INL/RPT-23-73896-Revision-0

Presentation for the MeV school based on Multi-physics/Multi-Scale simulations, using EBR-II validation data

August 2023

Changing the World's Energy Future

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Idaho National Laboratory

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Computational Scientists

Validation of Pronghorn's Subchannel code using the EBR-II shutdown heat removal tests.

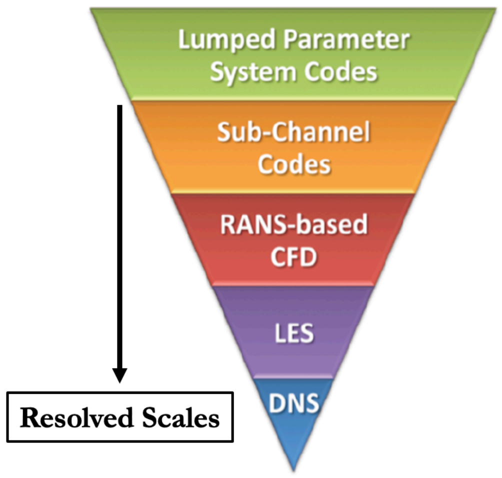
Outline

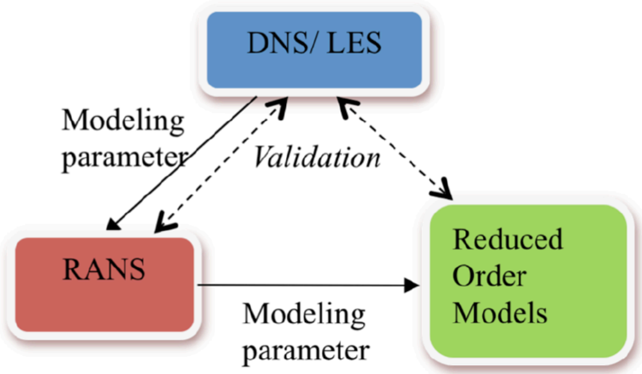
- Motivation
- Benchmark Description
- Model Development
- Simulation Results

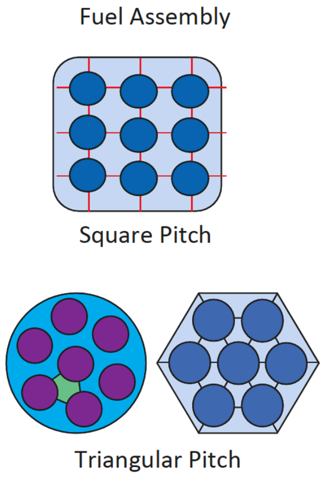
Motivation

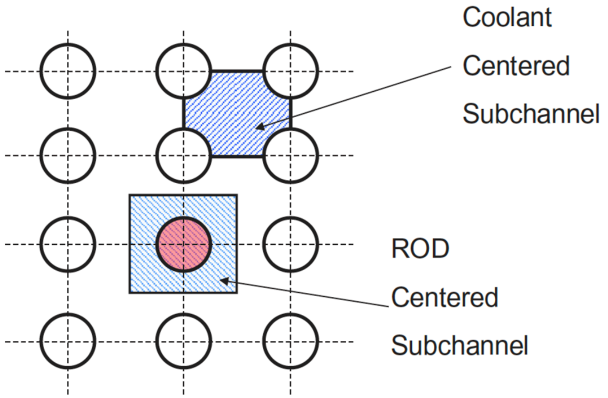
Overview

1. The system level thermal hydraulic analysis codes like RELAP, RETRAN, ATHLET are used to get the balance of plant.
2. The results of this analysis provide the boundary conditions used for the core level/component analysis.
3. The detailed analysis of the reactor core is typically performed using the **sub-channel** thermal hydraulic codes.









A **sub-channel** is defined as the ideal flow passage formed between number a of rods and/or duct-wall.

sub-channel equations are derived by integrating the conservation equations over **sub-channel** volumes

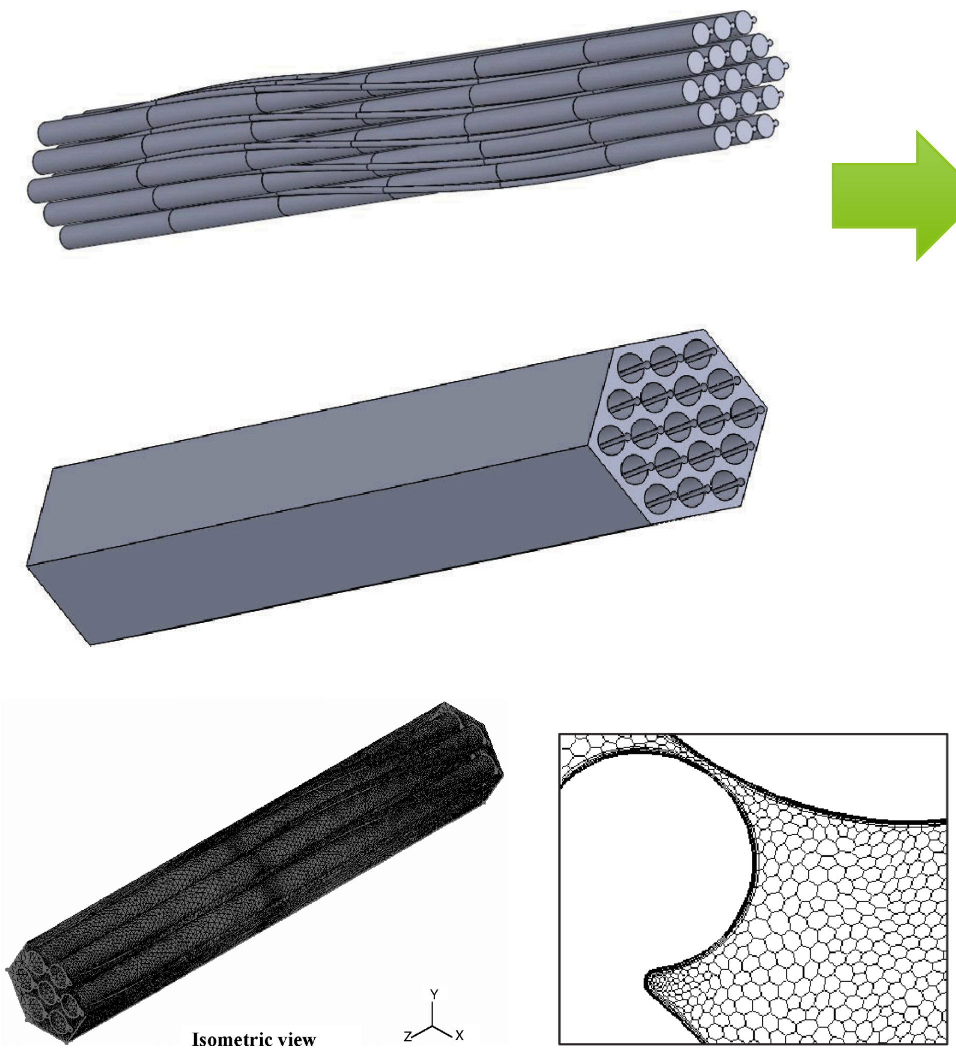
Subchannel codes are thermal-hydraulic codes that offer an efficient compromise for the simulation of a nuclear reactor core, between CFD and system codes

Context

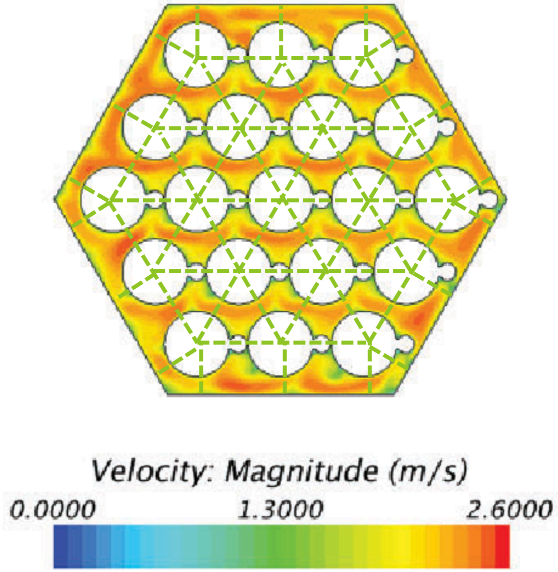
- Pronghorn is an engineering-scale, coarse-mesh, thermal-hydraulics tool for supporting reactor-core simulations of advanced nuclear reactors.
- Most of the current efforts in Pronghorn have been devoted in developing porous finite-volume capabilities and adapting closure correlations for coarse-mesh thermal-hydraulics modeling.
- However, for liquid-metal reactors (LMRs) with wire-wrapped fuel pin assemblies, a pin-level thermal-hydraulic resolution is required for most safety case studies (pin rupture, channel blockage, etc.).
- For this purpose, a new Subchannel application is developed in MOOSE, which affords the required flow field resolution, while still preserving an engineering-scale approach.
- This new solver can be natively coupled to Pronghorn and other MOOSE objects to enable full-core, multi-physics, multi-scale engineering studies.

