E-07	3.0E-05	7.0E-05	2.5E-04	Gamma	0.50	7.14E+03
Running/ Alternating	FTS	EB/PL/KS	1.5E-03	1.5E-02	2.0E-02	6.0E-02	Beta	1.20	6.00E+01
	FTR	EB/PL/KS	1.5E-06	5.0E-06	6.0E-06	1.2E-05	Gamma	3.00	5.00E+05
All	ELS	SCNID/IL	5.0E-10	5.0E-08	1.2E-07	5.0E-07	Gamma	0.50	4.17E+06
	ELL	ELS/EPIX	1.0E-12	2.0E-09	9.0E-09	4.0E-08	Gamma	0.30	3.33E+07

A.2.46.5 Breakdown by System

TDP UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.46-8. Results are shown only the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.46-8. TDP p and λ by system.

Operation	System	FTS	FTR≤1H	FTR>1H
Standby	AFW	4.8E-03	2.5E-03	-
	HCI	1.3E-02	2.8E-03	-
	RCI	7.5E-03	4.1E-03	-
	MFW	5.5E-03	-	-
Operation	System	FTS		FTR
Running/ Alternating	MFW	2.3E-02		6.0E-06
Operation	System	ELS		
All	AFW	3.5E-07		
	HCI	-		
	RCI	-		
	MFW	-		

A.2.47 Transformer (TFM) Data Sheet

A.2.47.1 Component Description

The transformer (TFM) boundary includes the transformer unit. The failure mode for TFM is listed in Table A.2.47-1.

Table A.2.47-1. TFM failure modes.

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

A.2.47.2 Data Collection and Review

Data for TFM UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. Failures were identified using the FTOP failure mode. There are 4544 TFMs from 98 plants in the EPIX data. The systems included in the TFM data collection are listed in Table A.2.47-2 with the number of components included with each system.

Table A.2.47-2. TFM systems.

Operation	System	Description	Number of Components
Running	ACP	Plant ac power	4544
	Total		4544

The data review process is described in detail in Section A.1. Table A.2.47-3 summarizes the data obtained from EPIX and used in the TFM analysis. Note that the hours are calendar hours.

Table A.2.47-3. TFM unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Running	FTOP	81	199027200 h	4544	98	1.3%	35.7%

A.2.47.3 Data Analysis

The TFM data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.47-4.

Table A.2.47-4. Empirical distributions of MLEs for p and λ for TFMs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Running	FTOP	Component	0.00E+00	0.00E+00	4.07E-07	0.00E+00
		Plant	0.00E+00	0.00E+00	1.01E-06	3.81E-06
		Industry	-	-	4.07E-07	-

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.47-3, only 1.3% of the TFMs experienced a FTOP over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 98.7% portion of the distribution, and non-zero values above 98.7%.

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.47-5 for TFMs.

Table A.2.47-5. Fitted distributions for p and λ for TFMs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution Type	α	β
Running	FTOP	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	1.44E-10	2.36E-07	9.04E-07	4.08E-06	Gamma	0.314	3.468E+05
		SCNID/IL	1.61E-09	1.86E-07	4.09E-07	1.57E-06	Gamma	0.500	1.221E+06

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

A.2.47.4 Industry-Average Baselines

Table A.2.47-6 lists the industry-average failure rate distributions. The data set was sufficient (Section A.1) for empirical Bayes analyses to be performed. The industry-average distribution is based on the empirical Bayes analysis results at the plant level. This industry-average failure rate does not account for any recovery.

Table A.2.47-6. Selected industry distributions of p and λ for TFMs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution Type	α	β
Running	FTOP	EB/PL/KS	1.44E-10	2.36E-07	9.04E-07	4.08E-06	Gamma	0.314	3.468E+05

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.47-7 shows the rounded values for the TFM FTOP failure mode.

Table A.2.47-7. Selected industry distributions of p and λ for TFMs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution Type	α	β
Running	FTOP	EB/PL/KS	1.0E-10	2.0E-07	9.0E-07	4.0E-06	Gamma	0.30	3.33E+05

A.2.47.5 Breakdown by System

The TFM component is only in one system, the ac power system.

A.2.48 Tank (TNK) Data Sheet

A.2.48.1 Component Description

The tank (TNK) boundary includes the tank. The failure modes for TNK are listed in Table A.2.48-1.

Table A.2.48-1. TNK failure modes.

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

A.2.48.2 Data Collection and Review

Data for TNK UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1997–2004. There are 1398 TNKs from 101 plants in the data originally gathered from EPIX. These data were then further partitioned into pressurized and unpressurized components. The systems and operational status included in the TNK data collection are listed in Table A.2.48-2 with the number of components included with each system.

Table A.2.48-2. TNK systems.

Operation	System	Description	Number of Components
All (Pressurized)	CCW	Component cooling water	76
	CDS	Condensate system	4
	CHW	Chilled water system	8
	CIS	Containment isolation system	11
	CRD	Control rod drive	10
	CSR	Containment spray recirculation	15
	CTS	Condensate transfer system	3
	CVC	Chemical and volume control	156
	EPS	Emergency power supply	33
	ESW	Emergency service water	7
	HCS	High pressure core spray	5
	HPI	High pressure injection	76
	HVC	Heating ventilation and air conditioning	2
	LPI	Low pressure injection	165
	MFW	Main feedwater	6
	MSS	Main steam	87
	Other	Other	18
	RCI	Reactor core isolation	3
	RCS	Reactor coolant	6
	RRS	Reactor recirculation	1
	SLC	Standby liquid control	29
	TBC	Turbine building cooling water	6
	Total		727
All (Unpressurized)	AFW	Auxiliary feedwater	4
	CCW	Component cooling water	127
	CDS	Condensate system	24
	CHW	Chilled water system	6
	CIS	Containment isolation system	24
	CSR	Containment spray recirculation	42
	CTS	Condensate transfer system	21
	CVC	Chemical and volume control	64

Operation	System	Description	Number of Components
	EPS	Emergency power supply	139
	ESW	Emergency service water	12
	FWS	Firewater	6
	HCI	High pressure coolant injection	12
	HCS	High pressure core spray	12
	HPI	High pressure injection	32
	IAS	Instrument air	3
	ICS	Ice condenser	5
	LCS	Low pressure core spray	2
	LPI	Low pressure injection	38
	MFW	Main feedwater	4
	MSS	Main steam	20
	Other	Other	19
	RCI	Reactor core isolation	11
	SLC	Standby liquid control	43
	TBC	Turbine building cooling water	1
	Total		671

The data review process is described in detail in Section A.1. Table A.2.48-3 summarizes the data obtained from EPIX and used in the TNK analysis. Note that the hours for ELS are calendar hours.

Table A.2.48-3. TNK unreliability data.

Component Operation	Failure Mode	Data After Review		Counts		Percent With Failures	
		Failures	Demands or Hours	Components	Plants	Components	Plants
Pressurized	ELS	1.5	50948160 h	727	96	0.3%	2.1%
Unpressurized	ELS	1	47023680 h	671	101	0.3%	2.0%

A.2.48.3 Data Analysis

The TNK data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.48-4.

Table A.2.48-4. Empirical distributions of MLEs for p and λ for TNKs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Pressurized	ELS	Component	0.00E+00	0.00E+00	2.94E-08	0.00E+00
		Plant	0.00E+00	0.00E+00	1.34E-07	0.00E+00
		Industry	-	-	2.94E-08	-
Unpressurized	ELS	Component	0.00E+00	0.00E+00	2.13E-08	0.00E+00
		Plant	0.00E+00	0.00E+00	2.02E-08	0.00E+00
		Industry	-	-	2.13E-08	-

The MLE distributions at the component and plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.48-3, 0.3% of the TNKs experienced a ELS over the period 1998–2002, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 99.7% portion of the distribution, and non-zero values above 99.7%.

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table A.2.48-5 for TNKs.

Table A.2.48-5. Fitted distributions for p and λ for TNKs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Pressurized	ELS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.55E-10	1.79E-08	3.93E-08	1.51E-07	Gamma	0.500	1.272E+07
Unpressurized	ELS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.25E-10	1.45E-08	3.19E-08	1.23E-07	Gamma	0.500	1.567E+07

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

A.2.48.4 Industry-Average Baselines

Table A.2.48-6 lists the industry-average failure rate distributions. For ELS, the EB/PL/KS result indicated and α parameter lower than 0.3. As explained in Section A.1, in these cases a lower limit of 0.3 (upper bound on the uncertainty band) was assumed. The selected ELL mean is the ELS mean multiplied by 0.07, with an assumed α of 0.3. The 0.07 multiplier is based on limited EPIX data for large leaks as explained in Section A.1.

Table A.2.48-6. Selected industry distributions of p and λ for TNKs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Pressurized	ELS	SCNID/IL	1.55E-10	1.79E-08	3.93E-08	1.51E-07	Gamma	0.500	1.272E+07
	ELL	ELS/EPIX	2.94E-13	6.70E-10	2.75E-09	1.26E-08	Gamma	0.300	1.091E+08
Unpressurized	ELS	SCNID/IL	1.25E-10	1.45E-08	3.19E-08	1.23E-07	Gamma	0.500	1.567E+07
	ELL	ELS/EPIX	2.39E-13	5.44E-10	2.23E-09	1.02E-08	Gamma	0.300	1.343E+08

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.48-7 shows the rounded values for the TNK failure modes.

Table A.2.48-7. Selected industry distributions of p and λ for TNKs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Pressurized	ELS	SCNID/IL	1.5E-10	2.0E-08	4.0E-08	1.5E-07	Gamma	0.50	1.00E+07
	ELL	ELS/EPIX	3.0E-13	7.0E-10	3.0E-09	1.5E-08	Gamma	0.30	1.00E+08
Unpressurized	ELS	SCNID/IL	1.2E-10	1.5E-08	3.0E-08	1.2E-07	Gamma	0.50	1.67E+07
	ELL	ELS/EPIX	2.0E-13	5.0E-10	2.0E-09	9.0E-09	Gamma	0.30	1.50E+08

A.2.48.5 Breakdown by System

TNK UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.48-8. Results are shown only the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.48-8. TNK p and λ by system.

		Pressurized	Un-pressurized
Operation	System	ELS	ELS
All	AFW	-	-
	CCW	-	-
	CDS	-	-
	CHW	-	-
	CIS	-	-
	CSR	-	-
	CTS	-	-
	CVC	-	-
	EPS	-	-
	ESW	-	-
	FWS	-	-
	HCI	-	-
	HCS	-	-
	HPI	2.8E-07	-
	IAS	-	-
	ICS	-	-
	LCS	-	-
	LPI	-	-
	MFW	-	-
	MSS	2.5E-07	-
	Other	-	1.1E-06
	RCI	-	-
	SLC	-	-
	TBC	-	-

A.2.49 Traveling Screen Assembly (TSA) Data Sheet

A.2.49.1 Component Description

The traveling screen (TSA) component boundary includes the traveling screen, motor, and drive mechanism. The failure mode for TSA is listed in Table A.2.49-1.

Table A.2.49-1. TSA failure modes.

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

A.2.49.2 Data Collection and Review

Data for the TSA UR baseline were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002. There are 125 TSAs from 35 plants in the data. After removing data without demand information (see Section A.1) there were 125 components in 35 plants. The systems included in the TSA data collection are listed in Table A.2.49-2 with the number of components included with each system.

Table A.2.49-2. TSA systems.

Operation	System	Description	Number of Components	
			Initial	After Review
All	CWS	Circulating water system	125	125
	ESW	Emergency cooling water	71	71
	Total		196	196

Table A.2.49-3 summarizes the data used in the TSA analysis. Note that the PG hours are calendar hours. Also, TSA PG events that were caused by problems with the screen wash system were included.

Table A.2.49-3. TSA unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	PG	29	8584800 h	196	36	13.8%	38.9%

A.2.49.3 Data Analysis

The TSA data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.42-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.49-3, 13.8% of the TSAs experienced a PG over the period 1998–2002, so the distribution of MLEs, at the component level, involves zeros for the 0% to 86.2% portion of the distribution, and non-zero values above 86.2%.

Table A.2.49-4. Empirical distributions of MLEs for p and λ for TSAs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
All	PG	Component	0.00E+00	0.00E+00	3.38E-06	2.28E-05
		Plant	0.00E+00	0.00E+00	5.03E-06	2.28E-05
		Industry	-	-	3.38E-06	-

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.49-5.

Table A.2.49-5. Fitted distributions for p and λ for TSAs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	PG	JEFF/CL	2.47E-06	3.40E-06	3.44E-06	4.54E-06	Gamma	29.500	8.585E+06
		EB/PL/KS	1.87E-08	2.14E-06	4.68E-06	1.80E-05	Gamma	0.502	1.072E+05
		SCNID/IL	1.35E-08	1.56E-06	3.44E-06	1.32E-05	Gamma	0.500	1.455E+05

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

A.2.49.4 Industry-Average Baselines

Table A.2.49-6 lists the industry-average failure rate distribution for the TSA component. For the PG failure mode, the data set was sufficient (see Section A.1) for empirical Bayes analyses to be performed. Therefore, the industry-average distribution is based on the empirical Bayes analysis results at the plant level for PG.

Table A.2.49-6. Selected industry distributions of p and λ for TSAs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	PG	EB/PL/KS	1.87E-08	2.14E-06	4.68E-06	1.80E-05	Gamma	0.502	1.072E+05

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.49-7 shows the rounded values for the TSA failure mode.

Table A.2.49-7. Selected industry distributions of p and λ for TSAs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	PG	EB/PL/KS	2.0E-08	2.5E-06	5.0E-06	2.0E-05	Gamma	0.50	1.00E+05

A.2.49.5 Breakdown by System

TSA UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.46-8. Results are shown only the systems and failure modes with failures. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.49-8. TSA p and λ by system.

Operation	System	PG
Standby	ESW	6.9E-06
	CWS	1.6E-06

A.2.50 Vacuum Breaker Valve (VBV) Data Sheet

A.2.50.1 Component Description

The vacuum breaker valve (VBV) component boundary includes the valve, the valve operator, local circuit breaker, and local instrumentation and control circuitry. The failure modes for VBV are listed in Table A.2.50-1.

Table A.2.50-1. VBV failure modes.

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

A.2.50.2 Data Collection and Review

Data for VBV UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1998–2002 using RADS. There are 168 VBVs from 20 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1) there were 160 components in 19 plants. The systems included in the VBV data collection are listed in Table A.2.50-2 with the number of components included with each system.

Table A.2.50-2. VBV systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
All	CIS	Containment isolation system	47	45	43
	VSS	Vapor suppression	121	115	96
	Total		168	160	139

The VBV data set obtained from RADS was further reduced to include only those VBVs with ≤ 20 demands/year. See Section A.1 for a discussion concerning this decision to limit the component populations for valves. Table A.2.50-3 summarizes the data used in the VBV analysis.

Table A.2.50-3. VBV unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
All	FTO	3	7301	139	16	2.2%	18.8%
	FTC	2	7301	139	16	1.4%	12.5%

Figure A.2.50-1 shows the range of valve demands per year in the VBV data set (limited to ≤ 20 demands/year). The demands per year range from approximately 3.8 to 20. The average for the data set is 10.5 demands/year.

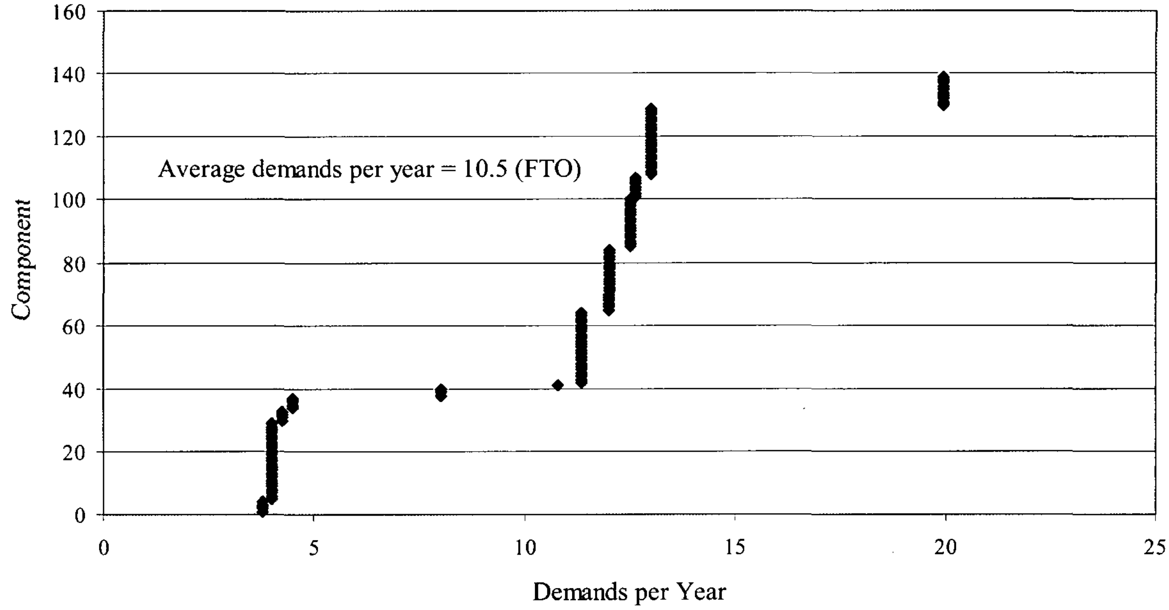

Figure A.2.50-1. VBV demands per year distribution.

A.2.50.3 Data Analysis

The VBV data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.50-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.50-3, the VBVs experienced 3 FTOs over the period 1998–2002, so the distribution of MLEs, at the component level, involves zeros for the 0% to 97.8% portion of the distribution, and non-zero values above 97.8%.

Table A.2.50-4. Empirical distributions of MLEs for p and λ for VBVs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
All	FTO	Component	0.00E+00	0.00E+00	5.86E-04	0.00E+00
		Plant	0.00E+00	0.00E+00	1.31E-03	1.39E-03
		Industry	-	-	4.11E-04	-
	FTC	Component	0.00E+00	0.00E+00	2.91E-04	0.00E+00
		Plant	0.00E+00	0.00E+00	5.96E-04	1.21E-03
		Industry	-	-	2.74E-04	-

Empirical Bayes analyses were performed at both the component and plant level. The simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and $\alpha = 0.5$. Results from these analyses are presented in Table A.2.50-5. These results were used to develop the industry-average distributions for FTO and FTC.

Table A.2.50-5. Fitted distributions for p and λ for VBVs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.89E-06	2.18E-04	4.79E-04	1.84E-03	Beta	0.500	1.043E+03
	FTC	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.35E-06	1.56E-04	3.42E-04	1.32E-03	Beta	0.500	1.460E+03

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

A.2.50.4 Industry-Average Baselines

Table A.2.50-6 lists the selected industry distributions of p and λ for the VBV failure modes. The data set was not sufficient for either failure mode (see Section A.1) for empirical Bayes analyses to be performed. Therefore, SCNID analyses were performed to provide failure rate distributions for FTO and FTC. These industry-average failure rates do not account for any recovery.

Table A.2.50-6. Selected industry distributions of p and λ for VBVs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	SCNID/IL	1.89E-06	2.18E-04	4.79E-04	1.84E-03	Beta	0.500	1.043E+03
	FTC	SCNID/IL	1.35E-06	1.56E-04	3.42E-04	1.32E-03	Beta	0.500	1.460E+03

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.50-7 shows the rounded values for the VBV failure modes.

Table A.2.50-7. Selected industry distributions of p and λ for VBVs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
All	FTO	SCNID/IL	2.0E-06	2.5E-04	5.0E-04	2.0E-03	Beta	0.50	1.00E+03
	FTC	SCNID/IL	1.2E-06	1.5E-04	3.0E-04	1.2E-03	Beta	0.50	1.67E+03

A.2.50.5 Breakdown by System

VBV UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.50-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.50-8. VBV p and λ by system.

System	FTO	FTC
CIS	-	-
VSS	6.1E-04	4.3E-04

A.2.51 Manual Valve (XVM) Data Sheet

A.2.51.1 Component Description

The manual valve (XVM) component boundary includes the valve and valve operator. The failure modes for XVM are listed in Table A.2.41-1.

Table A.2.51-1. XVM failure modes.

Operation	Failure Mode	Parameter	Units	Description
Standby	FTO/C	p	-	Failure to open or failure to close
	PLG	λ	1/h	Plug
	ELS	λ	1/h	External leak small
	ELL	λ	1/h	External leak large
	ILS	λ	1/h	Internal leak small
	ILL	λ	1/h	Internal leak large

A.2.51.2 Data Collection and Review

Data for XVM UR baselines were obtained from the Equipment Performance and Information Exchange (EPIX) database, covering 1997–2004 using RADS. There are 119 XVMs from 13 plants in the data originally gathered by RADS. After removing data without demand information (see Section A.1) there were 109 components in 13 plants. The systems included in the XVM data collection are listed in Table A.2.51-2 with the number of components included with each system.

Table A.2.51-2. XVM systems.

Operation	System	Description	Number of Components		
			Initial	After Review	≤ 20 Demands per Year
Standby	AFW	Auxiliary feedwater	5	5	5
	CCW	Component cooling water	24	19	19
	CHW	Chilled water system	1	1	-
	CIS	Containment isolation system	27	27	27
	CSR	Containment spray recirculation	2	2	2
	CVC	Chemical and volume control	11	10	10
	ESW	Emergency service water	16	15	14
	HPI	High pressure injection	6	5	5
	LCI	Low pressure coolant injection	6	4	4
	LPI	Low pressure injection	10	10	10
	MFW	Main feedwater	1	1	1
	MSS	Main steam	6	6	6
	SLC	Standby liquid control	4	4	4
	Total		119	109	107

The XVM data set obtained from RADS was further reduced to include only those XVMs with ≤ 20 demands/year. See Section A.1 for a discussion concerning this decision to limit certain component populations. The XVM population in RADS is significantly larger than 107. However, most of these components do not have an entry showing hours or demands. It was decided to use the larger population (1121) for the PLG and ELS failure mode calculations, since only calendar time is required for the exposure. Table A.2.51-3 summarizes the data used in the XVM analysis. Note that the hours for PLG, ELS, and ILS are calendar hours.

Table A.2.51-3. XVM unreliability data.

Mode of Operation	Failure Mode	Data		Counts		Percent With Failures	
		Events	Demands or Hours	Components	Plants	Components	Plants
Standby	FTO/C	1	2017	107	12	0.9%	8.3%
	PLG	0	78559680 h	1121	81	0.0%	0.0%
	ELS	3	78559680 h	1121	81	2.8%	25.0%
	ILS	0	7498560 h	107	12	0.0%	0.0%

Figure A.2.51-1 shows the range of valve demands per year in the XVM data set (limited to ≤ 20 demands/year). The demands per year range from approximately 1 to 12. The average for the data set is 2.4 demands/year.

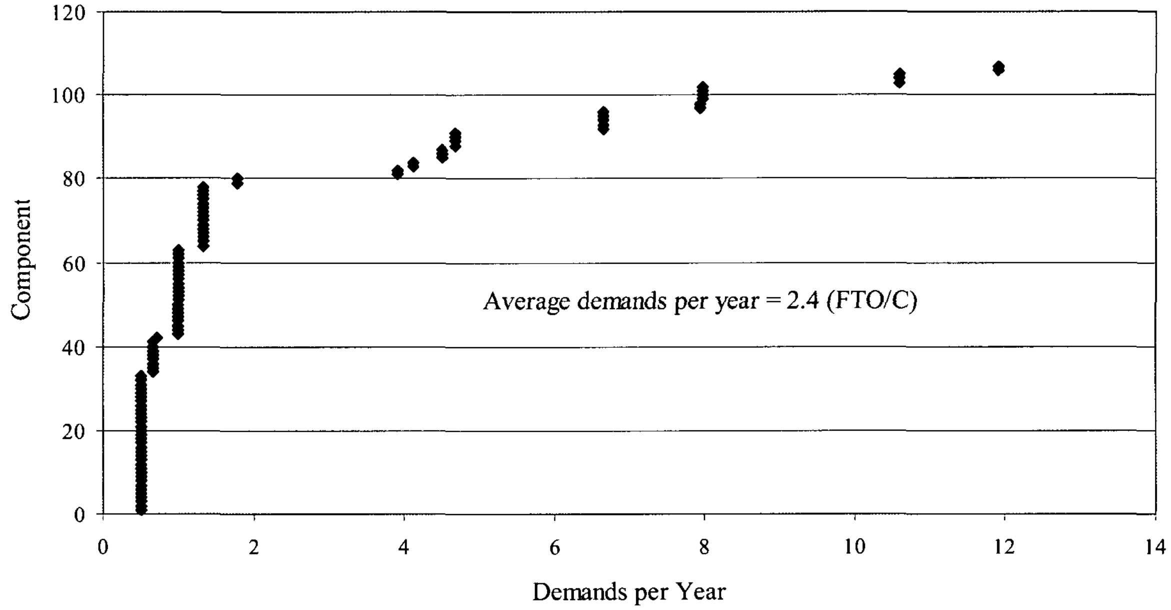

Figure A.2.51-1. XVM demands per year distribution.

A.2.51.3 Data Analysis

The XVM data can be examined at the component, plant, or industry level. At each level, maximum likelihood estimates (MLEs) are failures/demands (or hours). At the component or plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for all three levels are presented in Table A.2.51-4.

The MLE distributions at the component and plant levels typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table A.2.51-3, only 0.9% of the XVMs experienced a FTO/C over the period 1997–2004, so the empirical distribution of MLEs, at the component level, involves zeros for the 0% to 99.1% portion of the distribution, and non-zero values above 99.1%.

Table A.2.51-4. Empirical distributions of MLEs for p and λ for XVMs.

Operating Mode	Failure Mode	Aggregation Level	5%	Median	Mean	95%
Standby	FTO/C	Component	0.00E+00	0.00E+00	1.75E-03	0.00E+00
		Plant	0.00E+00	0.00E+00	1.56E-02	0.00E+00
		Industry	-	-	4.96E-04	-
	PLG	Component	-	-	-	-
		Plant	-	-	-	-
		Industry	-	-	0.00E+00	-
	ELS	Component	0.00E+00	0.00E+00	3.82E-08	0.00E+00
		Plant	0.00E+00	0.00E+00	3.23E-07	0.00E+00
		Industry	-	-	3.82E-08	-
	ILS	Component	-	-	-	-
		Plant	-	-	-	-
		Industry	-	-	0.00E+00	-

Empirical Bayes analyses were performed at both the component and plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean of industry data and α = 0.5. Results from these analyses are presented in Table A.2.51-5.

Table A.2.51-5. Fitted distributions for p and λ for XVMs.

Operation	Failure Mode	Analysis Type	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTO/C	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	2.93E-06	3.39E-04	7.43E-04	2.86E-03	Beta	0.500	6.720E+02
	PG	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	2.50E-11	2.90E-09	6.36E-09	2.45E-08	Gamma	0.500	7.855E+07
	ELS	JEFF/CL	1.38E-08	4.04E-08	4.46E-08	8.95E-08	Gamma	3.500	7.856E+07
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	1.75E-10	2.03E-08	4.45E-08	1.71E-07	Gamma	0.500	1.122E+07
	ILS	EB/CL/KS	-	-	-	-	-	-	-
		EB/PL/KS	-	-	-	-	-	-	-
		SCNID/IL	2.62E-10	3.03E-08	6.67E-08	2.56E-07	Gamma	0.500	7.499E+06

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

A.2.51.4 Industry-Average Baselines

Table A.2.51-6 lists the selected industry distributions of p and λ for the XVM failure modes. The industry-average distributions for FTO/C, ILS, and ELS are not sufficient (Section A.1) for the empirical Bayes method; therefore, a SCNID analysis was performed to provide failure rate distributions. The selected ELL mean is the ELS mean multiplied by 0.07, with an assumed α of 0.3. The selected ILL mean is the ILS mean multiplied by 0.02, with an assumed α of 0.3. The 0.07 and 0.02 multipliers are based on limited EPIX data for large leaks as explained in Section A.1. These industry-average failure rates do not account for any recovery.

