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Release of a High Temperature Engineering Test Reactor (HTTR) Steady-State Multiphysics Model to the Virtual Test Bed

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Changing the World's Energy Future

Idaho National Laboratory

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Final Edge of Poster

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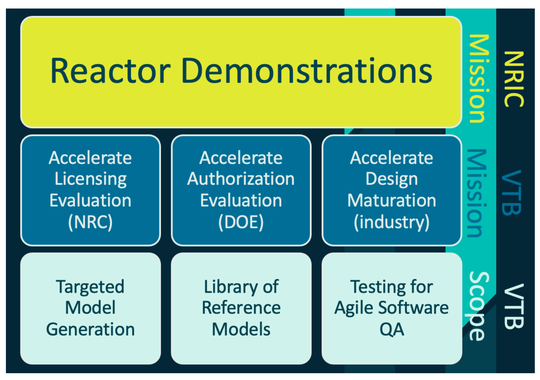
Introduction

The National Reactor Innovation Center (NRIC) accelerates the demonstration and deployment of advanced nuclear energy through inspiring stakeholders and the public, empowering innovators, and delivering successful outcomes. The Virtual Test Bed (VTB) supports this mission by providing an open-source repository of advanced test reactor models for industry, academia, and the public to utilize.

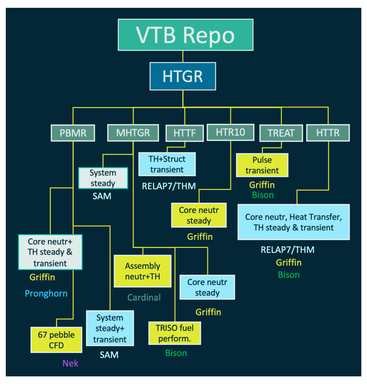
During my time at Idaho National Laboratory (INL), I:

- Verified the input files of the High Temperature Engineering Test Reactor
- Generated computational results
- Created user documentation for the HTTR
- Uploaded a steady-state HTTR model to the Virtual Test Bed
- Authored a conference publication on the model



Left: NRIC mission, VTB missions, and VTB scopes.

Right: The tree of HTGR models in the VTB repository, including the new HTTR model.



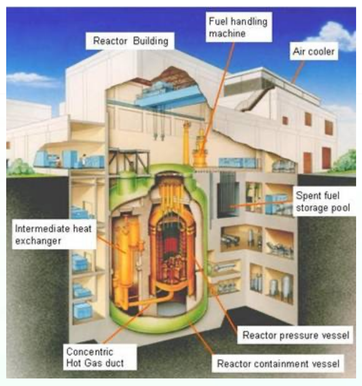
Virtual Test Bed

The VTB is a NRIC initiative aiming to:

- facilitate the use of advanced modeling & simulation (M&S) tools developed by NEAMS
- host a wide variety of example challenge problems based on advanced reactor designs
- provide an open-source virtual space for building and testing various components, systems, and complete pilot plants
- accelerate safety evaluations and continuous software development to avoid legacy software issues while enabling rapid code development

High Temperature Test Reactor (HTTR)

- The High Temperature Engineering Test Reactor (HTTR) is a graphite moderated and helium cooled prismatic reactor by the Japan Atomic Energy Agency (JAEA).
- It was designed to test the safety of high temperature gas cooled reactors (HTGRs), but was shut down following the Fukushima accident and restarted in 2021 following a safety review.

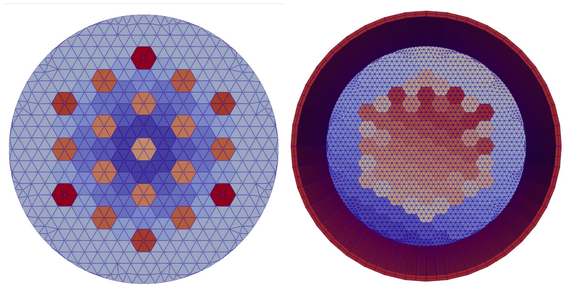


Right: Drawing of the HTTR, the first and only HTGR in Japan [1].

