INL/MIS-23-74198-Revision-0

The Griffin Reactor MultiPhysics Application

August 2023

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Javier Ortensi

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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Javier Ortensi, Ph.D.

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NEAMS

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy

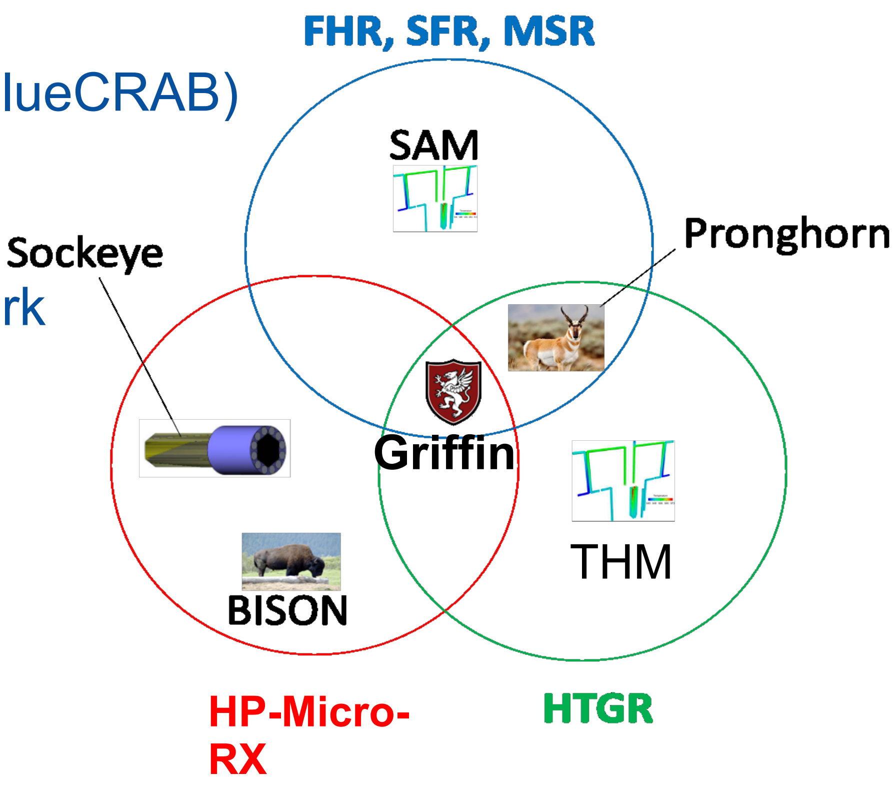
INL Idaho National Laboratory

Overview

- Development Philosophy
- Summary of Capabilities
- Cross Section Capabilities for PBRs
- Depletion Capabilities for PBRs
- Multiphysics Capabilities for PBRs
- Workflow to Prepare Data for Source Term Calculations for PBRs
- Uncertainty Quantification

Griffin Development Philosophy

- A generalized tool for reactor physics
  - Part of the Comprehensive Reactor Analysis Bundle (BlueCRAB)
- Multiphysics-oriented
  - Provides native coupling to all MOOSE-based tools
  - Takes advantage from common investment in framework
  - Supports thermal expansion via mesh displacement
  - Controls execution of multiple tools
- Flexible and Extendable
  - Regular and unstructured geometries
  - Various types of calculations (variable fidelity)
  - Easy addition of functionality
- Robust
  - Strict software development cycle (GitHub platform)
  - Mostly C++ based (code quality, maximizes reuse of existing code)
  - Consistent with NQA-1 process and highest level of rigor for safety software



