The Status of The KIT Contribution to The Rostov-2 VVER-1000 Multi-Physics Transient Benchmark

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Outline

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- Tools
- Rostov-2 VVER-1000 Core
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- SSS2 Pin Level Core Modeling
- SCF Sub-channel Level Core Modelling
- SSS2/SCF Criticality Simulation Features
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- CASMO5 FA Models
- PARCS Model
- Comparison of SSS2/SCF and PARCS Results
- Conclusion and Outlook

Objectives

- Core analysis with improved neutronic methodologies to account for increased heterogeneity and complex material composition.
  - **Use of high-fidelity Serpent2(SSS2)/Subchanflow(SCF)* for the analysis of VVER-cores.**
  - **Use of PARCS/SCF and TRACE/PARCS for 3D Nodal Core analysis.**

- Provide a reference solution for Rostov-2 Benchmark** Phase I with high-fidelity **pin-by-pin SSS2/SCF.**

- Development of the detailed model for the begin-of-cycle (BOC) Rostov-2 VVER-1000 **fresh-core**.

* Diego Ernesto Ferraro. 2021. Monte Carlo-based multi-physics analysis for transients in Light Water Reactors. PhD thesis, Karlsruhe Institute of Technologie (KIT), Karlsruhe, GERMANY

** M. Avramova, K. Ivanov, K. Velkov, S. Nikonov, P. Gordienko, B. Shumskiy and O. Kavun, "Benchmark on reactivity compensation of boron dilution by stepwise insertion of control rod cluster into the VVER-1000 core, Specifications and Support Data, Version 1.6," OECD/NEA. NEA/EGMPEBV/DOC(2021), Paris, 2021.

Tools

The master-slave SSS2/SCF coupling

Main aspects:

- Codes are integrated in a single tool.
- Interchange of fields internally by memory.
- Coupled flow control managed by master code SSS2.

CASMO5

- 2D lattice neutronic behavior analysis code.

PARCS: Purdue Advanced Reactor Core Simulator

- 3D multi group neutron diffusion solver code.

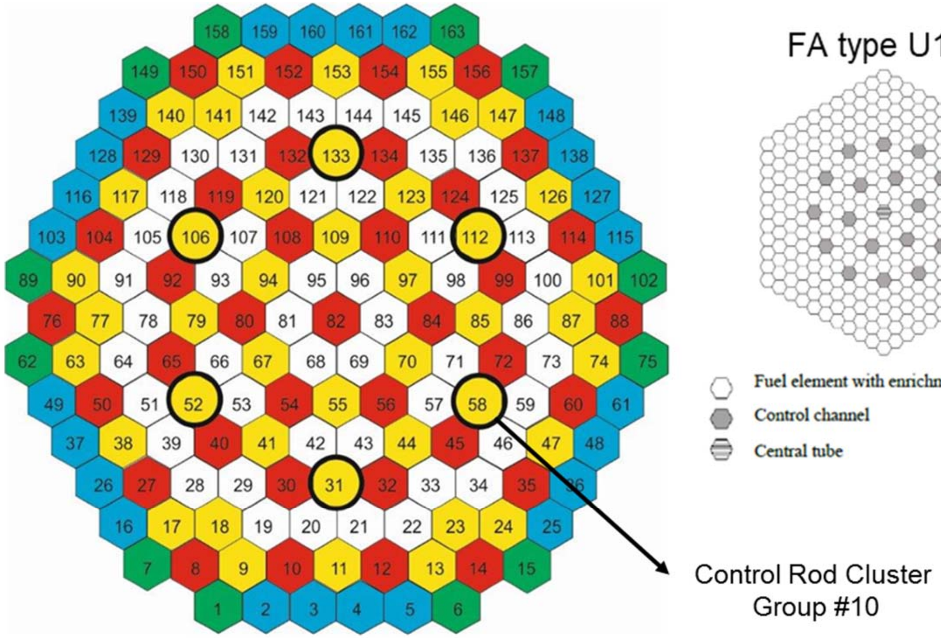
Rostov-2 VVER 1000 Core (1/2)
BOC Characteristics

- Core loading at BOC (Date: 20.02.2010)
  - Effective day (TEF)= 0.0
  - Fuel Assemblies: 163 FAs with 5 different types loaded
  - Control Assemblies: 10 CR group banks located in 61 FAs
    - Control Rod position: CR group 1-9 out and only CR group 10 72.9% (from core bottom) inserted
  - Boric Acid concentration: 6.5 g/kg
    - Boric Acid (H_3BO_3) density= 1.435 g/cm^3

- Thermal-hydraulic parameters at BOC
  - Core power= 44.4 MW
  - T_{inlet}= 552.95 K
  - System Pressure= 15.7 MPa
  - Total circuits mass flow rate (100% total flow)=87342.7 m^3/h (18558.29 kg/s)
    - Core mass flow rate (97% of the total mass circuit flow) =18001.53 kg/s

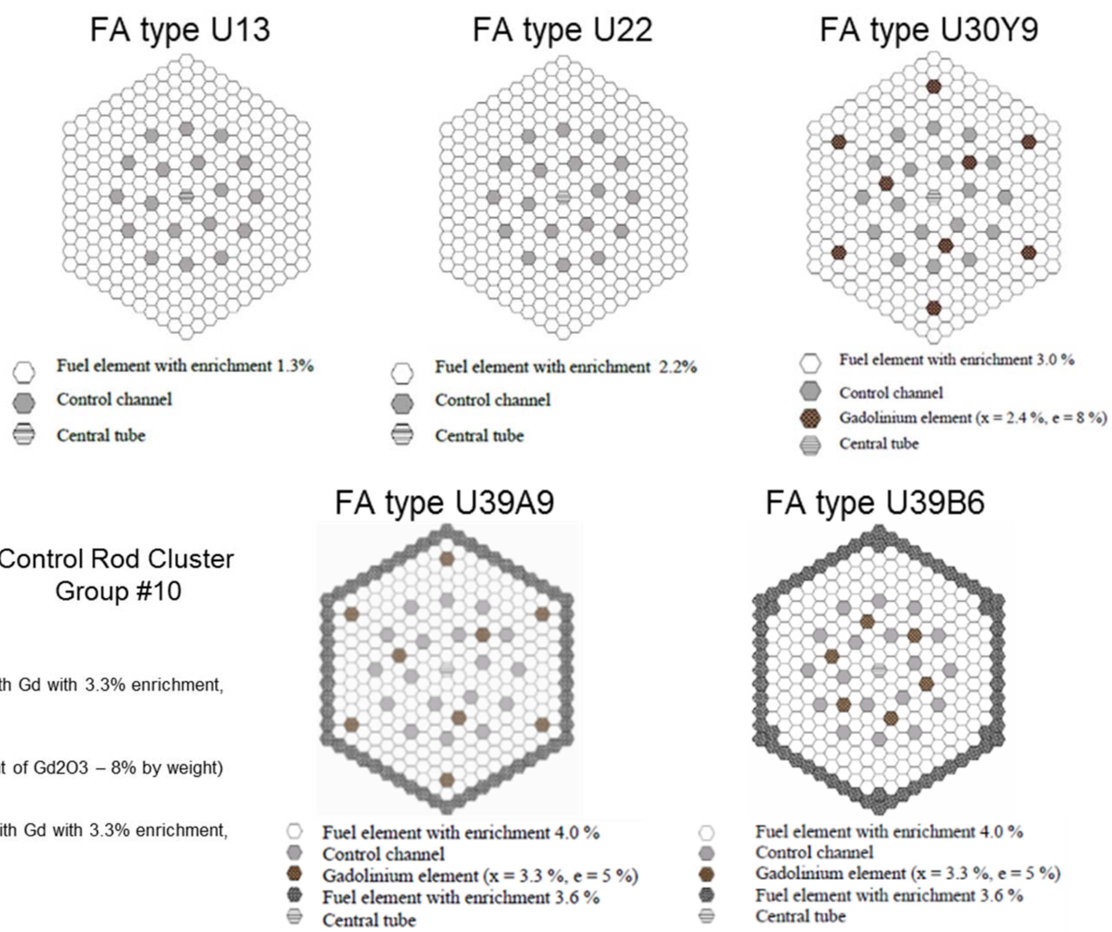
Rostov-2 VVER 1000 Core (2/2)

