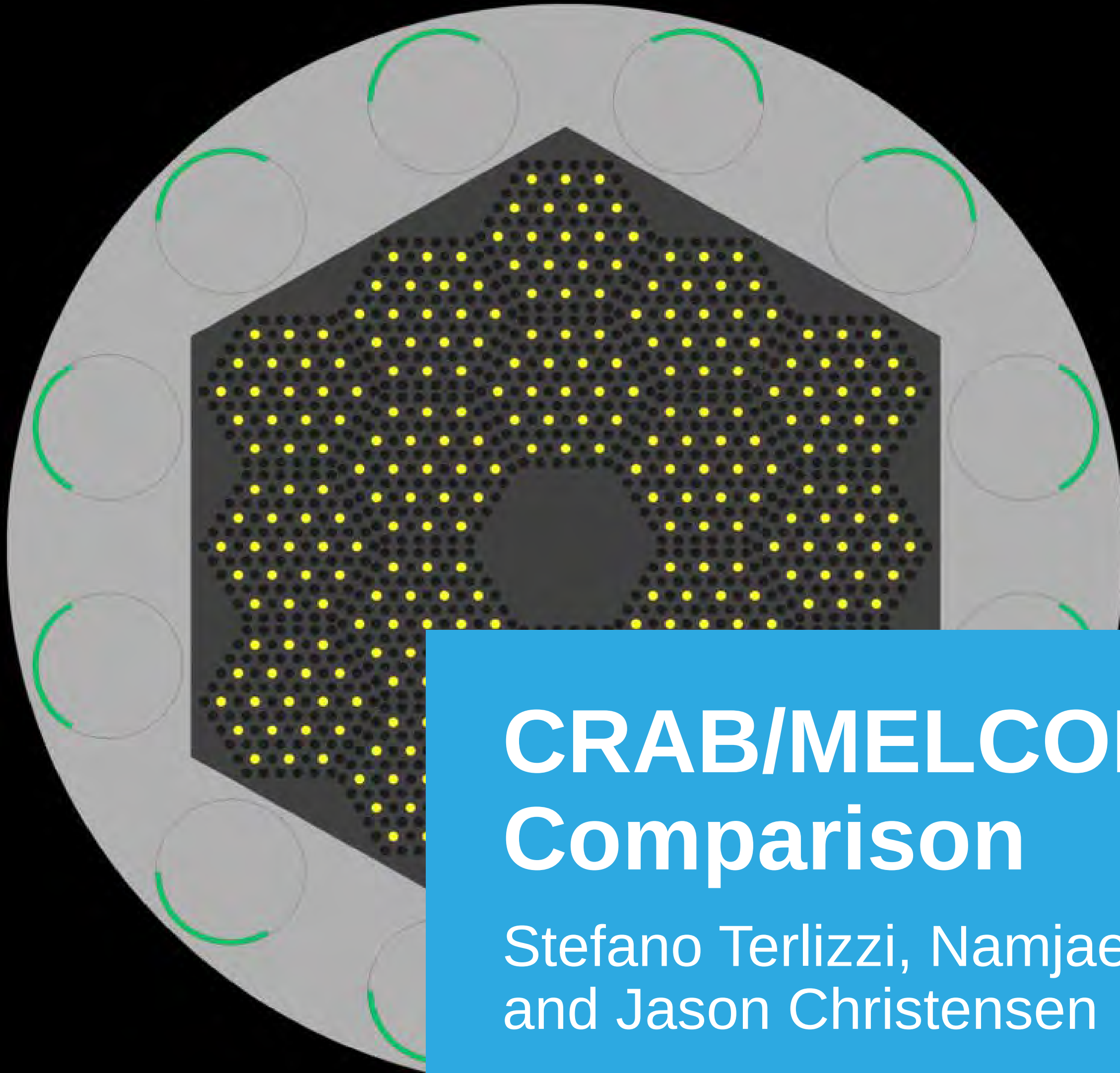


March 5, 2024

Presenter: Stefano Terlizzi

CRAB/MELCOR Code to Code Comparison

Stefano Terlizzi, Namjae, Choi, Mustafa Jaradat, and Jason Christensen

Project Overview

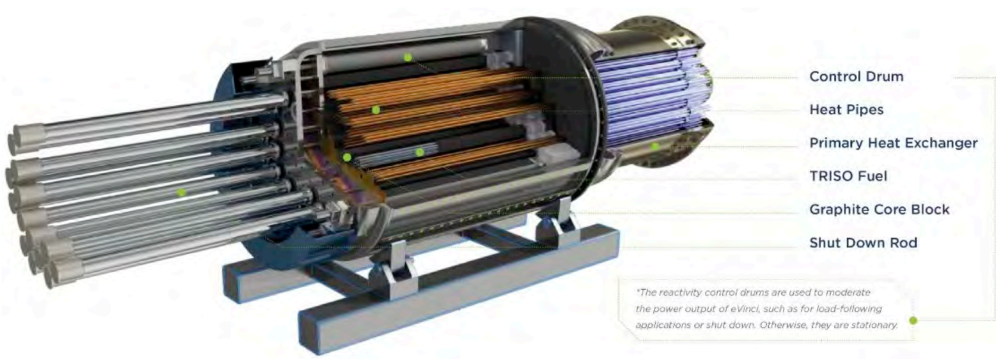
- Development of a CRAB/MELCOR workflow for mechanistic source term analyses in advanced reactors, including heat pipe reactors.
- Comparison and publication of results from CRAB/MELCOR vs. results from the WEC-developed FATE code.

BLUECRAB

1. Power Density
2. Decay Heat
3. Kinetic Parameters
4. Nuclides Inventories

MELCOR

1. Spatial distribution of Fission Products



https://www.westinghousenuclear.com/energy-systems/evinci-microreactor

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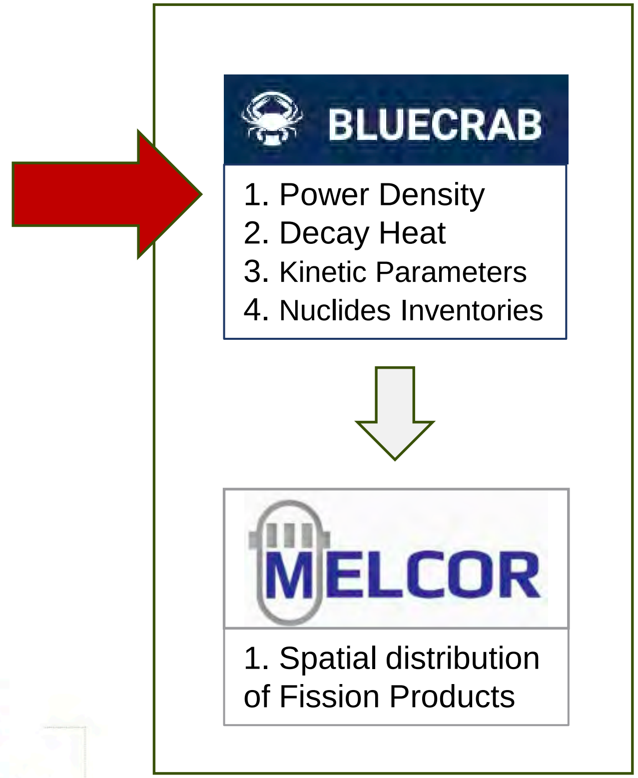

