INSIGHTS FROM AN INTERNAL FIRE AND FLOOD PRA OF A MODERN PWR SPENT FUEL POOL

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An Internal Fire and Flood "Screening" Probabilistic Risk Assessment (PRA) was conducted for fire and flood events that may potentially cause fuel damage in the spent fuel pool (SFP) associated with a modern (i.e., GEN 3+) PWR nuclear power plant. This SFP has a standard SFP cooling systems as well as a number of back-up make-up systems, most of which are not specifically designed for seismic events. The original design has been augmented with an additional external emergency make-up/spray system utilizing an on-site water source and pumper fire trucks, which will be designed for seismic events. The screening PRA found that it was possible to screen out internal fire and flood without the need to perform a detailed PRA. The results of this analysis showed that the total bounding FDF from fire represented less than 1% of the total SFP FDF from all other hazards (both internal and external) with one scenario contributing about half of that amount and no other scenario contributing more than a few percent. The results of this analysis also showed that the total bounding FDF from flood represented less than 1% of the total SFP FDF from all other hazards (both internal and external) with one scenario contributing about 10% of that amount and no other scenario contributing more than a few percent.

I. INTRODUCTION

This paper presents a screening assessment for the risk of internal fire and internal flood that may potentially cause fuel damage in the spent fuel pool (SFP)

The paper covers the screening of internal fire and flood hazards except for those induced by seismic events. It has been carried out for the Spent Fuel Pool (SFP) of a GEN 3+ following the Technical Guidance for Spent Fuel Pool Hazard Screening, which was developed as part of this project [1].

I.1 Objective and Approach to Screening

The purpose of this analysis is to identify a screening approach for internal flood hazards and report the results of the screening. The screening analysis is to identify any internal fire or flood hazard that requires limited or detailed PRA analysis. These analyses are performed using a process of successive screening to eliminate insignificant fire and flood areas and sources by deterministic criteria and to judiciously use quantitative screening as allowed by the ASME/ANS PRA Standard [2].

I.2 Basis for Quantitative Screening Criteria

The quantitative screening criteria on fuel damage frequency is taken from the ASME/ANS PRA Standard [2], which is focused on the core damage frequency for fuel in the reactor and generally involve conditions with an intact containment. For the SFP, there is no containment and a fuel damage event directly leads to a radionuclide release in general.

Nevertheless, there are substantial conservatisms in the SFP analysis related to the extended time available for mitigating actions that allows the 1E-9/yr FDF for the sum of all scenarios from an area to be an adequate screening criterion. In addition, similar to the screening criterion used for external events,[1] if the total FDF for all scenarios in the plant is less than 1E-7/yr using a demonstrably conservative analysis, it can be said that the contribution to risk is not significant.

[1] The screening criterion for an entire hazard is taken from EXT-C1, Criterion 3, reduced one order of magnitude because this spent fuel pool is part of an advanced reactor design and so expected to have lower risk goal than current generation reactors.

II. INTERNAL FIRE SCREENING

The methodology for performing internal fires screening analysis is discussed herein [1]. It is intended to help identify vulnerabilities associated with fire hazards that may impact the SFP operations and determine if those vulnerabilities require detailed analysis as part of the SFP PRA.

II.1 Overview

The general approach for conducting the fire screening assessment is designed to meet the screening requirements of ASME/ANS RA-Sa-2009, "*Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications"* [2], Part 4 and recent EPRI research [3]. It consists of two categories of screening; initial (qualitative) and final (quantitative).

The initial screening process is qualitative. A set of qualitative screening criteria establish the basis for screening. If a particular fire hazard cannot be screened by application of the qualitative analysis then a more detailed, quantitative analysis is required. This can be a final screening analysis rather than a full scale PRA as long as the screening process is sufficiently conservative. A set of quantitative criteria establishes the basis for screening, and a demonstrably conservative analysis is performed to show that the risk of potential fuel damage in the SFP will be insignificant. One type of such an analysis is a bounding analysis. The bounding screening for fires is typically a quantification of full-fire-area burnout scenarios, which damage all equipment and cables in the area and reflect a conservative fire modeling approach.

