Initiating Event Data Sheet

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

1.1 Initiating Event Description

The Large Loss-of-Coolant Accident at Boiling Water Reactors (LLOCA (BWR)) is a break size greater than 0.1 square feet (or an approximately 5-inch inside diameter pipe equivalent for liquid and steam) in a pipe in the primary system boundary.

1.2 Data Collection and Review

Information for the LLOCA (BWR) baseline was obtained from *Estimating Loss-of-Coolant Accident (LOCA) Frequencies through the Elicitation Process* (Ref. 5). In that document, the LLOCA frequency was estimated based on an expert elicitation process "…to consolidate service history data and PFM [probabilistic fracture mechanics] studies with knowledge of plant design, operation, and material performance." Reference 5 is a draft document. Results obtained from that document could change when the final report is issued.

Table 7.1 in Reference 5 presents frequencies for LOCAs exceeding various sizes indicated by gallon per minute (gpm) break flow and effective pipe size break. Six different sizes are listed, ranging from 0.5-inch diameter (> 100 gpm) to 31-inch or 41-inch diameter (> 500,000 gpm). The frequencies presented for each size indicate the frequency of LOCAs of that size or greater occurring. In addition, frequencies for each size are presented for current day conditions (assuming an average of 25 years of operation) and for end-of-life conditions (40 years of operation). For this study, frequencies appropriate for current day conditions were used.

From Table 7.1 in Reference 5, the LLOCA frequency (in reactor calendar years or rcy's) for BWRs is 6.1E-6/rcy (> 7 inch). To convert this to reactor critical years (rcry's), it was assumed that reactors are critical 90% of each year. Converting to rcry's, the result is

(6.1E-6/rcy)(1 rcy/0.9 rcry) = 6.78E-6/rcry.

The associated error factor (95th percentile divided by median) from Reference 5 is

(2.0E-5/rcy)/(2.2E-6/rcy) = 9.1,

which converts to an α of 0.47.

1.3 Industry-Average Baselines

Table 1 lists the industry-average frequency distribution.

Table 1. Selected industry distribution of λ for LLOCA (BWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
Ref. 5	1.90E-08	2.91E-06	6.78E-06	2.66E-05	Gamma	0.470	6.932E+04

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

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

Table 2. Selected industry distribution of λ for LLOCA (BWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
Ref. 5	3.0E-08	3.0E-06	7.0E-06	2.5E-05	Gamma	0.50	7.14E+04

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

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

2.1 Initiating Event Description

The Large Loss-of-Coolant Accident at Pressurized Water Reactors (LLOCA (PWR)) is a pipe break in the primary system boundary with an equivalent inside diameter greater than 6 inch.

2.2 Data Collection and Review

Information for the LLOCA (PWR) baseline was obtained from *Estimating Loss-of-Coolant Accident (LOCA) Frequencies through the Elicitation Process* (Ref. 5). In that document, the LLOCA frequency was estimated based on an expert elicitation process "…to consolidate service history data and PFM [probabilistic fracture mechanics] studies with knowledge of plant design, operation, and material performance." Reference 5 is a draft document. Results obtained from that document could change when the final report is issued.

Table 7.1 in Reference 5 presents frequencies for LOCAs exceeding various sizes indicated by gallon per minute (gpm) break flow and effective pipe size break. Six different sizes are listed, ranging from 0.5-inch diameter (> 100 gpm) to 31-inch or 41-inch diameter (> 500,000 gpm). The frequencies presented for each size indicate the frequency of LOCAs of that size or greater occurring. In addition, frequencies for each size are presented for current day conditions (assuming an average of 25 years of operation) and for end-of-life conditions (40 years of operation). For this study, frequencies appropriate for current day conditions were used.

From Table 7.1 in Reference 5, the LLOCA frequency (in reactor calendar years or rcy's) for PWRs is 1.2E-6/rcy (> 7 inch). To convert this to reactor critical years (rcry's), it was assumed that reactors are critical 90% of each year. Converting to rcry's, the result is

(1.2E-6/rcy)(1 rcy/0.9 rcry) = 1.33E-6/rcry.

The associated error factor (95th percentile divided by median) from Reference 5 is

(3.9E-6/rcy)/(3.1E-7/rcy) = 10.5,

which converts to an α of 0.42.

2.3 Industry-Average Baselines

Table 3 lists the industry-average frequency distribution.

Table 3. Selected industry distribution of λ for LLOCA (PWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
Ref. 5	1.90E-09	5.10E-07	1.33E-06	5.43E-06	Gamma	0.420	3.158E+05

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

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

Table 4. Selected industry distribution of λ for LLOCA (PWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
Ref. 5	1.2E-09	4.0E-07	1.2E-06	5.0E-06	Gamma	0.40	3.33E+05

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

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

3.1 Initiating Event Description

The Medium Loss-of-Coolant Accident at Boiling Water Reactors (MLOCA (BWR)) initiating event is defined for boiling water reactors (BWRs) as a pipe break in the primary system boundary with a break size between 0.004 to 0.1 square feet (or an approximately 1- to 5-inch inside diameter pipe equivalent) for liquid and between 0.05 to 0.1 square feet (or an approximately 4- to 5-inch inside diameter pipe equivalent) for steam.

3.2 Data Collection and Review

Information for the MLOCA (BWR) baseline was obtained from *Estimating Loss-of-Coolant Accident (LOCA) Frequencies Through the Elicitation Process* (Ref. 5). In that document, the MLOCA frequency was estimated based on an expert elicitation process "…to consolidate service history data and PFM [probabilistic fracture mechanics] studies with knowledge of plant design, operation, and material performance." Reference 5 is a draft document. Results obtained from that document could change when the final report is issued.

Table 7.1 in Reference 5 presents frequencies for LOCAs exceeding various sizes indicated by gallon per minute (gpm) break flow and effective pipe size break. Six different sizes are listed, ranging from 0.5-inch diameter (> 100 gpm) to 31-inch or 41-inch diameter (> 500,000 gpm). The frequencies presented for each size indicate the frequency of LOCAs of that size or greater occurring. In addition, frequencies for each size are presented for current day conditions (assuming an average of 25 years of operation) and for end-of-life conditions (40 years of operation). For this study, frequencies appropriate for current day conditions were used.

From Table 7.1 in Reference 5, the MLOCA frequency (in reactor calendar years or rcy's) for BWRs is

1.0E-4/rcy – 6.1E-6/rcy = 9.39E-5/rcy,

where 1.0E-4/rcy is for LOCAs with an effective break size greater than 1.875-inch inside diameter, and 6.1E-6/rcy is the LLOCA value. To convert this to reactor critical years (rcry's), it was assumed that reactors are critical 90% of each year. Converting to rcry's, the result is

(9.39E-5/rcy)(1 rcy/0.9 rcry) = 1.04E-4/rcry.

The associated error factor (95^{th} percentile divided by median) associated with the > 1.875-inch category from Reference 5 is

(3.2E-4/rcy)/(4.8E-5/rcy) = 6.7,

which converts to an α of 0.61.

3.3 Industry-Average Baselines

Table 5 lists the industry-average frequency distribution.

Table 5. Selected industry distribution of λ for MLOCA (BWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
Ref. 5	1.05-06	5.54E-05	1.04E-04	3.72E-04	Gamma	0.610	5.865E+03

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

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

Table 6. Selected industry distribution of λ for MLOCA (BWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
Ref. 5	9.0E-07	5.0E-05	1.0E-04	4.0E-04	Gamma	0.60	6.00E+03

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

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

4.1 Initiating Event Description

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

4.2 Data Collection and Review

Information for the MLOCA (PWR) baseline was obtained from *Estimating Loss-of-Coolant Accident (LOCA) Frequencies through the Elicitation Process* (Ref. 5). In that document, the MLOCA frequency was estimated based on an expert elicitation process "…to consolidate service history data and PFM [probabilistic fracture mechanics] studies with knowledge of plant design, operation, and material performance." Reference 5 is a draft document. Results obtained from that document could change when the final report is issued.

Table 7.1 in Reference 5 presents frequencies for LOCAs exceeding various sizes indicated by gallon per minute (gpm) break flow and effective pipe size break. Six different sizes are listed, ranging from 0.5-inch diameter (> 100 gpm) to 31-inch or 41-inch diameter (> 500,000 gpm). The frequencies presented for each size indicate the frequency of LOCAs of that size or greater occurring. In addition, frequencies for each size are presented for current day conditions (assuming an average of 25 years of operation) and for end-of-life conditions (40 years of operation). For this study, frequencies appropriate for current day conditions were used.

From Table 7.1 in Reference 5, the MLOCA frequency (in reactor calendar years or rcy's) for BWRs is

4.6E-4/rcy – 1.2E-6/rcy = 4.59E-4/rcy,

where 4.6E-4/rcy is for LOCAs with an effective break size greater than 1.625-inch inside diameter, and 1.2E-6/rcy is the LLOCA value. To convert this to reactor critical years (rcry's), it was assumed that reactors are critical 90% of each year. Converting to rcry's, the result is

(4.59E-4/rcy)(1 rcy/0.9 rcry) = 5.10E-4/rcry.

The associated error factor (95^{th} percentile divided by median) associated with the > 1.625-inch category from Reference 5 is

(1.4E-3/rcy)/(1.4E-4/rcy) = 10.0,

which converts to an α of 0.44.

4.3 Industry-Average Baselines

Table 5 lists the industry-average frequency distribution.

Table 7. Selected industry distribution of λ for MLOCA (PWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
Ref. 5	9.72E-07	2.05E-04	5.10E-04	2.05E-03	Gamma	0.440	8.627E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

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

Table 8. Selected industry distribution of λ for MLOCA (PWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
Ref. 5	5.0E-07	2.0E-04	5.0E-04	2.0E-03	Gamma	0.40	8.00E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

5 Loss of Vital AC Bus (LOAC)

5.1 Initiating Event Description

From Reference 3, the Loss of Vital AC Bus (LOAC) initiating event is any sustained de-energization of a safety-related bus due to the inability to connect to any of the normal or alternative electrical power supplies. The bus must be damaged or its power source unavailable for reasons beyond an open, remotely-operated feeder-breaker from a live power source. Examples include supply cable grounds, failed insulators, damaged disconnects, transformer deluge actuations, and improper uses of grounding devices.

5.2 Data Collection and Review

Data for the LOAC baseline were obtained from the IEDB, as accessed using RADS. However, the SPAR event tree model for LOAC assumes loss of a 4160 Vac safety bus (or in a few cases a 480 Vac safety bus) with no recovery. The LOAC events in the IEDB were reviewed to identify the subset of events that matched the event tree modeling assumptions in SPAR. That review resulted in approximately 75% of the original LOAC events in the IEDB being dropped. (However, those dropped events are still included in the TRAN or other IE categories.)

Using the process outlined in Section D.1.2 of Reference 6, the optimized baseline period for LOAC is 1992–2002. Figure 1 shows the trend of the full LOAC data set and the baseline period used in this analysis. RADS was used to collect the LOAC data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table 9 summarizes the baseline data obtained from RADS and used in the LOAC analysis.

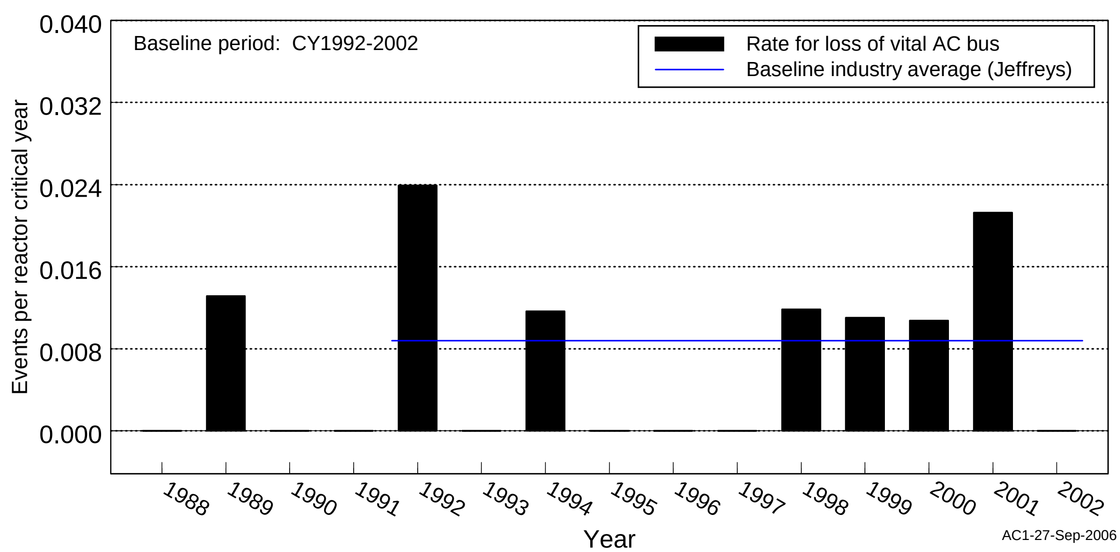

Figure 1. LOAC trend plot.