Principles of subchannel formulation

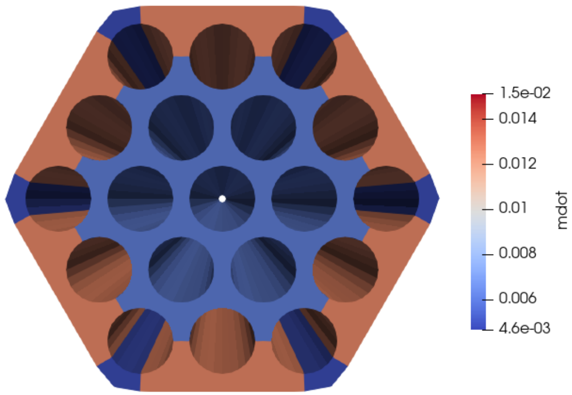
Wire-wrapped fuel assembly



CFD simulation

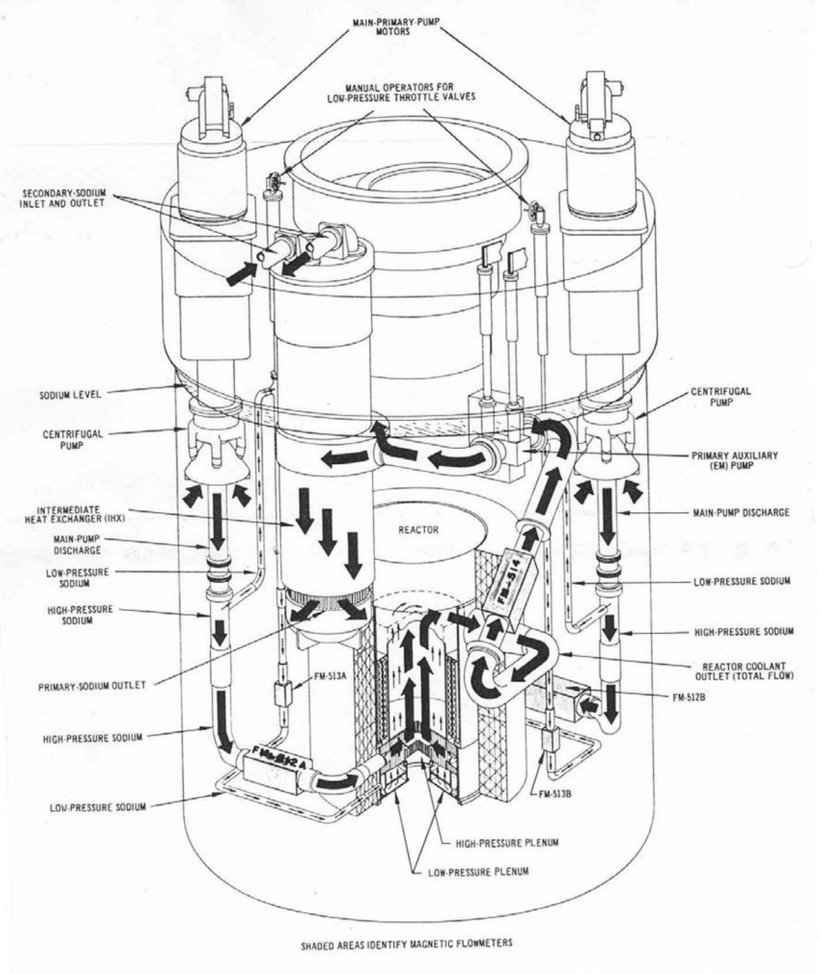


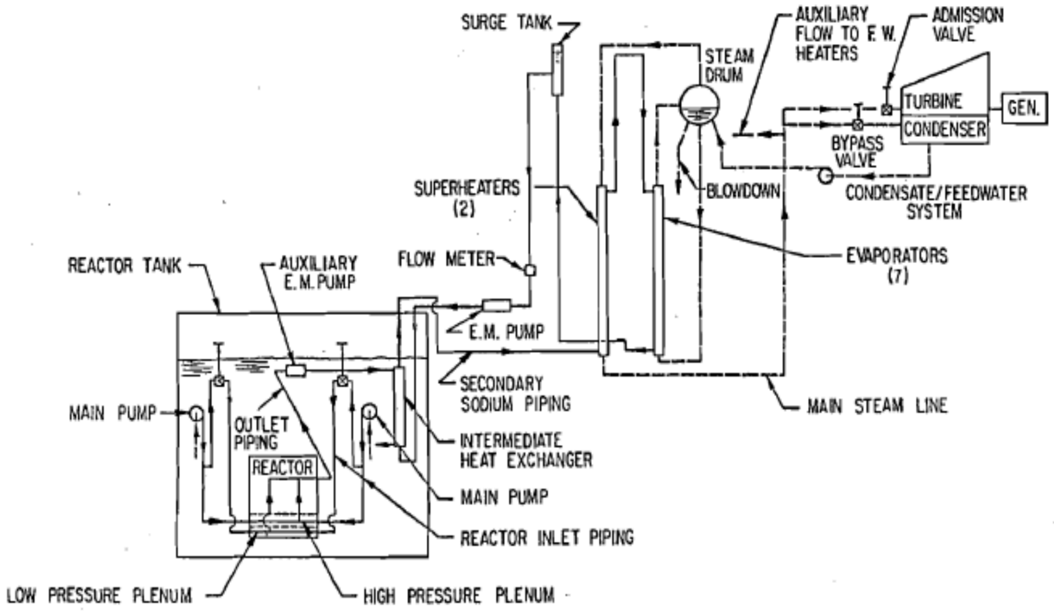
Subchannel model



Resolves:
Mass, momentum (axial and cross directions), and energy balance
Requires:
Closure correlations for friction factors, localized pressure losses, and turbulent mixing coefficients

EBR-II





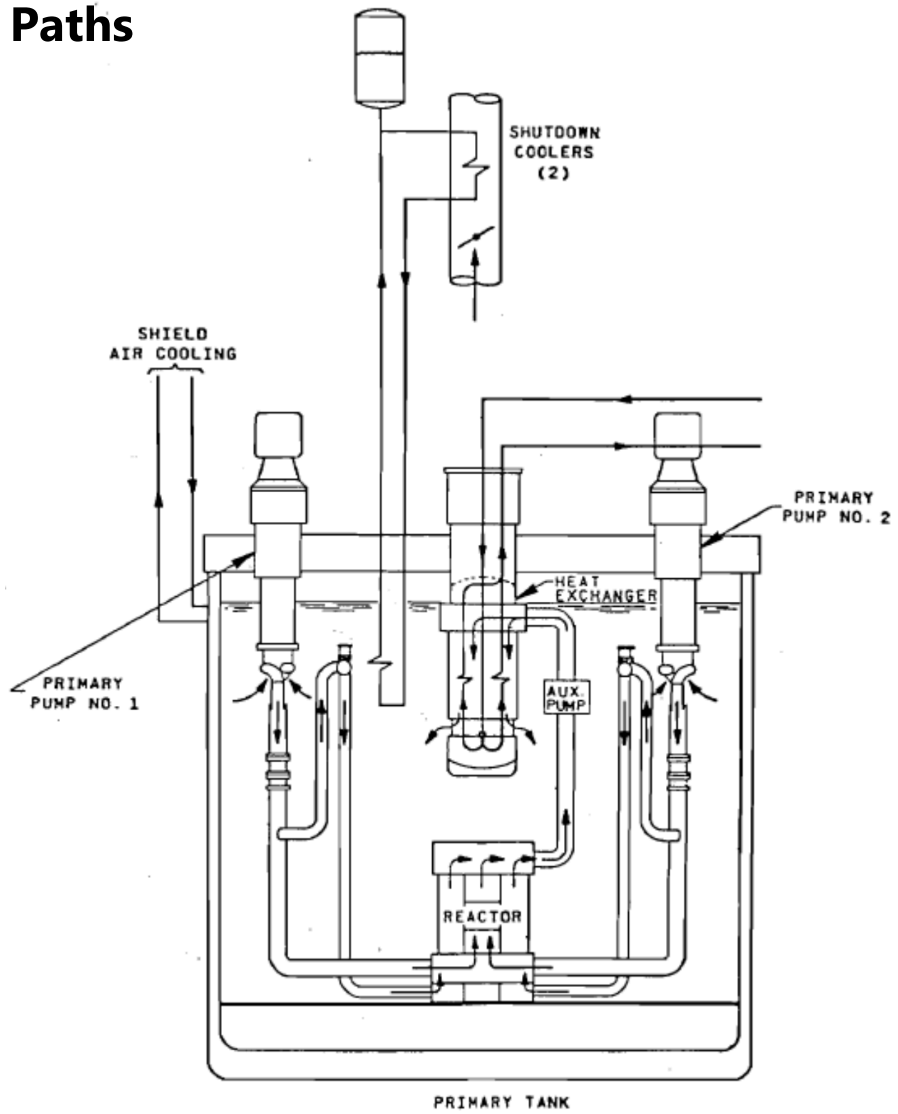
EBR-II Plant Schematic

Benchmark Description

SHRT-17, SHRT-45R Tests

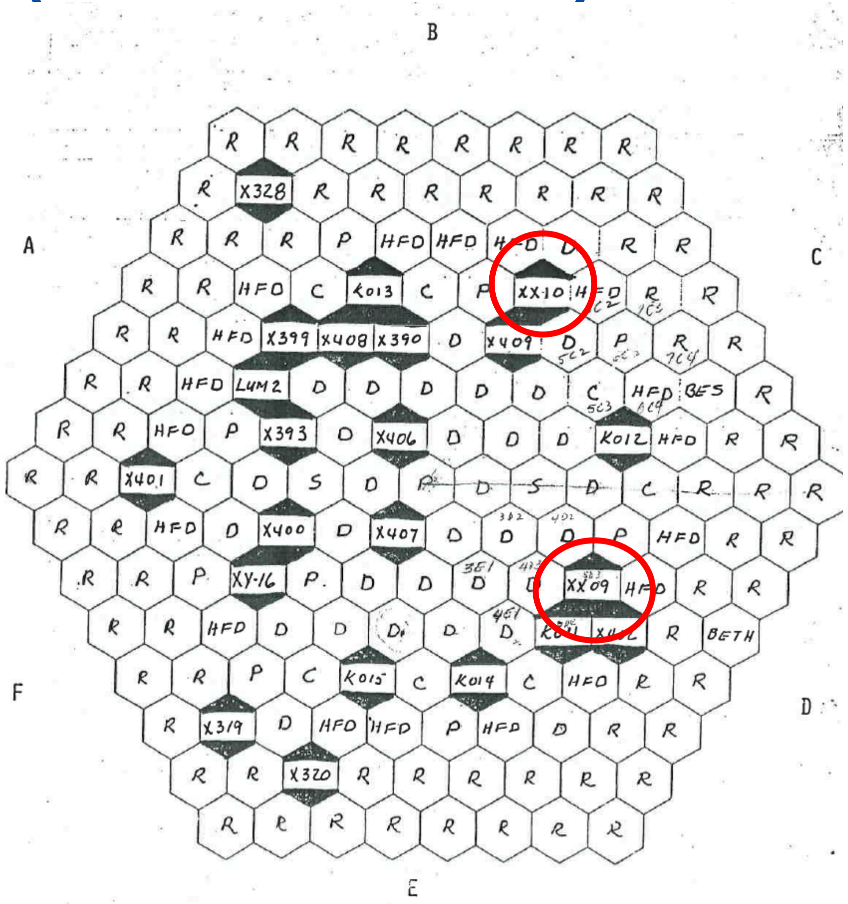
- The Shutdown Heat Removal Test (SHRT) program was carried out in EBR-II between 1984 and 1986.
- On June 20, 1984, the SHRT-17 loss of flow test, was conducted where a loss of electrical power to all the plant sodium coolant pumps, was initiated to demonstrate the effectiveness of natural circulation cooling characteristics.
- Starting from full power and flow, both the primary and intermediate-loop coolant pumps were simultaneously tripped, and the reactor was scrammed to simulate a protected loss-of-flow accident.
- Temperatures in the reactor quickly rose to high, but acceptable levels, as the natural circulation characteristics cooled the reactor down to safe decay heat levels.
- Similarly, to SHRT-17, the SHRT-45R test was initiated by a trip of the primary and intermediate pumps under the rated-power condition at 60.0 MW, but without scram of the reactor. Negative feedback effects drove reactor power down.