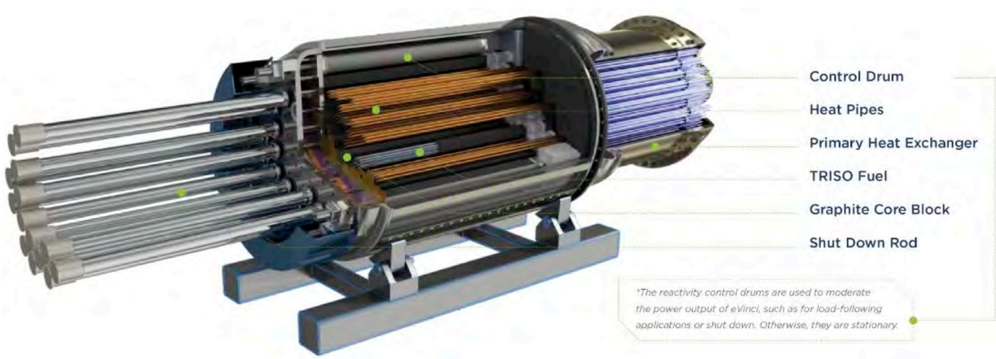

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The Comprehensive Reactor Analysis Bundle (CRAB)

BLUECRAB

Griffin — Steady state and transient neutronics

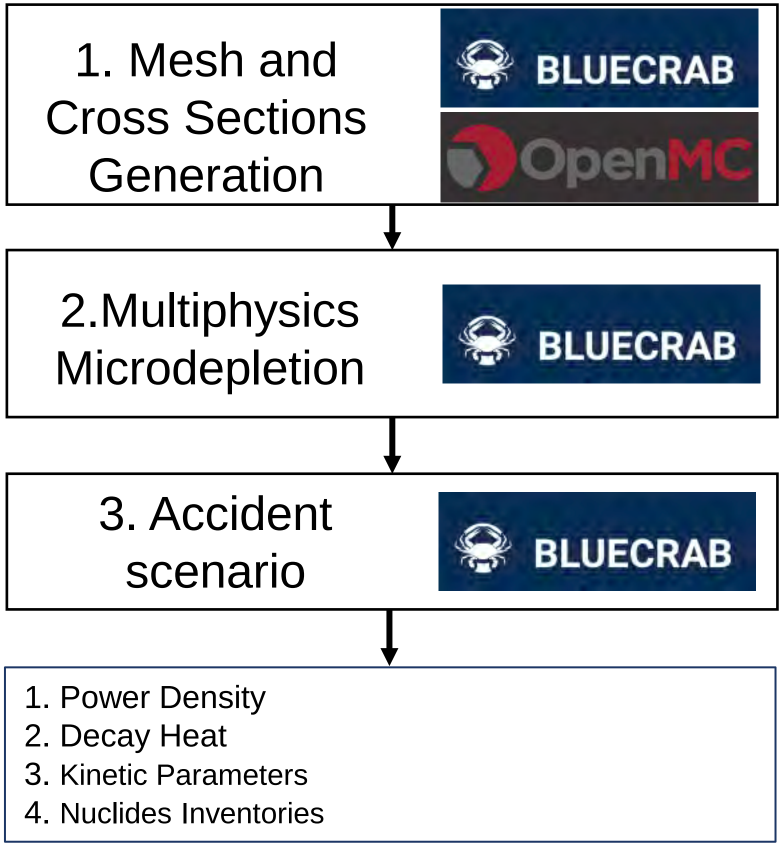
Bison — Thermal and mechanics analysis

Sockeye — Heat pipes modeling

- Code based on the Multiphysics Object-Oriented Simulation Environment (MOOSE)
- Includes several codes for the analysis of advanced nuclear reactors
- In this work:
  - **Griffin** is used for neutronics
  - **Bison** for solid conduction
  - **Sockeye** for heat pipes modeling
- Microscopic cross sections for Griffin are generated by using the OpenMC continuous energy Monte Carlo code.

CRAB-based Workflow For Mechanistic Source Term

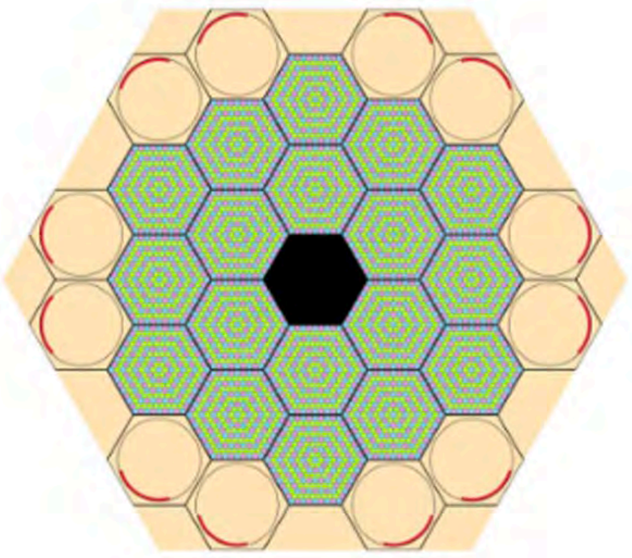
1. Mesh creation with MOOSE and microscopic cross sections preparation with OpenMC.
2. Microdepletion with thermal feedback until End Of Life (EOL).
3. Perform accident transient scenario calculations at EOL.



Behne, Patrick Alan, Mohammad Jaradat, Mustafa Kamel, Choi, Namjae, Terlizzi, Stefano, and Laboure, Vincent M. *Development of a BlueCRAB/MELCOR Framework for Supporting Realistic Mechanistic Source Term Calculations in Microreactors*. United States: N. p., 2023. Web. doi:10.2172/2203272.

