EXTENSION OF SERPENT2/SUBCHANFLOW COUPLING FOR HEXAGONAL FUEL ASSEMBLIES

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Presentation Outline

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- Motivations and Objectives.
- Serpent and SubChanFlow Overview.
- General Coupling Approach.
- Peculiarities of the Hexagonal Geometry.
- Extended Coupling Demonstration:
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    - VVER-1000 FA Modelling.
    - Comparison between Serpent2 and TRIPOLI4 at HZP condition.
    - Demonstration of the thermal-hydraulic feedback effect.
- Summary.

Motivations and Objectives

- **Motivations:**
  - Providing a high-fidelity tool for a more accurate prediction of local safety parameters for:
    - Eastern PWR reactors (e.g. VVER).
    - Lead-cooled fast reactors.

- **Objectives:**
  - Extending the current spatial mapping and data exchange of Serpent2/SubChanFlow for hexagonal geometries.
  - Testing the new implementation against a single VVER-1000 FA.

Serpent and SubChanFlow Overview

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- **Serpent:**
  - A reactor physics dedicated Monte Carlo Code developed at VTT.
  - Has a built-in Doppler Broadening routine that result in an accurate temp. modeling.
  - Can accurately represent S(α,β) thermal scattering data at any selected temp.
  - Version 2.1.29 was used in this study.

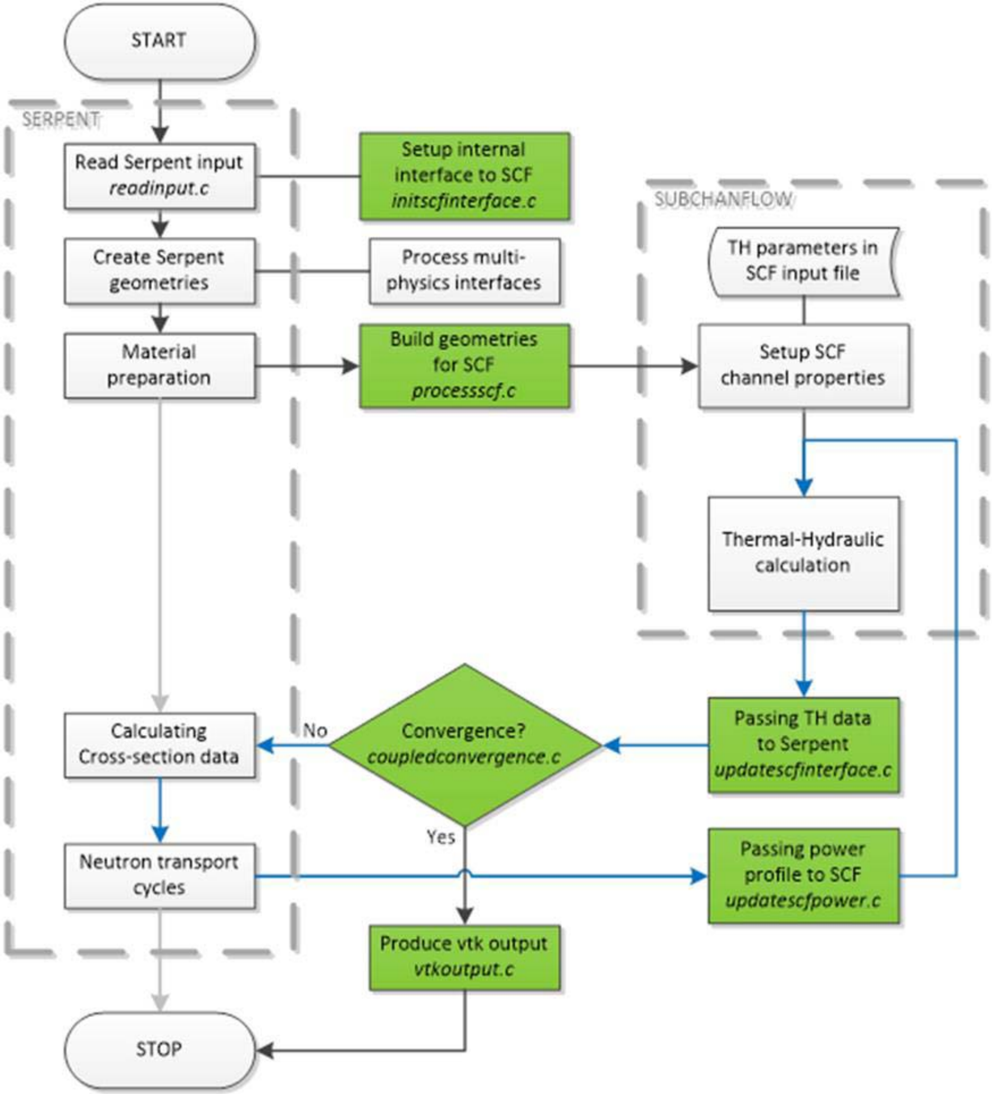
- **SubChanFlow:**
  - A sub-channel thermal-hydraulics code developed by INR/KIT.
  - Can handle both rectangular and hexagonal geometries.
  - Available fluids: water, lead, lead-bismuth, sodium, helium, and air
  - Version 3.5 was used in this work.

