한국원자력학회
Korean Nuclear Society

Verification of GAMMA+ and CORONA with Two-Column Problem

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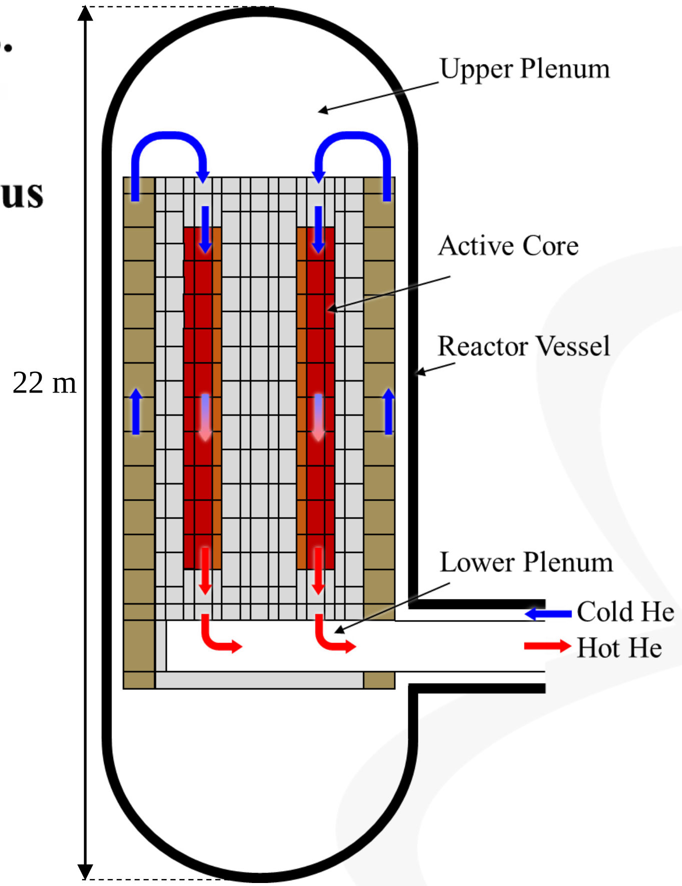
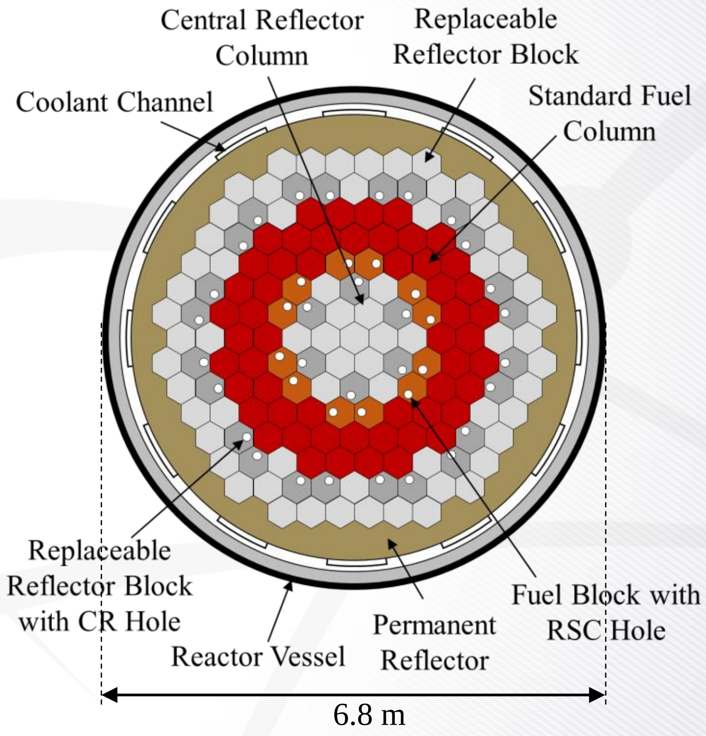
PRESENTATION TITLE

CONTENTS

» MHTGR-350 Benchmark

- ❑ To compare the various solution methods available in the High Temperature Reactors.
- ❑ For code-to-code comparisons to justify agreements or disagreements between various methods.
- ❑ Thermal capacity: 350 MWth
- ❑ Primary coolant: He @ 6.39 MPa
- ❑ Moderator: Graphite
- ❑ Inlet / outlet temp: 259°C / 687°C
- ❑ Mass flow rate: 157.1 kg/s
- ❑ Reactor vessel height: 22 m
- ❑ Reactor vessel outside diameter: 6.8 m

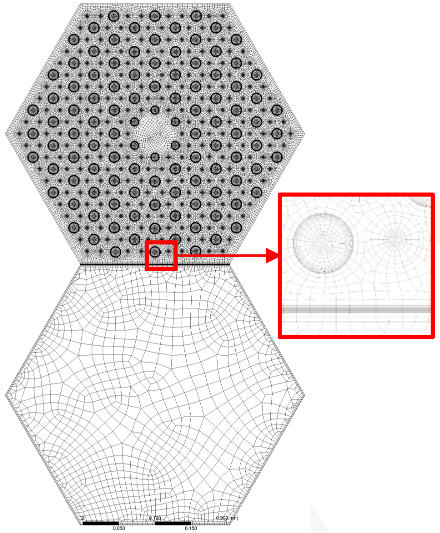




J. Ortensi, V. Seker, C. Ellis, et al., OECD/NEA coupled neutronics/thermal-fluids benchmark of the MHTGR-350MW core design. Volume I: reference design definition and Volume II: definition of the steady-state exercise. Nuclear Energy Agency, 2015.

