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CORONA Code Verification Study on MHTGR-350 Core

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1. Introduction

High Temperature Gas-cooled Reactor (HTGR) has been selected among the Gen-4 reactors in Korea Atomic Energy Research Institute (KAERI) due to its many merits including inherent safety.

KAERI has started a public-private partnership project to develop a 90 MWth HTGR for supplying process heat. Heated steam will be supplied to industrial complexes. Various analysis tools are being developed to enable the safe and efficient design of HTGRs. One of these design tools is the Core Reliable Optimization and Thermo-Fluid Network Analysis (CORONA) code[1], which can be used to assess flow distribution, temperature profiles and hot spot temperatures in the core with a level of accuracy similar to that of commercial CFD software.

As part of the verification and validation (V&V) activities, the results calculated by the CORONA code have been compared with various numerical and experimental data. However, few studies have examined full-core V&V calculations. In this paper, one sixth of the MHTGR350 core has been selected for comparison of the results calculated by the CORONA code with those calculated by the ANSYS CFX software[2].

2. Methods and Results

The MHTGR-350 is a prismatic block-type HTGR that generates 350 MW_{th} in Fig. 1. The inlet temperature is 259 °C and the operating pressure is 6.39 MPa. The bypass gap between the blocks is assumed to be 2 mm. There are two types of control hole: the control rod (CR) hole and the reserve shut-down control (RSC) hole. Therefore, there are three flow regions: the coolant hole, the bypass hole, and the control hole.

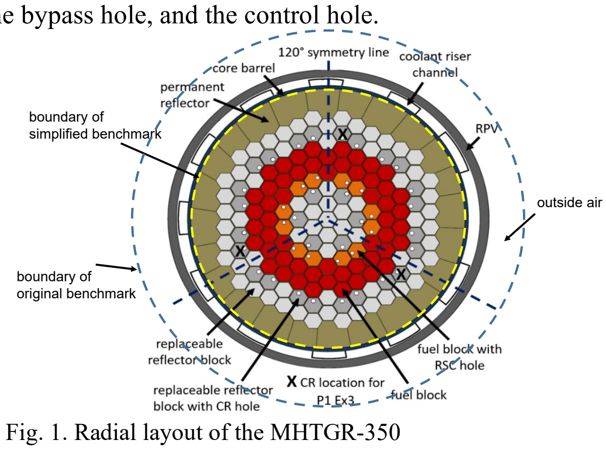


Fig. 1. Radial layout of the MHTGR-350

2.1 Modelling

The CORONA code simulates one-sixth of the MHTGR-350 core, as shown in Fig. 2.

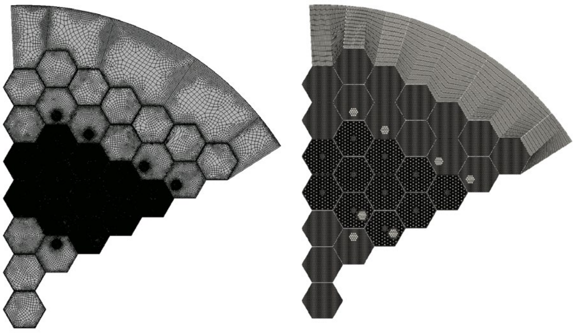


Fig. 2. Meshes of CFX(left) and CORONA code(right)

The total number of nodes is 184,965,596(fluid : 97,956,029) for CFX calculation and 23,363,200(fluid : 127,000) for CORONA calculation. The computational time was 2 days and 21 hours for the CFX with 12 CPUs and 1 hour and 42 minutes for the CORONA code with 14 CPUs. The SST turbulence model was applied to the CFX and the modified Dittus-boelter correlation was applied to the CORONA code.

