Rates of Initiating Events at

U.S. Nuclear Power Plants

1988–2012

This report presents an analysis of initiating event (IE) frequencies at United States (U.S.) commercial nuclear power plants since each plants Low-Power License date. The evaluation is based on the operating experience from fiscal year 1988 through 2012, as reported in Licensee Event Reports (LERs). This is the latest update to NUREG/CR-5750 (Reference 1), updating data, frequency estimates, trends, and figures.

1 LATEST FREQUENCIES AND TRENDS

This report displays occurrence rates (baseline frequencies) for the categories of initiating events that contribute to the NRC's Industry Trend monitoring program and others. Sixteen initiating event groupings are trended and displayed. BWR and PWR initiators are plotted separately for initiating events with different occurrence rates for the two plant types. Each figure is annotated with the p-value[1] for the possible presence of a trend over the most recent 10 years.

1.1 Baseline Frequencies

In accordance with the Industry Trends Program (ITP), particular starting years have been identified for each of these initiating events for baseline periods during which the initiating event frequencies are approximately constant.

The maximum likelihood estimate (the total number of events divided by the total number of reactor critical years) is plotted for each occurrence rate in each fiscal year. For each baseline period, the maximum likelihood estimate is the total event count (summed over the calendar years in the baseline period), divided by the corresponding sum of reactor critical years. In addition, the mean of the distribution used in the ITP (Jeffreys or empirical Bayes) is presented in Table 1.

The limits in each year are simple 5^{th} and 95^{th} percent confidence bounds. For the baseline period, the horizontal limits are computed from the predictive distribution (Poisson-Gamma) that describes the number of events that would be expected in a following year based on the number of events (plus 0.5), the occurrence time in the baseline period, and the exposure time in the following year. The predictive bounds for the baseline period assume that the occurrences are following a constant rate for that period and the future. Comparing future data with those bounds helps to determine whether the data are changing.

1. Statistical significance is defined in terms of the 'p-value.' A p-value is a probability indicating whether to accept or reject the null hypothesis that there is no trend in the data. P-values of less than or equal to 0.05 indicate that we are 95% confident that there is a trend in the data (reject the null hypothesis of no trend.) By convention, we use the "Michelin Guide" scale: p-value < 0.05 (statistically significant), p-value < 0.01 (highly statistically significant); p-value < 0.001 (extremely statistically significant).

Initiating events occur infrequently in nuclear power plants (NPP). Among the categories currently trended on the IE web page, six have prediction limits on the counts of at least 6, while the count limits for the remaining 10 IEs are either 3 events per year or 2 events per year. The IEs in the first category occur more commonly, and are described here as "infrequent," while the other initiators are sparse. Four of the sparse initiators continue to employ baseline periods that use as much of the U.S. NPP historic data as possible.

1.1.1 Re-Evaluation of Baseline Periods for Baseline Frequencies

New baseline periods ending in 2010 are being sought. For the four very sparse initiators, using all the data is still desirable. The total number of baseline period events for any of these initiators is still less than 5, although the reporting period data time span has increased from 15 years to 23 years.

Treating the other six initiators with prediction limits of 2 or 3 events per year the same as the very sparse initiators results in baseline periods with reasonable properties. That is, the hypothesis of homogeneity between years is not rejected, and significant trends are not seen. These periods are "long," as with the very sparse initiators. The starting year is not changed while the ending year is moved to 2010.

For the remaining six initiators with relatively high original baseline period prediction limits (greater than 5 events in a future year), moving just the ending year to 2010 results in some baseline periods with significant decreasing trends. Also, for LOOP, the hypothesis of homogeneous data across years is rejected (the p-value is extremely highly significant). An alternate choice is to preserve the length of the baseline periods for these initiators. The initial choices for baseline periods included sufficient data to characterize performance. Keeping the length of the period as initially established in the Industry Trend Program continues that pattern while using the more current data (2010). This choice works well for all of the IEs except LOOP. The new baseline data are homogenous and do not exhibit a significant trend.

Special Considerations for LOOP

Basing the selection for LOOP on the original baseline period length produces a new period (2003 to 2010) that also fails the qualifications for baseline periods. The data are not homogenous with regard to year, and there is a highly statistically significant decreasing trend. Moreover, a different criterion for selection of the LOOP baseline is appropriate because the original selection was based on when the electrical distribution systems were deregulated (1997), rather than on data needs.

LOOP performance during operational periods varies widely from year to year. The events are often not independent. The probability of a grid or weather related LOOP affecting more than one unit at a multi-unit site is relatively high (the estimate is 0.39; see 2011 LOOP Update). The data have more scatter than the other IE categories. The data from 2001 to 2004 typify this scatter, with 2, 0, 12, and 5 events, respectively. On the other hand, there were no LOOP events in 2010, the target ending year of the baseline periods.

In addition to the 2003-2010 period for LOOP, the period from 2002 to 2010 and the period from 2004 to 2010 were considered for the baseline period for LOOP. The longer period had the same problems of highly significant between-year differences and decreasing trend. However, the 2004-2010 period performs better and is now used for detecting trends (see Table 1). The p-value for a test of homogeneity continues to reject the hypothesis, but it is no longer highly statistically significant (0.018). The trend drops below significance (to 0.079), although the goodness-of-fit test for the Poisson regression remains poor (p-value 0.015).

Table 1 summarizes the updated baseline data. It includes the data totals, the upper prediction limit that could be used in an evaluation of short-term trends, and information about representative industry gamma distributions for each initiator frequency.

1.2 Trends

Table 2 shows the current 10-year trends for the sixteen IEs being tracked and data for the current year. The Trend column reports the p-value and an indication of increasing or decreasing for statistically significant p-values. The p-value is also shown in each figure. In addition, the current year (2012) IE count is shown and is compared to its prediction limit (PL).