Table 9. LOAC frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
8	965.8	1992–2002	111	7.2%

5.3 Data Analysis

The LOAC data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table 10.

Table 10. Empirical distributions of MLEs for λ for LOAC.

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	8.16E-03	9.84E-02
Industry	-	-	8.28E-03	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 9, only 7.2% of the plants experienced a LOAC over the period 1992–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 92.8% portion of the distribution, and non-zero values above 92.8%.

An empirical Bayes analysis was performed at the plant level but failed to converge. (This most likely was the result of insufficient variation between plants.) Therefore, assuming homogeneous data, a Bayesian update of the Jeffreys noninformative prior using the industry data was calculated. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and α = 0.5. Results from these analyses are presented in Table 11.

Table 11. Fitted distributions for λ for LOAC.

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	4.49E-03	8.46E-03	8.80E-03	1.43E-02	Gamma	8.500	9.658E+02
SCNID/IL	3.46E-05	4.00E-03	8.80E-03	3.38E-02	Gamma	0.500	5.681E+01

Note – JEFF/IL is a Bayesian update of the Jeffreys noninformative prior using industry data and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

5.4 Industry-Average Baselines

Table 12 lists the industry-average frequency distribution. The Bayesian update of the Jeffreys noninformative prior was selected. This industry-average frequency does not account for any recovery.

Table 12. Selected industry distribution of λ for LOAC (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	4.49E-03	8.46E-03	8.80E-03	1.43E-02	Gamma	8.500	9.658E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

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

Table 13. Selected industry distribution of λ for LOAC (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	5.0E-03	9.0E-03	9.0E-03	1.5E-02	Gamma	9.00	1.00E+03

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

6 Loss of Component Cooling Water (LOCCW)

6.1 Initiating Event Description

From Reference 3, the Loss of Component Cooling Water (LOCCW) initiating event is a complete loss of the component cooling water (CCW) system. CCW is a closed-cycle cooling water system that removes heat from safety-related equipment and discharges the heat through a heat exchanger to an open-cycle service water system.

6.2 Data Collection and Review

Data for LOCCW baselines were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2 of Reference 6, the optimized baseline period for LOCCW is 1988–2002. (No events were identified, so the entire period was chosen for the baseline.) RADS was used to collect the LOCCW data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table 14 summarizes the data obtained from RADS and used in the LOCCW analysis.

Table 14. LOCCW frequency data.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
0	1282.4	1988–2002	113	0.0%

6.3 Data Analysis

The LOCCW data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. (However, with no events, all MLEs for LOCCW are zero.) The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table 15.

Table 15. Empirical distributions of MLEs for λ for LOCCW.

Aggregation Level	5%	Median	Mean	95%
Plant	-	-	-	-
Industry	-	-	0.00E+00	-

Note – Percentiles and the mean have units of events/rcry.

With no events, no empirical Bayes analysis could be performed at the plant level. However, the simplified constrained noninformative distribution (SCNID) was generated, based on a Bayesian update of the Jeffreys noninformative prior with industry data and $\alpha = 0.5$. Results from these analyses are presented in Table 16.

Table 16. Fitted distributions for λ for LOCCW.

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	1.53E-06	1.77E-04	3.90E-04	1.50E-03	Gamma	0.500	1.282E+03

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

6.4 Industry-Average Baselines

Table 17 lists the industry-average frequency distribution. With no events, the empirical Bayes analysis could not be performed. Therefore, the SCNID analysis results were used. This industry-average frequency does not account for any recovery.

Table 17. Selected industry distribution of λ for LOCCW (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	1.53E-06	1.77E-04	3.90E-04	1.50E-03	Gamma	0.500	1.282E+03

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

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

Table 18. Selected industry distribution of λ for LOCCW (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	1.5E-06	2.0E-04	4.0E-04	1.5E-03	Gamma	0.50	1.25E+03

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

7 Loss of Condenser Heat Sink at Boiling Water Reactors (LOCHS (BWR))

7.1 Initiating Event Description

From Reference 3, the Loss of Condenser Heat Sink at Boiling Water Reactors (LOCHS (BWR)) initiating event is defined as at least one of the following:

1. A complete closure of at least one main steam isolation valve in each main steam line.
2. A decrease in condenser vacuum that leads to an automatic or manual reactor trip, or manual turbine trip; or a complete loss of condenser vacuum that prevents the condenser from removing decay heat after a reactor trip. In addition, reactor trips that are the indirect result of a low condenser vacuum, such as a loss of feedwater caused by condensate pumps tripping on high condensate temperature because of loss of vacuum, are counted.
3. The failure of one or more turbine bypass valves to maintain the reactor pressure and temperature at the desired operating condition.

7.2 Data Collection and Review

Data for the LOCHS (BWR) baseline were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2 of Reference 6, the optimized baseline period for LOCHS (BWR) is 1996–2002. Figure 2 shows the trend of the full LOCHS (BWR) data set and the baseline period used in this analysis. RADS was used to collect the LOCHS (BWR) data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table 19 summarizes the data obtained from RADS and used in the LOCHS (BWR) analysis.

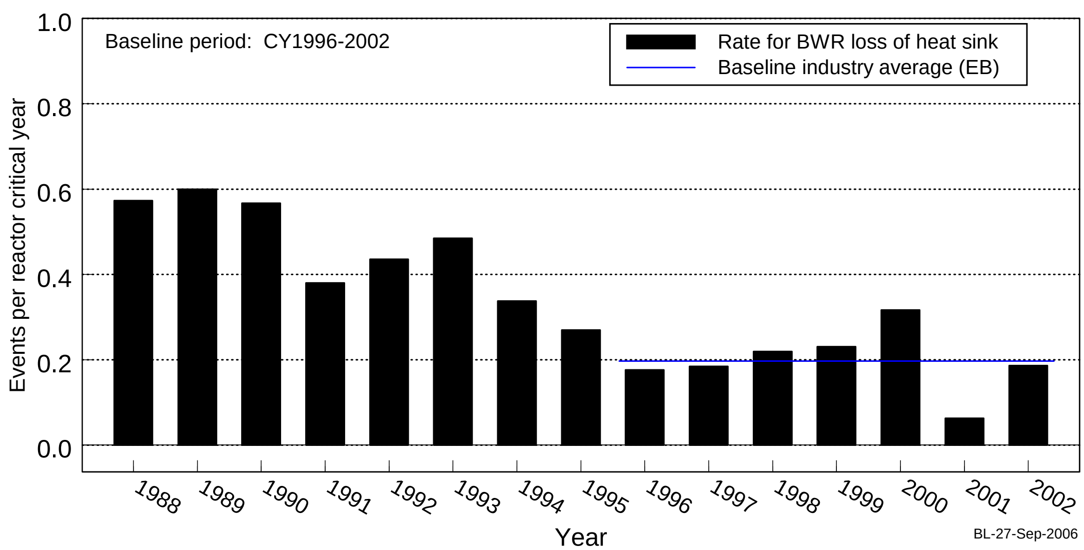

Figure 2. LOCHS (BWR) trend plot.

Table 19. LOCHS (BWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
41	208.6	1996–2002	35	71.4%

7.3 Data Analysis

The LOCHS (BWR) data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table 20.

Table 20. Empirical distributions of MLEs for λ for LOCHS (BWR).

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	1.56E-01	1.96E-01	4.91E-01
Industry	-	-	1.97E-01	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 19, 71.4% of the plants experienced a LOCHS (BWR) over the period 1996–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 28.6% portion of the distribution, and non-zero values above 28.6%.

An empirical Bayes analysis was performed at the plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table 21.

Table 21. Fitted distributions for λ for LOCHS (BWR).

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	1.11E-01	1.91E-01	1.97E-01	3.03E-01	Gamma	11.080	5.632E+01
SCNID/IL	7.82E-04	9.05E-02	1.99E-01	7.64E-01	Gamma	0.500	2.514E+00

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

7.4 Industry-Average Baselines

Table 22 lists the industry-average frequency distribution. The data set was sufficient for an empirical Bayes analysis to be performed. This industry-average frequency does not account for any recovery.

Table 22. Selected industry distribution of λ for LOCHS (BWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	1.11E-01	1.91E-01	1.97E-01	3.03E-01	Gamma	11.080	5.632E+01

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

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

Table 23. Selected industry distribution of λ for LOCHS (BWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	1.2E-01	2.0E-01	2.0E-01	3.0E-01	Gamma	12.00	6.00E+01

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

8 Loss of Condenser Heat Sink at Pressurized Water Reactors (LOCHS (PWR))

8.1 Initiating Event Description

From Reference 3, the Loss of Condenser Heat Sink at Pressurized Water Reactors (LOCHS (PWR)) initiating event is defined as at least one of the following:

1. A complete closure of at least one main steam isolation valve in each main steam line.
2. A decrease in condenser vacuum that leads to an automatic or manual reactor trip, or manual turbine trip; or a complete loss of condenser vacuum that prevents the condenser from removing decay heat after a reactor trip. In addition, reactor trips that are the indirect result of a low condenser vacuum, such as a loss of feedwater caused by condensate pumps tripping on high condensate temperature because of loss of vacuum, are counted.
3. The failure of one or more turbine bypass valves to maintain the reactor pressure and temperature at the desired operating condition.

8.2 Data Collection and Review

Data for the LOCHS (PWR) baseline were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2 of Reference 6, the optimized baseline period for LOCHS (PWR) is 1995–2002. Figure 3 shows the trend of the full LOCHS (PWR) data set and the baseline period used in this analysis. RADS was used to collect the LOCHS (PWR) data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table 24 summarizes the data obtained from RADS and used in the LOCHS (PWR) analysis.

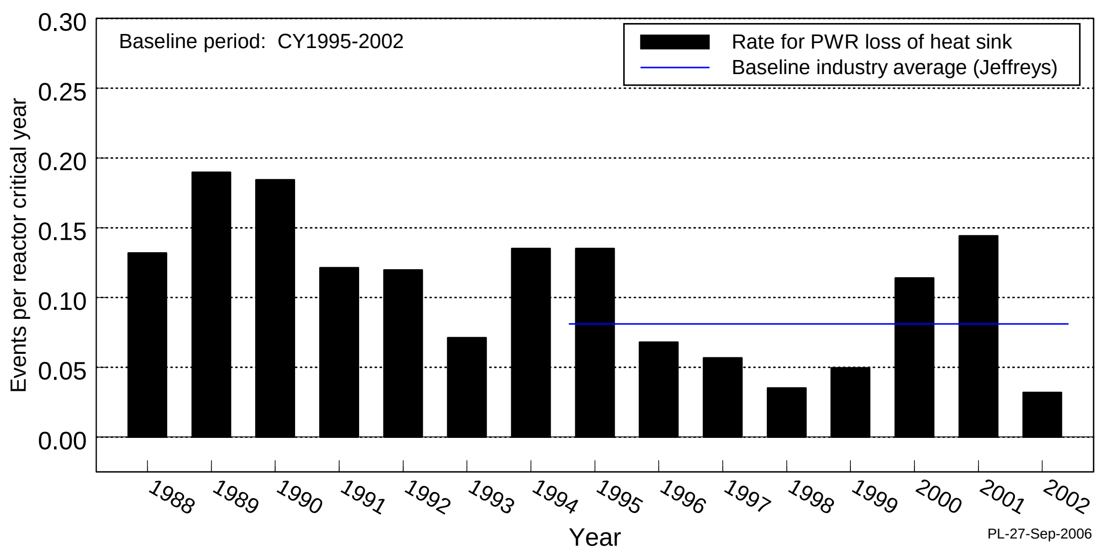

Figure 3. LOCHS (PWR) trend plot.

Table 24. LOCHS (PWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
38	475.0	1995–2002	73	38.4%

8.3 Data Analysis

The LOCCW data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table 25.

Table 25. Empirical distributions of MLEs for λ for LOCHS (PWR).

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	8.09E-02	2.78E-01
Industry	-	-	8.00E-02	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 24, 38.4% of the plants experienced a LOCHS (PWR) over the period 1995–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 61.6% portion of the distribution, and non-zero values above 61.6%.

An empirical Bayes analysis was performed at the plant level but failed to converge. (This most likely was the result of insufficient variation between plants.) Therefore, assuming homogeneous data, a Bayesian update of the Jeffreys noninformative prior using the industry data was calculated. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and α = 0.5. Results from these analyses are presented in Table 26.

