Coupling of the Thermal-Hydraulic System Code (RELAP5) and the Monte-Carlo Neutronics Code (Serpent)

By:

Rabie Abu Saleem
Mohammad Mustafa
Mohammad Shahin
Outline:

- Introduction
- Components of Coupling
- Convergence Criteria
- Codes
- Benchmarking and Problem Details
- Models and Meshing
- Methodology & Results
- Conclusions and Future Work
Introduction

- Interdependence between several physics.
Components of Coupling

1. Coupling method
   1. Loose

2. Coupled codes.
   2. System code (RELAP5) with MC code (Serpent)

3. Transient vs. steady state.
   3. Steady state

4. Spatial mesh overlay.
   4. Fixed

5. Coupling approaches.
   5. Serial

6. Convergence criteria.
   6. Several criteria compared
Convergence Criteria

- Monte-Carlo Inherent Uncertainty

\[ |NP_{j,i}^{\text{Current}} - NP_{j,i}^{\text{Previous}}| \leq \sigma_{j,i}^{\text{Previous}} \]

- Relative Change in Fuel and Cladding Temperatures

\[ \left| \frac{T_{j,i}^{\text{Current}} - T_{j,i}^{\text{Previous}}}{T_{j,i}^{\text{Current}}} \right| \leq \epsilon \]
Coupled Codes

• Serpent (*for neutron kinetics*)
  ➢ 3D continuous energy MC reactor physics calculation code.
  ➢ Developed by VVT Technical Research Centre of Finland.

• RELAP5 (*for thermal hydraulics*)
  ➢ Best-estimate simulation of LWR coolant system during postulated transients and accidents.
  ➢ Developed by the U.S. Nuclear Regulatory Commission (NRC).
Benchmarking and Problem Details

- OECD/NEA and U.S. NRC PWR MOX/UCO2 Core Transient Benchmark.

- Core design parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of fuel assemblies</td>
<td>193</td>
</tr>
<tr>
<td>Power level (MWth)</td>
<td>3565</td>
</tr>
<tr>
<td>Assembly pitch (cm)</td>
<td>21.42</td>
</tr>
</tbody>
</table>
### Benchmarking and Problem Details

- **Assembly Design Parameters:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel lattice, fuel rods per assembly</td>
<td>17x17, 264</td>
</tr>
<tr>
<td>Number of control rod guide tubes</td>
<td>24</td>
</tr>
<tr>
<td>Number of instrumentation guide tubes</td>
<td>1</td>
</tr>
<tr>
<td>Pin pitch (cm)</td>
<td>1.26</td>
</tr>
<tr>
<td>Active fuel length (cm)</td>
<td>365.76</td>
</tr>
</tbody>
</table>
Benchmarking and Problem Details

- Assembly Boundary conditions:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet temperature (K)</td>
<td>560.00</td>
</tr>
<tr>
<td>Inlet flow rate (kg/s)</td>
<td>82.12</td>
</tr>
<tr>
<td>Outlet pressure (MPa)</td>
<td>15.50</td>
</tr>
<tr>
<td>Single assembly power MW(th)</td>
<td>18.47</td>
</tr>
</tbody>
</table>
Materials Arrangement in Fuel Pin

<table>
<thead>
<tr>
<th>Cell Radius</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>r0 - r1</td>
<td>fuel</td>
</tr>
<tr>
<td>r1 - r2</td>
<td>gap</td>
</tr>
<tr>
<td>r2 - r3</td>
<td>clad</td>
</tr>
</tbody>
</table>

Pin Dimensions

<table>
<thead>
<tr>
<th>Cell Radius</th>
<th>Dimension (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>r1</td>
<td>0.3951</td>
</tr>
<tr>
<td>r2</td>
<td>0.4010</td>
</tr>
<tr>
<td>r3</td>
<td>0.4583</td>
</tr>
</tbody>
</table>

Benchmarking and Problem Details
Benchmarking and Problem Details

- Approximations for Guide tube:

<table>
<thead>
<tr>
<th>Cell radius</th>
<th>material</th>
</tr>
</thead>
<tbody>
<tr>
<td>r0 - r1</td>
<td>water</td>
</tr>
<tr>
<td>r1 - r2</td>
<td>clad</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cell Radius</th>
<th>Fuel (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>r1</td>
<td>0.5624</td>
</tr>
<tr>
<td>r2</td>
<td>0.6032</td>
</tr>
</tbody>
</table>
**Models and Meshing**

- RELAP5 Model

\[ A_{flow} = A_{assembly} - n_{fuelrods} \times A_{rod} - n_{guidtubes} \times A_{tubes} \]
Models and Meshing

- Serpent Model

![Diagram of Serpent Model with 24 levels and 1000x100x100 dimensions]
Models and Meshing

- Serpent Model – Material composition

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (g/cm$^3$)</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>UO$_2$</td>
<td>10.24</td>
<td>$U^{235}$: 4.2 wt%, $U^{238}$: 95.8 wt%</td>
</tr>
<tr>
<td>Cladd</td>
<td>6.504</td>
<td>Zr: 98.23 wt%, Sn: 1.5 wt%, Fe: 0.12 wt%, Cr: 0.1 wt%, N: 0.05 wt%</td>
</tr>
<tr>
<td>Coolant</td>
<td>0.75206</td>
<td>$H_2O$ at 560 K and 15.5 MPa</td>
</tr>
</tbody>
</table>
Methodology and Results

• Scheme I (Serpent 1st)

Driving Script: BASH Shell
Exchanging File: Python 2.7
Convergence Testing: MATLAB
Results of Scheme I
Results of Scheme I
Methodology and Results

• Scheme II (RELAP5 First)

Driving Script: BASH Shell
Exchanging File: Python 2.7
Convergence Testing: MATLAB
Results of Scheme II
Methodology and Results

• Scheme II (Volume-Weighted Average Fuel Temperature Feedback)

\[ T_{avg} = 0.0278 \, T_1 + 0.083 \, T_2 + 0.1389 \, T_3 + 0.194 \, T_4 + 0.25 \, T_5 + 0.3056 \, T_6 \]
Methodology and Results

• Scheme II (Volume-Weighted Average Fuel Temperature Feedback)
Methodology and Results

- Convergence of the Normalized Axial Power
Methodology and Results

- Effect of temperature feedback calculations
Methodology and Results

- Convergence of Fuel Temperature
Methodology and Results

- Convergence of Cladding Temperature
Methodology and Results

• Convergence of Coolant Temperature
Methodology and Results

• Convergence of Coolant Density
Summary, Conclusions & Future Work

- Different coupling schemes were used, and different convergence criteria were tested.
- Scheme starting with RELAP5 showed better consistency in results shown by the normalized axial power distribution.
- Method of implementing temperature feedback can significantly influence the convergence. Using volume-weighted average for the effective fuel temperature shows good convergence behaviour.
- Continuation of this work can be through: implementation to different benchmark problems, coupling of other reactor physics and using different codes with different methods for cross section generation.
THANK YOU