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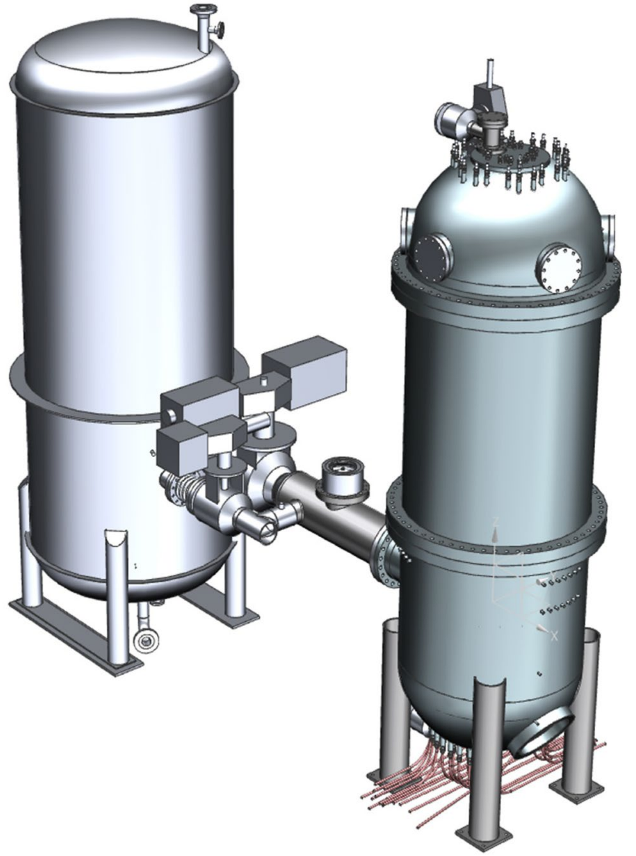
Modeling of HTTF Using RELAP5-3D

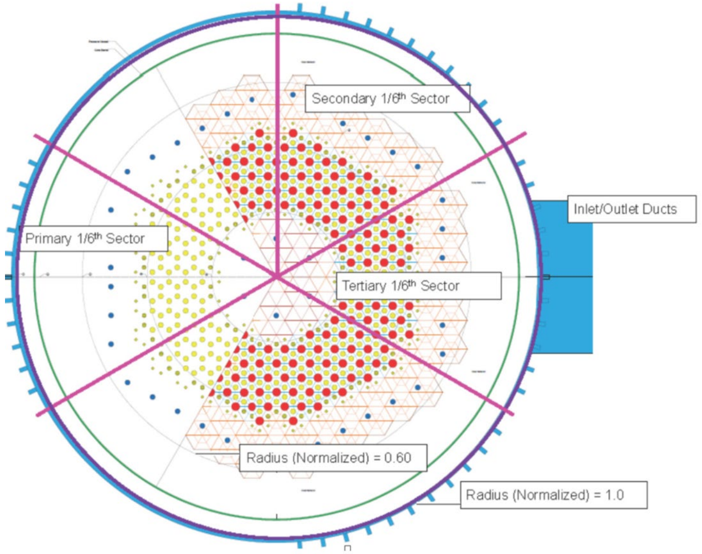
ART
Advanced Reactor Technologies

Overview

- HTTF Overview
- HTTF Test Matrix
- REALP5-3D
  - Model
  - Results PG-26 and PG-27
- HTTF Benchmark
- Conclusions

HTTF Overview





- HTTF at Oregon State University (OSU)
  - Reference: General Atomics' modular high-temperature gas-cooled reactor
    - Helium cooled, electrically heated
    - 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
  - Over 500 instruments
  - Designed primarily to investigate depressurized (DCC) and pressurized (PCC) conduction cooldown transients

HTTF Test Matrix (2019)

