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Implementation of support for Monte Carlo lattice code SERPENT 2 in GenPMAXS

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presented by V. Sanchez

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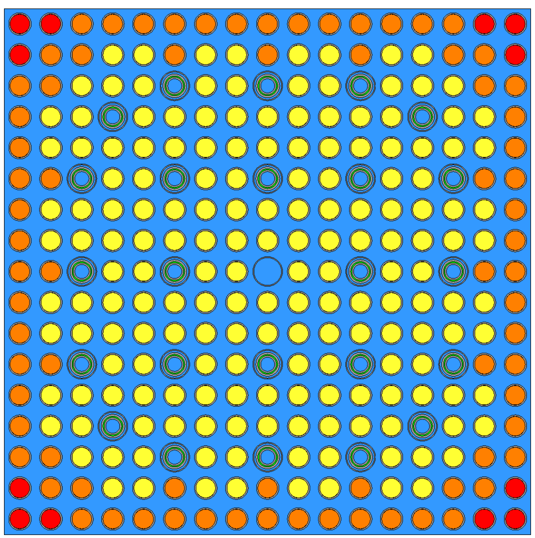
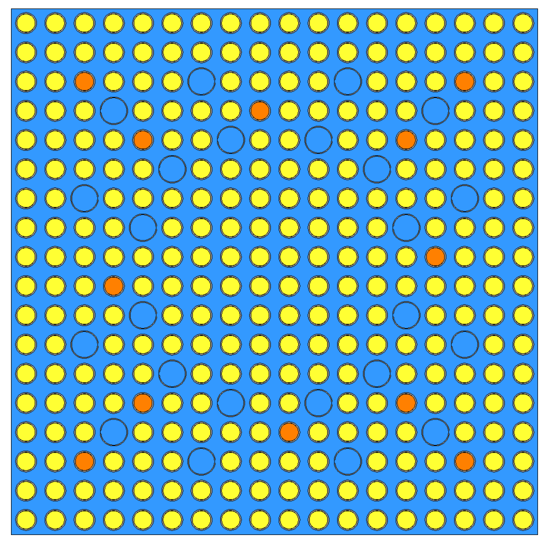
Reactor Physics and Dynamic Group (RPD)





Agenda

- Introduction
  - Few-group effective cross sections
  - GenPMAXS
  - Serpent 2

- GenPMAXS processing features for Serpent 2
  - Few-group cross sections
  - 1D (reflector) assembly discontinuity factors
  - Group-wise form functions

- Selected verification cases

- Availability

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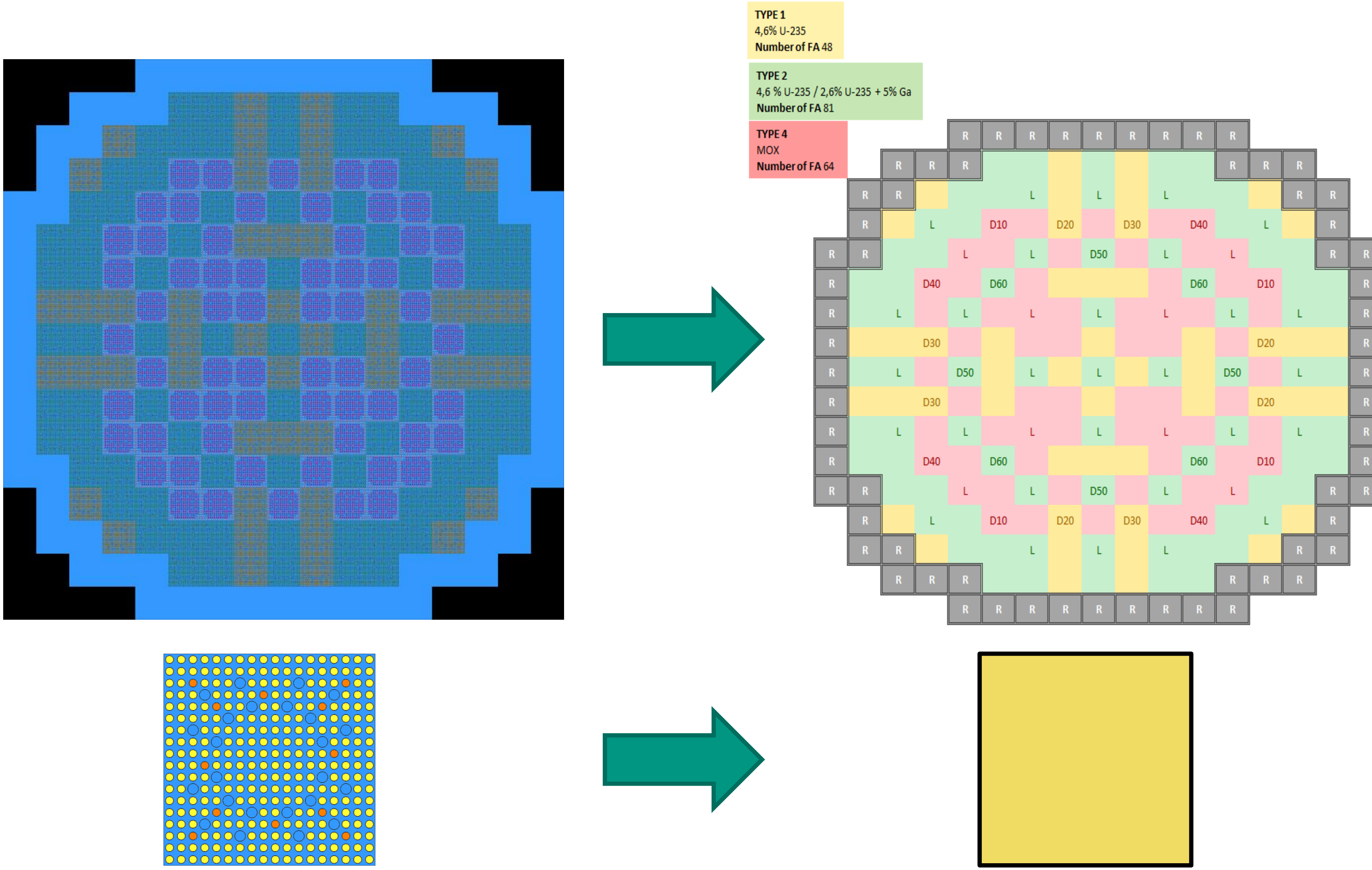
Few-group effective cross sections (1/2)



