Idaho
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MASTER

Lockheed
Idaho Technologies Company

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APPENDICES

List of Acronyms

DB	- Design Basis
DF	- Dispersion Factor
EF	- Error Factor
FCE	- First Cycle Extraction
FDP	- Fluorinel Dissolution Process
ICPP	- Idaho Chemical Processing Plant
ICDB	- Instrument Calibration Database
IFR	- Individual Failure Rates
INEL	- Idaho National Engineering Laboratory
MIPS	- Maintenance, Inventory, and Procurement System
MTTF	- Mean Time To Failure
MU	- Make-up
NWCF	- New Waste Calciner Facility
PRA	- Probabitilistic Risk Assessment
ROVER	- Remote Operated Vehicle Experimental Reactor
SA	- Safety Assessment
SAR	- Safety Analysis Report
SRL	- Savannah River Laboratory
TR	- Transfer
TS/S	- Technical Specification/Standard
TS/SD	- Technical Specification/Standard Demand
UOR	- Unusual Occurrence Report
WSRC	- Westinghouse Savannah River Company

1. INTRODUCTION

This report represents the first major upgrade to the Idaho Chemical Processing Plant (ICPP) Failure Rate Database.[1] This upgrade incorporates additional site-specific and generic data while improving on the previous data reduction techniques. In addition, due to a change in mission at the ICPP, the status of certain equipment items has changed from operating to standby or off-line. A discussion of how this mission change influenced the relevance of failure data also has been included.

This report contains two data sources: the ICPP Failure Rate Database and a generic failure rate database. A discussion is presented on the approaches and assumptions used to develop the data in the ICPP Failure Rate Database. The generic database is included along with a short discussion of its application.

A brief discussion of future projects recommended to strengthen and lend credibility to the ICPP Failure Rate Database also is included.

2. PURPOSE

Most failure rate and failure probability data published are derived from nuclear power plant failure data. When faced with no alternative, this data may be used in support of probabilistic risk assessments (PRAs), safety analysis reports (SARs) and safety assessments (SAs) at facilities quite different from a nuclear power plant. However, if site-specific failure data exists, then the development and use of site-specific failure rates and failure probabilities is preferred. This report presents failure rates for the ICPP.

The ICPP Failure Rate and generic databases were developed to ensure that the probabilities and failure rate data used in site-specific PRAs, SARs and SAs are technically justifiable and supported by adequate documentation.

3. METHODOLOGY

This section discusses the methodologies used in developing the ICPP Failure Rate Database and criteria for selecting the generic database. Miscellaneous studies that augment the database development process are also discussed.

3.1 THE ICPP FAILURE RATE DATABASE

The following is a discussion of the approaches and assumptions used in estimating the site-specific failure rates, failure probabilities, and human-error probabilities for the ICPP Failure Rate Database. These include identifying equipment item failures, time frames of interest, number of component types of interest, and estimating mission times. Throughout this section, "equipment item" signifies an individual item (e.g. P-PM-101, AG-NCC-320) and "component type" indicates a group of equipment items (e.g., pumps, agitators).

3.1.1 Data Collection

The first step in developing the fractional failure rates for the failure rate database was to identify component types for which failure rates were needed. Fractional failure rates are defined as the fraction of the total population failing during a given time interval. Discussions with safety analysts identified the most common component types used in PRAs. A study of past PRAs identified still more component types for which failure rates were desired.[2]

The second step involved identifying a time frame or "window" for review of the failure data. Care was taken to establish a correct time frame because an overly large window would incorporate failures of equipment and instruments that have since been upgraded to a more reliable form. Likewise, a window that is too small would reduce the number of failures observed and would introduce statistical uncertainty into the resulting failure rate due to sample size. The identification of the window for the review of data is closely related to estimating the equipment operational time. Both areas are addressed later in this report.

The third step involved screening the available data sources to identify failure events. Equipment item and instrument failures were identified through several sources:

1) Maintenance work order records
2) Instrument calibration data sheets
3) Unusual Occurrence Reports (UORs)
4) Critique reports
5) Discussions with maintenance and operations staff.

ICPP maintenance work orders were accessed electronically through the Maintenance, Inventory, and Procurement System (MIPS), which is a database, stored on a Hewlett-Packard (HP) 3000 computer, that is used for ICPP maintenance management. The MIPS database contains records of all ICPP maintenance activity from 1985 to the present. The failure reports generated from the MIPS database are carefully scrutinized to separate failed equipment items from equipment items requiring other maintenance attention such as a preventive maintenance inspections. These tasks yield the total number of equipment items failing during the chosen time period.

The instrument calibration data sheets are accessed through another database on the ICPP production server called the Instrument Calibration Database (ICDB). The ICDB contains records of all instrument drifts (out-of-tolerance) and failures from 1985 to the present for all Group I, II, and III instruments. Group I instruments perform a primary role in monitoring and controlling safety parameters to adhere to technical specifications/standards (TS/S). Group II instruments are those instruments whose failure or inaccuracy will not lead to violation of TS/S but are judged important for the protection of employees, the general public, or the physical plant. Group III instruments are those have little or no safety or economical significance but may affect the efficiency of operations.[3] As with the maintenance work orders, instrument calibration data sheets from before 1985 can be viewed on microfilm. Only Group I instruments are investigated because failure or excessive drift of Group I instruments poses the greatest threat to the safety of any ICPP operation.

UORs, critique reports, and discussions with maintenance and operations staff are used to supplement or clarify the information obtained from the instrument and equipment databases.

In early studies, component type and instrument failures were identified for three major operating facilities: The Extraction Facility (CPP-601 and -602), the New Waste Calcining Facility (CPP-659), and the Fluorinel Dissolution Process and Fuel Storage Facility (CPP-666). Each of these facilities was reasoned to contain asufficiently different environment to warrant calculating separate failure rates for each facility. However, several years of study have indicated that the environments are not sufficiently different to warrant separate calculation of failure rates. Consequently, the failure rates reported are for all three facilities combined, calculated by combining raw data.

The fourth step in developing the fractional failure rate was to identify the total number of instruments or equipment items in existence in the facilities under study at the ICPP. Three databases, one for equipment, one for instruments, and one for valves, are maintained. The equipment and valve databases contain obsolete information, and require extensive review to separate the equipment items not in existence from those equipment items currently being used. The equipment items are grouped into categories related to the item's function. Once the equipment items have been categorized, the total number of equipment items are extracted from the equipment, instrument, and valve databases.

The last parameter to estimate is the individual equipment item mission time during which the failures were observed. Because equipment item failures are gathered for the three major facilities (CPP-601 and -602, CPP-659, and CPP-666), operating times for each of these facilities are of interest. Plant operation logs document the total time that the various facilities were operating. In the infancy of the database, estimates were obtained for the percentage of facility operating time that the equipment item was operated. This mission time estimate resulted in inaccurate estimates of the fractional failure rate because during plant operation many of the equipment items, although not running, are exposed to the same harsh conditions as if they were operating.

For this reason, the estimated time the equipment item was operated was changed to 100% of the time the facility was operated. This estimate failed to take into account sweep down and decontamination activities that occurred between operating periods. Consequently, the estimate for the mission time was changed to calendar time during which the failure data were collected.

The operational status of the plant during the prior calculations was always considered to contain significant amounts of operational activity. This activity subjected equipment items to operational or near operational conditions nearly all the time. Recently, portions of the ICPP have been placed in an off-line or stand-by status. This results in significant amounts of time during which equipment items are not subjected to operational conditions. Therefore, the mission time is selected to be the time between the first and last observed failure in a group of component types (e.g., agitators, airlifts, etc.).

3.1.2 Calculation of the Fractional Failure Rates

The following discussion covers the equations, assumptions, and approaches used to calculate the fractional failure rates reported in the ICPP Failure Rate Database (table 1). Appendix A provides the definitions of the variables used in the calculation of the fractional failure rates. Appendix B provides the facility operating times. All values and intermediate calculations involved in developing the fractional failure rates and error factors or dispersion factors are shown in appendix C. A sample of the calculational method used in the development of the failure rates is given in this report.

Once the failure data has been subgrouped to yield the failure events of interest, it is possible to estimate fractional failure rates and the uncertainty bounds. The analysis presented here is general and may be used for any subgroupings, even those that have no failures during the test period. The uncertainty bounds of those component types with no failures during the test period are calculated by using a Bayesian approach. In the following derivation, $\hat{\lambda}$ refers to Model I, $\bar{\lambda}$ refers to Model II, $\tilde{\lambda}$ is the adjusted value being reported and λ is a true value.

When subdividing the failure data (e.g., environment, failure and mode), care must be used to avoid too small of a sample size. Excessive subdivision dilutes the data and may lead to large uncertainties. If the uncertainty is too large, it may dominate the fault tree or probabilistic analysis and yield useless results.

Examination of the failure data reveals that one or more equipment items usually failed more than once during the test period. After the failure, the equipment item is repaired in a relatively short time compared to the mean time to failure (MTTF). As soon as the equipment is repaired to a nearly new condition, it is placed back into service. Because the equipment can be repaired and placed back into service in a small amount of time, compared to the MTTF, the total number of equipment items in operation remains essentially a constant.

The technique discussed is for estimating the MTTF of component types that fit the real life scenario of failure, repair, and replacement with Type I censoring. Type I censoring is the observation of failures during a specified period of time sometimes called time interval data. The failures of equipment items are assumed to be independent and random. The assumption of a Poisson distribution, given in equation (1), is used to estimate the true fractional failure rate. An estimate can then be calculated because the failure rate (λ) for the Poisson distribution is assumed to be constant.

$$P(x) = \frac{\mu^x e^{-\mu}}{x!}, \quad x = 0, 1, 2, \ldots \qquad (1)$$

Using the Poisson distribution and $\mu = \lambda t$, the only parameter required to be estimated is the mean fractional failure rate, λ. Rather than estimate the fractional failure rate directly, an estimate for the fractional failure rate is calculated by estimating the MTTF.[4] For Type I censoring with replacement, equation (2) provides an estimate for the MTTF and the fractional failure rate.

$$MTTF = \frac{Nt^*}{n} = \frac{1}{\lambda} \qquad (2)$$

In equation (2) n is the number of failures observed during the test period (mission time), t^* and N is the total number of equipment items in service. The combination of N and t^* is considered to be the total exposure time or total equipment time, t. For a Poisson distributed random variable, X, the distribution mean (μ) and variance (σ^2) are the same, $\mu = \sigma^2 = \lambda t$. This point estimate can be used in probabilistic analyses as an estimate of the true fractional failure rate. At this point an examination of the accuracy of the estimated fractional failure rate must be conducted.

MODEL I

The estimated standard deviation of the Poisson distributed random variable is simply $\sqrt{\lambda\, t}$, and the estimated standard error ($\hat{\varepsilon}$) of the estimated mean fractional failure is given by equation (3).[5]

$$\hat{\varepsilon} = \frac{\sqrt{\lambda\, t}}{t} = \frac{\sqrt{n}}{N\, t^*} \qquad (3)$$

The standard error is an appraisal of the uncertainty of the estimated mean fractional failure rate. In probabilistic analyses, the potential exists for having equipment items that may originate from any segment of the population. Therefore, it is necessary to estimate the confidence intervals of the underlying distribution of failure rates for the equipment items.

Bain and Engelhardt[6] provide a formula for the $100\gamma\%$ confidence interval of a Poisson distribution based on the χ^2 distribution.[6] Studies at the ICPP traditionally use $\gamma = 90\%$. Estimates for the upper and lower 90% confidence limits can be found using a Bayesian adjustment, calculated by equation (4) where (2n + 1) is the χ^2 degrees of freedom.

$$\hat{\lambda}_L = \frac{\chi^2_{0.05}(2n+1)}{2t}$$

$$\hat{\lambda}_U = \frac{\chi^2_{0.95}(2n+1)}{2t} \tag{4}$$

Equation (4) can be used to calculate the 90% confidence limits for any number of observed failures including zero. For individual equipment items with no failures, the 50th percentile or median of the χ^2 distribution can be used as an estimate for the mean fractional failure rate.

$$\hat{\lambda} = \frac{\chi^2_{0.50}(1)}{2t} = \frac{0.455}{2t} = \frac{0.23}{t} \tag{5}$$

For equipment items with a large number of failures (n > 30), upper (p = .95), lower (p = .05), and median (p = .50) values of the χ^2 distribution can be estimated using equation (6).[7]

$$\chi^2_p = \tfrac{1}{2}\,(z_p + \sqrt{2\nu - 1})^2 \tag{6}$$

where z_p is the corresponding percentile to the standard normal distribution and $\nu = 2n + 1$, the χ^2 degrees of freedom.

This method was used to estimate the mean fractional failure rate and the confidence limits for each individual equipment item within a component types or instrument group. The data was then pooled and an estimate for the mean fractional failure rate and the confidence limits were calculated for the component type or instrument group. The confidence limits of the pooled data model the random variation in the number of observed failures assuming that there is no difference between equipment items in a component type or instrument group. A dispersion factor for this distribution can be calculated using equation (7). A dispersion factor is an alterative measure to the variance of a distribution and is only applicable to distributions exclusively containing nonnegative values.

$$DF_{\chi^2} = \sqrt{\frac{\hat{\lambda}_U}{\hat{\lambda}_L}} \tag{7}$$

MODEL II

Estimating the variation between equipment items in a component type was accomplished by calculating the sample arithmetic mean ($\overline{\lambda}$) and variance (s^2) of the individual equipment items' estimated mean fractional failure rates. Assuming that the failure rates are lognormally distributed and that $\overline{\lambda}$ is the mean of the lognormal distribution, the calculated mean and variance can be transformed into their lognormal counterparts using equation (8).[8]

$$\zeta^2 = \ln(1 + \frac{s^2}{\overline{\lambda}^2})$$
$$\eta = \ln(\overline{\lambda}) - \tfrac{1}{2}\zeta^2 \tag{8}$$

Sufficient information is now available to obtain the measures of the variation between equipment items. Estimates for the upper and lower 90% confidence limits can be calculated using equation (9).

$$\overline{\lambda}_L = e^{(\eta - 1.645\zeta)}$$
$$\overline{\lambda}_U = e^{(\eta + 1.645\zeta)} \tag{9}$$

An error factor for the lognormal distribution modeling the variation between individual equipment item can be calculated using equation (10).

$$EF = e^{1.645\,\zeta} \tag{10}$$

Neither model individually accounts for all the variations observed in the data. It is possible to combine the two models mathematically to account for the two types of variation modeled. This combination was accomplished by increasing the 90% confidence limits of the lognormal distribution obtained for the sample arithmetic mean and variance of the individual equipment items, and using equations (8), (9), and (10) to calculate the parameters (μ, σ^2, and EF) for an adjusted lognormal distribution. The error factor for the combined distribution is simply $EF * DF_{\chi^2}$. The mean, variance, upper and lower limits, and error factor derived using this method are presented in chapter 4. The upper and lower confidence limits are the end points of the 90% confidence interval, that is, the true value of the fractional failure rate falls between the upper and lower values with 90% confidence.

3.2 GENERIC DATA

In the development of most site-specific databases, the site-specific failure data will not yield all required failure rates and event probabilities. It becomes necessary to examine generic databases for many needed failure rates not supported by site-specific data.

The search for a generic database led to a Westinghouse Savannah River Company (WSRC) report[9] that aggregates component type failure data from several sources into a recommended failure rate. However, this generic database cannot be considered a completely independent source of failure data because ICPP equipment failure data are included in the aggregate. The WSRC report examined several popular generic databases used by the nuclear industry to derive failure rates from component type failure data. The WSRC report presents "recommended" failure rates derived from several equipment failure databases because many of the equipment failure databases contain several different failure rates under the same component type heading. Data considered useful to the ICPP were extracted from the WSRC report and are shown in appendix D.

3.3 MISCELLANEOUS STUDIES

Approximately 90% of the data in the ICPP failure rate database are generated from studies performed at the ICPP. This translates into 14 of the 27 database references as shown in the event database. Two of these references concentrate efforts on developing failure rates for many of the component types and instrument groups at the ICPP.[10,11] This section focuses on 11 of the remaining studies and provides a brief discussion of each study. A discussion of the statistical approach used in each report will not be presented because, in general, the approaches are straight forward and much less cumbersome than the approach previously discussed.

Technical Specification/Standard Violation Report.[12] This study calculates the human error rates associated with Technical Specification/ Standard (TS/S) violation at the ICPP. TS/S define the safety envelope (operating limits, conditions, and requirements) in which the processes and facilities of the ICPP should be operated to ensure the health and safety of the public and operating personnel. TS/S violations were obtained for the period from 1981 to 1989 from UORs. To determine the human error rate associated with a TS/S violation, an estimate must be made for the number of demands on a TS/S. This estimate was obtained by interviewing 17 operators. Each operator was asked to estimate the number of times/day a TS/S task must be carried out. This number, when converted to the appropriate units and multiplied by the total operating hours of the facility, yields an estimate for the number of times that a TS/S task has been carried out. Dividing this number into the total number of TS/S violations yields the human error rate associated with a single TS/S violation. Three different error rates are obtained from this study:

1) The rate of a human error resulting in a TS/S violation (1.0E-3 /demand)
2) The rate of a human error resulting in a TS/S violation given that a second person is present to verify the actions of the first person (1.0E-4 /demand)
3) The rate of a TS/S violation leading to a significant criticality barrier violation (3.1E-5 /demand).

Power Outage Study.[13] This study calculates the frequency of loss of off-site power to an ICPP facility for more than half an hour to be 1.4E-2/y. In addition, this study calculated the loss of an uninterruptible power source (UPS) to be 2E-2/y. This study was the planned followup to the "Power Outage Frequency for the ICPP" report[14] cited in WIN 330. The number of off-site power losses during the period 1982-1990 were collected by reviewing UORs.

Report on Chemical Makeup Errors.[15] Proper chemical makeup and adjustment helps protect against a criticality at the ICPP. Therefore, during January of 1987 a human factors study was performed to determine a probability for chemical makeup errors at the ICPP. This study concluded that an error rate of 2E-2 per chemical makeup should be used.

Maintenance Error Controversy.[16] The scope of this study was to develop error rates for calibration and maintenance errors. This study focused on the perceived difference between the Department of Defense (DOD) and the Department of Energy (DOE). A study of DOD data led to a failure rate of 1E-1 for maintenance error as typical. The DOE used estimates for human failure rates of 1E-3. Because maintenance activities and calibration activities are often similar, the question arises as to the applicability of maintenance failure rates to calibration errors. The DOD value contained no credit for recovery (a person correcting his/her own error). Establishing this credit and accounting for different conditions at the ICPP, the following frequencies were derived:

Mean*	Range	Type of Error
2E-2 /d	6E-3 to 1E-1	general maintenance work
2E-2 /d	3E-3 to 8E-2	maintenance work recognized as consequential
2E-3 /d	1E-4 to 3E-2	preventive maintenance and calibration of instruments
3E-4 /d	1E-4 to 1E-3	maintenance work recognized as life threatening

* The mean value is calculated assuming a lognormal distribution.

CPP-601 Volume Measurement Error.[17] This study calculates the error rate for a volume measurement error, with and without checking the measurement, at the CPP-601 facility. The CPP-601 facility extracts unused uranium from spent uranium fuel rods. The results of this study are important in accurately assessing the potential for a makeup with too little poison for a tank containing

U-235. This study reports an error rate of 2E-1 /transfer for a volume measurement error greater than 20% given a volume balance error. A volume balance error is defined as a failure to record the volume of a tank between transfers into or out of the tank. It also reports an error rate of 6.5E-2 /transfer for a volume measurement error greater than 20% given no volume balance error.

Data Analysis Study of Inadvertent Transfers.[18] This study calculates the error rate for inadvertent transfer to be 1.5E-3 /transfer. The number of inadvertent transfers was compiled from UORs and critique reports between 1982 and 1986. An estimate was also obtained for the total number of transfers performed during this same time period. The error rate for an inadvertent transfer was calculated by dividing the number of inadvertent transfers by the number of total transfers made during the same time period. The study approaches the problem using both a classical approach (shown above) and a Bayesian approach.

Frequency of Plugging for Various Components.[19] This study develops frequencies for the plugging of sample lines, airlifts, bubble probes, and jet lines. Incidents of plugging were obtained from plant personnel and MIPS. The following frequencies were calculated:

Component	Plugging Frequency
Airlifts	1.7E-0/y
Probes	2.1E-1/y
Jets	2.8E-3/y
Sample lines	1.3E-1/y

Studies on Sampling/Analytical Errors.[20] Proper sampling and analysis is a primary barrier against criticality at the ICPP. Therefore, sampling and analysis errors are a major concern. Currently, a error rate of 1E-2 /demand is assigned to a sampling/analytical error. This number is a general human error probability with no data proving that it is applicable to the sampling and analytical processes at the ICPP. Therefore, during January and February of 1987, two studies were performed to determine the error rate for a sampling or analytical error. Unfortunately, neither study resulted in a more applicable error rate than 1E-2 /demand. However, many points discussed in the studies provided new insights into properly identifying and quantifying sampling and analytical errors.

