

Modeling of Phenix EOL experiments with Serpent-DYN3D

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hzdr

 **HELMHOLTZ**
ZENTRUM DRESDEN
ROSSENDORF

Outline

- DYN3D quick overview
- XS generation
- Thermal expansion models
- Phenix EOL tests
- Summary

Reactor dynamics code DYN3D

- 3D multi-group nodal diffusion + TH feedback
- Rectangular and hexagonal geometries
- Developed for LWR applications

Extending DYN3D for SFR application

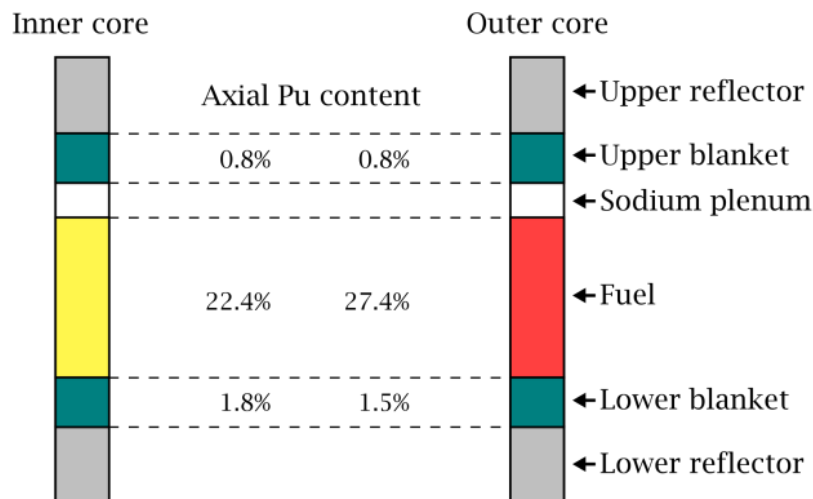
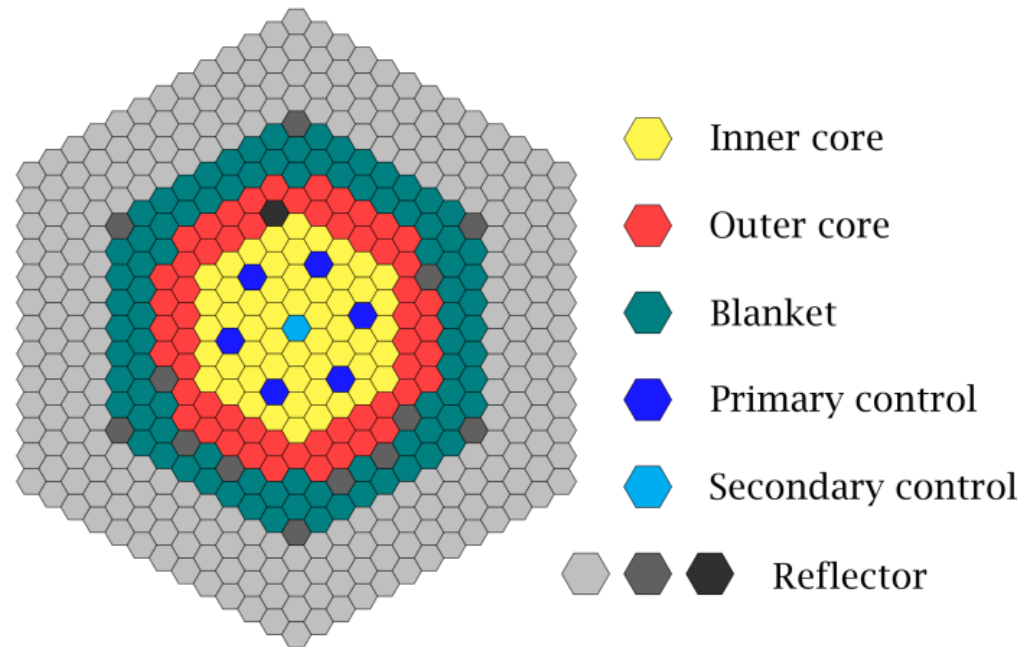
- Serpent-based few-group XS generation approach
- TH module updated with Na properties
- New models for thermal expansion feedbacks
 - Axial fuel rod expansion
 - Radial diagrid expansion
- Ongoing: coupling with a system code ATHLET

Objectives

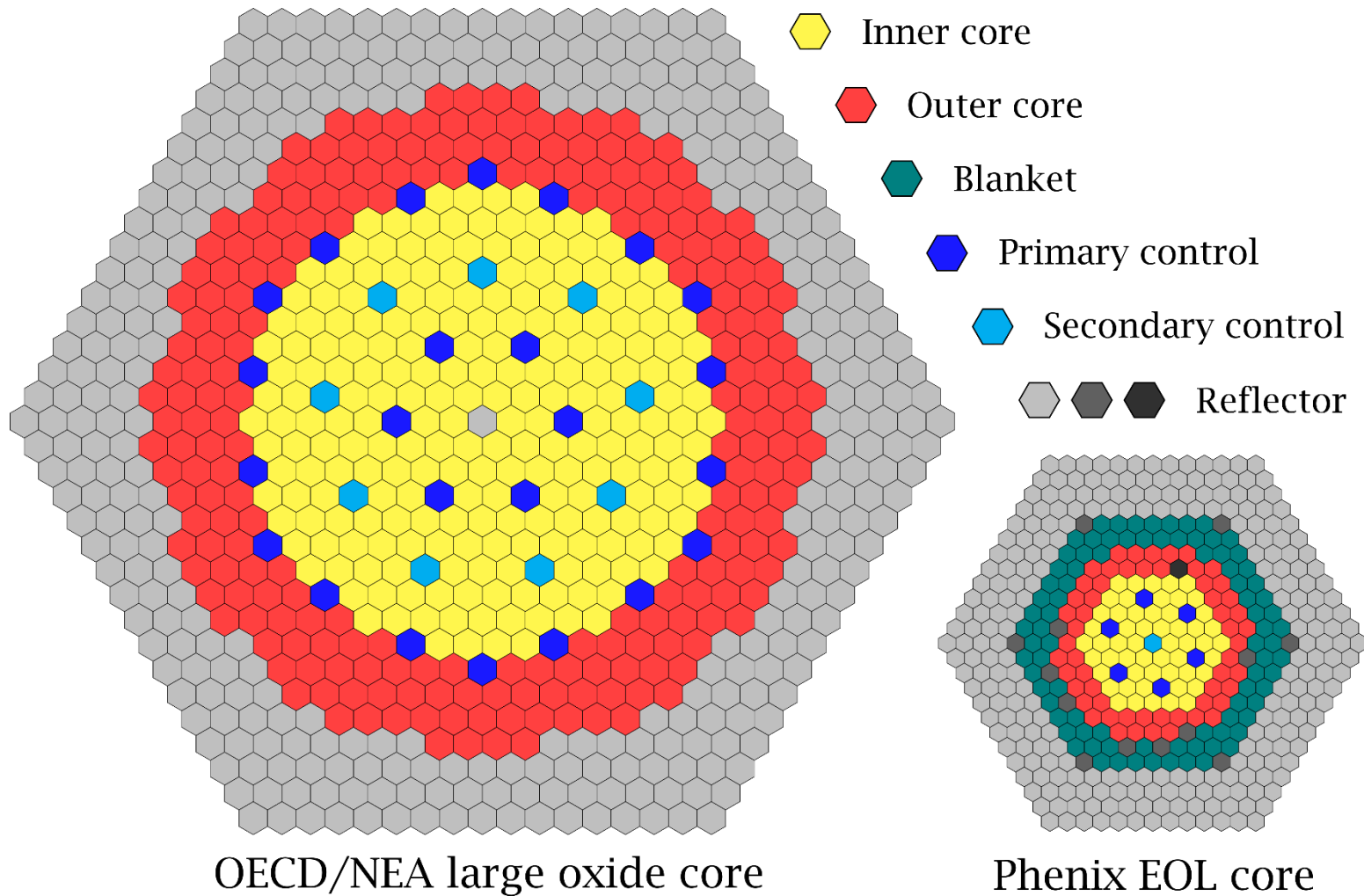
- Validation of the Serpent-DYN3D
- Using Phenix EOL experiments
 - Steady-state: Control rod shift tests
 - Transient: Initial stage of natural circulation test

Phenix EOL core

- Fuel: MOX
- Assemblies
 - 54 inner + 56 outer
 - 86 blanket
 - 252 reflector
- Control
 - 6 primary CRs
 - 1 secondary CR
 - 14 diluents
- 6 axial zones



