Review of Multiple Spurious Operation Scenarios from NEI 00-01 for Enhancing Fire Probabilistic Safety Analysis in Domestic Nuclear Power Plants

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1. Introduction

In the deterministic fire safety analysis of domestic nuclear power plants (NPPs), the analyses of multiple spurious operations (MSOs) are being conducted using the MSO scenarios of NEI 00-01[1]. Until now, fire probabilistic safety assessment (PSA) for operational domestic NPPs has been primarily executed using the EPRI (Electrical Power Research Institute) method [2]. To ensure the credibility of fire PSA, peer reviews of PSA for domestic NPPs have been undertaken in accordance with the ASME/ANS PRA (probabilistic risk assessment) standard [3]. While the standard [3] doesn't mention that fire PSA address MSOs or include results from deterministic MSO analysis, it does explicitly state that fire PSA should take into account fire-induced equipment spurious operations that lead to initiating events or affect the availability of mitigating systems.

Fire-induced equipment spurious operations can arise from the equipment itself malfunctioning or from the spurious operation or loss of functions such as signals or electricity supporting equipment actuation. Meanwhile, the USNRC administrative document EGM 09-02[4] defines MSOs based on circuit failures as follows. Single spurious actuations involve a single fire induced circuit fault that causes undesired operation of one or more systems or components. Multiple spurious actuations are multiple fire induced circuit faults causing an undesired operation of one or more systems or components. According to the MSO definition in EGM 09-02, a single equipment spurious operation can be attributed to an MSO. Consequently, a review of the MSO scenarios outlined in NEI 00-01[1] becomes essential to enhancing fire PSA technology for domestic NPPs. This study examined the applicability of the general PWR (pressurized water reactor) MSO scenarios listed in NEI 00-01 for a domestic reference NPP in the context of fire PSA.

2. Methods and Results

2.1 Methodology for MSO Analysis in NEI 00-01

The MSO analysis process in accordance with NEI 00-01 is based on the industry generic MSO list (NEI 00-01 Appendix G) and involves a panel of experts who determine the applicability of this generic MSO list to the NPP under consideration. The analysis also assesses the presence of any unique MSO-related equipment or systems that are specific to the analyzed NPP. Using a comprehensive database comprising equipment, cables, fire barriers, etc., fire areas where MSOs may occur are identified. Notably, even if a list of MSO scenarios is identified through expert review, the actual occurrence of MSOs depends on the presence of equipment or systems within the same fire areas. Mitigation strategies are developed to address identified MSO-related equipment or cable concerns. These MSO scenarios are classified into required or important scenarios essential for post-fire safe shutdown. The strategies for MSO mitigation include circuit analysis, operator manual actions, fire modeling, and potential design modifications.

2. 2 MSO Analysis in Fire PSA

The process of conducting MSO analysis within fire PSA closely resembles that of deterministic fire safety shutdown analysis, but differs in the following ways.

- MSO analysis target scenarios: Deterministic fire safety analysis evaluates scenarios affecting all equipment across multiple trains within safety shutdown-related systems. Conversely, fire PSA examines scenarios that impact any equipment under consideration within the fire PSA scope.
- Main control room fire: The Main Control Room (MCR) bench-board comprises multiple panels, each equipped with switches to control multiple equipment trains. A fire originating from a single panel can trigger MSOs across multiple equipment trains. In deterministic analysis, if a MCR fire can be mitigated through remote shutdown panels or alternative panels, conducting separate MSO analysis for the MCR is not necessary. However, fire PSA accounts for the possibility of MSOs during MCR fire analysis.
- Classification of MSO scenarios: In deterministic fire safety shutdown analyses, MSO countermeasures vary based on the significance of MSO scenarios. In contrast, fire PSA permits the application of all available mitigation strategies from deterministic analysis, irrespective of the classification of MSO scenarios.