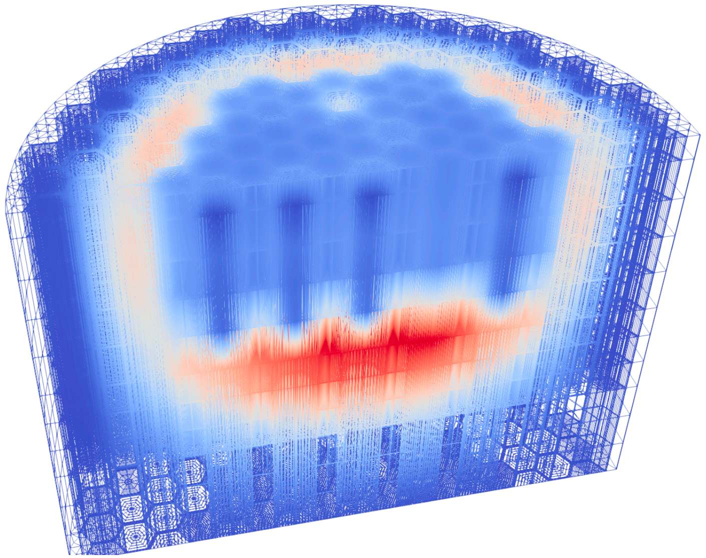
Griffin Capabilities Summary

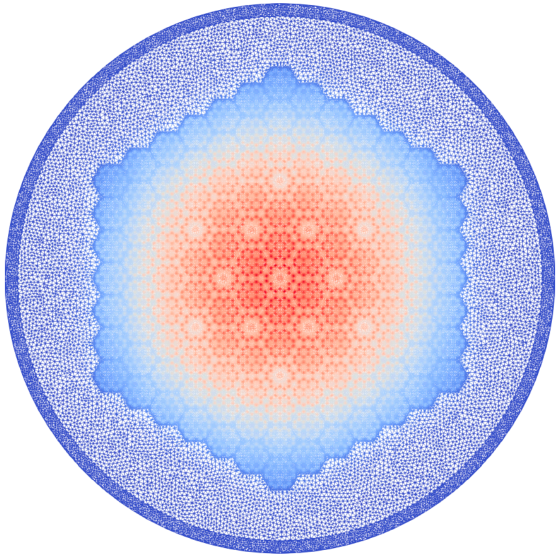
Transport Solvers (neutron and gamma)

- PKE, Diffusion, HFEM-PN, DFEM-SN
- CMFD acceleration
- k-eigenvalue, adjoint, source, time-dependent solvers
- Improved quasi-static method for transients

Other

- Phonon, electron, thermal radiation transport





Reactor Physics

- Static depletion
- Dynamic depletion (PBRs, MSRs)
- Homogenization equivalence and power reconstruction
- Decay heat
- Cusping treatment
- Criticality search
- Delayed neutron precursor advection
- Point kinetic parameter calculation
- Fast and thermal spectrum cross section
- Multiphysics coupling with heat-conduction, thermal-fluids, and thermo-mechanics

Griffin Cross Section Capabilities for PBRs

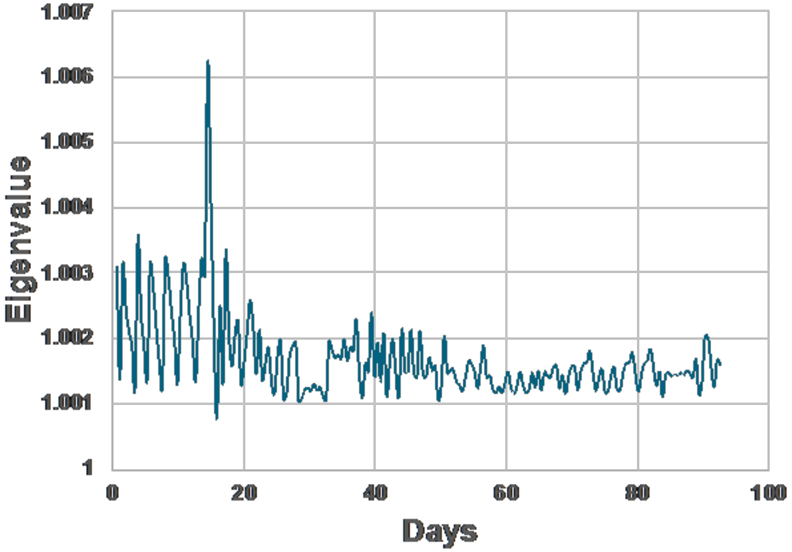
- We are developing two workflows for XS preparation for PBRs
  - Two-step (a priory)
  - Online with leakage correction
- Based on a standard fine-group library with 300-400 isotopes
- User-based broad group structure
- Double heterogeneity treatment method* (Hansol Report)
- Self-shielding method * (Hansol Report)
  - Full core Dancoff factors with variable porosity

