Risk Profiles from Seismic PSA for HANARO Research Reactor

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1. Introduction

According to the requirements of the Citizen Verification Team (2017.4 ~ 2018.3), 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. A risk profile for nuclear facilities can be derived from a probabilistic risk assessment (PSA) as a presentation tool to show how risks vary across comparable entities. The risk profiles can be generally expressed in a log-log scale of complementary cumulative density function (CCDF) as a multiplication of off-site release frequency (Level 1&2 PSA results) and population-weighted risk (Level 3 PSA results). In a mathematical meaning, the integral value of the CCDF corresponds to the average individual risk.

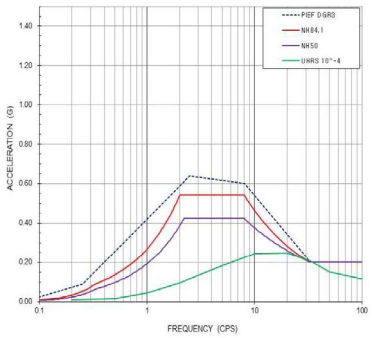
The paper focuses on the risk profile based on the level 1/2/3 PSA for seismic events at the HANARO research reactor.

2. Development and Results of the Seismic Risk Profiles for HANARO Research Reactor

2.1 Accident Sequences for HANARO Seismic Events

A preliminary seismic PSA model for HANARO facilities has been developed in 2021[1] with the sufficient conservatism and the site-specific research outputs as follows:

1) Development and use of site-specific seismic hazard curve [2]
2) Use of generic ground response spectrum (NUREG/CR-0098) with even more conservatism (NH84.1 in Figure right), instead of site-specific uniform hazard response spectrum (UHRS)



3) HANARO-specific fragility analysis for SSC (Structure, System and Component) by separation of variable (SOV) approach, not conservative deterministic failure margin (CDFM) approach for seismic margin analysis (SMA)
4) A bounding approach with no detailed plant response analysis using seismic event tree and fault tree (ET/FT) developed under very conservative assumptions, for instance, it is assumed that the event of the seismic-induced structure (reactor building) collapse leads to release all fission products at the ground level immediately.

For more detailed plant response analysis, seismic ET/FT was modified using the results of the additional walkdowns, expert judgment, and so on. In other word, seismic-induced RCI (Reactor Concrete Island) integrity was considered additionally as shown in Fig. 1.

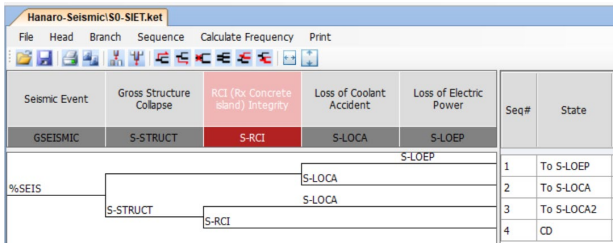


Fig. 1 Revised Seismic Event Tree

The branch probability of RCI integrity (S-RCI) is assumed to be 0.1 by expert judgment based on minimum acceptable barrier thickness requirements for local damage prediction against tornado-generated missiles (standard review plan 3.5.3). Note that the RCI wall thickness (~90cm) is about twice more than the maximum value (~46cm) of all barrier thickness requirements prescribed in SPR 3.5.3.

As a result, the frequencies and characteristics of each major accident scenario included in the seismic risk profiles for HANARO are summarized in Table 1. The most appropriate number of bins, three (3), was determined for the seismic PSA for HANARO by the results of the sensitivity study on the number of bins (e.g., 3, 4 or 5 bins). Compared to the five source term categories (STC) for HANARO internal events PSA [3], one additional STC (STC 2S: ground early release after reactor building collapse) is defined for the seismic PSA for HANARO:

STC 1) No release (NR),
STC 2) Early ground release (EG),
STC 2S) Early ground release by structure collapse (EG-S),
STC 3) Early release through chimney (EC),

STC 4) Late ground release (LG),
STC 5) Late release through chimney (LC).

Refer to the other paper [3], for more information on the Table 1.

Table 1. The Results of Accident Sequences in the Seismic PSA for HANARO Research Reactor

