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RELAP5-3D Modeling of the OECD-NEA HTTF Benchmark

July 2022

Changing the World's Energy Future

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Idaho National Laboratory

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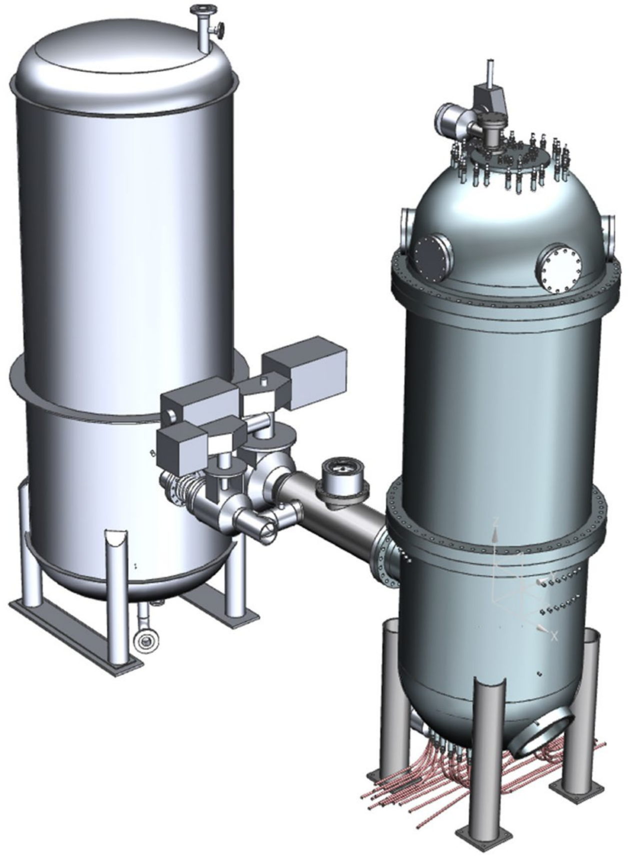
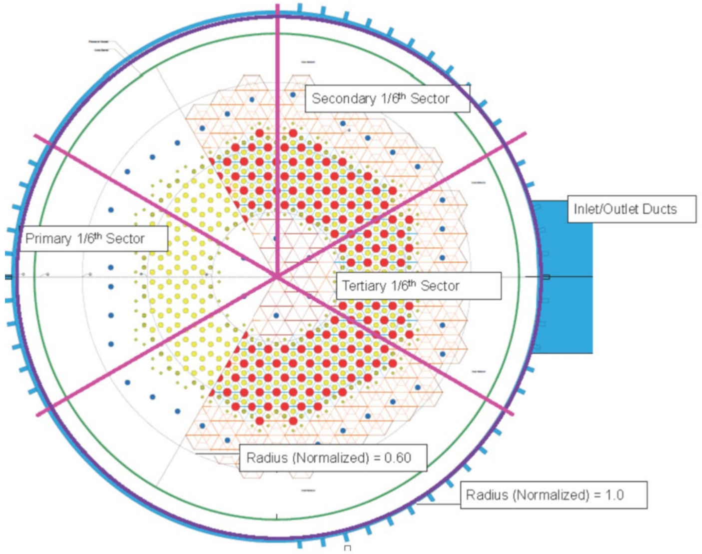
ART Advanced Reactor Technologies

GAS-COOLED REACTORS

HTTF Overview





- HTTF at Oregon State University (OSU)
  - Reference: General Atomics' modular high-temperature gas-cooled reactor
    - Helium cooled, electrically heated (2.2 MW)
    - Prismatic graphite blocks in the core and reflectors
      - Alumina ceramic blocks are used to simulate the core and top and bottom reflectors
  - One-fourth scale in length and diameter
  - Most of the coolant channels in the core are full scale
  - Lower pressure compared to the prototype reactor (0.7 MPa)
  - Over 500 instruments
  - Designed primarily to investigate depressurized (DCC) and pressurized (PCC) conduction cooldown transients

