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

Lewis I. Gross[1], Patrick Shriwise[2,1], Benjamin Lindley[1] and Paul P.H. Wilson[1]
University of Wisconsin-Madison[1], Argonne National Lab[2]

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Outline

1. Virtual Test Bed Gas-Cooled Microreactor
2. OpenMC Model
3. Results and Discussion
4. Next Steps

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Virtual Test Bed [1]

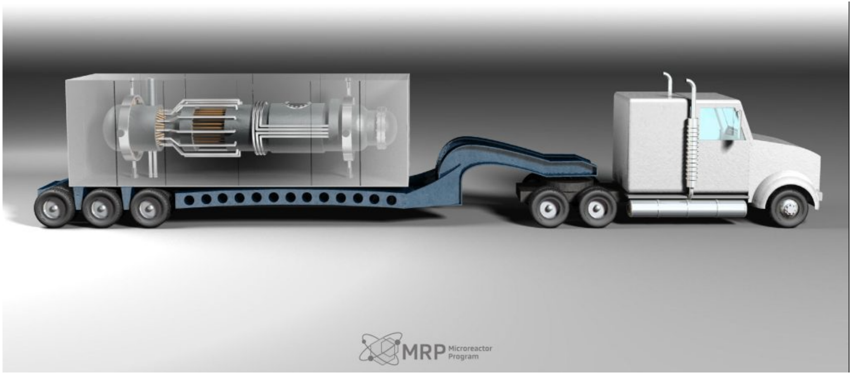
NRIC National Reactor Innovation Center

NEAMS

MOOSE

Microreactors [2]

Microreactors [2]



High Temperature Gas Reactors and TRISO Fuel

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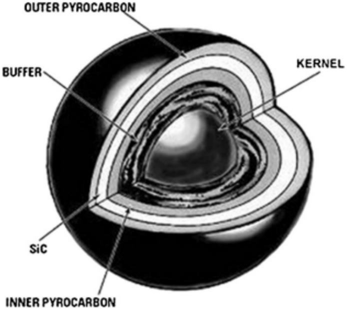
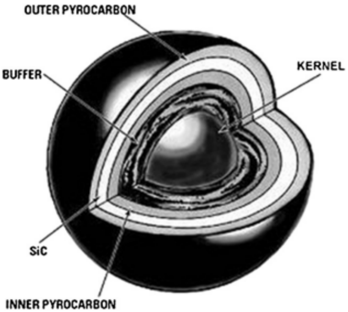


Image from [3]



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- TRISO fuel synergizes with HTGRs
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  - Typically packed into graphite compacts or into spherical pebbles for PBRs

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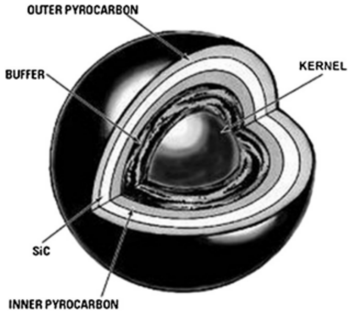

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  - Melting temperature significantly higher than operational temperatures [3]
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  - Typically packed into graphite compacts or into spherical pebbles for PBRs
- TRISO modeling challenges
  - Five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

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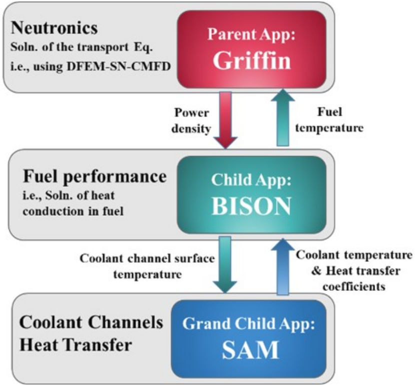

MultiApp hierarchy of preliminary GCMR models. Image from [5].

