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A Study on Uncertainty Quantification of Reflood Model using CIRCÉ Methodology

Seong Su JEON[a*], Soon Joon HONG[a], Deog-Yeon Oh[b], Young Seok Bang[b]
[a]*FNC Technology Co. Ltd., 130-206, Seoul National University, Daehak-Dong, Gwanak-Gu, Seoul, 151-742, Korea*
[b]*Korea Institute of Nuclear Safety, 19 Kusong-Dong, Yuseong-Gu, Daejeon 305-338, Korea*
[*]*Corresponding author: ssjeon@fnctech.com*

1. Introduction

In the uncertainty analysis with the best estimate codes, it is difficult to determine the uncertainties of correlations or constitutive relationships. So far the only proposed approach is based on the expert judgment. For this case, the uncertainty range of important parameters can be wide and inaccurate so that the confidence level of the BEPU calculation results can be decreased.

In order to solve this problem, recently CEA (France) proposes a statistical method/tool of data analysis, called CIRCÉ(Calcul des Incertitudes Relatives aux Corréla-tions Élementaires or Calculation of the Uncertainties Related to the Elementary Correlations). The CIRCÉ method is intended to quantify the uncertainties of the correlations of a code. It may replace the expert judgment generally used.

In this study, an uncertainty quantification of reflood model was performed using CIRCÉ methodology. In this paper, the application process of CIRCÉ methodology and main results are briefly described. This research is expected to be useful to improve the present audit calculation methodology, KINS-REM.

2. CIRCÉ Methodology [1]

CIRCÉ is an inverse method of quantification of uncertainty. It is aimed at estimating the uncertainty of non-measurable physical models (via parameters associated with these physical models), and for that, it uses measured data(e.g. clad temperature) sensitive to these physical models(e.g. reflood model).

For a given experiment of intermediate type, the user determines the physical models describing the physical phenomena potentially influential on the experimental data. This choice is made by expert judgment and with the help of sensitivity calculations. On this basis, CIRCÉ uses the measured quantities of the intermediate experiment, called experimental responses, and the corresponding code values, called code responses.

More precisely, let us denote as α_i (i = 1, I, with I = 1, 2 or 3, rarely more) the parameters considered by CIRCÉ and associated with the physical models relevant in the considered experiment. The parameters are supposed to follow a normal law. CIRCÉ gives an estimation of the mean value (also called bias) and the standard deviation of each parameter. To obtain these results, CIRCÉ combines the differences between the experimental results and the corresponding code results, and derivatives of each code response with respect to each parameter. This process is summarized in Fig. 1.

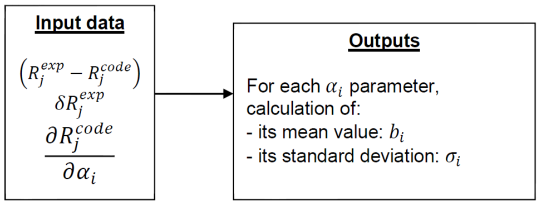

Figure 1 Inputs and outputs of CIRCÉ

3. Considered Reflood Experiment: FEBA

In order to test and apply the CIRCÉ methodology, this study used the FEBA reflood experiment. The MARS-KS nodalization of FEBA is shown in Fig. 2. Time-dependent volume, TDV-150, was used to provide the inlet boundary condition for cooling water. The inlet flow rate of the cooling water was controlled by the time-dependent junction, TDJ-155. The pipe component, C450, was used to model the coolant channel. The reflood phenomenon is observed in this channel. The time-dependent volume, TDV-650, was used to provide the outlet boundary conditions for the pressure outlet. The heat structure, HS450-0, was used to calculate the heat transferred from the fuel to the coolant. HS450-1 was used to calculate the heat transfer between the coolant and the housing which encloses the fuel rod bundle. Using this MARS-KS nodalization, the uncertainty analysis was performed to test the CIRCÉ methodology.

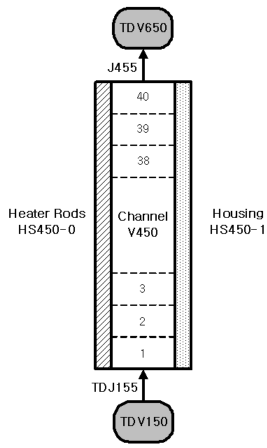

Figure 2 MARS-KS nodalization for FEBA experiment

4. Selection of Considered Reflood Models

MARS-KS code dialing parameters for reflood models are shown in Table 1. From the sensitivity tests, this study selected the IP14(dry/wet wall criteria) and IP16(interfacial heat transfer of drop-steam) as important reflood models for FEBA analysis.