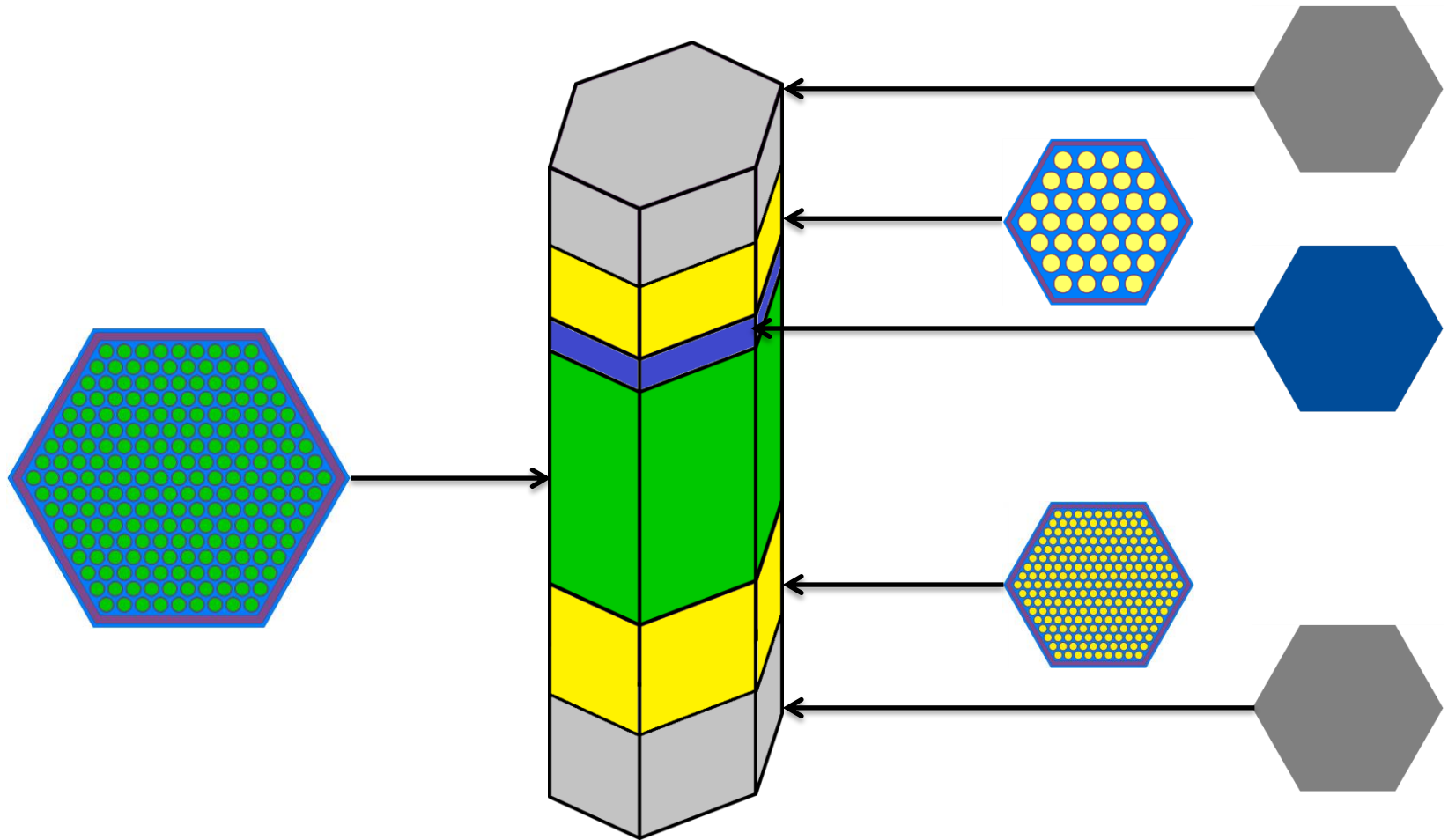
Phenix vs. large oxide SFR



Few-group XS generation

Serpent models for fuel materials

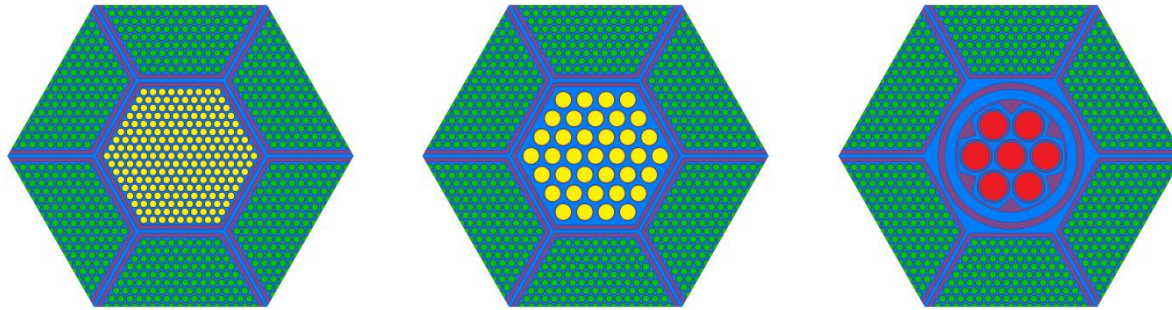
- 3D assembly model



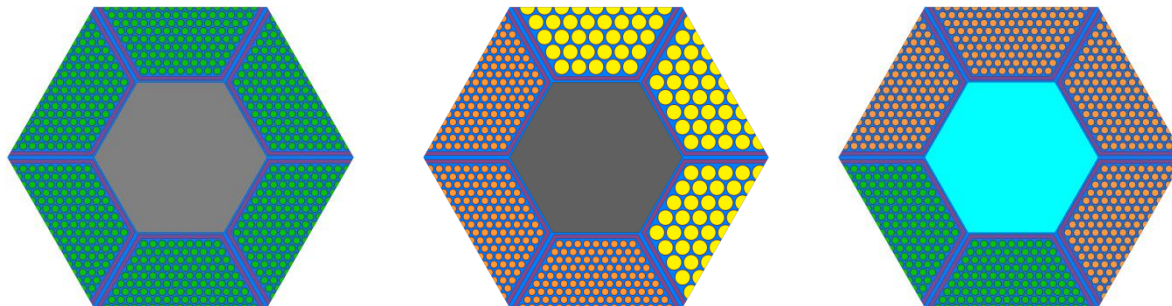
Serpent models for non-multiplying regions

- 2D super-cell model
- Super-homogenization factors (SPH)

Blankets and control rods



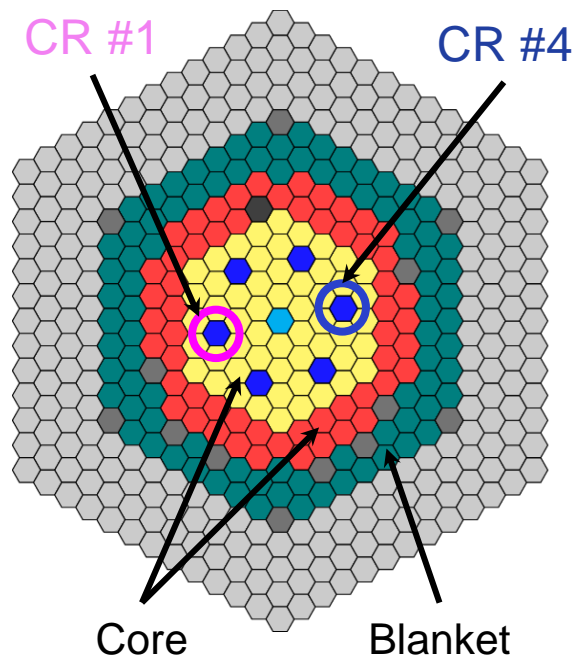
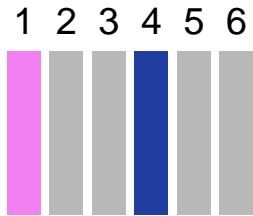
Homogenized assemblies, inside reflectors and diluent



Phenix EOL control rod shift test

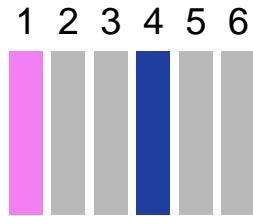
Control rod shift sequence

Reference state

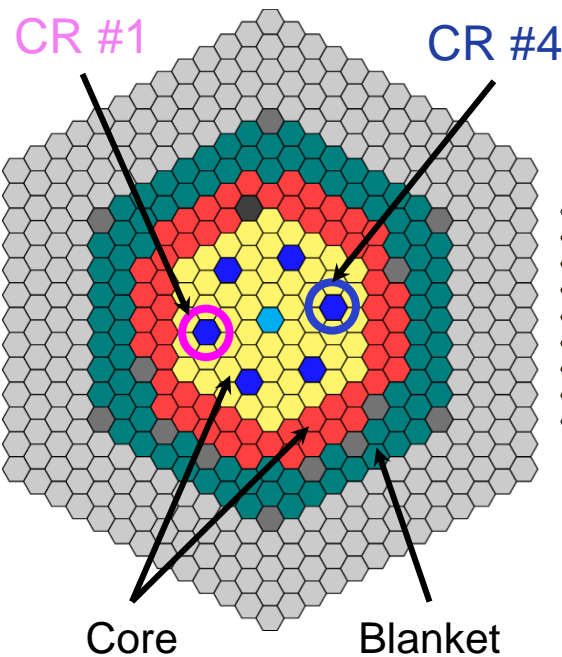
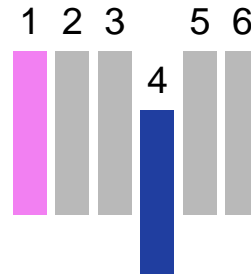