Few-group effective cross sections (2/2)

- Multi-group time-dependent diffusion equation

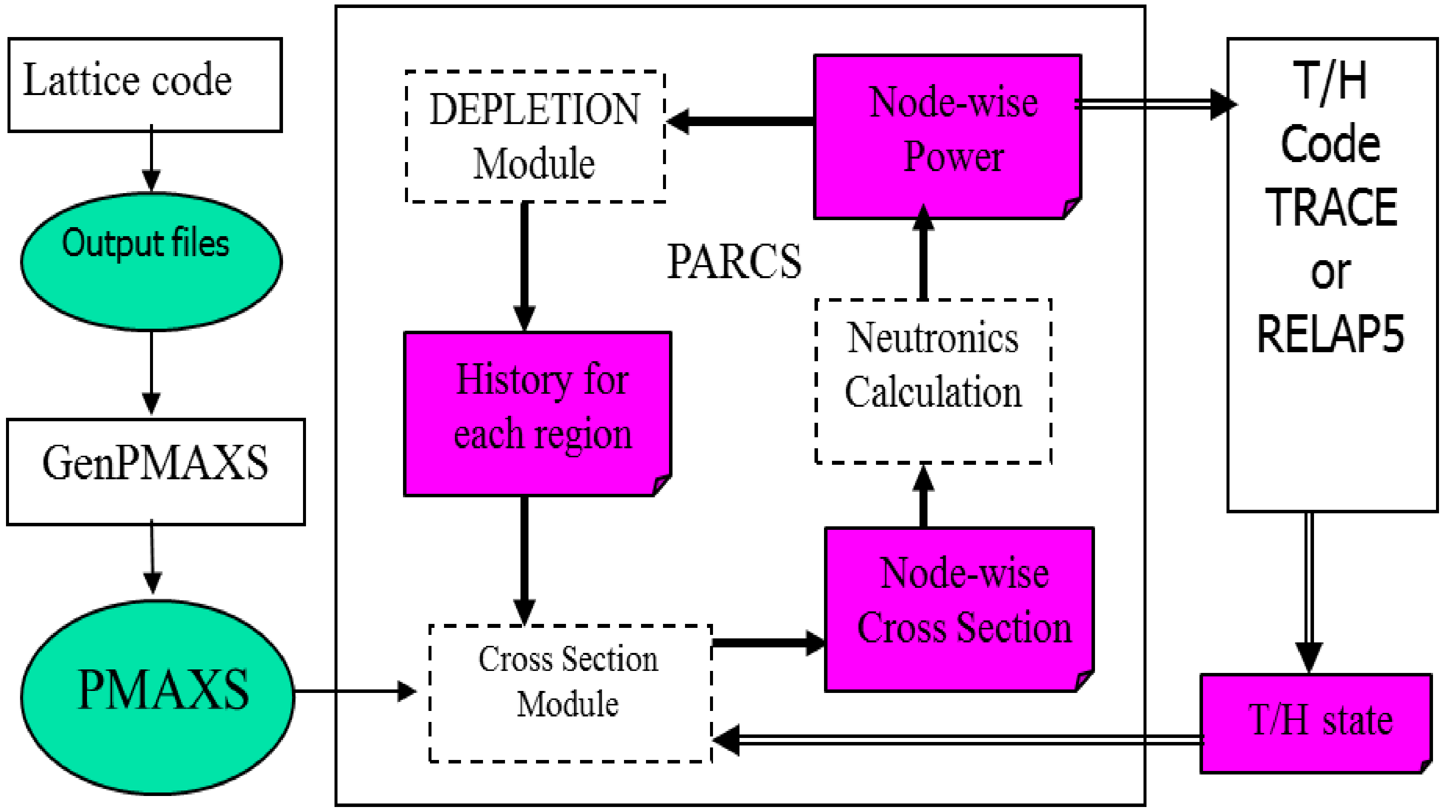
$$\frac{\partial}{v_g \partial t}\Phi_g - D_g \Delta\Phi_g + \Sigma_{rg}\Phi_g = \frac{1}{k_{eff}}\chi_{g,p}\sum_{g'}(1-\beta_{g'})\nu\Sigma_f\Phi_{g'}$$

