Modelling Thermodynamics and Fluid Mechanics in a Nuclear Reactor Core

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Introduction

High Temperature Gas Reactors (HTGR) will be demonstrated by the UK's Advanced Modular Reactor (AMR) programme.

Steady-state and time-dependent scenarios must first be simulated to underpin the safety of these HTGR technologies.

Objectives

Simulate Japan's High Temperature Engineering Test Reactor (HTTR) using coarse-mesh Computational Fluid Dynamics (CFD).

Establish HTTR CFD and nuclear thermal hydraulics models with built-in flexibility to enable scaling from 30 MWth to 250 MWth.

CFD Methodology

- 3D Fuel block geometry is simplified from 31 fuel rods to 6, as shown in **Figure 1** below, to reduce CFD mesh complexity [1].

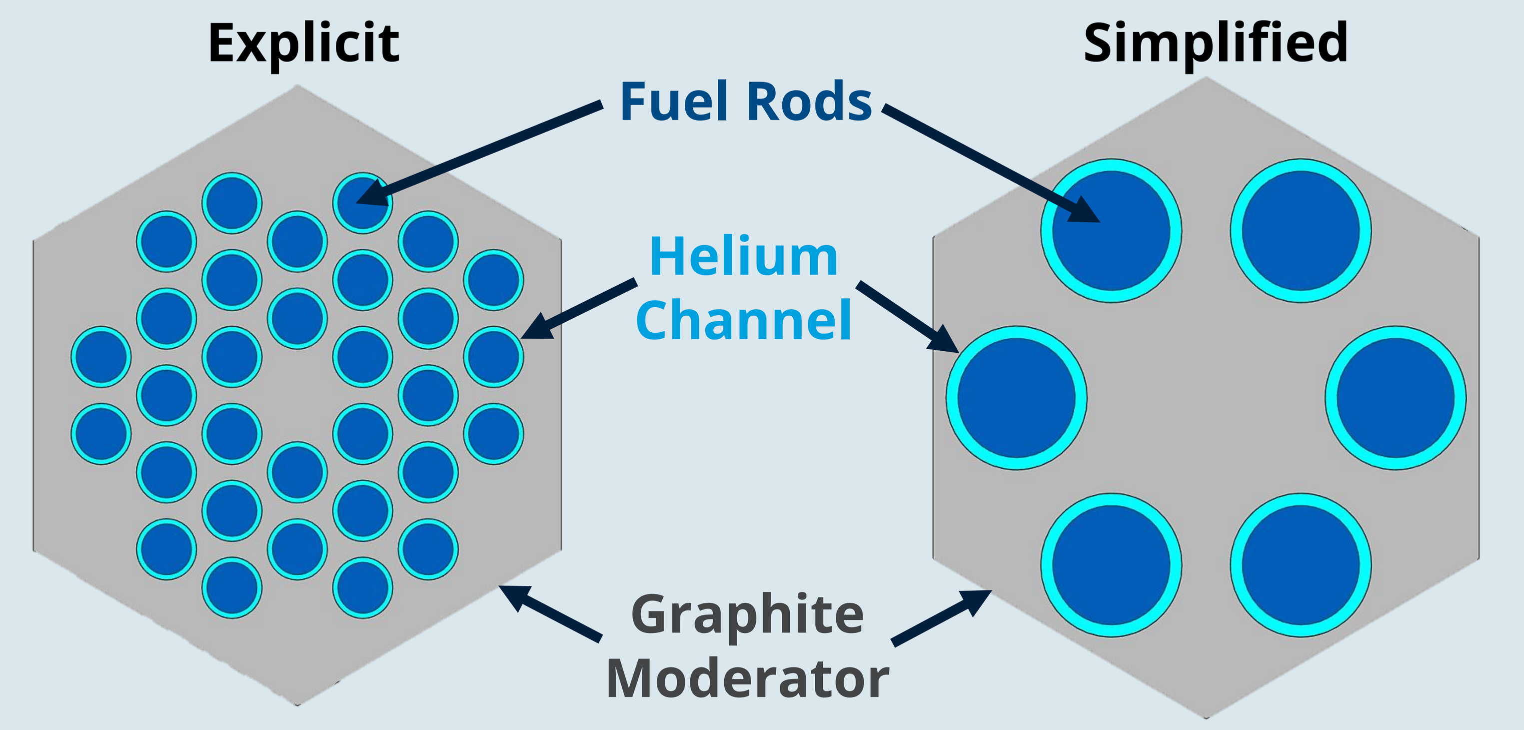

Figure 1. Comparison between explicit and simplified fuel blocks

- Augmentation factors for pressure drop and heat transfer calculations are applied in **Ansys Fluent** to account for the reduction in wetted surface area when simplifying 31 channels to 6.
- The simplified 6-channel CFD model solves significantly faster, which improves commercial viability of the verification process.

Thermal Hydraulics Methodology

- Temperatures of the fuel rods, helium coolant, and graphite moderator shown in **Figure 2** are calculated using a 2-dimensional axisymmetric **Flownex®** model shown in **Figure 3**.

