INL/CON-24-76987-Revision-0

CRAB/MELCOR Code to Code Comparison

March 2024

Stefano Terlizzi, Namjae Choi, Mustafa Kamel Mohammad Jaradat, Jason Albert Christensen

Changing the World's Energy Future

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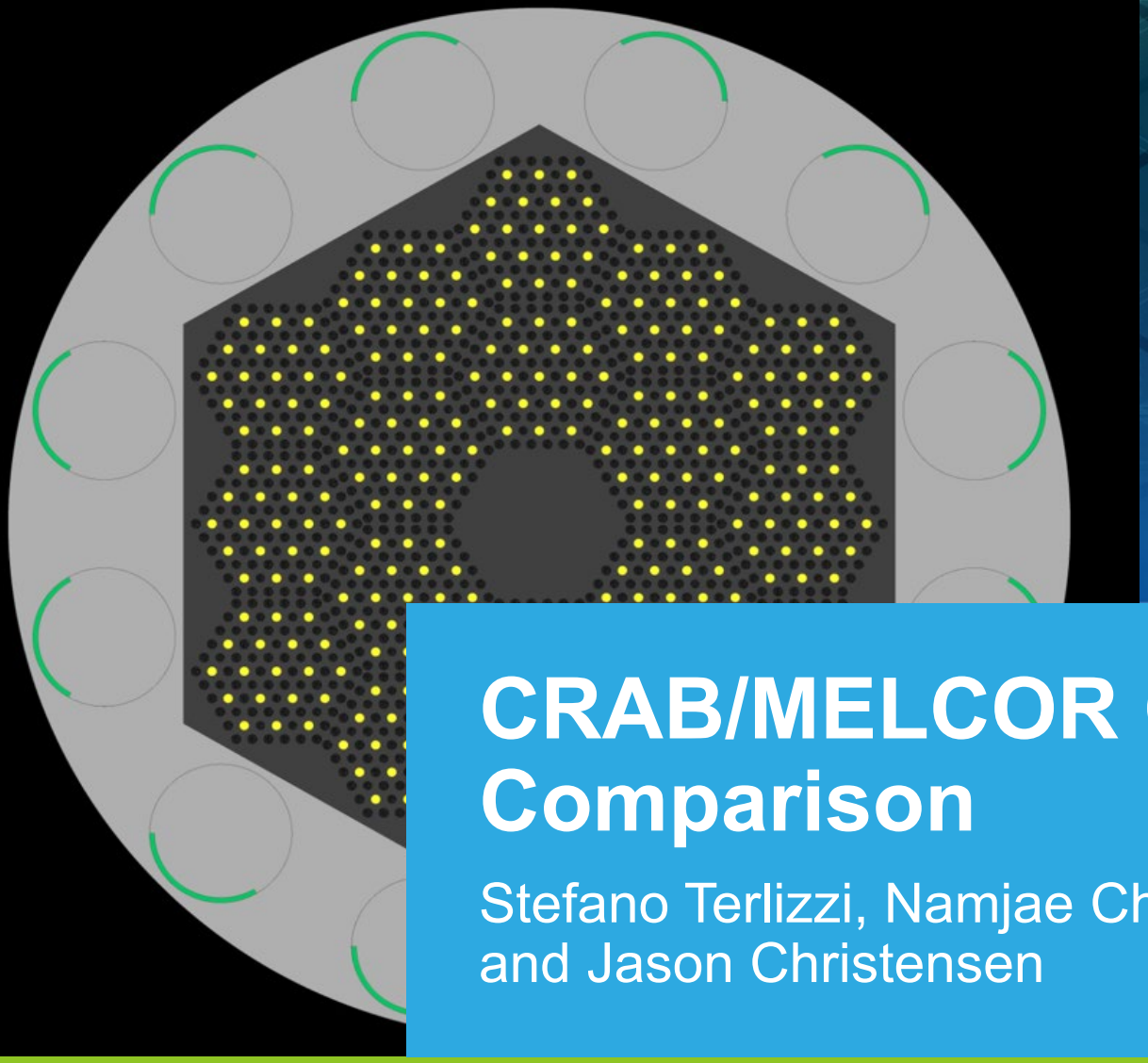

March 5, 2024

Presenter: Stefano Terlizzi

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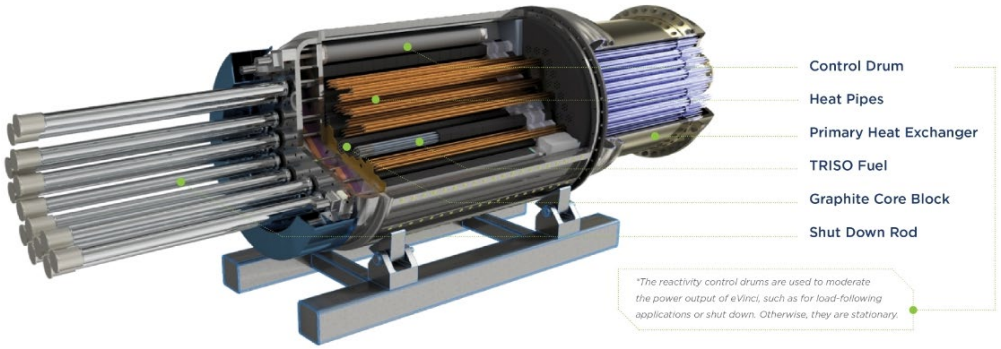
Introduction

- **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.