$$+\sum_{\substack{g' \\ g\neq g'}}\Sigma_{s,gg'}\Phi_{g'} + \sum_m \chi_{g,d,m}\lambda_m C_m$$

$$\frac{\partial}{\partial t}C_m = \frac{1}{k_{eff}}\sum_{g'}\beta_{g',m}\nu\Sigma_f\Phi_{g'} - \lambda_m C_m$$

- Few-group cross sections parameterized by thermal-hydraulic states in multidimensionable tables
- Cross sections interpolated from multi-dimensional table
- Infinite lattice calculations for each fuel assembly type typically lead to sub- or over-critical system ⇒ B1 approximation, critical spectrum correction
- Local information may be restored from coarse mesh results using pin power reconstruction

GenPMAXS



Overview of GenPMAXS/PARCS/TRACE code system(1)

(1) Figure taken from: T. Downar et al., *GenPMAXS v 6.1.1 - Code for Generating the PARCS Cross Section Interface File PMAXS,* January 2013

Lattice code Serpent(2)

- Developed by VTT Technical Research Center of Finland
- Continuous energy (CE) Monte Carlo (MC) code with built-in burn-up calculation capability especially designed to generate few-group XS for deterministic reactor simulators (e.g. PARCS)
- Significantly faster than other MC codes (up 60 times faster than MCNP(3))
  - Combination of Woodcock delta-tracking and typical surface-to-surface ray tracing
  - Use of unionized energy grid for point-wise cross sections
- 2D fuel lattice, 3D fuel lattice and 3D full core calculations
- Complex fuel geometries may be handled without major geometric approximations

(2) J. Leppänen, *Serpent – a Continuous-energy Monte Carlo Reactor Physics Burnup Calculation Code*, VTT Technical Research Centre of Finland, March 6 (2013)
(3) http://virtual.vtt.fi/virtual/montecarlo/validation/lattice_calculations/

Serpent 1 release vs. Serpent 2 beta

- Serpent 2 unlike Serpent 1 can produce full set of few-group constants based on a leakage corrected critical spectrum (B1 approximation)
- The ADF card new in Serpent 2 can provide all information necessary for discontinuity factor computation, Serpent 1 cannot tally scalar quantities on surfaces
- ASCII output structure changed from Serpent 1 to Serpent 2
- Serpent 2 beta is hybrid parallel, significantly reducing memory demand for large models

▶ Introduce Serpent 2 support based on existing Serpent 1 support in GenPMAXS v6.1.1

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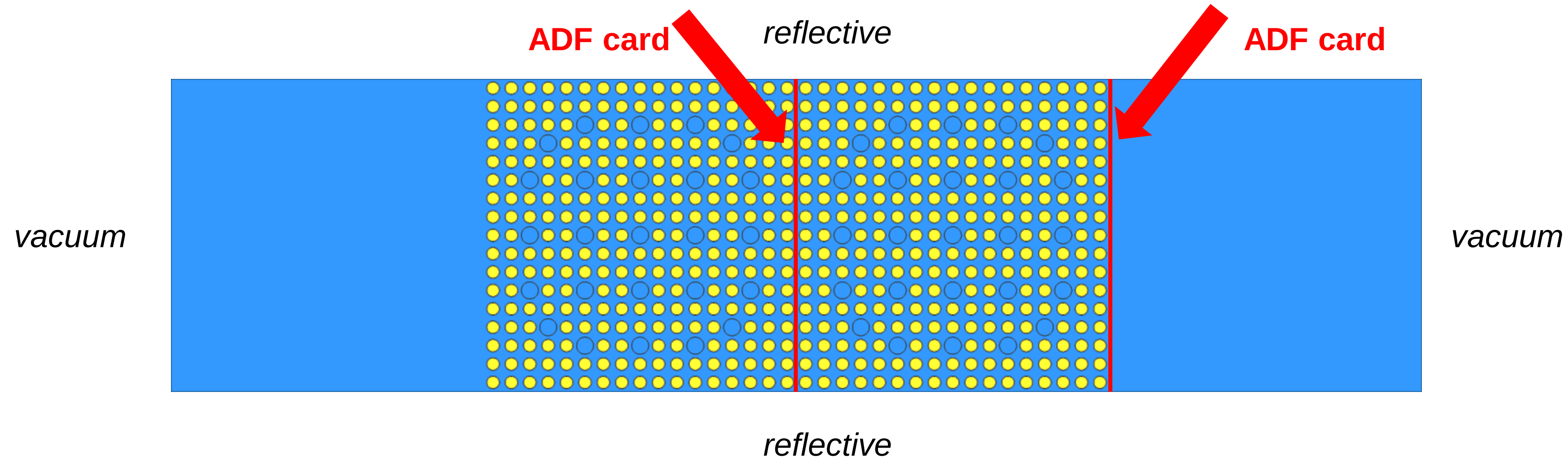
Few-group cross section libraries