Table 26. Fitted distributions for λ for LOCHS (PWR).

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	6.08E-02	8.04E-02	8.11E-02	1.04E-01	Gamma	38.500	4.750E+02
SCNID/IL	3.19E-04	3.69E-02	8.11E-02	3.11E-01	Gamma	0.500	6.169E+00

Note – JEFF/IL is a Bayesian update of the Jeffreys noninformative prior using industry data and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

8.4 Industry-Average Baselines

Table 27 lists the industry-average frequency distribution. The Bayesian update of the Jeffreys noninformative prior was selected. This industry-average frequency does not account for any recovery.

Table 27. Selected industry distribution of λ for LOCHS (PWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	6.08E-02	8.04E-02	8.11E-02	1.04E-01	Gamma	38.500	4.750E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 28 shows the rounded value.

Table 28. Selected industry distribution of λ for LOCHS (PWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	6.0E-02	8.0E-02	8.0E-02	1.0E-01	Gamma	40.00	5.00E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

9 Loss of Vital DC Bus (LODC)

9.1 Initiating Event Description

From Reference 3, the Loss of Vital DC Bus (LODC) initiating event is any sustained de-energization of a safety-related bus due to the inability to connect to any of the normal or alternative electrical power supplies. The bus must be damaged or its power source unavailable for reasons beyond an open, remotely-operated feeder-breaker from a live power source. Examples include supply cable grounds, failed insulators, damaged disconnects, transformer deluge actuations, and improper uses of grounding devices.

9.2 Data Collection and Review

Data for the LODC baseline were obtained from the IEDB, as accessed using RADS. However, the SPAR event tree model for LODC assumes no recovery of the failed dc bus and assumes the bus powers significant safety features. The LODC events in the IEDB were reviewed to identify the subset of events that matched the event tree modeling assumptions in SPAR. That review resulted in two of three LODC events in the IEDB being dropped.

Using the process outlined in Section D.1.2 of Reference 6, the optimized baseline period for LODC is 1988–2002. (With only one event, the entire period is used for the baseline.) Figure 4 shows the trend of the full LODC data set and the baseline period used in this analysis. RADS was used to collect the LODC data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table 29 summarizes the data obtained from RADS and used in the LODC analysis.

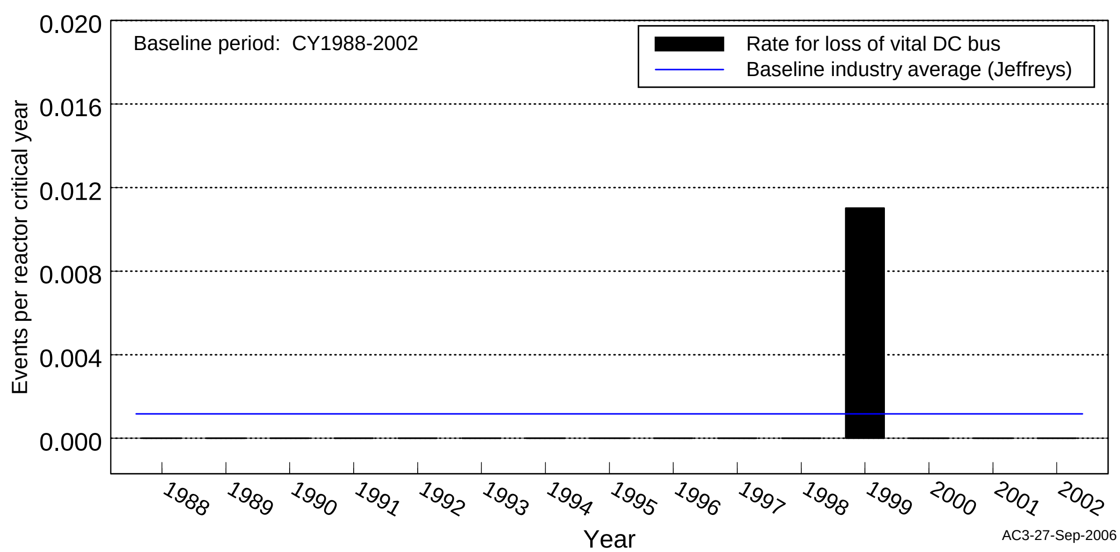

Figure 4. LODC trend plot.

Table 29. LODC frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
1	1282.4	1988–2002	113	0.9%

9.3 Data Analysis

The LODC data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table 30.

Table 30. Empirical distributions of MLEs for λ for LODC.

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	8.87E-04	0.00E+00
Industry	-	-	7.80E-04	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 29, only 0.9% of the plants experienced a LODC over the period 1988–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 99.1% portion of the distribution, and non-zero values above 99.1%.

Because of only one event, the empirical Bayes analysis was not performed. However, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table 31.

Table 31. Fitted distributions for λ for LODC.

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	4.60E-06	5.32E-04	1.17E-03	4.49E-03	Gamma	0.500	4.274E+02

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

9.4 Industry-Average Baselines

Table 32 lists the industry-average frequency distribution. With only one event, an empirical Bayes analysis could not be performed. Therefore, the SCNID analysis results were used. This industry-average frequency does not account for any recovery.

Table 32. Selected industry distribution of λ for LODC (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	4.60E-06	5.32E-04	1.17E-03	4.49E-03	Gamma	0.500	4.274E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

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

Table 33. Selected industry distribution of λ for LODC (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	5.0E-06	5.0E-04	1.2E-03	5.0E-03	Gamma	0.50	4.17E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

10 Loss of Instrument Air at Boiling Water Reactors (LOIA (BWR))

10.1 Initiating Event Description

From Reference 3, the Loss of Instrument Air at Boiling Water Reactors (LOIA (BWR)) initiating event is a total or partial loss of an instrument or control air system that leads to a reactor trip or occurs shortly after the reactor trip. Examples include ruptured air headers, damaged air compressors with insufficient backup capability, losses of power to air compressors, line fitting failures, improper system line-ups, and undesired operations of pneumatic devices in other systems caused by low air header pressure.

10.2 Data Collection and Review

Data for the LOIA (BWR) baseline were obtained from the IEDB, as accessed using RADS. However, the SPAR event tree model for LOIA assumes no recovery of the instrument air system failure. The LOIA events in the IEDB were reviewed to identify the subset of events that matched the event tree modeling assumptions in SPAR. That review resulted in approximately 70% of the events in the IEDB being dropped. Using the process outlined in Section D.1.2 of Reference 6, the optimized baseline period for LOIA (BWR) is 1991–2002. Figure 5 shows the trend of the full LOIA (BWR) data set and the baseline period used in this analysis. RADS was used to collect the LOIA (BWR) data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table 34 summarizes the data obtained from RADS and used in the LOIA (BWR) analysis.

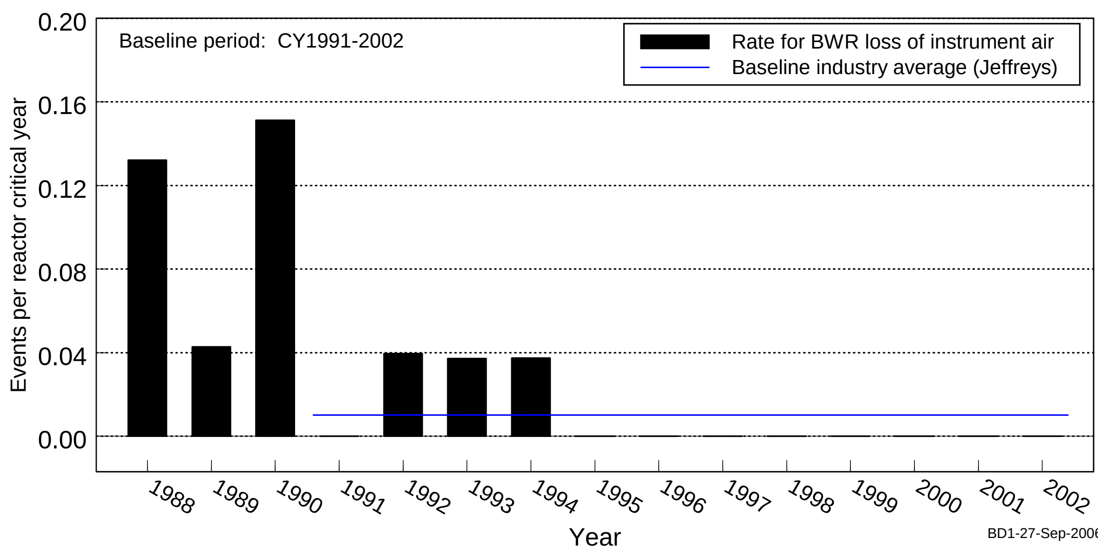

Figure 5. LOIA (BWR) trend plot.

Table 34. LOIA (BWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
3	343.3	1991–2002	36	8.3%

10.3 Data Analysis

The LOIA (BWR) data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry). At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table 35.

Table 35. Empirical distributions of MLEs for λ for LOIA (BWR).

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	9.53E-03	1.10E-01
Industry	-	-	8.74E-03	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 34, only 8.3% of the plants experienced a LOIA (BWR) over the period 1998–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 91.7% portion of the distribution, and non-zero values above 91.7%.

An empirical Bayes analysis was performed at the plant level but failed to converge. (This most likely was the result of insufficient variation between plants.) Therefore, assuming homogeneous data, a Bayesian update of the Jeffreys noninformative prior using the industry data was calculated. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and α = 0.5. Results from these analyses are presented in Table 36.

Table 36. Fitted distributions for λ for LOIA (BWR).

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	3.16E-03	9.24E-03	1.02E-02	2.05E-02	Gamma	3.500	3.433E+02
SCNID/IL	4.01E-05	4.64E-03	1.02E-02	3.92E-02	Gamma	0.500	4.902E+01

Note – JEFF/IL is a Bayesian update of the Jeffreys noninformative prior using industry data and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

10.4 Industry-Average Baselines

Table 37 lists the industry-average frequency distribution. The Bayesian update of the Jeffreys noninformative prior was selected. This industry-average frequency does not account for any recovery.

Table 37. Selected industry distribution of λ for LOIA (BWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	3.16E-03	9.24E-03	1.02E-02	2.05E-02	Gamma	3.500	3.433E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 38 shows the rounded value.

Table 38. Selected industry distribution of λ for LOIA (BWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	3.0E-03	9.0E-03	1.0E-02	2.0E-02	Gamma	4.00	4.00E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

11 Loss of Instrument Air at Pressurized Water Reactors (LOIA (PWR))

11.1 Initiating Event Description

From Reference 3, the Loss of Instrument Air at Pressurized Water Reactors (LOIA (PWR)) initiating event is a total or partial loss of an instrument or control air system that leads to a reactor trip or occurs shortly after the reactor trip. Examples include ruptured air headers, damaged air compressors with insufficient backup capability, losses of power to air compressors, line fitting failures, improper system line-ups, and undesired operations of pneumatic devices in other systems caused by low air header pressure.

11.2 Data Collection and Review

Data for the LOIA (PWR) baseline were obtained from the IEDB, as accessed using RADS. Similar to what was done for LOIA (BWR), the LOIA (PWR) events in the IEDB were reviewed to ensure the events matched the SPAR event tree modeling assumptions. That review resulted in some of the events being dropped. (However, none were dropped in the baseline period chosen.) Using the process outlined in Section D.1.2 of Reference 6, the optimized baseline period for LOIA (PWR) is 1997–2002. Figure 6 shows the trend of the full LOIA (PWR) data set and the baseline period used in this analysis. RADS was used to collect the LOIA (PWR) data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table 39 summarizes the data obtained from RADS and used in the LOIA (PWR) analysis.

