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RELAP5-3D Solutions to Exercise 1 of the OECD-NEA HTTF Benchmark

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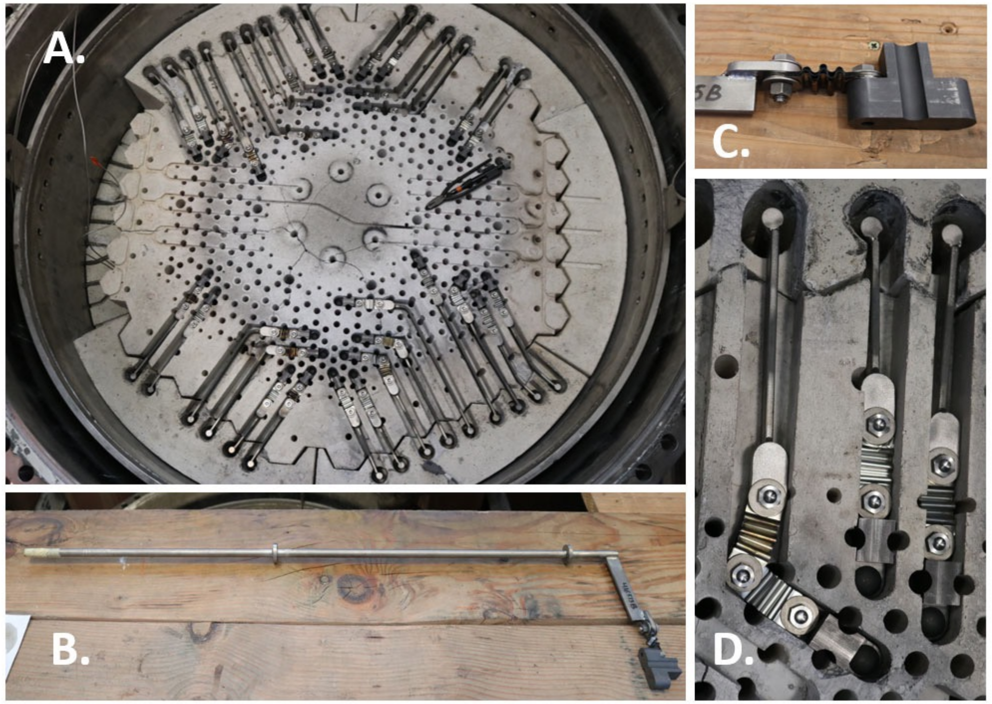
FAILURE IS NOT AN OPTION.

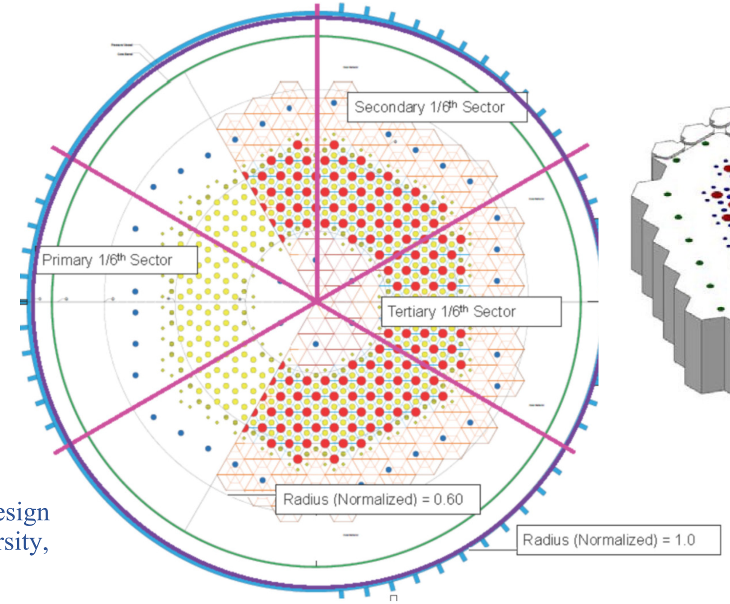
Prismatic gas-cooled microreactors are approaching deployment

