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Confirmation for Proper Quantitative Screening of Domestic Fire PSA

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1. Introduction

The objective of vulnerability evaluation in the area of probabilistic risk/safety assessment (PRA or PSA) is identifying combinations of hazards and plant response that lead to high risk. Among various hazards, a hazard from internal fire occurred in nuclear power plants (NPPs) has been received a great attention. So, since early 1990s, a lot of fire PSAs were performed for enhancing the safety of domestic NPPs.

Since a NPP has complex physical configuration leading to a complex analysis, it is divided into a number of physical compartments, for the purpose of a fire PSA. The analysis then considers the impact of fires in a given compartment, and fires that might impact multiple compartments. Therefore, we need to establish a basic process for defining the global plant analysis boundary and partitioning of the plant into fire compartments, so called physical analysis units (PAUs). In order to optionally reduce the number of PAUs, the fire PSA utilizes a task with screening process.

The objective of quantitative screening (QNS) analysis is to identify PAUs that can be shown to be insignificant contributors to fire risk based on limited quantitative considerations. Reasonable screening criteria should be used where information has yet to be determined. As new information becomes available and detailed analysis has been done, a fire model can be refined with realistic criteria in order to eliminate the cumulative impact of screened-out PAUs, i.e., residual risk. Furthermore, a PSA needs to ensure that a reasonable risk profile of a facility should be obtained regardless of how small the individual risk contributors may be.

In this paper, we'd like to suggest an evaluation method for properly identifying realistic cumulative impact of screened-out PAUs in fire PSA. Full-scale examples applying this method will be given to support the regulatory decision making, that is, to do a confirmation of an estimated risk profile during a technical review of domestic fire PSAs.

2. PRA Standard for QNS of Fire Analysis

The purpose of QNS of fire analysis is optionally to allow screening of fire compartments (or PAUs) and fire scenarios based on preliminary estimates of fire risk contribution and using established screening criteria. This approach also considers the cumulative risk associated with the screened-out PAUs (i.e., the ones not retained for detailed analysis) to ensure that a practical estimate of risk profile (as opposed to vulnerability) in terms of fire is obtained. General acceptance criteria for risk-informed applications are given in R.G. 1.200 [1].

Regarding the core damage frequency (CDF), QNS value of 1E-6/yr is applied for individual PAU in the EPRI Fire PRA Implementation Guide [2], while recent guidelines, such as NUREG/CR-6850 [3], give a QNS value of 1E-7/yr for individual PAU.

The ASME PRA standard requirement [4], i.e., HLR-QNS-A, states that if QNS is performed, the fire PSA shall establish QNS criteria to ensure that the estimated cumulative impact of screened-out PAUs on CDF and large early release frequency (LERF) is small. The standard also requires, as a minimum, to verify the QNS process does not screen the highest risk fire areas. Table I shows the key points of the requirements of the ASME PRA standard, as well as those of NUREG/CR-6850.

Table I. QNS criteria in terms of estimated cumulative impact of screened-out PAUs on CDF and LERF

Quantification Type	NUREG/CR-6850	RG 1.200 (for Cat. II)	RG 1.200 (for Cat. III)
Sum of CDF for all screened-out fire PAUs	<10% of internal event average CDF	The sum of the CDF contribution for all screened-out fire PAUs is <10% of the estimated total CDF of fire events	The sum of the CDF contribution for all screened-out fire PAUs is <1% of the estimated total CDF of fire events
Sum of LERF for all screened-out fire PAUs	<10% of internal event average LERF	The sum of the LERF contribution for all screened-out fire PAUs is <10% of the estimated total LERF of fire events	The sum of the LERF contribution for all screened-out fire PAUs is <1% of the estimated total LERF of fire events

3. Current QNS Practices in Domestic Fire PSA

Most of fire analysis in Korea has been performed utilizing EPRI Fire PRA Implementation Guide, which consists of (1) identification of SSCs and cables, (2) definition of areas and PAUs, (3) qualitative screening, (4) QNS, and (5) detailed analysis of non-screened-out areas and PAUs.