Table A.2.51-6. Selected industry distributions of p and λ for XVMs (before rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTO/C	SCNID/IL	2.93E-06	3.39E-04	7.43E-04	2.86E-03	Beta	0.500	6.720E+02
	PG	SCNID/IL	2.50E-11	2.90E-09	6.36E-09	2.45E-08	Gamma	0.500	7.855E+07
	ELS	SCNID/IL	1.75E-10	2.03E-08	4.45E-08	1.71E-07	Gamma	0.500	1.122E+07
	ELL	ELS/EPIX	3.34E-13	7.60E-10	3.12E-09	1.43E-08	Gamma	0.300	9.620E+07
	ILS	SCNID/IL	2.62E-10	3.03E-08	6.67E-08	2.56E-07	Gamma	0.500	7.499E+06
	ILL	ILS/EPIX	1.43E-13	3.25E-10	1.33E-09	6.10E-09	Gamma	0.300	2.250E+08

For use in the SPAR models, the industry-average failure rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table A.2.51-7 shows the rounded values for the XVM failure modes.

Table A.2.51-7. Selected industry distributions of p and λ for XVMs (after rounding).

Operation	Failure Mode	Source	5%	Median	Mean	95%	Distribution		
							Type	α	β
Standby	FTO/C	SCNID/IL	3.0E-06	3.0E-04	7.0E-04	2.5E-03	Beta	0.50	7.14E+02
	PG	SCNID/IL	2.5E-11	2.5E-09	6.0E-09	2.5E-08	Gamma	0.50	8.33E+07
	ELS	SCNID/IL	1.5E-10	2.0E-08	4.0E-08	1.5E-07	Gamma	0.50	1.25E+07
	ELL	ELS/EPIX	3.0E-13	7.0E-10	3.0E-09	1.5E-08	Gamma	0.30	1.00E+08
	ILS	SCNID/IL	3.0E-10	3.0E-08	7.0E-08	2.5E-07	Gamma	0.50	7.14E+06
	ILL	ILS/EPIX	1.2E-13	3.0E-10	1.2E-09	5.0E-09	Gamma	0.30	2.50E+08

A.2.51.5 Breakdown by System

XVM UR results (Jeffreys means of system data) are compared by system and failure mode in Table A.2.51-8. Results are shown only for systems and failure modes with failures in the data set. Because some system and failure mode data sets are limited (few or only one failure and/or limited demands or hours), the results should be viewed with caution.

Table A.2.51-8. XVM p and λ by system.

System	FTO/C	PG	ELS	ILS
AFW	-	-	-	-
CCW	-	-	-	-
CDS	-	-	-	-
CHW	-	-	2.1E-07	-
CIS	-	-	-	-
CRD	-	-	-	-
CSR	-	-	-	-
CTS	-	-	-	-
CVC	-	-	2.4E-07	-
CWS	-	-	-	-
EPS	-	-	-	-
ESW	2.3E-03	-	-	-
FWS	-	-	-	-
HCI	-	-	-	-
HCS	-	-	-	-
HPI	-	-	5.9E-07	-
IAS	-	-	-	-
IPS	-	-	-	-
LCI	-	-	-	-
LCS	-	-	-	-
LPI	-	-	-	-
MFW	-	-	-	-
MSS	-	-	-	-
NSW	-	-	-	-
RCI	-	-	-	-
RCS	-	-	-	-
RPS	-	-	-	-
RRS	-	-	-	-
SGT	-	-	-	-
SLC	-	-	-	-
TBC	-	-	-	-

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Appendix B

Component/Train Unavailability Summaries

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Appendix B

Component/Train Unavailability Summaries

B.1 Introduction

This appendix provides supporting information and additional detail concerning the component/train unavailability (UA) parameter estimates presented in Section 6. UA as used in this report refers to UA resulting from test or maintenance (TM) outages while a plant is in critical operation. Baseline estimates reflect industry-average performance for component/train UA, where U.S. commercial nuclear power plants are defined as the industry. UA parameter estimates were obtained from a hierarchy of sources, as explained in Section 6. The preferred source is the Nuclear Regulatory Commission (NRC) Mitigating Systems Performance Index (MSPI) Program (Ref. B-1). Other sources include the Reactor Oversight Process (ROP) safety system unavailability (SSU) (Ref. B-2) and a review of UA data from individual plant examination (IPE) risk assessments (Ref. B-3). This appendix explains in how data from each of these sources were used to obtain industry-average UA parameter estimates.

B.2 Unavailability Estimates from the MSPI Database

The MSPI UA data cover four major safety systems and select cooling support systems. The four major safety systems are the emergency power system (EPS), high-pressure injection (HPI), decay heat removal, and residual heat removal (RHR). Within the EPS are emergency diesel generators (EDGs) and hydro turbine generators (HTGs). HPI systems include high-pressure safety injection (HPSI), high-pressure coolant injection (HPCI), high-pressure core spray (HPCS), and feedwater (FWR) injection. Decay heat removal systems include auxiliary feedwater system (AFWS), reactor core isolation cooling (RCIC), and isolation condenser (IC). RHR systems are separated into pressurized water reactor (PWR) and boiling water reactor (BWR) categories. Cooling support systems include emergency service water (ESW), normal service water (NSW), RHR service water (RHRSW) for BWRs, and component cooling water (CCW). Test and maintenance outage data for these systems are collected for pump (or EDG or HTG) trains, heat exchanger (HTX) trains, and piping header (HDR) trains. Outage data are reported within two categories, planned and unplanned. Planned outages include test durations (for those tests that render the train unavailable given an unplanned demand during the test) and planned maintenance outages such as periodic preventive maintenance or overhauls. Unplanned outages are typically incurred when a component fails and the train must be taken out of service in order to repair the component. Unplanned outages may also occur if a component exhibits incipient or degraded performance that might lead to a complete failure and a decision is made to repair the component.

MSPI program guidance for collection of UA data closely matches the requirements for use in PRAs. For example, only train outages during critical operation are considered, overhaul outages during critical operation are considered, and outages resulting from support system UA are not included. (The support system outages are modeled separately within the support systems.)

The MSPI UA data include two sources, the MSPI basis documents (covering UA over 2002–2004), and the UA data supplied quarterly to the NRC as part of the ongoing reporting of MSPI program results (starting with the second quarter of 2006). The UA data supplied quarterly cover at least back to the third quarter of 2003 (to ensure 3 years of data needed to calculate the performance indices). (Some plants reported data further back than the third quarter of 2003.) In order to obtain UA estimates closest to the desired period, 1998–2002, the data from the MSPI basis documents were used.

The MSPI basis documents present baseline UA data covering 2002–2004. These basis documents cover all 103 operating commercial nuclear power plants in the U.S. The basis documents were submitted to NRC in April 2006. Approximately 15% of the plants did not report unplanned outages in their basis documents because the MSPI program guidance indicates that the UA baselines should use industry-average unplanned UA estimates rather than plant-specific estimates. The other 85% of the plants reported the unplanned UA data even though industry-average estimates were used in their baseline calculations. For these 85% of the plants, the actual unplanned outages were identified within the basis documents and used in this data collection effort. For the other 15%, the industry-average contribution was assumed.

For each train within a system, the train UA was determined by summing the planned and unplanned outage hours and dividing by the plant critical operation hours during 2002–2004. This resulted in a set of train UA outages for each train UA event covered. The number of train estimates within a set ranged from four to more than 200. Each set of train estimates was then fit to a beta distribution using a maximum likelihood estimate approach. For sets with fewer than five train estimates, an average α of 2.5 was assumed. Results are presented in Table B-1.

Table B-1. MSPI UA data and fitted distributions.

EDG UA (219 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.0134	0.0134
SD	0.0079	0.0070
95%	0.0257	0.0267
50%	0.0121	0.0122
5%	0.0048	0.0043
EF	2.12	2.18
α		3.586
β		263.3

HPCS EDG UA (8 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.0133	0.0133
SD	0.0054	0.0055
95%	-	0.0235
50%	-	0.0126
5%	-	0.0057
EF	-	1.87
α		5.761
β		426.1

HPSI MDP UA (196 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.00412	0.00412
SD	0.0031	0.0027
95%	0.0100	0.0093
50%	0.0034	0.0036
5%	0.0009	0.0009
EF	2.93	2.61
α		2.348
β		567.5

HPCS MDP UA (8 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.0131	0.0131
SD	0.0163	0.0104
95%	-	0.0336
50%	-	0.0104
5%	-	0.0016
EF	-	3.22
α		1.537
β		115.9

AFWS MDP UA (122 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.00395	0.00395
SD	0.0023	0.0025
95%	0.0082	0.0088
50%	0.0037	0.0034
5%	0.0005	0.0009
EF	2.20	2.59
α		2.387
β		602.2

NSW MDP UA (6 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.0164	0.0164
SD	0.0068	0.0065
95%	-	0.0283
50%	-	0.0156
5%	-	0.0074
EF	-	1.82
α		6.278
β		376.1

ESW MDP UA (223 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.0130	0.0130
SD	0.0226	0.0128
95%	0.0507	0.0387
50%	0.0060	0.0091
5%	0.0002	0.0007
EF	8.41	4.26
α		1.000
β		75.9

RHRSW MDP UA (8 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.00576	0.00576
SD	0.0061	0.0050
95%	-	0.0156
50%	-	0.0044
5%	-	0.0005
EF	-	3.55
α		1.320
β		227.9

Table B-1. (continued).

CCW MDP UA (133 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.00591	0.00591
SD	0.0073	0.0052
95%	0.0184	0.0162
50%	0.0037	0.0045
5%	0.0006	0.0005
EF	4.99	3.61
α		1.288
β		216.7

All MDP UA (696 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.00751	0.00751
SD	0.0141	0.0075
95%	0.0226	0.0224
50%	0.0041	0.0052
5%	0.0006	0.0004
EF	5.54	4.28
α		1.000
β		132.2

HPCI TDP UA (24 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.0130	0.0130
SD	0.0061	0.0071
95%	0.0229	0.0264
50%	0.0130	0.0117
5%	0.0047	0.0039
EF	1.77	2.25
α		3.288
β		249.9

RCIC TDP UA (30 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.0107	0.0107
SD	0.0046	0.0049
95%	0.0181	0.0198
50%	0.0109	0.0099
5%	0.0039	0.0041
EF	1.66	1.99
α		4.703
β		435.9

AFWS TDP UA (69 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.00544	0.00544
SD	0.0034	0.0037
95%	0.0116	0.0125
50%	0.0050	0.0046
5%	0.0006	0.0011
EF	2.31	2.70
α		2.177
β		398.0

AFWS DDP UA (5 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.00970	0.00970
SD	0.0035	0.0029
95%	-	0.0149
50%	-	0.0094
5%	-	0.0054
EF	-	1.59
α		10.946
β		1117.7

SWS DDP UA (5 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.02950	0.0295
SD	0.0131	0.0117
95%	-	0.0510
50%	-	0.0280
5%	-	0.0131
EF	-	1.82
α		6.134
β		201.8

FWR Injection UA (4 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.0160	0.0160
SD	0.0093	0.0100
95%	-	0.0352
50%	-	0.0140
5%	-	0.0037
EF	-	2.52
α		2.500
β		153.7

Table B-1. (continued).

IC Injection UA (6 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.00586	0.00586
SD	0.0062	0.0052
95%	-	0.0161
50%	-	0.0044
5%	-	0.0005
EF	-	3.65
α		1.265
β		214.5

ESW Header UA (53 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.00865	0.00865
SD	0.0132	0.0086
95%	0.0331	0.0258
50%	0.0052	0.0060
5%	0.0000	0.0004
EF	6.39	4.28
α		1.000
β		114.7

RHRSW Header UA (38 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.00363	0.00363
SD	0.0032	0.0027
95%	0.0105	0.0090
50%	0.0031	0.0030
5%	0.0000	0.0005
EF	3.45	3.02
α		1.747
β		480.1

RHR BWR HTX UA (70 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.00762	0.00762
SD	0.0040	0.0039
95%	0.0147	0.0150
50%	0.0068	0.0070
5%	0.0031	0.0025
EF	2.16	2.15
α		3.759
β		489.7

RHR PWR HTX UA (145 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.00518	0.00518
SD	0.0036	0.0031
95%	0.0118	0.0111
50%	0.0044	0.0046
5%	0.0014	0.0013
EF	2.68	2.43
α		2.748
β		527.7

CCW HTX UA (73 Trains, 2002 - 2004)

Statistic	Train Data	Beta Distribution (note a)
Mean	0.00723	0.00723
SD	0.0073	0.0072
95%	0.0248	0.0216
50%	0.0039	0.0050
5%	0.0000	0.0004
EF	6.40	4.29
α		1.000
β		137.3

Acronyms – AFWS (auxiliary feedwater system), BWR (boiling water reactor), EDG (emergency diesel generator), EF (error factor), FWCI (feedwater coolant injection), HPCS (high-pressure core spray), HPCI (high-pressure coolant injection), HPSI (high-pressure safety injection), HTG (hydro turbine generator), IC (isolation condenser), PWR (pressurized water reactor), RCIC (reactor core isolation cooling), RHR (residual heat removal), SD (standard deviation), UA (unavailability)

Note a - Maximum likelihood estimate approach. For cases with fewer than 5 trains, an average α of 2.5 was assumed.

B.3 Unavailability Estimates from the ROP SSU Database

ROP SSU data are available for the same four major safety systems listed for the MSPI data. However, the ROP SSU data do not distinguish types of pumps for the AFWS. In addition, ROP SSU data do not include the cooling water systems covered by the MSPI Program. ROP SSU data include planned, unplanned, and fault exposure outages, as well as required hours. The fault exposure outages were used in the ROP as surrogates for component unreliability (UR). Because component UR is modeled separately in the standardized plant analysis risk (SPAR) models, the fault exposure outages were not included in UA calculations using the ROP SSU data.

ROP SSU data are available for 1997 through the first quarter of 2006 (after which they were replaced by the MSPI data). These data were used for two purposes: one was to determine train UA values for hydro turbine generators (HTGs), and the other was to compare with the MSPI UA results. HTG UAs from the MSPI program cover two HTGs and overhead and underground transmission lines to the three Oconee plants. One of the two trains reported (for each of the three plants) is defined as two parallel HTGs feeding the overhead transmission line. The other train is defined as the same two parallel HTGs feeding the underground transmission line. Because most of the UA is associated with the transmission lines, this train definition does not reflect actual HTG UA. Therefore, the ROP SSU data were used instead. In the ROP SSU, the train definitions more appropriately reflect HTG UA (similar to EDG and CTG UA).

The ROP SSU data at first glance do not appear to be an ideal data source for obtaining UA estimates for plant critical operation. The ROP assumes that for the EPS and RHR, these systems are required for both critical and shutdown operation. Therefore, outages occurring during either critical or shutdown operation are reported. Also, the required hours for such systems are calendar hours rather than critical operation hours. Because EPS UA can be significantly different for critical operation compared with shutdown operation, this combining of critical and shutdown outages appears to make the ROP SSU data for those systems inapplicable for this report. However, the ROP SSU has a list of exceptions for shutdown operation (instances in which test or maintenance outages should not be reported) that effectively result in the shutdown operation outages being similar to the critical operation outages. The same is true for the RHR. Therefore, even though the ROP SSU data for EPS and RHR include both critical and shutdown operation, the results are reasonable approximations for critical operation. (However, the results are not appropriate for shutdown operation risk assessment use.)

Two additional potential objections concerning use of the ROP SSU data for risk assessment use are the following: planned component overhaul performed during plant critical operation does not need to be reported and support system contributions to frontline safety system UA are included in the ROP SSU data. For risk assessment use, component overhauls during critical operation should be included in UA estimates, while support system UA should be modeled separately.

In spite of these potential objections, the ROP SSU data covering 1998–2002 were collected to obtain train UA estimates. Only planned and unplanned outages were considered. These results were then compared with the MSPI train UA results discussed previously. This comparison is described in Section 6 of the main report, along with the comparison results.

B.4 Unavailability Estimates from IPEs

IPE UA estimates are summarized in Reference B-3. That summary identified UA tabular data in IPEs for 61 plants. The raw data are presented in Appendix A of Reference B-3. Results were then arranged by group name in Appendix B in that reference. Finally, statistical analysis results for group UAs were presented in Appendix C. This report uses results from Appendix C in Reference B-3 but with modifications as explained below.

The IPE UA data represent plant-specific performance typically during the latter 1980s. As indicated in Sections 6 and 9, UA performance generally has improved since then. This improvement is summarized in Table B-2, where IPE UA estimates are compared with comparable MSPI (2002–2004) and ROP SSU (1998–2002) UA estimates. In general, the older IPE UA estimates are approximately twice the newer MSPI and ROP SSU estimates. Therefore, for those UA events supported by IPE data (with UA estimates > 0.005), the IPE mean from Reference B-3 was divided by two. However, for IPE data with UA estimates <0.005, the IPE result was used directly. This distinction was made because of the belief that as the UA drops below approximately 0.005, further improvements are unlikely. (There were no direct comparisons possible between the IPE results and the MSPI and ROP SSU results for IPE UAs less than 0.005.) In all cases, the simplified constrained noninformative distribution ($\alpha = 0.5$) was used. IPE UA estimates are summarized in Table B-3.

Table B-2. Comparison of IPE and ROP SSU UA estimates.

System Train	IPE UA (1980s) (61 Plants)	MSPI UA (2002 - 2004) (103 Plants)	IPE/MSPI	ROP SSU UA (1998 - 2002) (103 Plants)	IPE/ROP
EDG	0.0270	0.0134	2.01	0.0090	3.00
HPCI TDP	0.0310	0.0130	2.38	0.0112	2.77
HPSI MDP	0.0094	0.0041	2.28	0.0050	1.88
HPCS MDP	0.0140	0.0131	1.07	0.0068	2.06
RCIC TDP	0.0280	0.0107	2.62	0.0129	2.17
AFWS MDP	0.0100	0.0040	2.53	0.0050	2.00
AFWS TDP	0.0240	0.0054	4.41	0.0050	4.80
AFWS DDP	0.0030	0.0097	0.31	0.0050	0.60
RHR BWR	0.0100	0.0076	1.31	0.0073	1.37
RHR PWR	0.0089	0.0052	1.72	0.0052	1.71
		Average	2.06	Average	2.24

Acronyms - AFWS (auxiliary feedwater system), BWR (boiling water reactor), DDP (diesel-driven pump), EDG (emergency diesel generator), HPCI (high-pressure coolant injection), HPSI (high-pressure safety injection), IPE (Individual Plant Examination), MDP (motor-driven pump), MSPI (mitigating systems performance index), PWR (pressurized water reactor), RCIC (reactor core isolation cooling), RHR (residual heat removal), ROP (Reactor Oversight Process), SSU (Safety System Unavailability), TDP (turbine-driven pump), UA (unavailability)

Table B-3. IPE UA estimates.

Train Unavailability Event	Description	Data Source	Data	Recommended Probability Distribution				
			IPE (Ref. B-3)	Distribution (note a)	Mean	α	β	Error Factor
AHU-TM	Air Handling Unit Test or Maintenance	IPEs	Table C-1, CFC-FAN-TM	Beta (IPEs, SCNID)	2.48E-03	0.50	2.01E+02	8.4
BAC-TM	Bus (ac) Test or Maintenance	IPEs	Table C-1, ACP-BAC-TM	Beta (IPEs, SCNID)	2.15E-04	0.50	2.33E+03	8.4
BCH-TM	Battery Charger Test or Maintenance	IPEs	Table C-1, CDP-BCH-TM	Beta (IPEs, SCNID)	2.20E-03	0.50	2.27E+02	8.4
CHL-TM	Chiller Test or Maintenance	IPEs	Table C-1, EHV-FAN-TM-TRN	Beta (IPEs/2, SCNID)	1.98E-02	0.50	2.48E+01	8.2
CTF-TM	Cooling Tower Fan Test or Maintenance	IPEs	Table C-1, OLW-FAN-TM	Beta (IPEs, SCNID)	1.86E-03	0.50	2.68E+02	8.4
CTG-TM	Combustion Turbine Generator Test or Maintenance	IPEs	Table C-1, GTG-TM	Beta (IPEs/2, SCNID)	5.00E-02	0.50	9.50E+00	7.7
EOV-TM	Explosive-Operated Valve Test or Maintenance	IPEs	Table C-1, SLC-EPV-TM	Beta (IPEs, SCNID)	5.52E-04	0.50	9.05E+02	8.4
FAN-TM	Fan Test or Maintenance	IPEs	Table C-1, EHV-FAN-TM	Beta (IPEs, SCNID)	2.00E-03	0.50	2.50E+02	8.4
HTX-TM	Heat Exchanger Test or Maintenance	IPEs	Table C-1, RHR-HTX-TM	Beta (IPEs, SCNID)	2.74E-03	0.50	1.82E+02	8.4
MDC-TM	Motor-Driven Compressor Test or Maintenance	IPEs	Table C-1, IAS-MDC-TM	Beta (IPEs/2, SCNID)	1.30E-02	0.50	3.80E+01	8.3
PDP-TM	Positive Displacement Pump Test or Maintenance	IPEs	Table C-1, CVC-PDP-TM	Beta (IPEs, SCNID)	3.19E-03	0.50	1.56E+02	8.4

Acronyms - AHU (air-handling unit), BAC (bus ac), BCH (battery charger), CHL (chiller), CNID (constrained noninformative distribution), CTF (cooling tower fan), CTG (combustion turbine generator), EOV (explosive-operated valve), FAN (fan), HTX (heat exchanger), IPE (Individual Plant Examination), LL (lower limit), MDC (motor-driven compressor), PDP (positive displacement pump), SCNID (simplified constrained noninformative distribution), TM (test or maintenance)

Note a - The format for the distributions is the following: distribution type (source for mean, source for α factor). If the source for the mean indicates IPE/2, these are cases in which the IPE value was divided by two to reflect more current performance.

B.5 References

B-1. U.S. Nuclear Regulatory Commission, "Mitigating Systems Performance Index (MSPI)," http://nrc.gov/NRR/OVERSIGHT/ASSESS/mspi.html.

B-2. U.S. Nuclear Regulatory Commission, "Reactor Oversight Process (ROP)," http://nrc.gov/NRR/OVERSIGHT/ASSESS/index.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

System Special Event Summaries

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Tables

Appendix C

System Special Event Summaries

C.1 Data Review Process

C.1.1 Introduction

System special events address performance issues related to operation of the high-pressure coolant injection (HPCI), high-pressure core spray (HPCS), and reactor core isolation cooling (RCIC) systems during unplanned demands. Examples of special events include the probability of a pump having to restart during its mission, failure of the pump to restart, failure of injection valves to reopen, and others. This appendix provides supporting information and additional detail concerning the special event parameter estimates presented in Section 7. These estimates reflect industry-average performance for special events, where U.S. commercial nuclear power plants are defined as the industry. Special event parameter estimates were obtained from the RCIC, HPCI, and HPCS system studies (Refs. C-1, 2, and 3), as updated in Reference C-4.

C.1.2 Parameter Estimation Using System Study Data

The updated system study data (Ref. C-4) were used to quantify the special events. Data from these studies were obtained from a review of unplanned demands described in licensee event reports (LERs). These data are updated yearly, and such updates can include changes to previous data. The database used for this study was the one covering 1988 through 2004. However, to match the periods used for component UR and UA, data up through 2002 were used. In addition, because the unplanned demand data are sparse compared with test demand data and trends may exist, the start date for each special event was optimized. Optimization in this case indicates that yearly data were examined, starting with 2002 and working backward in time, to identify the maximum length baseline period with performance representative of the year 2000. In addition, a minimum of 5 years was specified. Typically, the system study data indicate more events and failures in the early years and fewer events and failures in the latter years, so the early years with poorer performance were not included in the baseline period used to quantify the special events. Statistical analyses were performed to evaluate whether a trend existed within each potential baseline period. The starting year that resulted in the highest p-value (lowest probability of a trend existing) was then chosen. In addition, if there were no events or only one event, then the entire period, 1988–2002, was used. This optimization of the period used to characterize current performance resulted in baseline periods with start years of 1988 to 1998, but all ending in 2002.

System study data for each optimized baseline period include the total number of events and total number of demands (or hours) for the industry. In addition, similar data are available by year. The updated system study data are not organized by plant, so an empirical Bayes analysis at the plant level was not performed. However, for one special event there were enough data to perform an empirical Bayes analysis at the year level. For all of the special events except one, the mean is the posterior mean of a Bayesian update of the Jeffreys noninformative prior with industry data, termed the Jeffreys mean. All but two special events use an α of 0.5 from the simplified constrained noninformative distribution (SCNID). One event uses the Jeffreys α and the other uses the empirical Bayes result for α.

C.2 System Special Event Data Sheets

C.2.1 HPCS Special Events Data Sheet

If a LOCA should occur, a low reactor water level signal or high drywell pressure signal initiates the HPCS and its support equipment. The system can also be placed in operation manually. If the leak rate is less than the HPCS system flow rate, the HPCS system automatically stops when a high reactor water level signal shuts the HPCS injection valve. The injection valve will automatically reopen upon a subsequent low water level signal. Suction piping for the HPCS pump is provided from the condensate storage tank (CST) and the suppression pool. Such an arrangement provides the capability to use reactor-grade water from the CST when the HPCS system functions to back up the RCIC system. In the event that the CST water supply becomes exhausted or is not available, automatic switchover to the suppression pool water source ensures a cooling water supply for long-term operation of the system.

C.2.1.1 Special Event Description

The HPCS special events are listed in Table C.2.1-1.

Table C.2.1-1. HPCS special events.

Special Event	Parameter	Units	Description
SUC-FTFR	p	-	Failure to transfer (to the suppression pool)
SUC-FRFTFR	p	-	Failure to recover transfer failure

C.2.1.2 Data Collection and Review

Using the process outlined in Section C.1.2, the optimized baseline period for each special event is listed in Table C.2.1-2. Results include total number of events and either total demands or total hours for the U.S. commercial nuclear power plant industry. The table summarizes the data used in the HPCS special event analysis.

Table C.2.1-2. HPCS special event data.

Special Event	Data Source	Data After Review	
		Events	Demands or Hours
SUC-FTFR	System Study (1988 - 2002)	1	478
SUC-FRFTFR	System Study (1988 - 2002)	1	1

C.2.1.3 Industry-Average Baselines

Table C.2.1-3 lists the industry-average distributions for the HPCS special events.

Table C.2.1-3. Selected industry distributions of p for HPCS (before rounding).

Event	5%	Median	Mean	95%	Distribution		
					Type	α	β
SUC-FTFR	1.23E-05	1.43E-03	3.13E-03	1.20E-02	Beta	0.500	1.592E+02
SUC-FRFTFR	3.26E-02	9.51E-01	7.50E-01	1.00E+00	Beta	0.500	1.667E-01

For use in the SPAR models, the industry-average event probabilities and rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table C.2.1-4 shows the rounded values for the HPCS special events.

Table C.2.1-4. Selected industry distributions of p for HPCS (after rounding).

Event	5%	Median	Mean	95%	Distribution		
					Type	α	β
SUC-FTFR	1.2E-05	1.5E-03	3.0E-03	1.2E-02	Beta	0.50	1.66E+02
SUC-FRFTFR	5.0E-02	1.0E+00	8.0E-01	1.0E+00	Beta	0.50	1.25E-01

C.2.2 HPCI Special Events Data Sheet

The HPCI system is actuated by either a low reactor water level or a high drywell pressure. Initially the system operates in an open loop mode, taking suction from the condensate storage tank (CST), and injecting water into the reactor pressure vessel (RPV) via one of the main feedwater lines. When the level in the CST reaches a low-level setpoint, the HPCI pump suction is aligned to the suppression pool. To maintain RPV level after the initial recovery, the HPCI system is placed in manual control, which may involve controlling turbine speed, diverting flow through minimum flow or test lines, cycling the injection motor-operated valve (MOV), or complete stop-start cycles.

The HPCI system is also used manually to help control RPV pressure following a transient. In this mode, the turbine-driven pump is operated manually with the injection valve closed and the full-flow test line MOV open. Turbine operation with the injection line isolated and the test line open allows the turbine to draw steam from the RPV, thereby reducing RPV pressure. Operation of the system in the pressure control mode may also occur with intermittent injection of coolant to the RPV. As steam is being drawn off the RPV, the RPV water inventory is reduced, resulting in the need for level restoration. When level restoration is required, the injection valve is opened and the test line MOV is closed. Upon restoration of RPV water inventory, the system is returned to the pressure control line-up. This cycling between injection and pressure control can be repeated as necessary.

C.2.2.1 Special Event Description

The HPCI special events are listed in Table C.2.2-1.

Table C.2.2-1. HPCI special events.