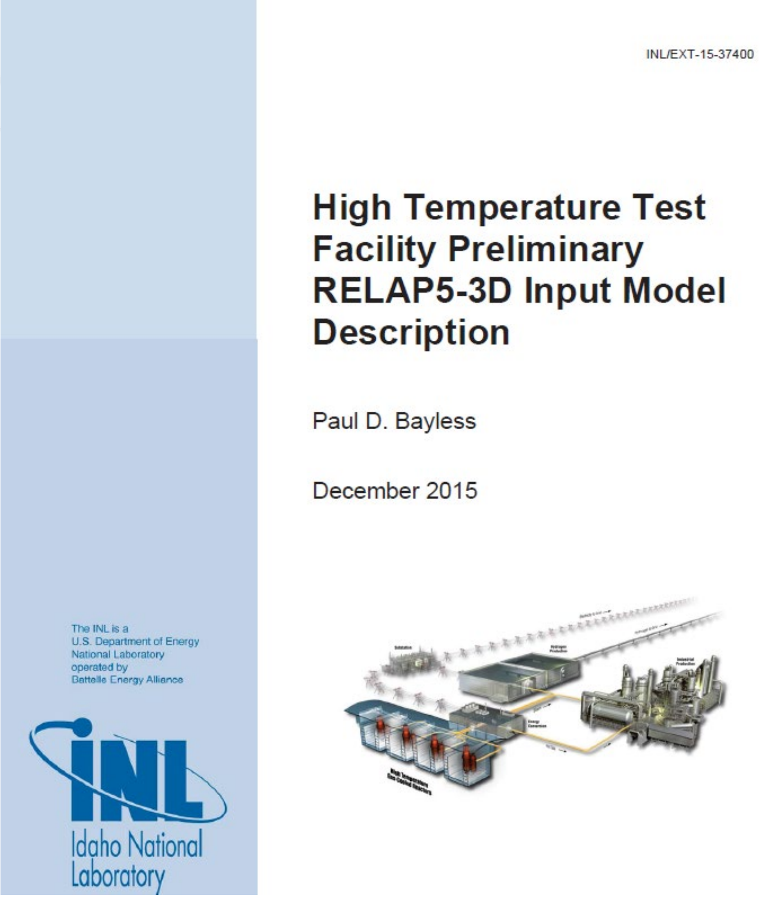
Test Number	Title	Date
OSU-HTTF-TEST-27	Low Power (<350kW) Complete Loss of Flow, 2 Heaters	May 24, 2019
OSU-HTTF-TEST-26	Low Power (<350kW) Double Ended Inlet-Outlet Crossover Duct Break, 2 Heaters	Jun 3, 2019
OSU-HTTF-TEST-35	Zero Power Crossover Duct Exchange Flow and Diffusion Test 1	Jun 4, 2019
OSU-HTTF-TEST-28	Low Power (<350kW) Lower Plenum Mixing Test	Jul 24, 2019
OSU-HTTF-TEST-29	Low Power (<350kW) Double Ended Inlet-Outlet Crossover Duct Break, Hybrid Heater	Jul 26, 2019
OSU-HTTF-TEST-34	Low Power (<350kW) Asymmetric Core Heatup Full Hybrid Heater	Aug 1, 2019
OSU-HTTF-TEST-32	Low Power (<350kW) Asymmetric Core Heatup	Aug 29, 2019
OSU-HTTF-TEST-30	Low Power (<350kW) Lower Plenum Mixing, Constant Temperature Test	Aug 30, 2019
OSU-HTTF-TEST-31	Low Power (<350kW) Pressure Vessel Bottom Break with Restored Forced Convection Cooling Test	Aug 31, 2019
OSU-HTTF-TEST-33	Zero Power Long Term Cooldown Test	Sep 4, 2019

- Figure of Main Interest is:
  - (Depressurized) Core cooling under decay heat conditions
  - Gas-mixing phenomena, natural convection, possible flow reversal

- First tests investigated to assess code models
  - PG-26: Depressurized Conduction Cooldown transient (DCC)
  - PG-27: Pressurized Conduction Cooldown transient (PCC)