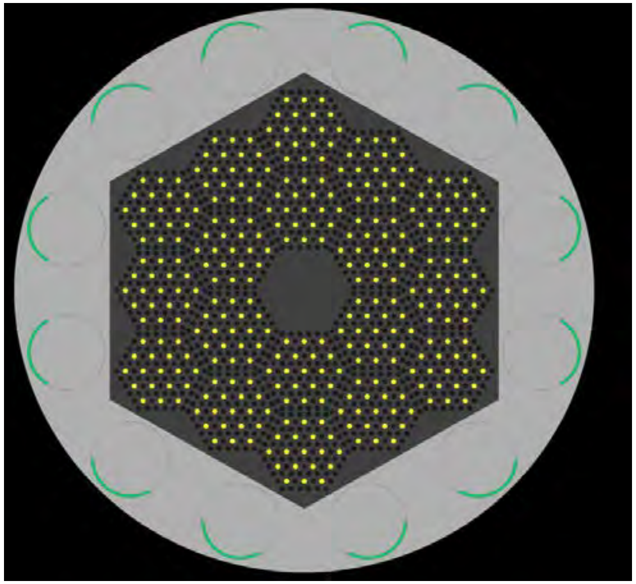
Creating an eVinci^{TM}-like HP-MR model

FY23



Simplified Microreactor Benchmark Assessment (SiMBA) problem

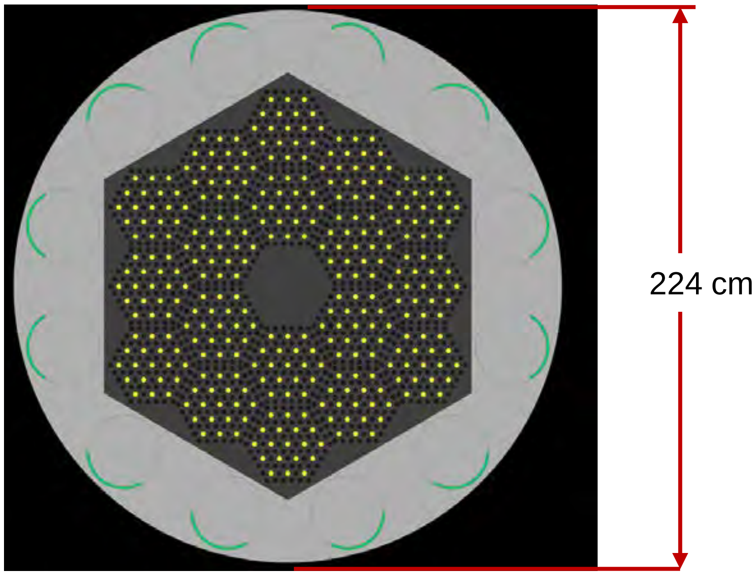
FY24

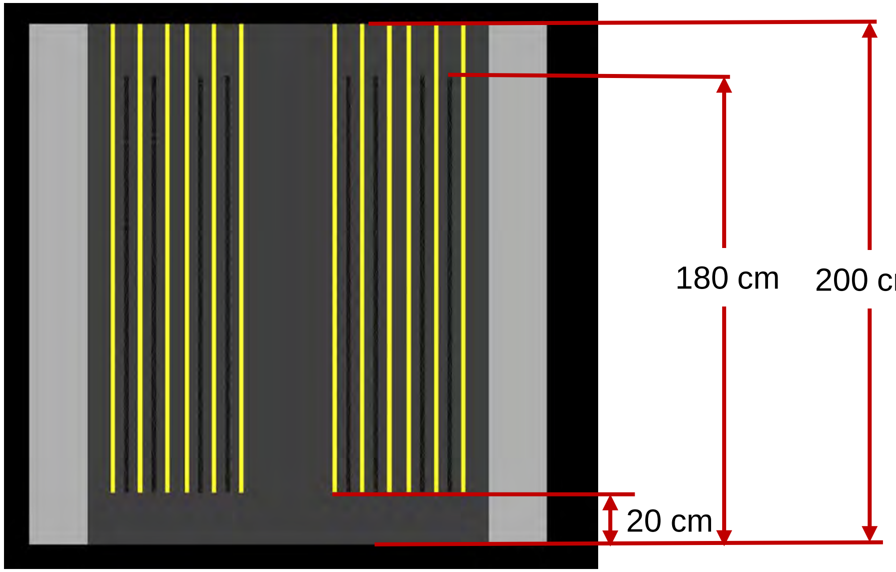


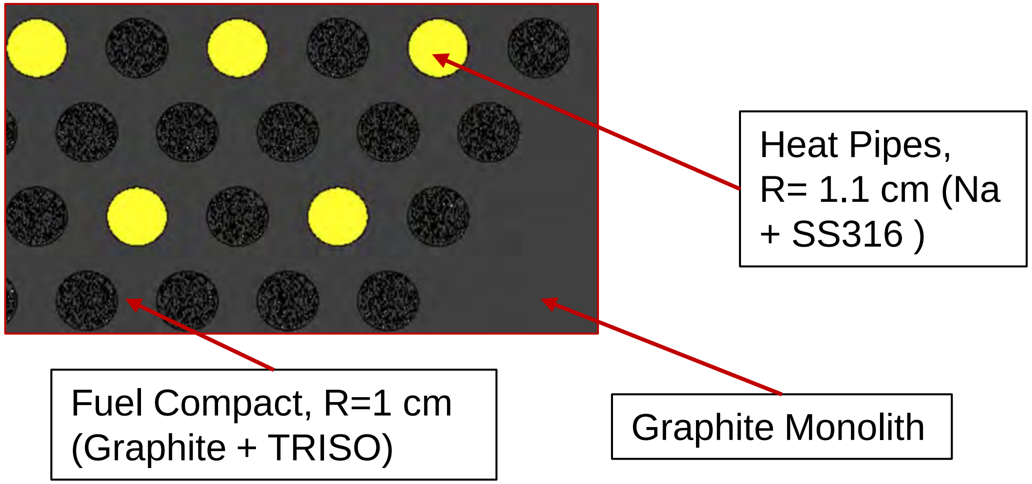
5 MW_{th} eVinci-like Heat-Pipe-cooled microreactor

Stefano Terlizzi, Vincent Labouré, Asymptotic hydrogen redistribution analysis in yttrium-hydride-moderated heat-pipe-cooled microreactors using DireWolf, Annals of Nuclear Energy, Volume 186, 2023, 109735,

Creating an eVinci™-like HP-MR model







Neutronics Characteristics

- Effective multiplication factor for different operating conditions.

