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Initiating Event Rates at U.S. Nuclear Power Plants

1988–2013

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Idaho National Laboratory

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ABSTRACT

Analyzing initiating event rates is important because it indicates performance among plants and also provides inputs to several U.S. Nuclear Regulatory Commission (NRC) risk-informed regulatory activities. This report presents an analysis of initiating event frequencies at U.S. commercial nuclear power plants since each plant's low-power license date. The evaluation is based on the operating experience from fiscal year 1988 through 2013 as reported in licensee event reports. Engineers with nuclear power plant experience staff reviewed each event report since the last update to this report for the presence of valid scrams or reactor trips at power. To be included in the study, an event had to meet all of the following criteria: includes an unplanned reactor trip (not a scheduled reactor trip on the daily operations schedule), sequence of events starts when reactor is critical and at or above the point of adding heat, occurs at a U.S. commercial nuclear power plant (excluding Fort St. Vrain and LaCrosse), and is reported by a licensee event report. This report displays occurrence rates (baseline frequencies) for the categories of initiating events that contribute to the NRC's Industry Trends Program. Sixteen initiating event groupings are trended and displayed. Initiators are plotted separately for initiating events with different occurrence rates for boiling water reactors and pressurized water reactors. p-values are given for the possible presence of a trend over the most recent 10 years. A highly statistically significant decreasing trend was identified for the loss of main feedwater.

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ACRONYMS

BWR	boiling water reactor
LER	licensee event report
LOOP	loss of offsite power
NRC	Nuclear Regulatory Commission
PWR	pressurized water reactor

Initiating Event Rates at U.S. Nuclear Power Plants
1988–2013

An initiating event is an unplanned event that occurs while a nuclear power plant is in critical operation and requires that plant to shut down to achieve a stable state. Analyzing initiating event rates is important because it indicates performance among plants and also provides inputs to several U.S. Nuclear Regulatory Commission (NRC) risk-informed regulatory activities (such as plant inspections of risk-important systems) and NRC staff technical reviews of proposed license amendments, including risk-informed applications. The objectives of the initiating event study are to

1. Provide revised, historical frequencies for the occurrence of initiating events in U.S. nuclear power plants
2. Compare these estimates based on operating experience to estimates used in probabilistic risk assessments, individual plant examinations, and other regulatory issues
3. Review the operating data from an engineering perspective to determine trends and patterns of plant performance for specific plants, plant types [i.e., pressurized water reactor (PWR) or boiling water reactor (BWR)], and the industry.

This report presents an analysis of initiating event frequencies at U.S. commercial nuclear power plants since each plant's low-power license date. The evaluation is based on the operating experience from fiscal years 1988 through 201, 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.

To determine initiating event rates, engineers with nuclear power plant experience reviewed each LER since the last update to this report for the presence of valid scrams or reactor trips at power. To be included in this study, an event had to meet all of the following criteria:

- Includes an unplanned reactor trip (not a scheduled reactor trip on the daily operations schedule)
- Sequence of events starts when reactor is critical and at or above the point of adding heat
- Occurs at a U.S. commercial nuclear power plant (excluding Fort St. Vrain and LaCrosse)
- Is reported in an LER.

Each reactor trip event was then reviewed for the following information:

- All occurrences of risk-significant events in the reactor trip sequence that could impact the ability to remove reactor decay heat
- The first event in the sequence of events that caused or led to the unplanned, automatic, or manual reactor trip
- The occurrence of a manual reactor trip.

The information was collected into two groups or data sets:

1. The initial plant fault group—contains the reactor trip event initiator for each reactor trip
2. The functional impact group—contains one or more risk-significant events that occur during each reactor trip.

1. BASELINE FREQUENCIES

This report displays occurrence rates (baseline frequencies) for the categories of initiating events that contribute to the NRC's Industry Trends Program and other programs. 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[a] for the possible presence of a trend over the most recent 10 years.

For each of these initiating events, a baseline period during which the initiating event frequencies are approximately constant was identified. New baseline periods were adopted in the 2012 edition of this report (Reference 2). These same baseline periods are used again in the present report. All baseline periods end in 2010 but have different starting years, according to how long the frequencies appear to have been stable and how many years are necessary to achieve a reasonable sample size.

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. The mean of the distribution used in the Industry Trends Program (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.

Initiating events occur infrequently in nuclear power plants. Of the 16 initiating event categories currently trended, only five have prediction limit event counts of 6 or more. The initiating events in this category are labeled "infrequent." The other initiators (which have event count of 2 or 3), are labeled "sparse." Four of the sparse initiators continue to have baseline periods that use as much of the U.S. nuclear power plants historic data as possible. Also, for loss of offsite power (LOOP) events, 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.

Table 1 summarizes the updated baseline data. For each initiator frequency, the table lists the total number of events and reactor critical years, the upper prediction limit that could be used in an evaluation of short-term trends, and information about representative industry gamma distributions. Note that for LOOP events, no recent period with homogeneous data across years exists. This baseline will be re-evaluated as future data are collected to see if a more suitable baseline period can be constructed.

a. 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).

2. TRENDS

Table 2 shows the current 10-year trends for the sixteen initiating events being tracked plus data for the current year, including the p-value, the update year event count, and a comparison with its prediction limit.

Older updates of this report have shown the trend from calendar year 1988. In this update, as in last year's 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 there have been no events in the past 10 years.

