Modeling of Phenix EOL experiments with Serpent-DYN3D

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Outline

- Motivation
- Phenix End-of-Life core
- Serpent-DYN3D codes sequence
- Experiments and selected results
  - Control rod S-curves
  - Control rod shift tests
- Conclusions

Motivation

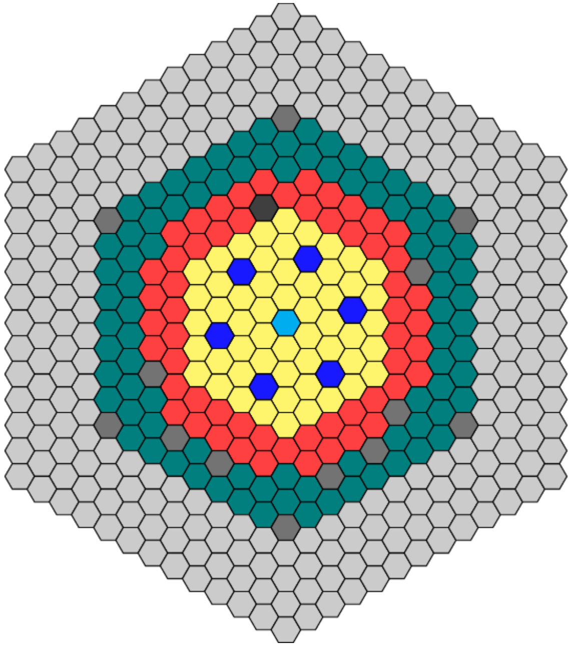
- Reactor dynamics code DYN3D
  - 3D multi-group nodal diffusion
  - Internal thermal hydraulic model
  - Multi-physics coupling (e.g., ATHLET, CFX, TRANSURANUS, etc.)
  - Originally developed for LWRs

- Currently under extension for SFR applications

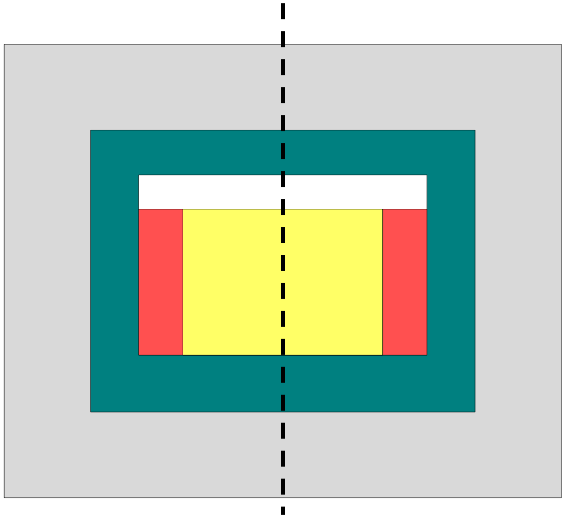
- Verification and validation is needed
  - Phenix EOL control rod withdrawal experiments

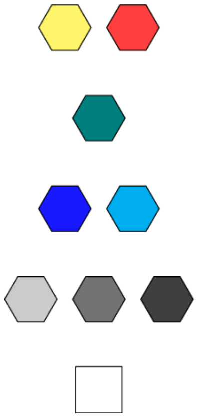
Phenix EOL core

Radial layout



Axial layout





Inner and outer core

Blanket

Primary and secondary control

Reflectors

Sodium plenum

Power, MWth	560
Inlet/Outlet temp, C	400/560
Fissile core diameter, m	1.50
Fissile core height, m	0.85
Fissile core volume, m^3	1.51

Serpent-DYN3D codes sequence

Calculation methodology

- Full core nodal diffusion solution with DYN3D

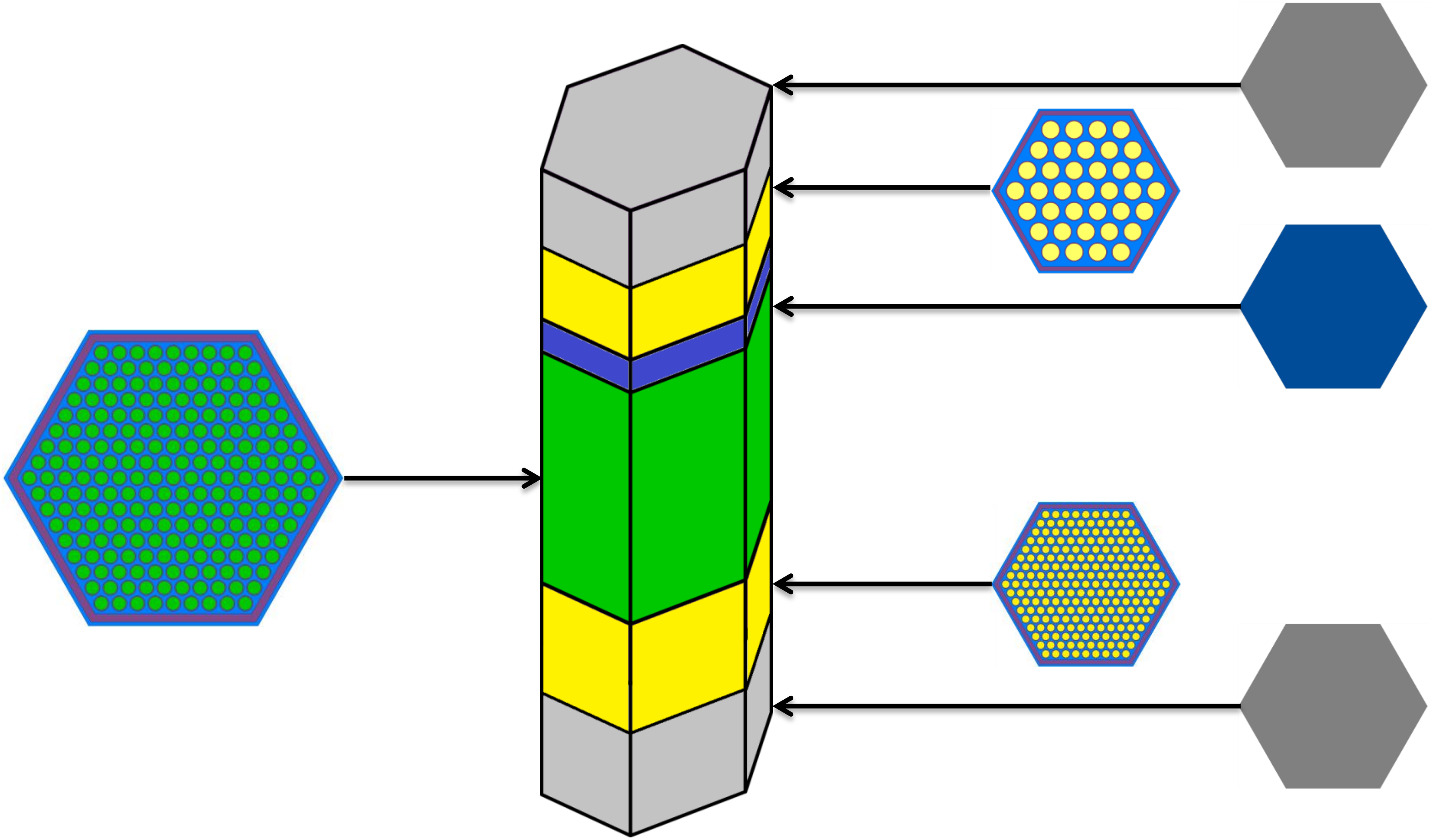
- Homogenized few-group cross sections (XS) for DYN3D
  - Using Serpent
  - 24 energy groups (subset of ECCO-33)
  - 2D and 3D lattice based models (next slides)