It is well known that certain deterministic or probabilistic characteristics of a building or compartment will result in a probabilistically insignificant contribution to the risk metrics of fuel damage for the SFP internal fire PRA model. Recognizing this, the ASME/ANS PRA Standard [2] provides a number of possible criteria that can be used to screen out buildings or areas that do not need to be included in the quantified PRA model.

In other words, the ASME/ANS PRA Standard allows several levels of qualitative and quantitative screening that can be used to limit the number of fire sources and fire areas that need to be considered in the detailed quantitative evaluation.

Figure 1 is a flow diagram of the screening process for fires potentially affecting the SFP operations. Details about each screening step are outlined in the following sections.

II.2 Inputs

The following inputs are required:

- Reactor fire PRA model and documentation.
- ASME/ANS RA-Sa-2009 PRA Standard [2].
- Fire frequency data
- SFP Level 1 and Level 2 internal events PRA models and documentation.
- Fire scenario impact tables for SFP equipment and related support systems.

These inputs were developed using methods developed by the USNRC and EPRI [4,5]

II.3 Bounding Estimates of Mitigation Capability

A series of quantifications were performed on the internal events model to develop screening values of conditional fuel damage probability (CFDP) for fire scenarios. These CFDPs were "weighted" to cover all OCPs; that is, a CFDP was calculated for each OCP under the conditions specified, and then multiplied by the fraction of time in each OCP and the results summed Note that for screening risk purposes a CFDP floor value of 1E-7 is used to calculate the FDF, in order to account for possible unknowns in the use of the internal events model for the flood scenarios, in particular uncertainties in the minimum joint HEP for dependent human actions [6, 7].

II.4 Bounding Estimate of Fuel Damage Frequency

The fuel damage frequency for each scenario is calculated by multiplying the fire scenario frequency (IGN) and the Conditional Fuel Damage Probability (CFDP):