Griffin Depletion Capabilities for PBRs

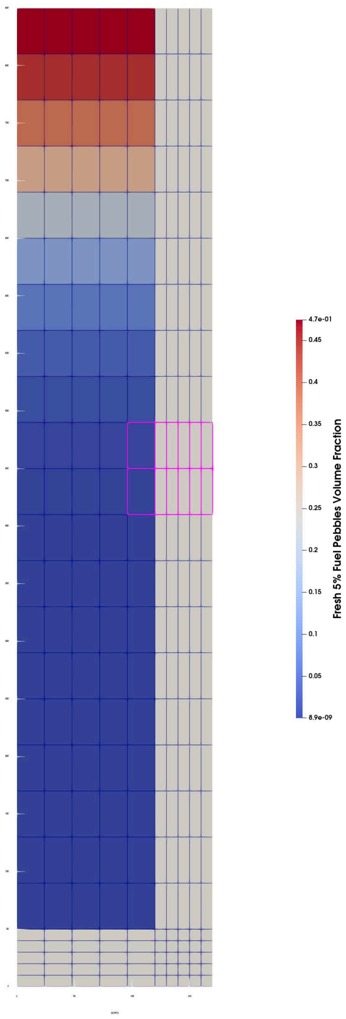
- Depletion equations are solved on a collection of 1D streamlines
  - Eulerian approach for advection
  - Burnup groups instead of pebble passes
  - Direct and running-in algorithms
  - Decay and transmutation handled by Griffin CRAM solver for running-in
- Griffin Solvers for the Bateman Equations
  - CRAM (Traditional, Gauss-Seidel 50% faster)
  - Adding and doubling method (ADM) for systems < 300 nuclides
  - Can track non-nuclides quantities in the in the decay and transmutation matrix
    - decay energy, fissions per initial heavy metal atom (FIMA), kinetic energy released per unit mass (KERMA), and displacements per atom (DPA)
- Pseudo Isotope generation
  - Griffin includes the capability to generate pseudo isotopes to preserve quantities
    - Decay heat (from 1,671 -> 342 nuclides)
    - Decay photons (from 1,738 -> 378 nuclides)

Sample Running-In Calculation – Sample Results

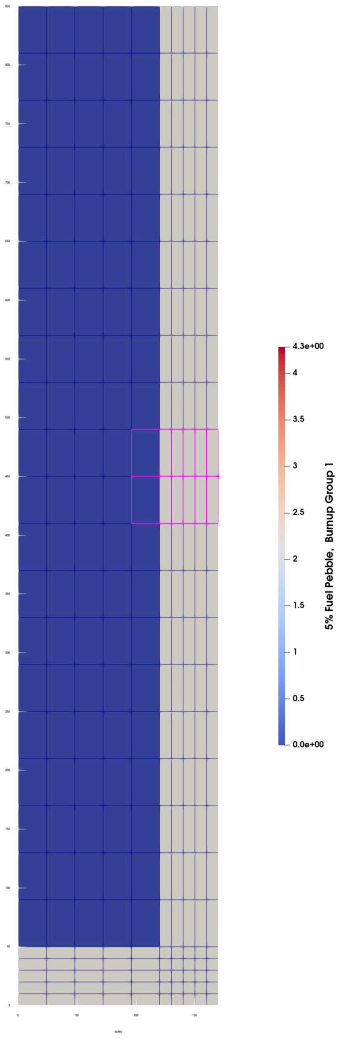
- Pebble volume fractions for 5% enriched fuel shown to the right for fresh fuel and the next two burnup groups for first 90 days of simulation
- Reactivity currently managed by varying the pebble feed rate
    - Flow rate varied from 0 to 7 pebble per minute
- Currently working on using both a variable feed rate and control rods to manage fuel and reactivity
- Improving logic used to automatically control the feed rate and give user more options to control logic