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

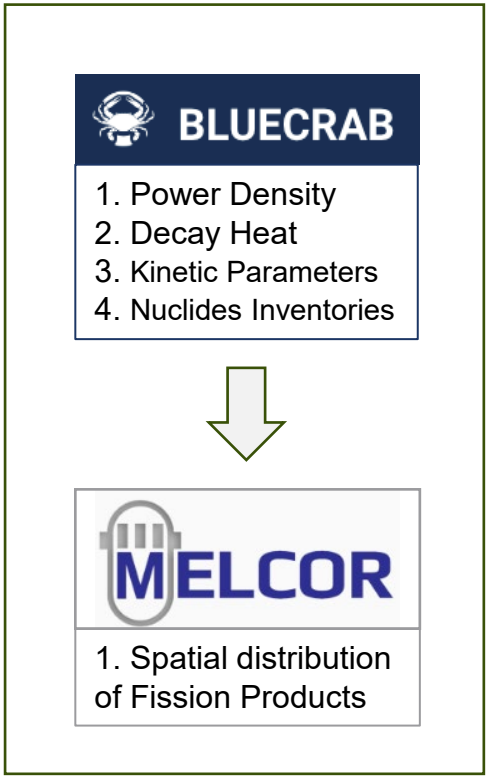


Figure 1. eVinci™ rendering and workflow CRAB-MELCOR workflow

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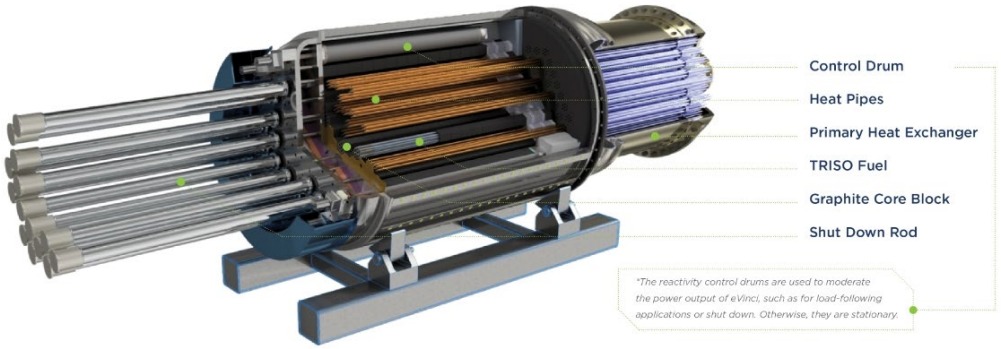

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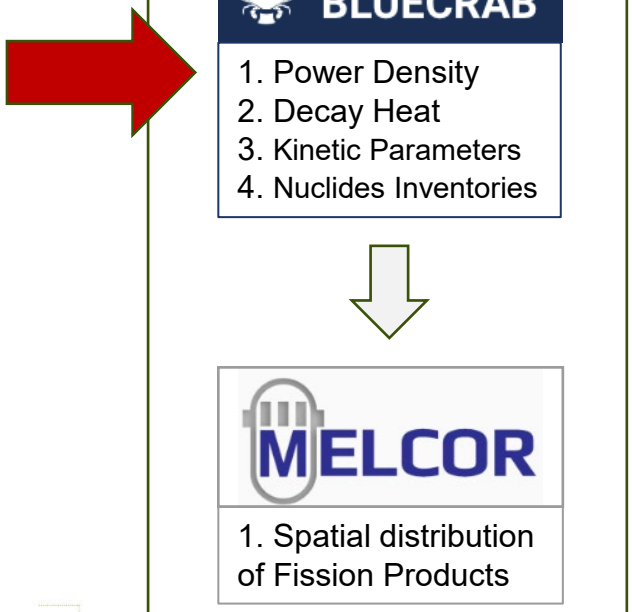


Figure 1. eVinci™ rendering and workflow CRAB-MELCOR workflow

The Comprehensive Reactor Analysis Bundle (CRAB)

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.