Study of the Effects of Crane Related Failures at the ICPP.[21] This study was accomplished to determine the frequency of crane-related failures at the ICPP. This study determined the frequency of crane-related failure based on the failure cause and on failure results. The study also presented the failure rates of cranes based on the two categories of crane types: mobile and facility. The failure rates calculated are given below.

Category	Failure Rate
All cranes	1.1E-05 /yr
Facility cranes	1.0E-05 /yr
Mobile cranes	7.1E-05 /yr
Load drops	3.2E-06 /yr
Other equip./mat. damage	4.2E-06 /yr
Damage to crane	4.6E-06 /yr

4. RESULTS

This database is divided into two databases: a failure rate database and an event database. The failure rate database, shown in table 1, presents the fractional failure rates calculated for the ICPP.

In table 1, the first column identifies the component type or instrument group (i.e., agitators, pumps, level loop, etc.). The "Failure Mode" column identifies the cause of the component type or instrument group mode of failure. In most cases, the mean fractional failure rate ($\bar{\lambda}$) reported is for all modes of failure. However, when supported by the data collected, other failure modes are identified. The "$\bar{\lambda}$" column records the mean fractional failure rate of the equipment or instrument component. The fractional failure rates are reported in units of h^{-1}. The "Exposure" column, which has been used in some ICPP failure rate database report formats, from the WIN-330 report has been deleted.[22] A review of the fractional failure rates reported in WIN-330 did not support the assumption that increased failure rates result from an equipment item being subjected to hostile environments such as acid or radiation. In the development of PRAs for the ICPP, the mean fractional failure rate and mission time are used to calculate a mean probability of the occurrence of the basic events. These probabilities are assumed to be lognormally distributed. As a measure of dispersion, an error factor is utilized to calculate a confidence interval for the failure rate. The "Error Factor," when multiplied and divided by the median value, yields the upper and lower bounds, respectively, of the 90% confidence interval.

The event database, shown in table 2, reports event frequencies relevant to the ICPP. The information provided in this table is similar to the information provided in table 1, except that a "Reference" column has been added. The "Reference" column identifies the study or report that generated the failure rate. Also, the "Failure Mode" column has not been included in table 2 because some of the sources of this data were generated outside the ICPP and do not contain such information.

Table 1: ICPP Component Type and Instrument Group Failure Rates

Component Type/ Instrument Group	Failure Mode	λ	λ_m	EF	Std Error
Agitators	All	9.79E-06	5.14E-06	6.48	1.23E-05
Airlifts	All	1.17E-05	6.04E-06	6.63	1.49E-05
Casks	All	8.17E-05	2.48E-05	12.66	3.48E-05
Cranes	All	1.16E-04	6.54E-05	5.79	3.92E-05
	Electrical	2.05E-05	1.23E-05	9.15	1.65E-05
	Lift	2.05E-05	1.04E-05	6.82	1.65E-05
	Brakes	1.79E-05	9.13E-06	6.73	1.54E-05
	Bridge	1.10E-05	3.92E-06	10.66	1.21E-05
	Other	5.62E-05	3.28E-05	5.53	2.73E-05
Filters	All	7.65E-06	3.41E-06	8.08	1.02E-05
	Plug	4.32E-06	2.89E-06	4.38	7.67E-06
	Leak	4.40E-06	3.10E-06	3.97	7.75E-06
	Other	7.09E-06	3.14E-06	8.15	9.83E-06
Glovebox	All	5.64E-05	2.08E-05	10.19	2.82E-05
	Gloves	4.21E-05	1.34E-05	12.02	2.44E-05
	Leak	8.68E-06	2.98E-06	11.08	1.11E-05
	Other	1.88E-05	8.20E-06	8.35	1.63E-05
Hoist	All	1.05E-05	3.49E-06	11.48	1.22E-05
	Block	6.93E-06	2.63E-06	9.85	9.92E-06
	Cable	6.81E-06	2.75E-06	9.17	9.83E-06
	Hook	6.76E-06	2.86E-06	8.64	9.80E-06
	Other	7.64E-06	2.92E-06	9.80	1.04E-05
Hood	All	4.92E-05	1.13E-05	16.86	4.97E-05
Heat Exchangers and Condensors	All	9.33E-06	4.10E-06	8.24	1.13E-05
	Leak	6.36E-06	3.15E-06	7.04	9.35E-06
	Other	7.24E-06	3.13E-06	8.43	9.97E-06
Jets	All	5.40E-06	2.84E-06	6.45	8.66E-06
	Leak	4.16E-06	3.13E-06	3.47	7.60E-06
	Plug	4.67E-06	2.87E-06	5.07	8.06E-06
	Other	5.07E-06	2.80E-06	6.01	8.39E-06
Manipulators	All	1.05E-04	5.19E-05	7.07	3.71E-05
	Boot	8.39E-06	4.06E-06	7.26	1.05E-05
	Cable	8.65E-06	4.58E-06	6.40	1.06E-05
	Grip	1.57E-05	6.40E-06	9.03	1.43E-05
	Motion	1.71E-05	8.28E-06	7.27	1.50E-05
	Fail to Run	9.30E-06	4.05E-06	8.34	1.10E-05
	Tong	6.42E-06	3.89E-06	5.19	9.17E-06
	Wrist	8.62E-06	5.07E-06	5.45	1.06E-05
	Other	5.42E-05	2.22E-05	9.02	2.66E-05

Table 1: (Contd.) ICPP Component Type and Instrument Group Failure Rates

Component Type/ Instrument Group	Failure Mode	λ	λ_m	EF	Std Error
Pumps	All	2.39E-05	1.05E-05	8.24	1.78E-05
	Charge	5.06E-06	2.03E-06	9.25	8.21E-06
	Leak	5.95E-06	3.29E-06	6.00	8.89E-06
	Oiler	5.16E-06	2.26E-06	8.27	8.28E-06
	Plug	4.84E-06	2.25E-06	7.68	8.02E-06
	Fail to Run	4.97E-06	2.28E-06	7.81	8.13E-06
	Other	1.63E-05	7.48E-06	7.76	1.47E-05
Sampler Sys	All	1.04E-05	4.80E-06	7.70	1.19E-05
	Plug	5.42E-06	2.96E-06	6.10	8.59E-06
	Needle	5.16E-06	2.87E-06	5.95	8.39E-06
	Other	8.58E-06	4.15E-06	7.25	1.08E-05
Valves	All	1.03E-06	5.60E-07	6.18	3.63E-06
	Leak	2.52E-07	7.59E-08	12.80	1.79E-06
	Plug	6.58E-08	8.38E-09	28.22	9.17E-07
	Other	7.53E-07	3.65E-07	7.24	3.10E-06
Gate	All	3.61E-06	2.69E-06	3.53	6.79E-06
	Leak	3.22E-06	2.88E-06	2.19	6.42E-06
	Plug	3.26E-06	2.91E-06	2.19	6.46E-06
	Other	3.46E-06	2.73E-06	3.09	6.65E-06
Ball	All	4.30E-06	2.77E-06	4.66	7.41E-06
	Leak	3.43E-06	2.71E-06	3.08	6.61E-06
	Plug	3.28E-06	2.89E-06	2.29	6.47E-06
	Other	3.98E-06	2.67E-06	4.34	7.13E-06
Globe	All	4.02E-06	2.49E-06	4.99	7.16E-06
	Leak	3.48E-06	2.80E-06	2.95	6.67E-06
	Plug	4.98E-06	2.93E-06	5.44	7.98E-06
	Other	3.88E-06	2.54E-06	4.54	7.04E-06
Solenoid	All	3.88E-06	2.90E-06	3.50	7.04E-06
	Leak	2.62E-05	2.94E-06	31.26	1.83E-05
	Plug	2.62E-05	2.94E-06	31.26	1.83E-05
	Other	3.88E-06	2.90E-06	3.50	7.04E-06
Misc	All	1.01E-05	7.10E-06	3.99	1.14E-05
	Leak	5.23E-06	2.94E-06	5.84	8.17E-06
	Plug	4.41E-06	2.58E-06	5.49	7.51E-06
	Other	8.07E-06	5.41E-06	4.35	1.02E-05
Needle	All	4.57E-06	2.61E-06	5.71	7.64E-06
	Leak	4.08E-06	2.87E-06	3.99	7.22E-06
	Plug	2.62E-05	2.94E-06	31.26	1.83E-05
	Other	4.50E-06	2.45E-06	6.14	7.58E-06

Table 1: (Contd.) ICPP Component Type and Instrument Group Failure Rates

Component Type/ Instrument Group	Failure Mode	$\bar{\lambda}$	$\bar{\lambda}_m$	EF	Std Error
OV	**All**	7.18E-06	3.53E-06	7.12	9.58E-06
	Leak	4.91E-06	2.70E-06	6.04	7.92E-06
	Plug	5.87E-06	2.91E-06	7.04	8.66E-06
	Other	6.11E-06	3.04E-06	6.97	8.83E-06
Butterfly	**All**	8.10E-06	4.95E-06	5.11	1.02E-05
	Leak	5.06E-06	3.15E-06	4.97	8.04E-06
	Plug	2.62E-05	2.94E-06	31.26	1.83E-05
	Other	6.74E-06	4.10E-06	5.16	9.28E-06
Three-way	**All**	6.11E-06	3.42E-06	5.88	8.83E-06
	Leak	2.62E-05	2.94E-06	31.26	1.83E-05
	Plug	4.68E-06	2.87E-06	5.09	7.73E-06
	Other	5.81E-06	3.21E-06	5.99	8.62E-06
Ventilation	**All**	2.42E-05	1.22E-05	6.92	1.80E-05
	Belt	6.53E-06	2.94E-06	7.98	9.32E-06
	Leak	5.24E-06	2.66E-06	6.78	8.35E-06
	Rotor	5.94E-06	2.83E-06	7.42	8.88E-06
	Fail to Run	6.24E-06	2.71E-06	8.36	9.11E-06
	Other	1.57E-05	7.70E-06	7.15	1.45E-05
Vessels	**All**	6.70E-06	2.23E-06	11.48	9.34E-06
	Leak	3.81E-06	2.80E-06	3.63	7.04E-06
	Plug	3.94E-06	2.58E-06	4.55	7.16E-06
	Other	6.04E-06	2.13E-06	10.75	8.86E-06
Unit Heaters	**All**	1.09E-05	4.81E-06	8.25	1.19E-05
	Leak	5.03E-06	2.75E-06	6.08	8.45E-06
	Plug	5.23E-06	2.27E-06	8.38	8.61E-06
	Other	9.38E-06	3.95E-06	8.71	1.15E-05
Window, Cell	**All**	1.22E-05	5.30E-06	8.34	1.41E-05

Table 1: (Contd.) ICPP Component Type and Instrument Group Failure Rates

Component Type/ Instrument Group	Failure Mode	λ	$\tilde{\lambda}_m$	EF	Std Error
Analysis Loop	Drift	3.67E-05	2.35E-05	4.70	3.50E-06
	Fail	1.47E-05	8.75E-06	5.33	2.22E-06
Density Loop	Drift	2.81E-05	2.31E-05	2.78	2.47E-06
	Fail	1.13E-05	7.83E-06	4.09	1.57E-06
Diff Press	Drift	1.75E-05	1.34E-05	3.32	3.19E-06
	Fail	1.41E-05	8.92E-06	4.85	2.86E-06
Flow, Gas	Drift	4.04E-05	3.13E-05	3.24	6.29E-06
	Fail	2.73E-05	1.39E-05	6.77	5.17E-06
Flow, Liquid	Drift	3.22E-05	1.64E-05	6.78	1.09E-05
	Fail	3.26E-05	2.16E-05	4.44	1.10E-05
Level Loop	Drift	5.05E-05	3.50E-05	4.09	4.75E-06
	Fail	8.93E-06	5.73E-06	4.70	2.00E-06
Pressure	Drift	2.28E-05	1.80E-05	3.10	6.79E-06
	Fail	1.71E-05	6.25E-06	10.33	5.88E-06
Pulse	Drift	4.97E-05	2.58E-05	6.58	1.94E-05
	Fail	3.58E-05	8.08E-06	17.08	5.96E-03
Radiation, Criticality	Drift	5.60E-05	4.69E-05	2.66	4.74E-06
	Fail	2.26E-05	1.50E-05	4.45	3.01E-06
Radiation, General	Drift	3.82E-05	2.32E-05	5.19	3.02E-06
	Fail	3.80E-05	3.39E-05	2.19	3.01E-06
Temp Loop	Drift	2.39E-05	1.73E-05	3.76	4.56E-06
	Fail	2.24E-05	1.42E-05	4.77	4.41E-06
Vibration Loop	Drift	5.00E-05	3.37E-05	4.32	1.12E-05
	Fail	3.11E-05	1.27E-05	9.07	8.83E-06

Table 2. Event Frequencies and Probabilities

Event	Failure Rates		Error Factor	Ref
Airlifts - Plug	1.70E+00	/year		19
Chemical Makeup Errors (Conservative)	2.00E-03	/MU		15
Crane, Load Drop	3.23E-06	/hour	1.4	21
Earthquake (0.24g @ surface)	1.00E-04	/year	5.0	23
Earthquake (0.18g @ surface)	5.00E-04	/year	2.0	23
Earthquake (0.13g @ surface)	1.70E-03	/year	3.0	23
Extreme Wind (70 mph)	1.25E-03	/year		26
Extreme Wind (84 mph)	3.30E-04	/year		26
Extreme Wind (95 mph)	3.30E-05	/year		26
Fire Protection System (supervised, DB)	2.00E-03	/demand		25
Fire Protection System (unsupervised, DB)	5.00E-02	/demand		25
Flood (Elevation 4916.6 flood crest)	1.00E-04	/year		26
Human Error-TS/S Violation[a] (best two-man)	1.00E-04	/demand	2.0	12
Human Error (Error of Commission)	3.00E-03	/demand		31
Human Error-TS/S Violation[b] (best one-man)	1.00E-03	/demand	2.0	12
Human Error (Error of Omission)	1.00E-02	/demand		31
Human Error (Second man checker)	1.00E-01	/demand		31
Inadvertent Transfer (All types, historical)	1.50E-03	/Tranfer	2.0	18
Inadvertent Transfer (Uranium bearing, current)	4.00E-05	/Tr	2.0	18
Instrument Probe - Plug	2.40E-05	/hour		19
Instrument Calibration and Preventative Maintenance Error	2.00E-03	/demand	1.5	18
Jets - Plug	2.80E-03	/year		19

a Verification by second man required.

b Verification by second man not required.

Table 2. (Contd.) Event Frequencies and Probabilities

Event	Failure Rates		Error Factor	Ref
Level/Density Probe, Process Vessel [H-Canyon, Savannah River Laboratory (SRL)]	4.30E-04	/hour		27
Loss of Normal Power	1.00E+00	/year		13
Loss of Stand-by Power	5.00E-01	/year		13
Loss of UPS Power	4.00E-02	/year		13
Maintenance, Life Threatening	3.00E-04	/demand	3.0	16
Maintenance, General	2.00E-02	/demand	5.0	16
Maintenance, Consequential	2.00E-02	/demand	4.0	16
Sample Line - Plug	1.30E-01	/year		19
Sample Error, Process Operations	1.00E-05	/Sample		28
Sample Error - CPP (conservative)	1.00E-02	/Sample		20
Significant Criticality Safety Violation	3.10E-05	/TS/SD[c]		12
Sump Monitor - Plug (SRL)	2.00E-04	/hour		29
Sump Monitor - Unavailability	2.00E-03	/hour		29
Tornado	> 1.00E-06	/year		30
Volcano on Snake River Plain	>>1.00E-05	/year		24
Vol. Measurement Err >20% (With Vol. Bal. Err.)[d]	2.00E-01	/Tr		17
Vol. Measurement Err >20% (No Vol. Bal. Err.)[e]	6.50E-02	/Tr		17

c Technical Specifications/Standards Demand

d Volume measurement not taken between solutions being transferred either into or out of a tank.

e Volume measurement taken between solutions being transferred either into or out of the tank.

The event database is a collection of data compiled from 21 sources. Fourteen of these 21 sources are the result of reports generated at the ICPP. These 14 reports make up more than 70% of the data in the event database. The remaining 30% of the data is gleaned from the seven studies generated outside the ICPP. Safety analysts familiar with the operation of the ICPP assisted in the selection of external reports with information applicable to the ICPP failure rate databases.

5. RECOMMENDATIONS

The work to improve and validate this database needs to be continually updated. Many databases become stagnant because the information within the database is either outdated or unreliable. To prevent this from happening, several actions must be taken. One is to perform an annual or biannual review of new site-specific failure events. This review ensures that the database is maintained as a living document. Secondly, standard, past approaches or philosophies concerning data-gathering techniques and calculations cannot be accepted over the long-term. A periodic check should be made of assumptions used in performing past studies that contributed data to the database. New insights and better data collection techniques may be in existence.

Also, the database should be shared outside the ICPP with other sites that have chemical processing environments. This will increase the use of the database, and provide justification for administrative and financial support for future database developments.

The role of the ICPP failure rate database is to provide technically accurate and defendable data to be used in PRAs performed at the ICPP and similar facilities. With this in mind, the following projects are recommended as future activities.

Assumption Verification. Several assumptions are made in the derivation of the statistical model employed to develop the fractional failure rates. These assumptions should be investigated, especially the assumption that a component type will follow a lognormal failure distribution. The selection of the distribution used to model the upper and lower confidence can have a significant effect on the error factor or dispersion factor calculated.

Error Factors. The traditional assumption of a lognormal distribution has led most analysts to become accustomed to reporting failure rates with an associated error factor. The conventional definition of the error factor has limitations in its applicability to distributions other than the lognormal distribution.

Drift Identification. In many PRA applications, the availability of an instrument is desired. Unfortunately, for most applications, the availability is calculated by assuming the instrument drifts out-of-tolerance at half the calibration interval and remains out-of-tolerance for the remainder of the calibration interval.

Miscalibration. One of the most difficult parameters to estimate is the contribution of human error to the overall compromise of a system. Accurate estimation of the human error probability (HEP) is the basis for a study.

Analytical Errors. Sampling a process at critical points is often a primary barrier against accidents and releases in processing systems and nuclear facilities. Therefore, the failure to correctly sample is a key issue in any probabilistic analyses.

Most reports generated at the ICPP and used for information in the event database are becoming old and possibly outdated. Efforts should continue to review and update each of these studies.

As much as possible, the ICPP Failure Rate Database is intended to be a defendable source of reliable data. Although application of this data is primarily concentrated at the ICPP, use outside of the ICPP could be of benefit, especially to those facilities with environments similar to those found at the ICPP.

Also, the ICPP Failure Rate Database is intended to be a living database. New information will be added and old information will be discarded periodically. This will ensure that the failure rates and failure probabilities are representative of current technology and expertise.

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APPENDIX A

APPENDIX A

DEFINITIONS

This appendix provides a brief description of the parameters and equations used to calculate the site-specific failure rates and error factors at the Idaho Chemical Processing Plant. The parameters in this appendix represent the minimum amount of raw data required before failure rates can be calculated using the procedures derived.

APPENDIX A

DEFINITIONS

n = number of failures observed during the test period

N = total number of equipment items (pop) operating during the test period

t^* = mission time

$t = N\, t^*$ = exposure time

μ = the true distribution mean of a probability distribution

σ^2 = the true distribution variance

$p(x) = \frac{\mu^x e^{-\mu}}{x!}$, $x = 0, 1, 2, \ldots$ = the Poisson prob. distribution function.

$\hat{\lambda} = \frac{n}{N\, t^*}$ = the estimate for the true mean fractional failure rate.

$\hat{\varepsilon} = \frac{\sqrt{n}}{t}$ = Standard Error.

$\hat{\lambda}_L$ & $\hat{\lambda}_U = \frac{\chi^2_p\ (2n + 1)}{2\ t}$ = 90% confidence limits for $\hat{\lambda}$.

$DF_{\chi^2} = \sqrt{\frac{\hat{\lambda}_U}{\hat{\lambda}_L}}$ = the dispersion factor of the χ^2 distribution.

$\overline{\lambda} = \frac{\sum \hat{\lambda}_i}{N}$ = the sample mean fractional failure rate.

$s^2 = \frac{\sum\ (\hat{\lambda}_i - \overline{\lambda})^2}{N - 1}$ = the variance of the sample mean frational failure rate.

$$f(x) = \frac{1}{\sqrt{2\pi}\,\zeta\,x}\, e^{-\frac{(\ln(x) - \eta)^2}{2\zeta^2}}$$ = the lognormal prob. distribution function.

$$\zeta^2 = \ln\left(1 + \frac{s^2}{\overline{\lambda}^2}\right)$$ = the lognormal variance.

