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An Uncertainty Analysis of Radioactive Material Release for L3 PSA

Hyunae Park, Seungwoo Kim, Dong Ha Kim and Moosung Jae*
Department of Nuclear Engineering, Hanyang University, Seoul, 04763, Korea
**Corresponding author: jae@hanyang.ac.kr*

1. Introduction

The accident frequency and information about the radioactive materials released into the environment are used for the Level 3 PSA. However, there is a great deal of uncertainty in the phenomenon of severe accidents of nuclear power plant. It includes the accident progression in the core as well as in the containment. In particular, source term behavior is more complicated than others, resulting in a wide range of uncertainty band.

In terms of Level 3 PSA, the release fraction of the important fission products such as Cs and I out of the containment gives a great impact on health effects such as early fatality and cancer fatality of the people near by the plant. As there is little research done in this area, uncertainty analysis of the source term release was performed using MELCOR 2.2.

2. Methods and Results

2.1 Accident Scenario

LOCCW-6 of WH600 was selected as a reference case, because it was found to be one of dominant scenario in the late containment failure mode. In this scenario, loss of component cooling water (LOCCW) occurs and all safety systems except the passive system.

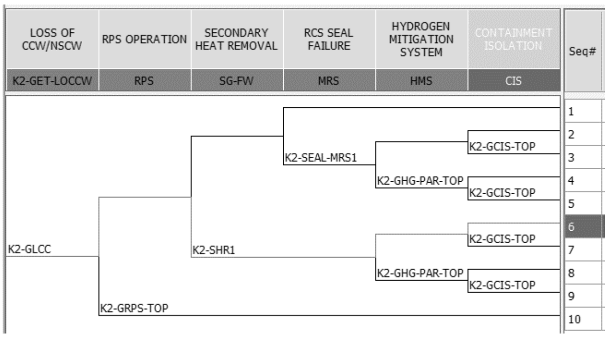

Fig. 1. WH600 LOCCW ET

2.2 Sensitivity Analysis

In this study, 22 candidates of uncertainty variables were selected, and their distributions and ranges were determined using the accident progress of the selected scenario, MELCOR manual, and references.[1, 2, 4] Each variable is categorized into a phenomenon that is expected to affect the release fraction. There are 3 phenomenon categories of core melting(COR), containment pressure(CT), behavior of fission product(FP).

Sensitivity analysis was performed on the candidates to determine which variables to use for the final uncertainty assessment. The release fractions of Cs and I were calculated with the minimum and maximum values of the MELCOR model variables. Although the information of the variables was obtained by references, 20% of the base value was selected as the range when the reference range was out of the base value of the model used in the study. In the case of distribution of variables, uniform distribution was assumed for unknown variables through reference. Table 1 shows the list of variables, their definitions, the ranges of variables and their effect on release fraction as a rate of change. The rate of change of the release fraction is expressed as the ratio of the release fraction to the base case like equation 1.

$$R_n = \frac{RF_{max,n} - RF_{min,n}}{RF_{base,n}} \quad (1)$$

R_n is rate of change about nuclide group n, RF_{max} and RF_{min} are release fraction calculated with maximum and minimum values of the MELCOR model variables. RF_{base} is release fraction of base case.

Variables related to fission product behavior, which are expected to affect the release fraction relatively, were selected with lower criteria than those of the other two categories. variables with a difference of more than 10% from the sensitivity analysis for FP and variables with a difference of more than 20% for the remaining variables were reflected in the final uncertainty assessment. If only one of Cs and I exceeds 10% (20% in core melting category and containment pressure category), it was selected as a final parameter. Finally, 13 variables (5 parameters in core melting category , 2 in containment pressure category and 6 in fission product behavior category) were selected using the sensitivity analysis results.