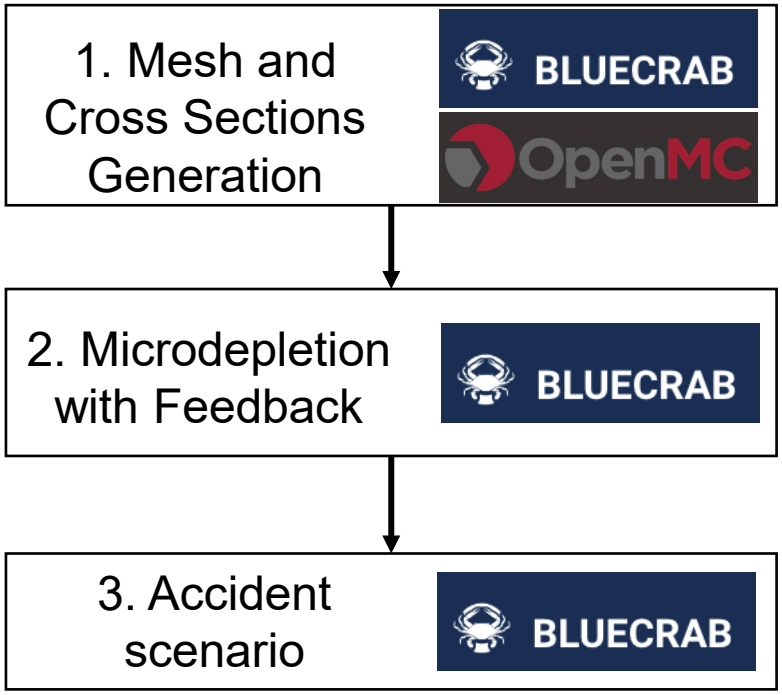
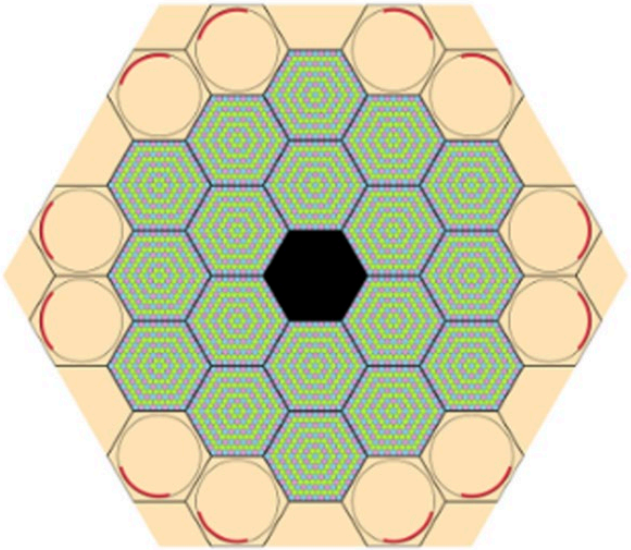


Figure 2. Integrated BlueCRAB-MELCOR workflow.

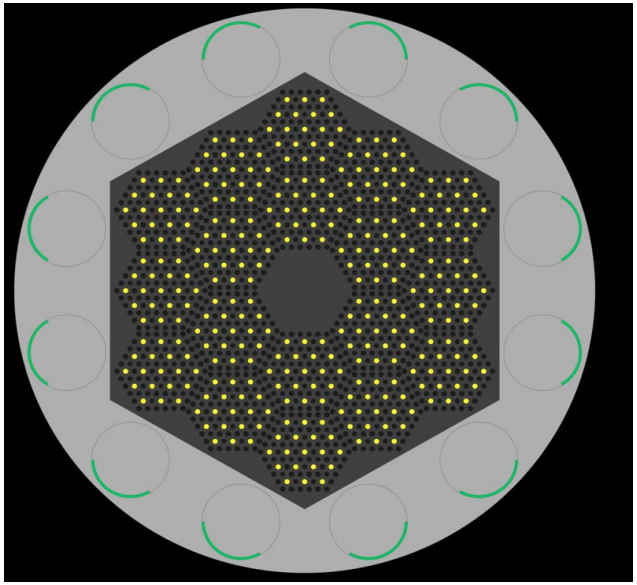
Creating an eVinci^{TM}-like HP-MR model

FY23



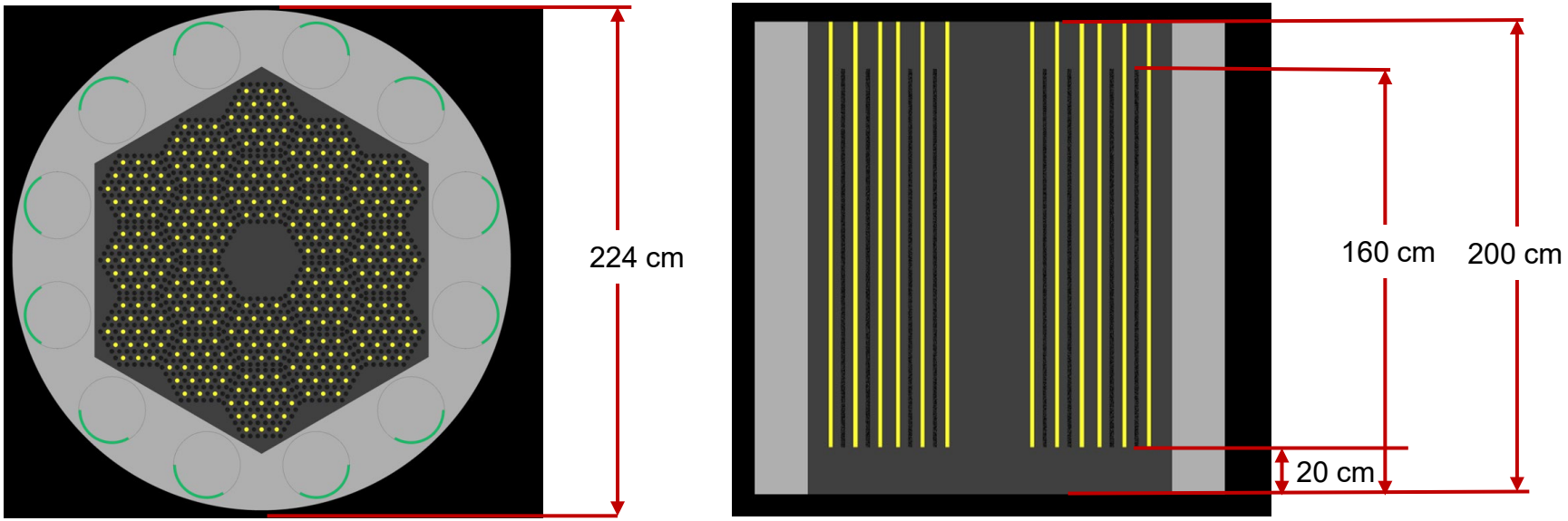
Simplified Microreactor Benchmark Assessment (SiMBA) problem

