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High Temperature Gas-Cooled Reactor Thermal Hydraulics Benchmark Problem 2 Description: Depressurized Conduction Cooldown

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Changing the World's Energy Future

Robert Forrester Kile

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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Robert F. Kile

Problem 2: Depressurized Conduction Cooldown Modeling

Based on PG-29

ART Advanced Reactor Technologies

GAS-COOLED REACTORS

Problem is broken into 3 exercises

1. Fixed boundary conditions (code-to-code comparison, systems codes and coupled systems code/computational fluid dynamics [CFD] modeling)
    a. Full-power steady-state
    b. Depressurized conduction cooldown (DCC) from full-power steady-state
    c. PG-29-like initial and boundary conditions
2. Open boundary conditions (code-to data comparison/best-estimate modeling/validation, systems codes, and coupled systems code/CFD modeling)
3. Error scaling (High Temperature Test Facility [HTTF]-to-modular high temperature gas-cooled reactor [MHTGR] comparison, systems code modeling only)

Exercise 1A: Full-power steady state

- This exercise is identical in problems 2 and 3
- Concerned with the vessel (including everything inside), reactor cavity cooling system (RCCS), and air cavity between the vessel and RCCS
  - Inlet flow and pressure boundary conditions
  - Outlet pressure boundary condition
- HTTF was never operated under these conditions, but they provide a simple set of boundary conditions to compare models
- Power is distributed uniformly throughout the core

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

Thermophysical properties to be used

- When measured values are reported in the HTTF facility description, use those values 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
- Some important values (such as emissivities) are not stated in the HTTF facility description. We have attempted to specify values in all those cases. If we have missed something, please let us know
- Emissivity values should be those in the table on the right (also Table 3–18 in the specs.)
- Are there thermophysical properties your code/model requires that we have not specified?
  - We are specifying $k, \rho c_p, \& \epsilon$

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 pressure vessel	0.25
Polished stainless steel for RCCS panels	0.074