RELAP5-3D Model

- Paul Bayless’ quality-controlled model used as basis


INL/EXT-15-37400

High Temperature Test Facility Preliminary RELAP5-3D Input Model Description

Paul D. Bayless

December 2015

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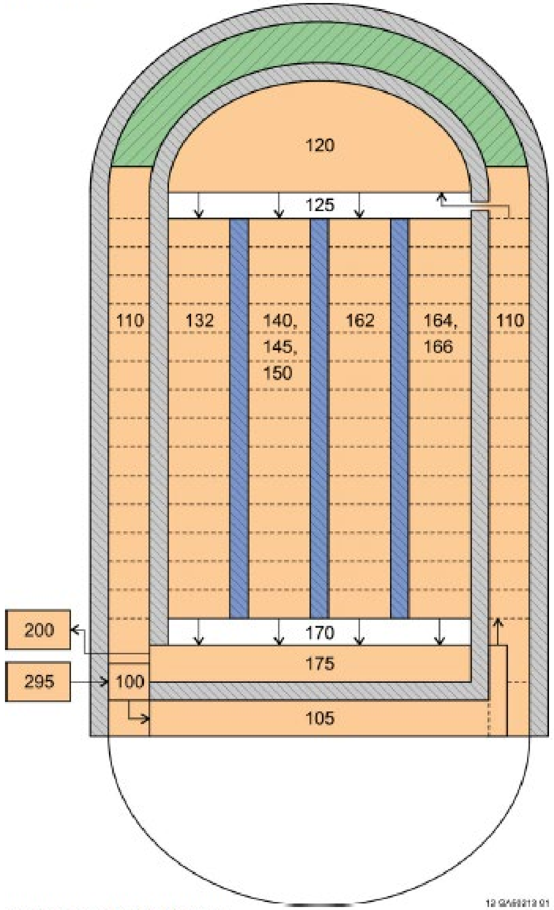


ressure vessel nodalization.

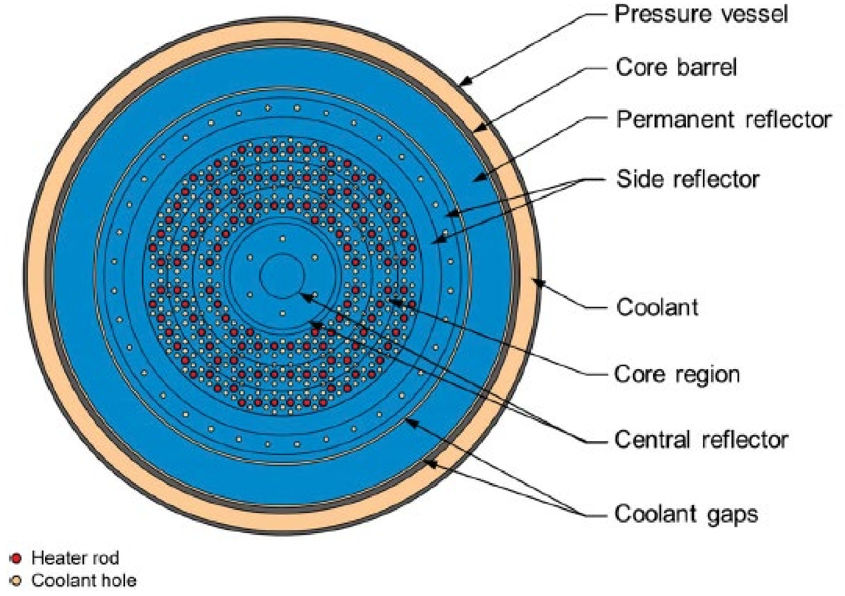
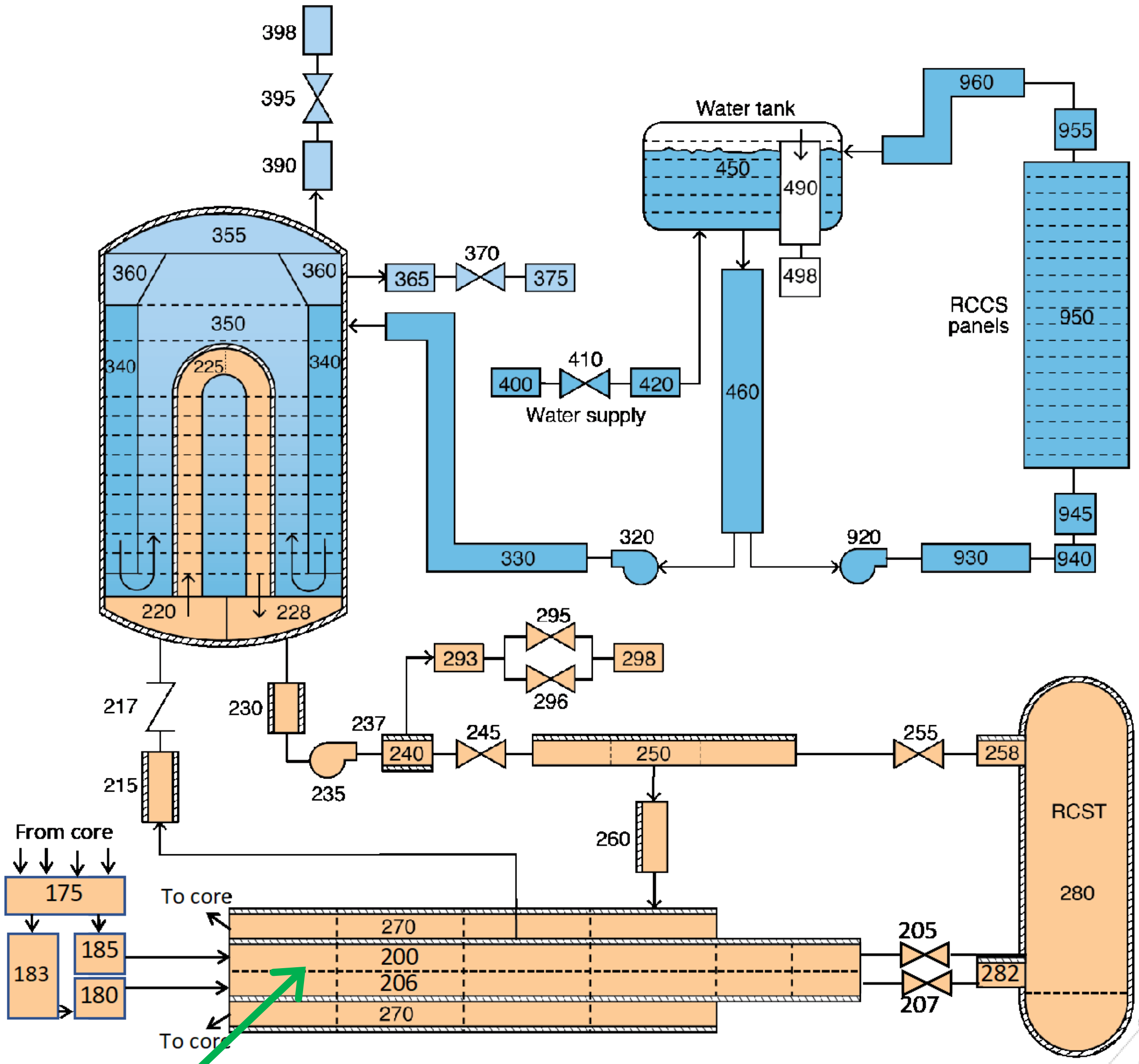