- Additional XS correction
  - To improve nodal diffusion solution
  - Superhomogenization (SPH) factors
    - CRs, first row of blankets, inside reflectors

- Reference
  - Full core Serpent solution
  - Measurements

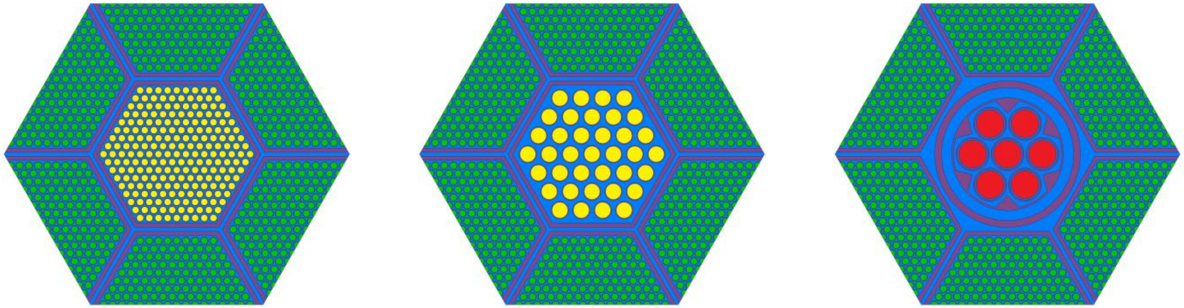
Serpent models for XS generation

- Fuel material – 3D sub-assembly model

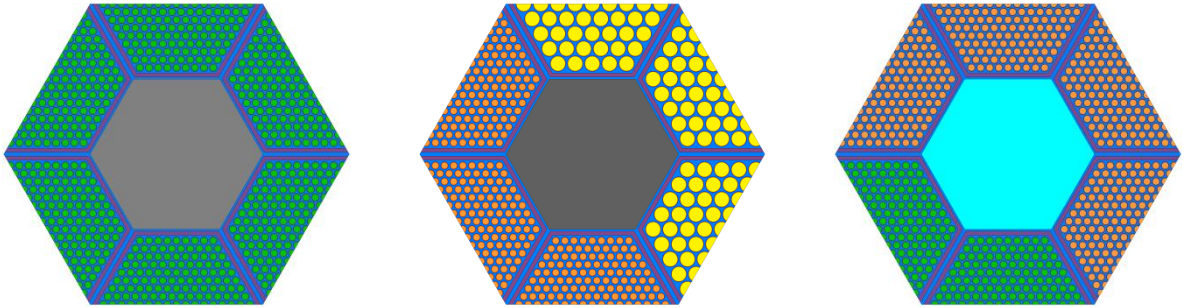


Serpent models for XS generation

- Non-multiplying regions – 2D super-cell model
  - Blankets and Control rods



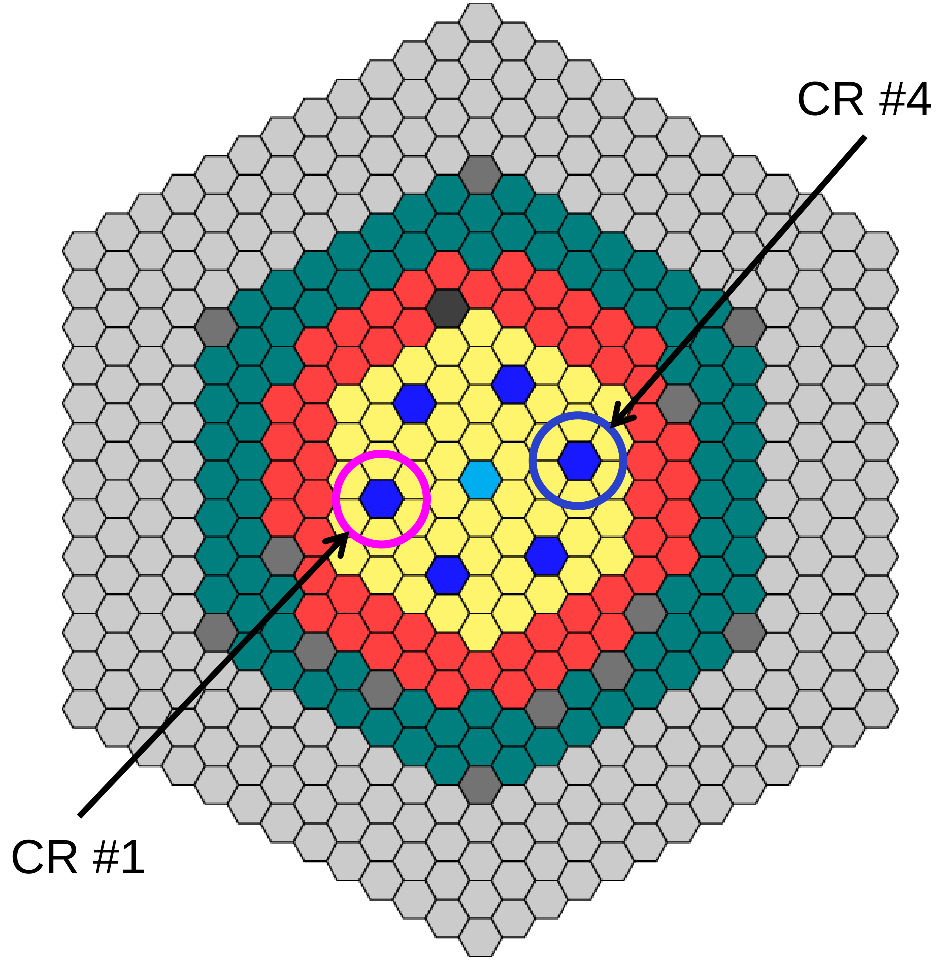
  - Homogenized assemblies, Inside reflectors and Diluent



Experiments and selected results:

Control rod S-curves

CR withdrawal – Off-power tests



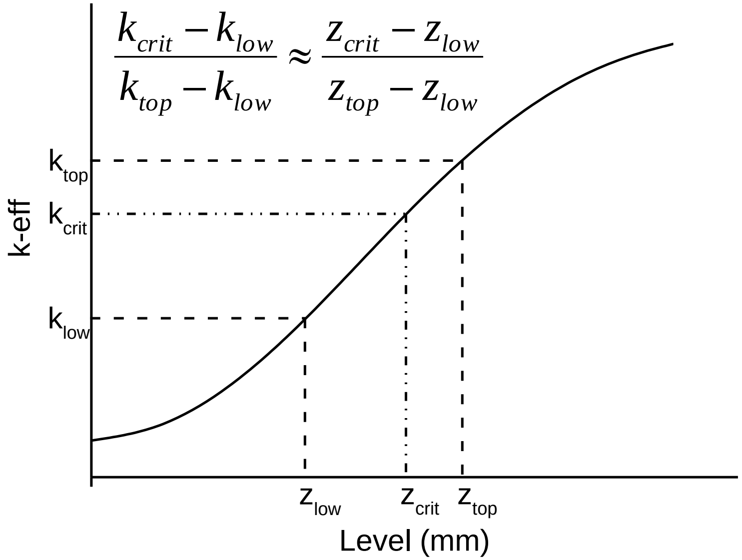
Measurements

- Control rod worth
- Low power (~50 kW)
- Balancing method

Balancing method for Serpent and DYN3D

- Matlab script for automatization

- Criticality search with CR movement

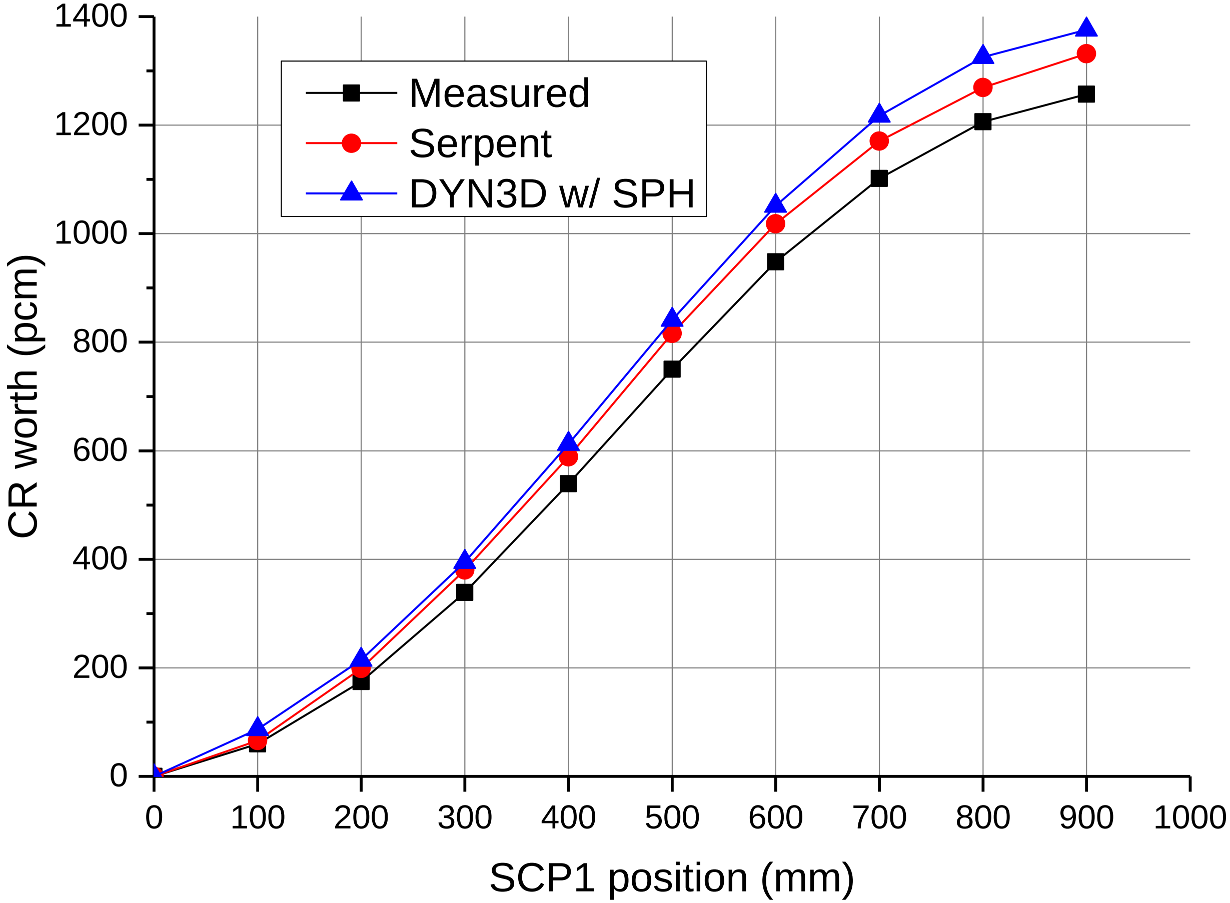


- S-curve calculation
  - Start with two k-eff calculations: rodded and unrodded
  - Linear approximation for the next CR position
  - Several full core calculations
  - Starting with poor statistics for acceleration
  - Improve statistics when 3σ confidence intervals overlap

