Seismically-Induced Internal Fire and Flood (SIFF) Events Assessment at Leibstadt NPP, Switzerland

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Abstract: Seismically-induced secondary hazards such as seismically-induced fire and flood (SIFF) events have gained greater attention following major earthquakes like the Tōhoku and Virginia Earthquakes in 2011 and Kashiwazaki-Kariwa earthquake in 2007. Secondary hazards/effects proved to be of higher likelihood than originally assumed in the plant design basis. Different organizations like USNRC, EPRI, ASME, IAEA and WENRA worked to strengthen the requirements and methods for evaluating the protection against such hazards. The Swiss regulatory authority (ENSI) has also issued heightened requirements for seismic verification of existing Nuclear Power Plants (NPPs), mandating deterministic and probabilistic SIFF assessments. To fulfil ENSI requirements and to stay up-to-date with international developments, Leibstadt NPP (KKL) performed a systematic and comprehensive assessment of SIFF events based on the state-of-the-art EPRI methodology, covering both deterministic and probabilistic aspects in an integrated manner. The main objectives of SIFF assessment undertaken by KKL were to: (i) apply a robust, stage-wise, top-down screening process using qualitative and quantitative criteria (e.g., walkdown observations, seismic fragilities, risk measures); (ii) demonstrate the plant safe shutdown capability for unscreened SIFF events, if any; (iii) evaluate quantitatively the additional risk impact due to SIFF using PSA; and (iv) analyze the risk associated with explosive materials and seismic interactions. The data and analysis from the latest fire and flood deterministic and probabilistic studies at KKL were used as a starting point in the SIFF analysis, including about 3900 potential fire ignition sources and 9100 flood sources. Post application of KKL SIFF methodology, all the fire and flood sources were screened out except 2 flood sources (possibility of spray due to seismically-induced rupture of fire sprinklers) that were deterministically evaluated to demonstrate that plant safe shutdown capability remains unaffected due to these 2 flood scenarios. External experts were engaged for independent peer reviews, one of whom was a principal contributor to EPRI methodology. This paper describes the methods used and the insights gained from the SIFF study at KKL and depicts how a systematic top-down screening approach has proved to be effective and practical. It also discusses some relevant observations and recommendations for future similar industrial projects.

1. INTRODUCTION

The Great Tōhoku Earthquake in 2011 (magnitude of 9.0) induced tsunami waves higher than 10 meters leading to the accident at Fukushima Daiichi Nuclear Power Plant (NPP) [1]. The ground motions experienced during this event exceeded the plant design basis. Following this event, many countries have performed comprehensive safety assessment of their NPPs to re-evaluate the risk due to external hazards (including seismic hazard). Regulatory authorities and international organisations worldwide have put more emphasis, in particular, on the assessment of risk due to seismically-induced secondary hazards (or combination hazards).

Seismically-induced Internal Fires and Floods (SIFF) assessment has gained greater attention in recent times. For instance, the recommendation by **Near-Term Task Force of U.S. NRC** in Section 4.1.2 [2] refers to evaluation of potential enhancements to NPP capability to prevent or mitigate seismically-induced fires and floods. The updated code case of **ASME PRA Standard** [3] also prescribes the assessment of secondary hazards, featuring the procedure for evaluation of SIFF events. Requirement TU3.1 of **WENRA Safety Reference Levels** [4,5,6] concerning assessment of external hazards stipulates the consideration of consequential hazards and causally-linked hazards including SIFF events.

In Switzerland, the **Swiss Federal Nuclear Safety Inspectorate (ENSI)** also initiated the EU stress test and mandated a re-evaluation of the safety of all Swiss NPPs against earthquakes, external flooding and a combination thereof [7]. As part of regulatory requirements, ENSI directed NPP operators to update their seismic safety studies in accordance with:

- ENSI-AN-8567 [8] requiring **deterministic** verification to demonstrate that safe shutdown can be achieved post seismic event, followed by consequential fires or floods, or explosions, and
- ENSI-A05 [9] requiring **probabilistic** estimation of risk of seismically-induced internal fires and floods in Seismic PRA.