Exercise 1A Results of Interest

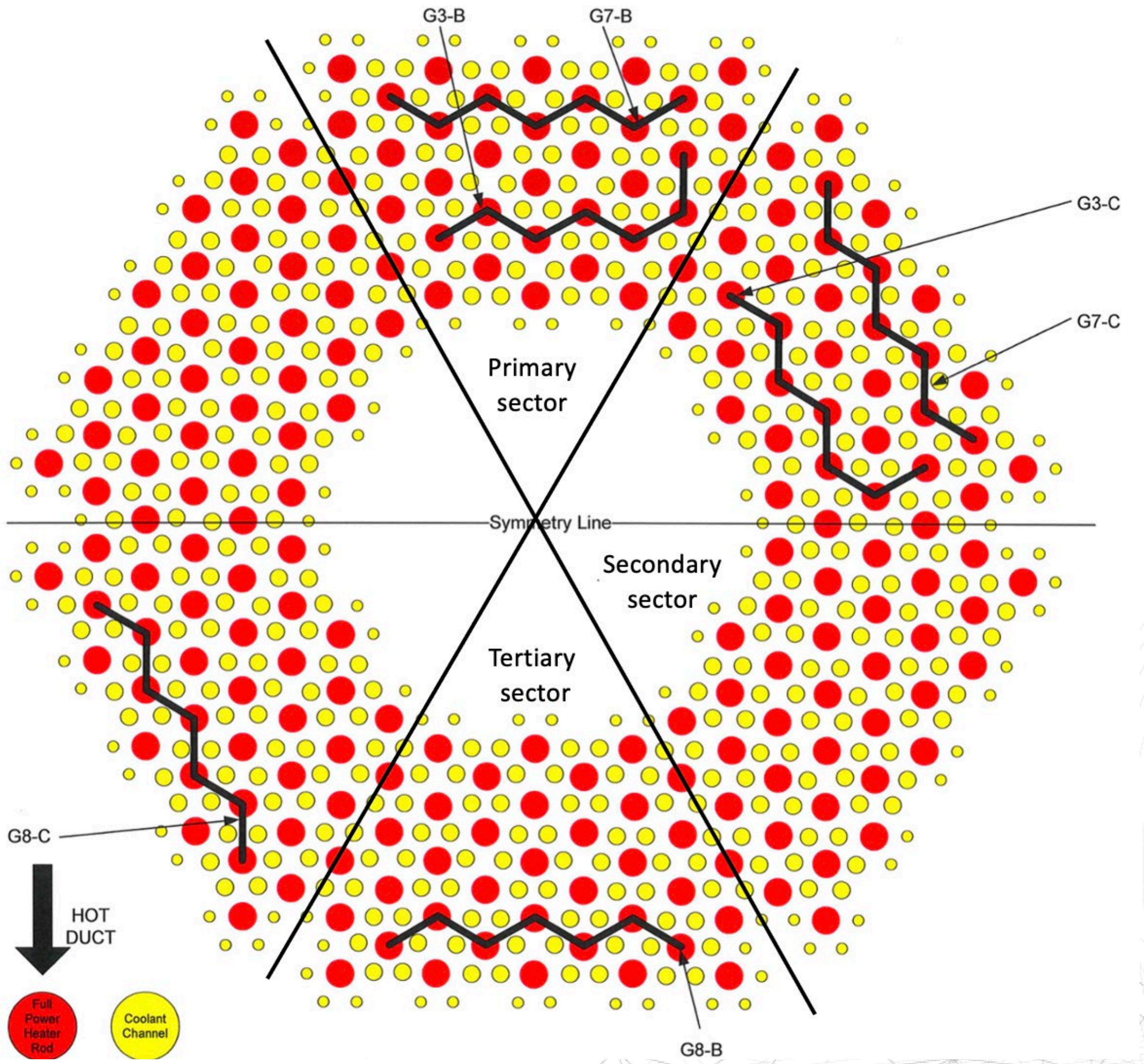
- Radial block temperature (K) profile (from inner reflector up to and including outer reflector)
- Radial helium temperature (K) profile Permanent reflector temperature (K) Core barrel temperature (K)
- Reactor vessel temperature (K) at the following locations
- Heater rod temperature (K) radial distribution
- All radial temperature distributions should be done at the following axial locations
  - Top of block 1
  - Top of block 3
  - Top of block 5
  - Top of block 7
  - Top of block 9
- RCCS Water outlet temperature (K)
- Mass flow rate (kg/s) at each radial position
- Pressure drop (kPa) from top of core to bottom
- Energy removed by RCCS
- Energy removed by air flow through RCCS cavity

Exercise 1B: DCC from full-power steady state

- Results from Exercise 1A provide initial conditions
- This is very similar to Exercise 1B from problem 3, but with a depressurization component
- Inlet flow rate reduced from 1.0 kg/s to 0.0 kg/s linearly over 1.0 seconds starting at 0.0 seconds
- Outlet pressure reduced from 0.7 MPa to 0.1 MPa linearly starting at 0.0 seconds
- At t=0.0 seconds, use power of 2.2 MW, then follow normalized power vs. time specified in Table 3-19 of the benchmark specifications
- Power should still be distributed uniformly throughout the facility
- RCCS and cavity flow rates are maintained at their values from Exercise 1A
- Provide the same results as are requested from Exercise 1A, but over time
- Run to a problem time of at least 40 hours

Exercise 1C: DCC with PG-29-like boundary conditions

- Time-dependent pressure, power, and flow rate boundary conditions are specified in benchmark specifications
  - When possible, you should interpolate linearly between time steps
- Heat generation in PG-29 is azimuthally asymmetric, but all may not be able to model the asymmetry
- The heaters in the primary sector should be used in each of the 1/6 sectors for this exercise
- Heat should be split evenly among these heaters, ½ in the outer set and ½ in the inner set
- Initial conditions are also provided in benchmark specifications
- Exercise should be run until a problem time of 27 hours
- Interested in same outputs as 1A/1B



