Evaluation of Fire-Induced Multiple Spurious Operations at Leibstadt NPP

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Abstract: Leibstadt Nuclear Power Plant (KKL) recently performed a detailed full-scope Fire Probabilistic Safety Assessment (Fire PSA), to meet the augmented Swiss regulatory requirements on PSA, whilst also aligning with IAEA, ASME PRA standard and other international best practices.

The overall Fire PSA framework was based on NUREG/CR-6850, with specific guidance such as NUREG-2169 for fire ignition frequencies, NUREG-1921 for human reliability analysis, NUREG-2178, NUREG/CR-7010, NUREG-2232, and others for fire modelling. The analysis approach was adapted in specific tasks such as quantitative screening, multi-compartment analysis and detailed fire scenario refinement, to bring in more pragmatism to the analysis.

Fire-induced Multiple Spurious Operations (MSOs) are significant contributors to risk for majority of the BWRs worldwide. It is therefore important for any modern Fire PSA to address MSOs that could result in initiating events (IEs) or impact safe shutdown functions. The guidance NEI 00-01 provides deterministic methods for post-fire safe shutdown analysis and risk-informed methods that can be used in combination for MSO evaluation. To stay up to date with international experience, KKL conducted a thorough review of potential MSOs using this guidance as a basis.

The verification process began with the selection of generic MSOs applicable to BWR/6 according to NEI 00-01, followed by a categorization of these events into four groups: (i) Event is applicable and spurious actuations resulting in failure of component/train/system are modelled at basic event level in KKL PSA, (ii) Event is applicable and modelled as initiating event in KKL PSA, (iii) Event is applicable and captured in fire-impacts assessment through bounding consequences, and (iv) Potentially risk significant events requiring further analysis. Subsequently, an expert panel comprising specialists in Fire Protection, Fire Safe Shutdown Analysis, Walkdowns, Electrical, Control & Instrumentation, PRA, and Plant Operations, conducted a thorough evaluation of events in category (iv), to disposition or retain the MSOs.

Majority of the generic MSOs from NEI 00-01 were screened out for KKL by crediting the robust design features and established operational practices of the plant. For the retained MSOs, conditional probabilities of hot-shorts from NUREG/CR-7150 were incorporated in the PSA model, for specific component and / or cable failure modes. Through the verification process, it was concluded that all critical plant specific MSOs are captured in the study.

This paper discusses the overall methodology, and how to make best use of plant inputs and knowledge of expert panel to effectively evaluate the fire-induced MSOs.

Keywords: Fire PSA, Multiple Spurious Operations, NEI 00-01, Hot-shorts.

1. INTRODUCTION

The Leibstadt Nuclear Power Plant (KKL) undertook an ambitious project to update and modernize its full scope internal Fire Probabilistic Safety Assessment (Fire PSA) study to meet the augmented Swiss regulatory requirements on PSA (Regulation ENSI-A05 [1]) whilst also aligning with IAEA SSG-3 [2], ASME/ANS PRA standard requirements [3] and other international best practices.

The overall framework was based on NUREG/CR-6850 [4], with application of latest guidance in different areas such as fire ignition frequencies, human reliability analysis, detailed fire modelling and multiple spurious operations (MSOs). The analysis approach was adapted in specific tasks such as quantitative screening, multi-compartment analysis and detailed fire scenario refinement, to bring in more pragmatism to the analysis.

The original internal fire analysis of KKL was re-evaluated during the period 2012-2015 to consider the latest enhancements in KKL PSA internal events study existing then and to address the comments of IAEA IPSART mission conducted in 2014. The re-evaluation was limited to update of fire impacts evaluation and re-quantification of a specific set of scenarios. Subsequently, from the Periodic Safety Review (PSR) 2016, the Swiss Regulatory Authority ENSI issued certain action points related to checking the validity of existing detailed analysis and accuracy of earlier fire simulation studies.

In the period 2019-2021, KKL completely revamped the internal Fire PSA study based on augmented ENSI-A05 requirements [1], while also aligning the study with international best practices. This project also took benefit of the recent enhancements in KKL databases viz. components list, cable routing, fire loads, ventilation connections between compartments, fire suppression features, etc. and latest internal events PSA model.

Fire compartments retained after quantitative screening[1], were considered as risk significant and subjected to detailed refinement stage, where the consequences of fire were analysed at scenario level. For these compartments, a detailed verification of MSOs has been performed in line with NEI 00-01 guide [5].

The verification process began with the selection of generic MSOs applicable to BWR/6, followed by categorization of the MSO events into four categories, namely: (i) Event is applicable and spurious actuations resulting in failure of component/train/system are modelled at basic event level in KKL PSA, (ii) Event is applicable and modelled as initiating event in KKL PSA, (iii) Event is applicable and captured in fire-impacts assessment through bounding consequences, and (iv) Potentially risk significant events requiring further analysis. Subsequently, an expert panel comprising specialists in fire protection, fire safe shutdown analysis, plant walkdowns, electrical, control & instrumentation, PSA, and plant operations, conducted a thorough evaluation of events in category (iv), to disposition or retain the MSOs. Section 2 discusses the details of this verification process.