Figure 2. Primary pressure vessel radial nodalization.

RELAP5-3D Model

- Changes to Paul's base model
  - Replaced hot duct with "split" hot duct
    - Hope to see countercurrent single-phase flow
  - Primary helium blower BC replaced with circulator model



"Split" hot duct

RELAP5-3D PG-26

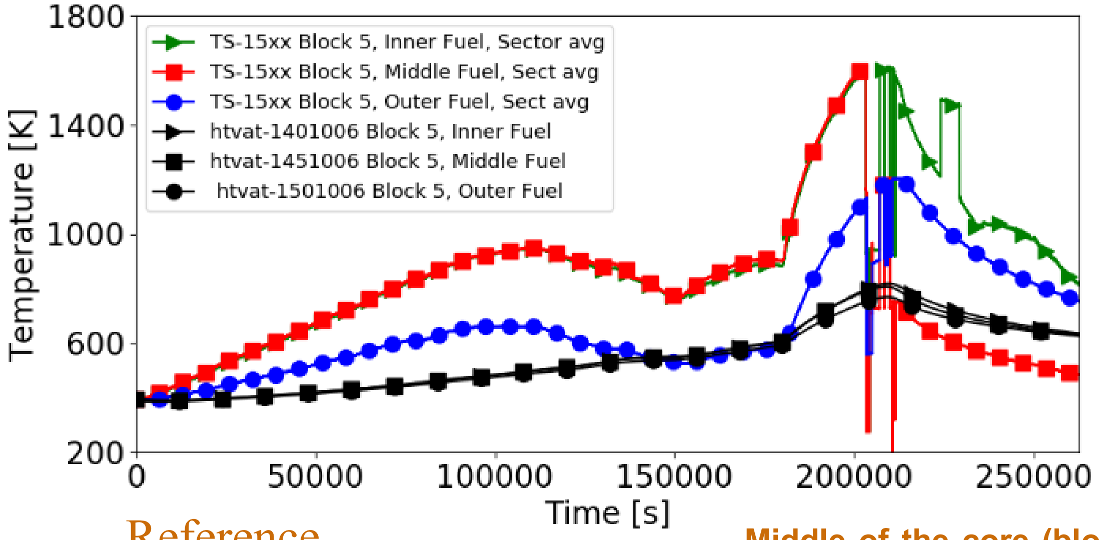
- PG-26: Double Ended Inlet-Outlet Crossover Duct Break
  - **<350kW (two heaters) DCC**
  - Test from 5/30/2019 to 6/03/2019 (**72 hours**)
  - DCC was initiated in the 50th hour of the test
  - Ceramics reached temperatures of near 1400°C