Special Event	Parameter	Units	Description
MOV-PMINJ	*p*	-	Injection valve probability of multiple injections
MOV-FTRO	*p*	-	Injection valve fails to reopen
MOV-FRFTRO	*p*	-	Failure to recover injection valve failure to reopen
SUC-FTFR	*p*	-	Failure to transfer (to the suppression pool)
SUC-FRFTFR	*p*	-	Failure to recover transfer failure

C.2.2.2 Data Collection and Review

Using the process outlined in Section C.1.2, the optimized baseline period for each special event is listed in Table C.2.2-2. Results include total number of events and either total demands or total hours for the U.S. commercial nuclear power plant industry. The table summarizes the data used in the RCIC special event analysis.

Table C.2.2-2. HPCI special event data.

Special Event	Data Source	Data After Review	
		Events	Demands or Hours
MOV-PMINJ	System Study (1995 - 2002)	2	17
MOV-FTRO	System Study (1988 - 2002)	1	8
MOV-FRFTRO	System Study (1988 - 2002)	1	1
SUC-FTFR	System Study (1989 - 2002)	0	1270
SUC-FRFTFR	System Study (1989 - 2002)	0	0

C.2.2.3 Industry-Average Baselines

Table C.2.2-3 lists the industry-average distributions for the HPCI special events.

Table C.2.2-3. Selected industry distributions of p for HPCI (before rounding).

Event	5%	Median	Mean	95%	Distribution		
					Type	α	β
MOV-PMINJ	6.88E-04	7.65E-02	1.39E-01	4.88E-01	Beta	0.500	3.100E+00
MOV-FTRO	8.70E-04	9.58E-02	1.67E-01	5.70E-01	Beta	0.500	2.500E+00
MOV-FRFTRO	3.26E-02	9.51E-01	7.50E-01	1.00E+00	Beta	0.500	1.667E-01
SUC-FTFR	1.55E-06	1.79E-04	3.93E-04	1.51E-03	Beta	0.500	1.271E+03
SUC-FRFTFR	6.16E-03	5.00E-01	5.00E-01	9.94E-01	Beta	0.500	5.000E-01

For use in the SPAR models, the industry-average event probabilities and rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table C.2.2-4 shows the rounded values for the HPCI special events.

Table C.2.2-4. Selected industry distributions of p for HPCI (after rounding).

Event	5%	Median	Mean	95%	Distribution		
					Type	α	β
MOV-PMINJ	8.0E-04	8.0E-02	1.5E-01	5.0E-01	Beta	0.50	2.83E+00
MOV-FTRO	8.0E-04	8.0E-02	1.5E-01	5.0E-01	Beta	0.50	2.83E+00
MOV-FRFTRO	5.0E-02	1.0E+00	8.0E-01	1.0E+00	Beta	0.50	1.25E-01
SUC-FTFR	1.5E-06	2.0E-04	4.0E-04	1.5E-03	Beta	0.50	1.25E+03
SUC-FRFTFR	6.0E-03	5.0E-01	5.0E-01	1.0E+00	Beta	0.50	5.00E-01

C.2.3 RCIC Special Events Data Sheet

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

Operation of RCIC for long-term missions involves providing adequate RPV water level for periods up to several hours. For these long-term missions, either the control room operator would manually initiate the RCIC system, or the system would automatically start at the predetermined low reactor water level setpoint. At this point, the system would inject until the system was shut down by the operator or the high level trip setpoint was reached, at which time the RCIC turbine steam supply and coolant injection valves would close. With the continued steam generated by decay heat and corresponding lowering of vessel level (as a result of safety relief valve or turbine bypass valve operation), the system would be restarted during the event and the cycle repeated one or more times.

C.2.3.1 Special Event Description

The RCIC special events are listed in Table C.2.3-1.

Table C.2.3-1. RCIC special events.

Special Event	Parameter	Units	Description
TDP-PRST	p	-	TDP probability of restart
TDP-FRST	p	-	TDP restart failure per event
TDP-FRFRST	p	-	Failure to recover TDP restart failure
SUC-FTFRI	λ	1/h	Failure to transfer back to injection mode (pump recirculation valve)
SUC-FRFTFR	p	-	Failure to recover transfer failure
MOV-PMINJ	p	-	Injection valve probability of multiple injections
MOV-FTRO	p	-	Injection valve fails to reopen
MOV-FRFTRO	p	-	Failure to recover injection valve failure to reopen

C.2.3.2 Data Collection and Review

Using the process outlined in Section C.1.2, the optimized baseline period for each special event is listed in Table C.2.3-2. Results include total number of events and either total demands or total hours for the U.S. commercial nuclear power plant industry. The table summarizes the data used in the RCIC special event analysis.

Table C.2.3-2. RCIC special event data.

Special Event	Data Source	Data After Review	
		Events	Demands or Hours
TDP-PRST	System Study (1996 - 2002)	6	47
TDP-FRST	System Study (1991 - 2002)	1	17
TDP-FRFRST	System Study (1991 - 2002)	0	1
SUC-FTFRI	System Study (1988 - 2002)	1	198 h
SUC-FRFTFR	System Study (1988 - 2002)	0	1
MOV-PMINJ	System Study (1998 - 2002)	14	28
MOV-FTRO	System Study (1988 - 2002)	1	38
MOV-FRFTRO	System Study (1988 - 2002)	1	1

C.2.3.3 Industry-Average Baselines

Table C.2.3-3 lists the industry-average distributions for the RCIC special events. The SCNID was used for six of the eight events. TDP-PRST uses the Jeffreys distribution because the empirical Bayes analysis (looking for year-to-year variation) failed but indicated little variation between years. Finally, MOV-PMINJ uses the empirical Bayes results.

Table C.2.3-3. Selected industry distributions of p and λ for RCIC (before rounding).

Event	5%	Median	Mean	95%	Distribution		
					Type	α	β
TDP-PRST	6.43E-02	1.30E-01	1.35E-01	2.23E-01	Beta	6.500	4.150E+00
TDP-FRST	3.74E-04	4.23E-02	8.33E-02	3.06E-01	Beta	0.500	5.500E+00
TDP-FRFRST	1.54E-03	1.63E-01	2.50E-01	7.71E-01	Beta	0.500	1.500E+00
SUC-FTFRI	2.98E-05	3.45E-03	7.58E-03	2.91E-02	Gamma	0.500	6.598E+01
SUC-FRFTFR	1.54E-03	1.63E-01	2.50E-01	7.71E-01	Beta	0.500	1.500E+00
MOV-PMINJ	2.32E-01	5.03E-01	5.03E-01	7.73E-01	Beta	4.180	4.130E+00
MOV-FTRO	1.54E-04	1.77E-02	3.85E-02	1.40E-01	Beta	0.500	1.300E+01
MOV-FRFTRO	3.26E-02	9.51E-01	7.50E-01	1.00E+00	Beta	0.500	1.667E-01

For use in the SPAR models, the industry-average event probabilities and rates were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table C.2.3-4 shows the rounded values for the RCIC special events.

Table C.2.3-4. Selected industry distributions of p and λ for RCIC (after rounding).

Event	5%	Median	Mean	95%	Distribution		
					Type	α	β
TDP-PRST	7.0E-02	1.5E-01	1.5E-01	2.5E-01	Beta	6.00	3.40E+01
TDP-FRST	4.0E-04	4.0E-02	8.0E-02	3.0E-01	Beta	0.50	5.75E+00
TDP-FRFRST	1.5E-03	1.5E-01	2.5E-01	8.0E-01	Beta	0.50	1.50E+00
SUC-FTFRI	3.0E-05	4.0E-03	8.0E-03	3.0E-02	Gamma	0.50	6.20E+01
SUC-FRFTFR	1.5E-03	1.5E-01	2.5E-01	8.0E-01	Beta	0.50	1.50E+00
MOV-PMINJ	2.5E-01	5.0E-01	5.0E-01	8.0E-01	Beta	4.00	4.00E+00
MOV-FTRO	1.5E-04	2.0E-02	4.0E-02	1.5E-01	Beta	0.50	1.25E+01
MOV-FRFTRO	5.0E-02	1.0E+00	8.0E-01	1.0E+00	Beta	0.50	1.25E-01

C.3 References

C-1. J.P. Poloski et al., *Reliability Study: Reactor Core Isolation Cooling System, 1987 – 1993*, U.S. Nuclear Regulatory Commission, NUREG/CR-5500, Vol. 7, September 1999.

C-2. J.P. Poloski et al., *Reliability Study: High-Pressure Core Spray System, 1987 – 1993*, U.S. Nuclear Regulatory Commission, NUREG/CR-5500, Vol. 8, September 1999.

C-3 G.M. Grant et al., *Reliability Study: High-Pressure Coolant Injection (HPCI) System, 1987 – 1993*, U.S. Nuclear Regulatory Commission, NUREG/CR-5500, Vol. 4, September 1999.

C-4 U.S. Nuclear Regulatory Commission, "Reactor Operational Experience Results and Databases, System Studies," http://nrcoe.inel.gov/results.

Appendix D

Initiating Event Summaries

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Initiating Event Summaries

D.1 Data Review Process

D.1.1 Introduction

This appendix provides supporting information and additional detail concerning the initiating event (IE) parameter estimates presented in Section 8. These estimates reflect industry-average frequencies for IEs, where U.S. commercial nuclear power plants are defined as the industry. Only those IEs occurring while plants are critical are covered. Low-power and shutdown IEs are not addressed.

IE frequency estimates were obtained from a hierarchy of sources, as explained in Section 8. The preferred source is the Nuclear Regulatory Commission initiating event database (IEDB, Ref. D-1), as accessed using the Reliability and Availability Database System (RADS, Ref. D-2). Most IE parameter estimates were obtained from this source. The IEDB uses IE definitions presented in *Rates of Initiating Events at U.S. Nuclear Power Plants: 1987–1995* (Ref. D-3). Other sources used include *Reevaluation of Station Blackout Risk at Nuclear Power Plants* (Ref. D-4) and *Estimating Loss-of-Coolant Accident (LOCA) Frequencies through the Elicitation Process* (Ref. D-5). This appendix explains in detail how data from each of these sources were used to obtain industry-average IE parameter estimates.

D.1.2 Parameter Estimation Using Licensee Event Report Data

The IEDB and the RADS software are described in Section 8. IE data are collected from licensee event reports (LERs) at the plant level. The RADS software was used to search the IEDB for specific initiating event information and process that information. RADS processes IE data to determine total number of events and total reactor critical years (rcry's) over the calendar year period specified. In addition, RADS presents yearly results for the period chosen.

Initial RADS searches were performed using data from 1988–2002. These data were then examined to determine an optimized baseline period (ending in 2002). Optimization in this case indicates that yearly data were examined, starting with 2002 and working backward in time, to identify a baseline period with performance representative of the year 2000. In addition, a minimum of 5 years was specified for potential baseline periods. Often the IE data indicate more events in the early years and fewer events in the latter years, so the early years with poorer performance were not included in the baseline period used to quantify the IE frequencies. Statistical trend evaluations were performed for potential baseline periods. The starting year that resulted in the highest p-value (weakest evidence for existence of a trend) was then chosen. Additionally, if there were no events or only one event during 1988–2002, then the entire period was chosen as the baseline. Finally, if there were only two events and they occurred during the first 3 years (probability of this is less than 0.05 assuming a constant occurrence rate), then the baseline period started with the first year with no events. This optimization of the period used to characterize current performance resulted in baseline periods with start years of 1988 to 1998, but all ending in 2002.

Once the baseline period was determined, RADS again was used to collect the IE data over that period. These data (total events and total reactor critical years by plant) were then analyzed statistically to determine potential frequency distributions. The statistical analysis process is similar to that used to analyze component unreliability data, as explained in Section 5 and Appendix A.

For six IEs, the IEDB events were reviewed to screen out events that were not applicable with respect to the standardized plant analysis risk (SPAR) event tree modeling of such events. This screening effort was needed only for those six IEs; other IE modeling in SPAR agreed with the IE definitions used in the IEDB.

D.1.3 Parameter Estimation Using Other Sources

The loss of offsite power (LOOP) frequency distribution was obtained directly from Reference D-4. LOCA frequencies (except for the small LOCA for pressurized water reactors or PWRs) were obtained from Reference D-5. Table 7.1 in that report was used. In addition, results for current day conditions were used, rather than for end-of-life conditions. Specific details concerning the LOCA frequencies are presented in the individual subsections in Section D.2.

D.2 Initiating Event Data Sheets

D.2.1 Large Loss-of-Coolant Accident at Boiling Water Reactors (LLOCA (BWR)) Data Sheet

D.2.1.1 Initiating Event Description

The Large Loss-of-Coolant Accident at Boiling Water Reactors (LLOCA (BWR)) is a break size greater than 0.1 square feet (or an approximately 5-inch inside diameter pipe equivalent for liquid and steam) in a pipe in the primary system boundary.

D.2.1.2 Data Collection and Review

Information for the LLOCA (BWR) baseline was obtained from *Estimating Loss-of-Coolant Accident (LOCA) Frequencies through the Elicitation Process* (Ref. D-5). In that document, 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." Reference D-5 is a draft document. Results obtained from that document could change when the final report is issued.

Table 7.1 in Reference D-5 presents frequencies for LOCAs exceeding various sizes indicated by gallon per minute (gpm) break flow and effective pipe size break. Six different sizes are listed, ranging from 0.5-inch diameter (> 100 gpm) to 31-inch or 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 operation) and for end-of-life conditions (40 years of operation). For this study, frequencies appropriate for current day conditions were used.

From Table 7.1 in Reference D-5, the LLOCA frequency (in reactor calendar years or rcy's) for BWRs is 6.1E-6/rcy (> 7 inch). To convert this to reactor critical years (rcry's), it was assumed that reactors are critical 90% of each year. Converting to rcry's, the result is

(6.1E-6/rcy)(1 rcy/0.9 rcry) = 6.78E-6/rcry.

The associated error factor (95th percentile divided by median) from Reference D-5 is

(2.0E-5/rcy)/(2.2E-6/rcy) = 9.1,

which converts to an α of 0.47.

D.2.1.3 Industry-Average Baselines

Table D.2.1-1 lists the industry-average frequency distribution.

Table D.2.1-1. Selected industry distribution of λ for LLOCA (BWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
Ref. D-5	1.90E-08	2.91E-06	6.78E-06	2.66E-05	Gamma	0.470	6.932E+04

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.1-2 shows the rounded value.

Table D.2.1-2. Selected industry distribution of λ for LLOCA (BWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
Ref. D-5	3.0E-08	3.0E-06	7.0E-06	2.5E-05	Gamma	0.50	7.14E+04

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.2 Large Loss-of-Coolant Accident at Pressurized Water Reactors (LLOCA (PWR)) Data Sheet

D.2.2.1 Initiating Event Description

The Large Loss-of-Coolant Accident at Pressurized Water Reactors (LLOCA (PWR)) is a pipe break in the primary system boundary with an equivalent inside diameter greater than 6 inch.

D.2.2.2 Data Collection and Review

Information for the LLOCA (PWR) baseline was obtained from *Estimating Loss-of-Coolant Accident (LOCA) Frequencies through the Elicitation Process* (Ref. D-5). In that document, 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." Reference D-5 is a draft document. Results obtained from that document could change when the final report is issued.

Table 7.1 in Reference D-5 presents frequencies for LOCAs exceeding various sizes indicated by gallon per minute (gpm) break flow and effective pipe size break. Six different sizes are listed, ranging from 0.5-inch diameter (> 100 gpm) to 31-inch or 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 operation) and for end-of-life conditions (40 years of operation). For this study, frequencies appropriate for current day conditions were used.

From Table 7.1 in Reference D-5, the LLOCA frequency (in reactor calendar years or rcy's) for PWRs is 1.2E-6/rcy (> 7 inch). To convert this to reactor critical years (rcry's), it was assumed that reactors are critical 90% of each year. Converting to rcry's, the result is

(1.2E-6/rcy)(1 rcy/0.9 rcry) = 1.33E-6/rcry.

The associated error factor (95th percentile divided by median) from Reference D-5 is

(3.9E-6/rcy)/(3.1E-7/rcy) = 10.5,

which converts to an α of 0.42.

D.2.2.3 Industry-Average Baselines

Table D.2.2-1 lists the industry-average frequency distribution.

Table D.2.2-1. Selected industry distribution of λ for LLOCA (PWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
Ref. D-5	1.90E-09	5.10E-07	1.33E-06	5.43E-06	Gamma	0.420	3.158E+05

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.2-2 shows the rounded value.

Table D.2.2-2. Selected industry distribution of λ for LLOCA (PWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
Ref. D-5	1.2E-09	4.0E-07	1.2E-06	5.0E-06	Gamma	0.40	3.33E+05

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.3 Medium Loss-of-Coolant Accident at Boiling Water Reactors (MLOCA (BWR)) Data Sheet

D.2.3.1 Initiating Event Description

The Medium Loss-of-Coolant Accident at Boiling Water Reactors (MLOCA (BWR)) initiating event is defined for boiling water reactors (BWRs) as a pipe break in the primary system boundary with a break size between 0.004 to 0.1 square feet (or an approximately 1- to 5-inch inside diameter pipe equivalent) for liquid and between 0.05 to 0.1 square feet (or an approximately 4- to 5-inch inside diameter pipe equivalent) for steam.

D.2.3.2 Data Collection and Review

Information for the MLOCA (BWR) baseline was obtained from *Estimating Loss-of-Coolant Accident (LOCA) Frequencies Through the Elicitation Process* (Ref. D-5). In that document, 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." Reference D-5 is a draft document. Results obtained from that document could change when the final report is issued.

Table 7.1 in Reference D-5 presents frequencies for LOCAs exceeding various sizes indicated by gallon per minute (gpm) break flow and effective pipe size break. Six different sizes are listed, ranging from 0.5-inch diameter (> 100 gpm) to 31-inch or 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 operation) and for end-of-life conditions (40 years of operation). For this study, frequencies appropriate for current day conditions were used.

From Table 7.1 in Reference D-5, the MLOCA frequency (in reactor calendar years or rcy's) for BWRs is

1.0E-4/rcy – 6.1E-6/rcy = 9.39E-5/rcy,

where 1.0E-4/rcy is for LOCAs with an effective break size greater than 1.875-inch inside diameter, and 6.1E-6/rcy is the LLOCA value. To convert this to reactor critical years (rcry's), it was assumed that reactors are critical 90% of each year. Converting to rcry's, the result is

(9.39E-5/rcy)(1 rcy/0.9 rcry) = 1.04E-4/rcry.

The associated error factor (95^{th} percentile divided by median) associated with the > 1.875-inch category from Reference D-5 is

(3.2E-4/rcy)/(4.8E-5/rcy) = 6.7,

which converts to an α of 0.61.

D.2.3.3 Industry-Average Baselines

Table D.2.3-1 lists the industry-average frequency distribution.

Table D.2.3-1. Selected industry distribution of λ for MLOCA (BWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
Ref. D-5	1.05-06	5.54E-05	1.04E-04	3.72E-04	Gamma	0.610	5.865E+03

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.3-2 shows the rounded value.

Table D.2.3-2. Selected industry distribution of λ for MLOCA (BWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
Ref. D-5	9.0E-07	5.0E-05	1.0E-04	4.0E-04	Gamma	0.60	6.00E+03

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.4 Medium Loss-of-Coolant Accident at Pressurized Water Reactors (MLOCA (PWR)) Data Sheet

D.2.4.1 Initiating Event Description

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

D.2.4.2 Data Collection and Review

Information for the MLOCA (PWR) baseline was obtained from *Estimating Loss-of-Coolant Accident (LOCA) Frequencies through the Elicitation Process* (Ref. D-5). In that document, 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." Reference D-5 is a draft document. Results obtained from that document could change when the final report is issued.

Table 7.1 in Reference D-5 presents frequencies for LOCAs exceeding various sizes indicated by gallon per minute (gpm) break flow and effective pipe size break. Six different sizes are listed, ranging from 0.5-inch diameter (> 100 gpm) to 31-inch or 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 operation) and for end-of-life conditions (40 years of operation). For this study, frequencies appropriate for current day conditions were used.

From Table 7.1 in Reference D-5, the MLOCA frequency (in reactor calendar years or rcy's) for BWRs is

4.6E-4/rcy – 1.2E-6/rcy = 4.59E-4/rcy,

where 4.6E-4/rcy is for LOCAs with an effective break size greater than 1.625-inch inside diameter, and 1.2E-6/rcy is the LLOCA value. To convert this to reactor critical years (rcry's), it was assumed that reactors are critical 90% of each year. Converting to rcry's, the result is

(4.59E-4/rcy)(1 rcy/0.9 rcry) = 5.10E-4/rcry.

The associated error factor (95th percentile divided by median) associated with the > 1.625-inch category from Reference D-5 is

(1.4E-3/rcy)/(1.4E-4/rcy) = 10.0,

which converts to an α of 0.44.

D.2.4.3 Industry-Average Baselines

Table D.2.3-1 lists the industry-average frequency distribution.

Table D.2.4-1. Selected industry distribution of λ for MLOCA (PWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
Ref. D-5	9.72E-07	2.05E-04	5.10E-04	2.05E-03	Gamma	0.440	8.627E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.4-2 shows the rounded value.

Table D.2.4-2. Selected industry distribution of λ for MLOCA (PWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
Ref. D-5	5.0E-07	2.0E-04	5.0E-04	2.0E-03	Gamma	0.40	8.00E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.5 Loss of Vital AC Bus (LOAC) Data Sheet

D.2.5.1 Initiating Event Description

From Reference D-3, 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. 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.

D.2.5.2 Data Collection and Review

Data for the LOAC baseline were obtained from the IEDB, as accessed using RADS. However, the SPAR event tree model for LOAC assumes loss of a 4160 Vac safety bus (or in a few cases a 480 Vac safety bus) with no recovery. The LOAC events in the IEDB were reviewed to identify the subset of events that matched the event tree modeling assumptions in SPAR. That review resulted in approximately 75% of the original LOAC events in the IEDB being dropped. (However, those dropped events are still included in the TRAN or other IE categories.)

Using the process outlined in Section D.1.2, the optimized baseline period for LOAC is 1992–2002. Figure D.2.5-1 shows the trend of the full LOAC data set and the baseline period used in this analysis. RADS was used to collect the LOAC data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table D.2.5-1 summarizes the baseline data obtained from RADS and used in the LOAC analysis.

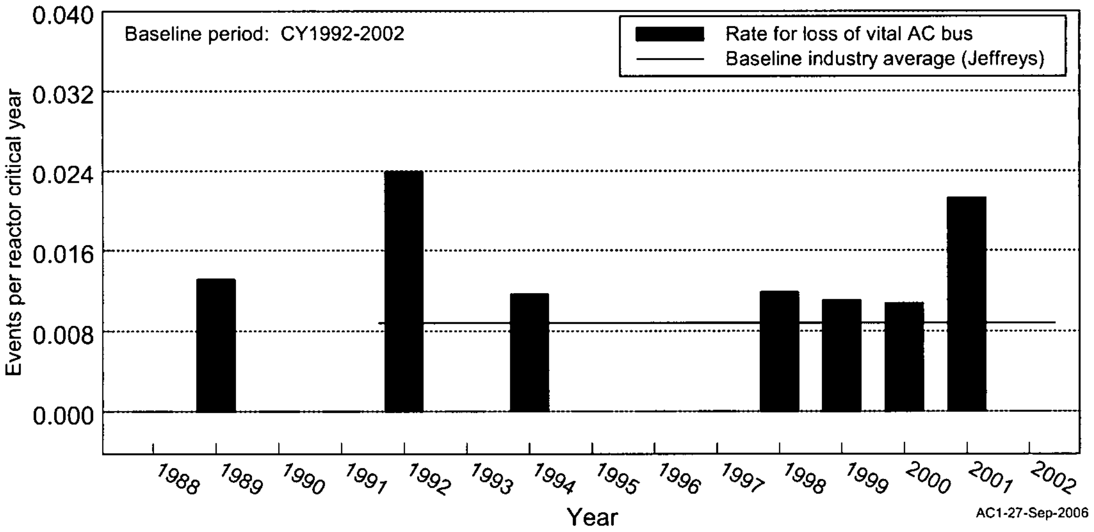

Figure D.2.5-1. LOAC trend plot.

Table D.2.5-1. LOAC frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
8	965.8	1992–2002	111	7.2%

D.2.5.3 Data Analysis

The LOAC data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table D.2.5-2.

Table D.2.5-2. Empirical distributions of MLEs for λ for LOAC.

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	8.16E-03	9.84E-02
Industry	-	-	8.28E-03	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table D.2.5-1, only 7.2% of the plants experienced a LOAC over the period 1992–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 92.8% portion of the distribution, and non-zero values above 92.8%.

An empirical Bayes analysis was performed at the plant level but failed to converge. (This most likely was the result of insufficient variation between plants.) Therefore, assuming homogeneous data, a Bayesian update of the Jeffreys noninformative prior using the industry data was calculated. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table D.2.5-3.

Table D.2.5-3. Fitted distributions for λ for LOAC.

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	4.49E-03	8.46E-03	8.80E-03	1.43E-02	Gamma	8.500	9.658E+02
SCNID/IL	3.46E-05	4.00E-03	8.80E-03	3.38E-02	Gamma	0.500	5.681E+01

Note – JEFF/IL is a Bayesian update of the Jeffreys noninformative prior using industry data and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.5.4 Industry-Average Baselines

Table D.2.5-4 lists the industry-average frequency distribution. The Bayesian update of the Jeffreys noninformative prior was selected. This industry-average frequency does not account for any recovery.

Table D.2.5-4. Selected industry distribution of λ for LOAC (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	4.49E-03	8.46E-03	8.80E-03	1.43E-02	Gamma	8.500	9.658E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

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

Table D.2.5-5. Selected industry distribution of λ for LOAC (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	5.0E-03	9.0E-03	9.0E-03	1.5E-02	Gamma	9.00	1.00E+03

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.6 Loss of Component Cooling Water (LOCCW) Data Sheet

D.2.6.1 Initiating Event Description

From Reference D-3, the Loss of Component Cooling Water (LOCCW) initiating event is a complete loss of the component cooling water (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.

D.2.6.2 Data Collection and Review

Data for LOCCW baselines were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2, the optimized baseline period for LOCCW is 1988–2002. (No events were identified, so the entire period was chosen for the baseline.) RADS was used to collect the LOCCW data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table D.2.6-1 summarizes the data obtained from RADS and used in the LOCCW analysis.

Table D.2.6-1. LOCCW frequency data.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
0	1282.4	1988–2002	113	0.0%

D.2.6.3 Data Analysis

The LOCCW data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. (However, with no events, all MLEs for LOCCW are zero.) The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table D.2.6-2.

Table D.2.6-2. Empirical distributions of MLEs for λ for LOCCW.

Aggregation Level	5%	Median	Mean	95%
Plant	-	-	-	-
Industry	-	-	0.00E+00	-

Note – Percentiles and the mean have units of events/rcry.

With no events, no empirical Bayes analysis could be performed at the plant level. However, the simplified constrained noninformative distribution (SCNID) was generated, based on a Bayesian update of the Jeffreys noninformative prior with industry data and $\alpha = 0.5$. Results from these analyses are presented in Table D.2.6-3.

Table D.2.6-3. Fitted distributions for λ for LOCCW.

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	1.53E-06	1.77E-04	3.90E-04	1.50E-03	Gamma	0.500	1.282E+03

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.6.4 Industry-Average Baselines

Table D.2.6-4 lists the industry-average frequency distribution. With no events, the 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 D.2.6-4. Selected industry distribution of λ for LOCCW (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	1.53E-06	1.77E-04	3.90E-04	1.50E-03	Gamma	0.500	1.282E+03

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.6-5 shows the rounded value.

Table D.2.6-5. Selected industry distribution of λ for LOCCW (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	1.5E-06	2.0E-04	4.0E-04	1.5E-03	Gamma	0.50	1.25E+03

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.7 Loss of Condenser Heat Sink at Boiling Water Reactors (LOCHS (BWR)) Data Sheet

D.2.7.1 Initiating Event Description

From Reference D-3, the Loss of Condenser Heat Sink at Boiling Water Reactors (LOCHS (BWR)) initiating event is defined as at least one of the following:

1. A complete closure of at least one main steam isolation valve in each main steam line.
2. 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.
3. The failure of one or more turbine bypass valves to maintain the reactor pressure and temperature at the desired operating condition.