Introduction

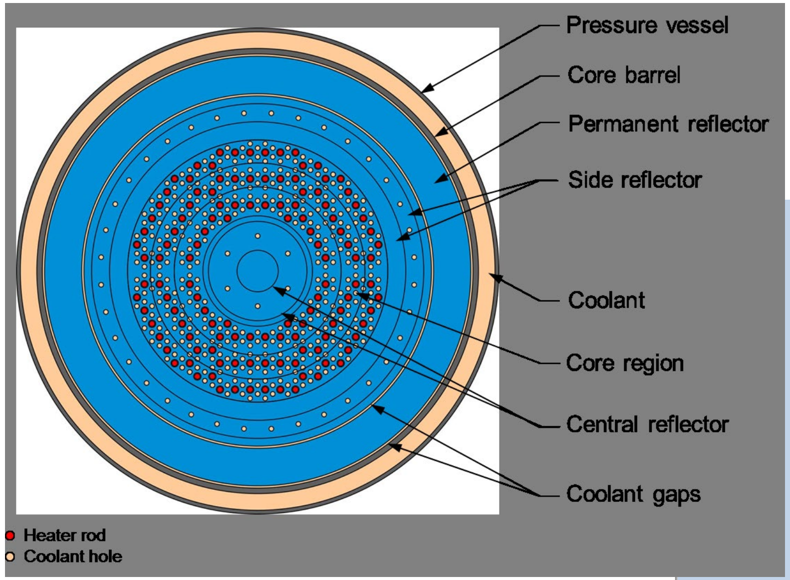
- HTTF provides an opportunity to develop a single-physics, integral-effects thermal hydraulics benchmark for block-type gas-cooled reactors based on experimental data
  - mHTGR-350 benchmark was multiphysics, which introduces some uncertainty in single-physics solutions
- Benchmark lead by ART/GCR includes code-to-code and code-to-data comparisons
  - Comparing RELAP5-3D and SAM to one another
    - An opportunity to assess a well-established tool (RELAP5-3D) with a NEAMS tool (SAM)
      - SAM modeling is funded by NEAMS and conducted at ANL
  - Comparing both codes to measured data
    - An improvement on the mHTGR-350 benchmark, which was purely computational
- HTTF Benchmark was accepted by the OECD-NEA in February of 2022
  - Development of benchmark is led by ART

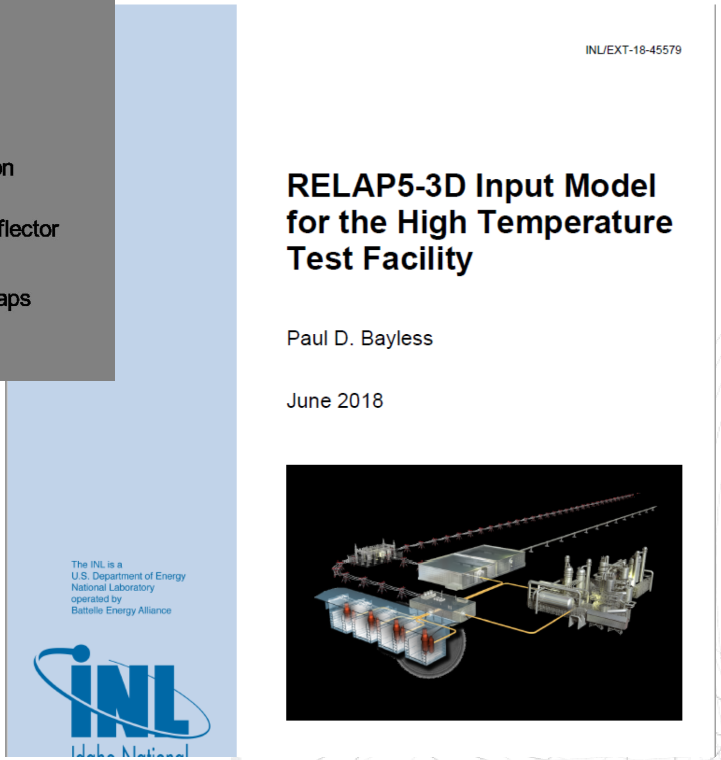
HTTF benchmark consists of 3 exercises, each with sub-exercises for systems code, CFD, and coupled systems code-to-CFD