	Hot Conditions(1100 K)	Cold Conditions (300 K)
CDs in	0.949447 (20)	9.9884E-01 (56)
CDs out	1.08214 (28)	1.12753 (28)

- Point Kinetic Parameters

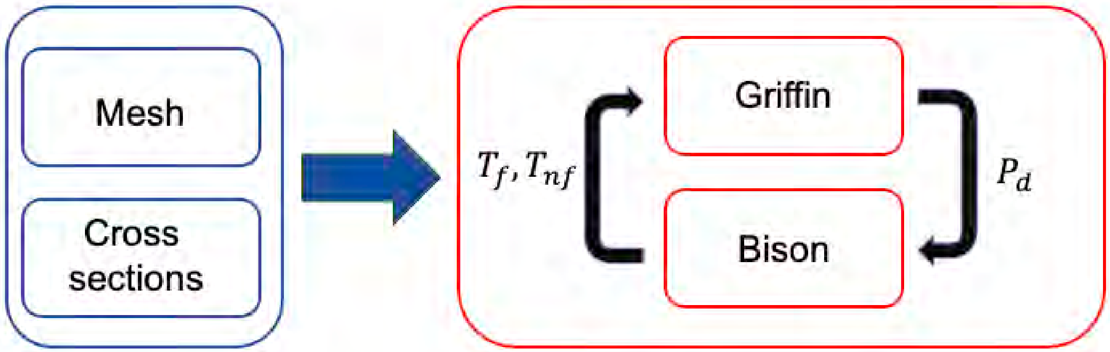
Parameter	New Value
Beta-eff (CD out, hot)	6.54179E-03 (970)
Lambda-eff (CD out, hot)	1.95734E-04 (157)

- Burnup and operational life

Parameter	Value
Power, MW_{th}	5.0
Time, years	4.0
BU, MWd/kg_{UO2}	2.17655E+01

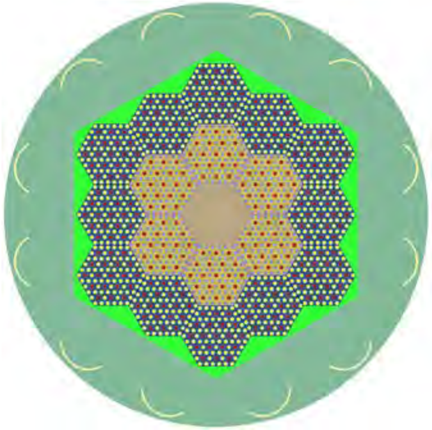
Steady-state Multiphysics Calculations

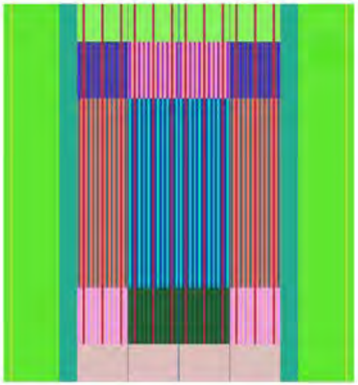
- Griffin and Bison coupled through the MOOSE MultiApps system
  - Griffin is run to simulate the neutron transport in the core.
  - Bison that is utilized to solve for the temperature
- Currently, the HPs are simulated through convective boundary conditions where the heat transfer coefficient is obtained from Sockeye by imposing realistic wall temperature profiles.
- Future work will be focused on explicitly modeling the HPs with Sockeye.



Multigroup Cross Section Generation / OpenMC Model

- OpenMC code was used to generate microscopic cross sections in the multigroup format to perform Griffin
  - deterministic neutron transport calculation.
  - micro-depletion calculation to determine the isotopic composition of the burned fuel.
- A full core OpenMC model was developed considering
  - 20 regions in the axial and radial direction to account for spectral changes in the core.
  - 11 energy group structure.
  - 233 isotopes for microscopic cross sections generation in the fuel region.
  - 3 cross section tabulation points (burnup, fuel temperature, and non-fuel)
- The cross sections generated by OpenMC were directly converted into ISOXML format by using the Griffin code's newly developed capability to process OpenMC output files (OpenMC-to-ISOXML converter).

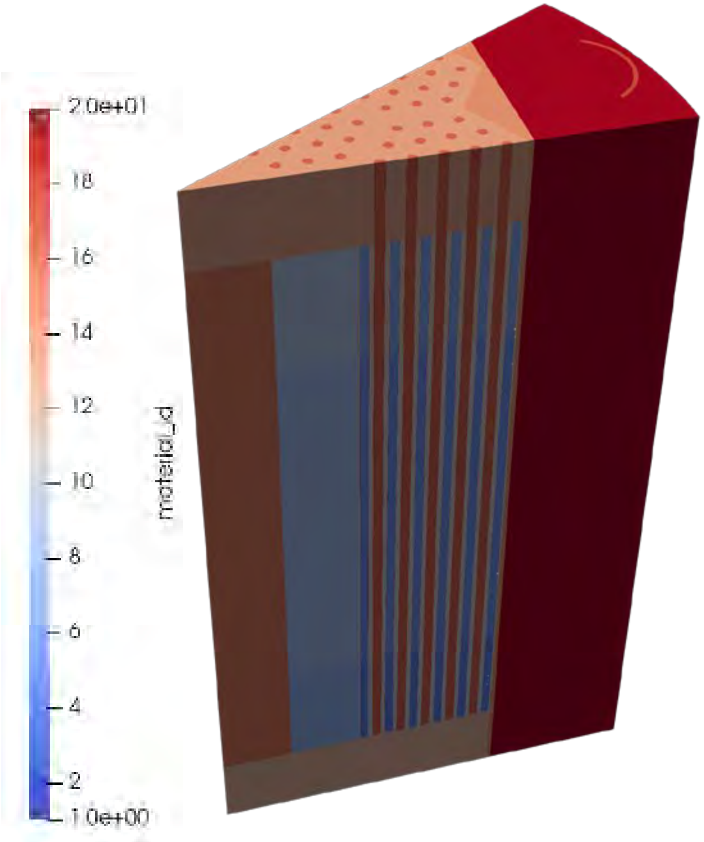




Steady State Neutronic Verification

- Comparison of eigenvalues between OpenMC and Griffin at several temperatures has proven the soundness of Griffin model and the cross-sections converter.