Variables selected from the core melting category are Molten clad drainage rate, Melt relocation heat transfer coefficient, Fractional local dissolution of UO2 in molten Zr, Porosity of fuel debris beds, and Thermal radiation exchange parameters. The variables selected in the containment pressure category are Total mass of structures represented by this penetration, Multiplier on containment steam condensation rate. Variables selected from the fission product behavior category include Particle slip factor in Cunningham slip correction, Particle-particle agglomeration sticking probability, Gas / particle thermal conductivity ratio in thermophoresis deposition velocity, Factor in Thermal Accommodation Coefficient, Boundary layer thickness for diffusion deposition, Aerosol particles effective material density.

Table I: Result of Sensitivity Analysis of Uncertainty Parameter

Category	Parameter	Description	Distribution			Rate of Change	
			Distribution Type	Lower Bound	Upper Bound	Cs	I
COR	COR_SC / 1131(2)	Zircaloy melt breakout temperature	Beta	2100	2540	-2%	7%
	COR_SC / 1132(1)	Melting temperature of UO2-ZrO2 eutectic	Normal	2343	2615	0%	0%
	COR_SC / 1141(2)	Molten clad drainage rate	Log triangular	0.1	2	-24%	0%
	COR_SC / 1020(1)	Solid core debris radial relocation time constant	Uniform	100	1000	1%	2%
	COR_SC / 1020(2)	Molten core debris radial relocation time constant	Uniform	10	100	-6%	10%
	COR_CHT / HFRZZR	Melt relocation heat transfer coefficient	Uniform	2000.0	22000.0	-26%	-24%
	COR_CMT / FUOZR	Fractional local dissolution of UO2 in molten Zr	Uniform	0.0	0.5	-41%	-18%
	COR_LP / HDBH2O	Falling debris quenching parameters	Uniform	125.0	398.0	14%	2%
	COR_EDR / DHYPD	Particulate debris characteristic size following relocation to lower plenum	Log Normal	0.010	0.015	11%	11%
	COR_ZP / PORDP	Porosity of fuel debris beds	Uniform	0.1	0.5	-110%	-102%
	COR_RF / FCELR	Thermal radiation exchange parameters	Triangular	0.100	0.72	-72%	-26%
CT	COR_PEN / XMPN	Total mass of structures represented by this penetration	Uniform	3.58337	5.37505	-22%	-24%
	COR_PEN / AXPN	Total effective conduction area of structures represented by this penetration	Uniform	2.55E-03	3.82E-03	17%	2%
	COR_PEN / DFLPN	Initial diameter of failure opening for ejection of molten core materials	Uniform	0.12	0.18	2%	-2%
	HS_LBT / XHTFCL	Multiplier on containment steam condensation rate	Triangular	1.0	2.0	-51%	-40%
FP	RN1_MS00 / CHI	Shape factor associated with aerosol settling	Beta	1.0	3.37	3%	-2%
	RN1_MS00 / FSLIP	Particle slip factor in Cunningham slip correction	Beta	1.22	1.3	-39%	-42%
	RN1_MS00 / STICK	Particle-particle agglomeration sticking probability	Beta	0.55	1.0	32%	20%
	RN1_MS01 / TKGOP	Gas/particle thermal conductivity ratio in thermophoresis deposition velocity	Log Uniform	0.006	0.06	9%	25%
	RN1_MS01 / FTHERM	Factor in Thermal Accommodation Coefficient	Uniform	2.21	2.5	-3%	-13%
	RN1_MS01 / DELDIF	Boundary layer thickness for diffusion deposition	Uniform	5.0E-06	1.99E-05	-15%	3%
	RN1_ASP / RHONOM	Aerosol particle effective material density	Beta	1000.0	5000.0	-55%	-39%

2.3 Uncertainty Analysis

100 samples were generated using the LHS(Latin hypercube sampling) method for the 13 selected variables. LHS is a method of generating a random sample set for a multi-dimensional variable having a distribution. By using the LHS method, the number of trials can be reduced while maintaining randomness in variable sample selection. .[1, 4]

MELCOR calculations were performed using these 100 samples and 85 valid results were obtained. In each case, 144 hours were calculated from the time of the accident by MELCOR code. In the scenario used in this study, the release of radioactive material started 72 hours after the accident. Figure 2 shows the cumulative release fraction for 72 hours from the start of the release. The boxes in the graph represent the 5th and 95th percentiles of the fraction, and the line in the middle of the box represents the median. The bars at the top and bottom of the box represent the maximum and minimum values of the release fraction. The point in the center of the box is the average value of the release fraction.