Table 1. MARS-KS code dialing parameter

	Process/Phenomena	**Code Model**	**Key parameter Reference Value**	**Input Multiplier**
Wall Heat Transfer	TCHF	Chen Nucleate Boiling AECL Lookup Table Pool boiling CHF(Zuber)	hmic (Microscopic HT) Multiplier Multiplier	IP1 IP2 IP3
	Transition Boiling Heat Transfer (surface - liquid contact heat transfer)	Modified Weismann correlation	hmax (Const 4500 Criteria 0.1, 0.2 m)	IP4
	Film Boiling Heat Transfer	Bromley void weighted QF heat transfer	Input multiplier (Const value 1440, 1880)	IP5
	Droplet Contact Heat Transfer	forslund-rohsenow eqn.	Factor	IP6
	Convection to Superheated Vapor	Turbulent Laminar Natural convection	Input Multiplier (Linear interpolation between Reynold number 3000 and 10000)	IP7
	Dispersed Phase Enhancement of Convective Flow	Droplet enhancement factor (TRACE)	Factor : 25	IP8
Interfacial Drag4)4	Local Void Fraction	Interfacial drag for BBY	Bestion model	IP9
	Liquid Entrainment	Ishii-Mishima entrainment	F11 Factor	IP10
	Liquid Ligaments, Drop Sizes, Interfacial Area, Droplet Number Density	We number	4.0	IP11
Interfacial Heat Transfer	Interfacial HT of IANN/ISLG	IHT of subcooled liquid	Const value	IP12
	Interfacial Area of IANN/ISLG	Roughness	Surface area	IP13
	Interfacial HT of Drop flow	IHT of drop-steam	TRACE Blowing factor	IP16
Flow regime	Inverted annular in hot wall flow regime	Dry/wet wall criteria Tg = Tsat+30 deg-C	Const value ; 30	IP14
	liquid chunk flow regime	transition criteria : void fraction 0.6 < ISFB < 0.9	Const values 0.6	IP15

5. Selection of Considered Response

Figure 3 shows the MARS-KS calculation result(clad temperature) for FEBA experiment(Case 216, 590 mm). The dot line indicates the selected response points. This study selected total 93 responses from the FEBA experiments.

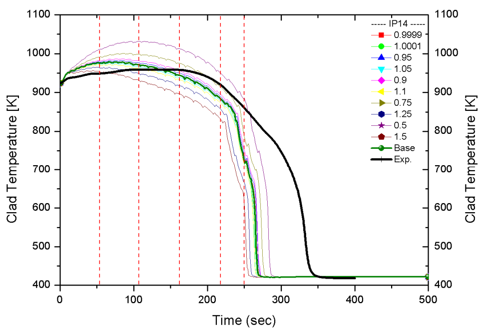

Figure 3 Calculation Result (Case 216, 590 mm)

6. Generation of Derivatives

Since the derivatives become different according to the increment of IP(see Fig. 4), the final derivative for each response is determined by averaging all derivatives obtained from the various increments.

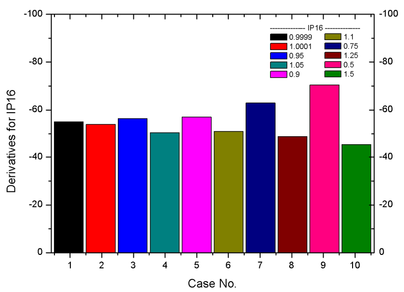

Figure 4 Comparison of derivatives (Response no. 1)

7. CIRCÉ Results

Table 2 shows the CIRCÉ results for IP14 and IP16. Table 3 shows the final uncertainties of reflood models.

Table 2. CIRCÉ results

Parameter	Bias of α_i	Deviation	95% Range
α_1	-0.308055	0.101592	-0.50718 ~ -0.10893
α_2	0.057595	0.464151	-0.85214 ~ 0.967331

Table 3. Final uncertainty of reflood models

Parameter	Bias of p_i	Distribution	95% Range
IP14	-0.308055	Normal	0.492825 ~ 0.891065
IP16	0.057595	Normal	0.147859 ~ 1.967331

8. Envelop Calculations

Figure 5 shows the envelop calculation results using the uncertainties obtained from CIRCÉ. Figure 6 shows the response distribution. Generally, uncertainty analysis results were satisfactory.

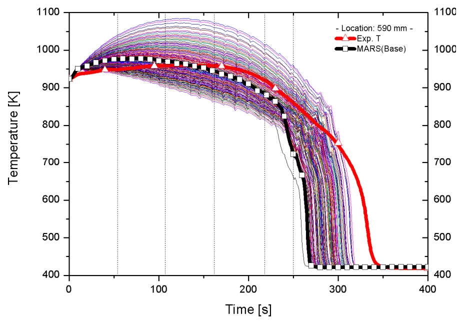

Figure 5 Envelop calculation Results (Case 214, 590 mm)

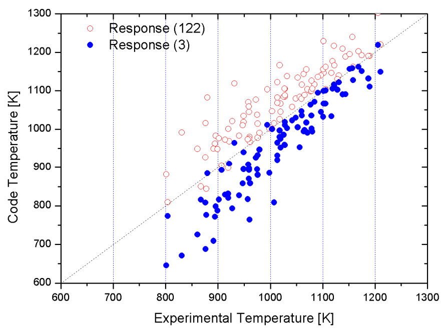

Figure 6 Response distribution

9. Conclusion

In this study, an uncertainty quantification of reflood model was performed using CIRCÉ methodology. The application of CIRCÉ provided the satisfactory results. This research is expected to be useful to improve the present audit calculation methodology, KINS-REM.

REFERENCES

[1] Agnès de Crécy, CIRCÉ: A methodology to quantify the uncertainty of the physical models of a code, CEA, 2012.