- Calculation time (AMD 64x2300 MHz): ~1 day for 10-point S-curve

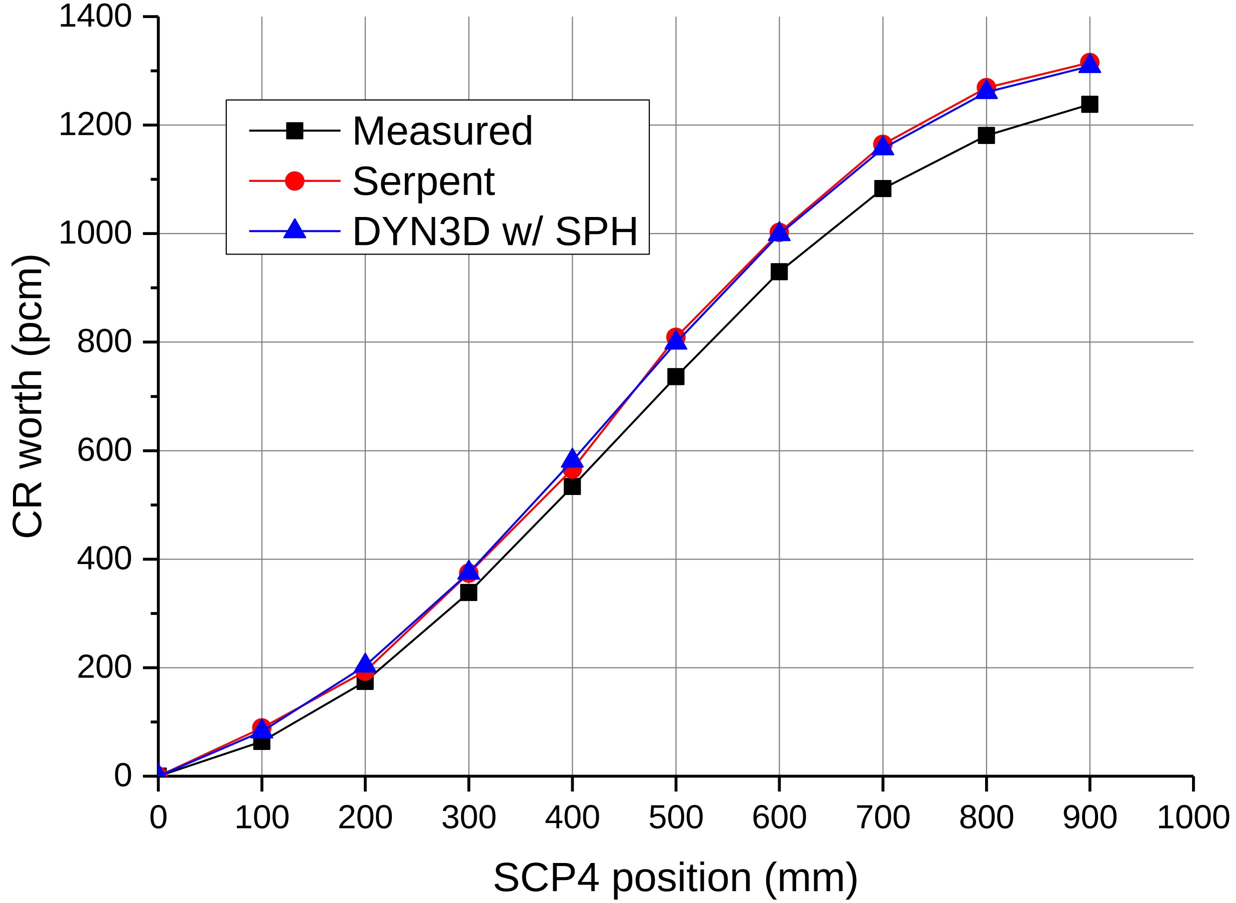
Control rod #1 S-curve

Measured (pcm)	Serpent		DYN3D	
	CR worth	Diff. (pcm)	CR worth	Diff. (pcm)
1257	1331	74	1376	119



Control rod #4 S-curve

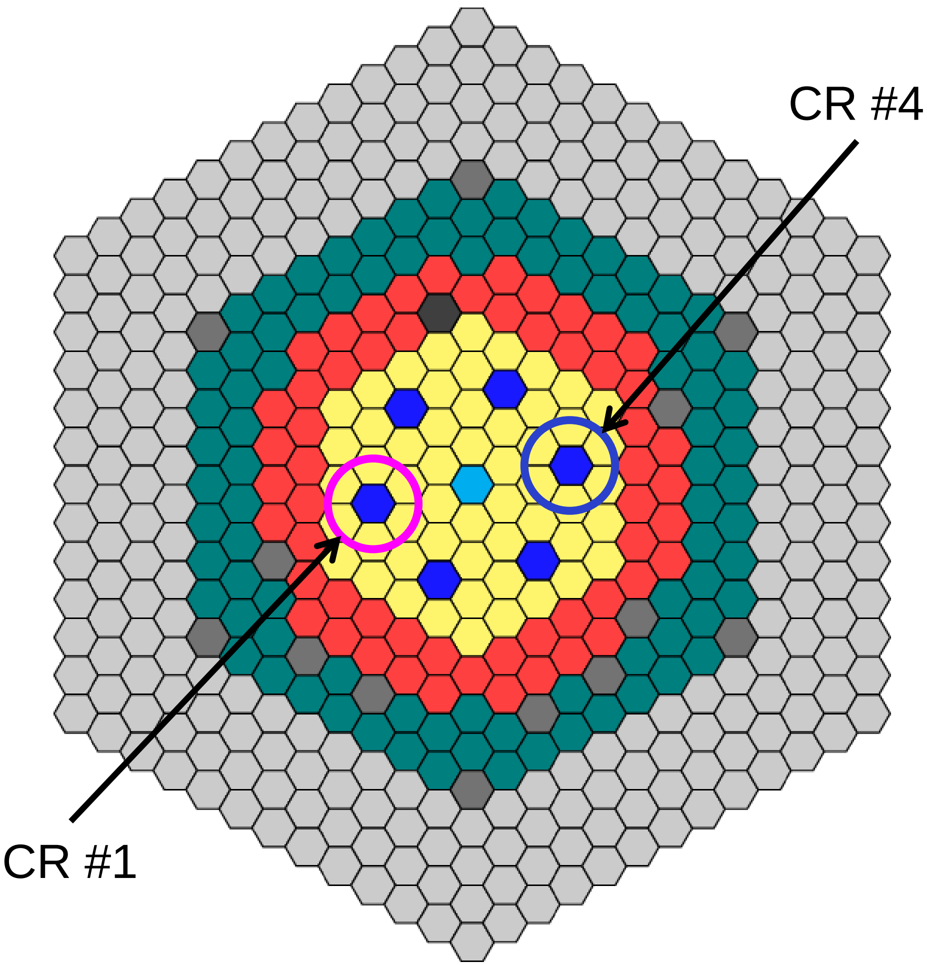
Measured (pcm)	Serpent		DYN3D	
	CR worth	Diff. (pcm)	CR worth	Diff. (pcm)
1238	1315	77	1309	70



Experiments and selected results:

Control rod shift tests

CR withdrawal – On-power tests



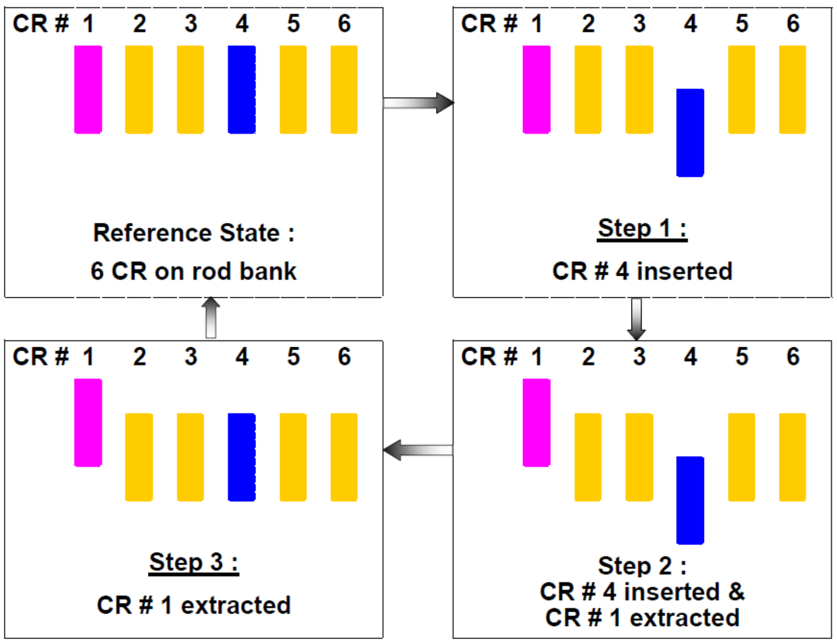
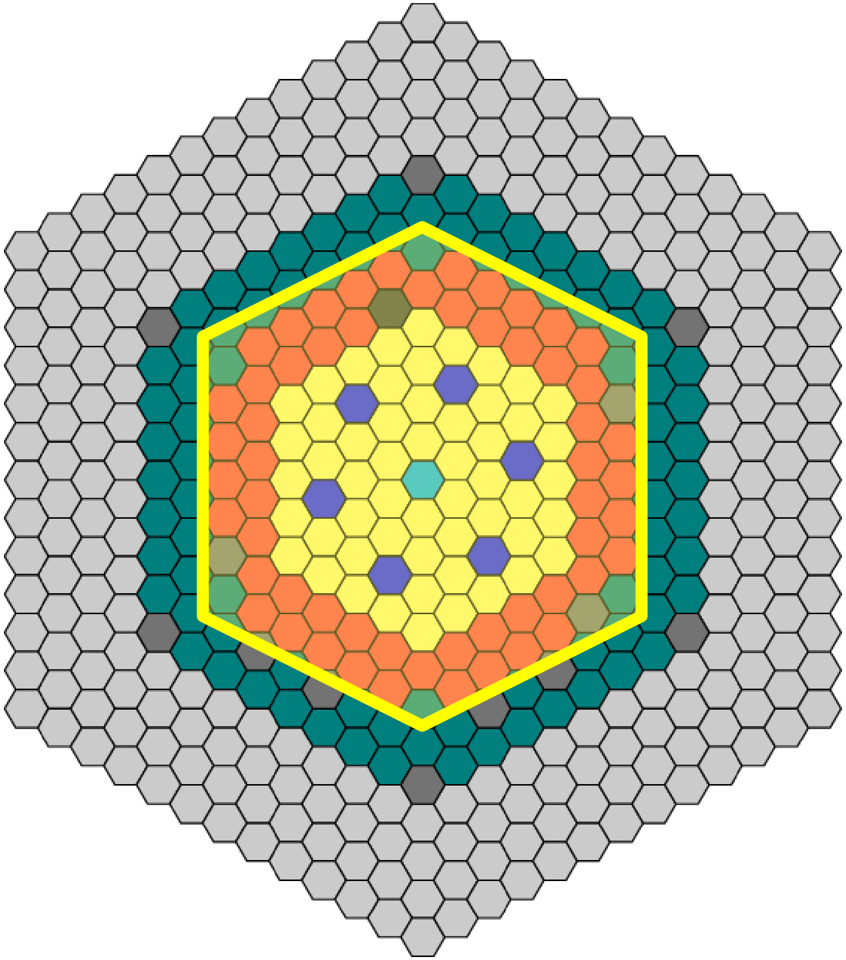


