Deterministic Sensitivity Studies and Correlation Analysis for Evaluating the Impact of Uncertainty Variables on LBLOCA Consequence

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1. Introduction

In the best estimate plus uncertainty (BEPU) method, an identification of uncertainty variables affecting an accident consequence is an essential task. The Pearson correlation coefficient has been usually used as a measure to identify important parameters and determine their ranking [1-2]. In the previous study [3], the APR-1400 LBLOCA were analyzed by applying the 3rd order Wilks' formula and with considering 18 uncertainty parameters, and the multiple linear regression analysis was performed for evaluating the impact of uncertainty variables on LBLOCA consequence. However, in order to evaluate the adequacy of the multiple linear regression analysis results, additional deterministic sensitivity studies and statistical analysis need to be performed. Therefore, in this study, deterministic sensitivity studies and correlation analysis were additionally performed to validate the results of the multiple linear regression analysis.

2. Statistical Results for Impact of Uncertainty Parameters on APR-1400 LBLOCA

In this study, the correlation analysis was additionally performed using 'R' program [4]. In the evaluation, the important uncertainty parameters were identified by the hypothesis test, and their ranking was determined through correlation coefficients. Table I shows the influential uncertainty variables on the blowdown and reflood PCTs evaluated by the correlation analysis. The uncertainty parameters correlated with the blowdown PCT were analyzed to be 6 of the 18 variables. For the reflood PCT, 5 parameters were analyzed to be correlated.

Table I: Rank of influential uncertainty variables by correlation analysis

Rank	Blowdown PCT	Reflood PCT
1	Fuel conductivity	Groeneveld CHF
2	Gap conductance	Fuel conductivity
3	Break CD	Chen transition boiling
4	Groeneveld CHF	Gap conductance
5	Pump 2-f head	Core power
6	Core power	-

Table II shows the the influential uncertainty variables on the blowdown and reflood PCTs evaluated by multiple linear regression analysis [3]. The uncertainty parameters having an influence on blowdown PCT were analyzed to be 9 of the 18 variables, and 10 parameters were analyzed to be important parameters explaining significant amount of variation in the reflood PCT.

Table II: Rank of influential uncertainty variables [3]

Rank	Blowdown PCT	Reflood PCT
1	Fuel conductivity	Groeneveld CHF
2	Break CD	Fuel conductivity
3	Gap conductance	Chen transition boiling
4	Groeneveld CHF	Gap conductance
5	Pump 2-f head	Core power
6	Core power	Dittus-Boelter vapor
7	Dittus-Boelter vapor	Decay heat
8	Chen transition boiling	Break CD
9	Decay heat	Pump 2-f head
10		SIT water inventory

3. Results and Discussion

In this study, the parameters which were evaluated to have little influence on PCTs, were excluded in the BEPU calculations by setting their mean values, and the comparisons with the blowdown and reflood PCTs results applying all uncertainty parameters were made.

For the blowdown PCT, the correlation analysis found that 6 parameters are important. Fig. 1 shows the comparison of the results considering all uncertainty variables with those applying only 6 uncertainty parameters from the correlation analysis. The most of data were within ±5% error bounds, but about 27% of the data were outside of the ±1% error ranges. The mean relative error between these results was evaluated to be ~ 0.8%.

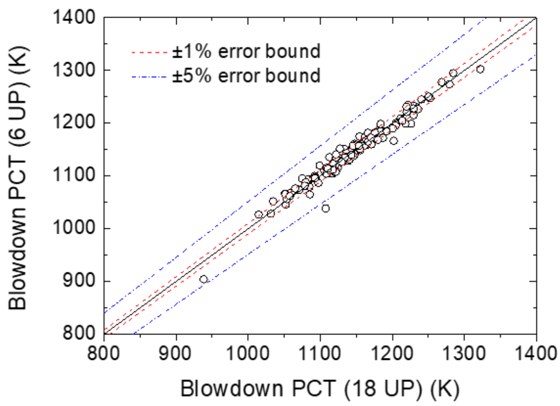

Fig. 1. Comparison of blowdown PCT from the correlation analysis

On the other hand, the multiple linear regression analysis showed that 9 parameters have an influence on the blowdown PCT. Fig. 2 shows the comparison with results from the multiple linear regression analysis. As shown in this figure, two results were almost coincident and the most were in the ±1% error bounds. The mean relative error between these results was evaluated to be 0.15%, in that the consideration of only 9 parameters could fully explain the variation of blowdown PCT.