For the QNS analysis, fire ignition frequencies of all sources are calculated, and fire-induced initiating events, non-suppression possibility of fire barriers between PAUs, and equipment (including cable) failures are considered. After that, conditional core damage probability (CCDP) is estimated for each PAU, including CCDP of fire propagation model between neighboring PAUs. A scenario CDF of PAU itself is estimated combining an initiating event frequency and corresponding CCDP. For each PAU, CDF caused by propagating to neighboring PAUs are also estimated. Finally, these CDFs are summed, and the CDF result is compared with screening criteria. Table II shows the QNS value for individual PAU utilized in fire PSAs of domestic NPPs.

Table II. QNS values in terms of CDF for individual PAU, utilized in Domestic Fire PSAs

QNS value	NPPs adopted the criteria	Remark
1.0E-6/yr	K2, K3/4, HB1/2, HU1/2, W2/3/4	EPRI-TR-105928 (1995) [4]
1.0E-7/yr	HB3/4, HU3/4, HB5/6, HU5/6, SK1/2, SK3/4, SH1/2, SW1/2	NUREG/CR-6850 (2005) [3]

Unfortunately, up to now, domestic fire PSAs have no practical consideration for following the ASME PRA standard requirement in terms of the cumulative impact of screened-out PAUs on CDF and LERF.

Table III. The scope identification for the QNS in fire PSAs

NPPs	# of Total PAUs	# of PAUs in the Scope of QNS	# of detailed analysis PAUs	# of S/O PAUs	Ratio (%) (Note 1)
K2	75	53	18	35	34.0
K3/4	156	130	11	119	8.5
HB1/2	173	88	18	70	20.5
HU2	310	275	14	261	5.1
HB3/4	110	58	10	48	17.2
HU3/4	115	44	14	30	31.8
W2/3/4	121	88	14	74	15.9
HB5/6	120	57	9	48	15.8
HU5/6	141	56	8	48	14.3
SK1/2	190	74	15	59	20.3
SK3/4	308	228	8	220	3.5
SW1/2	192	87	15	72	17.2
SH1/2	373	274	9	265	3.3

(Note 1) Ratio = (# of detailed analysis PAUs / # of PAUs in the Scope of QNS) * 100

Table III also shows the numbers of PAUs in the scope of QNS, including the numbers of PAUs in the scope of detailed analysis, identified in all domestic NPPs by the utility. It is noted that the ratios shown in Table III, defined with the number of detailed analysis PAUs divided by the numbers of PAUs in the scope of QNS, are varied from 3.3% to 34.0% with reflecting QNS values for individual PAU, as denoted in Table II.

4. Suggestion of an Evaluation Method

In order to technically assess the cumulative impact of screened-out PAUs of domestic fire PSAs, in the calculation scope of full power mode CDF, we'd like to suggest an evaluation method. The method should be easily-adapted without needing more analysis resources.

Let a fraction (*f*), reflecting of the cumulative impact of screened-out PAUs, to have following formula;

$$f(\%) = \frac{CDF_x}{CDF_0 + CDF_x} \times 100 \quad (1)$$

where,

$$CDF_x = \alpha \times \sum_{k=1}^{n} CDF_{screened-out,k}$$

CDF_0 = *Baseline total CDF after detailed analysis*

$$Avg.\ \alpha = \sum CDF_{0,i} / \sum CDF_{before-detail,i}$$

$$\text{Max.}\ \alpha = \max(CDF_{0,i}/CDF_{bd,i})$$

$$\text{Min.}\ \alpha = \min(CDF_{0,i}/CDF_{bd,i})$$

The motivation of this study is on the question how much portion of the cumulative sum of screened-out PAUs can contribute to real profile of risk. In Eq. (1), CDF_x is the sum of CDF value of all screened-out PAUs times an alpha factor, which means some kind of the intensity of residual risk, reflecting the variation of degree of screened-out risk level. $\Sigma CDF_{screened-out}$ means total CDF of all screened-out PAUs during QNS analysis, and $CDF_{before-detail}$ (or CDF_{bd}) also means a preliminary value of CDF for a PAU requiring detailed analysis after the QNS analysis step. Using this approach, therefore, we can ultimately bring the fraction bounds, *f,* which is the corresponding value representing the sum of the CDF contribution for all screened-out fire PAUs, as previously identified in Table I.