$\eta = \ln(\overline{\lambda}) - \frac{1}{2}\zeta^2$ = the lognormal mean.

$\overline{\lambda}_L$ & $\overline{\lambda}_U = e^{\eta \mp 1.645\,\zeta}$ = 90% confidence limits for $\overline{\lambda}$.

$EF_{\ln} = e^{1.645\,\zeta}$ = the error factor (lognormal distribution).

$\overline{\lambda}_m = e^{\eta}$ = the median (50th %) of the lognormal distribution.

APPENDIX B

APPENDIX B
PLANT OPERATION HISTORY

This appendix presents the operating times of the various facilities during which equipment failures were observed. Initially, failure rates were calculated separately. This is because the environments and operating conditions at each facility were considered sufficiently diverse to produce differing failure rates. However, a recent review of the facilities indicated that the environments are not sufficiently diverse to warrant separation of the failures. Therefore, the failures from each facility were combined. Also, in the past, the operating time of the facility was used as the estimate for the mission time (t^*). However, this estimate failed to take into account sweep down and decontamination activities that occurred between operating periods. Therefore, the estimate for the mission time was changed to be the calendar time during which the failures were observed. This estimate assumes significant amounts of operational activity is occurring at the ICPP. Currently, substantial amounts of the Idaho Chemical Processing Plant have been placed in extended off-line or shutdown status. Therefore, the mission time is selected to be the between the first and last observed failures.

Update: July 1995

Key: N/A Prior to facility startup
-- No process in operation
/// Number of hours run time/down time

References: * - BJH-3-88
& - PPL-1-89
# - SSC-1-92
% - RCH/TGA-7-95

Date			Hrs	FDP up	FDP down	FCE up	FCE down	2nd/3rd Cycle up	2nd/3rd Cycle down	Denitrator up	Denitrator down	NWCF up	NWCF down	Zr (E Cell) up	Zr (E Cell) down	Al (G Cell) up	Al (G Cell) down	Electro up	Electro down	Rover up	Rover down
02/26/74	03/26/74	*	696	NA		380	316	--	696	--	696	NA		--	696	--	696	--	696	--	696
03/27/74	04/26/74	*	744	NA		720	24	--	744	--	744	NA		--	744	150	594	--	744	--	744
04/27/74	05/26/74	*	720	NA		340	380	--	720	--	720	NA		--	720	290	430	--	720	--	720
05/27/74	06/26/74	*	744	NA		0	744	--	744	--	744	NA		--	744	0	744	--	744	--	744
06/27/74	07/26/74	*	720	NA		0	720	--	720	--	720	NA		--	720	0	720	--	720	--	720
07/27/74	08/26/74	*	744	NA		540	204	--	744	--	744	NA		--	744	520	224	--	744	--	744
08/27/74	09/26/74	*	744	NA		230	514	370	374	340	404	NA		180	564	150	594	--	744	--	744
09/27/74	10/26/74	*	720	NA		610	110	--	720	--	720	NA		680	40	640	80	--	720	--	720
10/27/74	11/26/74	*	744	NA		480	264	10	734	10	734	NA		440	304	450	294	--	744	--	744
11/27/74	12/26/74	*	720	NA		310	410	280	440	280	440	NA		320	400	310	410	--	720	--	720
12/27/74	01/09/75	*	336	NA		70	266	180	156	250	86	NA		--	336	--	336	--	336	--	336
	Total:		7632	-----------		3680	3952	840	6792	880	6752	-----------		1620	6012	2510	5122	0	7632	0	7632
02/04/75	02/17/75	*	336	NA		336	0	50	286	0	336	NA		--	336	--	336	336	0	--	336
04/08/75	04/26/75	*	456	NA		390	66	150	306	190	266	NA		--	456	--	456	430	26	--	456
04/27/75	05/26/75	*	720	NA		100	620	420	300	430	290	NA		--	720	--	720	40	680	--	720
09/27/75	10/26/75	*	720	NA		290	430	--	720	--	720	NA		--	720	--	720	340	380	--	720
10/27/75	11/26/75	*	744	NA		210	534	320	424	260	484	NA		--	744	--	744	100	644	--	744
11/27/75	12/26/75	*	720	NA		380	340	50	670	50	670	NA		--	720	--	720	290	430	--	720
12/27/75	01/26/76	*	744	NA		80	664	--	744	--	744	NA		--	744	--	744	130	614	--	744
	Total:		4440	-----------		1786	2654	990	3450	930	3510	-----------		0	4440	0	4440	1666	2774	0	4440
01/27/76	02/26/76	*	744	NA		--	744	40	704	20	724	NA		--	744	--	744	200	544	--	744
02/27/76	03/26/76	*	696	NA		90	606	270	426	210	486	NA		--	696	--	696	260	436	--	696
03/27/76	04/26/76	*	744	NA		110	634	140	604	140	604	NA		--	744	--	744	60	684	--	744

Update: July 1995

Key: N/A Prior to facility startup
- - No process in operation
Number of hours run time/down time

References:
* - BJH-3-88
& - PPL-1-89
# - SSC-1-92
% - RCH/TGA-7-95

Date			Hrs	FDP		FCE		2nd/3rd Cycle		Denitrator		NWCF		Zr (E Cell)		Al (G Cell)		Electro		Rover	
				up	down	up	down	up	down	up	down	up	down	up	down	up	down	up	down	up	down
04/27/76	05/26/76	*	720	NA		280	440	- -	720	- -	720	NA		- -	720	- -	720	430	290	- -	720
05/27/76	06/26/76	*	744	NA		330	414	- -	744	- -	744	NA		330	414	- -	744	- -	744	- -	744
06/27/76	07/26/76	*	720	NA		0	720	- -	720	- -	720	NA		0	720	- -	720	- -	720	- -	720
07/27/76	08/26/76	*	744	NA		320	424	- -	744	- -	744	NA		320	424	- -	744	- -	744	- -	744
08/27/76	09/26/76	*	744	NA		160	584	- -	744	- -	744	NA		70	674	- -	744	- -	744	- -	744
09/27/76	10/26/76	*	720	NA		10	710	- -	720	- -	720	NA		0	720	- -	720	- -	720	- -	720
10/27/76	11/26/76	*	744	NA		80	664	420	324	210	534	NA		- -	744	- -	744	- -	744	- -	744
	Total:		7320	----------		1380	5940	870	6450	580	6740	----------		720	6600	0	7320	950	6370	0	7320
03/01/77	03/26/77	*	624	NA		460	164	- -	624	- -	624	NA		450	174	- -	624	- -	624	- -	624
03/27/77	04/26/77	*	744	NA		740	4	- -	744	- -	744	NA		740	4	700	44	- -	744	- -	744
04/27/77	05/26/77	*	720	NA		710	10	- -	720	- -	720	NA		700	20	710	10	- -	720	- -	720
05/27/77	06/12/77	*	408	NA		390	18	- -	408	- -	408	NA		280	128	240	168	- -	408	- -	408
08/12/77	08/26/77	*	360	NA		140	220	- -	360	- -	360	NA		- -	360	- -	360	310	50	- -	360
08/27/77	09/18/77	*	552	NA		230	322	- -	552	- -	552	NA		- -	552	- -	552	470	82	- -	552
10/22/77	10/26/77	*	120	NA		- -	120	- -	120	- -	120	NA		- -	120	- -	120	- -	120	- -	120
10/27/77	11/26/77	*	744	NA		- -	744	- -	744	- -	744	NA		- -	744	- -	744	- -	744	- -	744
	Total:		4272	----------		2670	1602	0	4272	0	4272	----------		2170	2102	1650	2622	780	3492	0	4272
07/11/78	07/31/78	*	504	NA		370	134	- -	504	- -	504	NA		470	34	- -	504	- -	504	- -	504
08/01/78	08/31/78	*	744	NA		700	44	- -	744	- -	744	NA		680	64	- -	744	- -	744	- -	744
09/01/78	09/30/78	*	720	NA		570	150	- -	720	- -	720	NA		530	190	- -	720	- -	720	- -	720
10/01/78	10/17/78	*	408	NA		160	248	- -	408	- -	408	NA		0	408	- -	408	- -	408	- -	408
	Total:		2376	----------		1800	576	0	2376	0	2376	----------		1680	696	0	2376	0	2376	0	2376
03/17/79	04/23/79	*	912	NA		500	412	90	822	- -	912	NA		30	882	- -	912	- -	912	- -	912

Update: July 1995

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Date			Hrs	FDP		FCE		2nd/3rd Cycle		Denitrator		NWCF		Zr (E Cell)		Al (G Cell)		Electro		Rover	
				up	down	up	down	up	down	up	down	up	down	up	down	up	down	up	down	up	down
04/26/79	05/17/79	*	528	NA		--	528	380	148	420	108	NA		--	528	--	528	--	528	--	528
	Total:		1440	-----------		500	940	470	970	420	1020	-----------		30	1410	0	1440	0	1440	0	1440
09/19/80	09/30/80	*	288	NA		140	148	--	288	--	288	NA		30	258	--	288	--	288	--	288
10/01/80	10/31/80	*	744	NA		710	34	--	744	--	744	NA		720	24	--	744	--	744	--	744
11/01/80	11/30/80	*	720	NA		700	20	--	720	--	720	NA		700	20	--	720	--	720	--	720
12/01/80	12/22/80	*	528	NA		450	78	--	528	--	528	NA		400	128	--	528	--	528	--	528
	Total:		2280	-----------		2000	280	0	2280	0	2280	-----------		1850	430	0	2280	0	2280	0	2280
01/01/81	01/31/81	*	744	NA		--	744	--	744	--	744	NA		--	744	--	744	--	744	--	744
02/01/81	02/28/81	*	672	NA		--	672	--	672	--	672	NA		--	672	--	672	--	672	--	672
03/01/81	03/31/81	*	744	NA		710	34	--	744	--	744	NA		600	144	520	224	--	744	--	744
04/01/81	04/30/81	*	720	NA		510	210	60	660	--	720	NA		400	320	320	400	--	720	--	720
05/01/81	05/31/81	*	744	NA		--	744	290	454	120	624	NA		--	744	--	744	--	744	--	744
06/01/81	06/30/81	*	720	NA		--	720	460	260	480	240	NA		--	720	--	720	--	720	--	720
07/01/81	07/31/81	*	744	NA		--	744	--	744	--	744	NA		--	744	--	744	--	744	--	744
08/01/81	08/31/81	*	744	NA		48	696	--	744	--	744	NA		--	744	--	744	510	234	--	744
09/01/81	09/30/81	*	720	NA		330	390	196	524	160	560	NA		--	720	--	720	420	300	--	720
10/01/81	10/31/81	*	744	NA		360	384	294	450	240	504	NA		--	744	--	744	370	374	--	744
11/01/81	11/30/81	*	720	NA		310	410	--	720	--	720	NA		--	720	--	720	300	420	--	720
12/01/81	12/31/81	*	744	NA		--	744	--	744	--	744	NA		--	744	--	744	--	744	--	744
	Total:		8760	-----------		2268	6492	1300	7460	1000	7760	-----------		1000	7760	840	7920	1600	7160	0	8760
01/01/82	01/31/82	*	744	NA		--	744	--	744	--	744	NA		--	744	--	744	--	744	--	744
02/01/82	02/28/82	*	672	NA		--	672	--	672	--	672	NA		--	672	--	672	--	672	--	672
03/01/82	03/31/82	*	744	NA		--	744	480	264	330	414	NA		--	744	--	744	--	744	--	744

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Date			Hrs	FDP		FCE		2nd/3rd Cycle		Denitrator		NWCF		Zr (E Cell)		Al (G Cell)		Electro		Rover	
				up	down	up	down	up	down	up	down	up	down	up	down	up	down	up	down	up	down
04/01/82	04/30/82	*	720	NA		--	720	110	610	--	720	NA		--	720	--	720	--	720	--	720
05/01/82	05/31/82	*	744	NA		--	744	--	744	--	744	62	682	--	744	--	744	--	744	--	744
06/01/82	06/30/82	*	720	NA		--	720	--	720	--	720	388	332	--	720	--	720	--	720	--	720
07/01/82	07/31/82	*	744	NA		--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
08/01/82	08/31/82	*	744	NA		--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
09/01/82	09/30/82	*	720	NA		180	540	230	490	--	720	575	145	--	720	250	470	--	720	--	720
10/01/82	10/31/82	*	744	NA		400	344	--	744	--	744	744	0	--	744	390	354	--	744	--	744
11/01/82	11/30/82	*	720	NA		570	150	--	720	--	720	720	0	--	720	500	220	--	720	--	720
12/01/82	12/31/82	*	744	NA		30	714	340	404	400	344	744	0	--	744	--	744	--	744	--	744
	Total:		8760	----------		1180	7580	1160	7600	730	8030	3233	2647	0	8760	1140	7620	0	8760	0	8760
01/01/83	01/31/83	*	744	NA		--	744	--	744	--	744	744	0	--	744	--	744	--	744	--	744
02/01/83	02/28/83	*	672	NA		--	672	--	672	--	672	288	384	--	672	--	672	--	672	--	672
03/01/83	03/31/83	*	744	NA		--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
04/01/83	04/30/83	*	720	NA		40	680	--	720	--	720	720	0	--	720	--	720	--	720	190	530
05/01/83	05/31/83	*	744	NA		170	574	--	744	--	744	744	0	--	744	--	744	--	744	100	644
06/01/83	06/30/83	*	720	NA		340	380	--	720	--	720	720	0	--	720	--	720	--	720	640	80
07/01/83	07/31/83	*	744	NA		90	654	--	744	--	744	744	0	--	744	--	744	--	744	110	634
08/01/83	08/31/83	*	744	NA		--	744	140	604	--	744	744	0	--	744	--	744	--	744	--	744
09/01/83	09/30/83	*	720	NA		--	720	260	460	180	540	720	0	--	720	--	720	--	720	--	720
10/01/83	10/31/83	*	744	NA		110	634	170	574	310	434	254	490	--	744	--	744	--	744	--	744
11/01/83	11/30/83	*	720	NA		190	530	--	720	--	720	--	720	--	720	--	720	--	720	300	420
12/01/83	12/31/83	*	744	NA		580	164	--	744	--	744	--	744	--	744	--	744	--	744	560	184
	Total:		8760	----------		1520	7240	570	8190	490	8270	5678	3082	0	8760	0	8760	0	8760	1900	6860

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Date			Hrs	FDP		FCE		2nd/3rd Cycle		Denitrator		NWCF		Zr (E Cell)		Al (G Cell)		Electro		Rover	
				up	down	up	down	up	down	up	down	up	down	up	down	up	down	up	down	up	down
01/01/84	01/31/84	*	744	NA		625	119	--	744	--	744	369	375	--	744	--	744	--	744	462	282
02/01/84	02/29/84	*	696	NA		23	673	582	114	471	225	696	0	--	696	--	696	--	696	--	696
03/01/84	03/31/84	*	744	NA		358	386	91	653	196	548	383	361	--	744	--	744	--	744	365	379
04/01/84	04/30/84	*	720	NA		639	81	--	720	--	720	316	404	--	720	--	720	--	720	561	159
05/01/84	05/31/84	*	744	NA		557	187	139	605	--	744	688	56	--	744	--	744	--	744	407	337
06/01/84	06/30/84	*	720	NA		367	353	239	481	361	359	362	358	--	720	--	720	--	720	67	653
07/01/84	07/31/84	*	744	NA		--	744	344	400	467	277	--	744	--	744	--	744	--	744	--	744
08/01/84	08/31/84	*	744	NA		--	744	444	300	204	540	--	744	--	744	--	744	--	744	--	744
09/01/84	09/30/84	*	720	NA		--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720
10/01/84	10/31/84	*	744	NA		--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
11/01/84	11/30/84	*	720	NA		--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720
12/01/84	12/31/84	*	744	NA		--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
	Total:		8784	----------		2569	6215	1839	6945	1699	7085	2814	5970	0	8784	0	8784	0	8784	1862	6922
01/01/85	01/31/85	*	744	NA		--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
02/01/85	02/28/85	*	672	NA		--	672	--	672	--	672	--	672	--	672	--	672	--	672	--	672
03/01/85	03/31/85	*	744	NA		--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
04/01/85	04/30/85	*	720	NA		65	655	--	720	--	720	--	720	--	720	--	720	--	720	--	720
05/01/85	05/31/85	*	744	NA		118	626	--	744	--	744	--	744	--	744	--	744	--	744	--	744
06/01/85	06/30/85	*	720	NA		--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720
07/01/85	07/31/85	*	744	NA		201	543	--	744	--	744	--	744	--	744	--	744	--	744	--	744
08/01/85	08/31/85	*	744	NA		141	603	--	744	--	744	--	744	--	744	92	652	--	744	--	744
09/01/85	09/30/85	*	720	NA		497	223	--	720	--	720	--	720	--	720	344	376	--	720	--	720
10/01/85	10/31/85	*	744	NA		614	130	--	744	--	744	--	744	--	744	505	239	--	744	--	744

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Date			Hrs	FDP		FCE		2nd/3rd Cycle		Denitrator		NWCF		Zr (E Cell)		Al (G Cell)		Electro		Rover	
				up	down	up	down	up	down	up	down	up	down	up	down	up	down	up	down	up	down
11/01/85	11/30/85	*	720	NA		513	207	--	720	--	720	--	720	--	720	406	314	--	720	--	720
12/01/85	12/31/85	*	744	NA		550	194	--	744	--	744	--	744	--	744	431	313	--	744	--	744
	Total:		8760	-----------		2699	6061	0	8760	0	8760	0	8760	0	8760	1778	6982	0	8760	0	8760
01/01/86	01/31/86	*	744	NA		160	584	--	744	--	744	--	744	--	744	--	744	--	744	--	744
02/01/86	02/28/86	*	672	NA		--	672	--	672	--	672	--	672	--	672	--	672	--	672	--	672
03/01/86	03/31/86	*	744	NA		--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
04/01/86	04/30/86	*	720	NA		--	720	350	370	108	612	--	720	--	720	15	705	--	720	--	720
05/01/86	05/31/86	*	744	NA		--	744	288	456	393	351	--	744	--	744	--	744	--	744	--	744
06/01/86	06/30/86	*	720	NA		--	720	592	128	154	566	--	720	--	720	--	720	--	720	--	720
07/01/86	07/31/86	*	744	NA		--	744	--	744	87	657	--	744	--	744	--	744	--	744	--	744
08/01/86	08/31/86	*	744	NA		--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
09/01/86	09/30/86	*	720	NA		77	643	--	720	--	720	--	720	--	720	--	720	--	720	--	720
10/01/86	10/31/86	*	744	NA		251	493	--	744	--	744	--	744	--	744	--	744	--	744	--	744
11/01/86	11/30/86	*	720	NA		145	575	--	720	--	720	--	720	--	720	--	720	--	720	--	720
12/01/86	12/31/86	*	744	631	113	158	586	--	744	--	744	--	744	--	744	--	744	--	744	--	744
	Total:		8760	631	113	791	7969	1230	7530	742	8018	0	8760	0	8760	15	8745	0	8760	0	8760
01/01/87	01/31/87	*	744	514	230	148	596	--	744	--	744	--	744	--	744	--	744	--	744	--	744
02/01/87	02/28/87	*	672	624	48	268	404	--	672	--	672	--	672	--	672	--	672	--	672	--	672
03/01/87	03/31/87	*	744	681	63	183	561	--	744	--	744	--	744	--	744	--	744	--	744	--	744
04/01/87	04/30/87	*	720	720	0	325	395	--	720	--	720	--	720	--	720	--	720	--	720	--	720
05/01/87	05/31/87	*	744	744	0	252	492	--	744	--	744	--	744	--	744	--	744	--	744	--	744
06/01/87	06/30/87	*	720	720	0	274	446	--	720	--	720	--	720	--	720	--	720	--	720	--	720
07/01/87	07/31/87	*	744	736	8	210	534	--	744	--	744	--	744	--	744	--	744	--	744	--	744