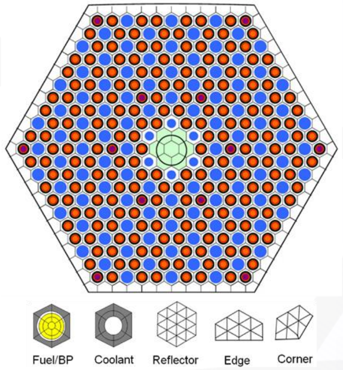
CFD, GAMMA+, and CORONA

- **CFD (Computational Fluid Dynamics) codes**
  - 3-D solid conduction and fluid analysis
  - High resolution
  - Local information (local flow field, flow separation)
  - High computational cost and time
- **GAMMA+ (H.S. Lim, 2006)**
  - 1-D solid conduction and 1-D fluid analysis
  - Transient analysis
  - Low computational cost
  - Low resolution
- **CORONA (N.I. Tak, 2011)**
  - 3-D solid conduction and 1-D fluid analysis
  - Low computational cost
  - High resolution of solid temperature distribution



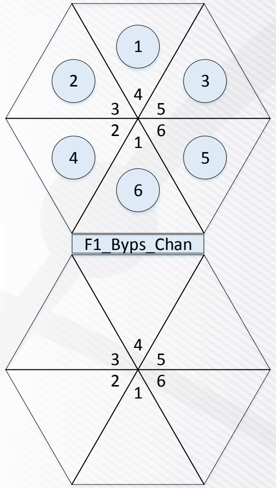
CFD

Local Detailed Analysis



CORONA

Core T-F Design & Analysis



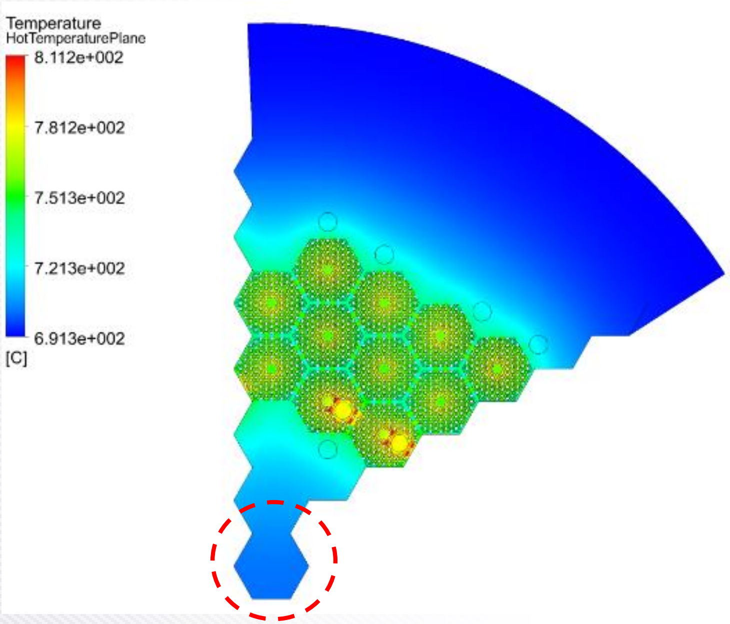
GAMMA+

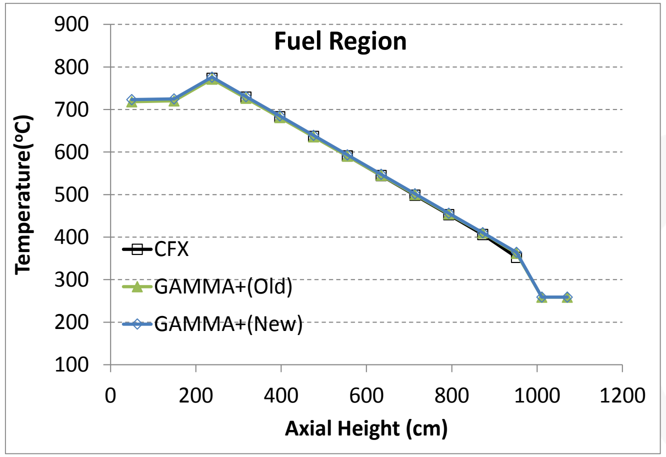
System T-F Transient Analysis

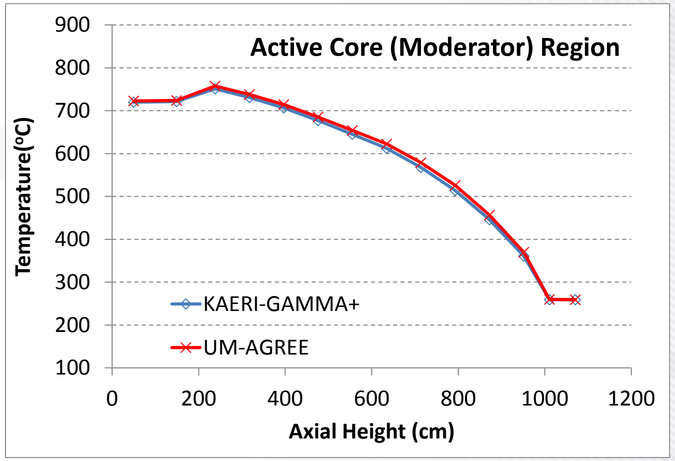
01 Introduction

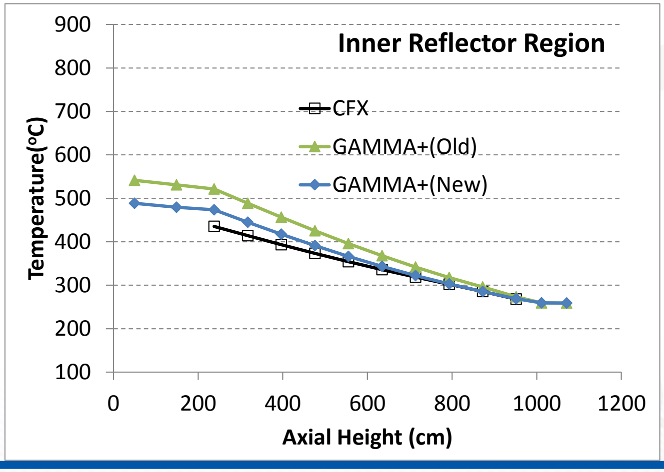
» MHTGR-350 Benchmark

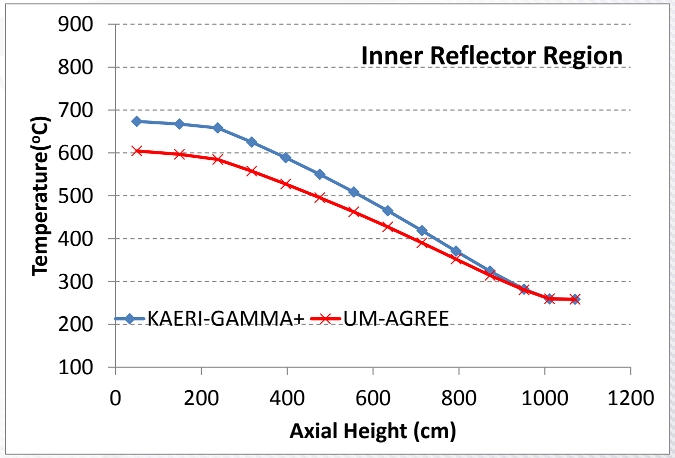
- ❑ **The overall test results were in good agreement between GAMMA+, CFX, and AGREE.**
- ❑ **Slight temperature difference were observed in inner reflector block region.**