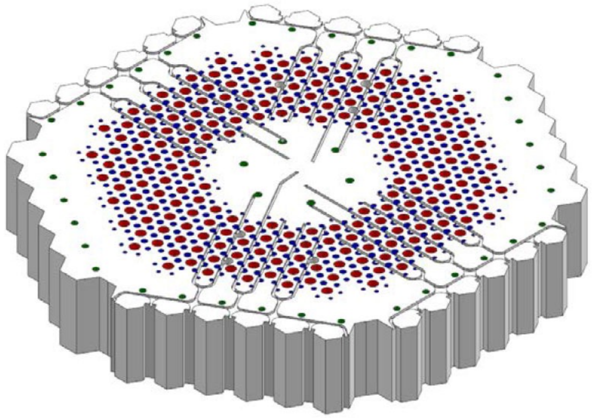
- Ultra Safe Nuclear Corporation and BWXT are planning to deploy prismatic block gas-cooled microreactors by the end of the decade
- While prismatic HTGRs have been built previously (Fort St. Vrain, High Temperature Engineering Test Reactor, etc.), many modern thermal hydraulics tools have not been validated for prismatic HTGR modeling
- To provide a set of verification and validation problems, the DOE Advanced Reactor Technologies – Gas Cooled Reactor (ART-GCR) campaign has spearheaded the development of an HTGR thermal hydraulics benchmark based on the High Temperature Test Facility (HTTF)

The High Temperature Test Facility

- HTTF is an integral-effects thermal hydraulics test facility for prismatic HTGRs built at Oregon State University (OSU)
- Non-nuclear facility heated by graphite resistive heater rods
- Facility contains > 500 instruments capable of providing high-quality time-dependent data about the state of the facility







Gutowska, I. and Woods, B., “OSU High Temperature Test Facility Design Technical Report,” OSU-HTTF-ADMIN-005-R2, Oregon State University, Corvallis, OR, 2019.

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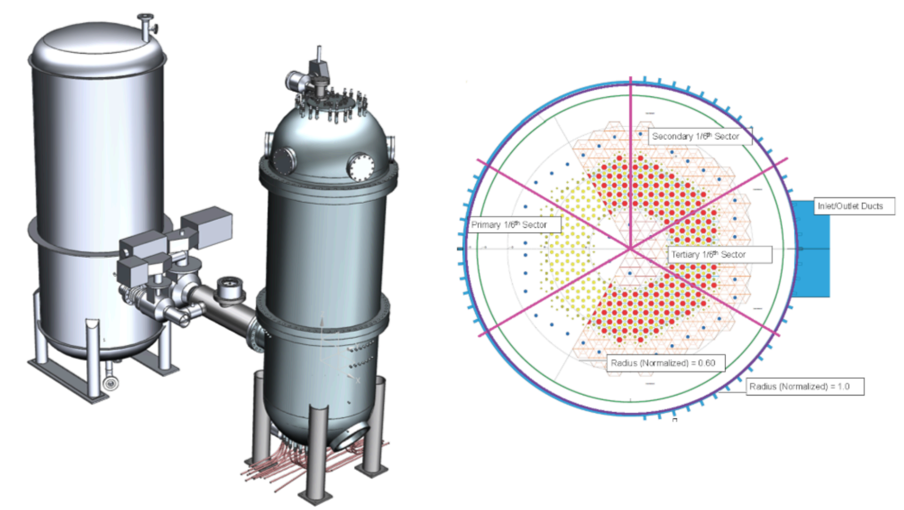
OECD-NEA High Temperature Gas-Cooled Reactor Thermal Hydraulics Code Validation Benchmark

- HTTF is being used to develop a thermal hydraulics code validation benchmark
- Benchmark is being spearheaded by the DOE ART – GCR campaign
  - Input from INL, ANL, OSU, UTK, CNL and others
- Benchmark includes problems for lower plenum mixing, depressurized conduction cooldown (DCC), and pressurized conduction cooldown (PCC)
- Benchmark problems include exercises for code-to-code comparison, best-estimate modeling, and error scaling
- Benchmark has interest from participants in Belgium, Canada, Italy, Korea, Poland, UK, and US

Thermal hydraulic code validation benchmark for high temperature gas-cooled reactors using HTTF data (HTGR T/H)

Ongoing

Benchmark | Reactor physics | Thermal hydraulics | ...