FIG. 13. Schematic overview of the control rods shift. *

* Fig. 13 was extracted from the final benchmark report

CR withdrawal – On-power tests



Measurements

- Sodium outlet temperature
- Thermocouples at outlet (120 S/As)
- Flow rate remained constant
- Power shape perturbations from:

$$P_i = \dot{m}_i \cdot C_p(Na) \cdot (T_{out} - T_{in})$$

Core description deficiencies

- Average core description
  - Materials
  - Burnup
  - Temperatures

- $P_i = \dot{m}_i \cdot C_p(Na) \cdot (T_{out} - T_{in})$

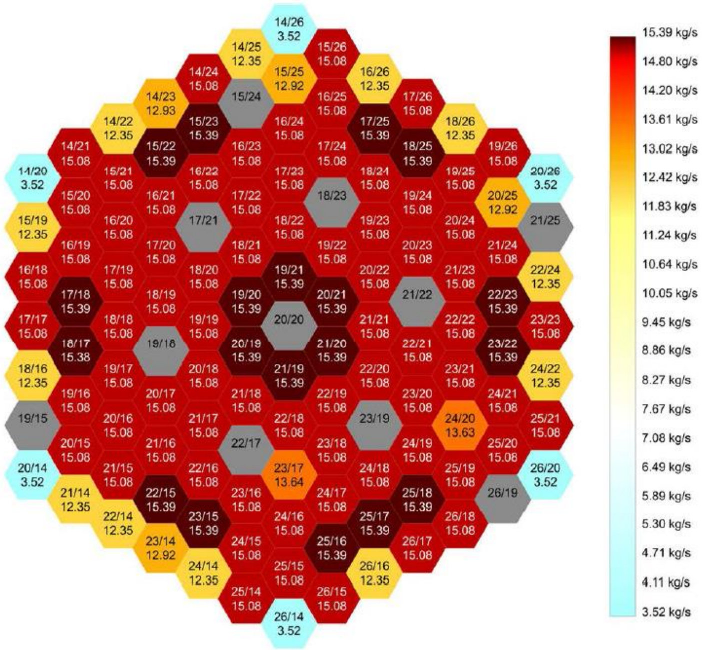


FIG. 30. Flows per S/A (initial state).

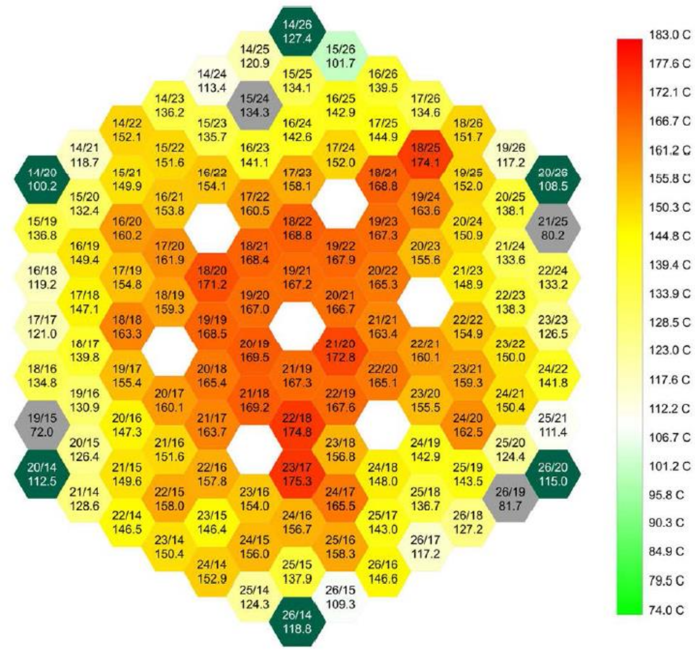
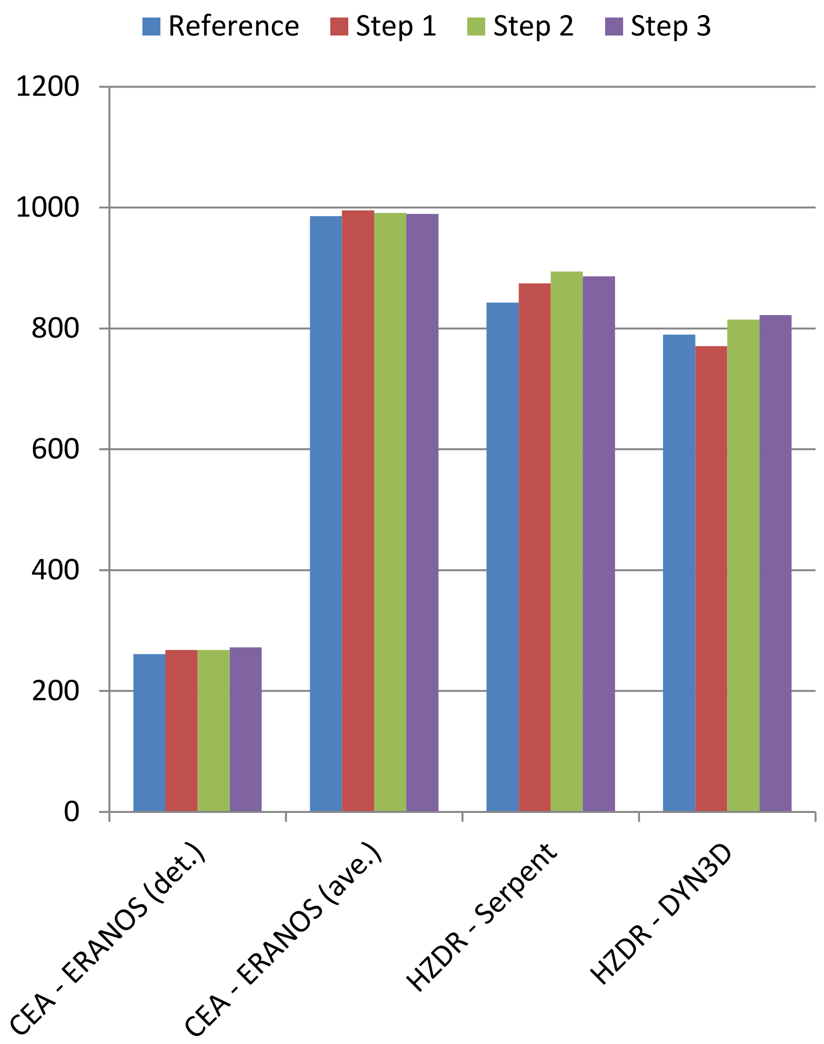