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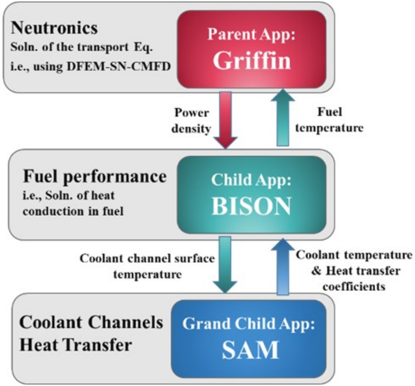

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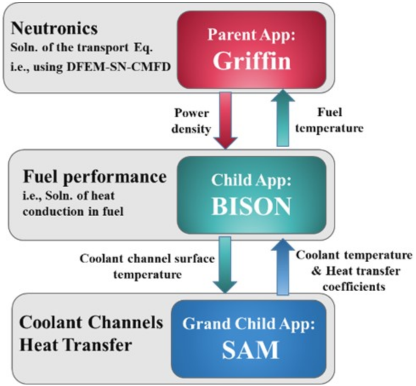
- For a full core model, it will be prohibitively expensive to model every TRISO explicitly
  - $O(10^{13})$ per assembly



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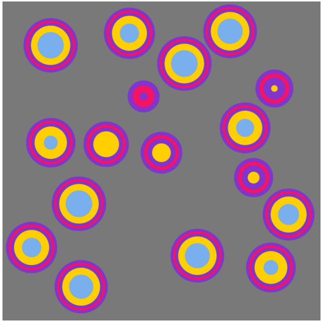
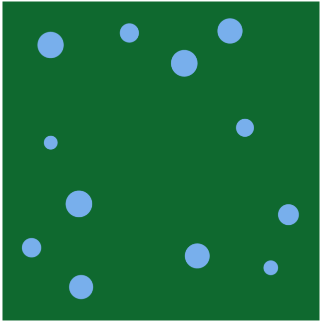


explicit



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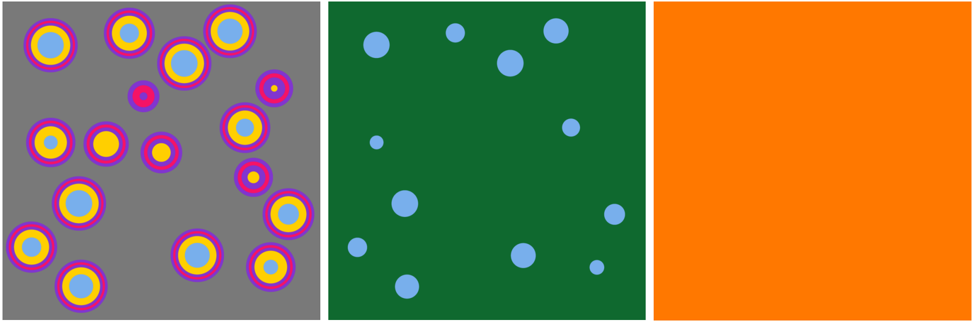

explicit kernel only full volume

- 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

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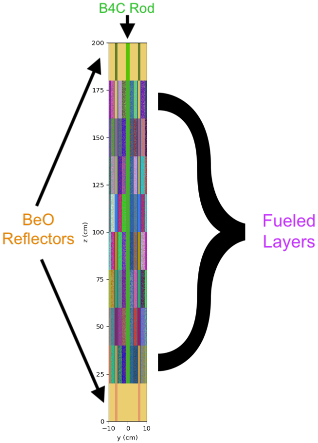

YZ slice of reactor

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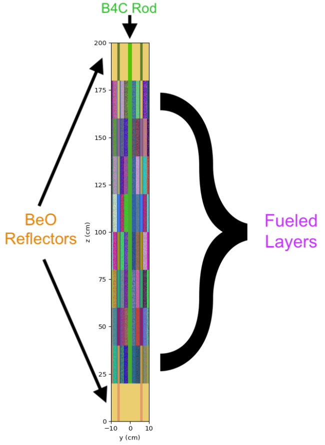