  and thermocouples began failing
    - Heater power was reduced
    - In the 59th hour heater 110 quit operation
    - The other heater, 104, was secured
  - Cool down data collected until the 72nd hour

- Figure of main interest are:
  - (Depressurized) Core cooling under decay heat conditions
  - Gas mixing phenomena, natural convection, possible flow reversal
- Different possible model approaches using RELAP5-3D:
  - Model the facility state right before the DCC starts as RELAP5-3D steady-state and only the DCC as RELAP5-3D transient
    - Goal: Get a well-defined facility state modeled before the transient of interest starts
    - Difficulties: Difficult to characterize the steady state before the DCC starts.
  - Model the whole transient including the heat-up phase as RELAP5-3D transient
    - Goal: "Better" facility state before transient starts, better known initial conditions at time zero
    - Difficulties: More difficult to model, need HTTF boundary conditions (stem generator behavior, etc.) during the heat-up.
  - Main modeling concern: No primary helium mass flows measured

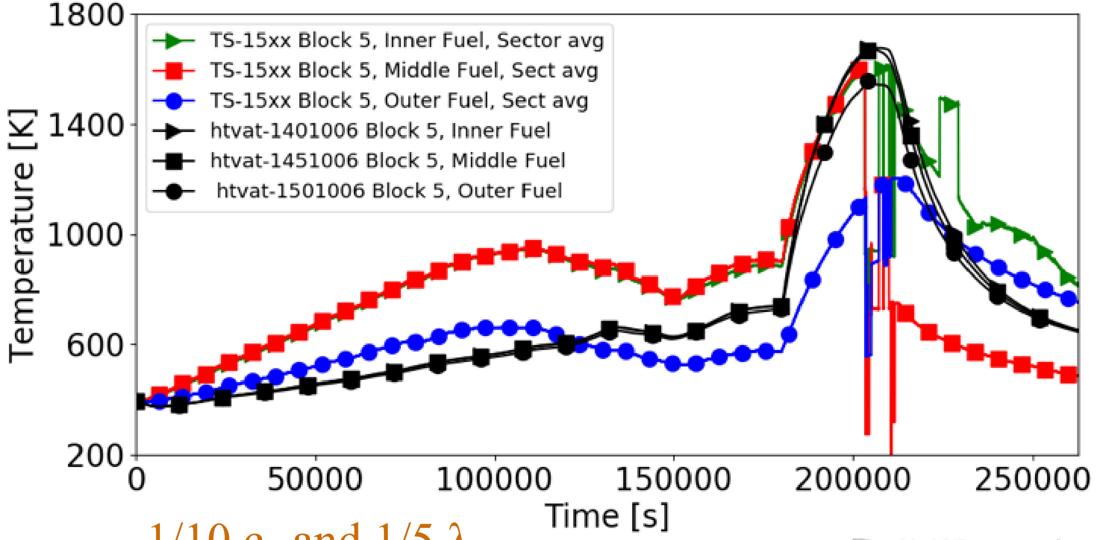
RELAP5-3D PG-26 Results

- Different possible model approaches using RELAP5-3D:
  - Model the facility state before the DCC starts as steady-state and only the DCC as transient
  - Model the whole transient including the heat-up phase as RELAP5-3D transient
- Reference
  - Best value for helium mass flow rate (15g/s)
- Sensitivity
  - 1/10 cp and 1/5 thermal conductivity
- Friction in the primary loop might be underestimated
  - Natural convection flow paths in RELAP5-3D (not observed in experiment)
    - lower (outlet) plenum → upper hot duct → RCST → lower hot duct → lower outlet plenum
    - RCST → Cold duct → Core → Hot duct → RCST
  - Sensitivity to friction shows:
    - Disappearance of natural convection
    - Natural convection and heat loss through the vessel walls are not a major contributor to the core temperature distribution



Reference

Middle of the core (block 5) ceramic temperatures in the fuel region.