FIG. 12. Sodium heating per S/As - initial state.

* Fig. 12 and 30 were extracted from the final benchmark report

Core reactivity during all steps

	Serpent, pcm	DYN3D, pcm	Difference, pcm
Reference state	843	790	**-53**
Step 1	874	771	**-103**
Step 2	894	815	**-79**
Step 3	886	822	**-64**



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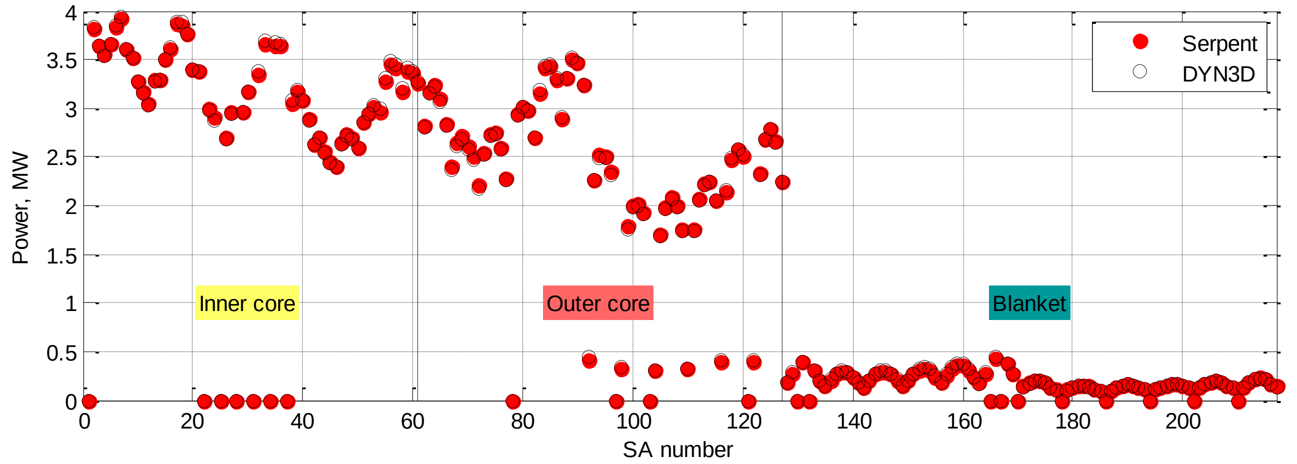
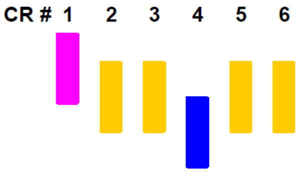
Radial power distribution: DYN3D vs. Serpent

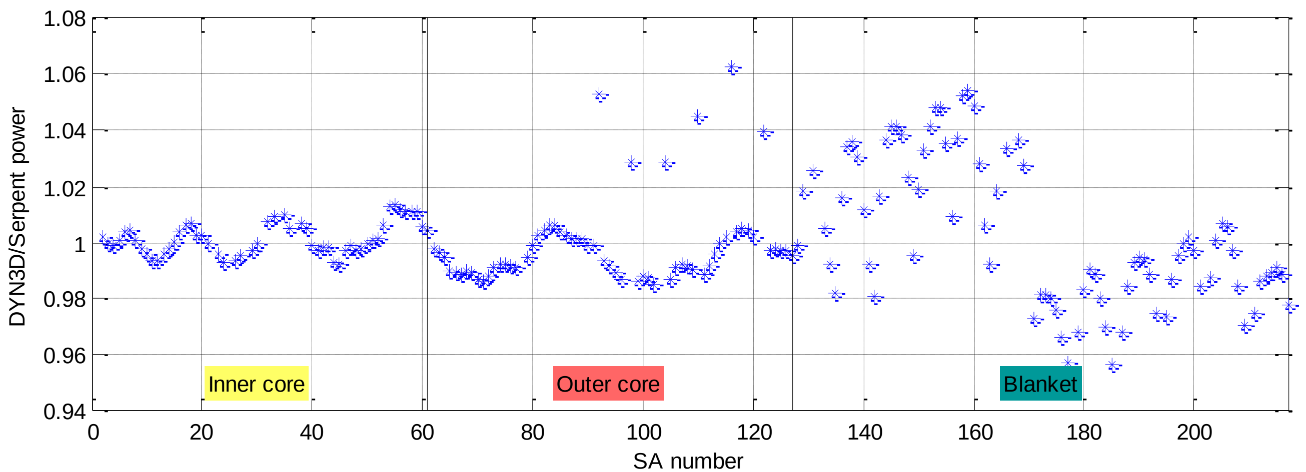
Core	Average relative difference, %	Maximal relative difference, %
	DYN3D vs. Serpent	DYN3D vs. Serpent
Reference state	0.33	1.15
Step 1	0.29	1.03
Step 2	0.34	1.15
Step 3	0.35	1.19
Blanket	Average relative difference, %	Maximal relative difference, %
	DYN3D vs. Serpent	DYN3D vs. Serpent
Reference state	1.56	4.45
Step 1	1.48	4.32
Step 2	1.57	4.73
Step 3	1.57	4.63