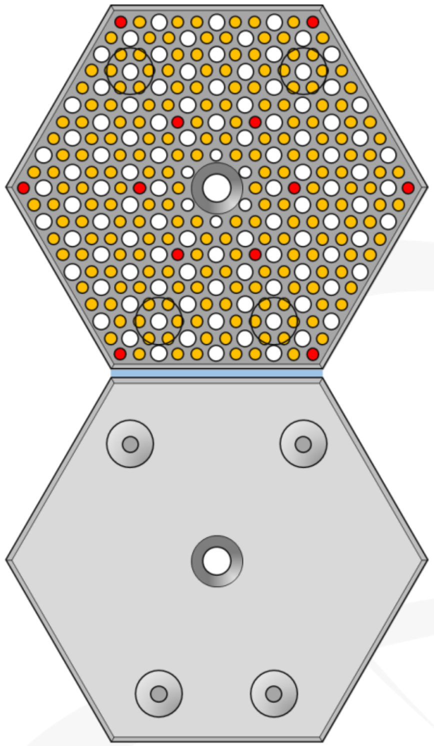


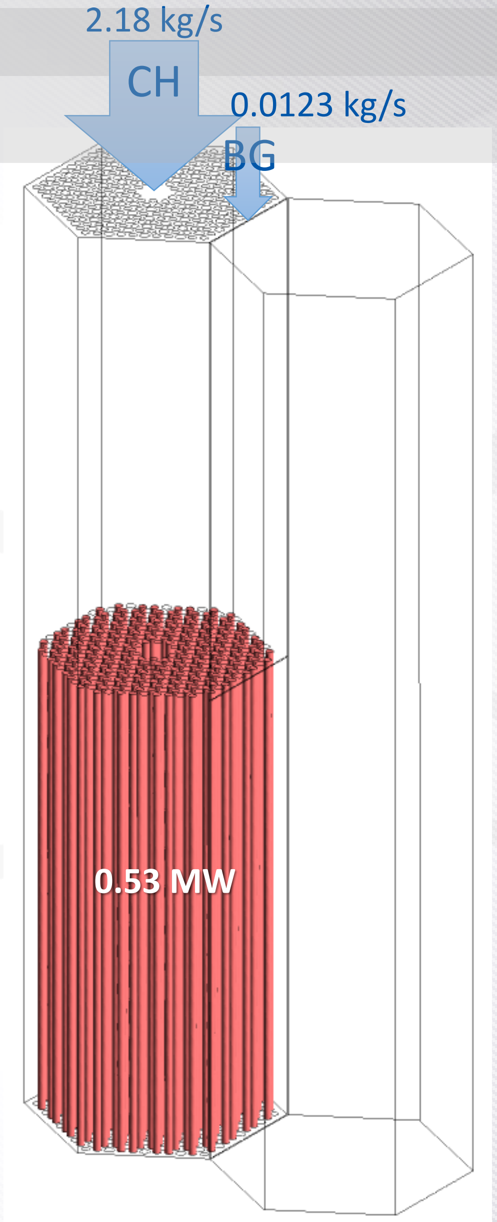


02 Two-Column Problem

» Conditions

- ❑ 1 reflector column, 1 fuel column (1 bypass gap)
- ❑ 2 layers (1 fuel layer)
- ❑ Power: 0.53 MW (2.512×10^7 W/m^3 for fuel compact)
- ❑ Total flow rate: 2.19 kg/s
  - CH: 2.18 kg/s, BG: 0.0123 kg/s (0.56%)
- ❑ Pressure: 6.39 MPa
- ❑ Inlet Temperature: 259°C
- ❑ There exists 1 bypass gap between two columns, heat transfer between columns occurs through only the bypass gap.