Control rod shift sequence

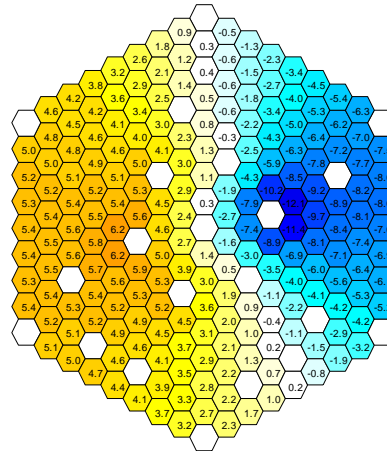
Reference state



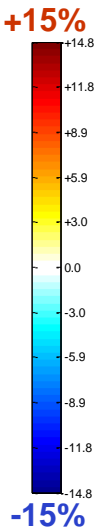
Control rod shift sequence



Step 1

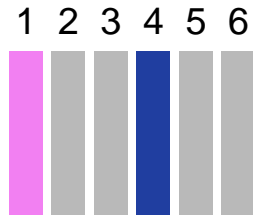


Deviation of power distribution relative to the reference state

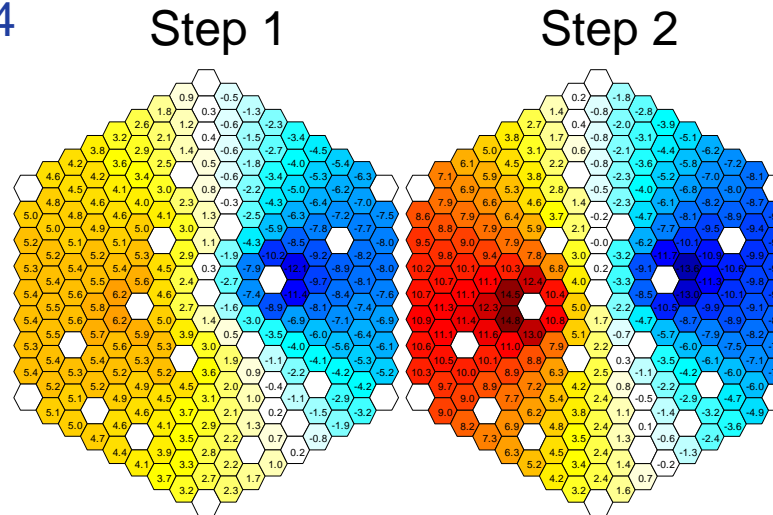
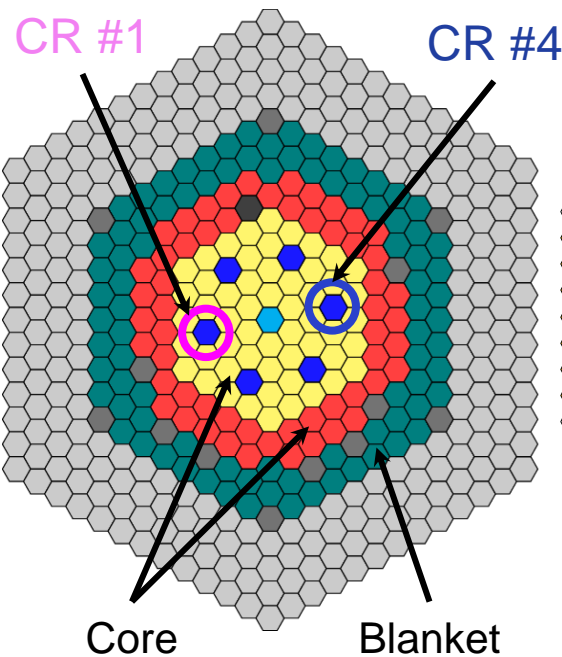
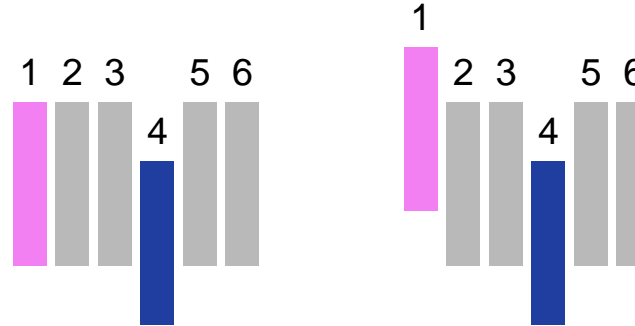


Control rod shift sequence

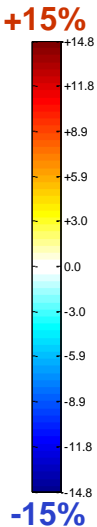
Reference state



Control rod shift sequence

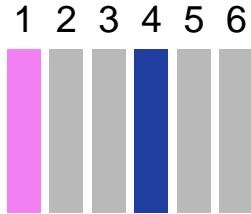


Deviation of power distribution relative to the reference state

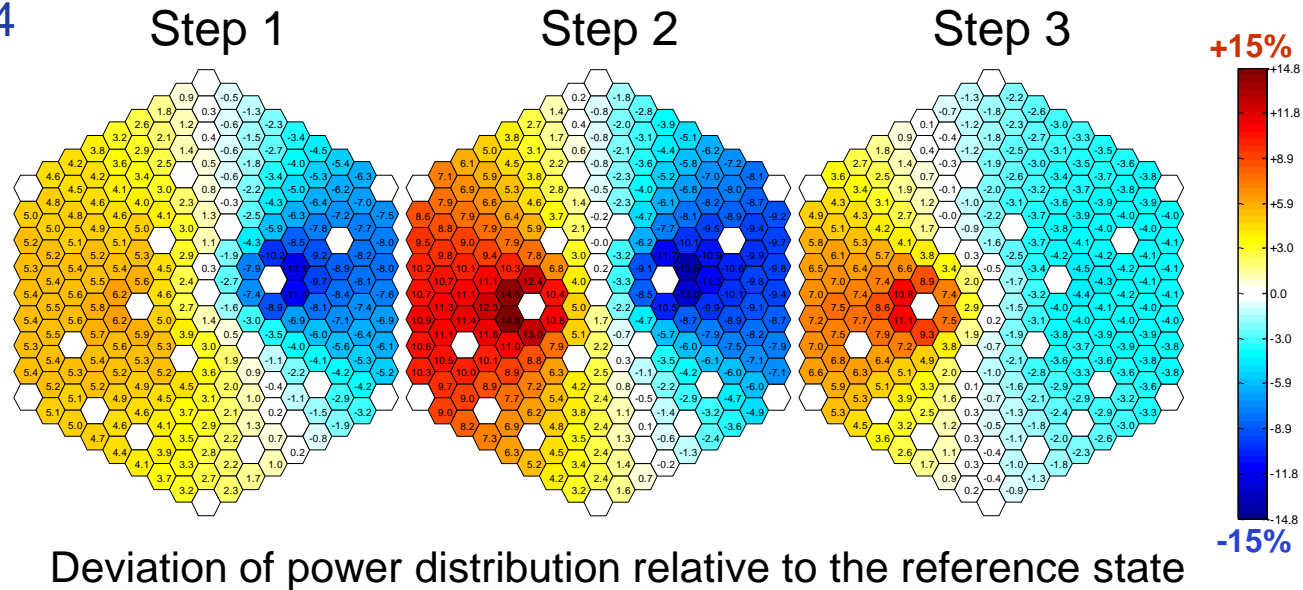
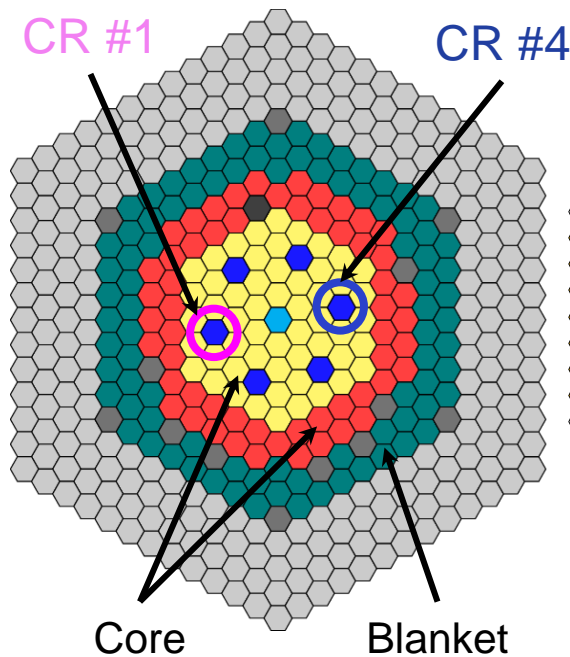
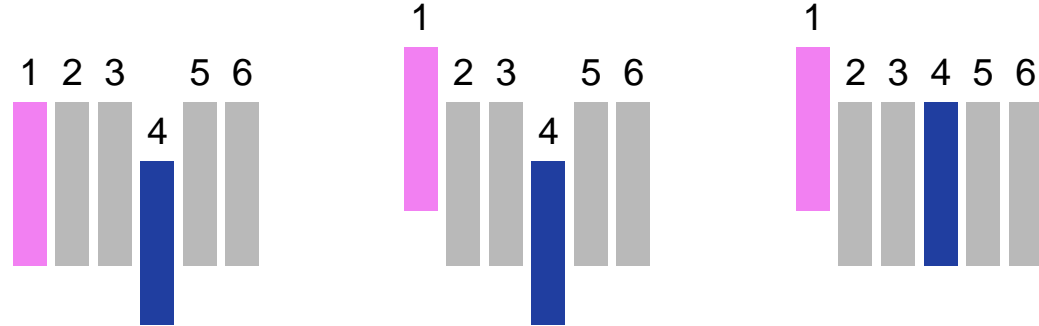


