# Gamma Heating Consideration in Thermal Analysis with the CORONA Code

Nam-il Tak,* Jeong-Hun Lee, Sung Nam Lee, Chang Keun Jo
*Korea Atomic Energy Research Institute, 111, Daedeok-daero 989 Beon-gil, Yuseong-gu, Daejeon 34057, Korea*
**Corresponding author: takni@kaeri.re.kr*

## 1. Introduction

Korea Atomic Energy Research Institute (KAERI) has been developing a computer code named CORONA [1] for thermo-fluid analysis of a prismatic gas-cooled reactor core. In the past, gamma heating was neglected in CORONA calculations in order to conservatively estimate the fuel temperature. All kinds of power generation in the non-fuel zone is called "gamma heating" in this work since the gamma heating mostly contributes to power generation in the non-fuel zone. In this work, the capability to consider the gamma heating in CORONA calculations was implemented and verified using two numerical benchmarks. The results of a commercial computational fluid dynamics code, ANSYS CFX [2], were used for a comparison.

## 2. Conceptual Problem

Fig. 1 shows a conceptual drawing of the conceptual problem developed in this work. A reflector column with six coolant channels was considered as a conceptual problem. Uniform volumetric heat source exists in the graphite column due to the gamma heating. The heat was cooled by helium coolant flowing through the six coolant channels. Table I provides the design conditions for the conceptual problem. The amount of the heat applied is much larger than that of typical gamma heating condition in order to amplify the phenomena. Constant graphite conductivity was used to simplify the problem. The flow in the coolant channels are turbulent (i.e., Re=20000~35000).

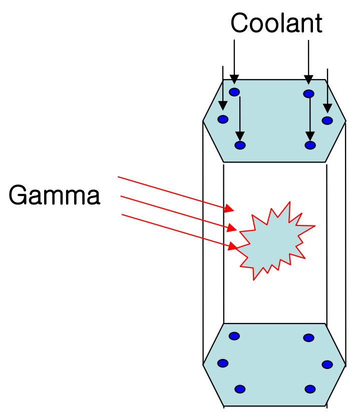



Fig. 1. Reflector column with six coolant channels developed for conceptual problem.

Fig. 2 compares the temperature contours obtained by the CORONA and CFX codes for the conceptual problem. It shows that the temperature contour obtained by CORONA is qualitatively reasonable and well agrees with that by CFX. The difference in the maximum temperature of the plane is 7 $^{o}$C.

Table I: Design conditions for the conceptual problem

| Conditions | Value |
|---|---|
| Column height (cm) | 640 |
| Hexagonal column flat-to-flat distance (cm) | 36 |
| Number of coolant channels | 6 |
| Diameter of coolant channel (cm) | 1.5875 |
| Total gamma heat (MW) | 0.3 |
| Power density of gamma heating (MW/m$^3$) | 0.422 |
| Helium inlet temperature ($^{o}$C) | 259 |
| Helium pressure (MPa) | 6.4 |
| Helium flow rate (kg/s) | 0.08 |
| Conductivity of graphite block (W/mK) | 30 |

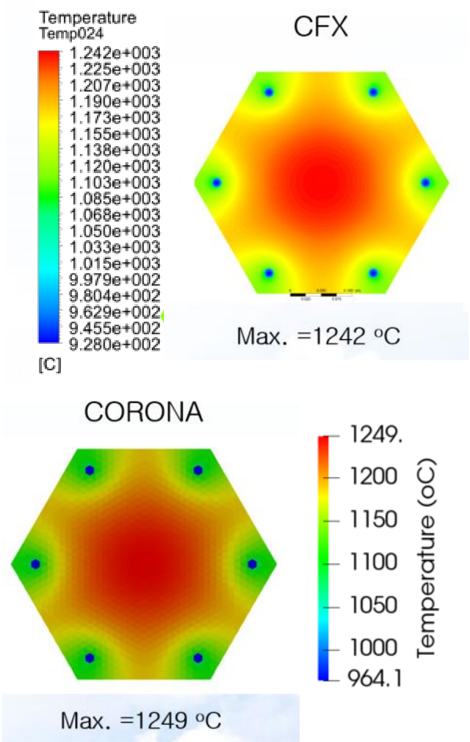



Fig. 2. Temperature contours obtained by CFX and CORONA for the conceptual problem (plotted at 24cm from the bottom).

For a quantitative comparison, radially averaged axial temperature profiles were compared in Fig. 3. The figure shows a good accuracy of the CORONA calculation. It seems that a slight temperature difference shown in the top region of the column is mainly due to the difference in the convective heat transfer coefficient as shown in Fig. 4. CORONA uses the empirical correlation of McEligot et al. [3] for the heat transfer coefficient whereas the heat transfer coefficient is not used in the CFX calculation but it is extracted using the numerical solutions.