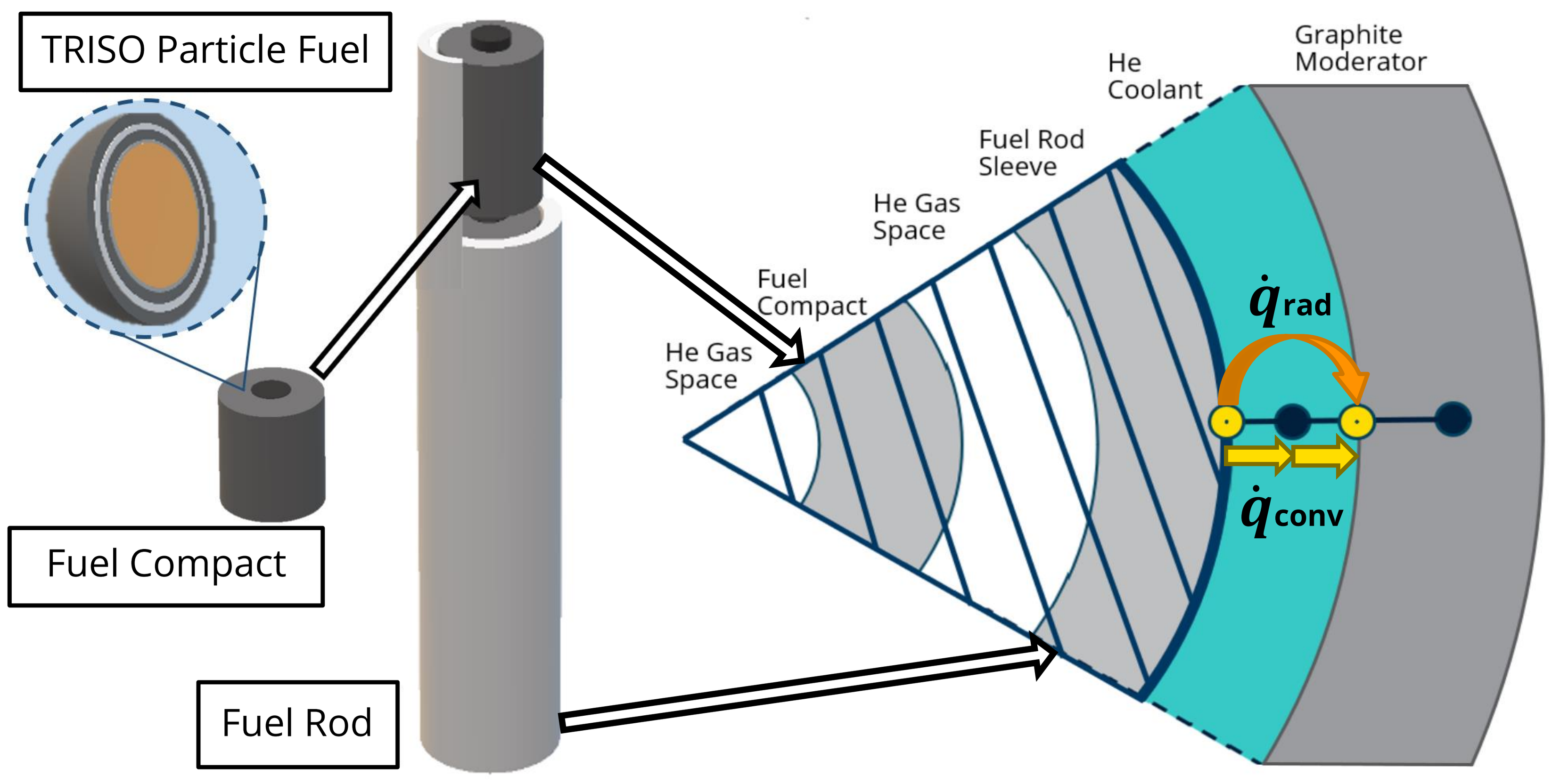

Figure 2. Heat transfer path through component-level geometry

- A Flownex® model for an individual fuel block, shown in **Figure 3**, was used to verify the thermal hydraulic behaviour of the 5-high fuel block stack. This model is then applied to the full HTTR core.