Control rod shift sequence

Reference state



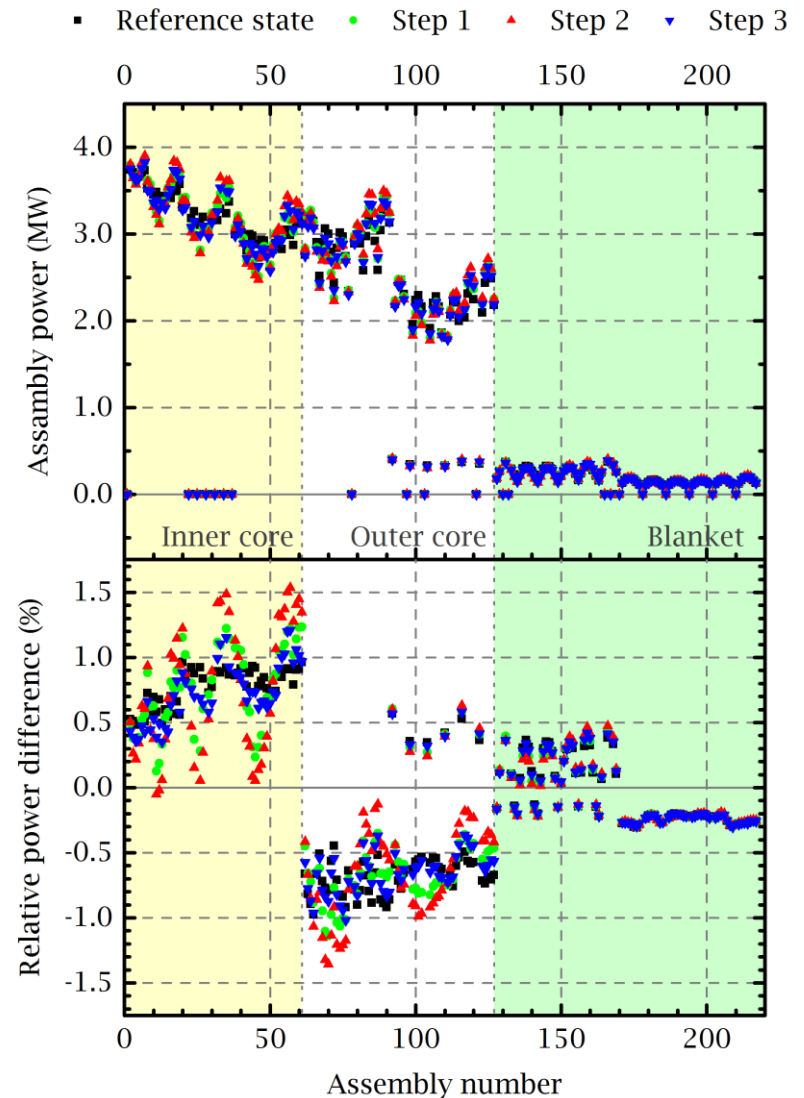
Control rod shift sequence



Results: Serpent vs. DYN3D

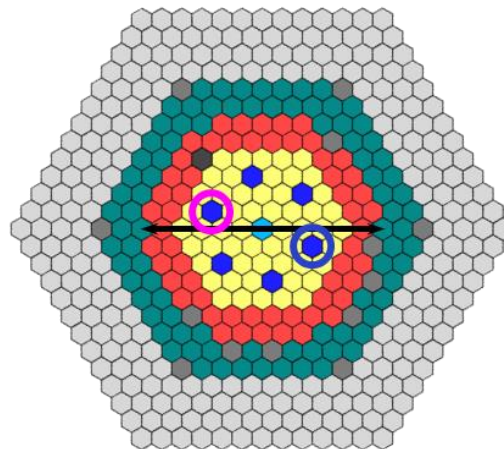
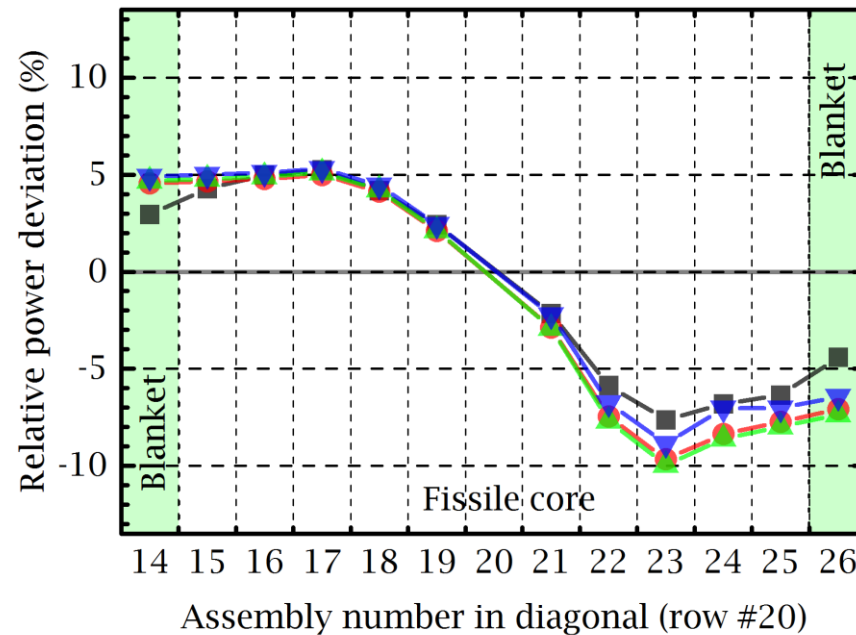
ρ , pcm	Serpent, pcm	Serpent vs. DYN3D
Ref. state	584 ± 2	162
Step 1	592 ± 2	157
Step 2	596 ± 2	161
Step 3	596 ± 2	165

Radial power	Ave. diff (%)	Max diff (%)
Ref. state	0.5159	0.9750
Step 1	0.5093	1.2344
Step 2	0.5020	1.5328
Step 3	0.4951	1.2114



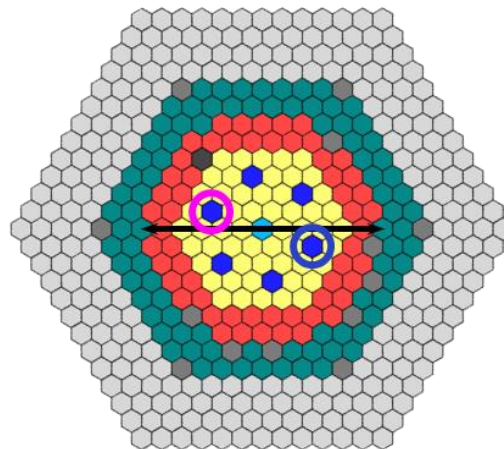
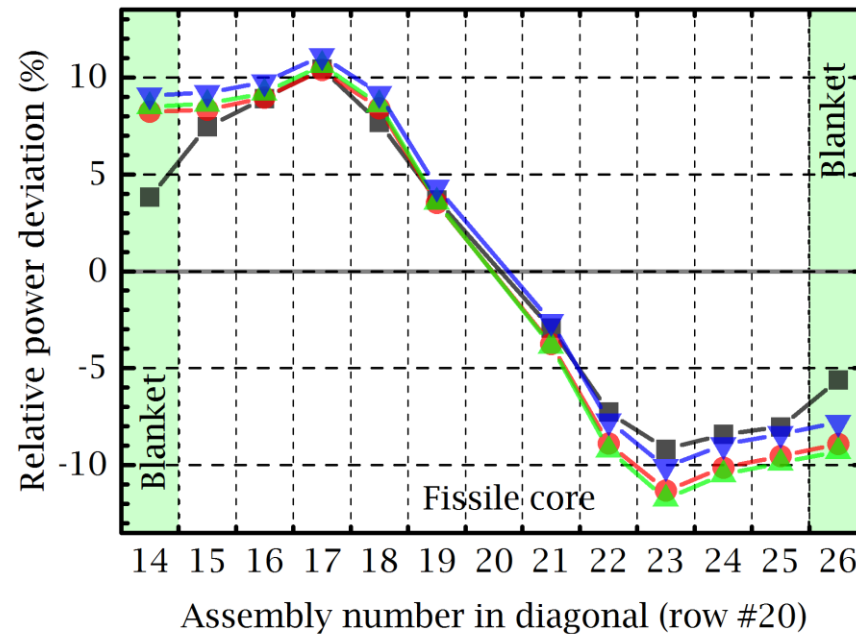
Results: Radial power shift - step 1

—■— Measured —●— Serpent —▲— DYN3D —▼— ERANOS (CEA)



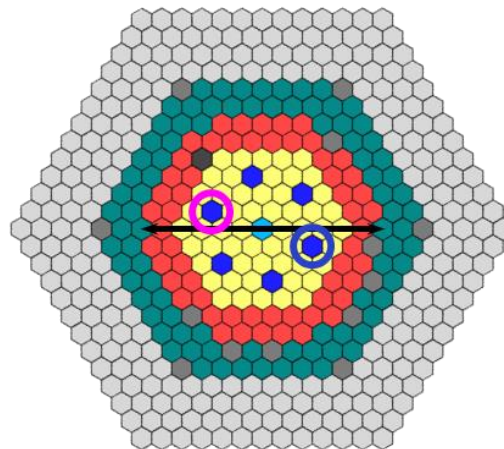
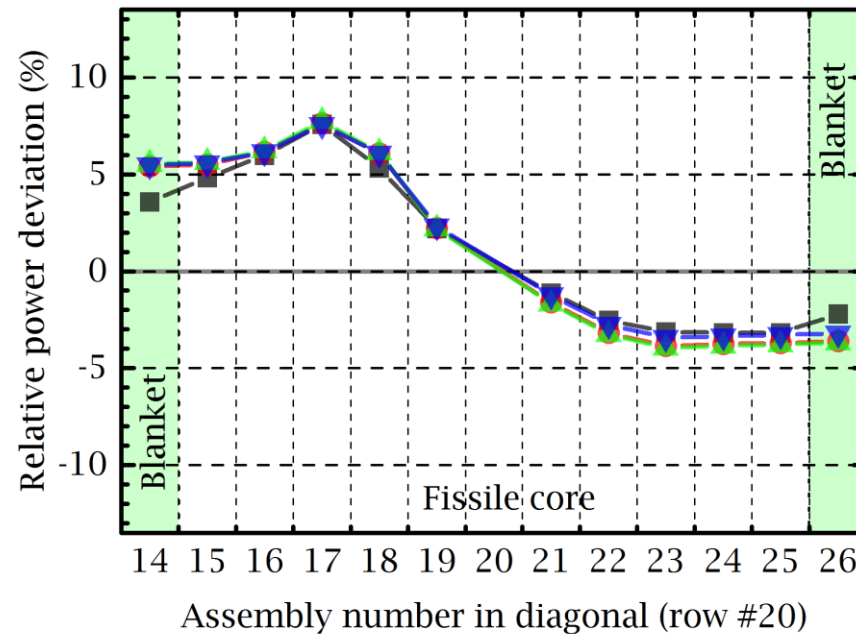
Results: Radial power shift - step 2

—■— Measured —●— Serpent —▲— DYN3D —▼— ERANOS (CEA)



Results: Radial power shift - step 3

—■— Measured —●— Serpent —▲— DYN3D —▼— ERANOS (CEA)