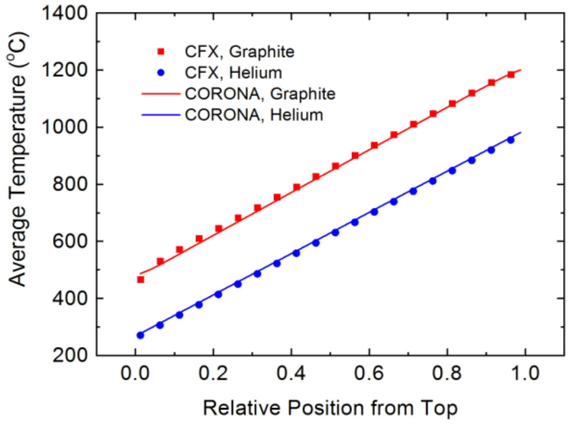



Fig. 3. Comparison of radially averaged axial temperature profiles for the conceptual problem.

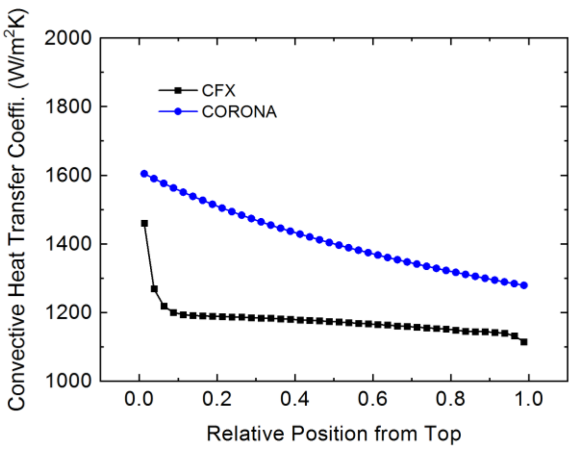



Fig. 4. Comparison of convective heat transfer coefficients in the conceptual problem.

### 3. Control Fuel Column

As a practical test example, a control fuel column problem was developed in this work. Fig. 5 shows a control fuel column which contains a large hole in the center for the control rod insertion. Six fuel blocks are stacked to form an active core.

The control rod is inserted until the bottom of the second fuel block from the top reflector. The geometry and dimensions of the control rod are provided in Fig. 6. The main design parameters for the control fuel column are shown in Table II and the boundary conditions for the test calculation are summarized in Table III. The gamma heating fraction of 10% was adopted in this work. This value is slightly larger than typical one (6~8%). Therefore, the calculated impact of the gamma heating would be close to a limiting case.

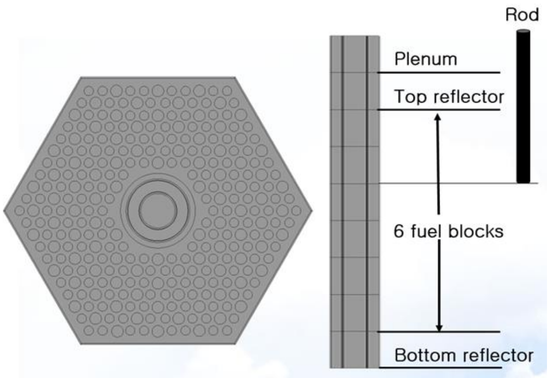
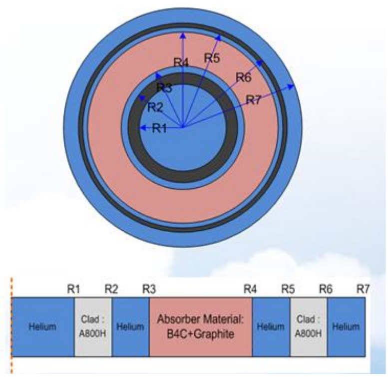



Fig. 5. Control fuel column considered in this work.




(R1=2.33, R2=2.53, R3=2.58, R4=4.08, R5=4.13, R6=4.33, R7=5.08 cm)
Fig. 6. Geometry and dimensions of control rod.

Table II: Main design parameter for the control fuel column

| Parameters | Value |
|---|---|
| Column height (cm) | 640 |
| Active core height (cm) | 480 |
| Hexagonal column flat-to-flat distance (cm) | 36 |
| Diameter of fuel hole (cm) | 1.27 |
| Number of fuel holes | 192 |
| Diameter of coolant channel (cm) | 1.5875 |
| Number of coolant channels | 96 |
| Diameter of control rod channel (cm) | 10.16 |
| Outer diameter of control rod cladding (cm) | 8.66 |
| Position of control rod tip from bottom (cm) | 400 |
| Bypass gap size (mm) | 2 |
| Crossflow gap size (mm) | 0 |

Table III: Boundary conditions for the control fuel column problem

| Conditions | Value |
|---|---|
| Column power (MW) | 3.1818 |
| Gamma heating fraction (%) | 10 |
| Power density in fuel compact (MW/m$^3$) | 25 (uniform) |
| Gamma power density in non-fuel zone (MW/m$^3$) | 0.56973 (uniform) |
| Helium inlet temperature (°C) | 259 |
| Helium pressure (MPa) | 6.39 |
| Helium flowrate (kg/s) | 1.43 |

Fig. 7 compares the temperature contours obtained by CORONA and CFX at the control rod tip position. The figure shows a good agreement. The difference in the maximum fuel temperature is 9 ºC. Table IV summarizes the main results obtained by CORONA and CFX. All the global parameters shown in Table IV agree each other.