1/10 c_p and 1/5 λ.

RELAP5-3D PG-26 Publications

ANS Annual meeting 2021

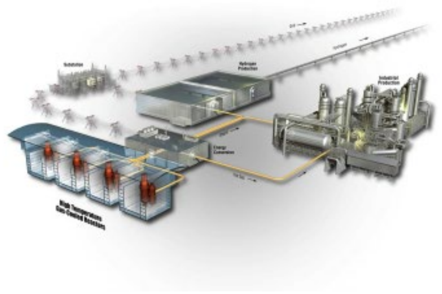
INL/EXT-20-59902

RELAP5-3D Modeling of High Temperature Test Facility Test PG-26

September 2020

Changing the World's Energy Future

Aaron S. Epiney



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Modeling of HTTF test PG-26 using RELAP5-3D and SAM

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INTRODUCTION

The High Temperature Test Facility (HTTF) at Oregon State University (OSU) is a scaled integral effect test facility designed to investigate transient behavior in High-Temperature Gas-cooled nuclear Reactors (HTGR) with prismatic fuel and reflector blocks [1]. Several tests have been completed at the HTTF including Depressurized Conduction Cooldown (DCC) and Pressurized Conduction Cooldown (PCC) transients.

This summary reports on the analysis of test PG-26 using the INL system code RELAP5-3D [2] as well as the ANL system code SAM [3]. Test PG-26 is a progression of the Double Ended Inlet-Outlet Crossover Duct Break transient that is referred to as a DCC [4]. Core initial conditions (i.e., before the DCC started) have been met using low power (<100 kW) and two of ten available electric heater banks. The DCC transient was initiated during the 50th hour of the test. The break valves were opened, and hot helium from the core and cold helium from the Reactor Cavity Simulation Tank (RCST) started mixing. The gases flowed in a countercurrent fashion, where the top half of the hot duct contained hot helium that flowed in one direction and cold helium that flowed in the other direction in the bottom half of the duct. After the pressure and density reached equilibrium, the event entered a diffusion mode. The onset of a reverse natural circulation was not observed during the DCC period of the test.

Test PG-26 poses several modeling challenges:

- **No helium mass flow measurements**: The HTTF facility is not equipped to directly measure the helium flow rate in the Primary Coolant System (PCS). However, to get the right energy balance and core conditions before the DCC transient, knowledge of the helium mass flow rate is needed.
- **No steady state**: HTTF did not reach a fully developed steady state (temperature distribution) during PG-26. On the one hand, the ceramic core blocks take a long time to completely cool down to room temperature. To avoid having to wait unreasonably long times between tests, a
- **Limited knowledge of heat flow**: The Reactor Cavity Colling System (RCCS) was activated during the test. The water temperature difference over the RCCS is very small during the whole test, indicating that nearly no heat is evacuated by it. However, the natural convection inside the cavity between the vessel and the RCCS panels is probably a large contributor to heat removal off the vessel wall (not measured), and air inside that cavity can escape since it is not airtight.

Also, the core ceramic temperatures go down during the core heat-up from ~120,000 s to 150,000 s (See Fig. 1). This is due to the steam generator behavior and heater power. The steam generator started producing steam around 80,000 s and pressurized up to about 110,000 s. At that time, the steam generator pressure was manually reduced, and the inventory was refilled with cold city water. This reduced the steam generator temperature, which affected the core inlet gas temperature.

Another phenomenon that happened during the PG-26 test was thermal stratification. For example, helium temperatures measured in the lower (outlet) plenum of the vessel show a strongly non-uniform temperature distribution. Thermal stratification plays an important role in determining the temperatures for helium flows leaving the plenum as well as for determining the structure temperatures encompassing the helium plenum.