Summary: control rod shift test

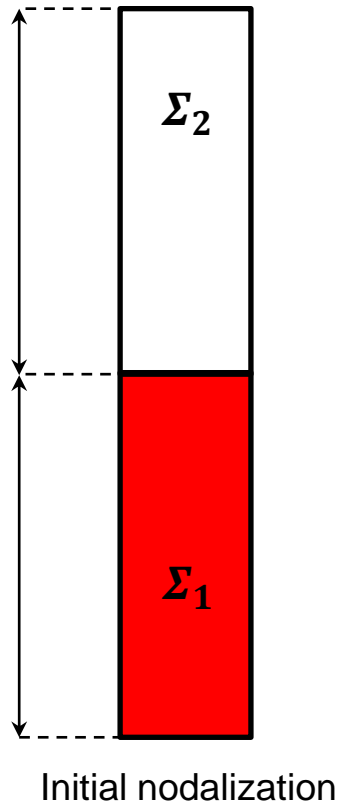
- Very good agreement between Serpent and DYN3D
 - About 160 pcm difference in k-eff
 - Up to 1.5% difference in radial power distribution
- Some discrepancies compared to experiment
 - Averaged core model: materials, burnup, temperatures

Thermal expansion models

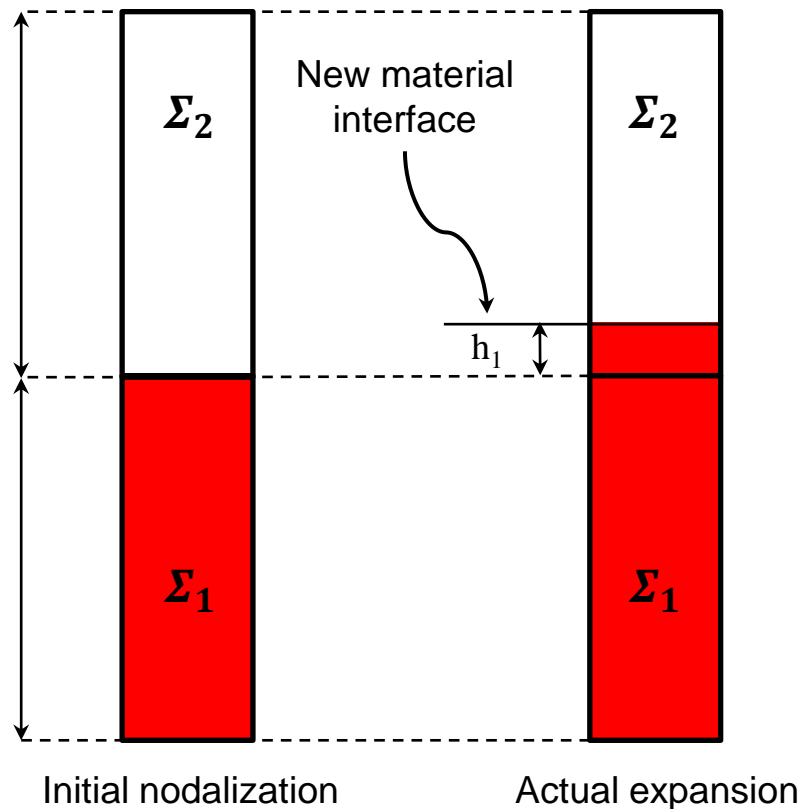
Axial thermal expansion of fuel rods

- Important negative reactivity feedback
 - Increased radial leakage
 - Reduced fuel density
 - Increased amount of sodium
 - Small insertion of control rods
- Driving temperature (assumption):
 - Fuel (open gas gap)
 - Cladding (closed gas gap)
- Fuel-performance code for more detailed modelling

DYN3D model for *axial* expansion of *fuel rods*

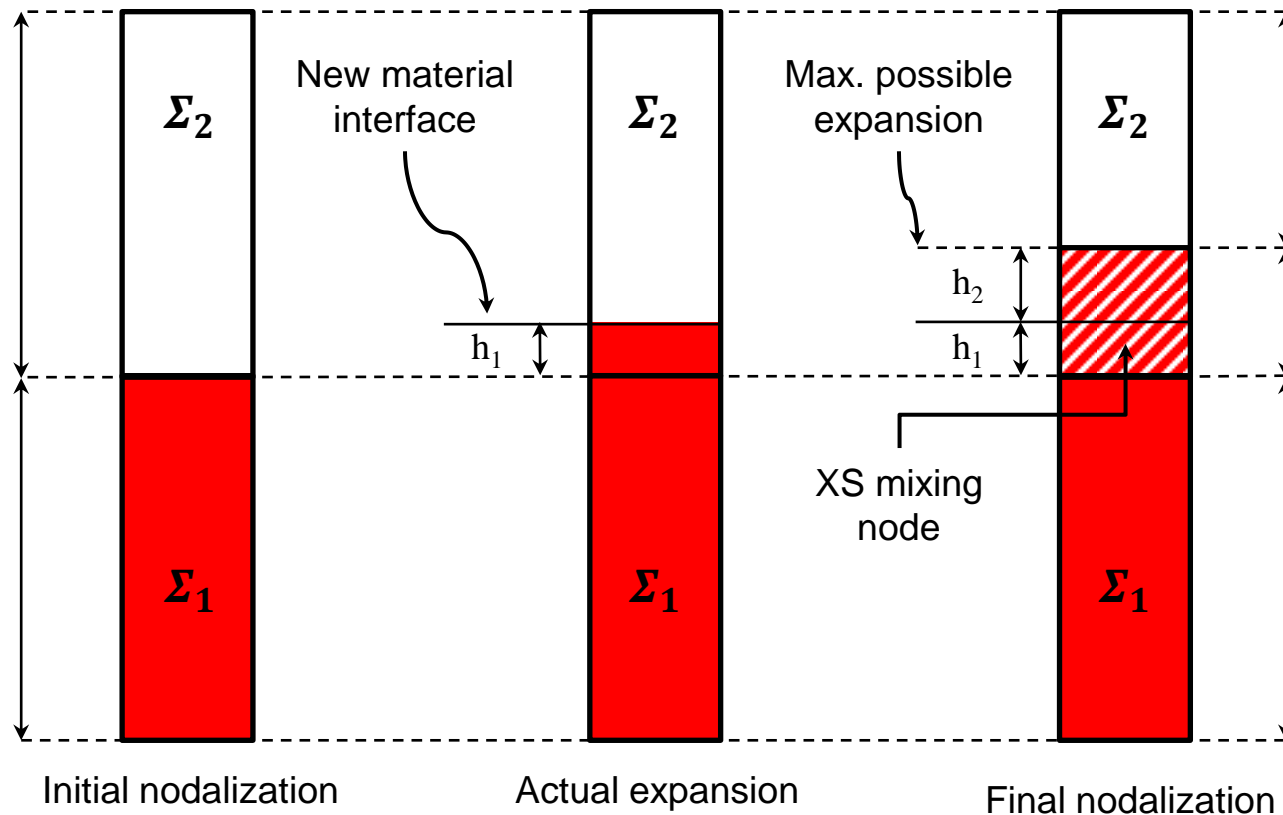


DYN3D model for *axial* expansion of *fuel rods*



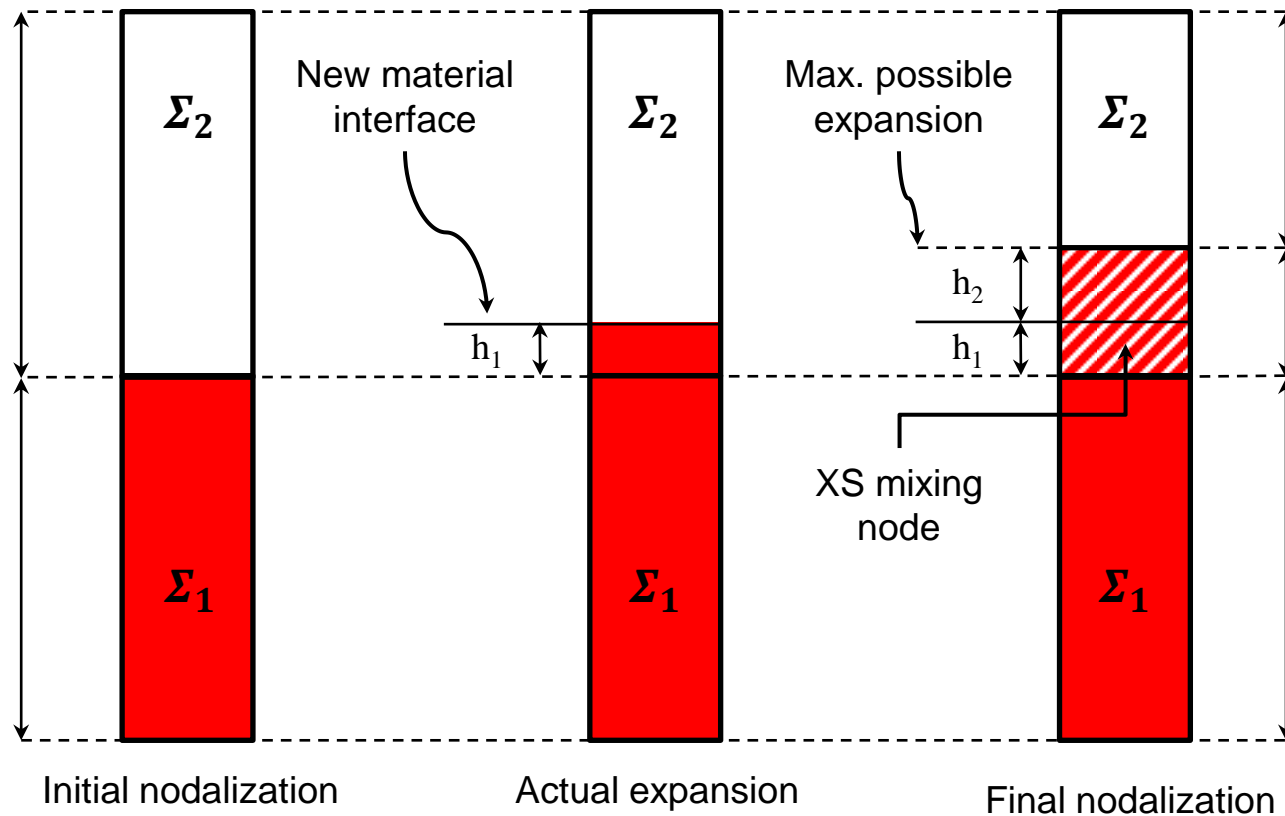
- Axial expansion is non-uniform and space-dependent
- Nodal code restriction \rightarrow Same height for all nodes in one layer
- How to bypass this restriction?

