ESFR-SMART
sodium fast reactor safety

Modeling core deformations and related reactivity effects in SFRs

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Event:	Serpent UGM
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Where:	TUM, Garching

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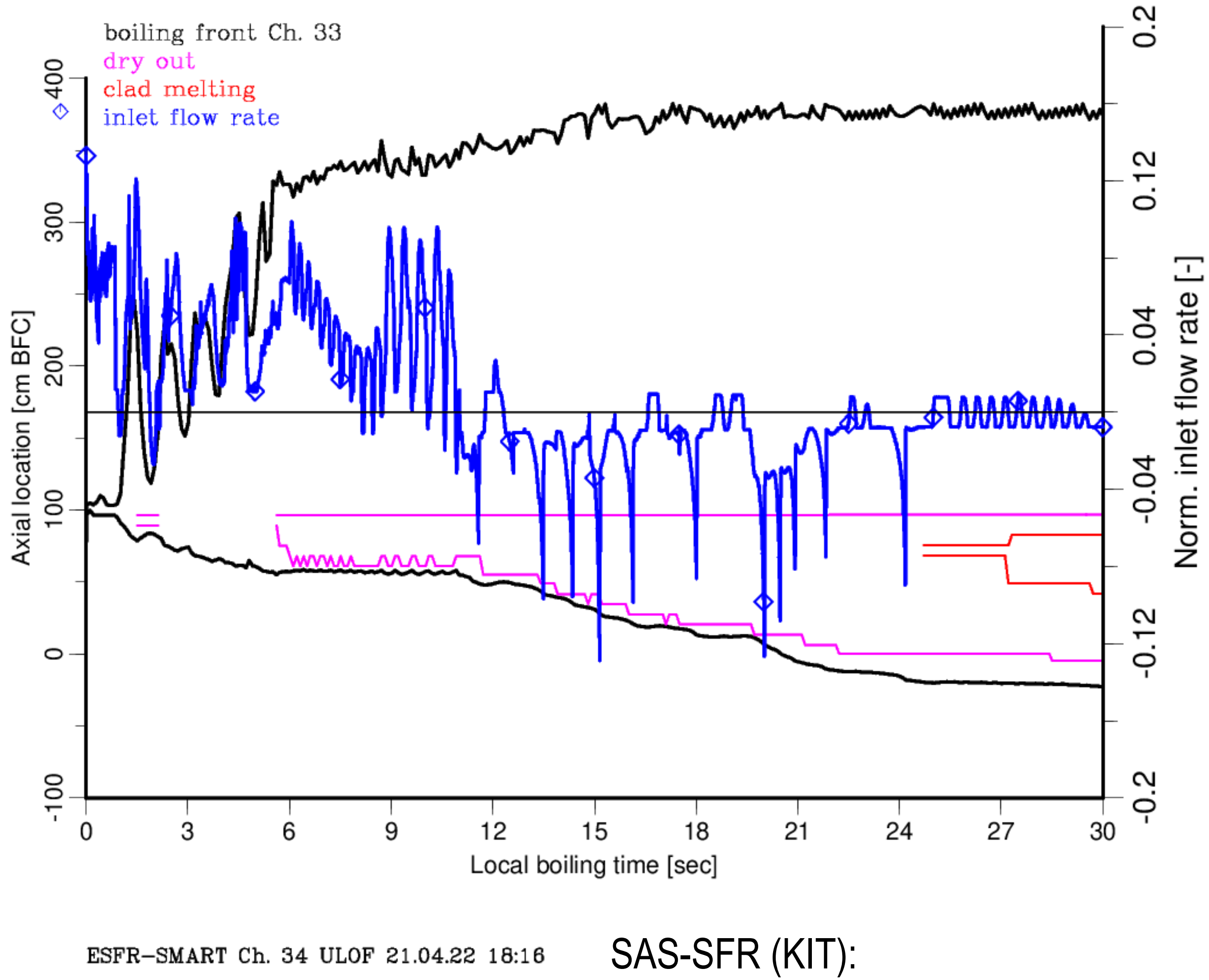
Outline

- Motivation and goals
- Methods to model reactivity effects cause by core deformations
- Application to the Phenix core

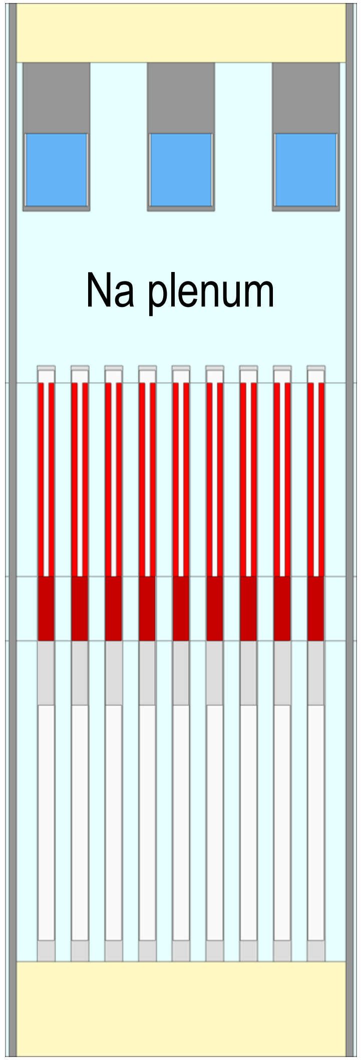
ULOF in SFR: boiling, dry-out and clad melting fronts



SAS-SFR (KIT):

Motivations

- ESFR fuel SA design
  - No upper fertile blanket
  - Large sodium plenum
  - Upper neutron absorber