Previous updates have shown the trend from CY 1988. Starting with the 2012 update, the trends are based on data from the most recent 10 years. Plots of the data and trend line follow. The baseline periods and prediction limit bounds are marked. The vertical bounds in each year are confidence bounds. A separate link provides tables of LERs associated with the events and tables of the plotted data.

The trend line plot for partial loss of service water does not show because it drops abruptly from the data value for 2003 to zero and stays there. It matches the data almost exactly.

Table 1. Baseline initiating event periods, prediction limits, and frequencies. (cont)

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Initiating event category	Figure No.	Baseline Period (ending 2010) (CY)			Prediction Limit (PL)			Industry Gamma Distribution				
		Start	No. of events	Reactor critical years	Period length (future year)	95% event count	95% Rate	Test of homo-geneity	Type[1]	Mean	α	β
Loss of offsite power	Figure 1	2004	11	664.57	93.6	5	5.34E-02	Rejects (Note 2)	EB/yr	1.66E-02	0.4	22.4
Loss of vital AC bus	Figure 2	1992	11	1722.24	93.6	3	3.21E-02	0.53	NI	6.68E-03	11.5	1722.2
Loss of vital DC bus	Figure 3	1988	1	2038.63	93.6	2	2.14E-02	(Note 3)	NI	7.36E-04	1.5	2038.6
Very small LOCA	Figure 4	1992	2	1722.24	93.6	2	2.14E-02	1.00	NI	1.45E-03	2.5	1722.2
Partial loss of CCW	Figure 5	1988	4	2038.63	93.6	2	2.14E-02	0.24	NI	2.21E-03	4.5	2038.6
Loss of feedwater	Figure 6	2001	49	946.02	93.6	10	1.07E-01	0.10	EB/PL	5.19E-02	1.5	28.9
Partial loss of service water	Figure 7	1988	4	2038.63	93.6	2	2.14E-02	0.24	NI	2.21E-03	4.5	2038.6
BWR loss of instrument air	Figure 8	1991	4	600.19	31.5	2	6.35E-02	1.00	NI	7.50E-03	4.5	600.2
BWR stuck open SRV	Figure 9	1993	9	548.67	31.5	3	9.52E-02	0.91	NI	1.73E-02	9.5	548.7
BWR loss of heat sink	Figure 10	2004	25	225.72	31.5	8	2.54E-01	0.33	EB/PL	1.11E-01	1.2	10.7
BWR general transients	Figure 11	2005	141	194.02	31.5	33	1.05E+00	0.36	EB/PL	7.33E-01	6.5	8.8
PWR loss of instrument air	Figure 12	1997	7	856.76	62.1	3	4.83E-02	0.84	NI	8.75E-03	7.5	856.8

1. This column indicates the method of obtaining the Gamma distribution. EB/yr indicates that the Empirical Bayes method was used and the yearly data is the source of the variability. EB/PL indicates that the Empirical Bayes method was used and the plant to plant data is the source of the variability. NI means that the non-informative prior was used to obtain a distribution (this generally means that the data were sparse or that there is no variability in the data).

2. The p-value is 0.02, which is statistically significant but not highly statistically significant. LOOP performance during operational periods varies widely from year to year and the events are often not independent. At this point, it is not feasible to obtain a baseline period that is homogeneous.

3. No test p-value is reported because there is only one event in the industry exposure time from 1988 to 2010.

Table 1. Baseline initiating event periods, prediction limits, and frequencies. (cont)

Initiating event category	Figure No.	Baseline Period (ending 2010) (CY)			Prediction Limit (PL)			Industry Gamma Distribution				
		Start	No. of events	Reactor critical years	Period length (future year)	95% event count	95% Rate	Test of homo-geneity	Type[1]	Mean	α	β
PWR steam generator tube rupture	Figure 13	1991	2	1205.98	62.1	2	3.22E-02	1.00	NI	2.07E-03	2.5	1206.0
PWR stuck open SRV	Figure 14	1988	2	1365.97	62.1	2	3.22E-02	1.00	NI	1.83E-03		
PWR loss of heat sink	Figure 15	2003	30	500.03	62.1	8	1.29E-01	0.17	NI	6.10E-02	30.5	500.0
PWR general transients	Figure 16	2006	200	313.26	62.1	52	8.37E-01	0.23	EB/PL	6.39E-01	3.3	5.2

Table 2. Current initiating event data and trend summary

Initiating event category	Figure No.	All data (since 1987)		Most Recent 10 years			Update year (FY)				
		No. of events	Reactor critical years	No. of events	Reactor critical years	Trend (P-Value)	No. of events	Reactor critical years	Frequency (MLE)	95% PL event count	Count compared with PL
Loss of offsite power	Figure 1	75	2217.53	35	941.5	0.174	5	91.7	5.45E-02	5	Same (Note a)
Loss of vital AC bus	Figure 2	13	2217.53	4	941.5	0.388	1	91.7	1.09E-02	3	Lower
Loss of vital DC bus	Figure 3	2	2217.53	1	941.5	1.000	0	91.7	0.00E+00	2	Lower
Very small LOCA	Figure 4	5	2217.53	1	941.5	0.428	0	91.7	0.00E+00	2	Lower
Partial loss of CCW	Figure 5	4	2217.53	3	941.5	0.222	0	91.7	0.00E+00	2	Lower
Loss of feedwater	Figure 6	207	2217.53	44	941.5	0.001↓	1	91.7	1.09E-02	10	Lower
Partial loss of service water	Figure 7	4	2217.53	2	941.5	- (Note b)	0	91.7	0.00E+00	2	Lower
BWR loss of instrument air	Figure 8	12	734.61	1	321.3	0.605	0	32.5	0.00E+00	2	Lower
BWR stuck open SRV	Figure 9	16	734.61	3	321.3	0.216	0	32.5	0.00E+00	3	Lower
BWR loss of heat sink	Figure 10	155	734.61	36	321.3	0.012↓	2	32.5	6.15E-02	8	Lower
BWR general transients	Figure 11	885	734.61	231	321.3	0.012↓	18	32.5	5.54E-01	33	Lower
PWR loss of instrument air	Figure 12	16	1482.92	4	620.2	0.503	0	59.2	0.00E+00	3	Lower
PWR steam generator tube rupture	Figure 13	3	1482.92	0	620.2	1.000	0	59.2	0.00E+00	2	Lower
PWR stuck open SRV	Figure 14	2	1482.92	0	620.2	1.000	0	59.2	0.00E+00	2	Lower
PWR loss of heat sink	Figure 15	114	1482.92	34	620.2	0.137	2	59.2	3.38E-02	8	Lower
PWR general transients	Figure 16	1724	1482.92	413	620.2	0.007↓	25	59.2	4.23E-01	52	Lower