DYN3D model for *axial* expansion of *fuel rods*



- Additional “mixing” node is defined
- **New** material interface **always** remains inside the “mixing” node
- The materials are **(re)homogenized** based on the relative height

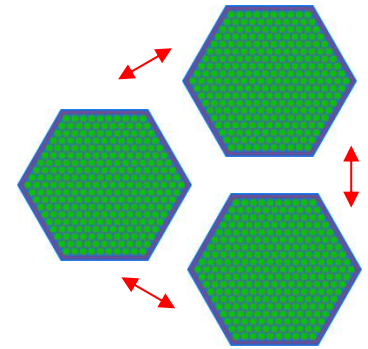
DYN3D model for *axial* expansion of *fuel rods*



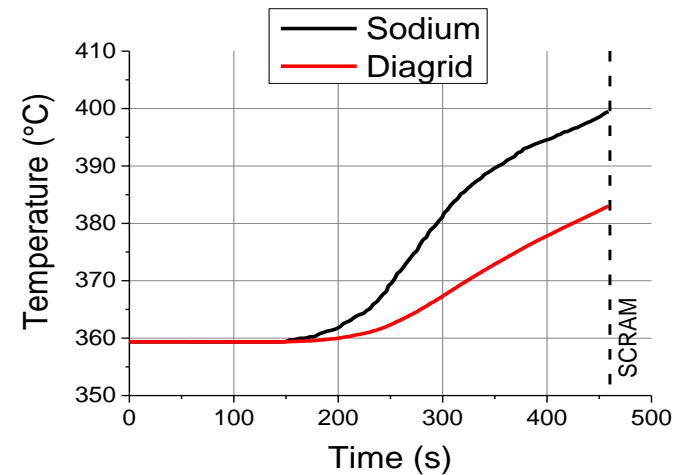
$$\Sigma_{mix} = \frac{h_1 \cdot \Sigma_1 + h_2 \cdot \Sigma_2}{h_1 + h_2}$$

DYN3D model for *radial* expansion of *diagrid*

- Diagrid expansion
 - Radial expansion increases the assembly pitch size
 - More sodium between assemblies
 - Increased radial dimensions
 - Negative feedback
- Assumption
 - Driven by the average inlet coolant temperature
 - Sub-assembly pitch size expands uniformly
- Model for DYN3D
 - Adjusting pitch size at each time step
 - XS parametrized with relative diagrid expansion
 - 1D heat structure model for the time delay



**Representation from Konstantin Mikityuk (PSI)*



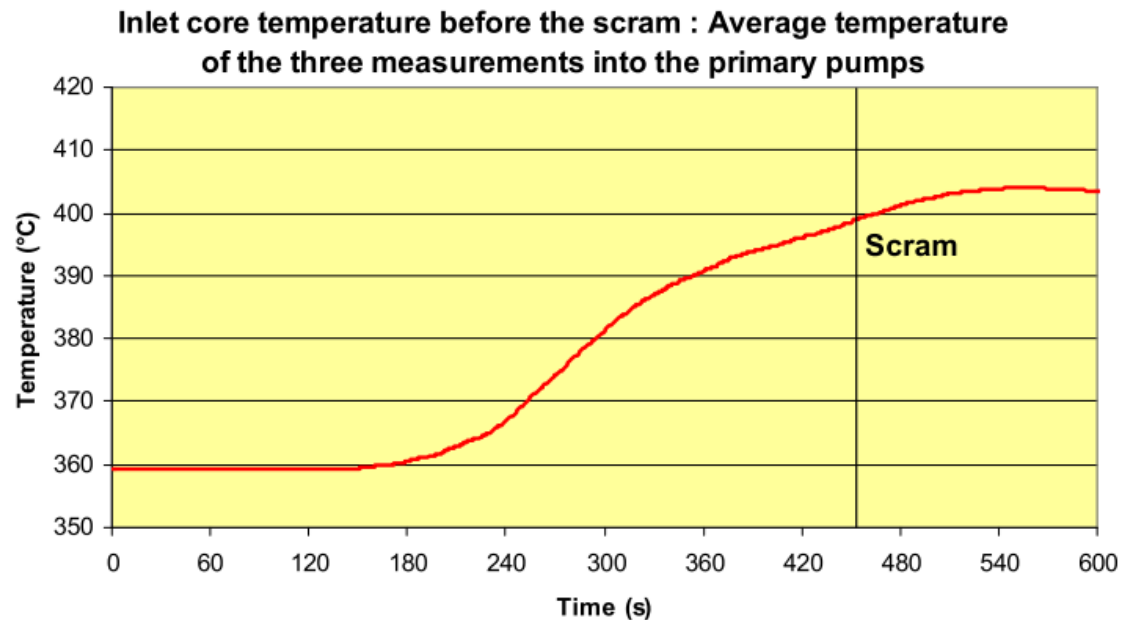
Summary: Expansion models

- Axial fuel rod expansion
 - Based on fixed mesh and volume weighted XS mixing
 - All SAs can be treated independently → Non-uniform profiles
- Radial diagrid expansion
 - Uniform expansion model with average inlet temperature
 - Dynamically changing pitch size Verified for steady states
 - Heated structure for delayed heat-up

Initial phase of the natural convection test

Transient scenario

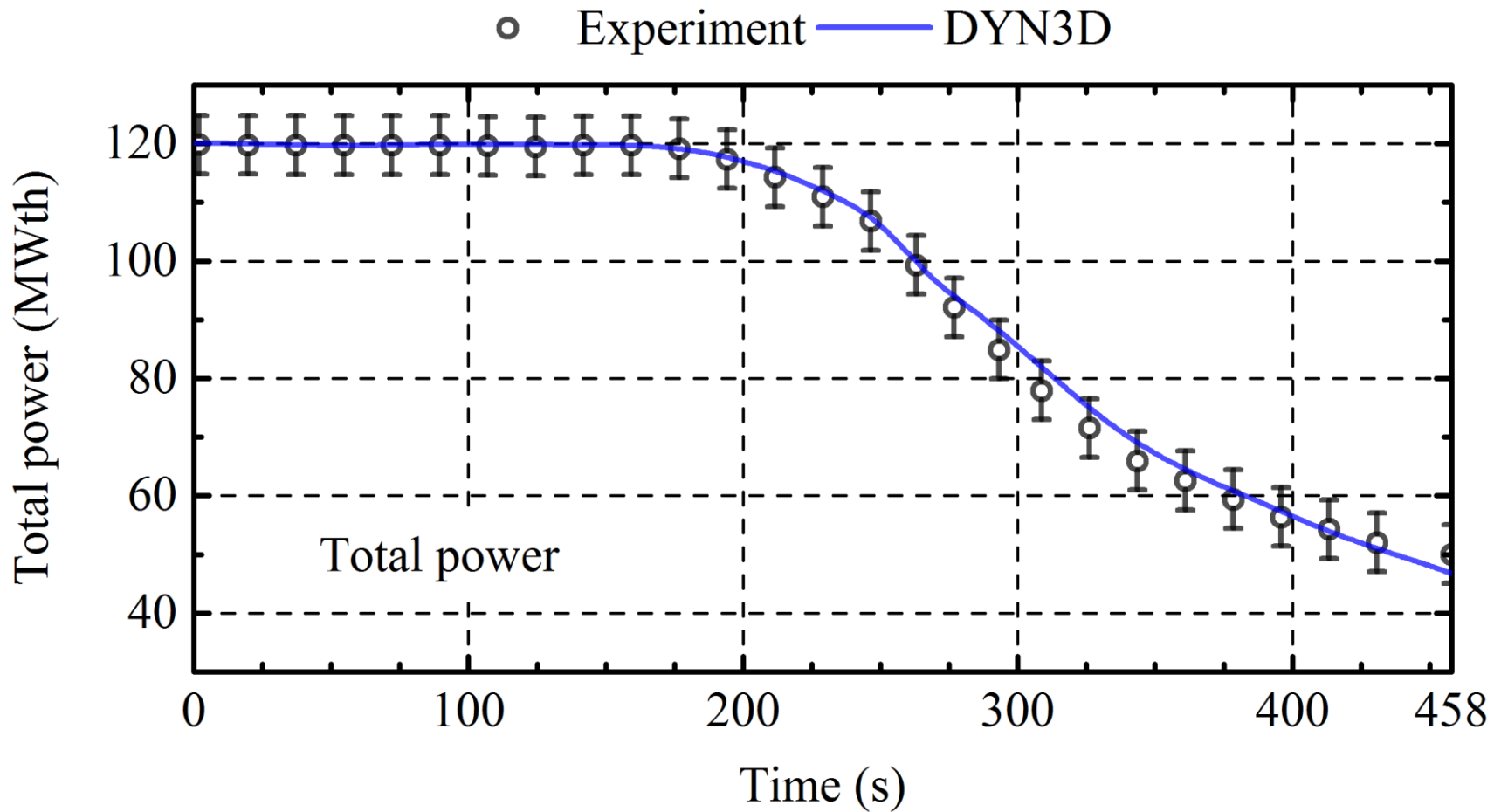
- Initial power = 120 MWth
- Dry out of steam generators at $t=0$ s, SCRAM at $t=458$ s
- Increase in inlet sodium temperature (no heat sink)
- Constant mass flow rate