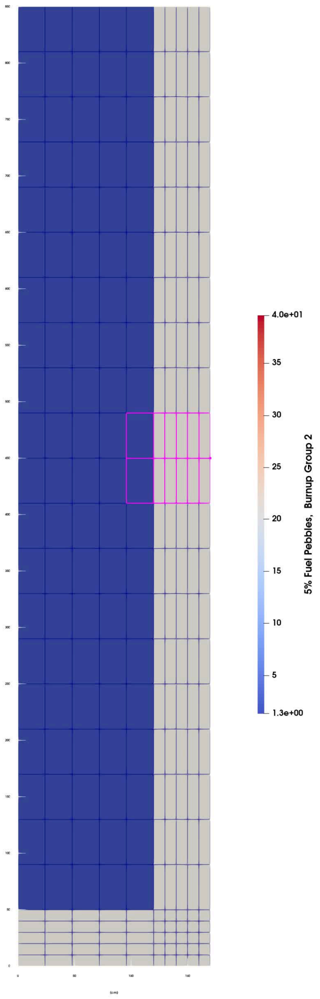
Burnup group 1



Burnup group 2

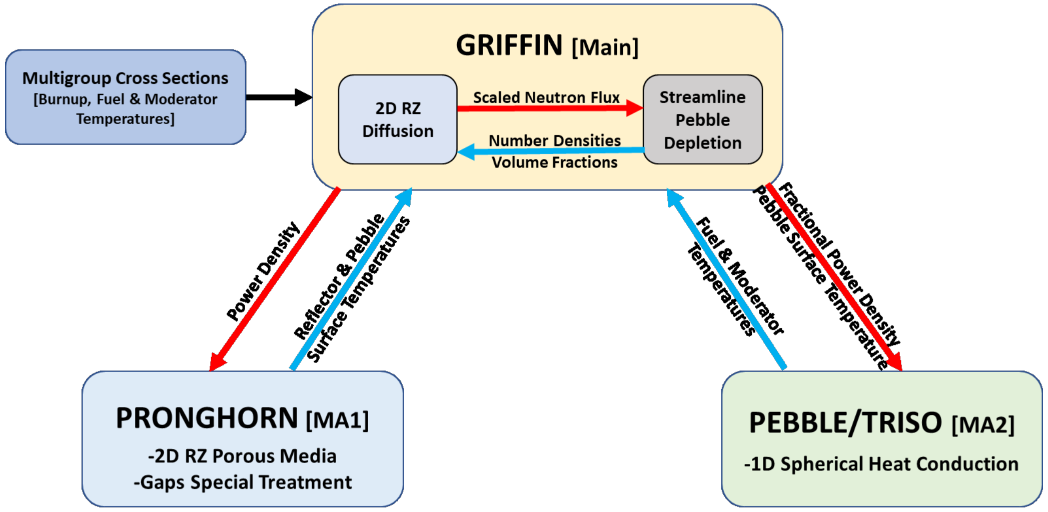


Burnup group 3



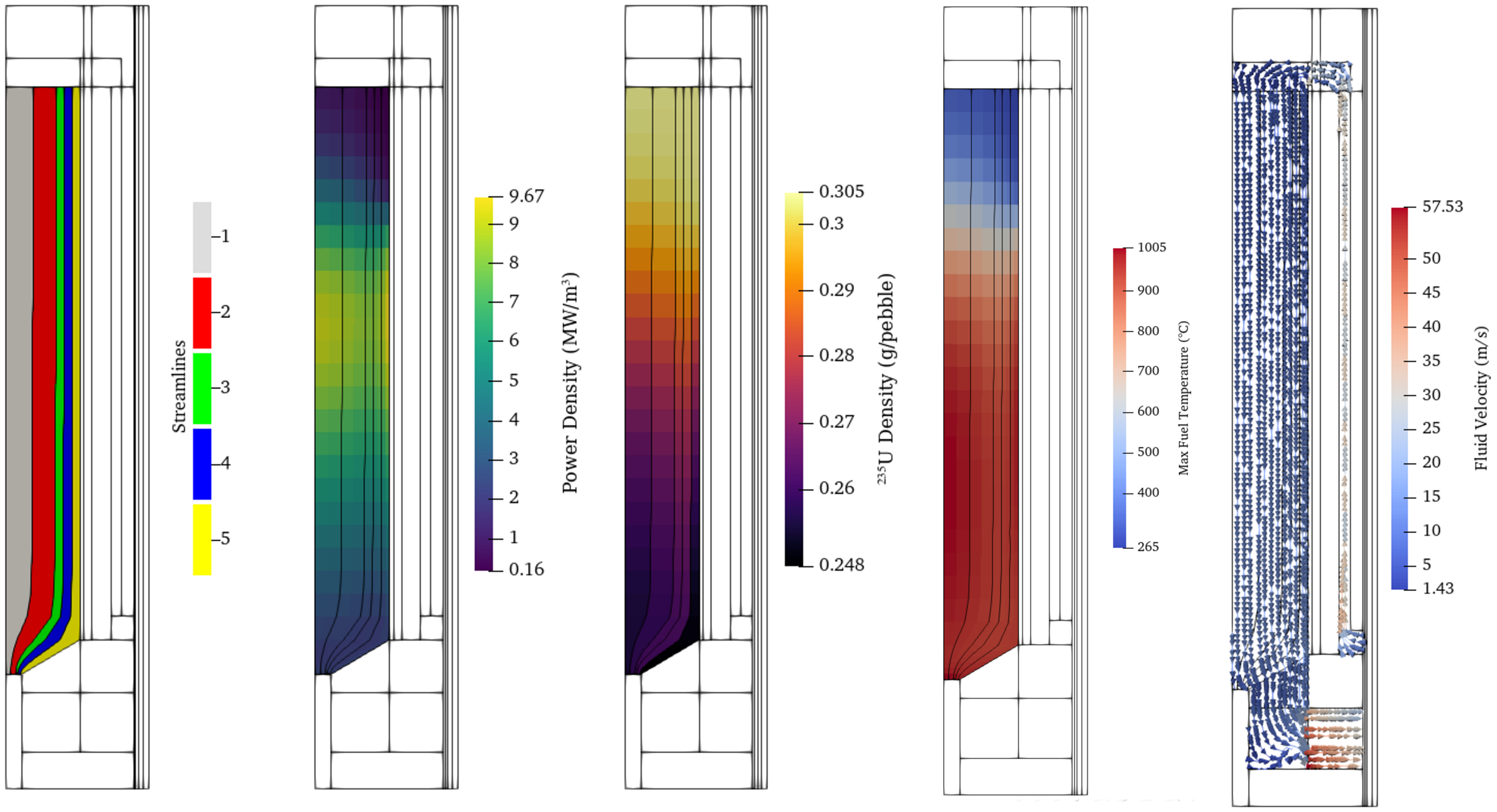
Griffin Multiphysics Coupling

- Coupled multi-physics calculations for realistic results