- Exercise 1: Fixed boundary conditions
  - Well-defined boundary conditions
  - Focus on code-to-code comparisons, not on matching experimental data
- Exercise 2: Best estimate boundary conditions
  - Participants use their judgement and code capabilities to provide best match to experimental data
  - Focus on code validation
- Exercise 3: Error scaling from HTTF to mHTGR-350
  - Validation extrapolation
  - Identify relationships between error and uncertainty in HTTF and in mHTGR-350

RELAP5-3D model descends from NQA-1 model developed here at INL

- Phase 1 activities use a core- and vessel-only model
- Reactor cavity cooling system (RCCS) includes small gap between vessel and water flow channels
- Small air flow rate is allowed in the RCCS cavity
- Thermophysical properties used in the model have some significant uncertainties
  - Thermal conductivity vs effective thermal conductivity
  - Emissivities measured only at low temperatures or not at all

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RELAP5-3D Input Model for the High Temperature Test Facility

Paul D. Bayless

June 2018

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RELAP5-3D modeling has focused on two transients: PG-26 and PG-27

PG-26: DCC

- Low-power double-ended inlet/outlet duct crossover break
- Taking PG-26 models developed in FY 21 and using RAVEN to perform calibration studies
- Developing DCC benchmark based on calibrated RELAP5-3D/RAVEN models

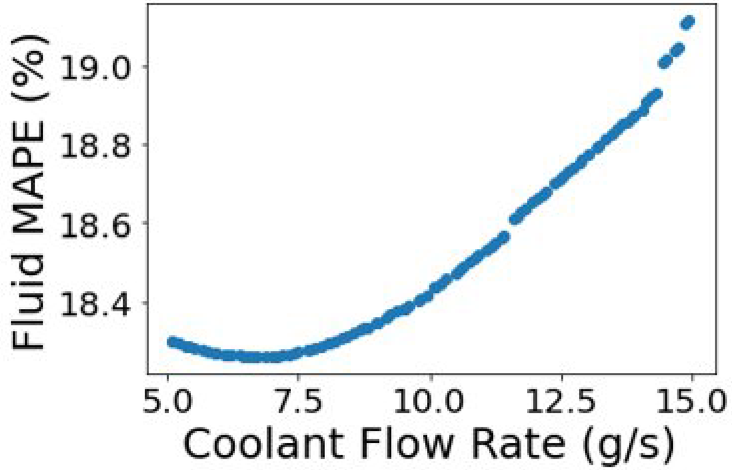
PG-27: PCC

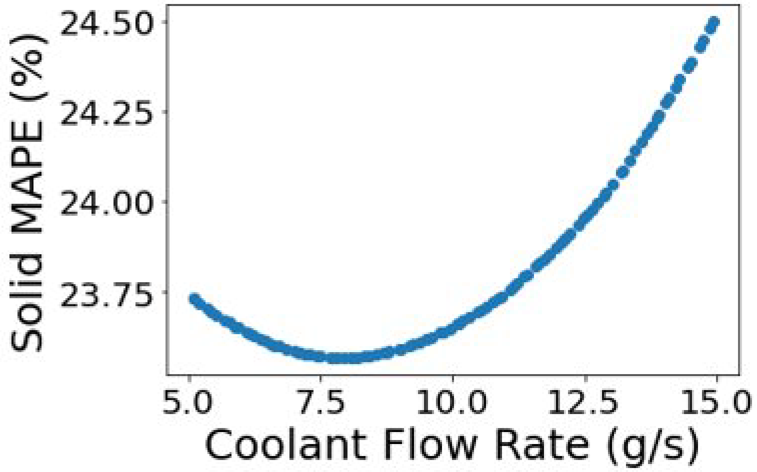
- Low-power complete loss of flow
- Using Phase 1 boundary conditions for PG-27 developed by Argonne National Lab to perform RELAP5-3D/SAM code-to-code comparison
  - Phase 1A: Full-power steady-state
  - Phase 1B: PCC from full-power steady-state
  - Phase 1C: PG-27-like steady-state
  - Phase 1D: PCC from PG-27-like steady-state