EBR-II Primary Tank Sodium Flow Paths



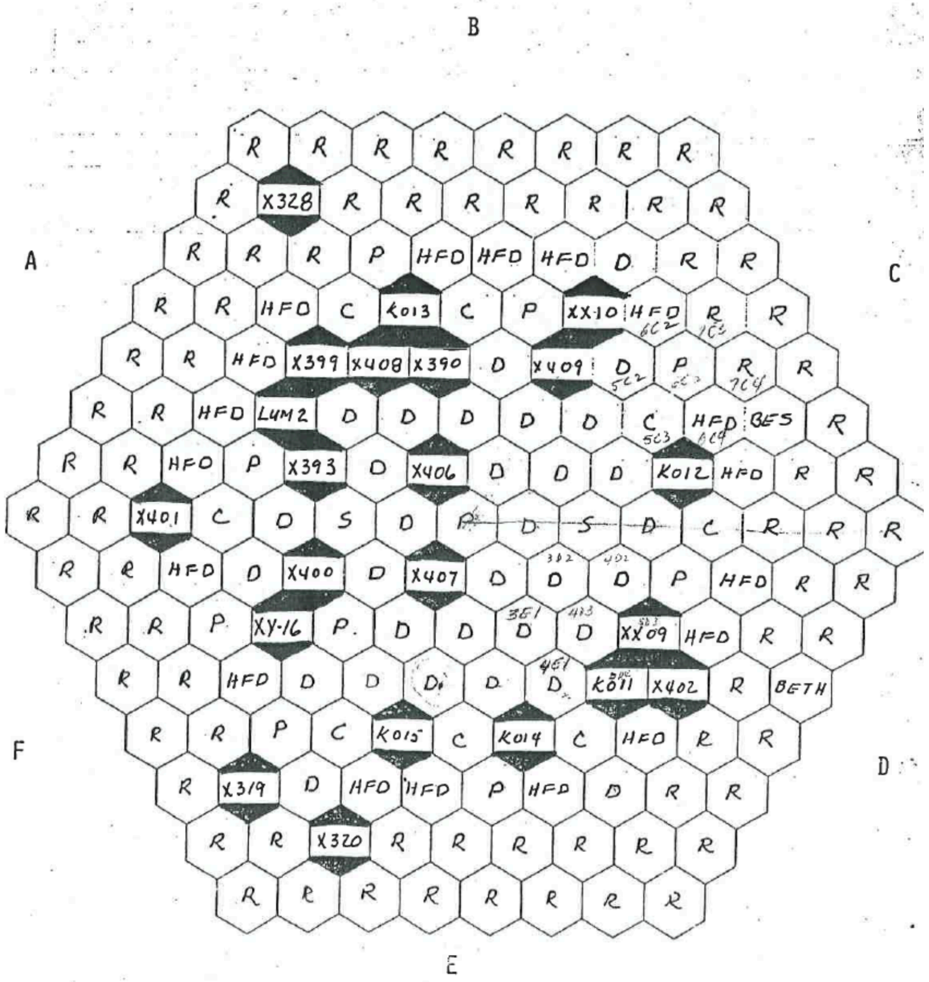
Instrumented Subassemblies (XX09 & XX10)

- There are two instrumented subassemblies in the reactor core, which are labeled as XX09 and XX10.
- The XX09 is a kind of driver subassembly loaded in the 5th row (4th ring) and the XX10 is a specific subassembly in which fuel pins, are replaced by stainless steel pins.
- the XX09 subassembly contains 61 pins wrapped by wire spacers. Diameters of the cladding and wire are 4.419 mm and 1.244 mm, respectively. Two out of the 61 pins contain flow meters instead of fuel slugs.

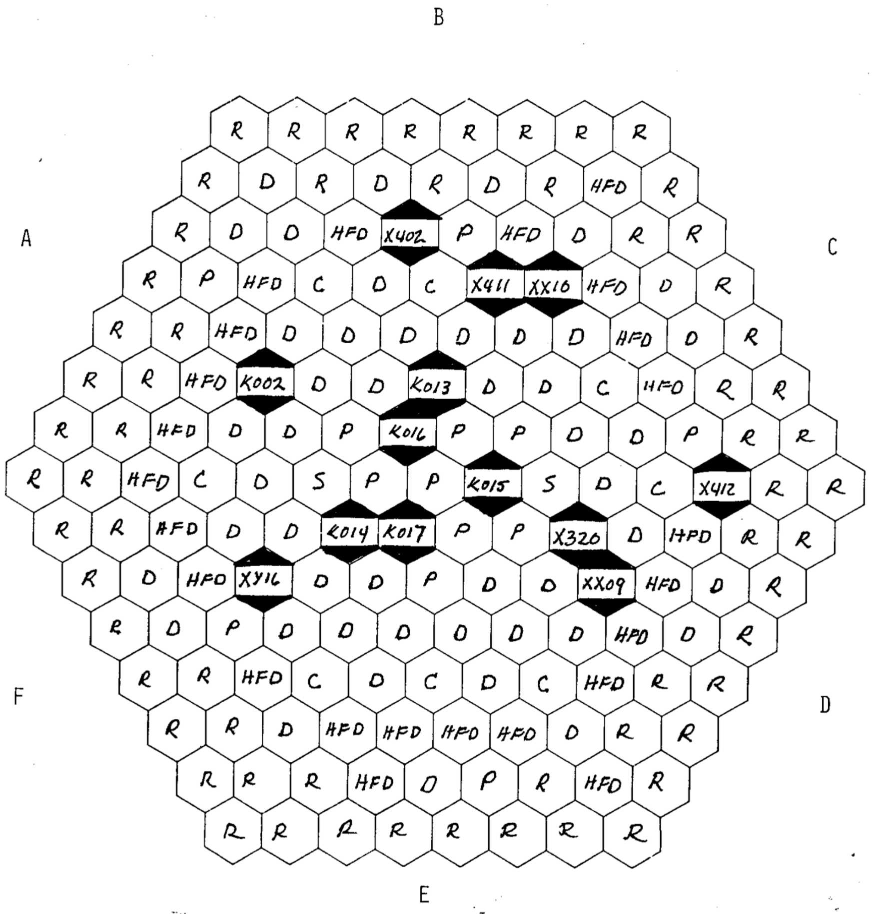


SHRT-17 Core Loading Pattern (First 8 Rows)

Instrumented Subassemblies Layout (XX09 & XX10)

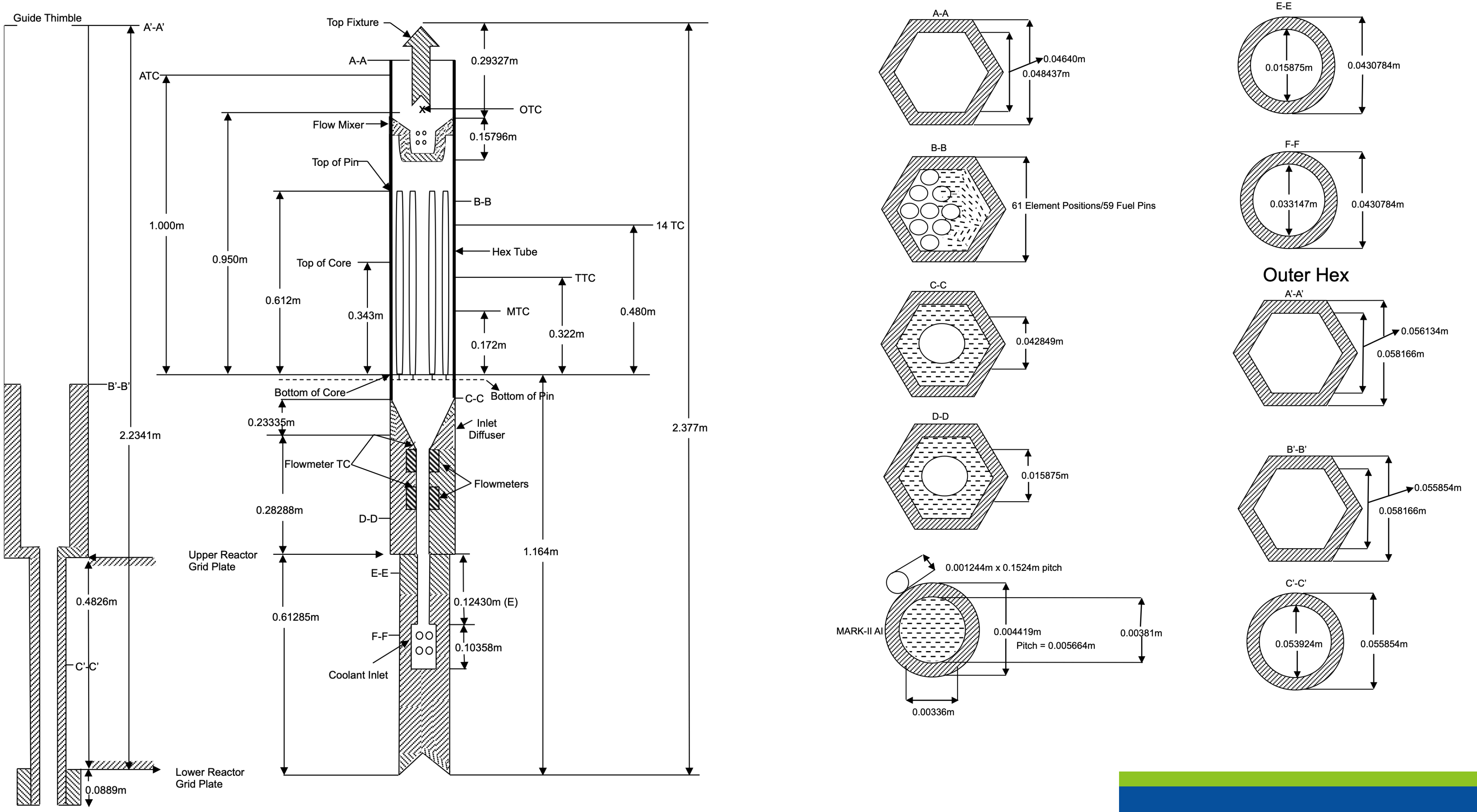


SHRT-17 Core Loading Pattern (First 8 Rows)