Core Loading



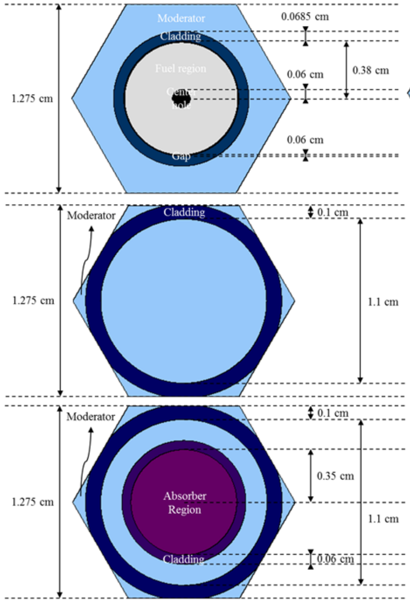
- FA type U39A9 with Uranium-235 3.89% average enrichment (243 fuel rods with 4.0% enrichment, 60 fuel rods with 3.6% enrichment, 9 fuel rods with Gd with 3.3% enrichment, content of Gd2O3 – 5%)
- FA type U30Y9 with Uranium-235 2.98% average enrichment (303 fuel rods with 3.0% enrichment, 9 fuel rods with Gd with 2.4% enrichment, content of Gd2O3 – 8% by weight)
- FA type U39B6 with Uranium-235 3.9 % average enrichment (240 fuel rods with 4.0% enrichment, 66 fuel rods with 3.6 % enrichment, 6 fuel rods with Gd with 3.3% enrichment, content of Gd2O3 – 5%)
- FA type U22 with Uranium-235 2.2% enrichment
- FA type U13 with Uranium-235 1.3% enrichment

Fuel-loading map of the reactor core of Rostov Unit 2, Cycle 1

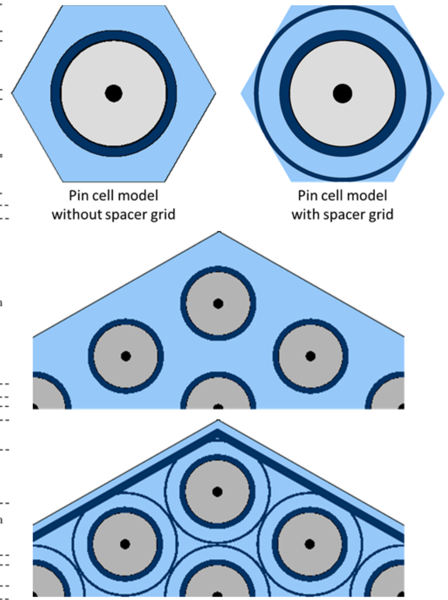


Radial arrangement of elements in the fuel assemblies

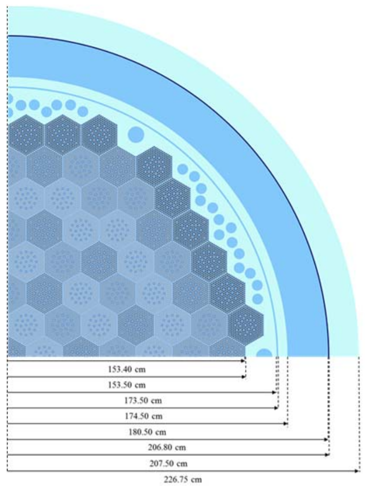
SSS2 Pin Level Core Modeling



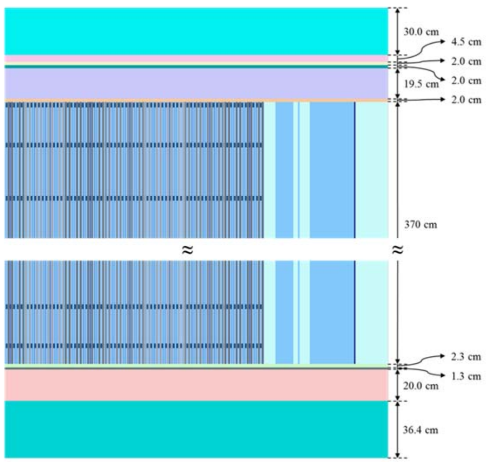
Pin cell models



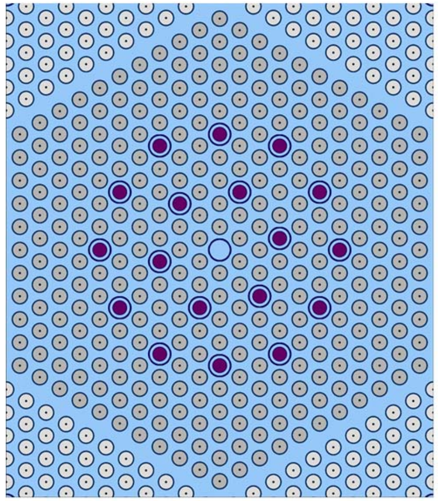
Spacer Grid views



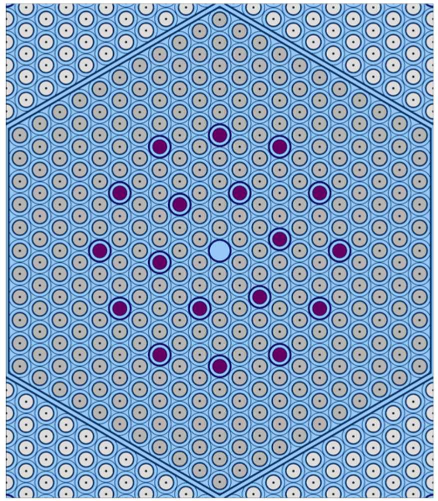
SERPENT2 XY cut figure of ¼ the core
with radial reflectors dimensions