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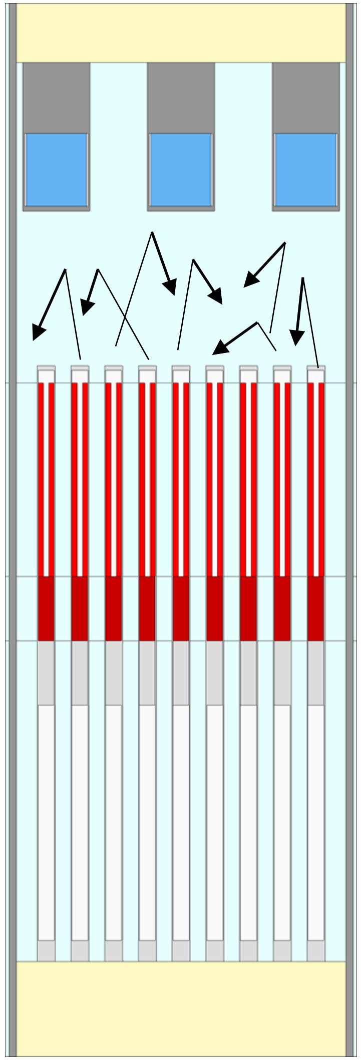

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- ESFR fuel SA design
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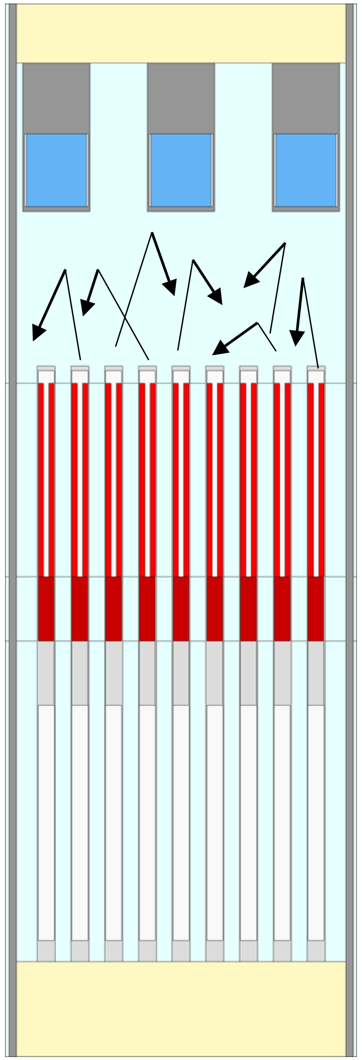
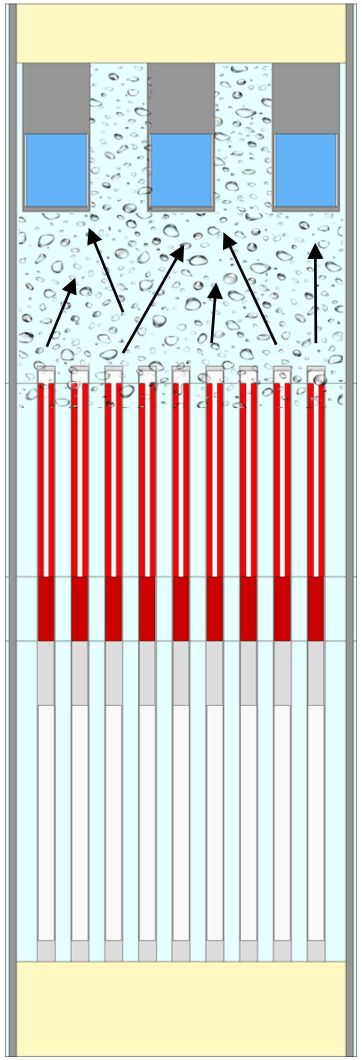
- In case of sodium boiling (e.g. ULOF)
  - Reduced reflection towards active core
  - Increased leakage towards neutron absorber





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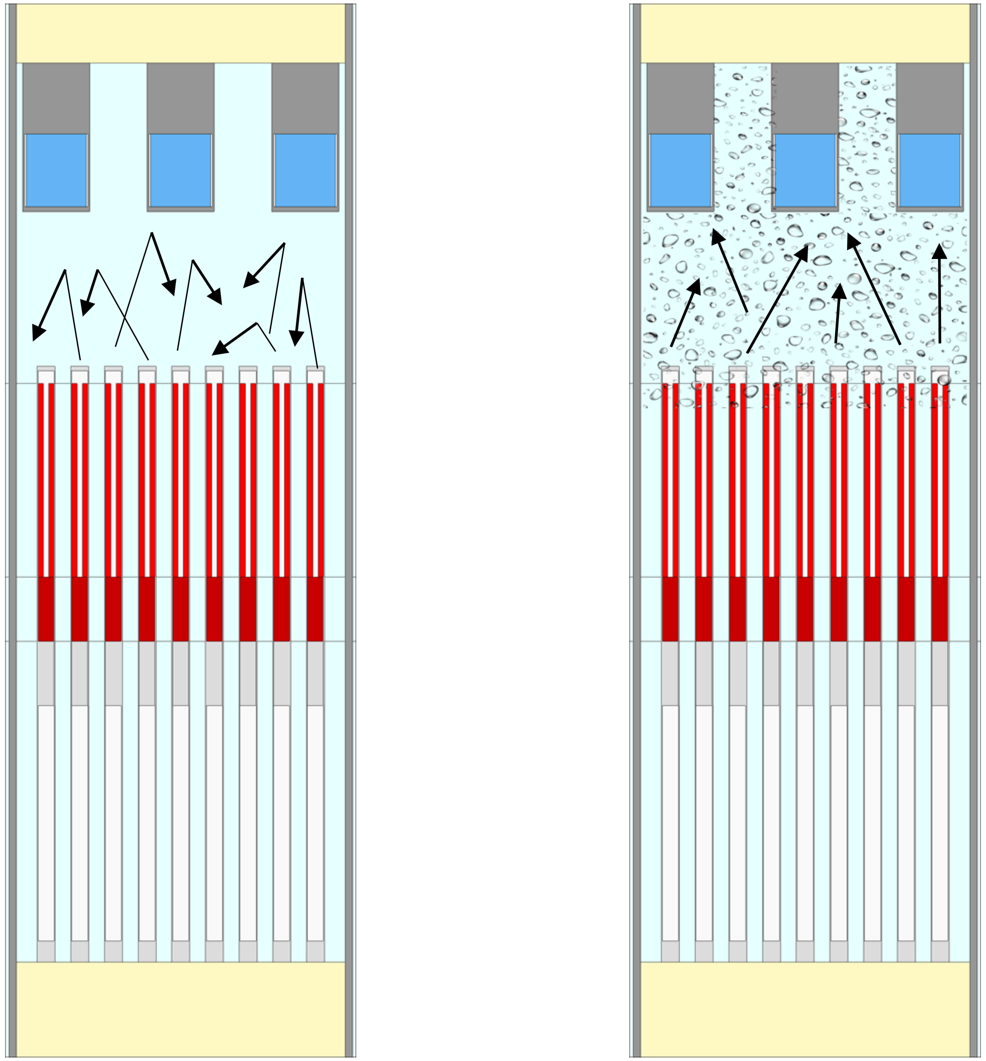
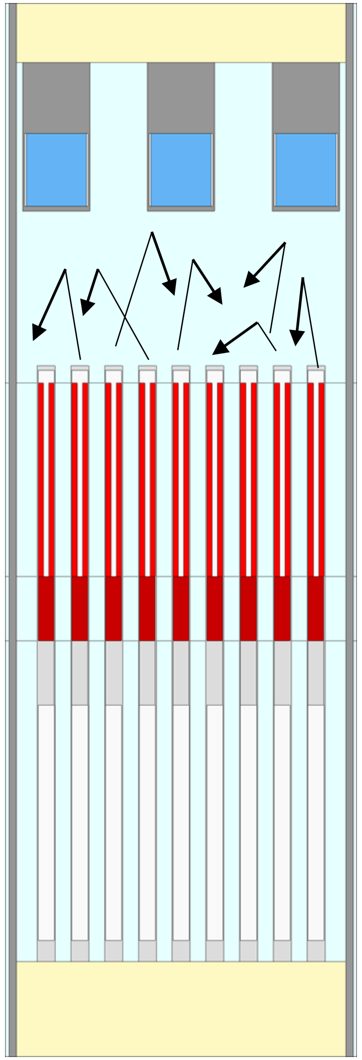
→low Sodium Void Reactivity Effect (SVRE)