- All MOOSE-based codes couple naturally by design in BlueCRAB
  - Griffin: neutronics, depletion
  - Pronghorn: porous media thermal hydraulics
  - Bison: pebble heat conduction model



Griffin Equilibrium Core Capabilities

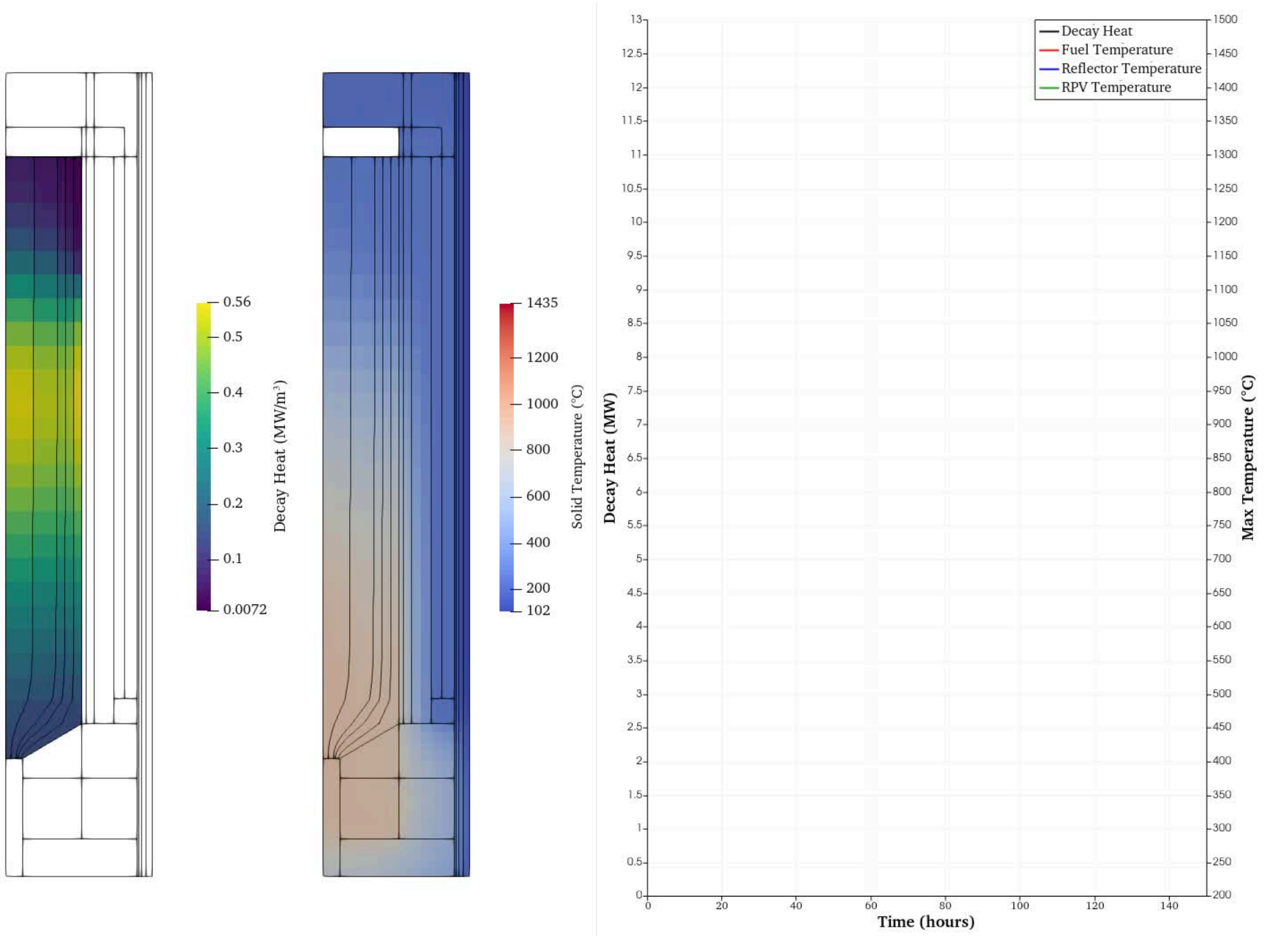
- Can use diffusion or SN-transport (2D cylindrical geometry or 3D cartesian) for neutronics
- Simple to move data between different meshes
- Streamlines support lower and upper cones



