Karlsruhe Institute of Technology

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

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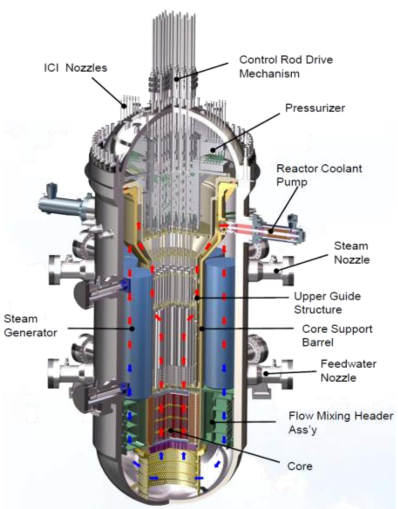
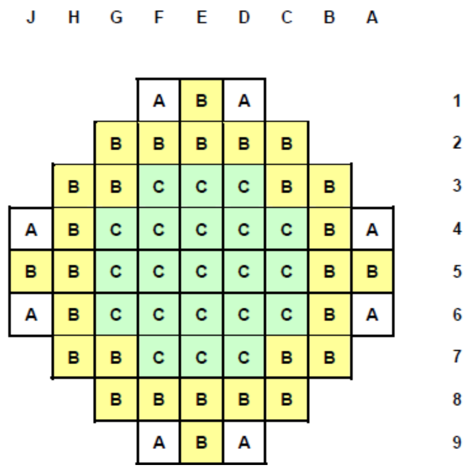
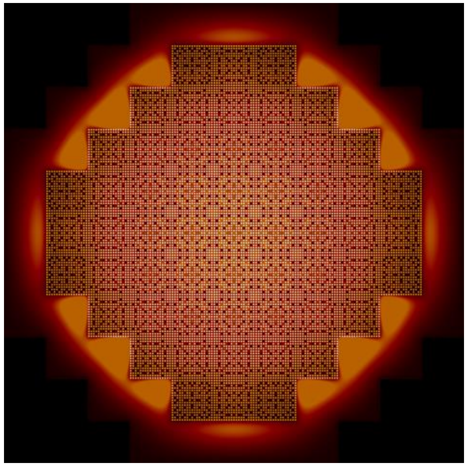






Outline

- 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_{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:**

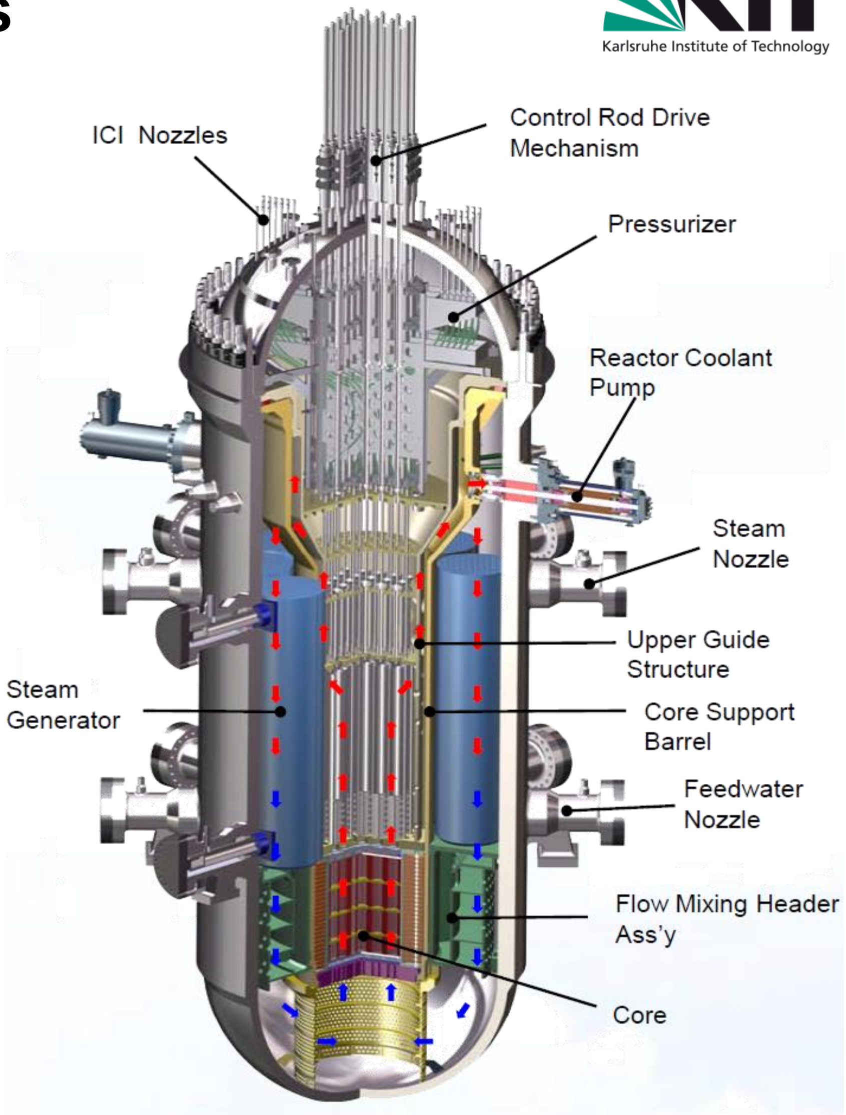
"*Nuclear reactors generally 300MW$_e$ equivalent or less, designed with modular technology using module factory fabrication, pursuing economies of series production and short construction times***"**

SMART Design Characteristics

System-Integrated **M**odular **A**dvanced **R**eac**T**or

Thermal core power	330 MW_{th}
Electrical output power	100 MW_e
Design lifetime	60 years
Refueling cycle	3 years
Fuel Material	4.95 w/o UO_2
No. of FA types	3
No. of FA in the reactor core	57
Core Specific power	2.6462E-02 kW/gU
Cooling mode	Forced Circulation
Operating pressure	15 MPa
Core inlet temperature	270 °C
Core outlet temperature	310 °C
Core coolant mass flow rate	1550 Kg/s

Source: IAEA-TECDOC-1444, "*Optimization of The Coupling of Nuclear Reactors and Desalination Systems*", June 2005



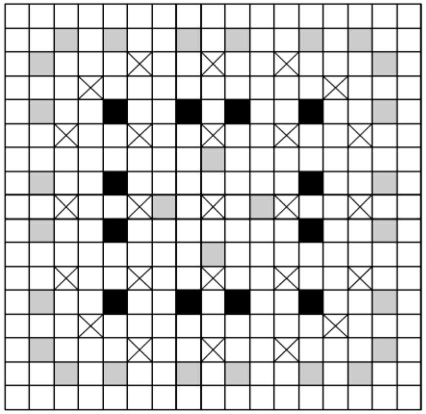
Source: Keun Bae Park, "*SMART: An Early Deployable Integral Reactor for Multi-Purpose Applications*", INPRO Dialogue Forum on Nuclear Energy Innovations: CUC for Small & Medium-sized Nuclear Power Reactors, 10-14 October 2011, Vienna, Austria

Reactor Core Characteristics

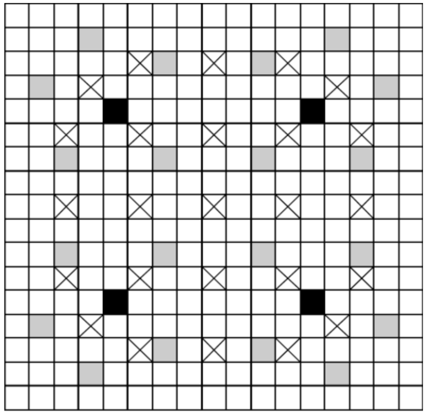
	J	H	G	F	E	D	C	B	A
1				A	B	A			
2			B	B	B	B	B		
3		B	B	C	C	C	B	B	
4	A	B	C	C	C	C	C	B	A
5	B	B	C	C	C	C	C	B	B
6	A	B	C	C	C	C	C	B	A
7		B	B	C	C	C	B	B	
8			B	B	B	B	B		
9				A	B	A			

A	4.95w/o U-235 / 28 Al_2O_3-B_4C Shim / 12 Gd_2O_3-UO_2
B	4.95w/o U-235 / 20 Al_2O_3-B_4C Shim / 4 Gd_2O_3-UO_2
C	4.95w/o U-235 / 24 Al_2O_3-B_4C Shim / 4 Gd_2O_3-UO_2