A highly statistically significant decreasing trend was identified for the loss of main feedwater (see Figure 6).

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

		Baseline Period (ending 2010) (calendar year)			Prediction Limit			Industry Gamma Distribution				
Initiating Event Category	**Figure Number**	**Start**	**Number of Events**	**Reactor Critical Years**	**Period Length (future year)**	**95% Event Count**	**95% Rate**	**Test of Homogeneity**	**Type[a]**	**Mean**	**α**	**β**
Loss of offsite power	Figure 1	2004	11	664.57	93.6	5	5.34E−02	Rejects[b]	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 c)	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
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	—[c]	—[c]
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

a. 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).

b. 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.

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

Table 2. Current initiating event data and trend summary.

Initiating Event Category	Figure Number	All Data (since 1987)		Most Recent 10 Years			Update Year (FY)				
		Number of Events	Reactor Critical Years	Number of Events	Reactor Critical Years	Trend (p-value)	Number of Events	Reactor Critical Years	Frequency (MLE)	95% Prediction Limit Event Count	Count Compared with Prediction Limit
Loss of offsite power	Figure 1	79	2307.4	27	938.4	0.078	4	89.9	4.45E-02	5	Same[a]
Loss of vital AC bus	Figure 2	13	2307.4	3	938.4	0.210	0	89.9	0	3	Lower
Loss of vital DC bus	Figure 3	2	2307.4	1	938.4	0.420	0	89.9	0	2	Lower
Very small LOCA	Figure 4	5	2307.4	1	938.4	0.340	0	89.9	0	2	Lower
Partial loss of CCW	Figure 5	4	2307.4	1	938.4	0.600	0	89.9	0	2	Lower
Loss of feedwater	Figure 6	211	2307.4	41	938.4	0.003	4	89.9	4.45E-02	10	Lower
Partial loss of service water	Figure 7	4	2307.4	0	938.4	1.000	0	89.9	0	2	Lower
BWR loss of instrument air	Figure 8	12	766.2	1	321.6	0.430	0	31.6	0	2	Lower
BWR stuck open SRV	Figure 9	16	766.2	2	321.6	0.350	0	31.6	0	3	Lower
BWR loss of heat sink	Figure 10	157	766.2	30	321.6	0.097	2	31.6	6.33E-02	8	Lower
BWR general transients	Figure 11	909	766.2	224	321.6	0.160	21	31.6	6.65E-01	33	Lower
PWR loss of instrument air	Figure 12	16	1541.2	3	616.7	0.640	0	58.3	0	3	Lower
PWR steam generator tube rupture	Figure 13	3	1541.2	0	616.7	1.000	0	58.3	0	2	Lower
PWR stuck open SRV	Figure 14	2	1541.2	0	616.7	1.000	0	58.3	0	2	Lower
PWR loss of heat sink	Figure 15	116	1541.2	32	616.7	0.097	2	58.3	3.43E-02	8	Lower
PWR general transients	Figure 16	1758	1541.2	375	616.7	0.790	33	58.3	5.66E-01	52	Lower

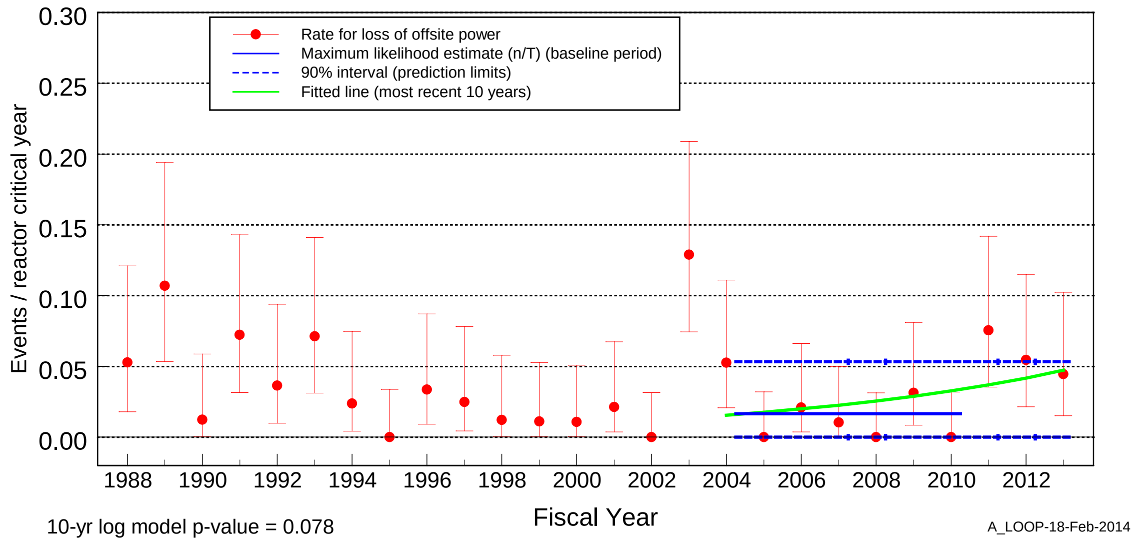

Figure 1. Loss of offsite power initiating event frequency.