$$\text{FDF} = \text{IGN} \times \text{CFDP}$$

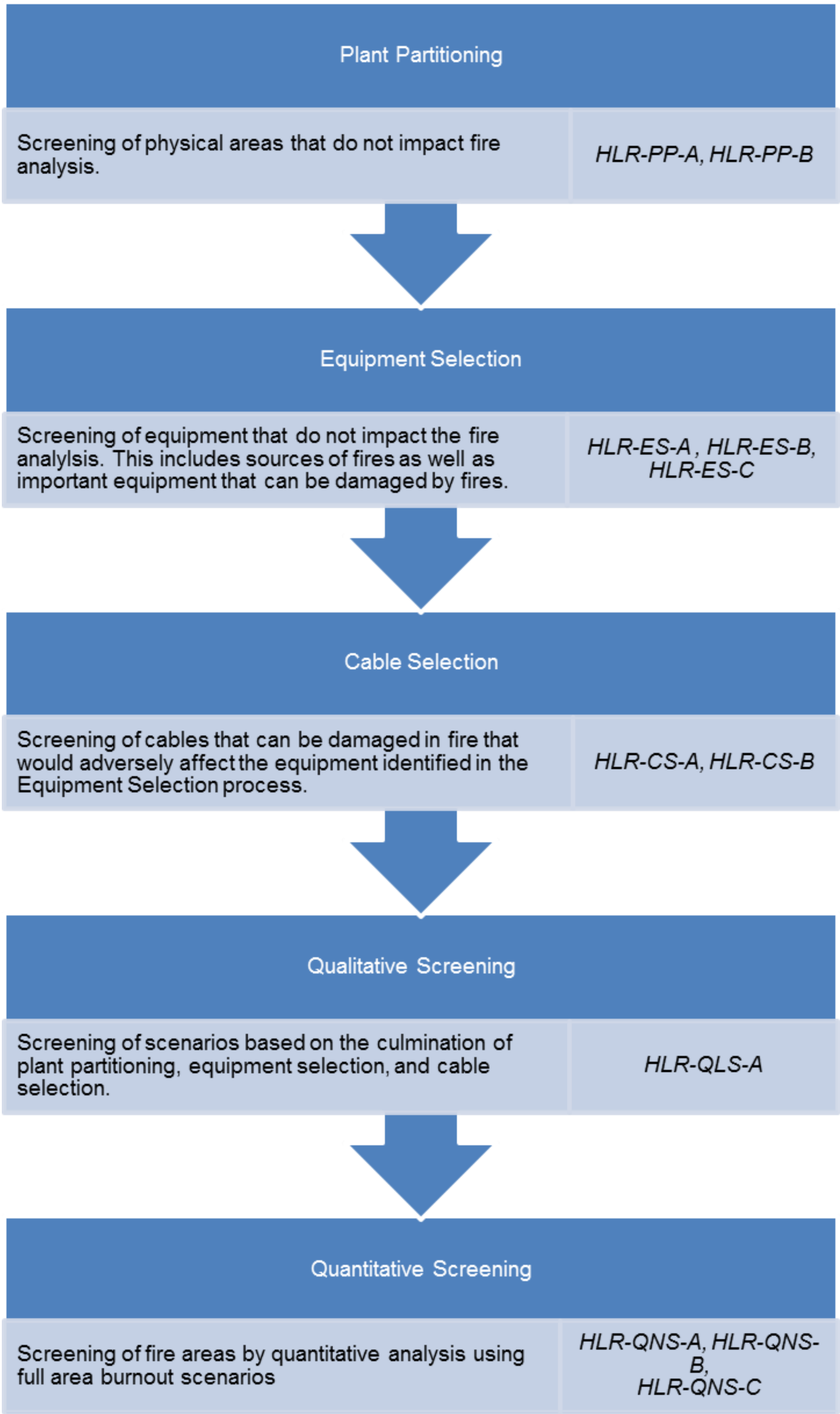

Figure 1. Flow Diagram for Fire Screening Process

II.4 Limitations and Uncertainties

There are various uncertainties associated with the fire screening:

- CFDPs to be used in the screening analysis were conservatively calculated by failing the entire train of all front line and support systems any time any part of one of those trains was affected and applying that CFDP to any scenario where any train on any system failed.
- In addition to the conservative CFDP calculation, a CFDP floor was placed on the scenario bins. If the calculated CFDP was less than 1E-7 for a certain scenario, the screening CFDP estimate was set to 1E-7, to account for the uncertainty associated with such small numbers, in particular those associated with human performance.
- The barrier failure probability for the multi-compartment scenarios was set to a screening value assuming that every multi-compartment pair shared a door, a damper, and a penetration.

Taking all of these uncertainties into consideration, the overall analysis is conservative and appropriate for a screening assessment, and therefore, the results can be used to determine if performing a detailed PRA is necessary. However, they cannot be used to state what the actual fuel damage frequency from fire is, nor can it be used to rank the relative risk of the different scenarios because the uncertainties discussed above will affect different scenarios to a different extent.

II.5 Results and Conclusion

The sum of FDF contributions of all fire scenarios is found to be far below the screening limit of 1E-7/yr. Only one scenario exceeds 1E-9, and no scenario is greater than 1E-8/yr. The conclusion is that internal fires pose negligible risk to the SFP operations, and therefore, no further fire risk analysis is required.

III. INTERNAL FLOOD SCREENING

The methodology for performing internal fires screening analysis is discussed herein [1]. It is intended to help identify vulnerabilities associated with fire hazards that may impact the SFP operations and determine if those vulnerabilities require detailed analysis as part of the SFP PRA.

III.1 Technical Approach

It is well known that certain deterministic or probabilistic characteristics of a building or compartment will result in a probabilistically insignificant contribution to the risk metrics of fuel damage for the SFP internal flooding PRA model. Recognizing this, the ASME/ANS PRA Standard [2] provides a number of possible criteria that can be used to screen out buildings or areas that do not need to be included in the quantified PRA model.

In other words, the ASME/ANS PRA Standard allows several levels of qualitative and quantitative screening that can be used to limit the number of flood sources and flood areas that need to be considered in the detailed quantitative evaluation.

The internal flood evaluation process consists of the following activities:

1. Identify critical buildings on-site that contain equipment or flood sources that could adversely impact SFP cooling.
2. Identify credible flood sources and propagation paths that could adversely impact SFP cooling.
3. Identify critical compartments within each building that contain equipment used to support SFP cooling.
4. Identify critical compartments.
5. Quantify flood initiators affecting SFP cooling (interrupts SFP cooling).
6. Implement a screening process on buildings and compartments.
7. If an internal flood cannot be screened out using qualitative or deterministic screening criteria, perform a demonstrably conservative or bounding quantitative analysis to screen out the event, without the need for detailed analysis.
8. Perform a detailed PRA evaluation on compartments that were not screened for consideration.