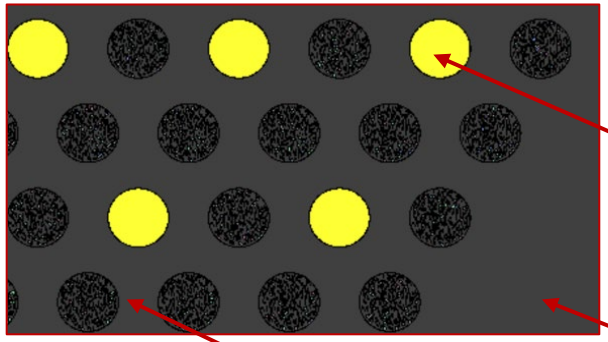
FY24



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

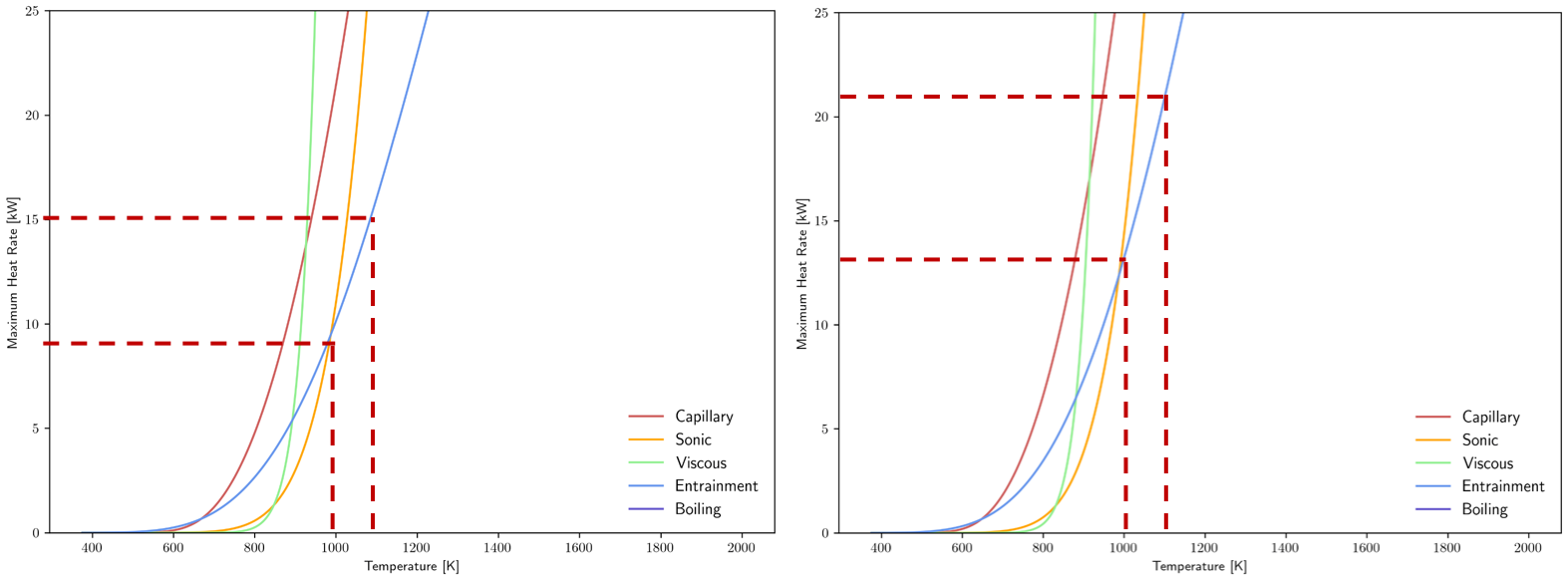
Creating an eVinci™-like HP-MR model





Heat pipe limits

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



Operating limits for heat pipes. The right figure reports the limits for 1-cm radius HPs, while the right figure reports the limiting curves for 1.1 cm. The dashed lines are used to highlight the limiting power value. It should be higher than 14.6 kW/HP.

