GAS-COOLED REACTOR

ADVANCED REACTOR TECHNOLOGIES PROGRAM

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Progress in the HTTF Benchmark and RELAP5-3D Gas-Cooled Reactor Validation

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2024 ART-GCR Program Review

Hybrid Meeting at INL

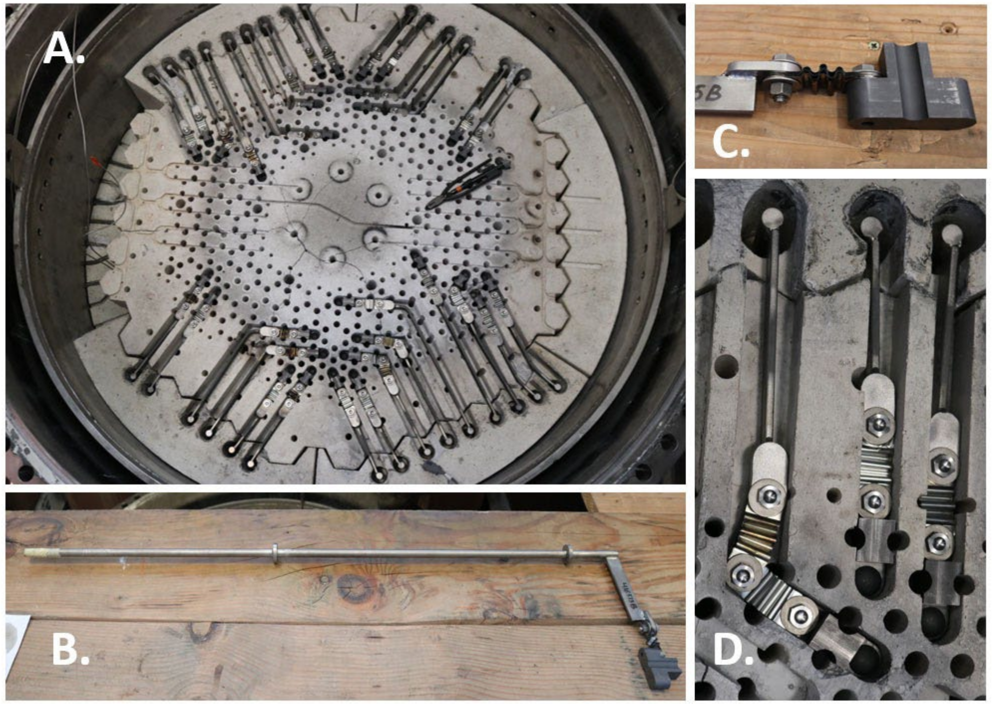
July 16-18, 2024

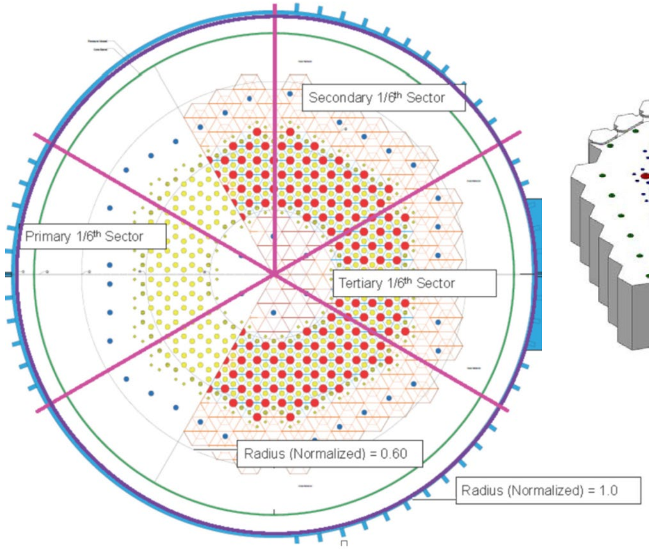
Introduction

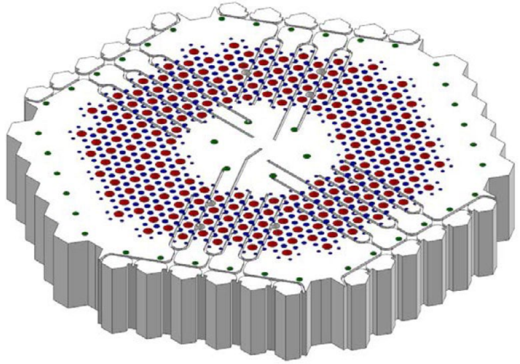
- Prismatic HTGRs are a concept approaching deployment as microreactors
  - USNC
  - BWXT
  - Radiant Nuclear
- Deploying these reactors requires modeling and simulation tools that have been validated for these systems, but most thermal hydraulics modeling and simulation tools were developed and validated for LWRs
