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The Preliminary Seismic Probabilistic Safety Assessment for HANARO Research Reactor

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1. Introduction

HANARO is the 30MW pool-type research reactor. It can be characterized by operation in atmospheric pressure under the saturation temperature, ultimate core cooling by natural convection with no external power, and so on. Thus, no fuel damage is expected actually in most of postulated initiating events due to the intrinsic safety features for HANARO. According to the requirements of the Citizen Verification Team (2018.3 ~ 2019.4), however, a research project was launched in 2019 to prove that the operating research facilities are fully satisfied with the domestic nuclear safety goals (e.g., less than 0.1% of individual risks) through the risk profile assessment of the research site.

This study focuses on, the preliminary seismic PSA for HANARO research reactor, which is one of the important contributor for research site risk assessment. Note that this paper is limited to the preliminary results of level 1 seismic PSA for HANARO.

2. Modeling

Level 1 seismic PSA is performed that consists of seismic hazard analysis, seismic fragility analysis, plant response analysis (event tree and fault tree analysis), and core damage frequency (CDF) quantification. The internal event PSA model for the HANARO research reactor becomes a base model for the seismic PSA. [1, 2]

A seismic PSA model was constructed to describe scenario and component failure by earthquake, and CDF values were obtained for each bin. Seismic event tree for HANARO is shown in Fig. 1 below.

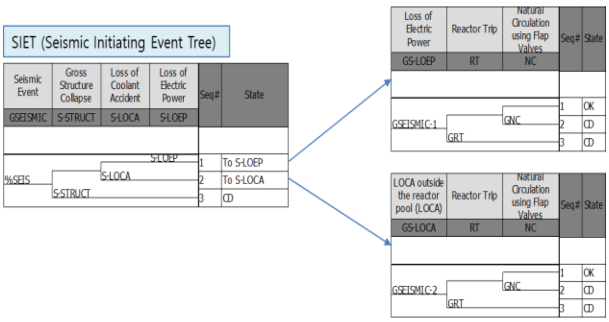

Fig. 1. Seismic event tree for HANARO

In this study, it is assumed that S-STRUCT (gross structure collapse) leads to core damage directly. And scenario except S-LOCA (loss of coolant accident) is assumed S-LOEP (loss of electric power) conservatively.

3. Hazard Analysis

A seismic hazard curve presents the annual frequency (or rate) of exceedance for different values of a selected ground motion parameter (acceleration, velocity, etc.). [3] In this study, the seismic hazard for KAERI site were analyzed which is shown in Fig. 2 [4].

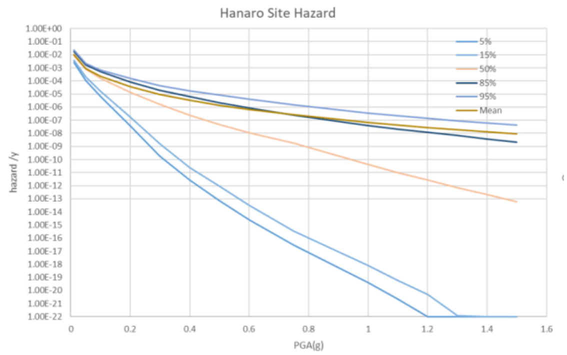

Fig. 2. HANARO seismic hazard curve

The seismic PSA is performed for 3 hazard bins, as shown in Table I. [4]

Table I: Seismic event frequency for each bin

Case	Range (PGA)	Representative PGA	IE. Freq
Bin 1	0.1-0.3	0.173	2.20E-04
Bin 2	0.3-0.5	0.387	8.20E-06
Bin 3	0.5-1.0	0.707	1.36E-06