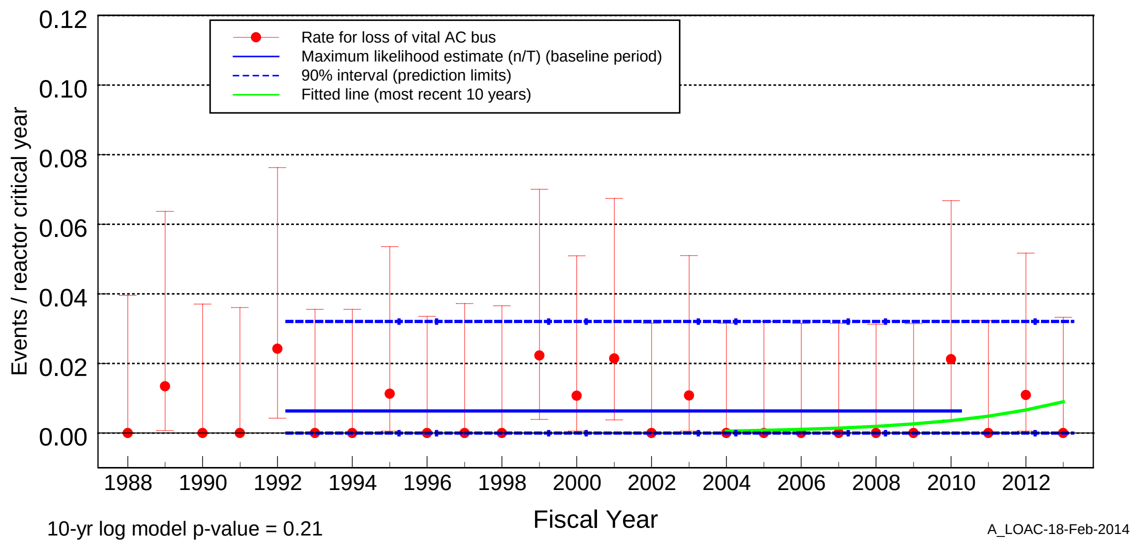

Figure 2. Loss of vital AC bus initiating event frequency.

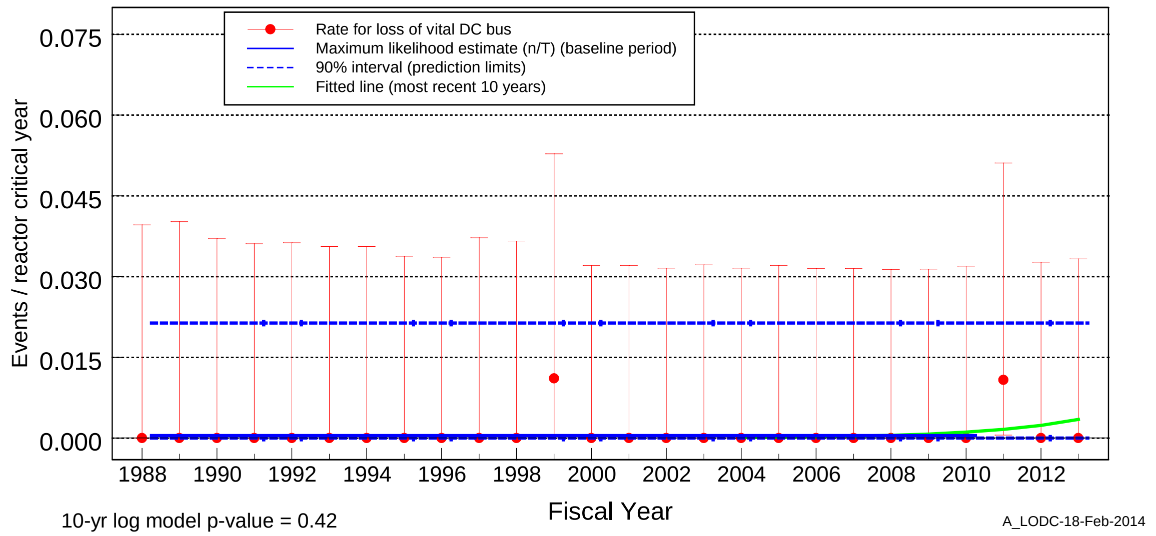

Figure 3. Loss of vital DC bus initiating event frequency.