The current study considers three cases, summarized in Table I, to investigate the flow distribution at the control holes. Case 1 assumes that all control holes are open at the boundary. In Case 2, the outlet diameter of the CR hole is reduced from 10.16 cm to 2.5 cm at the lower reflector. Case 3 is the same as Case 2 for the CR hole, but the RSC holes are treated as stagnant helium.

Table I: Study cases

	CR hole	RSC hole
Case 1	Open	Open
Case 2	Reduce at outlet	Open
Case 3	Reduce at outlet	Stagnant

The power profile used in this study comes from the OECD-NEA MHTGR benchmark study [3].

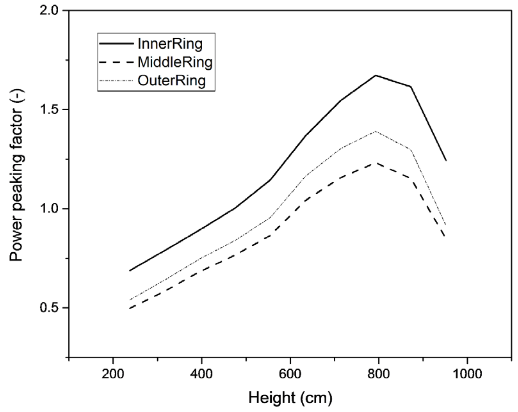


Fig. 3. Axial power profile[3]

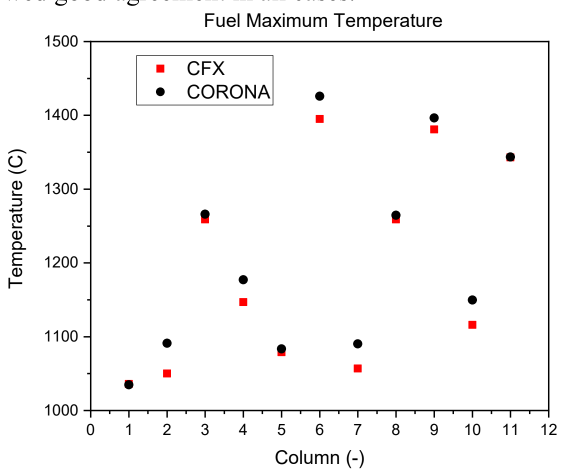
2.2 Results

The mass flow rates for each hole are summarized in Table II. For all three cases, the mass flow rates calculated by the CORONA code agreed well with the CFX results.

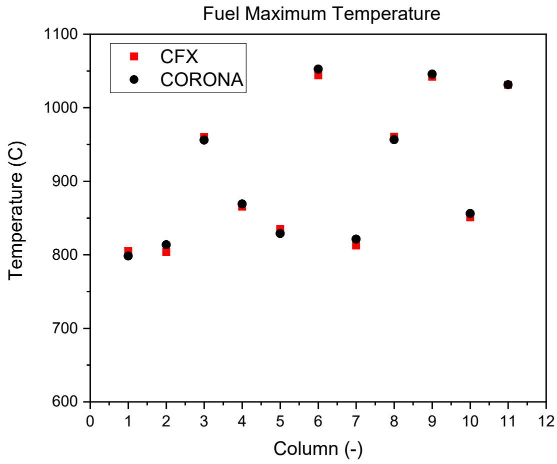
Table II: flow rate in the flow holes [kg/s]

	Coolant	Bypass	CR+RSC
Case 1(CFX)	13.25	1.78	11.15
CORONA	13.19	1.75	11.25
Case 2(CFX)	19.35	2.47	4.36
CORONA	19.45	2.37	4.36
Case 3(CFX)	22.63	2.85	0.71
CORONA	22.66	2.69	0.83