Generic Heat-Pipe cooled Micro-Reactor (g-HPMR)

Effective multiplication factor for different operating conditions.

	Hot	Cold
CDs in	0.939457 +/- 30 pcm	9.94662E-01+/- 46 pcm
CDs out	1.07215 +/-28 pcm	1.11754 +/- 26 pcm

Point Kinetic Parameters

Parameter	New Value
Beta-eff (CD out, hot)	6.82588E-03+/-0.00404
Lambda-eff (CD out, hot)	1.99075E-04 +/- 0.00069 s

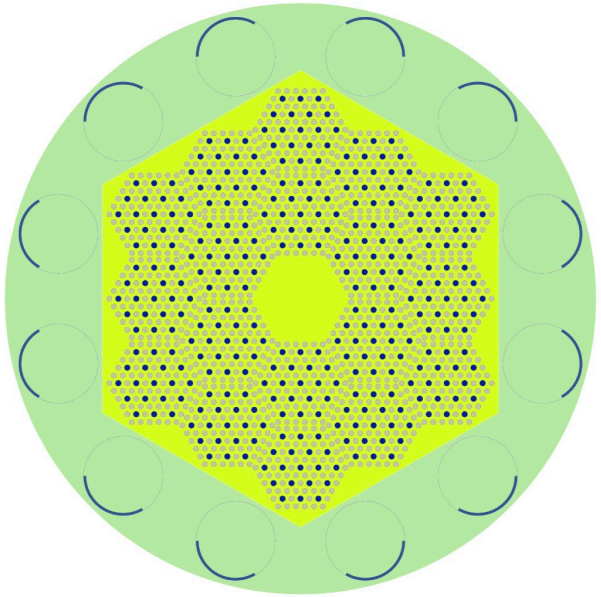
Burnup and operational life

Parameter	Value
Fuel density, g/cm^3	10.4
Fuel volume, cm^3	36380.6
Power, MW_{th}	5.0
Time, years	4.0
Fuel mass, kg	378.35824
BU, MWd/kg_{UO_2}	23.1526608

Power distribution and depletion

OpenMC cross sections preparation

- 11-groups multigroup cross sections
- Cross sections are tabulated with respect to fuel temperature, non-fuel temperature, and burnup (i.e., 3 parameters)
- Isotopes tracked: number …



OpenMC-to-ISOXML converter

- 11-groups multigroup cross sections
- Cross sections are tabulated with respect to fuel temperature, non-fuel temperature, and burnup (i.e., 3 parameters)
- Isotopes tracked: number …