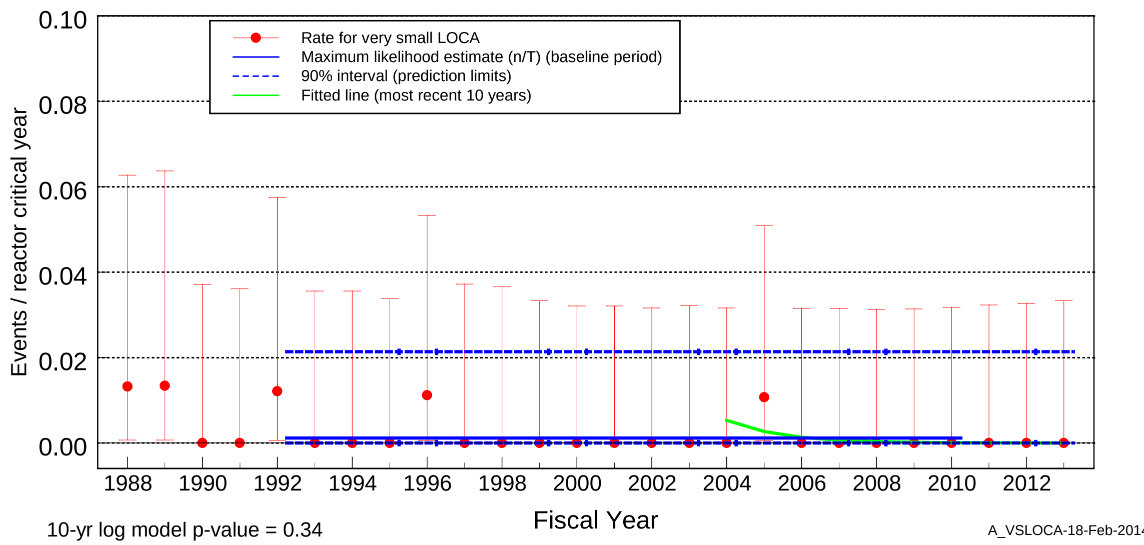

Figure 4. Very small loss of coolant accident initiating event frequency.

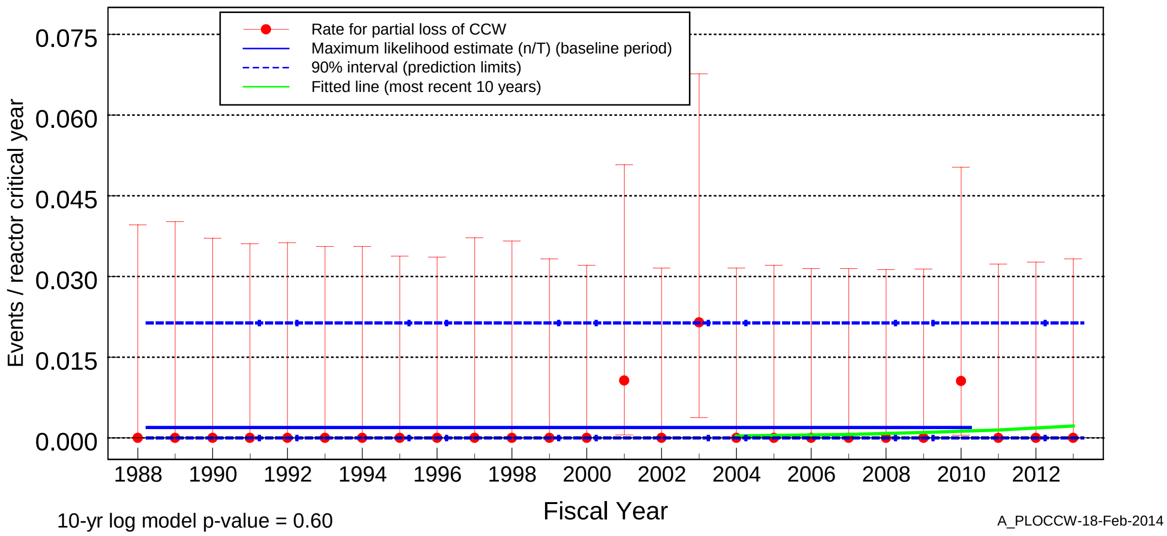

Figure 5. Partial loss of component cooling water initiating event frequency.

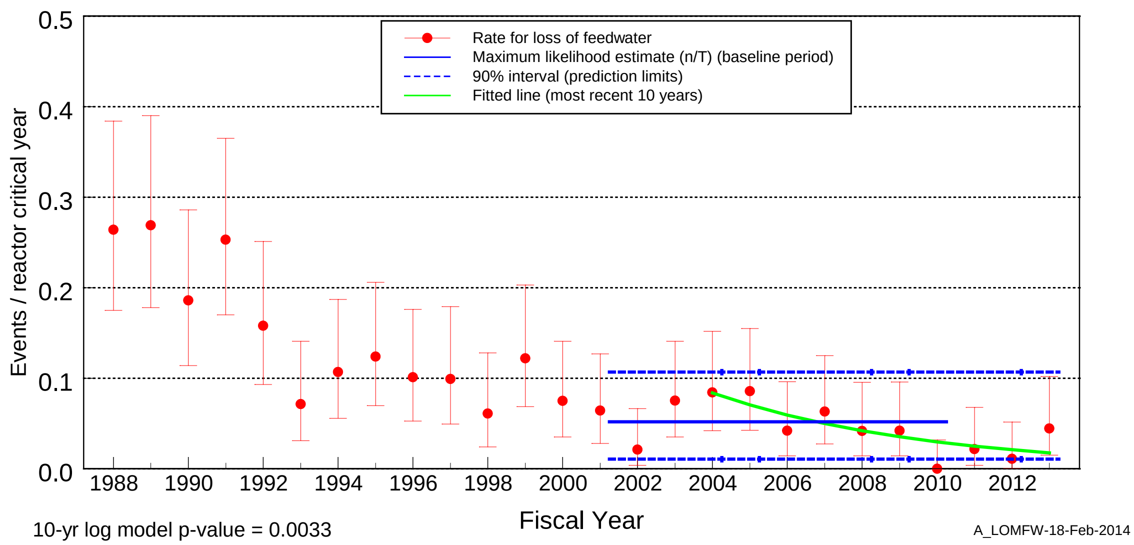

Figure 6. Loss of main feedwater initiating event frequency.