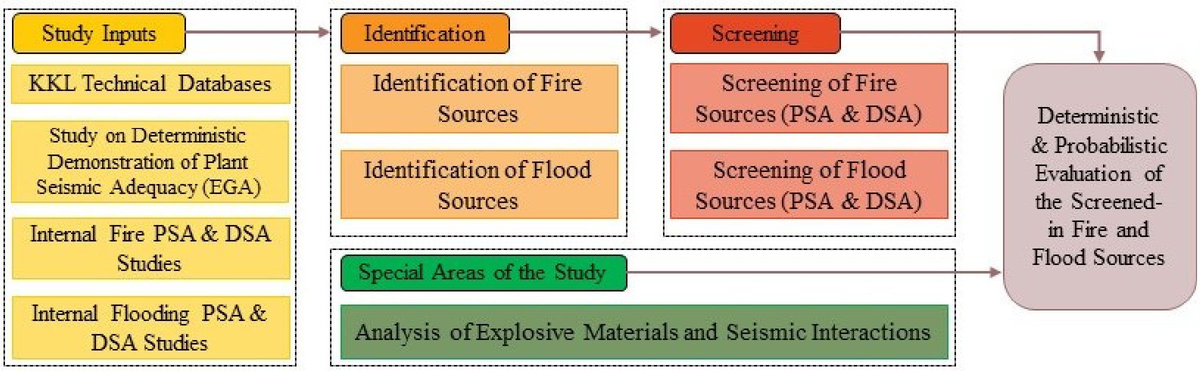
Subsequently, Leibstadt NPP (KKL) conducted a safety evaluation to assess the plant's seismic adequacy against the threat of SIFF events, to meet ENSI requirements. KKL has applied the state-of-the-art methodology developed by EPRI [10] for systematic assessment of SIFF events. The effectiveness of this methodology is reported proven through several pilot studies at U.S. NPPs. While this methodology is primarily intended to support risk-informed treatment of SIFF events in the context of seismic PRA, KKL suitably adapted the methodology to evaluate SIFF risk considering both deterministic and probabilistic perspectives in an integrated manner. In deterministic analysis, the SIFF sources are screened based on deterministic criteria and the sources that are screened in will be subjected to post-seismic safe shutdown analysis. To demonstrate plant seismic adequacy, at least one safe shutdown path (out of multiple defined paths) should remain unaffected by the seismically-induced fire/flood scenario. In contrast to this, in probabilistic analysis, the SIFF sources are screened based on probabilistic criteria and the screened in sources will be added to the Seismic Equipment List (SEL). The additional seismic-fire/flood risk will be quantified by modelling the seismically-induced fire/flood scenarios in Seismic PSA. The resultant risk will be added to the plant seismic risk.

This paper describes the methodological steps applied and the insights gained from SIFF assessment.

2. METHODOLOGY

The EPRI methodology [10] was used as the basis for development of KKL specific methodology that serves both deterministic and probabilistic objectives of SIFF assessment. Interdisciplinary insights from the latest deterministic and probabilistic safety studies conducted at the plant (seismic, internal fire and internal flooding) and their related databases were used in the process. **Figure 1** shows the prominent methodological steps/tasks at a glance.

Figure 1: Methodological Steps involved in SIFF Assessment



2.1. Identification of Fire & Flood Sources

The first step in the process is identification and disposition of fire/flood sources in all plant locations important to deterministic and probabilistic safety assessments.

2.1.1. Fire Ignition Sources

A comprehensive list of fire ignition sources (fire loads) in the plant is compiled from the output of the fire ignition frequency estimation process, within the Fire Probabilistic & Deterministic Safety Analyses (PSA & DSA) conducted recently at KKL. NUREG/CR-6850 [11] and NUREG-2169 [12] methodologies were widely used for these studies.

About **3900** ignition sources were identified from **472** fire compartments in **34** buildings and **2410** rooms. The fixed and transient ignition sources considered in the study are in accordance with the source groups presented in Table 6-1 of NUREG/CR-6850 (vol. 2) [11]. In addition to these 37 ignition source types listed in NUREG guidance [11], [12], ignition sources related to lubrication and fuel oil systems (such as lube oil collection system of a pump of the Diesel Generator (DG) fuel supply) were identified from KKL technical database and included in the list. This list was further validated through a comparison with the existing SEL (≈**12000** SSCs) to ensure that all fire loads are captured.

Certain equipment attributes that are considered vital for screening of fixed ignition sources were identified from KKL technical databases. For instance, safety and seismic classification, voltage (V) and power (kW) ratings for electrical equipment, lube oil and fuel quantity (litres) for pumps and tanks.

2.1.2. Flood Sources

A comprehensive list of flood sources in the plant is compiled from Flood PSA & DSA conducted recently, in accordance with EPRI-1019194.

About **9100** flood sources were identified from more than **50** inventory-retaining systems present in **26** buildings (**700**+ rooms) and **62** flood compartments that are within DSA & PSA scope. Typical flood source categories are presented in **Table 1**.