General Coupling Approach

- **Internal coupling.**
- **Power relaxed according to:**

$$\phi^n = \frac{1}{n}\sum_{i=1}^{n} \phi^i$$

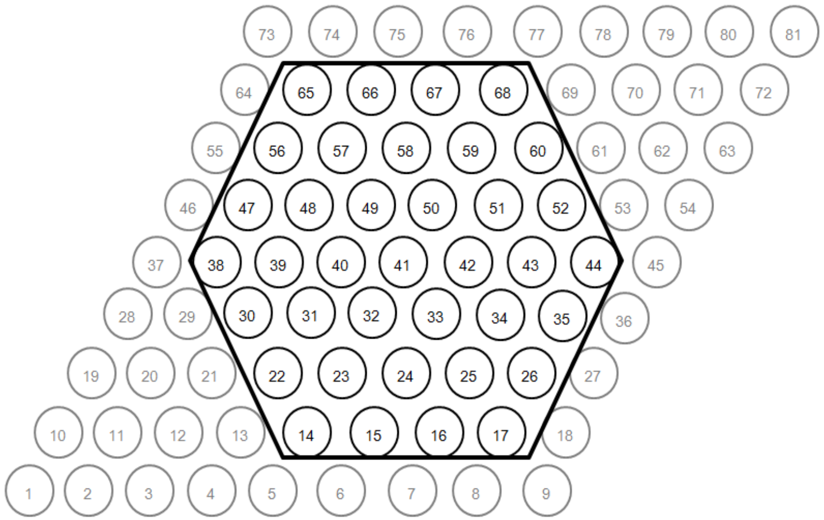
- **Convergence criteria is set for:**
  - Δk_{eff}
  - l^2-norm for Doppler temperature.
  - l^2-norm for Moderator density.