a) The number of occurrences exceeded the baseline prediction limit. The five events occurred in 91.7 years, while the 95% (or higher) count limit for the baseline period is 5 events in 93.6 years.

b) The PLOSWS p-value was essentially zero (highly significant) because the data had 2 occurrences in the first year of the 10-year period and none in the rest.

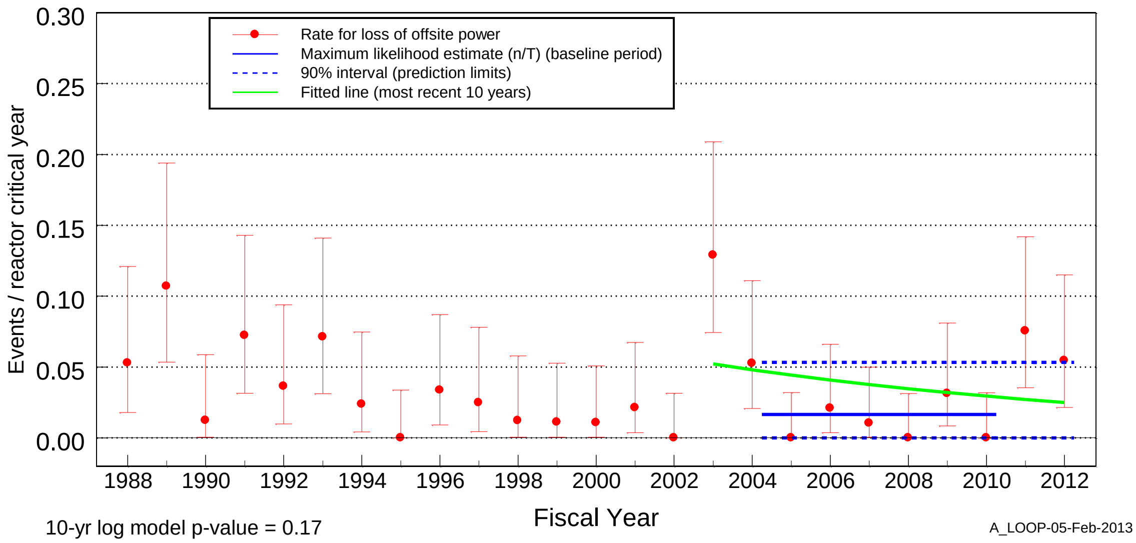

Figure 1. Frequency of initiating events with a loss of off-site power.

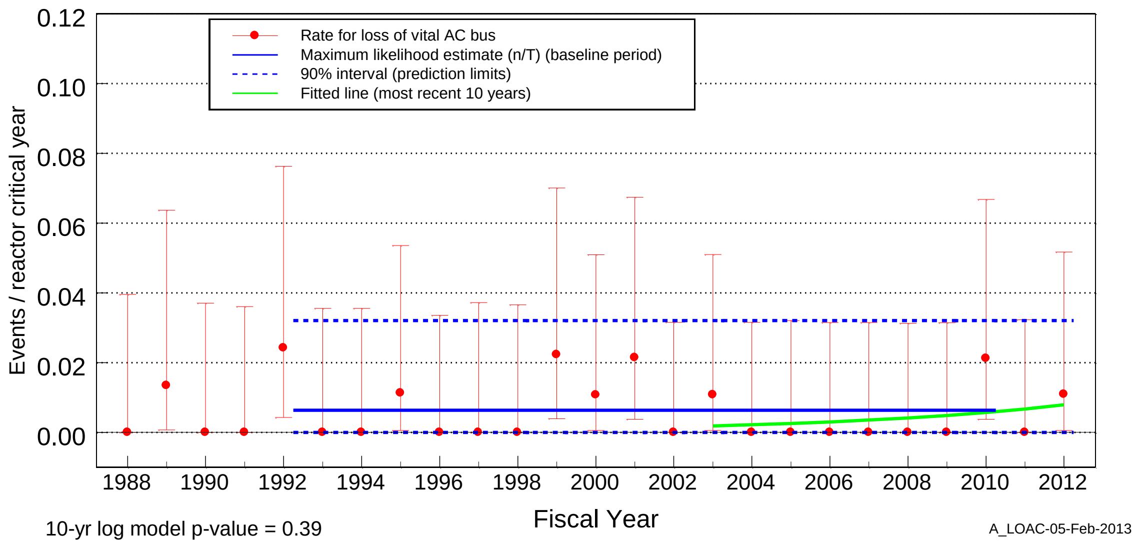

Figure 2. Frequency of initiating events with loss of vital AC bus.