Table 1: Typical Flood Sources considered in SIFF Assessment

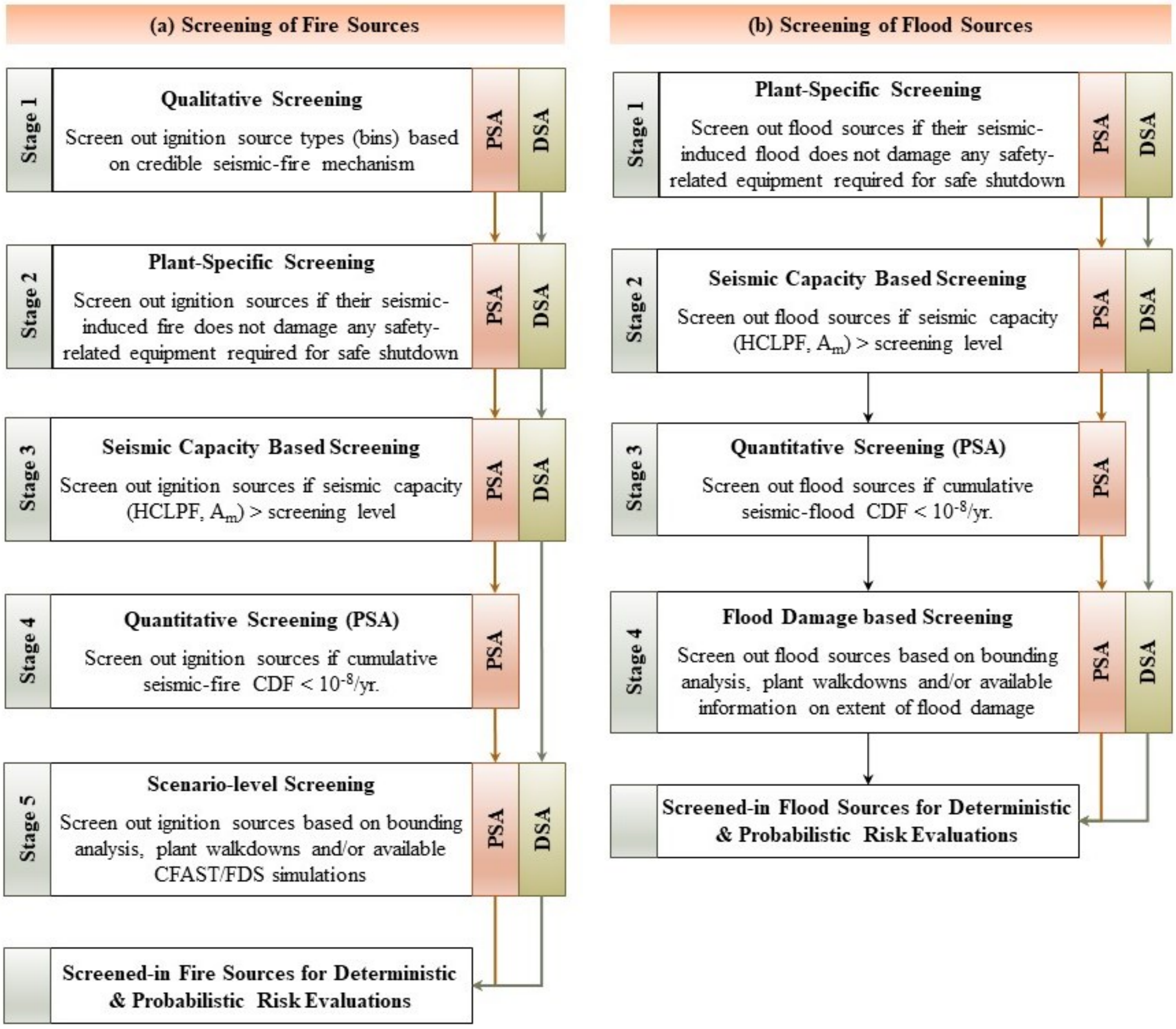
Flood Source Type	Flood Source Description
Piping	Main pipe and its pipe segments with diameter ≥ 25 mm
Tank	Containers, surge/expansion tanks, heat exchangers, etc.
Sprinkler	Firewater sprinklers present in selected locations
Deluge	Deluge fire protection system piping in selected locations

This list was further validated through a comparison with existing SEL to ensure that all flood sources were captured. The list excludes specific components connected to the piping such as valves, pumps, reducers, orifices, etc., because their seismic fragilities are bounded by the fragility of corresponding pipes, as per EPRI Seismic PRA Implementation Guide [13].

2.2. Screening of Seismically-induced Internal Fire & Flood Sources

A systematic top-down approach has been devised to screen out fire ignition sources and flood sources based on qualitative and quantitative criteria, plant-specific fire/flood impacts assessment, walkdown observations, seismic fragility estimates and risk measures. The overall screening process is illustrated in **Figure 2**. Applicability of screening stages and criteria differs for probabilistic and deterministic assessments. For example, the screening level selected for seismic-capacity based screening is different for PSA and DSA, and the quantitative screening of fire/flood sources based on their fire/flood core damage frequency (CDF) is only applicable to PSA (and not relevant to DSA).

Figure 2: Screening Stages for SIFF Sources



Note: If there are fire and/or flood sources retained after the specialised analysis of explosive materials and seismic interactions, those are also subjected to this top-down screening analysis.