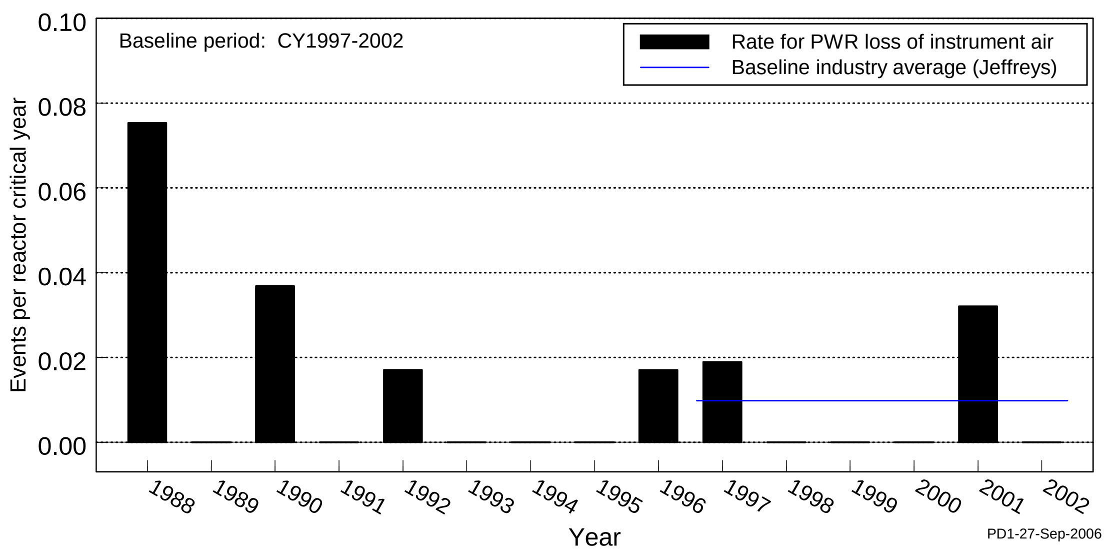

Figure 6. LOIA (PWR) trend plot.

Table 39. LOIA (PWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
3	356.9	1997–2002	70	2.9%

11.3 Data Analysis

The LOIA (PWR) data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table 40.

Table 40. Empirical distributions of MLEs for λ for LOIA (PWR).

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	8.86E-03	0.00E+00
Industry	-	-	8.41E-03	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 39, only 2.9% of the plants experienced a LOIA (PWR) over the period 1997–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 97.1% portion of the distribution, and non-zero values above 97.1%.

An empirical Bayes analysis was performed at the plant level but failed to converge. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table 41 for LOIA (PWR).

Table 41. Fitted distributions for λ for LOIA (PWR).

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	3.86E-05	4.46E-03	9.81E-03	3.77E-02	Gamma	0.500	5.099E+01

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

11.4 Industry-Average Baselines

Table 42 lists the industry-average frequency distribution. Because the empirical Bayes analysis did not converge, the SCNID distribution was used. This industry-average frequency does not account for any recovery.

Table 42. Selected industry distribution of λ for LOIA (PWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	3.86E-05	4.46E-03	9.81E-03	3.77E-02	Gamma	0.500	5.099E+01

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 43 shows the rounded value.

Table 43. Selected industry distribution of λ for LOIA (PWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	4.0E-05	4.0E-03	1.0E-02	4.0E-02	Gamma	0.50	5.00E+01

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

12 Loss of Main Feedwater (LOMFW)

12.1 Initiating Event Description

From Reference 3, the Loss of Main Feedwater (LOMFW) initiating event is a complete loss of all main feedwater flow. Examples include the following: trip of the only operating feedwater pump while operating at reduced power; the loss of a startup or an auxiliary feedwater pump normally used during plant startup; the loss of all operating feed pumps due to trips caused by low suction pressure, loss of seal water, or high water level (boiling water reactor vessel level or pressurized water reactor steam generator level); anticipatory reactor trip due to loss of all operating feed pumps; and manual reactor trip in response to feed problems characteristic of a total loss of feedwater flow, but prior to automatic reactor protection system signals. This category also includes the inadvertent isolation or closure of all feedwater control valves prior to the reactor trip; however, a main feedwater isolation caused by valid automatic system response after a reactor trip is not included. This category does not include the total loss of feedwater caused by the loss of offsite power.

12.2 Data Collection and Review

Data for the LOMFW baseline were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2 of Reference 6, the optimized baseline period for LOMFW is 1993–2002. Figure 7 shows the trend of the full LOMFW data set and the baseline period used in this analysis. RADS was used to collect the LOMFW data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table 44 summarizes the data obtained from RADS and used in the LOMFW analysis.

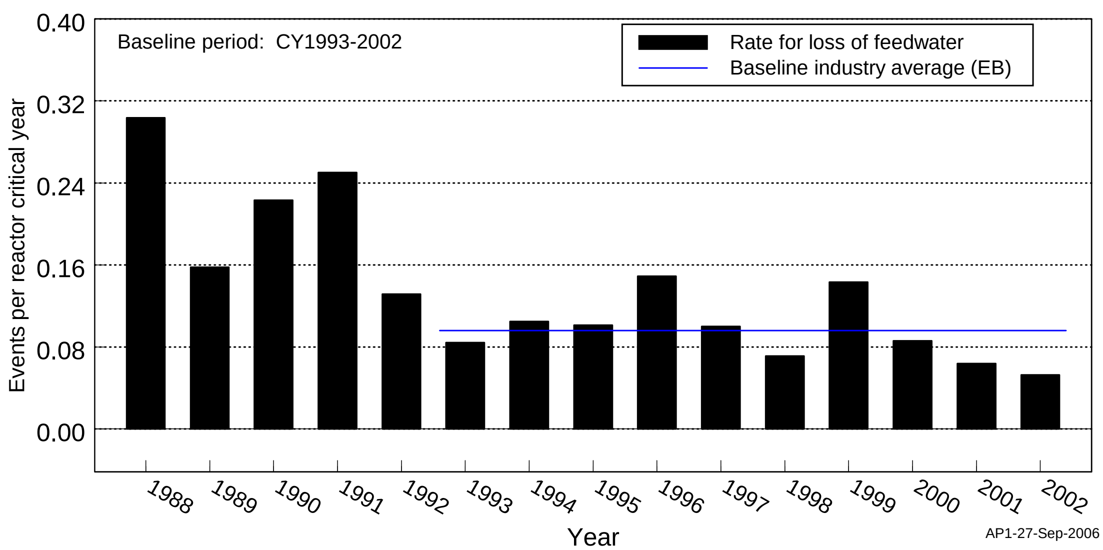

Figure 7. LOMFW trend plot.

Table 44. LOMFW frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
84	881.9	1993–2002	109	44.0%

12.3 Data Analysis

The LOMFW data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table 45.

Table 45. Empirical distributions of MLEs for λ for LOMFW.

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	9.61E-02	3.45E-01
Industry	-	-	9.52E-02	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 44, 44.0% of the plants experienced a LOMFW over the period 1993–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 56.0% portion of the distribution, and non-zero values above 56.0%.

An empirical Bayes analysis was performed at the plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table 46.

Table 46. Fitted distributions for λ for LOMFW.

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	9.06E-03	7.32E-02	9.59E-02	2.60E-01	Gamma	1.326	1.383E+01
SCNID/IL	3.77E-04	4.36E-02	9.58E-02	3.68E-01	Gamma	0.500	5.219E+00

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

12.4 Industry-Average Baselines

Table 47 lists the industry-average frequency distribution. The data set was sufficient for an empirical Bayes analysis to be performed. This industry-average frequency does not account for any recovery.

Table 47. Selected industry distribution of λ for LOMFW (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	9.06E-03	7.32E-02	9.59E-02	2.60E-01	Gamma	1.326	1.383E+01

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 47 shows the rounded value.

Table 48. Selected industry distribution of λ for LOMFW (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	8.0E-03	7.0E-02	1.0E-01	3.0E-01	Gamma	1.20	1.20E+01

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

13 Loss of Offsite Power (LOOP)

13.1 Initiating Event Description

From Reference 3, the Loss of Offsite Power (LOOP) initiating event is a simultaneous loss of electrical power to all safety-related buses that causes emergency power generators to start and supply power to the safety-related buses. The offsite power boundary extends from the offsite electrical power grid to the output breaker (inclusive) of the step-down transformer that feeds the first safety-related bus with an emergency power generator. The plant switchyard and service-type transformers are included within the offsite power boundary. This category includes the momentary or prolonged degradation of grid voltage that causes all emergency power generators to start (if operable) and load onto their associated safety-related buses (if available).

This category does not include a LOOP event that occurs while the plant is shutdown. In addition, it does not include any momentary undervoltage event that results in the automatic start of all emergency power generators, but in which the generators do not tie on to their respective buses due to the short duration of the undervoltage.

13.2 Data Collection and Review

The LOOP data were obtained directly from the report *Reevaluation of Station Blackout Risk at Nuclear Power Plants* (Ref. 4). A baseline period of 1997–2004 was used in that report. Table 49 summarizes the data used in the LOOP analysis. Figure 8 shows the trend of the full LOOP data set and the baseline period used in this analysis.

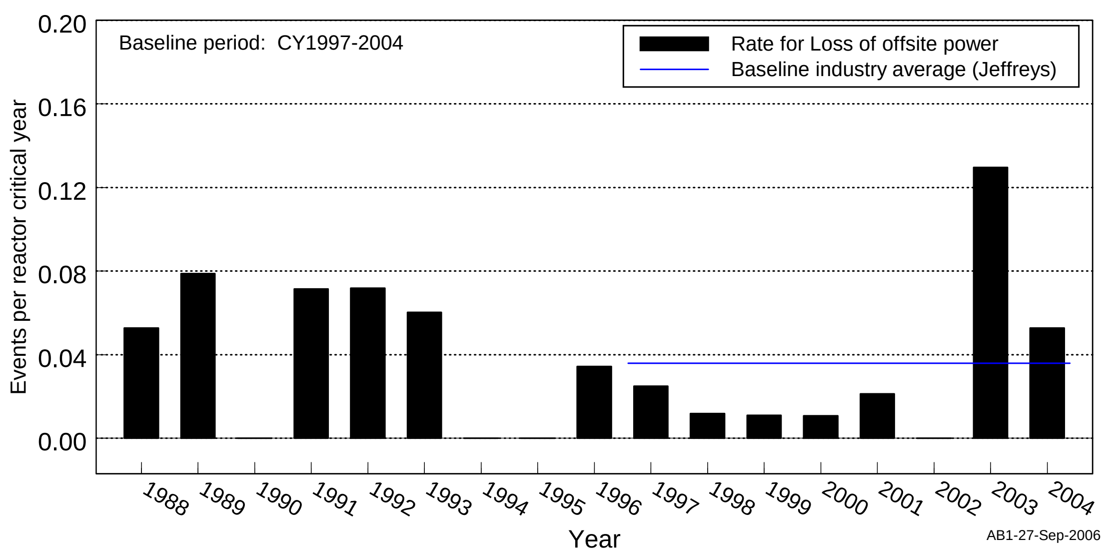

Figure 8. LOOP trend plot.

Table 49. LOOP frequency data for baseline period.

LOOP Category	Data After Review		Baseline Period	Counts Number of Plants	Percent of Plants with Events
	Events	Reactor Critical Years (rcry)			
Plant Centered	1	724.3	1997–2004	103	1.0%
Switchyard Centered	7	724.3	1997–2004	103	6.8%
Grid Related	13	724.3	1997–2004	103	12.6%
Weather Related	3	724.3	1997–2004	103	2.9%
Total LOOP	24	724.3	1997–2004	103	22.3%

13.3 Industry-Average Baselines

Table 50 lists the industry-average frequency distributions for the four LOOP categories and total LOOP. These industry-average frequencies do not account for any recovery.

Table 50. Selected industry distributions of λ for LOOP (before rounding).

Event	Source	5%	Median	Mean	95%	Distribution		
						Type	α	β
Plant Centered	LOOP	8.41E-06	9.42E-04	2.07E-03	7.96E-03	Gamma	0.500	2.414E+02
Switchyard Centered	LOOP	4.07E-05	4.71E-03	1.04E-02	3.98E-02	Gamma	0.500	4.829E+01
Grid Related	LOOP	7.33E-05	8.48E-03	1.86E-02	7.16E-02	Gamma	0.500	2.683E+01
Weather Related	LOOP	1.90E-05	2.20E-03	4.83E-03	1.86E-02	Gamma	0.500	1.035E+02
Total LOOP	LOOP	4.57E-03	2.87E-02	3.59E-02	9.19E-02	Gamma	1.580	4.402E+01

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

The SPAR models use the unrounded LOOP frequency distribution. However, for completeness, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 51 shows the rounded values for the LOOP initiating event.

Table 51. Selected industry distributions of λ for LOOP (after rounding).

Event	Source	5%	Median	Mean	95%	Distribution		
						Type	α	β
Plant Centered	LOOP	8.0E-06	9.0E-04	2.0E-03	8.0E-03	Gamma	0.50	2.50E+02
Switchyard Centered	LOOP	4.0E-05	5.0E-03	1.0E-02	4.0E-02	Gamma	0.50	5.00E+01
Grid Related	LOOP	8.0E-05	9.0E-03	2.0E-02	8.0E-02	Gamma	0.50	2.50E+01
Weather Related	LOOP	2.0E-05	2.5E-03	5.0E-03	2.0E-02	Gamma	0.50	1.00E+02
Total LOOP	LOOP	5.0E-03	3.0E-02	4.0E-02	1.0E-01	Gamma	1.50	3.75E+01

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

14 Loss of Emergency Service Water (LOESW)

14.1 Initiating Event Description

From Reference 3, the Loss of Service Water System (LOSWS) initiating event is a total loss of service water flow. The service water system (SWS) can be an open-cycle or a closed-cycle cooling water system. An open-cycle SWS takes suction from the plant's ultimate heat sink (e.g., the ocean, bay, lake, pond or cooling towers), removes heat from safety-related systems and components, and discharges the water back to the ultimate heat sink. A closed-cycle or intermediate SWS removes heat from safety-related equipment and discharges the heat through a heat exchanger to an open-cycle service water system.