  - Objective in this work is to validate RELAP5-3D for prismatic HTGR modeling based on HTTF data
- To provide a set of verification and validation problems, we have been spearheading the development of an HTGR thermal hydraulics benchmark based on the High Temperature Test Facility (HTTF)
  - In collaboration with Argonne National Lab/NEAMS Program, Oregon State University, Canadian Nuclear Labs, NRG, KAERI

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.

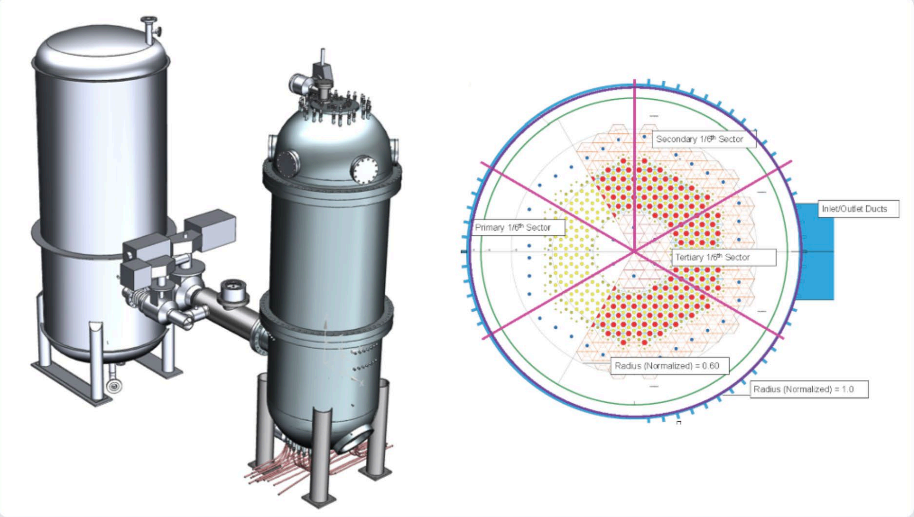
OECD-NEA High Temperature Gas-Cooled Reactor Thermal Hydraulics Code Validation Benchmark

- Benchmark is being spearheaded by ART-GCR
  - Input from INL, ANL, OSU, UTK, CNL and NRG
- 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, US, and more

