Uncertainty Analysis for OECD-NEA-UAM Benchmark Problem of TMI-1 PWR Fuel Assembly

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1. Introduction

Uncertainty quantification of code is a rising issue. In the design aspect, RIA(Reactivity Insertion Accident) and LOCA in safety regulation have been actively discussed to adjust the limit based on the recent experiment result. Best estimation method is necessarily required to meet the new safety limit. In addition, a quantification of code uncertainty is one of main questions that is continuously asked by the regulatory body like KINS. Utility and code developers solve the issue case by case because the general answer about this question is still opened.

Under the circumference, OECD-NEA has attracted the global consensus on the uncertainty quantification through the UAM benchmark program[1]. OECD-NEA benchmark II-2 problem is a problem on the uncertainty quantification of subchannel code. It is a problem that the uncertainty of fuel temperature and ONB location on the TMI-1 fuel assembly are estimated on the transient and steady condition. In this study, the uncertainty quantification of MATRA code is performed on the problem.

Workbench platform is developed to produce the large set of inputs that is needed to estimate the uncertainty quantification on the benchmark problem. Direct Monte Carlo sampling is used to the random sampling from sample PDF. Uncertainty analysis of MATRA code on OECD-NEA benchmark problem is estimated using the developed tool and MATRA code.

2. Methods and Results

2.1 Workbench platform of uncertainty evaluation

Direct Monte Carlo sampling method is applied to quantify the uncertainty on the subchannel analysis code. Code environment of subchannel analysis is different from the safety analysis. Number of sampling obtained by direct Monte Carlo sampling is noticeably reduced due to the relatively small number of constitutive model and input parameters different from typical safety analysis. The proper number of sampling is estimated as the 2000 samplings on the 16 number of parameters. Input files to run MATRA code are automatically generated by workbench platform shown in Fig. 1.

Fig. 2 shows the interface between workbench platform and MATRA. In the first step, reference calculation on the nominal operation condition is performed. Sample parameters extracted from sample PDF(probability density function) are combined to generate the input files of MATRA code. PDF distribution is selected in normal and flat distribution. After generation of input files, MATRA code is performed using them. Variance analysis and Spearman RCC(Rank Correlation Coefficient) to estimate the importance of parameters are performed based on the calculation results.

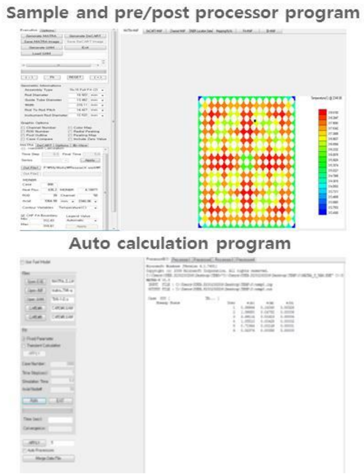


Fig.1. Workbech platform and interconnecting with MATRA code

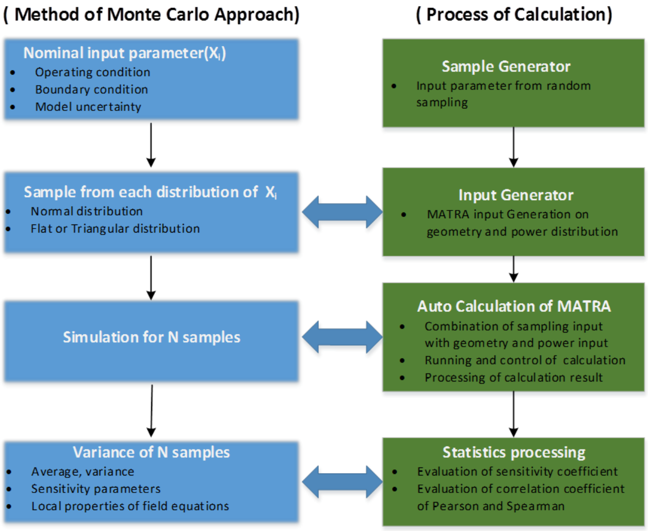


Fig.2. Flow chart of Monte Carlo Approach and process of calculation

2.2 Analysis Model

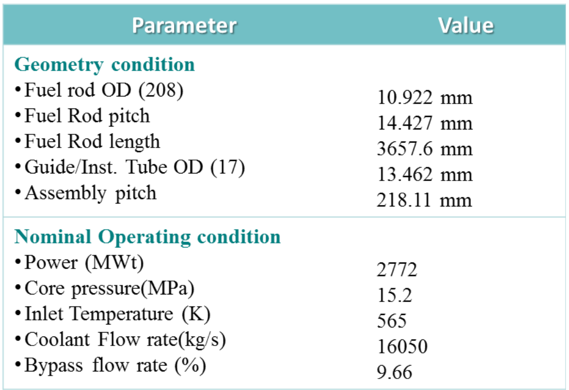
Thermal hydraulic feature for uncertainty analysis of TMI-1 fuel assembly is properly reflected in the MATRA code with ad-hoc thermal hydraulic models. Table I shows the constitutive models for the TH analysis of TMI-1 assembly.