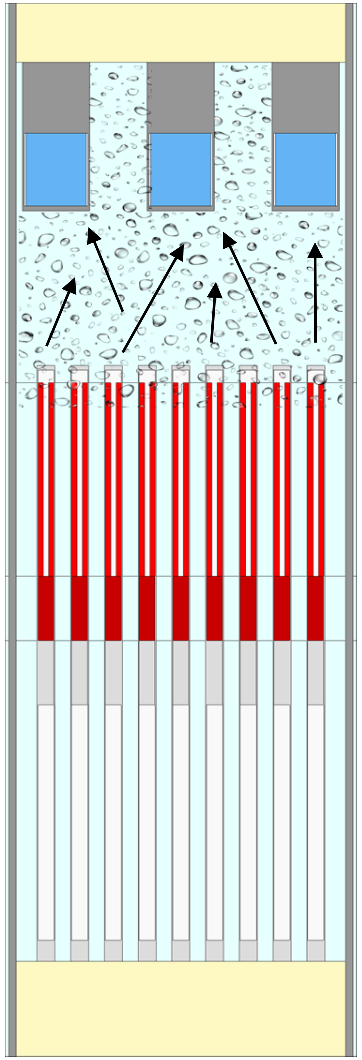


Motivations

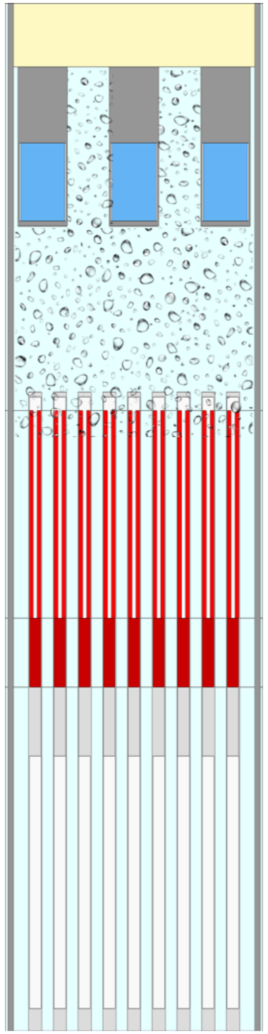
- Potential to stabilize reactor during ULOF
  - No reactivity excursion
  - No power runaway
  - Stabilized sodium boiling
  - No permanent dryout

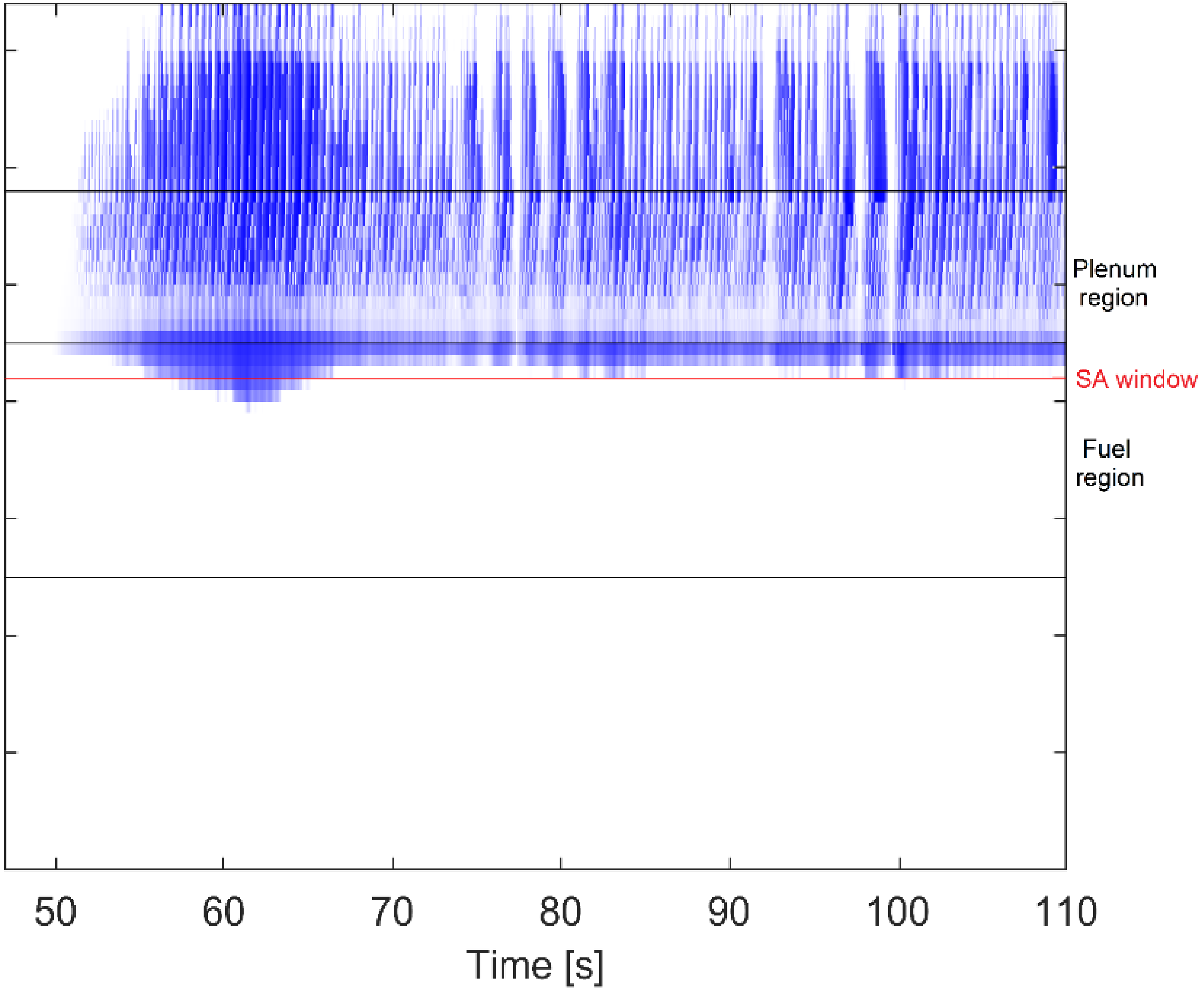
- Potential for the chugging boiling regime
  - Periodic generation / collapsing of the sodium vapor bubbles