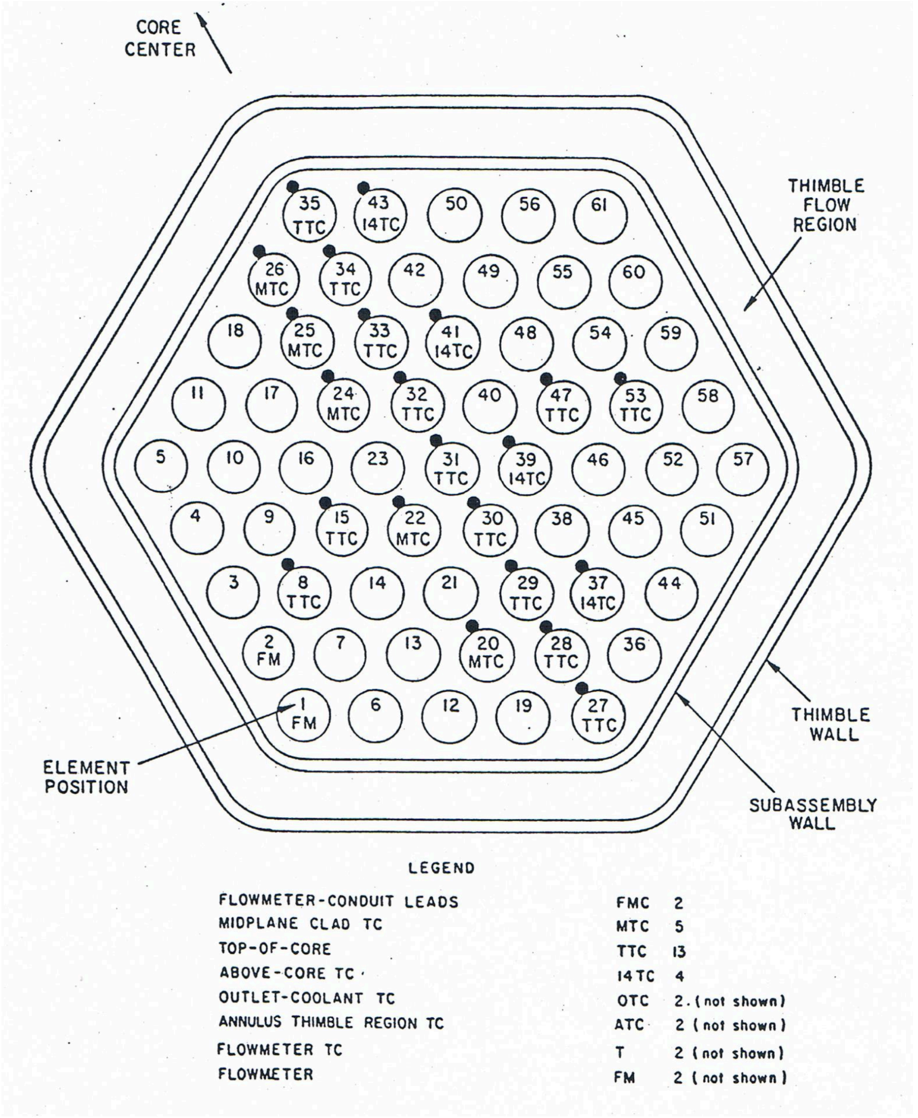


SHRT-45R Core Loading Pattern (First 8 Rows)

Instrumented Subassembly XX09

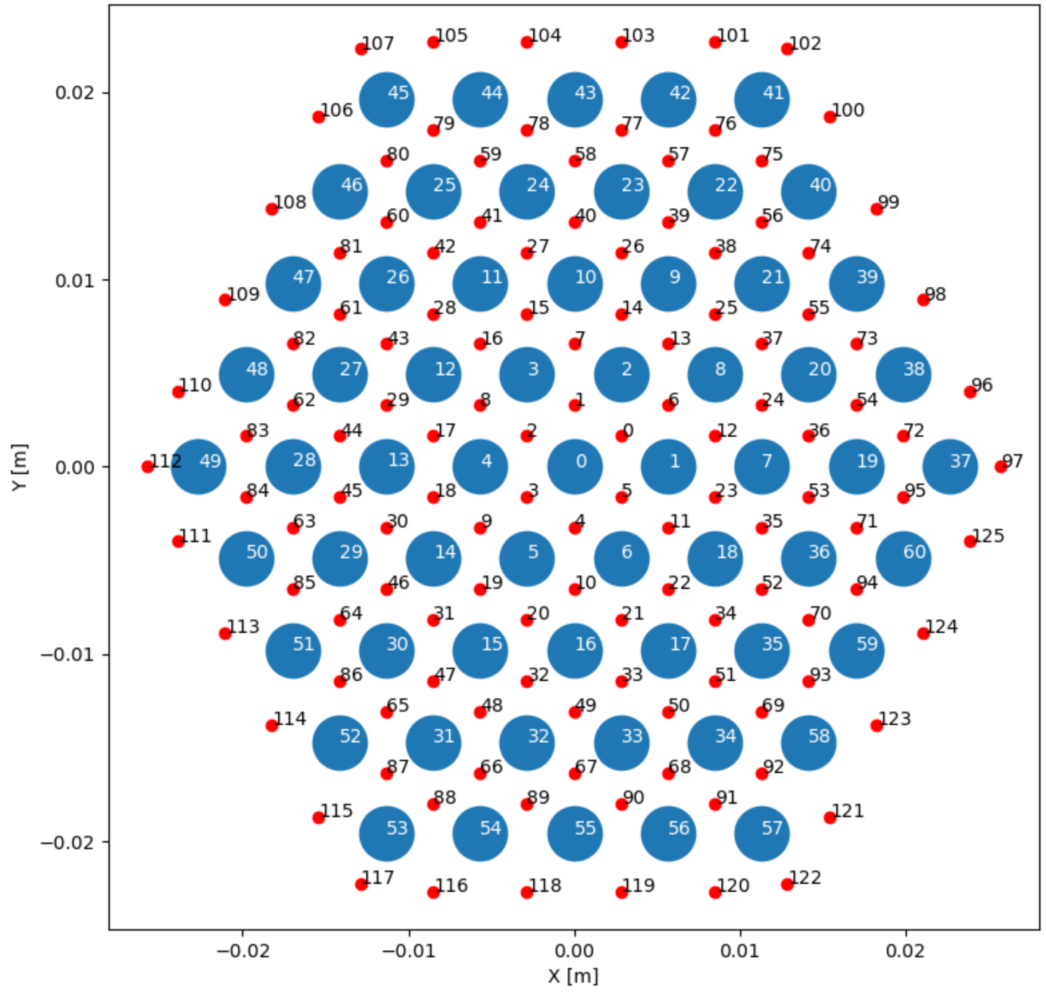


Instrumented Subassembly XX09



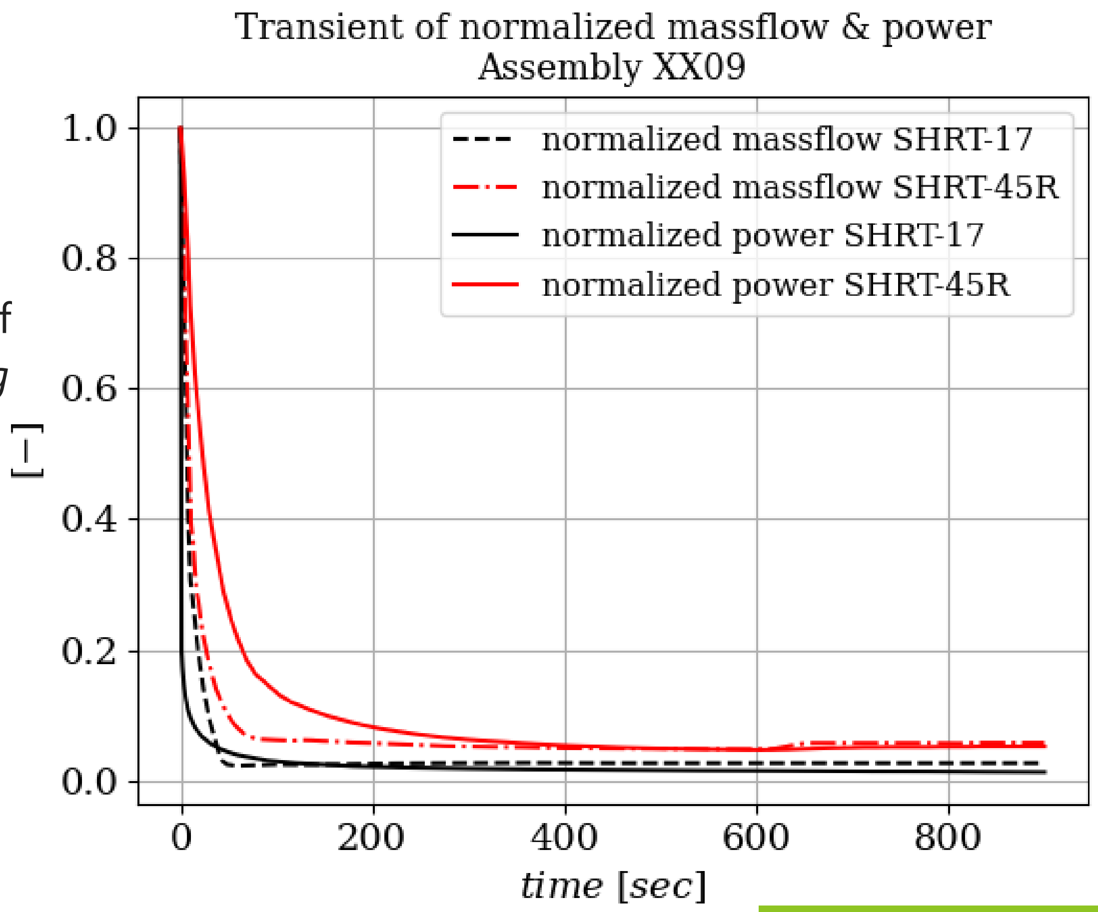
XX09 Instrumented subassembly instrument