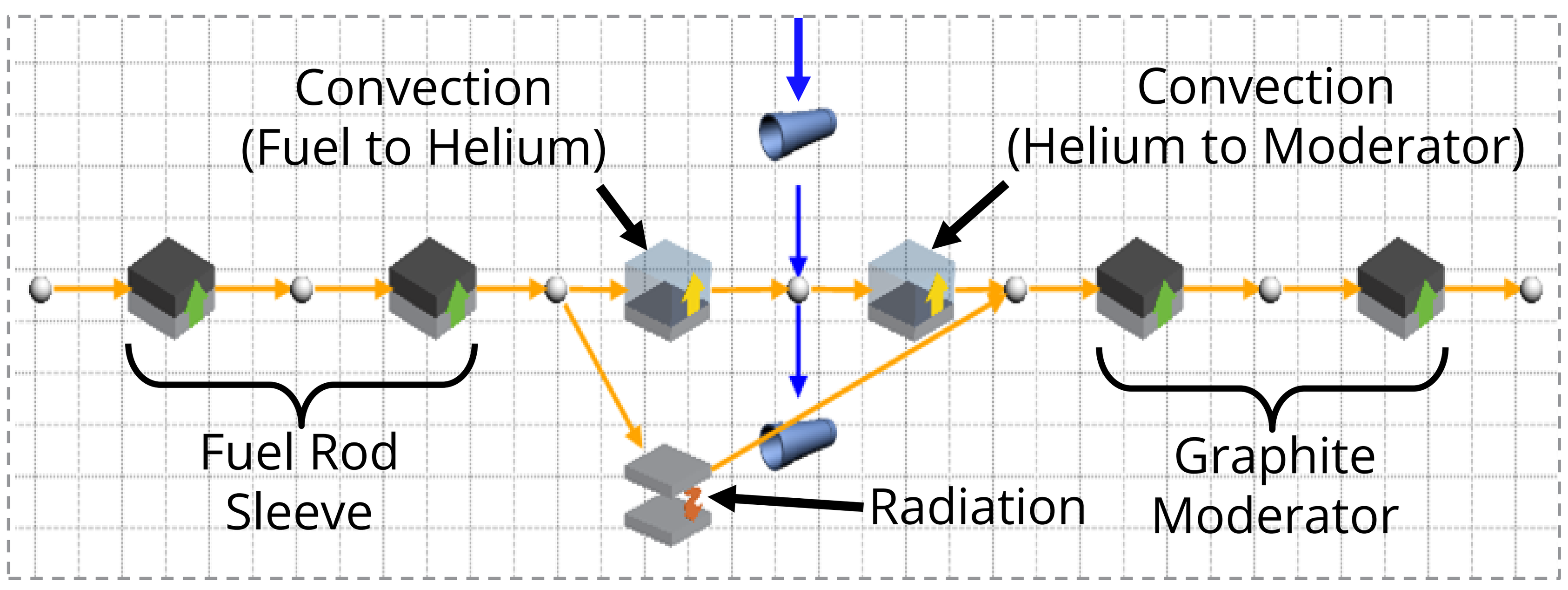

Figure 3. Flownex® model of the fifth fuel block in the fuel block stack

- The Flownex® model assumes the full HTTR core is axisymmetric, requiring the solid core geometries to be averaged into concentric rings: each with volume-averaged thermal properties [2].