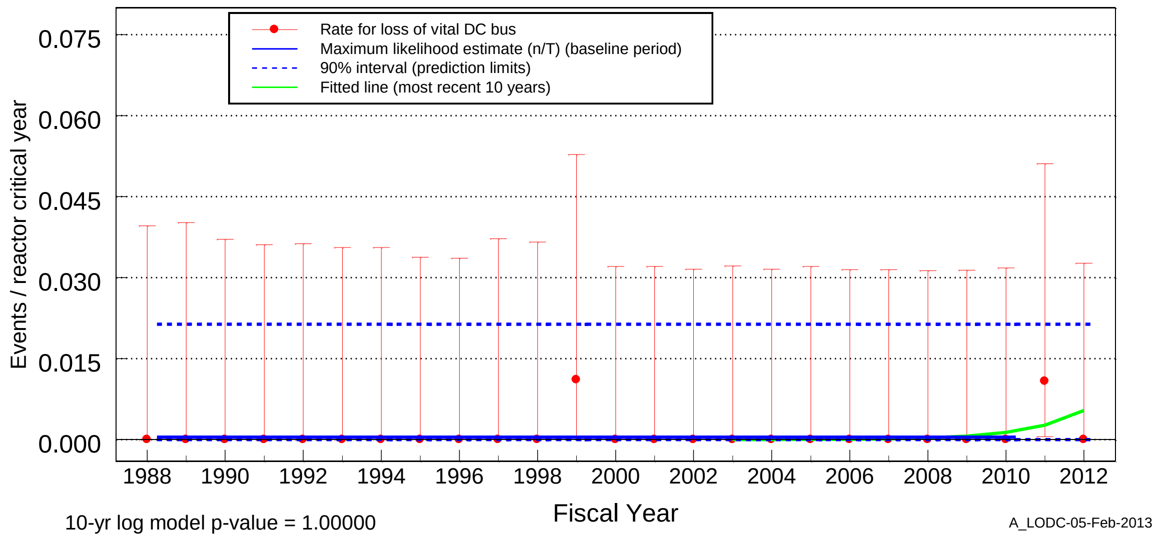

Figure 3. Frequency of initiating events with loss of vital DC bus.

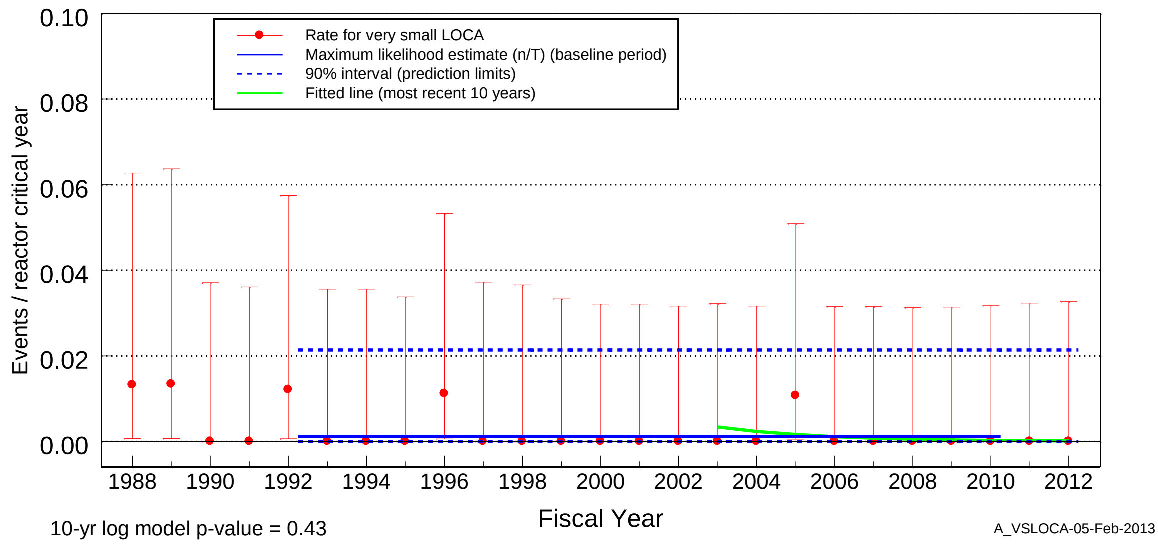

Figure 4. Frequency of initiating events with very small loss of coolant accident.

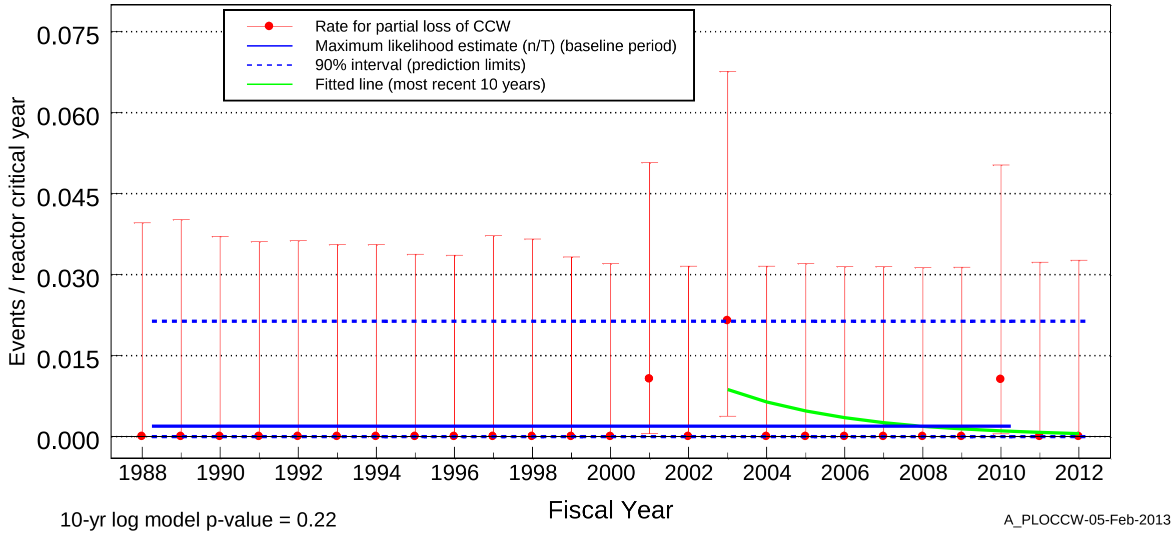

Figure 5. Frequency of initiating events with partial loss of component cooling water.