4. Fragility Analysis

The fragility curves of a SSC (Structure, System and Component) is defined as conditional failure probabilities for a given PGA level, that is expressed as the formula (1) below, where ϕ is the standard Gaussian cumulative distribution function. [5]

$$f' = P(A < a) \quad , \text{(Capacity < Response)}$$
$$f' = \emptyset\left(\frac{\ln\left(\frac{a}{A_m}\right) + \beta_U \emptyset^{-1}(Q)}{\beta_R}\right) \text{ with Q uncertainty level, or} \qquad (1)$$
$$f' = \emptyset\left(\frac{\ln\left(\frac{a}{A_m}\right)}{\beta_C}\right), \text{ with composite uncertainty } \beta_C = (\beta_R{}^2 + \beta_U{}^2)^{1/2}$$

The major SSCs analyzed in seismic events are gross structure collapse (S-STRUCT), loss of coolant accident (S-LOCA), shutdown rod drive (S-RPRDF-SRDM), and flap valves 003/004 (S-PCCVO-FLAP). The data for each SSC is shown in Table II.

Table II: Fragility data for each SSC

SSC	Am	Br	Bu	Bc
S-STRUCT	1.01	0.31	0.23	0.386
S-LOCA	0.838	0.24	0.32	0.400
S-RPRDF-SRDM	1	0.35	0.26	0.436
S-PCCVO-FLAP	1.52	0.36	0.26	0.444

Fig. 3 shows the seismic failure probability for each PGA level.

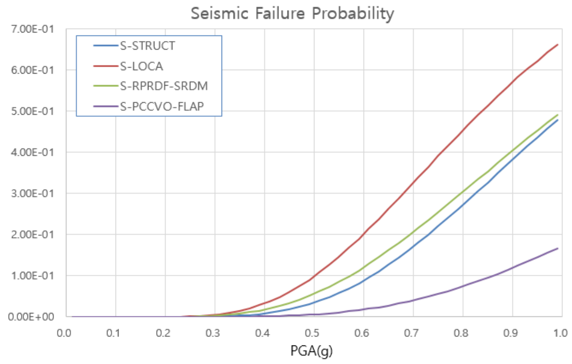

Fig. 3. Seismic failure probability for SSC

The failure probabilities of SSCs for the representative values for each bin is shown in Table III.

Table III: Seismic failure probability for SSC in each bin

SSC	Bin1	Bin2	Bin3
S-PCCVO-FLAP	5.014E-07	1.039E-03	4.241E-02
S-RPRDF-SRDM	2.895E-05	1.479E-02	2.133E-01
S-STRUCT	2.463E-06	6.511E-03	1.778E-01
S-LOCA	4.051E-05	2.683E-02	3.356E-01

5. Quantification

Quantification in this study was calculated using AIMS-PSA. After calculating the MCS by setting the hazard value differently for each bin, quantification was performed. The cut-off value was set to 1E-22. The CDFs for major scenario are shown in Table IV below.

Table IV: Preliminary quantification result for scenario

scenario	Bin 1	Bin 2	Bin 3	Sum	%
S-STRUCT	5.406E-10	5.337E-08	2.423E-07	2.962E-07	41.82
S-LOEP	6.886E-09	1.253E-07	1.836E-07	3.159E-07	44.59
S-LOCA	2.790E-13	3.456E-09	9.277E-08	9.623E-08	13.59
Total	7.427E-09	1.822E-07	5.187E-07	7.083E-07	

S-LOEP and S-STRUCT are the major contributor for all bins. S-LOEP is the scenario that LOEP is occur due to earthquake and major SSCs for accident mitigation is fail. The S-STRUCT is the structural destruction scenario, which is a scenario in which reactor building is damaged by earthquake. The accident accounts for the largest contributor in the total CDF. It is assumed that S-STRUCT leads do direct core damage conservatively.

The preliminary CDF values derived from each bin are 7.427E-09/yr, 1.822E-07/yr, and 5.187E-07/yr, respectively, indicating the total 7.083E-07/yr.

6. Summary and Conclusion

The seismic level 1 PSA was performed on HANARO research reactor. The preliminary seismic PSA model was developed and evaluated using AIMS-PSA, and the CDF result was calculated as 7.083E-07/yr. S-LOEP, which is the loss of electric power due to earthquake, accounts for the largest proportion among the scenarios.

Acknowledgements

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