N.IN.E. Nuclear and INdustrial Engineering

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Group constant generation for PARCS using Helios and Serpent and comparison to Serpent 3D model

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- Homogenized cross section generation
  - Fuel assemblies
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- Results comparison
  - k_{eff}
  - Radial power
  - Axial power
  - Reaction rates (fission and capture)
- Conclusions

Introduction

- The methodology of homogenized constants generation was applied to small PWR core, using:
  - Helios (deterministic lattice physics code)
  - Serpent 2
- PARCS nodal diffusion code is used with both sets for a 3D analysis of the reactor core
- Serpent 3D model is developed to stand as a reference solution
- Helios and Serpent cross section libraries were compared
- PARCS and Serpent 3D results were compared:
  - k_{eff}
  - Radial power
  - Axial power
  - Reaction rates (fission and capture)

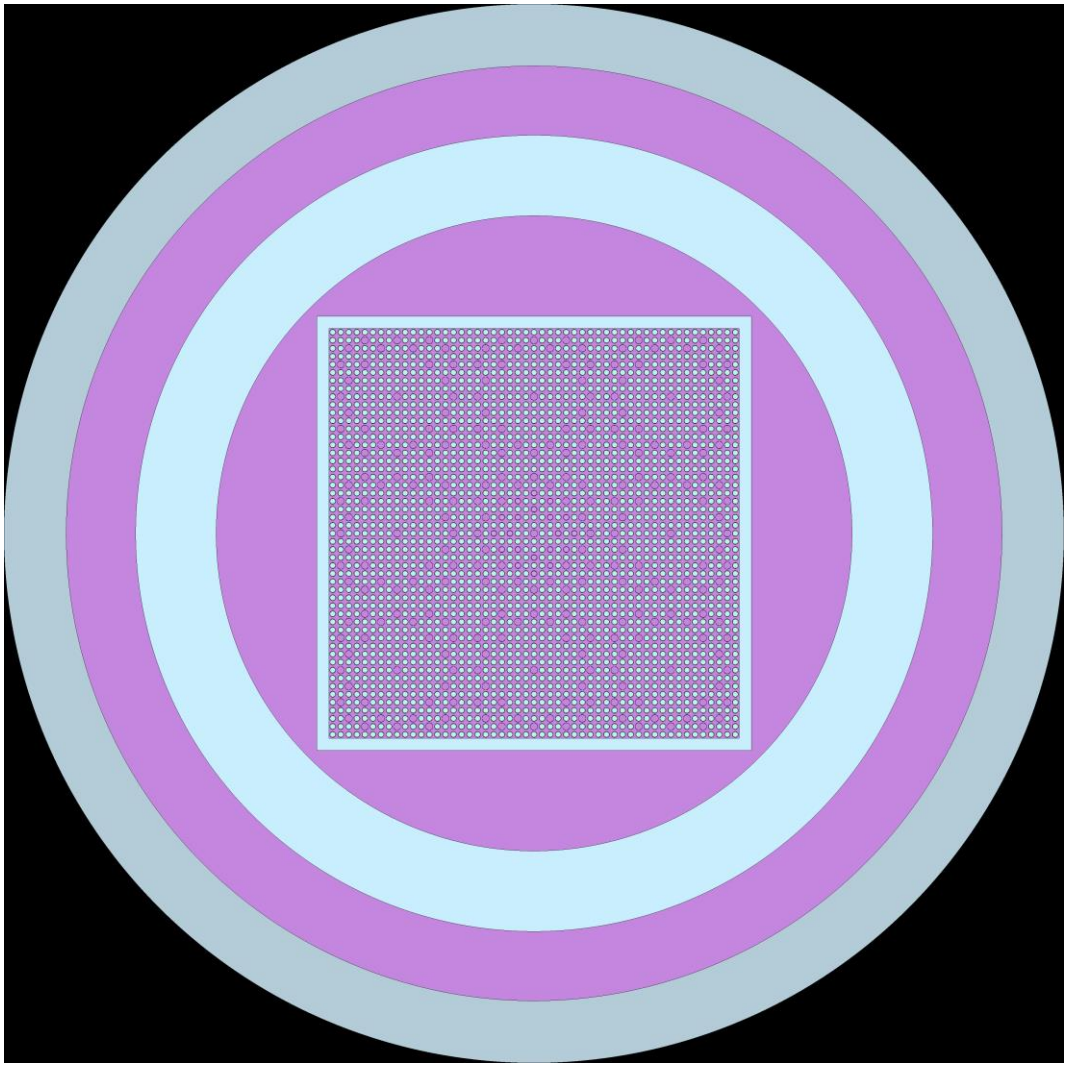
Description of the test case

- The chosen reactor core design is a small PWR made of 9 fuel assemblies (3x3)
- Each assembly is a 17x17 array loaded with UO_2, enriched to 4% ^{235}U
- Spacer grids, made by Inconel-718, are located at 5 different heights, 3 of them in the active core region
- Reactor power is 21 MWt

Materials in the core	
Part	*Material*
Fuel	UO_2 4% enrichment
Gap	Helium
Clad and Guide Tube	Zircaloy-4
Coolant	H_2O
Burnable absorber	Borosilicate glass
Insulating pellet	Al_2O_3
Baffle and Barrel	AISI 347
Pressure vessel	AISI 508
Spacer grid	Inconel-718