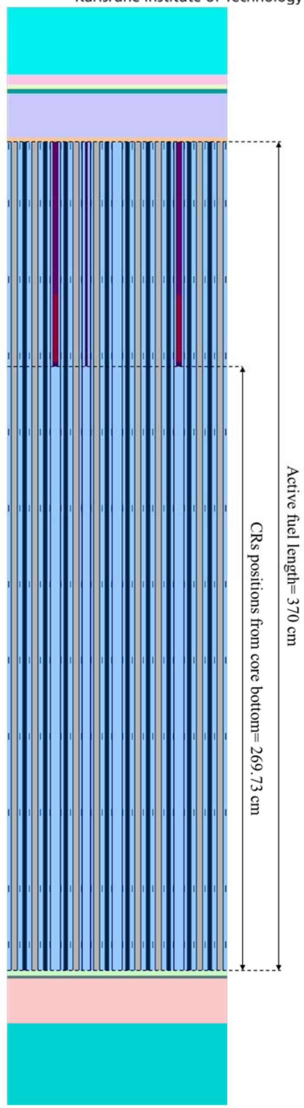
SERPENT2 XZ cut figure of ½ the core
with axial reflectors dimensions



Radial view of partly CR inserted FA model
without spacer grid

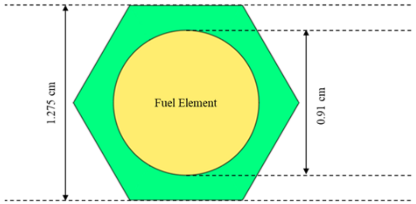


Radial view of partly CR inserted FA model
with spacer grid

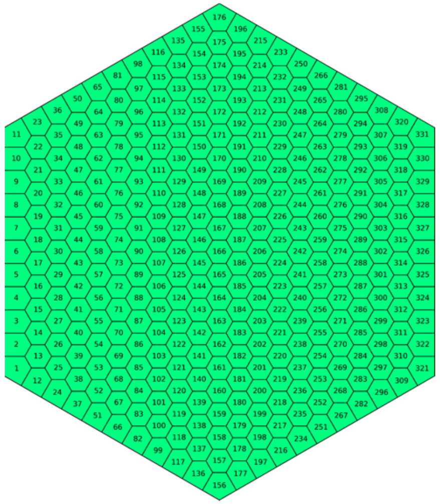


Axial view of partly CR inserted FA model
with spacer grid

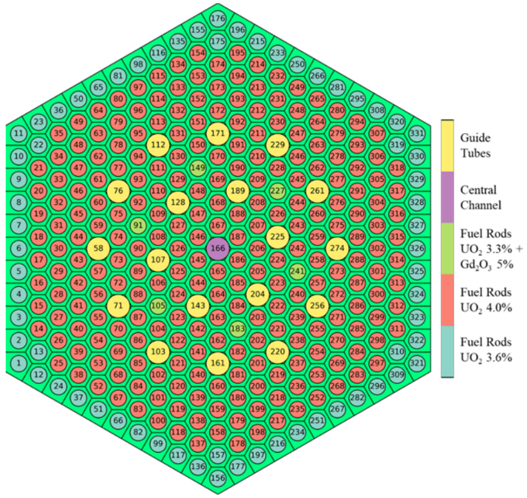
SCF Sub-channel Level Core Modelling



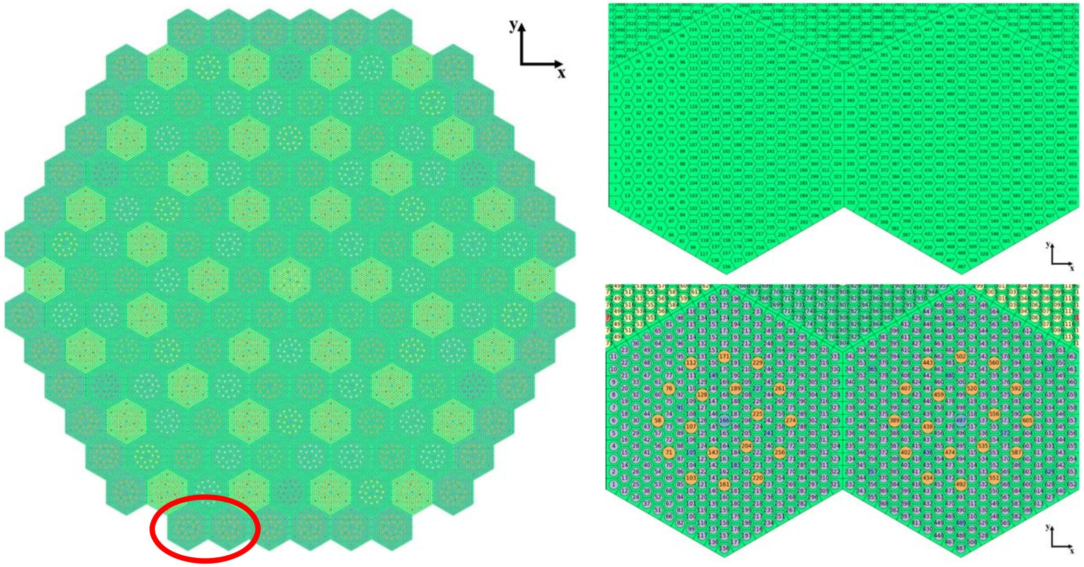
SCF rod centered model



SCF FA model - channel indexing



SCF FA model - rod indexing



SCF Core model - channel and rod indexing

- Python based preprocessor was used to generate rod and channel layout and connectivity relations and “ifc” files for code feedback exchange.