D.2.7.2 Data Collection and Review

Data for the LOCHS (BWR) baseline were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2, the optimized baseline period for LOCHS (BWR) is 1996–2002. Figure D.2.7-1 shows the trend of the full LOCHS (BWR) data set and the baseline period used in this analysis. RADS was used to collect the LOCHS (BWR) data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table D.2.7-1 summarizes the data obtained from RADS and used in the LOCHS (BWR) analysis.

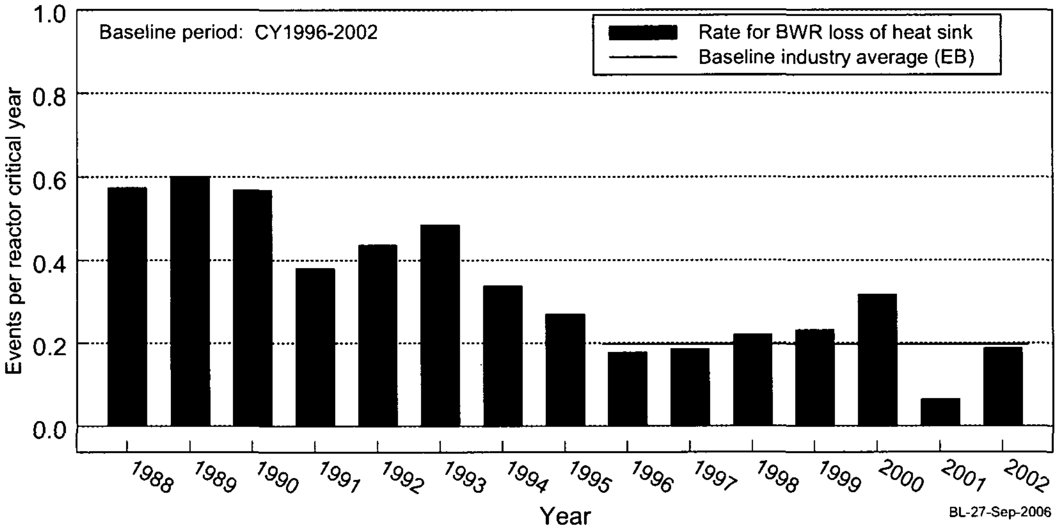

Figure D.2.7-1. LOCHS (BWR) trend plot.

Table D.2.7-1. 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)			
41	208.6	1996–2002	35	71.4%

D.2.7.3 Data Analysis

The LOCHS (BWR) data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table D.2.7-2.

Table D.2.7-2. Empirical distributions of MLEs for λ for LOCHS (BWR).

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	1.56E-01	1.96E-01	4.91E-01
Industry	-	-	1.97E-01	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table D.2.7-1, 71.4% of the plants experienced a LOCHS (BWR) over the period 1996–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 28.6% portion of the distribution, and non-zero values above 28.6%.

An empirical Bayes analysis was performed at the plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table D.2.7-3.

Table D.2.7-3. Fitted distributions for λ for LOCHS (BWR).

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	1.11E-01	1.91E-01	1.97E-01	3.03E-01	Gamma	11.080	5.632E+01
SCNID/IL	7.82E-04	9.05E-02	1.99E-01	7.64E-01	Gamma	0.500	2.514E+00

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.7.4 Industry-Average Baselines

Table D.2.7-4 lists the industry-average frequency distribution. The data set was sufficient for an empirical Bayes analysis to be performed. This industry-average frequency does not account for any recovery.

Table D.2.7-4. Selected industry distribution of λ for LOCHS (BWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	1.11E-01	1.91E-01	1.97E-01	3.03E-01	Gamma	11.080	5.632E+01

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.7-5 shows the rounded value.

Table D.2.7-5. Selected industry distribution of λ for LOCHS (BWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	1.2E-01	2.0E-01	2.0E-01	3.0E-01	Gamma	12.00	6.00E+01

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.8 Loss of Condenser Heat Sink at Pressurized Water Reactors (LOCHS (PWR)) Data Sheet

D.2.8.1 Initiating Event Description

From Reference D-3, the Loss of Condenser Heat Sink at Pressurized Water Reactors (LOCHS (PWR)) initiating event is defined as at least one of the following:

1. A complete closure of at least one main steam isolation valve in each main steam line.
2. 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.
3. The failure of one or more turbine bypass valves to maintain the reactor pressure and temperature at the desired operating condition.

D.2.8.2 Data Collection and Review

Data for the LOCHS (PWR) baseline were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2, the optimized baseline period for LOCHS (PWR) is 1995–2002. Figure D.2.8-1 shows the trend of the full LOCHS (PWR) data set and the baseline period used in this analysis. RADS was used to collect the LOCHS (PWR) data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table D.2.8-1 summarizes the data obtained from RADS and used in the LOCHS (PWR) analysis.

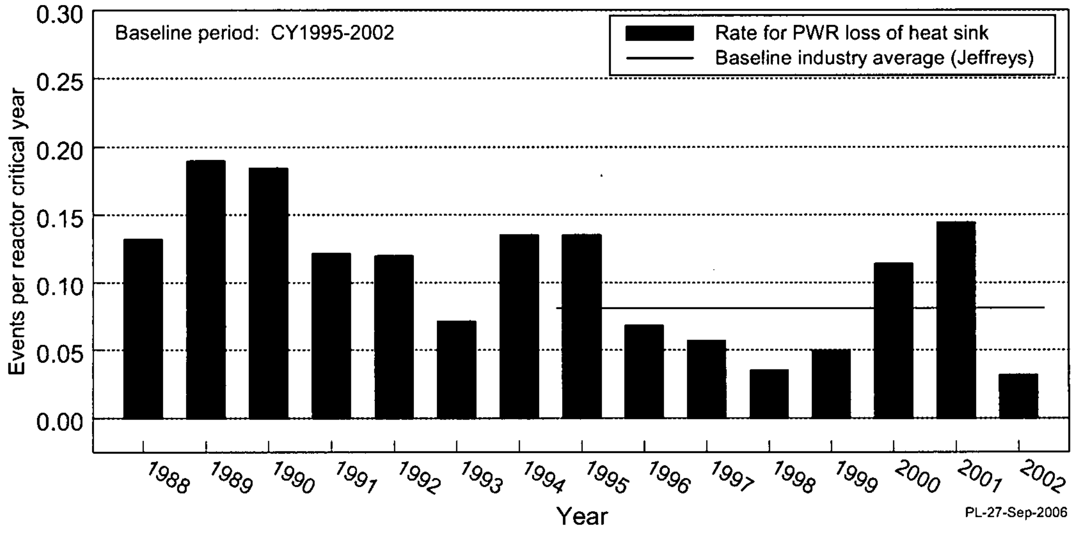

Figure D.2.8-1. LOCHS (PWR) trend plot.

Table D.2.8-1. 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)			
38	475.0	1995–2002	73	38.4%

D.2.8.3 Data Analysis

The LOCCW data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table D.2.8-2.

Table D.2.8-2. Empirical distributions of MLEs for λ for LOCHS (PWR).

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	8.09E-02	2.78E-01
Industry	-	-	8.00E-02	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table D.2.8-1, 38.4% of the plants experienced a LOCHS (PWR) over the period 1995–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 61.6% portion of the distribution, and non-zero values above 61.6%.

An empirical Bayes analysis was performed at the plant level but failed to converge. (This most likely was the result of insufficient variation between plants.) Therefore, assuming homogeneous data, a Bayesian update of the Jeffreys noninformative prior using the industry data was calculated. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table D.2.8-3.

Table D.2.8-3. Fitted distributions for λ for LOCHS (PWR).

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	6.08E-02	8.04E-02	8.11E-02	1.04E-01	Gamma	38.500	4.750E+02
SCNID/IL	3.19E-04	3.69E-02	8.11E-02	3.11E-01	Gamma	0.500	6.169E+00

Note – JEFF/IL is a Bayesian update of the Jeffreys noninformative prior using industry data and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.8.4 Industry-Average Baselines

Table D.2.8-4 lists the industry-average frequency distribution. The Bayesian update of the Jeffreys noninformative prior was selected. This industry-average frequency does not account for any recovery.

Table D.2.8-4. Selected industry distribution of λ for LOCHS (PWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	6.08E-02	8.04E-02	8.11E-02	1.04E-01	Gamma	38.500	4.750E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.8-5 shows the rounded value.

Table D.2.8-5. Selected industry distribution of λ for LOCHS (PWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	6.0E-02	8.0E-02	8.0E-02	1.0E-01	Gamma	40.00	5.00E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.9 Loss of Vital DC Bus (LODC) Data Sheet

D.2.9.1 Initiating Event Description

From Reference D-3, 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 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.

D.2.9.2 Data Collection and Review

Data for the LODC baseline were obtained from the IEDB, as accessed using RADS. However, the SPAR event tree model for LODC assumes no recovery of the failed dc bus and assumes the bus powers significant safety features. The LODC events in the IEDB were reviewed to identify the subset of events that matched the event tree modeling assumptions in SPAR. That review resulted in two of three LODC events in the IEDB being dropped.

Using the process outlined in Section D.1.2, the optimized baseline period for LODC is 1988–2002. (With only one event, the entire period is used for the baseline.) Figure D.2.9-1 shows the trend of the full LODC data set and the baseline period used in this analysis. RADS was used to collect the LODC data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table D.2.9-1 summarizes the data obtained from RADS and used in the LODC analysis.

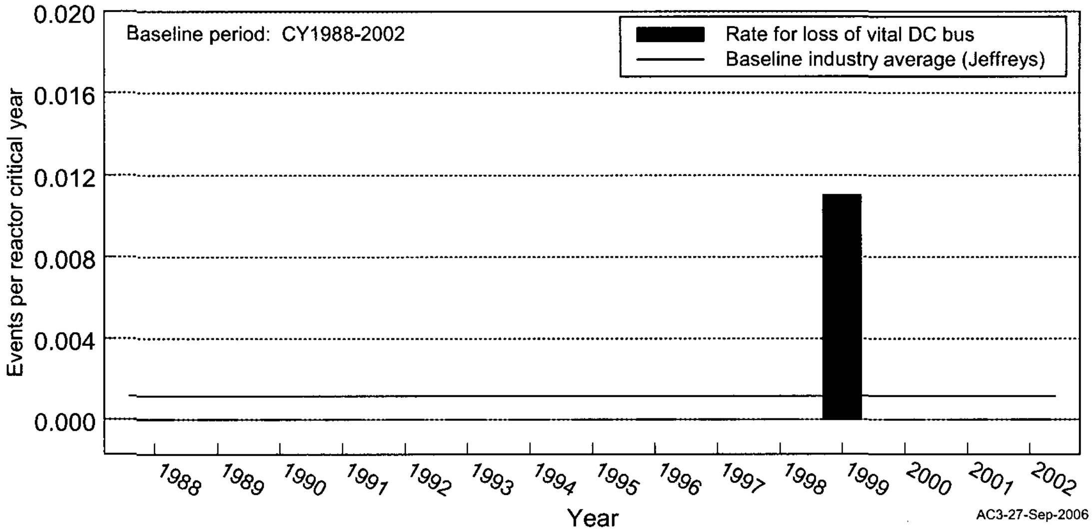

Figure D.2.9-1. LODC trend plot.

Table D.2.9-1. LODC frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
1	1282.4	1988–2002	113	0.9%

D.2.9.3 Data Analysis

The LODC data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table D.2.9-2.

Table D.2.9-2. Empirical distributions of MLEs for λ for LODC.

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	8.87E-04	0.00E+00
Industry	-	-	7.80E-04	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table D.2.9-1, only 0.9% of the plants experienced a LODC over the period 1988–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 99.1% portion of the distribution, and non-zero values above 99.1%.

Because of only one event, the empirical Bayes analysis was not performed. However, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table D.2.9-3.

Table D.2.9-3. Fitted distributions for λ for LODC.

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	4.60E-06	5.32E-04	1.17E-03	4.49E-03	Gamma	0.500	4.274E+02

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.9.4 Industry-Average Baselines

Table D.2.9-4 lists the industry-average frequency distribution. With only one event, 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 D.2.9-4. Selected industry distribution of λ for LODC (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	4.60E-06	5.32E-04	1.17E-03	4.49E-03	Gamma	0.500	4.274E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.9-5 shows the rounded value.

Table D.2.9-5. Selected industry distribution of λ for LODC (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	5.0E-06	5.0E-04	1.2E-03	5.0E-03	Gamma	0.50	4.17E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.10 Loss of Instrument Air at Boiling Water Reactors (LOIA (BWR)) Data Sheet

D.2.10.1 Initiating Event Description

From Reference D-3, 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.

D.2.10.2 Data Collection and Review

Data for the LOIA (BWR) baseline were obtained from the IEDB, as accessed using RADS. However, the SPAR event tree model for LOIA assumes no recovery of the instrument air system failure. The LOIA events in the IEDB were reviewed to identify the subset of events that matched the event tree modeling assumptions in SPAR. That review resulted in approximately 70% of the events in the IEDB being dropped. Using the process outlined in Section D.1.2, the optimized baseline period for LOIA (BWR) is 1991–2002. Figure D.2.10-1 shows the trend of the full LOIA (BWR) data set and the baseline period used in this analysis. RADS was used to collect the LOIA (BWR) data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table D.2.10-1 summarizes the data obtained from RADS and used in the LOIA (BWR) analysis.

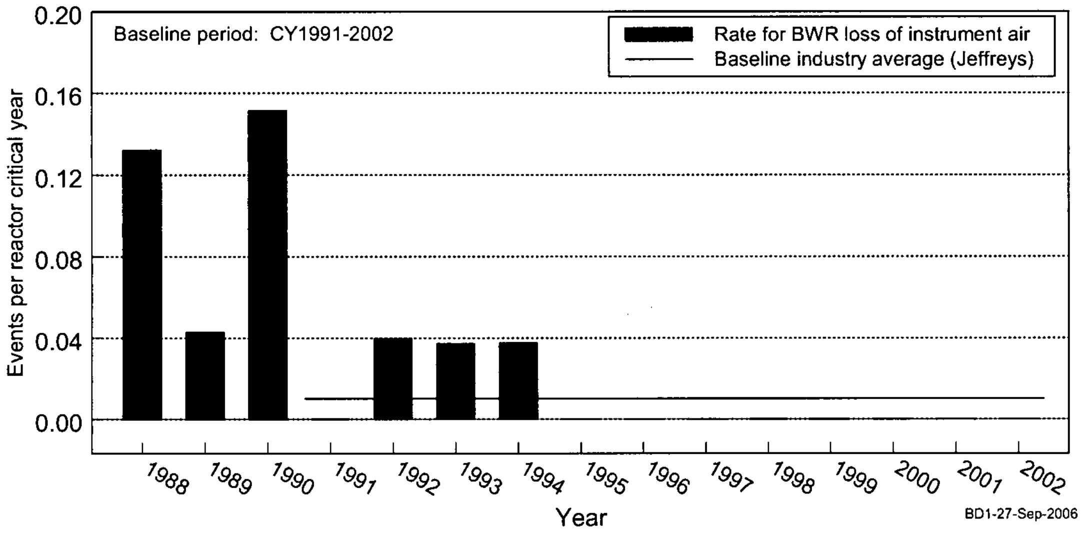

Figure D.2.10-1. LOIA (BWR) trend plot.

Table D.2.10-1. 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)			
3	343.3	1991–2002	36	8.3%

D.2.10.3 Data Analysis

The LOIA (BWR) data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry). At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table D.2.10-2.

Table D.2.10-2. Empirical distributions of MLEs for λ for LOIA (BWR).

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	9.53E-03	1.10E-01
Industry	-	-	8.74E-03	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table D.2.10-1, only 8.3% of the plants experienced a LOIA (BWR) over the period 1998–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 91.7% portion of the distribution, and non-zero values above 91.7%.

An empirical Bayes analysis was performed at the plant level but failed to converge. (This most likely was the result of insufficient variation between plants.) Therefore, assuming homogeneous data, a Bayesian update of the Jeffreys noninformative prior using the industry data was calculated. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table D.2.10-3.

Table D.2.10-3. Fitted distributions for λ for LOIA (BWR).

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	3.16E-03	9.24E-03	1.02E-02	2.05E-02	Gamma	3.500	3.433E+02
SCNID/IL	4.01E-05	4.64E-03	1.02E-02	3.92E-02	Gamma	0.500	4.902E+01

Note – JEFF/IL is a Bayesian update of the Jeffreys noninformative prior using industry data and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.10.4 Industry-Average Baselines

Table D.2.10-4 lists the industry-average frequency distribution. The Bayesian update of the Jeffreys noninformative prior was selected. This industry-average frequency does not account for any recovery.

Table D.2.10-4. Selected industry distribution of λ for LOIA (BWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	3.16E-03	9.24E-03	1.02E-02	2.05E-02	Gamma	3.500	3.433E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.10-5 shows the rounded value.

Table D.2.10-5. Selected industry distribution of λ for LOIA (BWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	3.0E-03	9.0E-03	1.0E-02	2.0E-02	Gamma	4.00	4.00E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.11 Loss of Instrument Air at Pressurized Water Reactors (LOIA (PWR)) Data Sheet

D.2.11.1 Initiating Event Description

From Reference D-3, the Loss of Instrument Air at Pressurized Water Reactors (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.

D.2.11.2 Data Collection and Review

Data for the LOIA (PWR) baseline were obtained from the IEDB, as accessed using RADS. Similar to what was done for LOIA (BWR), the LOIA (PWR) events in the IEDB were reviewed to ensure the events matched the SPAR event tree modeling assumptions. That review resulted in some of the events being dropped. (However, none were dropped in the baseline period chosen.) Using the process outlined in Section D.1.2, the optimized baseline period for LOIA (PWR) is 1997–2002. Figure D.2.11-1 shows the trend of the full LOIA (PWR) data set and the baseline period used in this analysis. RADS was used to collect the LOIA (PWR) data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table D.2.11-1 summarizes the data obtained from RADS and used in the LOIA (PWR) analysis.

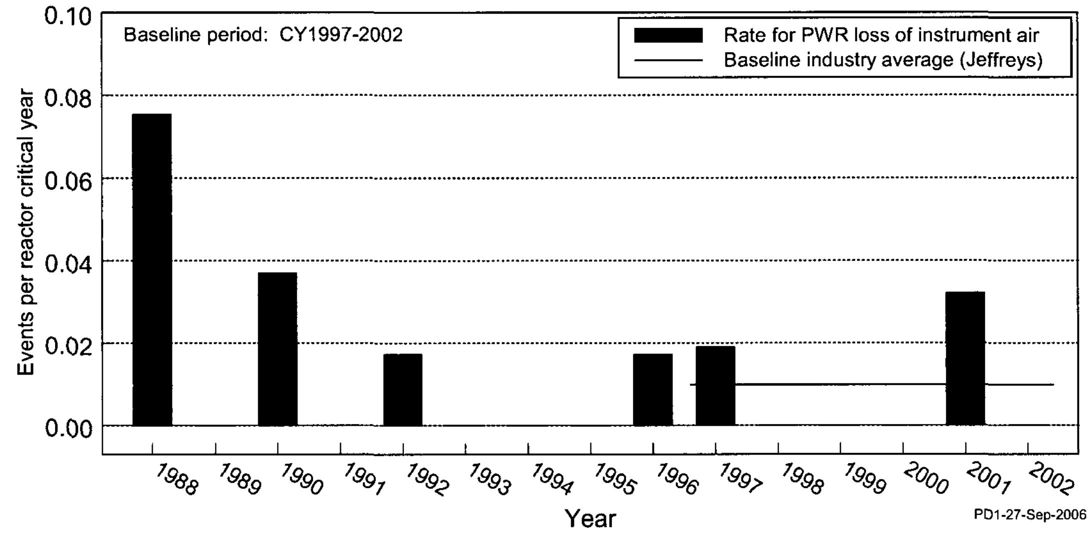

Figure D.2.11-1. LOIA (PWR) trend plot.

Table D.2.11-1. 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)			
3	356.9	1997–2002	70	2.9%

D.2.11.3 Data Analysis

The LOIA (PWR) data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table D.2.11-2.

Table D.2.11-2. Empirical distributions of MLEs for λ for LOIA (PWR).

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	8.86E-03	0.00E+00
Industry	-	-	8.41E-03	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table D.2.11-1, only 2.9% of the plants experienced a LOIA (PWR) over the period 1997–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 97.1% portion of the distribution, and non-zero values above 97.1%.

An empirical Bayes analysis was performed at the plant level but failed to converge. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table D.2.11-3 for LOIA (PWR).

Table D.2.11-3. Fitted distributions for λ for LOIA (PWR).

Analysis Type	5%	Median	Mean	95%	Distribution Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	3.86E-05	4.46E-03	9.81E-03	3.77E-02	Gamma	0.500	5.099E+01

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.11.4 Industry-Average Baselines

Table D.2.11-4 lists the industry-average frequency distribution. Because the empirical Bayes analysis did not converge, the SCNID distribution was used. This industry-average frequency does not account for any recovery.

Table D.2.11-4. Selected industry distribution of λ for LOIA (PWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution Type	α	β
SCNID/IL	3.86E-05	4.46E-03	9.81E-03	3.77E-02	Gamma	0.500	5.099E+01

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.11-5 shows the rounded value.

Table D.2.11-5. Selected industry distribution of λ for LOIA (PWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution Type	α	β
SCNID/IL	4.0E-05	4.0E-03	1.0E-02	4.0E-02	Gamma	0.50	5.00E+01

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.12 Loss of Main Feedwater (LOMFW) Data Sheet

D.2.12.1 Initiating Event Description

From Reference D-3, 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; the loss of a startup or an auxiliary feedwater pump normally used during plant startup; the loss of all operating feed pumps due to trips caused by low suction pressure, loss of seal water, or high water level (boiling water reactor vessel level or pressurized water reactor 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.

D.2.12.2 Data Collection and Review

Data for the LOMFW baseline were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2, the optimized baseline period for LOMFW is 1993–2002. Figure D.2.12-1 shows the trend of the full LOMFW data set and the baseline period used in this analysis. RADS was used to collect the LOMFW data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table D.2.12-1 summarizes the data obtained from RADS and used in the LOMFW analysis.

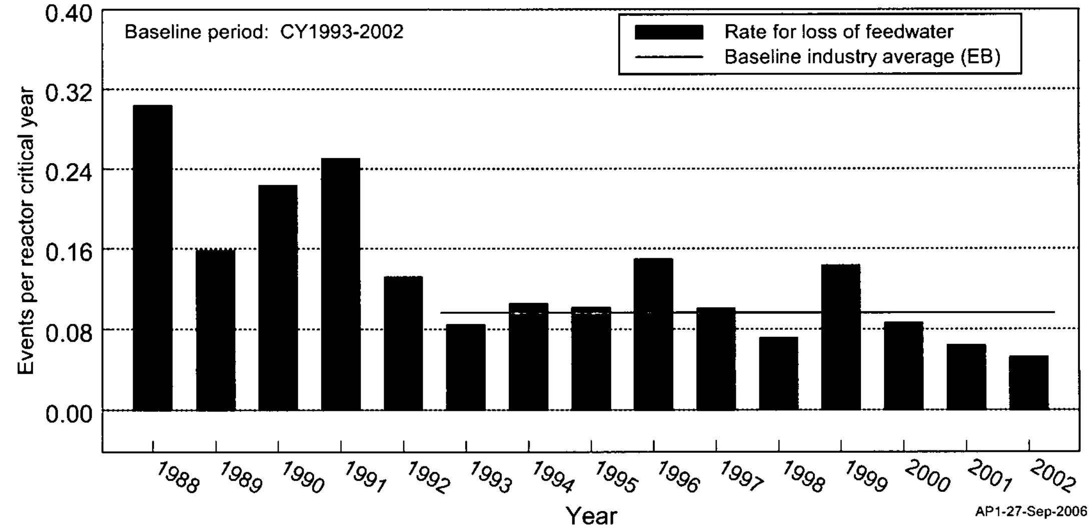

Figure D.2.12-1. LOMFW trend plot.

Table D.2.12-1. LOMFW frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
84	881.9	1993–2002	109	44.0%

D.2.12.3 Data Analysis

The LOMFW data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table D.2.12-2.

Table D.2.12-2. Empirical distributions of MLEs for λ for LOMFW.

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	9.61E-02	3.45E-01
Industry	-	-	9.52E-02	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table D.2.12-1, 44.0% of the plants experienced a LOMFW over the period 1993–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 56.0% portion of the distribution, and non-zero values above 56.0%.

An empirical Bayes analysis was performed at the plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table D.2.12-3.

Table D.2.12-3. Fitted distributions for λ for LOMFW.

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	9.06E-03	7.32E-02	9.59E-02	2.60E-01	Gamma	1.326	1.383E+01
SCNID/IL	3.77E-04	4.36E-02	9.58E-02	3.68E-01	Gamma	0.500	5.219E+00

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.12.4 Industry-Average Baselines

Table D.2.12-4 lists the industry-average frequency distribution. The data set was sufficient for an empirical Bayes analysis to be performed. This industry-average frequency does not account for any recovery.

Table D.2.12-4. Selected industry distribution of λ for LOMFW (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	9.06E-03	7.32E-02	9.59E-02	2.60E-01	Gamma	1.326	1.383E+01

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.12-4 shows the rounded value.

Table D.2.12-5. Selected industry distribution of λ for LOMFW (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	8.0E-03	7.0E-02	1.0E-01	3.0E-01	Gamma	1.20	1.20E+01

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.13 Loss of Offsite Power (LOOP) Data Sheet

D.2.13.1 Initiating Event Description

From Reference D-3, the Loss of Offsite Power (LOOP) 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.

D.2.13.2 Data Collection and Review

The LOOP data were obtained directly from the report *Reevaluation of Station Blackout Risk at Nuclear Power Plants* (Ref. D-4). A baseline period of 1997–2004 was used in that report. Table D.2.13-1 summarizes the data used in the LOOP analysis. Figure D.2.13-1 shows the trend of the full LOOP data set and the baseline period used in this analysis.

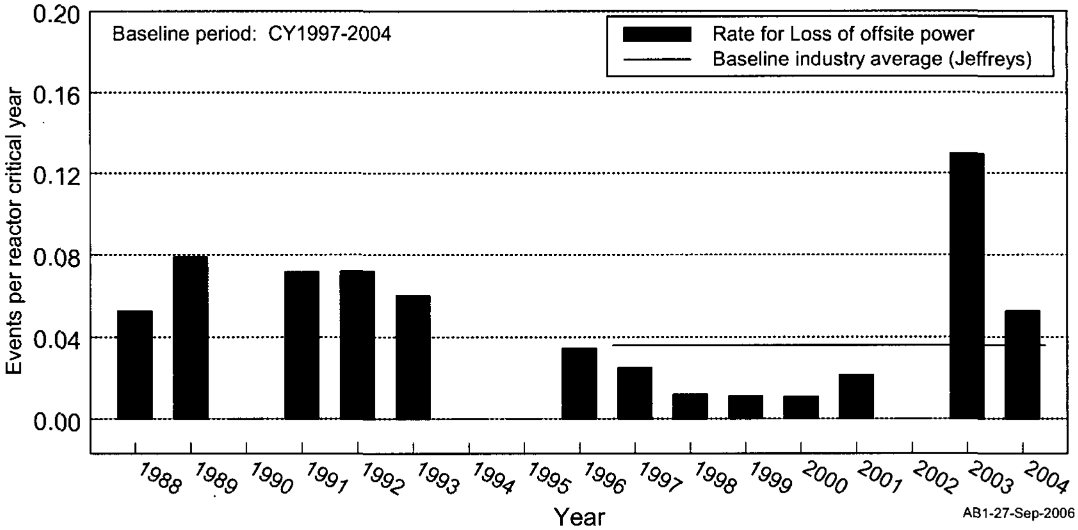

Figure D.2.13-1. LOOP trend plot.

Table D.2.13-1. 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)			
Plant Centered	1	724.3	1997–2004	103	1.0%
Switchyard Centered	7	724.3	1997–2004	103	6.8%
Grid Related	13	724.3	1997–2004	103	12.6%
Weather Related	3	724.3	1997–2004	103	2.9%
Total LOOP	24	724.3	1997–2004	103	22.3%

D.2.13.3 Industry-Average Baselines

Table D.2.13-2 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 D.2.13-2. Selected industry distributions of λ for LOOP (before rounding).