PG-26 work has focused on developing tools for calibration studies

- RAVEN post processors have been developed to compare calibration study results to measured data
  - Problem-specific post processors were developed to assess time-dependent and overall error
- Major challenge is defining the state of the facility at the beginning of the test
- HTTF has no measurement of primary coolant flow rate, so this is a calibration study parameter
  - Figures show preliminary impact of coolant flow rate on average helium and block temperature errors over time
- Some uncertainty in block thermophysical properties may be significant

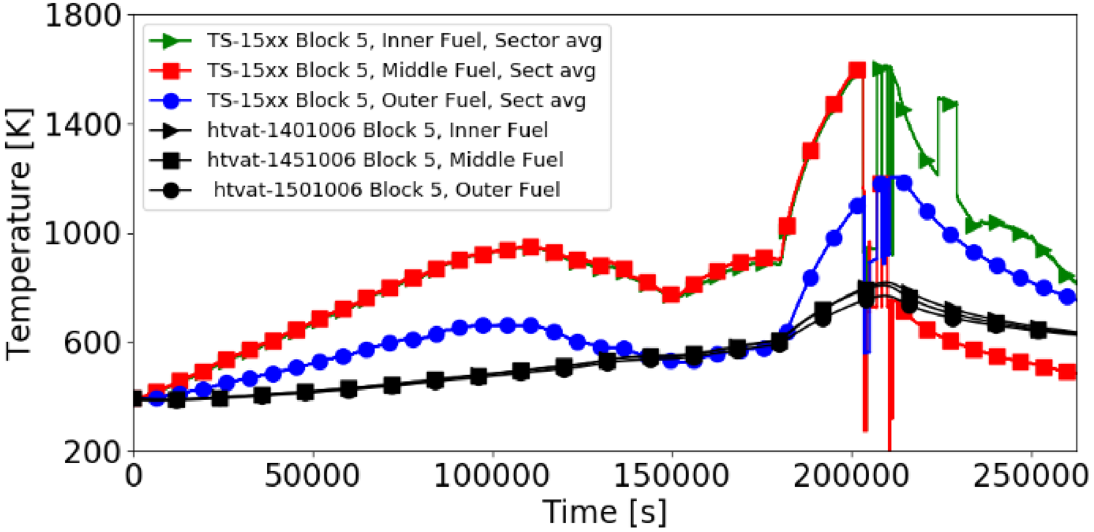
$$MAPE = mean\left(\frac{|Measured\ value\ - RELAP\ value|}{Measured\ Value} \times 100\%\right)$$





Upcoming PG-26 work includes calibration studies of thermophysical and fluid flow properties

- First study aims to calibrate coolant flow rate and thermophysical properties of core blocks
  - Assess agreement on the basis of temperatures
- Second study aims to calibrate friction losses, properties of coolant flow outside the core, in secondary loop, etc.
  - Assess agreement on the basis of temperature and pressure drops
- Current RELAP5-3D models significantly underpredict temperatures in the core, likely due to uncertainties in the exact state of the system



Measured (red, blue, green) and calculated (black) block temperatures from the nominal RELAP5-3D model

