Exploring Effects of Homogenization on an OpenMC Depletion Analysis of a TRISO Fueled, Helium Cooled Microreactor

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Outline

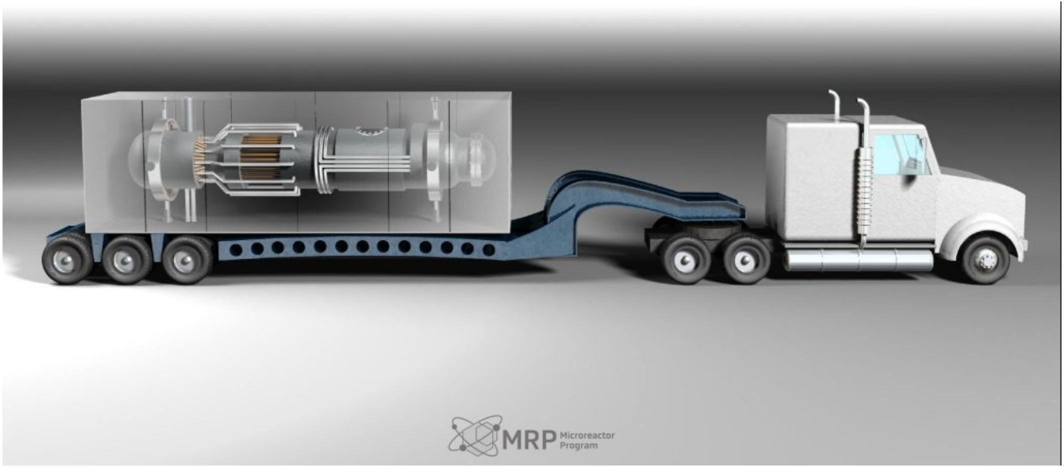
Table of Contents

Virtual Test Bed [1]

NRIC National Reactor Innovation Center

NEAMS

MOOSE


MRP Microreactor Program

High Temperature Gas Reactors and TRISO Fuel

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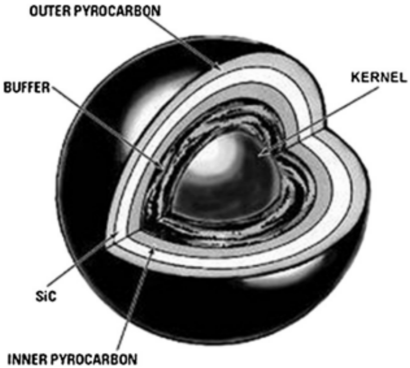

Image from [3]

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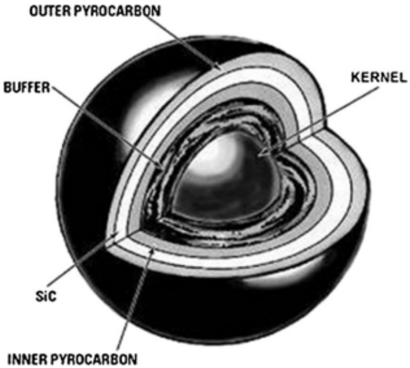

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- TRISO fuel synergizes with HTGRs
  - Melting temperature significantly higher than operational temperatures [3]
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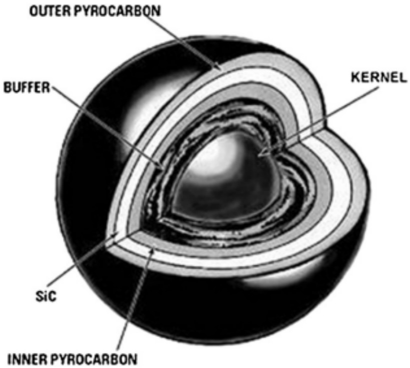