Event	Source	5%	Median	Mean	95%	Distribution		
						Type	α	β
Plant Centered	LOOP	8.41E-06	9.42E-04	2.07E-03	7.96E-03	Gamma	0.500	2.414E+02
Switchyard Centered	LOOP	4.07E-05	4.71E-03	1.04E-02	3.98E-02	Gamma	0.500	4.829E+01
Grid Related	LOOP	7.33E-05	8.48E-03	1.86E-02	7.16E-02	Gamma	0.500	2.683E+01
Weather Related	LOOP	1.90E-05	2.20E-03	4.83E-03	1.86E-02	Gamma	0.500	1.035E+02
Total LOOP	LOOP	4.57E-03	2.87E-02	3.59E-02	9.19E-02	Gamma	1.580	4.402E+01

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

The SPAR models use the unrounded LOOP frequency distribution. However, for completeness, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.13-3 shows the rounded values for the LOOP initiating event.

Table D.2.13-3. Selected industry distributions of λ for LOOP (after rounding).

Event	Source	5%	Median	Mean	95%	Distribution		
						Type	α	β
Plant Centered	LOOP	8.0E-06	9.0E-04	2.0E-03	8.0E-03	Gamma	0.50	2.50E+02
Switchyard Centered	LOOP	4.0E-05	5.0E-03	1.0E-02	4.0E-02	Gamma	0.50	5.00E+01
Grid Related	LOOP	8.0E-05	9.0E-03	2.0E-02	8.0E-02	Gamma	0.50	2.50E+01
Weather Related	LOOP	2.0E-05	2.5E-03	5.0E-03	2.0E-02	Gamma	0.50	1.00E+02
Total LOOP	LOOP	5.0E-03	3.0E-02	4.0E-02	1.0E-01	Gamma	1.50	3.75E+01

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.14 Loss of Emergency Service Water (LOESW) Data Sheet

D.2.14.1 Initiating Event Description

From Reference D-3, 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).

D.2.14.2 Data Collection and Review

Data for the LOESW baseline were obtained from the IEDB, as accessed using RADS. That search identified one LOSWS event at a plant with a SWS that had one running pump and one standby pump. However, that SWS was the normally-operating non-safety SWS. The ESW at that plant is a backup to the SWS and it started successfully when this event occurred. Therefore, this event is not a LOESW.

Using the process outlined in Section D.1.2, the optimized baseline period for LOESW is 1988–2002. (There were no events.) RADS was used to collect the LOESW data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table D.2.14-1 summarizes the data obtained from RADS and used in the LOESW analysis.

Table D.2.14-1. LOESW frequency data.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
0	1269.4	1988–2002	112	0.0%

D.2.14.3 Data Analysis

The LOESW data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. However, in this case there were no events, so all of the MLEs are zero. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table D.2.14-2.

Table D.2.14-2. Empirical distributions of MLEs for λ for LOESW.

Aggregation Level	5%	Median	Mean	95%
Plant	-	-	-	-
Industry	-	-	0.00E+00	-

Note – Percentiles and the mean have units of events/rcry.

With no events, an empirical Bayes analysis could not be performed. However, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table D.2.14-3.

Table D.2.14-3. Fitted distributions for λ for LOESW.

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	1.55E-06	1.79E-04	3.94E-04	1.51E-03	Gamma	0.500	1.269E+03

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.14.4 Industry-Average Baselines

Table D.2.14-4 lists the industry-average frequency distribution. With no events, the 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 D.2.14-4. Selected industry distribution of λ for LOESW (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	1.55E-06	1.79E-04	3.94E-04	1.51E-03	Gamma	0.500	1.269E+03

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.14-5 shows the rounded value.

Table D.2.14-5. Selected industry distribution of λ for LOESW (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	1.5E-06	2.0E-04	4.0E-04	1.5E-03	Gamma	0.50	1.25E+03

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.15 Partial Loss of Component Cooling Water System (PLOCCW) Data Sheet

D.2.15.1 Initiating Event Description

From Reference D-3, 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 component cooling water (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.

D.2.15.2 Data Collection and Review

Data for the PLOCCW baseline were obtained from the IEDB, as accessed using RADS. However, the SPAR event tree models for PLOCCW assume unrecovered loss of at least one safety system train. The PLOCCW events in the IEDB were reviewed to identify the subset of events that matched the event tree modeling assumptions in SPAR. That review resulted in approximately 80% of the original PLOCCW events in the IEDB being dropped. (However, those dropped events are still included in the transient or other IE categories.)

Using the process outlined in Section D.1.2, the optimized baseline period for PLOCCW is 1988–2002. (With only one event, the entire period is chosen for the baseline.) Figure D.2.15-1 shows the trend of the full PLOCCW data set and the baseline period used in this analysis. RADS was used to collect the PLOCCW data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table D.2.15-1 summarizes the data obtained from RADS and used in the PLOCCW analysis.

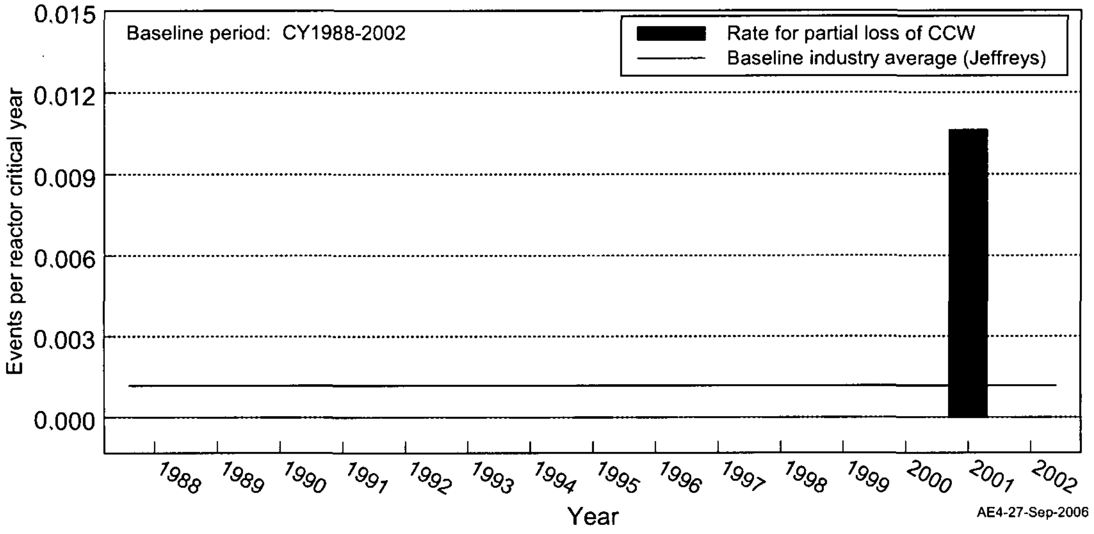

Figure D.2.15-1 PLOCCW trend plot.

Table D.2.15-1. PLOCCW frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
1	1282.4	1988–2002	113	0.9%

D.2.15.3 Data Analysis

The PLOCCW data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table D.2.15-2.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table D.2.15-1, only 1.9% of the plants experienced a PLOCCW over the period 1998–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 98.1% portion of the distribution, and non-zero values above 98.1%.

Table D.2.15-2. Empirical distributions of MLEs for λ for PLOCCW.

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	7.78E-04	0.00E+00
Industry	-	-	7.80E-04	-

Note – Percentiles and the mean have units of events/rcry.

With only one event, the empirical Bayes analysis could not be performed. However, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table D.2.15-3 for PLOCCW.

Table D.2.15-3. Fitted distributions for λ for PLOCCW.

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	4.60E-06	5.32E-04	1.17E-03	4.49E-03	Gamma	0.500	4.274E+02

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.15.4 Industry-Average Baselines

Table D.2.15-4 lists the industry-average frequency distribution. With only one event the 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 D.2.15-4. Selected industry distribution of λ for PLOCCW (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	4.60E-06	5.32E-04	1.17E-03	4.49E-03	Gamma	0.500	4.274E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.15-5 shows the rounded value for the PLOCCW initiating event.

Table D.2.15-5. Selected industry distribution of λ for PLOCCW (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	5.0E-06	5.0E-04	1.2E-03	5.0E-03	Gamma	0.50	4.17E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.16 Partial Loss of Emergency Service Water (PLOESW) Data Sheet

D.2.16.1 Initiating Event Description

From Reference D-3, 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).

D.2.16.2 Data Collection and Review

Data for the PLOESW baseline were obtained from the IEDB, as accessed using RADS. However, the SPAR event tree models for PLOESW assume unrecoverable loss of more than one safety system train. The PLOESW events in the IEDB were reviewed to identify the subset of events that matched the event tree modeling assumptions in SPAR. That review resulted in approximately 80% of the original PLOSWS events in the IEDB being dropped. (However, those dropped events are still included in the transient or other IE categories.)

Using the process outlined in Section D.1.2, the optimized baseline period for PLOESW is 1988–2002. (With only two events, the entire period is chosen for the baseline.) Figure D.2.16-1 shows the trend of the full PLOESW data set and the baseline period used in this analysis. RADS was used to collect the PLOESW data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table D.2.16-1 summarizes the data obtained from RADS and used in the PLOESW analysis.

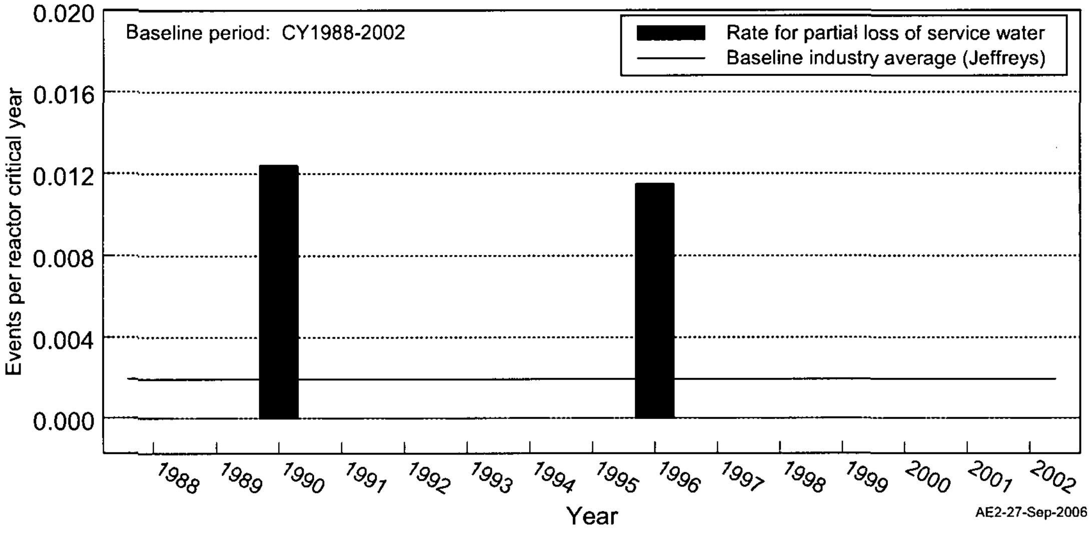

Figure D.2.16-1. PLOESW trend plot.

Table D.2.16-1. PLOESW frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
2	1282.4	1988–2002	113	1.8%

D.2.16.3 Data Analysis

The PLOESW data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table D.2.16-2.

Table D.2.16-2. Empirical distributions of MLEs for λ for PLOESW.

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	2.11E-03	0.00E+00
Industry	-	-	1.56E-03	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table D.2.16-1, only 1.8% of the plants experienced a PLOSWS over the period 1988–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 98.2% portion of the distribution, and non-zero values above 98.2%.

An empirical Bayes analysis was performed at the plant level. However, no results were obtained because of so few events. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table D.2.16-3 for PLOESW.

Table D.2.16-3. Fitted distributions for λ for PLOESW.

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	7.66E-06	8.87E-04	1.95E-03	7.49E-03	Gamma	0.500	2.565E+02

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.16.4 Industry-Average Baselines

Table D.2.16-4 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 D.2.16-4. Selected industry distribution of λ for PLOESW (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	7.66E-06	8.87E-04	1.95E-03	7.49E-03	Gamma	0.500	2.565E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.16-5 shows the rounded value.

Table D.2.16-5. Selected industry distribution of λ for PLOESW (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	8.0E-06	9.0E-04	2.0E-03	8.0E-03	Gamma	0.50	2.50E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.17 Steam Generator Tube Rupture (STGR) Data Sheet

D.2.17.1 Initiating Event Description

From Reference D-3, 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 gallons per minute (gpm). A 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 initiating event. The latter case would be classified as a functional impact. This category applies to pressurized water reactors (PWRs) only. This category includes excessive leakage caused by the failure of a previous SGTR repair (i.e., leakage past a plug).

D.2.17.2 Data Collection and Review

Two methodologies are summarized in this section. For one approach, information for the SGTR baseline was obtained from *Estimating Loss-of-Coolant Accident (LOCA) Frequencies through the Elicitation Process* (Ref. D-5). 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." Reference D-5 is a draft document. Results obtained from that document could change when the final report is issued.

From Table 7.3 in Reference D-5, the mean frequency for SGTR ((> 100 gpm) is 3.4E-3/reactor calendar year (rcy). To convert this to reactor critical years (rcry's), it was assumed that reactors are critical 90% of each year. Converting to rcry's, 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 Reference D-5 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 STGR baseline were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2, the optimized baseline period for STGR is 1991–2002. Figure D.2.17-1 shows the trend of the full STGR data set and the baseline period used in this analysis. RADS was used to collect the STGR data for that period. Results include total number of events and total rcry's for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table D.2.17-1 summarizes the data obtained from RADS and used in the STGR analysis.

Table D.2.17-1. STGR frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
2	706.4	1991–2002	76	2.6%

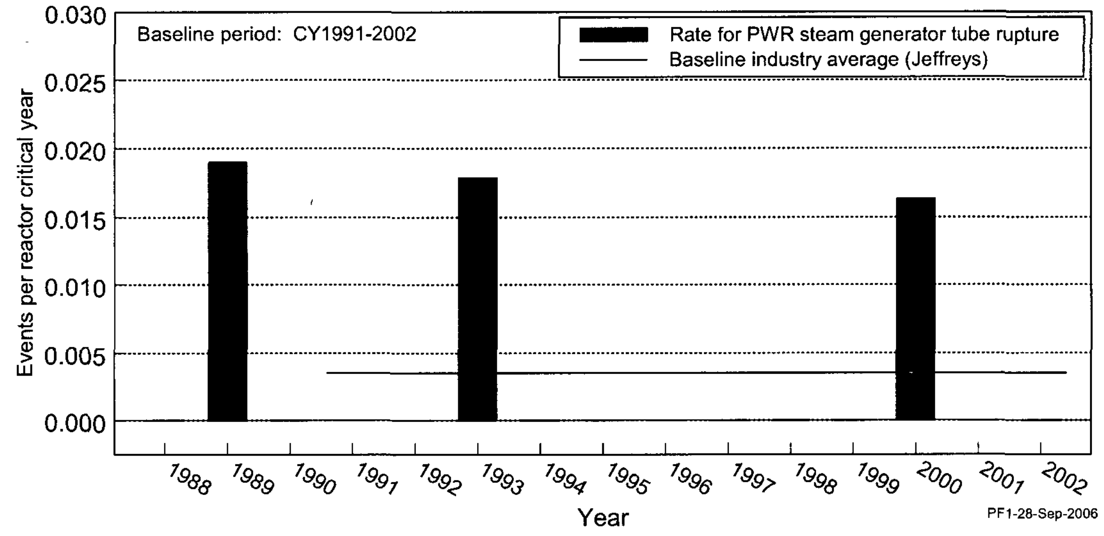

Figure D.2.17-1. SGTR trend plot.

D.2.17.3 Data Analysis

The STGR data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table D.2.17-2.

Table D.2.17-2. Empirical distributions of MLEs for λ for STGR.

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	2.83E-03	0.00E+00
Industry	-	-	2.83E-03	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table D.2.17-1, only 2.6% of the plants experienced a STGR over the period 1991–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 97.4% portion of the distribution, and non-zero values above 97.4%.

With only two events, the empirical Bayes analysis could not be performed. However, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table D.2.17-3 for STGR.

Table D.2.17-3. Fitted distributions for λ for STGR.

Analysis Type	5%	Median	Mean	95%	Distribution Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	1.39E-05	1.61E-03	3.54E-03	1.36E-02	Gamma	0.500	1.413E+02

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.17.4 Industry-Average Baselines

Table D.2.17-4 lists the industry-average frequency distribution. Two different approaches to estimating the frequency for SGTR were discussed – the expert elicitation approach from Reference D-5, and the data analysis using the IEDB. Because the expert elicitation process outlined in Reference D-5 resulted in a mean frequency for SGTR (3.78E-3/rcry) higher than that obtained from optimizing the SGTR data from the IEDB (3.54E-3/rcry), the IEDB results were used. This industry-average frequency does not account for any recovery.

Table D.2.17-4. Selected industry distribution of λ for STGR (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	1.39E-05	1.61E-03	3.54E-03	1.36E-02	Gamma	0.500	1.413E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.17-5 shows the rounded value.

Table D.2.17-5. Selected industry distribution of λ for STGR (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	1.5E-05	2.0E-03	4.0E-03	1.5E-02	Gamma	0.50	1.25E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.18 Small Loss-of-Coolant Accident at Boiling Water Reactors (SLOCA (BWR)) Data Sheet

D.2.18.1 Initiating Event Description

From Reference D-3, the Small Loss-of-Coolant Accident (SLOCA) initiating event is defined for a boiling water reactor (BWR) as a break size less than 0.004 square feet (or a 1-inch inside diameter pipe equivalent for liquid) and less than 0.05 square feet (or an approximately 4-inch inside diameter pipe equivalent for steam) in a pipe in the primary system boundary. However, the leakage must be greater than 100 gallons per minute (gpm), which is the upper limit for the very small LOCA, or VSLOCA.

D.2.18.2 Data Collection and Review

Two methodologies are summarized in this section. For one approach, information for the SLOCA (BWR) baseline was obtained from *Estimating Loss-of-Coolant Accident (LOCA) Frequencies through the Elicitation Process* (Ref. D-5). In that document, the SLOCA 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." Reference D-5 is a draft document. Results obtained from that document could change when the final report is issued.

Table 7.1 in Reference D-5 presents frequencies for LOCAs exceeding various sizes indicated by gpm break flow and effective pipe size break. Six different sizes are listed, ranging from 0.5-inch diameter (> 100 gpm) to 31-inch or 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 operation) and for end-of-life conditions (40 years of operation). For this study, frequencies appropriate for current day conditions were used.

From Table 7.1 in Reference D-5, the SLOCA frequency (in reactor calendar years or rcy's) for BWRs is

$$5.5\text{E-}4/\text{rcy} - 1.0\text{E-}4/\text{rcy} = 4.5\text{E-}4/\text{rcy},$$

where 5.5E-4/rcy is for LOCAs with an effective break size greater than 0.5-inch inside diameter, and 1.0E-6/rcy is the MLOCA value. To convert this to reactor critical years (rcry's), it was assumed that reactors are critical 90% of each year. Converting to rcry's, the result is

$$(4.50\text{E-}4/\text{rcy})(1\ \text{rcy}/0.9\ \text{rcry}) = 5.00\text{E-}4/\text{rcry}.$$

The associated error factor (95^{th} percentile divided by median) associated with the > 0.5-in. category from Reference D-5 is

$$(1.6\text{E-}3/\text{rcy})/(3.0\text{E-}4/\text{rcy}) = 5.3,$$

which converts to an α of 0.78.

For the other approach, data for the SLOCA (BWR) baseline were also obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2, the optimized baseline period for SLOCA (BWR) is 1988–2002. (With no events, the entire period is chosen for the baseline.) RADS was used to collect the SLOCA data for the baseline period. Results include total number of events and total rcry's for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table D.2.18-1 summarizes the data obtained from RADS and used in the SLOCA (BWR) analysis.

Table D.2.18-1. 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	415.8	1988–2002	36	0.0%

D.2.18.3 Data Analysis

With no events, the empirical Bayes analysis could not be performed. However, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table D.2.18-2.

Table D.2.18-2. Fitted distribution for λ for SLOCA (BWR).

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	4.72E-06	5.46E-04	1.20E-03	4.61E-03	Gamma	0.500	4.167E+02

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.18.4 Industry-Average Baselines

Table D.2.18-3 lists the industry-average frequency distribution. Two different approaches to estimating the frequency for SLOCA (BWR) were discussed – the expert elicitation approach from Reference D-5, and the data analysis using the IEDB. Because the IEDB contained no events and the resulting SCNID mean (1.20E-3/rcry) is higher than the expert elicitation estimate (5.00E-4/rcry), the expert elicitation distribution was chosen. (The IEDB was considered to be too limited in terms of current BWR experience to be used, given that no events had occurred.) This industry-average frequency does not account for any recovery.

Table D.2.18-3. Selected industry distribution of λ for SLOCA (BWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	1.26E-05	3.09E-04	5.00E-04	1.64E-03	Gamma	0.780	1.560E+03

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.18-4 shows the rounded value.

Table D.2.18-4. Selected industry distribution of λ for SLOCA (BWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	1.5E-05	3.0E-04	5.0E-04	1.5E-03	Gamma	0.80	1.60E+03

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.19 Small Loss-of-Coolant Accident at Pressurized Water Reactors (SLOCA (PWR)) Data Sheet

D.2.19.1 Initiating Event Description

From Reference D-3, the Small Loss-of-Coolant Accident (SLOCA) initiating event is defined for a pressurized water reactor (PWR) as a pipe break in the primary system boundary with an inside diameter between 0.5 and 2 inch.

D.2.19.2 Data Collection and Review

Two methodologies are summarized in this section. For one approach, information for the SLOCA (PWR) baseline was obtained from *Estimating Loss-of-Coolant Accident (LOCA) Frequencies through the Elicitation Process* (Ref. D-5). In that document, the SLOCA 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." Reference D-5 is a draft document. Results obtained from that document could change when the final report is issued.

Table 7.1 in Reference D-5 presents frequencies for LOCAs exceeding various sizes indicated by gallon per minute (gpm) break flow and effective pipe size break. Six different sizes are listed, ranging from 0.5-inch diameter (> 100 gpm) to 31-inch or 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 operation) and for end-of-life conditions (40 years of operation). For this study, frequencies appropriate for current day conditions were used.

From Table 7.1 in Reference D-5, the SLOCA frequency (in reactor calendar years or rcy's) for PWRs is

$$5.9\text{E-}3/\text{rcy} - 4.6\text{E-}4/\text{rcy} = 5.44\text{E-}3/\text{rcy},$$

where 5.9E-3/rcy is for LOCAs with an effective break size greater than 0.5-inch inside diameter (including SGTRs), and 4.6E-4/rcy is the MLOCA value. Because SPAR models SGTR as a separate initiator, the SGTR frequency must be subtracted from the above result. From Reference D-5, the SGTR mean frequency is 3.4E-3/rcy. Therefore, with the SGTR contribution removed, the SLOCA frequency for PWRs is

$$5.44\text{E-}3/\text{rcy} - 3.4\text{E-}3/\text{rcy} = 2.04\text{E-}3/\text{rcy}.$$

To convert this to reactor critical years (rcry's), it was assumed that reactors are critical 90% of each year. Converting to rcry's, the result is

$$(2.04\text{E-}3/\text{rcy})(1\ \text{rcy}/0.9\ \text{rcry}) = 2.27\text{E-}3/\text{rcry}.$$

The associated error factor (95th percentile divided by median) associated with the > 0.5-in. category from Reference D-5 is

$$(1.5\text{E-}2/\text{rcy})/(3.7\text{E-}3/\text{rcy}) = 4.1,$$

which converts to an α of 1.09.

For the other approach, data for the SLOCA (PWR) baseline were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2, the optimized baseline period for SLOCA (PWR) is 1988–2002. (With no events, the entire period is chosen for the baseline.) RADS was used to collect the SLOCA data for the baseline period. Results include total number of events and total rcry's for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table D.2.19-1 summarizes the data obtained from RADS and used in the SLOCA (PWR) analysis.

Table D.2.19-1. 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	866.6	1988–2002	77	0.0%

D.2.19.3 Data Analysis

The SLOCA (PWR) data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry). At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. However, with no events all the MLEs are zero. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table D.2.19-2.

Table D.2.19-2. Empirical distributions of MLEs for λ for SLOCA (PWR).

Aggregation Level	5%	Median	Mean	95%
Plant	-	-	-	-
Industry	-	-	0.00E+00	-

Note – Percentiles and the mean have units of events/rcry.

With no events, an empirical Bayes analysis could not be performed. However, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table D.2.19-3.

Table D.2.19-3. Fitted distributions for λ for SLOCA (PWR).

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	2.27E-06	2.62E-04	5.77E-04	2.22E-03	Gamma	0.500	8.666E+02

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.19.4 Industry-Average Baselines

Table D.2.19-4 lists the industry-average frequency distribution. Two different approaches to estimating the frequency for SLOCA (PWR) were discussed—the expert elicitation approach from Reference D-5, and the data analysis using the IEDB. Because the expert elicitation process outlined in Reference D-5 resulted in a mean frequency for SLOCA (PWR) (2.27E-3/rcry) higher than that obtained from optimizing the SGTR data from the IEDB (5.77E-4/rcry), the IEDB results were used. This industry-average frequency does not account for any recovery.

Table D.2.19-4. Selected industry distribution of λ for SLOCA (PWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	2.27E-06	2.62E-04	5.77E-04	2.22E-03	Gamma	0.500	8.666E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.19-5 shows the rounded value.

Table D.2.19-5. Selected industry distribution of λ for SLOCA (PWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	2.5E-06	2.5E-04	6.0E-04	2.5E-03	Gamma	0.50	8.33E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.20 Stuck Open Relief Valve at Boiling Water Reactors (SORV (BWR)) Data Sheet

D.2.20.1 Initiating Event Description

From Reference D-3, the Stuck Open Relief Valve at Boiling Water Reactors (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 main steam line safety valves (BWR) and automatic depressurization system relief valves (BWR). 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.

D.2.20.2 Data Collection and Review

Data for the SORV (BWR) baseline were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2, the optimized baseline period for SORV (BWR) is 1993–2002. Figure D.2.20-1 shows the trend of the full SORV (BWR) data set and the baseline period used in this analysis. RADS was used to collect the SORV (BWR) data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table D.2.20-1 summarizes the data obtained from RADS and used in the SORV (BWR) analysis.

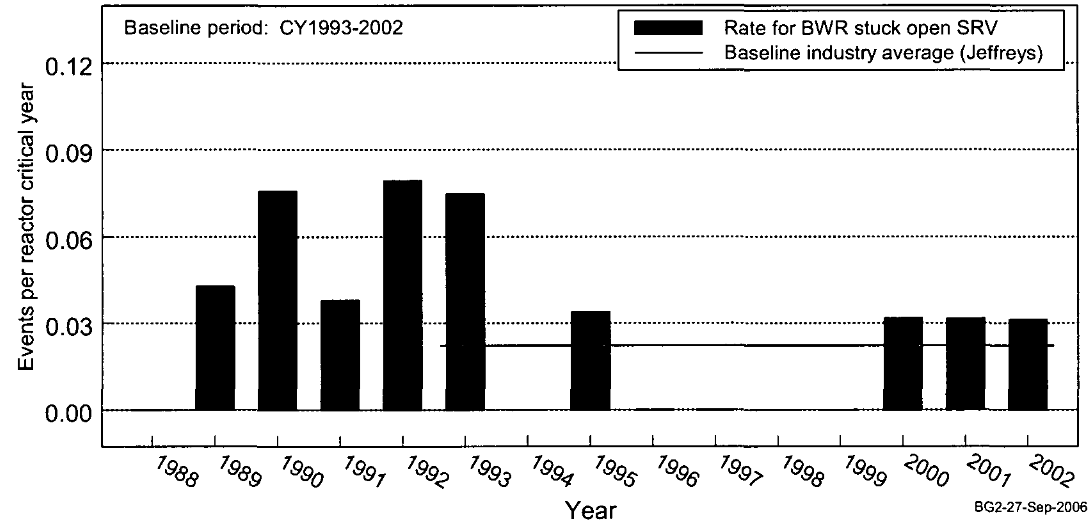

Figure D.2.20-1. SORV (BWR) trend plot.

Table D.2.20-1. SORV (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	291.7	1993–2002	36	16.7%

D.2.20.3 Data Analysis

The SORV (BWR) data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table D.2.20-2.

Table D.2.20-2. Empirical distributions of MLEs for λ for SORV (BWR).