1.3 Review Results of NEI 00-01's MSO List

The applicability of the generic MSO list of NEI 00-01 to the domestic reference NPP was reviewed with the latest circuit analysis techniques as documented in NUREG/CR-7150, vol.3 [5]. Six experts from both domestic and international, specializing in fire PSA, deterministic fire safety, system design, and abnormal operation procedure development, provided inputs that contributed to finalizing applicable scenarios. While NEI 00-01 presents 56 general scenarios, scenario numbers 33 and 49 contain two scenarios each, and scenario number 56 includes six variants, yielding a total of 63 scenarios. Among these, 43 scenarios (based on scenario numbers 38) were identified as applicable for the reference NPP in terms of PSA. Conversely, 20 scenarios (based on scenario numbers 18) were deemed non-applicable. The applicable scenarios were categorized as follows:

- Pre: 13 scenarios addressed in the previous fire PSAs of domestic NPPs.
- New: 21 new scenarios that need to be covered in the fire PSA.
- Other: 9 scenarios, mainly related to signals, to be included as new scenarios. PSA modeling of equipment spurious operation for new scenarios includes others (for example, signal) as well as the equipment itself.

Table I provides an illustrative example of NEI MSO scenarios identified in this study.

3. Concluding Remarks

This study aimed to enhance the fire PSA capabilities of domestic NPPs by assessing the relevance of MSO scenarios outlined in NEI 00-01 to a domestic reference NPP. As a result of this evaluation, 43 out of the 63 MSO scenarios were found applicable to the domestic reference NPP. This indicates a higher number of relevant scenarios compared to deterministic analysis of domestic NPP MSOs. The reason for the increased number of MSO scenarios deemed applicable for fire PSA is attributed to the consideration of MSO scenarios affecting any equipment or system. Future work will involve conducting a quantitative analysis of the identified MSO scenarios.

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REFERENCES

[1] NEI, “Guidance for Post Fire Safe Shutdown Circuit Analysis”, NEI 00-01, Revision 3, Nuclear Energy Institute, 2011.
[2] EPRI, “Fire PRA Implementation Guide”, EPRI TR-105928, EPRI, 1995.
[3] ASME/ANS, “Addenda to ASME/ANS RA-S-2008, Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications,” ASME/ANS RA-Sa-2009, The American Society of Mechanical Engineers, New York, U.S., Feb. 2009.
[4] EGM 09-002, “Enforcement Guidance Memorandum—Enforcement Discretion for Fire Induced Circuit Faults,” May 14, 2009. ADAMS Accession No. ML090300446.
[5] Subudhi, M. et al., “Joint Assessment of Cable Damage and Quantification of Effects from Fire (JACQUE-FIRE), Technical Resolution to Open Issues on Nuclear Power Plant Fire-Induced Electrical Circuit Failure”, NUREG/CR-7150 vol. 3, USNRC, 2017.

Table I: Example of NEI MSO scenarios identified for domestic reference NPP

ID	Description	Notes	Application	Category
1	Loss of all RCP Seal Cooling	Spurious isolation of seal injection header flow, AND Spurious isolation of CCW flow to Thermal Barrier Heat Exchanger(TBHX)	Yes	New
17	Interfacing System LOCA	Spurious opening of multiple series RHR suction valve from RCS	No	Not Applicable
18	Multiple Pressurizer PORVs	Spurious opening of multiple (two or three) Pressurizer PORVs with corresponding block valves in normal, open position	No	Not Applicable
23	Inadvertent Steam Dumping	Spurious opening of multiple atmospheric steam dump valves upstream of MSIV	Yes	New
49	Emergency Power	Non-synchronous paralleling of EDG with on-site and off-site sources through spurious breaker operations	Yes	New
50	Generic - Loss of Pump Suction	Spurious isolation of various combinations of pump suction valves	Yes	Pre
53	Generic Flow Diversion	Spurious operation of various valves causing flow diversion	Yes	Pre
56d	RWST Drain Down	Spurious high containment pressure on multiple channels causing spurious containment spray signal	Yes	Other