Fuel-Pin/Subchannel index



Boundary Conditions

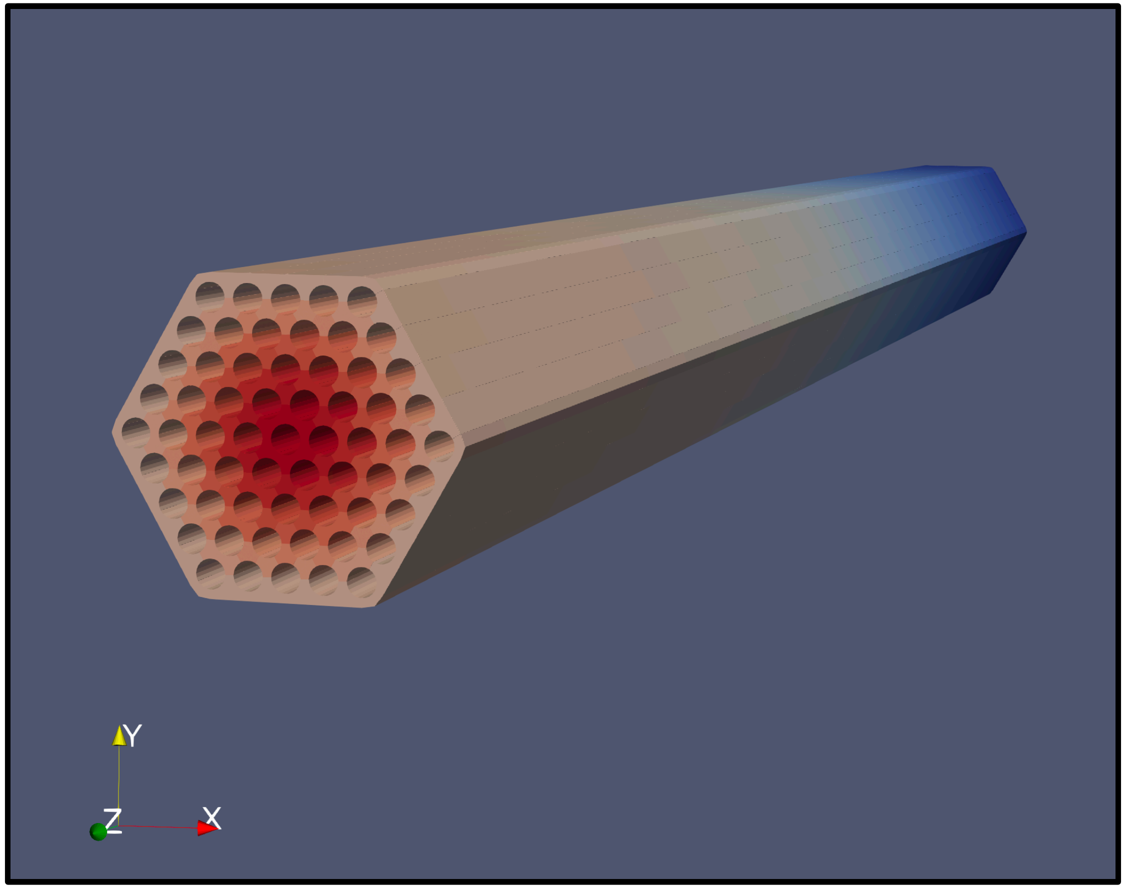
Experiment Parameter (Unit)	SHRT-17	SHRT-45R
Mass flow rate of XX09 (kg/sec)	2.45	2.427
Power of XX09 (kW)	486.2	379.8
Inlet coolant temperature (K)	624.7	616.4



Mochizuki, H., & Muranaka, K. (2018). Benchmark analyses for EBR-II shutdown heat removal tests SHRT-17 and SHRT-45R–(1,2) subchannel analysis of instrumented fuel subassembly. *Nuclear Engineering and Design*, *330*, 14-27.

Model Development

Subchannel Model



Subchanne
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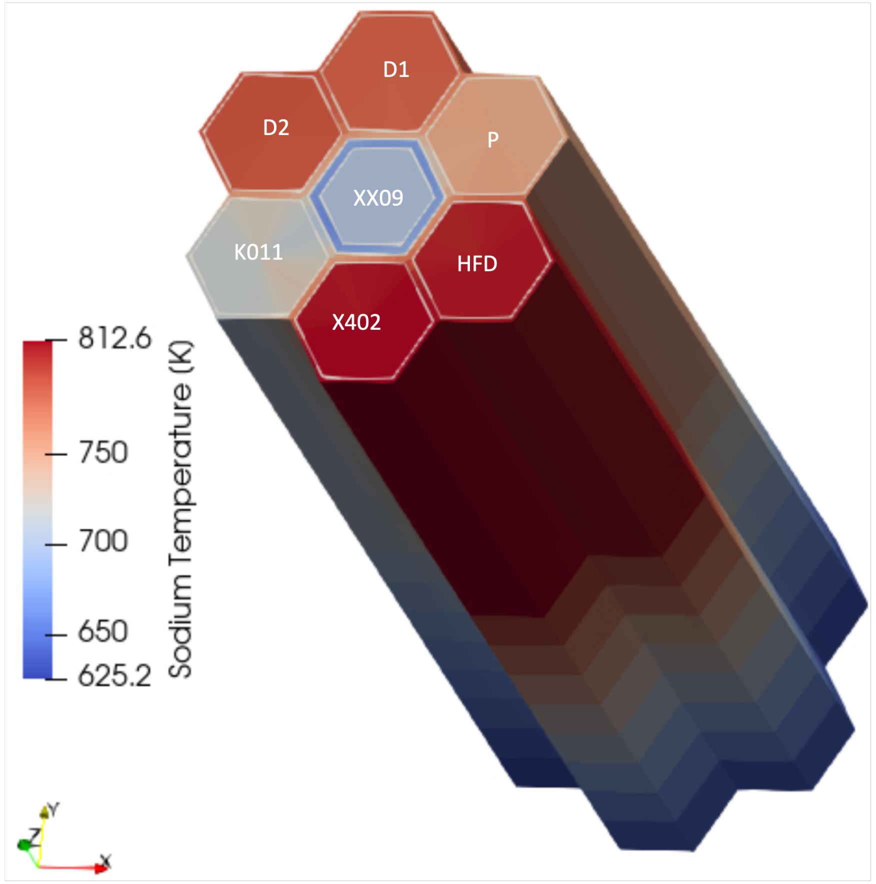
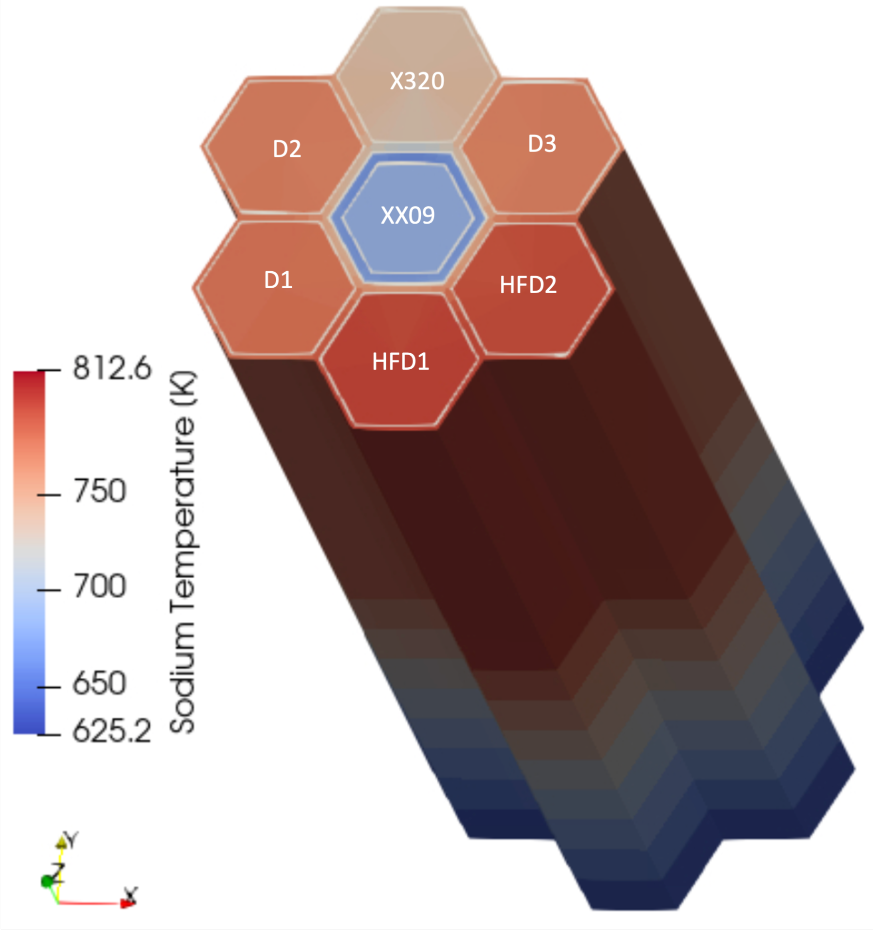
Pronghorn Models