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Date			Hrs	FDP		FCE		2nd/3rd Cycle		Denitrator		NWCF		Zr (E Cell)		Al (G Cell)		Electro		Rover	
				up	down	up	down	up	down	up	down	up	down	up	down	up	down	up	down	up	down
08/01/87	08/31/87	*	744	744	0	292	452	--	744	--	744	--	744	--	744	--	744	--	744	--	744
09/01/87	09/30/87	*	720	720	0	409	311	--	720	--	720	--	720	--	720	--	720	--	720	--	720
10/01/87	10/31/87	*	744	344	400	89	655	--	744	--	744	--	744	--	744	--	744	--	744	--	744
11/01/87	11/30/87	*	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720
12/01/87	12/31/87	*	744	432	312	157	587	--	744	--	744	--	744	--	744	--	744	--	744	--	744
	Total:		8760	6979	1781	2607	6153	0	8760	0	8760	0	8760	0	8760	0	8760	0	8760	0	8760
01/01/88	01/31/88	&	744	744	0	336	408	--	744	--	744	674	70	--	744	--	744	--	744	--	744
02/01/88	02/29/88	&	696	696	0	317	379	--	696	--	696	529	167	--	696	--	696	--	696	--	696
03/01/88	03/31/88	&	744	282	462	134	610	--	744	--	744	263	481	--	744	--	744	--	744	--	744
04/01/88	04/30/88	&	720	720	0	289	431	--	720	--	720	700	20	--	720	--	720	--	720	--	720
05/01/88	05/31/88	&	744	744	0	349	395	--	744	--	744	313	431	--	744	--	744	--	744	--	744
06/01/88	06/30/88	&	720	720	0	293	427	--	720	--	720	250	470	--	720	--	720	--	720	--	720
07/01/88	07/31/88	&	744	296	448	140	604	--	744	--	744	740	4	--	744	--	744	--	744	--	744
08/01/88	08/31/88	&	744	--	744	--	744	--	744	--	744	744	0	--	744	--	744	--	744	--	744
09/01/88	09/30/88	&	720	--	720	--	720	--	720	--	720	720	0	--	720	--	720	--	720	--	720
10/01/88	10/31/88	&	744	--	744	--	744	45	699	--	744	144	600	--	744	--	744	--	744	--	744
11/01/88	11/30/88	&	720	--	720	--	720	226	494	--	720	--	720	--	720	--	720	--	720	--	720
12/01/88	12/31/88	&	744	--	744	--	744	80	664	--	744	--	744	--	744	--	744	--	744	--	744
	Total:		8784	4202	4582	1858	6926	351	8433	0	8784	5077	3707	0	8784	0	8784	0	8784	0	8784
01/01/89	01/31/89	&	744	--	744	--	744	112	632	--	744	--	744	--	744	--	744	--	744	--	744
02/01/89	02/28/89	&	672	--	672	--	672	186	486	247	425	--	672	--	672	--	672	--	672	--	672
03/01/89	03/31/89	&	744	--	744	--	744	538	206	510	234	--	744	--	744	--	744	--	744	--	744
04/01/89	04/30/89	&	720	--	720	--	720	256	464	234	486	--	720	--	720	--	720	--	720	--	720

Update: July 1995

Key: N/A Prior to facility startup
-- No process in operation
Number of hours run time/down time

References: * - BJH-3-88
& - PPL-1-89
# - SSC-1-92
% - RCH/TGA-7-95

Date			Hrs	FDP		FCE		2nd/3rd Cycle		Denitrator		NWCF		Zr (E Cell)		Al (G Cell)		Electro		Rover	
				up	down	up	down	up	down	up	down	up	down	up	down	up	down	up	down	up	down
05/01/89	05/31/89	&	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
06/01/89	06/30/89	&	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720
07/01/89	07/31/89	&	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
08/01/89	08/31/89	&	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
09/01/89	09/30/89	&	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720
10/01/89	10/31/89	&	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
11/01/89	11/30/89	#	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720
12/01/89	12/31/89	#	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
	Total:		8760	0	8760	0	8760	1092	7668	991	7769	0	8760	0	8760	0	8760	0	8760	0	8760
01/01/90	01/31/90	#	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
02/01/90	02/28/90	#	672	--	672	--	672	--	672	--	672	--	672	--	672	--	672	--	672	--	672
03/01/90	03/31/90	#	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
04/01/90	04/30/90	#	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720
05/01/90	05/31/90	#	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
06/01/90	06/30/90	#	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720
07/01/90	07/31/90	#	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
08/01/90	08/31/90	#	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
09/01/90	09/30/90	#	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720
10/01/90	10/31/90	#	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
11/01/90	11/30/90	#	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720
12/01/90	12/31/90	#	744	--	744	--	744	--	744	--	744	732	12	--	744	--	744	--	744	--	744
	Total:		8760	0	8760	0	8760	0	8760	0	8760	732	8028	0	8760	0	8760	0	8760	0	8760
01/01/91	01/31/91	#	744	--	744	--	744	--	744	--	744	608	136	--	744	--	744	--	744	--	744

Update: July 1995

Key: N/A Prior to facility startup
-- No process in operation
Number of hours run time/down time

References:
* - BJH-3-88
& - PPL-1-89
# - SSC-1-92
% - RCH/TGA-7-95

Date			Hrs	FDP		FCE		2nd/3rd Cycle		Denitrator		NWCF		Zr (E Cell)		Al (G Cell)		Electro		Rover	
				up	down	up	down	up	down	up	down	up	down	up	down	up	down	up	down	up	down
02/01/91	02/28/91	#	672	--	672	--	672	--	672	--	672	--	672	--	672	--	672	--	672	--	672
03/01/91	03/31/91	#	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
04/01/91	04/30/91	#	720	--	720	--	720	287	433	--	720	661	59	--	720	--	720	--	720	--	720
05/01/91	05/31/91	#	744	--	744	--	744	140	604	--	744	744	0	--	744	--	744	--	744	--	744
06/01/91	06/30/91	#	720	--	720	--	720	--	720	168	552	720	0	--	720	--	720	--	720	--	720
07/01/91	07/31/91	#	744	--	744	--	744	--	744	114	630	--	744	--	744	--	744	--	744	--	744
08/01/91	08/31/91	#	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
09/01/91	09/30/91	#	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720
10/01/91	10/31/91	#	744	--	744	--	744	32	712	--	744	--	744	--	744	--	744	--	744	--	744
11/01/91	11/30/91	#	720	--	720	--	720	333	387	--	720	--	720	--	720	--	720	--	720	--	720
12/01/91	12/31/91	#	744	--	744	--	744	--	744	--	744	357	387	--	744	--	744	--	744	--	744
	Total:		8760	0	8760	0	8760	792	7968	282	8478	3090	5670	0	8760	0	8760	0	8760	0	8760
01/01/92	01/31/92	#	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
02/01/92	02/29/92	#	696	--	696	--	696	--	696	--	696	--	696	--	696	--	696	--	696	--	696
03/01/92	03/31/92	#	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
04/01/92	04/30/92	%	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720
05/01/92	05/31/92	%	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
06/01/92	06/30/92	%	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720
07/01/92	07/31/92	%	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
08/01/92	08/31/92	%	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
09/01/92	09/30/92	%	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720
10/01/92	10/31/92	%	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
11/01/92	11/30/92	%	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720

Update: July 1995

Key: N/A Prior to facility startup

-- No process in operation

Number of hours run time/down time

References: * - BJH-3-88

& - PPL-1-89

- SSC-1-92

% - RCH/TGA-7-95

Date			Hrs	FDP		FCE		2nd/3rd Cycle		Denitrator		NWCF		Zr (E Cell)		Al (G Cell)		Electro		Rover	
				up	down	up	down	up	down	up	down	up	down	up	down	up	down	up	down	up	down
12/01/92	12/31/92	%	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
	Total:		8784	0	8784	0	8784	0	8784	0	8784	0	8784	0	8784	0	8784	0	8784	0	8784
01/01/93	01/31/93	%	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
02/01/93	02/28/93	%	672	--	672	--	672	--	672	--	672	--	672	--	672	--	672	--	672	--	672
03/01/93	03/31/93	%	744	--	744	--	744	--	744	251	493	--	744	--	744	--	744	--	744	--	744
04/01/93	04/30/93	%	720	--	720	--	720	--	720	720	0	--	720	--	720	--	720	--	720	--	720
05/01/93	05/31/93	%	744	--	744	--	744	--	744	744	0	--	744	--	744	--	744	--	744	--	744
06/01/93	06/30/93	%	720	--	720	--	720	--	720	717	3	--	720	--	720	--	720	--	720	--	720
07/01/93	07/31/93	%	744	--	744	--	744	--	744	722	22	--	744	--	744	--	744	--	744	--	744
08/01/93	08/31/93	%	744	--	744	--	744	--	744	699	45	--	744	--	744	--	744	--	744	--	744
09/01/93	09/30/93	%	720	--	720	--	720	--	720	720	0	--	720	--	720	--	720	--	720	--	720
10/01/93	10/31/93	%	744	--	744	--	744	--	744	664	80	--	744	--	744	--	744	--	744	--	744
11/01/93	11/30/93	%	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720
12/01/93	12/31/93	%	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
	Total:		8760	0	8760	0	8760	0	8760	5238	3522	0	8760	0	8760	0	8760	0	8760	0	8760
01/01/94	01/31/94	%	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
02/01/94	02/28/94	%	672	--	672	--	672	--	672	--	672	--	672	--	672	--	672	--	672	--	672
03/01/94	03/31/94	%	744	--	744	696	48	696	48	--	744	--	744	--	744	--	744	--	744	--	744
04/01/94	04/30/94	%	720	--	720	384	336	384	336	--	720	--	720	--	720	--	720	--	720	--	720
05/01/94	05/31/94	%	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
06/01/94	06/30/94	%	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720
07/01/94	07/31/94	%	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
08/01/94	08/31/94	%	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744

Update: July 1995

Key: N/A Prior to facility startup
-- No process in operation
/// Number of hours run time/down time

References:
* - BJH-3-88
& - PPL-1-89
# - SSC-1-92
% - RCH/TGA-7-95

Date			Hrs	FDP		FCE		2nd/3rd Cycle		Denitrator		NWCF		Zr (E Cell)		Al (G Cell)		Electro		Rover	
				up	down	up	down	up	down	up	down	up	down	up	down	up	down	up	down	up	down
09/01/94	09/30/94	%	720	--	720	--	720	--	720	576	144	--	720	--	720	--	720	--	720	--	720
10/01/94	10/31/94	%	744	--	744	--	744	--	744	384	360	--	744	--	744	--	744	--	744	--	744
11/01/94	11/30/94	%	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720
12/01/94	12/31/94	%	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
	Total:		8760	0	8760	1080	7680	1080	7680	960	7800	0	8760	0	8760	0	8760	0	8760	0	8760
01/01/95	01/31/95	%	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
02/01/95	02/28/95	%	672	--	672	--	672	--	672	--	672	--	672	--	672	--	672	--	672	--	672
03/01/95	03/31/95	%	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
04/01/95	04/30/95	%	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720
05/01/95	05/31/95	%	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
06/01/95	06/30/95	%	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720	--	720
07/01/95	07/31/95	%	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744	--	744
	Total:		5088	0	5088	0	5088	0	5088	0	5088	0	5088	0	5088	0	5088	0	5088	0	5088
Total Operational Time:			157560	11812	44148	30388	127172	12584	144976	14942	142618	02624	95536	9070	148490	7933	149627	4996	152564	3762	153798

APPENDIX C

APPENDIX C

Intermediate Values Calculated

This appendix provides a table of some of the important intermediate values calculated during the analysis of the Idaho Chemical Processing Plant failure data. The appropriate combination of the Model I and Model II values yield the report failure rates and error factors.

Table C-1: Intermediate Values Calculated for ICPP failure Data

Component Type/ Instrument Group	Failure Mode	Reported Failure Rates λ	λ_m	EF	Standard Error	Basic Data n (fails)	N (pop)	t* (mission time)	MODEL 1 λ	$\lambda_{0.05}$	$\lambda_{0.95}$	DF_{χ^2}
Agitators	All	9.79E-06	5.14E-06	6.48	1.23E-05	19	59	64704	4.98E-06	3.37E-06	7.15E-06	1.46
Airlifts	All	1.17E-05	6.04E-06	6.63	1.49E-05	3	62	52776	9.17E-07	3.31E-07	2.15E-06	2.55
Casks	All	8.17E-05	2.48E-05	12.66	3.48E-05	23	47	67296	7.27E-06	5.10E-06	1.01E-05	1.41
Cranes	All	1.16E-04	6.54E-05	5.79	3.92E-05	252	31	75360	1.08E-04	9.71E-05	1.20E-04	1.11
	Electrical	2.05E-05	1.23E-05	9.15	1.65E-05	56	31	75360	2.40E-05	1.91E-05	2.97E-05	1.25
	Lift	2.05E-05	1.04E-05	6.82	1.65E-05	36	31	75360	1.54E-05	1.16E-05	2.01E-05	1.32
	Brakes	1.79E-05	9.13E-06	6.73	1.54E-05	30	31	75360	1.28E-05	9.43E-06	1.72E-05	1.35
	Bridge	1.10E-05	3.92E-06	10.66	1.21E-05	12	31	75360	1.54E-05	3.13E-06	8.06E-06	1.61
	Other	5.62E-05	3.28E-05	5.53	2.73E-05	118	31	75360	5.05E-05	4.33E-05	5.86E-05	1.16
Filters	All	7.65E-06	3.41E-06	8.08	1.02E-05	130	421	73296	4.25E-06	3.67E-06	4.89E-06	1.15
	Plug	4.32E-06	2.89E-06	4.38	7.67E-06	16	421	73296	5.19E-07	3.38E-07	7.68E-07	1.51
	Leak	4.40E-06	3.10E-06	3.97	7.75E-06	3	421	73296	9.72E-08	3.51E-08	2.28E-07	2.55
	Other	7.09E-06	3.14E-06	8.15	9.83E-06	78	421	73296	3.63E-06	3.10E-06	4.23E-06	1.17
Glovebox	All	5.64E-05	2.08E-05	10.19	2.82E-05	100	30	70824	4.71E-05	3.98E-05	5.53E-05	1.18
	Gloves	4.21E-05	1.34E-05	12.02	2.44E-05	70	30	70824	3.29E-05	2.70E-05	3.99E-05	1.22
	Leak	8.68E-06	2.98E-06	11.08	1.11E-05	3	30	70824	1.41E-06	5.10E-07	3.31E-06	2.55
	Other	1.88E-05	8.20E-06	8.35	1.63E-05	27	30	70824	1.27E-05	9.17E-06	1.73E-05	1.37
Hoist	All	1.05E-05	3.49E-06	11.48	1.22E-05	26	71	70464	5.20E-06	3.73E-06	7.10E-06	1.38
	Block	6.93E-06	2.63E-06	9.85	9.92E-06	5	71	70464	9.99E-07	4.57E-07	1.97E-06	2.07
	Cable	6.81E-06	2.75E-06	9.17	9.83E-06	6	71	70464	1.20E-06	5.89E-07	2.23E-06	1.95
	Hook	6.76E-06	2.86E-06	8.64	9.80E-06	3	71	70464	6.00E-07	2.17E-07	1.41E-06	2.55
	Other	7.64E-06	2.92E-06	9.80	1.04E-05	12	71	70464	2.40E-06	1.46E-06	3.76E-06	1.61
Hood	All	4.92E-05	1.13E-05	16.86	4.97E-05	9	24	19920	1.88E-05	1.06E-05	3.15E-05	1.73
Heat Exchangers\Condensors	All	9.33E-06	4.10E-06	8.24	1.13E-05	55	140	72792	5.40E-06	4.30E-06	6.70E-06	1.25
	Leak	6.36E-06	3.15E-06	7.04	9.35E-06	23	140	72792	2.26E-06	1.58E-06	3.14E-06	1.41
	Other	7.24E-06	3.13E-06	8.43	9.97E-06	32	140	72792	3.14E-06	2.33E-06	4.16E-06	1.34
Jets	All	5.40E-06	2.84E-06	6.45	8.66E-06	56	447	72000	1.74E-06	1.39E-06	2.16E-06	1.25
	Leak	4.16E-06	3.13E-06	3.47	7.60E-06	7	447	72000	2.17E-07	1.13E-07	3.88E-07	1.86
	Plug	4.67E-06	2.87E-06	5.07	8.06E-06	5	447	72000	1.55E-07	7.11E-08	3.06E-07	2.07
	Other	5.07E-06	2.80E-06	6.01	8.39E-06	52	447	72000	1.37E-06	1.06E-06	1.74E-06	1.28
Manipulators	All	1.05E-04	5.19E-05	7.07	3.71E-05	744	99	76440	9.83E-05	9.00E-05	1.07E-04	1.09
	Boot	8.39E-06	4.06E-06	7.26	1.05E-05	34	99	76440	4.49E-06	3.36E-06	5.91E-06	1.33
	Cable	8.65E-06	4.58E-06	6.40	1.06E-05	38	99	76440	5.02E-06	3.82E-06	6.51E-06	1.31
	Grip	1.57E-05	6.40E-06	9.03	1.43E-05	90	99	76440	1.19E-05	9.97E-06	1.41E-05	1.19
	Motion	1.71E-05	8.28E-06	7.27	1.50E-05	104	99	76440	1.37E-05	1.17E-05	1.61E-05	1.17
	Fail to Run	9.30E-06	4.05E-06	8.34	1.10E-05	41	99	76440	5.42E-06	4.16E-06	6.96E-06	1.29
	Tong	6.42E-06	3.89E-06	5.19	9.17E-06	22	99	76440	2.91E-06	2.02E-06	4.07E-06	1.42
	Wrist	8.62E-06	5.07E-06	5.45	1.06E-05	40	99	76440	5.29E-06	4.05E-06	6.81E-06	1.30

Table C-1: Intermediate Values Calculated for ICPP Failure Data

Component Type/ Instrument Group	Failure Mode	MODEL II				Adjusted Lognormal Distribution			
		$\overline{\lambda}$	$\overline{\lambda}_{0.05}$	$\overline{\lambda}_{0.95}$	EF	λ	$\lambda_{0.05}$	$\lambda_{0.95}$	EF
Agitators	All	7.75E-06	1.16E-06	2.28E-05	4.45	9.79E-06	7.93E-07	3.33E-05	6.48
Airlifts	All	5.10E-06	2.32E-06	1.57E-05	2.60	1.17E-05	9.11E-07	4.00E-05	6.63
Casks	All	1.02E-05	2.76E-06	2.23E-04	8.99	8.17E-05	2.76E-06	3.14E-04	12.66
Cranes	All	1.08E-04	1.25E-05	3.41E-04	5.22	1.16E-04	1.13E-05	3.79E-04	5.79
	Electrical	2.55E-05	1.67E-06	5.37E-05	5.18	2.05E-05	1.34E-06	1.12E-04	9.15
	Lift	1.71E-05	2.00E-06	5.37E-05	5.18	2.05E-05	1.52E-06	7.06E-05	6.82
	Brakes	1.47E-05	1.83E-06	4.55E-05	4.99	1.79E-05	1.36E-06	6.15E-05	6.73
	Bridge	7.60E-06	5.90E-07	2.60E-05	6.64	1.10E-05	3.67E-07	4.18E-05	10.66
	Other	5.13E-05	6.90E-06	1.56E-04	4.75	5.62E-05	5.93E-06	1.81E-04	5.53
Filters	All	6.87E-06	4.88E-07	2.39E-05	7.00	7.65E-06	4.22E-07	2.76E-05	8.08
	Plug	3.56E-06	9.93E-07	8.38E-06	2.90	4.32E-06	6.59E-07	1.26E-05	4.38
	Leak	3.21E-06	1.99E-06	4.83E-06	1.56	4.40E-06	7.79E-07	1.23E-05	3.97
	Other	6.31E-06	4.50E-07	2.19E-05	6.98	7.09E-06	3.86E-07	2.56E-05	8.15
Glovebox	All	4.92E-05	2.41E-06	1.80E-04	8.65	5.64E-05	2.04E-06	2.12E-04	10.19
	Gloves	3.54E-05	1.36E-06	1.33E-04	9.88	4.21E-05	1.12E-06	1.62E-04	12.02
	Leak	4.44E-06	6.85E-07	1.30E-05	4.35	8.68E-06	2.69E-07	3.30E-05	11.08
	Other	1.50E-05	1.35E-06	4.99E-05	6.09	1.88E-05	9.82E-07	6.85E-05	8.35
Hoist	All	8.00E-06	4.19E-07	2.90E-05	8.32	1.05E-05	3.04E-07	4.01E-05	11.48
	Block	4.13E-06	5.54E-07	1.25E-05	4.75	6.93E-06	2.67E-07	2.60E-05	9.85
	Cable	4.28E-06	5.83E-07	1.29E-05	4.71	6.81E-06	2.99E-07	2.52E-05	9.17
	Hook	3.77E-06	8.44E-07	9.71E-06	3.39	6.76E-06	3.31E-07	2.47E-05	8.64
	Other	5.34E-06	4.78E-07	1.78E-05	6.11	7.64E-06	2.98E-07	2.86E-05	9.80
Hood	All	2.94E-05	1.15E-06	1.10E-04	9.77	4.92E-05	6.68E-07	1.90E-04	16.86
Heat Exchangers\Condensors	All	7.92E-06	6.21E-07	2.71E-05	6.60	9.33E-06	4.98E-07	3.38E-05	8.24
	Leak	5.08E-06	6.29E-07	1.57E-05	5.00	6.36E-06	4.47E-07	2.22E-05	7.04
	Other	5.85E-06	4.96E-07	1.97E-05	6.30	7.24E-06	3.71E-07	2.63E-05	8.43
Jets	All	4.68E-06	5.50E-07	1.47E-05	5.17	5.40E-06	4.41E-07	1.83E-05	6.45
	Leak	3.36E-06	1.67E-06	5.85E-06	1.87	4.16E-06	9.00E-07	1.09E-05	3.47
	Plug	3.33E-06	1.17E-06	7.02E-06	2.45	4.67E-06	5.66E-07	1.46E-05	5.07
	Other	4.35E-06	5.97E-07	1.31E-05	4.69	5.07E-06	4.66E-07	1.68E-05	6.01
Manipulators	All	9.91E-05	7.99E-06	3.37E-04	6.49	1.05E-04	7.34E-06	3.67E-04	7.07
	Boot	6.92E-06	7.41E-07	2.22E-05	5.48	8.39E-06	5.59E-07	2.95E-05	7.26
	Cable	7.30E-06	9.34E-07	2.24E-05	4.90	8.65E-06	7.15E-07	2.93E-05	6.40
	Grip	1.37E-05	8.43E-07	4.86E-05	7.60	1.57E-05	7.09E-07	5.78E-05	9.03
	Motion	1.53E-05	1.34E-06	5.12E-05	6.19	1.71E-05	1.14E-06	6.02E-05	7.27
	Fail to Run	7.70E-06	6.27E-07	2.61E-05	6.45	9.30E-06	4.85E-07	3.38E-05	8.34
	Tong	5.31E-06	1.06E-06	1.42E-05	3.65	6.42E-06	7.50E-07	2.02E-05	5.19
	Wrist	7.41E-06	1.21E-06	2.13E-05	4.20	8.62E-06	9.30E-07	2.76E-05	5.45