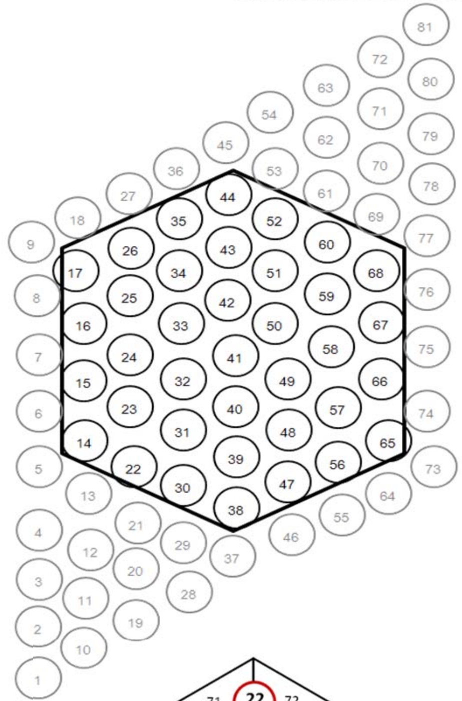


Peculiarities of the Hexagonal Geometry

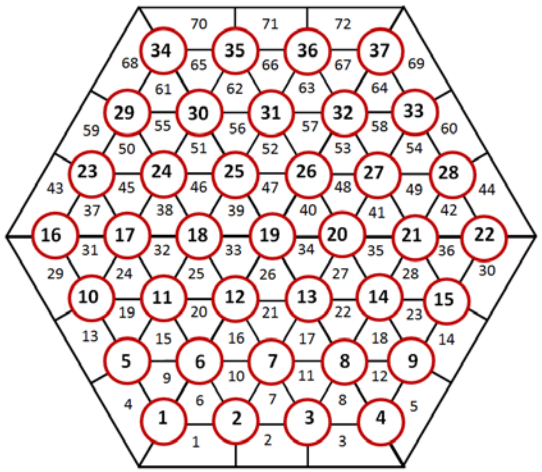
Spatial Mapping

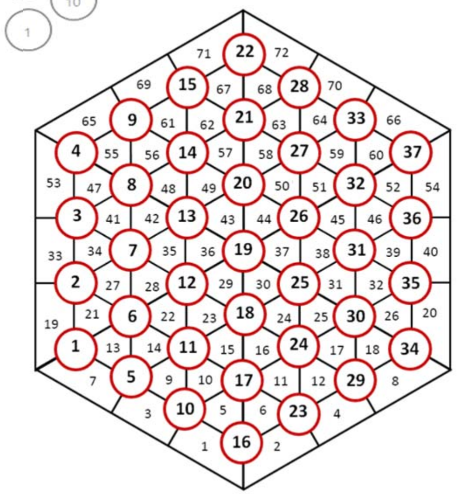
- **Serpent:**





- **SubChanFlow:**





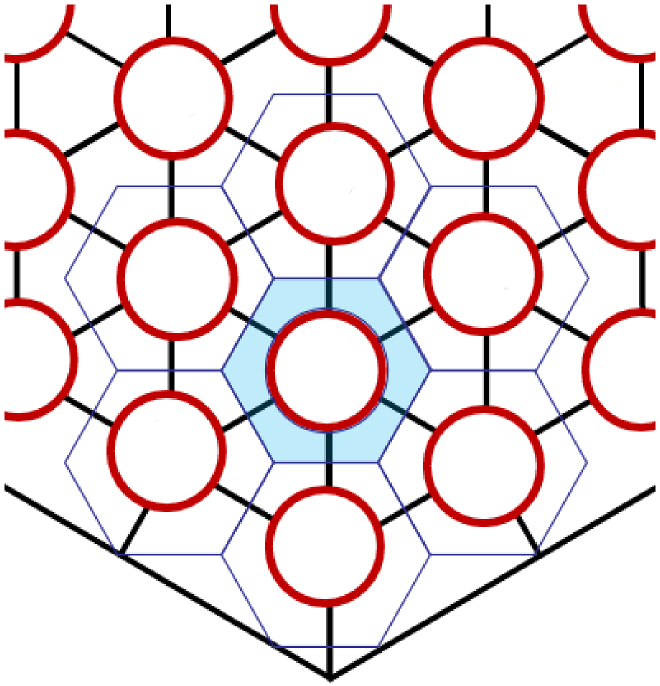
Peculiarities of the Hexagonal Geometry

Data Exchange

- **From SubChanFlow to Serpent2:**
  - Averaging 6 or 5 or 4 sub-channel fluid conditions.
  - Doppler temperature are computed as:

$$T_{\text{Doppler}} = (1 - \alpha)\, T_{f,c} + \alpha\, T_{f,s}$$

  - Cladding temperature is calculated as the average of inner and outer clad surface temperatures.
  - Gap temperature is calculated as the average of pellet surface and inner clad surface temperatures.