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

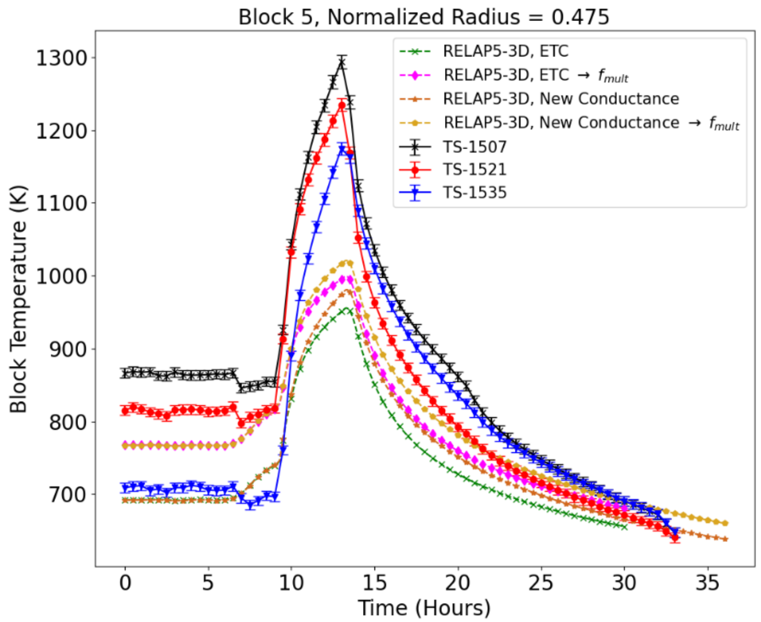
- Benchmark is broken down into 3 problems representing different physical phenomena
- Problems are broken down further into exercises, which represent different modeling approaches
  - Exercise 1: Code-to-Code comparison, fixed boundary conditions
  - Exercise 2: Code-to-Data comparison, open boundary conditions, validation
  - Exercise 3: Error scaling, quantifying how well codes validated based on HTTF provide insight into MHTGR
- Problems and exercises are intended for computational fluid dynamics (CFD), Systems codes (SYS), or coupled systems code/CFD models (COU)
- This FY has included RELAP5-3D modeling of Problem 2 and Problem 3 Exercises 1 and 2 and on

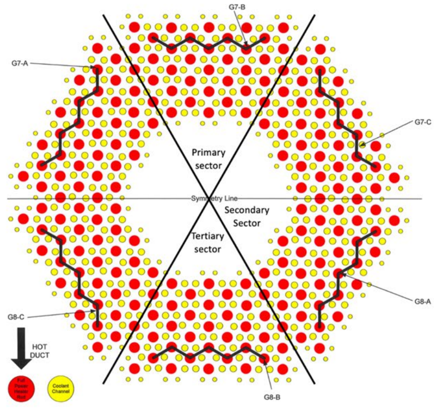
Problem	Experiment	Exercise 1	Exercise 2	Exercise 3
1 – Lower Plenum Mixing	PG-28	CFD/COU	CFD/COU	N/A
2 – DCC	PG-29	SYS/COU	SYS/COU	SYS
3 - PCC	PG-27	SYS/COU	SYS/COU	SYS

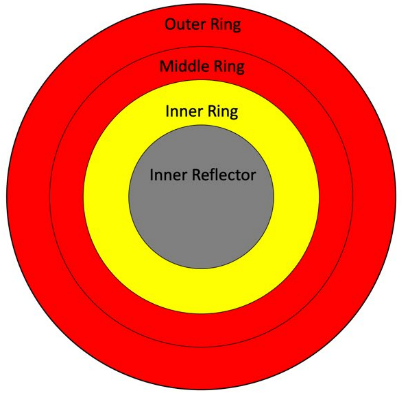
Development of a new RELAP5-3D Model of HTTF

Previous studies showed an ability to reproduce trends but not measured values

- These studies used a RELAP5-3D model described in INL/EXT-18-45579
- Validation studies based on PG-27 showed comparable steady state temperatures, but a temperature rise that was 11-48% too small in the core region
- We hypothesize that this is the result of the relatively coarse nodalization of the model, which lead to heat being generated in 73% of the heater rod volume in the model compared to 20% of the heater rod volume in the experiment
- We have created a new model to test whether a finer nodalization will be able to reproduce transient temperature rise