SSS2/SCF Criticality Simulation Features

- Serpent 2
  - Serpent 2 Version 2.1.32
  - Active cycle and inactive cycle: **5000** and **500**, respectively
  - Particle number: **10,000,000**
  - **tft** temperature card option for the multi-physics calculations
  - **ifc** used files for multi-physics interface
  - ENDF/B-VII neutron library

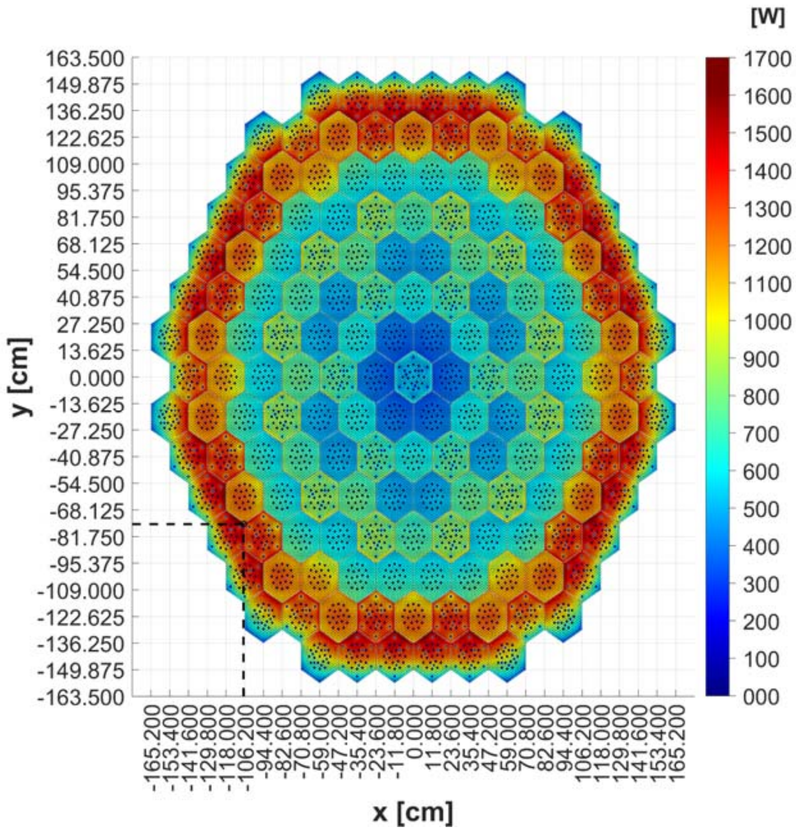
- Subchanflow
  - SCF Version 3.7.1
  - VVER-specific thermophysical properties in SCF was used.
  - Axially **30** nodes
  - Doppler temperature predicted as in benchmark formulation.

- Simulation Architecture
  - 100 OpenMPI node and 152 OpenMP task for the coupled simulation on HoreKa HPC (KIT/SCC).
    - Intel Xeon Platinum 8368
  - Convergence criteria:
    - rho : **5 pcm**
    - Fuel Temperature: **5 K**
    - Coolant Temperature: **5 K**
    - Coolant Density: **0.001 g/cm^3**

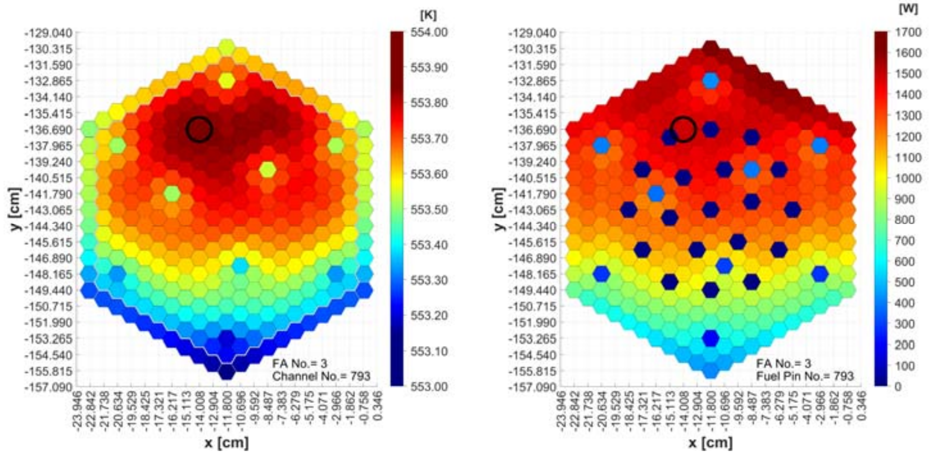
SSS2/SCF Core Analysis

- Global Results and Local Results

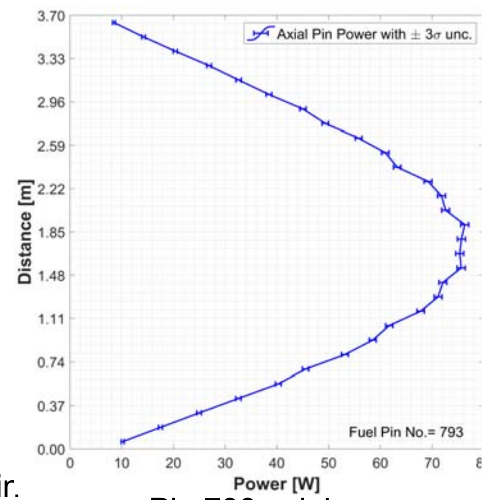
$k_{effective}$	0.997860 ± 0.0000029
$\rho_{initial}$	-214.5 pcm



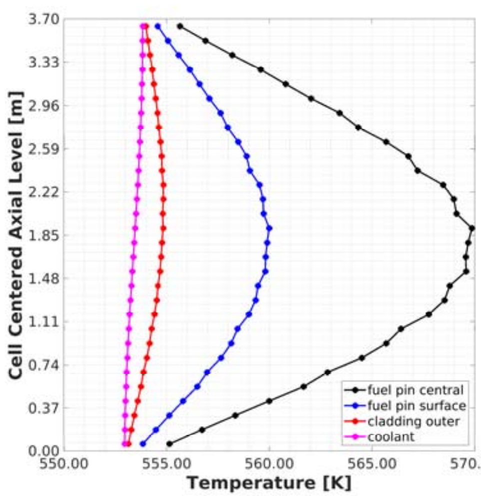
Pin power distribution in the core with the location of the pin with the highest power: FA number 26, pin number 8606



Sub-channel level coolant exit temperature distribution and Pin-level power distribution in the FA No. 3 and the sub-channel location which has the hottest coolant exit temperature