Void fraction in fuel SA during ULOF





Goals

- Methods development

  → To estimate core geometry distortions

  → To evaluate corresponding reactivity effects

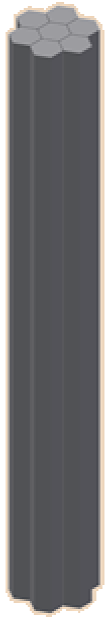
- Dedicated WP in the ESFR-SMART project

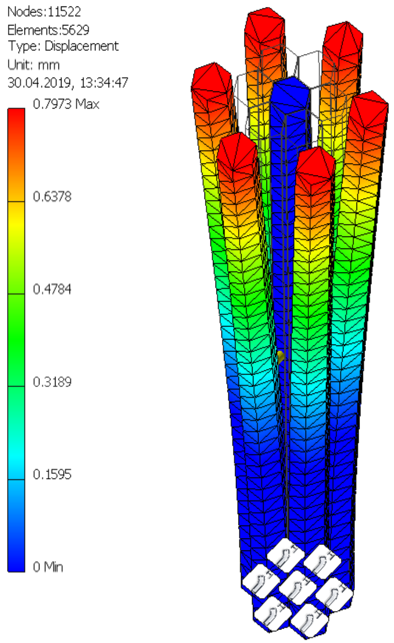
Modeling of mechanical core deformations (PSI)

- Based on NASTRAN finite element solver

CAD model

Finite Element Analysis with **NASTRAN**

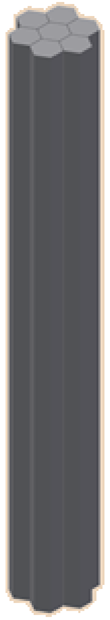


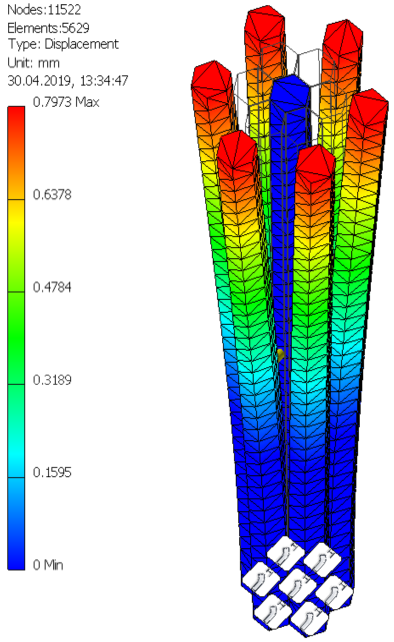


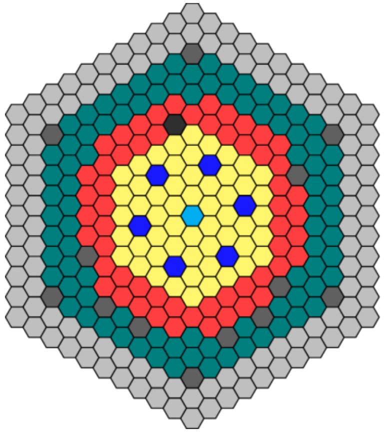
Modeling of mechanical core deformations (PSI)

- Based on NASTRAN finite element solver

CAD model → Finite Element Analysis with **NASTRAN** → Deformed geometry snapshots



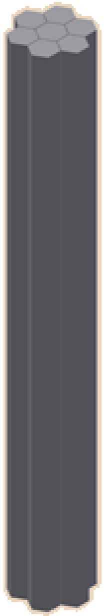


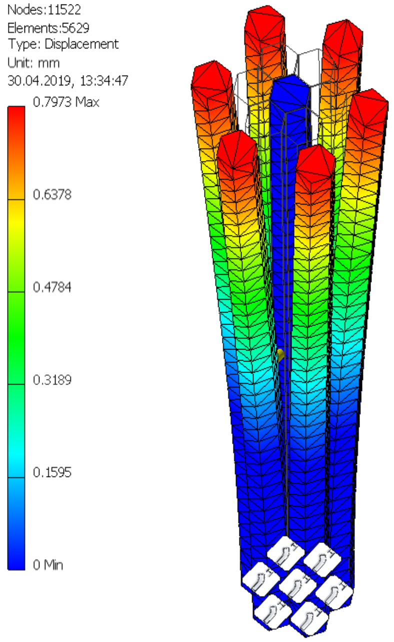


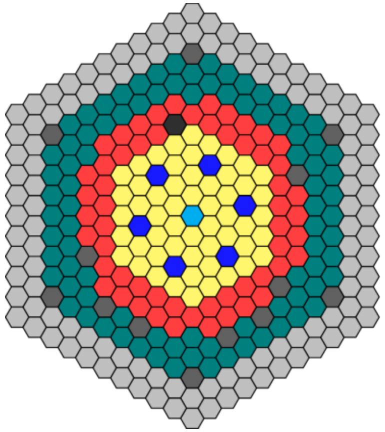
Modeling of reactivity effects (PSI)