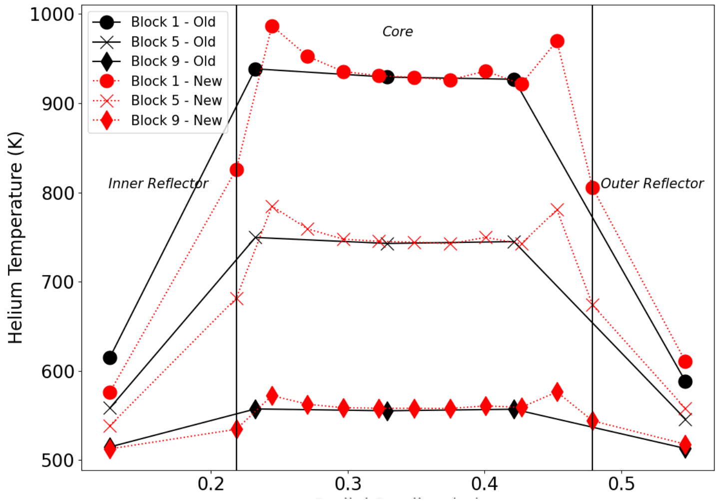


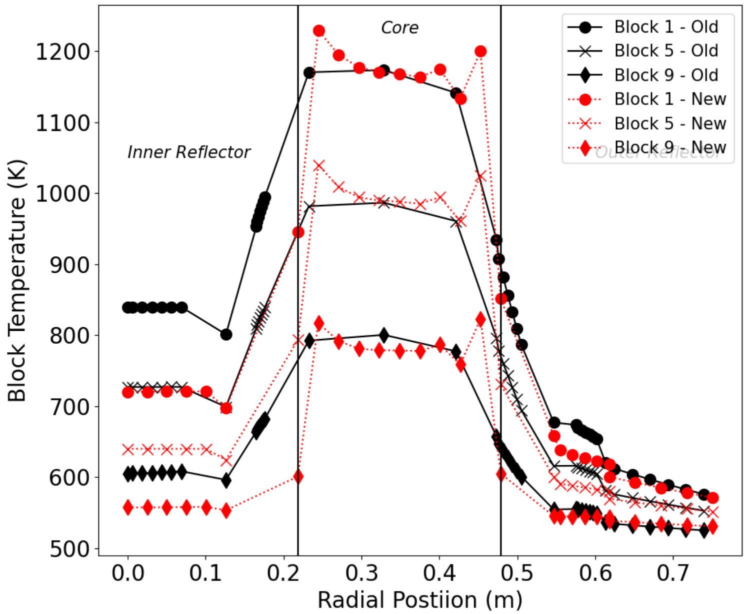


Comparisons between models show similar results but greater resolution

- Comparing the models at full-power steady state shows similar temperature distributions in the core, but with a higher resolution
- Temperature in the inner reflector is much lower, but this is consistent with results from other models
- Many of the steady-state differences shows that the new model is more consistent with results from other benchmark participants