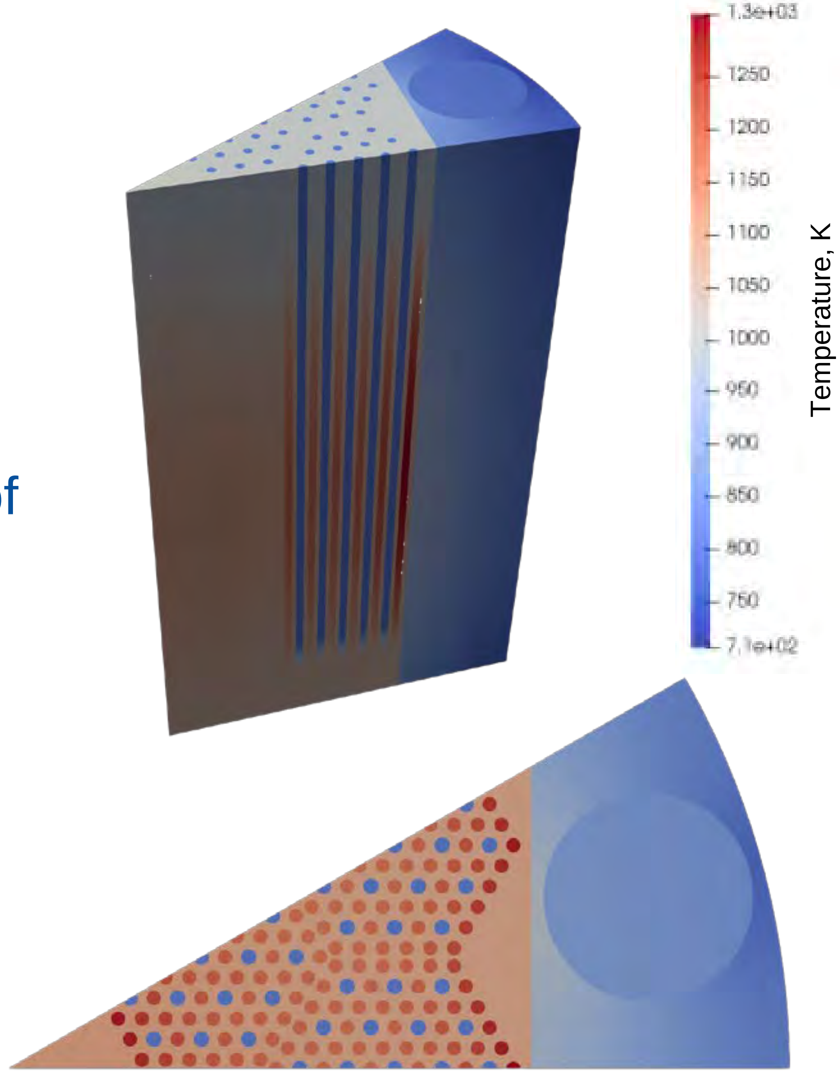
Temperature (K)	OpenMC	Griffin	Diff. (pcm)
700	1.05297 (15)	1.05597	300
800	1.04683 (14)	1.04992	309
900	1.04069 (15)	1.04350	281
1000	1.03526 (14)	1.03804	278
1100	1.02973 (15)	1.03240	267
1200	1.02407 (14)	1.02688	281



IDAHO NATIONAL LABORATORY

Steady State Coupled Calculations

- Griffin and Bison coupled calculations was performed.
- Simulation takes 22 minutes on 48 processors.
- Heat pipes are treated as heat sink with the bulk temperature of 800K by applying convective boundary condition.
  - Will be replaced with Sockeye when doing transient calculation.
- Coupled k_{eff} : 1.02542 (k_{eff} at 800K is 1.04992).



Summary and Future Work

- The first quarter of FY24 was focused on:
  - Definition of preliminary eVinci^{TM}-like reactor model
  - Creation of a BlueCRAB model for multiphysics microdepletion
  - Verification of Griffin vs. OpenMC and coupled calculations
- Ongoing and future work:
  - Cross sections library generation and verification for depletion calculation
  - Inclusion of explicit Sockeye model for HPs
  - Completion of transient scenario for heat-pipe failure

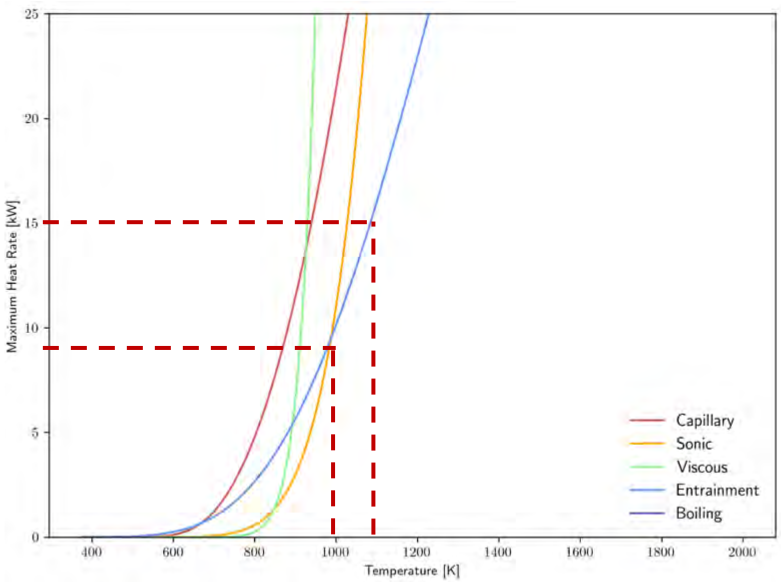
Idaho National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy.
INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.

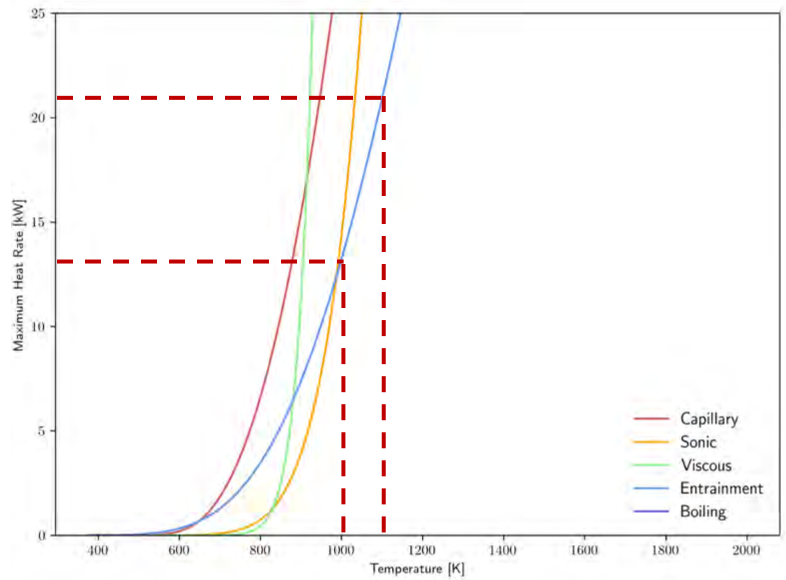
Heat pipe limits

- The heat pipes radius was chosen to respect operating limits computed from Sockeye [1].