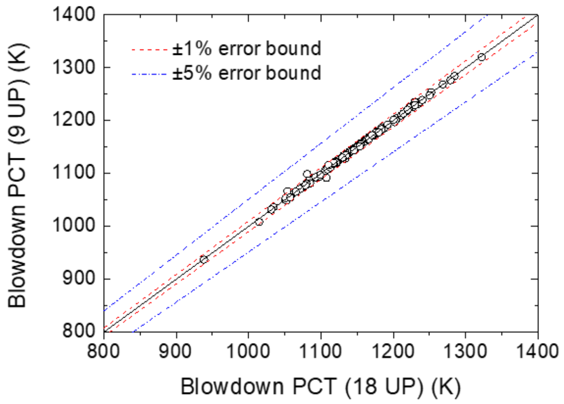

Fig. 2. Comparison of blowdown PCT from the regression analysis

For the reflood PCT, the correlation analysis found that 5 parameters are important. Fig. 3 shows the comparison of the reflood PCT results considering all uncertainty variables with those applying only 5 uncertainty parameters from the correlation analysis. As shown in this figure, the data were highly scattered and there were significant differences between the two results. The average relative error between the two results was estimated to be ~ 3%.

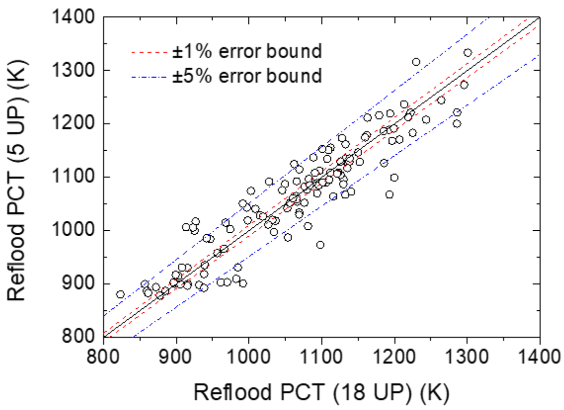

Fig. 3. Comparison of reflood PCT from the correlation analysis

Fig. 4 shows the comparison with results from the multiple linear regression analysis. The multiple linear regression analysis showed that 10 parameters have an influence on the reflood PCT. As shown in the figure, the degree of data dispersion was reduced compared to Fig. 3, and the most of data were within the ±5% error bounds. The mean relative error between these results was evaluated to be ~ 1.5%.

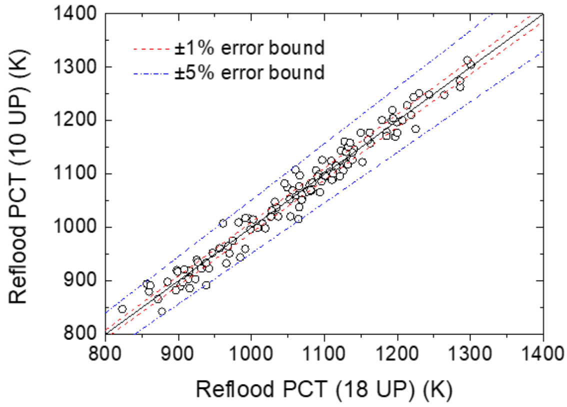

Fig. 4. Comparison of reflood PCT from the regression analysis

Additional deterministic sensitivity studies were performed to investigate the magnitude of influence of individual uncertainty parameter. In this study, the calculation results in which only one variable of interest was fixed to be the mean value, were compared to those considering all uncertainty parameters. Then, the PCT differences between the two results were calculated as follows;

$$\Delta \mathrm{PCT}_i = \left| PCT_{18,i} - PCT_{17,i} \right| \quad (\mathrm{i} = 1,2,\cdots,\mathrm{n}) \qquad (1)$$

where $PCT_{18,i}$ is the PCT with 18 uncertainty parameters and $PCT_{17,i}$ is the PCT with 17 variables excluding one variable of interest. Fig. 5 shows the mean of ΔPCT of uncertainty parameters.

