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Core Thermal-Fluid Analysis of a Micro Modular High Temperature Reactor Core

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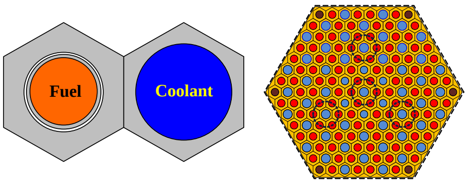
1. Introduction

The interesting on the safer reactor is increasing after a series of accidents. In addition, micro modular reactor without refueling is drawing new attention for the various purposes. The micro modular reactor might be applied to the isolated area including remote area where the transportation of the fuel is difficult due to the environmental limit. High Temperature Gas cooled Reactor (HTGR) might remove a residual heat without the electric supply even under the severe accidents. Moreover, the HTGR might provide a process heat as well as the electricity generation. Therefore, micro modular HTGR can be good opportunity in the special market like the remote area, the pole, the far-away mine region and island. Korea Atomic Energy Research Institute (KAERI) has been studying for micro modular HTGR (MiHTR) as a nuclear future technology. On the present study, the one of the MiHTR candidate cores is simulated to predict the temperature profile in the reactor core.

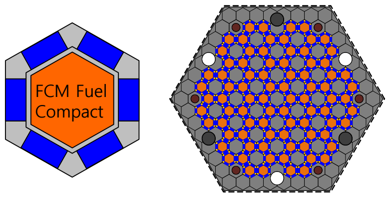
2. Pre calculation and Research

The micro modular reactor is defined as
1) Thermal power under 50MW
2) Non-refueling and long operation over 20years
3) Passive cooling system under the accidents
4) Modularity design/manufacturing

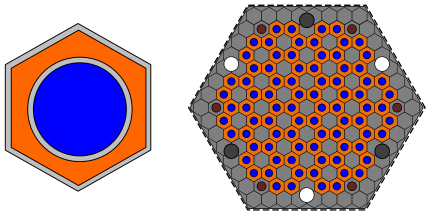
KAERI has conducted pre-calculation on several candidate reactor cores of MiHTR. The considered fuel compact and coolant arrangements in the fuel block are shown in Fig. 1. The unit cell in the Fig. 1. (a) was referred from MHTGR-350. The unit cell in the Fig. 1. (f) is similar to MHTGR-350, but the position of coolant and compact are switched.



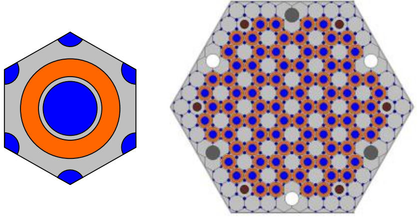
(a) reference from MHTGR



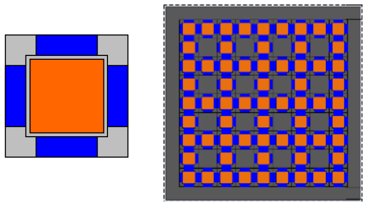
(b) hexagonal compact



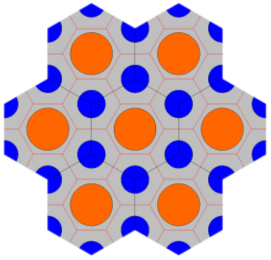
(c) hexagonal compact with inner cooling



(d) annular compact



(e) square compact



(f) multi-cooling compact

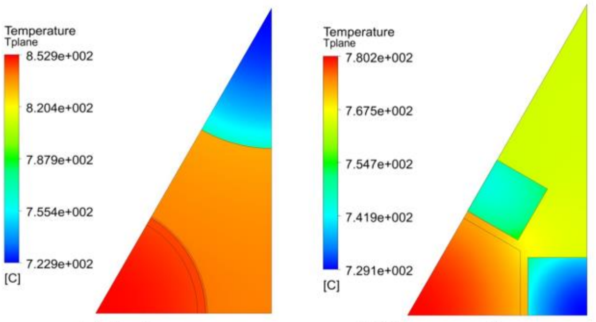
Fig. 1. Sketch of fuel block design of MiHTR

The pre-calculations were done by the CFX commercial S/W Ver18.2 [1]. The boundary conditions are written in Table I. The calculations were conducted for a twelfth domain of unit cell by assuming symmetric condition.

