Quantification of Functional Impact Classification on the Current U.S. Nuclear Fleet

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Sarah M. Ewing, Nancy Johnson, Piyush Sabharwall

Idaho National Laboratory, Idaho Falls, ID 83402
† Corresponding author: Sarah.Ewing@inl.gov

INTRODUCTION

Currently, nuclear power generates only a small fraction of the world's electricity, though it does have the potential to meet the needs of the world as long as its production can compete with the alternative energy base load producers. In U.S the commercial nuclear fleet comprises of Light Water Reactors (LWRs), consisting of Pressurized Water Reactors (PWRs) and Boiling Water Reactors (BWRs). Many plants experience multiple events each year, which lead to reactor trips or scrams. This subsequently leads to plants being off the grid, which is not an economically favorable situation in the current energy markets. This study helps identify functional impact (FI) event categories for both PWR's and BWR's. Understanding that not all events and their causes can be anticipated, current industry best practices implement lessons learned to provide challenges and issues identification. In turn these are studied to achieve improved operational practices, and design modifications. This leads to overall enhanced resiliency.

FI groups are the categories of initiating events (IE). IEs are unplanned events that occur while a nuclear plant is in critical operation, and requires that the plant be shut down to achieve a stable state [1]. When a risk cannot be eliminated, IEs are identified and studied to reduce the risk and contribute to the identification of mitigations, safer designs and operational practices. Breaking IE events into groups' results in the classification of FI groups.

A FI group is a risk-significant event category that could impact the ability of a NPP to remove decay heat from the reactor. Inability to remove decay heat from the reactor has the potential to lead to core damage.

For an event to be considered a FI, it must be associated with a manual or automatic reactor trip, irrespective of the order of events. In addition, the plant must be at or above the point of adding heat and the event must happen before or shortly after a reactor trip. One or more FIs may be identified in any individual reactor trip sequence. The relationship between FI sequence, and/or frequency per a plant event is outside the scope of this paper.

For example, the loss of offsite power (LOOP) can occur from eternal events (i.e. weather, human, wildlife etc.) [2, 3]. This results in an event that requires a transfer of power to an emergency source, such as a generator, which produces a reactor trip and then a closure of main steam isolation valves (MSIVS). The FI applicable to this reactor trip sequence would be LOOP and closure of at least one MSIV in each main steam line.

The results presented herein are focused on the analysis and evaluation of FI event categories. Only FI categories that can be found in IE studies [2, 4], Initialing Events Spreadsheet [5] and are recorded in a historical review of Licensee Event Reports (LERs) from 1988 through 2013. The results of this analysis can support plant decisions, design, procedures, and identify weakness.

FUNCTIONAL IMPACT EVENT CATEGORIES

Consideration for FI events are provided via categorization into the several groups. These categories are implemented by the Nuclear Regulatory Commission (NRC) and are defined in the IEs Coding Guidance [6].

<u>Loss of Offsite Power (LOOP)</u>: loss of electrical power to all safety-related buses at the same time resulting in the startup of emergency generators.

<u>Loss of Safety-Related AC or DC Bus</u>: de-energization of the any safety-related bus as a result of the inability to connect to a power source. For analysis purposes this is broken down into 2 categories <u>Loss of Safety-Related AC Bus</u> (LOAC) and <u>Loss of Safety-Related DC Bus</u> (LODC).

<u>Very small Loss of Coolant Accident (SLOCA)</u>: a 10 to 100 gallons per minute (gpm) loss that does not require high pressure injection use.

<u>Partial loss of Component Cooling Water (CCW)</u>: loss of one train of a multiple train system or partial loss of a single train system that provides cooling to components.

Loss of feed water (LOFW): total loss of feed water.

Partial Loss of Service Water (LOSW): loss of one train (i.e. power train) of a multiple train system or partial loss of a single train system of a safety or non-safety related service water systems.

Loss of Instrument Air (LOSA): partial or complete loss of instrument or control air system which is vital for the pneumatic system.

Stuck Open Safety and/or Relief Valve (SOV): an event of a primary safety and/or relief valve to close on its own or cannot be closed resulting in loss of primary coolant.

Loss of Heat Sink (LOHS): automatic or manual unintentional closure of any MSIVs, loss of condenser vacuum not due to condenser vacuum degradation and turbine bypass valves.

Steam Generator Tube Rupture (SGTR): one or more steam generator tube ruptures resulting is loss of primary coolant.

For additional and more detailed definitions the reader is referred to IEs reference material [7].

RESULTS AND DISCUSSION

All of the FI event data was gathered from 1988 through 2013. This data is publically available at www.nrc.gov and is located on the IEs webpage in the "Initiating Events Spreadsheet" [1]. The summarization of 25 years of FI for the entire United States NPP fleet is summarized in table I.

The data in table I is broken into BWR and PWR, with fleet total provided. As of 2013 in the United States there are 99 NPPs with 34 plants operating as BWR and 65 plants as PWR. In the date range considered (1988-2013) there are a fluctuating number of NPPs due to several being decommissioned; thus the plant count is the number of plants active in 2013. By the FI counts displayed in table I, LOHS is the most frequent event with 281 events. That is 281 events of LOHS in 99 plants for 25 years, or in a 25 year period 3 LOHS occur per a plant.