2.2.1. Seismically-Induced Internal Fires

The comprehensive list of fire ignition sources is subjected to five stages of screening in a sequential manner as shown in **Figure 2 (a)**.

Stage 1: Qualitative Screening

The likelihood of an ignition source causing fire depends on the seismic qualification of the equipment and the seismic failure mode. Industry experience has shown that seismically-induced fires have a higher likelihood of occurrence in ignition sources that are not seismically qualified. There are certain equipment types whose resulting failure mode during a seismic event cannot result in an ignition or fire. For example, failure of batteries subjected to vibratory ground motion may not result in sufficient energy to create a spark and ensuing fire. The first stage involves screening of such ignition source types (bins) which do not have credible seismic-fire mechanism.

Each ignition source bin is assessed for its seismic ruggedness or the possibility to ignite after a seismic failure (i.e., not prone to fail during a seismic event).

22 ignition source bins (out of 41) corresponding to transient ignition sources, cables, batteries, junction boxes, etc., were screened out based on the expert panel disposition (detailed evaluation by panel of experts providing insights on failure mode consideration of ignition source bins). Further, **2** bins were screened out because there were no ignition sources at KKL that can be assigned to Bin 16.1 (HEAF for segmented bus ducts) and Bin 16.3 (HEAF for low-voltage electrical cabinets 480-1000 V). All fire sources from remaining **17** ignition source bins were considered screened-in for further analysis as they have credible seismic-fire mechanism. The retained ignition sources such as air compressors, diesel generators, transformers (oil filled and dry), ventilation subsystems, etc., have ignition possibility post seismic-induced failure due to incipient fire conditions of static electrical components or arcing or spill of lube oil / fuel oil.

Stage 2: Plant-Specific Screening

Some seismically-induced fires may not impact any safety functions required for safe shutdown of the plant. This can be attributed to the small size of fire, or absence of any safety-related equipment or cables in the vicinity. For instance, seismically-induced fire from a non-safety service water system equipment can affect only other non-safety equipment in the vicinity, which will have no impact on plant safe shutdown functions.

The second stage involves evaluating the consequences of a seismically-induced fire specific to each ignition source (if it were to occur) based on its attributes and location in the plant. Following screening criteria were applied at this stage: An ignition source can be screened out

- if the consequential fire has no effect on the safety-related equipment or cables required to bring and maintain the plant in a safe shutdown state post-seismic event (i.e., components credited in the deterministic seismic shutdown paths or seismic PSA).
- if only passive safety-related equipment are present in the vicinity and those passive equipment are not associated with critical operator actions.
- If possibility of a hostile fire from ignition sources can be ruled out considering less oil/fuel quantity or inability to spill oil/fuel after a seismic failure.

Majority of ignition sources located in non-safety fire compartments were screened out based on these criteria. Further, ignition sources such as pumps, motors or air compressors which contain relatively less oil (or low rated power) were screened out.

Stage 3: Seismic Capacity-based Screening

At this stage, the screening criteria applied for probabilistic and deterministic assessments are differentiated based on the respective seismic demands on the fire sources. For deterministic assessment, the seismic demand considered is equivalent to the peak ground acceleration (PGA) of a design basis earthquake with an exceedance frequency of 10^{-4}/yr. For probabilistic assessment, the upper limit of seismic demand is deduced from the regulatory requirements prescribed for seismic PSA (refer to **Table 2**).

If the seismic capacity of an ignition source (expressed in terms of high confidence of low probability of failure [HCLPF] and median capacity [A_m]) is greater than the seismic demand, then ignition source will not seismically fail. Such ignition sources are screened out in this stage. The screening levels (i.e., seismic demands) defined for probabilistic and deterministic assessments are presented in **Table 2**.

Table 2: Screening Criteria for Seismic Capacity-based Screening

	Screening Level	Basis for Screening Level
PSA	HCLPF > 1.2g **AND** A_m > 3.0g	In line with regulatory requirement ENSI-A05 [9], a conservative target CDF was set at 1E-7/yr., for establishing the capacity-based screening criteria in

	Screening Level	Basis for Screening Level
		KKL Seismic PSA 2016. This resulted in a screening HCLPF = 1.2g and A_m = 3.0g. **Ignition sources having seismic capacity more than screening level are screened out.**
DSA	HCLPF ≥ 0.35g	For KKL, the PGA corresponding to an earthquake with exceedance frequency of 10^{-4}/yr., is equal to 0.35g. **Ignition sources that could withstand this earthquake with high certainty are screened out.**

During the screening process, some equipment were screened in for PSA but screened out for DSA. These equipment have their HCLPF values between 0.35g and 1.2g. After this screening stage, few ignition sources were screened in for PSA and none of the ignition sources were screened in for DSA i.e., all ignition sources were found to withstand design basis earthquake (HCLPF ≥ 0.35g).

