INITIATING EVENTS FREQUENCY DETERMINATION

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ABSTRACT

The paper describes work performed for the Nuclear Power Station (NPS). Work is related to the periodic initiating events frequency update for the Probabilistic Safety Assessment (PSA). Data for all relevant NPS initiating events (IE) were reviewed. The main focus was on events occurring during most recent operating history (i.e., last four years). The final IE frequencies were estimated by incorporating both NPS experience and nuclear industry experience. Each event was categorized according to NPS individual plant examination (IPE) initiating events grouping approach. For the majority of the IE groups, few, or no events have occurred at the NPS. For those IE groups with few or no NPS events, the final estimate was made by means of a Bayesian update with general nuclear industry values. Exceptions are rare loss-of-coolant-accidents (LOCA) events, where evaluation of engineering aspects is used in order to determine frequency.

1 INTRODUCTION

The objective was to update the IE frequencies based on the latest plant specific operating history and/or relevant industry data. Generic data are used in the case where plant specific data are judged insufficient. The primary source for generic data is NUREG/CR-5750 [1] and NUREG/CR-5496 [2].

The approach and methodology used for the IE update is similar to that used in the NPS IPE as well as methodology/techniques used in NUREG/CR-5750 [1].

The initiating events within the scope of this update effort include the following:

- T Transient (MSIVs and Feedwater Available)
- TMS MSIV Closure Transient (Feedwater Available)
- TFWMS MSIV Closure Transient with Loss of Feedwater
- LOSP Loss of Off-Site Power Transient
- IORV Inadvertent/Stuck Open Relief Valve
- LLOCA Large LOCA
- MLOCA Medium LOCA
- SLOCA Small LOCA
- TD1 Loss of 125 V DC Bus 1
- TD2 Loss of 125 V DC Bus 2
- TA3 Loss of 4,160 V AC Bus 3
- TA4 Loss of 4,160 V AC Bus 4
- TSW Loss of Service Water

The starting point for the IE frequency update was a review of the recent the NPS scram history. A description of the updating approach used for each IE group is presented in Section 2. Section 4 provides a summary table to compare the IPE IE frequencies to the updated IE frequencies.

2 INITIATING EVENTS FREQUENCY UPDATE

Review of selected initiating events is presented. The following describes update selection process, frequency units used, and the NPS criticality factor assessment.

It is important to be precise regarding frequency units used in the generic data and the NPS IPE. This is done in order to ensure consistent application of generic data to the NPS model. The majority of generic data is provided in units of per critical year. The NPS PSA has initiating event frequencies expressed in units of per calendar year (implies per reactor year).

The NPS plant specific criticality factor (CF) is evaluated for proper correction of the generic data that are based on average industry criticality factor.

Initiating event frequency data can be presented in terms of: (1) per reactor year, or (2) per critical year. A critical year is defined as 8760 hrs of plant operation above some specified power level (i.e., 25% of nominal power). Critical year is not the same as a reactor year unless the reactor is critical throughout the entire reactor year.

Because the NPS PSA uses an IE frequency of ‘per reactor year’, and a number of the reference data sources present IE frequency in ‘per critical year’, it is necessary to account for the difference between the two units when applying the generic/industry data to the NPS model.

The relationships between the generic frequency expressed in ‘per critical year’ ($f_{C\text{-}Gen.}$) and the NPS frequency expressed ‘per reactor year’ ($f_{R\text{-the NPS.}}$) is summarizes as follows.

$$f_{R\text{-the NPS}} = CF_{a\text{- NPS}} * f_{C\text{- NPS}} \quad (1)$$

$$f_{C\text{-the NPS}} = f_{C\text{-Gen.}} \quad (2)$$

$$f_{R\text{-the NPS}} = CF_{a\text{- NPS}} * f_{C\text{-Gen.}} \quad (3)$$

In order to calculate the ‘per reactor year’ IE frequency from ‘per critical year’ IE frequency, it is necessary to know the NPS’s **average criticality factor** ($CF_{a\text{- NPS}}$). The criticality factor is defined as the fraction of time when the reactor is critical. The industry/generic ‘per criticality year’ IE frequency is multiplied by the NPS average criticality factor to produce the equivalent per reactor year frequency before it is included in the updated PSA model.

Criticality factors are ranging from 0.84 to 1. They are all summed and divided by the total number of years to quantify average criticality factor.

Average Criticality Factor is $\mathbf{CF_{a\text{- NPS}} = 0.90}$.

There are two different aspects related to the initiating events frequency update method. One aspect is related to the **data source** selection and the other is related to **quantification**.