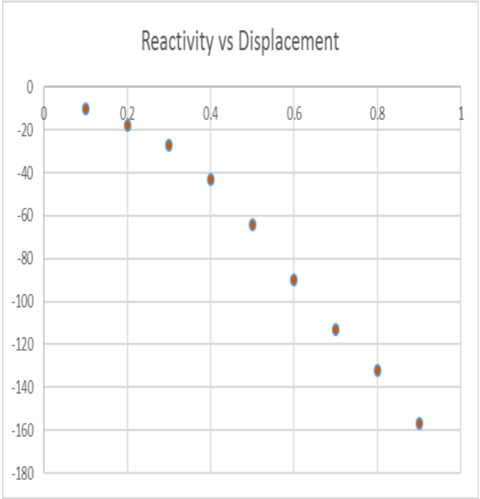
- Direct CAD-based Serpent simulations using NASTRAN geometry snapshots
- Reactivity coefficients for transient analysis with TH system code (coupled **0D** neutron kinetics/TH)

CAD model → Finite Element Analysis with **NASTRAN** → Direct Monte Carlo simulation with **Serpent** → Reactivity effects





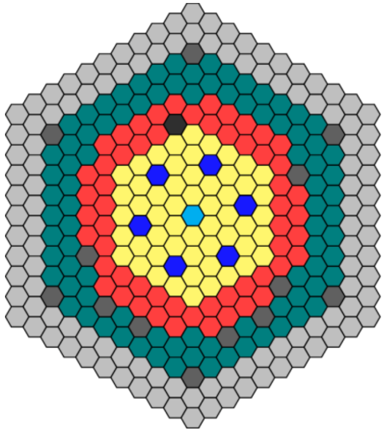


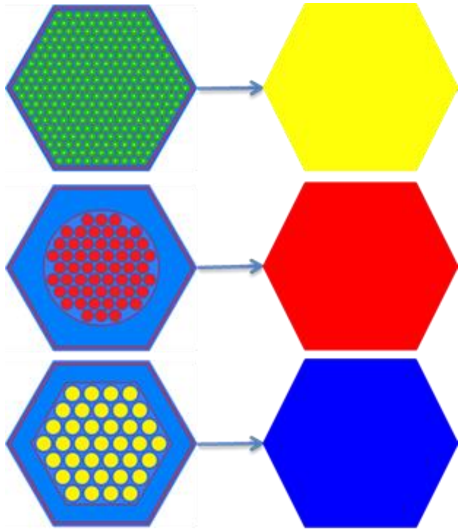


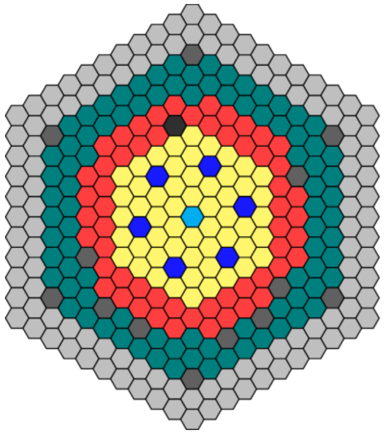
Modeling of reactivity effects (HZDR)

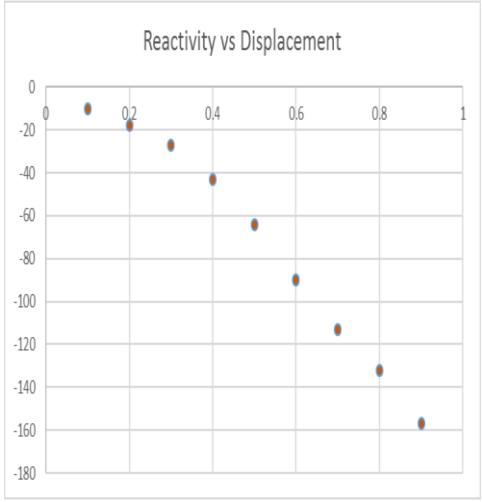
- Based on Serpent and DYN3D (nodal diffusion)
- Transient analysis with DYN3D (coupled **3D** neutron kinetics/TH)

Deformed geometry snapshots → Few-group XS with **Serpent** → Diffusion calculations with **DYN3D** → Coupled 3D NK/TH