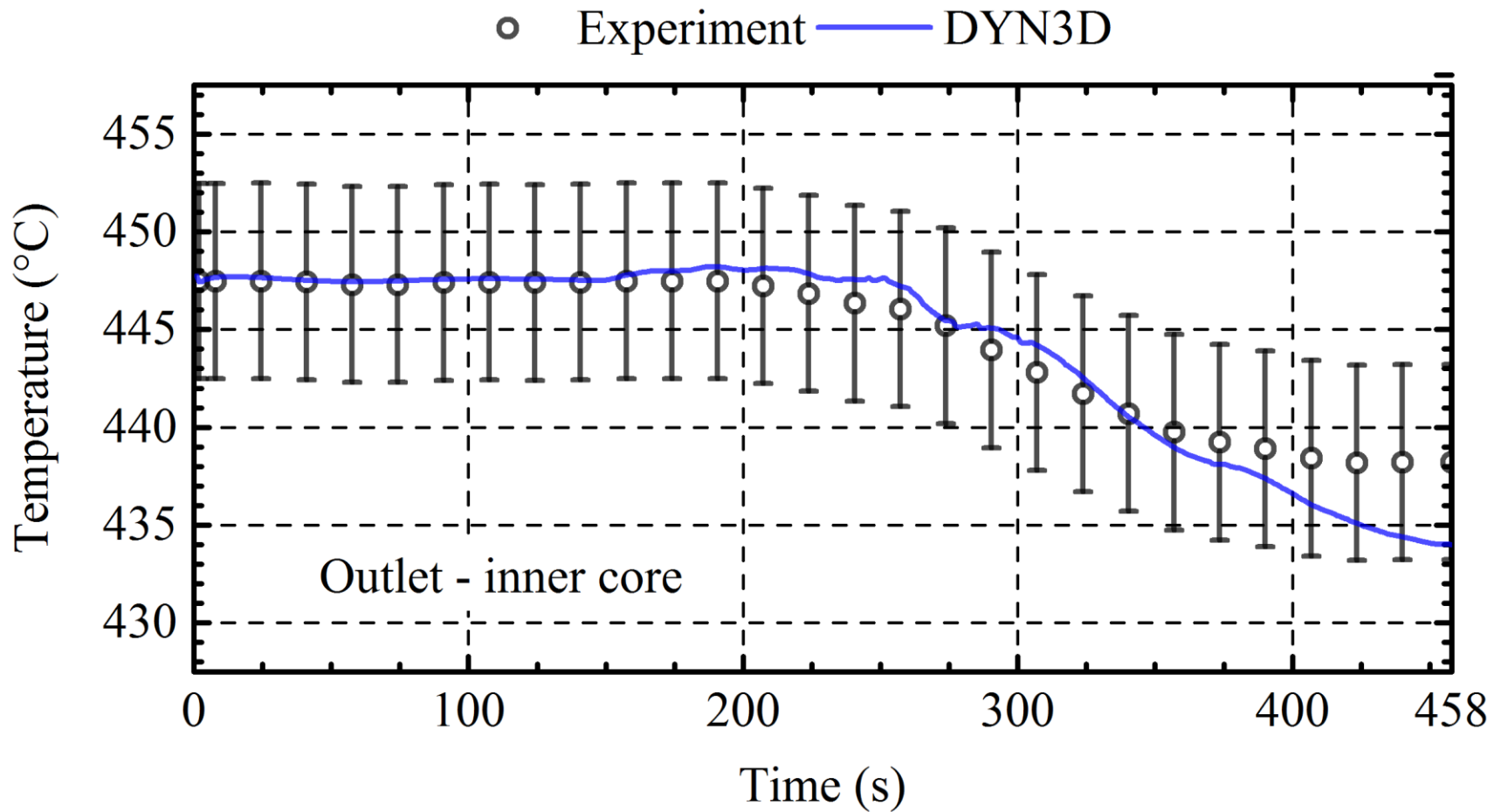
Modeling with Serpent-DYN3D

- Core only
- Perturbed BC : time-dependent inlet Na temperature
 - Given in the benchmark
- XS dependencies:
 - Fuel temperature
 - Sodium temperature
 - Axial expansion
 - Radial expansion