The first six activities have been implemented during the reactor PRA with the exception of identifying and assessing the additional equipment required only for the SFP. This equipment was added and those six activities were re-evaluated considering the additional equipment.

The key to defining the scope of the internal flooding assessment is to identify the complete list of potential internal flood sources and targets. The list is exhaustive, and is not constrained by 'size' or preconceived notions concerning hazard characteristics. With a complete set of internal flood hazards determined, the screening analysis is then performed against a set of screening criteria.

The screening process uses a set of successive screens to disposition flood zones regarding their inclusion in the quantitative model evaluation. This process was developed based on the ASME/ANS PRA Standard [2]. It is illustrated in Figure 2.

III.2 Bounding Estimates of Mitigation Capability

The bounding estimates of mitigation capability have been obtained by evaluating failure probabilities associated with systems, components, and human interactions in a reasonable but conservative manner. A series of runs were conducted on the SFP internal events model to develop CFDPs that would be applied to the scenarios to obtain screening estimates of fuel damage frequency. The CFDPs were then 'weighted' to cover all operating cycle phases (OCPs); namely, a CFDP was calculated for each OCP under the conditions specified, and then multiplied by the fraction of time of operation in each OCP and the results summed. Note that for screening risk purposes a CFDP floor value of 1E-7 is used to calculate the FDF, in order to account for possible unknowns in the use of the internal events model for the flood scenarios.

III.3 Bounding Estimate of Fuel Damage Frequency

The bounding quantitative assessment is performed by using the sum of the assessed flood (or spray) initiating event frequencies times the bounding estimate of the mitigation capability to prevent fuel damage in the SFP, i.e., conditional fuel damage probability (CFDP).

III.4 Analysis

The results of the SFP internal flood screening process rely heavily on the flood frequencies and impacts developed for the reactor PRA. These are provided as input to the screening process that defines the components that if failed by the internal flood would cause the SFP cooling system (FC) operating train to fail to perform its function. This following information is provided:

- Equipment ID
- Equipment description
- FC train supported by the equipment
- Additional equipment failures required to initiate a loss of the FC operating train

This information of then allows those areas that do not contain sufficient components whose failure would cause FC failure to be identified and screened out.

After this screening, a compilation of flood areas is left that could both cause an initiating event and affect multiple systems or components of mitigating systems. Using a relational database, the flood areas that contain flood events potentially resulting in a loss of the operating FC train were identified. Those flood areas that are retained after the qualitative screening are contained in the database with the following:

- Flood area
- Flood initiator scenarios that can result in loss of the operating FC train
- The total initiating event frequency associated with the flood area

Quantitative screening was applied to these flood areas to determine if any of these flood areas are potentially risk significant. Flood areas were screened out based on the quantitative criteria for low safety significance (Step G identified in Figure 2).

The quantitative criteria used to screen out the areas is 1E-9/yr. This uses the information that concludes that, because of the localization of effects of internal flood at this plant, the conditional fuel damage probability for the internal flood initiators is always <1E-7/yr. Therefore, using this bounding CFDP and the criteria leads to the conclusion that any internal flood area with a flood frequency less than 1E-2/yr can be automatically screened out without further analysis. After eliminating the screened areas, the remaining areas had to undergo more detailed quantitative analysis in order to determine if they were safety significant or not.