Regarding **data source selection**, in general, three different approaches were applied for the NPS initiating this frequency update: (1) the NPS plant specific data only, (2) generic data only, and (3) combined the NPS plant specific with generic data via Bayesian update approach.

Plant specific data source is used in the case where sufficient number of events occurred. Generic data source is used in the case where plant specific data never occurred and generic estimate is judged reasonable for particular NPS. Finally, Bayesian update of the plant specific data with the generic data is selected in the case where none or very few plant specific events have been occurred and where generic estimate alone is judged not reasonable for the NPS.

Regarding the **frequency quantification** method, two cases were applied:

(1) Single constant rate model, and

(2) Bayesian double stage model.

These cases are separately described in the following subsections.

2.1 Single Constant Rate Model

For the case with no or with very few events occurrences ([1], subsection 3.2.1, page 9), the single constant rate model was used to calculate the mean frequency. This model used a Jeffrey’s noninformative prior in a Bayes updated distribution. Noninformative priors are those that make minimal or no assumptions (and do not provide prior information) about the parameter, as explained by M. Modarres [7].

The mean frequency for this model is:

$$f = (n+0.5)/t \quad (4)$$

Where *n* is the number of observed events, and *t* is the total time period. For example the mean frequency for an event category with no events for both BWRs and PWRs is estimated as:

n = 0;   t = 729 [critical years]

f = (0+0.5)/729 = 6.9E-04 [per plant and critical year]

It is beyond the scope of this paper to describe further or provide justification for applying this approach. NUREG/CR-5750 applied this method to the cases where few events occurred and where no differences between plants and no variation in time were expected. For the particular NPS there is no between plant variation issue and only conditions regarding time invariability and small number of events has to be met. It should be noted that this approach is very similar and conservative compared to the approach usually applied in the IPEs (i.e., number of events divided by the time).

2.2 Bayesian Double Stage Model

A two stage Bayesian update approach was conducted by using the data module from RISKMAN PSA software [3].

Bayesian updates provide a means of changing estimate about event probability based on "new" evidence/knowledge related to that event. In practice, a prior probability density function (*pdf*) is used to represent relevant prior knowledge, including subjective judgment (knowledge) regarding the characteristics of the parameter and its distribution. When the prior knowledge is combined with other relevant information ("new" evidence), a posterior distribution is obtained, which better represents the parameter of interest.

3 SELECTED INITIATING EVENTS FREQUENCY UPDATE DESCRIPTION

Paper size is limiting more detail description about initiating events frequency update for all IEs. Therefore only selected IE groups are further discussed in more details. Transients are selected for the presentation in this paper.

3.1 Transients

Transients are the most frequent initiators and available number of plant specific events is sufficient to estimate their frequency. This is true for all transients except for loss of offsite power events. For this reason, transient initiating events are updated in separate subsections.

The IPE-developed transient IEs frequencies were based on the plant scram history from almost 14 years. Scram history for the last 13 years was reviewed for this update.

The purpose of the scram history review is to ensure that the initiating event "types" and "frequencies" used in the baseline PSA are still representative of plant experience. Review of scram events that occurred after the original IPE shows that there are no new transient "type" initiators. Regarding the transient "frequency" update, this evaluation is based on the most recent NPS experience but review covers the total scram.

This analysis is conducted with consideration of all the NPS power operating experience. Slow, controlled, manual shutdowns or scrams from low power (<25% nominal power) operation were not counted since they are assumed to be less challenging to operators and equipment.

Separate attention was dedicated to determine if and how the number of years influence trending and IE frequency. Two different trending evaluations are performed. The first trend evaluation considers a 5 year history interval and the second trend evaluation considers a 10 year interval.

In order to illustrate how this trending evaluation is performed, an example is described here. For 29th year and a 10-year trending interval, all data from 20th to 29th year are accounted for. Transient subcategory "T" occurred 5 times, subcategories "TMS" and "TFWMS" have occurred only once each. Applying approach defined in the section 3 from the NUREG/CR-5750 gives the following frequencies:

$F_{T\ 29th/10yr}$ = (5+0.5)/10 = 5.5E-01 [per reactor year]

$F_{TMS\ 29th/10yr} = (1+0.5)/10 = 1.5E\text{-}01$ [per reactor year]

$F_{TFWMS\ 29th/10yr} = (1+0.5)/10 = 1.5E\text{-}01$ [per reactor year]

The same approach as presented in the example is applied for each year back in the NPS operating history. Depending on the selected trending interval length, the first year for evaluation is the number of years after the NPS year of operation. Questions related to the "learning period" are relevant only for the first interval. Since the final result is based on the last 10 years of the plant experience and the NPS operated for almost 30 years, the NPS "learning period" is not an issue for new updated transient initiating event frequencies.