- Serpent 2 output processing based on Serpent 1.1.17 support in GenPMAXS
- GenPMAXS: SRC_kind variable of the %DAT_SRC input card set to 10
- GenPMAXS automatically distinguishes infinite spectrum and critical spectrum few-group constants
- Unlike Serpent 1 support:
  Full B1 corrected XS set, reflector ADF, 1D interface discontinuity factors (IDF) for fuel assemblies adjacent to reflectors and group-wise form functions can be processed

1D (reflector) assembly discontinuity factors (1/2)

- Serpent 2 ADF card: set adf <universe> <surface> <bc>
- GenPMAXS: all features of %ADF_1D card available for Serpent 2

%ADF_1D
A1DKERN, A1DNF, A1DNR
thick (1: A1DNF+A1DNR)
lateral (1: A1DNF+A1DNR) *SERPENT 2 beta only.*



1D (reflector) assembly discontinuity factors (1/2)

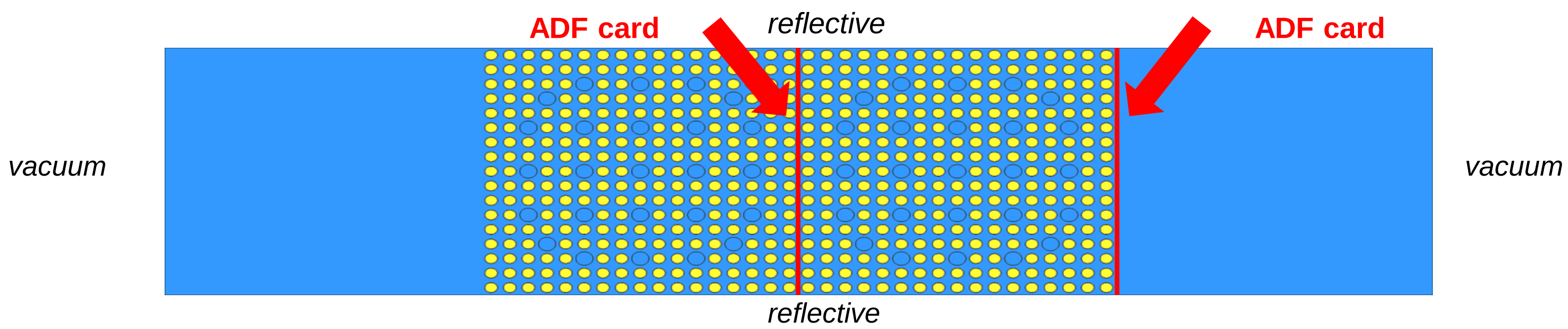
- Generic form of Generalized Equivalence Theory (GET) IDF

$$f_{GET}^{S} = \frac{\phi_S^{het}}{\phi_S^{hom}}$$

- Solve 1D diffusion equation with $\vec{J}_S^{het}$ and $\bar{\phi}_S^{het}$ as boundary condition

$$-D_g{}^i \ \frac{d^2}{du^2}\Phi_g{}^i(u) + \Sigma_R{}^i\Phi_g{}^i(u) = S_{g,i}(u)$$

- For consistency with PARCS spatial discretization use A1DKERN variable to choose method (e.g. NEM)



Group-wise form functions

- Serpent 2 PPW card: set ppw <universe> <lattice>
  (to be available with official release of Serpent 2.1.16)

- GenPMAXS: set lgff parameter to true on %JOB_OPT card

- GenPMAXS: new input card %SERPDAT

```
%SERPDAT
1
PITCH XBE YBE NPART NROWA NCOLA
```

  - PITCH: pin pitch of fuel assembly
  - XBE: distance of corner fuel pin from boundary in direction x
  - YBE: distance of corner fuel pin from boundary in direction y
  - NPART: part of fuel assembly modelled, e.g. NPART=0 full assembly
  - NROWA: number of fuel pin rows
  - NCOLA: number of fuel pin columns

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Few-group cross section libraries (1/2)