For this report, the definition was specialized to include only emergency service water (ESW) systems. Therefore, the initiating event is Loss of Emergency Service Water (LOESW).

14.2 Data Collection and Review

Data for the LOESW baseline were obtained from the IEDB, as accessed using RADS. That search identified one LOSWS event at a plant with a SWS that had one running pump and one standby pump. However, that SWS was the normally-operating non-safety SWS. The ESW at that plant is a backup to the SWS and it started successfully when this event occurred. Therefore, this event is not a LOESW.

Using the process outlined in Section D.1.2 of Reference 6, the optimized baseline period for LOESW is 1988–2002. (There were no events.) RADS was used to collect the LOESW data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table 52 summarizes the data obtained from RADS and used in the LOESW analysis.

Table 52. LOESW frequency data.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
0	1269.4	1988–2002	112	0.0%

14.3 Data Analysis

The LOESW data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. However, in this case there were no events, so all of the MLEs are zero. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table 53.

Table 53. Empirical distributions of MLEs for λ for LOESW.

Aggregation Level	5%	Median	Mean	95%
Plant	-	-	-	-
Industry	-	-	0.00E+00	-

Note – Percentiles and the mean have units of events/rcry.

With no events, an empirical Bayes analysis could not be performed. However, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table 54.

Table 54. Fitted distributions for λ for LOESW.

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	1.55E-06	1.79E-04	3.94E-04	1.51E-03	Gamma	0.500	1.269E+03

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

14.4 Industry-Average Baselines

Table 55 lists the industry-average frequency distribution. With no events, the empirical Bayes analysis could not be performed. Therefore, the SCNID analysis results were used. This industry-average frequency does not account for any recovery.

Table 55. Selected industry distribution of λ for LOESW (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	1.55E-06	1.79E-04	3.94E-04	1.51E-03	Gamma	0.500	1.269E+03

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 56 shows the rounded value.

Table 56. Selected industry distribution of λ for LOESW (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	1.5E-06	2.0E-04	4.0E-04	1.5E-03	Gamma	0.50	1.25E+03

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

15 Partial Loss of Component Cooling Water System (PLOCCW)

15.1 Initiating Event Description

From Reference 3, the Partial Loss of Component Cooling Water System (PLOCCW) initiating event is a loss of one train of a multiple train system or partial loss of a single train system that impairs the ability of the system to perform its function. Examples include pump cavitation, filter fouling, and piping rupture. The component cooling water (CCW) is a closed-cycle cooling water system that removes heat from safety-related equipment and discharges the heat through a heat exchanger to an open-cycle service water system.

These categories do not include a loss of a redundant component in a CCW as long as the remaining, similar components provide the required level of performance. For example, a loss of a single CCW pump is not classified as a partial loss of a CCW as long as the remaining operating or standby pumps can provide the required level of performance. A loss of CCW to a single component in another system because of a blockage or incorrect line-up that does not affect the cooling to other components serviced by the train is not included under this category, but is instead classified as a failure of the system that the single component serves.

15.2 Data Collection and Review

Data for the PLOCCW baseline were obtained from the IEDB, as accessed using RADS. However, the SPAR event tree models for PLOCCW assume unrecovered loss of at least one safety system train. The PLOCCW events in the IEDB were reviewed to identify the subset of events that matched the event tree modeling assumptions in SPAR. That review resulted in approximately 80% of the original PLOCCW events in the IEDB being dropped. (However, those dropped events are still included in the transient or other IE categories.)

Using the process outlined in Section D.1.2 of Reference 6, the optimized baseline period for PLOCCW is 1988–2002. (With only one event, the entire period is chosen for the baseline.) Figure 9 shows the trend of the full PLOCCW data set and the baseline period used in this analysis. RADS was used to collect the PLOCCW data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table 57 summarizes the data obtained from RADS and used in the PLOCCW analysis.

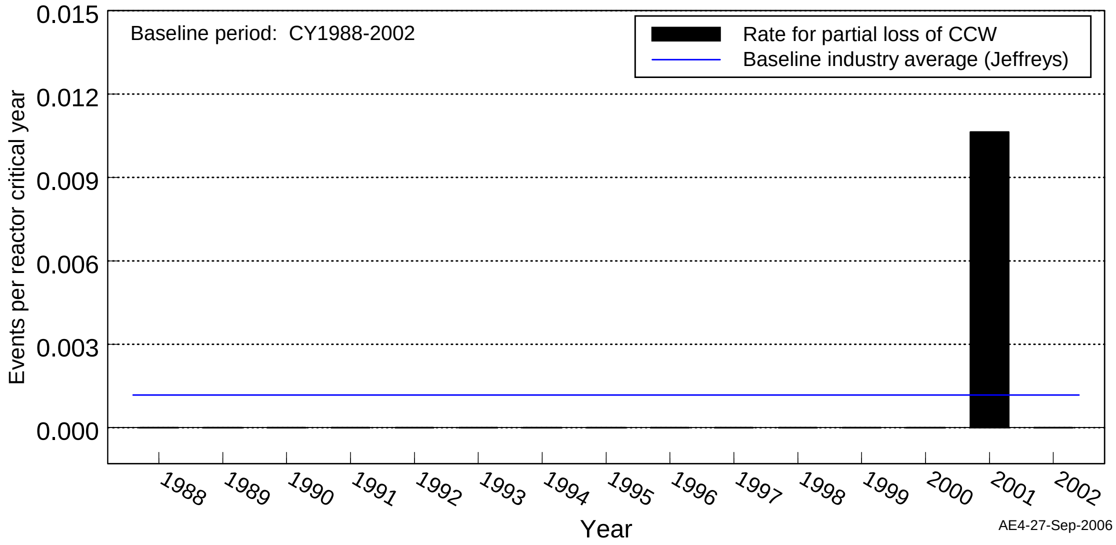

Figure 9 PLOCCW trend plot.

Table 57. PLOCCW frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
1	1282.4	1988–2002	113	0.9%

15.3 Data Analysis

The PLOCCW data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table 58.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 57, only 1.9% of the plants experienced a PLOCCW over the period 1998–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 98.1% portion of the distribution, and non-zero values above 98.1%.

Table 58. Empirical distributions of MLEs for λ for PLOCCW.

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	7.78E-04	0.00E+00
Industry	-	-	7.80E-04	-

Note – Percentiles and the mean have units of events/rcry.

With only one event, the empirical Bayes analysis could not be performed. However, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table 59 for PLOCCW.

Table 59. Fitted distributions for λ for PLOCCW.

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	4.60E-06	5.32E-04	1.17E-03	4.49E-03	Gamma	0.500	4.274E+02

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

15.4 Industry-Average Baselines

Table 60 lists the industry-average frequency distribution. With only one event the empirical Bayes analysis could not be performed. Therefore, the SCNID analysis results were used. This industry-average frequency does not account for any recovery.

Table 60. Selected industry distribution of λ for PLOCCW (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	4.60E-06	5.32E-04	1.17E-03	4.49E-03	Gamma	0.500	4.274E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 61 shows the rounded value for the PLOCCW initiating event.

Table 61. Selected industry distribution of λ for PLOCCW (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	5.0E-06	5.0E-04	1.2E-03	5.0E-03	Gamma	0.50	4.17E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

16 Partial Loss of Emergency Service Water (PLOESW)

16.1 Initiating Event Description

From Reference 3, the Partial Loss of Service Water System (PLOSWS) initiating event is a loss of one train of a multiple train system or partial loss of a single train system that impairs the ability of the system to perform its function. Examples include pump cavitation, strainer fouling, and piping rupture.

This category does not include loss of a redundant component in a SWS as long as the remaining, similar components provide the required level of performance. For example, a loss of a single SWS pump is not classified as a PLOSWS as long as the remaining operating or standby pumps can provide the required level of performance. A loss of service water to a single component in another system because of a blockage or incorrect line-up that does not affect the cooling to other components serviced by the train is not included under this category, but is instead classified as a failure of the system that the single component serves.

For this report, the definition was specialized to include only emergency service water (ESW) systems; therefore, the initiating event is Partial Loss of Emergency Service Water (PLOESW).

16.2 Data Collection and Review

Data for the PLOESW baseline were obtained from the IEDB, as accessed using RADS. However, the SPAR event tree models for PLOESW assume unrecoverable loss of more than one safety system train. The PLOESW events in the IEDB were reviewed to identify the subset of events that matched the event tree modeling assumptions in SPAR. That review resulted in approximately 80% of the original PLOSWS events in the IEDB being dropped. (However, those dropped events are still included in the transient or other IE categories.)

Using the process outlined in Section D.1.2 of Reference 6, the optimized baseline period for PLOESW is 1988–2002. (With only two events, the entire period is chosen for the baseline.) Figure 10 shows the trend of the full PLOESW data set and the baseline period used in this analysis. RADS was used to collect the PLOESW data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table 62 summarizes the data obtained from RADS and used in the PLOESW analysis.

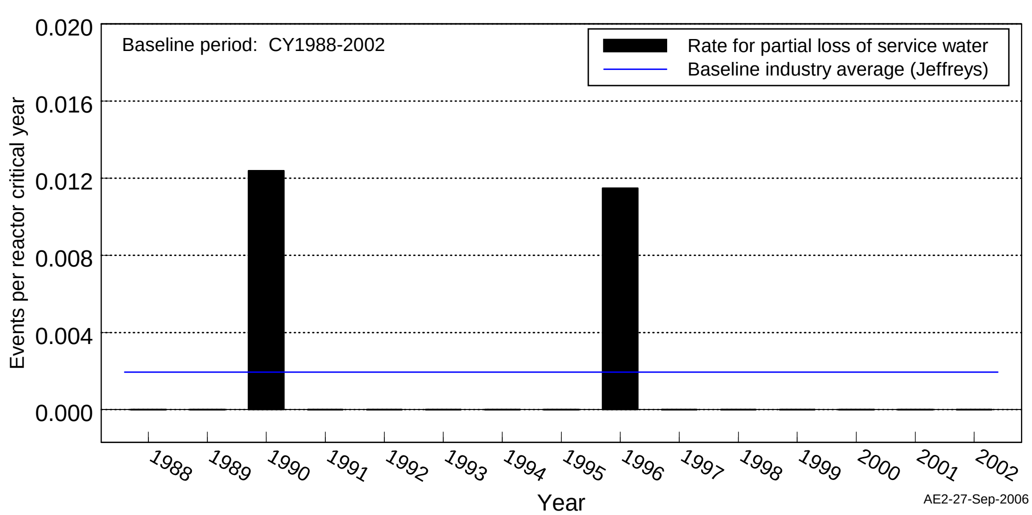

Figure 10. PLOESW trend plot.

Table 62. PLOESW frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
2	1282.4	1988–2002	113	1.8%

16.3 Data Analysis

The PLOESW data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table 63.

Table 63. Empirical distributions of MLEs for λ for PLOESW.

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	2.11E-03	0.00E+00
Industry	-	-	1.56E-03	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 62, only 1.8% of the plants experienced a PLOSWS over the period 1988–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 98.2% portion of the distribution, and non-zero values above 98.2%.

An empirical Bayes analysis was performed at the plant level. However, no results were obtained because of so few events. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table 64 for PLOESW.

Table 64. Fitted distributions for λ for PLOESW.

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	7.66E-06	8.87E-04	1.95E-03	7.49E-03	Gamma	0.500	2.565E+02

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

16.4 Industry-Average Baselines

Table 65 lists the industry-average frequency distribution. With only two events, an empirical Bayes analysis could not be performed. Therefore, the SCNID analysis results were used. This industry-average frequency does not account for any recovery.

Table 65. Selected industry distribution of λ for PLOESW (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	7.66E-06	8.87E-04	1.95E-03	7.49E-03	Gamma	0.500	2.565E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 66 shows the rounded value.