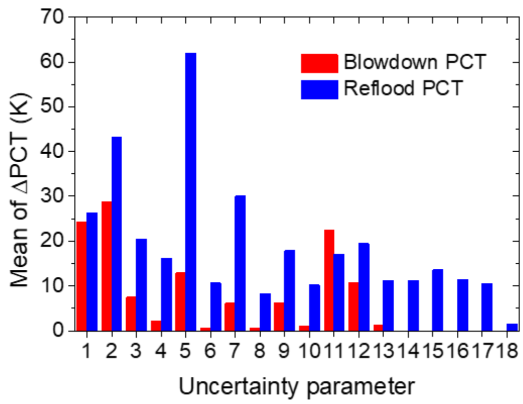

Fig. 5. Mean of ΔPCT for uncertainty parameters

Table III shows the influential uncertainty variables on the blowdown and reflood PCTs evaluated by deterministic sensitivity studies. The rank was determined based on the mean of ΔPCT in Fig. 5, and the parameters with the mean value of less than 2 K were excluded.

Table III: Rank of influential uncertainty variables by deterministic sensitivity studies

Rank	Blowdown PCT	Reflood PCT
1	Fuel conductivity	Groeneveld CHF
2	Gap conductance	Fuel conductivity
3	Break CD	Chen transition boiling
4	Groeneveld CHF	Gap conductance
5	Pump 2-f head	Core power
6	Core power	Pump 2-f head
7	Dittus-Boelter vapor	Dittus-Boelter vapor
8	Chen transition boiling	Break CD
9	Decay heat	Decay heat
10		SIT water inventory
11		SIT water temperature
12		Pump 2-f torque
13		SIT actuation pressure
14		Chen nucleate boiling
15		SIT loss coefficient
16		Bromley film boiling
17		Dittus-Boelter liquid

For the blowdown PCT shown in Table I, II, III, the correlation analysis showed a limitation in identifying the important uncertainty parameters. However, the multiple linear regression analysis could predict the same influential variables with those of deterministic sensitivity studies, and their ranking was almost same.

For the reflood PCT shown in Table I, II, III, all three methods predicted the same rank 1 to 5. However, the correlation analysis showed a limitation in identifying the important uncertainty parameters like the blowdown PCT. On the other hand, the multiple linear regression analysis showed more reasonable results than correlation analysis.

4. Conclusions

In this study, in order to evaluate the adequacy of multiple linear regression analysis results obtained in previous study [3], the deterministic sensitivity studies and correlation analysis were additionally performed. In the correlation analysis, the important uncertainty parameters were identified by the hypothesis test, and their ranking was determined through correlation coefficients. In the deterministic sensitivity studies, the rank was determined based on the mean of ΔPCT, and the parameters with the mean value of less than 2 K were excluded.

For the blowdown PCT, the correlation analysis showed a limitation in identifying the important uncertainty parameters. However, the multiple linear regression analysis could predict the same influential variables with those of deterministic sensitivity studies, and their ranking was almost same. For the reflood PCT, the correlation analysis also showed a limitation in identifying the important uncertainty parameters like the blowdown PCT. On the other hand, the multiple linear regression analysis showed more reasonable results than correlation analysis.

ACKNOWLEDGEMENT

This work was supported by the Nuclear Safety Research Program through the Korea Foundation of Nuclear Safety (KOFONS) and the Nuclear Safety and Security Commission (NSSC), Republic of Korea (Grant No. 1805004-0320-SB120).

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