GAMMA+ and CORONA

❑ The convective heat transfer coefficient model

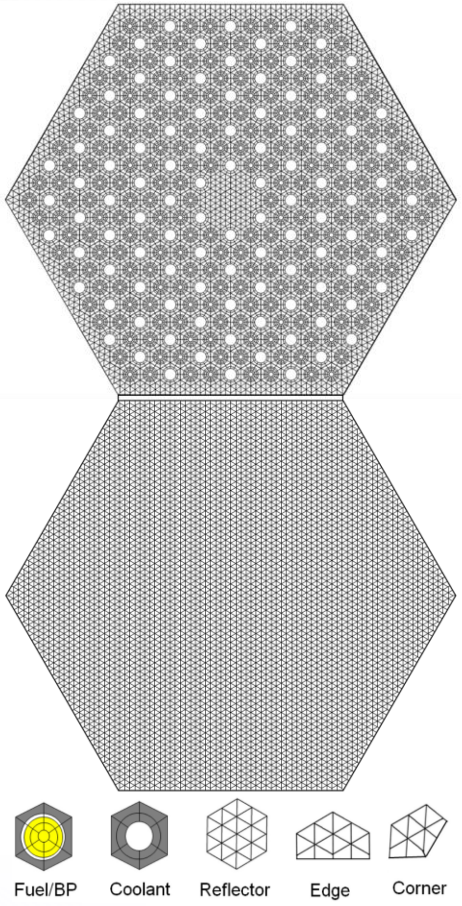
$$Nu = \frac{hD}{k}$$

For turbulent flow

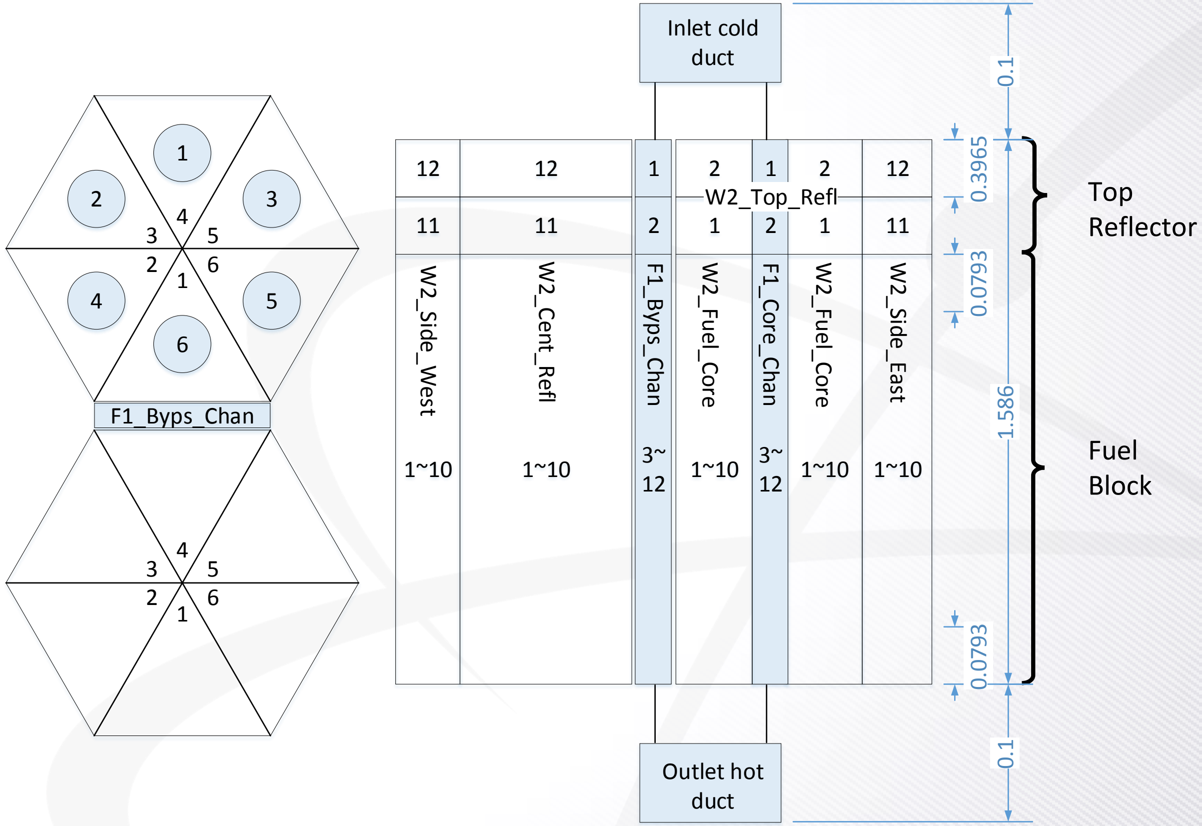
$$Nu = 0.021\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4}\left(\frac{T_s}{T_d}\right)^{-0.5}$$

For laminar flow

$$Nu = 4.36$$



CORONA mesh



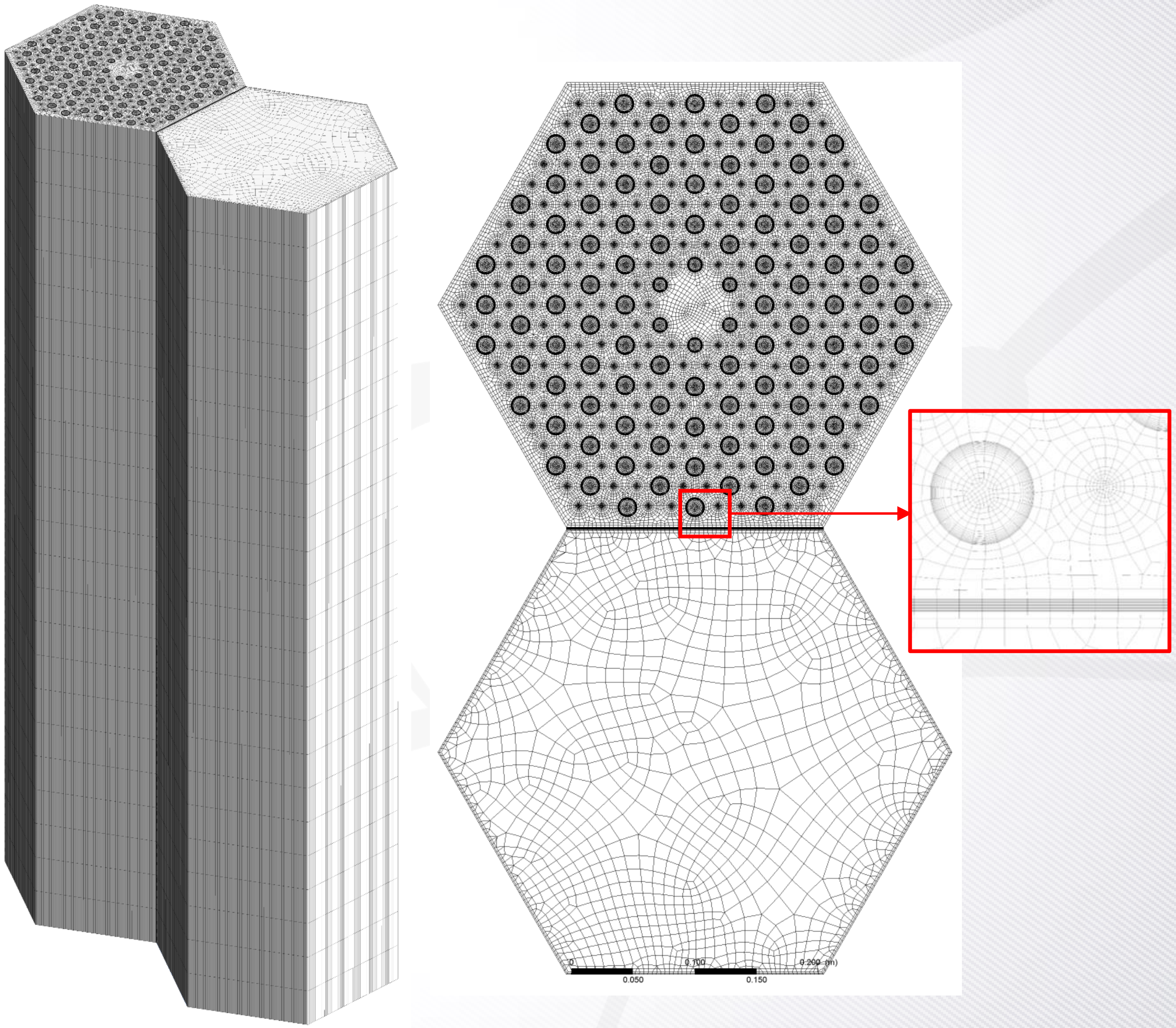
GAMMA+ nodalization

» CFD Simulation

- CFX 19
- Number of Nodes: 2.48 million
- Number of Elements: 2.13 million
- Wall y^+: 2.2