Figure 1 and Figure 2 present the graphical results for 5-yr interval and 10-yr interval respectively.

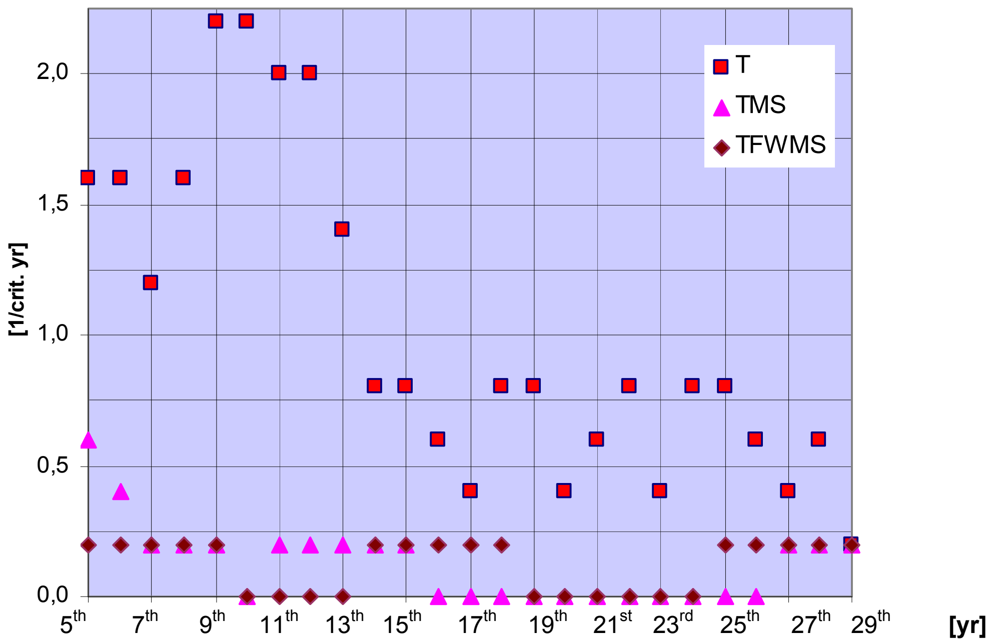

Figure 1. Transient IE 5-yr Rolling Frequencies Estimate

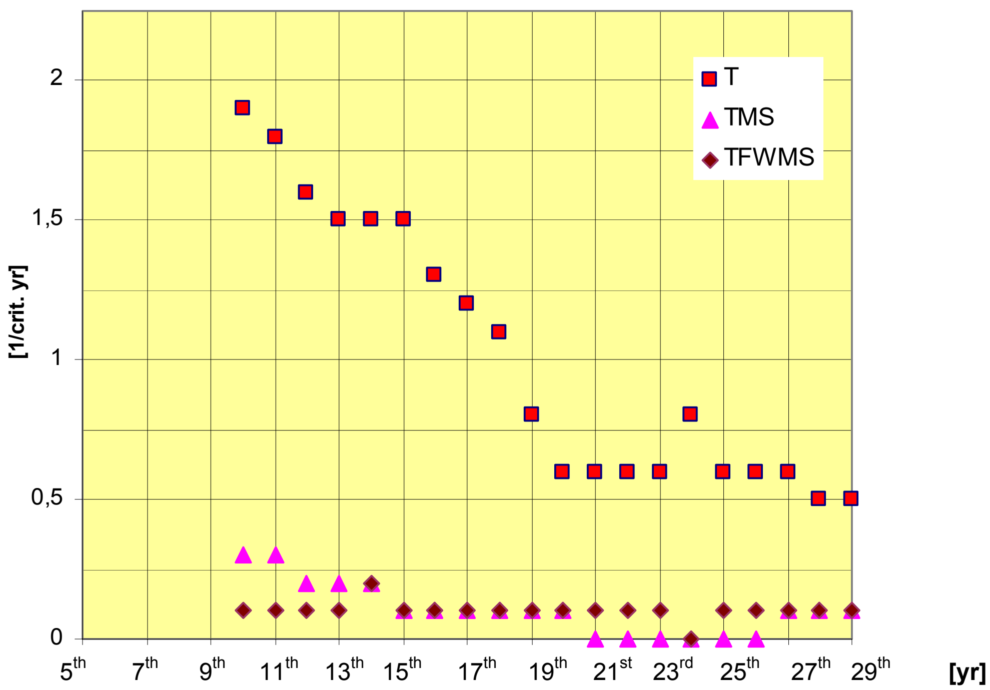

Figure 2. Transient IE 10-yr Rolling Frequencies Estimate

Even without some statistical analysis some important conclusions can be drawn from the presented results:

- It is clear that interval which is too short gives an unstable trending compared to medium size interval (i.e., last 10-yr).
- Trending gives convincing evidence that using only recent plant history for transient T is justifiable without any further (detailed) statistical evaluation.
- The other two transient events (TMS and TFWMS) are not so sensitive to the selected trending interval, and they result in frequency values that are about the same as for total plant operating experience. Because of the small number of TMS and TFWMS events and fairly constant trend it is judged reasonable to take in account the entire the NPS operating history for the TMS and TFWMS events.