Table I: MATRA models for uncertainty analysis of TMI-1 fuel assembly

Parameters	Values
Flow models	
- Field equations	Homogeneous mixture
- Subcooled boiling void fraction	Saha-Zuber model
- Bulk boiling void fraction	Chexal-Lellouche model
- Two-phase friction multiplier	Homogeneous model
Subchannel interaction models	
- Crossflow resistance factor	Reynolds dependent model
-Turbulent mixing parameter for single-phase	0.038
-Two-phase turbulent mixing model	Equal-mass-exchange model
Empirical TH models	
- Bundle friction factor	P/D correction factor model
- Spacer grid loss factor	
- Critical heat flux correlations	W-3
Numerical parameters	
- Number of axial nodes in active length	50 (Uniform node)
- Solution scheme	Marching scheme with SOR
- Boundary conditions	Inlet flow/Exit pressure
- Convergence criteria for	
axial flow	1.E-2
crossflow (internal/external)	1.E-3 / 1.E-1

The axial and radial power shape was provided by the SCALE code on the initial core condition[1]. PWR fuel assembly of B&W is 15 by 15 array with 6 MV(Mixing Vane) grid and 2 NMV(Non-Mixing Vane) grid. Nominal operating condition and geometry details of the fuel assembly are shown in Table II.

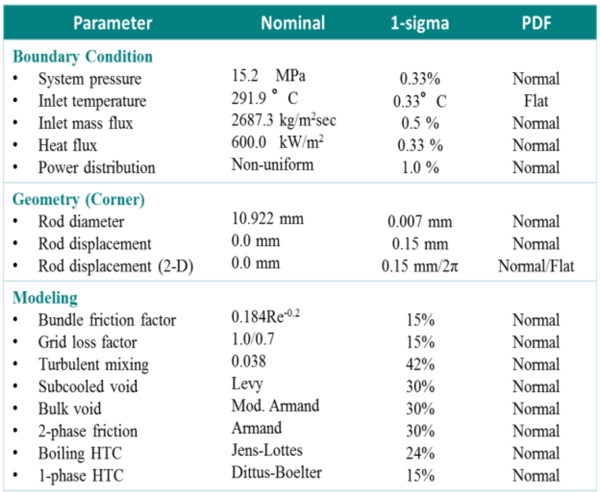
Table II: Fuel assembly geometry and nominal operating condition



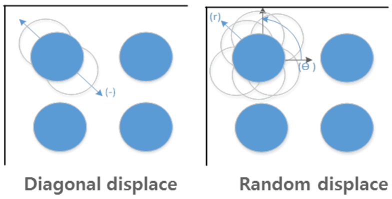
Parameter	Value
Geometry condition	
• Fuel rod OD (208)	10.922 mm
• Fuel Rod pitch	14.427 mm
• Fuel Rod length	3657.6 mm
• Guide/Inst. Tube OD (17)	13.462 mm
• Assembly pitch	218.11 mm
Nominal Operating condition	
• Power (MWt)	2772
• Core pressure(MPa)	15.2
• Inlet Temperature (K)	565
• Coolant Flow rate(kg/s)	16050
• Bypass flow rate (%)	9.66

It is assumed that all parameters in uncertainty analysis are statistically independent. Parameters are classified into boundary condition, geometry, constitutive modeling as shown in Table III. PDF, nominal values and 1-sigma values are provided for random sampling. The corner rod designated as number 1 is not only randomly displaced but also diagonal displaced to estimate the displacement effect as shown in Fig 3.

Table III: Nominal value and statistical condition of uncertainty parameters



Parameter	Nominal	1-sigma	PDF
Boundary Condition			
• System pressure	15.2 MPa	0.33%	Normal
• Inlet temperature	291.9 ° C	0.33° C	Flat
• Inlet mass flux	2687.3 kg/m^{2}sec	0.5 %	Normal
• Heat flux	600.0 kW/m^2	0.33 %	Normal
• Power distribution	Non-uniform	1.0 %	Normal
Geometry (Corner)			
• Rod diameter	10.922 mm	0.007 mm	Normal
• Rod displacement	0.0 mm	0.15 mm	Normal
• Rod displacement (2-D)	0.0 mm	0.15 mm/2π	Normal/Flat
Modeling			
• Bundle friction factor	0.184Re$^{-0.2}$	15%	Normal
• Grid loss factor	1.0/0.7	15%	Normal
• Turbulent mixing	0.038	42%	Normal
• Subcooled void	Levy	30%	Normal
• Bulk void	Mod. Armand	30%	Normal
• 2-phase friction	Armand	30%	Normal
• Boiling HTC	Jens-Lottes	24%	Normal
• 1-phase HTC	Dittus-Boelter	15%	Normal



Diagonal displace   Random displace

Fig.3. Rod displace modes to estimate effect of rod displacement

2.3 Uncertainty analysis for OECD-NEA(Steady-State)

Pin by pin analysis on a single assembly was performed on 2000 conditions that are evaluated from direct Monte Carlo sampling.