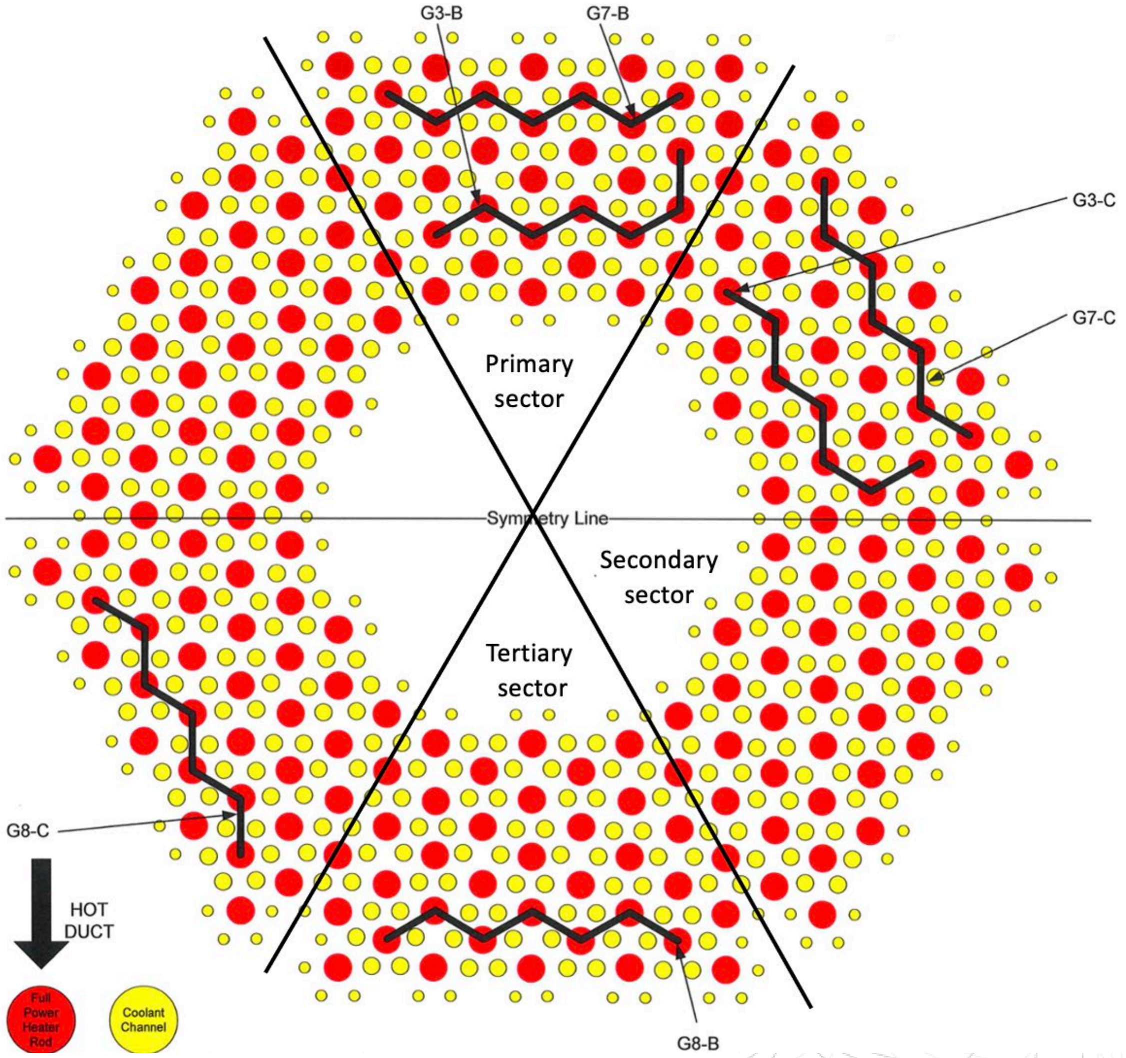
Sample of initial temperature table

- Table is a truncated version of the initial heater rod temperature table (Table 3-9)
- In a region bounded below by a position of 2.08788 m (relative to hot duct), bounded above by a position of 2.286 m, and by a radius of 0.288 m should have an initial heater rod temperature of 379.7 K
- There will be sharp discontinuities in initial temperatures
- These values are based on measured temperatures from working TCs at the initial time for these models