Stage 4: Quantitative Screening (PSA)

This stage involves numerical estimation of risk and so only applicable for PSA. Fire sources retained post Stage 3 can be further screened out based on their seismic-fire risk significance. The seismic-fire CDF for every ignition source is estimated as a function of the seismic hazard, seismic fragility, conditional probability of ignition (after seismic failure) and conditional core damage probability (CCDP) from existing Fire PSA study. It is worth noting that the fire risk is calculated at a fire compartment level to be conservative at this stage i.e., the compartment-level CCDP is estimated with an assumption that fire from an ignition source regardless of its fire potential and location will damage all SSCs (including safety-related SSCs) in the compartment without giving credit to fire suppression means and/or mitigation operator actions. Thus, the worst case PSA impacts are captured in this approach and possibility of multiple seismic-fire events is addressed.

To screen out ignition sources, a target CDF screening value was selected i.e., criterion corresponding to cumulative seismic-fire CDF ($SFCDF_{cum}$). The $SFCDF_{cum}$ is defined at a sufficiently low screening level of 1E-08/yr., which is equivalent to 1% of KKL seismic CDF. All ignition sources with the cumulative SFCDF lower than 1E-08/yr., were screened out from further analysis.

Only a handful of ignition sources were observed to be risk significant and screened-in for Stage 5.

Stage 5: Scenario Level Screening

This stage involves detailed analysis of seismic-fire risk in terms of potential consequences on plant safety and can be applied to screen out ignition sources retained for PSA or DSA. Several aspects can be examined to screen out fire sources at this stage, like reviewing the fire potential of ignition sources based on existing fire simulation studies or use of fire dynamic tools (FDTs), or oil spill potential. Moreover, the seismic-fire risk can be further refined to account for realistic damage at a fire scenario level (instead of compartment level).

Since all ignition sources were screened out at Stage 3 for DSA, this screening stage was only applicable to few ignition sources that were retained for PSA post Stage 4. For these ignition sources, seismic-fire risk was quantified at a scenario level ($SFCDF_{scen}$) using CCDP of the bounding or worst-case fire scenario originating from that ignition source, with information from existing Fire PSA study. The cumulative seismic-fire risk from all screened-in ignition sources was found to be lower than 1E-08/yr., so all ignition sources were screened out for PSA.

2.2.2. Seismically-Induced Internal Floods

Similar to fire sources, the comprehensive list of flood sources is subjected to four stages of screening in a sequential manner as shown in **Figure 2 (b)**.

Stage 1: Plant-Specific Screening

Around 9100+ flood sources have been identified in the plant. Owing to the enormous number of flood sources, plant-specific screening is performed prior to seismic-capacity based screening in order to optimize the list of flood sources requiring fragility estimation.

In this stage, flood sources can be screened out based on the following criteria:

- A flood source can be screened out if consequential flood in the compartment and along the propagation pathways has no effect on the safety-related equipment required to bring and maintain the plant in a safe shutdown state post-seismic event (i.e., components credited in the deterministic seismic shutdown paths or seismic PSA).

  Note: The impact of flood environment on various equipment types was already considered in KKL Internal Flooding PSA which is based on EPRI-1019194 [14].
- If flood sources are already considered in Loss of Coolant Accident (LOCA) analysis of the plant.
- If flood sources are expected to contain no (or negligible) inventory.
- Locations such as drywell have flooding-resistant equipment, so all flood sources in such locations can be screened out.

Majority of flood sources located in non-safety flood compartments were screened out based on these criteria, like service water system, nuclear island closed cooling water system, main cooling water system, etc.

Stage 2: Seismic Capacity-based Screening

Similar to fire assessment, screening criteria applied at this stage for PSA and DSA are differentiated based on the respective seismic demands on the flood sources. The screening levels (criteria) for PSA and DSA are defined in **Table 2**. If the seismic capacity (HCLPF and A_m) of a flood source is greater than the seismic demand, the flood source will not seismically fail.

After this screening stage, many flood sources were screened-in for PSA due to a high screening level of HCLPF 1.2g & A_m = 3g and few flood sources were screened-in for DSA which have seismic capacity (HCLPF) lower than 0.35g.

Stage 3: Quantitative Screening (PSA)

This screening stage is applicable only for PSA. Flood sources retained post Stage 2 can be further screened out based on their seismic-flood risk significance. The seismic-flood CDF for every flood source is estimated as a function of the seismic hazard, seismic fragility and conditional core damage probability (CCDP) from existing Flooding PSA study. At this stage, the flood risk is calculated at a flood scenario level per flood compartment. These flood scenarios are developed by grouping similar type of pipes located in the same flood compartment that are correlated on certain attributes (system, safety classification, etc.) with worst-case flood consequences. For example, seismically-induced rupture of any pipe in a flood scenario is considered to result in a major flood (out of the three flooding modes spray, flood and major flood). This approach is thus conservative and addresses the possibility of multiple seismic-flood scenarios.