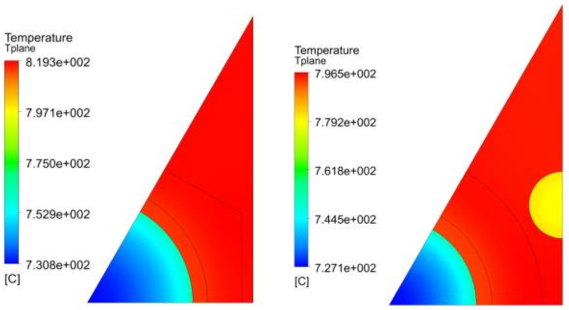
Table I: Boundary conditions

	Value
Power density(MW/m^3)	6.347
Inlet/Outlet Temp. (°C)	300/750
Mass flow(kg/s)	0.00087
Inlet Temp.(C)	259

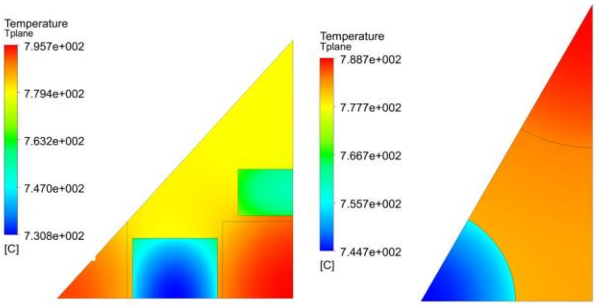
Fig. 2 and Table II show the computational results of the candidate unit cells of MiHTR. The candidate unit cells of (b)~(f) showed lower fuel temperature comparing with the results of the MHTGR reference(a). The design of case (b) and (f) reduced the maximum fuel temperature noticeably. The multi-cooling compact(f) was chosen as the pre-conceptual micro design considering the complexness and difficulties in the manufacturing of the hexagonal compact and the cooling ability.



(a) Reference (b) Hexagonal compact



(c) Hexagonal compact With inner cooling (d) Annular compact



(e) Square compact (f) Multi-cooling compact

Fig. 2. Temperature distribution by pre-calculation of unit cells of MiHTR fuel block

Table II: Pre-calculation results

	Max. Fuel Temp.(°C)	dT(in coolant)	Difference from(a)
(a)	853	111.6	-
(b)	**780**	**28.5**	**73.0**
(c)	819.3	84	33.7
(d)	796.5	69	56.5
(e)	795.7	58	57.3
(f)	**788.7**	**36.1**	**64.3**

3. Results of Core Thermal-Fluid Analysis

One sixth cores of MiHTR with multi-cooling compact were calculated as a consequence of pre-calculations. Fig. 3 represents the selected MiHTR core. Core Reliable Optimization & thermo-fluid Network Analysis (CORONA)[2] code was applied to predict thermo-fluid phenomena in the reactor core. The calculated conditions are explained in Table III. The compact peaking powers were obtained by the calculation of a core-physics code[3].

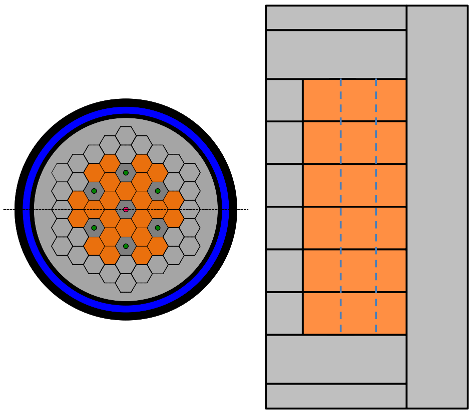
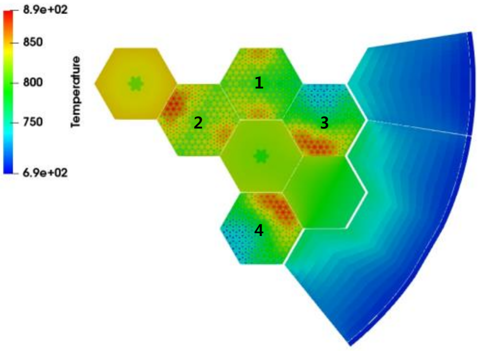