Majority of the generic MSOs of NEI 00-01 [5] were screened out for KKL given the robust design features and operational practices in the plant. For the retained MSOs, conditional probabilities of hot-shorts from NUREG/CR-7150 [6] were incorporated in PSA for specific component and / or cable failure modes.

2. VERIFICATION OF MULTIPLE SPURIOUS OPERATIONS

Fire-induced Multiple Spurious Operations (MSOs) are significant contributors to risk for majority of the BWRs worldwide. It is therefore important for any modern Fire PSA to address MSOs that could result in IEs or impact safe shutdown functions. Swiss regulatory requirements mandate the analysis of MSOs.

NEI 00-01 [5] provides detailed guidance for performing post fire safe shutdown analysis, addressing cable failures and MSOs. It reflects the insights gained from EPRI/NEI cable fire testing and CAROLFIRE cable fire testing [5, 6]. In summary, the guidance covers:

- Methodology for a focused-scope Fire PRA for assessing the risk significance of specific MSOs,
- Approach to identify and treat MSOs in case of fire,
- Generic lists of MSOs for BWRs and PWRs based on industry survey of US NPPs & feedback from pilot studies, and
- Important insights on treatment of associated circuits in post fire analysis and specifically the treatment of high/ low pressure interface components.

Large number of individual spurious operations associated with components important to safety (performing safety functions) is already modelled in KKL internal events PSA at basic event level, and also addressed within the scope of fire impacts evaluation task. For instance, control & instrumentation cables were assumed to cause worst possible spurious failure modes of the associated components, as shown in the examples in Figure 1 and Figure 2.

[1] Fire compartments with 99% cumulative contribution to CDF/ FDF were subjected to detailed refinement stage.

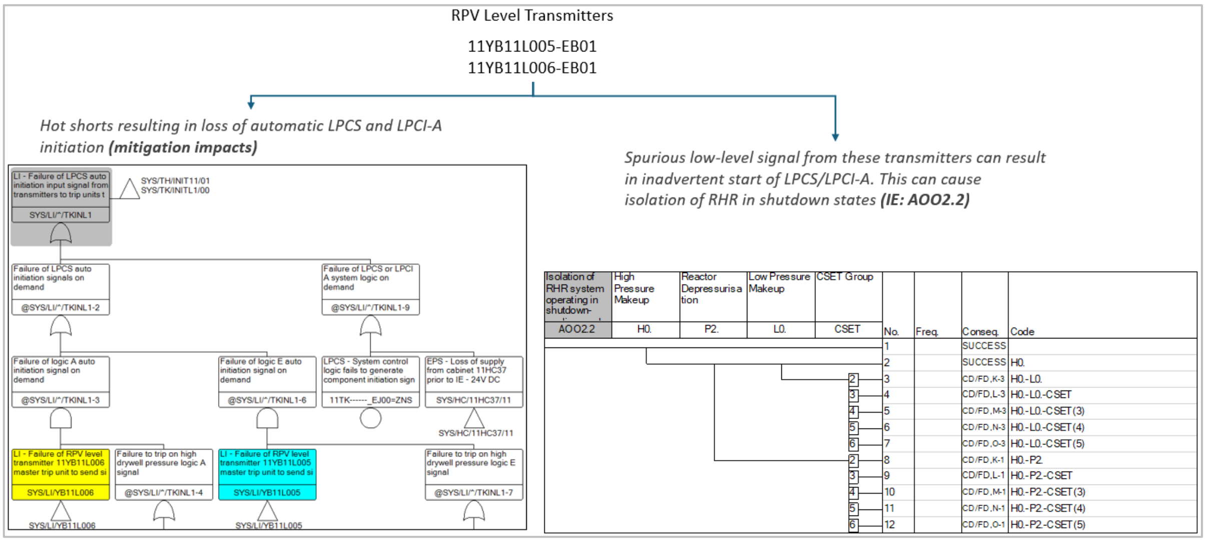

Figure 1. Modelling of spurious actuations for instrumentation components & associated cables