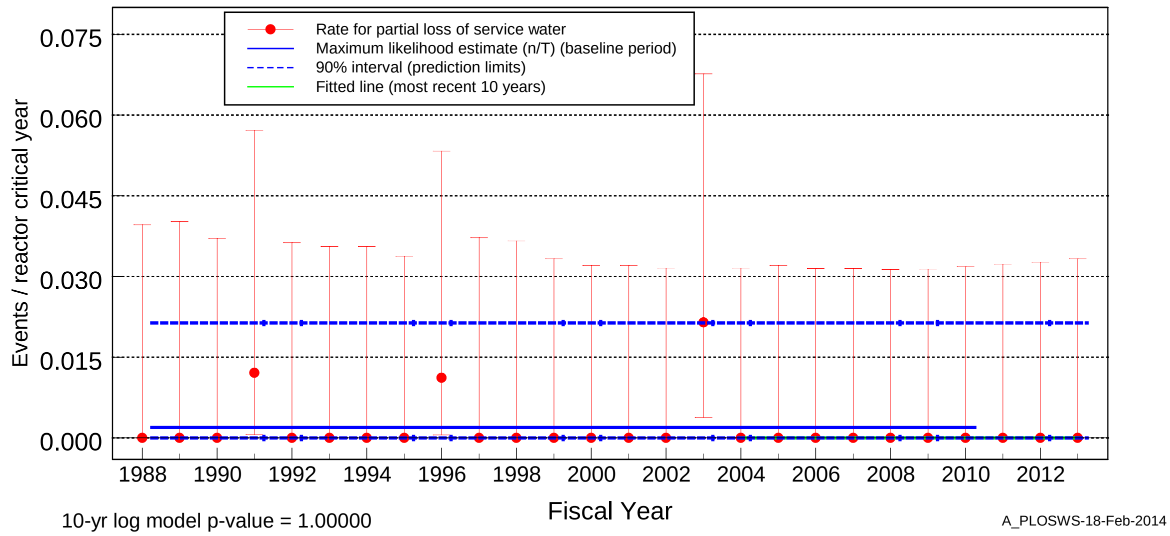

Figure 7. Partial loss of service water initiating event frequency.

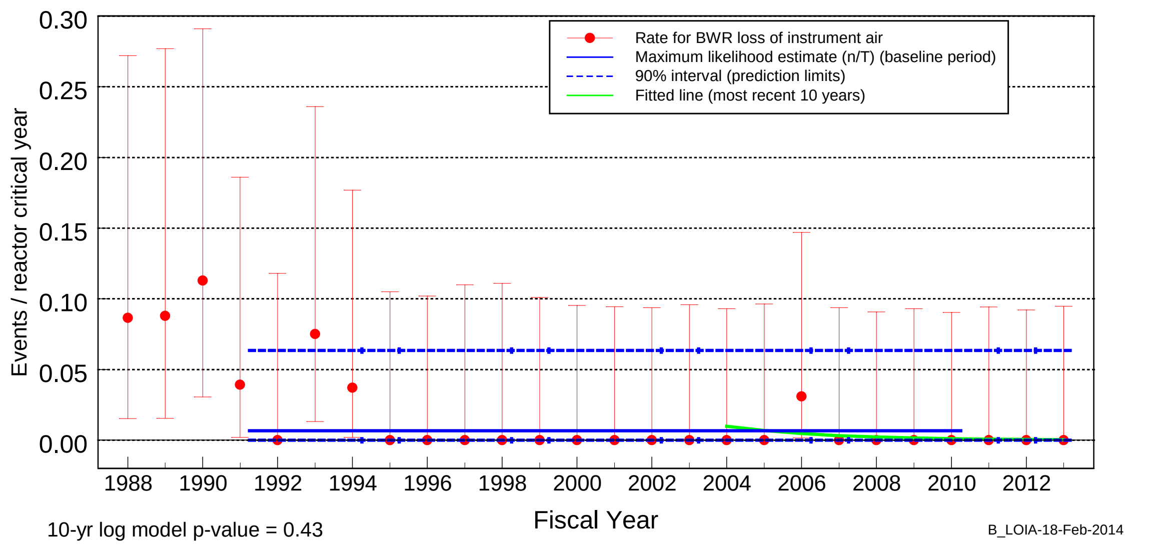

Figure 8. BWR loss of instrument air initiating event frequency.

