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Uncertainty of Thermal Parameter for the Pre-designed VHTR Core Based on CORONA

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1. Introduction

To design a VHTR core and analysis a steady state thermal-fluid parameters, the CORONA code has been developed by KAERI [1]. One of purposes of CORONA is to evaluate the maximum core hot spot temperature in the steady state conditions. And it is important to analyze the thermal margin of hot spot temperature in the core design. However parameters of thermal, fluid and structure used in core temperature analysis have uncertainties.

The purpose of this study is to produce a calculated thermal-fluid parameter including uncertainties using semi statistical method. The calculated results including uncertainty are compared to best estimate result.

2. Calculation Methods: Hot Channel Factor (HCF)

In the design on the nuclear reactor core, safety margin should be considered in terms of the thermal fluid analysis. In the calculation of the thermal fluid parameters could be encountered any uncertainties such as fabrication uncertainty, system uncertainty etc. To be more conservative, therefore, modification factors are used in the thermal fluid analysis.

Fig. 1 shows a schematic diagram to illustrate the semi-statistical hot channel factor (HCF) method. HCF is composed two part, direct and random uncertainties. The direct uncertainty is caused by system uncertainty such as core power, flow distribution etc. The direct uncertainties are calculated by multiplication of individual uncertainties. On the other hand, the random uncertainty has statistical properties. The overall random uncertainty is calculated by a square root sum of the random properties.

HCF is one of famous modification factors used in the core thermal fluid design. And semi-statistical method is complementary approach to the point between conservative calculation and optimistic calculation. The maximum fuel temperature using semi-statistical method is calculated by the equation below, where T is temperature, f is uncertainty sub-factor.

$$T_{f,max} = T_{inlet} + \sum_{i=1}^{m}\prod_{k=1}^{n1} f_{k,i}\Delta T_{i,nom} + \sqrt{\sum_{j=1}^{n2}\left[\sum_{i=1}^{m}(f_{i,j}-1)\prod_{k=1}^{n1} f_{k,i}\Delta T_{i,nom}\right]^2} \quad (1)$$

Table I shows the used calculation value of system and random sub-factors. Most of sub-factor values of the system and random are from HTTR design values [2] due to similarity between the pre-designed VHTR [3] and HTTR system. The sub-factor values which are not available from HTTR design document are determined by engineering judgement.

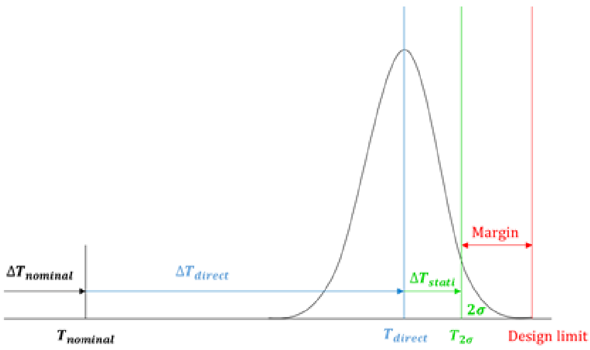

Fig. 1. Schematic of semi statistical hot channel factor method

3. Calculation Model and Boundary Conditions

Fig. 2 shows the configuration of reactor core model used in this study. Reactor core consists of fuel blocks (Fuel), reserved shutdown control fuel blocks (Fuel-RSC), control rod reflectors (Ref-CR) and Reflectors (Ref). The neutronics analysis and designs are carried out by DeCART [4] and CAPP [5]. The DeCART provides the radial core pin power profile for each block. The CAPP produces the radial and axial core block power distribution.

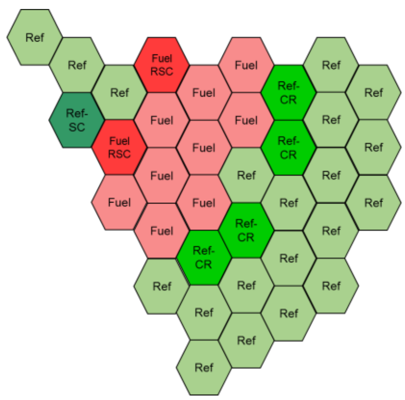

Fig. 2. 1/6 core assembly configurations

Core flow rate is calculated by the equation (2), where Q is core power, $\dot{m}$ is core coolant flow rate, C_p is heat capacity and T is temperature.

$$Q = \dot{m} C_p (T_{out} - T_{in}) \qquad (2)$$

Boundary conditions are obtained by 58.33(=350/6) MW core power. Only 1/6 part of core was simulated due to core symmetry. The main design parameters of this study are provided in Table II.