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	2.00E-02	1.18E-01
Industry	-	-	2.06E-02	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table D.2.20-1, only 16.7% of the plants experienced a SORV (BWR) over the period 1993–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 83.3% portion of the distribution, and non-zero values above 83.3%.

An empirical Bayes analysis was performed at the plant level but failed to converge. (This most likely was the result of insufficient variation between plants.) Therefore, assuming homogeneous data, a Bayesian update of the Jeffreys noninformative prior using the industry data was calculated. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table D.2.20-3.

Table D.2.20-3. Fitted distributions for λ for SORV (BWR).

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	1.01E-02	2.12E-02	2.23E-02	3.83E-02	Gamma	6.500	2.917E+02
SCNID/IL	8.76E-05	1.01E-02	2.23E-02	8.56E-02	Gamma	0.500	2.244E+01

Note – JEFF/IL is a Bayesian update of the Jeffreys noninformative prior using industry data and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.20.4 Industry-Average Baselines

Table D.2.20-4 lists the industry-average frequency distribution. The Bayesian update of the Jeffreys noninformative prior was selected. This industry-average frequency does not account for any recovery.

Table D.2.20-4. Selected industry distribution of λ for SORV (BWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	1.01E-02	2.12E-02	2.23E-02	3.83E-02	Gamma	6.500	2.917E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.22-5 shows the rounded value.

Table D.2.20-5. Selected industry distribution of λ for SORV (BWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	9.0E-03	2.0E-02	2.0E-02	4.0E-02	Gamma	6.00	3.00E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.21 Stuck Open Relief Valve at Pressurized Water Reactors (SORV (PWR)) Data Sheet

D.2.21.1 Initiating Event Description

From Reference D-3, the Stuck Open Relief Valve at Pressurized Water Reactors (SORV (PWR)) 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 pressurizer code safety valves (PWR). The stuck open SRV may or may not cause the automatic or manual actuation of high pressure injection systems.

D.2.21.2 Data Collection and Review

Data for the SORV (PWR) baseline were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2, the optimized baseline period for SORV (PWR) is 1988–2002. (With only two events, the entire period is chosen for the baseline.) Figure D.2.21-1 shows the trend of the full SORV (PWR) data set and the baseline period used in this analysis. RADS was used to collect the SORV (PWR) data for that period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table D.2.21-1 summarizes the data obtained from RADS and used in the SORV (PWR) analysis.

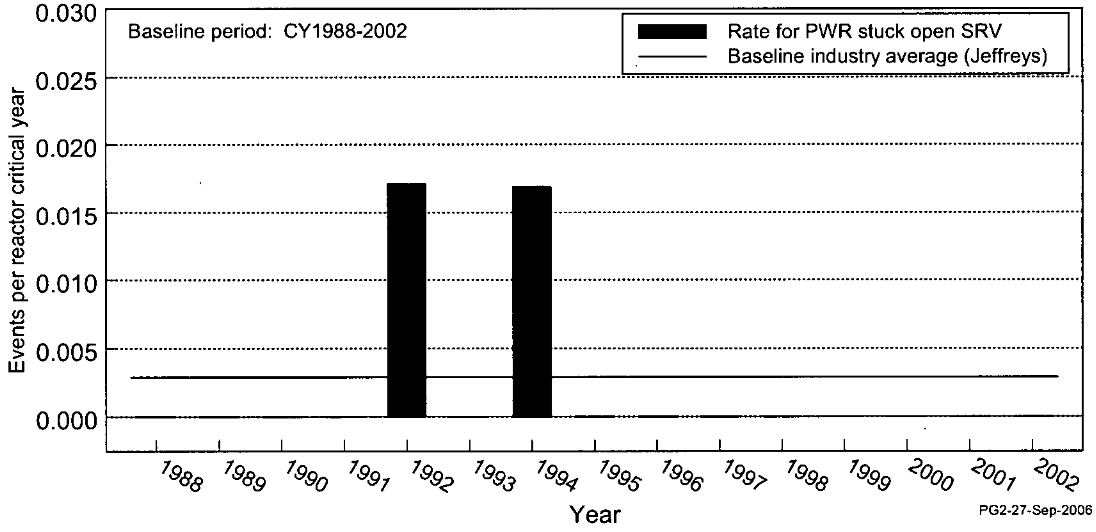

Figure D.2.21-1. SORV (PWR) trend plot.

Table D.2.21-1. SORV (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	866.6	1988–2002	77	2.6%

D.2.21.3 Data Analysis

The SORV (PWR) data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table D.2.21-2.

Table D.2.21-2. Empirical distributions of MLEs for λ for SORV (PWR).

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	2.20E-03	0.00E+00
Industry	-	-	2.31E-03	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table D.2.21-1, only 2.6% of the plants experienced a SORV (PWR) over the period 1988–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 97.4% portion of the distribution, and non-zero values above 97.4%.

With only two events, an empirical Bayes analysis could not be performed. However, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table D.2.21-3.

Table D.2.21-3. Fitted distributions for λ for SORV (PWR).

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	1.13E-05	1.31E-03	2.88E-03	1.11E-02	Gamma	0.500	1.733E+02

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.21.4 Industry-Average Baselines

Table D.2.21-4 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 D.2.21-4. Selected industry distribution of λ for SORV (PWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	1.13E-05	1.31E-03	2.88E-03	1.11E-02	Gamma	0.500	1.733E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.21-5 shows the rounded value.

Table D.2.21-5. Selected industry distribution of λ for SORV (PWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	1.2E-05	1.2E-03	3.0E-03	1.2E-02	Gamma	0.50	1.67E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.22 General Transient at Boiling Water Reactors (TRAN (BWR)) Data Sheet

D.2.22.1 Initiating Event Description

From Reference D-3, the General Transient at Boiling Water Reactors (TRAN (BWR)) initiating event is a general transient that results in automatic or manual reactor trips but does not degrade safety system response.

D.2.22.2 Data Collection and Review

Data for the TRAN (BWR) baseline were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2, the optimized baseline period for TRAN (BWR) is 1997–2002. Figure D.2.22-1 shows the trend of the full TRAN (BWR) data set and the baseline period used in this analysis. RADS was used to collect the TRAN (BWR) data for the baseline period. Only initial plant fault events as defined in Reference D-3 were used. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table D.2.22-1 summarizes the data obtained from RADS and used in the TRAN (BWR) analysis.

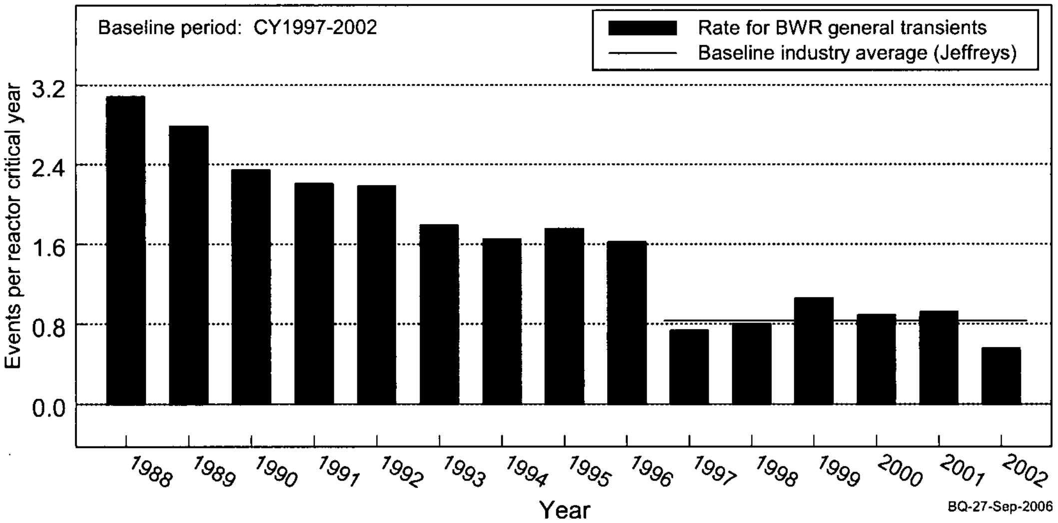

Figure D.2.22-1. TRAN (BWR) trend plot.

Table D.2.22-1. TRAN (BWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
149	180.2	1997–2002	35	97.1%

D.2.22.3 Data Analysis

The TRAN (BWR) data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table D.2.22-2.

Table D.2.22-2. Empirical distributions of MLEs for λ for TRAN (BWR).

Aggregation Level	5%	Median	Mean	95%
Plant	1.95E-01	7.43E-01	8.17E-01	1.53E+00
Industry	-	-	8.27E-01	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). However, for this initiating event, almost the entire distribution of MLEs is non-zero. For example, from Table D.2.22-1, 97.1% of the plants experienced a TRAN (BWR) over the period 1997–2002, so the empirical distribution of MLEs, at the plant level, involves zeros only for the 0% to 2.9% portion of the distribution, and non-zero values above 2.9%.

An empirical Bayes analysis was performed at the plant level but failed to converge. (This most likely was the result of insufficient variation between plants.) Therefore, assuming homogeneous data, a Bayesian update of the Jeffreys noninformative prior using the industry data was calculated. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table D.2.22-3.

Table D.2.22-3. Fitted distributions for λ for TRAN (BWR).

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	7.21E-01	8.28E-01	8.30E-01	9.44E-01	Gamma	149.500	1.802E+02
SCNID/IL	3.26E-03	3.78E-01	8.30E-01	3.19E+00	Gamma	0.500	6.026E-01

Note – JEFF/IL is a Bayesian update of the Jeffreys noninformative prior using industry data and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.22.4 Industry-Average Baselines

Table D.2.22-4 lists the industry-average frequency distribution. The Bayesian update of the Jeffreys noninformative prior was selected. This industry-average frequency does not account for any recovery.

Table D.2.22-4. Selected industry distribution of λ for TRAN (BWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	7.21E-01	8.28E-01	8.30E-01	9.44E-01	Gamma	149.500	1.802E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.22-5 shows the rounded value.

Table D.2.22-5. Selected industry distribution of λ for TRAN (BWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	7.0E-01	8.0E-01	8.0E-01	9.0E-01	Gamma	150.00	1.88E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.23 General Transient at Pressurized Water Reactors (TRAN (PWR)) Data Sheet

D.2.23.1 Initiating Event Description

From Reference D-3, the General Transient at Boiling Water Reactors (TRAN (PWR)) initiating event is a general transient that results in automatic or manual reactor trips but does not degrade safety system response.

D.2.23.2 Data Collection and Review

Data for the TRAN (PWR) baseline were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2, the optimized baseline period for TRAN (PWR) is 1998–2002. Figure D.2.23-1 shows the trend of the full TRAN (PWR) data set and the baseline period used in this analysis. RADS was used to collect the TRAN (PWR) data for the baseline period. Only initial plant fault events as defined in Reference D-3 were used. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table D.2.23-1 summarizes the data obtained from RADS and used in the TRAN (PWR) analysis.

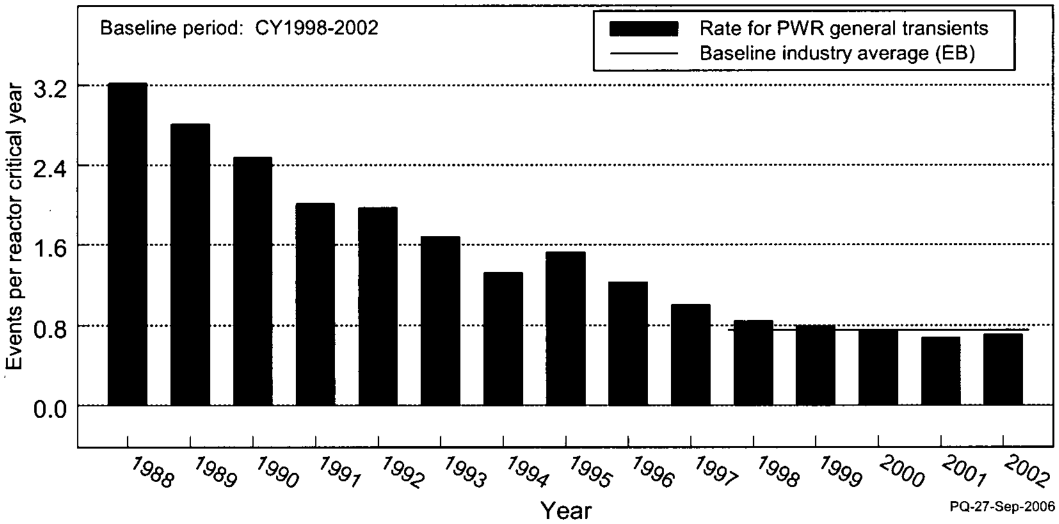

Figure D.2.23-1. TRAN (PWR) trend plot.

Table D.2.23-1. TRAN (PWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
228	304.0	1998–2002	69	92.8%

D.2.23.3 Data Analysis

The TRAN (PWR) data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry). At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table D.2.23-2.

Table D.2.23-2. Empirical distributions of MLEs for λ for TRAN (PWR).

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	6.61E-01	7.63E-01	1.76E+00
Industry	-	-	7.50E-01	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). However, for this initiating event, almost the entire distribution of MLEs is non-zero. For example, from Table D.2.23-4, 92.8% of the plants experienced a TRAN (PWR) over the period 1998–2002, so the empirical distribution of MLEs, at the plant level, involves zeros only for the 0% to 7.2% portion of the distribution, and non-zero values above 7.2%.

An empirical Bayes analysis was performed at the plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table D.2.23-3 for TRAN (PWR).

Table D.2.23-3. Fitted distributions for λ for TRAN (PWR).

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	4.84E-01	7.37E-01	7.51E-01	1.07E+00	Gamma	17.772	2.365E+01
SCNID/IL	2.96E-03	3.42E-01	7.52E-01	2.89E+00	Gamma	0.500	6.652E-01

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.23.4 Industry-Average Baselines

Table D.2.23-4 lists the industry-average frequency distribution. The data set was sufficient for an empirical Bayes analysis to be performed. This industry-average frequency does not account for any recovery.

Table D.2.23-4. Selected industry distribution of λ for TRAN (PWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	4.84E-01	7.37E-01	7.51E-01	1.07E+00	Gamma	17.772	2.365E+01

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.23-5 shows the rounded value.

Table D.2.23-5. Selected industry distribution of λ for TRAN (PWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	5.0E-01	7.0E-01	8.0E-01	1.2E+00	Gamma	20.00	2.50E+01

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.24 Very Small Loss-of-Coolant Accident (VSLOCA) Data Sheet

D.2.24.1 Initiating Event Description

From Reference D-3, the Very Small Loss of Coolant Accident (VSLOCA) initiating event is a pipe break or component failure that results in a loss of primary coolant between 10 to 100 gallons per minute (gpm), but does not require the automatic or manual actuation of high pressure injection systems. Examples include reactor coolant pump (for pressurized water reactors) or recirculating pump (for boiling water reactors) seal failures, valve packing failures, steam generator tube leaks, and instrument line fitting failures.

D.2.24.2 Data Collection and Review

Data for the VSLOCA baseline were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2, the optimized baseline period for VSLOCA is 1992–2002. Figure D.2.24-1 shows the trend of the full VSLOCA data set and the baseline period used in this analysis. RADS was used to collect the VSLOCA data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table D.2.24-1 summarizes the data obtained from RADS and used in the VSLOCA analysis.

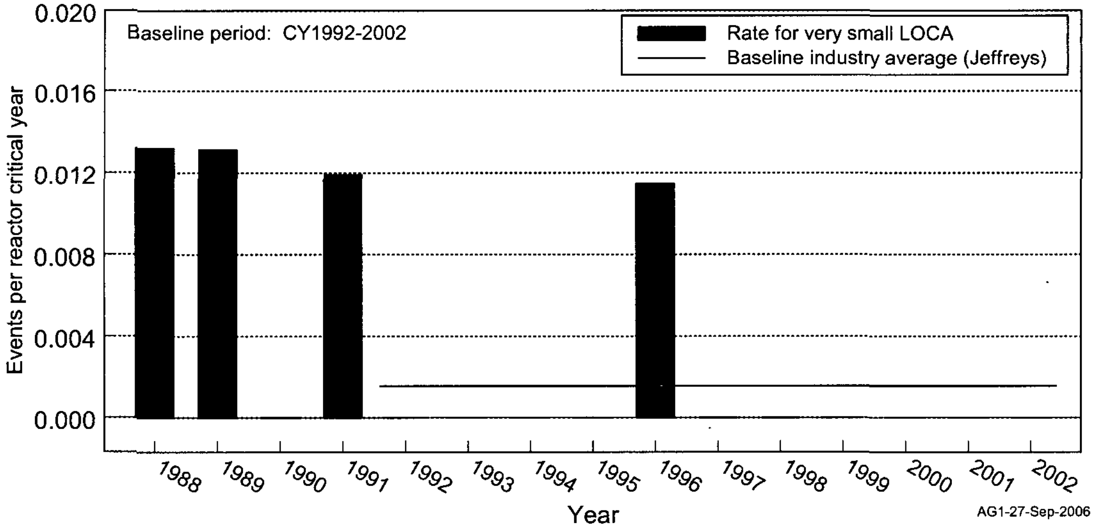

Figure D.2.24-1. VSLOCA trend plot.

Table D.2.24-1. VSLOCA frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
1	965.8	1992–2002	111	0.9%

D.2.24.3 Data Analysis

The VSLOCA data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry). At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table D.2.24-2.

Table D.2.24-2. Empirical distributions of MLEs for λ for VSLOCA.

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	1.23E-03	0.00E+00
Industry	-	-	1.04E-03	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table D.2.24-1, only 0.9% of the plants experienced a VSLOCA over the period 1992–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 99.1% portion of the distribution, and non-zero values above 99.1%.

Because of only one event an empirical Bayes analysis could not be performed. However, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table D.2.24-3 for VSLOCA.

Table D.2.24-3. Fitted distributions for λ for VSLOCA.

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	6.11E-06	7.07E-04	1.55E-03	5.97E-03	Gamma	0.500	3.220E+02

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.2.24.4 Industry-Average Baselines

Table D.2.24-4 lists the industry-average frequency distribution. Because of only one event, 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 D.2.24-4. Selected industry distribution of λ for VSLOCA (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	6.11E-06	7.07E-04	1.55E-03	5.97E-03	Gamma	0.500	3.220E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table D.2.24-5 shows the rounded value.

Table D.2.24-5. Selected industry distribution of λ for VSLOCA (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	6.0E-06	7.0E-04	1.5E-03	6.0E-03	Gamma	0.50	3.33E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

D.3 References

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D-3. J.P. Poloski et al., *Rates of Initiating Events at U.S. Nuclear Power Plants: 1987–1995*, U.S. Nuclear Regulatory Commission, NUREG/CR-5750, February 1999.

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D-5. R. Tregoning, L. Abramson, and P. Scott, *Estimating Loss-of-Coolant Accident (LOCA) Frequencies through the Elicitation Process*, U.S. Nuclear Regulatory Commission, NUREG-1829 (draft), June 2005.

Appendix E

Comparison with Other Sources

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Tables

Appendix E

Data Review Process

E.1 Introduction

The component unreliability (UR) baselines generated in Section 5 are generally based on Equipment Performance and Information Exchange (EPIX) data. These data are heavily weighted by test and operational demand data, rather than unplanned demand data. Section 9 presents comparisons of these baselines with results obtained from selected updated system studies (Refs. E-1 through E-5, as updated in E-6) and from emergency diesel generator unplanned demand performance (Ref. E-7). The updated system studies use data obtained from reviews of licensee event reports (LERs). Most of these data are from unplanned demands, although several system studies also include cyclic (approximately every 18 months) and quarterly (every 3 months) tests.

The component or train unavailability (UA) estimates generated in Section 6 are based on Mitigating Systems Performance Index Program data reported by U.S. commercial nuclear power plants to the Nuclear Regulatory Commission. The Section 6 UA probabilities were determined by adding test and maintenance outage hours over 2002–2004 for a given component or train and dividing that total by the hours the component or train was required to be operable. The updated system studies also provide information on what are termed maintenance-out-of-service (MOOS) events. These are unplanned demands on components that occurred while the component was out of service because of testing or maintenance. MOOS probabilities can be compared with the UA (from test or maintenance) estimates presented in Section 6. Section 9 compares the system study MOOS results with the UA baselines generated in Section 6.

A unique feature of the system studies is their analysis of whether failures were recovered within a short period. Recoveries typically were those that required only simple actions from the control room and only minutes to accomplish. Comparisons of system study results with EPIX results include both with and without recovery considered.

This appendix provides details behind the system study data used in Section 9. In addition, the statistical comparison methodologies summarized in Section 9 are explained in this appendix.

E.2 System Study Data

Table E-1 through Table E-5 summarize the data obtained from the updated system studies. Table E-1 presents data from the updated auxiliary feedwater system (AFWS) study. Data cover the performance of diesel-driven pumps (DDPs), motor-driven pumps (MDPs), and turbine-driven pumps (TDPs). As explained in Section 7, the data for each component type cover a period ending in 2002 (to match the end date for component UR data in Section 5) but with start dates that can vary. The data in Table E-1 are from what are termed optimized baseline periods. In simple terms, the data for a given component are examined to determine the baseline period ending in 2002 and starting in 1988 or later (and generally including at least five years) that exhibits the lowest probability of a trend existing. This baseline optimization ensures that if an overall trend exists in the data covering 1988–2002, only the more recent data representative of current performance (characterized as representative of the year 2000) are used.

The data presented in Table E-1 include the component, failure mode, failure events, demands or run hours, type of data, and the baseline period. For example, the first entry in Table E-1 covers the MDP MOOS events. There were two MOOS events during 2243 unplanned demands over 1988–2002. For the MDP fail to start (FTS) failure mode, there were two events during 638 unplanned demands over 1996–2002. (Note the different baseline period compared with the MOOS data.) Neither of the two FTS events were recovered, leaving two unrecovered FTS events during the 638 demands. Note that all of the system study data for the AFWS are unplanned demands, as denoted by "A" in the table.

Table E-2 presents data from the updated high-pressure coolant injection (HPCI) study. Data cover the performance of TDPs and motor-operated valves (MOVs). Note that the TDP data (other than for MOOS) include unplanned demands, cyclic tests, and quarterly tests. The TDP FTS data indicated a downward trend in failures over 1998–2002 (typically the shortest period considered). In particular, there were five failures in 1998–1999, but only one failure in 2000–2002. For this failure mode, only 2000–2002 was used as the baseline period. Note that there were no failures in 2003 and 2004, which supports the decision to use only 2000–2002.

Table E-3 presents data from the updated reactor core isolation cooling (RCIC) system study. Data cover the performance of TDPs and MOVs. Note that the TDP data (other than for MOOS) include unplanned demands, cyclic tests, and quarterly tests, similar to the HPCI study.

Table E-4 presents data from the updated high-pressure core spray (HPCS) system study. Data cover the performance of MDPs, emergency diesel generators (EDGs), and MOVs. Note that the MDP data (other than for MOOS) include unplanned demands, cyclic tests, and quarterly tests, similar to the HPCI study. In addition, the EDG data (other than for MOOS) include unplanned demands and cyclic tests.

Finally, Table E-5 presents data from the updated high-pressure safety injection (HPSI) system study. Only data for MDPs are presented. The data are from unplanned demands only.

The comparisons presented in Section 9 were generated by combining data from the tables presented in this appendix. For example, all TDP FTS data (from AFWS, HPCI, and RCIC) were combined to obtain the results presented in Section 9 (seven total failures in 1402 total demands). For completeness, the two comparison tables from Section 9 are also presented in this appendix as Tables E-6 and E-7. Statistical comparison results indicated in these tables are explained in the following section.

Table E-1. AFWS updated system study data.

Component Type	Failure Mode	System Study (Optimized Baselines) AFWS			
		Failures (note a)	D or T (note b)	Data	Period
MDP	MOOS	2	2243.0	A	1988 - 2002
	MOOS not recovered	1	2243.0	A	1988 - 2002
	FTS	3	638.0	A	1996 - 2002
	FTS not recovered	2	638.0	A	1996 - 2002
	FTR	2	3139.0	A	1988 - 2002
	FTR not recovered	1	3139.0	A	1988 - 2002
TDP	MOOS	1	625.0	A	1990 - 2002
	MOOS not recovered	1	625.0	A	1990 - 2002
	FTS	3	345.0	A	1995 - 2002
	FTS not recovered	2	345.0	A	1995 - 2002
	FTR	7	945.0	A	1989 - 2002
	FTR not recovered	6	945.0	A	1989 - 2002
DDP	MOOS	0	67.0	A	1988 - 2002
	MOOS not recovered	0	67.0	A	1988 - 2002
	FTS	1	67.0	A	1988 - 2002
	FTS not recovered	0	67.0	A	1988 - 2002
	FTR	1	36.3	A	1988 - 2002
	FTR not recovered	0	36.3	A	1988 - 2002
EDG	MOOS				
	FTS				
	FTS not recovered				
	FTLR				
	FTLR not recovered				
	FTR				
	FTR not recovered				
MOV	FTO				
	FTO not recovered				

Acronyms: A (actual, unplanned demand), AFWS (auxiliary feedwater system), CBK (circuit breaker), C (cyclic, 18-month test), D (demand), DDP (diesel-driven pump), EDG (emergency diesel generator), FTS (fail to start), FTR (fail to run), HPCS (high-pressure core spray), HPCI (high-pressure coolant injection), HPSI (high-pressure safety injection), MDP (motor-driven pump), MOV (motor-operated valve), Q (quarterly test), RCIC (reactor core isolation cooling), T (time in run hours), TDP (turbine-driven pump)

Note a - AFWS MDP FTR includes a single event from the mechanical driver portion. AFWS TDP FTR includes two events from the mechanical driver portion.

Note b - The entries for FTR failure modes are hours.

Table E-2. HPCI updated system study data.

Component Type	Failure Mode	System Study (Optimized Baselines) HPCI			
		Failures	D or T (note a)	Data	Period
MDP	MOOS				
	MOOS not recovered				
	FTS				
	FTS not recovered				
	FTR				
	FTR not recovered				
TDP	MOOS	1	94.0	A	1988 - 2002
	MOOS not recovered	1	94.0	A	1988 - 2002
	FTS	1	295.0	ACQ	2000 - 2002
	FTS not recovered	0	295.0	ACQ	2000 - 2002
	FTR	1	481.2	ACQ	1998 - 2002
	FTR not recovered	1	481.2	ACQ	1998 - 2002
DDP	MOOS				
	MOOS not recovered				
	FTS				
	FTS not recovered				
	FTR				
	FTR not recovered				
EDG	MOOS				
	MOOS not recovered				
	FTS				
	FTS not recovered				
	FTLR				
	FTLR not recovered				
	FTR				
	FTR not recovered				
MOV	FTO	0	71.0	A	1988 - 2002
	FTO not recovered	0	71.0	A	1988 - 2002

Acronyms: A (actual, unplanned demand), AFWS (auxiliary feedwater system), CBK (circuit breaker), C (cyclic, 18-month test), D (demand), DDP (diesel-driven pump), EDG (emergency diesel generator), FTS (fail to start), FTR (fail to run), HPCS (high-pressure core spray), HPCI (high-pressure coolant injection), HPSI (high-pressure safety injection), MDP (motor-driven pump), MOV (motor-operated valve), Q (quarterly test), RCIC (reactor core isolation cooling), T (time in run hours), TDP (turbine-driven pump)

Note a - The entries for the FTR failure modes are hours.

Table E-3. RCIC updated system study data.

Component Type	Failure Mode	System Study (Optimized Baselines) RCIC			
		Failures	D or T (note a)	Data	Period
MDP	MOOS				
	MOOS not recovered				
	FTS				
	FTS not recovered				
	FTR				
	FTR not recovered				
TDP	MOOS	1	158.0	A	1988 - 2002
	MOOS not recovered	1	158.0	A	1988 - 2002
	FTS	3	762.0	ACQ	1997 - 2002
	FTS not recovered	2	762.0	ACQ	1997 - 2002
	FTR	5	2796.3	ACQ	1988 - 2002
	FTR not recovered	4	2796.3	ACQ	1988 - 2002
DDP	MOOS				
	MOOS not recovered				
	FTS				
	FTS not recovered				
	FTR				
	FTR not recovered				
EDG	MOOS				
	MOOS not recovered				
	FTS				
	FTS not recovered				
	FTLR				
	FTLR not recovered				
	FTR				
	FTR not recovered				
MOV	FTO	0	199.0	A	1988 - 2002
	FTO not recovered	0	199.0	A	1988 - 2002

Acronyms: A (actual, unplanned demand), AFWS (auxiliary feedwater system), CBK (circuit breaker), C (cyclic, 18-month test), D (demand), DDP (diesel-driven pump), EDG (emergency diesel generator), FTS (fail to start), FTR (fail to run), HPCS (high-pressure core spray), HPCI (high-pressure coolant injection), HPSI (high-pressure safety injection), MDP (motor-driven pump), MOV (motor-operated valve), Q (quarterly test), RCIC (reactor core isolation cooling), T (time in run hours), TDP (turbine-driven pump)

Note a - The entries for the FTR failure modes are hours.