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  - Melting temperature significantly higher than operational temperatures [3]
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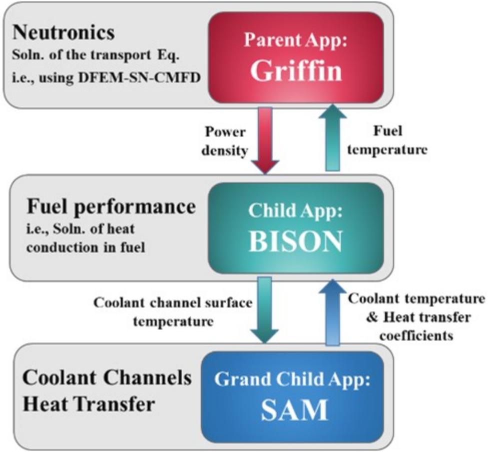
  - Typically packed into graphite compacts or into spherical pebbles for PBRs
- TRISO modeling challenges
  - Five surfaces per TRISO
  - Causes very many surface crossings per history
  - High memory requirement for fully explicit representation

Virtual Test Bed Gas Cooled Microreactor (VTB GCMR)

- Existing simulations using MOOSE tools
  - Multiphysics models, including accident and load-following transients: Griffin-BISON-SAM [4, 5, 6]
  - Balance of plant 1D thermal hydraulic simulation [7]



MultiApp hierarchy of preliminary GCMR models. Image from [5].

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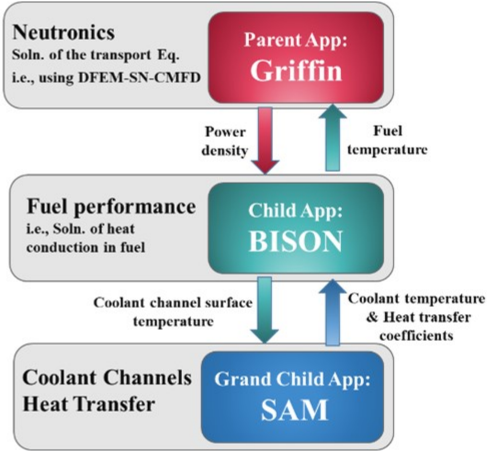
  - Plans to add this work's model to the VTB this summer



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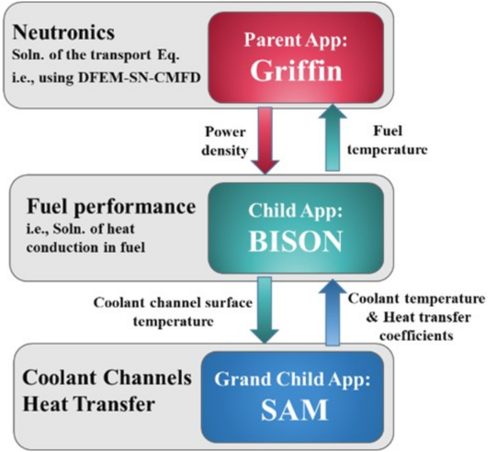
- For a full core model, it will be prohibitively expensive to model every TRISO explicitly
  - $O(10^{13})$ in this reactor



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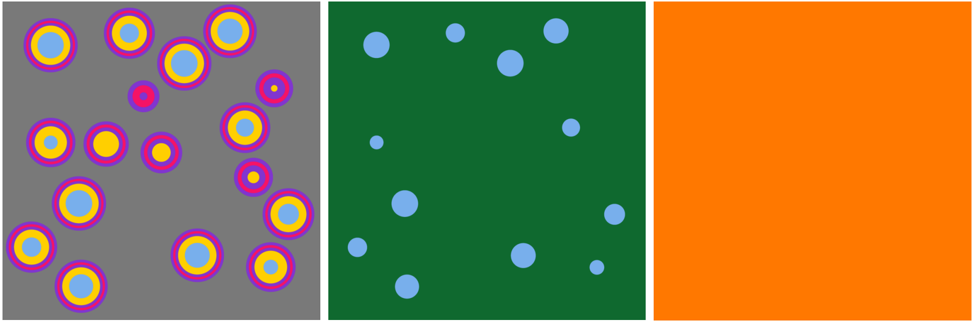