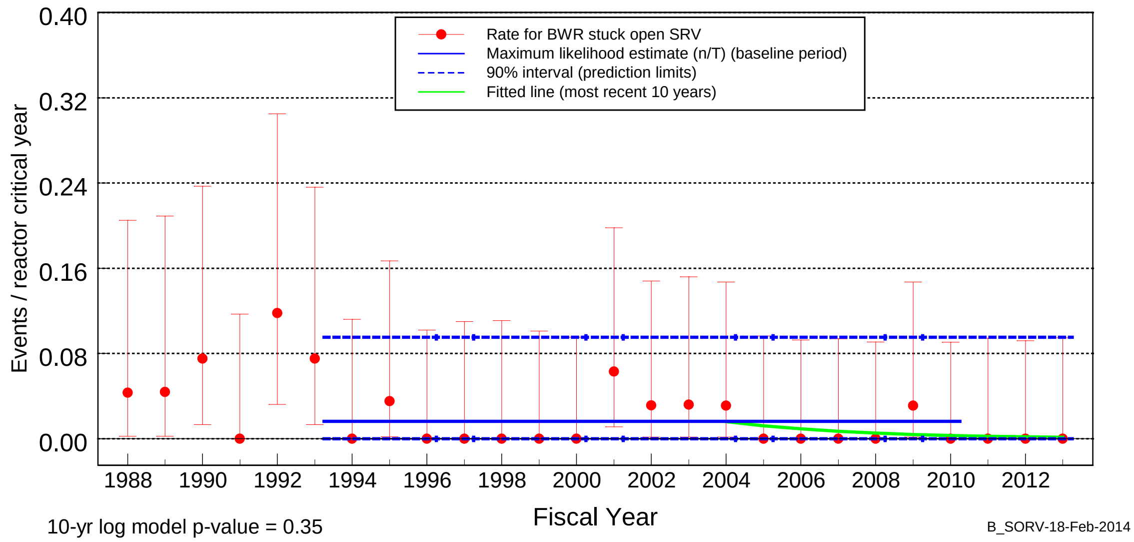

Figure 9. BWR stuck open safety relief valve initiating event frequency.

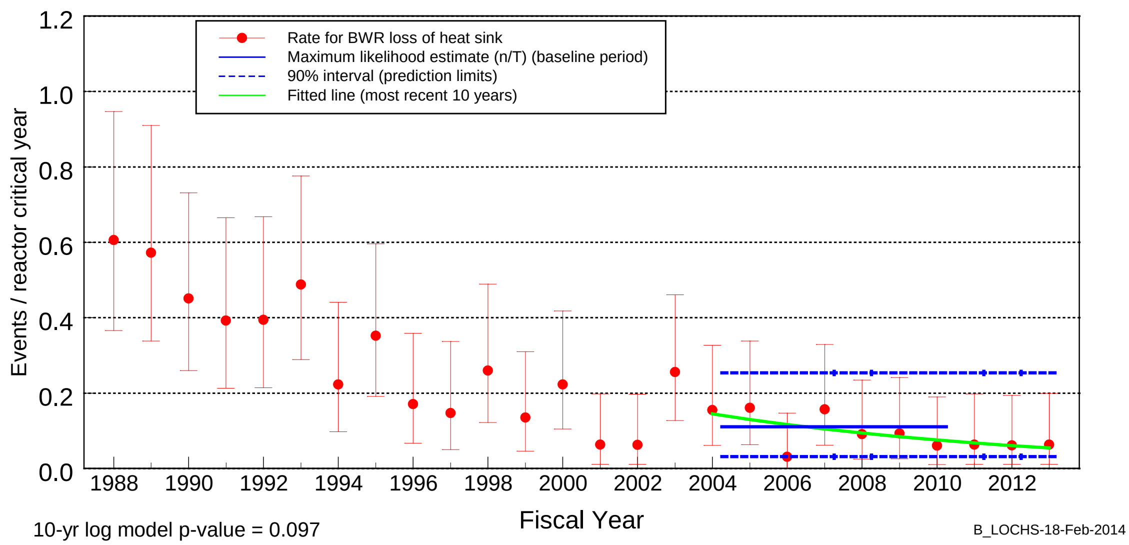

Figure 10. BWR loss of condenser heat sink initiating event frequency.

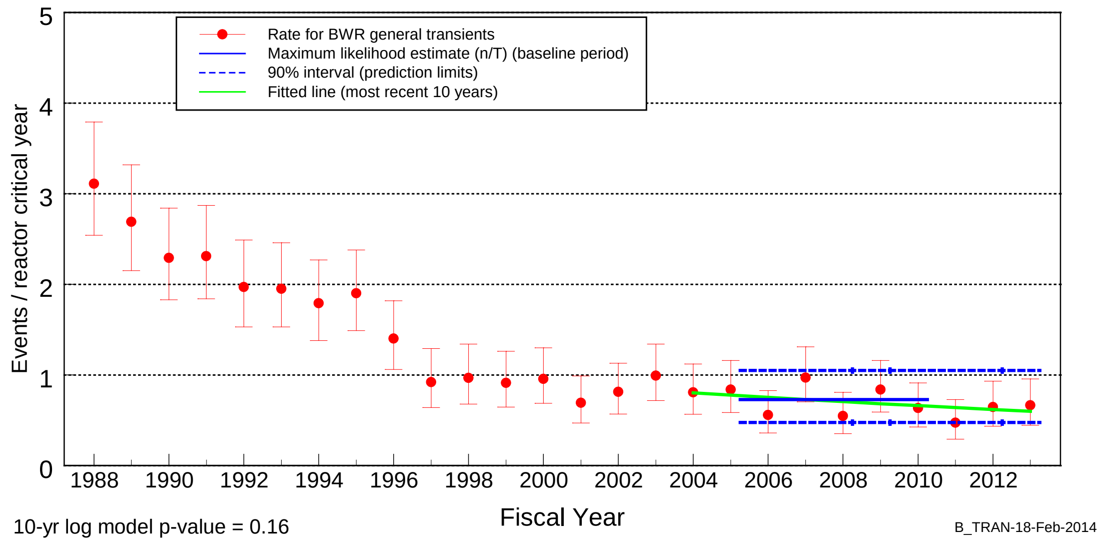

Figure 11. BWR general transients initiating event frequency.