Fluid model for Turbulent Model Sensitivity Test

Case Index	Coolant Channel	Bypass gap
CFX RNG k-ε	RNG k-ε	RNG k-ε
CFX laminar BG	RNG k-ε	Laminar
CFX SST BG	RNG k-ε	SST / intermittency transition
CFX SST CH BG	SST / intermittency transition	SST / intermittency transition



Computational Domain

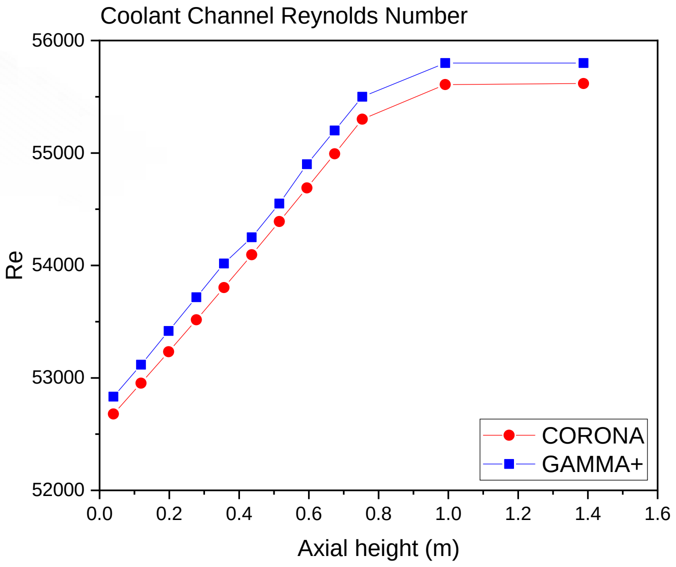
Reynolds Number and Temperature Distribution