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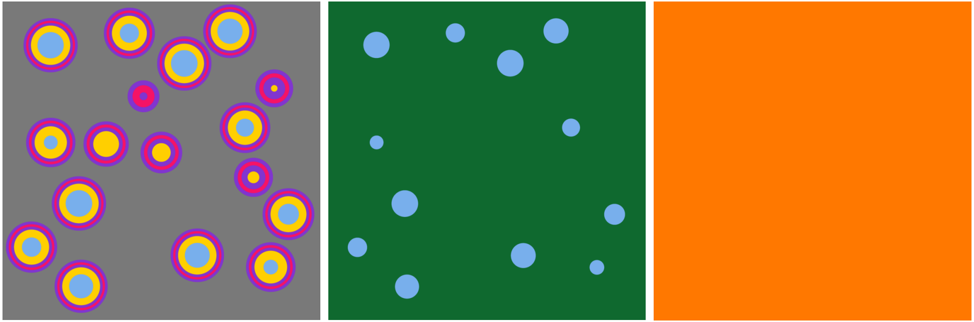

explicit　　kernel only　　full volume

- Burnup simulations at 100%, 50%, and 10% of full power (225 KWt).
- Compare each k_{inf} as a basis for deciding how proceed with a full core model.

Table of Contents

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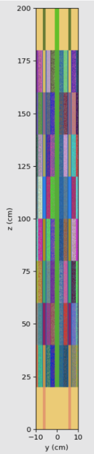

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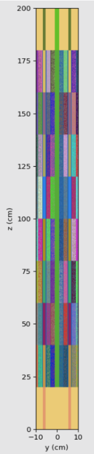

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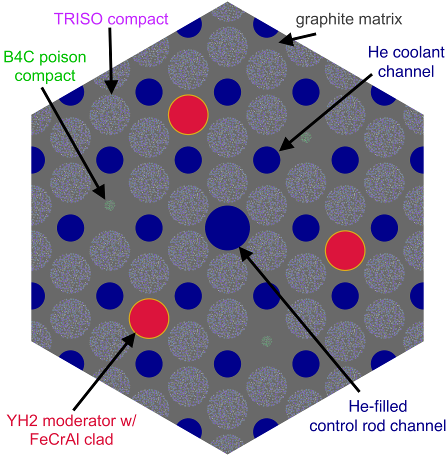

XY slice of reactor

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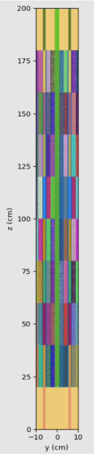

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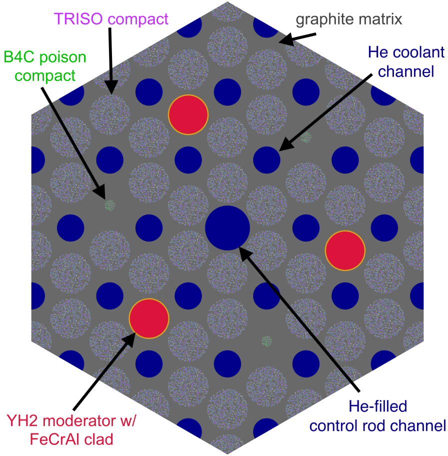

XY slice of reactor

- spatial depletion scheme
- 3-way radial symmetry cloning scheme
- 8 axial layers in the core
- 2 axial layers per reflector

