On the Use of Serpent for SMR Modeling and Cross Section Generation

Yousef Alzaben, Victor. H. Sánchez-Espinoza, Robert Stieglitz
Outline

- Objectives.
- SMR Definition.
- SMART Design Characteristics.
- Comparison and Results.
- Summary and Conclusion.
Objectives

- To study the impact of two different XS generation approaches: infinite lattice and full core on $K_{\text{eff}}$ and radial power distribution.

- Verifying Xenon/Samarium concentration between Serpent and PARCS.

- Verifying Xenon/Samarium microscopic absorption XS and Xe, I, and Pm fission yields between Serpent and SCALE/POLARIS.

- Adopting a SMR called SMART.
SMR Definition

According to World Nuclear Association, Small Modular Reactors (SMRs) are defined as:

“Nuclear reactors generally 300MW_e equivalent or less, designed with modular technology using module factory fabrication, pursuing economies of series production and short construction times”
## SMART Design Characteristics

**System-Integrated Modular Advanced Reactor**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal core power</td>
<td>330 MW&lt;sub&gt;th&lt;/sub&gt;</td>
</tr>
<tr>
<td>Electrical output power</td>
<td>100 MW&lt;sub&gt;e&lt;/sub&gt;</td>
</tr>
<tr>
<td>Design lifetime</td>
<td>60 years</td>
</tr>
<tr>
<td>Refueling cycle</td>
<td>3 years</td>
</tr>
<tr>
<td>Fuel Material</td>
<td>4.95 w/o UO&lt;sub&gt;2&lt;/sub&gt;</td>
</tr>
<tr>
<td>No. of FA types</td>
<td>3</td>
</tr>
<tr>
<td>No. of FA in the reactor core</td>
<td>57</td>
</tr>
<tr>
<td>Core Specific power</td>
<td>2.6462E-02 kW/gU</td>
</tr>
<tr>
<td>Cooling mode</td>
<td>Forced Circulation</td>
</tr>
<tr>
<td>Operating pressure</td>
<td>15 MPa</td>
</tr>
<tr>
<td>Core inlet temperature</td>
<td>270 °C</td>
</tr>
<tr>
<td>Core outlet temperature</td>
<td>310 °C</td>
</tr>
<tr>
<td>Core coolant mass flow rate</td>
<td>1550 Kg/s</td>
</tr>
</tbody>
</table>


Reactor Core Characteristics

Used Tools

- **Tools used in this work:**
  - SCALE/POLARIS version 6.2
  - GenPMAKS version 6.1.3.
  - PARCS version 32m10.

- **Microscopic cross section library used:**
  - Serpent: CE - ENDF/B-VII.0
  - SCALE/POLARIS: 252g - ENDF/B-VII.0

- **No. of energy groups used for cross section generation:**
  - 2 energy groups separated at 0.625 eV.
Cross Section Generation Strategy

Homogenization

1) Infinite lattice approach

2) Full core approach

Condensation

2 groups

Critical spectrum (B1 Method)

Preserving:
1. Reaction rate.
2. Leakage rate.
3. Flux boundary value.

System spectrum

GenPMAKS

.i_res.m

PARCS Full Core

PMAXS
## Comparison Between The Two Approaches

1\textsuperscript{st}: Infinite lattice approach

- 3 separated single fuel assembly models with reflective B.C. are required.

**Advantages:**
- Easy to construct an input model.
- Relatively fast running simulation.

**Disadvantages:**
- Several simulations needed.
- Full core model is needed as a reference solution.

**No. of histories used:**
- Neutrons per cycle: 100,000
- Active cycles: 500
- Inactive cycles: 150

2\textsuperscript{nd}: Full core approach

- A full core model is needed.

**Advantages:**
- Account for leakages in XS generation.
- Preserve actual heterogeneous flux.
- In a single run, all XSs are obtained as well as the reference solution.

**Disadvantages:**
- Complicated input model.
- Requires a lot of histories to provide reliable results.

**No. of histories used:**
- Neutrons per cycle: 20,000,000
- Active cycles: 2,000
- Inactive cycles: 200
Reference Full Core Radial Power Distribution and $K_{\text{eff}}$

Serpent radial power distribution

Serpent radial power uncertainty

Serpent $K_{\text{eff}}$: 1.040300 ± 3.9E-06
Comparison Between The Two Approaches in Radial Power Distribution and $K_{\text{eff}}$

1\textsuperscript{st}: Infinite lattice approach

\[ \Delta \rho = -327 \text{ pcm} \]

2\textsuperscript{nd}: Full core approach

\[ \Delta \rho = -8 \text{ pcm} \]
Xe/Sm Concentration Comparison Between Serpent and PARCS

- Carried out for a single fuel assembly: FA type A
- Serpent model is a 2D infinite lattice (with reflective B.C).
- PARCS model is a single node with reflective B.C.

Idea:

- Verify the migration of XS sets from Serpent to PARCS.