Benchmark Problems and Exercises

- Focus of this presentation is Exercise 1 of Problems 2 and 3
- Problem 2: Exercise 1 is broken into 3 sub-exercises
  - 1A: Full-power steady state
  - 1B: DCC from full-power steady state
  - 1C: PG-29-like DCC
- Problem 3: Exercise 1 is broken into 4 sub-exercises
  - 1A: Full-power steady state
  - 1B: PCC from full-power steady state
  - 1C: PG-27-like low-power steady state
  - 1D: PG-27-like low-power PCC
- Exercise 1A is identical between Problem 2 and Problem 3
- Exercise 1B is identical aside from the depressurization in Problem 2

Problem	Experiment	Exercise 1	Exercise 2	Exercise 3
1 – Lower Plenum Mixing	PG-28	CFD/COU	CFD/COU	N/A
2 – DCC	PG-29	SYS/COU	SYS/COU	SYS
3 - PCC	PG-27	SYS/COU	SYS/COU	SYS

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RELAP5-3D Model of HTTF

- Core is modeled with a set of concentric heat structures and coolant channels
- Regions containing coolant channels are modeled with a unit-cell approach
- Heater rods communicate with core blocks through radiation heat transfer
- Heat structures communicate with one another through conduction or radiation enclosures to ensure heat can be removed to the reactor cavity cooling system (RCCS)
- A few thermophysical properties have been altered from the original RELAP5-3D model to match benchmark specifications

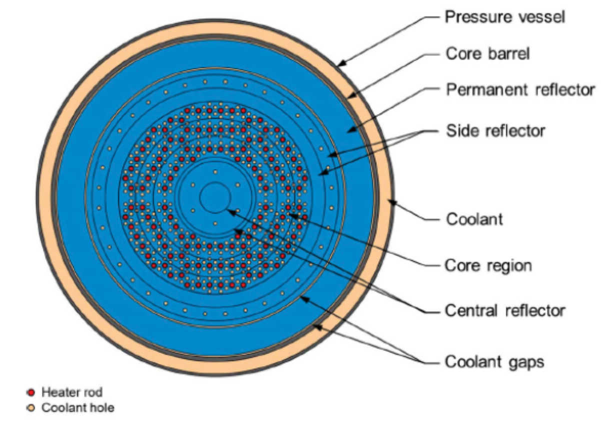
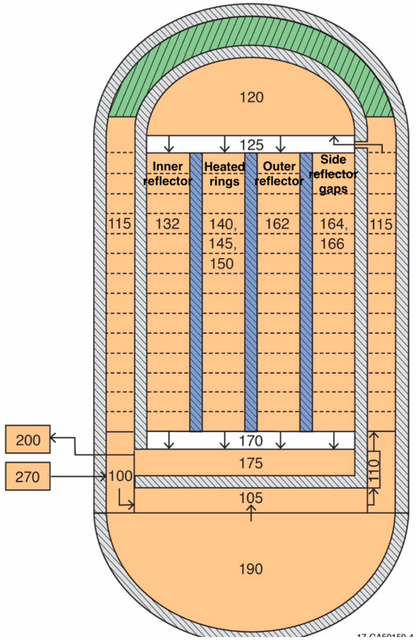
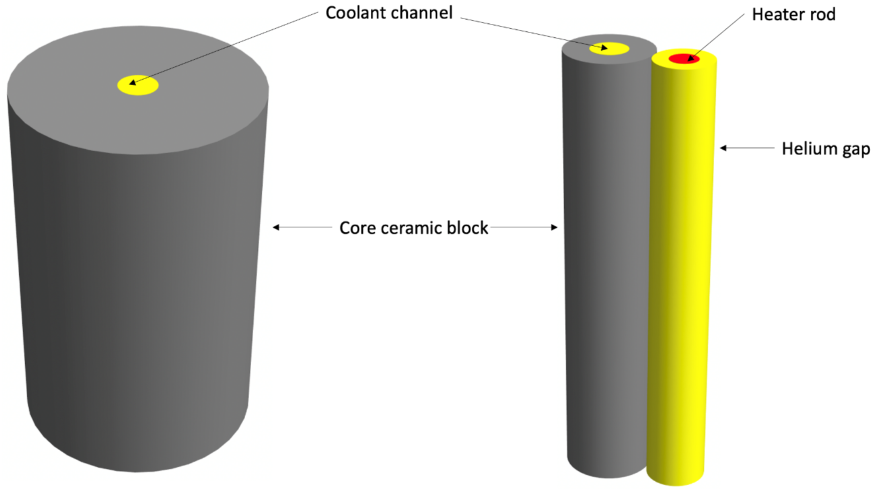