R=1 cm

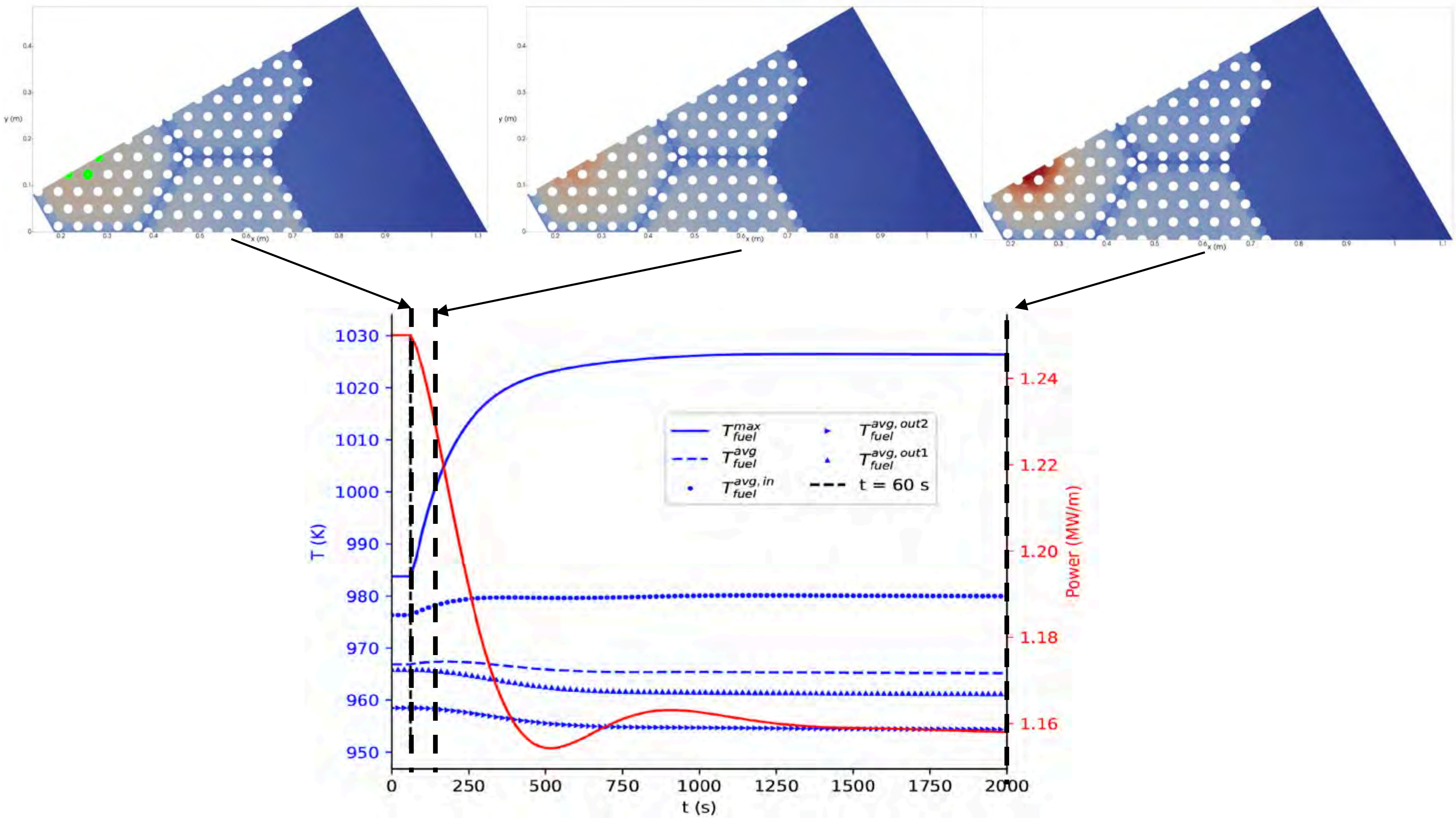


R=1.1 cm

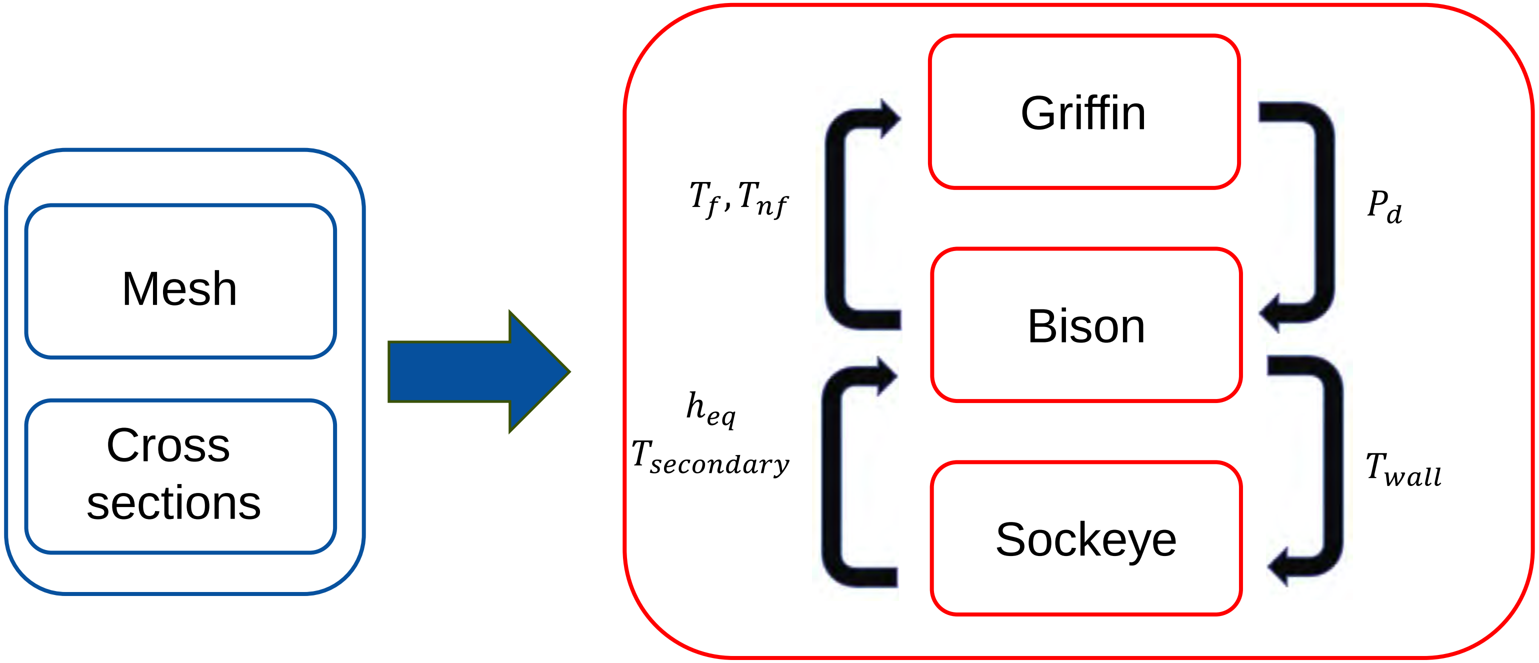


[1] Amir Faghri. *Heat Pipe Science and Technology*. Global Digital Press, second edition, 