To screen out flood sources, a target CDF screening value same as fire assessment is selected i.e., cumulative seismic-flood CDF ($SFLCDF_{cum}$) of 1E-08/yr. All flood sources with cumulative SFLCDF lower than 1E-08/yr., were screened out from further analysis.

The cumulative seismic-flood risk from all screened-in flood sources (scenarios) was found to be lower than 1E-08/yr., so all flood sources were screened out for PSA.

Stage 4: Flood Damage based Screening

This stage involves detailed analysis of seismic-flood risk in terms of potential consequences on plant safety and can be applied to screen out flood sources retained for PSA or DSA. Several aspects can be examined to screen out flood sources at this stage. For example, review of realistic flooding potential of the sources and impacts considering flood evolution, or if seismic-flood risk due to the sources does not add to existing plant seismic risk.

Detailed evaluation was conducted at this stage pertaining to DSA; majority of flood sources were screened out with valid justifications. The **2** sprinklers in two safety-related locations were screened-in for deterministic evaluation after this stage.

2.3. Analysis of Explosive Materials

According to Recommendation 4.60 of IAEA-SSG-64 [15], explosion hazards should be eliminated by design, as far as practicable, and priority should be given to design measures that prevent or limit the formation of explosive mixtures. IAEA provides recommendations to identify explosion hazards that could jeopardize plant safety while considering the subsequent effects of explosions.

ENSI-A05 [9] sets out the requirement for all Swiss NPPs to consider seismically-induced explosions from potential sources within the plant boundary.

After an extensive review of safety, design and operational aspects related to these explosive materials, the possibility of hydrogen/oxygen explosion during a seismic event and its impact on plant safe shutdown was judged unlikely.

- Hydrogen explosion is deemed unlikely in any hydrogen trailers given the trailer stations, structures, valves and pipes are made of non-combustible materials, adequate ventilation in trailer station and pipeline ducts to prevent formation of explosive mixture, redundant isolation and control modules equipped with leak sniffers to alert the operators during a pipe rupture and automatic isolation, and the presence of a protective wall and non-safety buildings to protect the safety buildings from potential effects of explosion (if it were to occur).
- Oxygen explosion is deemed unlikely given the entire floor slabs in any oxygen tank and transfer areas are made of non-combustible (nonorganic) concrete, no fire loads are present in the immediate vicinity of oxygen plant which prevents formation of an ignition mixture, and a simplified anchorage capacity calculation is performed which shows sufficient safety margins against earthquake.

Since the explosive materials were screened out considering the findings from detailed analysis and engineering justifications, the application of screening approach in Section 2.2 is not deemed necessary.

2.4. Seismic Interactions

Seismic interactions refer to physical interaction of any structure, support or component with a nearby component caused by relative motions due to earthquake. These are potential sources of component failures due to variety of causes such as proximity, structural failure and fall-off and seismically-induced fire and flooding.

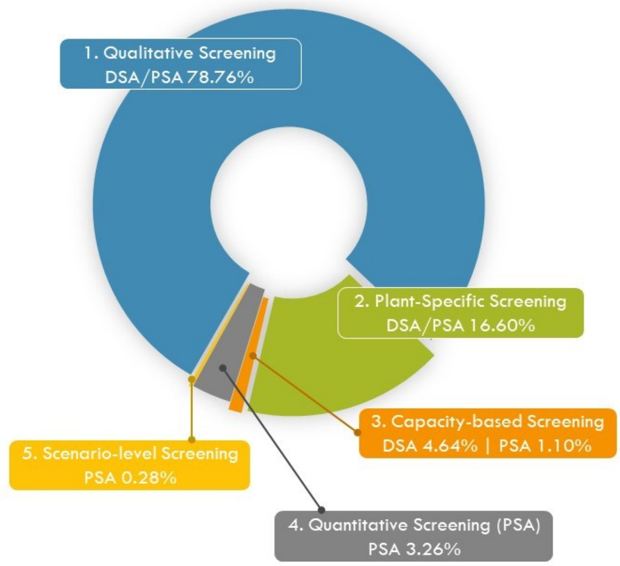
Potential candidates of seismic interactions are identified during plant walkdown conducted by seismic capability engineers (SCEs). The main focus of the walkdown was on identifying any unsupported pipes or tubes containing flammable liquid, unrestrained flammable gas cylinders, weakly supported cable trays, spatial interaction due to non-qualified tables/desks, long unrestrained piping runs, unanchored tanks, weakly supported pipes, etc. These are regarded as potential sources of seismic-fire/flood events.