Figure 2. Primary pressure vessel radial nodalization.





RELAP5-3D model description can be found in: Bayless, P., "RELAP5-3D Input Model for the High Temperature Test Facility," Idaho National Laboratory, Idaho Falls, ID, INL/EXT-18-45579, 2018.

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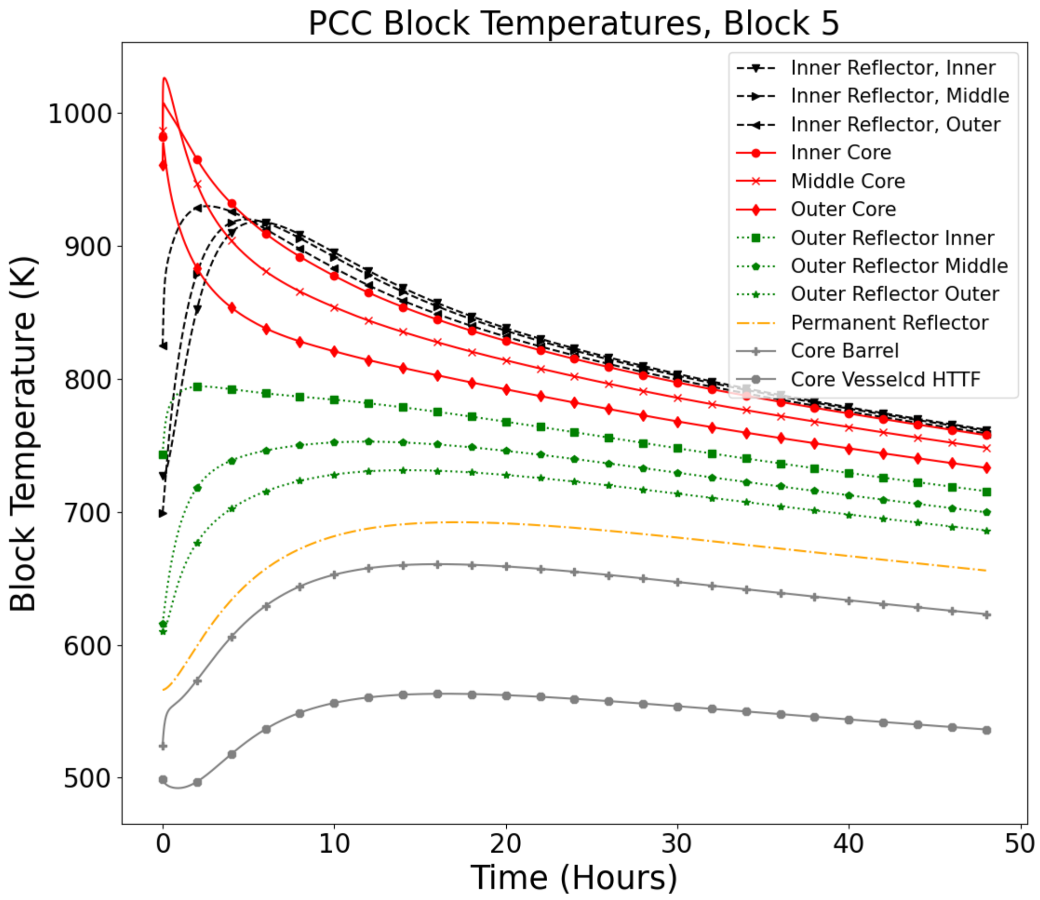
Exercise 1A and 1B problem definitions