Fig. 3. Schematic of MiHTR core

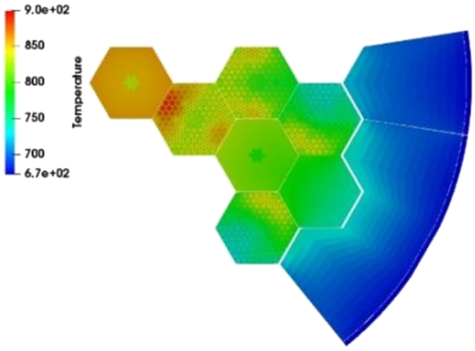
Table III: Core calculation conditions

	Enrichment	Burn up
Case 1a	13w/o	EFPD50
Case 1b	13w/o	EFPD3000
Case 1c	13w/o	EFPD5000
Case 1d	13w/o	EFPD6500
Case 2a	14w/o	EFPD50
Case 2b	14w/o	EFPD3000
Case 2c	14w/o	EFPD5000
Case 2d	14w/o	EFPD7000

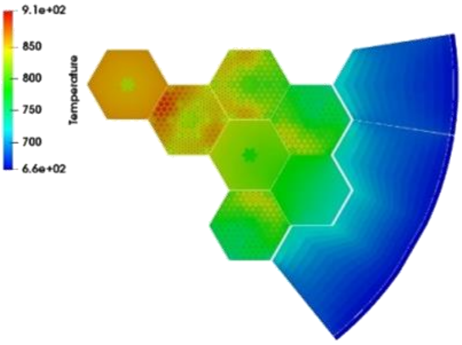
Fig. 4 represents the temperature distribution Cases 1a~1d at the position where the maximum fuel temperature was pointed. For the all burn-up ranges, the maximum fuel temperatures were below the design limit of 1250°C. As the operation time goes, the temperature distributions in the core were flattened. However, the outer surface temperatures of the permanent side reflector are quite high due to relative small reflector volume. Therefore, an additional thermal insulation is needed to reduce the temperature in a reactor pressure vessel (RPV).



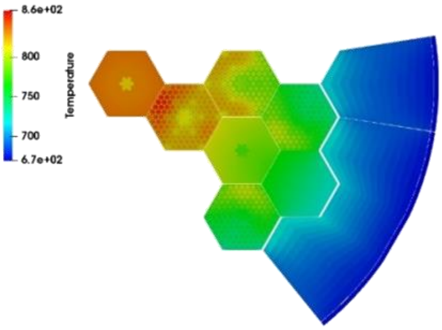
(a) Case 1a



(b) Case 1b



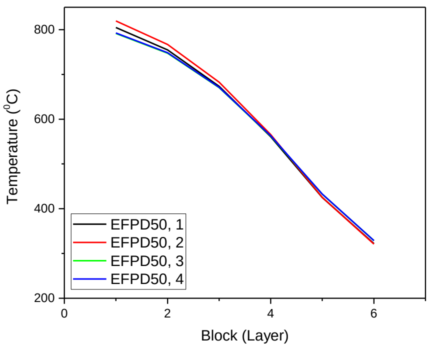
(c) Case 1c



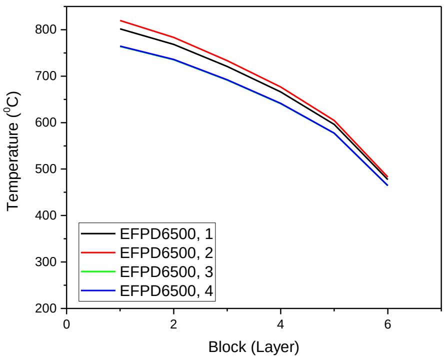
(d) Case 1d

Fig. 4. Temperature distribution of 13w/o loaded MiHTR core with burn-up

Fig. 5 represents the axial temperature profile by the blocks for the each fuel element in the case of 1a and 1d. As the operation time is increased, the temperature differences between the top and bottom are lessen.