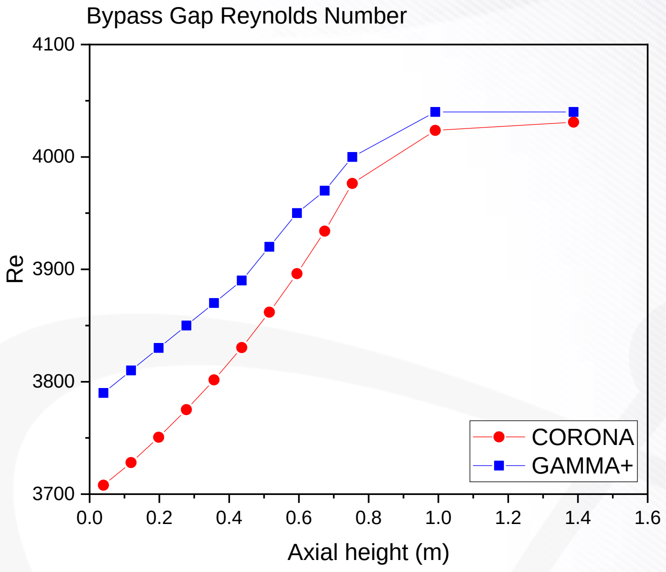
- Same mass flow rate condition

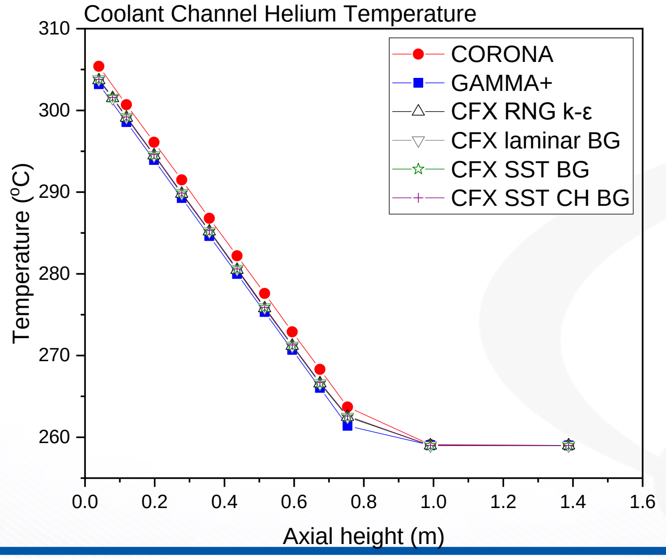
different fluid temperature

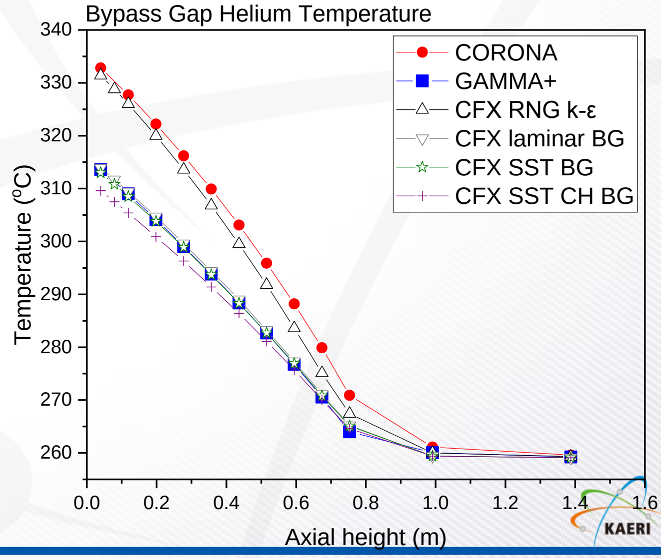
↓

different Reynolds number









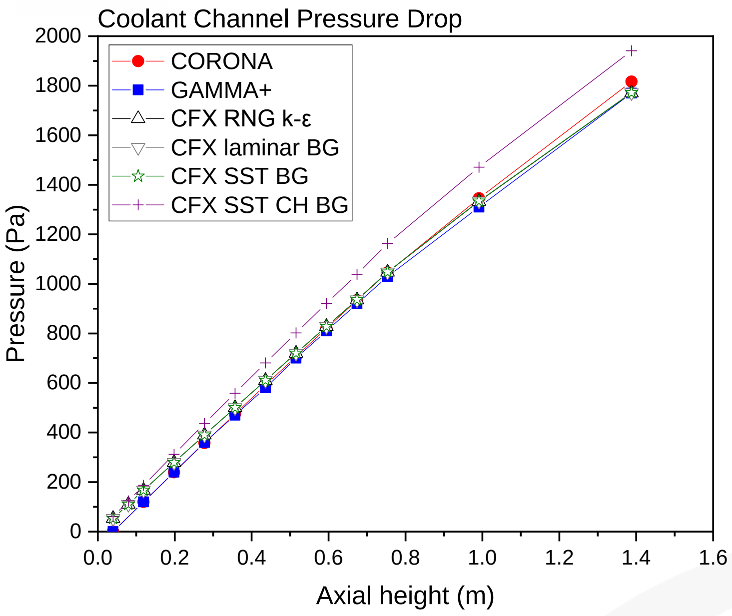
» Reynolds Number and Pressure Drop

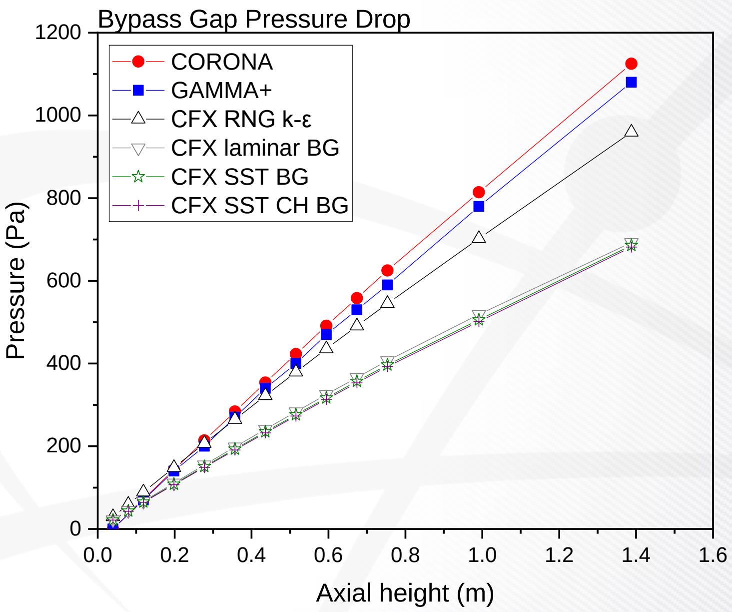
❑ Same mass flow rate condition

different fluid model

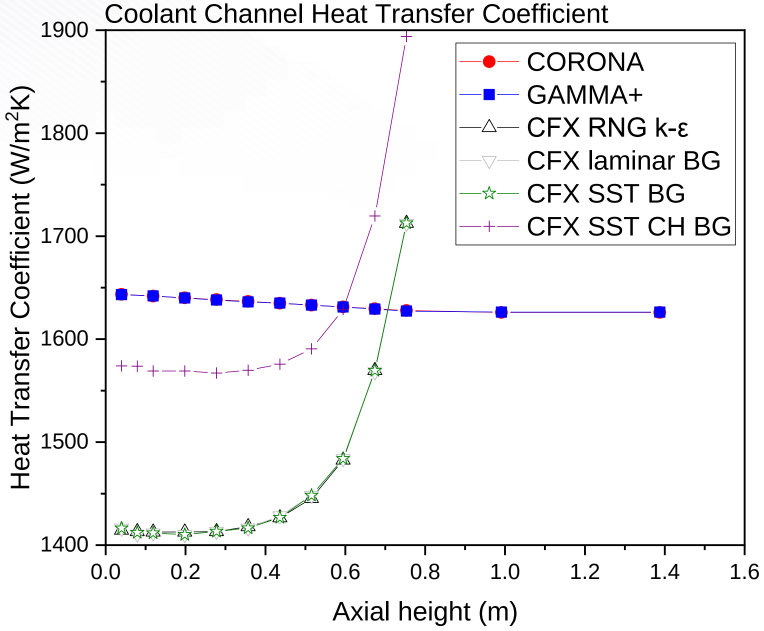
↓

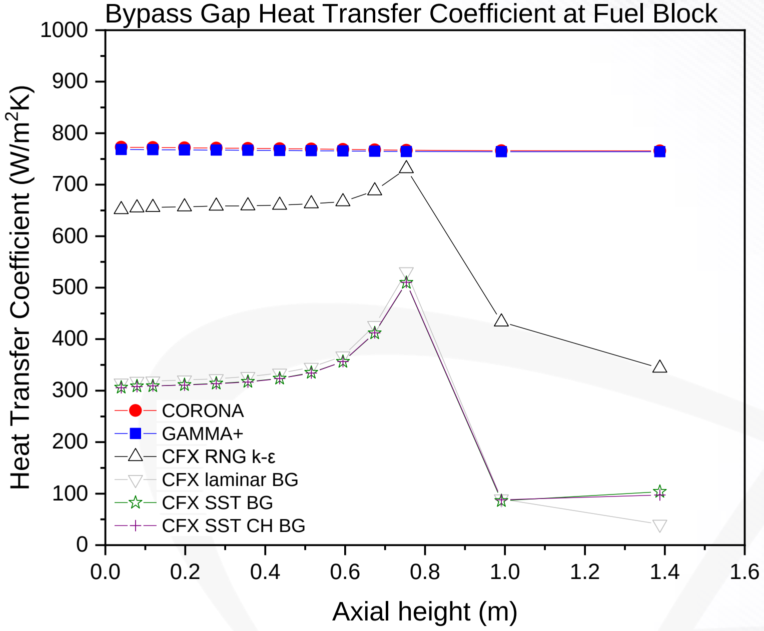
different pressure drop