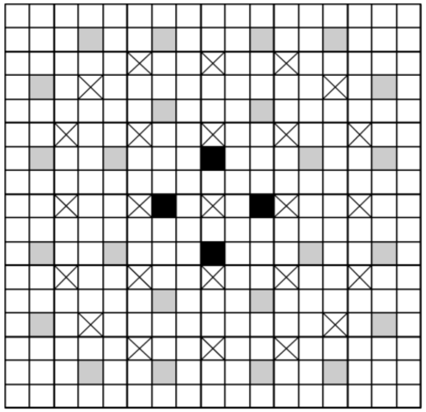
Source: IAEA-TECDOC-1444, "*Optimization of The Coupling of Nuclear Reactors and Desalination Systems*", June 2005



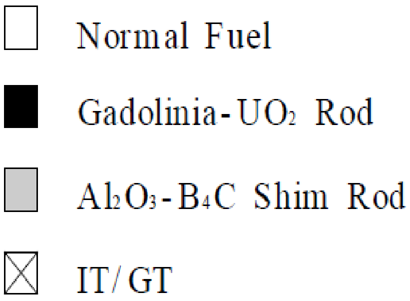
Fuel Assembly Type A



Fuel Assembly Type B



Fuel Assembly Type C



Used Tools

- **Tools used in this work:**
  - Serpent version 2.1.26.
  - SCALE/POLARIS version 6.2
  - GenPMAXS 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

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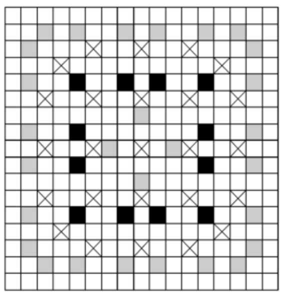
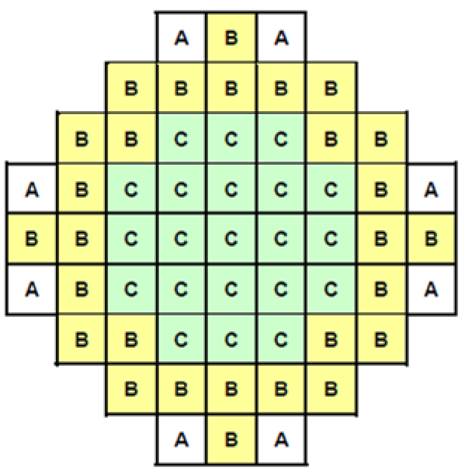
Homogenization

1) Infinite lattice approach



2) Full core approach



Condensation

2 groups

Critical spectrum (B1 Method)

System spectrum

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

.i_res.m

GenPMAXS

PMAXS

PARCS Full Core

Comparison Between The Two Approaches

1st: Infinite lattice approach

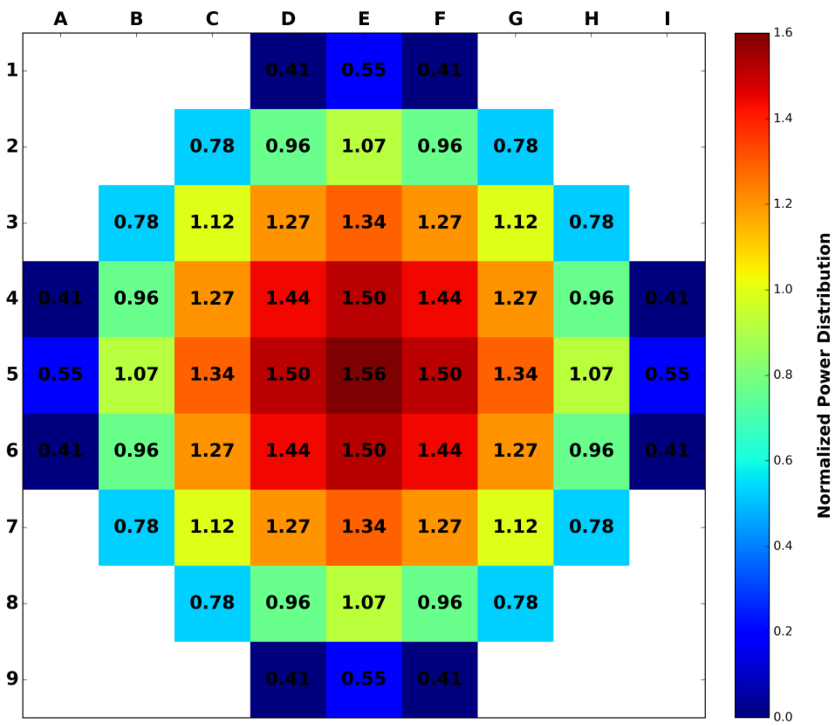
- 3 separated single fuel assembly models with reflective B.C. are required.
- **Advantages:**
  - Easy to construct an input model.
  - Relatively fast running simulation.
- **Disadvantages:**
  - Several simulations needed.
  - Full core model is needed as a reference solution.
- **No. of histories used:**
  - Neutrons per cycle: 100,000
  - Active cycles: 500
  - Inactive cycles: 150

2nd: Full core approach

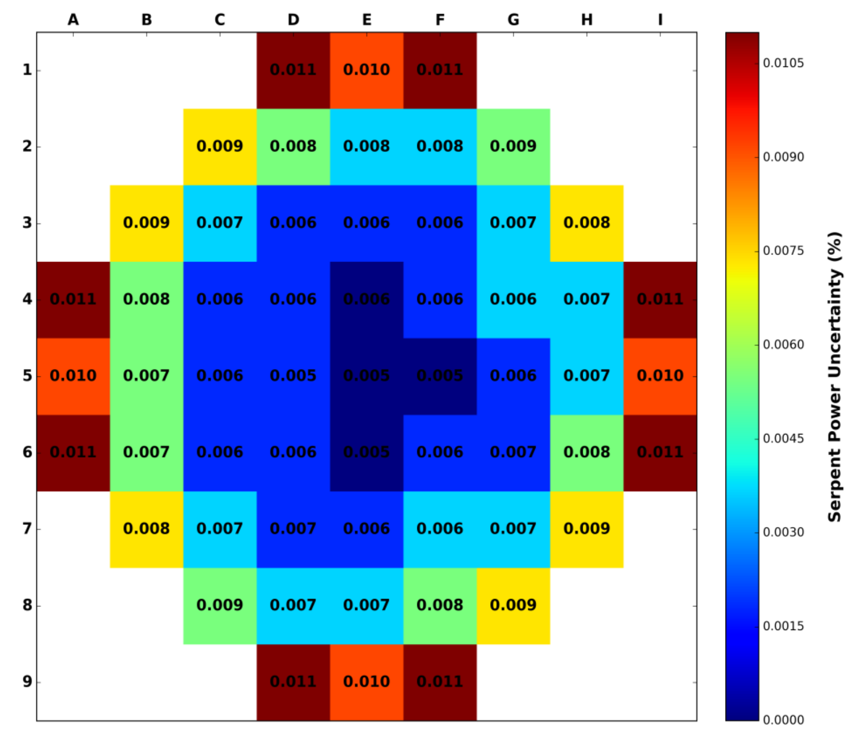
- A full core model is needed.
- **Advantages:**
  - Account for leakages in XS generation.
  - Preserve actual heterogeneous flux.
  - In a single run, all XSs are obtained as well as the reference solution.
- **Disadvantages:**
  - Complicated input model.
  - Requires a lot of histories to provide 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_{eff}