The analysis is showing the presence of a trend for event T and justifying use of a shorter interval for the transient T IE frequency quantification. The analysis demonstrates that 10-year history consideration results in more suitable frequency comparing to shorter interval (i.e., 5 years). Lack of data and small number of TMS and TFWMS events is base for taking in account whole the NPS operating history in final updating quantification. From the described analysis, new quantified transient IE frequencies are presented in the Table 1. Uncertainty is estimated assuming lognormal distribution with an error factor of 3(2).

Table 1. Transients IE (T, TMS, and TFWMS) Frequencies Update

Initiator	T	TMS	TFWMS
Frequency [1/reactor yr]	5.5E-01	1.8E-01 (1)	1.1E-01 (1)
5th percentile (2) [1/reactor yr]	1.5E-01	4.8E-02	2.9E-02
95th percentile (2) [1/reactor yr]	1.3E-00	4.3E-01	2.6E-01

(1) This result is conservative because NUREG/CR-5750 provides both generic and plant specific estimate much lower (e.g., Total Loss of Feedwater Flow Generic estimate = 8.5E 02, and the NPS specific estimate = 4.6E-02; Appendix G of [1]).

(2) Relevant lognormal distribution relations used for the uncertainty quantification are:

$$x_{05} = \frac{x_{50}}{EF}, \quad x_{95} = x_{50} * EF, \quad \text{and} \quad x_{50} = e^{\ln(\alpha) - \frac{[\ln(EF)]^2}{(1.645)^2 * 2}}.$$

where **EF** is error factor and α is mean frequency from Table 1.

It is noted that the transient T IE updated frequency is reduced almost three times in comparison with IPE. This result is expected because of the long and improved the NPS operating record. The new transient TMS frequency is reduced 40% compared to the IPE. The smaller generic value for this event is justified based on the small total number of the NPS specific events. Finally, the new transient TFWMS frequency is 10% higher than the IPE value.

3.2 LOSP Transient IE Frequency Update

Loss of offsite power transient (LOSP) IE is addressed separately from normal transients because of several reasons:

- It is a more rare event than other transients (i.e., there is not enough the NPS specific events for confident estimate),
- It is a very important event for nuclear power plant safety,
- There exists a detailed and high quality industry database and analysis for better estimates of the IE frequency,
- LOSP event can be a much more complex event at the analysis level (i.e., can be initiated from several separate events, and recovery is also important to analyze).

The LOSP IE frequency update is primarily based on the original IPE approach, and new industry experience data from NUREG/CR-5496, Evaluation of Loss of Offsite Power Events at Nuclear Power Plants: 1980-1996 [2].

In order to estimate the LOSP IE frequency for the NPS, a widely accepted approach ([2] and [4]) is to separate the evaluation into three parts according to the LOSP cause: (1) Plant-Centered, (2) Grid–Related, and (3) Severe Weather Caused.

3.2.1 Momentary and Sustained LOSP Events

More detail information about industry experience regarding LOSP events can be found in Reference [2]. In Reference [5], LOSP events are distinguished according to recovery time. All events with recovery time less than two minutes are classified as **momentary**, and the remainders of the events are classified as **sustained**. About 15% of the events were momentary. In this update only sustained events are judged relevant to the NPS LOSP initiating event.

3.2.2 Plant-Centered Portion of LOSP IE Frequency

According to Reference [2], there were 50 plant-centered LOSP initiating events during operation between 1980 and 1996 in the US. The NPS experienced one LOSP event during more than 28 years of operation. Based on Reference [2] there is no statistically significant unit-to-unit variability in 17 years of operating data, therefore it is acceptable to use generic estimate of plant-centered LOSP frequency for the NPS LOSP IE frequency update. A total of 46 events were sustained (i.e., last for more than 2 minutes), and they are used as a base for the new LOSP frequency[1]. From NUREG/CR-5496, Table 3-7, the LOSP frequency estimate is **4.00E-02 per critical year** for plant centered events. (90% uncertainty interval is from 6.39E-03 to 9.73E-02).