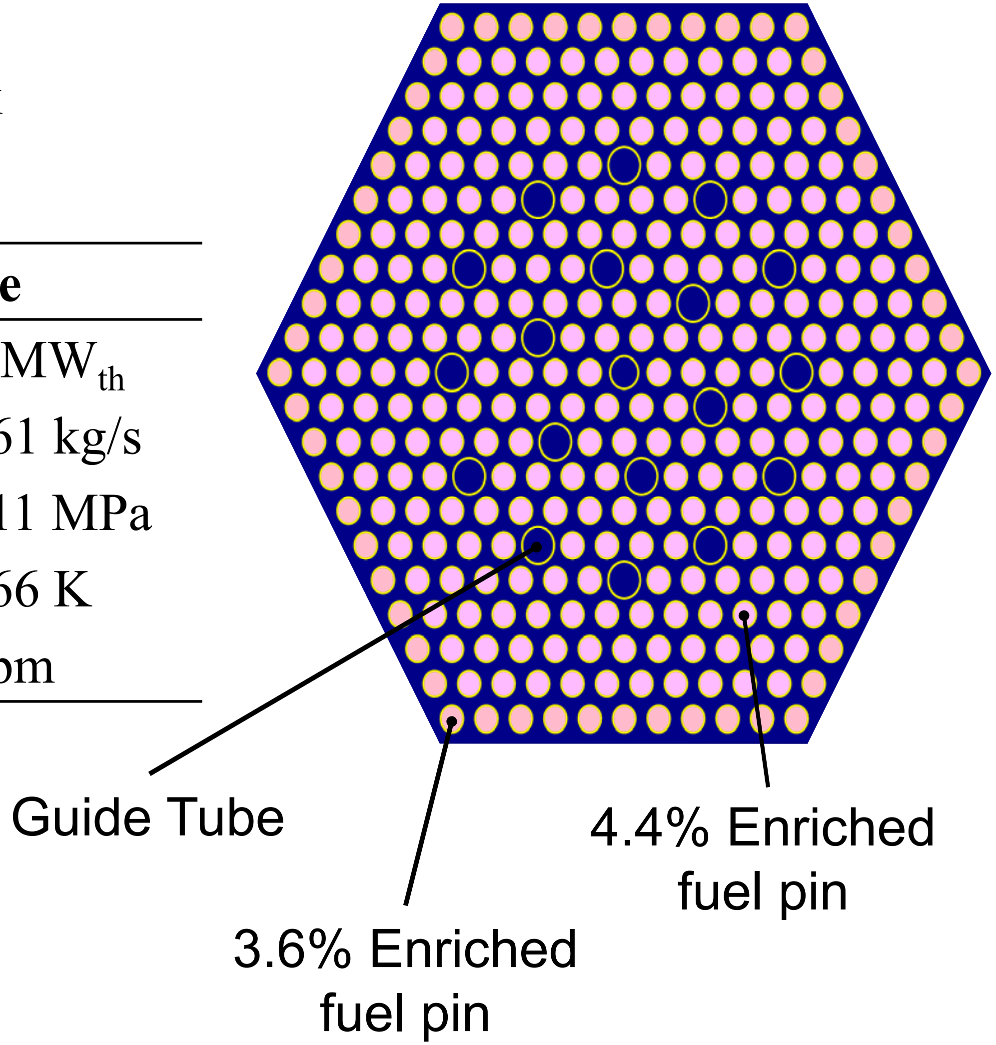


- **From Serpent2 to SubChanFlow:**
  - Pin Power or Fuel Assembly total power.

VVER-1000 FA Description

- Based on VVER lattice benchmark defined within NURISP Project.