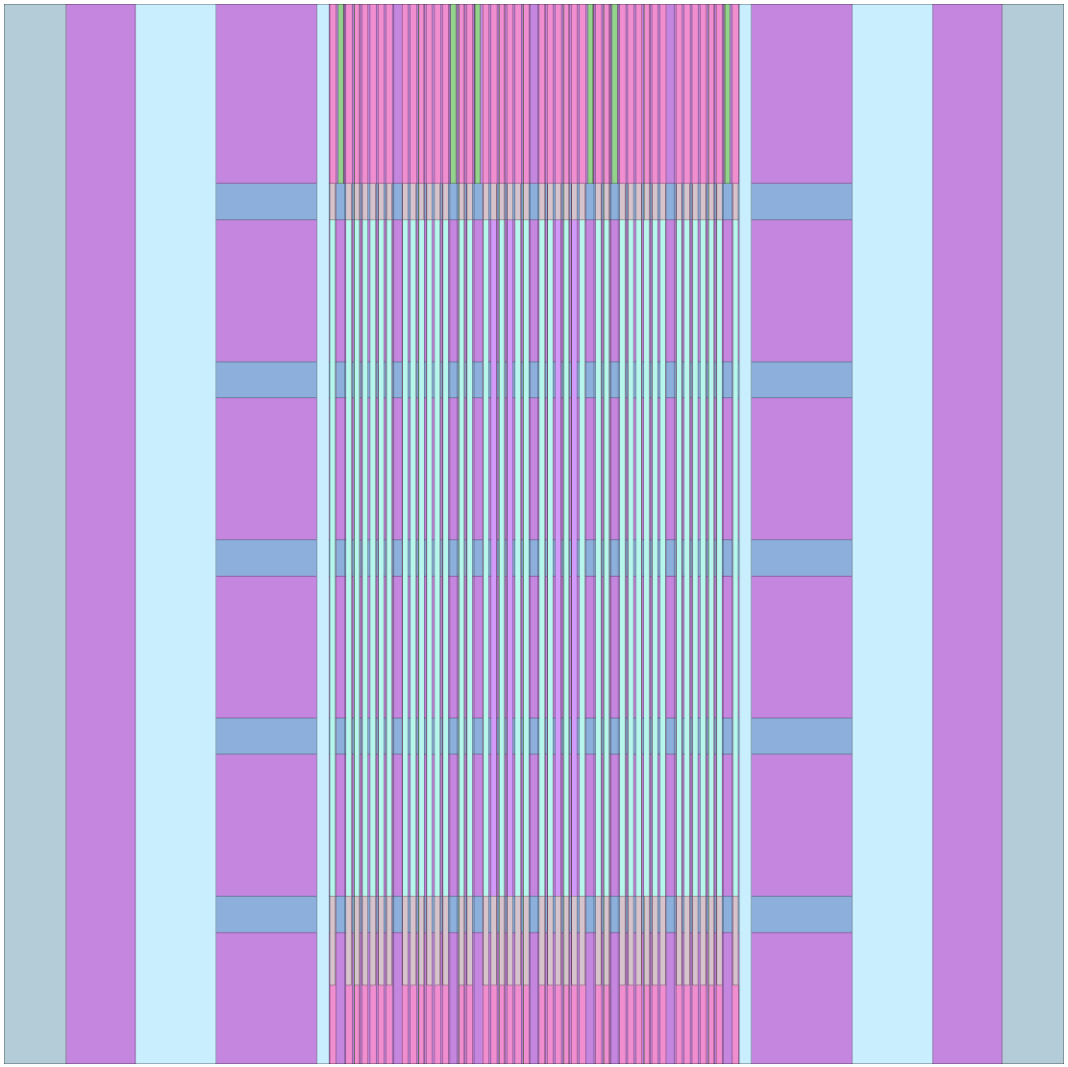
Geometrical characteristics of the reactor	
Parameter	*Value*
Pellet diameter, mm	8.50
Insulating pellet diameter, mm	8.47
Burnable absorber pellet diameter, mm	8.35
Clad inner diameter, mm	8.65
Clad outer diameter, mm	9.85
Guide tube inner diameter, mm	11.4
Guide tube outer diameter, mm	12.0
Fuel assembly pitch, mm	220.9
Baffle thickness, mm	19.5
Barrel inner diameter, mm	1026
Barrel outer diameter, mm	1286
Vessel inner diameter, mm	1510
Vessel outer diameter, mm	1710
Active fuel length, mm	781.2
Spacer grids height, mm	38

Description of the test case



Radial view of the PWR core, Serpent model

Description of the test case



Axial view of the PWR core, Serpent model

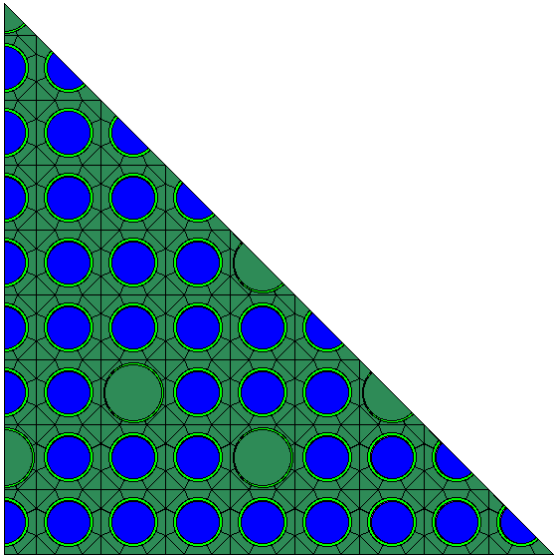
Codes and methods

- **Helios** is a commercial neutron and gamma transport and depletion code developed by Studsvik Scandpower
  - The transport method based on current coupling and collision probabilities
  - 2D unstructured mesh
  - Version 1.11 is used
- **Serpent** is a 3D continuous energy Monte Carlo reactor physics burnup calculation code, developed at VTT Technical Research Centre of Finland
  - Version 2.1.26 is used
- **PARCS** is a 3D reactor core simulator which solves the steady state and time dependent, multi group neutron diffusion equation. PARCS can be coupled to thermal-hydraulics system codes or used as stand alone code.
- Serpent and Helios outputs are converted in the PMAXS format used by PARCS using **GenPMAXS** code