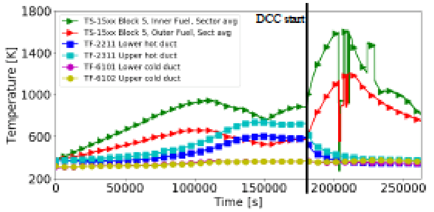
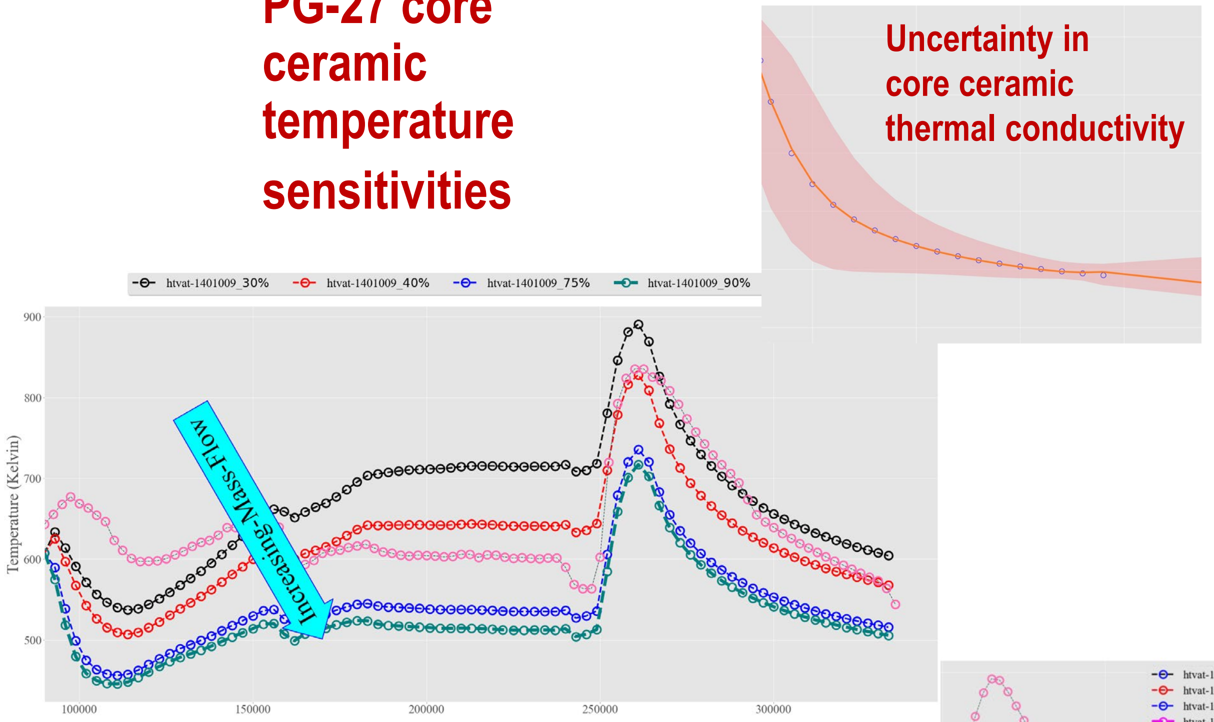


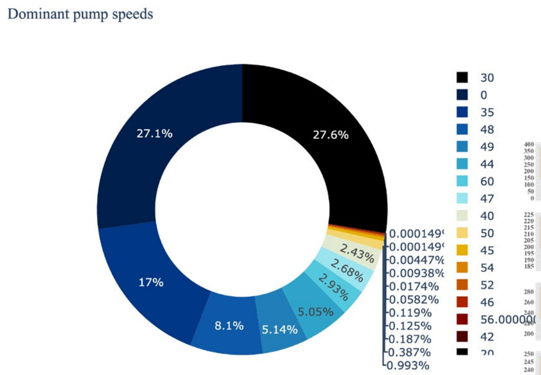
Fig. 1. Measured core ceramic (midcore around the inner and outer fuel rings) and helium (in the upper and lower part of the hot and cold ducts) temperatures.