Uncertainty of DNBR(Departure from Nucleate Boiling Ratio) estimated using W-3 correlation is evaluated as shown in Fig. 5. Grey shadow is uncertainty band which is evaluated from MC sampling results. Uncertainty of input parameters lies on evenly along the axial location within 1%.

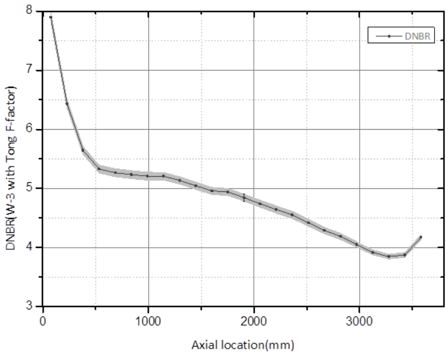


Fig.4. DNBR value and its uncertainty band along axial location

Uncertainty of coolant and cladding temperature is also evaluated as shown in Fig. 5. Cladding temperature is estimated using the 1-D conduction equation. The conduction equation is solved with the orthogonal collocation method with 3rd order accuracy[2].

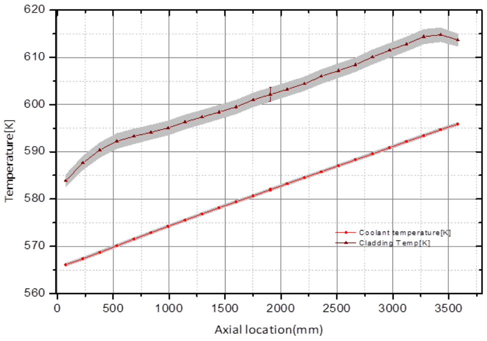


Fig.5. Cladding and coolant temperatures and its uncertainty band along axial location

Uncertainty of coolant temperature at hot channel along axial location is estimated with 0.3 K and it of cladding temperature is within 1.5 K. It is estimated under the present condition that temperatures are insensitive on the input parameters uncertainty.

Importance of input parameters for DNBR and temperature are evaluated by the Spearman rank correlation coefficient[3]. Spearman RCC(Rank Correlation Coefficient) defined as equation (1).

1	Pressure
2	Inlet mass flux
3	Average heat flux
4	Inlet fluid temp
5	Rod displacement(Corner)
6	Rod diameter(All)
7	Friction
8	Grid loss coefficient
9	TDC
10	Subcooled void
11	Bulk void model
12	2-phase multiplier
13	Nucleate boiling HTC
14	Single phase HTC

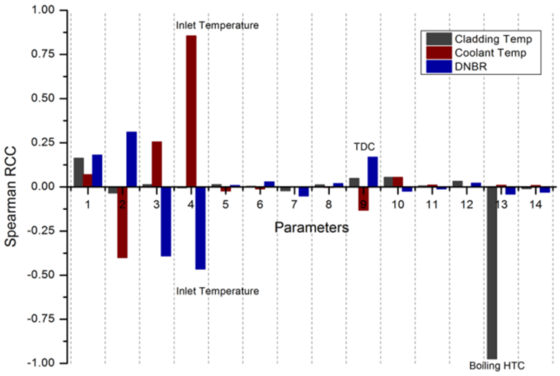


Fig.6. Importance of input parameters evaluated by Spearman RCC

$$\rho = 1 - \frac{6\sum d_i^2}{n\left(n^2-1\right)} \qquad (1)$$

where $d_i = x_i - y_i$ is the difference between ranks. It is known that the Spearman correlation is less sensitive than the Pearson correlation to strong outliers and is more well defined to nonlinear effects.

Fig. 6 shows the results of importance parameters on the DNBR and temperatures of cladding and coolant. In DNBR, the importance of parameters is an inlet temperature, local heat flux, pressure and TDC(Thermal Diffusion Coefficient), sequentially. In temperature, the importance of parameters is estimated that an inlet temperature and inlet mass flux mainly affected the coolant temperature. However, the cladding temperature is mainly affected on boiling heat transfer and pressure because wall temperature is strongly related with wall heat transfer coefficient and saturation condition.

3. Conclusions

Uncertainty analysis on OECD-NEA benchmark II-2 problem was performed to quantify the uncertainty of MATRA code. Direct Monte Carlo sampling is used to extract 2000 random parameters. Workbench program is developed to generate input files and post process of calculation results. Uncertainty affected by input parameters was estimated on the DNBR, the cladding and the coolant temperatures. In this problem, DNBR uncertainty of MATRA code was estimated with 1 % level in the normal operating condition.

REFERENCES

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