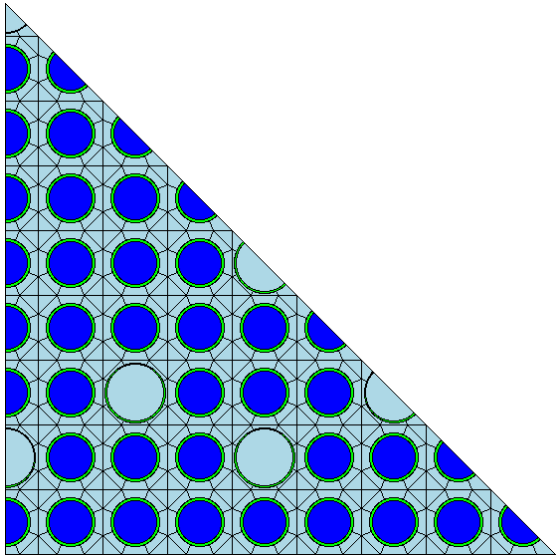
Homogenized cross section generation

- Cross section libraries
  - Helios: 190 energy groups based on ENDF/B-VI
  - Serpent: continuous energy ACE format based on ENDF/B-VI
- In Serpent 500 million neutron histories are simulated
- B1 methodology is used
- The chosen thermal cutoff energy is 0.625 eV
- 5 different cross section data sets are generated
  - Assembly 1a: fuel assembly w/o BA and w/o grids
  - Assembly 1b: fuel assembly w/o BA and with grids
  - Assembly 2a: fuel assembly with BA and w/o grids
  - Assembly 2b: fuel assembly with BA and with grids
  - Reflector

Homogenized cross section generation

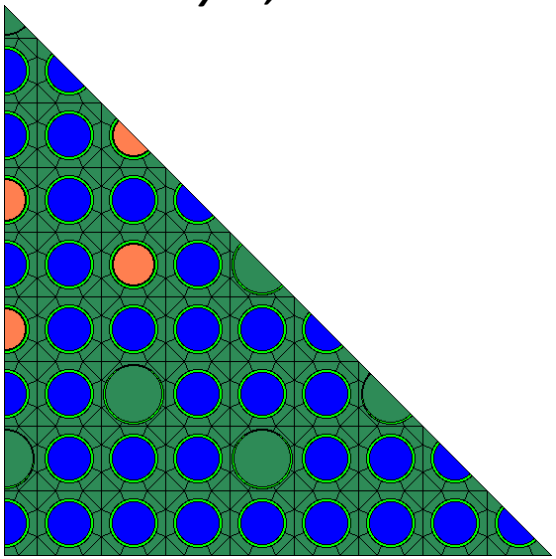


Assembly 1a, Helios model

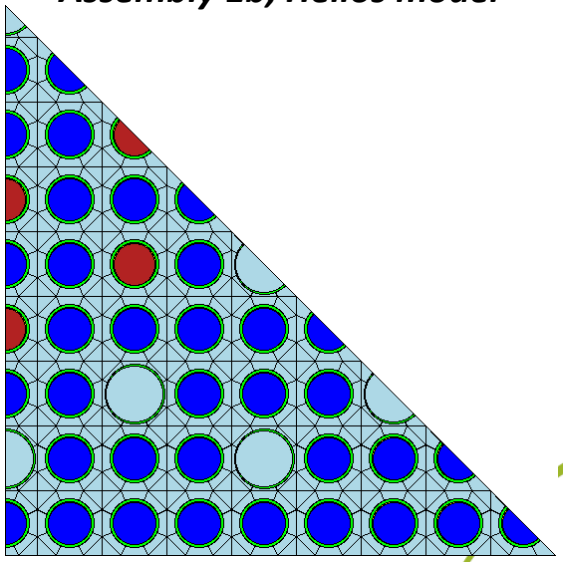


Assembly 1b, Helios model

In order to take into account the presence of the spacer grids, in assemblies 1b and 2b the moderator material is replaced with an **homogeneous mixture** of H2O and Inconel-718 preserving the mass of the components