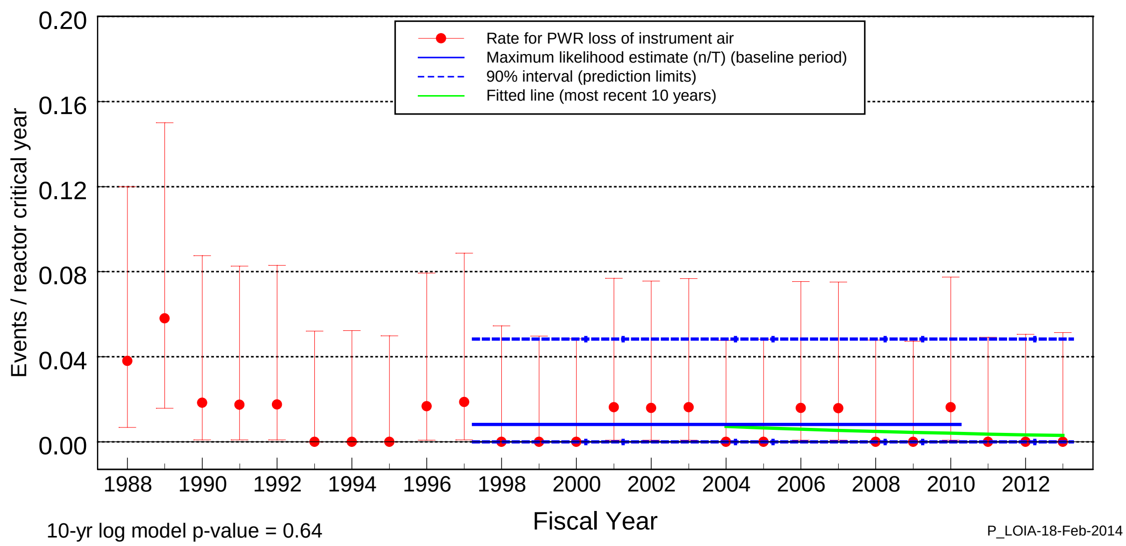

Figure 12. PWR loss of instrument air initiating event frequency.

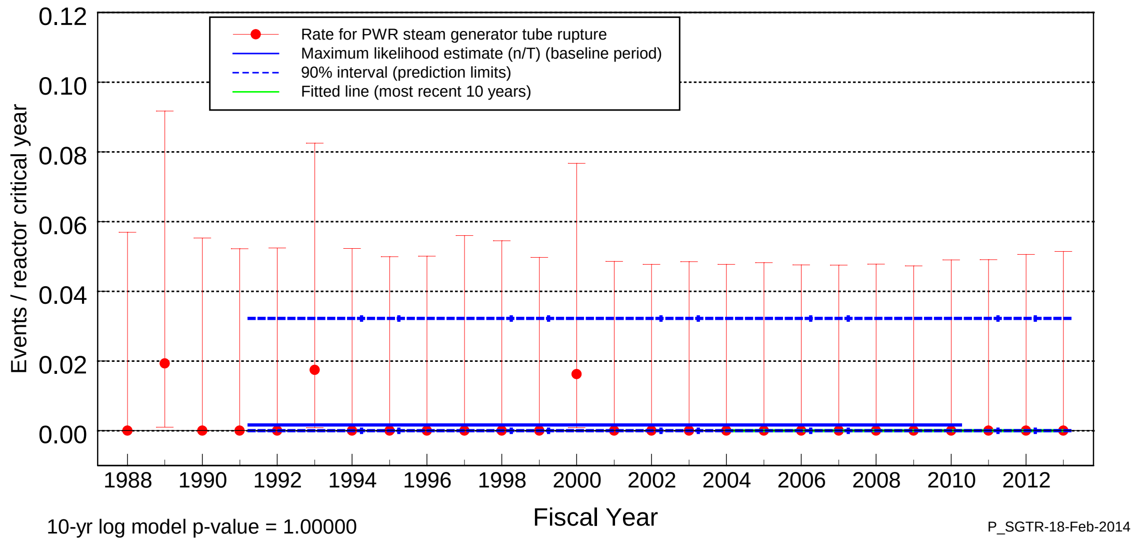

Figure 13. PWR steam generator tube rupture initiating event frequency.