Model	Bypass flow fraction
Legacy	12.7%
New	12.2%

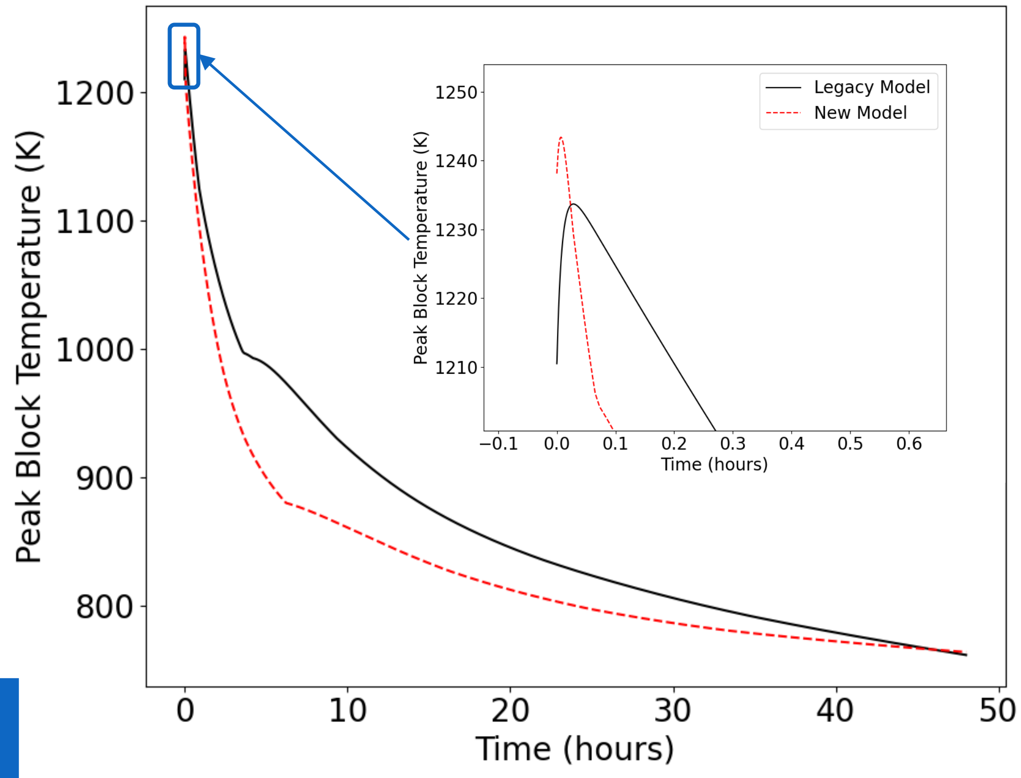




Transient shows same trends but with lower temperatures for much of the time

- Modeled a pressurized conduction cooldown
- Overall peak block temperature is 3 K higher in the new model than the legacy model, but core is cooler for much of the transient
- Differences from ~0.25-45 hours arise due to increased thermal resistance in new model between core and inner reflector
- This symmetric transient with power distributed throughout the core isn't what this model is made for, but this comparison provides confidence in the new model
- Ongoing work is investigating transients with more local and azimuthally asymmetric power

Model	Peak Block Temperature (K)
Legacy	1233.7
New	1236.7



Benchmark Results

Seven sets of results from six institutions

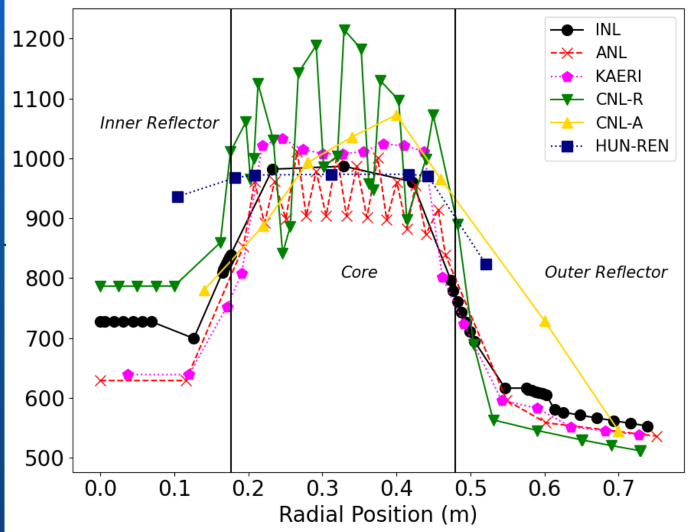
- Idaho National Laboratory (INL): RELAP5-3D, legacy model only
  - Results from new model will be part of the benchmark as well
- Argonne National Laboratory (ANL): SAM
- Korea Atomic Energy Research Institute (KAERI): GAMMA+
- Canadian Nuclear Laboratories (CNL): ARIANT, RELAP5-3D (CNL-A, CNL-R)
- Nuclear Research and Consultancy Group (NRG): SPECTRA
- HUN-REN Centre for Energy Research (HUN-REN): CATHARE