Model

The INL developed, graphite-moderated, helium-cooled steady-state HTTR model includes several applications:

- Neutronics – solves neutron transport equation and computes the power distribution for entire core
- Heat conduction – multi-scale split to capture global trends (axial heat flux in vertical ducts) and individual fuel assembly behavior; two solves to capture convection with thermal fluid and conductance between graphite sleeves
- Thermal-hydraulics – distributed individual channel calculations, low computational cost & compact syntax

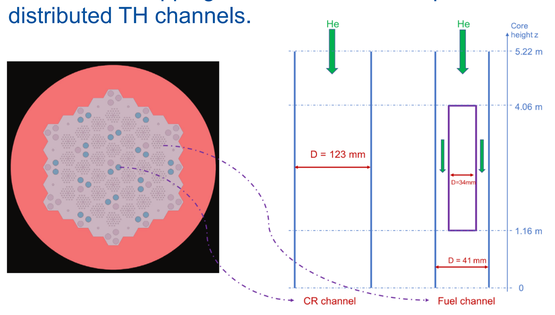


Left: The 3D homogenized mesh loaded by the neutronics application.

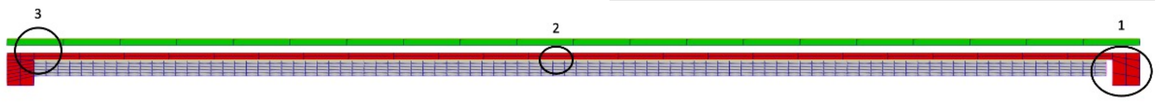
Right: The 3D full core homogenized mesh loaded by the heat transfer application.

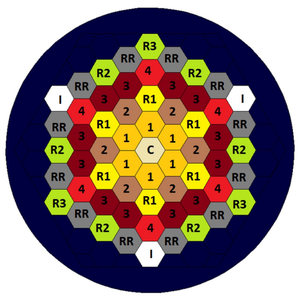
Bottom right: One-dimensional channels for thermal hydraulics.

Bottom left: Mapping between the core map and the distributed TH channels.



Below: The 2D mesh of one fuel pin (the fuel block is in grey, the graphite sleeve is in red, & the moderator block is in green; areas 1, 2, & 3 denote different thermal contact boundaries).





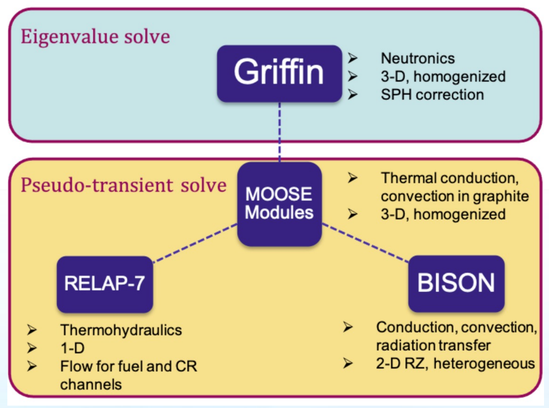
Left: The steady state model follows a radial core layout with a hexagonal lattice containing 30 fuel columns, 16 control rods, 12 replaceable reflectors, and 3 instrumentation columns surrounded by a permanent reflector.

Right: Each fuel column is composed of 9 blocks: 5 fuel pins fitted between 2 top and 2 bottom axial reflectors.