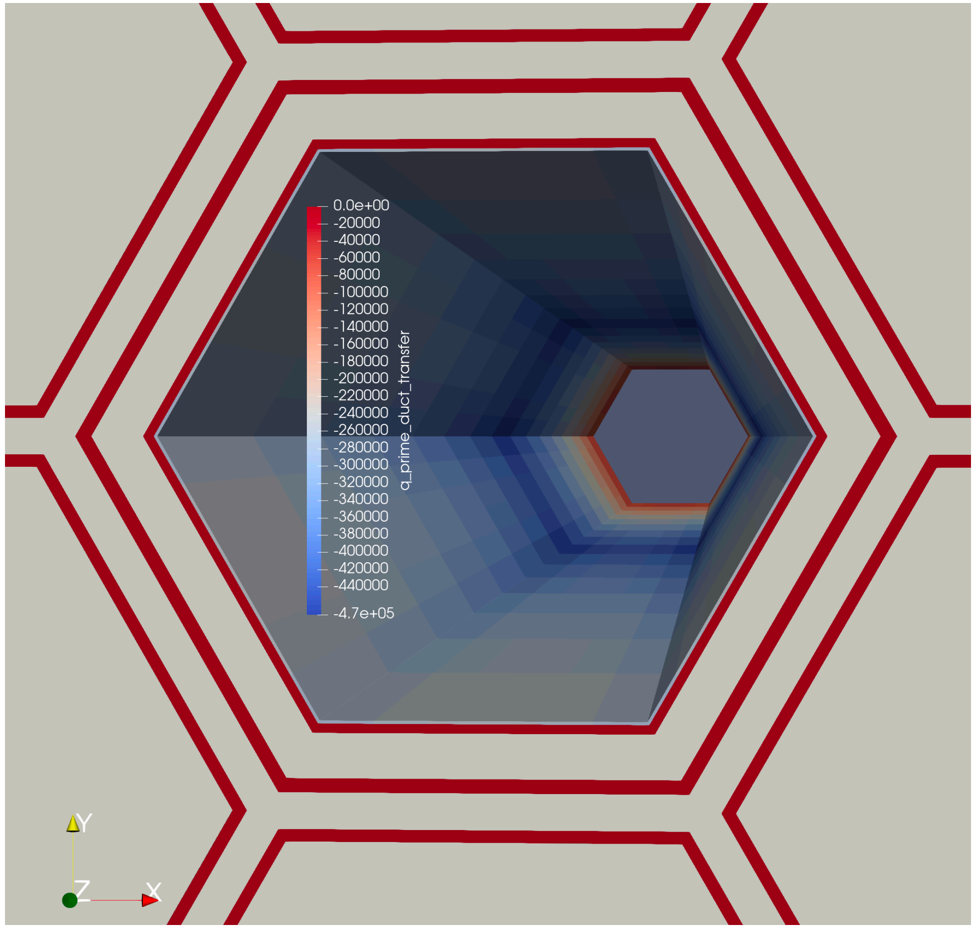


SHRT-17

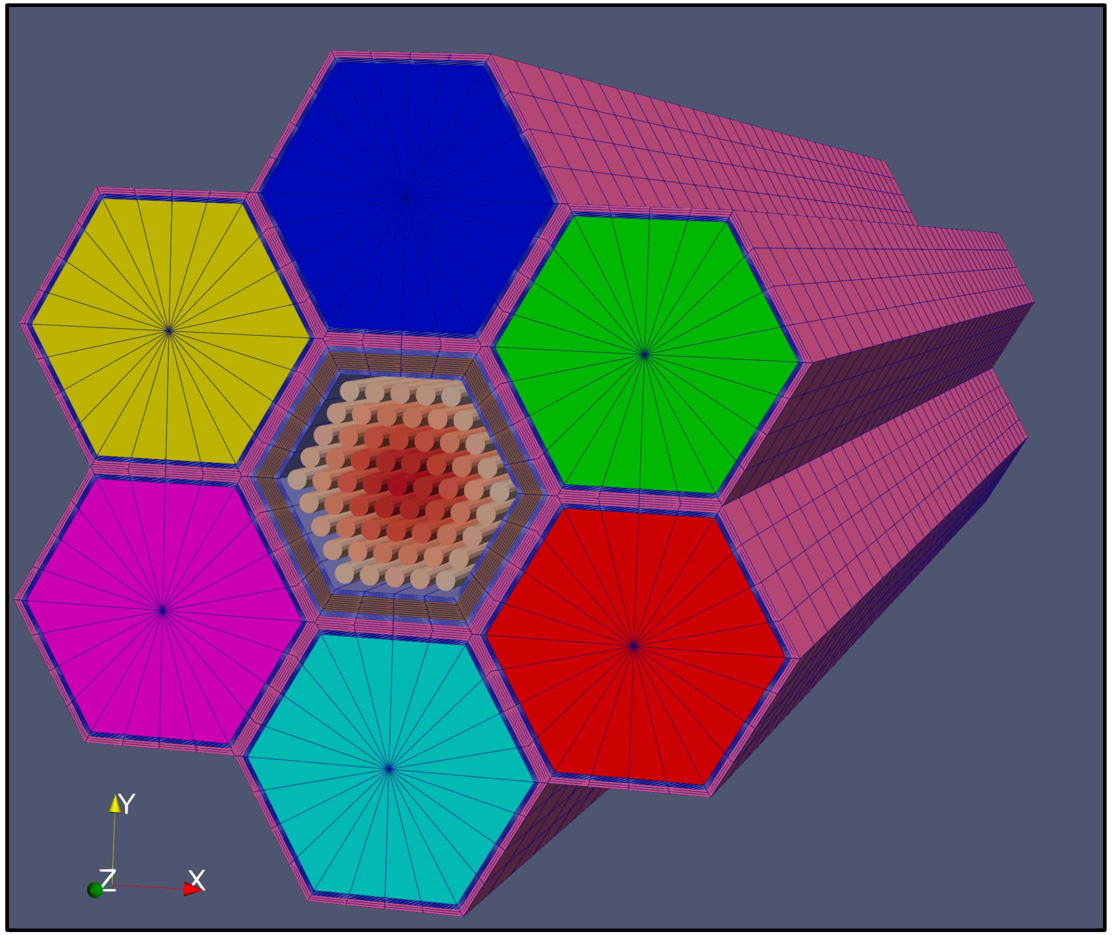


SHRT-45R

Coupled Simulation

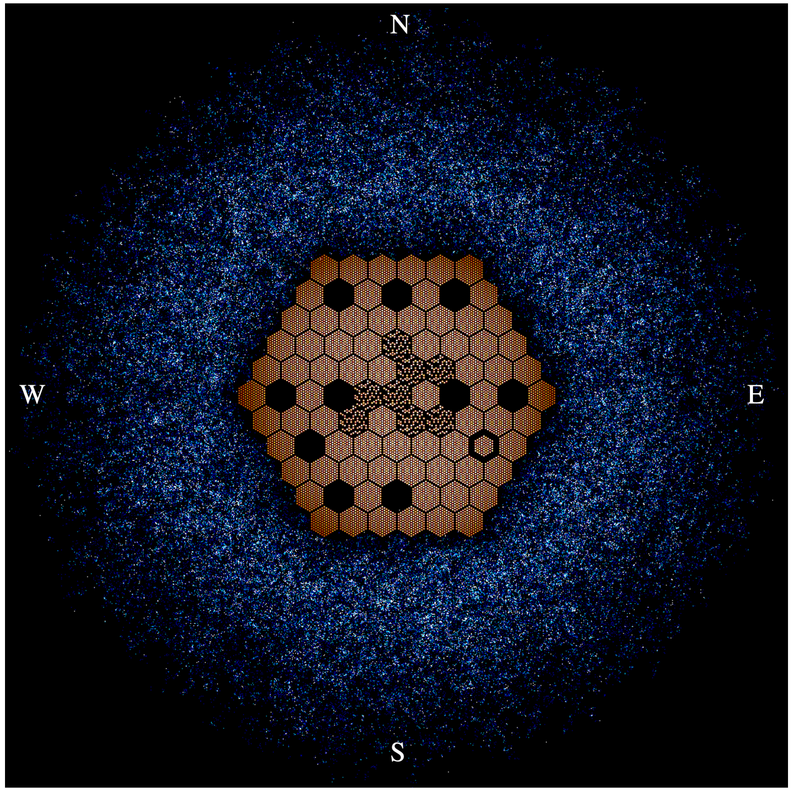


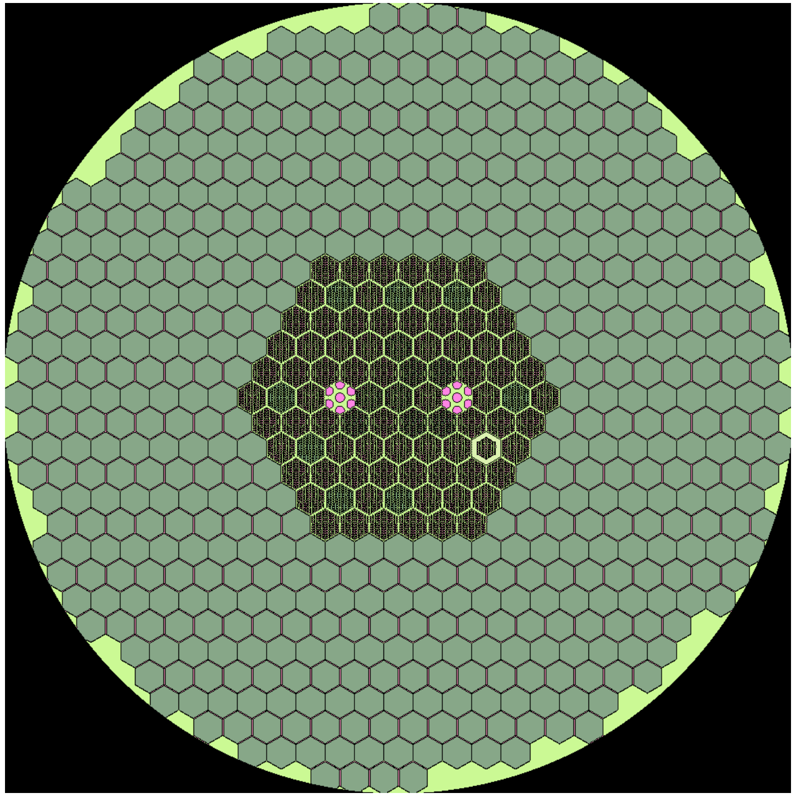
Linear heat-flux in Pronghorn

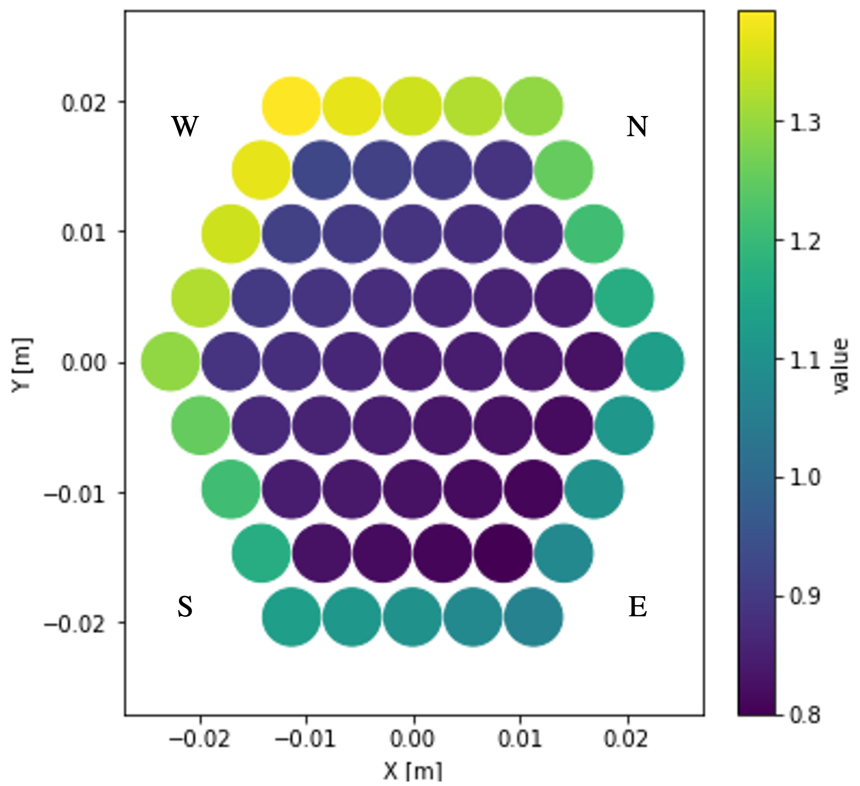


Coupled Simulation

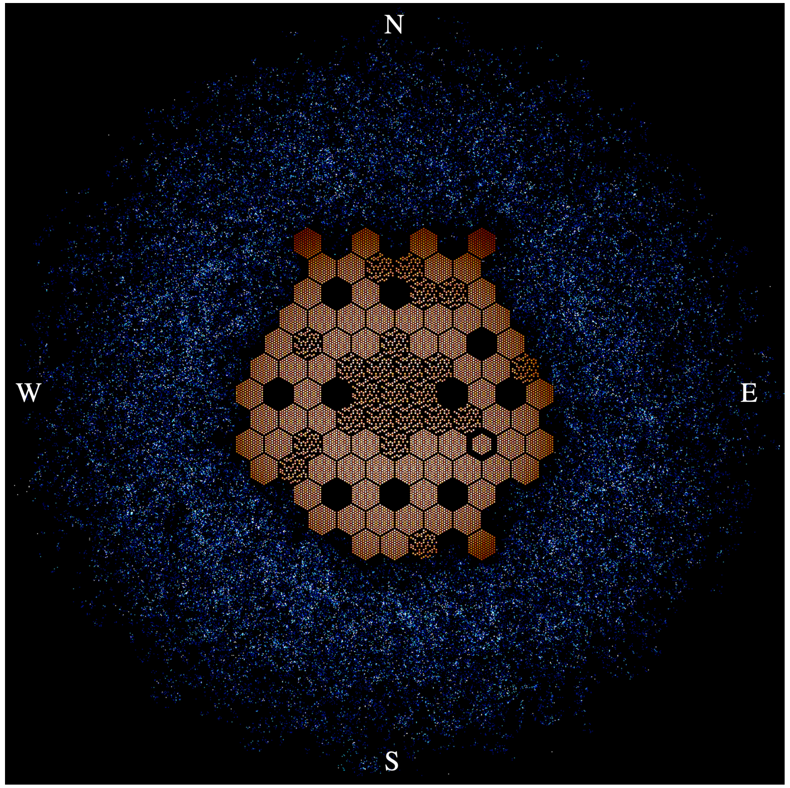
Serpent Model of EBR-II SHRT-17

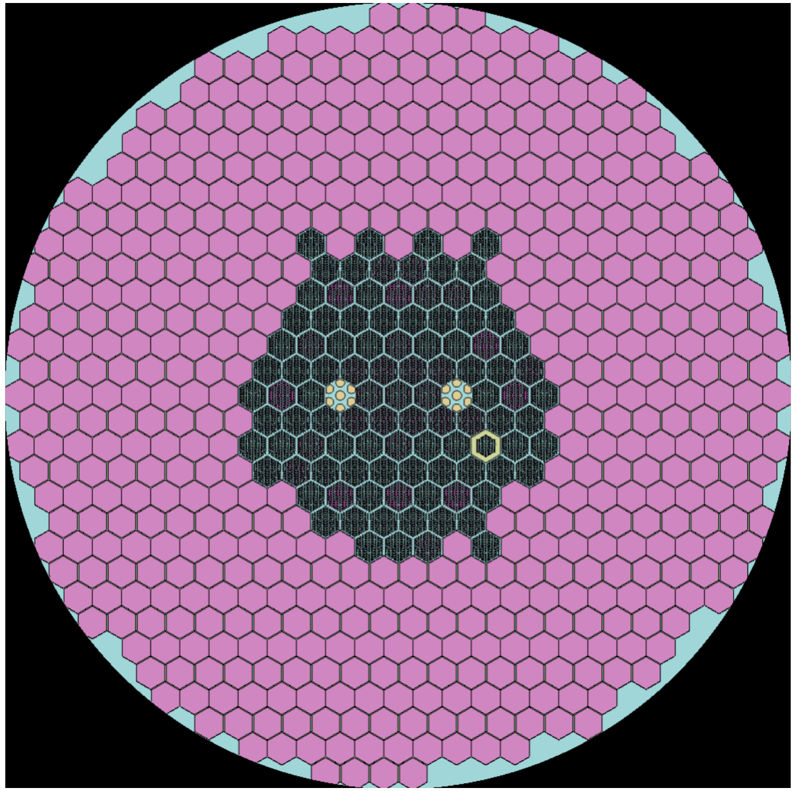


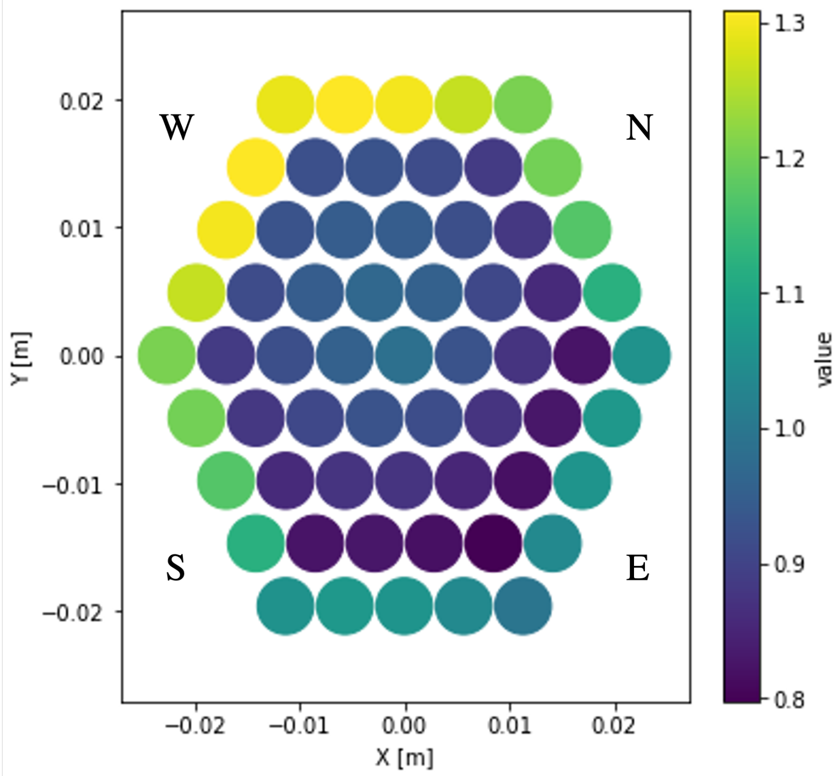




