A Risk Profile from Level 1/2/3 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 the HANARO research reactor.

2. Development and Results of the Preliminary Risk Profile for Hanaro Research Reactor

2.1 Modelling and Quantification of the Off-site Release Accident Sequences

First, the following range of level 1 & 2 PSA models was developed in order to obtain the main off-site release accident scenarios and quantify their frequencies for HANARO facilities:

1) Development of full-power PSA model for internal events (including internal fire) and external events (seismic only) at HANARO facilities [1,2,9]
2) Qualitative assessment of low power and shutdown PSA model for HANARO facilities (screening-out) [2]
3) Qualitative assessment of HANARO spent fuel pool including bounding thermal-hydrauric analysis (screening-out) [2]
4) Seismic hazard analysis of the research site [2,3]
5) Evaluation of seismic fragility for major structures and equipment of HANORO facilities [2]
6) Development of MELCOR input model and severe accident analysis for HANARO facilities [2,4,10]

As a result, the frequency and release characteristics of each major accident scenario included in the risk profile are summarized in Table 1. Note that the frequency and release characteristics of each internal fire accident scenario included in the risk profile are summarized in Table 2, separately.

Table 1. The Results of the Internal and Seismic PSA for HANARO

EVENT		IE	CD Sequence	IE Frequency	CDF	CD	Early/Late	STC
INTERNAL		%BT-LOCA	#BT-LOCA-2	6.85E-06	4.04E-07	O	L	4
		%BT-LOCA	#BT-LOCA-3	6.85E-06	4.49E-08	O	L	5
		%BT-LOCA	#BT-LOCA-4	6.85E-06	1.18E-11	O	L	4
		%BT-LOCA	#BT-LOCA-5	6.85E-06	1.31E-12	O	L	5
		%BT-LOCA	#BT-LOCA-6	6.85E-06	4.05E-14	O	E	2
		%BT-LOCA	#BT-LOCA-7	6.85E-06	4.50E-15	O	E	3
		%GTRN-AT	#GTRN-AT-3	5.65E+00	1.90E-09	X	L	1
		%GTRN-AT	#GTRN-AT-4	5.65E+00	2.30E-08	O	E	2
		%GTRN-AT	#GTRN-AT-5	5.65E+00	2.56E-09	O	E	3
		%GTRN-MT	#GTRN-MT-3	1.43E+00	4.80E-10	X	L	1
		%GTRN-MT	#GTRN-MT-4	1.43E+00	1.53E-12	O	E	2
		%GTRN-MT	#GTRN-MT-5	1.43E+00	1.70E-13	O	E	3
		%LOCA	#LOCA-2	9.89E-04	1.70E-09	O	L	4
		%LOCA	#LOCA-3	9.89E-04	1.89E-10	O	L	5
		%LOCA	#LOCA-4	9.89E-04	5.85E-12	O	E	2
		%LOCA	#LOCA-5	9.89E-04	6.50E-13	O	E	3
		%LOEP	#LOEP-2	1.92E+00	3.68E-06	X	L	1
		%LOPCS	#LOPCS-2	6.20E-02	1.07E-07	O	L	4
		%LOPCS	#LOPCS-3	6.20E-02	1.19E-08	O	L	5
		%LOPCS	#LOPCS-4	6.20E-02	1.26E-09	O	E	2
		%LOPCS	#LOPCS-5	6.20E-02	1.40E-10	O	E	3
		%LOSCS	#LOSCS-3	6.20E-02	2.08E-11	X	L	1
		%LOSCS	#LOSCS-4	6.20E-02	2.53E-10	O	E	2
		%LOSCS	#LOSCS-5	6.20E-02	2.81E-11	O	E	3
		%RIA	#RIA-3	1.67E+00	5.60E-10	X	L	1
		%RIA	#RIA-4	1.67E+00	6.81E-09	O	E	2
		%RIA	#RIA-5	1.67E+00	7.57E-10	O	E	3
		%SCFB	#SCFB-3	1.30E-05	4.23E-15	X	L	1
		%SCFB	#SCFB-5	1.30E-05	2.35E-07	O	E	2
		%SCFB	#SCFB-6	1.30E-05	2.62E-08	O	E	3
SEISMIC	BIN 1 (0.1~0.3g)	%SEIS	#GSEISMIC-4!	2.20E-04	5.42E-11	O	E	2S
		%SEIS	#GS-LOEP-2!	2.20E-04	5.31E-10	X	L	1
		%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-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-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-LOCA2-2!	2.20E-04	1.18E-15	O	E	2S
		%SEIS	#GS-LOCA2-3!	2.20E-04	1.41E-14	O	E	2S
	BIN 2 (0.3~0.5g)	%SEIS	#GSEISMIC-4!	8.20E-06	5.34E-09	O	E	2S
		%SEIS	#GS-LOEP-2!	8.20E-06	8.13E-09	X	L	1
		%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-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-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-LOCA2-2!	8.20E-06	5.00E-11	O	E	2S
		%SEIS	#GS-LOCA2-3!	8.20E-06	7.11E-10	O	E	2S
	BIN 3 (0.5~1.0g or over)	%SEIS	#GSEISMIC-4!	1.36E-06	2.42E-08	O	E	2S
		%SEIS	#GS-LOEP-2!	1.36E-06	2.48E-08	X	L	1
		%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-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-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-LOCA2-2!	1.36E-06	9.23E-09	O	E	2S
		%SEIS	#GS-LOCA2-3!	1.36E-06	4.64E-08	O	E	2S