Stack 1	Stack 2	Stack 3	Stack 4
RR	RR	RR	RR
RR	RR	RR	RR
6.7/2.0	7.9/2.0	9.4/2.0	9.9/2.0
5.2/2.5	6.3/2.5	7.2/2.5	7.9/2.5
4.3/2.5	5.2/2.5	5.9/2.5	6.3/2.5
3.4/2.0	3.9/2.0	4.3/2.0	4.8/2.0
3.4/2.0	3.9/2.0	4.3/2.0	4.8/2.0
RR	RR	RR	RR
RR	RR	RR	RR

The model uses the Multiphysics Object Oriented Simulation Environment (MOOSE) framework's MultiApp and Transfer systems for coupling, which enables us to capture:

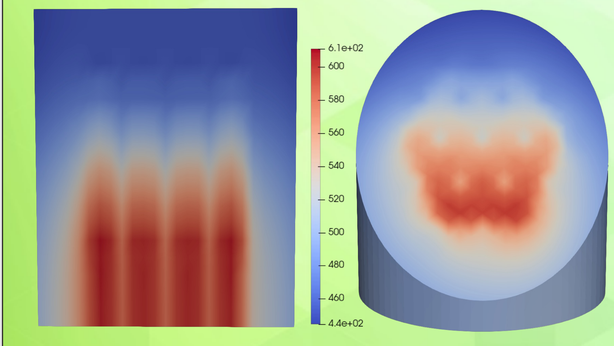
- Thermal feedback in neutronics (doppler, density feedback)
- Heat extraction (convection, conduction) in the solid calculation, axial power profile in fluid calculation
- Spatial heat source from neutronics to heat conduction



Above: The coupling schematics for how the different applications transfer data to each other.

Steady-State Results

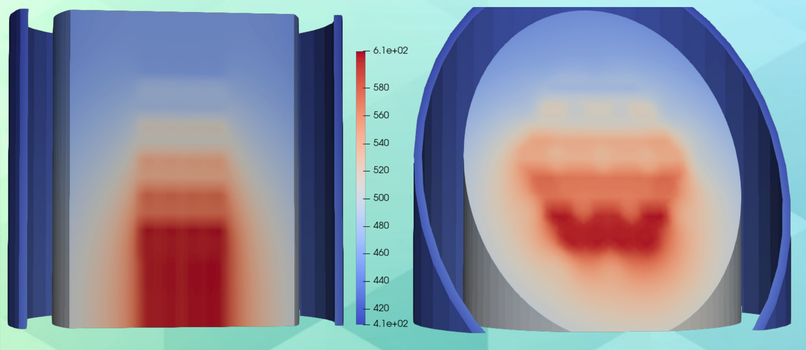
This model reproduces relatively well the measured excess reactivity, axial flux distribution, shutdown margin, and axial and radial power distribution. The eigenvalue was calculated to be 1.0123, which is satisfactory as the uncertainties in the graphite composition are very high.

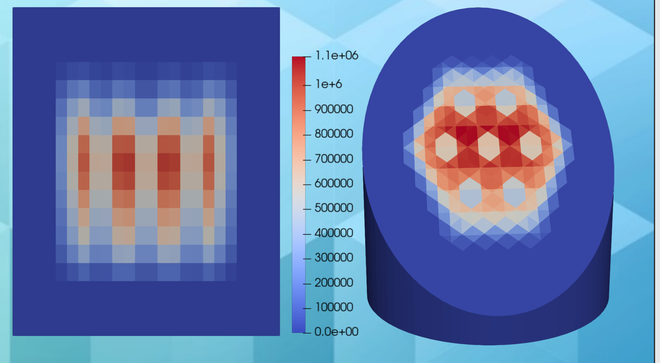


Left: Distribution of the moderator temperatures in the core (in K).

Middle: Distribution of the fuel temperatures in the core (in K).

Right: Computed fission power distribution in the core (W/m3).





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K. SWANSON and G. GIUDICELLI, "Release of a High Temperature Engineering Test Reactor (HTTR) Steady State Multiphysics Model to the Virtual Test Bed", Con. proc., Washington, D.C., Nov 12-17, Transactions of American Nuclear Society (2023).
[1] "Outline of High Temperature Engineering Test Reactor." *Japan Atomic Energy Agency HTGR Research and Development Center*, www.jaea.go.jp/04/o-arai/nhc/en/faq/httr.html. Accessed 12 July 2023.

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MOOSE

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