3.2.3 Grid-Related Portion of LOSP IE Frequency

There were a total of 6 grid-related LOSP events, according to Reference [2], between 1980 and 1996 in the US. Only two of them occurred in the power operating mode. The NPS experienced no grid-related LOSP events during power operation in more than 28 years of operation. Because of the small number of data, it was decided to use the generic estimate of grid-related LOSP frequency for the NPS LOSP IE frequency update. Reference [2] seems unclear about final estimate: there are two different values (Table ES-2 and Table 3-10) and there is a comment that data are very scarce and site specific. For this update, the value from Reference [2] Table 3-10 generic grid related LOSP frequency is **1.90E-03 per reactor year**. (Data is too sparse for uncertainty interval estimate.) Frequency unit is per reactor year because NUREG/CR-5496 does not distinguish between shutdown and operation modes for Grid and Weather related LOSP events. Grid-related LOSP events have become very rare – no events have occurred during the 1990s [2].

The probability of not recovering offsite power in 4 hours is an important part of the LOSP event analysis. However, because of paper space limitation this is left out.

LogNormalDist function, for quantifying cumulative value for t=240 min (4 hrs), the probability that power is not restored after 4 hours is 7.24E 02. Original IPE value is 8.0E-02.

4 RESULTS AND CONCLUSIONS

This paper presents an analysis of initiating event frequencies at Nuclear Power Station. The evaluation investigated initiating events occurred during last four years of operation. Because there were no events, or very few, for the majority of initiating events groups, extensive use is made of recent U.S. nuclear power plant experience documented in NUREG/CR-5750 “Rates of Initiating Events at U.S. Nuclear Power Plants: 1987 1995”. Additionally, the IPE loss-of-offsite-power event, utilized industry experience documented in NUREG/CR-5496 “Evaluation of Loss of Offsite Power Events at Nuclear Power Plants: 1980 1996”.

The primary objective of the study was to update the IE frequencies for the NPS PSA.

[1] NUREG/CR-5496 treated momentary LOSP events as not counted. Assumption is that if off-site power was recovered in less than 2 minutes than challenge to the plant was no different than from the general transient.

Table 2 presents the final estimates for the updated the NPS IE frequencies compared with original the NPS IPE IE frequencies and estimates from the corresponding NUREG/CR-5750 functional impact (FI) event category.

Table 2. NPS IEs Frequencies Comparison Between IPE, Update and NUREG/CR-5750 Values

NPS	IPE	Update-2002	NUREG/CR-5750
Initiator ID	Mean Frequency(1)	Mean Frequency(1)	Mean Frequency(2)
T	1.5E+00	5.5E-01	1.3E+00
TMS	3.0E-01	1.8E-01	1.5E-01
TFWMS	1.0E-01	1.1E-01	7.6E-02
LOSP	1.0E-01	3.8E-02	4.1E-02
LLOCA	1.0E-04	2.7E-05	2.7E-05
MLOCA	3.0E-04	3.6E-05	3.6E-05
SLOCA	1.0E-02	6.0E-03	6.0E-03
TD1	1.5E-03	9.4E-04	9.4E-04(3)
TD2	1.5E-03	9.4E-04	
TA3	1.5E-03	4.3E-03	8.5E-03(3)
TA4	1.5E-03	4.3E-03	
TSW	7.0E-04	7.9E-04	8.7E-04
IORV	5.6E-03	1.1E-02	4.1E-02

(1) This is frequency per reactor year

(2) Equivalent industry frequency per reactor year adjusted for the NPS's criticality factor.

(3) This is frequency per train with assumption of two trains per plant.

The updated the NPS IE frequencies are reasonably representative of the generic frequencies. The frequencies for the TA3, TA4, and IORV initiating events have increased. It is important to emphasize that this increase is driven by the generic data. This is because there were no TA3, TA4, nor IORV events at the NPS during the data review period.

The frequency for the transient initiating event (**T** - MSIVs and Feedwater Available) has decreased by factor of approximately 3. This is in accordance with recent operating experience.

Table 3 presents the data source selection and methodology approach for all NPS IE's.

Table 3. Data Evaluation Approach Selection for the NPS IE Frequency Update

Data source/ Methodology	Initiating Events
(1) the NPS plant specific data only	T, TMS, TFWMS
(2) Generic data only	LOSP, All LOCA's, TD1, TD2
(3) Combined the NPS plant specific with generic data via 2-stage Bayesian update approach	TA3, TA4, IORV
(4) Fault tree model.	TSW
(5) Product of transient IE frequencies and scram failure probability.	A, AMS, AFWMS, ALP

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