*) 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)

Table 2. The results of the Internal Fire PSA for HANARO

Fire-Induced IE	CD Sequence	IE Frequency	CDF	CD	Early/Late	STC
F-LOPCS (23개 화재시나리오)	#F-LOPCS-2!	4.10E-02	7.85E-08	X	L	1
F-LOEP (2개 화재시나리오)	#F-LOEP-2!	1.38E-02	2.64E-08	X	L	1
F-GTRN-AT (12개 화재시나리오)	#F-GTRN-AT-3!	2.07E-02	1.28E-11	X	L	1
F-GTRN-MT (16개 화재시나리오)	#F-GTRN-MT-3!	3.34E-02	1.11E-11	X	L	1
F-LOSCS (2개 화재시나리오)	#F-LOSCS-3!	3.34E-02	1.11E-11	X	L	1
합계 (55개 화재시나리오)		1.42E-01	1.05E-07			

*) source term category: 1(no release)

As shown in Table 1 and 2, the release characteristics of radioactive materials by accident type of HANARO facility were divided into six categories: 1) No release, 2) early ground release, 2S) early ground release by structure collapse, 3) early release through chimney, 4) late ground release, and 5) late release through chimney. According to the MELCOR results, first of all, it should be noted that some core damage accident scenarios defined in the level 1 PSA model do not have a source term release due to no core damage. The release time of the source term is assumed very conservatively to be 1 hour after accident occurrence, even though all accident sequences have a lot of time to core damage without any mitigation measures due to the design characteristics of research reactor. The release amount of the source term through the chimney was determined by the results of MELCOR simulations under the very conservative assumptions that all fission products of the core inventory are released from core to reactor building. In addition, in the event of an earthquake-induced collapse of the reactor building, it was assumed that all source terms were immediately released at the ground level.

2.2 Modelling and Quantification of Population-Weighted Risk

A site-specific MACCS2[1] input model for HANARO facilities [7] was developed to estimate the health effects of the surrounding population caused by the release of source terms.

2.3 Results of the Risk Profile

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.

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 average individual risk for HANARO facilities were evaluated as 3.57e-11/yr as shown in Table 3. This figure is comparable to the safety goal reference (0.1% rule), and according to the literature [8] it was reported that the comparative reference was 5e-7/yr for EF and 1e-6/yr for CF. (>> 3.57e-11/yr (negligible)).

Finally, the total risk profile, the risk profiles for internal events and seismic events are shown in Figure 1 through 3, respectively. The dominant risk contributor in HANARO is the seismic-induced RCI (Reactor Concreate Island) break scenario (STC 2S). Note that no acute fatality was estimated and no risk due to internal fire events was found for HANARO.