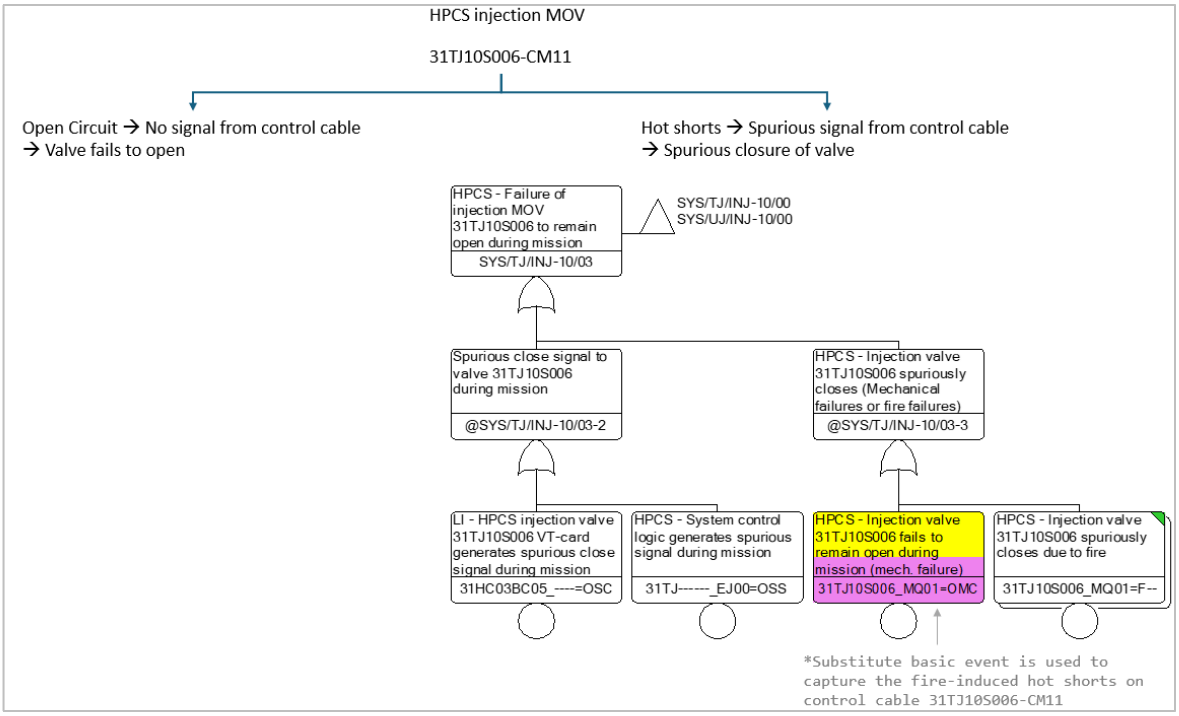

Figure 2. Modelling of spurious actuations for control cables

In an endeavour to stay abreast of the recent international experience, KKL performed a review of the MSO analysis against NEI 00-01 guidance [5]. The aim was to compare the MSOs already addressed during the fire impact evaluation task[2] against the generic MSO list in Appendix G and ensure that all critical MSOs discussed in NEI-00-01 [5] (and additionally BWROG NEDO-33638 report [7]) are checked for applicability to KKL and captured in Fire PSA study. While doing so, the review process also addressed the comments from IPSART mission related to consideration of MSOs.

The verification process was peer reviewed by an external expert from United States and supported by KKL plant experts. Figure 3 shows the verification approach and summary of MSO analysis.

[2] The fire induced impacts of cable failures were evaluated in detail in the impact evaluation task. In every fire compartment, all possible single spurious and multiple spurious operations of equipment, both intra-system and inter-system, were comprehensively evaluated to capture their effects on systems' response.