OpenMC Depletion Settings

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- Predictor-Corrector time integration scheme
  - requires two transport solves per time step
  - Constant Extrapolation/Constant Midpoint scheme from Isotalo et al. [9]
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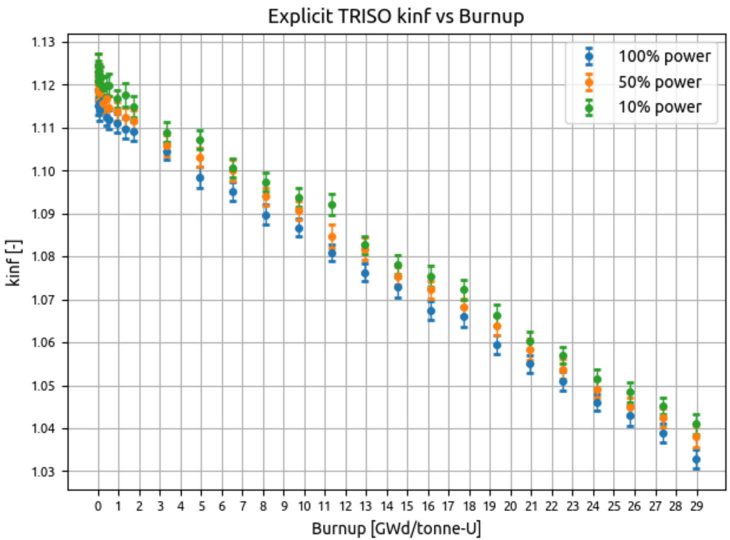
- Time Steps
  - Full power time steps: `[1]*5 + [5]*3 + [15]*3 + [60]*17` (days)
  - Burnup-consistent time steps for other powers

Table of Contents

Fully-explicit k_{inf} versus burnup with 2σ error bars up to $\sim$29 GWd/tonne-U



Comparing Eigenvalues

- Denote the first set of eigenvalues k_1 and the second set k_2, the $\Delta\rho$ between them is given by

$$\Delta\rho \equiv \rho_1 - \rho_2 = \frac{k_1 - 1}{k_1} - \frac{k_2 - 1}{k_2} = \frac{1}{k_2} - \frac{1}{k_1} \quad (1)$$

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- Average $\Delta\rho$ compared with the explicit reference at every power with 2σ uncertainties

$\overline{\Delta\rho}$	explicit - homogenized	explicit - kernel only
100% power	1533 $\pm$ 55 pcm	-158 $\pm$ 55 pcm
50% power	1495 $\pm$ 56 pcm	-193 $\pm$ 55 pcm
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- Kernel only $\Delta\rho$ on average performs about 1 order of magnitude better than full homogenization.

Table of Contents

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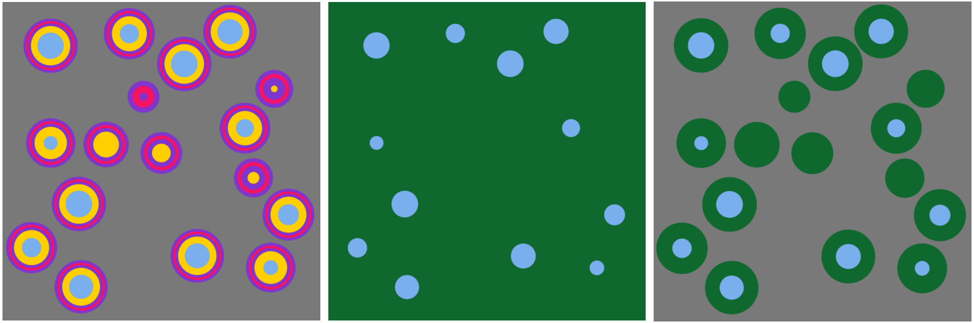
Two-layer TRISO Homogenization

- While the kernel only eigenvalue computation outperforms the fully homogenized in terms of accuracy, it would be desirable to lower $\Delta\rho$ below 100 pcm.
- The kernel only model moves SiC further from the fuel than it exists in the explicit model.
- Si is less efficient at thermalizing neutrons and absorbs more neutrons than C
- A next iteration on fuel homogenization would be to create a **two layer** homogenization



explicit | kernel only | two layer TRISO

Acknowledgements

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- The OpenMC team!
- The Center for High Throughput Computing at the University of Wisconsin - Madison
- Co-authors: Patrick Shriwise, Benjamin Lindley, and Paul P.H. Wilson.

