EXTENSION OF SERPENT2/SUBCHANFLOW COUPLING FOR HEXAGONAL FUEL ASSEMBLIES

Yousef Alzaben, Claus-Robert Ziegahn, Victor. H. Sánchez-Espinoza
Presentation Outline

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- Peculiarities of the Hexagonal Geometry.
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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

- **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 $S(\alpha, \beta)$ 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:
  - \( \Delta k_{\text{eff}} \)
  - \( l_2 \)-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.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>18.4 MW&lt;sub&gt;th&lt;/sub&gt;</td>
</tr>
<tr>
<td>Mass flow rate</td>
<td>105.61 kg/s</td>
</tr>
<tr>
<td>Outlet pressure</td>
<td>15.711 MPa</td>
</tr>
<tr>
<td>Coolant inlet temperature</td>
<td>561.66 K</td>
</tr>
<tr>
<td>Boron concentration</td>
<td>53 ppm</td>
</tr>
</tbody>
</table>

Guide Tube
4.4% Enriched fuel pin
3.6% Enriched fuel pin
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:
  - $\Delta k_{\text{eff}} = 5$ 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

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>TRIPOLI4 $K_\infty$</th>
<th>1.29400 ± 4.4E-5</th>
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<tr>
<td>Serpent2 $K_\infty$</td>
<td></td>
<td>1.28924 ± 8.9E-5</td>
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<tr>
<td>Reactivity difference (pcm)</td>
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<td>285</td>
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</tbody>
</table>

- Maximum pin power relative differences is within 3%
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.