Serpent radial power distribution



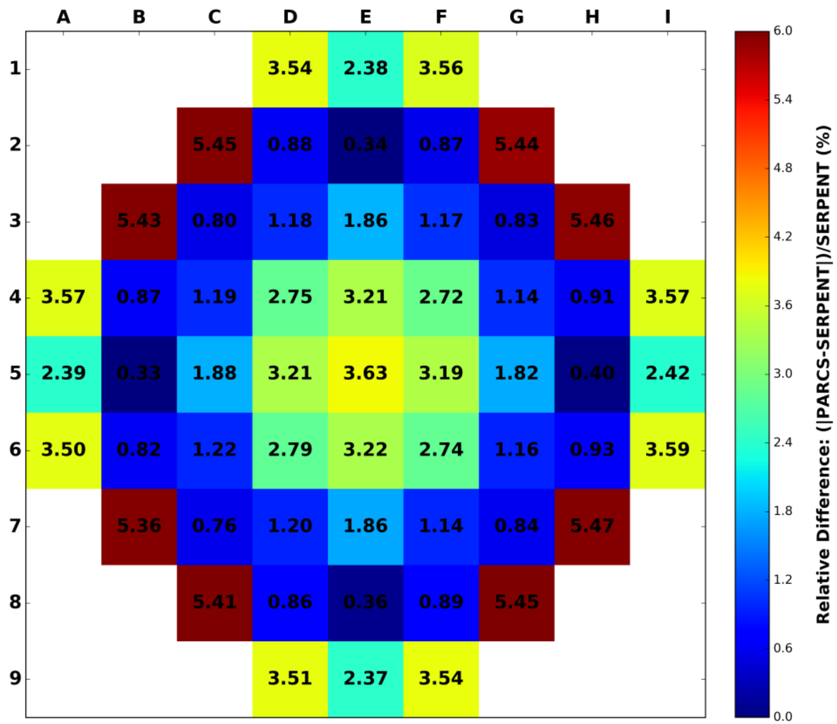
Serpent radial power uncertainty



Serpent K_{eff}: 1.040300 ± 3.9E-06

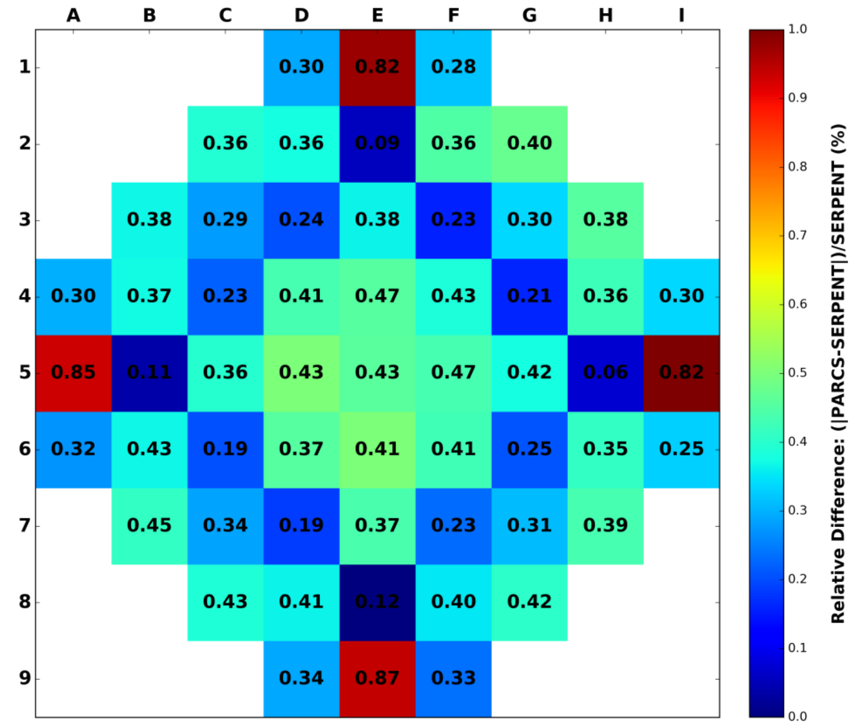
Comparison Between The Two Approaches in Radial Power Distribution and K_{eff}

1st: Infinite lattice approach



$\Delta\rho$ = -327 pcm

2nd: Full core approach



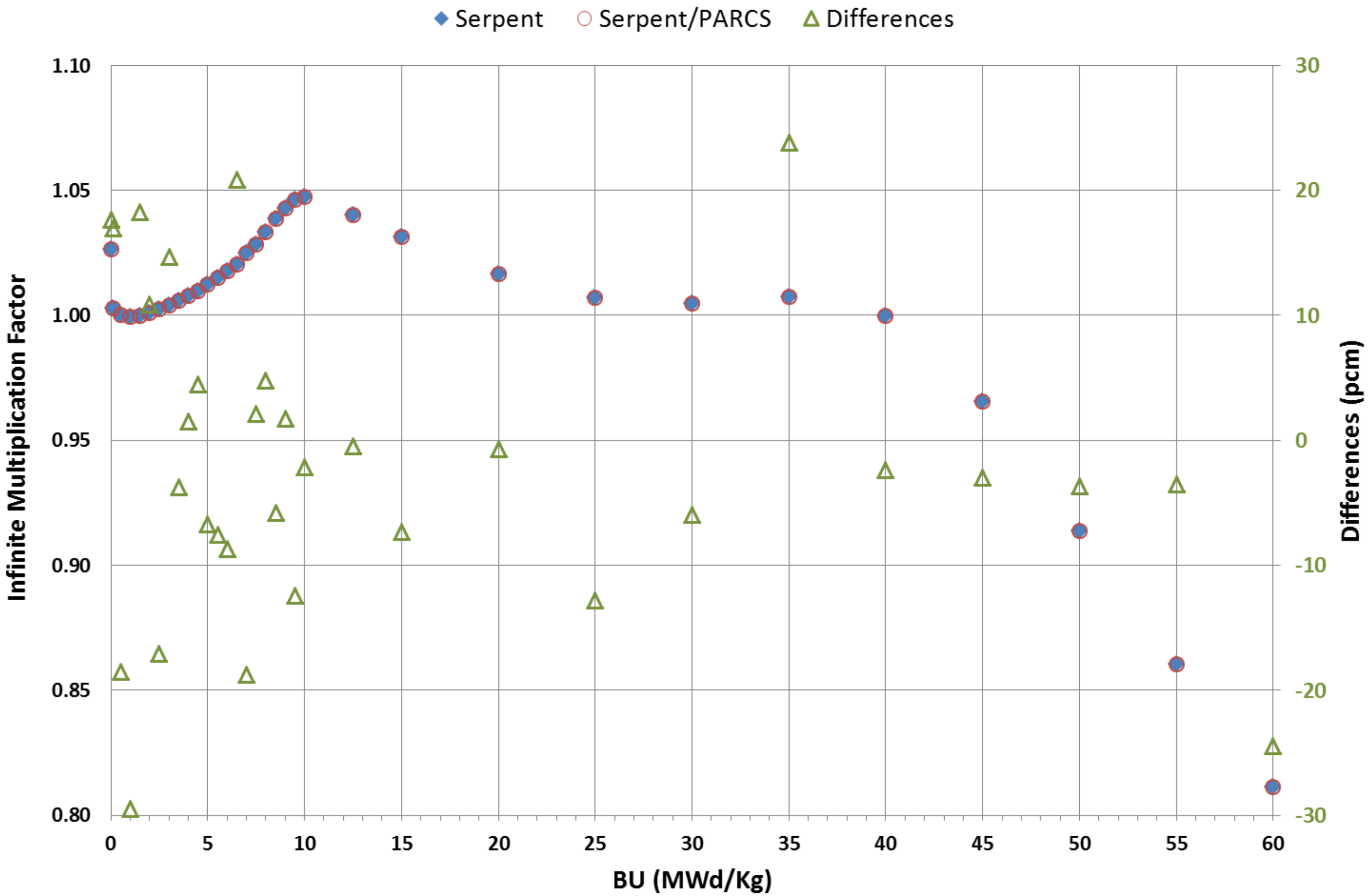
$\Delta\rho$ = -8 pcm

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_{inf} vs. Burnup, without taking into account equilibrium Xe/Sm effect in PARCS.
  2. K_{inf} and Xe-135 concentration vs. Burnup, taking into account equilibrium Xe/Sm effect in PARCS.