Figure 3 and 4 shows Cs and I release fraction according to time for the 95th percentile, 5th percentile, median and base case. The result shows that the release fraction of the base case is conservatively estimated.

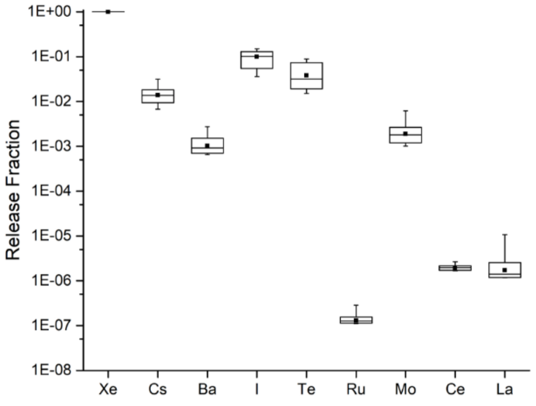

Fig. 2. Result of Uncertainty Analysis of Release Fraction

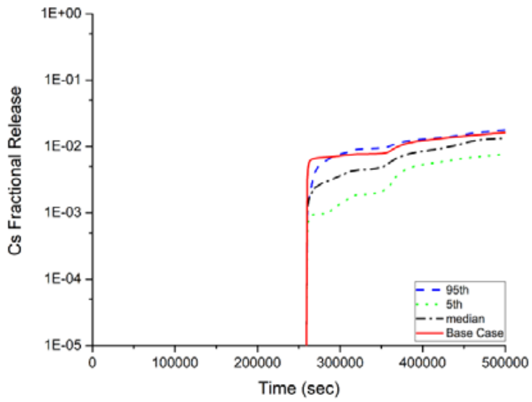

Fig. 3. Cs Release Fraction According to Time

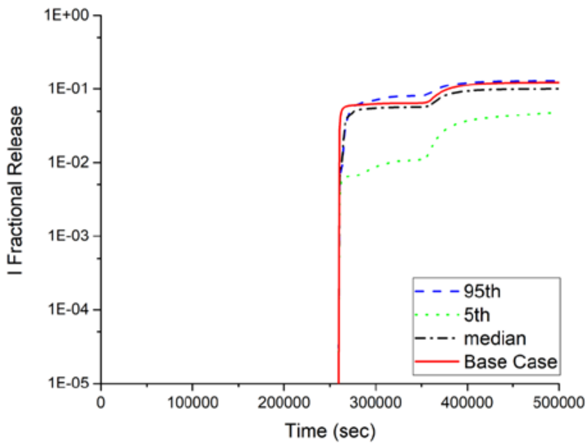

Fig. 4. I Release Fraction According to Time

3. Conclusions

In this study, uncertainty assessment of release fraction at WH600 was conducted. Unlike the previous MELCOR uncertainty study, which is an uncertainty assessment for severe accidents, this study conducted an uncertainty assessment focusing on the release fraction that could affect the L3 PSA. Sensitivity analysis was performed to select variables to be used for uncertainty analysis.

This study assesses the uncertainty of the release fraction through an uncertainty assessment and analyzes the factors that may affect this uncertainty. Uncertainty analysis shows that there is considerable uncertainty in the release fraction of the radioactive material. In the future, release fraction uncertainty will be evaluated for other types of reactors as well as other scenarios of WH600, and these results will be used in the L3 PSA.

This study established a framework for studying the uncertainty of radioactive materials released into the environment. This is expected to contribute not only to severe accident analysis but also to improving the reliability of L3 PSA.

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