Table E-4. HPCS updated system study data.

Component Type	Failure Mode	System Study (Optimized Baselines) HPCS			
		Failures	D or T (note a)	Data	Period
MDP	MOOS	1	37.0	A	1988 - 2002
	MOOS not recovered	1	37.0	A	1988 - 2002
	FTS	2	202.0	ACQ	1997 - 2002
	FTS not recovered	2	202.0	ACQ	1997 - 2002
	FTR	0	600.8	ACQ	1988 - 2002
	FTR not recovered	0	600.8	ACQ	1988 - 2002
TDP	MOOS				
	MOOS not recovered				
	FTS				
	FTS not recovered				
	FTR				
	FTR not recovered				
DDP	MOOS				
	MOOS not recovered				
	FTS				
	FTS not recovered				
	FTR				
	FTR not recovered				
EDG	MOOS	1	35.0	A	1988 - 2002
	MOOS not recovered	1	35.0	A	1988 - 2002
	FTS	0	138.0	AC	1988 - 2002
	FTS not recovered	0	138.0	AC	1988 - 2002
	FTLR	1	138.0	AC	1988 - 2002
	FTLR not recovered	1	138.0	AC	1988 - 2002
	FTR	1	2304.2	AC	1988 - 2002
	FTR not recovered	1	2304.2	AC	1988 - 2002
MOV	FTO	0	35.0	A	1988 - 2002
	FTO not recovered	0	35.0	A	1988 - 2002

Acronyms: A (actual, unplanned demand), AFWS (auxiliary feedwater system), CBK (circuit breaker), C (cyclic, 18-month test), D (demand), DDP (diesel-driven pump), EDG (emergency diesel generator), FTS (fail to start), FTR (fail to run), HPCS (high-pressure core spray), HPCI (high-pressure coolant injection), HPSI (high-pressure safety injection), MDP (motor-driven pump), MOV (motor-operated valve), Q (quarterly test), RCIC (reactor core isolation cooling), T (time in run hours), TDP (turbine-driven pump)

Note a - The entries for the FTR failure modes are hours.

Table E-5. HPSI updated system study data.

Component Type	Failure Mode	System Study (Optimized Baselines) HPSI			
		Failures	D or T (note a)	Data	Period
MDP	MOOS	0	210.0	A	1988 - 2002
	MOOS not recovered	0	210.0	A	1988 - 2002
	FTS	1	124.0	A	1991 - 2002
	FTS not recovered	1	124.0	A	1991 - 2002
	FTR	0	146.8	A	1988 - 2002
	FTR not recovered	0	146.8	A	1988 - 2002
TDP	MOOS				
	MOOS not recovered				
	FTS				
	FTS not recovered				
	FTR				
	FTR not recovered				
DDP	MOOS				
	MOOS not recovered				
	FTS				
	FTS not recovered				
	FTR				
	FTR not recovered				
EDG	MOOS				
	MOOS not recovered				
	FTS				
	FTS not recovered				
	FTLR				
	FTLR not recovered				
	FTR				
	FTR not recovered				
MOV	FTO				
	FTO not recovered				

Acronyms: A (actual, unplanned demand), AFWS (auxiliary feedwater system), CBK (circuit breaker), C (cyclic, 18-month test), D (demand), DDP (diesel-driven pump), EDG (emergency diesel generator), FTS (fail to start), FTR (fail to run), HPCS (high-pressure core spray), HPCI (high-pressure coolant injection), HPSI (high-pressure safety injection), MDP (motor-driven pump), MOV (motor-operated valve), Q (quarterly test), RCIC (reactor core isolation cooling), T (time in run hours), TDP (turbine-driven pump)

Note a - The entries for the FTR failure modes are hours.

Table E-6. Comparison of component UR baseline data with updated system study data.

Component	Failure Mode	Updated System Study Data (note a)					EPIX Data (1998 - 2002) (note b)				Statistical Comparison (note c)
		Failures	Demands or Hours	Probability	Rate (1/h)	Comment	Failures	Demands or Hours	Probability	Rate (1/h)	
MDP STBY	FTS	6	964.0	6.74E-03			104	82137.0	1.47E-03		Significant difference
	FTS not recovered	5	964.0	5.70E-03							Significant difference
	FTR<1H (note d)	2	964.0		2.59E-03		12	32495.0		3.78E-04	Significant difference
	FTR<1H not recovered	1	964.0		1.56E-03						No significant difference
	FTR>1H (note d)	0	2922.6		1.71E-04	No events	2.8	568826.0		5.80E-06	No significant difference
	FTR>1H not recovered	No data				No data					No comparison possible
TDP STBY	FTS	7	1402.0	5.35E-03			46	7627.0	6.88E-03		No significant difference
	FTS not recovered	4	1402.0	3.21E-03							No significant difference
	FTR<1H (note d)	10	1402.0		7.49E-03		18	7188.0		2.64E-03	Significant difference
	FTR<1H not recovered	8	1402.0		6.06E-03						Significant difference
	FTR>1H (note d)	3	2820.4		1.24E-03		0	6803.0		7.35E-05	Significant difference
	FTR>1H not recovered	2	2820.4		8.86E-04						Significant difference
DDP STBY	FTS	1	67.0	2.21E-02			9	5161.0	3.88E-03		Significant difference
	FTS not recovered	0	67.0	7.35E-03		No events					No significant difference
	FTR<1H (note d)	1	36.3		4.13E-02		4	3277.0		1.58E-03	Significant difference
	FTR<1H not recovered	0	36.3		1.38E-02						Limited system study data and no failures
	FTR>1H (note d)	No data					No data				No comparison possible
	FTR>1H not recovered	No data									No comparison possible
MOV	FTO/C	0	305.0	1.63E-03		No events	244	232264.0	1.07E-03		No significant difference
EDG (HPCS) (note e)	FTS	0	138.0	3.60E-03		No events	3	870.9	3.44E-03		No significant difference
	FTS not recovered	No data									No comparison possible
	FTLR	0	138.0	3.60E-03		No events	0	699.4		7.15E-04	Limited system study data and no failures
	FTLR not recovered	No data									No comparison possible
	FTR>1H	2	2304.2		1.08E-03		1	1618.7		9.27E-04	No significant difference
	FTR>1H not recovered	2	2304.2		1.08E-03						No significant difference

Table E-6. (continued).

Component	Failure Mode	Updated System Study Data (note a)					EPIX Data (1998 - 2002) (note b)				Statistical Comparison (note c)
		Failures	Demands or Hours	Probability	Rate (1/h)	Comment	Failures	Demands or Hours	Probability	Rate (1/h)	
EDG (w/o HPCS) (note f)	FTS	1	162.0	9.20E-03			98	24206.0	4.53E-03		No significant difference
	FTS not recovered	1	162.0	9.20E-03							No significant difference
	FTLR	4	162.0	2.76E-02			61	21342.0		2.90E-03	Significant difference
	FTLR not recovered	2	162.0	1.53E-02							Significant difference
	FTR>1H	3	1286.0		2.72E-03		50	59875.0		8.48E-04	Significant difference
	FTR>1H not recovered	3	1286.0		2.72E-03						Significant difference

Acronyms - DDP (diesel-driven pump), EDG (emergency diesel generator), EPIX (Equipment Performance and Information Exchange), FTLR (fail to load and run for 1 h), FTO/C (fail to open or close), FTR <1H (fail to run for 1 h), FTR>1H (fail to run after 1 h), FTS (fail to start), HPCS (high-pressure core spray), MDP (motor-driven pump), MOV (motor-operated valve), RCIC (reactor core isolation cooling), SPAR (standardized plant analysis risk), TDP (turbine-driven pump)

Note a - See Appendix E for the data collection details. The probability or rate is a Bayesian update of the Jeffreys noninformative prior.

Note b - EPIX results are from Table 5-1. Some mean values are from empirical Bayes analyses and are not Bayesian updates of the Jeffreys noninformative prior.

Note c - See Appendix E for an explanation of the statistical analyses performed.

Note d - The SPAR database divides FTR into FTR (<1h) and FTR (>1h). The system study FTR data were subdivided into these same two categories for this comparison. Each demand was assumed to include 1 h of run time.

Note e - The SPAR database does not include the HPCS EDG. Results presented in this table were obtained from an additional search of EPIX data.

Note f - Updated system study data were obtained from Reference 68. Data cover unplanned demands (bus undervoltage) over 1997 - 2003.

Table E-7. Comparison of component UA baseline data with updated system study data.

Component	Failure Mode	Updated System Study Data (note a)					MSPI Data (2002 - 2004) (note b)				Statistical Comparison (note c)
		Failures	Demands or Hours	Probability	Rate (1/h)	Comment	Failures	Demands or Hours	Probability	Rate (1/h)	
MDP STBY	MOOS (AFWS)	2	2243.0	1.11E-03			N/A	N/A	3.95E-03		No significant difference
	MOOS (HPSI)	0	210.0	2.37E-03		No events	N/A	N/A	4.12E-03		No significant difference
	MOOS (HPCS)	1	37.0	3.95E-02			N/A	N/A	1.31E-02		Significant difference
TDP STBY	MOOS (AFWS)	1	625.0	2.40E-03			N/A	N/A	5.44E-03		No significant difference
	MOOS (HPCI)	1	94.0	1.58E-02			N/A	N/A	1.30E-02		No significant difference
	MOOS (RCIC)	1	158.0	9.43E-03			N/A	N/A	1.07E-02		No significant difference
DDP STBY	MOOS (AFWS)	0	67.0	7.35E-03		No events	N/A	N/A	9.70E-03		No significant difference
EDG (HPCS)	MOOS	1	35.0	4.17E-02			N/A	N/A	1.33E-02		Significant difference
EDG (w/o HPCS) (note d)	MOOS	1	95.0	1.56E-02			N/A	N/A	1.34E-02		No significant difference
	MOOS not recovered	0	95.0	5.21E-03		No events					No significant difference

Acronyms - AFWS (auxiliary feedwater system), DDP (diesel-driven pump), EDG (emergency diesel generator), HPCI (high-pressure coolant injection), HPCS (high-pressure core spray), HPSI (high-pressure safety injection), MDP (motor-driven pump), MOOS (maintenance out of service), MSPI (mitigating systems performance index), RCIC (reactor core isolation cooling), TDP (turbine-driven pump)

Note a - See Appendix E for the data collection details. The probability or rate is a Bayesian update of the Jeffreys noninformative prior.

Note b - The MSPI results are from Table 6-1.

Note c - See Appendix E for an explanation of the statistical analyses performed.

Note d - Updated system study data were obtained from Reference 68. Data cover unplanned demands (bus undervoltage) over 1997 - 2003.

E.3 Statistical Comparison Methods

The component UR (EPIX) and component/train UA (MSPI) data were compared with updated system study data from selected baseline periods. For the EPIX comparisons, in which both data sets provide failures and demands or exposure time, simple hypothesis tests were performed. For the MSPI UA comparisons, only the system studies provided failure counts (maintenance-out-service or MOOS events). In those cases, the location of the MOOS Jeffreys mean in the probability distribution estimated from the MSPI UA data was determined. The results are contained in Table E-8, and summarized below following a brief description of the methods.

More detailed statistical comparisons could be performed if the system study data were aggregated by plant. However, the data are not presently available in that form. If system study data were to be aggregated by plant, then statistical comparisons could allow for plant-to-plant variation. The analyses in this appendix assume that there is a constant occurrence rate for all plants. Comparison results assuming plant-to-plant variation might differ from those presented in this appendix.

For probabilities obtained from EPIX data, each set of failure counts was treated as binomial with the failure probability (p) estimated by the failure count divided by the number of demands, and its variance estimated by p times ($1-p$), divided by the number of demands. The comparison considered the absolute value of the difference in probabilities from the two data sources. If the two data sources are the same, the data can be pooled. The combined estimate (p^*) for the failure probability is the sum of the failures divided by the sum of the demands. An estimate for the variance of the difference in probabilities is p^* times ($1-p^*$) times ($1/d_1 + 1/d_2$), where d_1 and d_2 are demand counts for the two data sources. With a large enough number of demands, the estimated difference divided by its standard deviation is approximately normally distributed. To make a two-sided test, the normal distribution exceedance probability for the computed ratio is multiplied by two.

For rates obtained from EPIX data, the test of differences considered whether the ratio of the failure rates from the two sources could be equal to 1.0. The larger rate was divided by the smaller rate to compute the test statistic. To perform the test, both estimated rates had to exceed zero, so both failure counts had to exceed zero. The estimated ratio was compared with an F distribution with $2f_2$ and $2f_1$ degrees of freedom, where f_1 was the number of failures in the numerator failure rate and f_2 was the number of failures in the denominator rate. The selection of an F distribution is based on considering the exposure times to be approximately equal to the time required for the observed failures to occur. In each failure data population, the (uncensored) time to observe f failures is chi-squared with $2f$ degrees of freedom when the occurrence rate is constant. Any F distribution is (by definition) a ratio of chi-squared variates, each divided by its degrees of freedom. The probability of the F-distributed variate being as large, or larger, than the computed ratio of failure rates was computed. As with the probabilities, to make a two-sided test, the exceedance probability was multiplied by two.

For probabilities and rates for which one source had no failures, a statistical test for differences is based on the proportion of the demands or exposure time in the data source with failures. Under the null hypothesis of no differences, the failures are expected to be allocated in proportion to the demands or exposure time. If only one failure occurred, a statistically significant difference would only be observed if the source with the failure had less than 5% of the total demands or exposure time.

For the component/train UA comparisons in Table E-7, the MSPI data are not in the form of failures and demands. An indication of the differences in the MSPI UA and system study MOOS data in these cases is shown by the position of the MOOS Jeffreys mean in the MSPI UA distribution (from Appendix B). If the MOOS estimate lies within the 5th and 95th percentiles of the MSPI UA distribution, then no significant difference exists.

A final tool for assessing the difference in the two data sources is provided by the fact that, in all but two of the estimates containing demands or hours for both sources, the listed EPIX demands or hours are at least three times larger than the system study demands or hours. In many cases, the EPIX demands or hours are at least ten times greater. An assessment of the system study data under the (null hypothesis) assumption that the failures occur with a constant probability or rate equal to the listed EPIX probability or rate provides another measure of the agreement of the two data sets. The chi-square statistic for the system study data was computed. This statistic is the squared difference between the observed and expected occurrences, divided by the expected occurrences. The expected occurrences are computed as the EPIX probability or rate, multiplied by the system study demands or exposure time. The statistic has one degree of freedom under the null hypothesis. The significance level is not doubled for a two-sided test, because this test is not symmetric with regard to the two distributions. Also, the chi-squared statistic is always non-negative. The statistic has the benefit that it does not require raw failure and demand or exposure counts for the MSPI UA data.

E.4 Statistical Comparison Results

Referring to Table E-6, the EPIX FTS estimate for MDPs is significantly lower than the system study estimate. This difference is remains significant even after recovery is considered in the system study data. For failure to run for the first hour of operation (FTR≤1H), the system study result is again significantly higher than the EPIX result. With recovery considered in the system study data, this difference is no longer significant. For failure to run beyond the first hour (FTR>1H), the system study data are insufficient to distinguish differences.

For standby TDPs, the FTS estimates (with and without recovery) are comparable. However, the system study FTR≤1H estimate is higher, with applicable p-values less than 1%. When recovery is considered, the p-values increase to between 1% and 5% (the EPIX estimate is still the lower estimate). The FTR>1H estimate is lower for the EPIX data because no failures were observed in the EPIX data and three failures (with a fairly short total run time) were recorded in the system study data. This difference remains statistically significant, even after one of the failures is eliminated when recovery actions are considered.

Differences in the standby DDP data from the two sources are not statistically significant if recovery is considered. The normal distribution "z" statistic is statistically significant for FTS (p-value 0.014), since a failure was recorded in the system study data with very few demands. However, since this failure was recovered, the net FTS probabilities did not differ significantly. A similar situation occurred for FTR≤1H. Here, the differences were more pronounced because the EPIX failures were fewer than for FTS. No data were available for FTR>1H.

The system study MOV and most of the HPCS EDG data are insufficient to show any statistically significant difference. For HPCS EDG FTR>1H, the system studies have more data than EPIX. The occurrence rates are comparable.

Finally, for the non-HPCS EDG the data for FTS are not significantly different from a statistical point of view. The FTLR data are significantly higher in the system studies, even with recovery considered. For FTR>1H, the system study rate estimate is higher than the EPIX rate. The F test for differences shows a statistically significant p-value of 0.03. However, there are over 40 times more hours of experience in the SPAR data. If the FTR>1H rate is constant and equal to the EPIX estimate, the difference is not statistically significant (the chi-squared test p-value was 0.067). The system study failures were not recovered.

Referring to Table E-7, the component/train UA estimates obtained from MSPI data are not significantly different from the system study MOOS results for most entries. However, the HPCS MDP MOOS estimate is significantly higher than the MSPI result, and so is the EDG (HPCS) MOOS estimate. However, both MOOS estimates involve only a single event.

Table E-8 provides a summary of where any statistically significant differences were found.

Table E-8. Summary of statistical comparison results.

	Statistical Result by Failure Mode (notes a and b)							
Component (note c)	UA or MOOS	UA or MOOS (not recovered)	FTS or FTO	FTS (not recovered)	FTR ≤1H (FTLR for EDG)	FTR≤1H (FTLR) (not recovered)	FTR>1H	FTR>1H (not recovered)
MDP	Yes (HPCS)	NA	Yes	Yes	Yes	—	—	NA
TDP	—	NA	—	—	Yes	Some	Yes	Yes
DDP	—	NA	Yes	—	Yes	—	NA	NA
EDG (HPCS)	Yes	NA	—	NA	—	NA	—	—
EDG (not HPCS)	—	—	—	—	Yes	Yes	Some	Some
MOV	NA	NA	—	NA	NA	NA	NA	NA

Note a - Yes (significant differences, p-value less than 0.001), Some (p-value less than 0.05), — (not statistically significant), NA (comparison is not applicable or there are no data for the comparison)
Note b - FTLR (fail to load and run for 1 h), FTO (fail to open), FTR≤1H (fail to run for 1 h), FTR>1H (fail to run beyond 1 h), FTS (fail to start), MOOS (maintenance-out-service), UA (unavailability)
Note c - DDP (diesel-driven pump), EDG (emergency diesel generator), HPCS (high-pressure core spray), MDP (motor-driven pump), MOV (motor-operated valve), TDP (turbine-driven pump)

E.5 References

E-1. J.P. Poloski et al., *Reliability Study: Auxiliary/Emergency Feedwater System, 1987 – 1995*, U.S. Nuclear Regulatory Commission, NUREG/CR-5500, Vol. 1, August 1998.

E-2. G.M. Grant et al., *Reliability Study: High-Pressure Coolant Injection (HPCI) System, 1987 – 1993*, U.S. Nuclear Regulatory Commission, NUREG/CR-5500, Vol. 4, September 1999.

E-3. J.P. Poloski et al., *Reliability Study: Reactor Core Isolation Cooling System, 1987 – 1993*, U.S. Nuclear Regulatory Commission, NUREG/CR-5500, Vol. 7, September 1999.

E-4. J.P. Poloski et al., *Reliability Study: High-Pressure Core Spray System, 1987 – 1993*, U.S. Nuclear Regulatory Commission, NUREG/CR-5500, Vol. 8, September 1999.

E-5. J.P. Poloski et al., *Reliability Study: High-Pressure Safety Injection System, 1987 – 1997*, U.S. Nuclear Regulatory Commission, NUREG/CR-5500, Vol. 9, September 1999.

E-6. U.S. Nuclear Regulatory Commission, "Reactor Operational Experience Results and Databases, System Studies," http://nrcoe.inel.gov/results.

E-7. S.A. Eide et al., *Reevaluation of Station Blackout Risk at Nuclear Power Plants*, U.S. Nuclear Regulatory Commission, NUREG/CR-6890, December 2005.

Appendix F

Maximum Likelihood Estimate Distributions

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Tables

Appendix F

Maximum Likelihood Estimate Distributions

F.1 Assumptions and Equations for the Three Populations

Appendix A addresses component unreliability (UR). Data for component UR are available at the component level for many of the components in Appendix A. This appendix summarizes information concerning estimates of component mean UR obtained from three levels—component, plant, and industry. This information is relevant when reviewing the empirical distributions of maximum likelihood estimates (MLEs) at the component, plant, and industry levels. Such information is typically presented in the third table within each component subsection in Appendix A (if data were available).

In parameter estimation for probabilistic risk assessments (PRAs), information for a specific component type has normally been reported at the plant level. The demands and failures for the individual components are pooled together. Sometimes the information from all the plants is pooled at the industry level. In this study three levels of data collection are considered, each with its own set of assumptions. Each level has its own assumptions and equations used in the parameter estimation process. Figure F-1 shows the relationship between these levels.

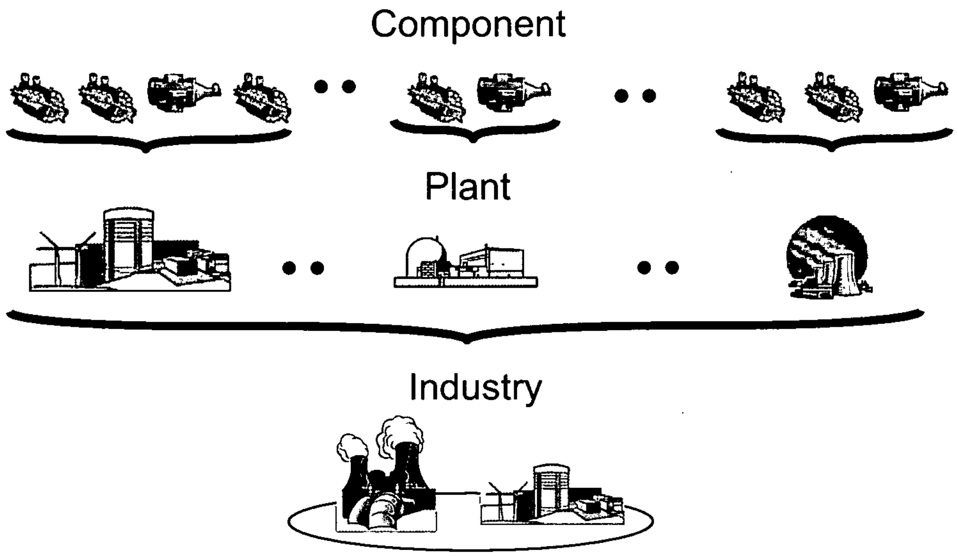

Figure F-1. Three population levels for parameter estimation.

F.1.1 Notation

The following list presents the notation used in the parameter estimation equations presented in this section:

n = number of plants (units)

k_i = number of components at plant i

$K = \sum_{i=1}^{n} k_i$ = total number of components

f_{ij} = number of failures for component c_{ij}

d_{ij} = number of demands for component c_{ij}

$F_i = \sum_{j=1}^{k_i} f_{ij}$ = total number of failures in plant i

$D_i = \sum_{j=1}^{k_i} d_{ij}$ = total number of demands in plant i

$F = \sum_{i=1}^{n} F_i$ = total number of failures in the industry

$D = \sum_{i=1}^{n} D_i$ = total number of demands in the industry

F.1.2 Parameter Estimates Based on Component Data

Let c_{ij} denote the failure probability of component j in plant i. For this case, assume that there is a difference among the failure probabilities of the individual components. The parameter estimate for the failure probability of component j in plant i is given by the following equation:

$$\hat{c}_{ij} = \frac{f_{ij}}{d_{ij}} = \text{estimate of } c_{ij} \tag{F-1}$$

The mean failure probability of the component level population estimates is given by:

$$\overline{C} = \frac{1}{K} \sum_{i=1}^{n} \sum_{j=1}^{k_i} \hat{c}_{ij} \tag{F-2}$$

F.1.3 Parameter Estimates Based on Data Pooled at the Plant Level

Let p_i denote the failure probability of the similar components in plant i. Assume that there is no difference among the component failure probabilities within a plant (i.e., $c_{i1} = \cdots = c_{ik_i}$), but there is a difference in the failure probabilities among plants. The reliability data for the components in plant i are pooled. The parameter estimate for the failure probability for plant i is given by:

$$\hat{p}_i = \frac{\sum_{j=1}^{k_i} f_{ij}}{\sum_{j=1}^{k_i} d_{ij}} = \frac{F_i}{D_i} \tag{F-3}$$

The mean failure probability for the plant level parameter estimates is given by:

$$\overline{P} = \frac{1}{n}\sum_{i=1}^{n} \hat{p}_i \tag{F-4}$$

F.1.4 Parameter Estimates Based on Data Pooled at the Industry Level

Let I denote the industry-wide failure rate for all of the components. Assume that that there is no difference among failure probabilities of the components (all the c_{ij} are equal) and the plants (all the p_i are equal). The industry level mean failure probability is given by:

$$\bar{I} = \frac{F}{D} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{k_i} f_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{k_i} d_{ij}} \tag{F-5}$$

F.2 *Relationship between the Population Means*

The industry mean is a weighted average of the overall plant level means and also of the component level means. This is shown below.

$$\bar{I} = \sum w_i \hat{p}_i \text{ where } w_i = \frac{D_i}{D} \tag{F-6}$$

This follows from the following steps:

$$\bar{I} = \frac{\sum_{i=1}^{n} F_i}{D} = \frac{\sum_{i=1}^{n} \frac{F_i}{D_i} D_i}{D} = \sum_{i=1}^{n} \left(\frac{D_i}{D} \right) \frac{F_i}{D_i} = \sum_{i=1}^{n} \left(\frac{D_i}{D} \right) \hat{p}_i = \sum_{i=1}^{n} w_i \hat{p}_i \tag{F-7}$$

A similar argument shows the following for the component level means:

$$\bar{I} = \sum_{i=1}^{n} \sum_{j=1}^{k_i} v_{ij} \hat{c}_{ij} \text{ where } v_{ij} = \frac{d_{ij}}{D} \tag{F-8}$$

The industry mean equals the plant-level mean ($\bar{I} = \overline{P}$) if and only if all the D_i are equal. Similarly, the industry mean will equal the component-level mean ($\bar{I} = \overline{C}$) if and only if all the d_{ij} are equal. All three means will be equal ($\bar{I} = \overline{P} = \overline{C}$) if the number of components is the same in each plant and the number of demands is the same for each component.

F.3 Summary of Assumptions

Table F-1 contains a summary of the assumptions for each population.

Table F-1. Summary of assumptions for the three populations.

Component-Level Population	Plant-Level Population	Industry-Level Population
1. Difference in behavior among similar components within a plant and/or among plants.	1. Components within a plant have similar behavior 2. Differences among plants	1. No difference in behavior among components within a plant or among plants

APPENDIX G

Resolution of Comments

Appendix G

Resolution of Comments

Various organizations within the U.S. Nuclear Regulatory Commission (NRC) were invited to comment on this report, which was issued as the draft *Industry Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants* (S. Eide et al., May 2006). Comments were received from the following individuals and organizations:

- Office of Nuclear Regulatory Research, Division of Probabilistic Risk and Applications (RES-1)
- Office of Nuclear Reactor Regulation, Division of Risk Assessment, Probabilistic Risk Assessment Licensing Branch (NRR)
- Office of Nuclear Regulatory Research (RES-2).

G.1 Listing of Comments and Resolutions

Table G-1 lists the comments and their resolutions.

Table G-1. List of comments and resolutions.