- Table shows boundary conditions for Exercise 1A
- For Exercise 1B in both problems, inlet flow rate reduced linearly from 1.0 to 0.0 kg/s linearly over 1 second
- For Exercise 1B in both problems, ANS-94 decay heat standard is used starting at t=0 seconds
- For Problem 2 Exercise 1B, core depressurizes from 0.7 to 0.1 MPa linearly over 20 seconds

Parameter	Value
Helium Inlet Temperature (K)	500.0
Helium Pressure (MPa)	0.7
Helium Flow Rate (kg/s)	1.0
RCCS Inlet Temperature (K)	313.2
RCCS Water Pressure (MPa)	0.1
RCCS Flow Rate (kg/s)	1.0
RCCS Cavity Temperature (K)	300.0
RCCS Cavity Air Flow Rate (g/s)	25
Power (MW)	2.2

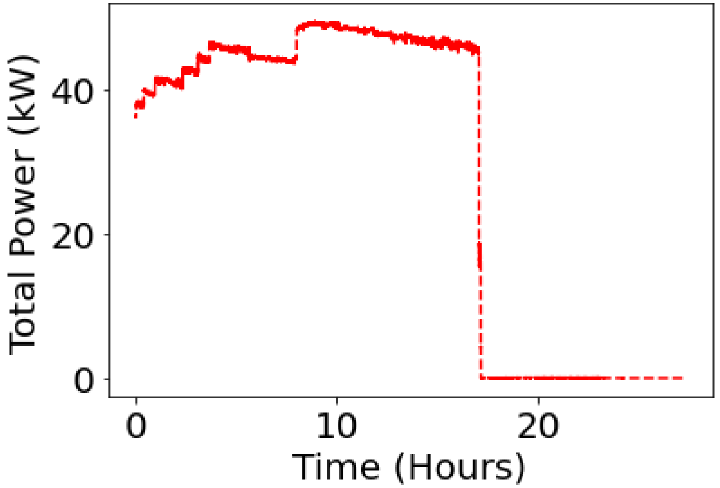
Results for Problem 2: Exercise 1B and Problem 3: Exercise 1B are very similar

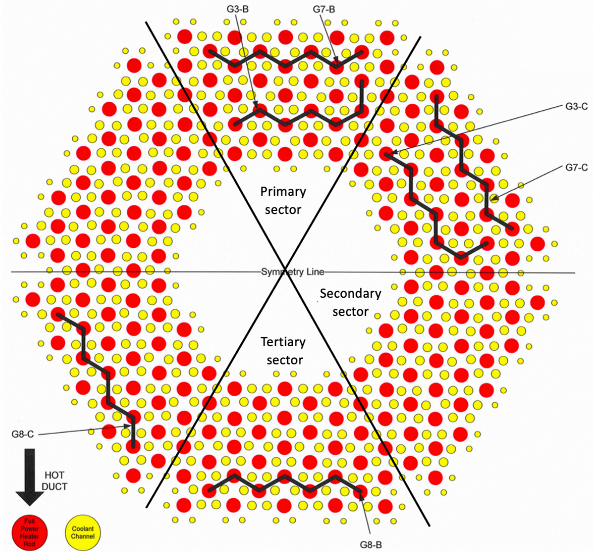
- Figure shows temperatures over time near core midplane for Problem 3: Exercise 1B
- Temperatures at Block 5 differ by < 10 K over 40 hours between Problem 2 and 3: Exercise 1B
- In Problem 2: Exercise 1B, natural circulation flow rate is 0.006 g/s
- In Problem 3: Exercise 1B, natural circulation flow rate is 0.32 g/s
- Natural circulation is relatively unimportant in HTTF