Table C-1: Intermediate Values Calculated for ICPP failure Data

Component Type/ Instrument Group	Failure Mode	Reported Failure Rates				Basic Data			MODEL 1			
		λ	λ_m	EF	Standard Error	n (fails)	N (pop)	t* (mission time)	λ	$\lambda_{0.05}$	$\lambda_{0.95}$	DF_{χ^2}
Manipulators (Contd.)	Other	5.42E-05	2.22E-05	9.02	2.66E-05	375	99	76440	4.96E-05	4.55E-05	5.39E-05	1.09
Pumps	All	2.39E-05	1.05E-05	8.24	1.78E-05	583	380	75216	2.04E-05	1.85E-05	2.24E-05	1.10
	Charge	5.06E-06	2.03E-06	9.25	8.21E-06	31	380	75216	1.08E-06	8.00E-07	1.44E-06	1.34
	Leak	5.95E-06	3.29E-06	6.00	8.89E-06	75	380	75216	2.62E-06	2.16E-06	3.16E-06	1.21
	Oiler	5.16E-06	2.26E-06	8.27	8.28E-06	40	380	75216	1.40E-06	1.07E-06	1.80E-06	1.30
	Plug	4.84E-06	2.25E-06	7.68	8.02E-06	26	380	75216	9.10E-07	6.52E-07	1.24E-06	1.38
	Fail to Run	4.97E-06	2.28E-06	7.81	8.13E-06	32	380	75216	1.12E-06	8.30E-07	1.48E-06	1.34
	Other	1.63E-05	7.48E-06	7.76	1.47E-05	379	380	75216	1.33E-05	1.22E-05	1.44E-05	1.09
Sampler Sys	All	1.04E-05	4.80E-06	7.70	1.19E-05	68	142	73440	6.52E-06	5.32E-06	7.93E-06	1.22
	Plug	5.42E-06	2.96E-06	6.10	8.59E-06	13	142	73440	1.25E-06	7.74E-07	1.92E-06	1.58
	Needle	5.16E-06	2.87E-06	5.95	8.39E-06	5	142	73440	4.79E-07	2.19E-07	9.43E-07	2.07
	Other	8.58E-06	4.15E-06	7.25	1.08E-05	50	142	73440	4.79E-06	3.78E-06	6.02E-06	1.26
Valves	All	1.03E-06	5.60E-07	6.18	3.63E-06	1020	13037	78288	9.99E-07	9.49E-07	1.05E-06	1.05
	Leak	2.52E-07	7.59E-08	12.80	1.79E-06	233	13037	78288	2.28E-07	2.05E-07	2.54E-07	1.11
	Plug	6.58E-08	8.38E-06	28.22	9.17E-07	51	13037	78288	5.00E-08	3.93E-08	6.24E-08	1.26
	Other	7.53E-07	3.65E-07	7.24	3.10E-06	736	13037	78288	7.21E-07	6.78E-07	7.66E-07	1.06
Gate	All	3.61E-06	2.69E-06	3.53	6.79E-06	249	5063	78288	6.28E-07	5.65E-07	6.96E-07	1.11
	Leak	3.22E-06	2.88E-06	2.19	6.42E-06	61	5063	78288	1.54E-07	1.24E-07	1.89E-07	1.23
	Plug	3.26E-06	2.91E-06	2.19	6.46E-06	11	5063	78288	2.78E-08	1.65E-08	4.44E-08	1.64
	Other	3.46E-06	2.73E-06	3.09	6.65E-06	177	5063	78288	4.47E-07	3.94E-07	5.04E-07	1.13
Ball	All	4.30E-06	2.77E-06	4.66	7.41E-06	330	3012	78288	1.40E-06	1.28E-06	1.53E-06	1.09
	Leak	3.43E-06	2.71E-06	3.08	6.61E-06	71	3012	78288	3.01E-07	2.47E-07	3.65E-07	1.22
	Plug	3.28E-06	2.89E-06	2.29	6.47E-06	21	3012	78288	8.91E-08	6.14E-08	1.26E-07	1.43
	Other	3.98E-06	2.67E-06	4.34	7.13E-06	238	3012	78288	1.01E-06	9.06E-07	1.12E-06	1.11
Globe	All	4.02E-06	2.49E-06	4.99	7.16E-06	99	1477	78288	8.56E-07	7.24E-07	1.01E-06	1.18
	Leak	3.48E-06	2.80E-06	2.95	6.67E-06	16	1477	78288	1.38E-07	9.02E-08	2.05E-07	1.51
	Plug	4.98E-06	2.93E-06	5.44	7.98E-06	1	1477	78288	8.65E-09	1.52E-09	3.38E-08	4.71
	Other	3.88E-06	2.54E-06	4.54	7.04E-06	82	1477	78288	7.09E-07	5.89E-07	8.47E-07	1.20
Solenoid	All	3.88E-06	2.90E-06	3.50	7.04E-06	4	575	78288	8.89E-08	3.69E-08	1.88E-07	2.26
	Leak	2.62E-05	2.94E-06	31.26	1.83E-05	0	575	78288	5.11E-09	4.37E-11	4.27E-08	31.26
	Plug	2.62E-05	2.94E-06	31.26	1.83E-05	0	575	78288	5.11E-09	4.37E-11	4.27E-08	31.26
	Other	3.88E-06	2.90E-06	3.50	7.04E-06	4	575	78288	8.89E-08	3.69E-08	1.88E-07	2.26
Misc	All	1.01E-05	7.10E-06	3.99	1.14E-05	173	273	78288	8.09E-06	7.13E-06	9.16E-06	1.13
	Leak	5.23E-06	2.94E-06	5.84	8.17E-06	41	273	78288	1.92E-06	1.47E-06	2.46E-06	1.29
	Plug	4.41E-06	2.58E-06	5.49	7.51E-06	12	273	78288	5.61E-07	3.42E-07	8.81E-07	1.61
	Other	8.07E-06	5.41E-06	4.35	1.02E-05	120	273	78288	5.61E-06	4.82E-06	6.51E-06	1.16
Needle	All	4.57E-06	2.61E-06	5.71	7.64E-06	20	269	78288	9.50E-07	6.49E-07	1.35E-06	1.44
	Leak	4.08E-06	2.87E-06	3.99	7.22E-06	7	269	78288	3.32E-07	1.72E-07	5.93E-07	1.86

Table C-1: Intermediate Values Calculated for ICPP Failure Data

Component Type/ Instrument Group	Failure Mode	MODEL II $\bar{\lambda}$	MODEL II $\bar{\lambda}_{0.05}$	MODEL II $\bar{\lambda}_{0.95}$	MODEL II EF	Adjusted Lognormal Distribution λ	Adjusted Lognormal Distribution $\lambda_{0.05}$	Adjusted Lognormal Distribution $\lambda_{0.95}$	Adjusted Lognormal Distribution EF
Manipulators (Contd.)	Other	5.06E-05	2.68E-06	1.84E-04	8.28	5.42E-05	2.46E-06	2.00E-04	9.02
Pumps	All	2.22E-05	1.41E-06	7.87E-05	7.48	2.39E-05	1.28E-06	8.66E-05	8.24
	Charge	4.04E-06	2.95E-07	1.40E-05	6.88	5.06E-06	2.20E-07	1.88E-05	9.25
	Leak	5.28E-06	6.62E-07	1.63E-05	4.96	5.95E-06	5.48E-07	1.97E-05	6.00
	Oiler	4.26E-06	3.54E-07	1.44E-05	6.38	5.16E-06	2.73E-07	1.87E-05	8.27
	Plug	3.87E-06	4.04E-07	1.25E-05	5.56	4.84E-06	2.93E-07	1.72E-05	7.68
	Fail to Run	4.05E-06	3.90E-07	1.33E-05	5.84	4.97E-06	2.91E-07	1.78E-05	7.81
	Other	1.53E-05	1.05E-06	5.33E-05	7.13	1.63E-05	9.64E-07	5.81E-05	7.76
Sampler Sys	All	8.99E-06	7.61E-07	3.03E-05	6.31	1.04E-05	6.23E-07	3.70E-05	7.70
	Plug	4.16E-06	7.65E-07	1.15E-05	3.87	5.42E-06	4.85E-07	1.81E-05	6.10
	Needle	3.52E-06	1.00E-06	8.23E-06	2.87	5.16E-06	4.82E-07	1.71E-05	5.95
	Other	7.31E-06	7.23E-07	2.39E-05	5.75	8.58E-06	5.73E-07	3.01E-05	7.25
Valves	All	9.99E-07	9.55E-08	3.29E-06	5.87	1.03E-06	9.07E-08	3.46E-06	6.18
	Leak	2.28E-07	6.60E-09	8.72E-07	11.49	2.52E-07	5.93E-09	9.71E-07	12.80
	Plug	5.00E-08	3.47E-10	1.88E-07	22.40	6.58E-08	2.97E-10	2.36E-07	28.22
	Other	7.21E-07	5.36E-08	2.49E-06	6.81	7.53E-07	5.05E-08	2.64E-06	7.24
Gate	All	3.44E-06	8.45E-07	8.55E-06	3.18	3.61E-06	7.61E-07	9.49E-06	3.53
	Leak	3.06E-06	1.62E-06	5.11E-06	1.78	3.22E-06	1.31E-06	6.31E-06	2.19
	Plug	2.96E-06	2.19E-06	3.89E-06	1.33	3.26E-06	1.33E-06	6.37E-06	2.19
	Other	3.29E-06	1.00E-06	7.46E-06	2.73	3.46E-06	8.85E-07	8.44E-06	3.09
Ball	All	4.09E-06	6.51E-07	1.18E-05	4.26	4.30E-06	5.95E-07	1.29E-05	4.66
	Leak	3.18E-06	1.07E-06	6.87E-06	2.54	3.43E-06	8.79E-07	8.35E-06	3.08
	Plug	3.01E-06	1.80E-06	4.63E-06	1.60	3.28E-06	1.26E-06	6.62E-06	2.29
	Other	3.76E-06	6.84E-07	1.04E-05	3.91	3.98E-06	6.15E-07	1.16E-05	4.34
Globe	All	3.66E-06	5.88E-07	1.05E-05	4.23	4.02E-06	4.99E-07	1.24E-05	4.99
	Leak	3.05E-06	1.43E-06	5.49E-06	1.96	3.48E-06	9.50E-07	8.28E-06	2.95
	Plug	2.94E-06	2.54E-06	3.38E-06	1.15	4.98E-06	5.40E-07	1.59E-05	5.44
	Other	3.53E-06	6.72E-07	9.63E-06	3.79	3.88E-06	5.60E-07	1.15E-05	4.54
Solenoid	All	3.01E-06	1.87E-06	4.50E-06	1.55	3.88E-06	8.28E-07	1.02E-05	3.50
	Leak	2.94E-06	2.94E-06	2.94E-06	1.00	2.62E-05	9.40E-08	9.18E-05	31.26
	Plug	2.94E-06	2.94E-06	2.94E-06	1.00	2.62E-05	9.40E-08	9.18E-05	31.26
	Other	3.01E-06	1.87E-06	4.50E-06	1.55	3.88E-06	8.28E-07	1.02E-05	3.50
Misc	All	9.51E-06	2.01E-06	2.50E-05	3.52	1.01E-05	1.78E-06	2.83E-05	3.99
	Leak	4.48E-06	6.52E-07	1.33E-05	4.52	5.23E-06	5.04E-07	1.72E-05	5.84
	Plug	3.41E-06	7.55E-07	8.83E-06	3.42	4.41E-06	4.70E-07	1.42E-05	5.49
	Other	7.47E-06	1.45E-06	2.02E-05	3.74	8.07E-06	1.25E-06	2.35E-05	4.35
Needle	All	3.70E-06	6.61E-07	1.03E-05	3.95	4.57E-06	4.58E-07	1.49E-05	5.71
	Leak	3.19E-06	1.33E-06	6.16E-06	2.15	4.08E-06	7.19E-07	1.14E-05	3.99

Table C-1: Intermediate Values Calculated for ICPP failure Data

Component Type/ Instrument Group	Failure Mode	Reported Failure Rates				Basic Data			MODEL 1			
		λ	λ_m	EF	Standard Error	n (fails)	N (pop)	t* (mission time)	λ	$\lambda_{0.05}$	$\lambda_{0.95}$	DF_{χ^2}
Needle (Contd.)	Plug	2.62E-05	2.94E-06	31.26	1.83E-05	0	269	78288	1.09E-08	9.34E-11	9.12E-08	31.26
	Other	4.50E-06	2.45E-06	6.14	7.58E-06	13	269	78288	6.17E-07	3.83E-07	9.52E-07	1.58
OV	All	7.18E-06	3.53E-06	7.12	9.58E-06	51	176	78288	3.70E-06	2.92E-06	4.63E-06	1.26
	Leak	4.91E-06	2.70E-06	6.04	7.92E-06	15	176	78288	1.09E-06	7.00E-07	1.63E-06	1.53
	Plug	5.87E-06	2.91E-06	7.04	8.66E-06	1	176	78288	7.26E-08	1.28E-08	2.84E-07	4.71
	Other	6.11E-06	3.04E-06	6.97	8.83E-06	35	176	78288	2.54E-06	1.91E-06	3.33E-06	1.32
Butterfly	All	8.10E-06	4.95E-06	5.11	1.02E-05	58	143	78288	5.18E-06	4.15E-06	6.40E-06	1.24
	Leak	5.06E-06	3.15E-06	4.97	8.04E-06	18	143	78288	1.61E-06	1.08E-06	2.33E-06	1.47
	Plug	2.62E-05	2.94E-06	31.26	1.83E-05	0	143	78288	2.05E-08	1.76E-10	1.72E-07	31.26
	Other	6.74E-06	4.10E-06	5.16	9.28E-06	40	143	78288	3.57E-06	2.74E-06	4.60E-06	1.30
Three - Way	All	6.11E-06	3.42E-06	5.88	8.83E-06	26	130	78288	2.55E-06	1.83E-06	3.49E-06	1.38
	Leak	2.62E-05	2.94E-06	31.26	1.83E-05	0	130	78288	2.26E-08	1.93E-10	1.89E-07	31.26
	Plug	4.68E-06	2.87E-06	5.09	7.73E-06	4	130	78288	3.93E-07	1.63E-07	8.31E-07	2.26
	Other	5.81E-06	3.21E-06	5.99	8.62E-06	22	130	78288	2.16E-06	1.50E-06	3.03E-06	1.42
Ventilation	All	2.42E-05	1.22E-05	6.92	1.80E-05	305	195	75216	2.08E-05	1.89E-05	2.28E-05	1.10
	Belt	6.53E-06	2.94E-06	7.98	9.32E-06	39	195	75216	2.66E-06	2.03E-06	3.43E-06	1.30
	Leak	5.24E-06	2.66E-06	6.78	8.35E-06	18	195	75216	1.23E-06	8.21E-07	1.78E-06	1.47
	Rotor	5.94E-06	2.83E-06	7.42	8.88E-06	32	195	75216	2.18E-06	1.62E-06	2.89E-06	1.34
	Fail to Run	6.24E-06	2.71E-06	8.36	9.11E-06	34	195	75216	2.32E-06	1.73E-06	3.05E-06	1.33
	Other	1.57E-05	7.70E-06	7.15	1.45E-05	182	195	75216	1.24E-05	1.10E-05	1.40E-05	1.13
Vessels	All	6.70E-06	2.23E-06	11.48	9.34E-06	192	746	76848	3.35E-06	2.97E-06	3.77E-06	1.13
	Leak	3.81E-06	2.80E-06	3.63	7.04E-06	21	746	76848	3.66E-07	2.53E-07	5.17E-07	1.43
	Plug	3.94E-06	2.58E-06	4.55	7.16E-06	18	746	76848	3.14E-07	2.10E-07	4.55E-07	1.47
	Other	6.04E-06	2.13E-06	10.75	8.86E-06	153	746	76848	2.67E-06	2.33E-06	3.04E-06	1.14
Unit Heaters	All	1.09E-05	4.81E-06	8.25	1.19E-05	98	171	76944	7.45E-06	6.29E-06	8.77E-06	1.18
	Leak	5.03E-06	2.75E-06	6.08	8.45E-06	15	71	70464	1.14E-06	7.33E-07	1.71E-06	1.53
	Plug	5.23E-06	2.27E-06	8.38	8.61E-06	7	71	70464	5.32E-07	2.76E-07	9.50E-07	1.86
	Other	9.38E-06	3.95E-06	8.71	1.15E-05	76	71	70464	5.78E-06	4.77E-06	6.95E-06	1.21
Window, Cell	All	1.22E-05	5.30E-06	8.34	1.41E-05	30	72	61248	6.80E-06	4.99E-06	9.10E-06	1.35

Table C-1: Intermediate Values Calculated for ICPP Failure Data

Component Type/ Instrument Group		Failure Mode	MODEL II $\bar{\lambda}$	MODEL II $\bar{\lambda}_{0.05}$	MODEL II $\bar{\lambda}_{0.95}$	MODEL II EF	Adjusted Lognormal Distribution $\tilde{\lambda}$	Adjusted Lognormal Distribution $\tilde{\lambda}_{0.05}$	Adjusted Lognormal Distribution $\tilde{\lambda}_{0.95}$	Adjusted Lognormal Distribution EF
	Needle (Contd.)	Plug	2.94E-06	2.94E-06	2.94E-06	1.00	2.62E-05	9.40E-08	9.18E-05	31.26
		Other	3.45E-06	6.29E-07	9.54E-06	3.90	4.50E-06	3.99E-07	1.50E-05	6.14
	OV	All	6.14E-06	6.24E-07	1.99E-05	5.65	7.18E-06	4.95E-07	2.51E-05	7.12
		Leak	3.83E-06	6.82E-07	1.07E-05	3.96	4.91E-06	4.46E-07	1.63E-05	6.04
		Plug	2.99E-06	1.95E-06	4.34E-06	1.49	5.87E-06	4.13E-07	2.05E-05	7.04
		Other	5.08E-06	5.77E-07	1.61E-05	5.28	6.11E-06	4.37E-07	2.12E-05	6.97
	Butterfly	All	7.17E-06	1.20E-06	2.04E-05	4.12	8.10E-06	9.70E-07	2.53E-05	5.11
		Leak	4.14E-06	9.31E-07	1.06E-05	3.38	5.06E-06	6.32E-07	1.56E-05	4.97
		Plug	2.94E-06	2.94E-06	2.94E-06	1.00	2.62E-05	9.40E-08	9.18E-05	31.26
		Other	5.83E-06	1.03E-06	1.63E-05	3.98	6.74E-06	7.94E-07	2.12E-05	5.16
	Three - Way	All	5.04E-06	8.02E-07	1.46E-05	4.26	6.11E-06	5.81E-07	2.01E-05	5.88
		Leak	2.94E-06	2.94E-06	2.94E-06	1.00	2.62E-05	9.40E-08	9.18E-05	31.26
		Plug	3.24E-06	1.27E-06	6.47E-06	2.26	4.68E-06	5.64E-07	1.46E-05	5.09
		Other	4.72E-06	7.61E-07	1.36E-05	4.22	5.81E-06	5.36E-07	1.93E-05	5.99
Ventilation		All	2.27E-05	1.93E-06	7.65E-05	6.29	2.42E-05	1.76E-06	8.40E-05	6.92
		Belt	5.40E-06	4.80E-07	1.80E-05	6.13	6.53E-06	3.69E-07	2.35E-05	7.98
		Leak	4.10E-06	5.79E-07	1.23E-05	4.60	5.24E-06	3.93E-07	1.80E-05	6.78
		Rotor	4.86E-06	5.09E-07	1.57E-05	5.55	5.94E-06	3.81E-07	2.10E-05	7.42
		Fail to Run	5.08E-06	4.30E-07	1.71E-05	6.31	6.24E-06	3.24E-07	2.27E-05	8.36
		Other	1.44E-05	1.22E-06	4.87E-05	6.33	1.57E-05	1.08E-06	5.51E-05	7.15
Vessels		All	6.04E-06	2.19E-07	2.27E-05	10.19	6.70E-06	1.94E-07	2.56E-05	11.48
		Leak	3.29E-06	1.11E-06	7.10E-06	2.54	3.81E-06	7.72E-07	1.02E-05	3.63
		Plug	3.26E-06	8.34E-07	7.96E-06	3.09	3.94E-06	5.66E-07	1.17E-05	4.55
		Other	5.39E-06	2.26E-07	2.00E-05	9.41	6.04E-06	1.98E-07	2.29E-05	10.75
Unit Heaters		All	9.67E-06	6.88E-07	3.36E-05	6.99	1.09E-05	5.83E-07	3.97E-05	8.25
		Leak	3.92E-06	6.91E-07	1.10E-05	3.98	5.03E-06	4.53E-07	1.68E-05	6.08
		Plug	3.45E-06	5.02E-07	1.02E-05	4.52	5.23E-06	2.71E-07	1.90E-05	8.38
		Other	8.12E-06	5.47E-07	2.85E-05	7.21	9.38E-06	4.53E-07	3.44E-05	8.71
Window, Cell		All	9.78E-06	8.58E-07	3.27E-05	6.18	1.22E-05	6.36E-07	4.42E-05	8.34