For the identification of case name, B415_750 includes reactor operating condition (B=BOC), and core inlet/outlet temperatures (415/750 °C)

4. Result and Discussion

Fig. 3 shows the calculated maximum temperature distribution in B415_750 case. Each fuel block has two different temperatures. Upper temperature is best estimate column temperature using CORONA and bottom temperature includes uncertainties. The average difference in the column temperature is 85 °C. When the uncertainties are included, the predicted maximum temperature of column temperature is 1121.7 °C, which is below the design limits, <1250.

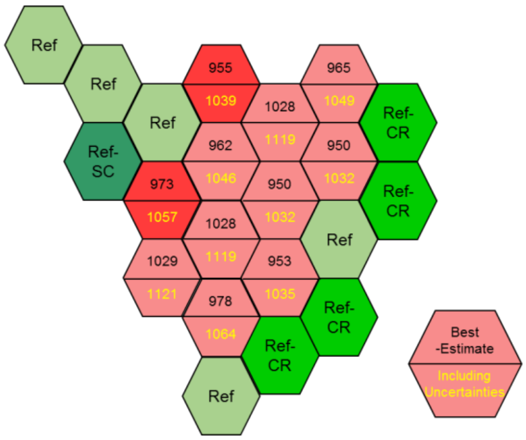

Fig. 3. Maximum temperature by each column (B415_750)

Table III shows the summary of thermal-fluid parameters of 290/415 °C inlet temperature case in outlet temperature 750 °C condition. Even including uncertainties results, both of cases are satisfied the design limit. Between best estimate and including uncertainty results have difference of ~100 °C. As the core inlet temperature increases, the best estimate core maximum temperature decreases and gap of the best estimate and including uncertainty result also decreases.

5. Conclusions

In this paper, thermal-fluid parameters were analyzed for pre-designed core with semi statistical uncertainty method, named HCF. The core temperature with HCF method increased on the each blocks, at least 82 °C. However even increased temperature, maximum temperature does not exceed the design limit, >1250 °C.

Further work of uncertainty study is required to produce the various boundary conditions such as higher outlet temperature conditions. And in this study, most of HCF sub factors are employed from the HTTR. But more intensive studies on HCF sub factors are required for our own design.

ACKNOWLEDGEMENTS

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Table I. Summary of sub factors of system and random in this work

		Sub factor	Coolant	Boundary	Graphite	He Gap	Compact
System		Core Thermal Power	1.025	1.025	1.025	1.025	1.025
		Power Distribution (Radial)	1.03	1.03	1.03	1.03	1.03
		Power Distribution (Axial)	1	1.04	1.04	1.04	1.04
		Coolant Flow Rate	1.01	1.008	1	1	1
		Coolant Flow Distribution	1.04	1.032	1	1	1
Random	Fabrication	Compact Diameter	1	1	1	1.37	1.012
		Fuel Channel Diameter	1	1	1	1.37	1
		Coolant Channel Diameter	1	1.014	1	1	1
		Channel Center Distance	1	1	1.012	1	1
		Block Effective Heat Transfer Height	1	1.002	1.002	1.002	1.002
	Properties	Coolant Heat Capacity	1.002	1.001	1	1	1
		Coolant Heat Conductivity	1	1.018	1	1	1
		Coolant Viscosity	1	1.012	1	1	1
		Gap Effective Heat Conductivity	1	1	1	1.03	1
		Compact Heat Conductivity	1	1	1	1	1.012
		Graphite Block Heat Conductivity	1	1	1.015	1	1
	Heat Transfer Coefficient	Coolant Channel Coefficient	1	1.1	1	1	1
		Bypass Flow Heat Transfer Coefficient	1	1.05	1	1	1

Table II. Summary of reactor core boundary conditions

Parameter	Value	
Core Power [MW]	58.33 (=350/6)	
Core inlet Temperature [°C]	290	415
Core outlet Temperature [°C]	750	
Lower Plenum Pressure [MPa]	7	
Core Flow Rate [kg/s]	24.43	33.55

Table III. Summary of thermal-fluid parameter including uncertainties.

Case	B290_750	B415_750
	Tin = 290 °C	Tin = 415 °C
Best-Estimate Max. Fuel Temp [°C]	1094	1029
Max. Fuel Temp. with Uncertainties [°C]	1208 (+113)	1122 (+93)