Bottom Elevation/Outer Radius (m)	0.288	0.37	0.473
2.286	379.7	667.3	389.8
2.08788	379.7	667.3	398.8
1.88976	515.1	667.3	447.2
1.69164	515.1	667.3	447.2
1.49352	346.3	605.8	421.7
1.2954	346.3	544.3	421.7
1.09728	468.7	314.5	440.3
0.89916	468.7	314.5	440.3
0.70104	596.4	314.5	485.2
0.50292	596.4	314.5	485.2

Exercise 2: Best-estimate modeling of PG-29

- Participants are free to develop their own coolant flow rate, power distribution, pressure, etc. boundary conditions based on the data
- Figure on the right shows the heater rods that were used as part of the hybrid heater configuration
  - There is no information on how heat was distributed among the active rods, so you will have to determine how to model that
- If you have the ability to model the asymmetry, please report block and helium temperatures (K) in each of the 3 sectors and compare to TCs at radial positions 5, 7, and 9 (6, 8, and 10 for helium)
  - Assess temperatures at the top of blocks 3, 5, and 7
- Everyone should provide azimuthal average block and helium temperature (K) at radial positions corresponding to TC positions 5, 7, and 9 (6, 8, and 10 for helium)
  - Assess temperatures at the top of blocks 1, 3, 5, 7, and 9



Exercise 3: Error scaling from HTTF to MHTGR

- **Goal:** Understand in some quantitative sense how well validation of systems codes based on HTTF applies to modeling a full-scale, higher power, higher pressure MHTGR
- Several techniques exist for understanding the relationship between a scaled test facility (HTTF) and a full-scaled system (MHTGR)
  - Dynamic System Scaling, Representativity, Physics-Informed Coverage Mapping, etc.
  - Theoretically applicable to systems other than MHTGR, but MHTGR is the reference concept for HTTF
- We are not specifying which approach you must use
- MHTGR-350 benchmark provides a detailed description of the reference reactor system to consider
- We are providing some reference results and sensitivity coefficients from the RELAP5-3D MHTGR-350 ring model if you do not want to develop your own MHTGR-350 models
  - If you would like to see some additional sensitivities or figures of merit, we may be able to accommodate that
  - You may develop your own sensitivity coefficients if you would prefer to use them

MHTGR-350 Sensitivity Parameters for Error Scaling

- Explored 11 MHTGR-350 input parameters
- All parameters sampled according to normal distributions
- If sampler encountered non-physical values, those cases were neglected
- Same parameters are sampled, according to the same distributions, for DCC and PCC (Problem 2 and Problem 3)
- Some of these parameters, like fuel thermophysical properties, do not have an analogue in HTTF. ***This is on purpose***. We know that HTTF will have some distortions compared to a reactor.

Parameter	Mean	Standard Deviation
Inlet Temperature (K)	532.0	2.142
Coolant Flow Rate (kg/s)	157.0	1.127
Block Thermal Conductivity Multiplier (-)	1.0	0.300
Block Heat Capacity Multiplier (-)	1.0	0.150
Fuel Thermal Conductivity Multiplier (-)	1.0	0.100
Fuel Heat Capacity Multiplier (-)	1.0	0.100
Friction Multiplier	1.5	0.167
HTC Multiplier	1.0	0.150
Decay Heat Multiplier	1.0	0.035
Coast-down Time (s)	25	5.000
SCRAM Time (s)	42	15.000

Error scaling figures of merit

- Currently considering 4 figures of merit
  - Peak block temperature over the entire transient
  - Peak coolant outlet temperature over the entire transient
  - Instantaneous maximum block temperature
  - Instantaneous maximum coolant outlet temperature
- Are there additional figures of merit you would like to see?
- We do not currently have any figures of merit assessing how natural circulation in HTTF behaves relative to MHTGR-350

Error Scaling Sensitivity Coefficients

- We provide some reference non-dimensionalized sensitivity coefficients in the benchmark specifications
- These sensitivity coefficients are calculated as follows, where L is a linear regression coefficient, $\bar{X}$ is the mean value of an input parameter, and $\bar{Y}$ is the mean value of an output parameter

$$S = L \times \frac{\bar{X}}{\bar{Y}}$$

- For time-dependent metrics, these sensitivity coefficients are calculated at each time step
- Is there anything else you would like to see from MHTGR-350 for reference results?

Questions or Needs?