Xe/Sm Concentration Comparison Between Serpent and PARCS

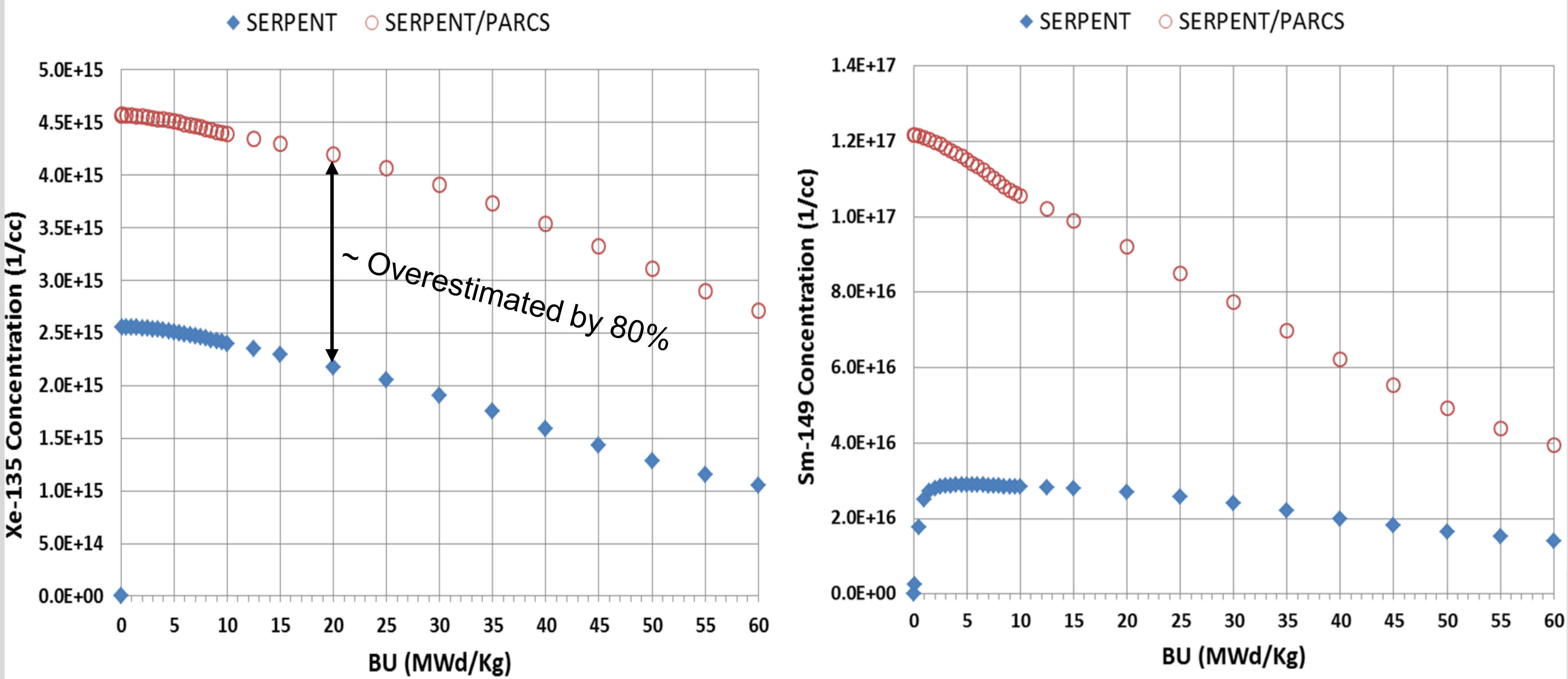
- Without taking into account equilibrium Xe/Sm effect in PARCS.



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.



Xe/Sm Concentration Calculation

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

$$N_{Xe}^{\infty} = \frac{(\gamma_{Xe} + \gamma_I)\sum_{g=1}^{G}(\Sigma_{f,g} * \phi_g)}{\lambda_{Xe} + \sum_{g=1}^{G}(\sigma_{a,g}^{Xe} * \phi_g)}$$

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

$$N_{Sm}^{\infty} = \frac{\gamma_{Pm}\sum_{g=1}^{G}(\Sigma_{f,g} * \phi_g)}{\sum_{g=1}^{G}(\sigma_{a,g}^{Sm} * \phi_g)}$$

Where:

γ_i: Fission yield of isotope i

$\Sigma_{f,g}\phi_g$: Fission rate at energy group g.

$\sigma_{a,g}^{Xe}$ and $\sigma_{a,g}^{Sm}$: 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):

$$\sigma_{i,g}^{abs} \neq \frac{\Sigma_{i,g}^{abs}}{N_i * volume\ ratio}$$ Where i: Xe135 or Sm149

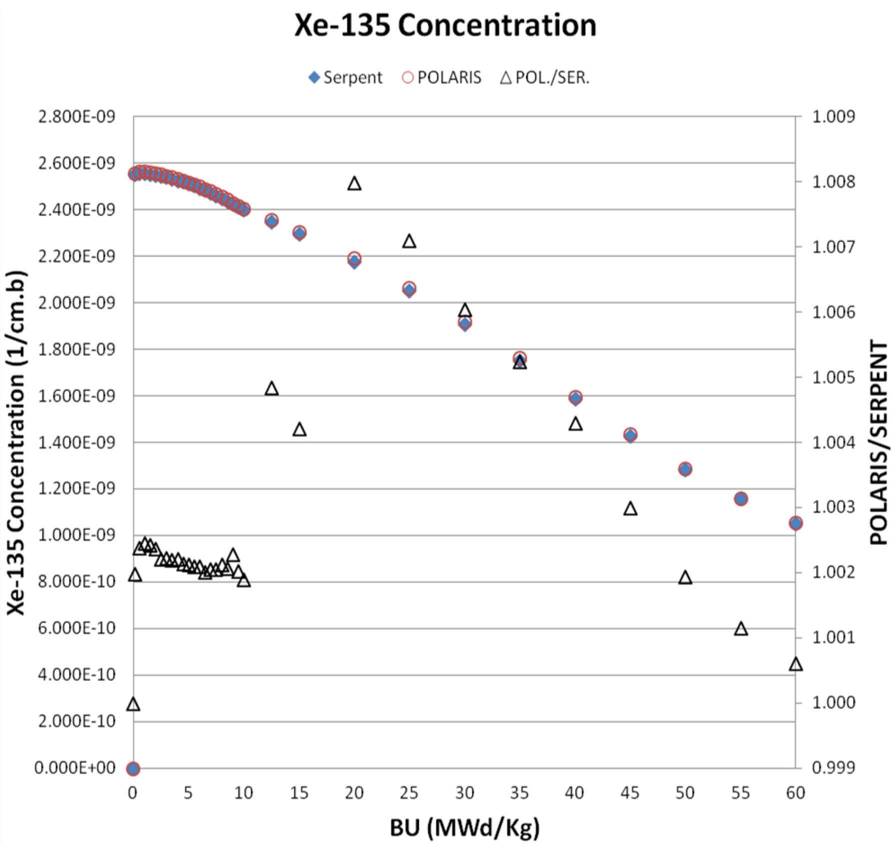
- In GenPMAXS, the macroscopic absorption cross section is taken from "INF_RABSXS". It should be defined as:

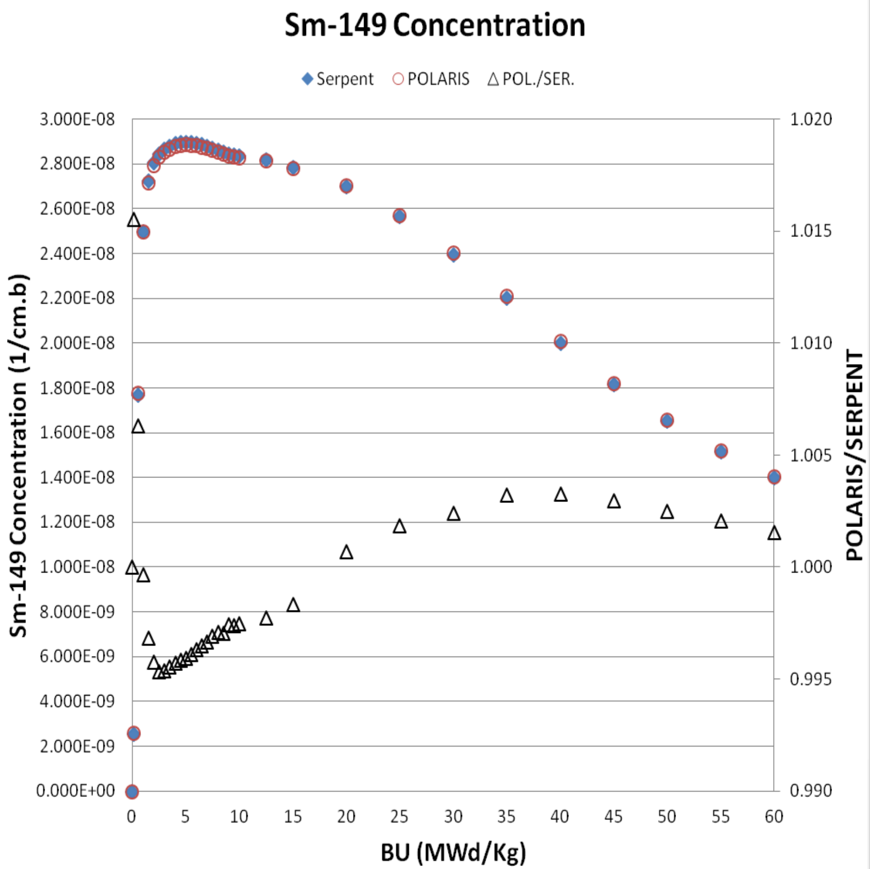
"INF_RABSXS - INF_XE135_MACRO_ABS - INF_SM149_MACRO_ABS"