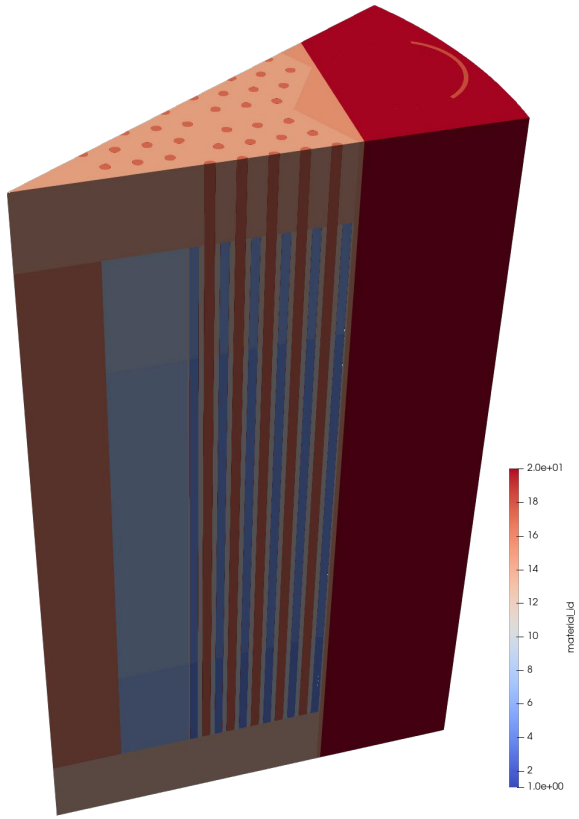
Steady State Neutronic Verification

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

Comparison of OpenMC and Griffin (P_3 DFEM-S_N) k_{eff}

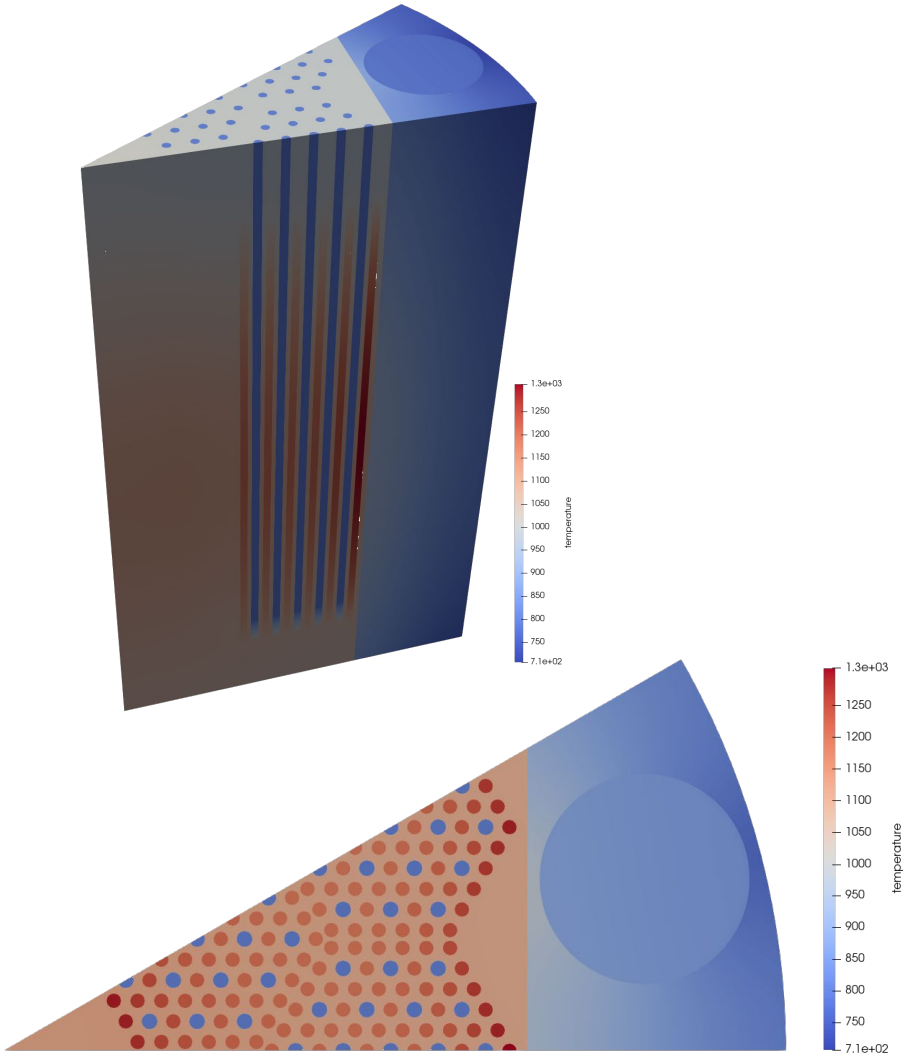
Temperature (K)	OpenMC	Griffin	Diff. (pcm)
700	1.05297 (15)	1.05597	300
800	1.04683 (14)	1.04992	309
900	1.04069 (15)	1.04350	281
1000	1.03526 (14)	1.03804	278
1100	1.02973 (15)	1.03240	267
1200	1.02407 (14)	1.02688	281

Griffin Cross Section Zones



Steady State Coupled Calculations

- Bison was coupled with Griffin.
- 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).



Testing Depletion Coupled Calculations

Summary and Future Work

- The first quarter of FY24 was focused on:
  - Definition of an eVinci™-like reactor model
  - Creation of a BlueCRAB model for multiphysics microdepletion
  - Verification of neutronics and OpenMC-ISOXML converter
- 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

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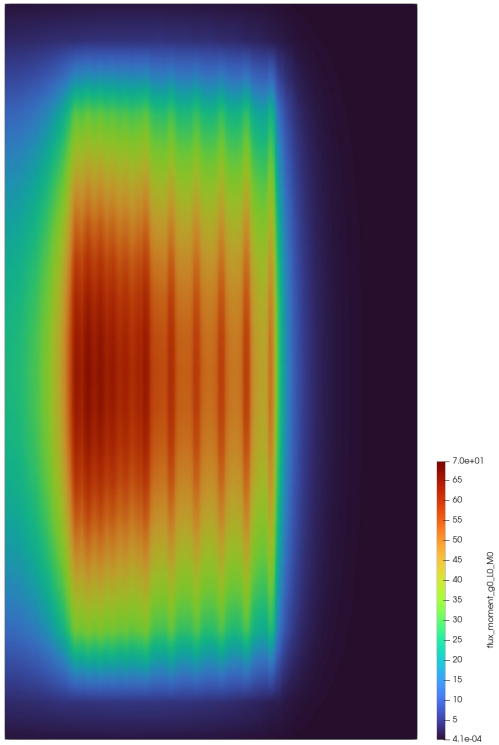
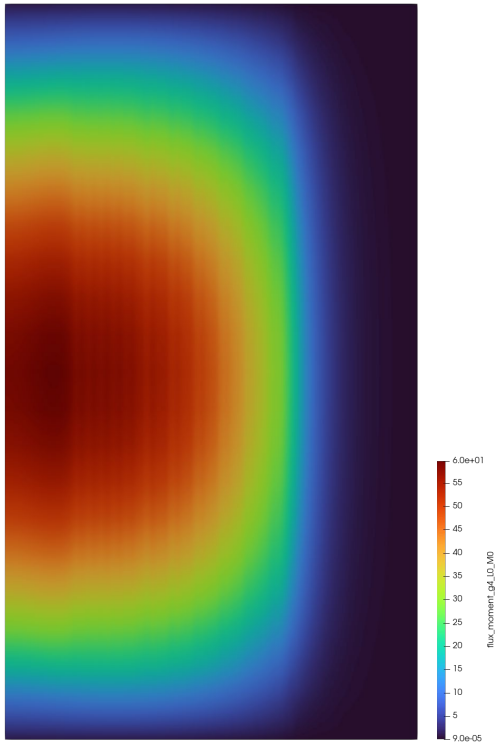
Flux at Side