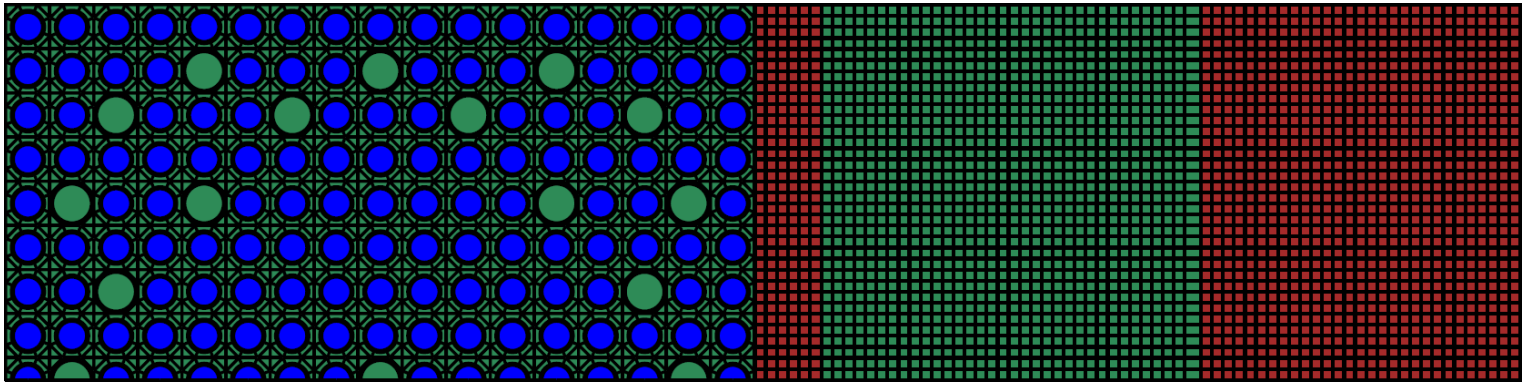
Assembly 2a, Helios model



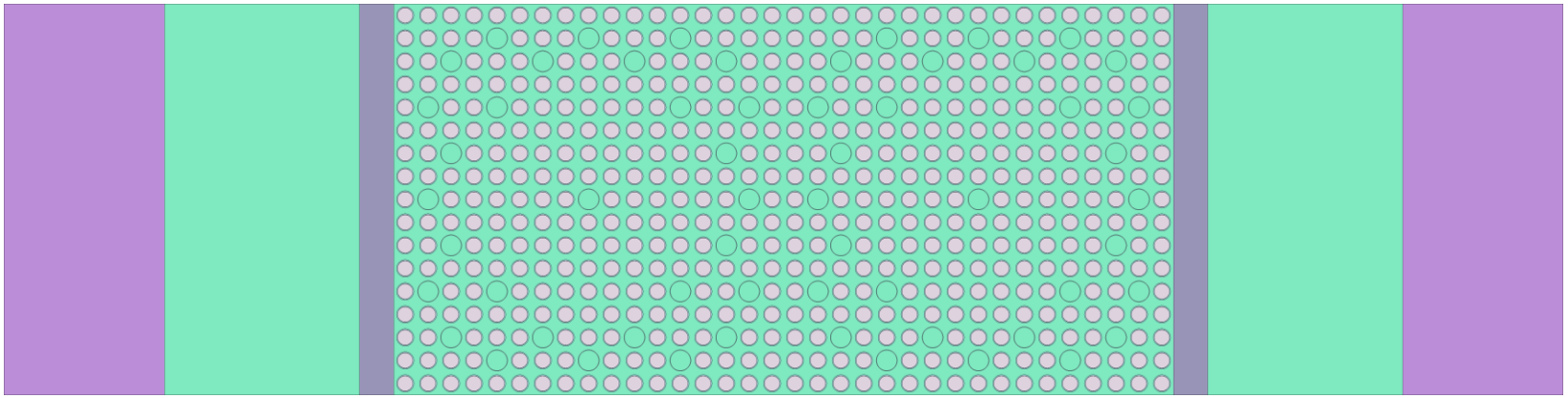
Assembly 2b, Helios model

Homogenized cross section generation

Reflector modeling



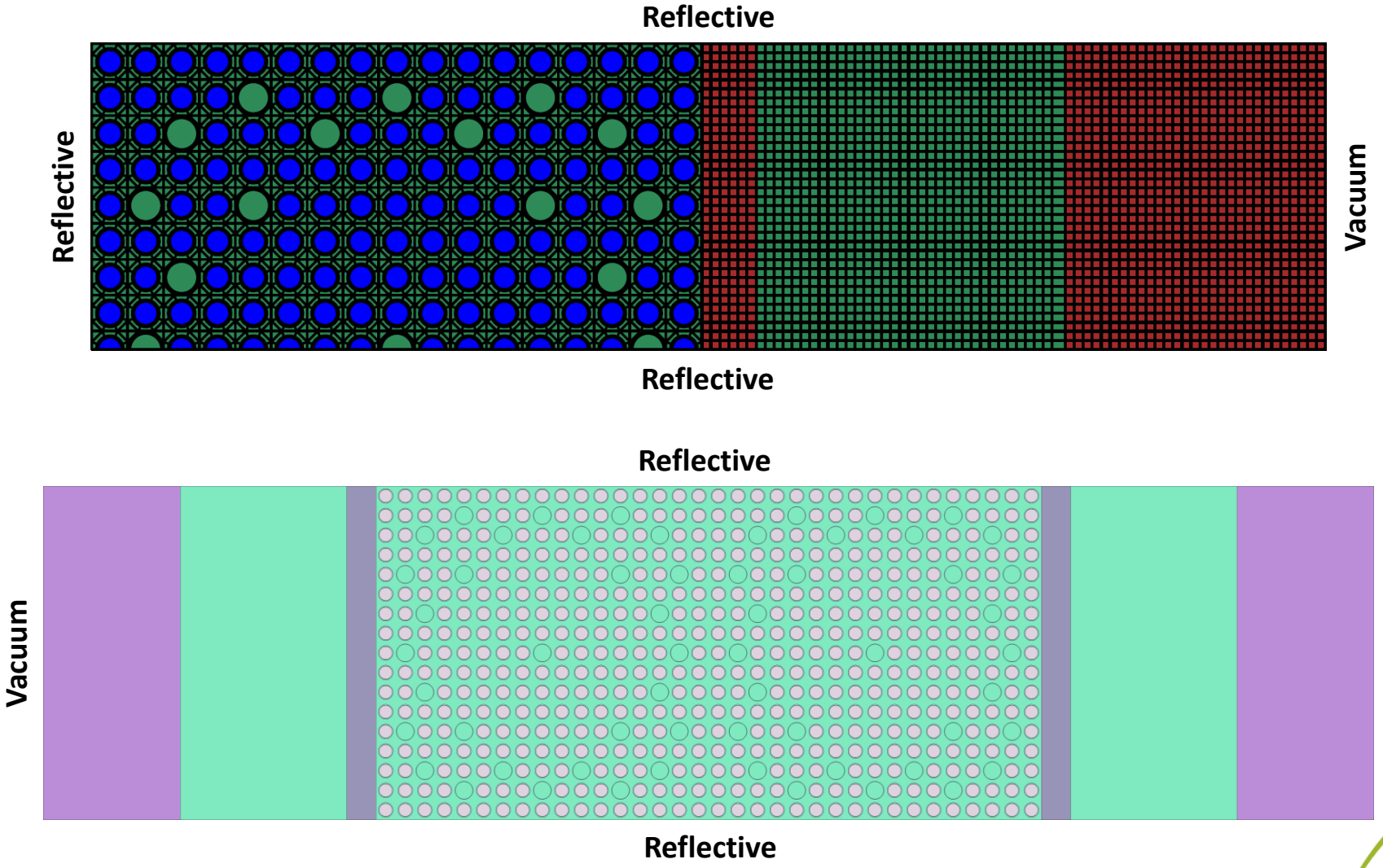
Reflector, Helios model



Reflector, Serpent model

Homogenized cross section generation

Reflector modeling – Boundary conditions



Homogenized cross section generation

Helios – Serpent comparison: Fuel assembly w/o grids

Assembly 1a – w/o burnable abs		
Parameter	*Helios results*	*Serpent – Helios Rel Diff %*
D_1	1.4034E+00	0.32%
D_2	3.8203E-01	2.24%
$\Sigma_{a,1}$	9.2493E-03	0.59%
$\Sigma_{a,2}$	9.4402E-02	-0.34%
$\nu\Sigma_{f,1}$	7.6081E-03	-0.76%
$\nu\Sigma_{f,2}$	1.6599E-01	-0.63%
$\Sigma_{s,1\leftarrow 1}$	5.0385E-01	1.02%
$\Sigma_{s,2\leftarrow 1}$	1.6508E-02	0.93%
$\Sigma_{s,1\leftarrow 2}$	1.5243E-03	-0.60%
$\Sigma_{s,2\leftarrow 2}$	1.3520E+00	-2.50%
ADF_1	1.0002E+00	-0.15%
ADF_2	9.9934E-01	2.25%