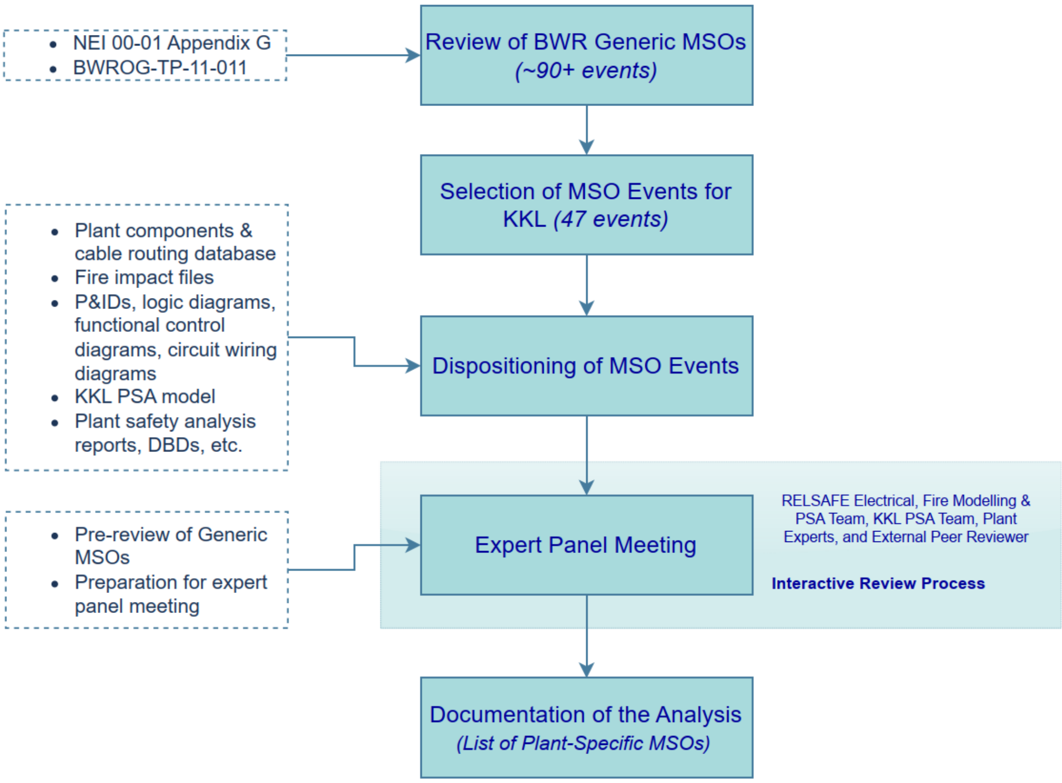

Figure 3. MSOs verification approach for KKL

2.1. Identification of Applicable MSOs from NEI 00-01

This step involved a review of the generic MSO list in Appendix G of NEI 00-01 [5] to identify the events relevant to BWR and check their applicability to KKL design (BWR-6). A total of 45 events were identified as starting point for the review. In addition, 2 events were identified from BWROG NEDO-33638 report [7]. In total 47 MSO events were identified within the scope of review for KKL.

2.2. Detailed Analysis and Dispositioning of MSOs

A detailed review was performed to categorise the MSO events into one of the following categories:

(i) Event is applicable and modelled already as resulting in component / train / system failure in KKL PSA,
(ii) Event is applicable and modelled as initiating event in KKL PSA,
(iii) Event is applicable and represented through bounding consequences in fire impact evaluation process (i.e., failures disabling the main system/train/component itself),
(iv) Event requiring further detailed analysis.

For example, the generic MSO event involving spurious opening of reactor pressure vessel (RPV) head vent valves (B21-2a[3]) would result in intermediate steam loss of coolant accident (LOCA) type scenario, which is already modelled in KKL PSA and considered in impact evaluation of respective fire compartments (see Figure 4). So, this event was categorized under type (ii).

[3] See Appendix G of NEI 00-01 [5].

NEI 00-01 Appendix G - Generic List of MSOs for BWR					
MPL	**#**	**Scenario Description**	**Notes**	**Relevant Safety Function**	**Plant Type**
B21	2a	(Main Steam) Head vent valves (2) Spuriously Open.	Valve Numbers MS-V-1, MS-V-2 or similar. Scenario may be screened, depending on line size and criteria for required versus available RCS Injection rate. Refer to the PRA criteria about how big of a steam line break is of concern, and use that to determine if the Scenario is of interest.	Reactor Coolant Makeup Control	All

Clarifications/Queries to KKL Operations Team	Responses from KKL Operations Team	Summary of Expert Panel Discussions	MSO Event Analysis Remarks/Conclusions	MSO Event Screening Status and Remarks
Are the MCC modules of RPV head vent valves 10YB10S002 and 10YB10S003 racked-out/electrically disconnected during normal plant operation and connected only during refuelling and hydrostatic testing plant operating modes (refer P&ID 613101_1_051 Marked.pdf)? The MCC cabinets are 10JC56 and 10JC59 located in ZC16R111 (Steuerschrankraum A).	The two valves could be opened at any time and are not disconnected during operation.	The possibility to electrically disconnect one of the RPV head vent valves was discussed with KKL operations and electrical personnel such that this MSO event can be precluded by design. KKL experts mentioned that it is relatively easy to rack out the MCC of MOV, however this would also require changes to the overall logic wiring of annunciators in the plant. The proposed recommendation is not straightforward to implement. The panel agrees with the screening justifications for this MSO event.	MSO event is already addressed in impact evaluation of following compartments ZC00P136, ZE00P134, ZE00P131 and ZE00P148 and the relevant IE (L-DW-IS_GENERAL) is modelled in PSA. Refer impact files FI-ZC00P136_R2, FI-ZE00P131_R2, FI-ZE00P134_R2 and FI-ZE00P148_R2 in Attachment B3. *Refer Attachment E for details of the analysis.*	Event is screened in and modelled as initiating event L-DW-IS_GENERAL in KKL PSA model.

Figure 4. MSO event B21-2a causing intermediate steam LOCA

A total of 21 MSO events assigned to category (iv) were subjected to a more detailed evaluation process. Electrical single line diagrams, wiring diagrams, functional control diagrams, P&IDs, control function flow diagrams and walkdown inputs were utilized for this evaluation. Specific design and operational aspects were clarified with plant personnel, and their responses were incorporated in the analysis to determine the applicability of MSOs to KKL. Table 1 shows an example of the detailed analysis for event G33-2ae[3], involving spurious opening of Reactor Water Clean-Up (RWCU) isolation valves, which may divert the RPV inventory elsewhere.