Quantity	Value
Power	18.4 MW_{th}
Mass flow rate	105.61 kg/s
Outlet pressure	15.711 MPa
Coolant inlet temperature	561.66 K
Boron concentration	53 ppm



VVER-1000 FA Modeling

- **Boundary conditions:**
  - **Serpent:** Neutron flux radially reflective and axially black.
  - **SubChanFlow:** Coolant inlet temperature of 561.66 K and outlet pressure of 15.711 MPa.
- Nuclear data library: JEFF3.1.1
- Pin-wise coupling of 30 axial meshes for the TH feedback.
- Neutron histories: 100,000 particles/cycle; 500 cycles; and 150 inactive cycles.
- Convergence Criteria:
  - $\Delta k_{eff} = 5$ pcm
  - l^2-norm for Doppler temperature = 0.5%
  - l^2-norm for Moderator density = 0.5%

Comparison between Serpent2 and TRIPOLI4 at HZP condition

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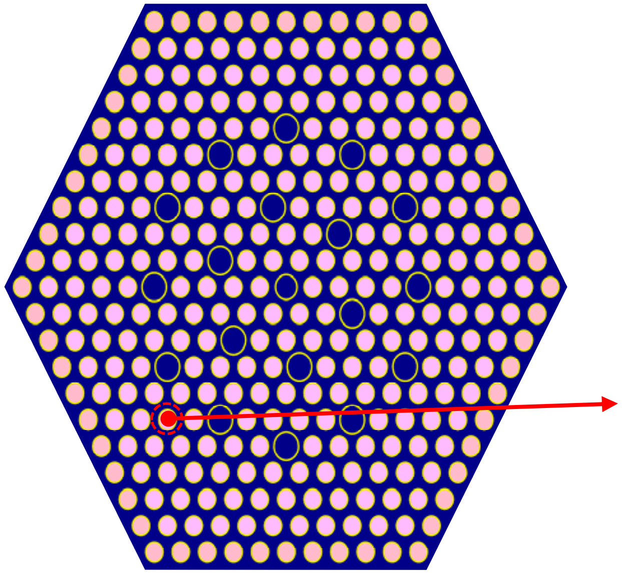
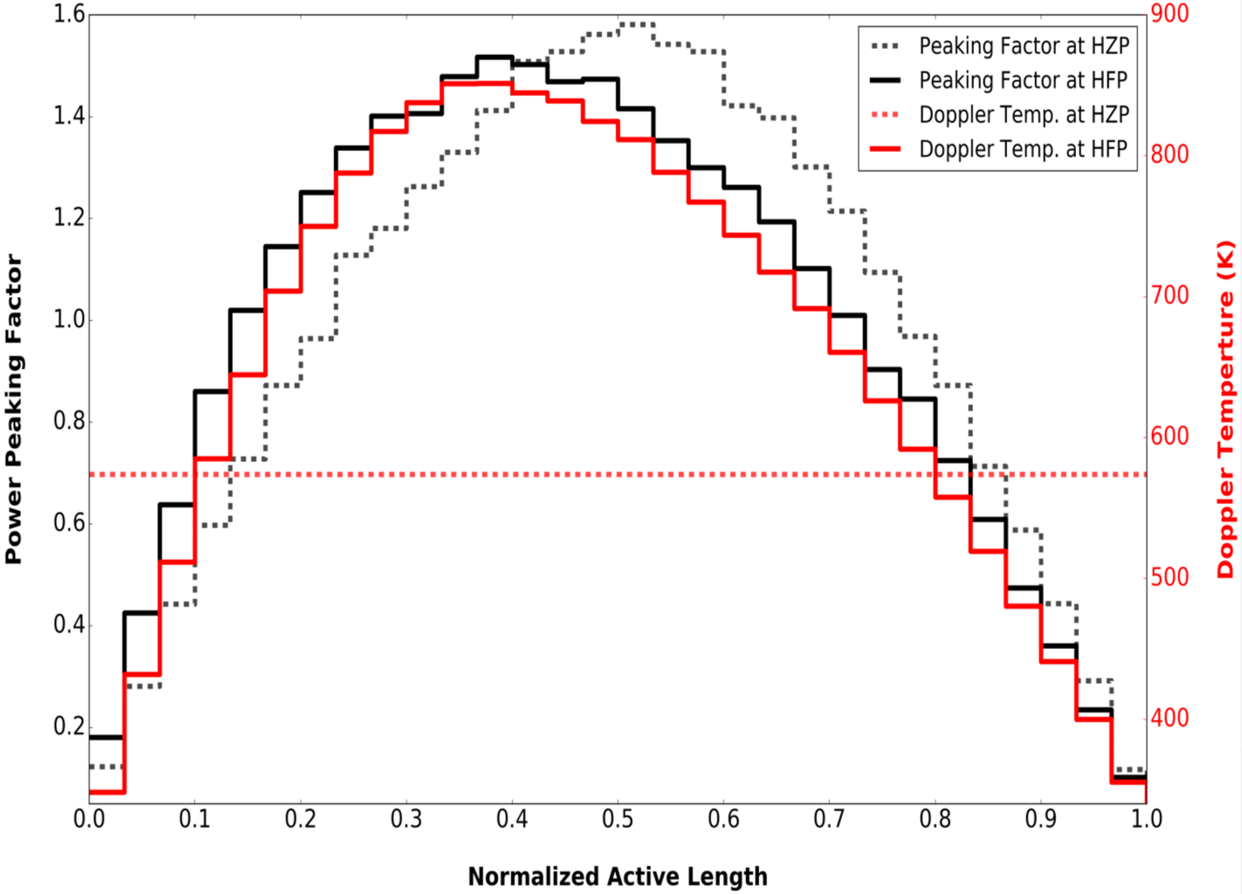
	Value
TRIPOLI4 K_∞	1.29400 ± 4.4E-5
Serpent2 K_∞	1.28924 ± 8.9E-5
Reactivity difference (pcm)	285