Assembly 2a – with burnable abs		
Parameter	*Helios results*	*Serpent – Helios Rel Diff %*
D_1	1.4388E+00	0.29%
D_2	3.8176E-01	2.20%
$\Sigma_{a,1}$	9.6419E-03	0.55%
$\Sigma_{a,2}$	1.0405E-01	-0.14%
$\nu\Sigma_{f,1}$	7.1538E-03	-0.74%
$\nu\Sigma_{f,2}$	1.5546E-01	-0.65%
$\Sigma_{s,1\leftarrow 1}$	5.0383E-01	1.08%
$\Sigma_{s,2\leftarrow 1}$	1.6862E-02	1.00%
$\Sigma_{s,1\leftarrow 2}$	1.6142E-03	-0.25%
$\Sigma_{s,2\leftarrow 2}$	1.3551E+00	-2.51%
ADF_1	1.0377E+00	0.49%
ADF_2	1.1140E+00	2.23%

Helios – Serpent comparison: Fuel assembly with grids

Assembly 1b – w/o burnable abs		
Parameter	*Helios results*	*Serpent – Helios Rel Diff %*
D_1	1.3431E+00	0.49%
D_2	3.8865E-01	1.76%
$\Sigma_{a,1}$	9.8417E-03	0.61%
$\Sigma_{a,2}$	1.0250E-01	-0.38%
$\nu\Sigma_{f,1}$	7.5225E-03	-0.76%
$\nu\Sigma_{f,2}$	1.6160E-01	-0.65%
$\Sigma_{s,1\leftarrow1}$	5.1209E-01	0.96%
$\Sigma_{s,2\leftarrow1}$	1.5041E-02	0.78%
$\Sigma_{s,1\leftarrow2}$	1.8374E-03	0.62%
$\Sigma_{s,2\leftarrow2}$	1.2705E+00	-2.18%
ADF_1	9.9967E-01	0.13%
ADF_2	9.9996E-01	2.33%

Assembly 2b – with burnable abs		
Parameter	*Helios results*	*Serpent – Helios Rel Diff %*
D_1	1.3726E+00	0.47%
D_2	3.8791E-01	1.72%
$\Sigma_{a,1}$	1.0231E-02	0.53%
$\Sigma_{a,2}$	1.1228E-01	-0.20%
$\nu\Sigma_{f,1}$	7.0626E-03	-0.76%
$\nu\Sigma_{f,2}$	1.5121E-01	-0.67%
$\Sigma_{s,1\leftarrow1}$	5.1194E-01	1.00%
$\Sigma_{s,2\leftarrow1}$	1.5279E-02	0.84%
$\Sigma_{s,1\leftarrow2}$	1.9372E-03	1.04%
$\Sigma_{s,2\leftarrow2}$	1.2730E+00	-2.18%
ADF_1	1.0355E+00	0.40%
ADF_2	1.1110E+00	2.20%

Helios – Serpent comparison: Reflector

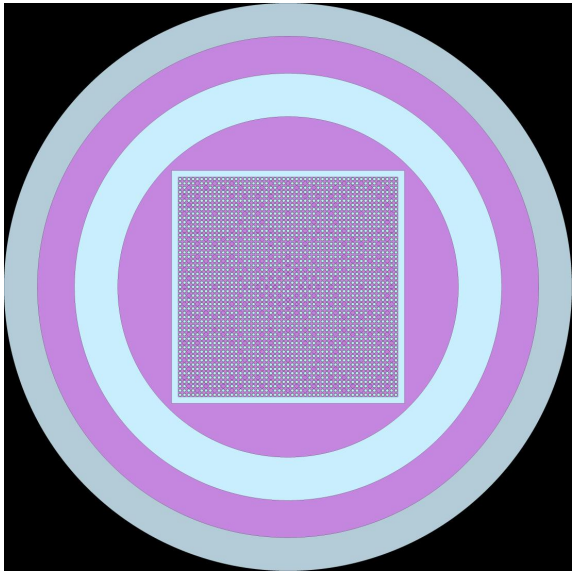
Reflector		
Parameter	*Helios results*	*Serpent – Helios Rel Diff %*
D_1	1.2632E+00	-0.23%
D_2	2.4485E-01	4.21%
$\Sigma_{a,1}$	2.1612E-03	-1.53%
$\Sigma_{a,2}$	2.3888E-02	-0.94%
$\Sigma_{s,1\leftarrow 1}$	6.2863E-01	0.71%
$\Sigma_{s,2\leftarrow 1}$	2.5053E-02	8.15%
$\Sigma_{s,1\leftarrow 2}$	4.6094E-04	-4.28%
$\Sigma_{s,2\leftarrow 2}$	2.0334E+00	-3.31%
ADF_1	1.0839E+00	3.32%
ADF_2	2.5255E-01	0.50%