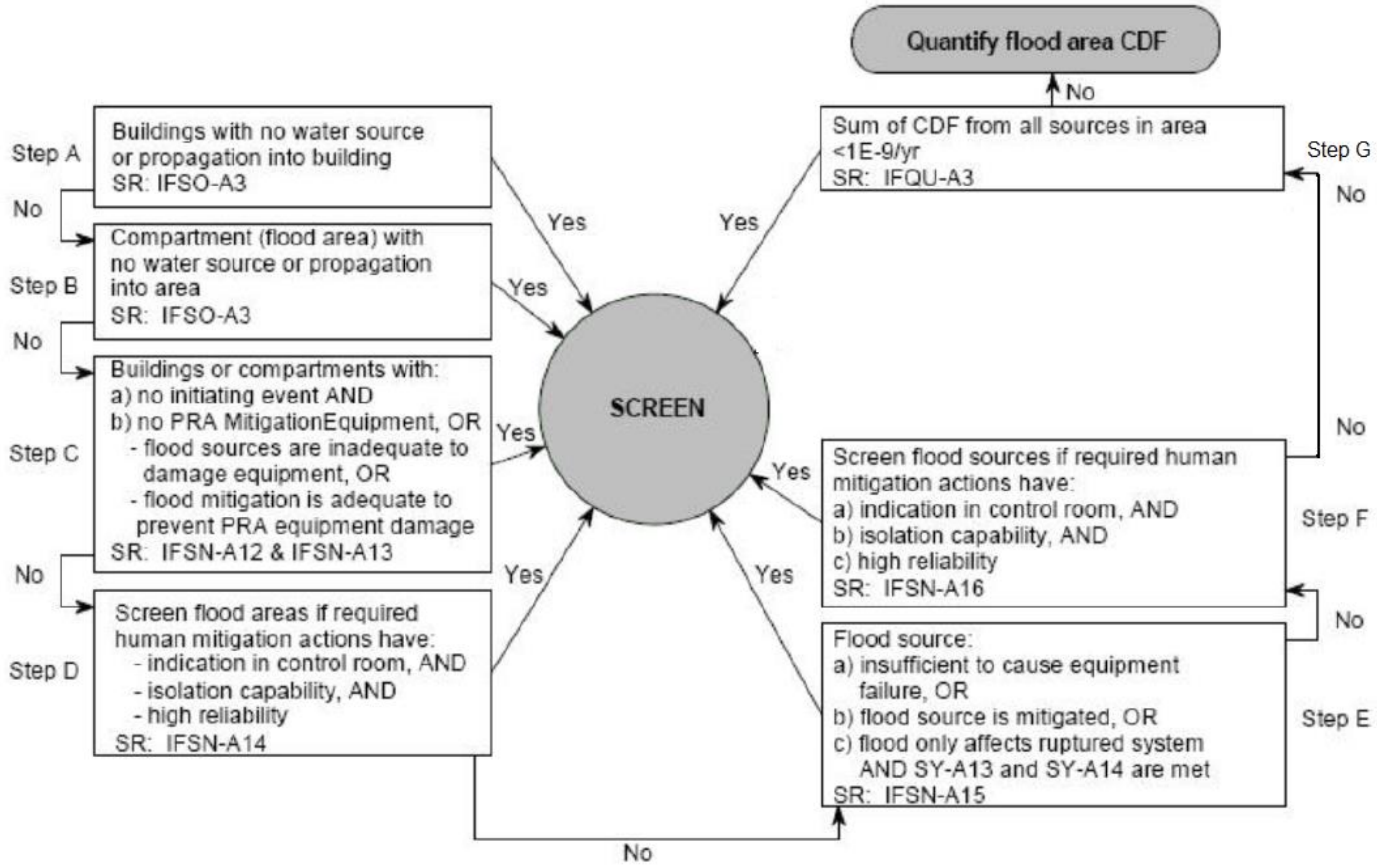

Figure 2. Internal Flood Screening Process[(1), (2)]

(1) In this study for spent fuel pool, the term 'fuel damage frequency (FDF)' is considered in place of 'core damage frequency (CDF)'.
(2) Only internal flood initiators impacting normal SFP cooling operation are considered.

These retained flood areas contain SSCs essential to normal FC operation and for which the summation of flood hazard frequencies for the flood area is greater than 1E-2/yr. The areas were are retained were evaluated based on the following:

- The flood area designator
- The flood scenarios affecting the area
- The initiating flood frequency

The flood scenarios for these areas were then evaluated using the demonstrably conservative quantitative screening approach previously described. The summary results of this screening flood hazard calculation were developed in the databse, with quantitative values determined for all scenarios that could not be qualitatively screened (i.e., they had a non-zero CFDP).