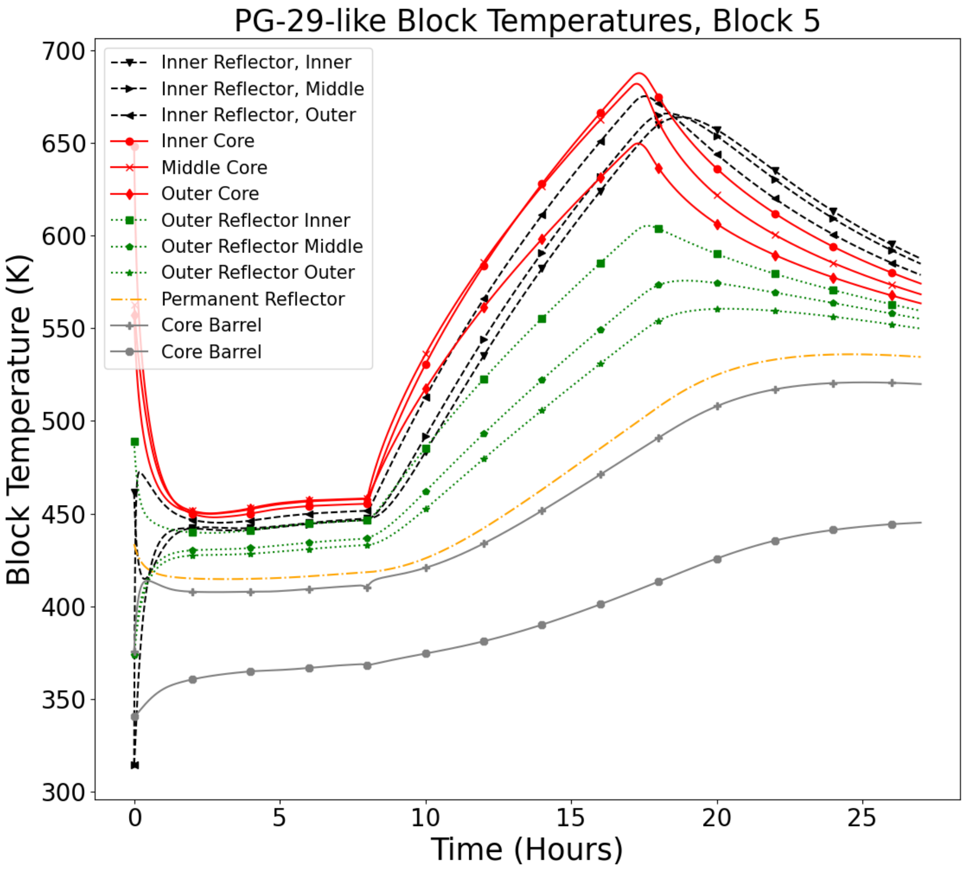


Problem 2: Exercise 1C

- Flow is 0.07 kg/s for the first 8 hours, then 0.0 kg/s
- Time-dependent outlet pressure boundary condition based on measured data from HTTF
- Power distributed around all 360° of the core assuming heater banks from primary (top middle) sector are used
- Initial temperature is based on the average temperature of working thermocouples in the experiment, but the RELAP5-3D model finds a new semi-steady state prior to the onset of the DCC at 8 hours