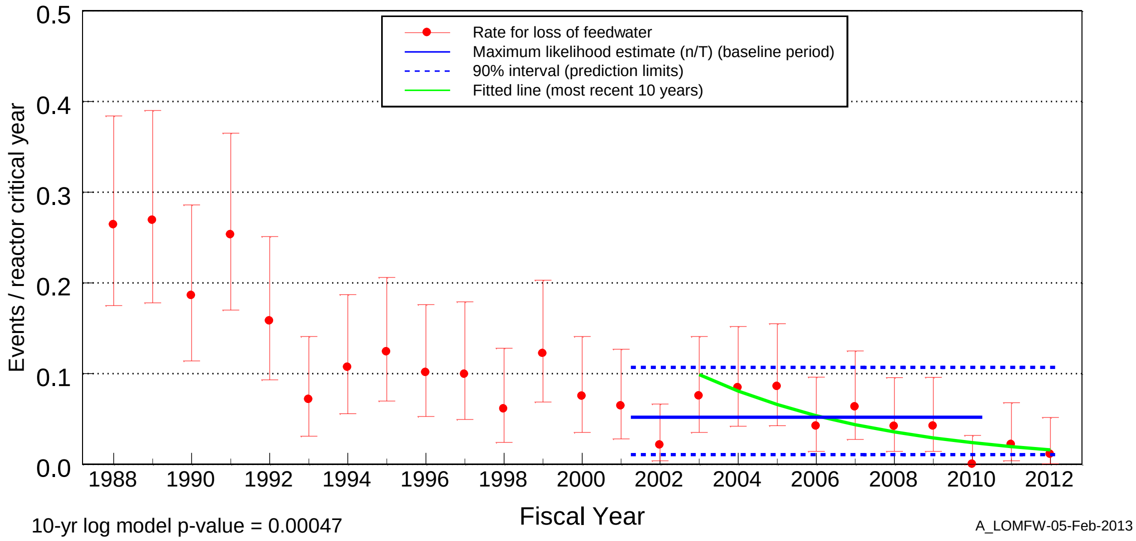

Figure 6. Frequency of initiating events with loss of feedwater.

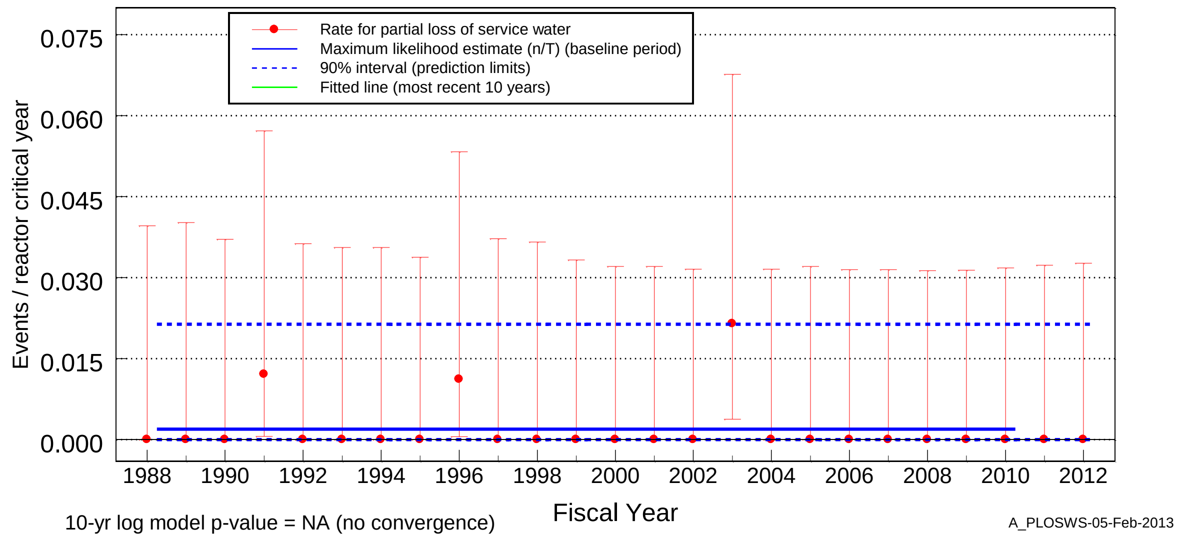

Figure 7. Frequency of initiating events with partial loss of service water.

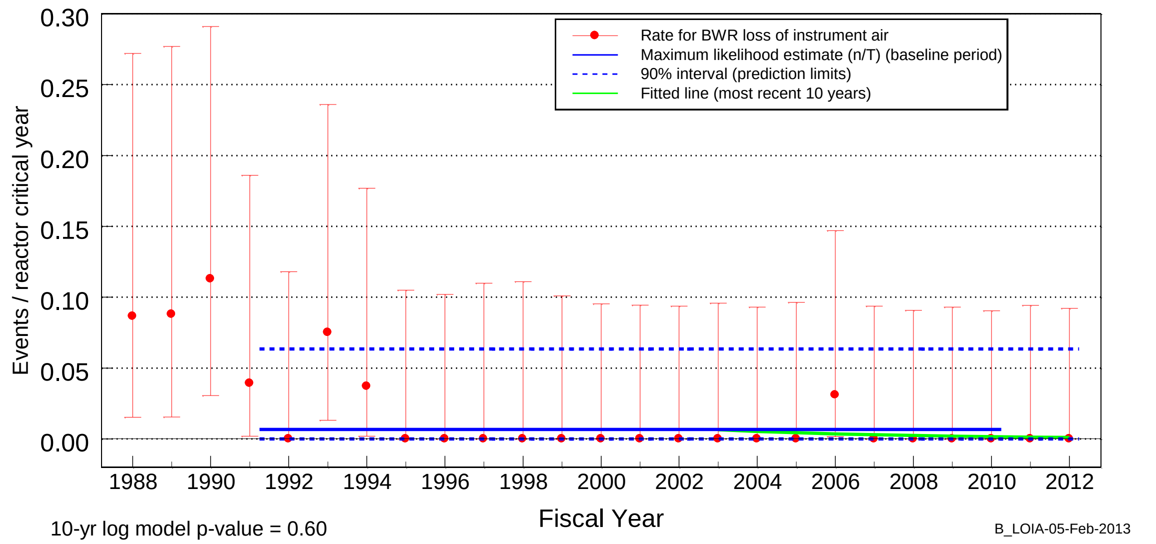

Figure 8. Frequency of BWR initiating events with loss of instrument air.