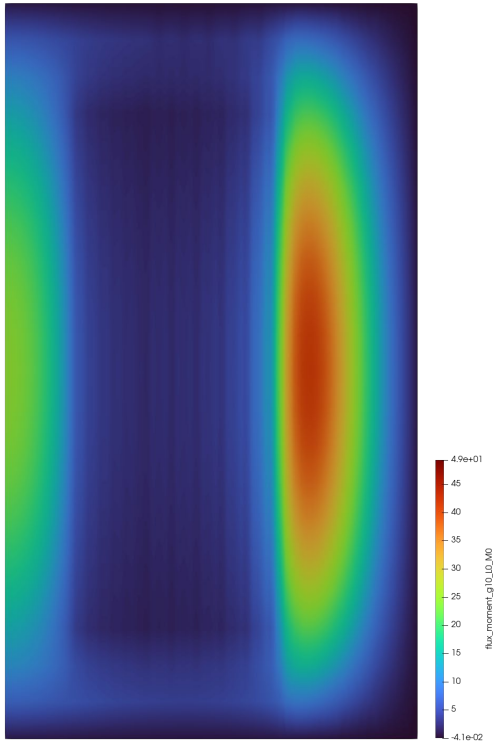
Fast Flux (G1)



Intermediate Flux (G5)

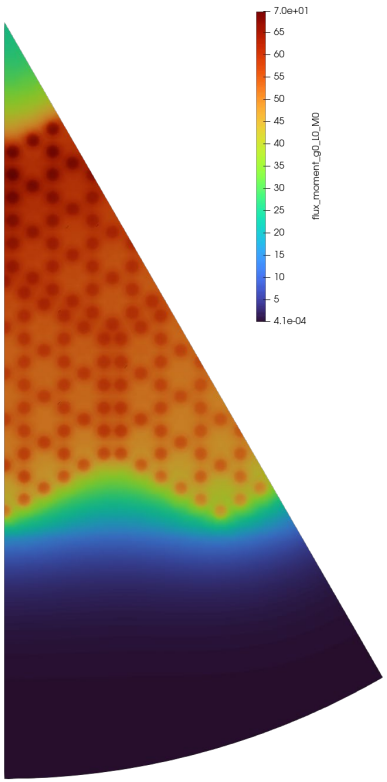


Thermal Flux (G11)

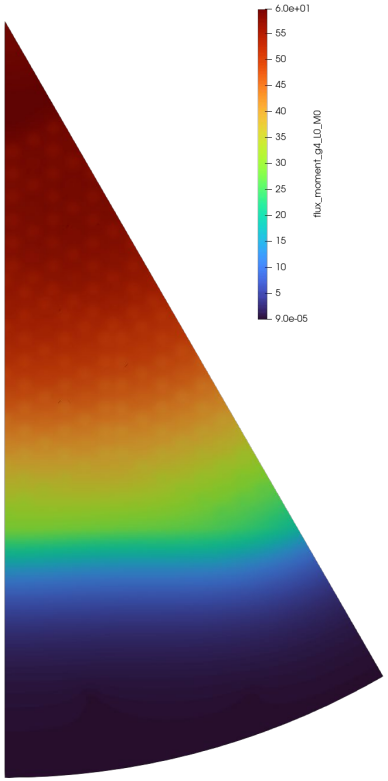


Flux at Center Plane

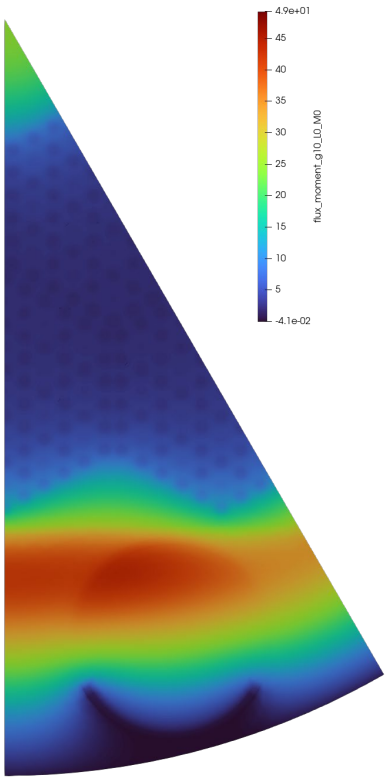
Fast Flux (G1)



Intermediate Flux (G5)



Thermal Flux (G11)