Serpent Model of EBR-II SHRT-45R

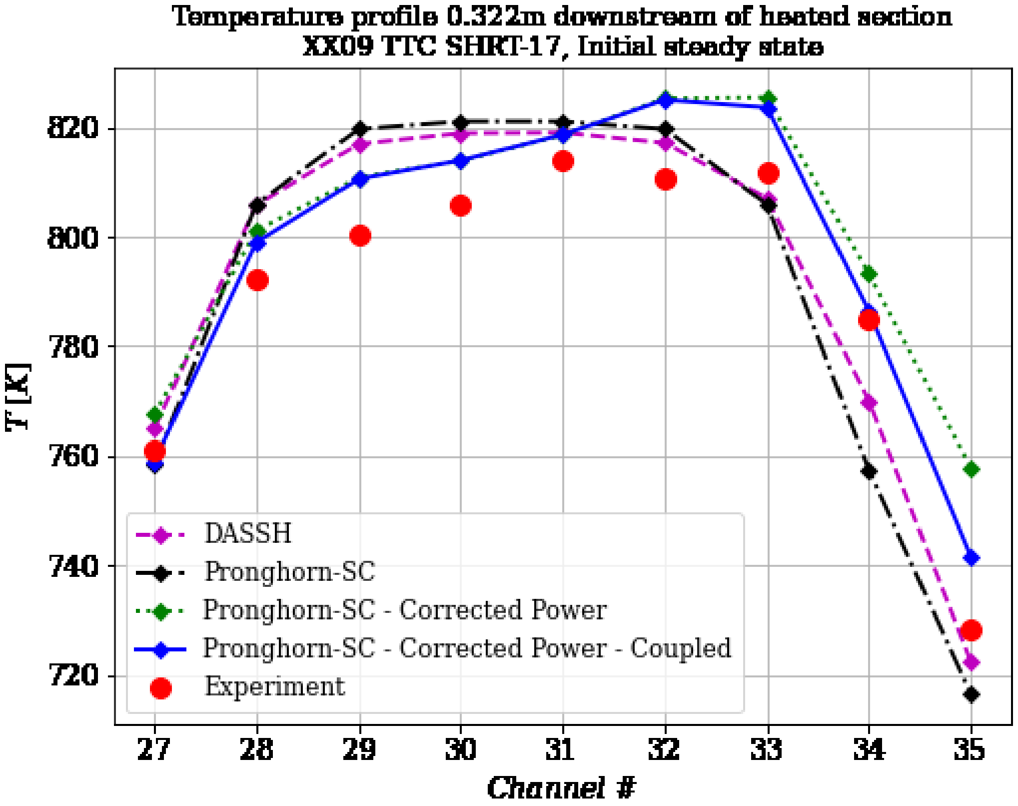


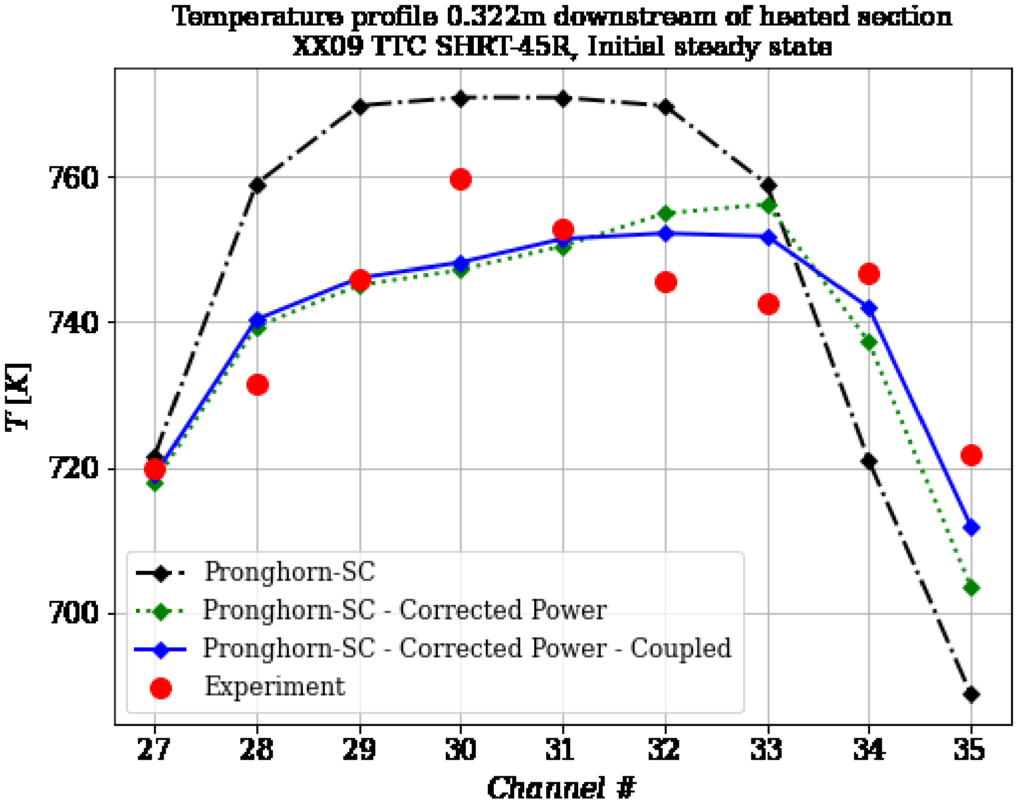




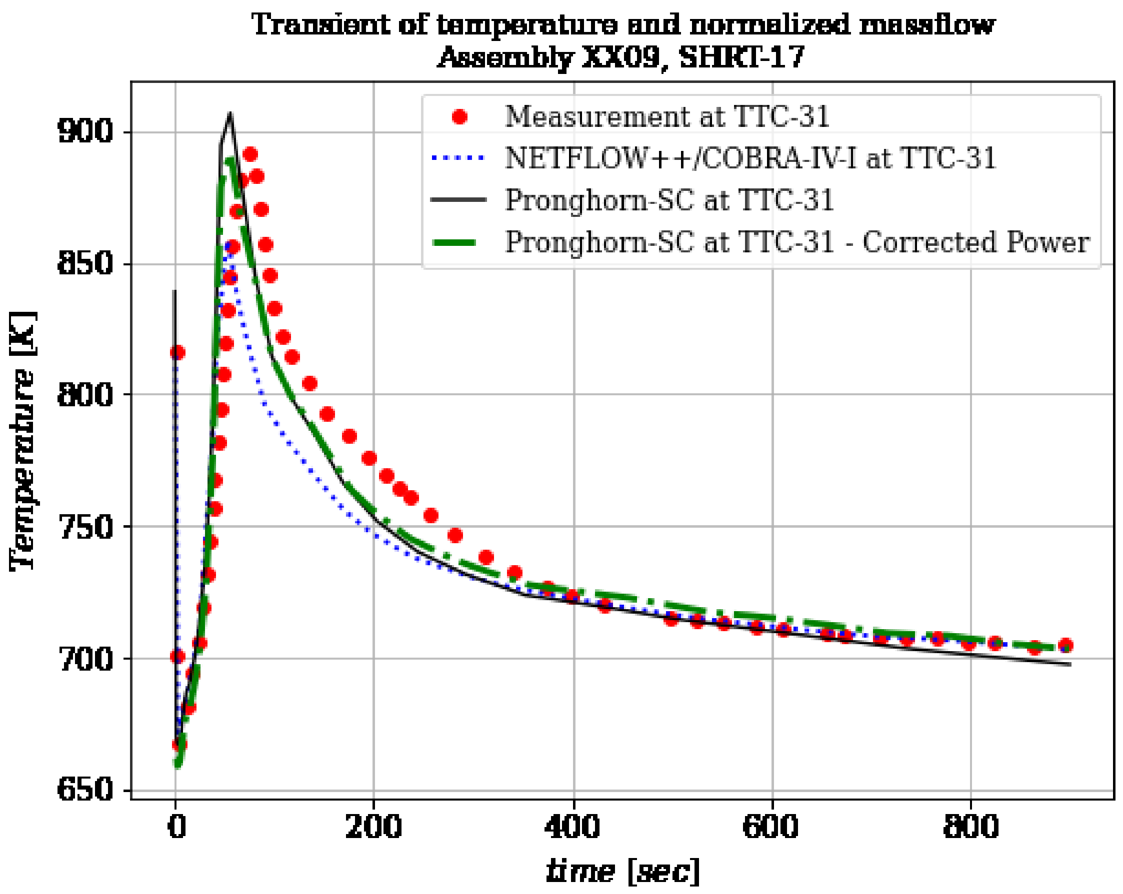
Simulation Results

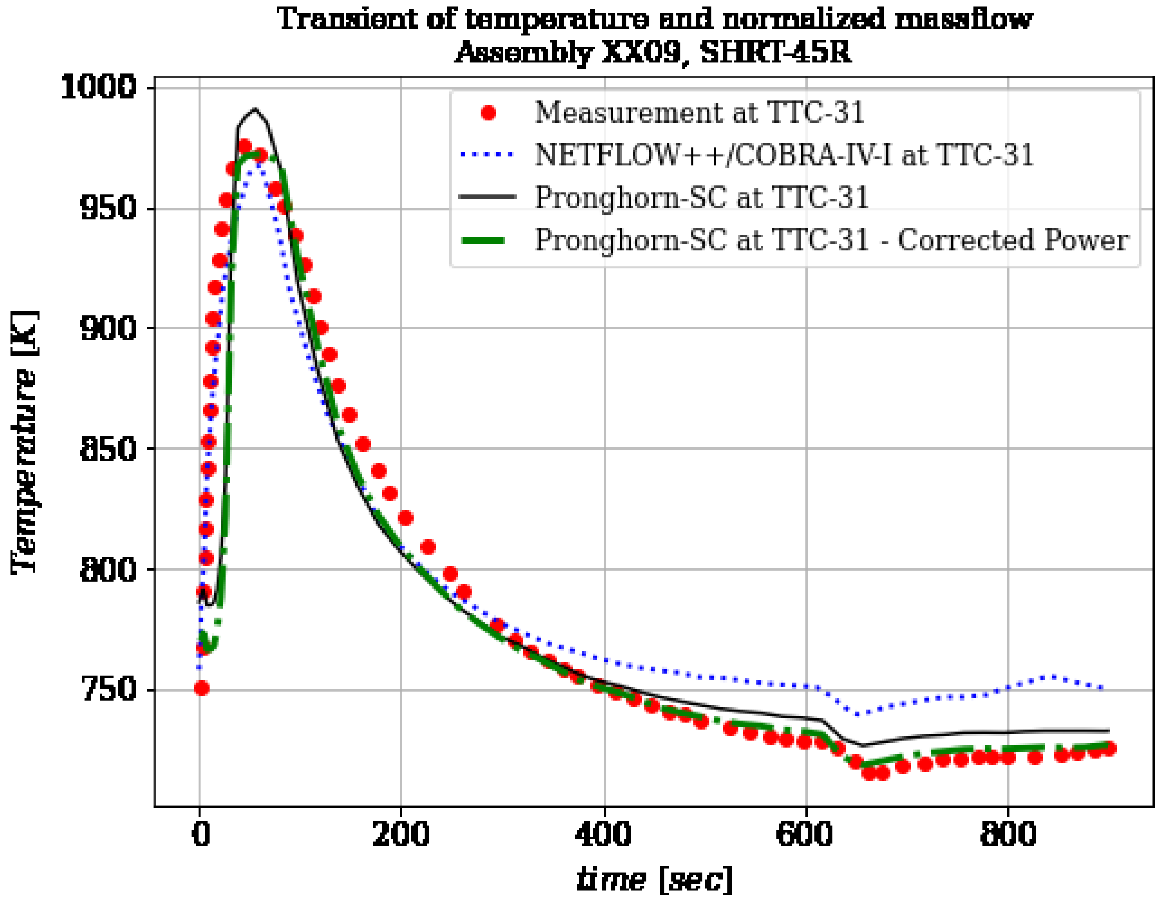
Results of Subchannel at initial Steady State





Results of Subchannel Transient



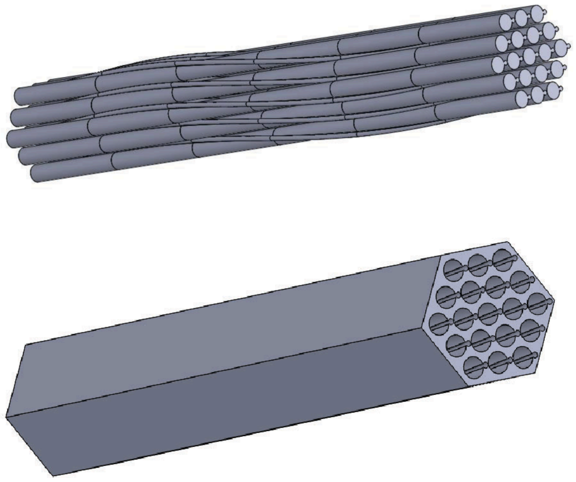


END (Questions???)

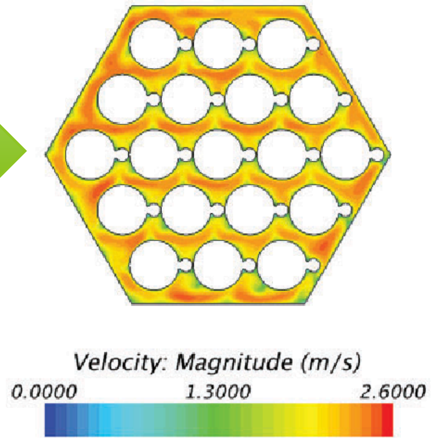
Expansion of Pronghorn's Subchannel code to Sodium Fast Reactors