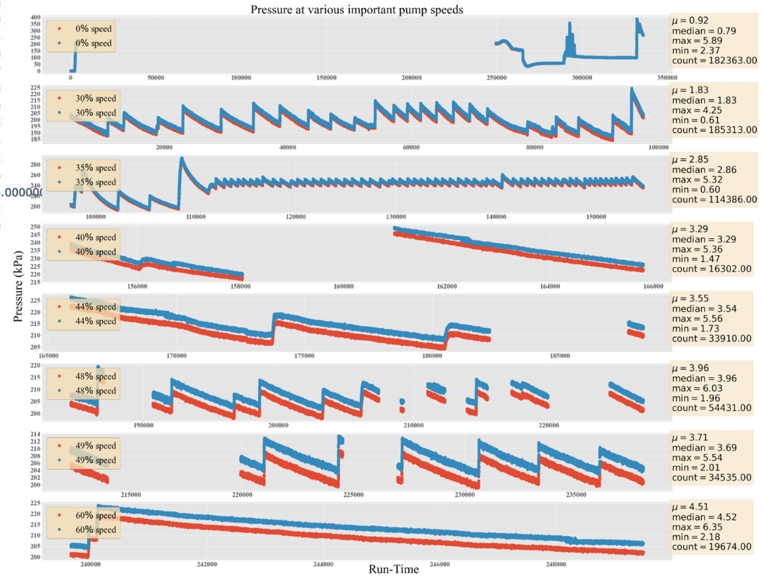
RELAP5-3D PG-27 Results

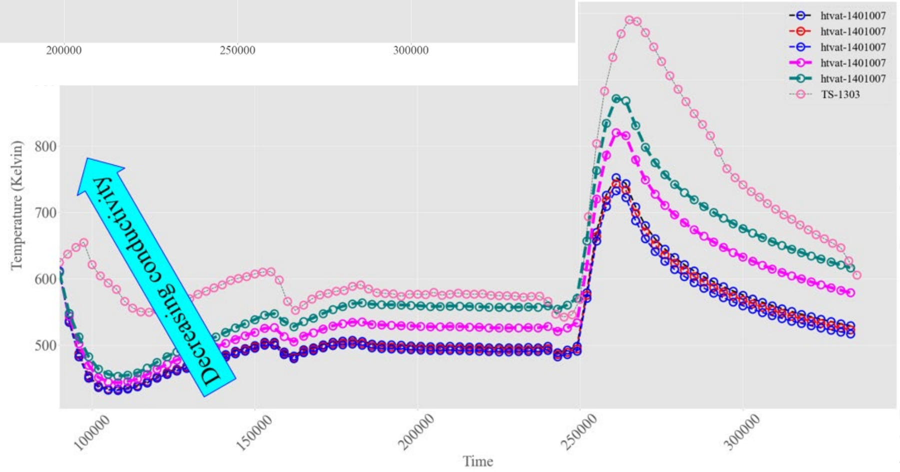
- Like PG-26, but PCC
- Similar modeling challenges
- E.g., frequent blower speed changes
  - Inlet pressure and blower speed not consistent

PG-27 core ceramic temperature sensitivities









RELAP5-3D PG-27 Publications

- Submitted NURETH abstract on HTTF PG-27 using REALP5-3D.
  => Abstract accepted for full paper.

- DOE FY21 Milestone report end of September.

HTTF Benchmark

- INL, ANL, OSU and CNL are currently considering a code-to-code-to-data HTTF code validation benchmark
  - System code, CFD, error scaling and coupled exercises considered
  - Selection of suitable HTTF data ongoing
  - Multiple exercises considered
    - Fixed BCs for code-to-code comparison
    - ‘best estimate’ BCs, where each team uses their own approach
      - For example: It is necessary to use an effective thermal conductivity for modeling HTTF core and HTGR fuel blocks when using a system analysis code like SAM
    - Uncertainty scaling from HTTF to MHTGR
  - Different modeling approaches will be systematically compared in the benchmark

Conclusions

- There is a lot of high quality HTTF data available for code benchmarks
  - Let's make use of it!
- HTTF modeling started at INL:
  - System codes model for RELAP5-3D has successfully been developed
  - Models used to model the HTTF test PG-26 and PG-27
    - Uncertainties in input data and boundary conditions propagated in the models
- PG-26 and PG-27 initial RELAP5-3D calculations provide some insights and point to missing or uncertain data
- International HTTF benchmark currently considered by INL, ANL, OSU and CNL
  - Hopefully more simulation work going on… Stay tuned!

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