Figures provided by Zach Prince

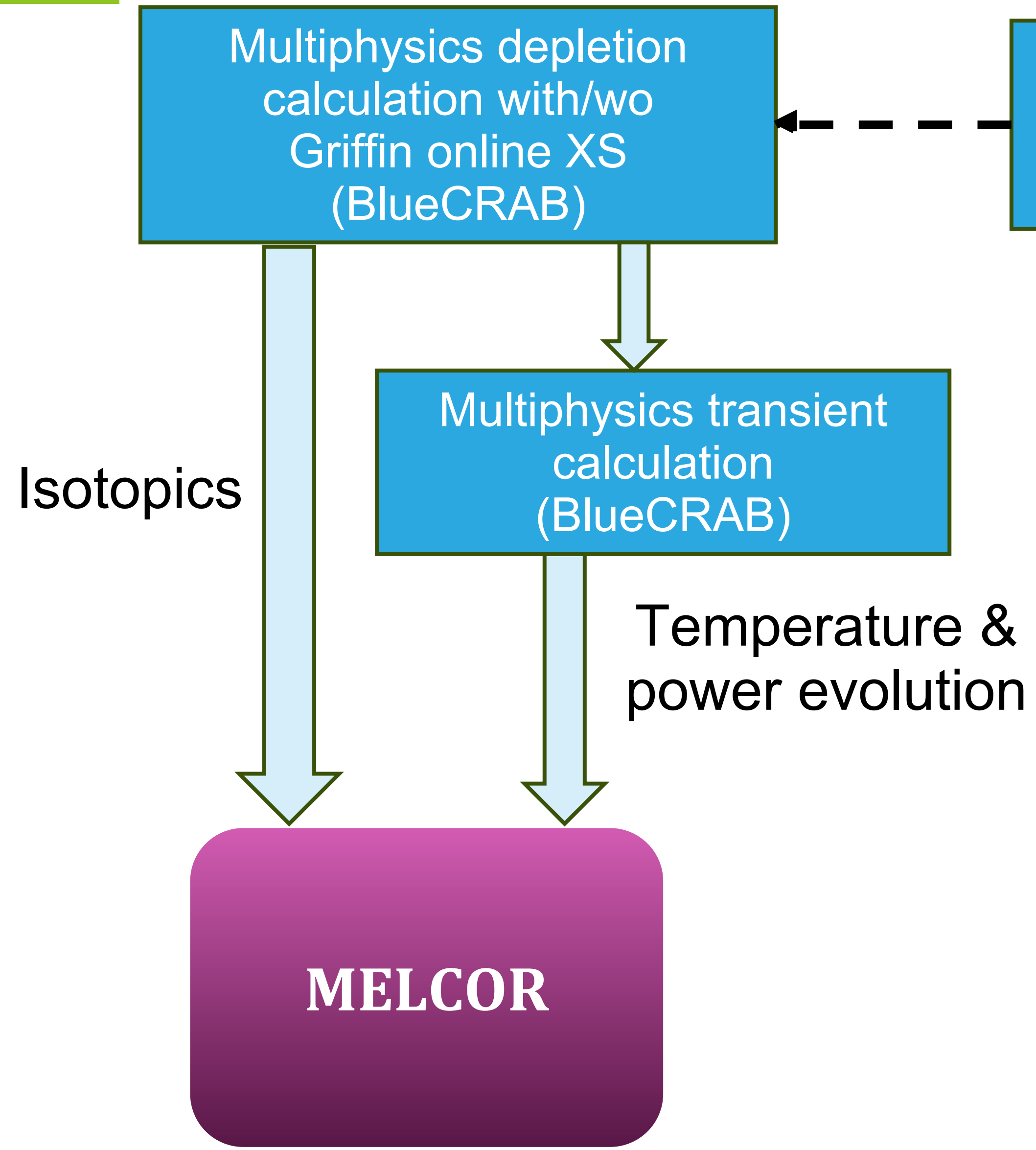
Griffin Equilibrium Core Capabilities

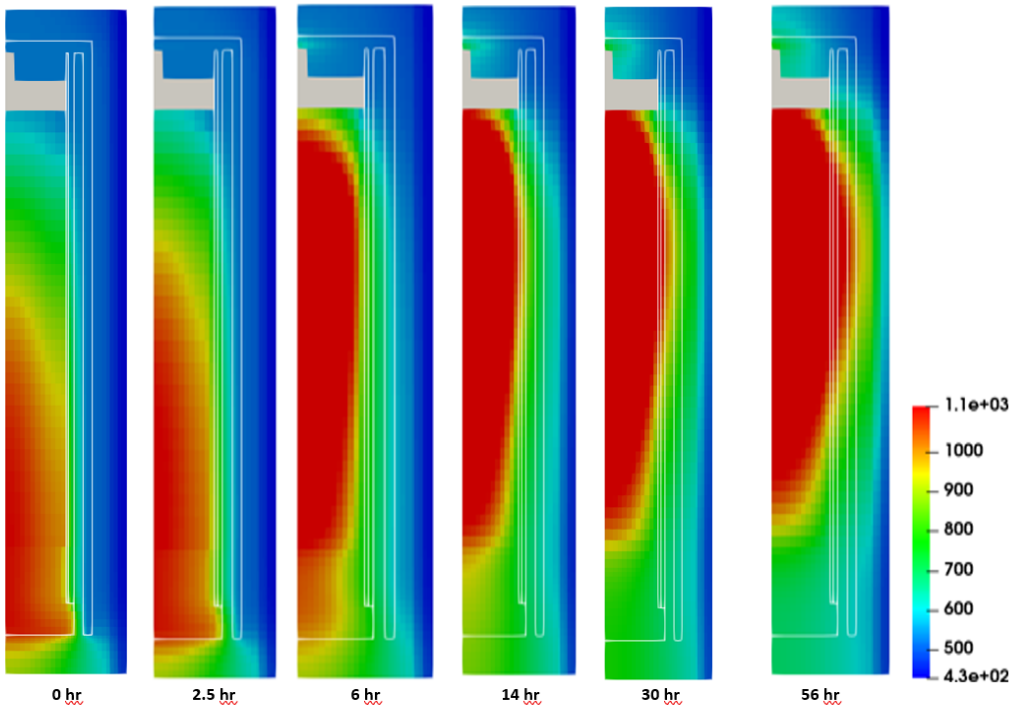
- Ability to easily start accident or transient calculations using moose multiphysics capabilities from a calculated equilibrium core solution
- Decay heat calculations using either an explicit approach with pseudo nuclides or using DIN-25485 standard
- Griffin generally very fast allowing many calculations to be performed