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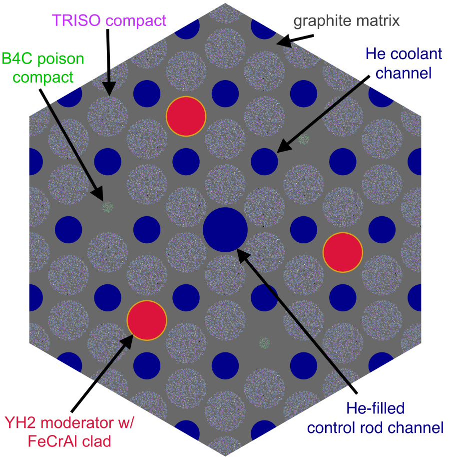
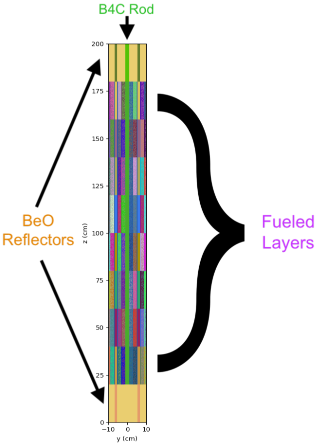


XY slice of reactor



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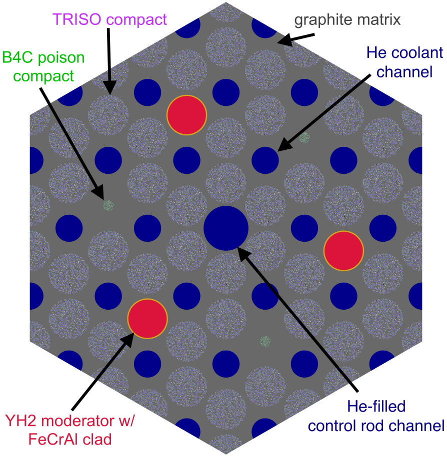

XY slice of reactor

- 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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- Constant Extrapolation/Constant Midpoint (CE/CM) time integration scheme from Isotalo et al. [9]
  - 25 inactive and 75 active batches with 10000 particles per batch
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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

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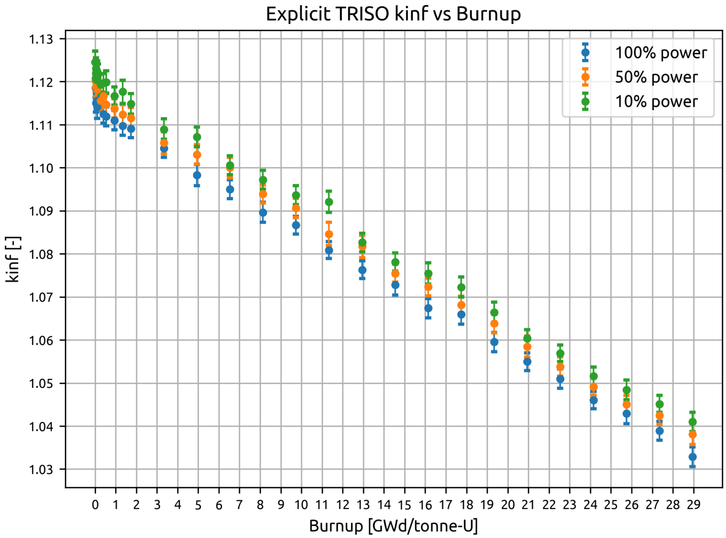
Fully-explicit k_{inf} versus burnup with 2σ error bars up to ∼29 GWd/tonne-U



Comparing Eigenvalues

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- 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
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- Kernel only $\Delta\rho$ on average performs about 1 order of magnitude better than full homogenization.

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- Si is less efficient at thermalizing neutrons and absorbs more neutrons than C.