III.5 Limitations and Uncertainties

There are both conservative and non-conservative uncertainties in the analysis, but the overall assessment is that the analysis is quite conservative and this appropriate for screening.

III.5.1 Slow Developing Scenarios (Conservative)

One of the largest uncertainties associated with the quantitative assessment is that associated with the time available for recovery actions. Typically[2] in the past, events have been screened from internal and external event PRA consideration based on the following guidance:

- QL-5: The event is slow in developing such that it can be demonstrated that there is sufficient time to eliminate the source of the threat or to provide an adequate response.

For this Gen 3+ NPP, no credit is automatically assigned in the screening process for the slow developing nature of the loss of SFP cooling effects on the pool. Rather, there is a bounding HEP that is developed to characterize those sequences and this is input into a quantitative screening process.

III.5.2 Screening Initiators (Conservative)

There may be conservatisms in the way that the calculation of initiating event frequencies are calculated. Specifically, when unscreened piping appears in an area, it is treated as a possible initiating event for the scenario.

III.5.3 Propagation (Conservative)

The CFDP calculations are based on the Appendix IV-A. Those spreadsheets represent all of the flood propagation paths that were defined by internal flooding analysis for the reactor PRA. No flood propagation effects have been identified that affect both trains of the SFP cooling system or both trains of SFP make-up systems.

III.5.4 Mission Time (Conservative)

The mission time to reach a safe stable configuration is expanded from that used in the at-power PRA, i.e., 24 hours, to 7 days.

III.5.5 Flood Protection of SFP Cooling (Conservative)

According to the System Design Criteria Manual, the Spent Fuel Pool Cooling (SFPC) Loop is protected from floods. Each train of the Spent Fuel Pool Cooling Loop is protected from flooding due to postulated failures in the other train or other fluid systems in the Auxiliary Building. The system is qualified to withstand postulated adverse environmental conditions. Despite this design criteria, flooding of both SFP cooling trains is included in the internal flood model.

III.5.6 CCW Pipe Failure (Conservative)

If CCW pipe is identified in a scenario, it is assumed that the operating train of the SFPC Loop fails due to the pipe break.

[2] EPRI-1022997 [7] provides screening criteria recommended for use in the qualitative screening analysis based on the review of the criterion from published applicable documents.

III.5.7 Fuel Damage as the Screening Metric (Non-Conservative)

The quantitative screening criteria on fuel damage frequency is taken from the ASME/ANS PRA Standard [2], which is focused on the core damage frequency for fuel in the reactor and generally involve conditions with an intact containment. For the SFP, there is no containment and a fuel damage event directly leads to a radionuclide release in general. Therefore, the screening criterion does not take into account release frequency, only fuel damage frequency.

III.5.8 Scope of Analysis (Non-Conservative)

The scope of the internal flood does not include internal floods that can result in core damage and containment failure. Such events are expected to be of a very low frequency. However, their occurrence could cascade to affect the SFP or its cooling and makeup systems or be correlated with adverse effects on these systems.

III.6 Results and Conclusion

The sum of FDF contributions of all flood scenarios is found to be far below the screening limit of 1E-7/yr. Only one scenario exceeds 1E-9, and no scenario is greater than 1E-8/yr. The conclusion is that internal floods can be stated to be a negligible contributor to SFP risk. The total bounding FDF from flood represented less than 1% of the total SFP FDF from all other hazards (both internal and external) with one scenario contributing about 10% of that amount and no other scenario contributing more than a few percent.

IV. CONCLUSION

The SFP for a Gen 3+ nuclear power plant has been evaluated to assess whether there are internal fire or flood initiators and sequences that can lead to significant risk associated with the spent fuel pool (SFP) operation in terms of fuel damage frequency (FDF). Successive qualitative and quantitative screening processes have been implemented.

The result of the screening processes provides the fire and flood areas and scenarios that represent potentially significant contributors to the SFP fuel damage frequency. A more detailed quantitative analysis was then performed for those fire and flood areas and scenarios using a demonstrably conservative approach in order to further screen them from consideration as risk contributors. The final result indicates that internal fire and flood are not significant contributors to plant risk, and therefore, this screening probabilistic risk assessment (PRA) is sufficient and a detailed PRA does not need to be conducted for internal fire and flood.

V. REFERENCES

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