Reviewer	Comment Number	Comment	Comment Resolution	Report Revision
RES-1	1	We have completed the review of the above mentioned draft report. The report presents updated estimates of U.S. commercial nuclear power plant performance for component unreliability, component/train unavailability, system special events, and initiating event frequencies. The report describes in detail how the data are collected and what methodology of parameter distributions is used. In this report, a fundamental improvement was the distinction between standby and alternating/running component basic events and the breakdown of the fail to run data into the first hour and beyond the first hour statistics for emergency diesel generators, cooling units, and selected pumps. Change was initiated because the failure to run rates were significantly different for standby versus running/alternating states of some components. Significant differences were also observed between failure rates for the first hours versus the time period beyond the first hour. A separate section was included in this report describing how the database elements met the requirement of draft Regulatory Guide 1.200 and/or Standard for Probabilistic Risk Assessment developed by the American Society of Mechanical Engineers. Section 7 describes how the system special events are used in the standardized plant analysis risk (SPAR) models. These events are related to the high-pressure coolant injection (HPCI), high-pressure core spray (HPCS), and reactor core isolation cooling (RCIC) systems. Since these systems are only applicable to boiling water reactors (BWRs), it will help the report users if this can be clarified in the report. Therefore, our comment is just to add a statement in Section 7 to clarify that the system special events are only applicable to BWRs. Given our only comment above, we recommend issuance of the subject report.	A sentence was added in the first paragraph of Section 7 indicating these events apply only to BWRs.	Section 7

Table G-1. (continued)

Reviewer	Comment Number	Comment	Comment Resolution	Report Revision
NRR	1	General Comments: The subject report represents an excellent step forward toward having an update of the industry average component failure rates and initiator frequency database. This database is needed by the Office of Nuclear Reactor Regulation (NRR) staff in their risk-informing licensing, inspection, and Reactor Oversight Process activities. However, we note that further beneficial insights could have been drawn in those cases where outlier features were encountered in the data analyses or in establishment of trends.	The analysis of outlier components is beyond the scope of the report. We believe that outlier in this case means a high failure probability or failure rate. Such analyses could be performed in follow-on efforts. The term outlier in the report covers two cases: significantly higher demands per year than components typically covered in the SPAR models, and significantly higher failure event counts compared with other components in the group being considered. The first case represents a different operational environment for the outlier component, while the second represents degraded performance.	None
NRR	2a	Detailed Comments: The report noted in many places (e.g., page vii) that current performance is significantly better, in most cases, compared to that of the past. Also, in the last paragraph of Chapter 3, page 7, the system studies identified significant plant-specific differences and that more recent data indicated that plants exhibiting the worst case performance are no longer outliers. The disappearance or decline of outliers is of interest to regulators. Potential root causes behind outlier features are of interest to NRR. Use of a standardized list of root causes can help in derivation of insights and determination of effectiveness of corrective actions undertaken. It is true that this is out of the defined scope of the draft report. However, it can be regarded as a worthwhile extension.	We agree that such work would be a worthwhile follow-on effort. However, it should be recognized that the descriptions of failure events in the Equipment Performance and Information Exchange (EPIX) database are in some cases limited, such that root causes may be difficult to identify. EPIX has a root cause field in the database with standardized codes, but that field may not have an entry (either the licensee did not perform a root cause or the results were not reported). Also, the common-cause failure database, which includes EPIX events, has a hierarchy of standard causes that is similar to the EPIX root cause codes. This cause hierarchy was developed from the evaluation of existing root cause lists and coding schemes.	None

Table G-1. (continued)

Reviewer	Comment Number	Comment	Comment Resolution	Report Revision
NRR	2b	Chapter 5 needs a more detailed and clearer discussion of component boundary definition and its consistency with data in EPIX, SPAR models, and especially in the licensee's Probabilistic Risk Assessments (PRAs).	Additional detail was added to Section 5 concerning component boundary definitions and to individual component sections in Appendix A.	Section 5.1, Appendix A
NRR	2c	In general, the processes developed in the report are reasonable. However, the process outlined in Table 5.2 needs to ensure consistency of the considered structures, systems and components boundaries in the data. Step 2 needs more clarification of what to do.	Appendix A presents the details concerning Step 2 ["Check consistency of the data (e.g., run hours do not exceed 24 h/d, start demands are greater than load run demands for emergency diesel generators)"]. Additional detail was added to cover all of the data processing involved in Step 2.	Appendix A, Section A.1.2
NRR	2d	In Chapter 8, no good reason was given to justify not addressing interfacing systems loss-of-coolant accidents.	An additional sentence was added to explain why these were not included. They were not included because they are plant specific and will be addressed in the SPAR program as individual models are updated.	Section 8
NRR	2e	In Chapter 9, tables and figures show many cases where comparisons show significant differences. Future updates of this report are recommended to explain possible reasons behind the most significant differences.	There are two different types of comparisons in Section 9: comparisons of current results with historical estimates, and comparison of current results with current unplanned demand data. Both might be appropriate for follow-on studies.	None

Table G-1. (continued)

Reviewer	Comment Number	Comment	Comment Resolution	Report Revision
NRR	2f	Chapter 10 (comparison with the American Society of Mechanical Engineers Standard) represents a commendable effort. However, many items were labeled “not applicable,” out of the scope of the report (e.g., common cause failure data). Staff use of the report information should go beyond SPAR models. Future versions of the report should aim at completeness of failure data and, as feasible, adhering to Support Requirements Capability Category III, since it covers requirements for the most demanding PRA applications that the staff may encounter in future risk-informed licensing activities.	Additional components and failure modes were added in the final report, all supported by EPIX data. Also, some of the existing component failure modes that were supported by the older Westinghouse Savannah River Company database were updated using EPIX data. Both efforts help to “aim at completeness of failure data.” Chapter 10 was added at the request of NRR. Chapter 10 in the draft report was reviewed by NRR and RES PRA analysts before it was published. They cautioned us not to address plant-specific requirements because the report contains industry-average parameter estimates. Many of the “not applicable” entries indicate that the requirement does not really apply to the development of an industry-average performance database. A risk model typically might collect plant-specific data and then use a Bayesian update process with the industry-average performance as the prior distribution. Many of the data requirements apply to the plant-specific data.	Section 5, Appendix A
RES-2	GC1	The draft report is clearly written and the results are likely to be useful to many. The remainder of the comments are intended to support the broad use of the results.	None required	None
RES-2	GC2	As pointed out in Chapter 9 of the report, many of the parameter estimates (mean values) are quite a bit lower than those used in NUREG-1150. Given the importance of 1150 in shaping views on risk, this is an important result and should be highlighted in the report. See Specific Comment 7.	We added a reference to NUREG-1150 in the Foreword.	Foreword

Table G-1. (continued)

Reviewer	Comment Number	Comment	Comment Resolution	Report Revision
RES-2	GC3	The report's parameterization of basic distributions doesn't match that used in SAPHIRE. (See Specific Comment 9.) Since the results of this work will be used in SPAR models, the relationship between the two should be made clear. It would be most helpful for this report to provide results that can be directly input into SAPHIRE without additional translations/calculations.	We plan to develop a separate document detailing the mapping of basic event and initiating event distributions presented in this report to the SPAR basic events. The document will also include any additional information related to the SPAR models on SAPHIRE to aid users.	None
RES-2	GC4	In some cases, insufficient discussion is provided regarding the technical basis for detailed modeling assumptions. Additional discussion should be provided. Assumptions for which the empirical basis is not very strong should be clearly highlighted (perhaps in an appendix). See, for example, Specific Comments 6, 23, 24, and 29-31.	Cases where the empirical basis is not as strong are explained in detail in the appendices. Also, they are noted in the Comments column in Tables 5-1, 6-1, 7-1, and 8-1.	None
RES-2	GC5	The heavy use of acronyms in the report reduces the clarity of the presentation. In particular, I don't see the benefit of using "UR" in place of "unreliability" and "UA" in place of "unavailability. I recommend eliminating these two acronyms.	These two acronyms were retained. The Mitigating Systems Performance Index (MSPI) program frequently uses these acronyms.	None
RES-2	GC6	Related to General Comment 4 (GC4), it would be helpful to clearly identify assumptions users are implicitly making when using the parameter estimates provided in the report.	See the response to GC4.	None

Table G-1. (continued)

Reviewer	Comment Number	Comment	Comment Resolution	Report Revision
RES-2	GC7	Also related to General Comment 4, it appears that somewhat arbitrary (if not unreasonable) approaches are being taken for a small number of parameters for which data are sparse. These include establishment of lower bounds of 0.3 and 2.0 for the α parameter, the multiplication of data-based estimates by reduction factors of 0.02 and 0.07, and the multiplication of IPE values by 0.5. (Note that the uncertainty in the correctness of these adjustments is not treated.) Although the results tables (e.g., Table 5-1) clearly identify some (but not all) of these adjustments, it would be easy for these adjustments to escape the notice of SPAR users not familiar with the contents of this report. The particular parameters for which these adjustments have been made should be explicitly identified in a table or appendix. This will provide the users with a simple tool to quickly see if there is potential for the adjustments to play a major role in the results. (Note that if ISLOCA models are built using the check valve leakage parameter estimates, there could be a major effect on the ISLOCA frequency.)	The lower bound of 2.0 for α for train UA (when the empirical Bayes analysis did not work) is no longer used. However, the remaining adjustments or multipliers are still used. The use of these adjustments is indicated in the summary Tables 5-1, 6-1, 7-1, 8-1 and the appendices. For example, the cases where the lower limit of 0.3 was used for α is indicated as "LL" in the column listing the distribution and sources for the mean and α in the summary tables. (See "Note a" in those tables.) For this reason, a separate table listing these cases was not added to the report. The ISLOCA modelers may have to review the check valve internal leakage events used in this report in order to ensure that only those events applicable to the ISLOCA events of concern are identified.	None
RES-2	GC8	NUREG/CR-6823 (the parameter estimation handbook) states (in the discussion on Poisson data) that "constrained noninformative priors have not been widely used, but they are mentioned for completeness." On the other hand constrained noninformative distributions play a major role in this assessment. It would be useful to incorporate a discussion of the advantages and disadvantages of this change in approach.	The reader can refer to NUREG/CR-6823 for more information on the constrained noninformative prior. Even though NUREG/CR-6823 indicates that the constrained noninformative priors have not been widely used, the NRC has used these distributions for many years in its assessments of operating experience (e.g., system studies, component studies, CCF studies, and the updated loss of offsite power and station blackout study [NUREG/CR-6890]). In addition, these distributions are used in the Mitigating Systems Performance Index Program (NUREG-1816). The text indicates that these distributions have a wide uncertainty band (error factor of approximately 8.4).	None

Table G-1. (continued)

Reviewer	Comment Number	Comment	Comment Resolution	Report Revision
RES-2	SC1	Chapter 2, Page 4, 5th paragraph, 6th sentence. A literal reading of the sentence could imply that the component populations and demands were overestimated, which would lead to underestimates of the failure probabilities. It might be useful to point out that the component populations and demands were estimated in such a way to ensure conservative failure probability estimates. (I presume this is what was done.)	Additional text was inserted to say that the estimates resulted in conservatively high failure probabilities.	Section 2
RES-2	SC2	Chapter 2. A table summarizing/characterizing the different data collection efforts discussed would help readers better understand the range of efforts and their relationships to one another and to the current effort.	Section 4 of NUREG/CR-6328 contains a detailed summary of data collection activities and sources. That document lists strengths and limitations of each effort. A table was not added to the report because the main focus of the report is the current data and results.	None
RES-2	SC3	Chapter 2, Page 6, 7th paragraph. The reporting criteria [for EPIX] should be provided. It would also be useful to indicate that, given the criteria, if there is room for variability in reporting and if such variability has been observed.	The general reporting criteria are that each utility report engineering information, failures, and demands (that can be estimated) for components within its Maintenance Rule Program. Some additional information is provided in Section 5 and Appendix A.	None
RES-2	SC4	Chapter 3, page 7, 1st bullet and 1st paragraph following bullets. Although it's discussed later in the report, it would be helpful to add a few words to provide specifics regarding credible sources. For example, the central role of EPIX could be pointed out here.	The word "credible" was removed. The sources valued most were those that were comprehensive in scope and consistent in their data collection methods.	Section 3

Table G-1. (continued)

Reviewer	Comment Number	Comment	Comment Resolution	Report Revision
RES-2	SC5	Chapter 3, Page 7, 2nd bullet and 3rd paragraph. The text in the third paragraph (1st sentence) isn't entirely consistent with the bullet. The bullet seems to be better put—I would think the idea is to characterize performance for the time period. The underlying assumption (supported by analysis?) is that the performance is stable enough such that the characterization is meaningful. The further assumption that must be made when using the resulting estimates in SPAR models is that the data for the time period analyzed are sufficiently representative for the (typically predictive) SPAR applications.	The bullet was rephrased and the paragraph was also modified to indicate that data up through 2002 were used. The remaining points in the paragraph still apply.	Section 3
RES-2	SC6	Chapter 6, text starting with Page 7 last paragraph, last sentence. The point that the previously identified outliers are no longer outliers appears to be quite significant. The principal source for this point appears to be Ref. 58, which is a conference paper (and subject to limited review). The report should provide more information regarding Ref. 58 to help the reader understand the strength of the basis for the point. Note that: • Ref. 58 indicates that it presents a limited review (2 IEs and 2 components subjected to "simplistic" analysis and 1 IE subjected to detailed analysis); • The simplistic approach uses a non-statistical approach for determining if the plant is in a degraded situation (the determination is based on whether the plant is in the "bottom 10"—there is no reference to the observed degree of variation in performance and whether a plant is with the "control band" or not, regardless of its ranking); and • The detailed analysis addressed a single case. It is not clear if a different conclusion would have been reached if more cases had been examined.	We agree that previous outliers in the system studies (covering performance around 1990) no longer being outliers (covering performance around 2000) is a significant observation. The simplistic comparisons in Ref. 58 cover IEs and components that had enough data (events or failures) to make such comparisons. It would be difficult to expand the comparisons to other IEs or components. The evidence, we believe, is sufficient to use industry-average performance in the SPAR models as the default. Guidance is being developed as part of another project to identify those special cases where plant-specific (outlier) performance may be appropriate.	None

Table G-1. (continued)

Reviewer	Comment Number	Comment	Comment Resolution	Report Revision
RES-2	SC7	Chapter 4, Page 9, 1st paragraph. Without arguing the reasonableness of the beta and gamma distributions versus the lognormal (as representations of state-of-knowledge, there is no compelling case that any parametric distribution is best), it is important to recognize that the choice of distributions may make a difference. Given the general reduction in mean values mentioned in General Comment 2, it is importance to discuss how much (if any) of this reduction is due to distributional assumptions.	Distributional assumptions generally have negligible effects on the reduction in means from the 1970s to the present. Most past mean results were maximum likelihood estimates (MLEs), which are failures divided by demands (or hours). The present results are typically Jeffreys means (or means obtained from the empirical Bayes analyses), and these approaches typically result in means that lie near the MLE obtained from the same data set. The details presented in Appendices A through D allow the reader to compare the various mean estimates obtainable from a specific data set. Several sentences were added to indicate that the historical comparisons were not impacted by choice of distributions.	Section 9.2
RES-2	SC8	Chapter 4, Page 9, Eq. 4-1. The gamma function should be defined.	Equation 4-2 was added to define the gamma function.	Section 4

Table G-1. (continued)

Reviewer	Comment Number	Comment	Comment Resolution	Report Revision
RES-2	SC9	Chapter 4, Equations. Although these equations show a conventional parameterization of the beta and gamma distributions, SAPHIRE employs slightly different forms. For the beta distribution, SAPHIRE employs (a,b) instead of (α,β). Further, SAPHIRE requires that the user supply the mean value, as defined by Eq. 4-2, and the "b" parameter. For the gamma distribution, SAPHIRE employs (r,λ) instead of (α,β). (To add to the confusion, note that SAPHIRE uses "λ" as a distribution parameter, whereas Eqs. 4-4 through 4-6 use it as the PRA rate parameter.) Further SAPHIRE requires that the user supply the mean value, as defined in Eq. 4-5, and the "λ" parameter. The relationships between the parameters used in this report and those used in SAPHIRE (and therefore SPAR) need to be clearly stated. It also might be helpful to provide an appendix providing versions of Table 5-1 etc. that are directly supportive of SAPHIRE.	See the response to GC3 (RES-2). Topics like this will be addressed in a separate document for SPAR model and SAPHIRE users.	None
RES-2	SC10	Chapter 4, Page 10, 2nd paragraph following equations. It would be helpful to readers to indicate that the relevant discussion in Ref. 16 is under the heading of "Parametric Empirical Bayes."	This change was made.	Section 4
RES-2	SC11	Chapter 4, page 10, 2nd paragraph following equations, parenthetical remark. The term "only several" should be defined/discussed.	Additional text was added to refer the reader to later in the section where these special cases are discussed.	Section 4

Table G-1. (continued)

Reviewer	Comment Number	Comment	Comment Resolution	Report Revision
RES-2	SC12	Chapter 4, Page 10, 2nd paragraph following equations. The text appears to address the case of when sufficient data were available. It isn't clear to what extent the later text addresses what was done when the data were not sufficient. There should be a clear discussion regarding this case.	Additional text was added to refer the reader to later in the section where these special cases are discussed. Also, Appendix A has additional information.	Section 4, Appendix A
RES-2	SC13	Chapter 4, Page 11, 1st bullet and 1st paragraph following bullets. The use of grouped data, of course, implies a homogeneity assumption. To help the reader better understand this assumption, more text is needed to discuss the different groupings (component-, plant-, and industry-level) used in the report. A very clear example (using real data) would be helpful.	Appendix F discusses these different groupings. A general discussion of emergency diesel generator data was added to better define component- and plant-level data. A reference to Appendix F was added to the text.	Section 4
RES-2	SC14	Chapter 4, Page 11, 2nd paragraph following bullets. Although pragmatic and perhaps not especially strong in its effect on results for realistic applications, the adjustment described seems to be pretty arbitrary. For the sake of transparency, it would be useful to denote (perhaps in an appendix) for which model parameters this adjustment was made (and also what were the EB estimates prior to the adjustment). See General Comment 7.	Cases where the EB analysis resulted in an α parameter estimate less than 0.3 are indicated in Appendix A. Also, the EB α estimate (before the 0.3 lower limit was applied) is presented. Finally, these cases are also noted in the summary Tables 5-1, 6-1, 7-1, and 8-1 (in the column describing the distribution and parameters). An additional sentence was added to indicate that the "Distribution (note a)" column in the tables indicates whether the lower limit of 0.3 was used ("LL" indicates it was used). See the response to GC7 (RES-2).	Section 4
RES-2	SC15	Chapter 5, 2nd paragraph, last sentence. Some indication of the numerical magnitude of the leakage rate associated with small internal leaks would be useful. If this magnitude is highly variable and very situation-specific, that also would be useful to know.	We added that water system internal leakages range from 1 to 50 gallons per minute (gpm). However, many of the containment isolation system valve leakages are reported as standard cubic feet per hour (SCFH). Internal leakages in these cases were defined as events that resulted in failure of the local leak rate test (LLRT). These LLRT limits can vary by plant and valve.	Section 5

Table G-1. (continued)

Reviewer	Comment Number	Comment	Comment Resolution	Report Revision
RES-2	SC16	Table 5-1 and similar tables. Given the strong reverse J-shape of many of the distributions, the error factor is not as informative as a listing of key percentiles (e.g., 5th, 50th, and 95th). These latter should be provided.	These percentiles are listed in the appendices.	None
RES-2	SC17	Chapter 5, Table 5-1. For analysts not familiar with plant-to-plant variability assessments, the strong reverse J-shaped distributions for cases where there appear to be strong data (e.g., TDP STBY FTS) is surprising. This outcome and its reason should be pointed out in Chapter 5. This would also explain why the state of knowledge is stronger for such events as TDP RUN FTS where it isn't clear from superficial examination that the data are stronger.	The data are summarized in detail in the appendices. The reverse J-shape results when the α parameter is small ($\alpha < 1$), indicating more variation between plants. Such variation can be observed even in data sets with many of the plants having observed failures ("strong data sets"). Although we have provided significant information on the data sets in the appendices, we have not provided discussions about the strong reverse J-shape distributions because our analyses have not gone to the level of detail needed to attempt to identify the reasons for these distributions. Some general reasons are sparse data and plant-to-plant variability.	None
RES-2	SC18	Section 5.2. It would be useful to point out that Appendix E contains a comparison of estimates based on EPIX vs. estimates from the system studies.	The second to the last paragraph in Section 5.2 was modified to refer to Appendix E as well as Section 9.	Section 5.2
RES-2	SC19	Section 5.3, Page 24, 1st paragraph. See Specific Comment 5.	The paragraph was reviewed and revised.	Section 5.3
RES-2	SC20	Section 5.3, Page 24, 3rd paragraph, 1st sentence. It isn't clear that, for users, when the results were generated is useful information. If there are technical reasons for caution with the estimates, these should be stated.	The wording was changed to indicate that use of 1997–2004 data is not reason for caution. The results are still representative of the year 2000.	Section 5.3

Table G-1. (continued)

Reviewer	Comment Number	Comment	Comment Resolution	Report Revision
RES-2	SC21	Section 5.3, Page 24, 3rd paragraph, 3rd sentence. The qualifier "in general" would seem to imply that there was a trend for one of the leakage rates. If so, the particular leakage should be identified and the magnitude of the trend discussed.	Formal trend analyses were not conducted for the leakage data. However, the trend plots from the Reliability and Availability Database System (RADS) software were generated and reviewed. If trends appeared to be present, the overall estimate was still appropriate for the year 2000. (Higher estimates on one side of 2000 were compensated by lower estimates on the other side of 2000.) A sentence was added to explain this. Follow-on studies may provide more sophisticated trend analyses.	Section 5.3
RES-2	SC22	Section 5.3, Page 25, 1st paragraph. Does Appendix A identify the outlier components? If not, it would be useful to identify such components somewhere in the report.	Words were added to the paragraph to indicate that "outlier" refers to components within a given component and failure mode combination.	Section 5.3
RES-2	SC23	Section 5.5, Page 27, 2nd paragraph. See General Comments 4 and 6. The three cases should be explicitly identified, and the sets of comparison data (leading to the modeling assumptions employed) should also be explicitly identified.	The three cases are indicated in Table 5-1. Also, those cases are now identified in the text of Section 5.5.	Section 5.5
RES-2	SC24	Table 5-1. The notes in the Comments section of the table should be explicitly linked to appropriate discussions in the text, so the reader can immediately determine the technical basis for the adjustments mentioned.	In each of the Tables 5-1, 6-1, 7-1, and 8-1, a general note was added in the Comments column to indicate that details concerning the notes are in the appropriate appendix.	Tables 5-1, 6-1, 7-1, and 8-1
RES-2	SC25	Section 5.5, Page 27, text following 2nd paragraph. A transition sentence (indicating that the following discussion shows how the parameters in Table 5-1 can be used to estimate failure probabilities for different mission times) would be helpful. Also, a table summarizing the material presented in the text could be useful.	A transition sentence was added. We did not add a summary table because we feel the text explains the situation.	Section 5.5

Table G-1. (continued)

Reviewer	Comment Number	Comment	Comment Resolution	Report Revision
RES-2	SC26	Section 5.5, Page 28, last paragraph. See Specific Comment 23—the "nine components with sufficient data" should be explicitly identified.	The identifiers for the nine components were added to the second paragraph in Section 5.5.	Section 5.5
RES-2	SC27	Section 5.5, Page 27, 2nd paragraph and Page 28, last paragraph. Some discussions should be provided as to why the geometric average is appropriate. Given the very large range of values (1.2 to 600) for the ratio. It isn't clear that any simple adjustment scheme should be used with substantial caveats. See Specific Comment 24 and General Comment 7.	This approach was used for two components. It is understood that this approach is highly uncertain. Therefore, the α parameter was set to the lower limit of 0.3 for these two cases. These cases are identified in Table 5-1 and Section 5.5, and additional details are provided in Appendix A. A sentence was added to indicate that the geometric average is more appropriate than an arithmetic average given the wide range of ratios.	Section 5.5
RES-2	SC28	Section 6.2, last paragraph. It would be helpful to formally define the terms planned hours, unplanned hours, fault exposure hours, and required hours.	Additional information concerning these terms was added to Section 6.2.	Section 6.2
RES-2	SC29	Section 6.4, Page 33, 1st paragraph. Given the nature of UA data, it is reasonable to exclude reverse J-shaped distributions. (See Specific Comment 30.) That being said, setting the lower limit of α to 2.0 appears to be quite arbitrary. The parameters for which this was done (recognizing the possibility that some of the values of 2.0 in Table 6-1 could be data-based) should be explicitly identified. See General Comment 7.	See the response to SC30 concerning the reverse J-shaped distribution. The lower limit of 2.0 is no longer used. For two cases (with fewer than five trains), the empirical Bayes analysis failed. In those cases, an average α of 2.5 (average of values obtained form empirical Bayes results for other train types) was assumed. Those cases are indicated in Table 6-1 (in the "Distribution (note a)" column) and explained in Appendix B.	Table 6-1, Appendix B

Table G-1. (continued)

Reviewer	Comment Number	Comment	Comment Resolution	Report Revision
RES-2	SC30	Table 6-1. Several of the data-based distributions have small α values—this says that there is a significant probability that the unavailability could be extremely small. From an operations perspective, is this reasonable? Some discussion is needed.	The train UA data have changed significantly from the draft report. The ROP SSU data have been replaced by the Mitigating Systems Performance Index (MSPI) program UA data for 2002–2004. However, for certain train types, there are still cases where the UA is zero, even though such trains could have been taken out for maintenance during critical operation. Therefore, reverse J-shaped distributions may still be applicable.	Section 6, Appendix B
RES-2	SC31	Section 6.4, Page 33, 4th paragraph. See General Comment 7. Without further information on the factors leading to reductions in unavailability and on the applicability of these factors to the unavailabilities in question, the adjustments being made are not strongly supported. The parameters for which the adjustments were made should be highlighted.	Support for these adjustments (dividing the Individual Plant Examination UA estimates from the 1980s by two) is provided in Appendix B, Table B-2 and the accompanying text. We believe that the approach used is more applicable for estimating current performance than using the 1980s estimates without modification. The cases where this adjustment was made are identified in Table 6-1.	Section 6
RES-2	SC32	Section 6.4, Page 33, 4th paragraph, penultimate sentence. Is this supposed to refer to a lower bound (consistent with earlier discussion in the report)?	The draft report had a typographical error ("upper bound" should have been "lower bound"). The final report assumes an α of 0.5, rather than the lower bound of 0.3. This is explained in Section 6.4 and Appendix B.	Section 6.4, Appendix B
RES-2	SC33	Table 8-1. The mean value for IE-LLOCA (BWR) does not appear to match the information provided in NUREG-1829. (It may be possible that other parameters also don't match—I haven't checked.) Additional discussion is needed to explain the discrepancy.	Appendix A explains how the information in draft NUREG-1829 was used to generate the LOCA frequencies (within each applicable subsection in Section A.2).	None

Table G-1. (continued)

Reviewer	Comment Number	Comment	Comment Resolution	Report Revision
RES-2	SC34	Figures 9-1, etc. See Specific Comment 7. It is important to know how much of the difference is due to improved performance and how much is due to methodological differences.	For the cases listed in these figures (except for NUREG-1150), the original data (failures and demands) are known and the mean is either an MLE or a Jeffreys mean. Therefore, methodological differences are not the reason for the trends observed. Differences in data collection methods and interpretation of potential failure events may exist. These are harder to detect and may contribute some of the differences observed. However, most of the differences presented in the figures are believed to be the result of actual improvements in component performance. Most components exhibit a decreasing trend in the number of failures from the 1970s to present, with a leveling off during the last several years. Maintenance practices have also changed. One reason for the decrease in failures is conditioned monitoring maintenance. This could be a topic for further study. Several sentences were added in Section 9.2.	Section 9.2
RES-2	SC35	Figure 9-5 and perhaps others. The graphs should used symbols and colors that show when printed in black and white. (In Figure 9-5, the RCIC symbols don't show.)	The figures in Section 9 were modified as suggested.	Section 9 figures

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10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)
This report characterizes current industry-average performance for components and initiating events at U.S. commercial nuclear power plants. Studies have indicated that industry performance has improved since the 1980s and early 1990s, so the characterization of current industry-average performance is an important step in maintaining up-to-date risk models. Four types of events are covered: component unreliability (e.g., pump fail to start or fail 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 initiating event frequencies. Typically data for 1998–2002 were used to characterize current industry-average performance, although many initiating events required longer periods (ending in 2002) to adequately characterize frequencies. Results (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 (SPAR) models covering U.S. commercial nuclear power plants.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)
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