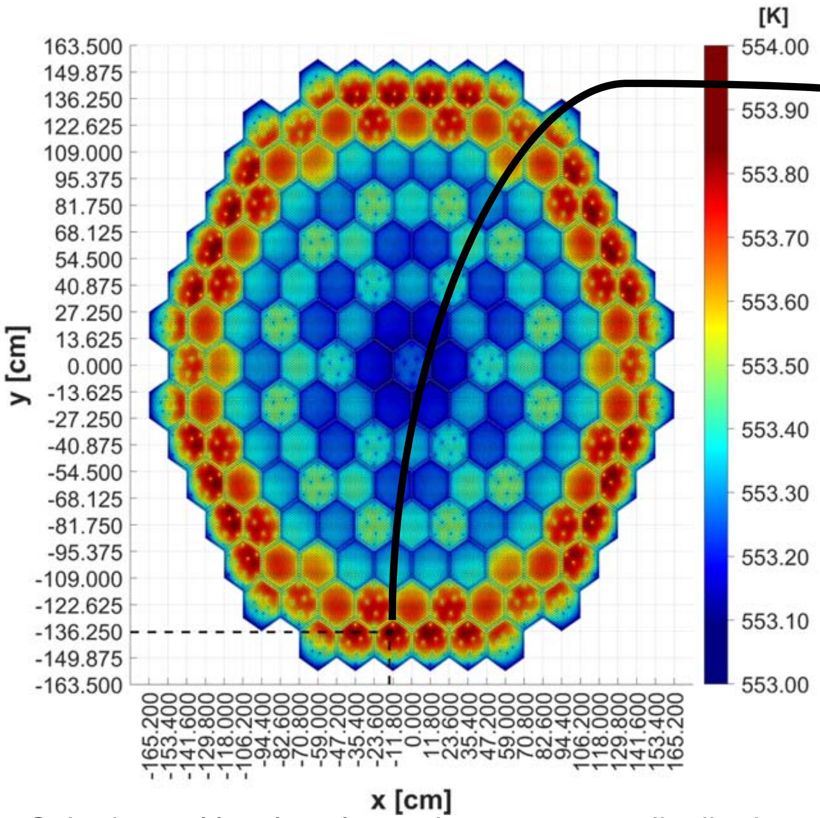
Pin 793 axial power distribution



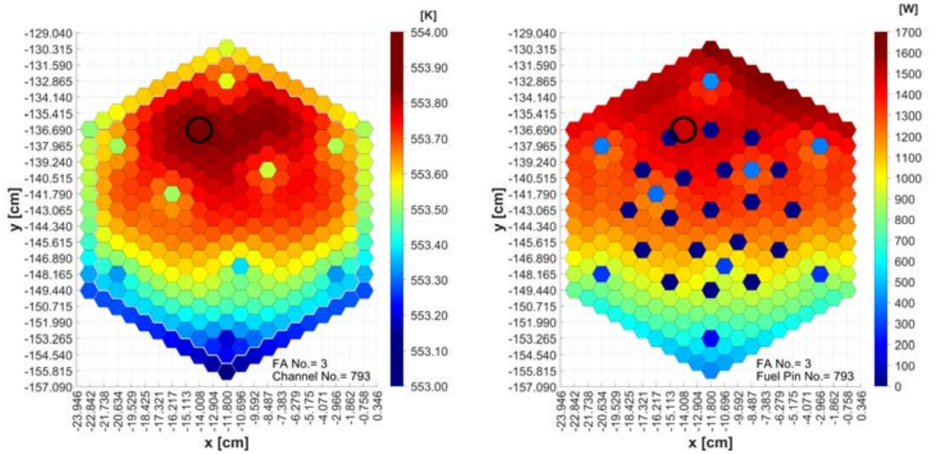
Pin 793 axial temperature distribution

SSS2/SCF Core Analysis

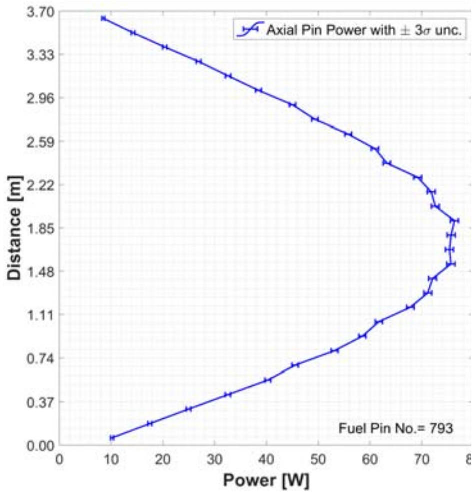
- Local Results



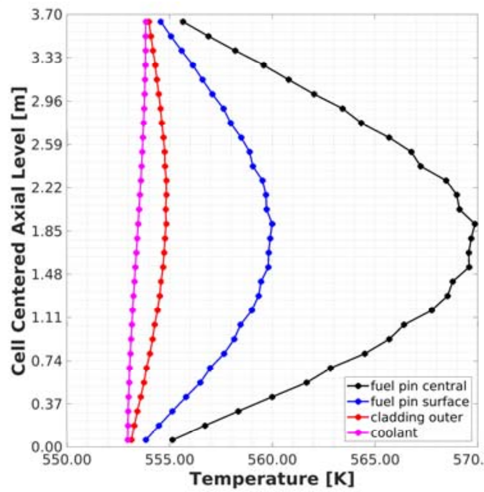
Sub-channel level coolant exit temperature distribution in the core and the sub-channel location which has the hottest coolant exit temperature



Sub-channel level coolant exit temperature distribution and Pin-level power distribution in the FA No. 3 and the sub-channel location which has the hottest coolant exit temperature