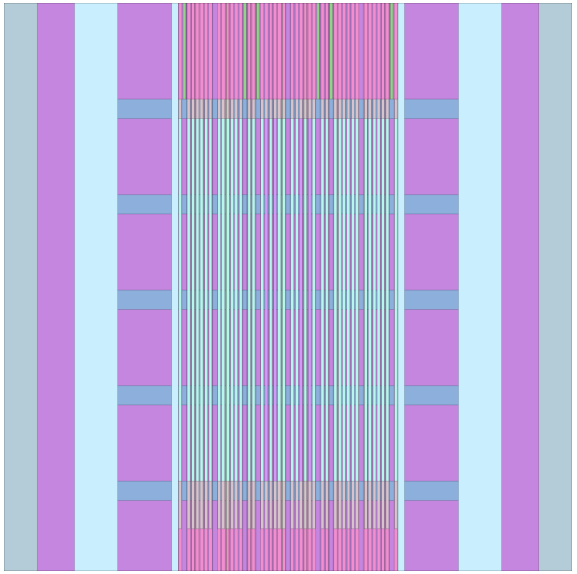
Codes and methods

- Additional information
  - Control rods are considered withdrawn in this calculation
  - Neutronic stand-alone calculation (no TH feedback)
  - Initial isotopic composition (burnup = 0)
- Serpent 3D calculation is run with 5 billions neutron histories

Results comparison - k_{eff}

Calculational sequence	k_{eff}	Deviation from reference (pcm)
Reference Serpent full core	1.08703 ± 0.000022	-
PARCS/Helios	1.088556	140.4
PARCS/Serpent	1.085013	-185.6





Results comparison – Radial power distribution

0.7854	1.138	0.7854
1.138	1.3067	1.138
0.7854	1.138	0.7854

PARCS/Helios

0.7888	1.138	0.7888
1.138	1.2927	1.138
0.7888	1.138	0.7888

PARCS/Serpent

0.7911	1.1306	0.7908
1.1308	1.3133	1.1308
0.7909	1.1306	0.7911

Reference Serpent full core

Results comparison – Radial power distribution

-0.72%	0.65%	-0.68%
0.64%	-0.50%	0.64%
-0.70%	0.65%	-0.72%

PARCS/Helios vs. Reference

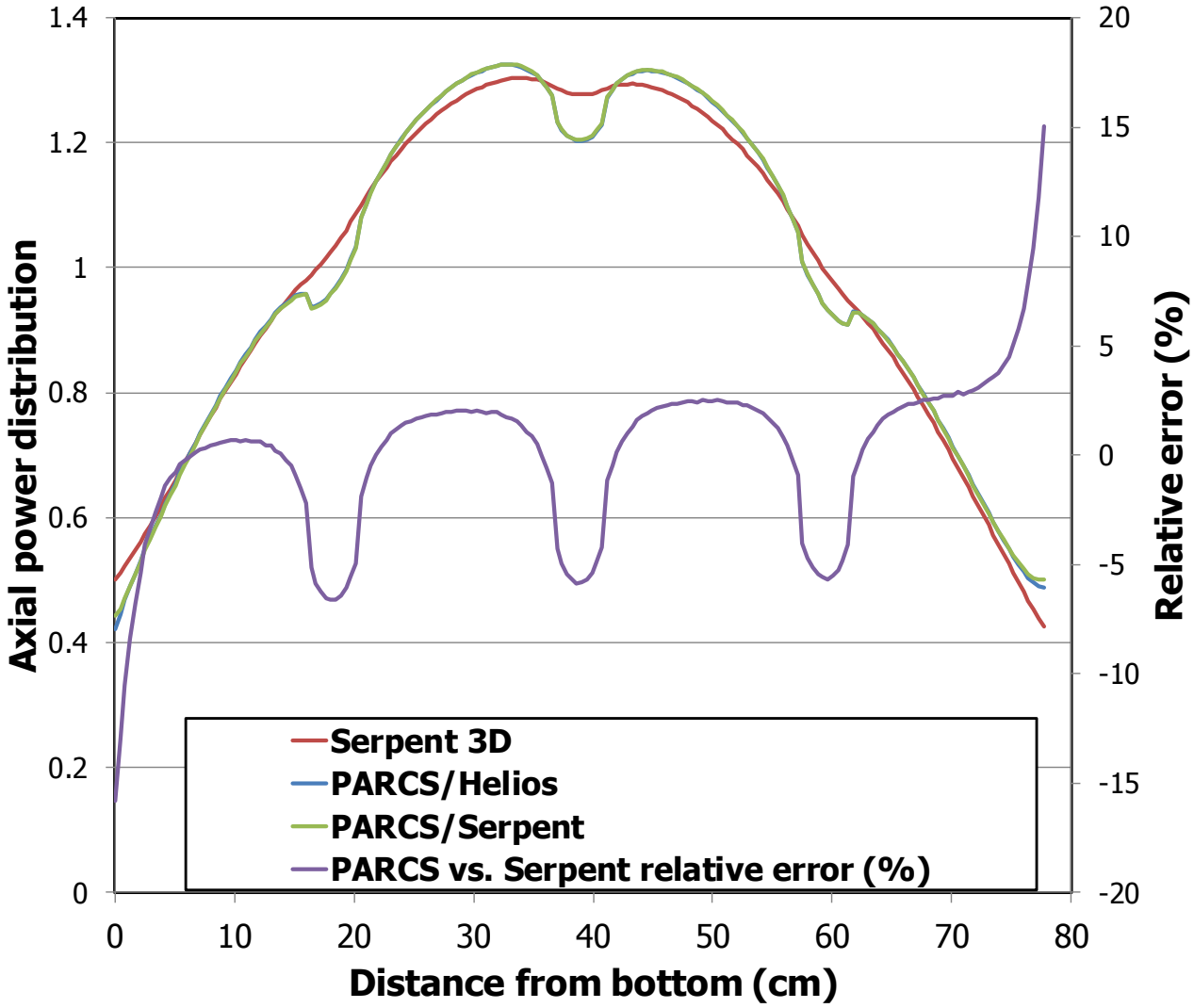
-0.29%	0.65%	-0.25%
0.64%	-1.57%	0.64%
-0.27%	0.65%	-0.29%