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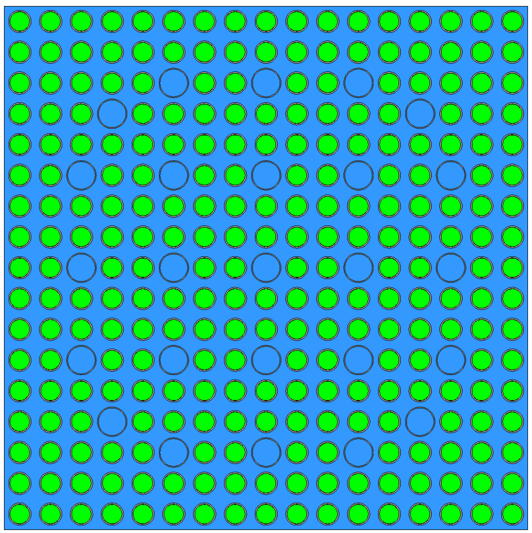
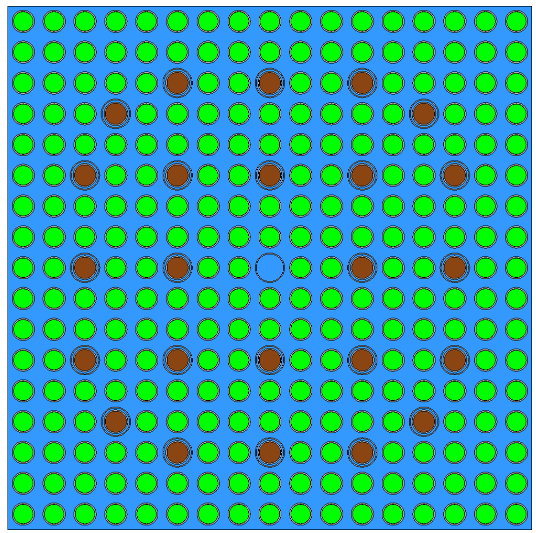
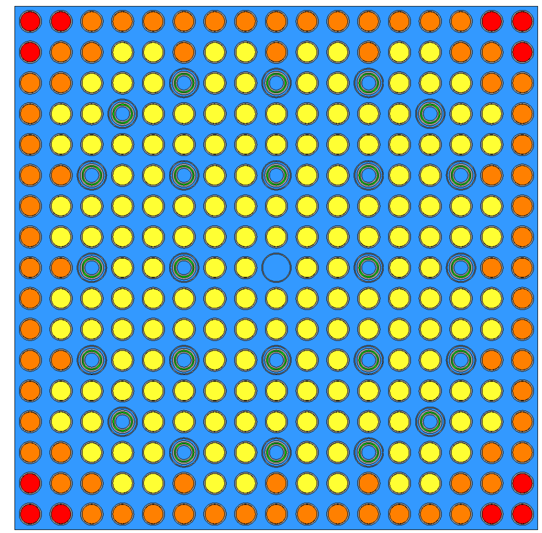
- 3 selected PWR MOX/UOX benchmark fuel assemblies (4)
- Serpent 2: 100,000,000 histories in 500 active cycles
  2g, 4g and 8g cross sections, conservative BC



UOX 0.15 GWd/tU



UOX CR 0.15 GWd/tU



MOX WABA 37.5 GWd/tU

(4) T. Kozlowski and T. J. Downar, *OECD/NEA AND U.S. NRC PWR MOX/UO_2 CORE TRANSIENT BENCHMARK – Final Specification,* OECD Nuclear Energy Agency/Nuclear Science Committee (2003)

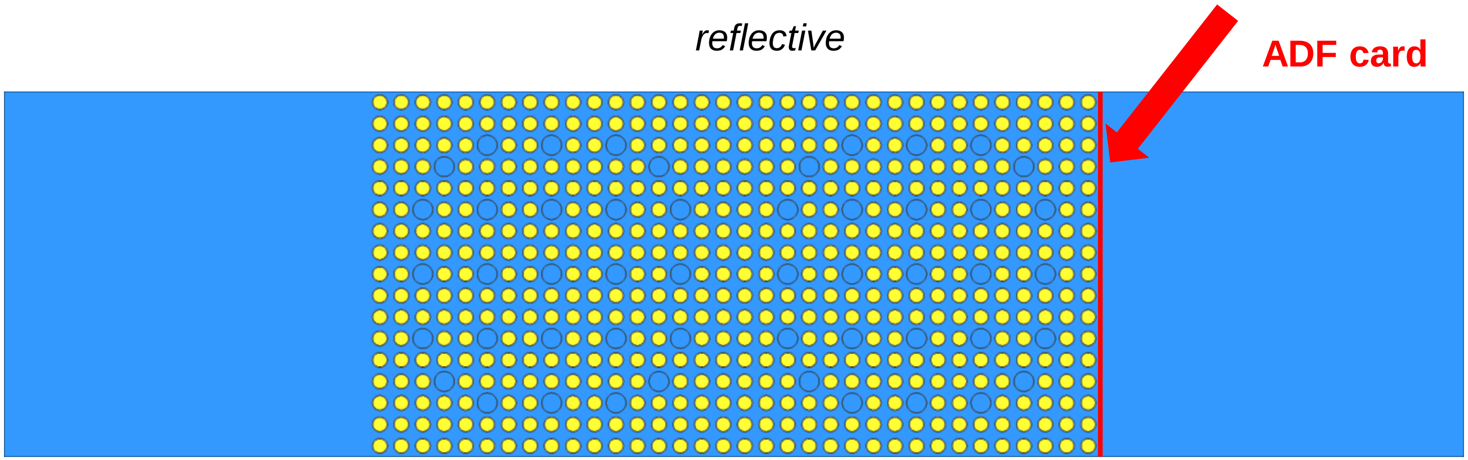
Few-group cross section libraries (2/2)