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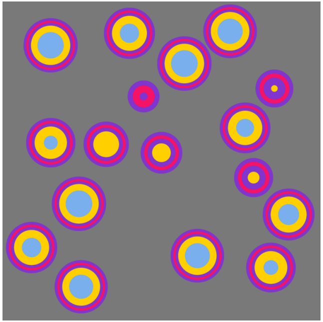
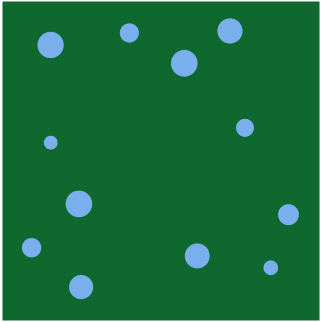
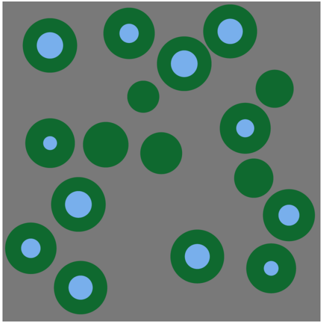
- The kernel only model moves SiC further from the fuel than it exists in the explicit model.
- Si is less efficient at thermalizing neutrons and absorbs more neutrons than C.
- A next iteration on fuel homogenization would be to create a **two layer** homogenization



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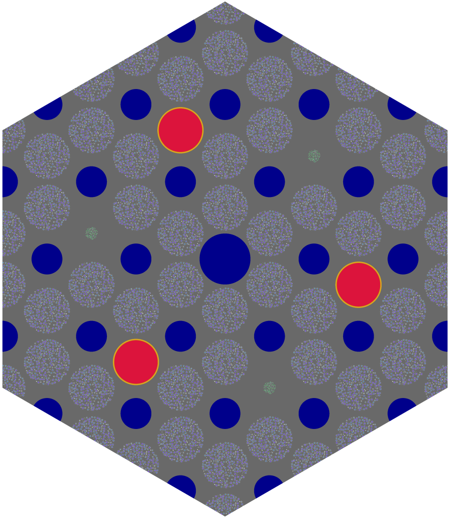
[11] *Depletion Chains*. URL: https://openmc.org/depletion-chains/.

Open Source Projects

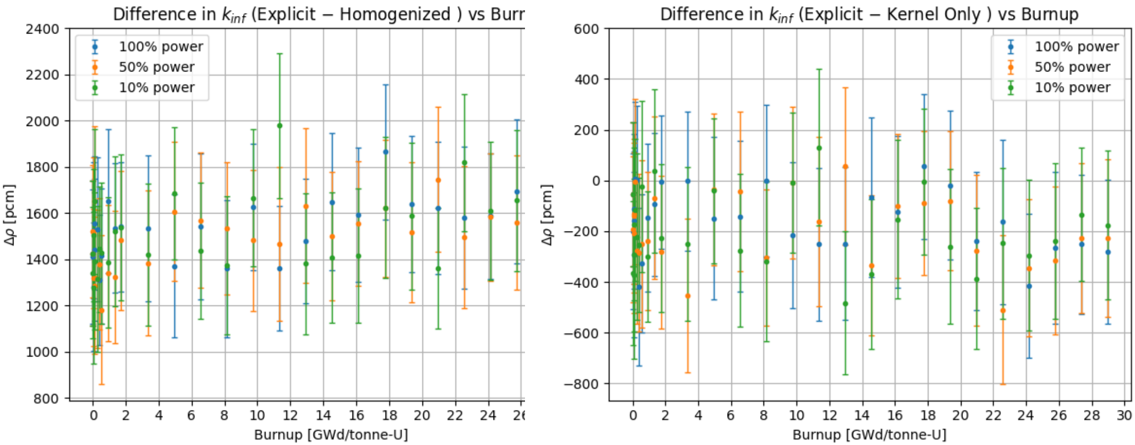
- OpenMC website: https://openmc.org
- OpenMC repository: https://github.com/openmc-dev/openmc
- OpenMC plotter: https://github.com/openmc-dev/plotter
- VTB: https://mooseframework.inl.gov/virtual_test_bed
- VTB repository: https://github.com/idaholab/virtual_test_bed
- Add me on LinkedIn (lewisgross1296)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



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 ~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