PARCS/Serpent vs. Reference

0.43%	0.00%	0.43%
0.00%	-1.07%	0.00%
0.43%	0.00%	0.43%

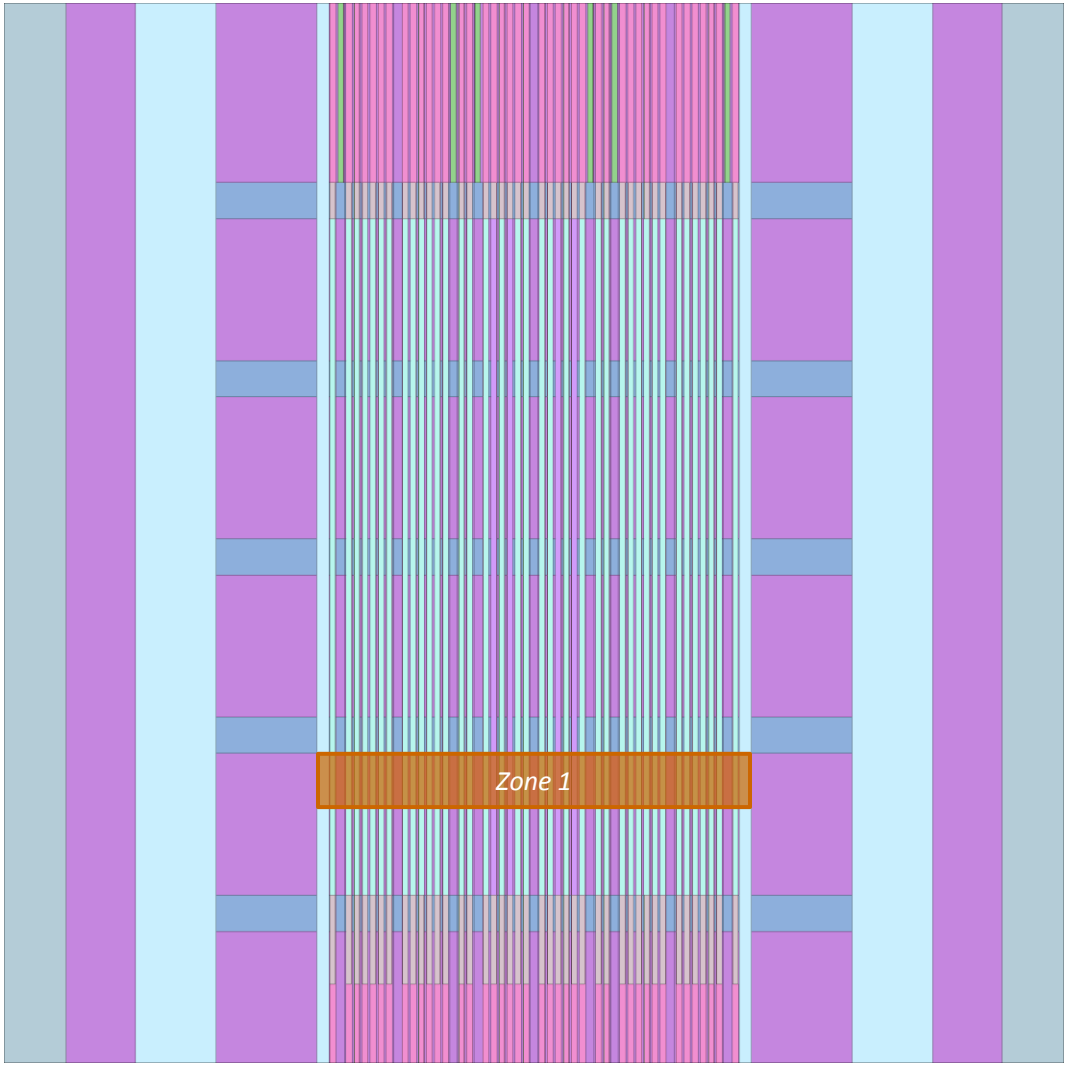
PARCS/Helios vs. PARCS/Serpent

Results comparison – Axial power distribution



Description of the test case

Results comparison – Reaction rates



Results comparison – Fission rate

2.872E+11	4.146E+11	2.872E+11
1.094E+12	1.575E+12	1.094E+12
4.146E+11	4.995E+11	4.146E+11
1.575E+12	1.769E+12	1.575E+12
2.872E+11	4.146E+11	2.872E+11
1.094E+12	1.575E+12	1.094E+12

PARCS/Serpent

2.826E+11	4.033E+11	2.821E+11
1.094E+12	1.554E+12	1.096E+12
4.047E+11	4.770E+11	4.024E+11
1.564E+12	1.715E+12	1.556E+12
2.830E+11	4.026E+11	2.826E+11
1.097E+12	1.554E+12	1.100E+12

Reference Serpent 3D

Group 1 results
Group 2 results

1.64	2.81	1.80
-0.04	1.38	-0.15
2.44	4.73	3.03
0.77	3.10	1.27
1.49	2.98	1.61
-0.25	1.39	-0.54

Relative differences %

Results comparison – Capture rate

6.008E+11	8.674E+11	6.008E+11
4.202E+11	6.052E+11	4.202E+11
8.674E+11	1.212E+12	8.674E+11
6.052E+11	1.112E+12	6.052E+11
6.008E+11	8.674E+11	6.008E+11
4.202E+11	6.052E+11	4.202E+11

PARCS/Serpent

6.044E+11	8.577E+11	6.003E+11
4.269E+11	6.063E+11	4.270E+11
8.573E+11	1.179E+12	8.552E+11
6.094E+11	1.104E+12	6.064E+11
6.017E+11	8.552E+11	6.029E+11
4.277E+11	6.059E+11	4.287E+11