- Maximum pin power relative differences is within 3%

					SSS2 T4 (SSS2-T4)/T4 * 100 No.				0.931 0.953 -2.3% 46									
								1.028 1.044 -1.5% 47		0.912 0.937 -2.6% 37								
							0.990 0.998 -0.8% 48		1.020 1.031 -1.1% 38		0.901 0.930 -3.1% 29							
						0.988 0.989 -0.1% 49		0.991 0.995 -0.4% 39		1.011 1.027 -1.5% 30		0.901 0.926 -2.7% 22						
					1.028 1.016 1.1% 50		0.995 0.993 0.2% 40		0.999 0.998 0.1% 31		1.013 1.026 -1.2% 23		0.902 0.926 -2.6% 16					
				1.047 1.030 1.6% 51		1.031 1.020 1.1% 41		1.023 1.013 0.9% 32		0.999 0.998 0.1% 24		1.014 1.026 -1.2% 17		0.896 0.926 -3.2% 11				
			1.055 1.040 1.4% 52		1.049 1.030 1.9% 42		0.000 0.000 - 33		1.024 1.011 1.3% 25		0.992 0.997 -0.5% 18		1.020 1.026 -0.6% 12		0.904 0.929 -2.7% 7			
		0.000 0.000 - 53		1.052 1.030 2.2% 43		1.056 1.025 3.0% 34		1.036 1.016 2.0% 26		1.000 0.991 0.9% 19		0.987 0.994 -0.7% 13		1.017 1.031 -1.3% 8		0.913 0.937 -2.6% 4		
	1.068 1.044 2.3% 54		1.059 1.028 3.0% 44		1.031 1.005 2.6% 35		1.046 1.018 2.8% 27		1.017 1.011 0.6% 20		0.994 0.987 0.7% 14		0.996 0.997 -0.1% 9		1.023 1.043 -1.9% 5		0.927 0.953 -2.7% 2	
1.085 1.055 2.9% 55		1.074 1.043 3.0% 45		1.059 1.035 2.3% 36		1.045 1.027 1.8% 28		0.000 0.000 - 21		1.024 1.008 1.5% 15		0.990 0.989 0.1% 10		0.999 1.012 -1.3% 6		0.891 0.906 -1.7% 3		0.947 0.980 -3.4% 1