Radial power distribution: DYN3D vs. Serpent

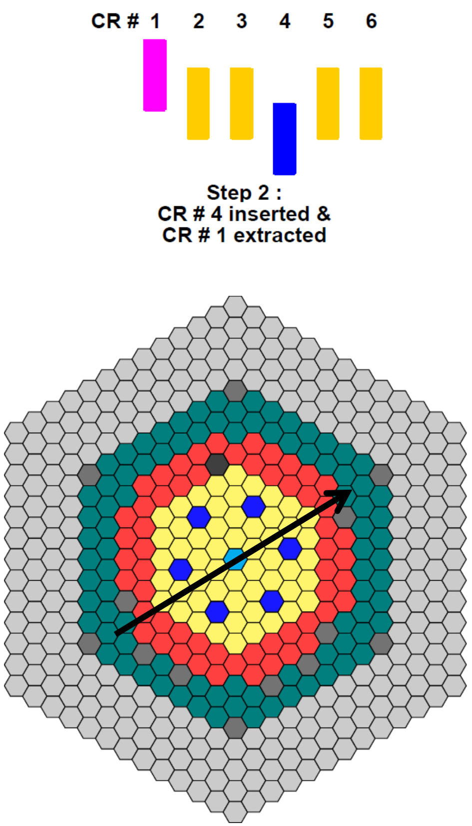


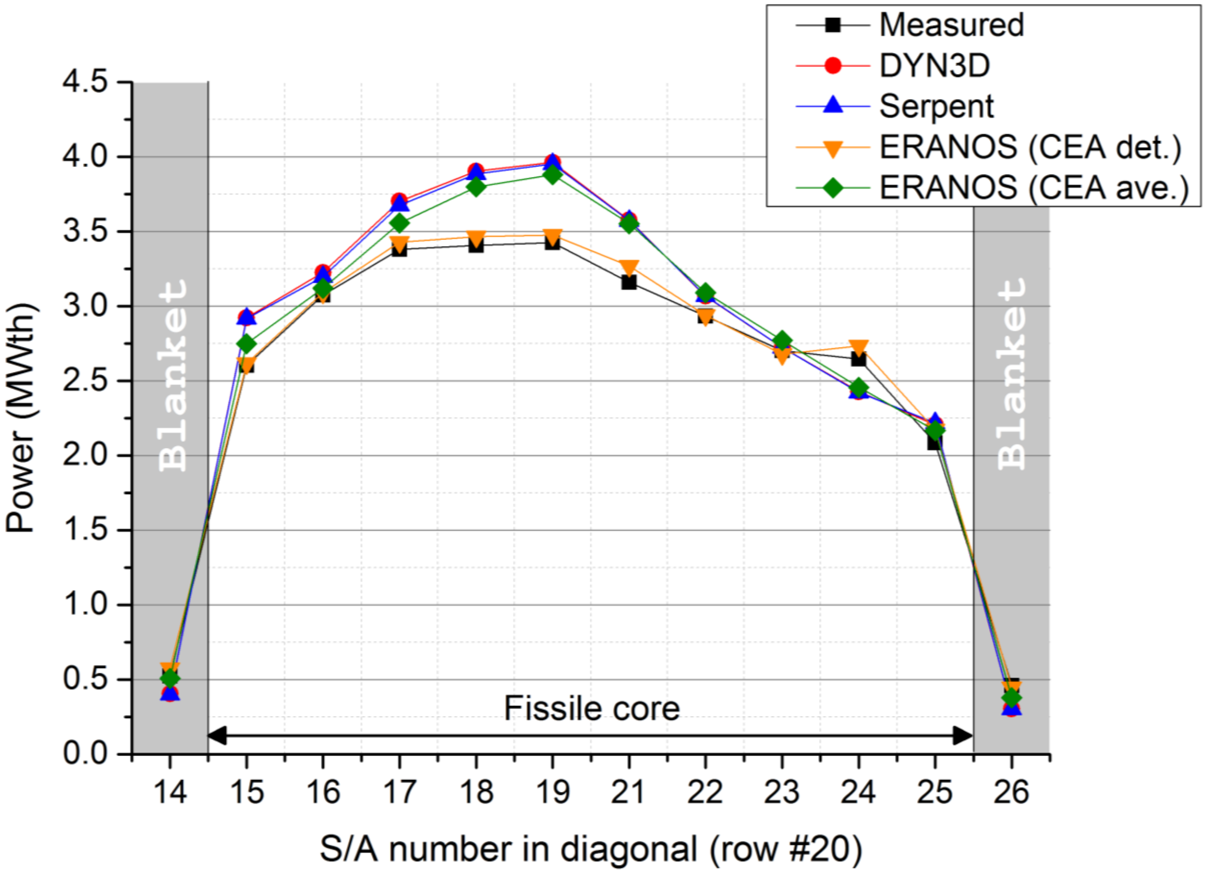


Step 2 :
CR # 4 inserted &
CR # 1 extracted



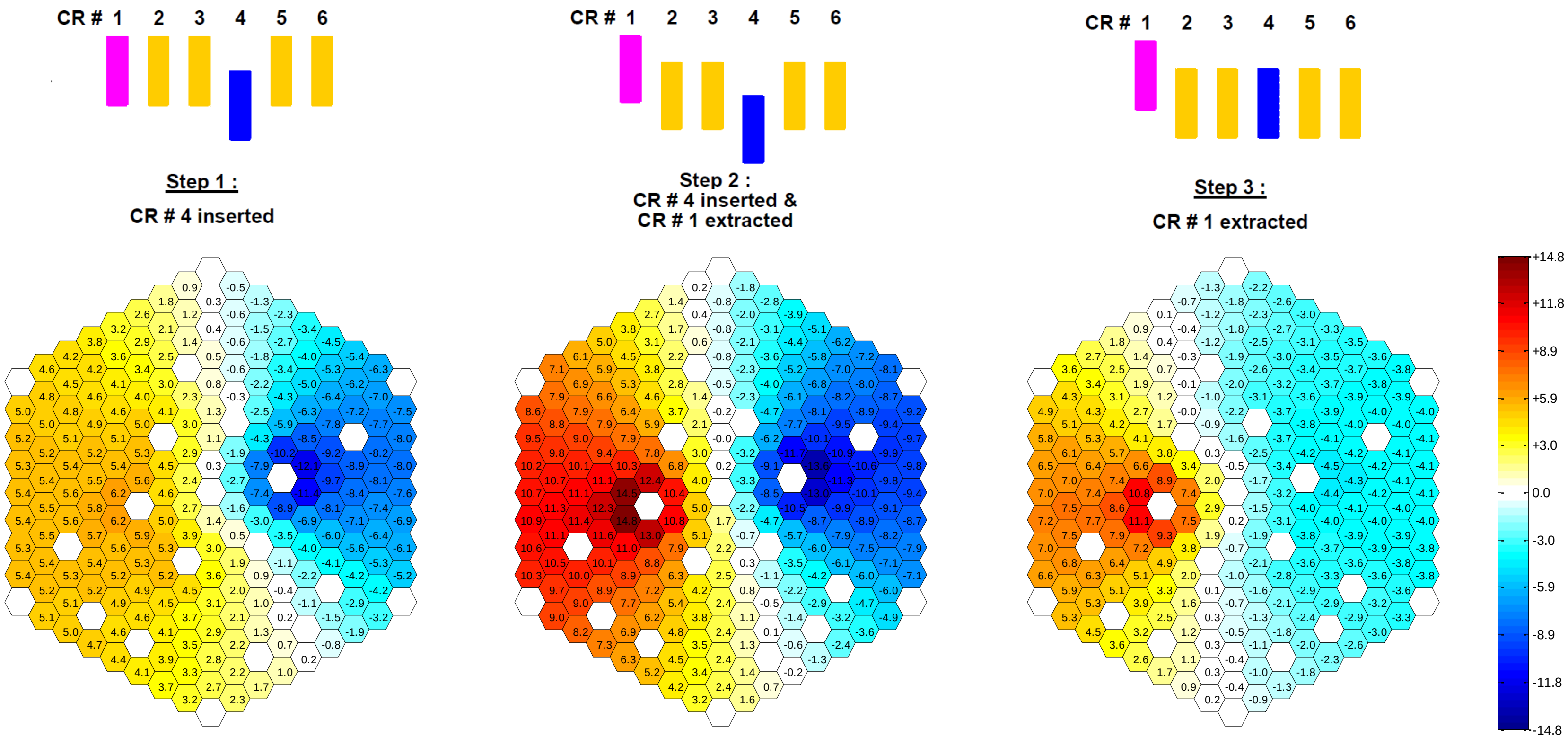
Radial power distribution: Step 2





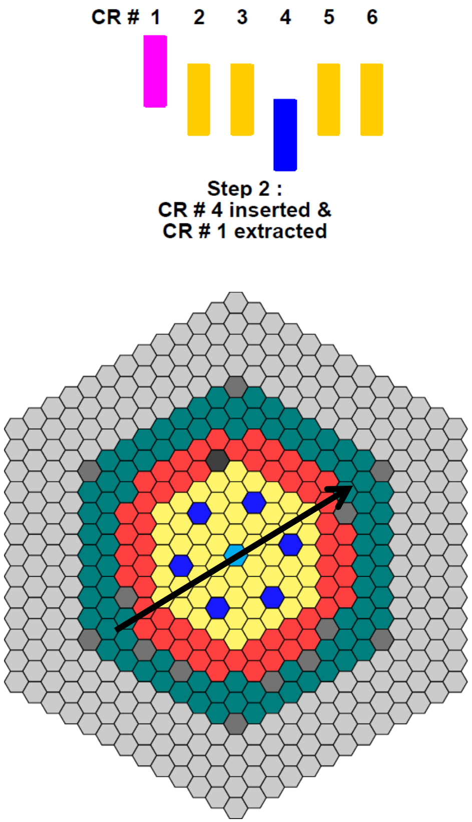
Note: The detailed core description was only available for CEA.

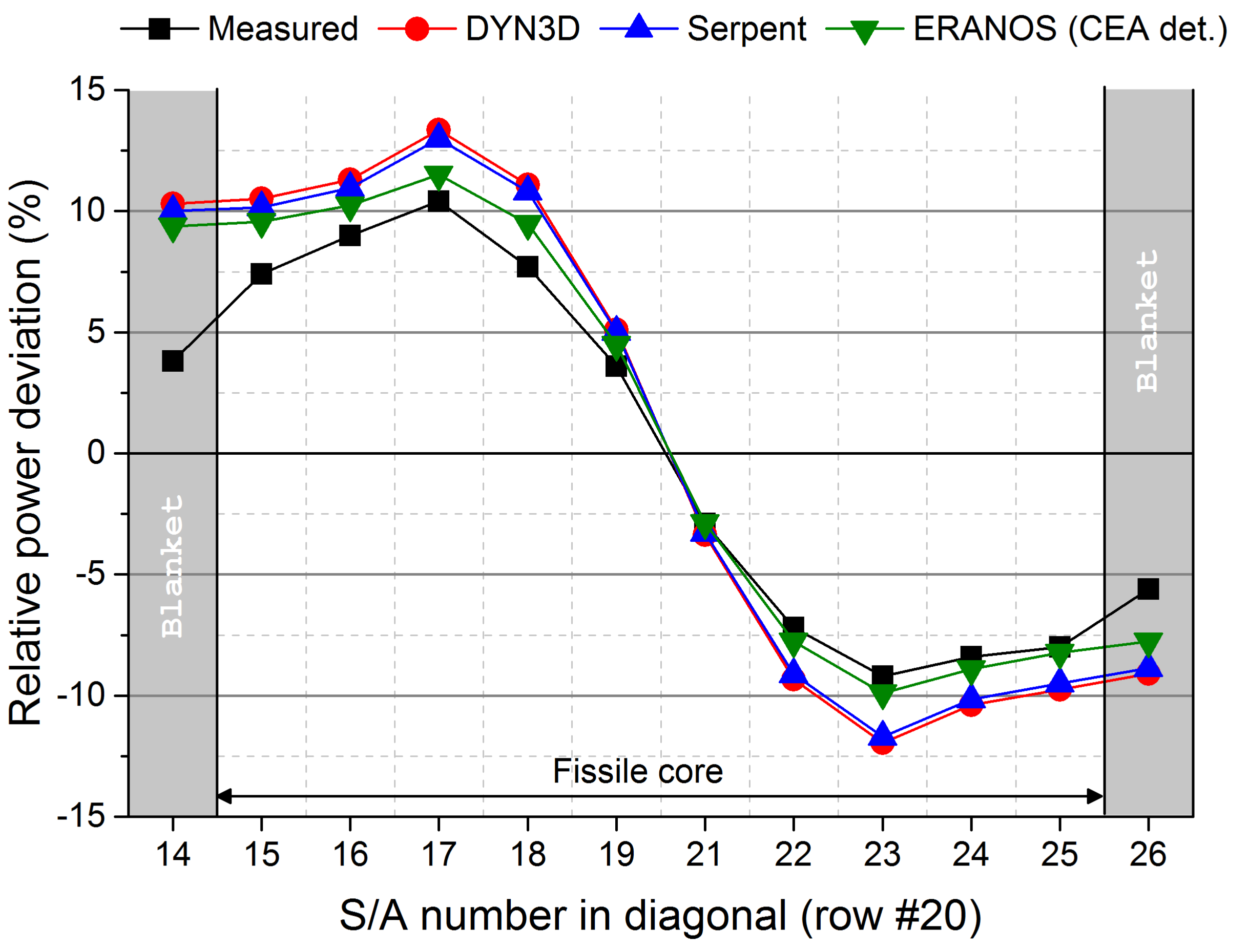
Power deviation distribution



	Step 1 Serpent / DYN3D	Step 2 Serpent / DYN3D	Step 3 Serpent / DYN3D
Max. positive dev.	+6.23 / 6.22%	+14.78 / 15.23%	+11.07 / 11.35%
Max. negative dev.	-12.08 / 12.19%	-13.61 / 13.90%	-4.52 / 4.66%

Radial power deviation profile: Step 2





Conclusions

- The Phenix EOL CR withdrawal benchmark was calculated
- DYN3D nodal diffusion solution
  - XS generated with Serpent
  - SPH factors were used for first neighbor nodes facing fuel assemblies
  - Full core Serpent solution as reference
- Very good agreement between DYN3D and Serpent in general
- Good agreement for CR S-curves between DYN3D and experiment
- CR shift tests
  - Good agreement: Serpent-DYN3D vs. other benchmark participants (CEA)
  - High discrepancies compared to experiment due to averaged core model

Thank you

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