PG-27 Phase 1A shows good agreement between RELAP5-3D and SAM

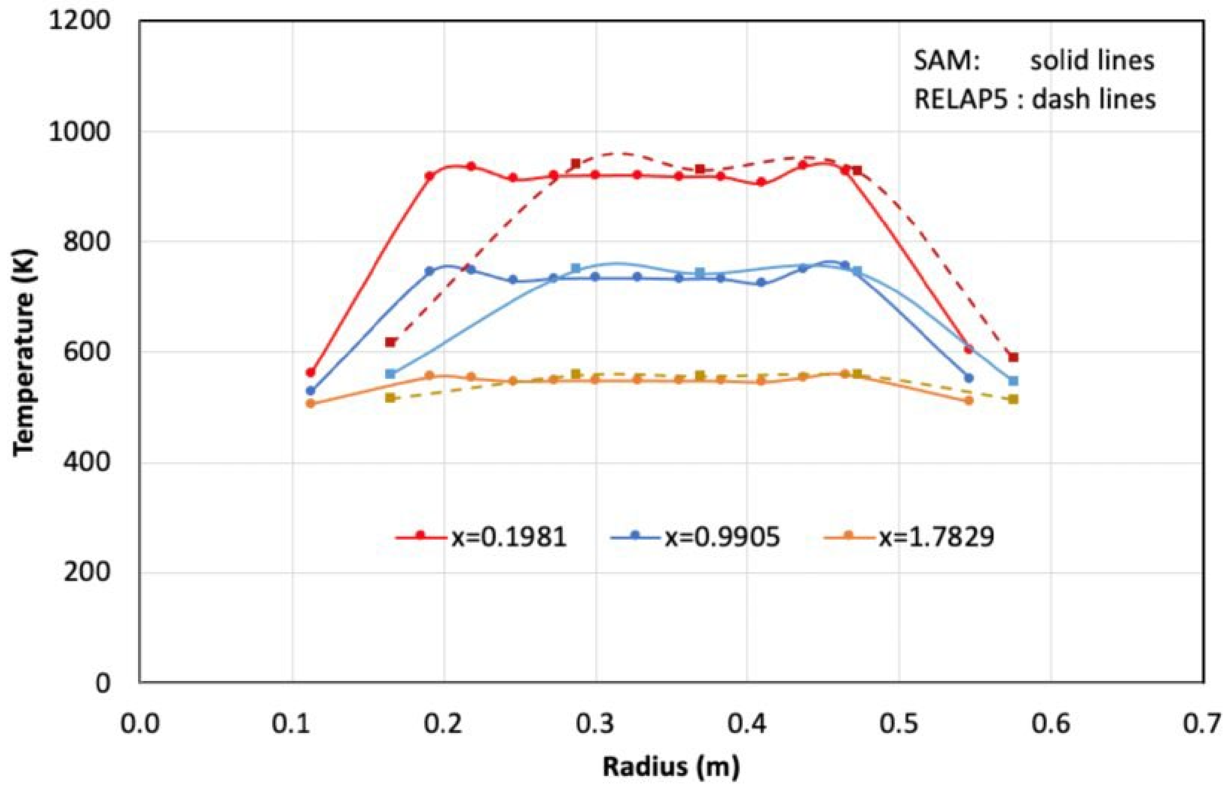
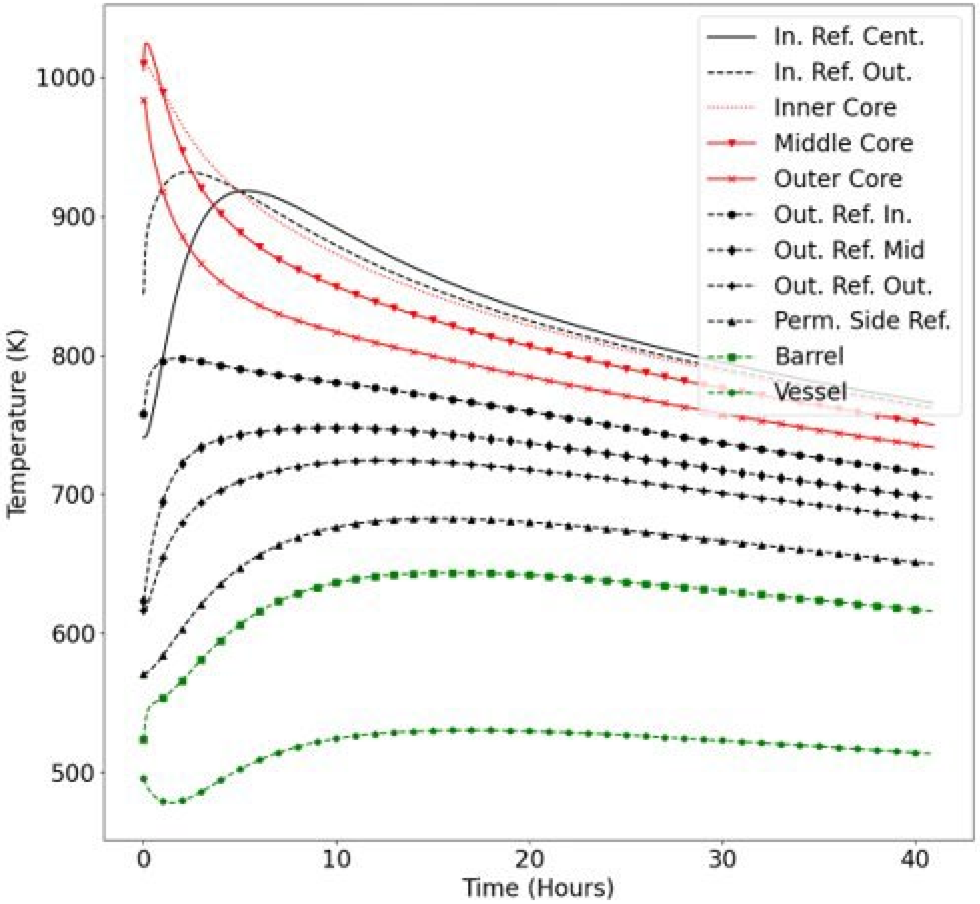