Table I. Number of events by FI group and reactor type from 1988 to 2013.

Functional Impact Category	Total	BWR	PWR
Loss of Offsite Power	78	32	46
Loss of Safety-Related AC Bus	13	8	5
Loss of Safety-Related DC Bus	2	0	2
Very small Loss of Coolant Accident	5	2	3
Partial loss of Component Cooling Water	4	1	3
Loss of Feedwater	202	68	134
Partial Loss of Service Water	4	1	3
Loss of Instrument Air	29	13	16
Stuck Open Safety and/or Relief Valve	17	15	2
Loss of Heat Sink	281	159	122
Steam Generator Tube Rupture	3	-	3
Total Number of Plants	99	34	65

For comparison purposes the FI events were standardized by the number of NPP, which is the number of FI events/ number of plants. The results of standardized FI count per NPP, for the NPP types are displayed in Fig. 1 and Fig. 2.

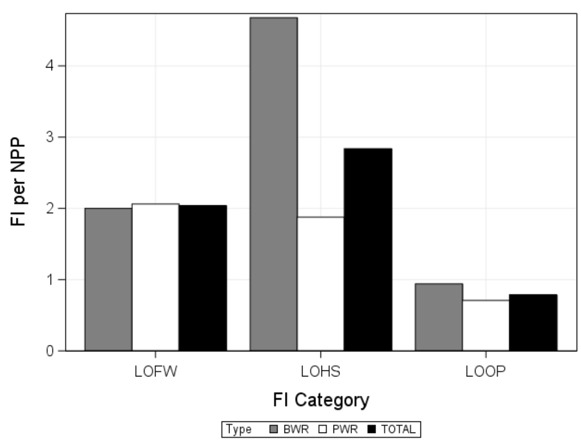

Fig. 1. The 3 most frequent FI events pre NPP broken into total, BWR and PWR for a 25 year period.

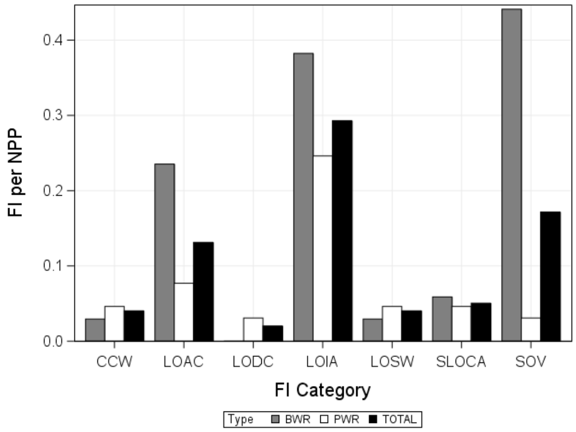

Fig. 2. The remaining FI events pre NPP, not displayed in Fig. 1, with steam generator tube rupture excluded. Results are presented by BWR and PWR NPP type alongside total for a 25 year period.

Even with this standardization LOHS still remains at the highest rate of incidence for the total and BWRs category; 3 and 5 events / plant respectively. For the 65 PWRs the most frequent FI category is LOFW with 2 events per a plant. In order to make an assessment of plant type and FI category, an Analysis of Variance (ANOVA) test was applied to the FI events/ number of plants data. An ANOVA statistical test checks for a difference of means between several groups, assuming independence between groups and normality of residuals. The detailed results of the ANOVA test as displayed in table II.

Table II. ANOVA results for the FI events/ number of plants by FI category and plant type.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	22.36	2.24	5.92	0.007
Error	9	3.40	0.38		
Corrected Total	19	25.76			

R-Sq	Coeff. Var.	Root MSE
0.87	88.01	0.61

Source	DF	Type III SS	Mean Square	F Value	Pr > F
FI Group	9	21.70	2.41	6.39	< 0.01
NPP Type	1	0.66	0.66	1.74	0.22

This resulted in the FI group being highly significant (p-value < 0.01) thus there are at least two FI groups that are statistically significantly different from each other. The plant type is not identified as statistically significant (p-value = 0.22), however there is a practical significance based upon the visual inspection of the data. As seen in Fig. 1 and Fig. 2, BWR FI / NPP is greater than PWR in 6 out of 10 categories. In the SOV category alone, a BWR is almost 15 times more likely to experience an event.

CONCLUSION

FI groups are the NRC's standardized categorization of risk-significant events that could impact the ability of a NPP to remove decay heat. An event must be linked to a reactor trip to be considered a FI. FI event categories were reviewed with consideration, for PWR and BWR, highlighting a general understanding of challenges and issues that commonly occur.

The review of the FI groups by an ANOVA resulted in a statistically significant difference between FI categories and a practical difference between plant types. Due to the fact that table I is the summary of 25 years, with roughly 99 plants active per a year (2,475 observations), there certainly are more rigorous analyses that could be applied to achieve a better understanding of the US NPP fleet. Many more in-depth analyses and results are contained in [2, 8]; with other analysis such as time series, event dependence, frequentist and Bayesian methods needing to be explored more fully. Results from these analysis can better inform plant and component design, NPP simulations, strategize generation of additional backup actions.

ACKNOWLEDGMENTS

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