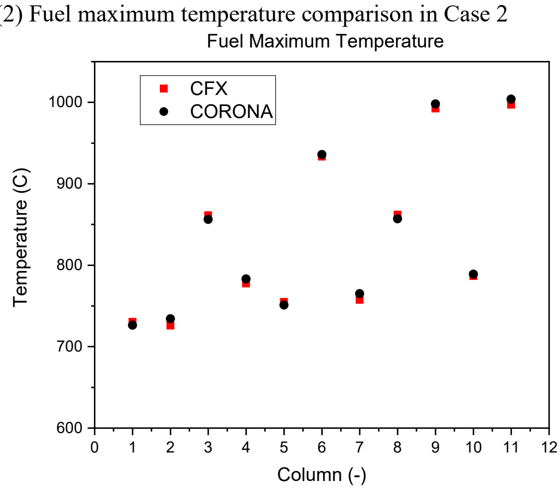
Figures 3 and 4 show the temperature comparison for each block, for maximum fuel and average moderator temperatures. There are slight differences in temperature due to small discrepancies in the flow rate in each region. However, the calculated results by CORONA and CFX showed good agreement in all cases.



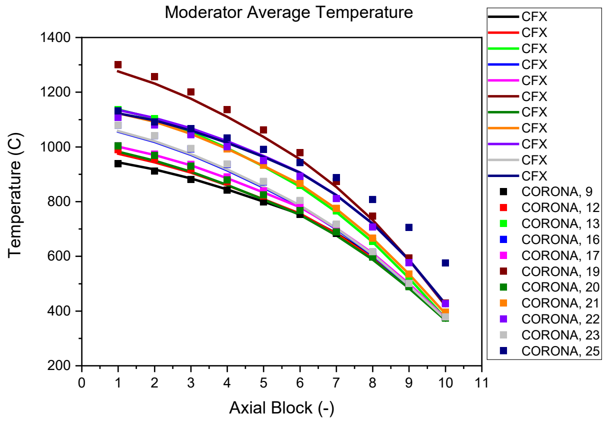
(1) Fuel maximum temperature comparison in Case 1



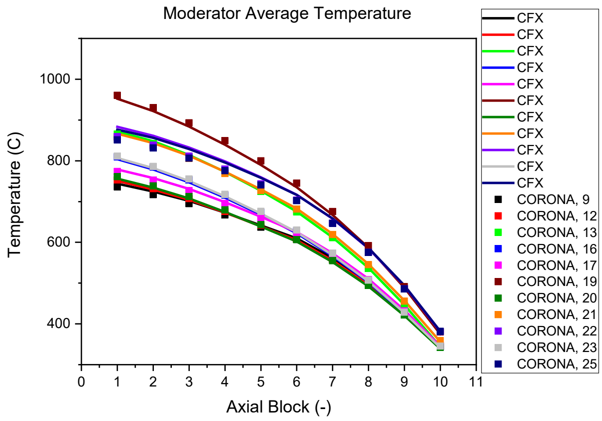
(2) Fuel maximum temperature comparison in Case 2



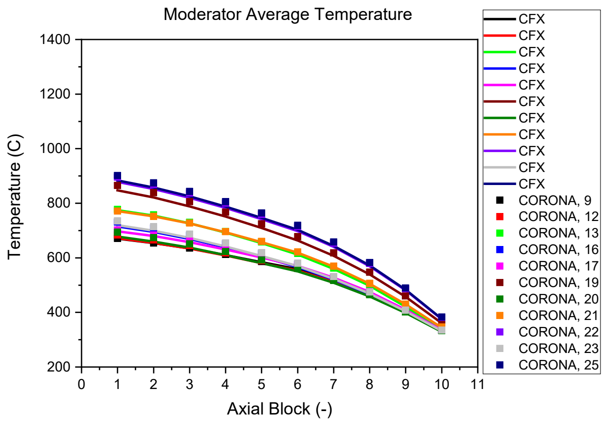
(3) Fuel maximum temperature comparison in Case 3
Fig. 3. Fuel maximum temperature comparison