KKL conducted a comprehensive plant walkdown in line with ENSI-A05 [9] requirement using EPRI Seismic PRA methodology [13]. Several rooms were inspected by multiple teams and all walkdown findings were stored in a database system which were subsequently resolved duly fulfilling the obligations of seismic housekeeping practices and verified by numerous periodic shift controls and ENSI inspections. At the end of this analysis, all potential candidates of seismic interactions were screened out and the application of screening approach in Section 2.2 is not deemed necessary.

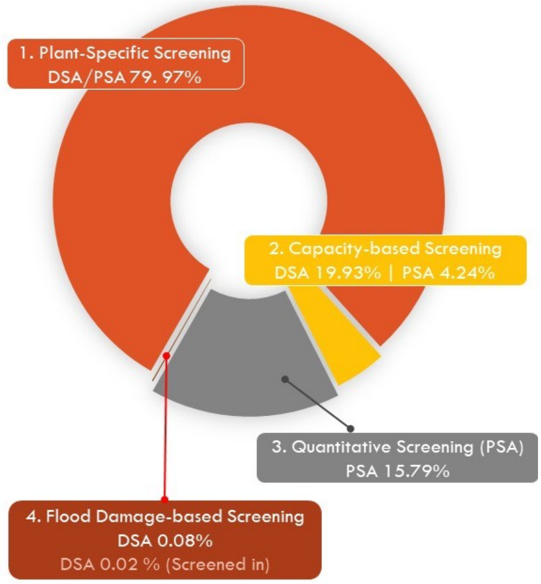
2.5. SIFF Screening Results

Figure 3 graphically illustrates the stage-wise screening results of SIFF sources.

Figure 3: Stage-wise Screening of SIFF Sources - Results



(a) Screening of Fire Sources



(b) Screening of Flood Sources

In case of fire, the first two stages of screening have proved effective in the elimination of majority of fire ignition sources. These fire sources have either no credible seismic-fire failure mode or their seismically-induced fire will not impact plant safety. In case of flood sources screening for DSA, majority of flood sources are eliminated in the first two stages i.e., either seismically-induced flood has no impact on plant safety, or the flood sources have adequate seismic capacity (HCLPF ≥ 0.35g). Whereas Stage 3 quantitative screening (post Stage 1) has proved effective in eliminating majority of flood sources for PSA considering the seismically-induced flood scenarios have relatively low risk contributions.

2.6. Deterministic and Probabilistic Evaluation of Risk

The application of a systematic top-down screening approach allowed to screen out all fire sources and flood sources (with the exception of 2 fire sprinklers retained for deterministic evaluation as there was no data available regarding the seismic qualification of these sprinklers).
2.6.1. Deterministic Evaluation

The seismically-induced rupture of these **2** fire sprinklers in electrical rooms with an overall sprinkler output flow rate of approx. 47-55 m^3/h is expected to damage safety electrical equipment in the vicinity by spray mechanism. These scenarios are considered highly hypothetical. KKL conducted a dedicated walkdown in the compartments housing these sprinklers and performed anchorage calculations for the sprinkler supports. It was concluded that these sprinklers will not lead to flooding during a seismic event. Even if these sprinklers were to lead to seismic induced flooding, the safe shutdown capability of KKL is not impacted by these scenarios.