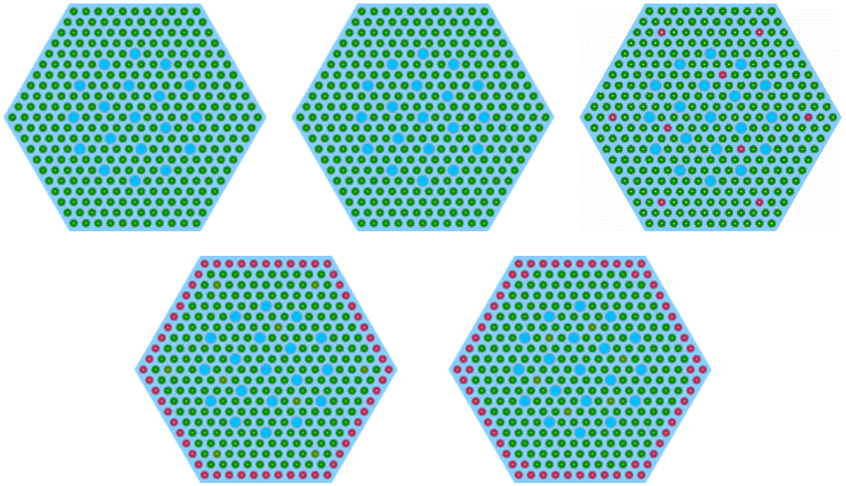
Pin 793 axial power distribution



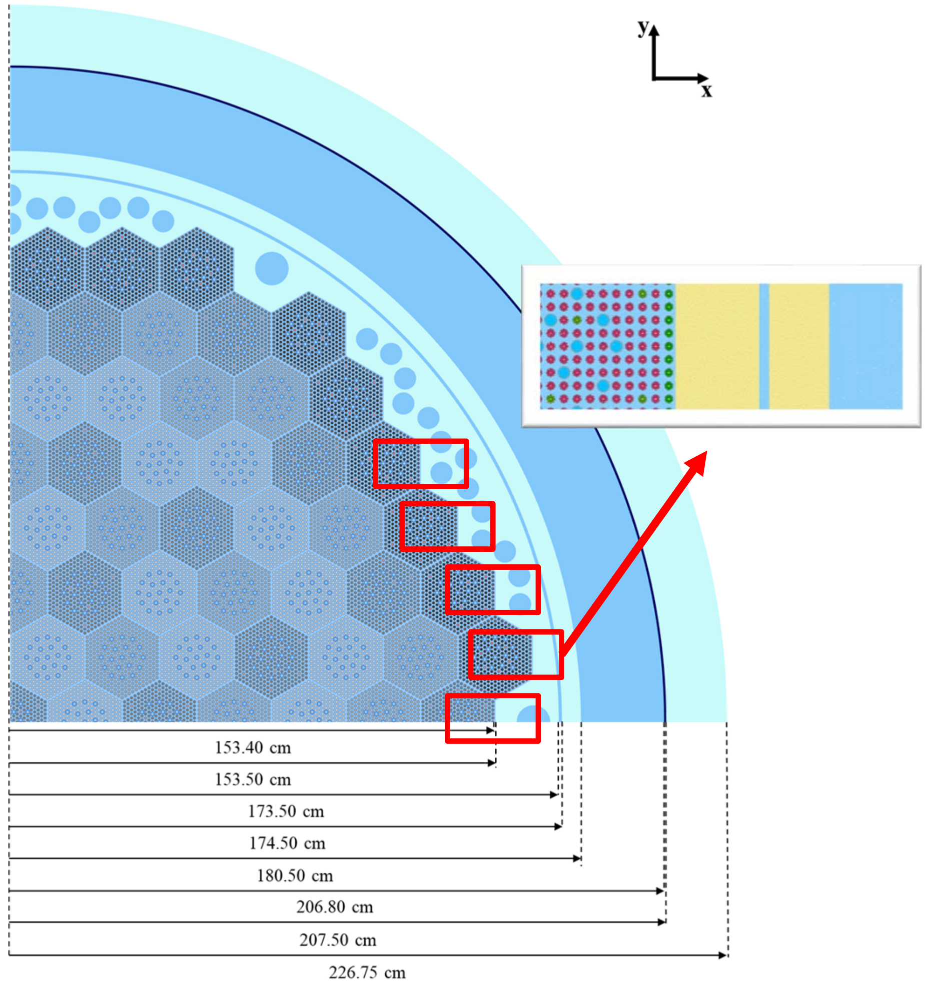
Pin 793 axial temperature distribution

CASMO5 FA MODELS

- CASMO5 Figures of FAs Models respectively: U13, U22, U30Y9, U39A9, U39B6



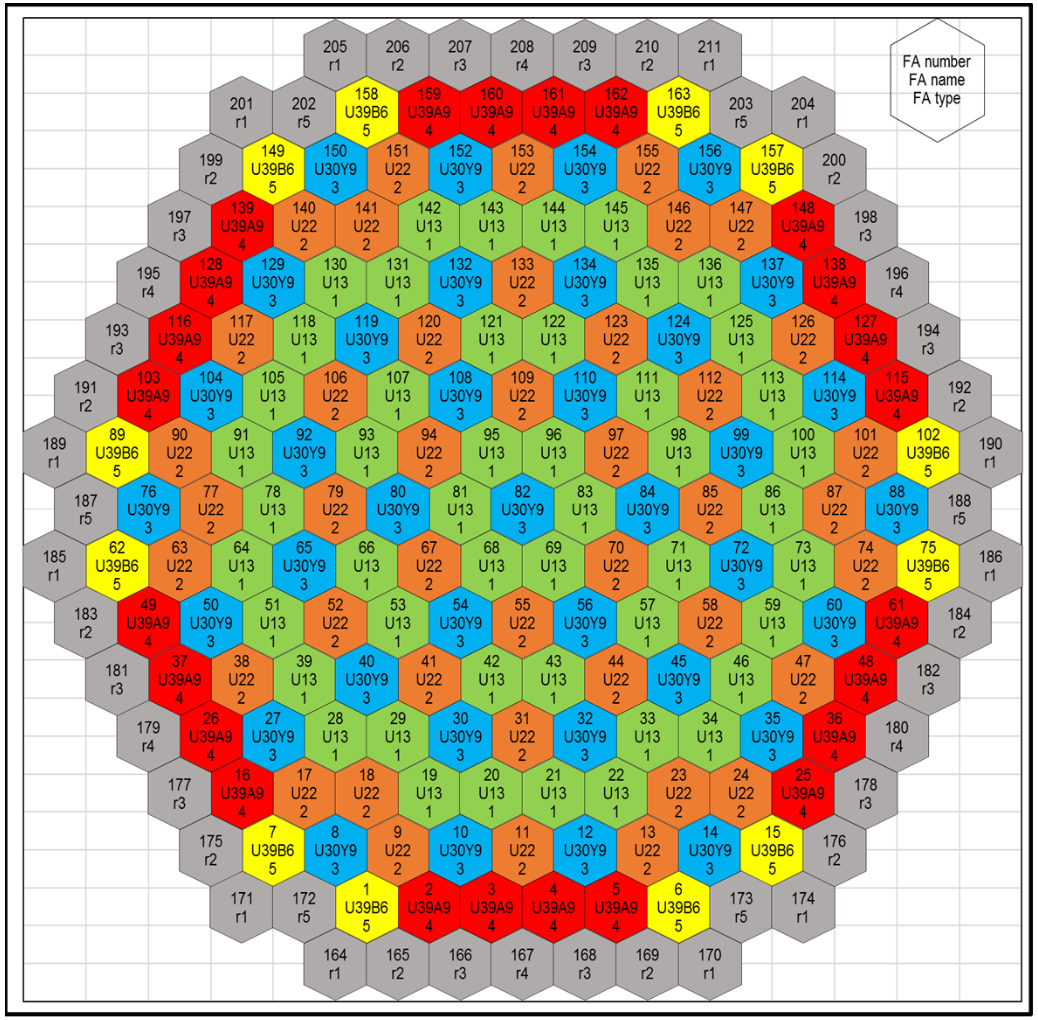
- 2D FAs Models, which were utilized to XS generation, were developed corresponds to the benchmark specification and SSS2 FAs models.



- 1D model for 5 radial reflector assemblies
- 1D model for top and bottom refl. assembl.