Table 1. Analysis of MSO event G33-2ae[4] (example)

Initial analysis of the scenario based on plant-specific configuration	RWCU is a normally operating system and so the pump suction and discharge Motor-operated valves (MOV) are normally open during plant startup, full power, shutdown, and hot standby conditions. However, there are some possible scenarios where a spurious opening of these valves (following their closure) may route the RPV inventory to RWCU system, as discussed below: a) Post-isolation of RWCU, spurious opening of RWCU suction/discharge valves will not lead to loss of RPV inventory as the pumps are not operational post isolation of the system. b) When the system is in operation, spurious opening of the normally closed RWCU drain valves connected to Radwaste or Main Condenser may divert the RPV inventory into Radwaste drain tank or Main Condenser.
Detailed analysis	The control cables of RWCU isolation valves are physically well segregated in all fire compartments, except the main control room (MCR) where manual controls to these valves are possible from a local panel. A simultaneous spurious opening of both valves due to fire-induced hot shorts is therefore not possible in any other fire compartment. In MCR, the control cables are related to the actuation pushbuttons of the valves. A fire in MCR will likely trigger SCRAM and containment isolation due to the fail-safe logic. Thus, either a fire in MCR leading to containment isolation or a scenario with one of the trip parameters triggered (e.g., low RPV water level) will prevent the RWCU valves from inadvertently opening, until the isolation signal disappears. In case of scenario (a), spurious opening of both RWCU pump suction valves will lead to retention of RPV inventory until the RWCU discharge valves (the retained inventory is slightly less than $1 m^3$). Since the RWCU pumps are not operational post isolation of the system, there will not be any RPV inventory loss due to spurious opening of the RWCU suction/discharge valves. In case of scenario (b), spurious opening of both valves can lead to diversion of RPV inventory to Radwaste drain or Main Condenser. Flow diversion to Radwaste drain is not possible due to the lock closed manual valve downstream of the normally closed MOV.

[4] The explanation provided in this table for detailed analysis is generic and plant-specific information such as equipment IDs, P&ID numbers, functional control diagram references, etc. are redacted from publication.

	For the flow diversion to main condenser, an additional MOV downstream of valve also needs to spuriously open. These valves are controlled from a local panel in MCR. Fire-induced hot shorts from control cables can lead to simultaneous spurious opening of the valves. Interlocks of the blowdown flow control valve would keep the valve in closed position, thereby not directing the RPV flow to main condenser even if the MOVs after the blowdown flow control valve were to open. These interlocks are not affected given a fire in MCR, as confirmed by plant experts. There are also additional possibilities to isolate the RWCU system. The flow measurement elements in the RWCU pipelines calculate the balance of mass in the system. These signals are sent as input to leak detection system, which then isolates RWCU in case of any difference in the pre-defined mass flow rate thresholds, thereby preventing any significant flow diversions from RPV.
Conclusion	The scenario requires simultaneous spurious opening of 4 valves in the right sequence, given a fire in main control room. Further, the interlock prevents spurious opening of the blowdown flow control valve thereby not directing the RPV flow to main condenser. Based on the number of sequential failures involved in this scenario, above design features and discussions with KKL plant experts, this MSO event is deemed improbable for KKL.

Note for Consideration of MSOs from Panels in Main Control Room

At KKL, three independent and redundant remote shutdown areas, and bunkerised control rooms are present in addition to the main control room. These areas contain controls for all equipment necessary to accomplish safe shutdown of the reactor in case of Safe Shutdown Earthquake (SSE) level earthquake or airplane crash or any external/ internal hazards.. Important plant parameters that are monitored in the main control room are also displayed in these areas.

All active control signals from MCR panel require coincident signals from component actuation pushbutton and release permissive pushbutton on the specific panel. For important MOVs, pumps etc., there are also pre-selection switches for selecting auto mode or manual mode. An additional spurious signal from these switches is also required for generating spurious operation of certain components in manual mode (in addition to the spurious signals from manual actuation push button and release permissive pushbutton). Figure 5 shows an illustration of MCR pushbutton operation under normal and fire conditions.

KKL plant operators confirmed that it is unlikely that both these commands will be triggered simultaneously due to fire induced hot shorts in cables within the MCR panel. Given the robust manual control scheme implemented at KKL and availability of independent and redundant control rooms to safely shutdown the reactor, fire-induced hot shorts due to panel fires in MCR consequently resulting in MSOs can be considered extremely unlikely. However, considering that there is some uncertainty in predictability of simultaneousness, chronology (which failure mode will occur first, open circuit or spurious hot short) and the probability of occurrence of spurious hot shorts in cables located within a common panel/cabinet, the events are treated as probable from Fire PSA standpoint and treated appropriately in fire impacts evaluation and MSO analysis.