Table 66. Selected industry distribution of λ for PLOESW (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	8.0E-06	9.0E-04	2.0E-03	8.0E-03	Gamma	0.50	2.50E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

17 Steam Generator Tube Rupture (STGR)

17.1 Initiating Event Description

From Reference 3, the Steam Generator Tube Rupture (STGR) initiating event is a rupture of one or more steam generator tubes that results in a loss of primary coolant to the secondary side of the steam generator at a rate greater than or equal to 100 gallons per minute (gpm). A SGTR can occur as the initial plant fault, such as a tube rupture caused by high cycle fatigue or loose parts, or as a consequence of another initiating event. The latter case would be classified as a functional impact. This category applies to pressurized water reactors (PWRs) only. This category includes excessive leakage caused by the failure of a previous SGTR repair (i.e., leakage past a plug).

17.2 Data Collection and Review

Two methodologies are summarized in this section. For one approach, information for the SGTR baseline was obtained from *Estimating Loss-of-Coolant Accident (LOCA) Frequencies through the Elicitation Process* (Ref. 5). In that document, the SGTR frequency was estimated based on an expert elicitation process "…to consolidate service history data and PFM [probabilistic fracture mechanics] studies with knowledge of plant design, operation, and material performance." Reference 5 is a draft document. Results obtained from that document could change when the final report is issued.

From Table 7.3 in Reference 5, the mean frequency for SGTR ((> 100 gpm) is 3.4E-3/reactor calendar year (rcy). To convert this to reactor critical years (rcry's), it was assumed that reactors are critical 90% of each year. Converting to rcry's, the result is

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

The associated error factor (95^{th} percentile divided by median) associated with the SGTR category from Reference 5 is

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

which converts to an α of 1.6.

For the other approach, data for the STGR baseline were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2 of Reference 6, the optimized baseline period for STGR is 1991–2002. Figure 11 shows the trend of the full STGR data set and the baseline period used in this analysis. RADS was used to collect the STGR data for that period. Results include total number of events and total rcry's for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table 67 summarizes the data obtained from RADS and used in the STGR analysis.

Table 67. STGR frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
2	706.4	1991–2002	76	2.6%

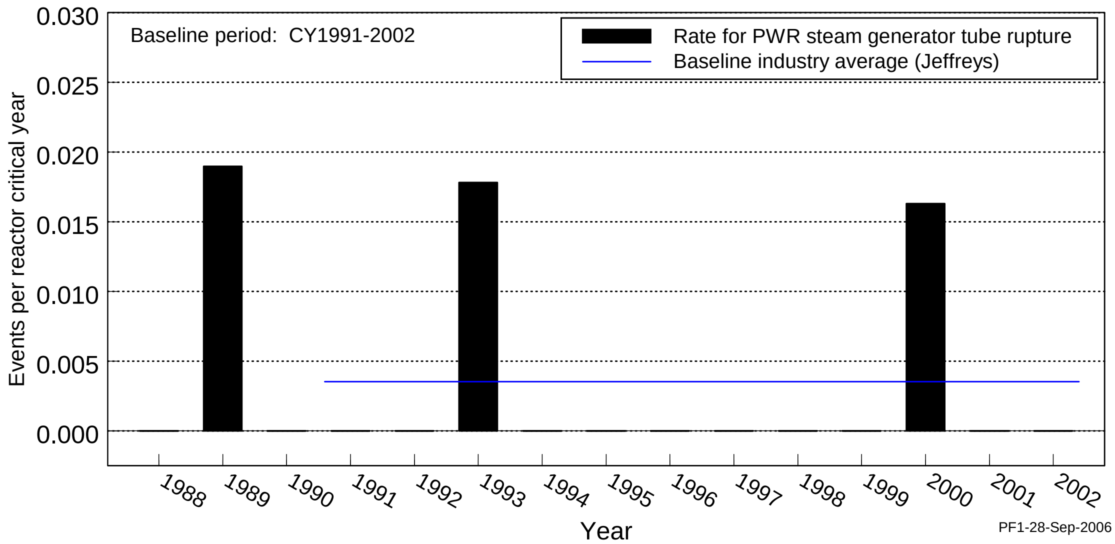

Figure 11. SGTR trend plot.

17.3 Data Analysis

The STGR data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table 68.

Table 68. Empirical distributions of MLEs for λ for STGR.

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	2.83E-03	0.00E+00
Industry	-	-	2.83E-03	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 67, only 2.6% of the plants experienced a STGR over the period 1991–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 97.4% portion of the distribution, and non-zero values above 97.4%.

With only two events, the empirical Bayes analysis could not be performed. However, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table 69 for STGR.

Table 69. Fitted distributions for λ for STGR.

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	1.39E-05	1.61E-03	3.54E-03	1.36E-02	Gamma	0.500	1.413E+02

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

17.4 Industry-Average Baselines

Table 70 lists the industry-average frequency distribution. Two different approaches to estimating the frequency for SGTR were discussed – the expert elicitation approach from Reference 5, and the data analysis using the IEDB. Because the expert elicitation process outlined in Reference 5 resulted in a mean frequency for SGTR (3.78E-3/rcry) higher than that obtained from optimizing the SGTR data from the IEDB (3.54E-3/rcry), the IEDB results were used. This industry-average frequency does not account for any recovery.

Table 70. Selected industry distribution of λ for STGR (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	1.39E-05	1.61E-03	3.54E-03	1.36E-02	Gamma	0.500	1.413E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 71 shows the rounded value.

Table 71. Selected industry distribution of λ for STGR (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	1.5E-05	2.0E-03	4.0E-03	1.5E-02	Gamma	0.50	1.25E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

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

18.1 Initiating Event Description

From Reference 3, the Small Loss-of-Coolant Accident (SLOCA) initiating event is defined for a boiling water reactor (BWR) as a break size less than 0.004 square feet (or a 1-inch inside diameter pipe equivalent for liquid) and less than 0.05 square feet (or an approximately 4-inch inside diameter pipe equivalent for steam) in a pipe in the primary system boundary. However, the leakage must be greater than 100 gallons per minute (gpm), which is the upper limit for the very small LOCA, or VSLOCA.

18.2 Data Collection and Review

Two methodologies are summarized in this section. For one approach, information for the SLOCA (BWR) baseline was obtained from *Estimating Loss-of-Coolant Accident (LOCA) Frequencies through the Elicitation Process* (Ref. 5). In that document, the SLOCA frequency was estimated based on an expert elicitation process "…to consolidate service history data and PFM [probabilistic fracture mechanics] studies with knowledge of plant design, operation, and material performance." Reference 5 is a draft document. Results obtained from that document could change when the final report is issued.

Table 7.1 in Reference 5 presents frequencies for LOCAs exceeding various sizes indicated by gpm break flow and effective pipe size break. Six different sizes are listed, ranging from 0.5-inch diameter (> 100 gpm) to 31-inch or 41-inch diameter (> 500,000 gpm). The frequencies presented for each size indicate the frequency of LOCAs of that size or greater occurring. In addition, frequencies for each size are presented for current day conditions (assuming an average of 25 years of operation) and for end-of-life conditions (40 years of operation). For this study, frequencies appropriate for current day conditions were used.

From Table 7.1 in Reference 5, the SLOCA frequency (in reactor calendar years or rcy's) for BWRs is

5.5E-4/rcy – 1.0E-4/rcy = 4.5E-4/rcy,

where 5.5E-4/rcy is for LOCAs with an effective break size greater than 0.5-inch inside diameter, and 1.0E-6/rcy is the MLOCA value. To convert this to reactor critical years (rcry's), it was assumed that reactors are critical 90% of each year. Converting to rcry's, the result is

(4.50E-4/rcy)(1 rcy/0.9 rcry) = 5.00E-4/rcry.

The associated error factor (95^{th} percentile divided by median) associated with the > 0.5-in. category from Reference 5 is

(1.6E-3/rcy)/(3.0E-4/rcy) = 5.3,

which converts to an α of 0.78.

For the other approach, data for the SLOCA (BWR) baseline were also obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2 of Reference 6, the optimized baseline period for SLOCA (BWR) is 1988–2002. (With no events, the entire period is chosen for the baseline.) RADS was used to collect the SLOCA data for the baseline period. Results include total number of events and total rcry's for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table 72 summarizes the data obtained from RADS and used in the SLOCA (BWR) analysis.

Table 72. SLOCA (BWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
0	415.8	1988–2002	36	0.0%

18.3 Data Analysis

With no events, the empirical Bayes analysis could not be performed. However, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table 73.

Table 73. Fitted distribution for λ for SLOCA (BWR).

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	4.72E-06	5.46E-04	1.20E-03	4.61E-03	Gamma	0.500	4.167E+02

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

18.4 Industry-Average Baselines

Table 74 lists the industry-average frequency distribution. Two different approaches to estimating the frequency for SLOCA (BWR) were discussed – the expert elicitation approach from Reference 5, and the data analysis using the IEDB. Because the IEDB contained no events and the resulting SCNID mean (1.20E-3/rcry) is higher than the expert elicitation estimate (5.00E-4/rcry), the expert elicitation distribution was chosen. (The IEDB was considered to be too limited in terms of current BWR experience to be used, given that no events had occurred.) This industry-average frequency does not account for any recovery.

Table 74. Selected industry distribution of λ for SLOCA (BWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	1.26E-05	3.09E-04	5.00E-04	1.64E-03	Gamma	0.780	1.560E+03

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 75 shows the rounded value.

Table 75. Selected industry distribution of λ for SLOCA (BWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	1.5E-05	3.0E-04	5.0E-04	1.5E-03	Gamma	0.80	1.60E+03

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

19 Small Loss-of-Coolant Accident at Pressurized Water Reactors (SLOCA (PWR))

19.1 Initiating Event Description

From Reference 3, the Small Loss-of-Coolant Accident (SLOCA) initiating event is defined for a pressurized water reactor (PWR) as a pipe break in the primary system boundary with an inside diameter between 0.5 and 2 inch.

19.2 Data Collection and Review

Two methodologies are summarized in this section. For one approach, information for the SLOCA (PWR) baseline was obtained from *Estimating Loss-of-Coolant Accident (LOCA) Frequencies through the Elicitation Process* (Ref. 5). In that document, the SLOCA frequency was estimated based on an expert elicitation process "…to consolidate service history data and PFM [probabilistic fracture mechanics] studies with knowledge of plant design, operation, and material performance." Reference 5 is a draft document. Results obtained from that document could change when the final report is issued.

Table 7.1 in Reference 5 presents frequencies for LOCAs exceeding various sizes indicated by gallon per minute (gpm) break flow and effective pipe size break. Six different sizes are listed, ranging from 0.5-inch diameter (> 100 gpm) to 31-inch or 41-inch diameter (> 500,000 gpm). The frequencies presented for each size indicate the frequency of LOCAs of that size or greater occurring. In addition, frequencies for each size are presented for current day conditions (assuming an average of 25 years of operation) and for end-of-life conditions (40 years of operation). For this study, frequencies appropriate for current day conditions were used.

From Table 7.1 in Reference 5, the SLOCA frequency (in reactor calendar years or rcy's) for PWRs is

5.9E-3/rcy – 4.6E-4/rcy = 5.44E-3/rcy,

where 5.9E-3/rcy is for LOCAs with an effective break size greater than 0.5-inch inside diameter (including SGTRs), and 4.6E-4/rcy is the MLOCA value. Because SPAR models SGTR as a separate initiator, the SGTR frequency must be subtracted from the above result. From Reference 5, the SGTR mean frequency is 3.4E-3/rcy. Therefore, with the SGTR contribution removed, the SLOCA frequency for PWRs is

5.44E-3/rcy – 3.4E-3/rcy = 2.04E-3/rcy.

To convert this to reactor critical years (rcry's), it was assumed that reactors are critical 90% of each year. Converting to rcry's, the result is

(2.04E-3/rcy)(1 rcy/0.9 rcry) = 2.27E-3/rcry.

The associated error factor (95th percentile divided by median) associated with the > 0.5-in. category from Reference 5 is

(1.5E-2/rcy)/(3.7E-3/rcy) = 4.1,

which converts to an α of 1.09.

For the other approach, data for the SLOCA (PWR) baseline were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2 of Reference 6, the optimized baseline period for SLOCA (PWR) is 1988–2002. (With no events, the entire period is chosen for the baseline.) RADS was used to collect the SLOCA data for the baseline period. Results include total number of events and total rcry's for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table 76 summarizes the data obtained from RADS and used in the SLOCA (PWR) analysis.

Table 76. SLOCA (PWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
0	866.6	1988–2002	77	0.0%

19.3 Data Analysis

The SLOCA (PWR) data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry). At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. However, with no events all the MLEs are zero. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table 77.

Table 77. Empirical distributions of MLEs for λ for SLOCA (PWR).

Aggregation Level	5%	Median	Mean	95%
Plant	-	-	-	-
Industry	-	-	0.00E+00	-

Note – Percentiles and the mean have units of events/rcry.

With no events, an empirical Bayes analysis could not be performed. However, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and α = 0.5. Results from these analyses are presented in Table 78.