Fig. 8 compares the radially averaged axial temperature profiles obtained by CORONA and CFX. It also shows a good agreement.

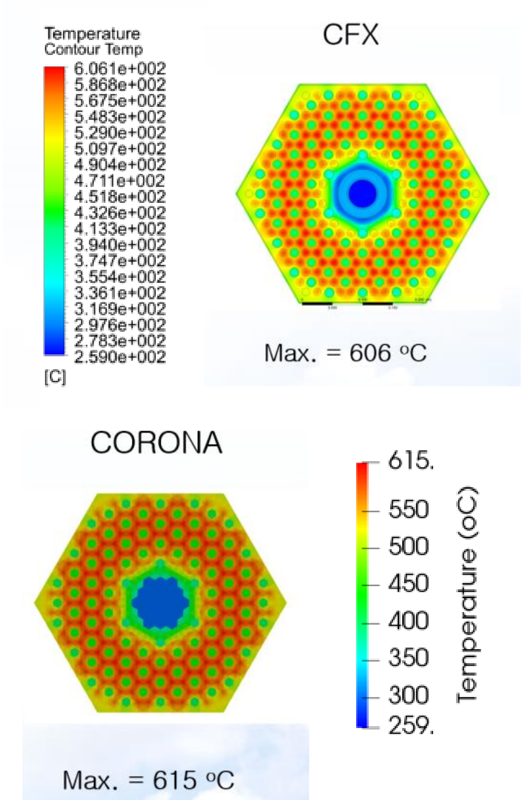



Fig. 7. Temperature contours obtained by CFX and CORONA for the control fuel column problem (plotted at control rod tip position).

Table IV: Comparison of main results for the control fuel column problem

| Conditions | CORONA | CFX |
|---|---|---|
| Bypass flow fraction (%) | 4.1 | 4.4 |
| Control channel flow fraction (%) | 17.3 | 16.6 |
| Max. fuel temperature (ºC) | 920 | 915 |
| Max. temperature of control rod cladding (ºC) | 311 | 314 |

In order to investigate the effect of the gamma heating, additional calculation was performed without the gamma heating. Fig. 9 and Table V summarize the result. As shown in Fig. 9, the effects of the gamma heating on the fuel and control rod channel temperatures are not significant. With the gamma heating, as expected, the maximum fuel temperature is reduced whereas the maximum cladding temperature of the control rod is increased. However, the amount of the impact is small.

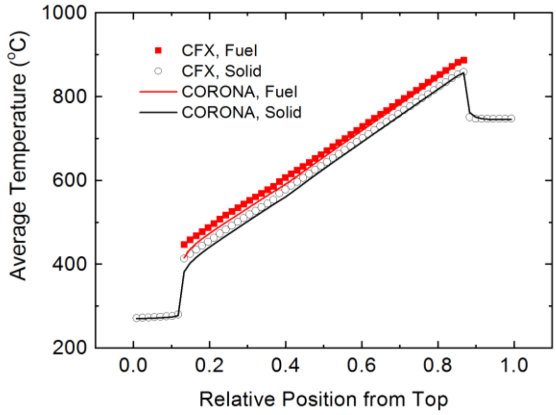



Fig. 8. Comparison of radially averaged axial temperature profiles for the control fuel column problem.

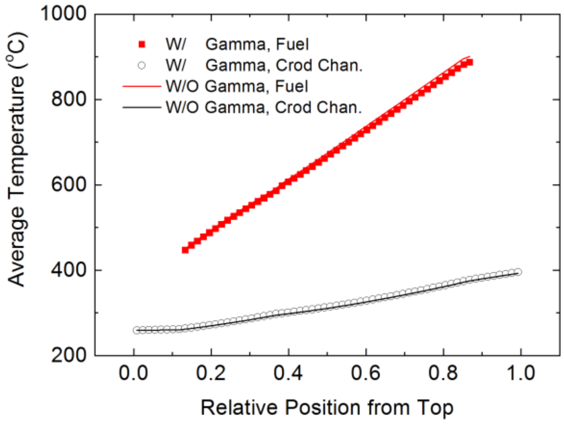



Fig. 9. Effect of gamma heating on temperatures of fuel and control rod channel.

Table V: Effect of gamma heating on maximum temperatures

| | Without Gamma Heating | With Gamma Heating |
|---|---|---|
| Maximum fuel temperature (ºC) | 938 | 920 |
| Max. temperature of control rod cladding (ºC) | 308 | 311 |

## 4. Conclusions

In this paper, an improvement was made for the CORONA code to consider the gamma heating in the thermal analysis of prismatic blocks. The capability of the CORONA code with this new feature was verified using the two benchmark examples. The results of the verification study show that the CORONA calculations are reliable and accurate. It was also found that the effect of the gamma heating would not be significant in the practical calculations. Nevertheless, it can be concluded that the accuracy for the thermal margin evaluation is improved with the new capability of the CORONA code. Further study will be performed for a full core model with the gamma heating to estimate the thermal margin more accurately.

**Acknowledgements**

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**REFERENCES**

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