Animation provided by Zach Prince

Griffin Source Term Data Workflow

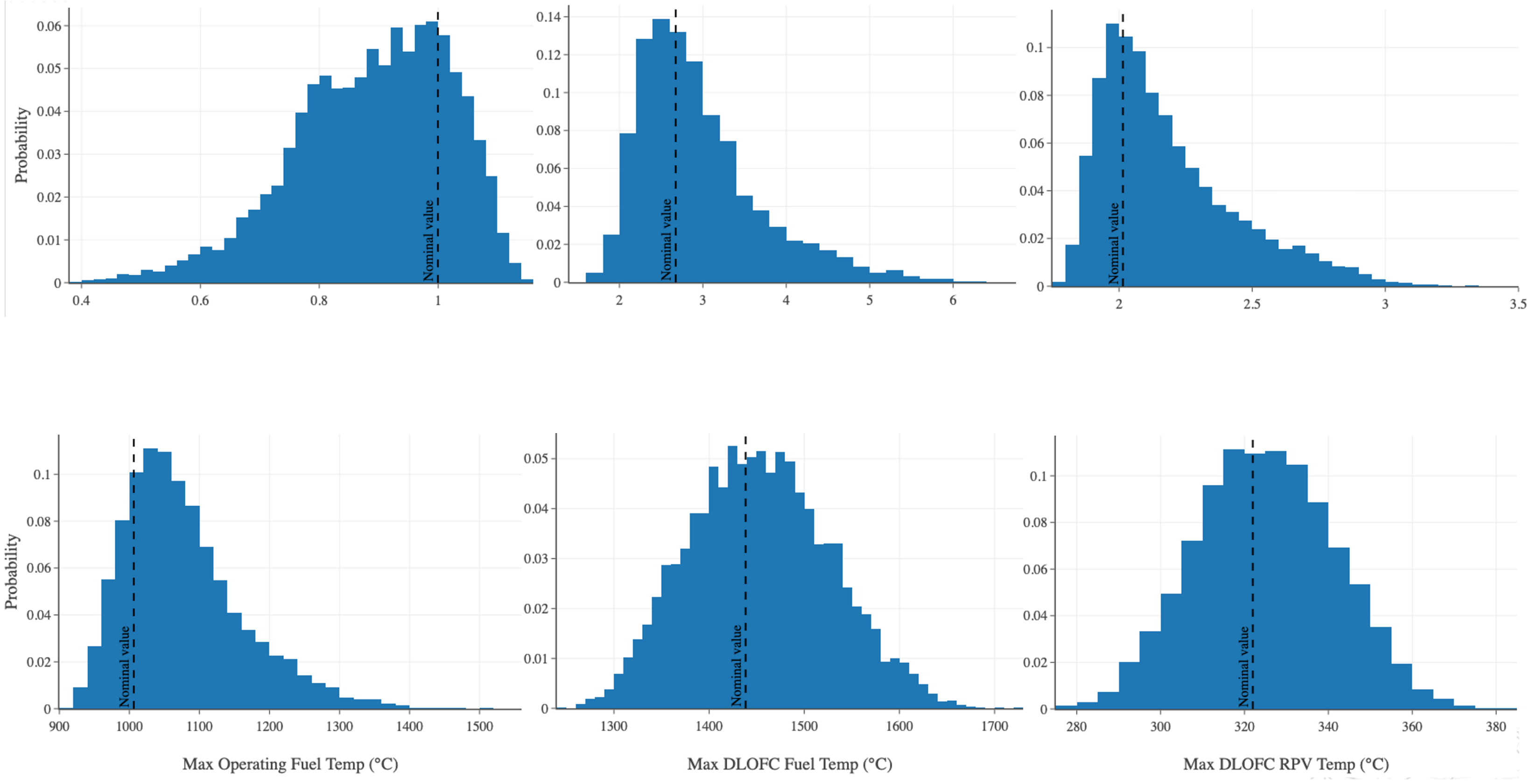




HTR-PM Solid temperature evolution during a DLOFC

Griffin Sensitivity Analysis

- Sample results with kernel radius, filling factor, enrichment, feed rate, burnup limit, total power, core radius, core height
- Latin hypercube (LHS) sampling with 10,000 samples



Figures provided by Zach Prince

Conclusions and Active Work

- Conclusions
  - Griffin pebble bed modelling capabilities leverage the easy coupling between MOOSE-based code for robust Multiphysics modeling
  - Efficient streamline modelling approach with efficient neutronics solvers means fast solves
    - Can leverage to do many runs for sensitivity analysis
- Active Current Work
  - Testing time-dependent problems with cones
  - Online cross section preparation
  - Ongoing use and validation of the modelling capabilities
  - Finalizing the running-in capability
    - Testing with more realistic models and coupling to thermal fluids calculations

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