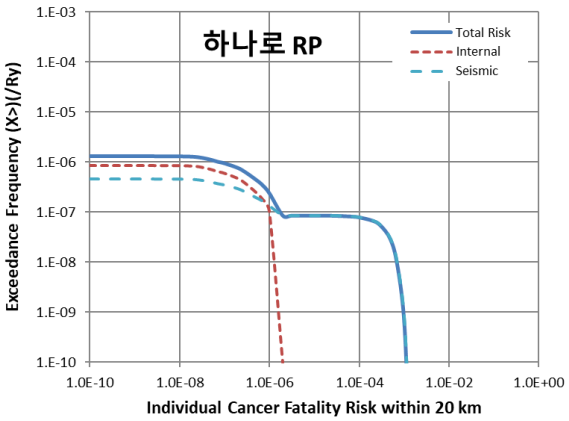

Figure 1. The Risk Profiles for HANARO (Total individual cancer fatality)

Table 3. The results of Individual Risk for HANARO

STC*	Event type CDF(/RY)(a)			population-weighted risk (b)(/person)				Acerage Individual Risk by Event Type (c=a*b)(/person-Ry)					
	Internal	Fire	Seismic	EF(~5km)	CF(~20Km)			EF(~5km)			CF(~20Km)		
				All	Internal	Fire	Seismic	Internal	Fire	Seismic	Internal	Fire	seizmic
1	3.68E-06	1.05E-07	3.34E-08	0	0	0	0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2S	-	-	8.60E-08	0	-	-	4.09E-04	-	-	0.00E+00	-	-	3.52E-11
2	2.67E-07	-	3.29E-07	0	4.39E-07	-	4.39E-07	0.00E+00	-	0.00E+00	1.17E-13	-	1.44E-13
3	2.96E-08	-	3.65E-08	0	1.50E-07	-	1.50E-07	0.00E+00	-	0.00E+00	4.45E-15	-	5.48E-15
4	5.13E-07	-	1.15E-08	0	4.30E-07	-	4.30E-07	0.00E+00	-	0.00E+00	2.20E-13	-	4.93E-15
5	5.70E-08	-	1.27E-09	0	1.46E-07	-	1.46E-07	0.00E+00	-	0.00E+00	8.32E-15	-	1.86E-16
Sub-total (A=∑a)	4.55E-06	1.05E-07	4.98E-07	Sum of Individual Risk(C=∑c)				0.00E+00	0.00E+00	0.00E+00	3.50E-13	0.00E+00	3.53E-11
Total (∑A)	5.15E-06			Total Average Individual Risk (∑C)				3.57E-11					

*) 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)

[1] MACCS2 (MELCOR Accident Consequence Code System Version 2) [5, 6]

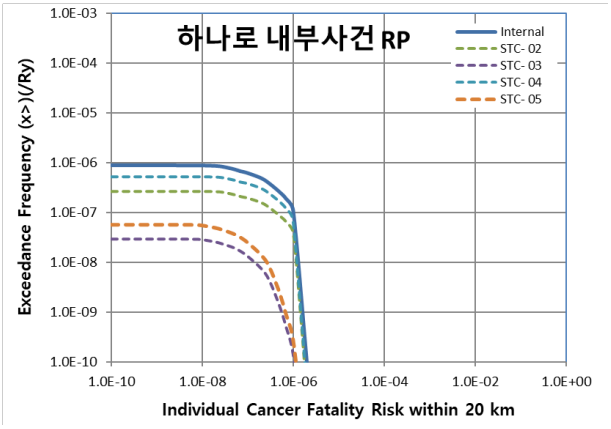

Figure 2. The Risk Profiles for HANARO Internal Evnets

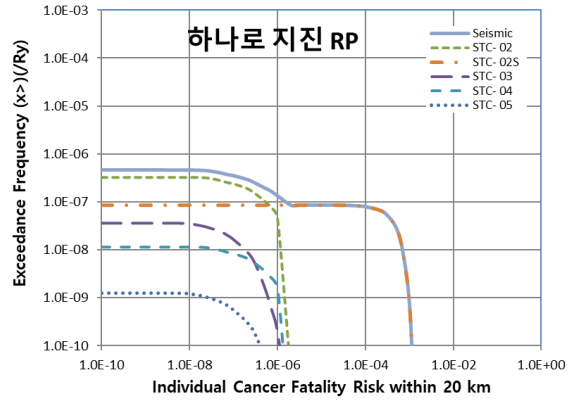

Figure 3. The Risk Profiles for HANARO Seismic Events

3. Conclusions

The risk profile for 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 HANARO facilities were evaluated as 3.57e-11/yr, which can be regarded to be insignificant through the comparison on the regulatory-side safety goal reference [8].

Acknowledgments

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