(1) Moderator average temperature comparison in Case 1

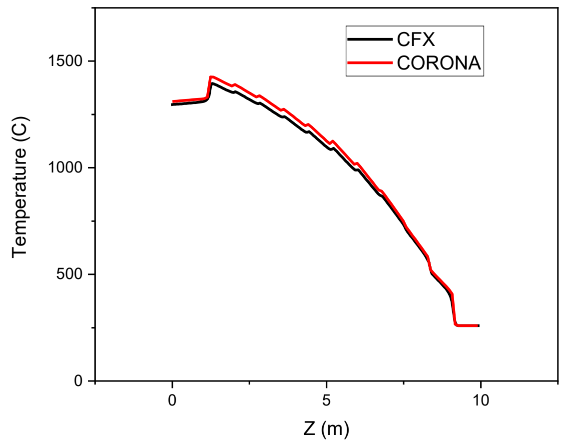


(2) Moderator average temperature comparison in Case 2

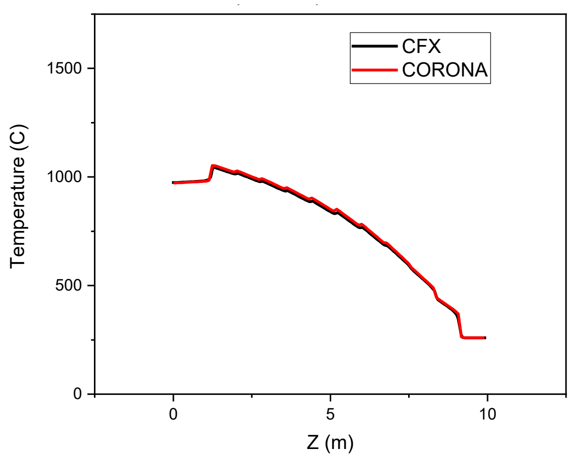


(3) Moderator average temperature comparison in Case 3
Fig. 4. Moderator average temperature comparison

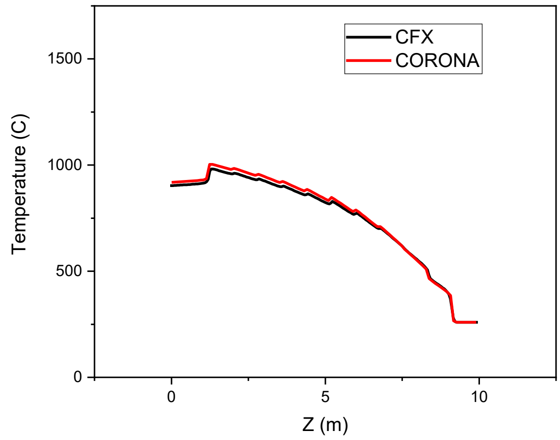
Figure 5 show the axial temperature comparison at the hot spot, where the maximum temperatures were reached. The calculated results by both the CORONA code and the CFX code matched very well.



(1) Axial temperature comparison in Case 1



(2) Axial temperature comparison in Case 2



(3) Axial temperature comparison in Case 3
Fig. 5. Axial fuel temperature variation at hot spot region

3. Conclusions

The CORONA code was verified using the ANSYS CFX results for the MHTGR-350 core. The mass flow rate and temperature distributions calculated by the CORONA code were almost identical to those calculated by ANSYS CFX. Future studies will consider the cross gap effect to investigate flow distributions and temperature profiles.

Acknowledgements

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[1] N. I. Tak, S. N. Lee, M. H. Kim, H. S. Lim, J. M. Noh, Development of a Core Thermo-Fluid Analysis Code for Prismatic Gas Cooled Reactors, Nucl. Eng. Technol., Vol. 46 (5), p. 641, 2014.

[2] https://www.anflux.com

[3] S. N. Lee, N. Tak, H. Lim, and C. K. Jo, Benchmark Calculations for Verification of Thermo-Fluid Analysis Codes Using Simplified Model of the OECD/NEA MHTGR-350 Core Design, Annals of Nuclear Energy, Vol. 139 107249, 2020.