Subchannel Code Resolves:
Mass, momentum (axial and cross directions), and energy balance
Requires:
Closure correlations for friction factors, localized pressure losses, and heat exchange coefficients

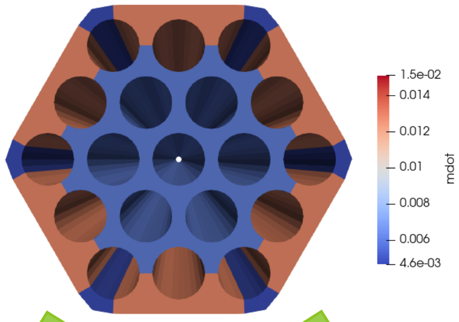
Wire-wrapped fuel assembly



CFD model

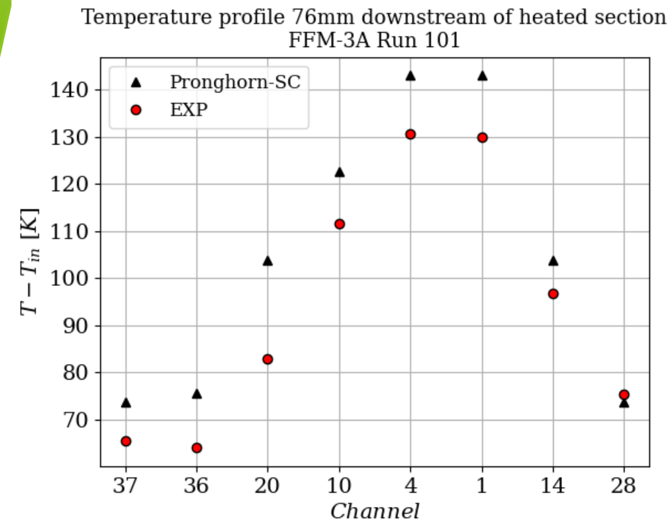


Subchannel model

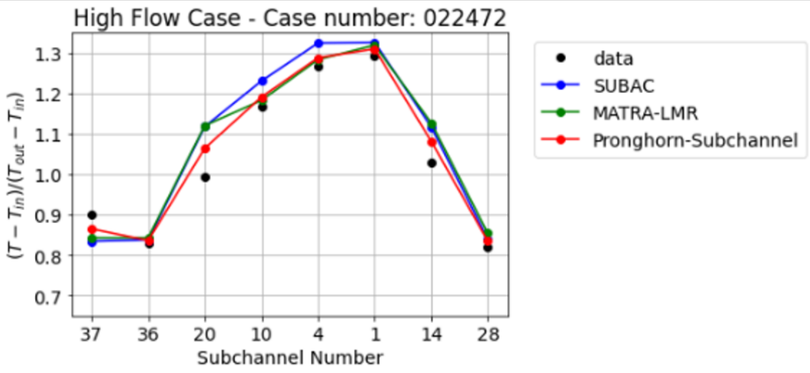


Validation

THORS blockage benchmark



ORNL 19-pin benchmark



Toshiba 37-pin benchmark