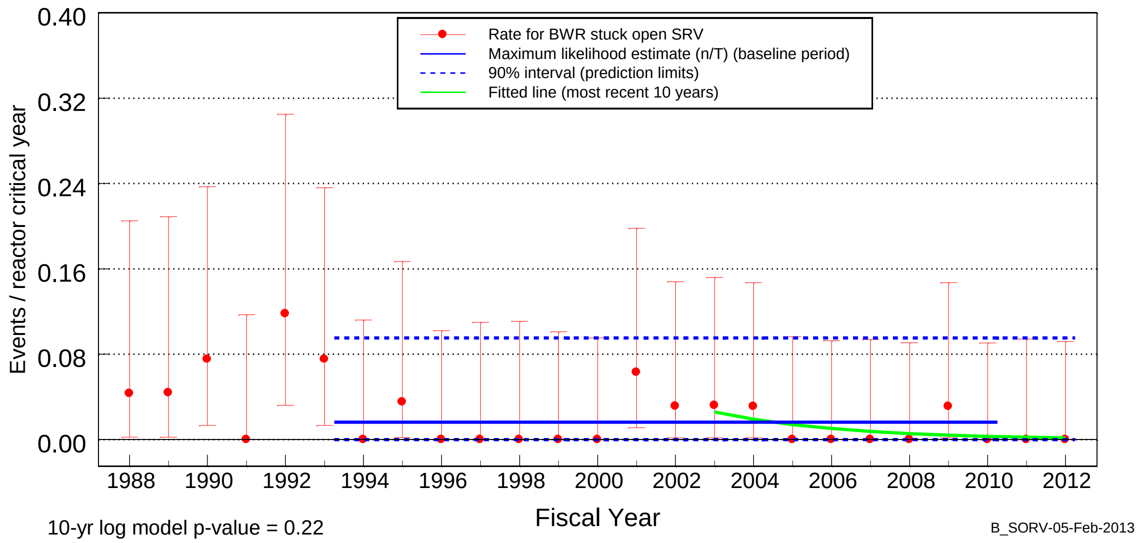

Figure 9. Frequency of BWR initiating events with stuck open safety relief valve.

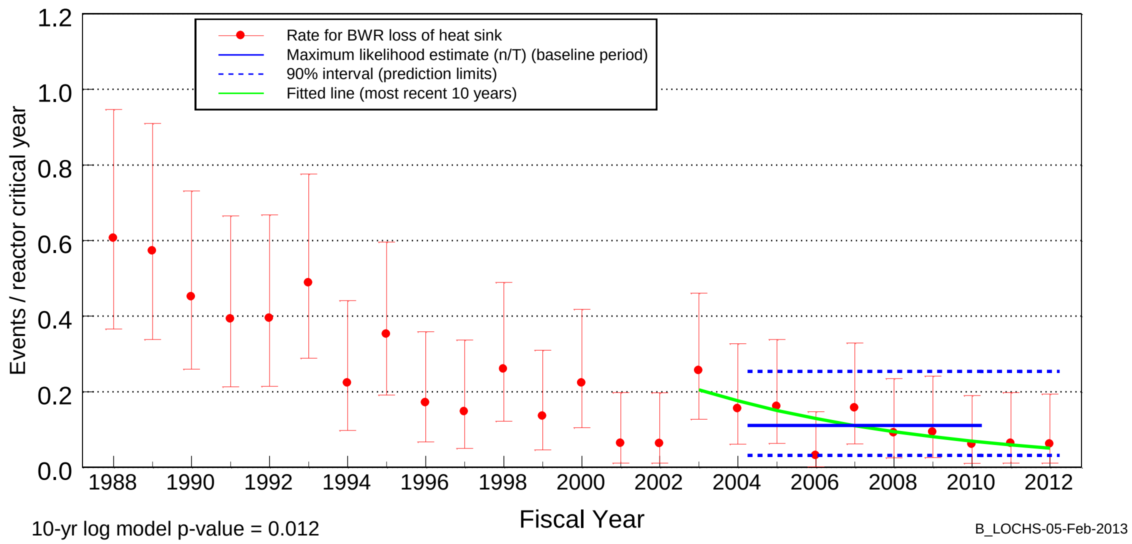

Figure 10. Frequency of BWR initiating events with loss of heat sink.