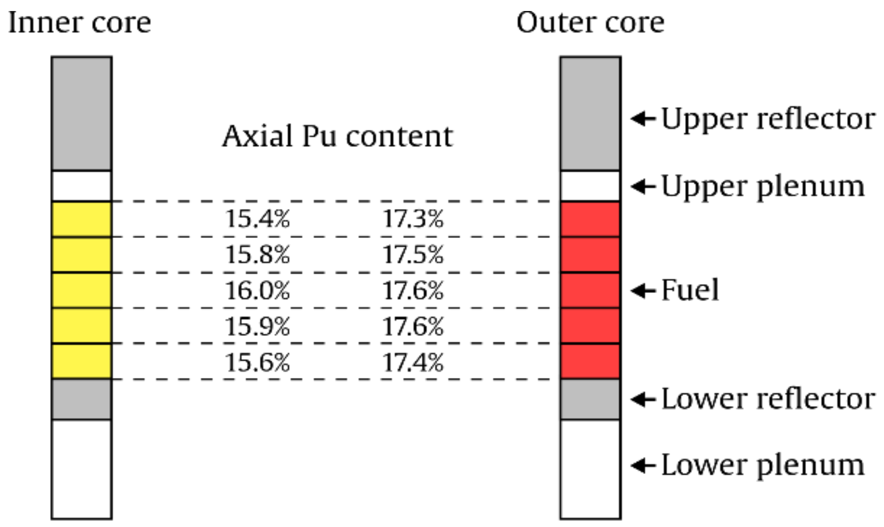


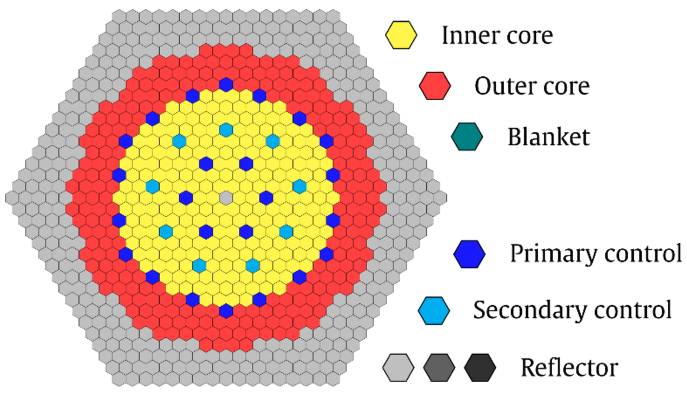


Modeling of non-uniform radial expansions in DYN3D

- Using coordinate transformation method
- Allows to model **non-uniform** expansion using a **fixed nodal mesh**
- Applicable to nodal diffusion codes like DYN3D and PARCS
- No need to change the diffusion solver
- Only few-group XS should be adjusted

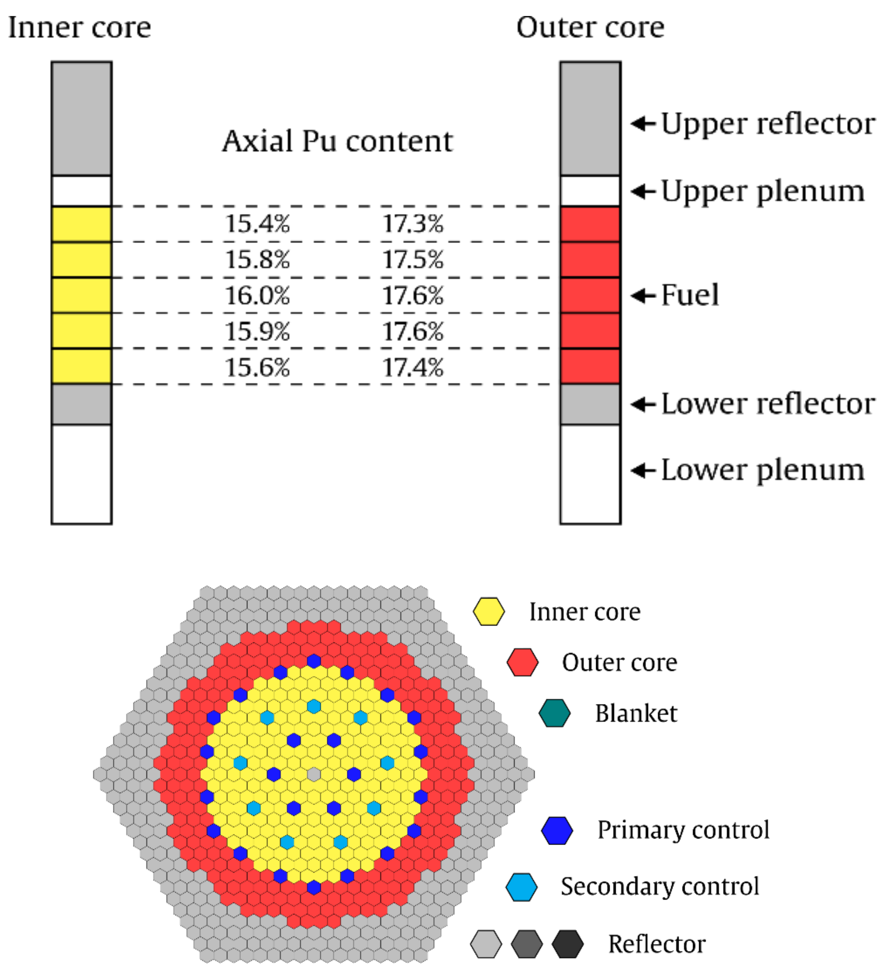
Verification of the coordinate transformation method