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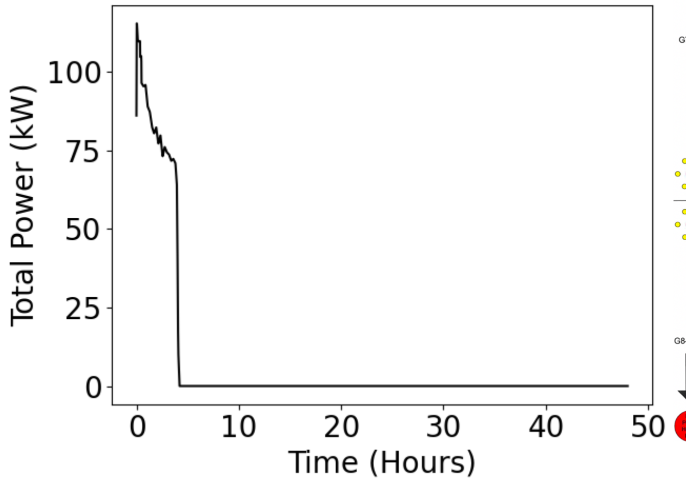
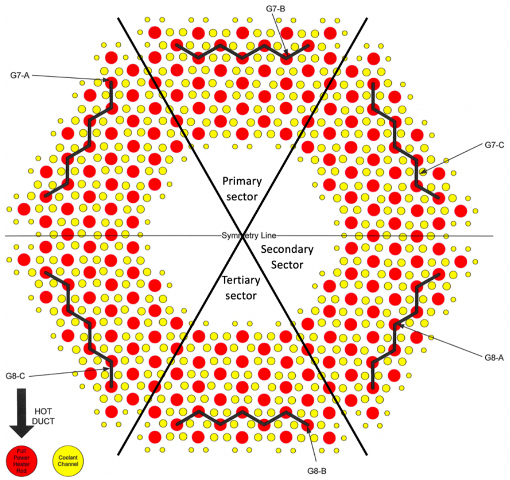
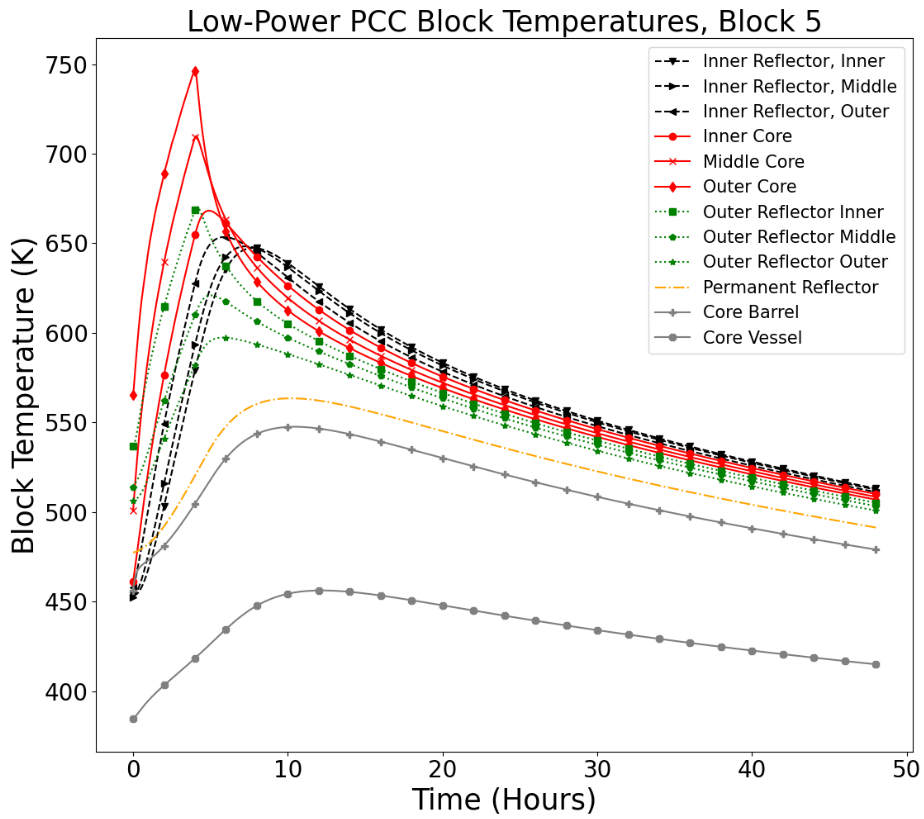
Problem 3: Exercise 1C and 1D

- Power is generated in the outer region of the facility
- Low-power steady-state has a power of 86 kW and a flow rate of 0.1 kg/s
- Power ramps up at t=0 to follow a power curve like the one from PG-27
- Temperature rise is larger in 1D than 1B, but this is because 1B has power and flow drop at the same time, while 1D has flow drop while power rises at first
- Outer core is the hottest part for the first few hours of the models because heat is generated primarily in the outer part of the core







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Conclusions and Ongoing Work

- We have presented RELAP5-3D results from ongoing benchmark activities
- Problem 2 and Problem 3 show similar results for Exercise 1B due to similar boundary conditions and the relatively low importance of natural circulation in HTTF
- The official benchmark kickoff was last week
- Code-to-code comparison activities are ongoing for early participants in the benchmark