» Heat Transfer Coefficient



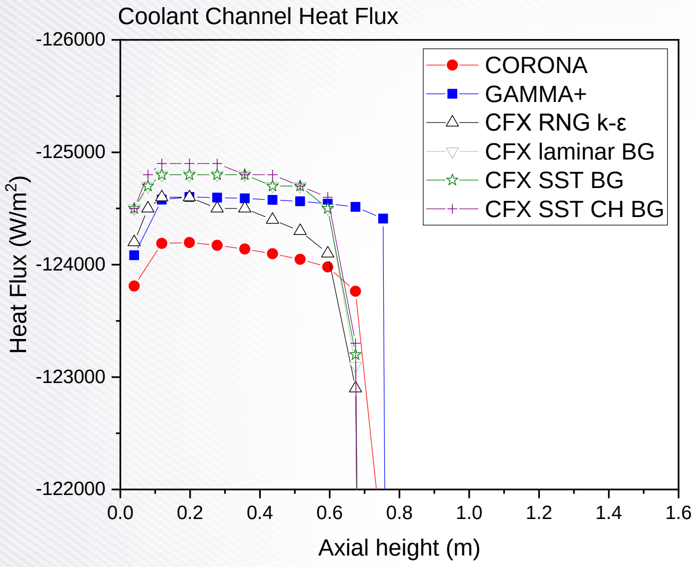


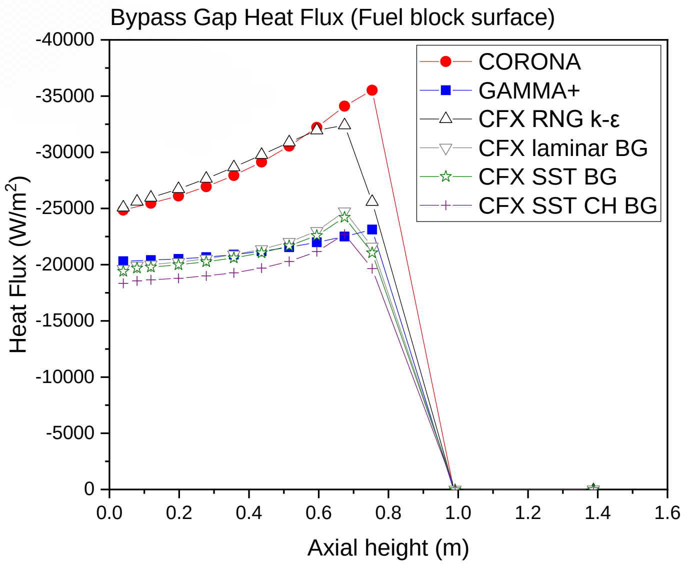
- ❑ **GAMMA+ and CORONA show good agreement in heat transfer coefficient.**
- ❑ **Value of heat transfer coefficient in CFX is obtained by arithmetic.**

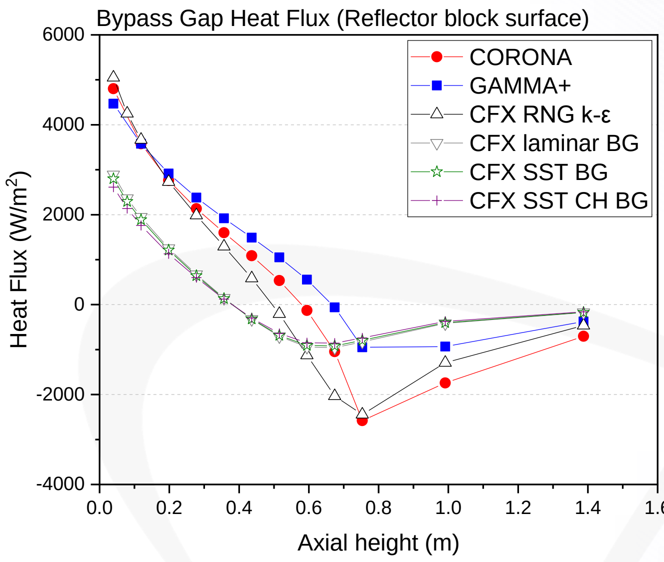
$$h = \frac{q}{T_w - T_f}$$

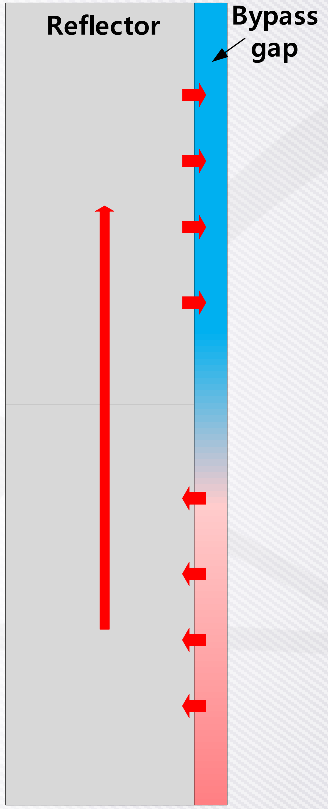
h: heat transfer coefficient [W/m^2]
q: heat flux [W/(m^2·K)]
T_w: wall temperature
T_f: fluid temperature