Table C-1: Intermediate Values Calculated for ICPP failure Data

Component Type/ Instrument Group	Failure Mode	Reported Failure Rates				Basic Data			MODEL 1			
		$\bar{\lambda}$	$\bar{\lambda}_m$	EF	Standard Error	n (fails)	N (pop)	t* (mission time)	$\hat{\lambda}$	$\hat{\lambda}_{0.05}$	$\hat{\lambda}_{0.95}$	DF_{χ^2}
Analysis Loop	Drift	3.67E-05	2.35E-05	4.70	3.50E-06	97	50	75366	3.25E-05	2.74E-05	3.83E-05	1.18
	Fail	1.47E-05	8.75E-06	5.33	2.22E-06	24	50	75366	8.04E-06	5.68E-06	1.11E-05	1.40
Density Loop	Drift	2.81E-05	2.31E-05	2.78	2.47E-06	123	73	62917	2.68E-05	2.31E-05	3.10E-05	1.16
	Fail	1.13E-05	7.83E-06	4.09	1.57E-06	35	73	62917	7.63E-06	5.73E-06	9.99E-06	1.32
Diff Press	Drift	1.75E-05	1.34E-05	3.32	3.19E-06	26	24	65943	1.51E-05	1.08E-05	2.06E-05	1.38
	Fail	1.41E-05	8.92E-06	4.85	2.86E-06	15	24	65943	8.69E-06	5.59E-06	1.30E-05	1.53
Flow, Gas	Drift	4.04E-05	3.13E-05	3.24	6.29E-06	38	18	52931	3.72E-05	2.83E-05	4.82E-05	1.31
	Fail	2.73E-05	1.39E-05	6.77	5.17E-06	21	18	52931	2.05E-05	1.42E-05	2.90E-05	1.43
Flow, Liquid	Drift	3.22E-05	1.64E-05	6.78	1.09E-05	7	4	60057	2.59E-05	1.35E-05	4.63E-05	1.86
	Fail	3.26E-05	2.16E-05	4.44	1.10E-05	6	4	60057	2.22E-05	1.09E-05	4.14E-05	1.95
Level Loop	Drift	5.05E-05	3.50E-05	4.09	4.75E-06	100	43	53626	4.47E-05	3.78E-05	5.25E-05	1.18
	Fail	8.93E-06	5.73E-06	4.70	2.00E-06	9	43	53626	4.02E-06	2.26E-06	6.73E-06	1.73
Pressure	Drift	2.28E-05	1.80E-05	3.10	6.79E-06	9	11	45005	1.82E-05	1.02E-05	3.05E-05	1.73
	Fail	1.71E-05	6.25E-06	10.33	5.88E-06	2	11	45005	4.05E-06	1.16E-06	1.12E-05	3.11
Pulse	Drift	4.97E-05	2.58E-05	6.58	1.94E-05	4	3	44184	3.02E-05	1.25E-05	6.38E-05	2.26
	Fail	3.58E-05	8.08E-06	17.08	5.96E-03	1	3	44184	7.54E-06	1.33E-06	2.95E-05	4.71
Radiation, Criticality	Drift	5.60E-05	4.69E-05	2.66	4.74E-06	141	52	44430	5.66E-05	4.92E-05	6.49E-05	1.15
	Fail	2.26E-05	1.50E-05	4.45	3.01E-06	45	52	44430	1.81E-05	1.40E-05	2.29E-05	1.28
Radiation, General	Drift	3.82E-05	2.32E-05	5.19	3.02E-06	143	86	52322	3.40E-05	2.96E-05	3.90E-05	1.15
	Fail	3.80E-05	3.39E-05	2.19	3.01E-06	27	86	52322	6.43E-06	4.64E-06	8.73E-06	1.37
Temp Loop	Drift	2.39E-05	1.73E-05	3.76	4.56E-06	24	17	66747	2.09E-05	1.48E-05	2.89E-05	1.40S
	Fail	2.24E-05	1.42E-05	4.77	4.41E-06	18	17	66747	1.57E-05	1.05E-05	2.27E-05	1.47
Vibration Loop	Drift	5.00E-05	3.37E-05	4.32	1.12E-05	16	6	65519	4.01E-05	2.61E-05	5.94E-05	1.51
	Fail	3.11E-05	1.27E-05	9.07	8.83E-06	10	6	65519	2.50E-05	1.45E-05	4.09E-05	1.68

Table C-1: Intermediate Values Calculated for ICPP Failure Data

Component Type/ Instrument Group	Failure Mode	MODEL II				Adjusted Lognormal Distribution			
		$\bar{\lambda}$	$\bar{\lambda}_{0.05}$	$\bar{\lambda}_{0.95}$	EF	$\tilde{\lambda}$	$\tilde{\lambda}_{0.05}$	$\tilde{\lambda}_{0.95}$	EF
Analysis Loop	Drift	3.35E-05	5.91E-06	9.37E-05	3.98	3.67E-05	5.01E-06	1.11E-04	4.70
	Fail	1.22E-05	2.29E-06	3.34E-05	3.81	1.47E-05	1.64E-06	4.66E-05	5.33
Density Loop	Drift	2.66E-05	9.65E-06	5.55E-05	2.40	2.81E-05	8.32E-06	6.43E-05	2.78
	Fail	9.92E-06	2.53E-06	2.43E-05	3.10	1.13E-05	1.92E-06	3.20E-05	4.09
Diff Press	Drift	1.55E-05	5.58E-06	3.24E-05	2.41	1.75E-05	4.05E-06	4.47E-05	3.32
	Fail	1.14E-05	2.81E-06	2.83E-05	3.17	1.41E-05	1.84E-06	4.32E-05	4.85
Flow, Gas	Drift	3.65E-05	1.26E-05	7.77E-05	2.48	4.04E-05	9.69E-06	1.01E-04	3.24
	Fail	2.17E-05	2.93E-06	6.57E-05	4.73	2.73E-05	2.05E-06	9.40E-05	6.77
Flow, Liquid	Drift	2.23E-05	4.48E-06	5.98E-05	3.65	3.22E-05	2.41E-06	1.11E-04	6.78
	Fail	2.45E-05	9.48E-06	4.93E-05	2.28	3.26E-05	4.86E-06	9.60E-05	4.44
Level Loop	Drift	4.66E-05	1.01E-05	1.21E-04	3.47	5.05E-05	8.55E-06	1.43E-04	4.09
	Fail	6.90E-06	2.10E-06	1.56E-05	2.73	8.93E-06	1.22E-06	2.70E-05	4.70
Pressure	Drift	1.92E-05	1.00E-05	3.23E-05	1.79	2.28E-05	5.82E-06	5.58E-05	3.10
	Fail	8.15E-06	1.88E-06	2.08E-05	3.32	1.71E-05	6.05E-07	6.45E-05	10.33
Pulse	Drift	3.19E-05	8.85E-06	7.53E-05	2.92	4.97E-05	3.92E-06	1.70E-04	6.58
	Fail	1.10E-05	2.23E-06	2.93E-05	3.62	3.58E-05	4.73E-07	1.38E-04	17.08
Radiation, Criticality	Drift	5.34E-05	2.03E-05	1.09E-04	2.32	5.60E-05	1.76E-05	1.25E-04	2.66
	Fail	2.00E-05	4.31E-06	5.22E-05	3.48	2.26E-05	3.37E-06	6.67E-05	4.45
Radiation, General	Drift	3.53E-05	5.11E-06	1.05E-04	4.53	3.82E-05	4.46E-06	1.20E-04	5.19
	Fail	3.53E-05	2.13E-05	5.40E-05	1.59	3.80E-05	1.55E-05	7.41E-05	2.19
Temp Loop	Drift	2.07E-05	6.42E-06	4.65E-05	2.69	2.39E-05	4.59E-06	6.50E-05	3.76
	Fail	1.84E-05	4.04E-06	4.62E-05	3.24	2.24E-05	2.99E-06	6.80E-05	4.77
Vibration Loop	Drift	4.14E-05	1.18E-05	9.65E-05	2.87	5.00E-05	7.80E-06	1.46E-04	4.32
	Fail	2.15E-05	2.35E-06	6.85E-05	5.40	3.11E-05	1.40E-06	1.15E-04	9.07

APPENDIX D

APPENDIX D

GENERIC EQUIPMENT FAILURE DATABASE

Appendix D contains generic failure rates. These failure rates are for equipment items or failure modes not studied. The tables in Appendix D are taken from a Westinghouse Savannah River report, "Savannah River Site Generic Database Development."[1]

Table D-1. Water System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Water Valve (Standby or Safety) Manual Fails to open/close	XVM-CC-W or XVM-OO-W	3.0E-4/d	10
Plugs	XVM-PG-W	5.0E-8/h	10
Leakage (internal)	XVM-LI-W	1.0E-6/h	10
Rupture (internal)	XVM-RI-W	5.0E-8/h	30
Leakage (external)	XVM-LE-W	1.0E-8/h	10
Rupture (external)	XVM-RE-W	5.0E-10/h	30
Check Fails to open	CKV-CC-W	5.0E-5/d	10
Fails to close	CKV-OO-W	1.0E-3/d	5
Plugs	CKV-PG-W	5.0E-8/h	10
Leakage (internal)	CKV-LI-W	1.0E-6/h	10
Rupture (internal)	CKV-RI-W	5.0E-8/h	30
Leakage (external)	CKV-LE-W	1.0E-8/h	10
Rupture (external)	CKV-RE-W	5.0E-10/h	30
Motor-Operated Fails to open/close	MOV-CC-W or MOV-OO-W	3.0E-3/d	5
Spurious operation	MOV-CO-W or MOV-OC-W	3.0E-7/h	5
Plugs	MOV-PG-W	5.0E-8/h	10
Leakage (internal)	MOV-LI-W	1.0E-6/h	10
Rupture (internal)	MOV-RI-W	5.0E-8/h	30
Leakage (external)	MOV-LE-W	1.0E-8/h	10
Rupture (external)	MOV-RE-W	5.0E-10/h	30
Air-Operated Fails to open/close	AOV-CC-W or AOV-OO-W	1.0E-3/d	30
Spurious operation	AOV-CO-W or AOV-OC-W	1.0E-6/h	5
Plugs	AOV-PG-W	5.0E-8/h	10

Table D-1. (Contd.) Water System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Water Valve (Standby or Safety) Manual Fails to open/close	XVM-CC-W or XVM-OO-W	3.0E-4/d	10
Leakage (internal)	AOV-LI-W	1.0E-6/h	10
Rupture (internal)	AOV-RI-W	5.0E-8/h	30
Leakage (external)	AOV-LE-W	1.0E-8/h	10
Rupture (external)	AOV-RE-W	5.0E-10/h	30
Solenoid-Operated Fails to open/close	SOV-CC-W or SOV-OO-W	1.0E-3/d	10
Spurious operation	SOV-CO-W or SOV-OC-W	5.0E-7/h	10
Plugs	SOV-PG-W	5.0E-8/h	10
Leakage (internal)	SOV-LI-W	1.0E-6/h	10
Rupture (internal)	SOV-RI-W	5.0E-8/h	30
Leakage (external)	SOV-LE-W	1.0E-8/h	10
Rupture (external)	SOV-RE-W	5.0E-10/h	30
Safety/Relief Fails to open	SRV-CC-W	3.0E-3/d	3
Fails to reclose	SRV-OO-W	3.0E-3/d	3
Leakage (internal)	SRV-LI-W	1.0E-6/h	10
Rupture (internal)	SRV-RI-W	5.0E-8/h	30
Leakage (external)	SRV-LE-W	1.0E-8/h	10
Rupture (external)	SRV-RE-W	5.0E-10/h	30
Vacuum-Breaker Fails to open	VBV-CC-W	1.0E-2/d	10
Fails to reclose	VBV-OO-W	1.0E-2/d	10
Leakage (internal)	VBV-LI-W	1.0E-6/h	10
Rupture (internal)	VBV-RI-W	5.0E-8/h	30
Leakage (external)	VBV-LE-W	1.0E-8/h	10

Table D-1. (Contd.) Water System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Water Valve (Standby or Safety) Manual Fails to open/close	XVM-CC-W or XVM-OO-W	3.0E-4/d	10
Rupture (external)	VBV-RE-W	5.0E-10/h	30
Explosive Fails to open	EXV-CC-W	1.0E-4/d	10
Leakage (internal)	EXV-LI-W	1.0E-6/h	10
Rupture (internal)	EXV-RI-W	5.0E-8/h	30
Leakage (external)	EXV-LE-W	1.0E-8/h	10
Rupture (external)	EXV-RE-W	5.0E-10/h	30
Valve (Control) Motor-Operated Fails open	CMV-FO-W	3.0E-6/h	10
Fails closed	CMV-FC-W	3.0E-6/h	10
Fails to respond	CMV-NR-W	3.0E-6/h	10
Plugs	CMV-PG-W	5.0E-8/h	10
Leakage (external)	CMV-LE-W	1.0E-8/h	10
Rupture (external)	CMV-RE-W	5.0E-10/h	30
Air-Operated Fails open	CAV-FO-W	3.0E-6/h	10
Fails closed	CAV-FC-W	3.0E-6/h	10
Fails to respond	CAV-NR-W	3.0E-6/h	10
Plugs	CAV-PG-W	5.0E-8/h	10
Leakage (external)	CAV-LE-W	1.0E-8/h	10
Rupture (external)	CAV-RE-W	5.0E-10/h	30
Solenoid-Operated Fails open	CSV-FO-W	3.0E-6/h	10
Fails closed	CSV-FC-W	3.0E-6/h	10
Fails to respond	CSV-FO-W	3.0E-6/h	10

Table D-1. (Contd.) Water System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Water Valve (Standby or Safety) Manual Fails to open/close	XVM-CC-W or XVM-OO-W	3.0E-4/d	10
Plugs	CSV-PG-W	5.0E-8/h	10
Leakage (external)	CSV-LE-W	1.0E-8/h	10
Rupture (external)	CSV-RE-W	5.0E-10/h	30
Pump Motor-Driven Fails to start	MDP-FS-W	3.0E-3/d	5
Fails to run	MDP-FR-W	3.0E-5/h	10
Overspeed	MDP-OS-W	5.0E-6/h	10
Fails to stop	MDP-NS-W	3.0E-3/d	5
Leakage (external)	MDP-LE-W	3.0E-8/h	10
Rupture (external)	MDP-RE-W	1.0E-9/h	30
Turbine-Driven Fails to start	TDP-FS-W	3.0E-2/d	3
Fails to run	TDP-FR-W	1.0E-4/h	30
Overspeed	TDP-OS-W	3.0E-5/h	10
Fails to stop	TDP-NS-W	3.0E-2/d	3
Leakage (external)	TDP-LE-W	3.0E-8/h	10
Rupture (external)	TDP-RE-W	1.0E-9/h	30
Diesel-Driven Fails to start	DDP-FS-W	1.0E-2/d	5
Fails to run	DDP-FR-W	5.0E-3/h	5
Overspeed	DDP-OS-W	1.0E-3/h	5
Fails to stop	DDP-NS-W	1.0E-2/d	5
Leakage (external)	DDP-LE-W	3.0E-8/h	10
Rupture (external)	DDP-RE-W	1.0E-9/h	30

Table D-1. (Contd.) Water System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Water Valve (Standby or Safety) Manual Fails to open/close	XVM-CC-W or XVM-OO-W	3.0E-4/d	10
Piping/Hose/Jumper Piping Leakage (external)	PIP-LE-W	3.0E-9/h-ft	10
Rupture (external)	PIP-RE-W	1.0E-10/h-ft	30
Plugs	PIP-PF-W	1.0E-10/h-ft	30
Hose Leakage (external)	HOS-LE-W	1.0E-9/h-ft	10
Rupture (external)	HOS-RE-W	1.0E-8/h-ft	10
Plugs	HOS-PG-W	1.0E-8/h-ft	10
Jumper Leakage (external)	JPR-LE-W	1.0E-6/h	10
Rupture (external)	JPR-RE-W	1.0E-8/h	30
Plugs	JPR-PG-W	5.0E-8/h	10
Vessel Tank (Unpressurized) Leakage (external)	TKU-LE-W	1.0E-8/h	10
Rupture (external)	TKU-RE-W	5.0E-10/h	30
Tank (Pressurized) Leakage (external)	TKP-LE-W	1.0E-8/h	10
Rupture (external)	TKP-RE-W	5.0E-10/h	30
Flange/Gasket Leakage (external)	FLG-LE-W	1.0E-8/h	10
Rupture (external)	FLG-RE-W	1.0E-10/h	30
Heat Exchanger Shell/Tube Fouling (tubes)	HTX-FL-W	1.0E-7/h	10
Plugs (tubes)	HTX-PG-W	3.0E-8/h	10

Table D-1. (Contd.) Water System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Water Valve (Standby or Safety) Manual Fails to open/close	XVM-CC-W or XVM-OO-W	3.0E-4/d	10
Leakage (tubes)	HTX-LI-W	1.0E-7/h	10
Rupture (tubes)	HTX-RI-W	5.0E-9/h	30
Leakage (shell)	HTX-LE-W	1.0E-8/h	10
Rupture (shell)	HTX-RE-W	5.0E-10/h	30
Heater (Electrical) Fails to heat	HTE-FH-W	1.0E-6/h	10
Overheats	HTE-OH-W	3.0E-7/h	10
Leakage (external)	HTE-LE-W	1.0E-7/h	10
Rupture (external)	HTE-RE-W	5.0E-9/h	30
Strainer/Filter Plugs	FLT-PG-W	3.0E-6/h	10
Leakage (internal)	FLT-LI-W	3.0E-6/h	10
Rupture (internal)	FLT-RI-W	5.0E-7/h	10
Orifice Plugs	ORF-PG-W	1.0E-6/h	3
Miscellaneous Travelling Screen Plugs	TRS-PG-W	5.0E-7/h	10

a. Modifications of the recommended mean for hourly failure rates may be appropriate for components subjected to hostile radioactive or chemical environments.

b. Error factor is the 95th percentile/50th percentile.