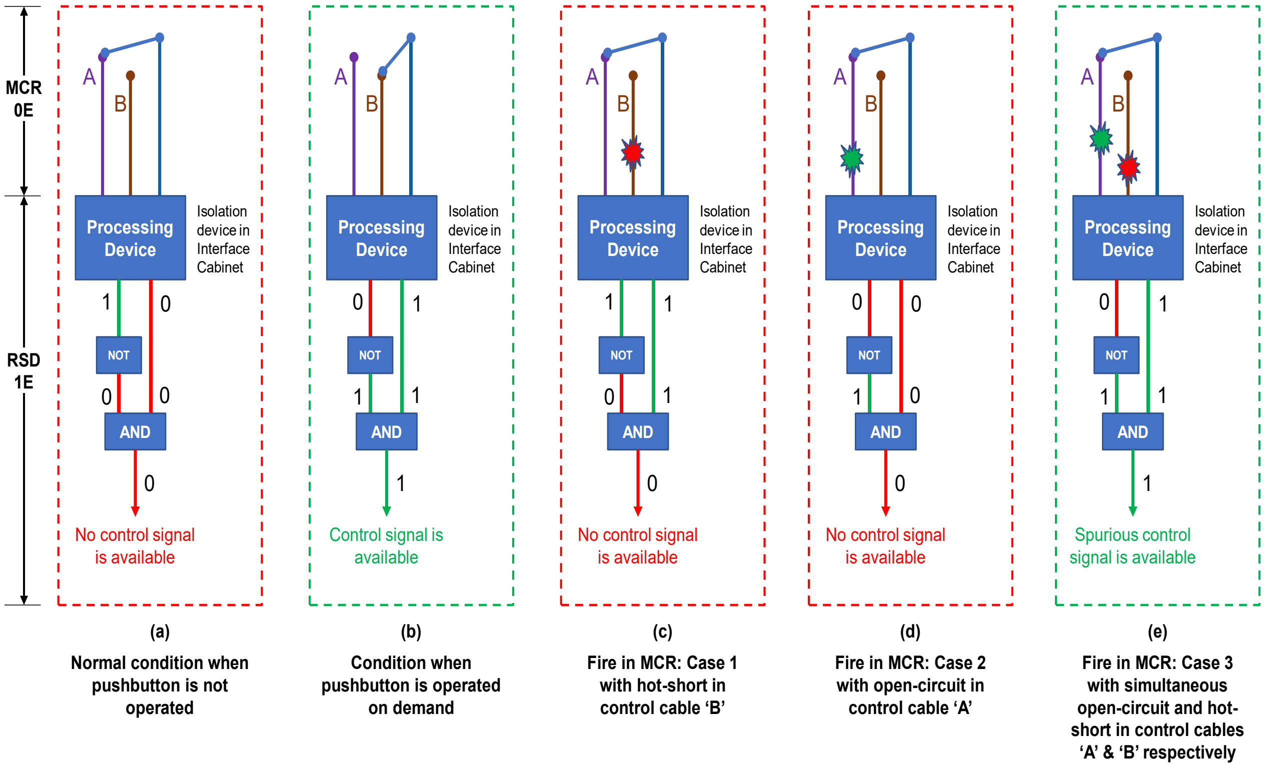

Figure 5. Operation of MCR pushbutton under normal and fire conditions

In order to confirm the screening basis for certain MSO events, additional clarifications were sought from KKL plant operations and electrical experts. In most cases, it was noted that the design features at KKL prevent occurrence of MSO scenarios (e.g., cable routing – good divisional separation, interlocks, electrical protection, circuit design aspects, fire protection design, etc.). Some MSO events were deemed not plausible due to operational practices followed in the plant (for instance, electrically disconnecting the MCCs or circuit breakers in particular operating states, which rules out the possibility of spurious operation of the end component). For certain MSO events, it was also noted that the plant had sufficient design margins to cope up, and so the consequences of MSO scenario are insignificant (this was verified from plant procedures, safety analysis, thermal hydraulic and flow diversion calculations).

For example, the MSO event involving spurious restart of reactor recirculation pumps influencing Residual heat removal (RHR) injection due to discharge backpressure from the recirculation pump (B31, 2-NEW-5[3]) is not possible for KKL. The plant experts confirmed that there is no automatic start logic implemented for recirculation pumps. Even if these were inadvertently started, the pumps would be automatically tripped by the protection logic.

2.3. Peer Review and Quality Assurance

An independent peer review of the MSO analysis was carried out by an experienced external expert from United States who is also one of the principal contributors to NEI 00-01 guidance [5]. The objectives of this review were to provide:

- Technical comments and feedback on the evaluation of generic MSOs recommended by NEI 00-01 [5] for applicability to KKL, and
- Feedback on the results of the screening process and application of accepted best practices.

Some of the important aspects discussed during the peer review process are summarised below:

- Scheme showing the component actuation pushbutton and release permissive pushbutton on MCR panel, which is a key design attribute for treatment of potential MSOs from MCR fires.

- Alternate control room panel transfer scheme (MOV schematic showing contacts, transfer switches and fusing) to understand the potential credit taken for these features in addressing MSO scenarios in MCR.
- Fire protection aspects of 1E qualified cables, and their considerations in dispositioning the MSO events.
- Electrical scheme depicting the control wiring, MCR switches, and temperature/ pressure interlocks for analysing spurious operation of RHR Shutdown cooling (SDC) high-low pressure interface.
- Plant design incorporating divisional separation of emergency diesel generators to disposition events concerning multiple loads being spuriously loaded onto a diesel generator.
- Working of limit/ torque switches along with implementation of their contacts in the control circuitry to determine their effects on MOVs.
- Potential for generating a spurious reactor high pressure signal opening all safety relief valves (SRVs) (both automatic depressurization system (ADS)-capable and standard SRVs) based on the number of cables damaged by fire.