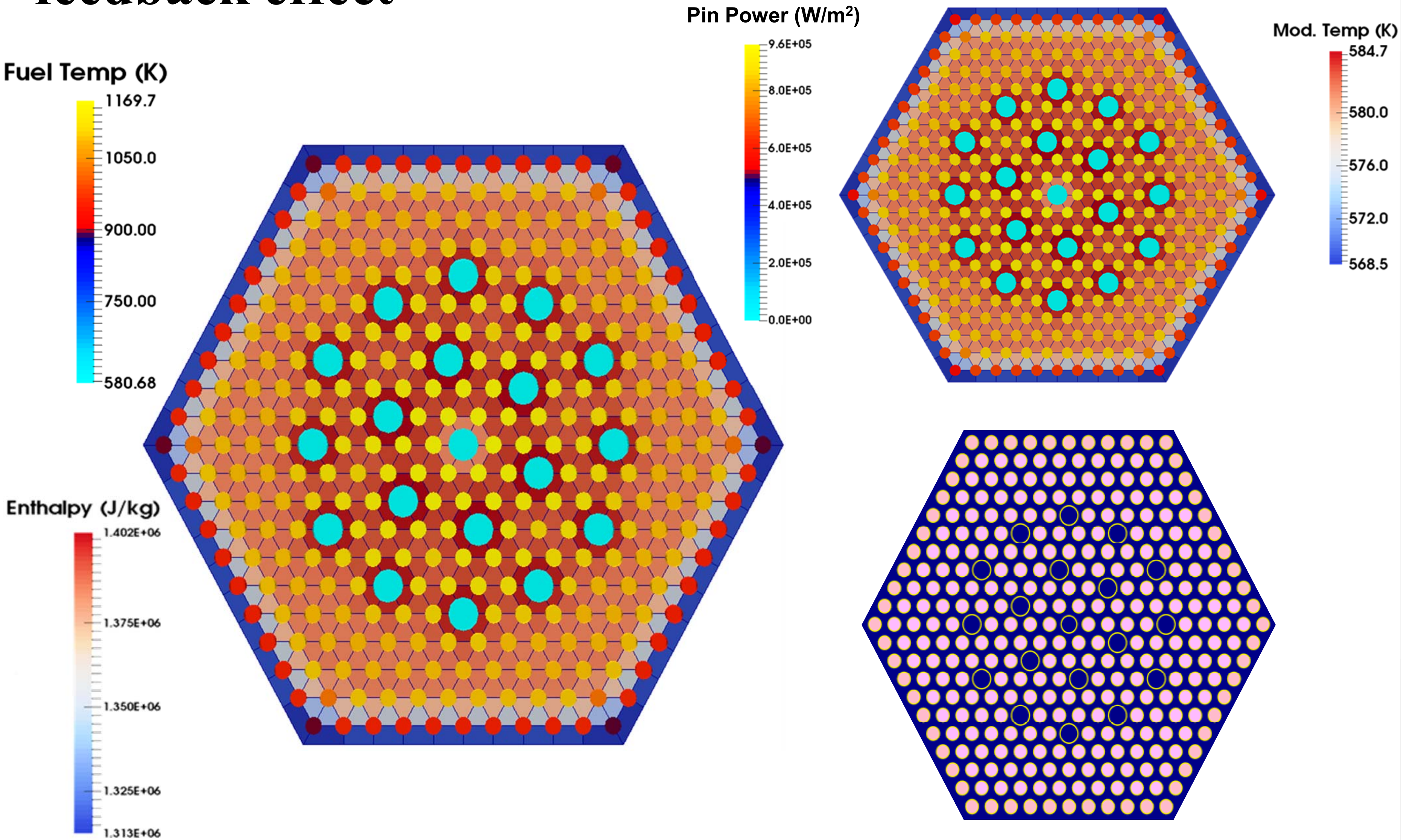
Demonstration of the thermal-hydraulic feedback effect





- **25 iterations between Serpent2 and SubChanFlow to converge the coupled solution.**

Demonstration of the thermal-hydraulic feedback effect



Summary

- Serpent2/SubChanFlow coupling has been extended for hexagonal geometries.
- A proof-of-implementation was demonstrated on a single VVER-1000 FA.
- The outcomes of the demo case proved the consistency of correct mapping between the two fields.
- This work pave the way for more realistic applications such as simulating full VVER-1000 reactor core at HFP condition.