Reference Serpent 3D

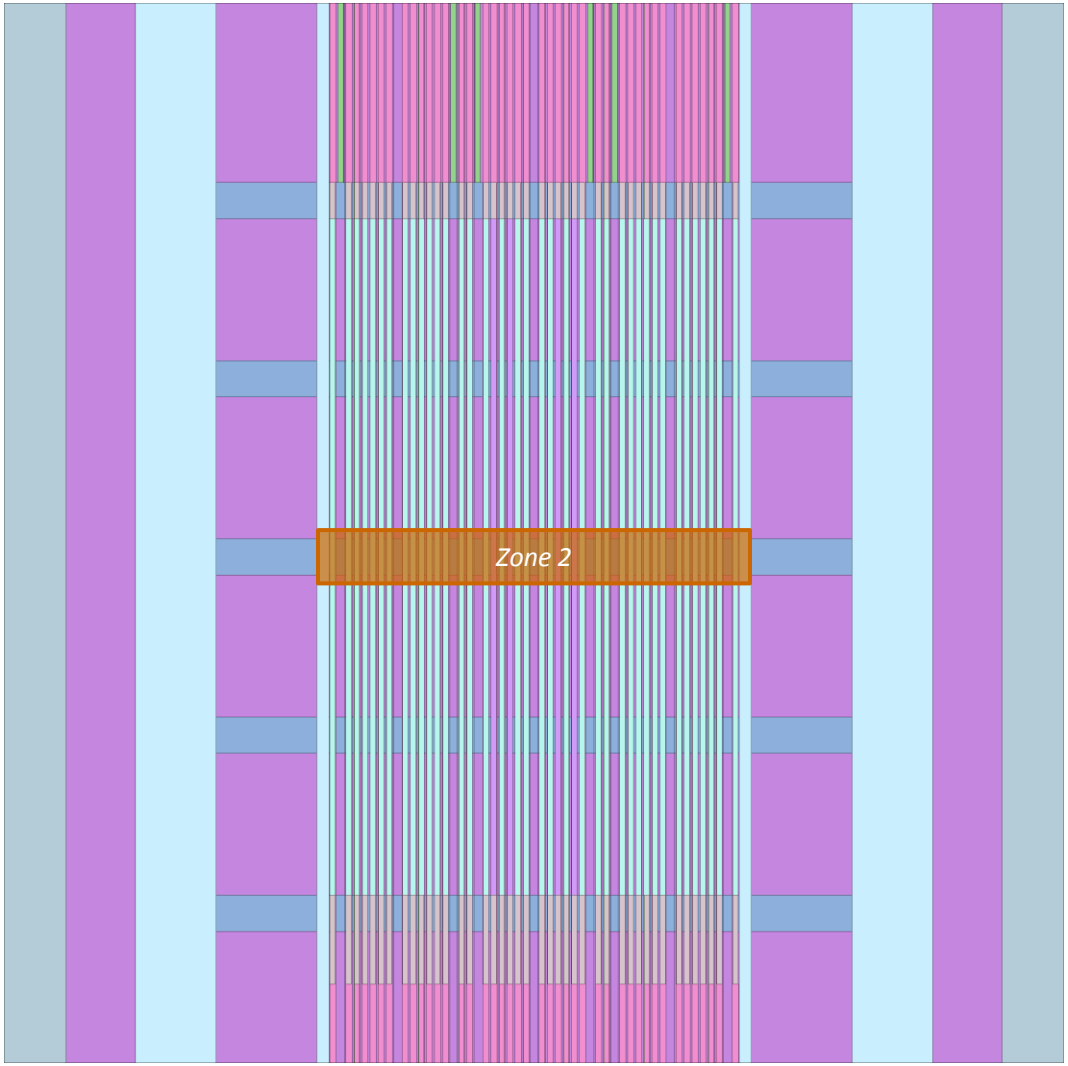
Group 1 results
Group 2 results

-0.59	1.13	0.09
-1.55	-0.19	-1.59
1.18	2.81	1.43
-0.68	0.73	-0.20
-0.14	1.42	-0.34
-1.75	-0.12	-1.97

Relative differences %

Description of the test case

Results comparison – Reaction rates



Results comparison – Fission rate

4.054E+11	5.851E+11	4.054E+11
1.416E+12	2.035E+12	1.416E+12
5.851E+11	7.034E+11	5.851E+11
2.035E+12	2.270E+12	2.035E+12
4.054E+11	5.851E+11	4.054E+11
1.416E+12	2.035E+12	1.416E+12

PARCS/Serpent

3.926E+11	5.617E+11	3.971E+11
1.389E+12	1.969E+12	1.402E+12
5.608E+11	6.647E+11	5.630E+11
1.971E+12	2.167E+12	1.983E+12
3.925E+11	5.604E+11	3.936E+11
1.387E+12	1.970E+12	1.389E+12

Reference Serpent 3D

Group 1 results
Group 2 results

3.27	4.16	2.10
1.94	3.35	1.00
4.33	5.82	3.93
3.24	4.78	2.61
3.29	4.42	2.99
2.03	3.30	1.93

Relative differences %

Results comparison – Capture rate

9.400E+11	1.357E+12	9.400E+11
7.697E+11	1.107E+12	7.697E+11
1.357E+12	1.880E+12	1.357E+12
1.107E+12	1.833E+12	1.107E+12
9.400E+11	1.357E+12	9.400E+11
7.697E+11	1.107E+12	7.697E+11

PARCS/Serpent

9.132E+11	1.301E+12	9.194E+11
7.603E+11	1.079E+12	7.666E+11
1.293E+12	1.778E+12	1.301E+12
1.080E+12	1.765E+12	1.086E+12
9.125E+11	1.296E+12	9.109E+11
7.604E+11	1.079E+12	7.610E+11

Reference Serpent 3D

Group 1 results
Group 2 results

2.93	4.27	2.24
1.24	2.57	0.41
4.94	5.72	4.27
2.47	3.80	1.92
3.01	4.66	3.19
1.23	2.52	1.14

Relative differences %

Conclusions

- The objective of this study was to show the methodology of homogenized constants generation, to compare the results of deterministic and Monte Carlo lattice physics code and to validate the full core results obtained with a nodal code against a full core Monte Carlo model
- In general, the difference between Helios and Serpent fuel assembly homogenized cross section data was less than 1%. Differences in diffusion coefficients and ADFs were less than 2.5%. Regarding the reflector, differences in diffusion coefficient, ADF and $\Sigma_{s,\, g' \leftarrow g}$ were slightly higher
- Full core calculations shown good results regarding k_{eff} and radial power distribution
- Regarding the axial power distribution, quite big differences between PARCS calculations and Serpent reference were observed. PARCS seems to underestimate the axial power in correspondence of the spacer grid locations

Conclusions and future work

THANK YOU FOR YOUR ATTENTION!