- 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:

$$\gamma_i = \frac{\sum_{g=1}^{G}(\gamma_{i,g} * \Sigma_{f,g} * \phi_g)}{\sum_{g=1}^{G}(\Sigma_{f,g} * \phi_g)}$$

Xe/Sm Atomic Density Comparison: SCALE/POLARIS vs. Serpent

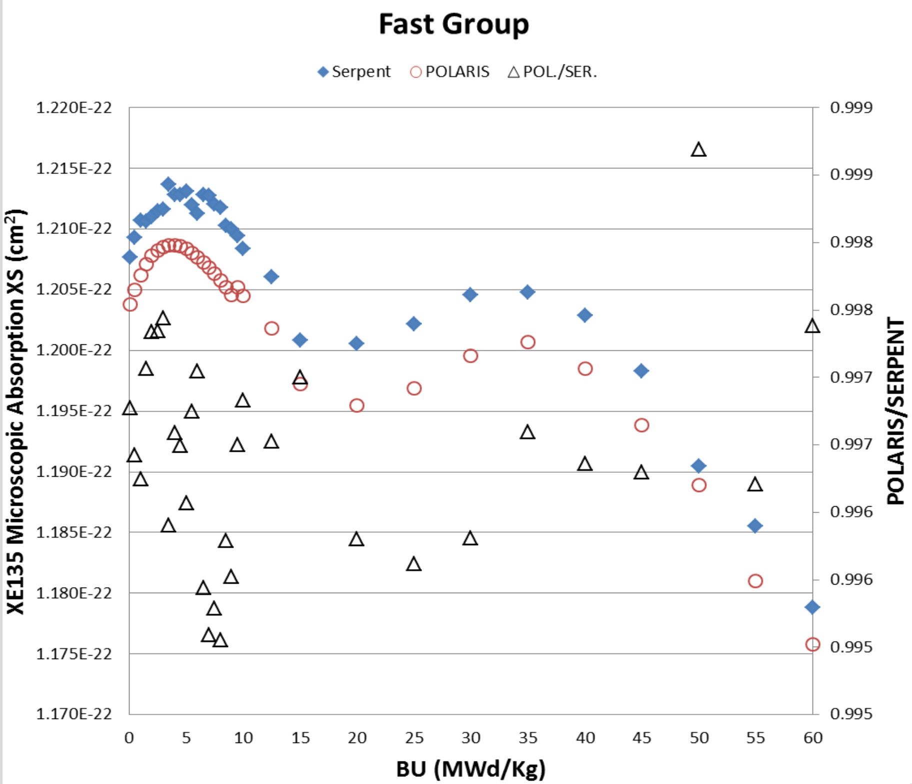


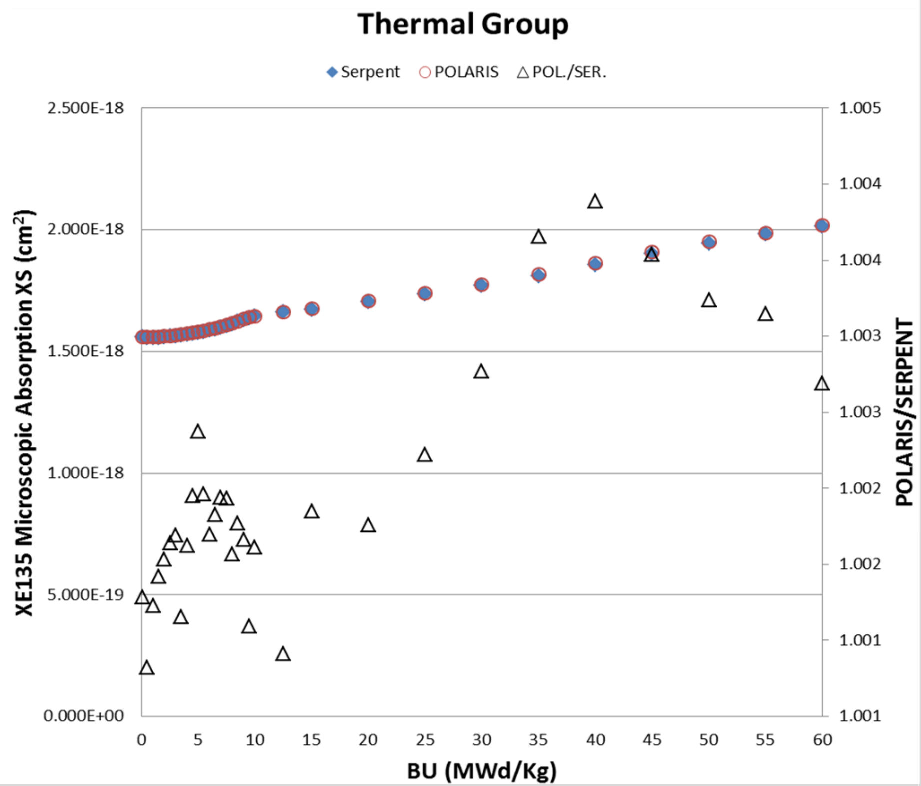


Xenon Microscopic Absorption XS Verification: SCALE/POLARIS vs. Serpent

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

$$\sigma_{Xe,g}^{abs} = \frac{\Sigma_{Xe,g}^{abs}}{N_i * volume\ ratio}$$

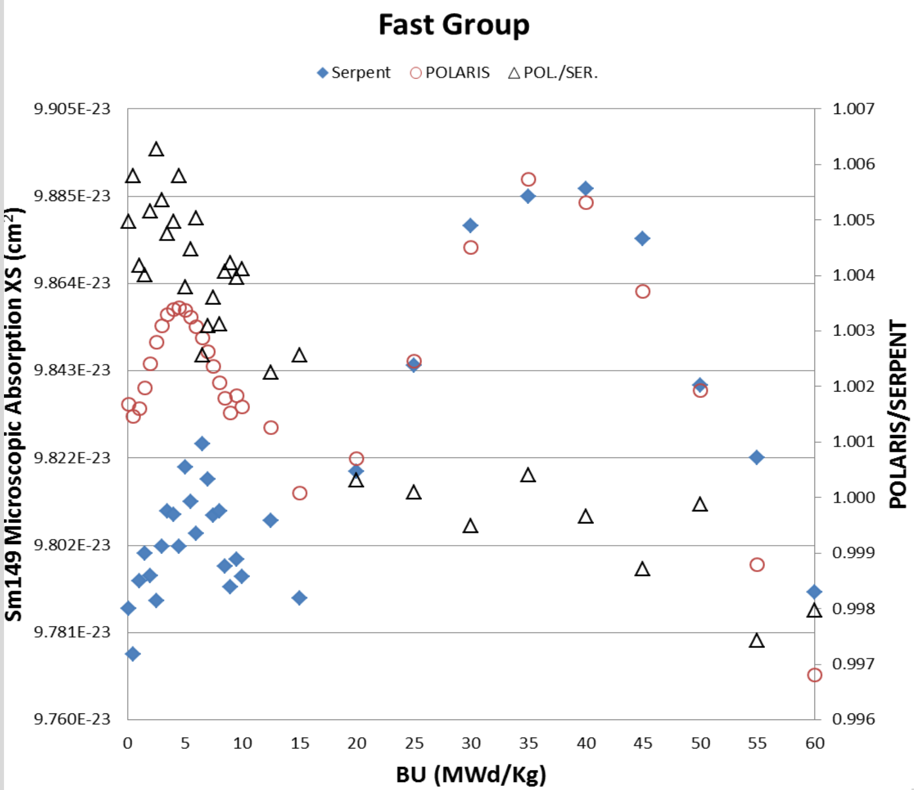


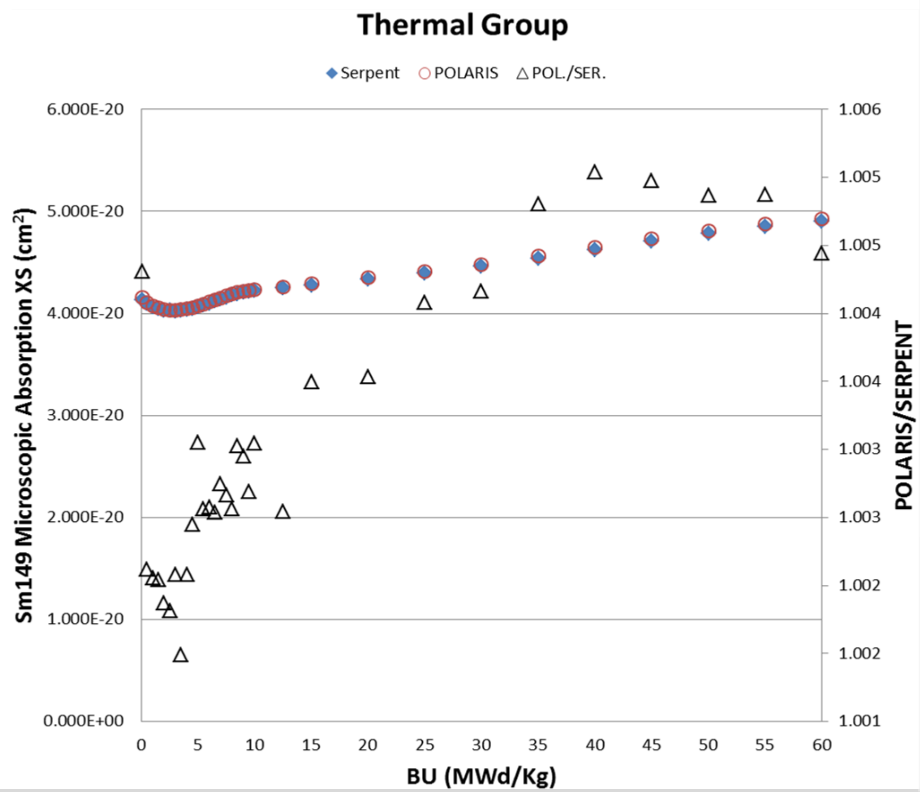