2016. ISBN 978-0-9842760-1-1.

Example of workflow in FY23



Multiphysics Calculations



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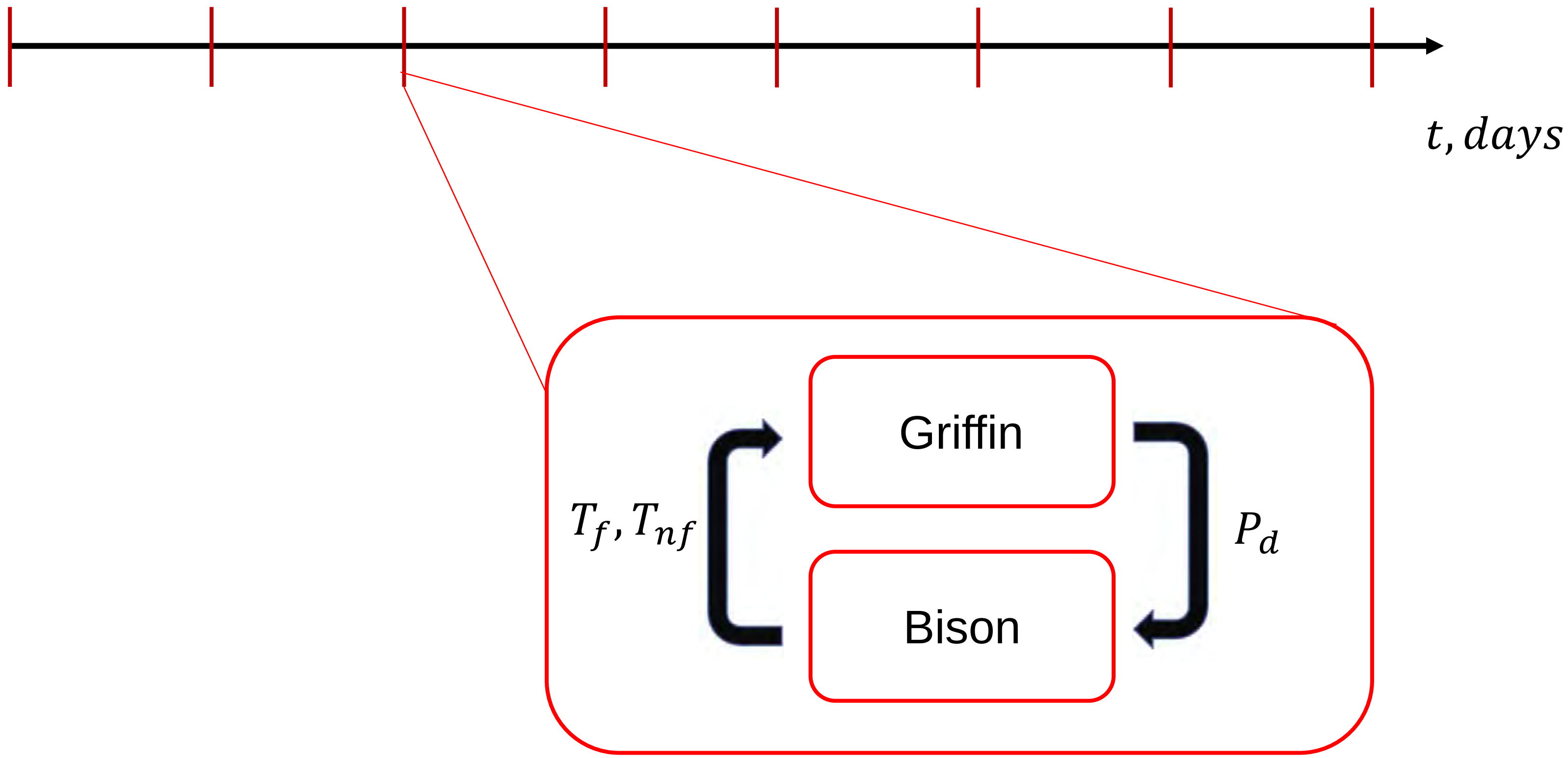