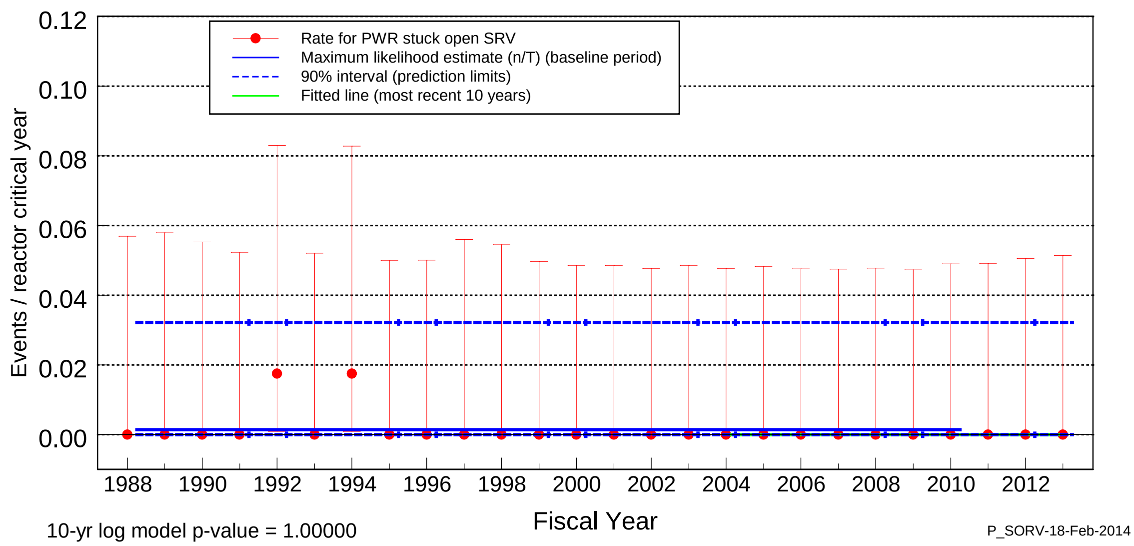

Figure 14. PWR stuck open safety relief valve initiating event frequency.

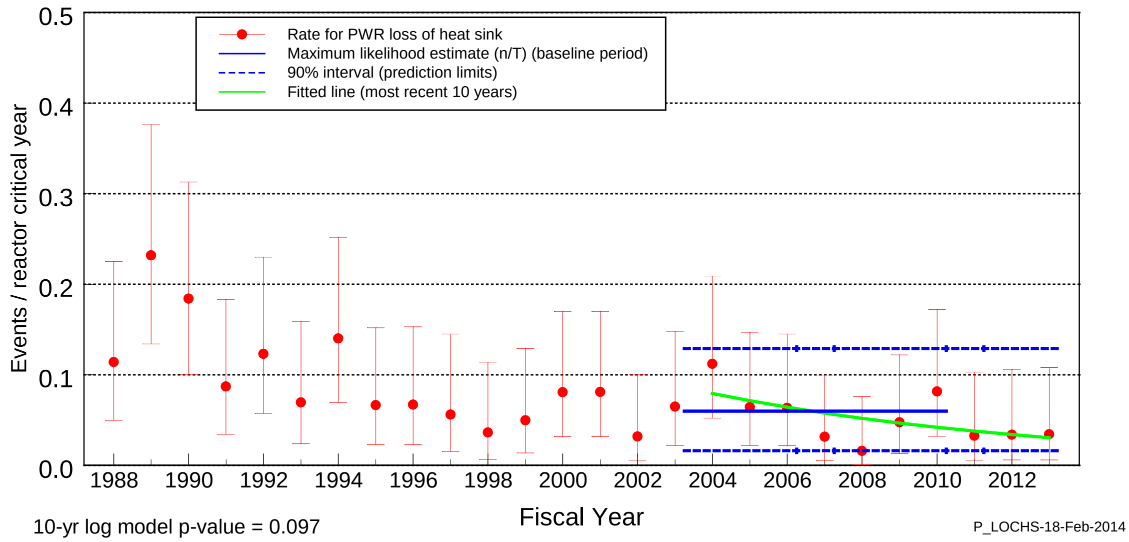

Figure 15. PWR loss of condenser heat sink initiating event frequency.

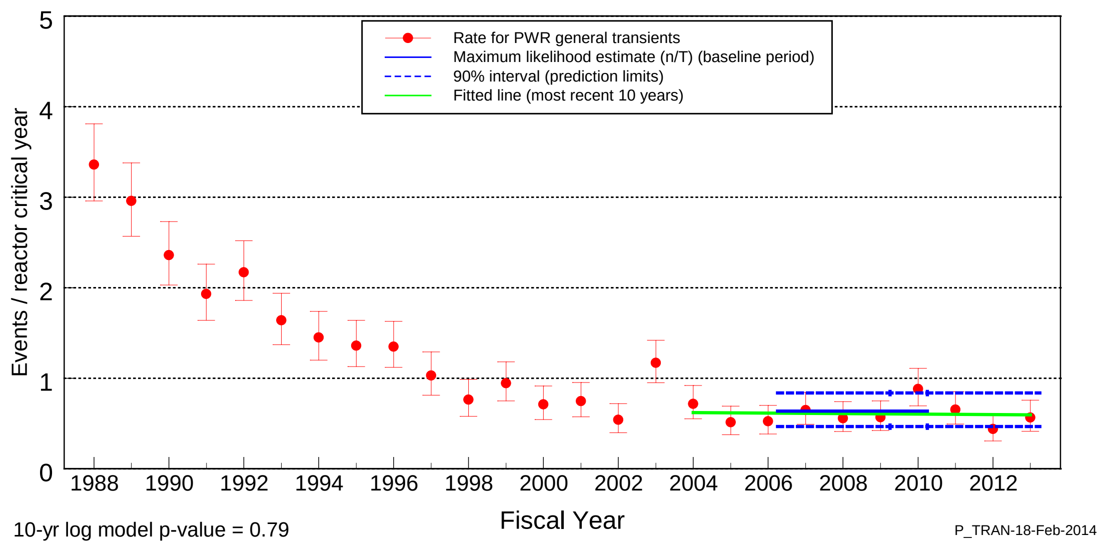

Figure 16. PWR general transients initiating event frequency.

3. REFERENCES

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.

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