Samarium Microscopic Absorption XS Verification: SCALE/POLARIS vs. Serpent

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

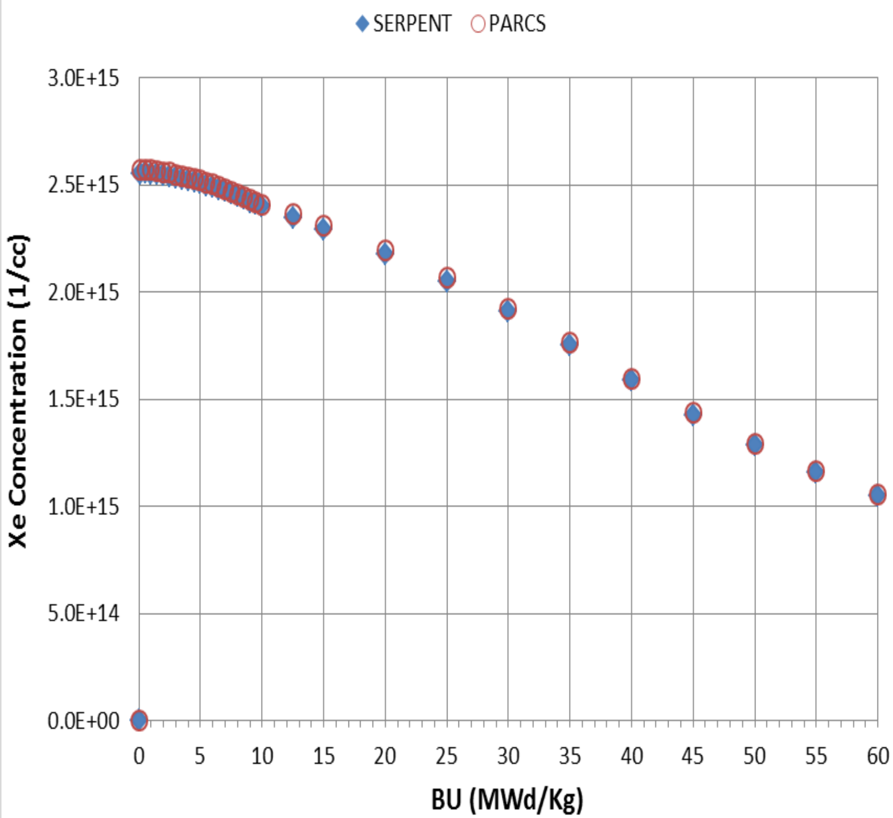
$$\sigma^{abs}_{Sm,g} = \frac{\Sigma^{abs}_{Sm,g}}{N_i * volume\ ratio}$$

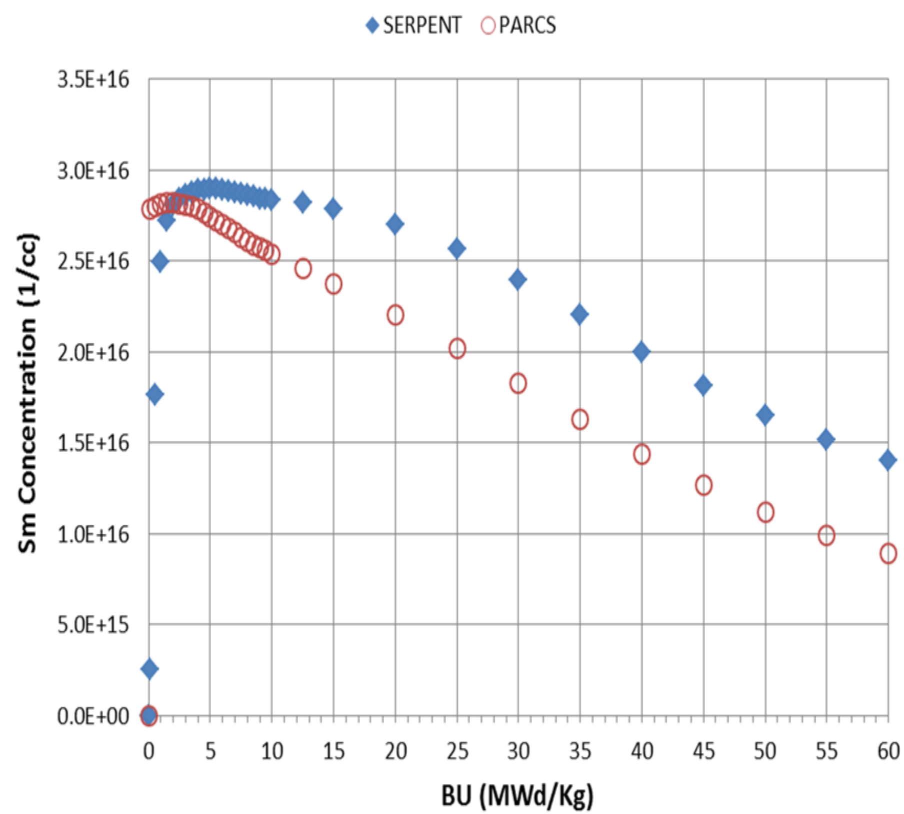




Xe/Sm Concentration Comparison between Serpent and PARCS

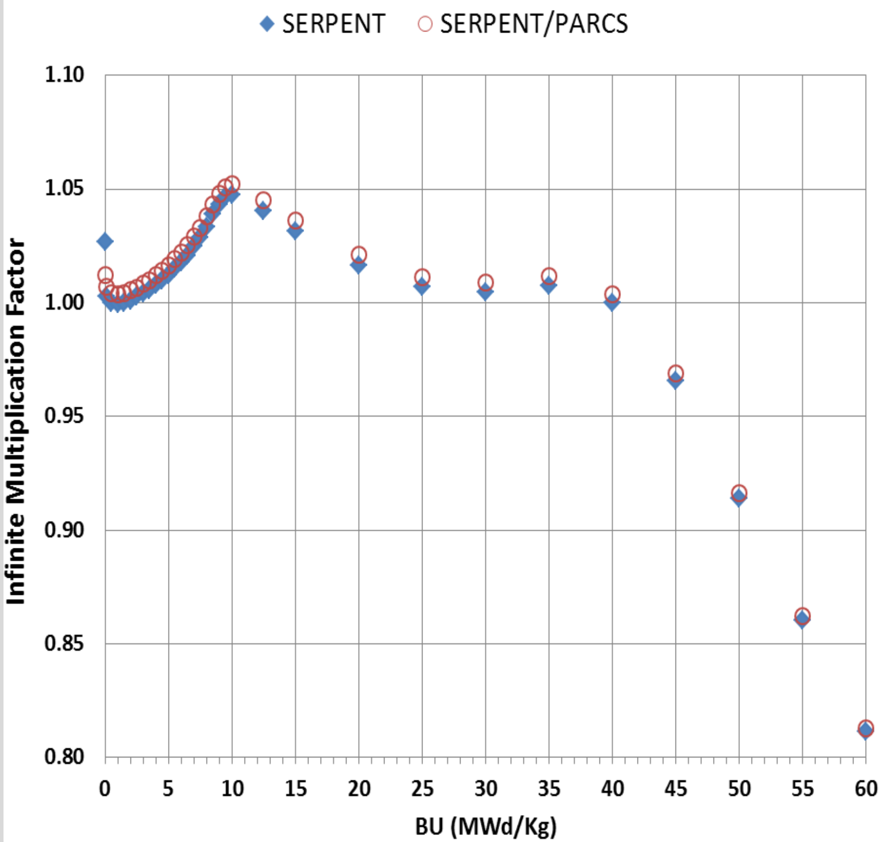
- The following results was produced after modifying Xe/Sm microscopic absorption XS and the definition of macroscopic absorption cross section in GenPMAXS, and Xe, I, Pm fission yield.