EVENT		IE	CD Sequence	IE Frequency	CDF	CD	Early/Late	STC
SEISMIC	BIN 1 (0.1~0.3g)	%SEIS	#GSEISMIC-4!	2.20E-04	5.42E-11	O	E	2S
		%SEIS	#GS-LOEP-3!	2.20E-04	5.73E-09	O	E	2
		%SEIS	#GS-LOEP-4!	2.20E-04	6.37E-10	O	E	3
		%SEIS	#GS-LOEP-2!	2.20E-04	5.31E-10	X	L	1
		%SEIS	#GS-LOCA-4!	2.20E-04	2.32E-13	O	E	2
		%SEIS	#GS-LOCA-5!	2.20E-04	2.58E-14	O	E	3
		%SEIS	#GS-LOCA-2!	2.20E-04	1.94E-14	O	L	4
		%SEIS	#GS-LOCA-3!	2.20E-04	2.15E-15	O	L	5
		%SEIS	#GS-LOCA2-2!	2.20E-04	1.41E-14	O	E	2
		%SEIS	#GS-LOCA2-3!	2.20E-04	1.18E-15	O	E	2
	BIN 2 (0.3~0.5g)	%SEIS	#GSEISMIC-4!	8.20E-06	5.34E-09	O	E	2S
		%SEIS	#GS-LOEP-3!	8.20E-06	1.06E-07	O	E	2
		%SEIS	#GS-LOEP-4!	8.20E-06	1.17E-08	O	E	3
		%SEIS	#GS-LOEP-2!	8.20E-06	8.13E-09	X	L	1
		%SEIS	#GS-LOCA-4!	8.20E-06	2.91E-09	O	E	2
		%SEIS	#GS-LOCA-5!	8.20E-06	3.23E-10	O	E	3
		%SEIS	#GS-LOCA-2!	8.20E-06	2.02E-10	O	L	4
		%SEIS	#GS-LOCA-3!	8.20E-06	2.24E-11	O	L	5
		%SEIS	#GS-LOCA2-2!	8.20E-06	7.11E-10	O	E	2
		%SEIS	#GS-LOCA2-3!	8.20E-06	5.00E-11	O	E	2S
	BIN 3 (0.5~1.0g or over)	%SEIS	#GSEISMIC-4!	1.36E-06	2.42E-08	O	E	2
		%SEIS	#GS-LOEP-3!	1.36E-06	1.43E-07	O	E	2
		%SEIS	#GS-LOEP-4!	1.36E-06	1.59E-08	O	E	3
		%SEIS	#GS-LOEP-2!	1.36E-06	2.48E-08	X	L	1
		%SEIS	#GS-LOCA-4!	1.36E-06	7.21E-08	O	E	2
		%SEIS	#GS-LOCA-5!	1.36E-06	8.01E-09	O	E	3
		%SEIS	#GS-LOCA-2!	1.36E-06	1.13E-08	O	L	4
		%SEIS	#GS-LOCA-3!	1.36E-06	1.25E-09	O	L	5
		%SEIS	#GS-LOCA2-2!	1.36E-06	4.64E-08	O	E	2
		%SEIS	#GS-LOCA2-3!	1.36E-06	9.23E-09	O	E	2

*) source term category: 1(no release), 2(Ground early release), 2S(Ground early release - Structure Collapse), 3(Chimney early release), 4(Ground late release, 5(Chimney late release)

2.2 Population-Weighted Seismic Risk for HANARO

A site-specific MACCS2[1] input model for HANARO facilities [6] was developed to estimate the health effects of the surrounding population caused by the release of source terms. The results of health effect are usually used by population-weighted risks, i.e., acute fatality (EF) and latent cancer fatality (CF), which are the results of MACCS2 execution.

2.3 Results of the Seismic Risk Profile for HANARO

In this study, a 5 km radius for EF and 20 km radius for CF were applied around HANARO reactor for population-weighted risk assessment. As a result, The CDF values derived from bin 1 ~ 3 are 6.96E-09/yr, 1.35E-07/yr, and 3.56E-07/yr, respectively, indicating the total 4.98E-07/yr. The average individual seismic risk for HANARO facilities were evaluated as 1.22e-11/yr as shown in Table 2. Note that no acute fatality was estimated. This figure is comparable to the safety goal reference (0.1% rule), and according to the literature [7] it was reported that the comparative reference was 5e-7/yr for EF and 1e-6/yr for CF. (>> 1.22e-11/yr (negligible)).

[1] MACCS2 (MELCOR Accident Consequence Code System Version 2) [4,5]

Table 2. The results of Average Individual Risk for HANARO Seismic Events

STC*	Seismic CDF(/RY)(a)	population-weighted risk (b)(/person)		Average Individual Risk (c=a*b)(/person-Ry)	
		EF(~5km)	CF(~20Km)	EF(~5km)	CF(~20Km)
1	3.34E-08	0	0	0.00E+00	0.00E+00
2S	2.96E-08	0	4.09E-04	0.00E+00	1.21E-11
2	3.85E-07	0	1.83E-07	0.00E+00	7.05E-14
3	3.65E-08	0	1.83E-07	0.00E+00	6.69E-15
4	1.15E-08	0	1.83E-07	0.00E+00	2.10E-15
5	1.27E-09	0	1.83E-07	0.00E+00	2.33E-16
Sub-total (A=∑a)	4.98E-07	Sum of Individual Risk (C=∑c)		0.00E+00	1.22E-11
Total Average Individual Risk (∑C)				1.22E-11	

*) STC: 1(no release), 2(Ground early release), 2S(Ground early release - Structure Collapse), 3(Chimney early release), 4(Ground late release, 5(Chimney late release)

Finally, the risk profiles (CF only within 20km) for source term categories of seismic events are shown in Fig. 2, respectively. Similar shapes of risk profiles (CCDF) for all STC except STC 2S are because most of fission products except noble gas is captured by reactor building wall or chimney with emergency ventilation system.

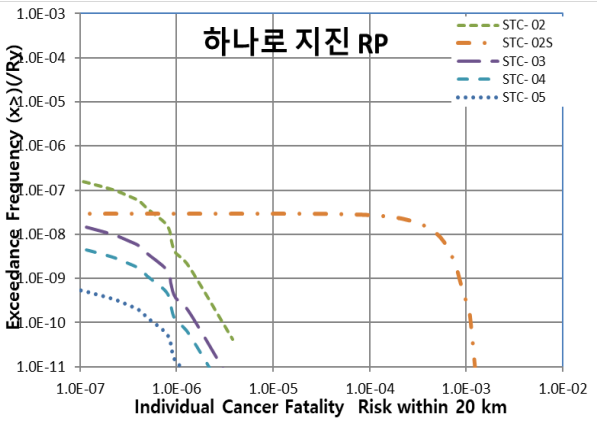


Fig. 2. The Seismic Risk Profiles for HANARO

3. Conclusions

The risk profile for seismic events in the HANARO research reactor was developed based on the conservative results of the level 1/2/3 PSA. As a result, the average individual risk for internal events of the HANARO facilities were evaluated as 1.22e-11/yr, which can be regarded to be insignificant through the comparison on the regulatory-side safety goal reference [7].

Acknowledgments

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