2.4. Expert Panel Review and Consolidation

A thorough pre-review of the generic MSOs from Appendix G was performed to identify events that can be screened out and those requiring detailed analysis and dispositioning as explained in Chapter 2.2. The analysis outcomes were documented in a traceable manner and shared with the expert panel in advance to optimize the time spent in expert panel reviews.

The expert panel meeting included a detailed presentation covering the following topics.

- Motives for fire PSA, overall methodological process and results of the screening stages (qualitative & quantitative stages)
- Treatment of single spurious operations and MSOs within KKL Fire PSA
- Specific approaches to evaluate fire-induced consequences on power, instrumentation, and control cables
- Verification of generic MSOs based on the NEI 00-01 (with some examples) and key outcomes of the analysis

The presentation was supported by necessary marked-up P&IDs, FCDs, wiring diagrams, and analysis spreadsheets to facilitate the discussion and review.

The expert panel had representatives from KKL PSA team, Operations and Electrical teams, an external Peer Reviewer, and RELSAFE PRA Consulting. The panel reviewed the analysis approach and ratified the justifications for considering or screening out the generic MSO events in Fire PSA. Engineering judgments and justifications provided for certain scenarios were acknowledged by KKL plant operation experts and the external peer reviewer.

Additional insights were obtained on MSO events causing spurious opening of ADS capable SRVs and/or ADS inhibit across all safety divisions. The panel shared beneficial perspectives and operational experience that strengthened the technical basis to disposition the MSO events. There were no additional (or similar) MSO event combinations identified that required plant specific evaluation.

The outcome of the expert panel review process resulted in identification of plant-specific MSOs, which were either confirmed to be already modelled in the internal events PSA or to be additionally considered in internal Fire PSA study.

3. MSO DOCUMENTATION PROCESS

The entire MSO evaluation process was conducted in a transparent and traceable manner, and duly documented as illustrated in Figure 6.

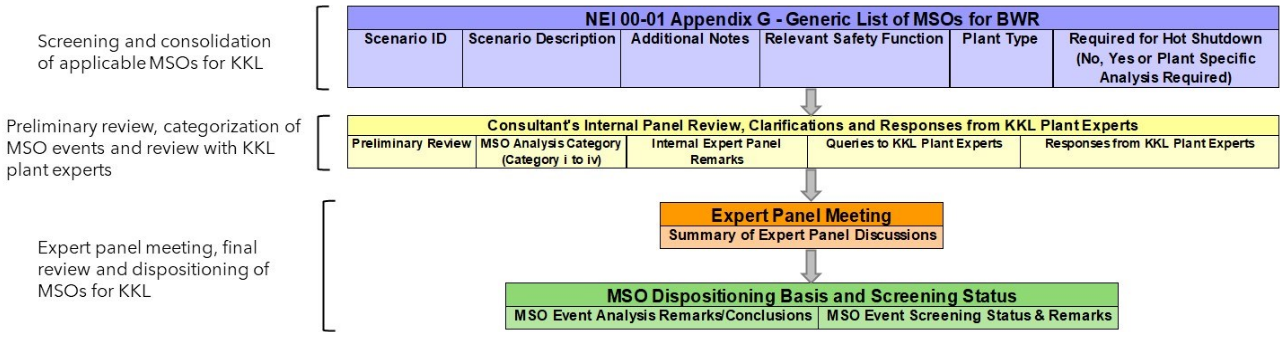

Figure 6. MSO analysis spreadsheet showing the traceability of work from initial screening until final dispositioning

4. MSO ANALYSIS SUMMARY

Figure 7 shows the summary of 47 generic MSO events evaluated in the current study. KKL plant has robust design with regard to physical and divisional separation concept, segregation of remote shutdown areas and bunker systems, divisional separation for cable routing, cable protections in important locations such as drywell and containment, grounding of all cable raceways and signal zero potentials, etc. These aspects combined with good operational practices played an important role in limiting the impacts of MSOs.

- 18 MSO events are not applicable to KKL due to design features in the plant. Presence of electrical interlocks, passive components in flow diversion paths, physical and electrical separation of cables, good operational practices such as racking out Motor control centres (MCCs), Circuit breakers (CBs), cross-tie CBs, and mitigation measures in emergency operating procedures preclude most of the risk-significant events.
- 29 MSO events are applicable to KKL, some result in initiating event while others affect mitigation functions. These events are already modelled in KKL PSA[5].