Results

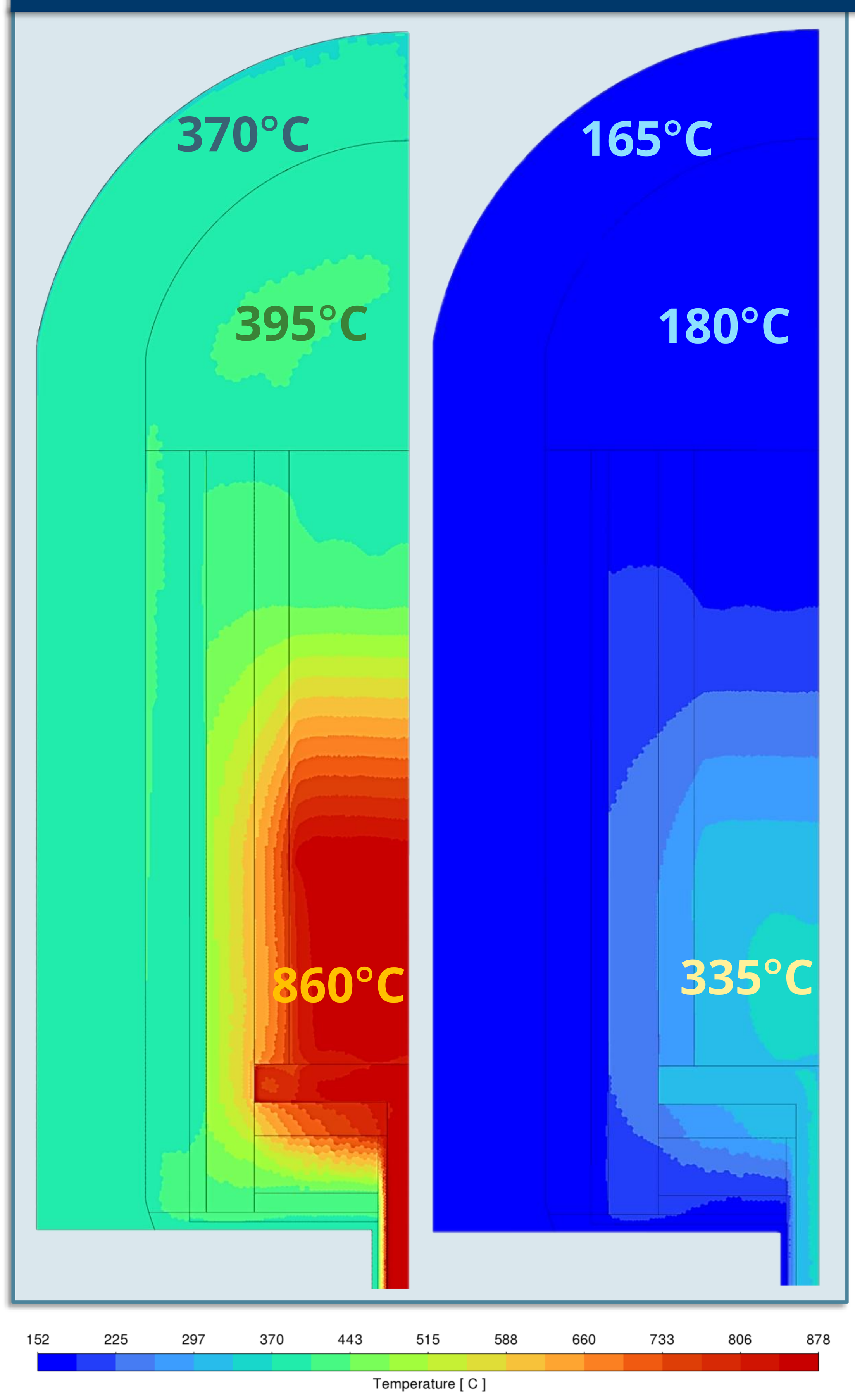

Figure 4. Temperature contours from Ansys Fluent of HTTR during full-power (left) and third-power (right) operation