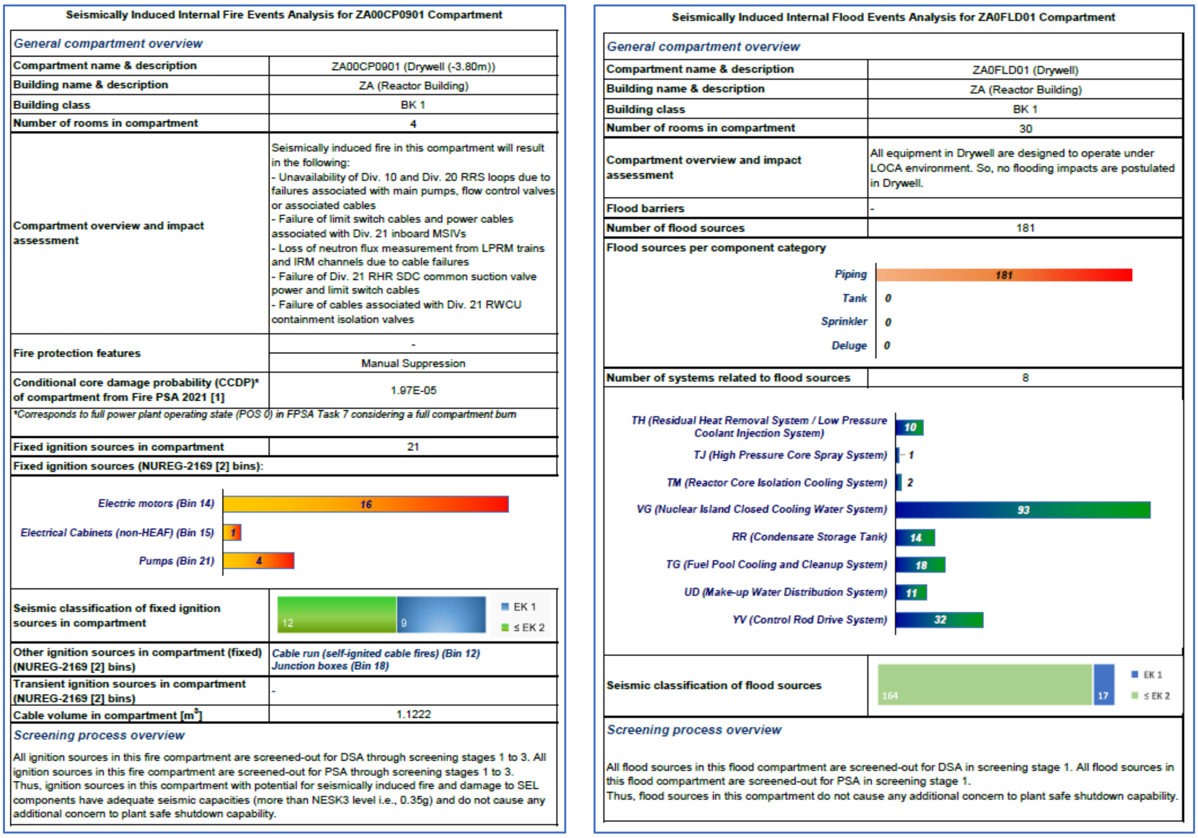
2.6.2. Probabilistic Evaluation

For the probabilistic evaluation of screened-in fire/flood sources, it was intended to use the KKL PSA model, which is a full scope multi-state Level 1, Level 1+ (containment system event trees to quantify plant damage states) and Level 2 PSA model covering full power, low power and shutdown states, incorporating internal events, internal hazards (internal fire, internal flooding and turbine missiles) and external hazards (seismic, aircraft crash, lightning, high winds, tornadoes, etc.). However, all fire/flood sources were screened out from probabilistic analysis due to adequate seismic capacities and/or low risk-significance (CCDP) of fire/flood scenarios. The overall residual risks from screened out seismically-induced fire and flood scenarios are lower than 1% of the plant's seismic risk.

2.7. Compartment-wise Fact Sheets

In order to visually illustrate the summary of screening results for each fire and flood compartment, an MS-Excel VBA tool was developed to generate compartment-wise fire/flood fact sheets. These fact sheets include compartment information (name, description, building, seismic classification, rooms, coordinates, elevation, floor material, etc.), description of impacts on plant safety, details of ignition sources (NUREG bins) or flood sources (based on types), overview of seismic interactions analysis and screening of fire/flood sources with specific screening rules. **Figure 4** shows a sample fire and flood compartment fact sheets.

Figure 4: Sample Compartment-wise Fact Sheets



3. CONCLUSION

The systematic top-down screening approach proved to be effective and practical when applied to both deterministic and probabilistic SIFF assessments. The outcome of the study met the requirements stipulated by the Swiss Nuclear Regulatory Authority. All fire and flood sources were screened out after the screening process (five stages for fire and four stages for flood sources screening) and the overall conclusion is that the risk from seismically-induced internal fires and floods is negligible compared to the plant seismic risk, which is bounding.

The possibility of seismically-induced explosions from explosive materials is deemed remote considering the design and control measures (such as location selection, shielding of safety buildings, anchorage, installed pressure regulation and monitoring devices to detect and isolate pipe ruptures) provide sufficient protection against seismic induced explosion. All possible seismic interactions identified during walkdown were found to be resolved and approved by Swiss regulator.

An independent international peer review (one of the reviewers is a principal contributor to EPRI methodology [10]) of the study was conducted to obtain technical comments and feedback on the application of EPRI methodology [10], validity of results from the screening process and use of accepted best practices. It was concluded that the screening and modelling of SIFF in PSA is consistent with EPRI methodology [10] and its implementation was done efficiently. The peer reviewer opined that the adaptation of EPRI methodology [10] for SIFF in the DSA was carried out in a reasonable manner. To reinforce the approach and methodological assumptions of this study, a review by TEPCO (Tokyo Electric Power Company) was also initiated, which has been recently completed.

This study proves that for a modern plant like KKL, SIFF effects are not expected to be of concern given KKL robust plant design in terms of clear physical and divisional separation of safety systems i.e., spatial segregation of electrical divisions, well separated remote shutdown areas and emergency bunker areas, divisional and spatial separation of cable routing with appropriate fire protection measures in important locations, well laid housekeeping practices (storage of transient combustibles), adequate floor and equipment drain capacities for flood mitigation, and several other plant design features to enhance nuclear safety.

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