Table 78. Fitted distributions for λ for SLOCA (PWR).

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	2.27E-06	2.62E-04	5.77E-04	2.22E-03	Gamma	0.500	8.666E+02

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

19.4 Industry-Average Baselines

Table 79 lists the industry-average frequency distribution. Two different approaches to estimating the frequency for SLOCA (PWR) were discussed—the expert elicitation approach from Reference 5, and the data analysis using the IEDB. Because the expert elicitation process outlined in Reference 5 resulted in a mean frequency for SLOCA (PWR) (2.27E-3/rcry) higher than that obtained from optimizing the SGTR data from the IEDB (5.77E-4/rcry), the IEDB results were used. This industry-average frequency does not account for any recovery.

Table 79. Selected industry distribution of λ for SLOCA (PWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	2.27E-06	2.62E-04	5.77E-04	2.22E-03	Gamma	0.500	8.666E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 80 shows the rounded value.

Table 80. Selected industry distribution of λ for SLOCA (PWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	2.5E-06	2.5E-04	6.0E-04	2.5E-03	Gamma	0.50	8.33E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

20 Stuck Open Relief Valve at Boiling Water Reactors (SORV (BWR))

20.1 Initiating Event Description

From Reference 3, the Stuck Open Relief Valve at Boiling Water Reactors (SORV (BWR)) initiating event is a failure of one primary system safety and/or relief valve (SRV) to fully close, resulting in the loss of primary coolant. The valves included in this category are main steam line safety valves (BWR) and automatic depressurization system relief valves (BWR). The stuck open SRV may or may not cause the automatic or manual actuation of high pressure injection systems.

This category includes a stuck open valve that cannot be subsequently closed upon manual demand or does not subsequently close on its own immediately after the reactor trip. The mechanism that opens the valve is not a defining factor. The different mechanisms than can open an SRV are transient-induced opening, manual opening during valve testing, and spurious opening.

20.2 Data Collection and Review

Data for the SORV (BWR) baseline were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2 of Reference 6, the optimized baseline period for SORV (BWR) is 1993–2002. Figure 12 shows the trend of the full SORV (BWR) data set and the baseline period used in this analysis. RADS was used to collect the SORV (BWR) data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table 81 summarizes the data obtained from RADS and used in the SORV (BWR) analysis.

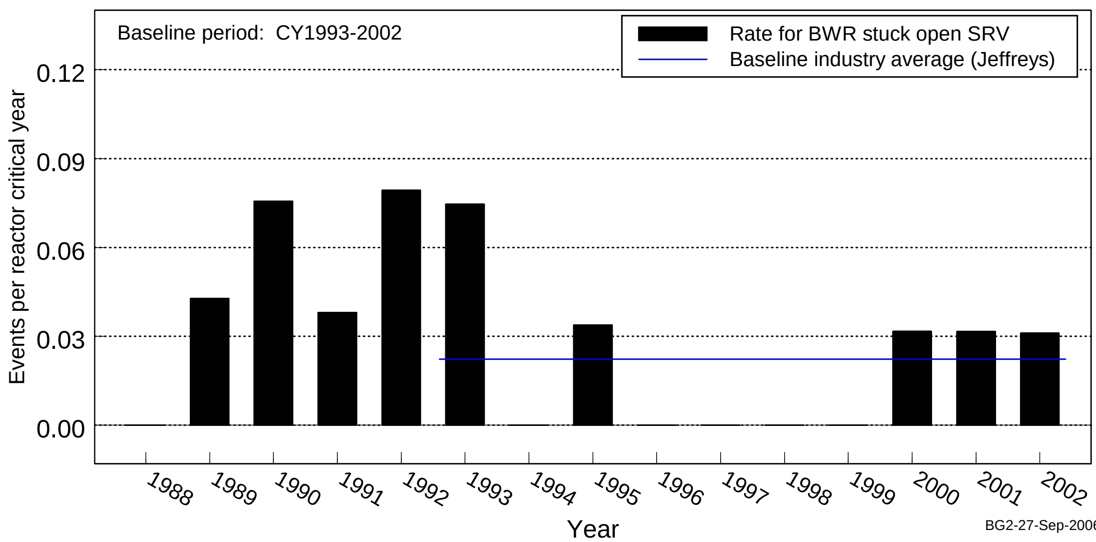

Figure 12. SORV (BWR) trend plot.

Table 81. SORV (BWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
6	291.7	1993–2002	36	16.7%

20.3 Data Analysis

The SORV (BWR) data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table 82.

Table 82. Empirical distributions of MLEs for λ for SORV (BWR).

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	2.00E-02	1.18E-01
Industry	-	-	2.06E-02	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 81, only 16.7% of the plants experienced a SORV (BWR) over the period 1993–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 83.3% portion of the distribution, and non-zero values above 83.3%.

An empirical Bayes analysis was performed at the plant level but failed to converge. (This most likely was the result of insufficient variation between plants.) Therefore, assuming homogeneous data, a Bayesian update of the Jeffreys noninformative prior using the industry data was calculated. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table 83.

Table 83. Fitted distributions for λ for SORV (BWR).

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	1.01E-02	2.12E-02	2.23E-02	3.83E-02	Gamma	6.500	2.917E+02
SCNID/IL	8.76E-05	1.01E-02	2.23E-02	8.56E-02	Gamma	0.500	2.244E+01

Note – JEFF/IL is a Bayesian update of the Jeffreys noninformative prior using industry data and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

20.4 Industry-Average Baselines

Table 84 lists the industry-average frequency distribution. The Bayesian update of the Jeffreys noninformative prior was selected. This industry-average frequency does not account for any recovery.

Table 84. Selected industry distribution of λ for SORV (BWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	1.01E-02	2.12E-02	2.23E-02	3.83E-02	Gamma	6.500	2.917E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 95 shows the rounded value.

Table 85. Selected industry distribution of λ for SORV (BWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	9.0E-03	2.0E-02	2.0E-02	4.0E-02	Gamma	6.00	3.00E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

21 Stuck Open Relief Valve at Pressurized Water Reactors (SORV (PWR))

21.1 Initiating Event Description

From Reference 3, the Stuck Open Relief Valve at Pressurized Water Reactors (SORV (PWR)) initiating event is a failure of one primary system safety and/or relief valve (SRV) to fully close, resulting in the loss of primary coolant. The valves included in this category are pressurizer code safety valves (PWR). The stuck open SRV may or may not cause the automatic or manual actuation of high pressure injection systems.

21.2 Data Collection and Review

Data for the SORV (PWR) baseline were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2 of Reference 6, the optimized baseline period for SORV (PWR) is 1988–2002. (With only two events, the entire period is chosen for the baseline.) Figure 13 shows the trend of the full SORV (PWR) data set and the baseline period used in this analysis. RADS was used to collect the SORV (PWR) data for that period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table 86 summarizes the data obtained from RADS and used in the SORV (PWR) analysis.

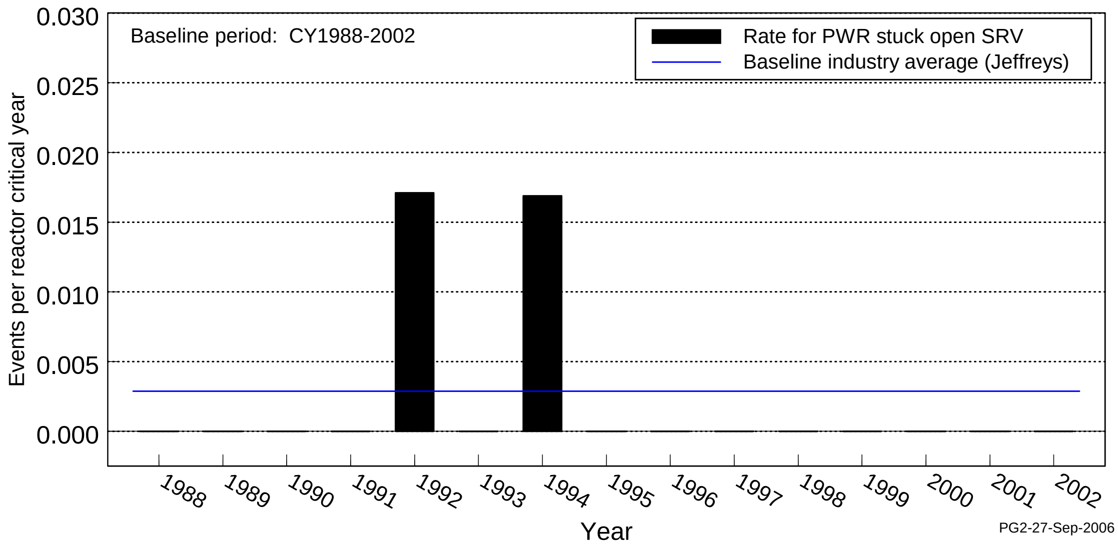

Figure 13. SORV (PWR) trend plot.

Table 86. SORV (PWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
2	866.6	1988–2002	77	2.6%

21.3 Data Analysis

The SORV (PWR) data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table 87.

Table 87. Empirical distributions of MLEs for λ for SORV (PWR).

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	2.20E-03	0.00E+00
Industry	-	-	2.31E-03	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 86, only 2.6% of the plants experienced a SORV (PWR) over the period 1988–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 97.4% portion of the distribution, and non-zero values above 97.4%.

With only two events, an empirical Bayes analysis could not be performed. However, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table 88.

Table 88. Fitted distributions for λ for SORV (PWR).

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	1.13E-05	1.31E-03	2.88E-03	1.11E-02	Gamma	0.500	1.733E+02

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

21.4 Industry-Average Baselines

Table 89 lists the industry-average frequency distribution. With only two events, an empirical Bayes analysis could not be performed. Therefore, the SCNID analysis results were used. This industry-average frequency does not account for any recovery.

Table 89. Selected industry distribution of λ for SORV (PWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	1.13E-05	1.31E-03	2.88E-03	1.11E-02	Gamma	0.500	1.733E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 90 shows the rounded value.

Table 90. Selected industry distribution of λ for SORV (PWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	1.2E-05	1.2E-03	3.0E-03	1.2E-02	Gamma	0.50	1.67E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

22 General Transient at Boiling Water Reactors (TRAN (BWR))

22.1 Initiating Event Description

From Reference 3, the General Transient at Boiling Water Reactors (TRAN (BWR)) initiating event is a general transient that results in automatic or manual reactor trips but does not degrade safety system response.

22.2 Data Collection and Review

Data for the TRAN (BWR) baseline were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2 of Reference 6, the optimized baseline period for TRAN (BWR) is 1997–2002. Figure 14 shows the trend of the full TRAN (BWR) data set and the baseline period used in this analysis. RADS was used to collect the TRAN (BWR) data for the baseline period. Only initial plant fault events as defined in Reference 3 were used. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table 91 summarizes the data obtained from RADS and used in the TRAN (BWR) analysis.

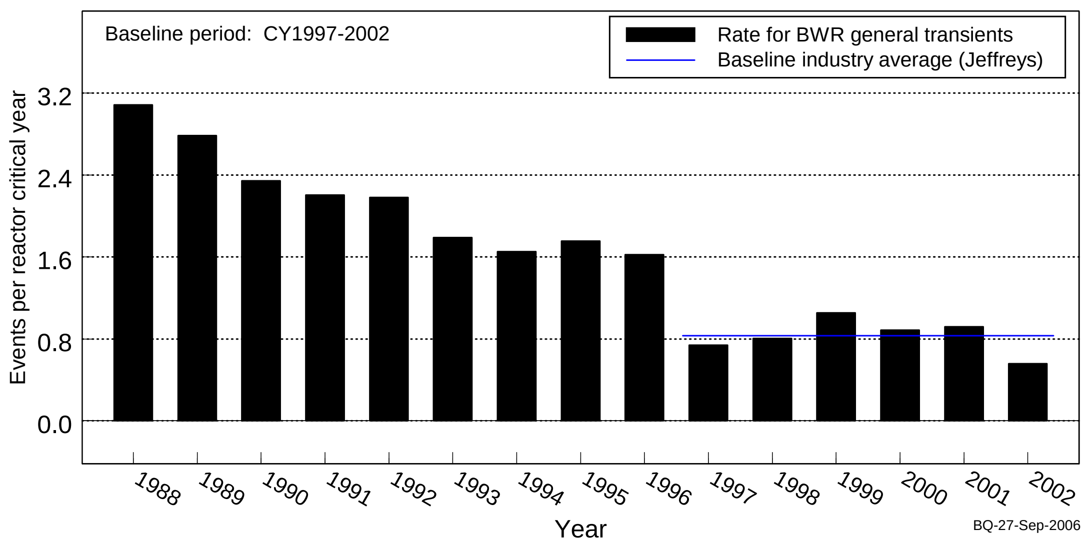

Figure 14. TRAN (BWR) trend plot.