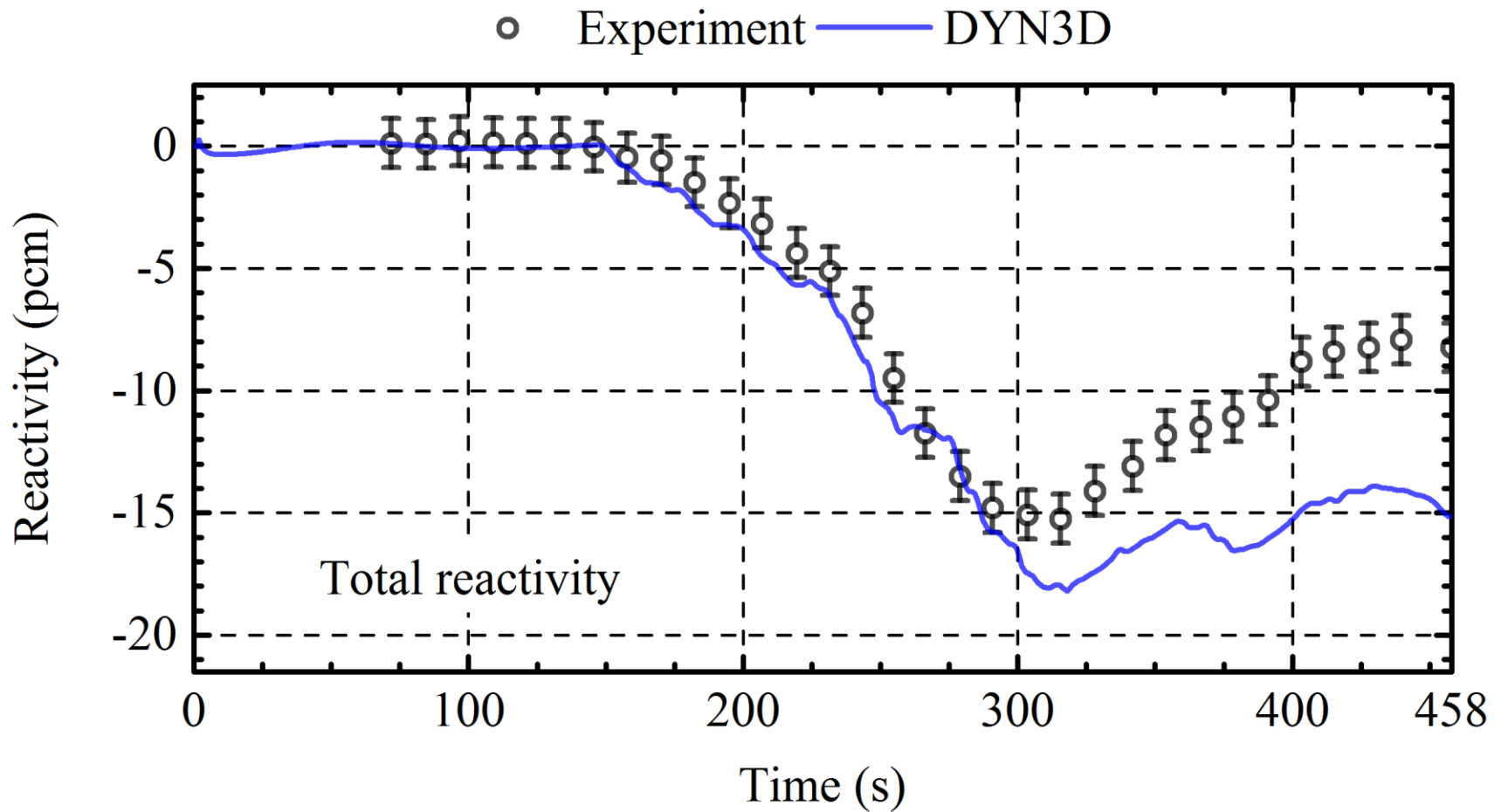
Results: Total power



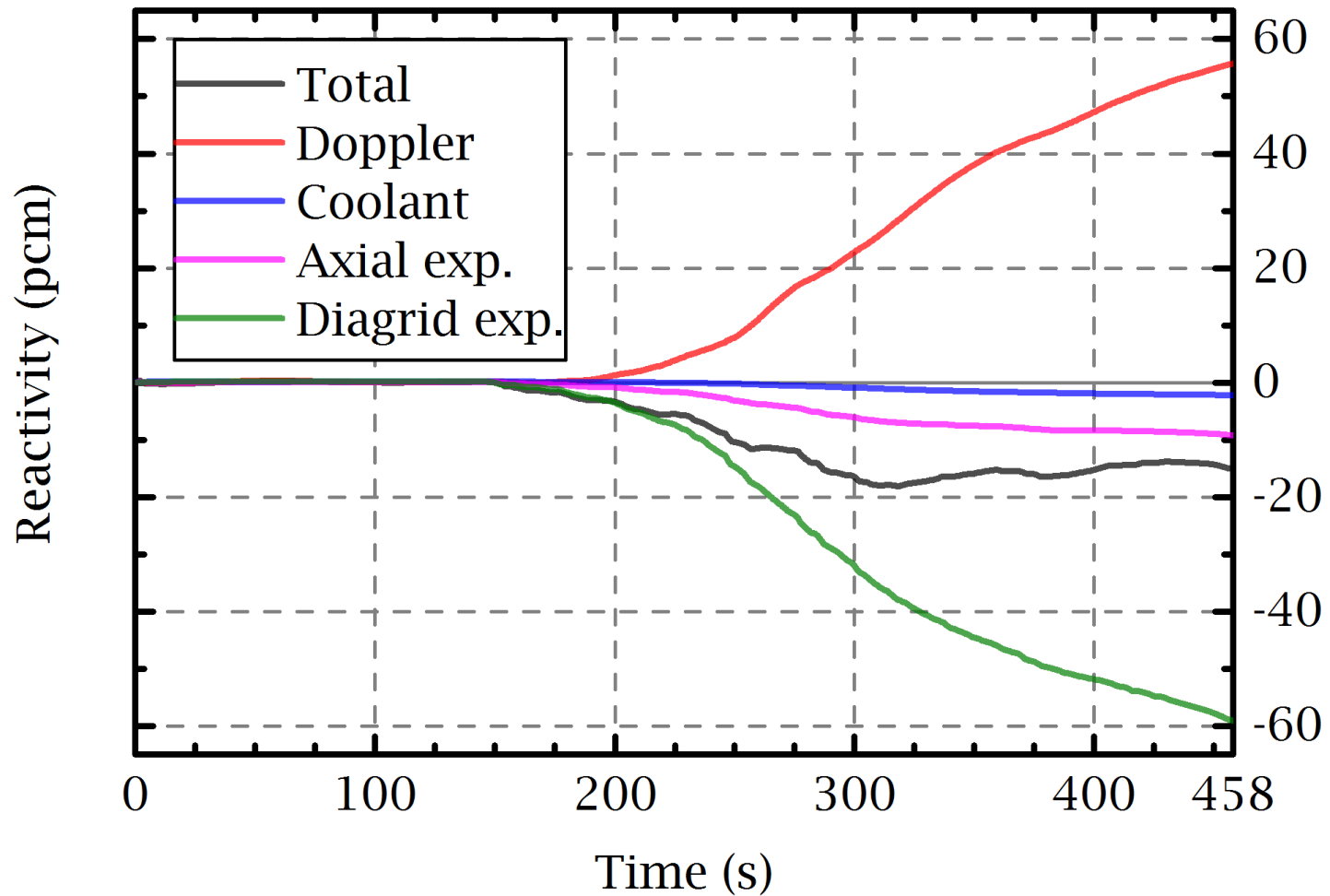
Results: Outlet Na temperature



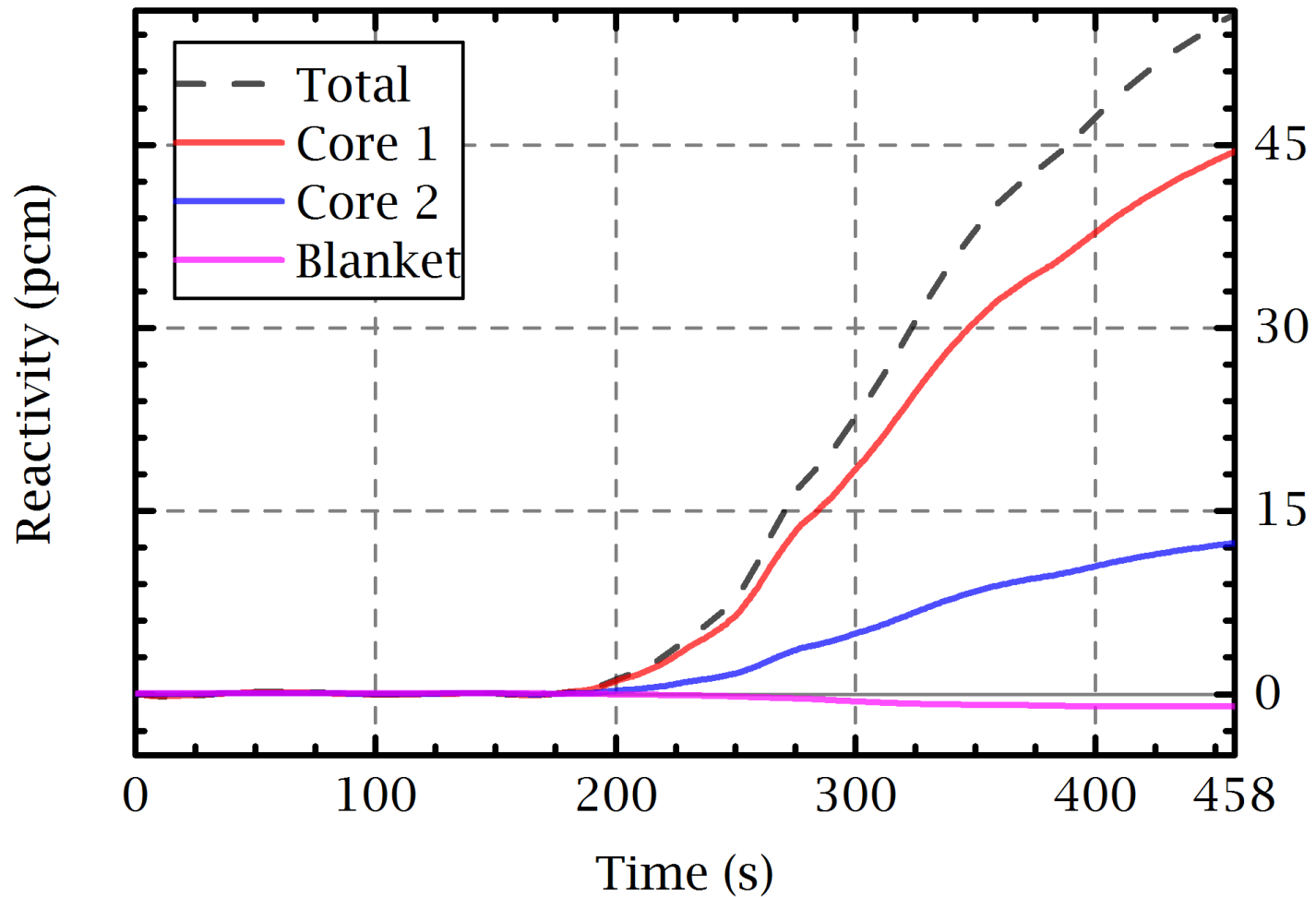
Results: total reactivity



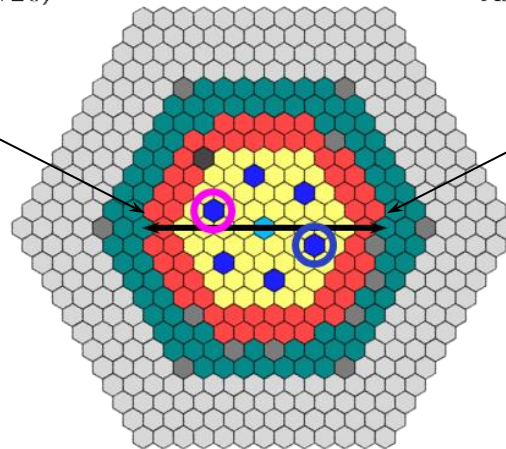
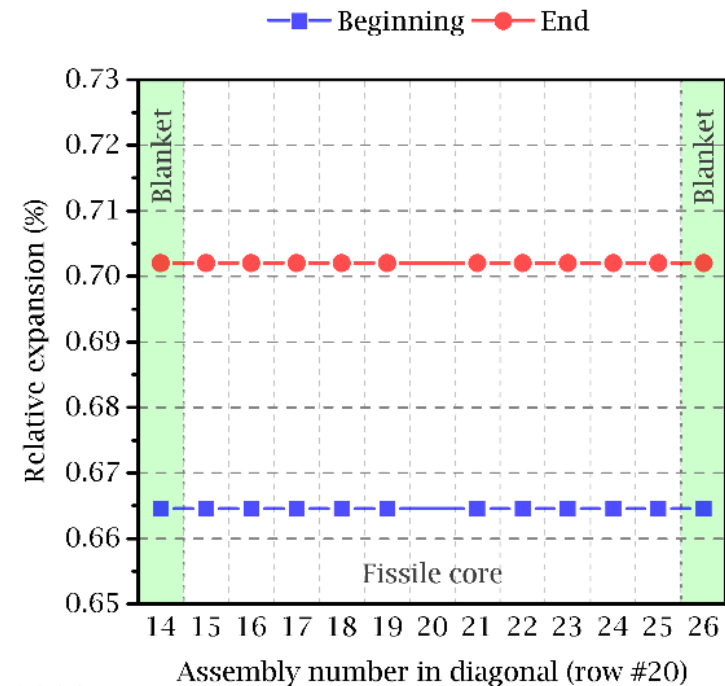
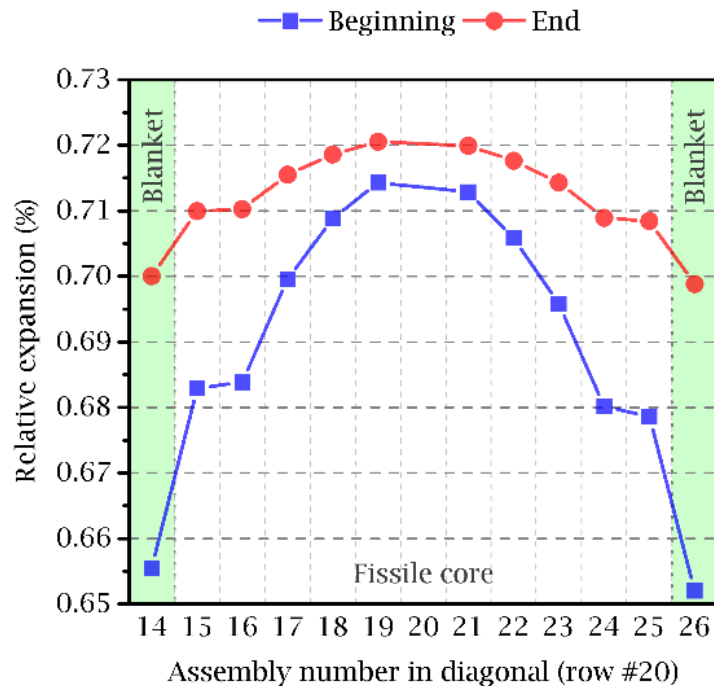
Results: reactivity decomposition



Results: Doppler reactivity per region



Results: Axial expansion profiles non-uniform vs. layer-uniform



Summary: Initial phase of natural convection test

- The expansion of the diagrid is the driving feedback
- The expansion of fuel rods is also important
- Good agreement in total power and outlet temperatures
- Good agreement in reactivity
 - Until vessel starts expanding

Ongoing work

- Coupling DYN3D with the system code ATHLET
- Modeling of the primary circuit
- Accounting for additional thermal expansion effects
 - Control rod drive line
 - Vessel
 - Strong back
- Further validation using Superphenix start-up tests

Thank you