Group structure

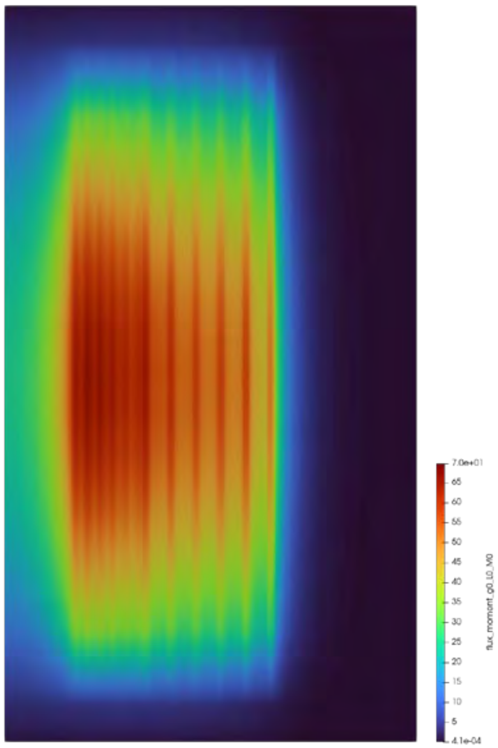
Group	Upper Energy [eV]	Lower Energy [eV]
1	4.000E+07	8.210E+05
2	8.210E+05	1.830E+05
3	1.830E+05	4.900E+04
4	4.900E+04	4.540E+02
5	4.540E+02	4.810E+01
6	4.810E+01	9.880E+00
7	9.880E+00	4.000E+00
8	4.000E+00	1.000E+00
9	1.000E+00	3.200E-01
10	3.200E-01	6.700E-02
11	6.700E-02	1.000E-05

HP-MR Dimensions

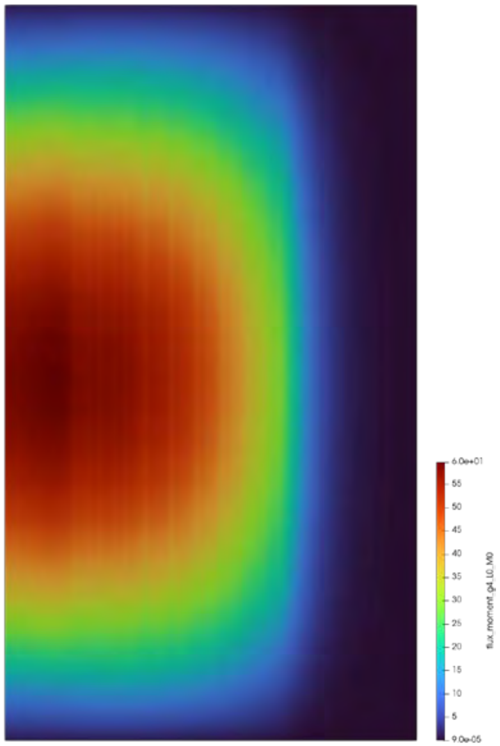
Parameter	Actual Value
Power, MW	5
Number of Assemblies	18
Assembly Pitch, cm	32
Number of fuel compacts in an assembly	72
Radius of fuel compact, cm	1
Heat Pipes/Assembly	19
Heat Pipe Radius	1.1
Pin Pitch	3.4 cm
Thickness of top axial reflector, cm	20
Thickness of bottom axial reflector, cm	20
Active Zone Height, cm	160
Number of control drums	12
Radius of control drum, cm	15
Arc width of poison strip in control drum, degree	120
Inner radius of poison strip, cm	14.0 (1.0 cm thick B_4C)
Geometry of radial reflector and canister	Hex/cylinder
Outer diameter of the core block, cylindrical for simplicity	Hexagonal, with 75 cm apothem
Outer diameter of radial reflector, cm	224.0 cm
Outer diameter of canister wall (or core barrel), cm	WEC provide
Central Hole	Graphite
TRISO packing fraction	36%

Flux at Side

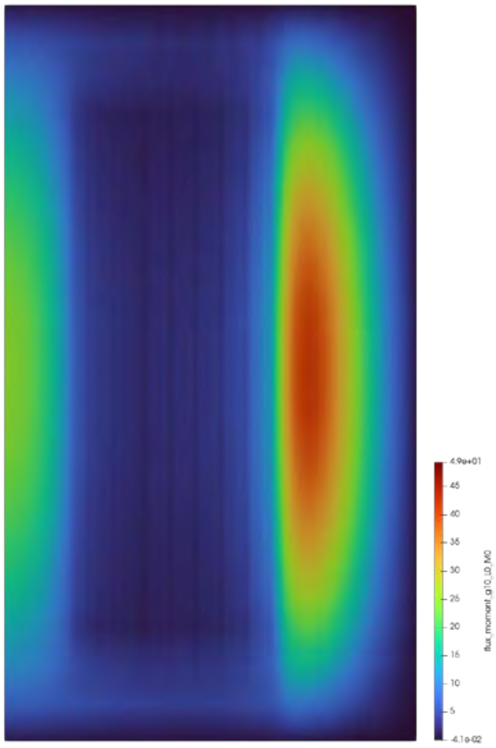
Fast Flux (G1)



Intermediate Flux (G5)

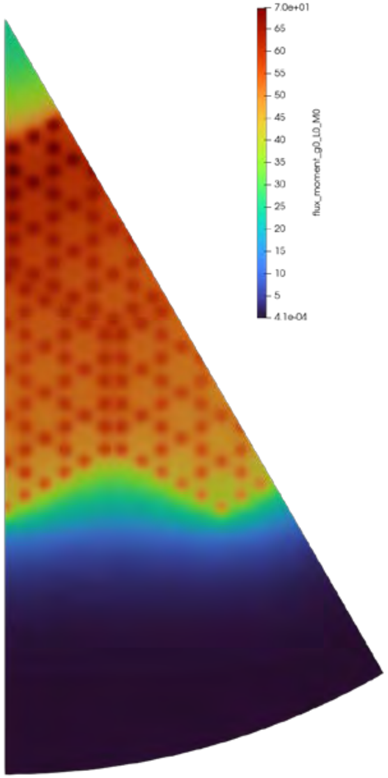


Thermal Flux (G11)

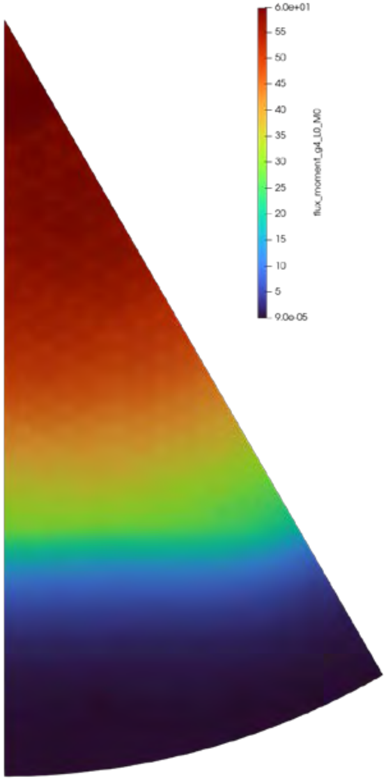


Flux at Center Plane

Fast Flux (G1)



Intermediate Flux (G5)



Thermal Flux (G11)