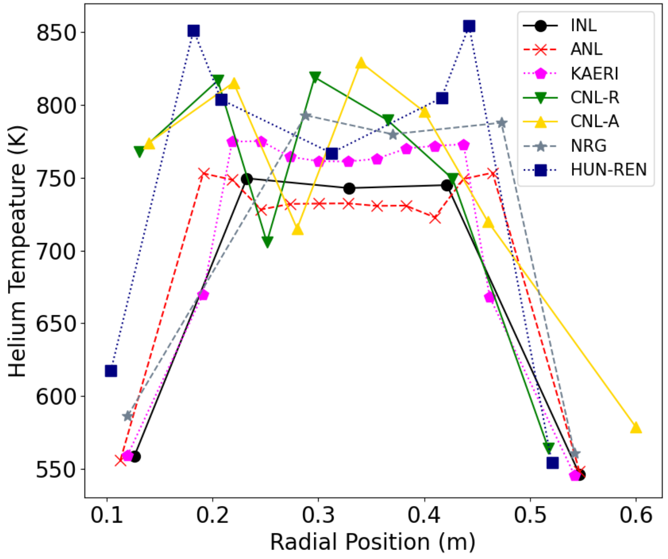
Problem 2 Exercise 1A: Full-power steady state

- Exercise 1 is code-to-code comparison, so no data are present here
- HTTF was never operated under these conditions, but they provide a simple set of boundary conditions for code-to-code comparison
- Temperatures are comparable to steady-state operation of full-power HTGR, providing some additional value in this comparison
- Objective in this comparison is to understand how modelling assumptions, nodalizations, and code capabilities impact results

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 Pressure (MPa)	0.1
RCCS Flow Rate (kg/s)	1.0
RCCS Cavity Air Inlet Temperature (K)	300.0
RCCS Cavity Air Flow (g/s)	25.0
Core Power (MW)	2.2

Problem 2 Exercise 1A Results show similar temperatures in the core but not the inner reflector



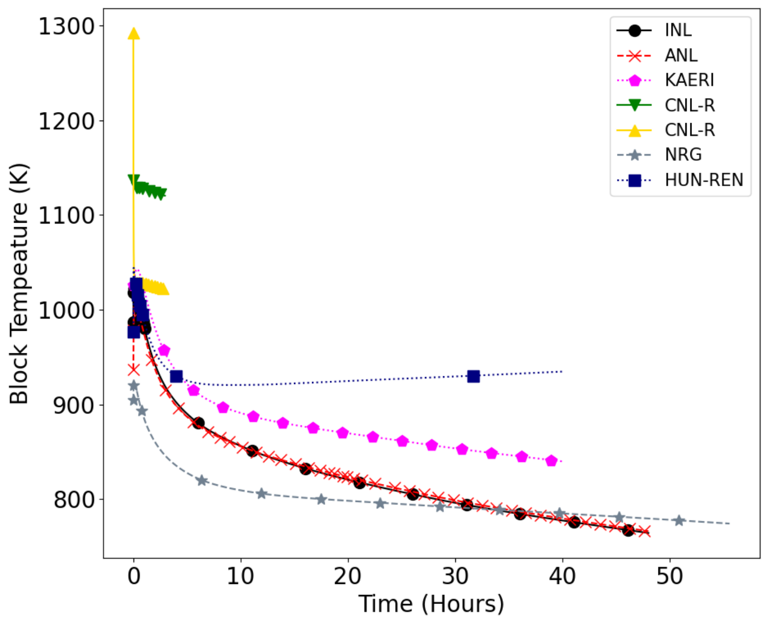


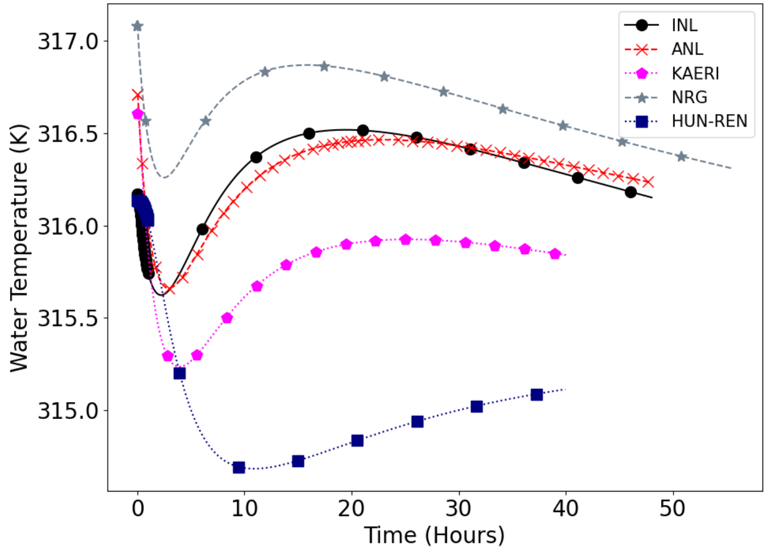
- CNL-R model includes heater rods in the temperatures shown in the figure, hence the considerably higher temperatures
- Helium flow and energy balance results are generally similar
- Temperatures in the core region show excellent agreement with one another
- There is little consistency on inner reflector temperatures
- A few differences to dissect between benchmark participants