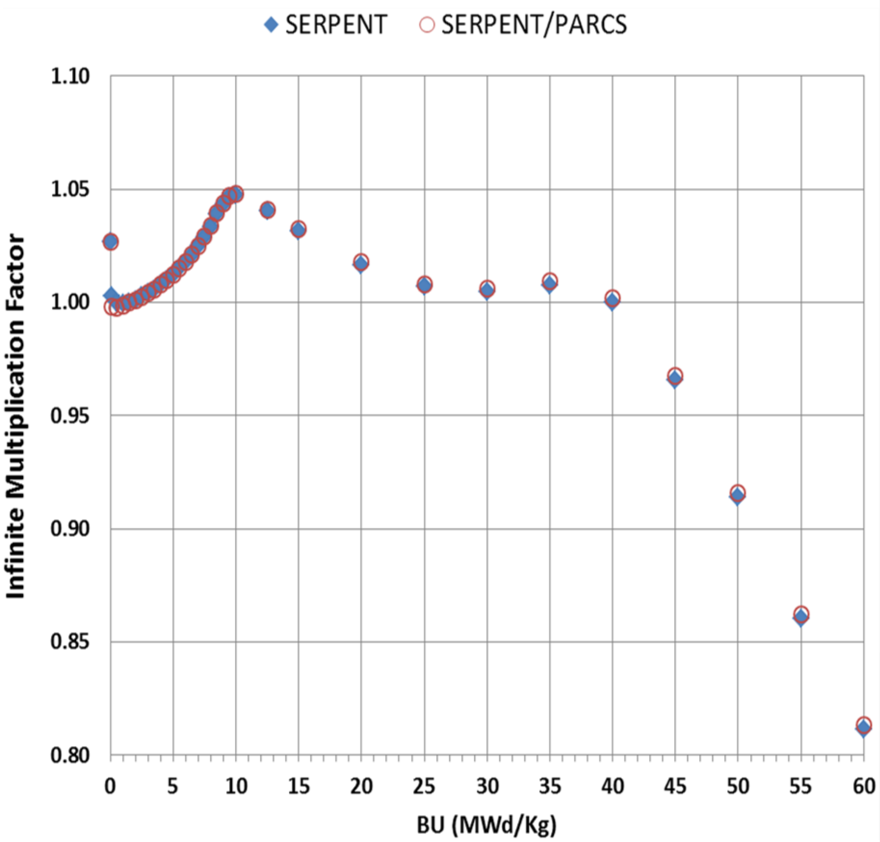


K_{inf} Comparison Between Serpent and PARCS After Solving Xe/Sm Problem

Before any modification

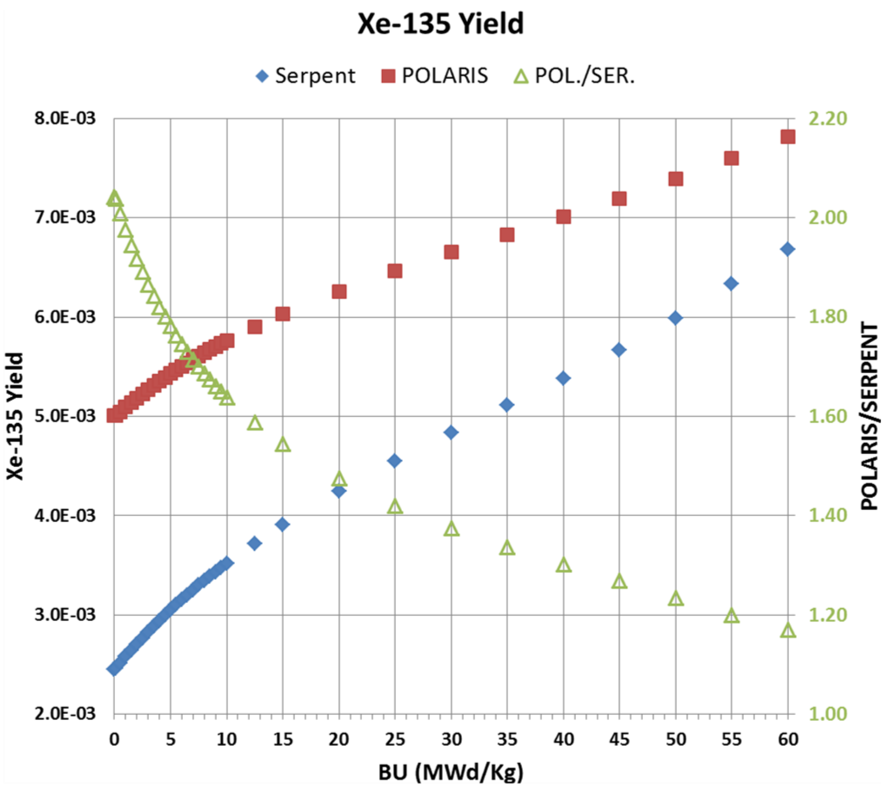


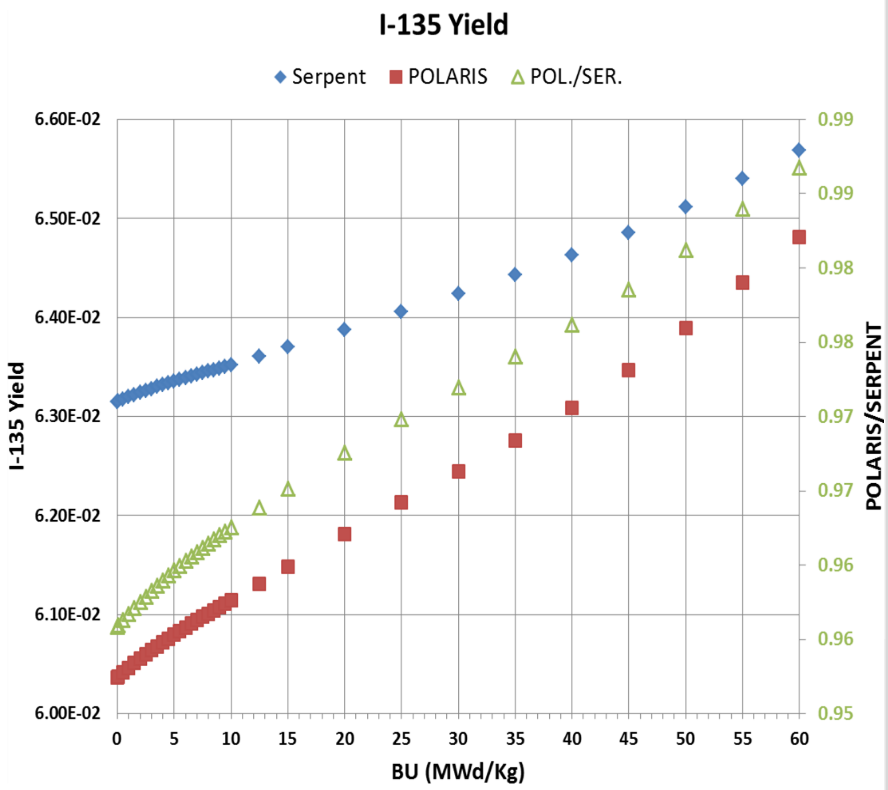
After the modifications



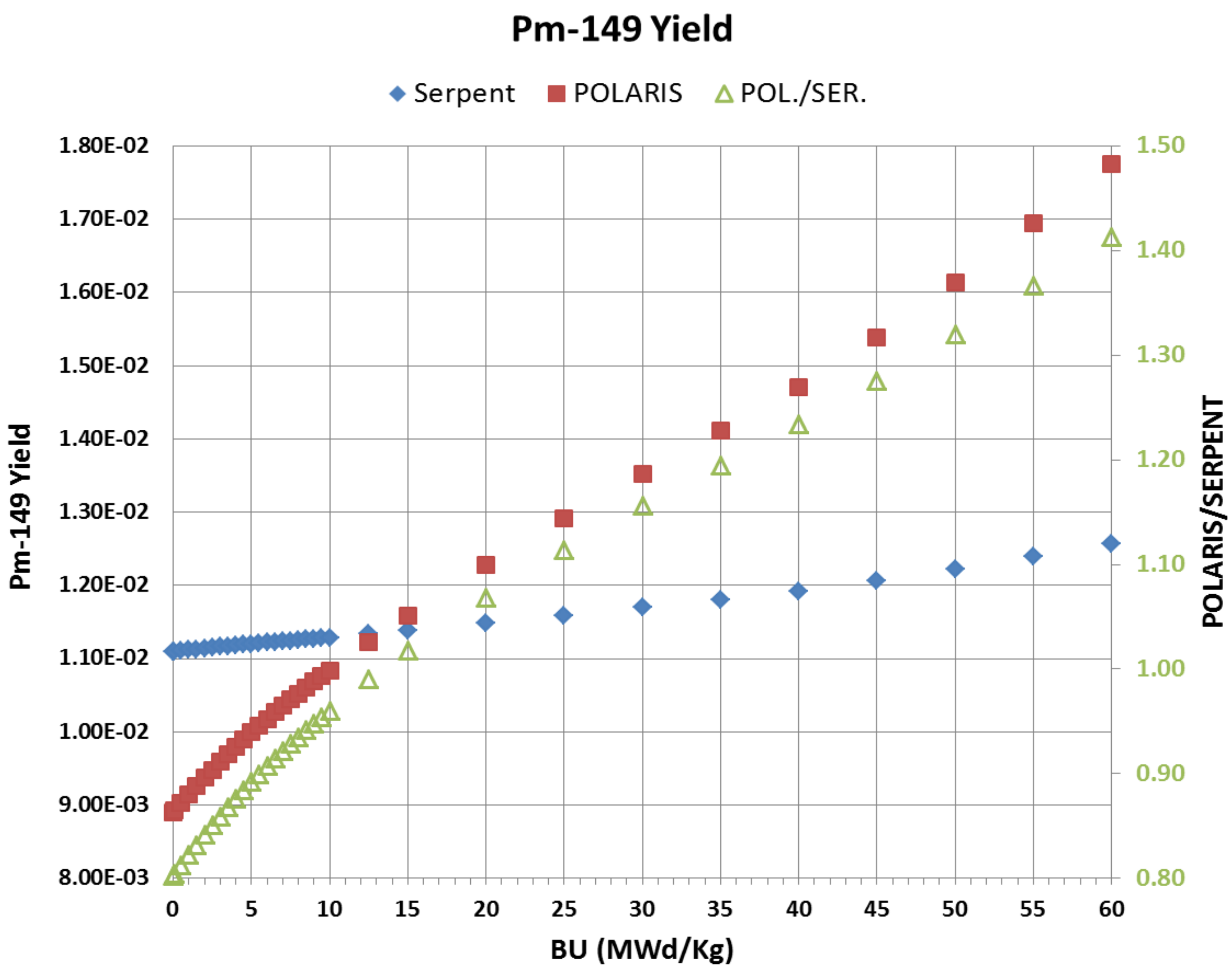
Xe, I, and Pm Fission Yield Verification: SCALE/POLARIS vs. Serpent

- Serpent fission yield was collapsed to a single energy group.



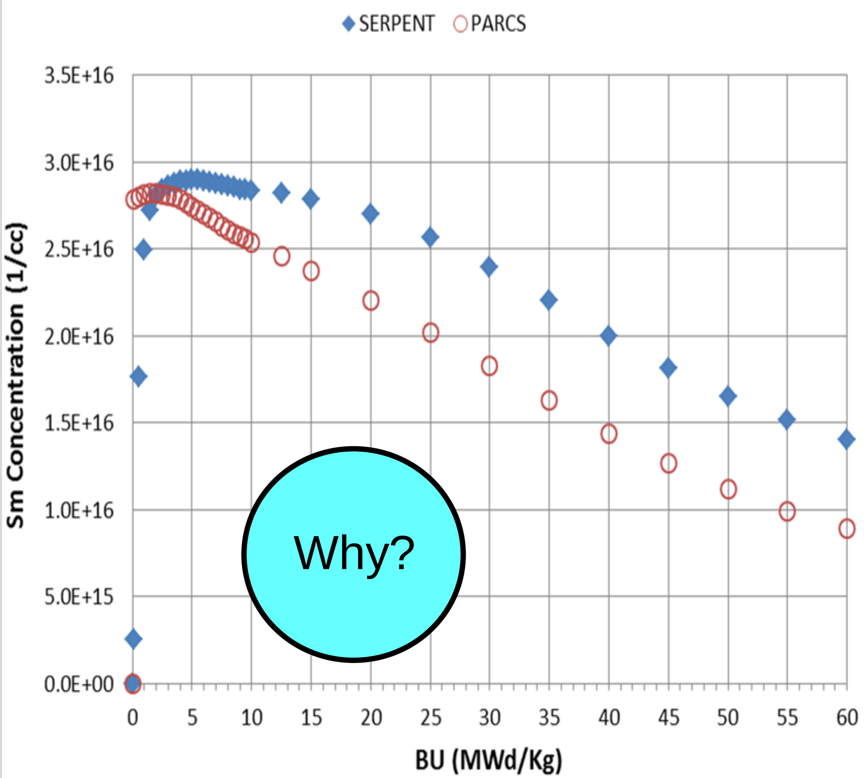