Image courtesy of Thanh Hua, Argonne National Laboratory

- PG-27 Phase 1 preliminary comparison between RELAP5-3D and SAM shows good agreement
- Used as-measured thermophysical properties from HTTF facility descriptions
  - Some values still unavailable, used same assumed values in those cases
- Helium (see figure) and block temperatures provide good agreement between RELAP5-3D and SAM for steady-state
- Phase 1B transient shows good agreement in natural circulation flow rate and comparable trends in most behavior
- Still ironing out minor differences between RELAP5-3D and SAM models

Preliminary solutions for PCC and DCC from full-power steady-state have been developed

- These transients were never conducted at HTTF
- Transients from full-power steady-state are useful in code-to-code comparison for identifying differences in solutions driven by code selection
- Initial comparisons between RELAP5-3D and SAM show faster heat removal in RELAP
  - Ongoing work to identify the cause of this difference
- These cases have been used for comparing impact of thermal conductivity vs effective thermal conductivity in HTTF



RELAP5-3D HTTF Modeling Publications

- Paper submitted for Generation 4 and Small Modular Reactors International Conference describing the benchmark[1]
- ANS summary for Winter Meeting submitted on importance of thermal conductivity in HTTF modeling[2]
- ANS summary submitted for Winter Meeting describing the HTTF benchmark[3]
- DOE FY 22 milestone due at end of September

[1]Epiney, Aaron S. et al., "Overview of HTTF Modelling and Benchmark Efforts for Code Validation for Gas-Cooled Reactor Applications," *Proceedings of the Fourth International Conference on Generation IV & Small Modular Reactos (G4SR-4),* Toronto, ON, Canda, October 3-6 2022.

[2]Kile, Robert F. et al., "Assessing the Impact of Effective Thermal Conductivity on Gas-cooled Reactor Transients in RELAP5-3D," *Transactions of the American Nuclear Society Winter Meeting*, Phoenix, AS, United States, November 13-17 2022

[3]Epiney, Aaron S. et al., "OECD/NEA High Temperature Test Facility (HTTF) Thermal-Hydraulics Benchmark: Proposed Exercises" *Transactions of the American Nuclear Society Winter Meeting*, Phoenix, AS, United States, November 13-17 2022

Conclusions

- A single-physics, integral effects thermal hydraulics benchmark based on HTTF and lead by ART has been accepted by the OECD-NEA
  - Provides an opportunity to validate RELAP5-3D, SAM, and other codes for gas-cooled reactor thermal hydraulics
  - Benchmark provides value for microreactor designers too based on HTTF's low power level
- HTTF benchmark specifications being finalized in FY 22
- Tools have been developed to calibrate RELAP5-3D models to measured HTTF data
- Preliminary results for Phase 1 of PG-27 benchmark show good agreement between RELAP5-3D and SAM
- FY 23 activities include developing solutions to the benchmark