Table D-2. Chemical Process System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Chemical Process Valve (Standby or Safety) Manual Fails to open/close	XVM-CC-C or XVM-OO-C	3.0E-4/d	10
Plugs	XVM-PG-C	5.0E-8/h	10
Leakage (internal)	XVM-LI-C	1.0E-6/h	10
Rupture (internal)	XVM-RI-C	5.0E-8/h	30
Leakage (external)	XVM-LE-C	5.0E-7/h	10
Rupture (external)	XVM-RE-C	3.0E-8/h	30
Check Fails to open	CKV-CC-C	5.0E-5/d	10
Fails to close	CKV-OO-C	1.0E-3/d	10
Plugs	CKV-PG-C	5.0E-8/h	10
Leakage (internal)	CKV-LI-C	1.0E-6/h	10
Rupture (internal)	CKV-RI-C	5.0E-8/h	30
Leakage (external)	CKV-LE-C	5.0E-7/h	10
Rupture (external)	CKV-RE-C	3.0E-8/h	30
Motor-Operated Fails to open/close	MOV-CC-C or MOV-OO-C	3.0E-3/d	10
Spurious operation	MOV-CO-C or MOV-OC-C	3.0E-7/h	10
Plugs	MOV-PG-C	5.0E-8/h	10
Leakage (internal)	MOV-LI-C	1.0E-6/h	10
Rupture (internal)	MOV-RI-C	5.0E-8/h	10
Leakage (external)	MOV-LE-C	5.0E-7/h	10
Rupture (external)	MOV-RE-C	3.0E-8/h	30
Air-Operated Fails to open/close	AOV-CC-C or AOV-OO-C	1.0E-3/d	30

Table D-2. (Contd.) Chemical Process System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Chemical Process Valve (Standby or Safety) Manual Fails to open/close	XVM-CC-C or XVM-OO-C	3.0E-4/d	10
Spurious operation	AOV-CO-C or AOV-OC-C	1.0E-6/h	10
Plugs	AVO-CO-C or AOV-OC-C	5.0E-8/h	10
Leakage (internal)	AOV-LI-C	1.0E-6/h	10
Rupture (internal)	AOV-RI-C	5.0E-8/h	30
Leakage (external)	AOV-LE-C	5.0E-7/h	10
Rupture (external)	AOV-RE-C	3.0E-8/h	30
Solenoid-Operated Fails to open/close	SOV-CC-C or SOV-OO-C	1.0E-3/d	10
Spurious operation	SOV-CO-C or SOV-OC-C	5.0E-7/h	10
Plugs	SOV-PG-C	5.0E-8/h	10
Leakage (internal)	SOV-LI-C	1.0E-6/h	10
Rupture (internal)	SOV-RI-C	5.0E-8/h	30
Leakage (external)	SOV-LE-C	5.0E-7/h	10
Rupture (external)	SOV-RE-C	3.0E-8/h	30
Safety/Relief Fails to open	SRV-CC-C	3.0E-3/d	10
Fails to reclose	SRV-OO-C	3.0E-3/d	10
Leakage (internal)	SRV-LI-C	1.0E-6/h	10
Rupture (internal)	SRV-RI-C	5.0E-8/h	30
Leakage (external)	SRV-LE-C	5.0E-7/h	10
Rupture (external)	SRV-RE-C	3.0E-8/h	30

Table D-2. (Contd.) Chemical Process System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Chemical Process Valve (Standby or Safety) Manual Fails to open/close	XVM-CC-C or XVM-OO-C	3.0E-4/d	10
Vacuum-Breaker Fails to open	VBV-CC-C	1.0E-2/d	10
Fails to reclose	VBV-OO-C	1.0E-2/d	10
Leakage (internal)	VBV-LI-C	1.0E-6/h	10
Rupture (internal)	VBV-RI-C	5.0E-8/h	30
Leakage (external)	VBV-LE-C	5.0E-7/h	10
Rupture (external)	VBV-RE-C	3.0E-8/h	30
Explosive Fails to open	EXV-CC-C	1.0E-4/d	10
Leakage (internal)	EXV-LI-C	1.0E-6/h	10
Rupture (internal)	EXV-RI-C	5.0E-8/h	10
Leakage (external)	EXV-LE-C	5.0E-7/h	10
Rupture (external)	EXV-RE-C	3.0E-8/h	30
Valve (Control) Motor-Operated Fails open	CMV-FO-C	3.0E-6/h	10
Fails closed	CMV-FC-C	3.0E-6/h	10
Fails to respond	CMV-NR-C	3.0E-6/h	10
Plugs	CMV-PG-C	5.0E-8/h	10
Leakage (external)	CMV-LE-C	5.0E-7/h	10
Rupture (external)	CMV-RE-C	3.0E-8/h	30
Air-Operated Fails open	CAV-FO-C	3.0E-6/h	10
Fails closed	CAV-FC-C	3.0E-6/h	10
Fails to respond	CAV-NR-C	3.0E-6/h	10
Plugs	CAV-PG-C	5.0E-8/h	10

Table D-2. (Contd.) Chemical Process System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Chemical Process Valve (Standby or Safety) Manual Fails to open/close	XVM-CC-C or XVM-OO-C	3.0E-4/d	10
Leakage (external)	CAV-LE-C	5.0E-7/h	10
Rupture (external)	CAV-RE-C	3.0E-8/h	30
Solenoid-Operated Fails open	CSV-FO-C	3.0E-6/h	10
Fails closed	CSV-FC-C	3.0E-6/h	10
Fails to respond	CSV-NR-C	3.0E-6/h	10
Plugs	CSV-PG-C	5.0E-8/h	10
Leakage (external)	CSV-LE-C	5.0E-7/h	10
Rupture (external)	CSV-RE-C	3.0E-8/h	30
Pump Motor-Driven Fails to start	MDP-FS-C	1.0E-2/d	10
Fails to run	MDP-FR-C	1.0E-4/h	10
Overspeed	MDP-OS-C	3.0E-5/h	10
Fails to stop	MDP-NS-C	1.0E-2/d	10
Leakage (external)	MDP-LE-C	1.0E-6/h	10
Rupture (external)	MDP-RE-C	5.0E-8/h	30
Turbine-Driven Fails to start	TDP-FS-C	3.0E-2/d	10
Fails to run	TDP-FR-C	1.0E-4/h	30
Overspeed	TDP-OS-C	3.0E-5/h	10
Fails to stop	TDP-NS-C	3.0E-2/d	10
Leakage (external)	TDP-LE-C	1.0E-6/h	10
Rupture (external)	TDP-RE-C	5.0E-8/h	30
Diesel-Driven Fails to start	DDP-FS-C	1.0E-2/d	10

Table D-2. (Contd.) Chemical Process System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Chemical Process Valve (Standby or Safety) Manual Fails to open/close	XVM-CC-C or XVM-OO-C	3.0E-4/d	10
Fails to run	DDP-FR-C	5.0E-3/h	10
Overspeed	DDP-OS-C	1.0E-3/h	10
Fails to stop	DDP-NS-C	1.0E-2/d	10
Leakage (external)	DDP-LE-C	1.0E-6/h	10
Rupture (external)	DDP-RE-C	5.0E-8/h	30
Piping/Hose/Jumper Piping Leakage (external)	PIP-LE-C	3.0E-9/h-ft	10
Rupture (external)	PIP-RE-C	1.0E-10/h-ft	30
Plugs	PIP-PG-C	1.0E-10/h-ft	30
Hose Leakage (external)	HOS-LE-C	1.0E-9/h-ft	10
Rupture (external)	HOS-RE-C	1.0E-8/h-ft	10
Plugs	HOS-PG-C	1.0E-8/h-ft	10
Jumper Leakage (external)	JPR-LE-C	1.0E-6/h	10
Rupture (external)	JPR-RE-C	1.0E-8/h	30
Plugs	JPR-PG-C	5.0E-8/h	10
Vessel Tank (Unpressurized) Leakage (external)	TKU-LE-C	1.0E-7/h	10
Rupture (external)	TKU-RE-C	5.0E-9/h	30
Tank (Pressurized) Leakage (external)	TKP-LE-C	1.0E-7/h	10
Rupture (external)	TKP-RE-C	5.0E-9/h	30

Table D-2. (Contd.) Chemical Process System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Chemical Process Valve (Standby or Safety) Manual Fails to open/close	XVM-CC-C or XVM-OO-C	3.0E-4/d	10
Flange/Gasket Leakage (external)	FLG-LE-C	1.0E-7/h	10
Rupture (external)	FLG-RE-C	1.0E-9/h	10
Heat Exchanger Shell/Tube Fouling (tubes)	HTX-FL-C	1.0E-6/h	10
Plugs (tubes)	HTX-PG-C	3.0E-7/h	10
Leakage (tubes)	HTX-LI-C	1.0E-6/h	10
Rupture (tubes)	HTX-RI-C	5.0E-8/h	30
Leakage (shell)	HTX-LE-C	1.0E-7/h	10
Rupture (shell)	HTX-RE-C	5.0E-9/h	30
Heater (Electrical) Fails to heat	HTE-FH-C	1.0E-5/h	10
Overheats	HTE-OH-C	3.0E-6/h	10
Leakage (external)	HTE-LE-C	1.0E-6/h	10
Rupture (external)	HTE-RE-C	5.0E-8/h	30
Strainer/Filter Plugs	FLT-PG-C	3.0E-6/h	10
Leakage (internal)	FLT-LI-C	3.0E-6/h	10
Rupture (internal)	FLT-RI-C	5.0E-7/h	10
Orifice Plugs	ORF-PG-C	1.0E-6/h	10
Miscellaneous Mixer/Blender Failure	MIX-FA-C	5.0E-6/h	10
Agitator Failure	AGI-FA-C	5.0E-6/h	10

Table D-2. (Contd.) Chemical Process System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Chemical Process Valve (Standby or Safety) Manual Fails to open/close	XVM-CC-C or XVM-OO-C	3.0E-4/d	10
Centrifuge Failure	CTF-FA-C	5.0E-6/h	10

a. Modifications of the recommended mean for hourly failure rates may be appropriate for components subjected to hostile radioactive or chemical environments.

b. Error factor is the 95th percentile/50th percentile.

Table D-3. Compressed Gas System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Compressed Gas Valve (Standby or Safety) Manual Fails to open/close	XVM-CC-G or XVM-OO-G	1.0E-3/d	10
Plugs	XVM-PG-G	5.0E-7/h	10
Leakage (internal)	XVM-LI-G	1.0E-5/h	10
Rupture (internal)	XVM-RI-G	5.0E-7/h	30
Leakage (external)	XVM-LE-G	1.0E-7/h	10
Rupture (external)	XVM-RE-G	5.0E-9/h	30
Check Fails to open	CKV-CC-G	1.0E-4/d	10
Fails to close	CKV-OO-G	3.0E-3/d	10
Plugs	CKV-PG-G	5.0E-7/h	10
Leakage (internal)	CKV-LI-G	1.0E-5/h	10
Rupture (internal)	CKV-RI-G	5.0E-7/h	30
Leakage (external)	CKV-LE-G	1.0E-7/h	10
Rupture (external)	CKV-RE-G	5.0E-9/h	30
Motor-Operated Fails to open/close	MOV-CC-G or MOV-OO-G	1.0E-2/d	10
Spurious operation	MOV-CO-G or MOV-OC-G	3.0E-7/h	10
Plugs	MOV-PG-G	5.0E-7/h	10
Leakage (internal)	MOV-LI-G	1.0E-5/h	10
Rupture (internal)	MOV-RI-G	5.0E-7/h	30
Leakage (external)	MOV-LE-G	1.0E-7/h	10
Rupture (external)	MOV-RE-G	5.0E-9/h	30
Air-Operated Fails to open/close	AOV-CC-G or AOV-OO-G	3.0E-3/d	30

Table D-3. (Contd.) Compressed Gas System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Compressed Gas Valve (Standby or Safety) Manual Fails to open/close	XVM-CC-G or XVM-OO-G	1.0E-3/d	10
Spurious operation	AOV-CO-G or AOV-OC-G	1.0E-6/h	10
Plugs	AOV-PG-G	5.0E-7/h	10
Leakage (internal)	AOV-LI-G	1.0E-5/h	10
Rupture (internal)	AOV-RI-G	5.0E-7/h	30
Leakage (external)	AOV-LE-G	1.0E-7/h	10
Rupture (external)	AOV-RE-G	5.0E-9/h	30
Solenoid-Operated Fails to open/close	SOV-CC-G or SOV-OO-G	3.0E-3/d	10
Spurious operation	SOV-CO-G or SOV-OC-G	5.0E-7/h	10
Plugs	SOV-PG-G	5.0E-7/h	10
Leakage (internal)	SOV-LI-G	1.0E-5/h	10
Rupture (internal)	SOV-RI-G	5.0E-7/h	30
Leakage (external)	SOV-LE-G	1.0E-7/h	10
Rupture (external)	SOV-RE-G	5.0E-9/h	30
Safety/Relief Fails to open	SRV-CC-G	1.0E-2/d	10
Fails to reclose	SRV-OO-G	1.0E-2/d	10
Leakage (internal)	SRV-LI-G	1.0E-5/h	10
Rupture (internal)	SRV-RI-G	5.0E-7/h	30
Leakage (external)	SRV-LE-G	1.0E-7/h	10
Rupture (external)	SRV-RE-G	5.0E-9/h	30
Vacuum-Breaker Fails to open	VBV-CC-G	3.0E-2/d	10

Table D-3. (Contd.) Compressed Gas System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal) Mean[a]	Error Factor[b]
Compressed Gas Valve (Standby or Safety) Manual Fails to open/close	XVM-CC-G or XVM-OO-G	1.0E-3/d	10
Fails to reclose	VBV-OO-G	3.0E-2/d	10
Leakage (internal)	VBV-LI-G	1.0E-5/h	10
Rupture (internal)	VBV-RI-G	5.0E-7/h	30
Leakage (external)	VBV-LE-G	1.0E-7/h	10
Rupture (external)	VBV-RE-G	5.0E-9/h	30
Valve (Control) Motor-Operated Fails open	CMV-FO-G	3.0E-6/h	10
Fails closed	CMV-FC-G	3.0E-6/h	10
Fails to respond	CMV-NR-G	3.0E-6/h	10
Plugs	CMV-PG-G	5.0E-7/h	10
Leakage (external)	CMV-LE-G	1.0E-7/h	10
Rupture (external)	CMV-RE-G	5.0E-9/h	30
Air-Operated Fails open	CAV-FO-G	3.0E-6/h	10
Fails closed	CAV-FC-G	3.0E-6/h	10
Fails to respond	CAV-NR-G	3.0E-6/h	10
Plugs	CAV-PG-G	5.0E-7/h	10
Leakage (external)	CAV-LE-G	1.0E-7/h	10
Rupture (external)	CAV-RE-G	5.0E-9/h	30
Solenoid-Operated Fails open	CSV-FO-G	3.0E-6/h	10
Fails closed	CSV-FC-G	3.0E-6/h	10
Fails to respond	CSV-NR-G	3.0E-6/h	10
Plugs	CSV-PG-G	5.0E-7/h	10

Table D-3. (Contd.) Compressed Gas System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Compressed Gas Valve (Standby or Safety) Manual Fails to open/close	XVM-CC-G or XVM-OO-G	1.0E-3/d	10
Leakage (external)	CSV-LE-G	1.0E-7/h	10
Rupture (external)	CSV-RE-G	5.0E-9/h	30
Compressor Motor-Driven Fails to start	MDC-FS-G	5.0E-3/d	5
Fails to run	MDC-FR-G	5.0E-5/h	3
Overspeed	MDC-OS-G	1.0E-5/h	5
Fails to stop	MDC-NS-G	5.0E-3/d	5
Leakage (external)	MDC-LE-G	3.0E-7/h	10
Rupture (external)	MDC-RE-G	1.0E-8/h	30
Piping/Hose/Jumper/Tube Piping Leakage (external)	PIP-LE-G	3.0E-8/h-ft	10
Rupture (external)	PIP-RE-G	1.0E-9/h-ft	30
Plugs	PIP-PG-G	1.0E-9/h-ft	30
Hose Leakage (external)	HOS-LE-G	1.0E-8/h-ft	10
Rupture (external)	HOS-RE-G	1.0E-7/h-ft	10
Plugs	HOS-PG-G	1.0E-7/h-ft	10
Jumper Leakage (external)	JPR-LE-G	1.0E-5/h	10
Rupture (external)	JPR-RE-G	1.0E-7/h	30
Plugs	JPR-PG-G	1.0E-7/h	30

Table D-3. (Contd.) Compressed Gas System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Compressed Gas Valve (Standby or Safety) Manual Fails to open/close	XVM-CC-G or XVM-OO-G	1.0E-3/d	10
Tube Leakage (external)	TUB-LE-G	3.0E-7/h-ft	10
Rupture (external)	TUB-RE-G	1.0E-8/h-ft	30
Plugs	TUB-PG-G	1.0E-8/h-ft	30
Vessel Tank (Pressurized) Leakage (external)	TKP-LE-G	1.0E-7/h	10
Rupture (external)	TKP-RE-G	5.0E-9/h	30
Cylinder (Pressurized) Leakage (external)	CYL-LE-G	1.0E-7/h	10
Rupture (external)	CYL-RE-G	5.0E-9/h	30
Flange/Gasket Leakage (external)	FLG-LE-G	1.0E-7/h	10
Rupture (external)	FLG-RE-G	1.0E-9/h	10
Heat Exchanger Shell/Tube Fouling (tubes)	HTX-FL-G	1.0E-5/h	10
Plugs (tubes)	HTX-PG-G	3.0E-6/h	10
Leakage (tubes)	HTX-LI-G	1.0E-5/h	10
Rupture (tubes)	HTX-RI-G	5.0E-7/h	30
Leakage (shell)	HTX-LE-G	1.0E-6/h	10
Rupture (shell)	HTX-RE-G	5.0E-8/h	30
Heater (Electrical) Fails to heat	HTE-FH-G	1.0E-6/h	10
Overheats	HTE-OH-G	3.0E-7/h	10
Leakage (external)	HTE-LE-G	1.0E-6/h	10

Table D-3. (Contd.) Compressed Gas System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Compressed Gas Valve (Standby or Safety) Manual Fails to open/close	XVM-CC-G or XVM-OO-G	1.0E-3/d	10
Rupture (external)	HTE-RE-G	5.0E-8/h	30
Vaporizer Failure	VAP-FA-G	1.0E-4/h	10
Air Dryer Failure	ADR-FA-G	5.0E-6/h	10
Filter Plugs	FLT-PG-G	3.0E-6/h	10
Leakage (internal)	FLT-LI-G	3.0E-6/h	10
Rupture (internal)	FLT-RI-G	5.0E-7/h	10
Orifice Plugs	ORF-PG-G	1.0E-6/h	10

a. Modifications of the recommended mean for hourly failure rates may be appropriate for components subjected to hostile radioactive or chemical environments.

b. Error factor is the 95th percentile/50th percentile.