Xe, I, and Pm Fission Yield Verification: SCALE/POLARIS vs. Serpent

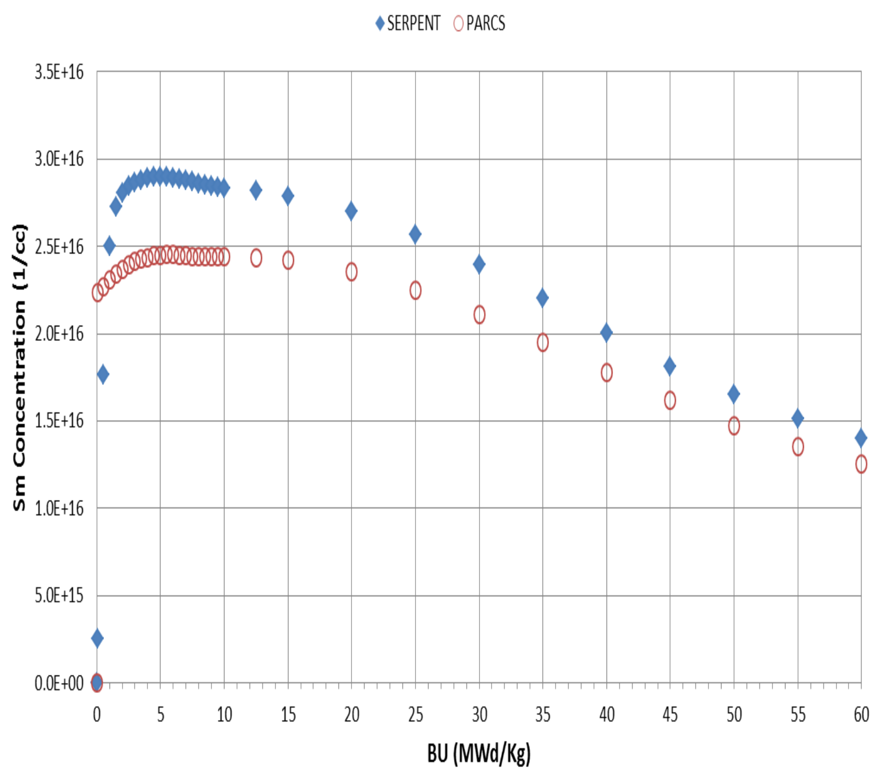


Sm149 Concentration Comparison Between Serpent and PARCS with POLARIS Fission Yields

With Serpent calculated fission yield



With POLARIS fission yield



Summary and Conclusion

- XS generation with the full core approach showed a better agreement with Serpent power distribution and K_{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?