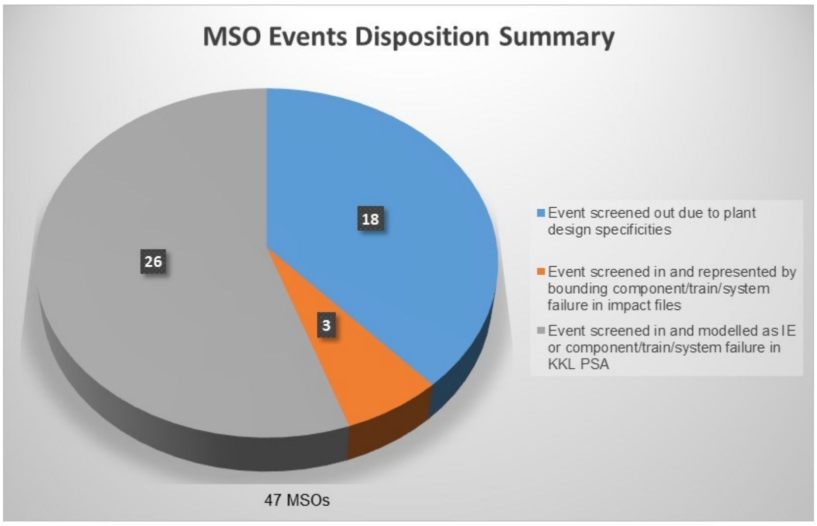

Figure 7. MSO analysis summary

5. CONCLUSION

KKL addressed the requirements of the Swiss Regulator ENSI and applied best practice methods from NEI and NUREG guidelines to systematically verify the fire-induced Multiple Spurious Operations (MSOs) as part of Internal Fire PSA study. The main goal of the study was to compare the MSOs identified during fire impact evaluation task against the generic MSO list in NEI 00-01 (Appendix G) [5] and ensure that all critical MSOs were assessed for applicability to KKL and appropriately captured in the study.

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[5] Spurious operation probabilities were refined at dominant scenario level to their expected likelihood using NUREG/CR-7150 guidance.

Evaluating fire-induced MSOs and their consequences is a complex task due to the uncertainty in predicting simultaneity, sequence of failure mode (i.e., determining whether spurious hot short or open circuit will occur first) and the probability of multiple spurious hot shorts occurring in cables located inside a panel, cabinet, or routed through cable trays. These aspects were addressed through a systematic methodological process with early involvement of plant experts and peer reviewer in the analysis. For instance, it was possible to localize the MSOs that can cause spurious ADS and/or ADS inhibit to specific set of panels and cabinets at KKL, through which a range of possible scenarios and consequences were thoroughly evaluated (e.g., spurious opening of all ADS SRVs or one ADS SRV with or without ADS inhibit, etc.). Another benefit is the improved understanding of the consequences of certain type of failures, like loss of reactor water through multiple stuck open scram discharge volume vent or drain valves, rapid depressurization or over-pressurization of drywell, excessive cooling of containment, etc.

These specificities were represented in the event sequence models, resulting in an accurate estimation of fire risk. In particular, the event sequence progression for spurious ADS actuation was modified to credit a new operator action to reclose the SRVs, which resulted in improved risk characterisation (previously the event was treated as unisolable, which was sub-optimal).

In summary, the robust design features and good operational practices in KKL play an important role in limiting the impact of MSOs, viz: physical and divisional separation concept, provision of remote shutdown areas and special bunkered systems, divisional/fire separation in cable routing, cable protections at key locations such as drywell and containment, grounding of cable raceways and signal zero potentials.

Acknowledgements

The authors would like to express their gratitude to KKL plant experts for sharing their immense plant experience, practical advice, and participation in technically enriching conversations that helped guide the MSO review process. The authors also wish to thank external peer reviewer for offering practical guidance, insights, and a variety of viewpoints based on his extensive knowledge and experience with NEI 00-01 [5] applications in US NPPs.

References

[1] ENSI-A05, Swiss Federal Nuclear Safety Inspectorate (ENSI), Probabilistic Safety Analysis (PSA): Quality and Scope, 2019.

[2] IAEA SSG-3, Development and Application of Level 1 Probabilistic Safety Assessment for Nuclear Power Plants, 2010.

[3] ASME/ANS RA-S-1.1-2022, Standard for Level 1/ Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications, 2022.

[4] United States Nuclear Regulatory Commission (USNRC), Electric Power Research Institute (EPRI), Fire PRA Methodology for Nuclear Power Facilities, NUREG/CR-6850, Volume 2: Detailed Methodology, September 2005.

[5] NEI-00-01, Guidance for Post Fire Safe Shutdown Circuit Analysis, Revision 4 (draft), September 2016.

[6] Joint Assessment of Cable Damage and Quantification of Effects from Fire (JACQUE-FIRE): Final Report (NUREG/CR-7150, Volume 1, BNL-NUREG-98204- 2012, EPRI 1026424), October 2012.

[7] BWROG Report No. BWROG-TP-11-011, Revision 0, June 2011 NEDO-33638, BWROG Assessments of Generic Multiple Spurious Operations (MSOs) in Post-Fire Safe Shutdown Circuit Analysis for Operating BWR Plants.