	Inner Reflector (kg/s)	Inner Core (kg/s)	Middle Core (kg/s)	Outer Core (kg/s)	Outer Reflector (kg/s)	Bypass Flow (%)
INL	0.026	0.231	0.306	0.335	0.101	12.7
ANL	0.026	0.233	0.311	0.334	0.095	12.1
KAERI	0.025	0.224	0.309	0.344	0.097	12.2
CNL-A	0.018	0.255	0.264	0.356	0.104	12.2
CNL-R	0.021	0.255	0.274	0.350	0.101	12.2
NRG	0.022	0.229	0.317	0.333	0.099	12.1
HUN-REN	0.024	0.233	0.316	0.328	0.098	12.2

Transient results show more variation

- Coolant flow rate ramped down linearly from 1.0 → 0.0 kg/s over 1.0 seconds
- Pressure ramped down linearly from 0.7 → 0.1 MPa over 20 seconds
- ANS-94 decay heat standard is used
- RCCS effectiveness significantly impacts long-term block temperatures
- CNL average temperatures include heater rods, thus the significantly higher temperatures
- INL and ANL models show very good agreement with one another





Conclusions

Conclusions

- New RELAP5-3D model has been developed, and assessment against legacy model shows similar performance for conditions that the legacy model was developed for
- Testing of the new model for situations with more local heat generation and azimuthal asymmetry are ongoing
- Validation activities with the new model are ongoing
- Results have been collected for Problem 2 Exercises 1A and 1B
  - All models show similar behavior in the core, but temperatures in the inner reflector can vary significantly
  - Performance of the RCCS significantly impacts transient block temperatures
- Exercises 1C and 2 are ongoing

Publications and Conference Participation

- OECD/NEA WPRS Benchmarks Workshop, 2024 included the second international workshop on the High Temperature Gas-Cooled Reactor Thermal Hydraulics Benchmark based on HTTF Data
- American Nuclear Society Annual Meeting included panel on CFD and System Code Validation for HTGR Applications Leveraging HTTF Data
- Hua, T., Kile, R., Lee, S. N., Zou, L., Epiney, A., "Code Benchmark of Pressurized Conduction Cooldown Transient in the High Temperature Test Facility," *International Congress on Advances in Nuclear Power Plants*, Las Vegas, NV, June 16-19, 2024.
  - ANL/NEAMS lead
- Kile, R. F., et al., "Code Benchmark of a Depressurized Conduction Cooldown Transient in the High Temperature Test Facility," *Advances in Thermal Hydraulics*, Orlando, FL, November 17-21, 2024
- Kile, R. F., Epiney, A. S., "Development of an Improved RELAP5-35 Model for the High Temperature Test Facility," *Advances in Thermal Hydraulics*, Orlando, FL, November 17-21, 2024
- Gutowska, I., Kile, R., Woods, B. G., Brown, N. R., "Intracore Natural Circulation Study in the High Temperature Test Facility," *Journal of Nuclear Engineering*, Submitted for Review (2024).
  - Oregon State University lead
- Kile, R. F., Epiney, A. S., Brown N. R., "RELAP5-3D Validation Studies Based on the High Temperature Test Facility," *Nuclear Engineering and Design,* vol 426, (2024), doi: 10.1016/j.nucengdes.2024.113401.

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Thank you to all our benchmark participants and organizers

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