Acknowledgements

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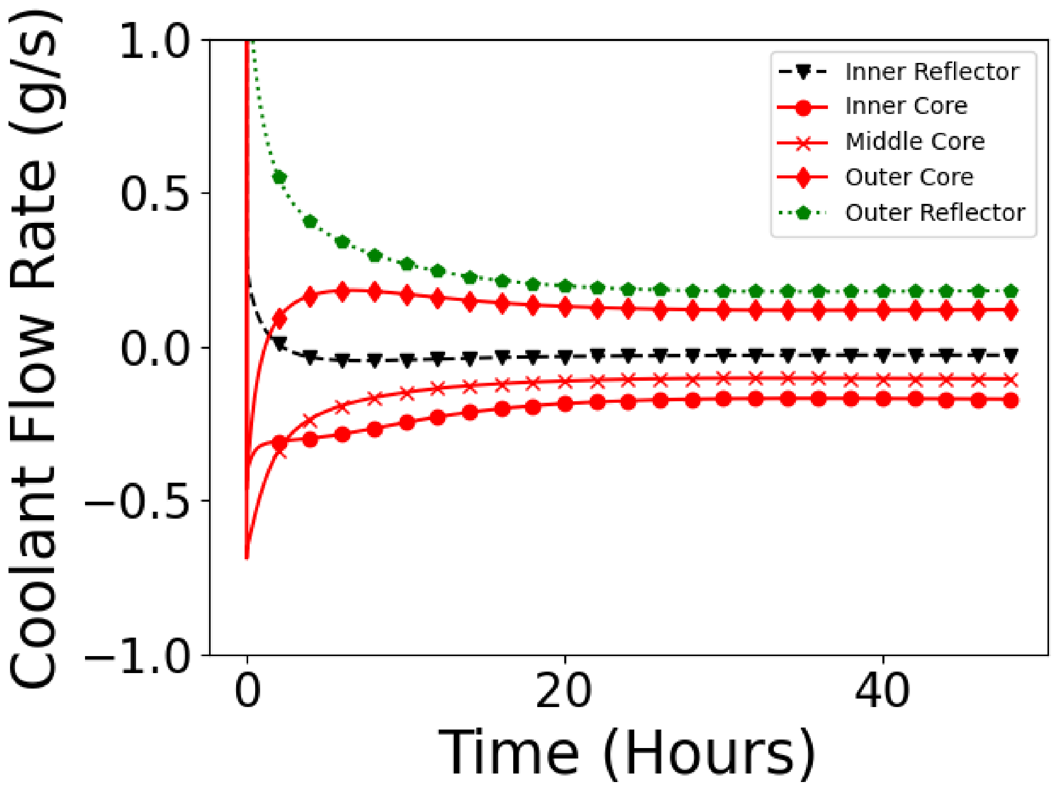
- This research made use of the resources of the High Performance Computing Center at Idaho National Laboratory, which is supported by the Office of Nuclear Energy of the U.S. Department of Energy and the Nuclear Science User Facility under contract number DE-AC07-05ID14157
- Thanks to Thanh Hua and Ling Zou of Argonne National Laboratory for defining Problem 3 conditions

Mass Flow over time from Problem 3: Exercise 1B

- Sign convention is positive downwards
- Flow reverses in the inner parts of the core but continues to go downward in the outer parts of the core
- Flow distributions are similar in Problem 2: Exercise 1B, but at much lower magnitude
- Natural circulation flow is a closed loop, with helium rising in the inner reflector, inner core, and middle core while falling in the outer core and outer reflector



Thermophysical properties

- When measured values are reported in the HTTF facility description, those values are used unless a different value is explicitly specified
  - For temperatures below the lowest temperature in the facility description, use the value at the lowest temperature in the facility description
  - For temperatures above the highest temperature in the facility description, use the value at the highest temperature in the facility description
- Aside from block thermal conductivity and emissivity values in the table on the right, most thermophysical properties are those from the original RELAP5-3D model
  - Block thermal conductivity is the measured HTTF block values

Material	Emissivity (-)
Graphite heater rods	0.9
Greencast 94-F (Core blocks)	0.581
ShotTech SiC 80 (Permanent reflector)	0.721
Stainless steel for core barrel	0.075
Stainless steel for pressure vessel	0.25
Polished stainless steel for RCCS panels	0.074