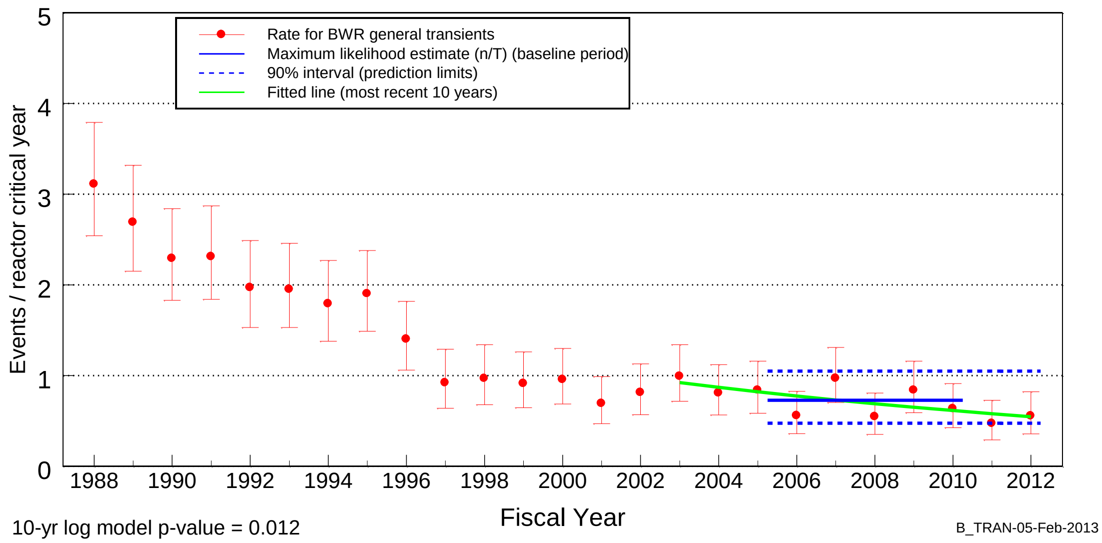

Figure 11. Frequency of BWR initiating events with general transients.

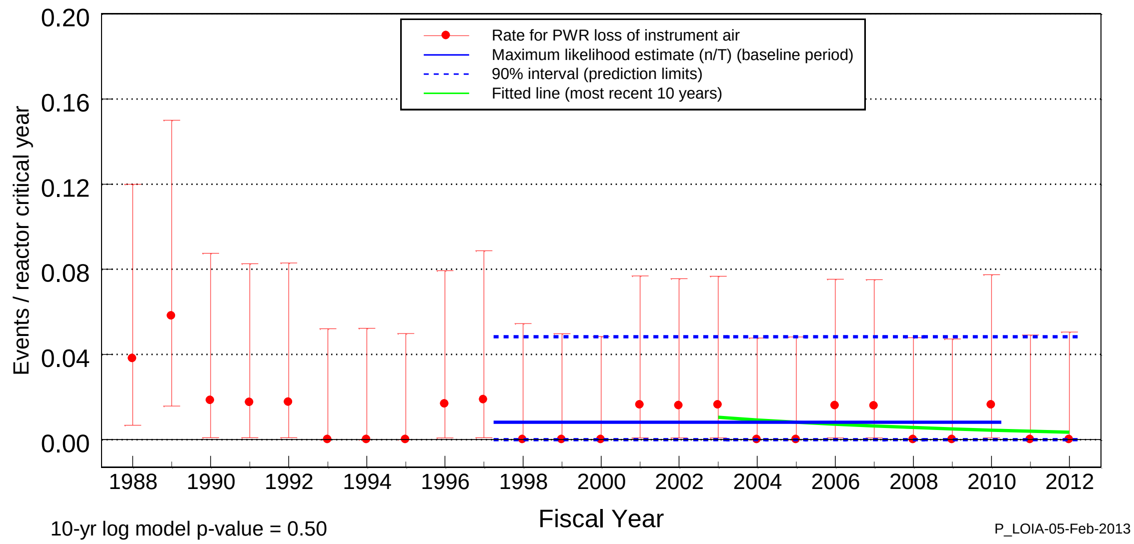

Figure 12. Frequency of PWR initiating events with loss of instrument air.

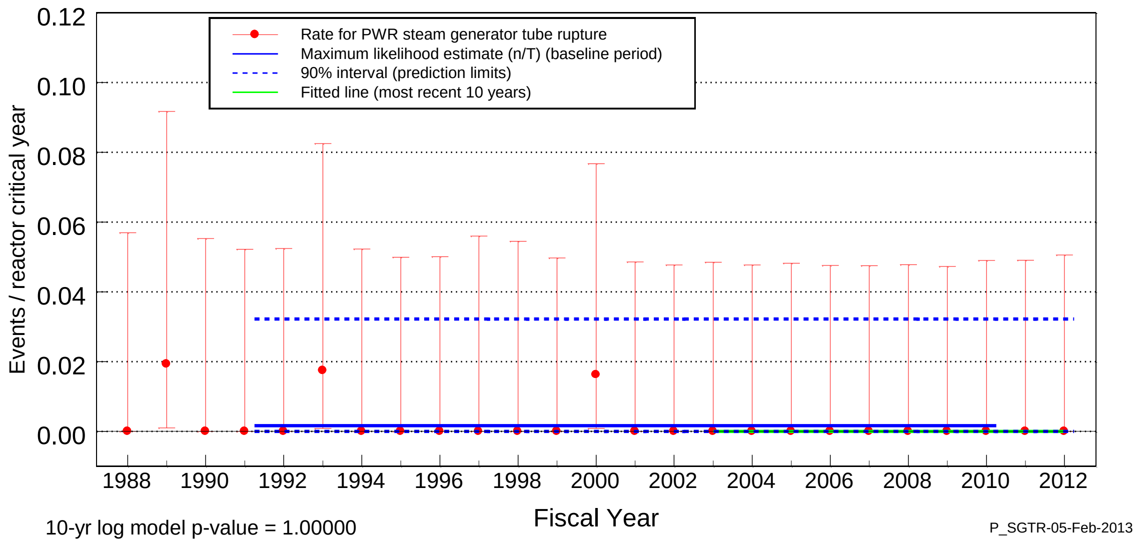

Figure 13. Frequency of PWR initiating events with steam generator tube rupture.