It is also noted that the proposed evaluation factor, called alpha factor (α) in this study, have a meaning about the degree of reduction ratio, following detailed analysis after the step of QNS analysis. The maximum alpha factor means that the CDF of corresponding PAU may be reduced at the least after detailed analysis. We can also calculate average value and minimum value of the alpha factor, respectively.

5. Application of the Proposed Evaluation Method

Fire PSAs are being recently updated due to the legal requirement on accident management program (AMP) for all domestic NPPs [5]. So, current values on baseline CDF for full power mode, CDF_0, are came from the AMP reports, as well as the values on CDF_{bd}. Then, the average, maximum, and minimum values of the alpha factor are readily calculated.

Figure 1 shows three kind of alpha factors for all domestic NPPs. It is noted that blue dots denote maximum, yellows are average, and greens are minimum alpha factor in the figure. We can see the uncertainty band in any NPPs and look at the deviations among NPPs. The largest range between maximum and minimum alpha factor may be broadened up to about 2.1E+5. It means that the level of details after a step of QNS analysis for some NPPs are considerably given a lot of weight.

Among domestic NPPs, HU2 unit has the highest value of alpha factors. It means that the baseline CDF of HU2 unit is not so much reduced following detailed analysis after the step of QNS analysis.

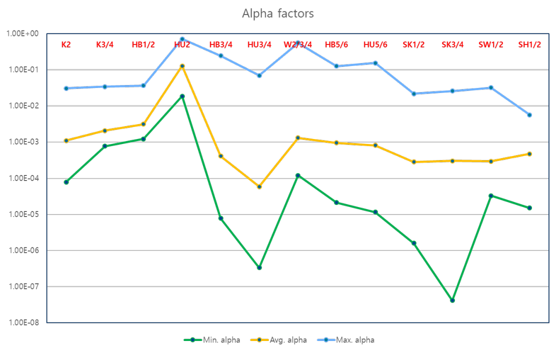

Figure 1. Alpha factors of all Domestic NPPs

After the calculation of alpha factors, we can get the fraction, *f*, with collecting all screened-out risk values for every NPP. Table IV shows the fraction for selected NPPs, where we can identify some NPPs may not meet the corresponding requirement of Capability Category II in the ASME standard, in terms of the application of maximum alpha factor.

It is noted that the level of details and/or CDF value of all screened-out PAUs for some NPPs, such as HB3&4 NPPs, are considerably more important.

If we want to decrease the maximum value *f* below 10%, and/or average value *f* below 1%, we should primarily touch the CDF_x in Eq. (1). Because it contains an alpha factor and sum of CDF value of all screened-out PAUs, the level of details for the case of having big alpha factor may be reconsidered, as well as reduction effort on the screened-out PAUs considering with the order of priority in terms of risk level.

Table IV. Calculated fractions on the cumulative impact of screened-out PAUs in terms of CDF

NPPs	Avg. *f*	Max. *f*	Remark
K2	0.03%	0.86%	
K3/4	0.43%	9.57%	
HB1/2	0.44%	7.24%	
HU2	1.48%	7.44%	
HB3/4	0.22%	56.89%	Not meet CC II of ASME PRA standard with max. *f* value
W2/3/4	0.06%	21.30%	ditto
HB5/6	0.12%	16.78%	ditto
SH1/2	0.85%	8.83%	

6. Conclusions

Since current methodology of traditional fire PSA generally needs much resources on time consumption and man-power for the analysis of all PAUs without QNS, meeting the HLR-QNS requirements of ASME PRA standard is not easy if we don't have any special technique.

This study has suggested an easily-adapted evaluation method for confirming corresponding ASME PRA standard requirement on the cumulative impact of screened-out PAUs. It shows that the application of proposed method to domestic fire PSAs can give good results in case of the adoption with the average α value. It is also noted that, for some not-good cases about the confirmation on the Capability Category II of ASME PRA standard with the maximum α value need more attention, so that further analysis should be required.

REFERENCES

[1] An Approach for Determining the Technical Adequacy of PRA Results for Risk-informed Activities, R.G. 1.200, Rev.2, U. S. NRC, March 2009.

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[5] Nuclear Safety Act, Article 20(2), NSSC, June 22 2015.