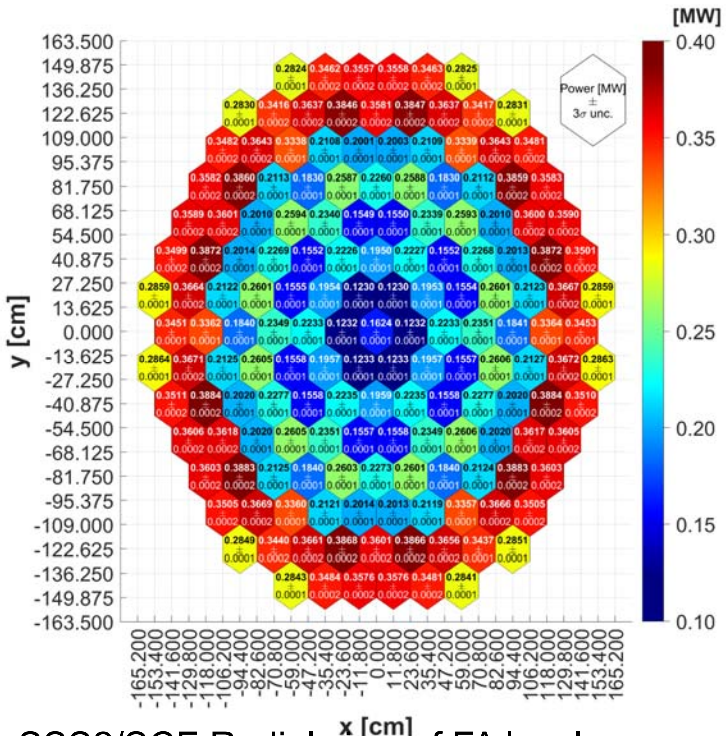
PARCS MODEL

- PARCS Version 3.3.1
- Internal TH feedback (Simple mass/energy solution)
- 2 energy groups
- 5 different FAs models
- 5 different radial and 2 top and 2 bottom reflector assemblies models
- 30 axial nodes

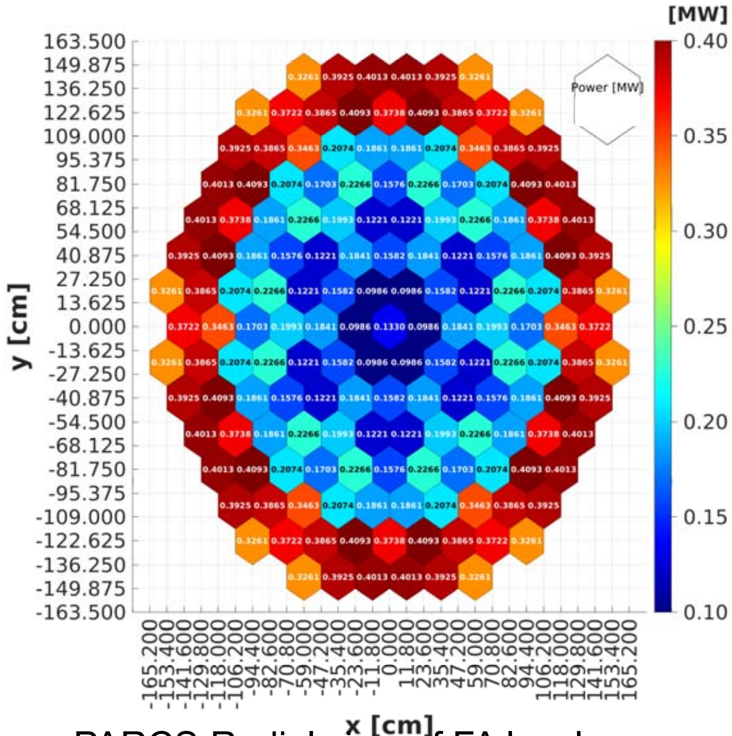


Comparison of SSS2/SCF and PARCS Results (1/2)

	$k_{effective}$
SSS2/SCF	0.997860 ± 0.0000029
PARCS standalone	0.997889
difference	2.9 pcm



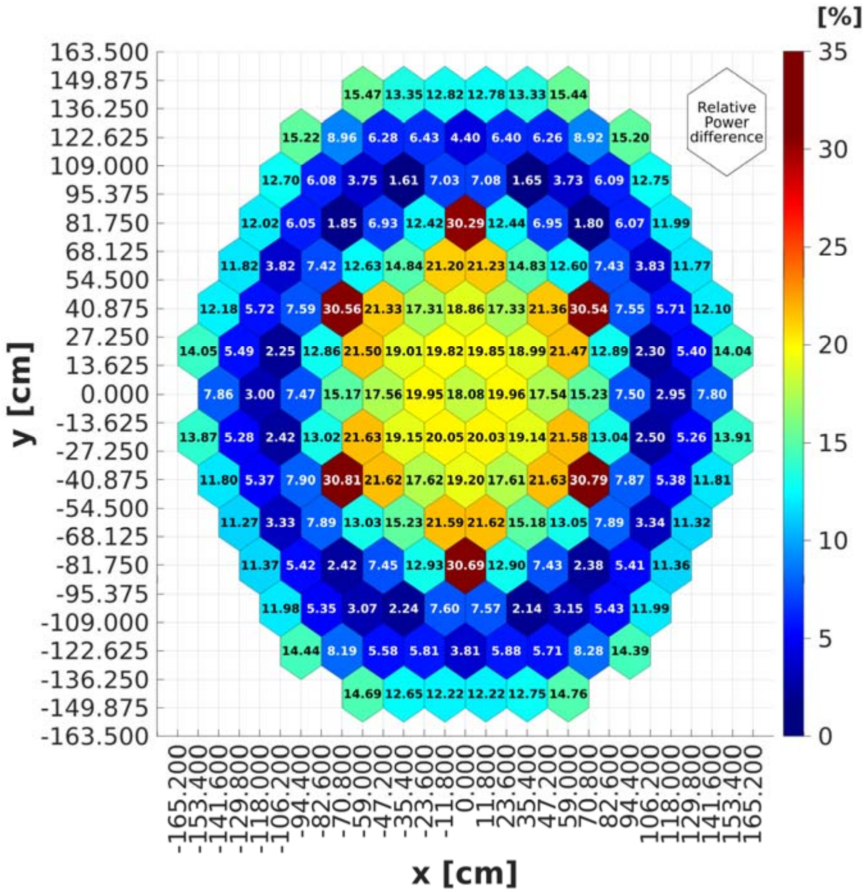
SSS2/SCF Radial view of FA level average power distribution



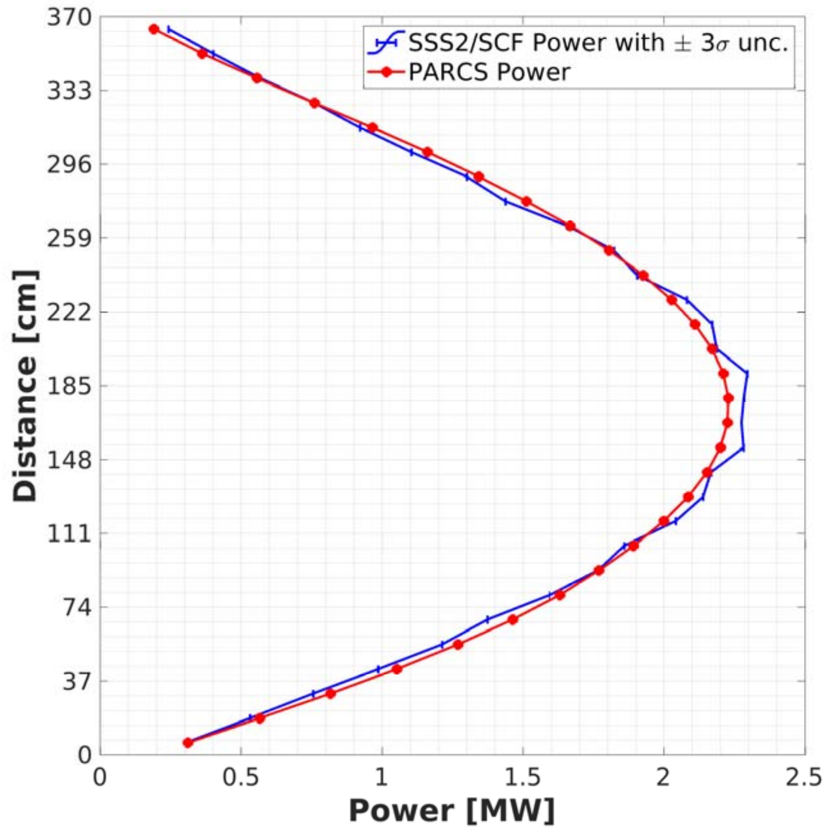
PARCS Radial view of FA level average power distribution