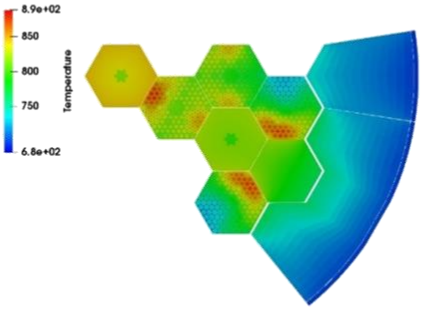
(a) Case 1a



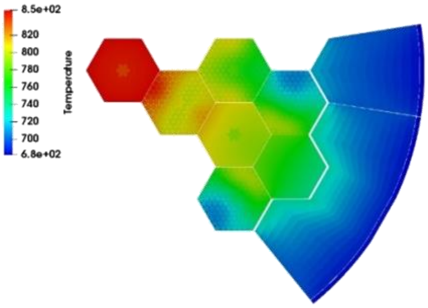
(b) Case 1d

Fig. 5. Temperature profile along the block of 13w/o loaded MiHTR core

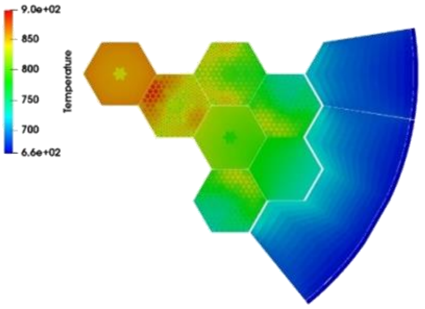
The temperature distributions at the hottest plane of case 2a~2d are shown in Fig. 6. The noticeable thermal differences by the enrichment were not shown on the present study compared with the results of case 1a~1d.



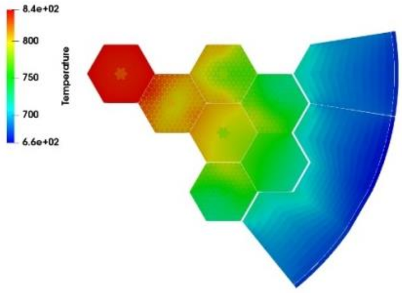
(a) Case 2a



(b) Case 2b



(c) Case 2c



(d) Case 2d

Fig. 6. Temperature distribution of 14w/o loaded MiHTR core with burn-up

4. Conclusions

The pre-calculations were conducted to find the optimized reactor core of MiHTR. The multi-cooling fuel block was selected as reference design of the MiHTR considering the manufacturing and cooling ability. The thermo-fluid calculations using CORONA code were done with the data from the core nuclear design analysis. The results showed that the maximum temperatures in the core were sufficiently below the design limit of the maximum fuel temperature. However, the temperatures of the permanent side reflector were relatively high due to small reflector outer radius. Therefore, further studies to meet the design limit of RPV maximum temperature will be conducted.

Acknowledgements

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[1] www.ansys.com

[2] N. I. Tak, M. H. Kim, H. S. Lim, and J. M. Noh, “A Practical Method for Whole Core Thermal Analysis of Prismatic Gas-Cooled Reactor”, *Nucl. Technol.*, Vol. 177, p. 352, 2012.

[3] Chang Keun Jo, “Core Nuclear Design of a Micro Modular High Temperature Gas-Cooled Reactor,” Tran. of. Korean Nuclear Society Autumn Meeting, Yeosu, Korea, Oct. 25~26, 2018.