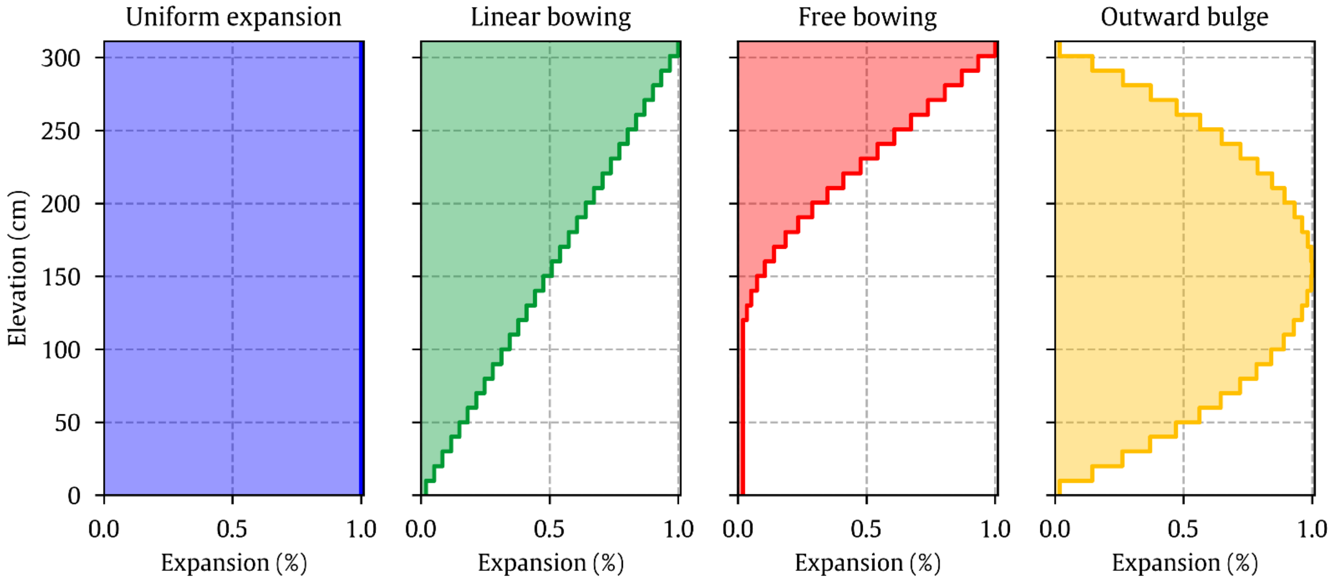


Radial layout

Verification of the coordinate transformation method

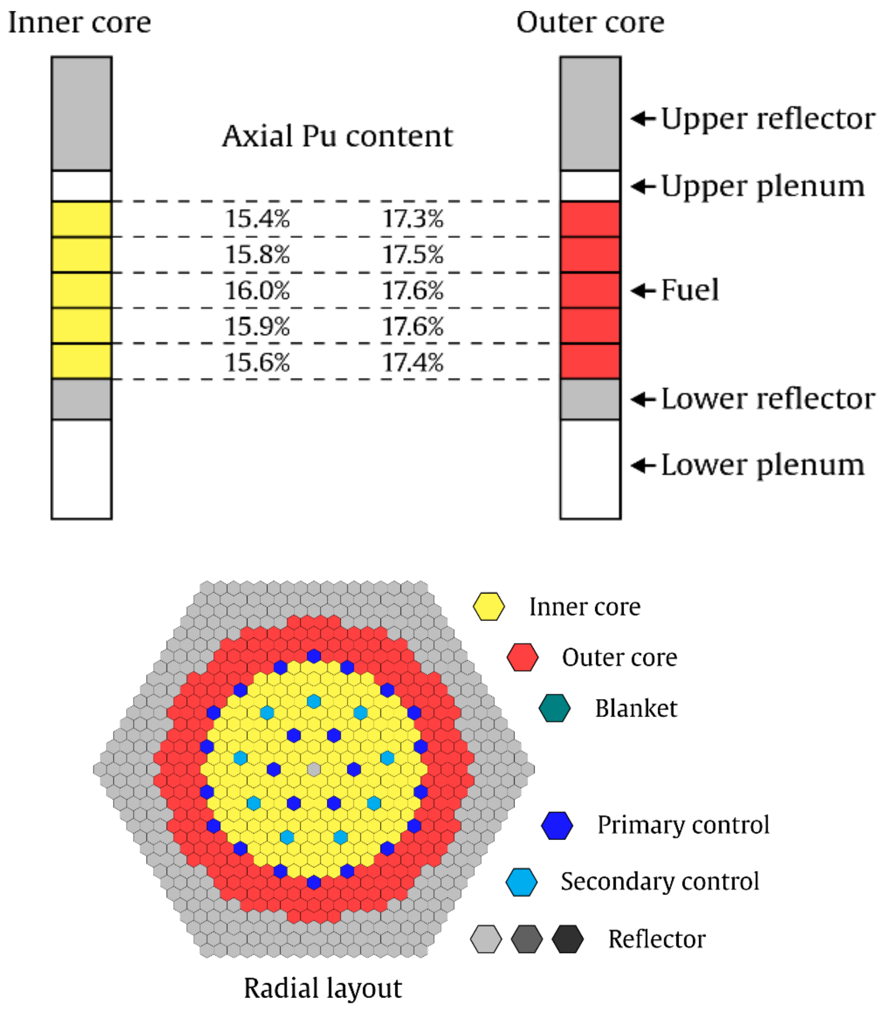


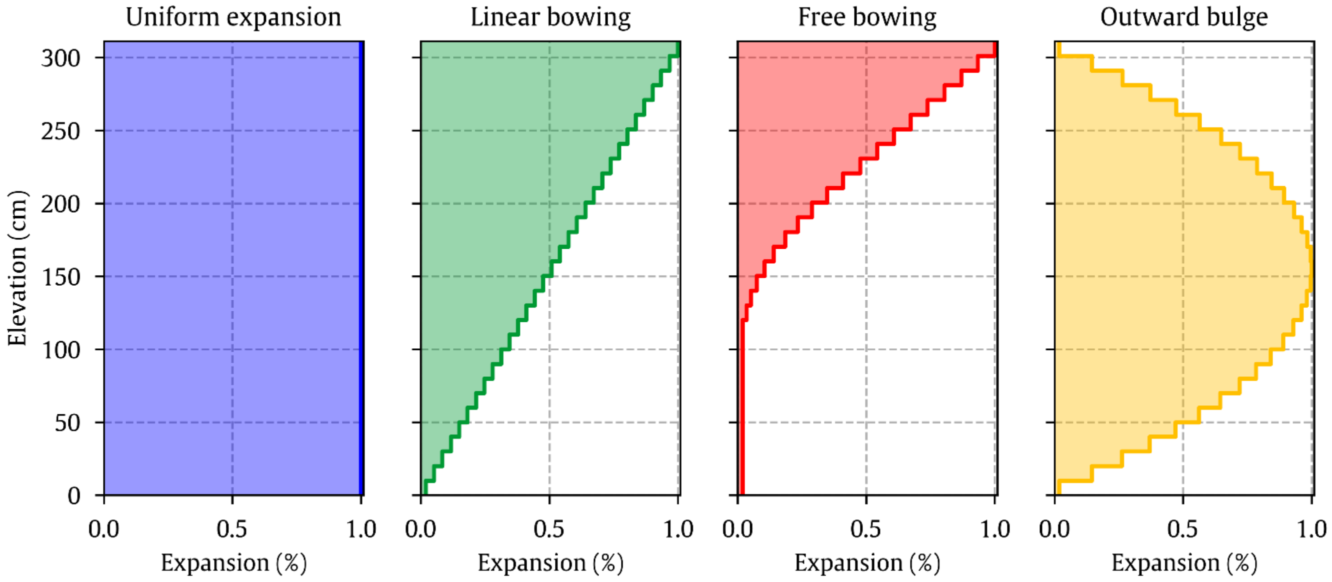
Radial layout



- Verification of DYN3D vs. Serpent
- Serpent: realistic geometry deformations
- DYN3D: fixed mesh + coordinate transformation