	UOX	Relative difference [pcm]	UOX CR	Relative difference [pcm]	MOX	Relative difference [pcm]
SERPENT2 CE	1.124280 $\pm$ 0.000043		0.849114 $\pm$ 0.000041		0.963678 $\pm$ 0.000043	
PARCS v3.0 diffusion 2g	1.124272	-0.8	0.849126	1.2	0.963674	-0.4
PARCS v3.0 diffusion 4g	1.124269	-1.1	0.849129	1.5	0.963675	-0.3
PARCS v3.0 diffusion 8g	1.124267	-1.3	0.849130	1.6	0.963677	-0.1
PARCS v3.0 SP3 2g	1.124272	-0.8	0.849126	1.2	0.963674	-0.4
PARCS v3.0 SP3 4g	1.124269	-1.1	0.849129	1.5	0.963675	-0.3
PARCS v3.0 SP3 8g	1.124267	-1.3	0.849130	1.6	0.963677	-0.1

PARCS achieves acceptable accuracy, GenPMAXS translated Serpent 2 output correctly

Reflector assembly discontinuity factors

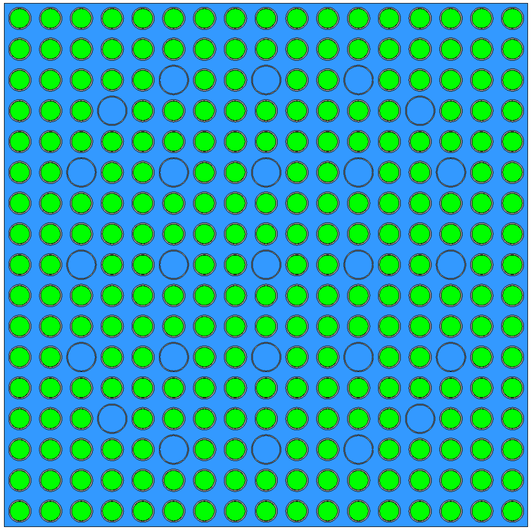
- Serpent 2: 100,000,000 histories in 500 active cycles
  2g cross sections (0.625 eV boundary)
- GenPMAXS: A1DKERN = NONE



Reflector ADF	GenPMAXS	createXSlib	Rel. Diff.
ADF_1	1.14620	1.14620	0.0
ADF_2	0.93430	0.93430	0.0

Pin power reconstruction – case 1 (1/2)

- Serpent 2: 100,000,000 histories in 500 active cycles
  2g cross sections (0.625 eV boundary)



UOX 0.15 GWd/tU

Code	k_{inf}	Rel. Diff. [pcm]
Serpent 2 CE	1.124230±0.00005	-
PARCS 2g NEM	1.1242304	0.04

Pin power reconstruction – case 1 (2/2)

10.0	2.2	0.4	-0.5	-0.7	-0.9	-1.0	-1.0	-0.9	-1.0	-1.0	-0.7	-0.8	-0.5	0.3	2.2	9.9
2.3	0.9	-0.2	-0.5	-1.2	1.0	-1.5	-1.3	0.9	-1.3	-1.3	1.1	-1.2	-0.5	-0.1	0.8	2.1
0.3	-0.1	-0.8	1.2	0.6	0.0	1.0	1.0	0.0	1.0	1.0	0.0	0.7	1.2	-0.9	-0.1	0.3
-0.4	-0.5	1.3	0.0	0.5	1.0	-1.5	-1.5	1.0	-1.4	-1.4	0.9	0.5	0.0	1.2	-0.5	-0.5
-0.7	-1.2	0.7	0.4	-1.9	0.9	-1.5	-1.4	1.0	-1.5	-1.5	0.8	-1.8	0.3	0.6	-1.2	-0.7
-0.8	1.0	0.0	1.0	0.9	0.0	1.0	1.0	0.0	1.0	1.0	0.0	0.8	0.9	0.0	0.9	-0.8
-0.9	-1.3	0.9	-1.5	-1.5	1.0	-1.5	-1.4	1.1	-1.3	-1.5	1.0	-1.6	-1.5	1.0	-1.4	-0.9
-1.0	-1.3	1.1	-1.4	-1.5	1.0	-1.3	-1.4	1.1	-1.3	-1.4	1.0	-1.5	-1.5	1.0	-1.4	-0.9
-0.8	0.9	0.0	1.0	1.0	0.0	1.1	1.1	0.0	1.0	1.1	0.0	1.0	0.9	0.0	1.1	-0.8
-1.0	-1.3	1.0	-1.4	-1.4	0.9	-1.3	-1.4	1.1	-1.3	-1.4	1.0	-1.5	-1.5	1.0	-1.3	-1.0
-1.0	-1.3	0.9	-1.4	-1.4	0.9	-1.5	-1.4	1.0	-1.4	-1.4	0.9	-1.5	-1.5	1.0	-1.3	-1.1
-0.8	0.9	0.0	1.0	0.9	0.0	0.8	1.1	0.0	1.0	0.9	0.0	0.9	1.0	0.0	1.0	-0.8
-0.7	-1.2	0.7	0.4	-1.8	0.9	-1.5	-1.4	1.0	-1.4	-1.5	0.9	-1.8	0.5	0.5	-1.1	-0.7
-0.4	-0.4	1.2	0.0	0.5	1.0	-1.4	-1.5	1.0	-1.4	-1.6	0.9	0.4	0.0	1.2	-0.6	-0.4
0.3	-0.1	-0.8	1.2	0.7	0.0	1.0	1.0	0.0	1.1	1.1	0.0	0.6	1.2	-0.8	-0.1	0.4
2.3	0.9	-0.1	-0.5	-1.1	1.0	-1.3	-1.2	1.0	-1.3	-1.3	1.0	-1.1	-0.5	-0.1	0.9	2.2
10.0	2.3	0.3	-0.5	-0.8	-0.7	-1.0	-1.0	-0.8	-0.9	-0.9	-0.8	-0.6	-0.5	0.3	2.3	10.0