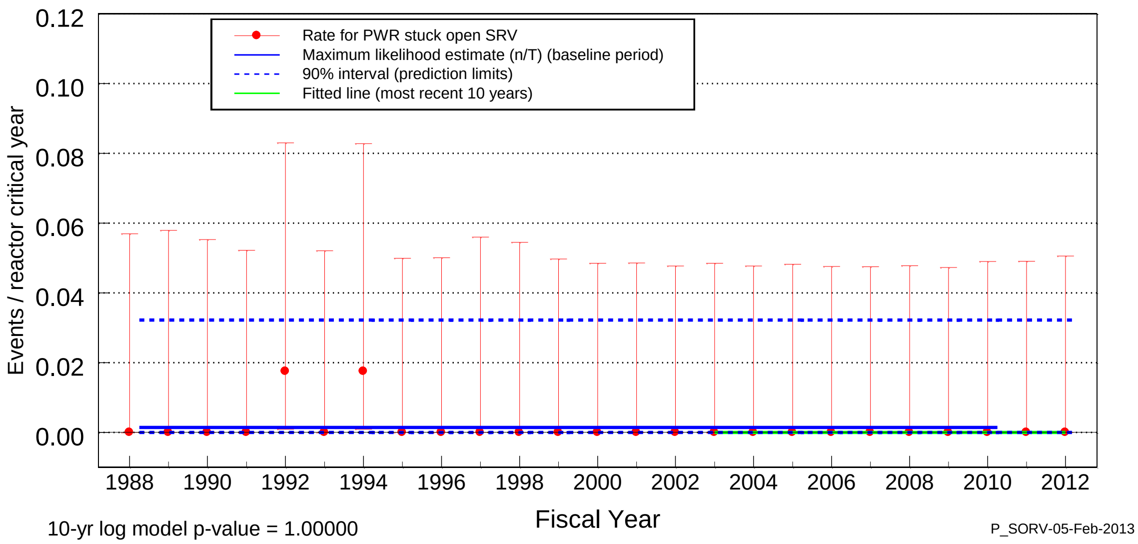

Figure 14. Frequency of PWR initiating events with stuck open safety relief valve.

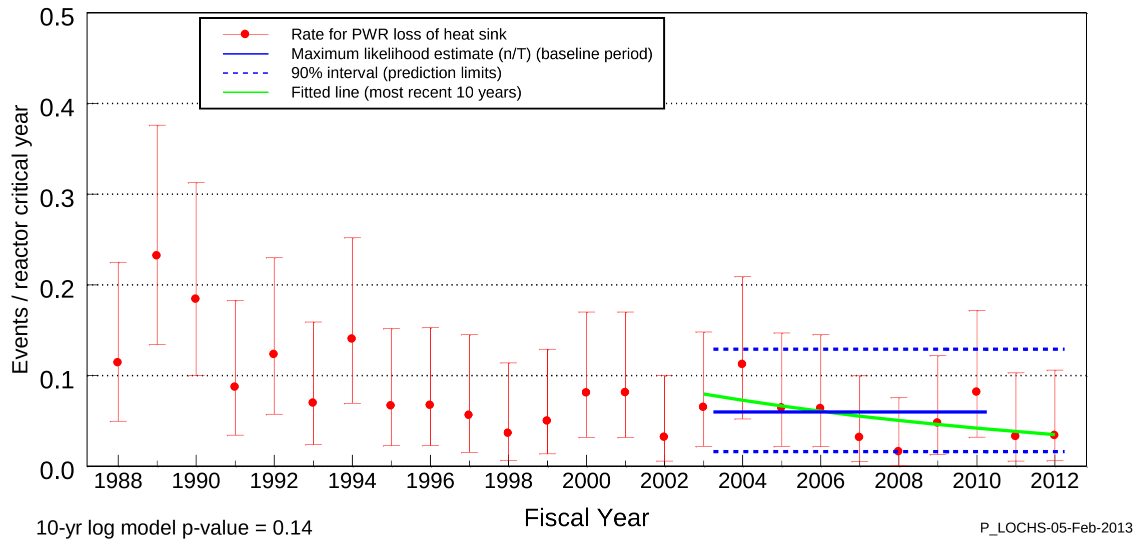

Figure 15. Frequency of PWR initiating events with loss of heat sink.

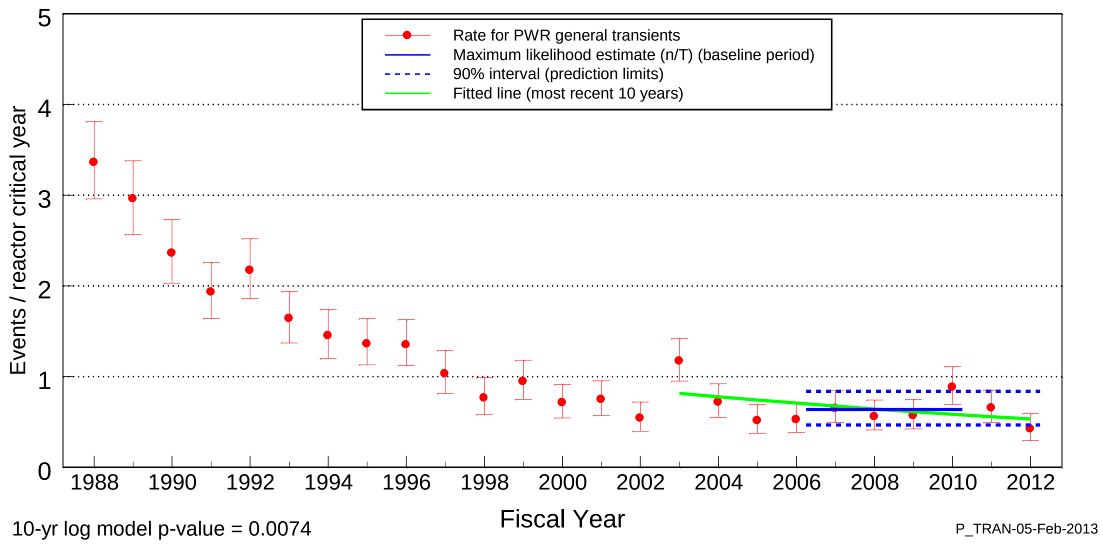

Figure 16. Frequency of PWR initiating events with general transients.

2 REFERENCE

1. J.P. Poloski, et al, *Rates of Initiating Events at U.S. Nuclear Power Plants: 1987-1995*, NUREG/CR-5750, U.S. Nuclear Regulatory Commission, February 1999.