The verification approach took place as follows:

1. $K_{\text{inf}}$ vs. Burnup, without taking into account equilibrium Xe/Sm effect in PARCS.
2. $K_{\text{inf}}$ and Xe-135 concentration vs. Burnup, taking into account equilibrium Xe/Sm effect in PARCS.
Xe/Sm Concentration Comparison Between Serpent and PARCS

Without taking into account equilibrium Xe/Sm effect in PARCS.

Conclusion: $\Sigma_f$, $\Sigma_a$, $\Sigma_s$ are correctly migrated to PARCS.
Xe/Sm Concentration Comparison Between Serpent and PARCS

- By taking into account equilibrium Xe/Sm effect in PARCS.

~ Overestimated by 80%
Xe/Sm Concentration Calculation

- Xe-135 concentration in equilibrium is calculated by PARCS as follows:

\[
N_{Xe}^∞ = \frac{(γ_{Xe} + γ_i) \sum_{g=1}^{G} (Σ_{f,g} \cdot φ_g)}{\lambda_{Xe} + \sum_{g=1}^{G} (σ_{a,g}^{Xe} \cdot φ_g)}
\]

- Sm-149 concentration in equilibrium is calculated by PARCS as follows:

\[
N_{Sm}^∞ = \frac{γ_{Pm} \sum_{g=1}^{G} (Σ_{f,g} \cdot φ_g)}{\sum_{g=1}^{G} (σ_{a,g}^{Sm} \cdot φ_g)}
\]

Where:

- \( γ_i \): Fission yield of isotope \( i \)
- \( Σ_{f,g} φ_g \): Fission rate at energy group \( g \).
- \( σ_{a,g}^{Xe} \) and \( σ_{a,g}^{Sm} \): Xe/Sm microscopic absorption XS at group \( g \), respectively.
- \( λ_{Xe} \): Xenon decay constant = 0.209167E-4 s\(^{-1}\)
Xe/Sm Concentration: Identifying the Problem

- In Serpent output (.i_res.m file):

\[ \sigma_{i,g}^{abs} \neq \sum_{i,g}^{abs} \frac{N_i \ast \text{volume ratio}}{N_i} \quad \text{Where } i: \text{Xe135 or Sm149} \]

- In GenPMAXS, the macroscopic absorption cross section is taken from “INF_RABSXS”. It should be defined as:

“INF_RABSXS - INF_XE135_MACRO_ABS - INF_SM149_MACRO_ABS”

- In GenPMAXS, the Xe, I, and Pm fission yield take the fast energy group only. PARCS needs a single energy fission yield only. The condensation to single group was done as follows:

\[ \gamma_i = \frac{\sum_{g=1}^{G} (\gamma_{i,g} \ast \Sigma_{f,g} \ast \phi_g)}{\sum_{g=1}^{G} (\Sigma_{f,g} \ast \phi_g)} \]
Xe/Sm Atomic Density Comparison: SCALE/POLARIS vs. Serpent

**Xe-135 Concentration**

![Graph showing Xe-135 concentration over BU (MWd/Kg)]

**Sm-149 Concentration**

![Graph showing Sm-149 concentration over BU (MWd/Kg)]
Xenon Microscopic Absorption XS Verification: SCALE/POLARIS vs. Serpent

- Serpent Xe-135 microscopic absorption XS was calculated based on:

\[ \sigma_{Xe,g}^{abs} = \frac{\sum_{Xe,g}^{abs}}{N_i \times \text{volume ratio}} \]

**Fast Group**

**Thermal Group**
Samarium Microscopic Absorption XS Verification: SCALE/POLARIS vs. Serpent

Serpent Sm-149 microscopic absorption XS was calculated based on:

$$\sigma_{Sm,g}^{abs} = \frac{\sum_{Sm,g}^{abs}}{N_i \ast \text{volume ratio}}$$

**Fast Group**

**Thermal Group**
Xe/Sm Concentration Comparison between Serpent and PARCS

The following results was produced after modifying Xe/Sm microscopic absorption XS and the definition of macroscopic absorption cross section in GenPMAINS, and Xe, I, Pm fission yield.
Comparison Between Serpent and PARCS
After Solving Xe/Sm Problem

Before any modification

After the modifications

![Graph Comparing Infinite Multiplication Factor Before and After Modifications](image)
Serpent fission yield was collapsed to a single energy group.
Xe, I, and Pm Fission Yield Verification: SCALE/POLARIS vs. Serpent

Pm-149 Yield

- Serpent
- POLARIS
- POL./SER.

BU (MWe/Kg)

Pm-149 Yield

POLARIS/SERPENT
Sm149 Concentration Comparison Between Serpent and PARCS with POLARIS Fission Yields

With Serpent calculated fission yield

With POLARIS fission yield

Why?
Summary and Conclusion

- XS generation with the full core approach showed a better agreement with Serpent power distribution and $K_{\text{eff}}$. However, the simulation time is much longer than the conventional approach.

- Disagreement in Serpent calculation for Xe/Sm microscopic absorption XS.

- After modifying Xe/Sm microscopic absorption XS in Serpent, a good agreement was found between Serpent and SCALE/POLARIS.

- An unknown source of differences between SCALE/POLARIS and Serpent in the fission yield calculation.
  → How does Serpent collapse fission yields?