Relative pin power errors PARCS vs. Serpent 2 in per cent

PARCS pin power reconstruction relationship for pin cell i:

$$p_{pin,i} = \sum_g \overline{\kappa}\, \overline{\Sigma_{fg}}\, \underbrace{\overline{\Phi_g}\, f_{g,i}}_{\Phi_{g,i}}$$

Serpent 2 pin power relationship for pin cell i:

$$p_{pin,i} = \sum_g \kappa_i\, \Sigma_{fg,i}\, \Phi_{g,i}$$
$$= \kappa_i\, \Sigma_{f,i}\, \Phi_i$$

Pin power reconstruction – case 2 (1/3)

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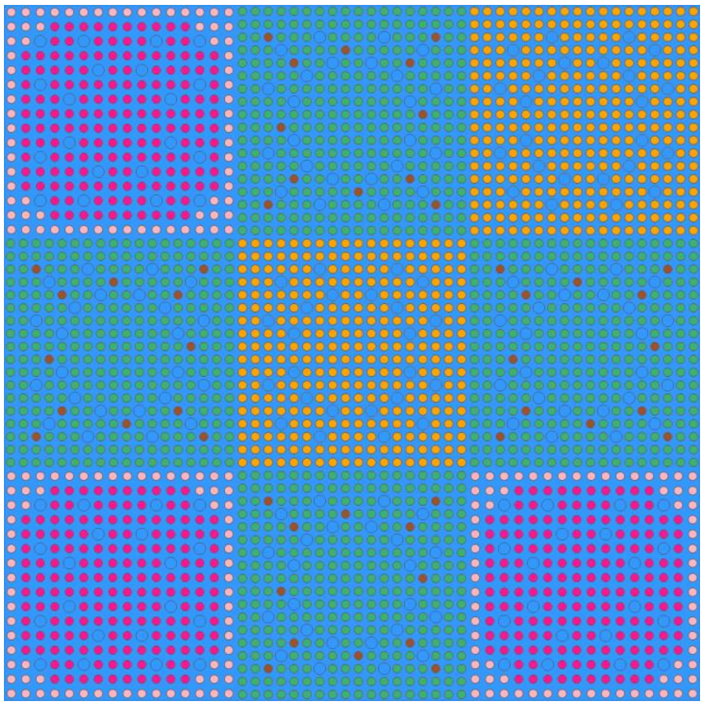
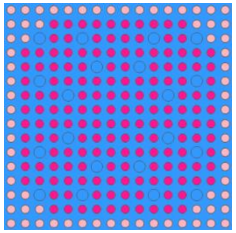
reflective

reflective

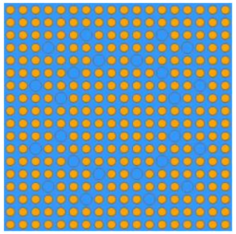


reflective

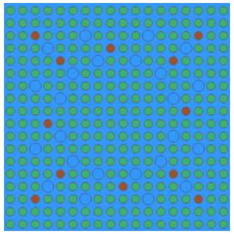
reflective



MOX, 0.0 GWd/tU
1.45 wt%
up to 2 wt% Pu



UOX, 0.0 GWd/tU
1.8 wt%



UOX, 0.0 GWd/tU
2.0 wt%
including Gd
poisoned rods

Fuel assemblies design based on AREVA fuel for KONVOI PWR

Pin power reconstruction – case 2 (2/3)

- Serpent 2: 2,000,000,000 histories in 500 active cycles
  2g cross sections (0.625 eV boundary)