Table 91. TRAN (BWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
149	180.2	1997–2002	35	97.1%

22.3 Data Analysis

The TRAN (BWR) data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry. At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table 92.

Table 92. Empirical distributions of MLEs for λ for TRAN (BWR).

Aggregation Level	5%	Median	Mean	95%
Plant	1.95E-01	7.43E-01	8.17E-01	1.53E+00
Industry	-	-	8.27E-01	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). However, for this initiating event, almost the entire distribution of MLEs is non-zero. For example, from Table 91, 97.1% of the plants experienced a TRAN (BWR) over the period 1997–2002, so the empirical distribution of MLEs, at the plant level, involves zeros only for the 0% to 2.9% portion of the distribution, and non-zero values above 2.9%.

An empirical Bayes analysis was performed at the plant level but failed to converge. (This most likely was the result of insufficient variation between plants.) Therefore, assuming homogeneous data, a Bayesian update of the Jeffreys noninformative prior using the industry data was calculated. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table 93.

Table 93. Fitted distributions for λ for TRAN (BWR).

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	7.21E-01	8.28E-01	8.30E-01	9.44E-01	Gamma	149.500	1.802E+02
SCNID/IL	3.26E-03	3.78E-01	8.30E-01	3.19E+00	Gamma	0.500	6.026E-01

Note – JEFF/IL is a Bayesian update of the Jeffreys noninformative prior using industry data and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

22.4 Industry-Average Baselines

Table 94 lists the industry-average frequency distribution. The Bayesian update of the Jeffreys noninformative prior was selected. This industry-average frequency does not account for any recovery.

Table 94. Selected industry distribution of λ for TRAN (BWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	7.21E-01	8.28E-01	8.30E-01	9.44E-01	Gamma	149.500	1.802E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 95 shows the rounded value.

Table 95. Selected industry distribution of λ for TRAN (BWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
JEFF/IL	7.0E-01	8.0E-01	8.0E-01	9.0E-01	Gamma	150.00	1.88E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

23 General Transient at Pressurized Water Reactors (TRAN (PWR))

23.1 Initiating Event Description

From Reference 3, the General Transient at Boiling Water Reactors (TRAN (PWR)) initiating event is a general transient that results in automatic or manual reactor trips but does not degrade safety system response.

23.2 Data Collection and Review

Data for the TRAN (PWR) baseline were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2 of Reference 6, the optimized baseline period for TRAN (PWR) is 1998–2002. Figure 15 shows the trend of the full TRAN (PWR) data set and the baseline period used in this analysis. RADS was used to collect the TRAN (PWR) data for the baseline period. Only initial plant fault events as defined in Reference 3 were used. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table 96 summarizes the data obtained from RADS and used in the TRAN (PWR) analysis.

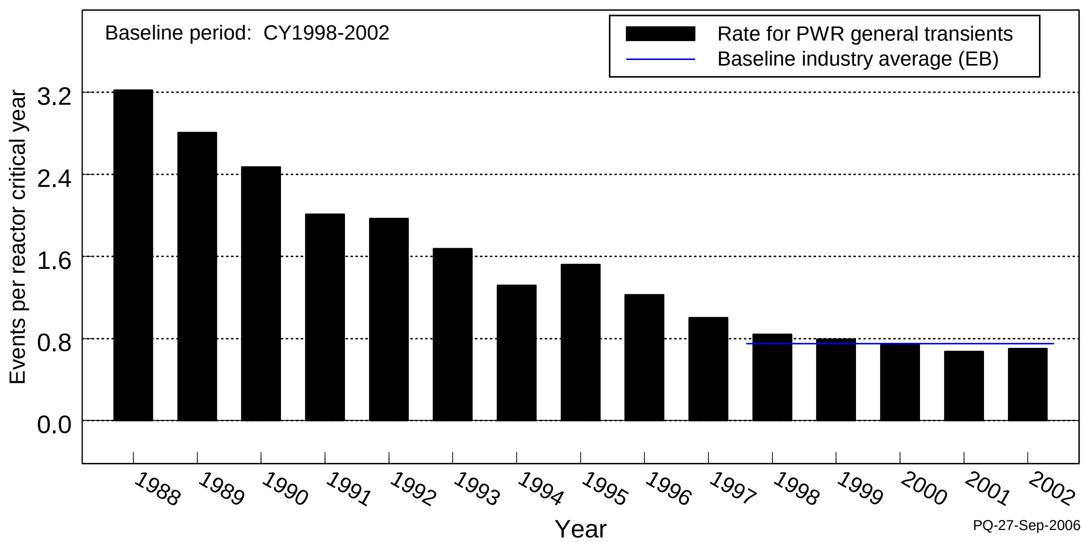

Figure 15. TRAN (PWR) trend plot.

Table 96. TRAN (PWR) frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
228	304.0	1998–2002	69	92.8%

23.3 Data Analysis

The TRAN (PWR) data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry). At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table 97.

Table 97. Empirical distributions of MLEs for λ for TRAN (PWR).

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	6.61E-01	7.63E-01	1.76E+00
Industry	-	-	7.50E-01	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). However, for this initiating event, almost the entire distribution of MLEs is non-zero. For example, from Table 99, 92.8% of the plants experienced a TRAN (PWR) over the period 1998–2002, so the empirical distribution of MLEs, at the plant level, involves zeros only for the 0% to 7.2% portion of the distribution, and non-zero values above 7.2%.

An empirical Bayes analysis was performed at the plant level. In addition, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table 98 for TRAN (PWR).

Table 98. Fitted distributions for λ for TRAN (PWR).

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	4.84E-01	7.37E-01	7.51E-01	1.07E+00	Gamma	17.772	2.365E+01
SCNID/IL	2.96E-03	3.42E-01	7.52E-01	2.89E+00	Gamma	0.500	6.652E-01

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

23.4 Industry-Average Baselines

Table 99 lists the industry-average frequency distribution. The data set was sufficient for an empirical Bayes analysis to be performed. This industry-average frequency does not account for any recovery.

Table 99. Selected industry distribution of λ for TRAN (PWR) (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	4.84E-01	7.37E-01	7.51E-01	1.07E+00	Gamma	17.772	2.365E+01

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 100 shows the rounded value.

Table 100. Selected industry distribution of λ for TRAN (PWR) (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	5.0E-01	7.0E-01	8.0E-01	1.2E+00	Gamma	20.00	2.50E+01

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

24 Very Small Loss-of-Coolant Accident (VSLOCA)

24.1 Initiating Event Description

From Reference 3, the Very Small Loss of Coolant Accident (VSLOCA) initiating event is a pipe break or component failure that results in a loss of primary coolant between 10 to 100 gallons per minute (gpm), but does not require the automatic or manual actuation of high pressure injection systems. Examples include reactor coolant pump (for pressurized water reactors) or recirculating pump (for boiling water reactors) seal failures, valve packing failures, steam generator tube leaks, and instrument line fitting failures.

24.2 Data Collection and Review

Data for the VSLOCA baseline were obtained from the IEDB, as accessed using RADS. Using the process outlined in Section D.1.2 of Reference 6, the optimized baseline period for VSLOCA is 1992–2002. Figure 16 shows the trend of the full VSLOCA data set and the baseline period used in this analysis. RADS was used to collect the VSLOCA data for the baseline period. Results include total number of events and total reactor critical years (rcry's) for the U.S. commercial nuclear power plant industry. These results also include the individual plant results for the same period. Table 101 summarizes the data obtained from RADS and used in the VSLOCA analysis.

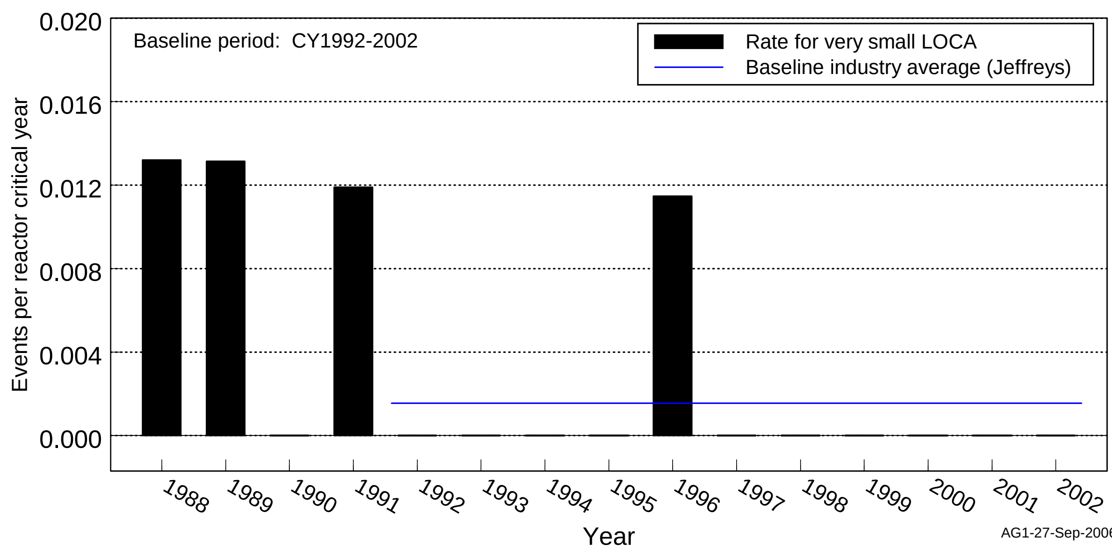

Figure 16. VSLOCA trend plot.

Table 101. VSLOCA frequency data for baseline period.

Data After Review		Baseline Period	Number of Plants	Percent of Plants with Events
Events	Reactor Critical Years (rcry)			
1	965.8	1992–2002	111	0.9%

24.3 Data Analysis

The VSLOCA data can be examined at the plant or industry level. At each level, maximum likelihood estimates (MLEs) are events/rcry). At the plant level, the MLEs are ordered from smallest to largest and the resulting empirical distribution parameters calculated. The industry level includes only one estimate, an industry MLE, so an empirical distribution cannot be obtained at this level. Results for both levels are presented in Table 102.

Table 102. Empirical distributions of MLEs for λ for VSLOCA.

Aggregation Level	5%	Median	Mean	95%
Plant	0.00E+00	0.00E+00	1.23E-03	0.00E+00
Industry	-	-	1.04E-03	-

Note – Percentiles and the mean have units of events/rcry.

The MLE distributions at the plant level typically provide no information for the lower portion of the distribution (other than to indicate zeros). For example, from Table 101, only 0.9% of the plants experienced a VSLOCA over the period 1992–2002, so the empirical distribution of MLEs, at the plant level, involves zeros for the 0% to 99.1% portion of the distribution, and non-zero values above 99.1%.

Because of only one event an empirical Bayes analysis could not be performed. However, the simplified constrained noninformative distribution (SCNID) was generated, based on the Jeffreys mean and $\alpha = 0.5$. Results from these analyses are presented in Table 103 for VSLOCA.

Table 103. Fitted distributions for λ for VSLOCA.

Analysis Type	5%	Median	Mean	95%	Distribution		
					Type	α	β
EB/PL/KS	-	-	-	-	-	-	-
SCNID/IL	6.11E-06	7.07E-04	1.55E-03	5.97E-03	Gamma	0.500	3.220E+02

Note –EB/PL/KS is an empirical Bayes analysis at the plant level with the Kass-Steffey adjustment, and SCNID/IL is a simplified constrained noninformative distribution at the industry level. Percentiles and the mean have units of events/rcry. The units for β are rcry.

24.4 Industry-Average Baselines

Table 104 lists the industry-average frequency distribution. Because of only one event, an empirical Bayes analysis could not be performed. Therefore, the SCNID analysis results were used. This industry-average frequency does not account for any recovery.

Table 104. Selected industry distribution of λ for VSLOCA (before rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	6.11E-06	7.07E-04	1.55E-03	5.97E-03	Gamma	0.500	3.220E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

For use in the SPAR models, the industry-average frequencies were rounded to 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, or 9.0 times the appropriate power of ten. Similarly, the α parameter was rounded. In order to preserve the mean value, the β parameter is presented to three significant figures. Table 105 shows the rounded value.

Table 105. Selected industry distribution of λ for VSLOCA (after rounding).

Source	5%	Median	Mean	95%	Distribution		
					Type	α	β
SCNID/IL	6.0E-06	7.0E-04	1.5E-03	6.0E-03	Gamma	0.50	3.33E+02

Note – Percentiles and the mean have units of events/rcry. The units for β are rcry.

25 References

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