Comparison of SSS2/SCF and PARCS Results (2/2)

- SSS2/SCF Neutronic and TH results and preliminary PARCS standalone Neutronic and TH results



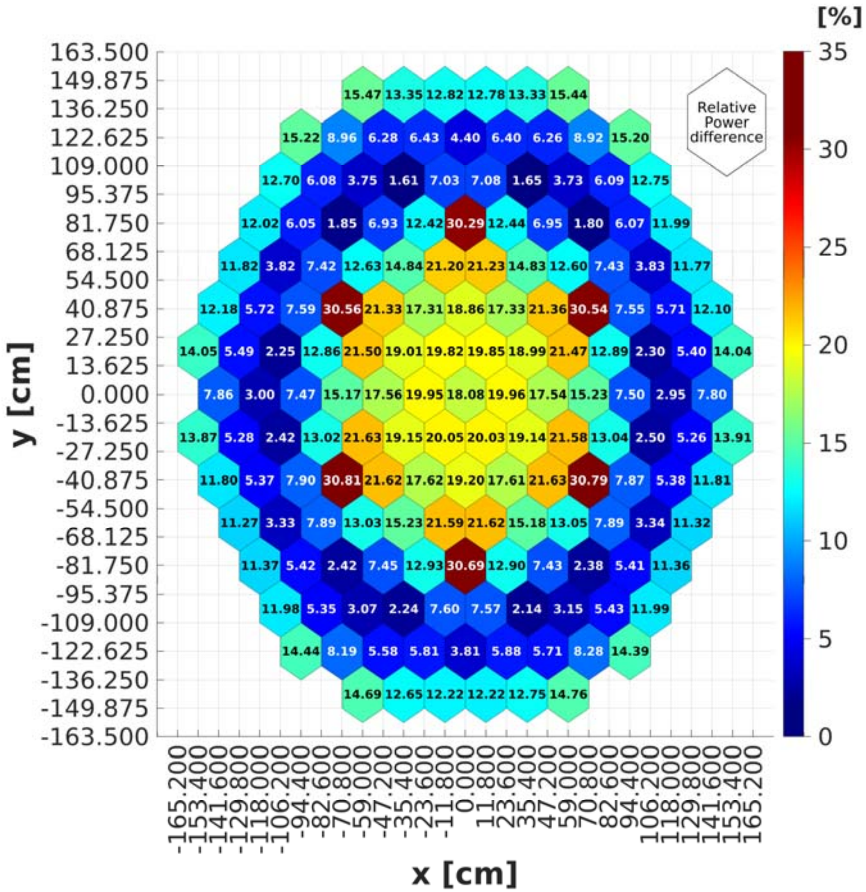
SSS2/SCF and PARCS FA level relative power difference



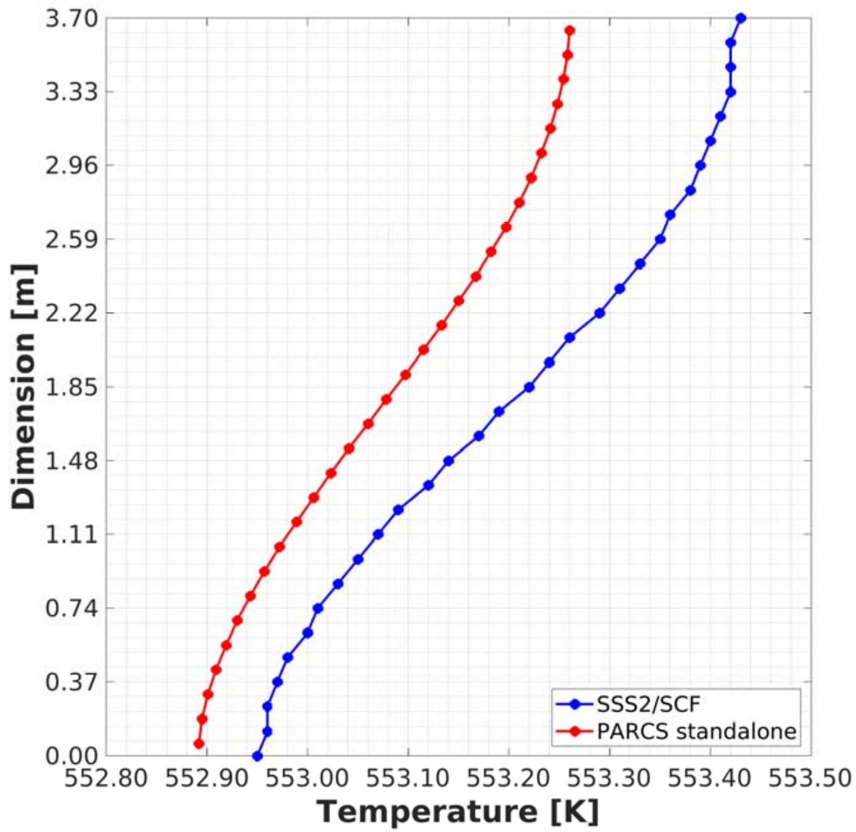
Core average axial power distribution

Comparison of SSS2/SCF and PARCS Results (2/2)

- SSS2/SCF Neutronic and TH results and preliminary PARCS standalone Neutronic and TH results



SSS2/SCF and PARCS FA level relative power difference



Core average axial coolant temperature distribution

Conclusion and Outlook

- Master-slave SSS2/SCF coupling works fine and stable.

- $k_{effective}$ results of the SSS2/SCF and PARCS standalone are compatible.
  - PARCS model will be improved to decrease the differences between SSS2/SCF and PARCS results.

- Next Steps:
  - Use of PARCS/SCF and TRACE/PARCS for 3D Nodal Core analysis
    - PARCS/SCF simulation will be carried out to analysis the BOC SS core condition and depletion of the core.

  - SSS2/SCF burnup simulation of Rostov-2 first cycle is still on going.

Thank you for your attention!