Table D-4. HVAC/Exhaust System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
HVAC/Exhaust Damper (Standby or Safety) Manual Fails to open/close	XDM-CC-H or XDM-OO-H	3.0E-3/d	10
Plugs	XDM-PG-H	5.0E-7/h	10
Leakage (internal)	XDM-LI-H	1.0E-5/h	10
Rupture (internal)	XDM-RI-H	5.0E-7/h	30
Leakage (external)	XDM-LE-H	1.0E-7/h	10
Rupture (external)	XDM-RE-H	5.0E-9/h	30
Motor-Operated Fails to open/close	MOD-CC-H or MOD-OO-H	3.0E-2/d	10
Spurious operation	MOD-CO-H or MOD-OC-H	3.0E-6/h	10
Plugs	MOD-PG-H	5.0E-7/h	10
Leakage (internal)	MOD-LI-H	1.0E-5/h	10
Rupture (internal)	MOD-RI-H	5.0E-7/h	10
Leakage (external)	MOD-LE-H	1.0E-7/h	10
Rupture (external)	MOD-RE-H	5.0E-9/h	30
Air-Operated Fails to open/close	AOD-CC-H or AOD-OO-H	1.0E-2/d	30
Spurious operation	AOD-CO-H or AOD-OC-H	1.0E-5/h	10
Plugs	AOD-PG-H	5.0E-7/h	10
Leakage (internal)	AOD-LI-H	1.0E-5/h	10
Rupture (internal)	AOD-RI-H	5.0E-7/h	10
Leakage (external)	AOD-LE-H	1.0E-7/h	10
Rupture (external)	AOD-RE-H	5.0E-9/h	30
Damper (Control) Motor-Operated Fails open	CMD-FO-H	3.0E-6/h	10
Fails closed	CMD-FC-H	3.0E-6/h	10

Table D-4. (Contd.) HVAC/Exhaust System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
HVAC/Exhaust Damper (Standby or Safety) Manual Fails to open/close	XDM-CC-H or XDM-OO-H	3.0E-3/d	10
Fails to respond	CMD-NR-H	3.0E-6/h	10
Plugs	CMD-PG-H	5.0E-7/h	10
Leakage (external)	CMD-LE-H	1.0E-7/h	10
Rupture (external)	CMD-RE-H	5.0E-9/h	30
Air-Operated Fails open	CAD-FO-H	3.0E-6/h	10
Fails closed	CAD-FC-H	3.0E-6/h	10
Fails to respond	CAD-NR-H	3.0E-6/h	10
Plugs	CAD-PG-H	5.0E-7/h	10
Leakage (external)	CAD-LE-H	1.0E-7/h	10
Rupture (external)	CAD-RE-H	5.0E-9/h	30
Fan/Blower Motor-Driven Fails to start	MDF-FS-H	5.0E-3/d	5
Fails to run	MDF-FR-H	3.0E-5/h	3
Overspeed	MDF-OS-H	5.0E-6/h	10
Fails to stop	MDF-NS-H	5.0E-3/d	10
Leakage (external)	MDF-LE-H	3.0E-7/h	10
Rupture (external)	MDF-RE-H	1.0E-8/h	30
Diesel-Driven Fails to start	DDF-FS-H	1.0E-2/d	10
Fails to run	DDF-FR-H	5.0E-3/h	10
Overspeed	DDF-OS-H	1.0E-3/h	10
Fails to stop	DDF-NS-H	1.0E-2/d	10
Leakage (external)	DDF-LE-H	3.0E-7/h	10

Table D-4. (Contd.) HVAC/Exhaust System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
HVAC/Exhaust Damper (Standby or Safety) Manual Fails to open/close	XDM-CC-H or XDM-OO-H	3.0E-3/d	10
Rupture (external)	DDF-RE-H	1.0E-8/h	10
Ducting Leakage (external)	DCT-LE-H	3.0E-7/h-ft	10
Rupture (external)	DCT-RE-H	1.0E-8/h-ft	30
Plugs	DCT-PG-H	1.0E-8/h-ft	30
Heat Exchanger Air Conditioning Unit/ Chiller Fails to start	ACU-FS-H	1.0E-2/d	10
Fails to run	ACU-FR-H	3.0E-5/h	10
Fan Cooler Unit Fails to start	FCU-FS-H	1.0E-2/d	5
Fails to run	FCU-FR-H	1.0E-5/h	3
Heater (Electrical) Fails to heat	HTE-FH-H	1.0E-6/h	3
Overheats	HTE-OH-H	3.0E-7/h	10
Heater (Gas) Fails to heat	HTG-FH-H	1.0E-3/h	10
Overheats	HTG-OH-H	3.0E-4/h	10
Filter Normal Plugs	FLT-PG-H	3.0E-6/h	10
Leakage (internal)	FLT-LI-H	3.0E-6/h	10
Rupture (internal)	FLT-RI-H	5.0E-7/h	10
Low-Efficiency Plugs	FLL-PG-H	3.0E-6/h	10
Leakage (internal)	FLL-LI-H	3.0E-6/h	10

Table D-4. (Contd.) HVAC/Exhaust System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
HVAC/Exhaust Damper (Standby or Safety) Manual Fails to open/close	XDM-CC-H or XDM-OO-H	3.0E-3/d	10
Rupture (internal)	FLL-RI-H	5.0E-7/h	10
HEPA Plugs	HPA-PG-H	3.0E-6/h	10
Leakage (internal)	HPA-LI-H	3.0E-6/h	10
Rupture (internal)	HPA-RI-H	5.0E-7/h	10
Sand Plugs	FLS-PG-H	3.0E-6/h	10
Leakage (internal)	FLS-LI-H	3.0E-6/h	10
Rupture (internal)	FLS-RI-H	5.0E-7/h	10
Baghouse Plugs	BAG-PG-H	3.0E-5/h	10
Leakage (internal)	BAG-LI-H	3.0E-5/h	10
Rupture (internal)	BAG-RI-H	5.0E-6/h	10
Miscellaneous Mist Eliminator Failure	MTE-FA-H	1.0E-4/h	10
Scrubber Failure	SBR-FA-H	1.0E-6/h	10
Precipitator Failure	PCP-FA-H	5.0E-5/h	10

a. Modifications of the recommended mean for hourly failure rates may be appropriate for components subjected to hostile radioactive or chemical environments.

b. Error factor is the 95th percentile/50th percentile.

Table D-5. Electrical Distribution System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal) Mean[a]	Error Factor[b]
Electric Power Generator Diesel-Driven Fails to start	DDG-FS-E	1.0E-2/d	3
Fails to run	DDG-FR-E	5.0E-3/h	3
Motor-Driven (ac to dc) Fails to start	MDG-FS-E	1.0E-5/h	10
Fails to run	MDG-FR-E	3.0E-5/h	10
Gas-Turbine-Driven Fails to start	GTG-FS-E	3.0E-2/d	10
Fails to run	GTG-FR-E	3.0E-4/h	10
Hydro-Turbine-Driven Fails to start	HDG-FS-E	3.0E-3/d	10
Fails to run	HDG-FR-E	3.0E-4/h	10
Battery Failure	BAT-FA-E	1.0E-5/h	3
Charger Rectifier Failure	RCT-FA-E	1.0E-5/h	3
Bus Metal-Enclosed Failure	BUM-FA-E	1.0E-7/h	5
Bare Failure	BUB-FA-E	1.0E-6/h	10
Cable/Joint/ Termination/Jumper Cable (Copper, 1000ft) Failure	CBL-FA-E	3.0E-6/h	3
Joint (Copper) Failure	JNT-FA-E	3.0E-6/h	30
Termination (Copper) Failure	TMN-FA-E	3.0E-7/h	10
Jumper (Power) Failure	JPR-FA-E	5.0E-6/h	10

Table D-5. (Contd.) Electrical Distribution System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Electric Power Generator Diesel-Driven Fails to start	DDG-FS-E	1.0E-2/d	3
Circuit Breaker General Fails to open/close	CBR-CC-E or CBR-OO-E or CBR-NR-E	5.0E-4/d	5
Spurious operation	CBR-CO-E or CBR-OC-E or CBR-SO-E	3.0E-7/h	10
Reactor Trip Fails to open	RTB-CC-E	5.0E-3/d	5
Spurious operation	RTB-CO-E	3.0E-6/h	10
Relay Protective Fails to open/close	RLP-CC-E or RLP-OO-E or RLP-NR-E	1.0E-3/d	10
Spurious operation	RLP-CO-E or RLP-OC-E or RLP-SO-E	1.0E-7/h	10
Control Fails to open/close	RLC-CC-E or RLC-OO-E or RLC-NR-E	1.0E-4/d	10
Spurious operation	RLC-CO-E or RLC-OC-E or RLC-SO-E	3.0E-7/h	30
Bistable Fails to open/close	BIS-CC-E or BIS-OO-E or BIS-NR-E	1.0E-5/d	10
Spurious operation	BIS-CO-E or BIS-OC-E or BIS-SO-E	3.0E-7/h	10
Switch Push-Button (Manual) Fails to open/close	XSP-CC-E or XSP-OO-E or XSP-NR-E	1.0E-6/h	10

Table D-5. (Contd.) Electrical Distribution System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Electric Power Generator Diesel-Driven Fails to start	DDG-FS-E	1.0E-2/d	3
Spurious operation	XSP-CO-E or XSP-OC-E or XSP-SO-E	1.0E-6/h	10
Rotary (Manual) Fails to open/close	XSR-CC-E or XSR-OO-E or XSR-NR-E	5.0E-8/h	10
Spurious operation	XSR-CO-E or XSR-OC-E or XSR-SO-E	5.0E-7/h	10
Key-Operated (Manual) Fails to open/close	XSK-CC-E or XSK-OO-E or XSK-NR-E	3.0E-7/h	10
Spurious operation	XSK-CO-E or XSK-OC-E or XSK-SO-E	1.0E-6/h	10
Automatic-Transfer Fails to open/close	ATS-CC-E or ATS-OO-E or ATS-NR-E	1.0E-6/h	10
Spurious operation	ATS-CO-E or ATS-OC-E or ATS-SO-E	1.0E-6/h	10
Limit Fails to open/close	LMS-CC-E or LMS-OO-E or LMS-NR-E	1.0E-6/h	10
Spurious operation	LMS-CO-E or LMS-OC-E or LMS-SO-E	1.0E-6/h	5
Fuse Fail to open	FUS-CC-E	1.0E-7/h	10
Premature opening	FUS-SO-E	1.0E-8/h	10
Inverter Failure	INV-FA-E	1.0E-5/h	3

Table D-5. (Contd.) Electrical Distribution System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Electric Power Generator Diesel-Driven Fails to start	DDG-FS-E	1.0E-2/d	3
Motor AC Fails to start	MRA-FS-E	3.0E-4/d	3
Fails to run	MRA-FR-E	5.0E-6/h	3
DC Fails to start	MRD-FS-E	3.0E-4/d	3
Fails to run	MRD-FR-E	1.0E-5/h	3
Synchro Failure	SYN-FA-E	1.0E-5/h	10
Transformer Power Failure	TFP-FA-E	1.0E-6/h	10
Instrumentation/Control Failure	TFI-FA-E	1.0E-6/h	10

a. Modifications of the recommended mean for hourly failure rates may be appropriate for components subjected to hostile radioactive or chemical environments.

b. Error factor is the 95th percentile/50th percentile.

Table D-6. Instrumentation and Control System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Instrumentation and Control Alarm/Annunciator Fails to alarm	ALR-NR-I	3.0E-5/h	10
Spurious operation	ALR-SO-I	5.0E-6/h	10
Sensor/Transmitter/ Transducer/Process Switch Temperature Failure	TST-FA-I	1.0E-6/h	3
Pressure Failure	PST-FA-I	1.0E-6/h	3
Differential Pressure Failure	DPS-FA-I	3.0E-6/h	10
Flow Failure	FST-FA-I	3.0E-6/h	3
Level Failure	LST-FA-I	5.0E-7/h	3
Humidity Failure	UST-FA-I	1.0E-5/h	10
pH Failure	HST-FA-I	5.0E-7/h	5
Oxygen Concentration Failure	OXC-FA-I	1.0E-5/h	10
CO_2 Concentration Failure	COC-FA-I	1.0E-4/h	10
Hydrogen Concentration Failure	HYC-FA-I	1.0E-5/h	3
Nitrogen Concentration Failure	NIC-FA-I	1.0E-5/h	3
Hydrocarbon Concentration Failure	HCC-FA-I	1.0E-5/h	3
Helium Concentration Failure	HEC-FA-I	1.0E-5/h	3
Speed Failure	SST-FA-I	1.0E-6/h	10

Table D-6. (Contd.) Instrumentation and Control System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Instrumentation and Control Alarm/Annunciator Fails to alarm	ALR-NR-I	3.0E-5/h	10
Seismic Failure	SET-FA-I	1.0E-6/h	5
Radiation Failure	RST-FA-I	5.0E-6/h	5
Indicator Failure	IND-FA-I	1.0E-5/h	10
Amplifier Failure	AMP-FA-I	5.0E-6/h	10
Modifier/Signal Conditioner Failure	SCR-FA-I	3.0E-7/h	3
Logic Module Failure	LOG-FA-I	3.0E-6/h	5
Recorder Failure	REC-FA-I	3.0E-5/h	30
Sampler Failure	SAM-FA-I	1.0E-5/h	10
Analyzer Failure	ANA-FA-I	5.0E-6/h	10
Timer Failure	TMR-FA-I	5.0E-6/h	10
Gas Chromatograph Failure	GCR-FA-I	5.0E-5/h	10
Voltage Regulator Failure	VRG-FA-I	3.0E-6/h	10
Transmitter Failure	TRM-FA-I	3.0E-6/h	10

Table D-6. (Contd.) Instrumentation and Control System Recommended Generic Failure Rates

System/Component/Failure Mode	Component Identifier	Recommended Failure Rate Distribution (log-normal)	
		Mean[a]	Error Factor[b]
Instrumentation and Control Alarm/Annunciator Fails to alarm	ALR-NR-I	3.0E-5/h	10
Transducer Failure	TRD-FA-I	1.0E-6/h	10
Programmable Logic Controller Failure	PLC-FA-I	3.0E-5/h	10

a. Modifications of the recommended mean for hourly failure rates may be appropriate for components subjected to hostile radioactive or chemical environments.

b. Error factor is the 95th percentile/50th percentile.

1. Savannah River Laboratory, "Savannah River Site Generic Database Development," WSRC-TC-93-262.

APPENDIX E

Appendix E

Example Calculation

This appendix provides a quick overview and walkthrough of the type of calculation developed and used in the Idaho Chemical Processing Plant (ICPP) database. The sample calculation contains fabricated data, therefore, the values generated have no true meaning and are not found within the ICPP failure rate database.

Appendix E

Example Calculation

<u>Overview</u>: This appendix is designed to quickly instruct the reader on the method used in calculating the λs, 5th percentiles, 95th percentiles, and the standard error reported within the ICPP database. The example will walk the reader through the calculation, step-by-step. The example contains sample data and does not calculate an actual λ reported.

To perform the calculation, the following pieces of information are required:

1) Specific listing of all equipment items in use
2) Listing of every failure for all equipment items
3) Mission time for each equipment item
4) Failure mode for each failure (if possible).

<u>Steps 1 through 5: Manipulation of the raw data</u> (MODEL #1)

Step #1 - Calculate $\hat{\lambda}$ for each equipment item,

where $\hat{\lambda} = \frac{n}{Nt^*}$, N=1 for individual equipment items.

Step #2 - Calculate the χ^2 distribution $\hat{\lambda}_L$ (5th percentile), using a Bayesian adjustment for each equipment item,

$$\hat{\lambda}_L = \frac{\chi^2_{0.05}(2n+1)}{2t}$$

Step #3 - Calculate χ^2 distribution $\hat{\lambda}_U$ (95th percentile) using a Bayesian adjustment for each equipment item,

$$\hat{\lambda}_U = \frac{\chi^2_{0.95}(2n+1)}{2t}$$

Step #4 - Calculate the Dispersion Factor (DF) for each equipment item,

$$DF_{\chi^2} = \sqrt{\frac{\hat{\lambda}_U}{\hat{\lambda}_L}}$$

Step #5 - Repeat steps 1-4 for the total group (total number of failures, and the mission time = Nt^*).

Note: If N is very large, difficulties arise in generating the χ^2 distribution values, and, thus, the following approximation was used:

$$\chi_p^2 = \frac{(x_p + \sqrt{2\nu - 1})^2}{2}$$

Where: x_p = *equivalent normal distribution percentile*

i.e. $x_{0.95} = 1.645$, $x_{0.05} = -1.645$

$\nu = 2n + 1$ (n = # *of failures*)

<u>Steps 6 through 10: Lognormal Distribution of the Individual Failure Rates</u> (MODEL #2)

Step #6 - Calculate $\bar{\lambda}$, based from the individual $\hat{\lambda}$s;

$$\bar{\lambda} = \sum_{i=1}^{N} \frac{\hat{\lambda}_i}{N}$$

Step #7 - Calculate the variance (s^2) and standard deviation (s) of the individual $\hat{\lambda}s$.

$$s^2 = \frac{\sum_{i=1}^{N} (\hat{\lambda}_i - \bar{\lambda})^2}{n-1}$$

$$s = \sqrt{s^2}$$

Step #8 - Using $\bar{\lambda}$ & s^2, calculate ζ^2 & η (lognormal variance and lognormal mean), using the following equations:

$$\zeta^2 = \ln(1 + \frac{s^2}{\bar{\lambda}^2})$$

$$\eta = \ln(\bar{\lambda}) - \frac{1}{2}\zeta^2$$

Step #9 - Generate the lognormal $\bar{\lambda}_L$, $\bar{\lambda}_M$, $\bar{\lambda}_U$: :

$$\bar{\lambda}_L = e^{\eta - 1.645\zeta}$$

$$\bar{\lambda}_U = e^{\eta + 1.645\zeta}$$

$$\bar{\lambda}_M = e^{\eta}$$

Step #10 - Calculate the lognormal Error Factor (EF).

$$EF = e^{1.645\zeta}$$

Steps 11 through 17: Adjusted Lognormal Distribution Calculation

(ADJUSTMENT)

Step #11 - Calculate the adjusted lognormal EF: adj EF=DF*EF

Step #12 - Calculate the adjusted lognormal mean, $\tilde{\eta}$, by:

$$\tilde{\eta} = \ln(\bar{\lambda}_M)$$

Step #13 - Calculate the adjusted standard deviation (ζ):

$$\zeta = \frac{\ln(adj\ EF)}{1.645}$$

Step #14 - Calculate the adjusted λ ($\tilde{\lambda}$),

$$\tilde{\lambda} = e^{(\eta + \frac{1}{2}\zeta^2)}$$

Step #15 - Generate the adjusted 90% confidence limits:

$$\tilde{\lambda}_L = \frac{\overline{\lambda}_L}{DF}$$

$$\tilde{\lambda}_U = \overline{\lambda}_U * DF$$

Step #16 - Calculate the adjusted variance and the adjusted standard deviation:

$$\tilde{\sigma}^2 = \frac{\tilde{\lambda}^2}{e^{\zeta^2} - 1}$$

$$\tilde{\sigma} = \sqrt{\tilde{\sigma}^2}$$

Step #17 - Calculate the standard error ($\hat{\varepsilon}$):

$$\hat{\varepsilon} = \frac{\sqrt{\tilde{\lambda} t^*}}{t^*}$$

Mission Time

Number of Failures (n)

Step #1
Failure Rate For Individual Equipment Items
$\lambda = n/Nt^*$

Step #2
χ^2 Lower Limit (5%)
$\chi^2_{0.05}(2n+1)/(2t)$

Model #1

Basic Data						
Equipment ID #	# of Fails	time (h)	λ hat	χ^2 LL	χ^2 UL	DF
CRN-FR-903	46	75360	6.10E-04	4.76E-04	7.73E-04	1.27
CRN-FS-901	21	75360	2.79E-04	1.92E-04	3.93E-04	1.43
CRN-FT-911	3	75360	3.98E-05	1.44E-05	9.33E-05	2.55
CRN-NCC-901	2	75360	2.65E-05	7.60E-06	7.35E-05	3.11
CRN-NCD-300	0	75360	3.05E-06	2.61E-08	2.55E-05	31.26
CRN-NCD-901	15	75360	1.99E-04	1.28E-04	2.98E-04	1.53
CRN-PM-145	1	75360	1.33E-05	2.33E-06	5.18E-05	4.71
CRN-PM-901	4	75360	5.31E-05	2.21E-05	1.12E-04	2.26
CRN-PM-902	0	75360	3.05E-06	2.61E-08	2.55E-05	31.26
Total	92	678240	1.36E-04	1.14E-04	1.61E-04	1.19

Step #3
χ^2 Upper Limit (95%)
$\chi^2_{0.95}(2n+1)/(2t)$

Step #4
Dispersion Factor
$\sqrt{(\chi^2_U/\chi^2_L)}$

Step #5
Repeat Steps #(1-4) for Total Group
(Please See Note in Write-up)

Model #2

Step #6
λ bar
$\Sigma\lambda_i / N$

Step #7
Calc. Variance and Standard Deviation
VAR=s^2 STD DEV=s

Step #8
Calculate ζ^2 & η, using λ bar and the variance
$\zeta^2=\ln(1+((\lambda \text{ bar})^2)/VAR)$
$\eta=\ln(\lambda \text{ bar})-½\zeta^2$

Lognormal Distribution of Individual Failure Rates	
λ bar	1.36E-04
Variance	4.10E-08
Std Dev	2.02E-04
ζ^2	1.1649
ζ	1.0793
η	-9.4829
5%	1.29E-05
50%	7.61E-05
95%	4.49E-04
EF	5.90

Step #9
Calculate 5%, 50%, & 95% of the lognormal distribution
$\lambda_L=\exp(\eta-1.645\zeta)$ (5%)
$\lambda_M=\exp(\eta)$ (50%)
$\lambda_U=\exp(\eta+1.645\zeta)$ (95%)

$\zeta=\sqrt{(\zeta^2)}$

Step #10
Generate the Log Normal Error Factor
$EF=\exp(1.645\zeta)$

Adjustment

Step #11
Calculate Adjusted EF
Adj EF=EF*DF_{TOTAL}

Step #12
Calculate Adj η
Adj $\eta = \ln(\lambda_M)$

Step #13
Calculate Adj ζ
Adj ζ = ln(adj EF)/1.645

adj ζ^2=(adj $\zeta)^2$

Adjusted Lognormal Distribution	
Adj λ (λ~)	1.53E-04
Adj Variance	7.69E-09
Adj Std Dev	8.77E-05
Adj ζ^2 (ζ^2~)	1.4007
Adj ζ (ζ~)	1.1835
Adj η (η~)	-9.4829
Adj 5% (λ_L~)	1.09E-05
Adj 50% (λ_M~)	7.61E-05
Adj 95% (λ_U~)	5.33E-04
Adj EF	7.01
Std Error (ε hat)	1.50E-05

Adj 50% = Lognormal 50%

Step #14
Calculate the adjusted failure rate λ~
adj $\lambda = \exp(\eta+½\zeta^2)$

Step #15
Generate the adjusted 90% confidence limits
adj λ_U = lognormal λ_U*DF
adj λ_L = lognormal λ_L/DF

Step #16
Calculate the adjusted variance and standard deviation
Adj $s^2=\lambda^2/(e^{\zeta^2}-1)$
Adj $s=\sqrt{(\text{adj } s^2)}$

Step #17
Finally, calculate the Standard Error
ε hat = √(adj λ * time) / time