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A Review on the CIRCÉ Methodology to Quantify the Uncertainty of the Physical Models of a Code

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1. Introduction

In the field of nuclear engineering, recent regulatory audit calculations of large break loss of coolant accident (LBLOCA) have been performed with the best-estimate code such as MARS, RELAP5 and CATHARE. Since the credible regulatory audit calculation is very important in the evaluation of the safety of the nuclear power plant (NPP), there have been many researches to develop rules and methodologies for the use of best-estimate codes. One of the major points is to develop the best estimate plus uncertainty (BEPU) method for uncertainty analysis.

As a representative BEPU method, NRC proposes the CSAU (Code scaling, applicability and uncertainty) methodology, which clearly identifies the different steps necessary for an uncertainty analysis. The general idea is 1) to determine all the sources of uncertainty in the code, also called basic uncertainties, 2) quantify them and 3) combine them in order to obtain the final uncertainty for the studied application. Using the uncertainty analysis such as CSAU methodology, an uncertainty band for the code response (calculation result), important from the safety point of view is calculated and the safety margin of the NPP is quantified. An example of such a response is the peak cladding temperature (PCT) for a LBLOCA.

However, there is a problem in the uncertainty analysis with the best estimate codes. Generally, it is very difficult to determine the uncertainties due to the empiricism of closure laws (also called 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 of data analysis, called CIRCÉ. 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, fundamental researches for the application of the CIRCÉ methodology to the MARS calculations are performed. In this paper, the CIRCÉ method is briefly introduced and the future research plan for MARS calculation is described. This fundamental research is expected to be useful to improve the present audit calculation methodology, KINS-REM.

2. Introduction of CIRCÉ [1]

CIRCÉ, which means "Calcul des Incertitudes Relatives aux Corrélations Élementaires" (it can be translated into English by: "Calculation of the Uncertainties Related to the Elementary Correlations") is a method and a tool developed by CEA. The CIRCÉ method is a statistical approach of data analysis and is applied as an alternative to the expert judgment often used to determine the uncertainty of the physical models. Estimating these uncertainties is a difficult problem because these models are, in the majority of the cases, not directly measurable.

In a case of very simple SET experiments where only one physical phenomenon, described by one physical model, is clearly dominant, the quantification of its uncertainty is rather simple. It is sufficient to shift the parameter associated with the involved physical model in order to fit the code value with each experimental data, and after that to do statistics with the different values of the parameter obtained with all the experimental data. But in the most frequent case, several physical models must be considered together, and this method does not apply any more. Such experiments are called "intermediate."

CIRCÉ is devoted to this problem: quantify the uncertainty of the parameters associated with physical models, when these physical models are not measurable (e.g. interfacial friction) and when the considered experiment is of intermediate type, i.e. with several influential physical models (e.g. reflood experiments). 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 sensitive to these physical models.

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 α_i parameters are supposed to follow a normal law. CIRCÉ gives an estimation of the b_i mean value (also called bias) and the σ_i standard deviation of each α_i parameter. To obtain these results, CIRCÉ combines the differences between the experimental results and the corresponding code results, denoted as $\left(R_j^{\exp} - R_j^{code}\right)$ and derivatives of each code response with respect to each parameter: $\dfrac{\partial R_j^{code}}{\partial \alpha_i}$. It is also possible to take into account the experimental uncertainties of the responses, denoted as ∂R_j^{exp}. This process is summarized on figure 1.

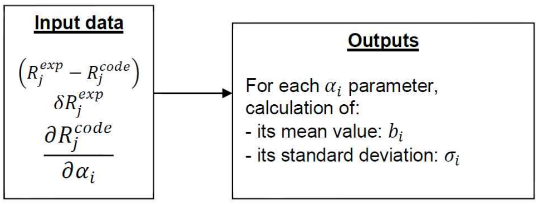
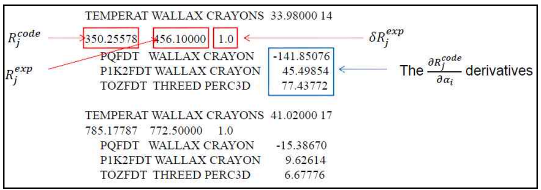


Figure 1 Inputs and outputs of CIRCÉ



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TEMPERAT WALLAX CRAYONS  41.02000 17
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    P1K2FDT WALLAX CRAYON          9.62614
    TOZFDT  THREED PERC3D          6.67776
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Figure 2 Structure of a CIRCÉ input data deck

3. FEBA Experiment

In order to test and apply the CIRCÉ method, this study used the FEBA reflood experiment. The MARS nodalization of FEBA is shown in Fig. 3. 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, HS-450, was used to calculate the heat transferred from the fuel to the coolant through the tube wall. Using this RELAP5 nodalization, the uncertainty analysis is performed to test the CIRCÉ method.

4. MARS Calculations

Table 1 shows the important models related with the reflood phase in LBLOCA. Using the CIRCÉ method, the uncertainty range of these models will be evaluated. Furthermore, MARS calculations will be performed with the uncertainty range. Fig. 4 shows the preliminary calculation results for the FEBA experiment. Unfortunately, all calculations were not completed. All results and important findings might be presented in the conference.

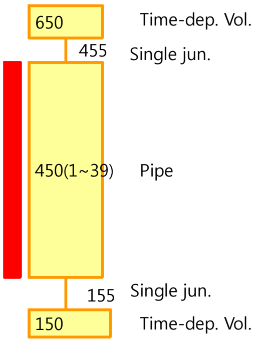

Figure 3 MARS nodalization for FEBA experiment

Table 1. Importan models for reflood phase of LBLOCA

	Code Model or User Input Model	Key Parameter	B.E. Value	Input
Wall Heat Transfer	TCHF	Chen Nucleate Boiling AECL Lookup Table Pool boiling CHF(Zuber)		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	Linear interpolation between Reynold number 3000 and 10000	IP7
	Dispersed Phase Enhancement of Convective Flow	Droplet enhancement factor (TRACE)	factor	IP8
Interfacial Drag	Local Void Fraction	Interfacial drag for BBY	Bestion model	IP9
	Liquid Entrainment	Ishii-Mishima entrainment	factor	IP10
	Liquid Ligaments, Drop Sizes, Interfacial Area, Droplet Number Density	We number	2.7	IP11
Interfacial Heat Transfer	Interfacial HT of IANN	IHT of subcooled liquid	Const value ; C=75	IP12
	Interfacial Area of IANN	Roughness	factor	IP13
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	IP15

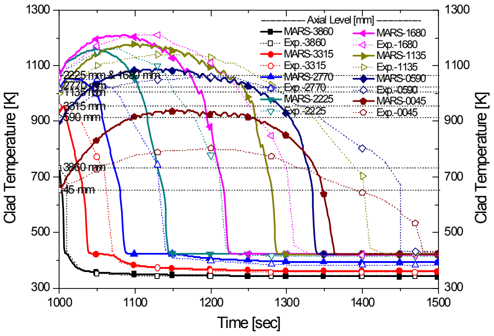

Figure 4 Pre-calculation results of FEBA experiment

5. Conclusion

NRC PIRT doesn't include the detailed phase of event sequence and system/component. And KAERI/ANL PIRT doesn't evaluate knowledge level. The new VHTR PIRT will be developed to obtain the completed PIRT shape by complementing the weakness of the PIRT of NRC, KAERI, and ANL.

REFERENCES

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