Neutronic analysis of SFR lattices: Serpent vs. HELIOS-2

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Outline

• Introduction

• Results of the burnup calculations: Serpent vs. HELIOS

• Analysis of the observed differences

• Summary and conclusions
Introduction

• DYN3D nodal code
  – 3D full core steady-state and transient calculations
  – Developed at HZDR for LWR application
  – Is being adopted for SFR analysis

• An important tasks
  – Selection of appropriate lattice code
  – Establishing of the few-group XS generation procedure

• Candidate lattice codes
  – Serpent Monte Carlo transport code
  – HELIOS-2 deterministic lattice transport code
Why to consider HELIOS?

• Solves the transport equation on 2D unstructured mesh
  – High level of geometrical flexibility
  – Handles complex fuel lattice configurations

• Uses updated nuclear data
  – ENDF/B-VII based cross section library

• We know how to use it

• But…
  – HELIOS-2 is mainly LWR oriented code
  – Applicability for fast reactors not demonstrated
In this presentation…

- Investigation of HELIOS-2 applicability for the SFR analysis
  - Via fuel assembly level depletion calculations
  - Using Serpent as a reference

In the following presentation…

- Serpent as a few-group XS generator for SFR analysis
Reference SFR sub-assembly model

- Fuel sub-assembly of ESFR (European SFR)
- 271 pins
- 14.5 wt% Pu MOX fuel
- 21.08 cm outer flat-to-flat
Results of burnup calculations
K-inf vs. burnup

- HELIOS-2 systematically overestimates k-inf
  - 800 pcm at BOL
  - 400 pcm at EOL
Safety related parameters at BOL

<table>
<thead>
<tr>
<th></th>
<th>Serpent</th>
<th>HELIOS-2</th>
<th>Rel. diff., pcm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doppler constant, pcm</td>
<td>-1227</td>
<td>-1147</td>
<td>80</td>
</tr>
<tr>
<td>Coolant void reactivity, pcm</td>
<td>2968</td>
<td>2742</td>
<td>-226</td>
</tr>
</tbody>
</table>

Serpent, $\sigma_{k\text{-inf}} = 8$ pcm

- In HELIOS-2
  - Doppler constant is “less” negative
  - Coolant void reactivity worth is underpredicted
**Actinide inventory**

- Good agreement in actinide concentration
  - U and Pu inventories agree within 1% (excluding Pu-239)
  - Max. discrepancy for Pu-239 is ~2%
  - Cm and Am inventories agree within 2.5%

Relative difference \( = \frac{\text{HELIOS} - \text{Serpent}}{\text{Serpent}} \)
Some reasons for observed differences
Actinide one-group $\sigma_a$

Relative difference = (HELIOS - Serpent)/Serpent

- HELIOS-2 underestimates absorption in U-238
  - 40% of total capture rates
- HELIOS-2 overestimates absorption in Pu-239
  - 25% of total fission rates
- Result: $k_{inf}$ HELIOS-2 > $k_{inf}$ Serpent
Resonance parameters in HELIOS-2

- The resonance parameters for HELIOS-2 were obtained by:
  - Solving the slowing-down equation
  - For mixtures of H and the resonance isotopes
  - Using different dilution levels.

- Slowing-down properties of H and Na-23 differ significantly
  - H-based resonance parameters are not fully appropriate for SFR applications
  - XS of resonance nuclides can be affected

<table>
<thead>
<tr>
<th>Energy range</th>
<th>$\sigma_a$ U-238, barn</th>
<th>Rel. diff., %</th>
<th>% of total absorption rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HELIOS-2</td>
<td>Serpent</td>
<td></td>
</tr>
<tr>
<td>Fast: 302 KeV - 20 MeV</td>
<td>0.2262</td>
<td>0.2291</td>
<td>-1.3</td>
</tr>
<tr>
<td>Unresolved: 19 KeV - 302 KeV</td>
<td>0.2466</td>
<td>0.2473</td>
<td>-0.3</td>
</tr>
<tr>
<td>Resolved I: 1 KeV - 19 KeV</td>
<td>0.6844</td>
<td>0.7127</td>
<td>-4.0</td>
</tr>
<tr>
<td>Resolved II: 1 eV - 1 KeV</td>
<td>1.3377</td>
<td>1.4516</td>
<td>-7.9</td>
</tr>
<tr>
<td>Total</td>
<td>0.3335</td>
<td>0.3374</td>
<td>-1.2</td>
</tr>
</tbody>
</table>
Effect of the flux weighting function in NJOY

- HELIOS-2 177-group X&Ss generated by NJOY
- Generic LWR spectrum is used to collapse pointwise ENDF data
- Not fully appropriate for fast reactor applications

**Difference in 177 group $\sigma_a$ of U-238 collapsed by NJOY using:**
- LWR spectrum (IWT=4 ) and fast reactor spectrum (IWT=8)
Neutron flux spectrum – reference case

- High differences near elastic scattering resonances
  - **Na-23** at 2.8 KeV and 53.2 KeV,
  - **O-16** at 434.3 KeV
The difference in flux is reduced
- At 2.8 KeV: from 14.8% to 4.5%
- At 53.2 Kev: from 17.8% to 4.7%
- Due to the absence of Na
Reasons for the differences in flux spectra

- In HELIOS-2 Na-23 and O-16 are not resonance nuclides
  - Infinitely diluted XS are used in calculations
  - **Self-shielding** of elastic scattering resonances is ignored
Summary and conclusions

• Burnup calculations of ESFR sub-assembly
  – Performed with HELIOS-2 and Serpent
  – Generally acceptable agreement between the codes

• HELIOS-2 can be used for scoping studies of SFR lattices

• But, HELIOS-2 modeling accuracy can be improved

• The following modifications are suggested:
  – Introduction of the resonance treatment for Na-23 and O-16
  – Generation of a master XS library using fast reactor weighting spectrum
  – Generation of the resonance parameter using Na-23 based mixtures
Thank you for your attention
and have a productive meeting!