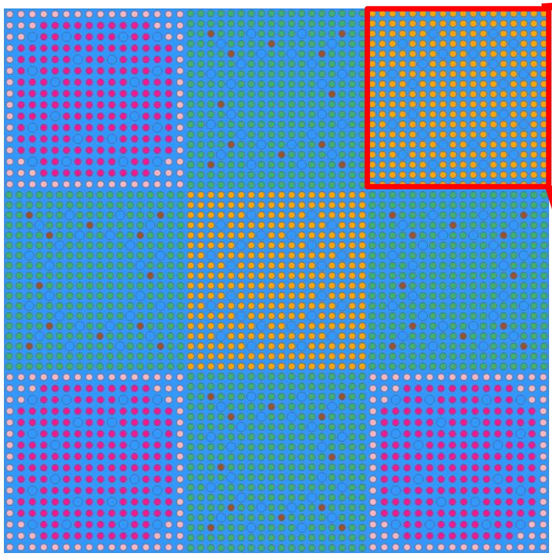
Code	k_{inf}	Rel. Diff. [pcm]
Serpent 2 CE	0.961211±0.00003	-
PARCS 2g NEM	0.960741	47.0

Serpent 2 CE
PARCS 2g
Rel. Diff. [%]

1.5441 *1.5386* **-0.36**	0.5843 *0.5904* **1.04**	0.4224 *0.4326* **2.41**
0.8849 *0.8845* **-0.04**	0.7056 *0.7123* **0.96**	0.5845 *0.5904* **1.01**
1.8449 *1.8281* **-0.91**	0.8848 *0.8845* **-0.04**	1.5445 *1.5386* **-0.38**

Normalized nodal powers as predicted by Serpent 2 and PARCS

Pin power reconstruction – case 2 (3/3)



23.27	6.91	6.89	5.59	4.62	3.60	2.70	3.06	3.66	3.66	3.36	2.90	3.39	4.93	5.62	6.53	6.60	6.15
6.92	6.95	5.74	4.64	4.22	2.31	0.37	2.08	3.63	3.43	2.12	0.63	2.23	4.00	5.04	6.10	6.71	6.87
7.62	6.48	4.07	1.43	2.10	-0.40	0.00	-0.63	1.91	2.29	-0.42	0.00	0.44	1.86	1.55	4.36	6.12	6.64
6.83	5.25	1.63	0.00	-0.73	-0.80	-2.42	-1.95	0.91	0.68	-1.74	-2.29	-0.04	-0.59	0.00	1.72	5.09	6.42
5.71	4.63	2.12	-0.67	-0.51	-2.41	-2.86	0.00	-0.76	-1.01	0.00	-2.75	-2.19	-0.33	-0.37	2.64	4.72	5.83
4.32	2.70	-0.05	-0.58	-2.07	0.00	-2.04	-0.77	1.51	1.20	-0.75	-1.80	0.00	-2.12	0.09	0.56	3.51	5.02
3.41	1.02	0.00	-2.39	-2.74	-2.33	0.98	2.97	3.83	3.78	2.71	1.35	-2.04	-2.29	-1.80	0.00	1.91	4.84
3.92	2.56	-0.43	-2.00	0.00	-1.17	2.42	4.04	5.22	5.13	4.47	2.76	-0.85	0.00	-1.40	0.52	3.60	5.15
4.14	3.48	1.82	0.54	-1.16	1.41	3.47	5.04	5.72	6.21	5.18	3.80	1.87	-0.59	1.22	3.32	4.93	5.95
3.80	3.44	2.07	0.28	-1.13	1.21	3.70	5.15	5.88	5.58	5.02	3.76	1.66	-0.32	1.80	3.83	5.16	6.30
3.16	2.07	-0.57	-2.22	0.00	-1.23	2.26	4.29	4.69	5.01	4.44	3.04	-0.59	0.00	0.05	2.81	4.52	5.71
2.84	0.25	0.00	-2.68	-3.10	-2.32	0.42	2.45	3.45	3.83	2.83	1.32	-1.87	-2.45	-0.10	0.00	3.32	5.25
3.44	2.45	-0.68	-0.83	-2.65	0.00	-2.67	-0.98	1.18	1.37	-1.13	-2.04	0.00	-2.11	-1.99	-0.05	1.34	4.62
5.00	3.79	1.12	-1.24	-0.88	-2.45	-3.24	0.00	-1.16	-1.17	0.00	-3.16	-2.42	-1.40	-2.21	-0.71	2.80	5.11
6.25	4.60	1.08	0.00	-1.15	-0.85	-2.56	-1.78	0.65	0.53	-2.13	-2.78	-0.66	-1.36	0.00	0.80	4.06	5.55
7.06	5.88	3.98	1.17	1.65	-0.25	0.00	-0.55	2.18	2.38	-0.54	0.00	-0.29	1.16	1.13	3.62	5.51	6.79
6.62	6.68	5.51	4.81	4.02	2.59	0.91	2.73	3.77	3.81	2.77	0.75	3.02	4.06	4.63	5.76	6.73	7.31
23.87	6.75	6.33	5.78	5.18	4.63	3.62	4.18	4.64	4.69	4.32	3.96	4.15	5.02	6.06	6.38	7.16	7.45

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Availability of extended GenPMAXS

- Cooperation with GenPMAXS developers
- Serpent 2 support expected to be available with GenPMAXS v6.2 release