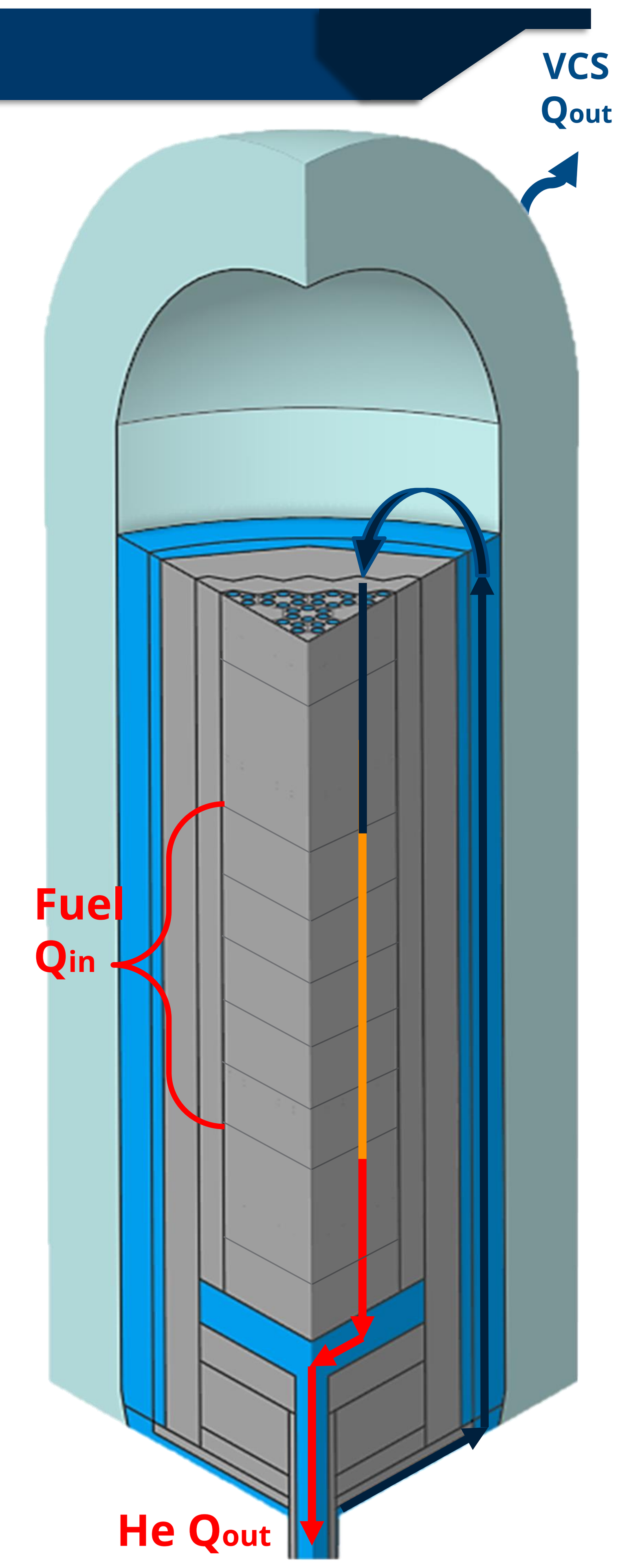

Figure 5. HTTR core CFD geometry

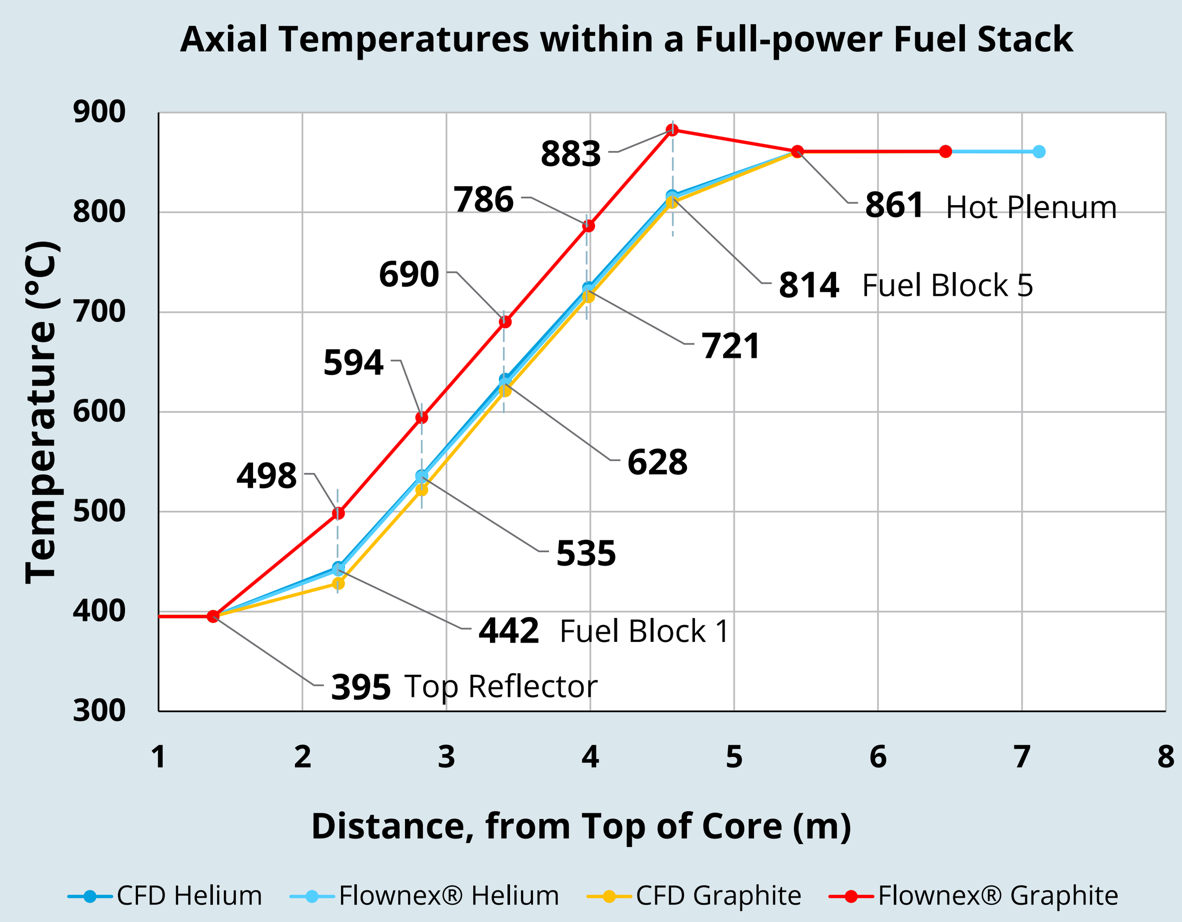

Figure 6. Graph of axial temperatures of a fuel stack

CFD Case Setup	Selection
Turbulence Model	SST k-omega
Radiation Model	Discrete Ordinates
Discretisation Method and Cell Count	Polyhedral 4,900,000

Full-power Boundary Condition	Value
Helium mass flow rate (kg/s) [3]	12.5
Helium inlet temperature (°C) [4]	395
Reactor pressure (MPa) [4]	4
Graphite grade	IG-110
Vessel Cooling System (VCS) temperature (°C)	40
VCS Convective Heat Transfer Coefficient (W/m^2K)	3

Conclusions

- A HTTR Core CFD model was made in Ansys Fluent and was compared to a HTTR thermal hydraulics model made in Flownex®, showing strong agreement between the predicted helium temperatures.
- Graphite temperatures predicted between Ansys Fluent and Flownex® vary by approximately 50°C, with work underway to investigate heat transfer coefficients.

Next Steps

Expand HTTR models to incorporate transient fault condition analysis, such as during a Loss of Forced Coolant scenario.

Investigate heat transfer correlations within Flownex® for component temperature predictions down to the graphite fuel compact.

[1] C. Wang et al. 2020. *Annals of Nuclear Energy*. A hybrid porous model for full reactor core scale CFD investigation of a prismatic HTGR.
[2] P. G. Rousseau and G. P. Greyvenstein. 2002. *Potchefstroom University for CHE*. Modelling of the HTTR in Flownet.
[3] N. Tsuji et al. 2013. *Nuclear Engineering and Design*. Study of the applicability of CFD calculation for HTTR reactor.
[4] S. Nakagawa et al. 2008. *Power and Energy Systems.* Improvement of Analysis Technology for HTGRs Using Data Obtained in HTTR.

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