» Heat Flux



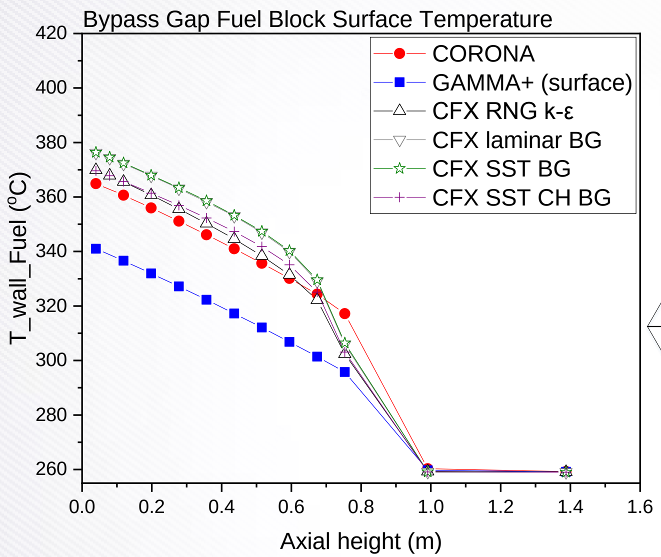


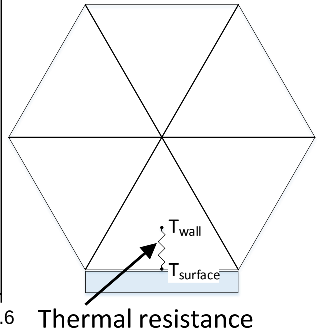


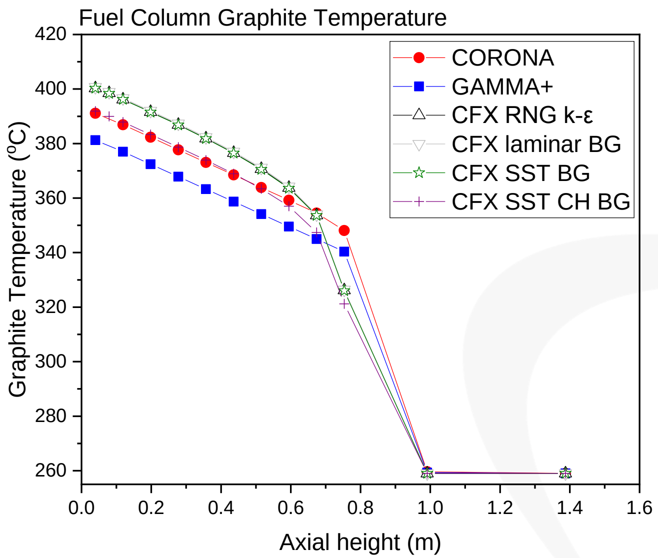


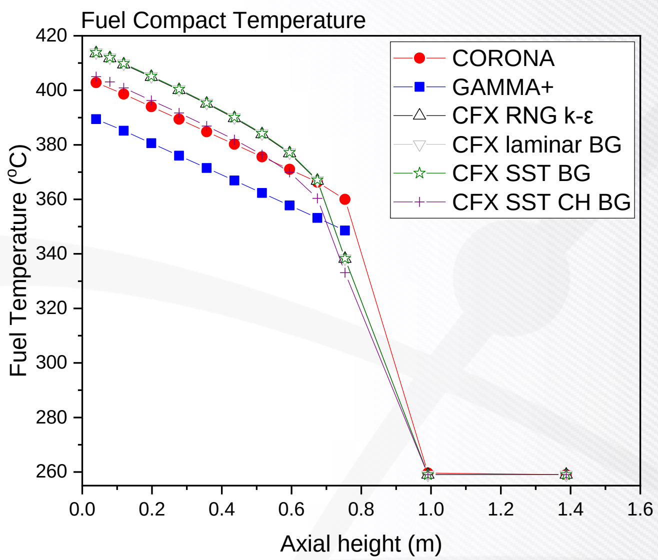
- ❑ **GAMMA+, CORONA, and CFX show good agreement in heat flux at coolant channel.**
- ❑ **Maximum difference of 35% (12400 W/m^2) were observed between CORONA and GAMMA+ at the fuel block surface in bypass gap while 1630 W/m^2 at reflector block surface.**
- ❑ **RNG k-ε model in CFX show good agreement with CORONA and laminar and SST intermittency model show good agreement with GAMMA+.**

» Fuel Block Temperature



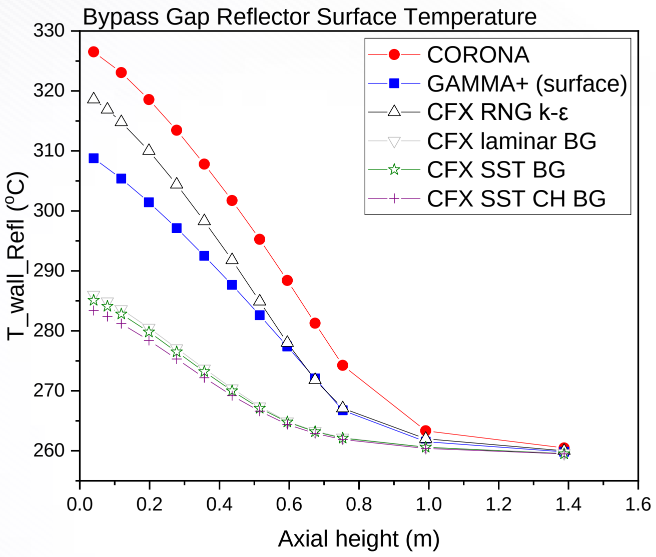


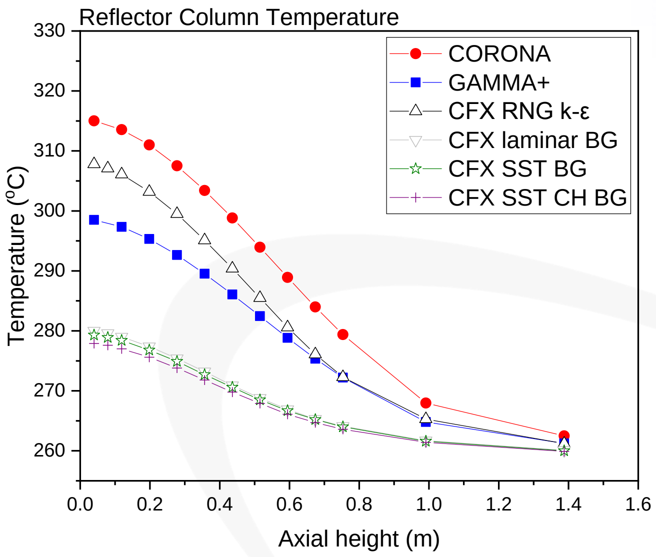




- ❑ **GAMMA+ predicts surface temperature 24°C lower than CORONA and calculation results of laminar model used in CFX is 11°C higher than that of CORONA.**
- ❑ **GAMMA+ predicts graphite temperature 10°C lower and fuel block temperature 13°C lower than CORONA.**

» Solid Temperature





- ❑ **CORONA predicts surface temperature of the reflector block 18°C higher than that of GAMMA+.**
- ❑ **CFX using RNG k-ε model is 8°C lower than that of CORONA and 10°C higher than that of GAMMA+.**

04 Conclusions

- ❑ GAMMA+ and CORONA were verified with two-column problem by comparing CFX calculation.
- ❑ The difference of the results between GAMMA+ and CORONA is in the same range of the difference of the calculation results between turbulence models in CFX.
- ❑ Considering calculation results of GAMMA+, CORONA, and CFX for the fuel block and fluid temperature at the coolant channel are in good agreement, it can be concluded that the calculation results of GAMMA+ and CORONA are both reasonable.
- ❑ In CFX calculations, large temperature difference between the turbulence models was observed in bypass gap and reflector block. Therefore, when analyzing heat transfer between fuel and reflector blocks with CFD code, turbulence model sensitivity test should be conducted and it is highly recommended that special attention is required when it comes to use of turbulence models for thermo-fluid analysis of HTGR core.

THANK YOU