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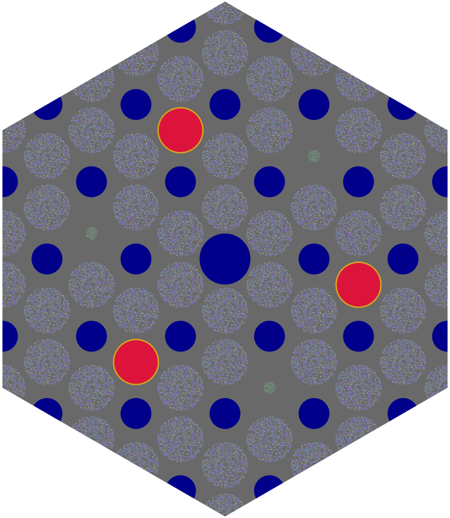
[11] *Depletion Chains*. URL: https://openmc.org/depletion-chains/.

Open Source Projects

- OpenMC website: https://openmc.org
- OpenMC repository: https://github.com/openmc-dev/openmc
- OpenMC plotter: https://github.com/openmc-dev/plotter
- VTB: https://mooseframework.inl.gov/virtual_test_bed
- VTB repository: https://github.com/idaholab/virtual_test_bed
- Add me on LinkedIn (lewisgross1296) and GitHub (lewisgross1296)!

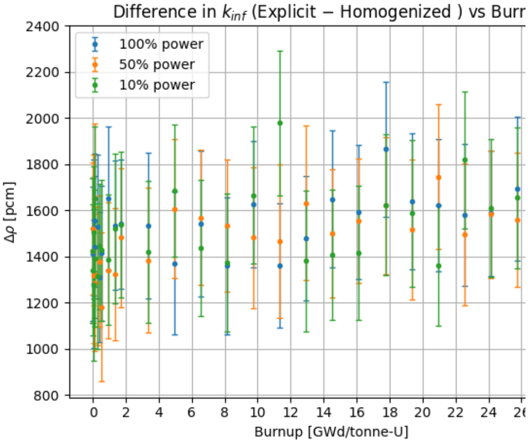


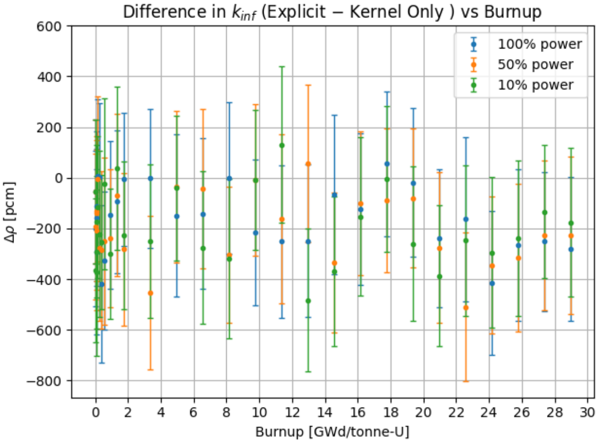
System Parameters

geometric parameters		
fuel compact radius	poison compact radius	moderator compact radius
0.90 cm	0.25 cm	0.843 cm
control compact radius	coolant compact radius	FeCrAl thickness
0.99 cm	0.60 cm	0.05 cm
Cr coating thickness	reflector heights	core height
0.007 cm	20 cm	160 cm

operation and design parameters		
fuel packing fraction	poison packing fraction	enrichment
40%	25%	19.95%
inlet temperature	outlet temperature	outlet pressure
873.15 K	1133.65 K	7 MPa

$\Delta\rho$ with 2σ error as a function of burnup up to $\sim$29 GWd/tonne-U





Equilibrium Xenon-135 Number Densities

Table: All units are atom per cubic centimeter. Since the first five time steps are used to converge xenon, the numbers below are the average of the fifth to the last value for xenon number density.

representation	explicit	kernel only	homogenized
100% power	2.43127×10^{16}	2.41845×10^{16}	1.19125×10^{15}
50% power	1.31047×10^{16}	1.30864×10^{16}	6.45668×10^{14}
10% power	2.82398×10^{15}	2.81919×10^{15}	1.38810×10^{14}

- These equilibrium values explain the observed trend at fresh fuel – and for much of the simulation – that lower power with the same total burnup has more excess reactivity.
- The higher the power, the more Xenon-135 is produced during the initial jump to steady state, contributing to a larger negative reactivity insertion.

Plutonium 241 at Each Power for the Fully Explicit Case