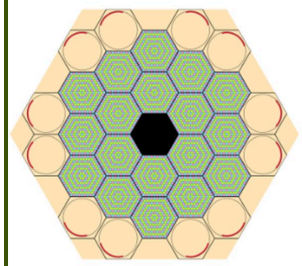


HP-MR Dimensions

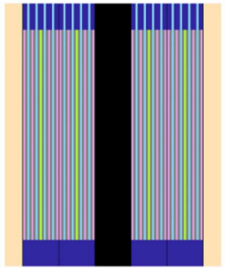
Parameter	Actual Value
Power, MW	5
Number of Assemblies	18
Assembly Pitch, cm	32
Number of fuel compacts in an assembly	72
Radius of fuel compact, cm	1
Heat Pipes/Assembly	19
Heat Pipe Radius	1.1
Pin Pitch	3.4 cm
Thickness of top axial reflector, cm	20
Thickness of bottom axial reflector, cm	20
Active 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%

Example of workflow in FY23

OpenMC **Cross sections**



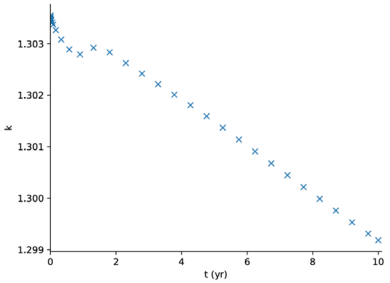
(a)



(b)

BLUECRAB **Mesh**

BLUECRAB



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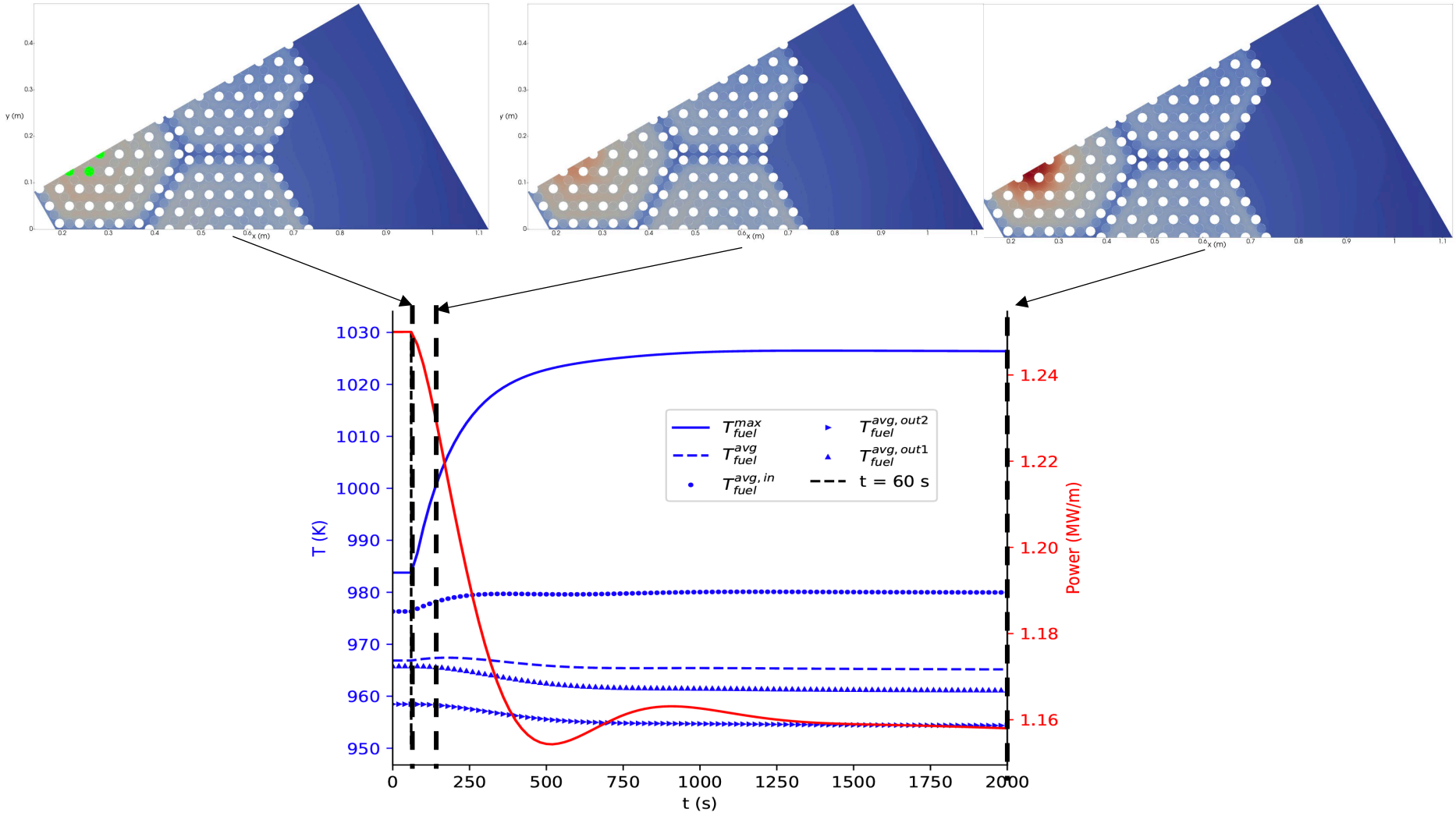

Microdepletion with feedback