Verification of the coordinate transformation method





	Uniform	Linear bowing	Free bowing	Outward bulge
Serpent, pcm	-425	-230	-70	-405
DYN3D, pcm	-413	-223	-65	-398
$\Delta\rho$, pcm	12	6	4	7

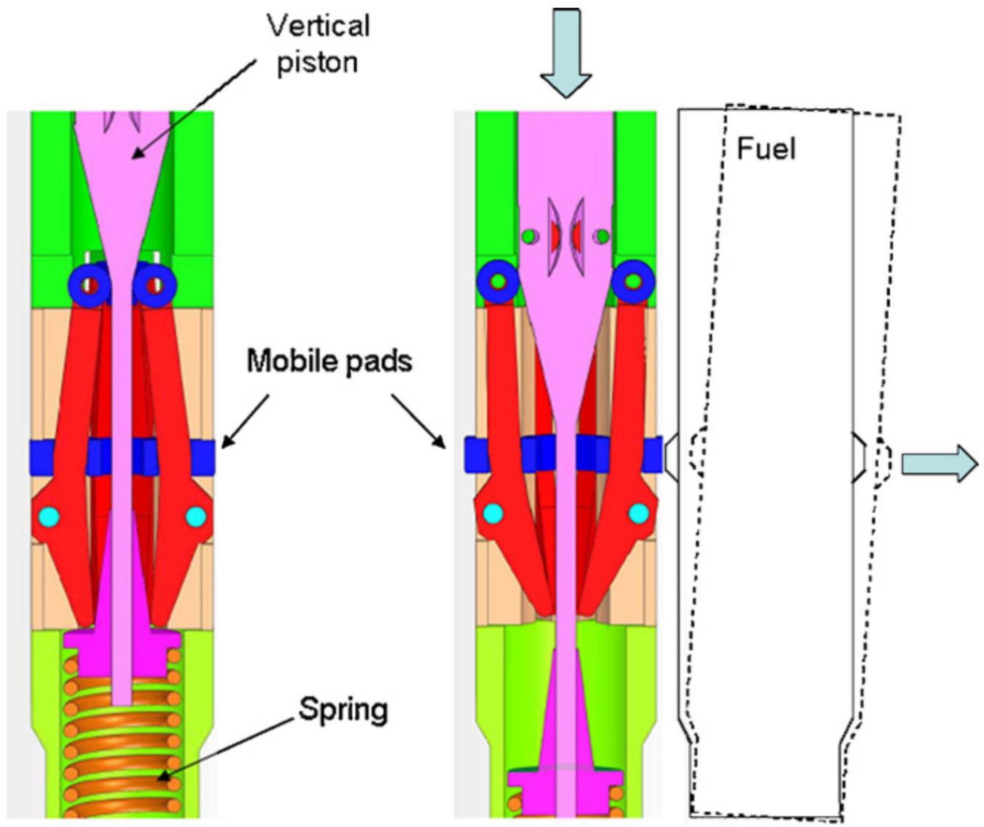
Test cases

- Steady-state analysis of the Phenix “flowering” tests

- Transient analysis of the postulated Phenix core deformation case

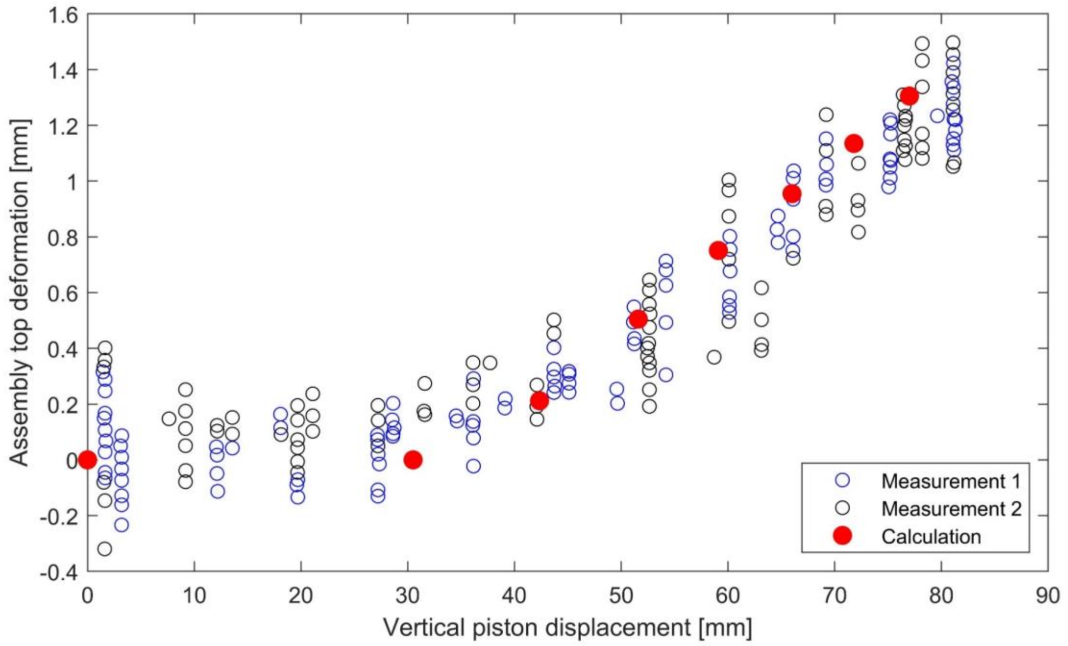
Validation using Phenix “flowering” tests

- Mechanical tests were conducted on the Phenix EOL core
- Identify potential reasons for “AURN”:
  - “Arrêt d’Urgence par Réactivité Negative”
  - 4 reactivity events at Phenix
- Step-wise deformations introduced by “flowering” device
- Reactivity effects were measured for every step
- The test was simulated with NASTRAN/Serpent



Validation using Phenix "flowering" tests

Displacement of the measured fuel assembly simulation vs. measurement



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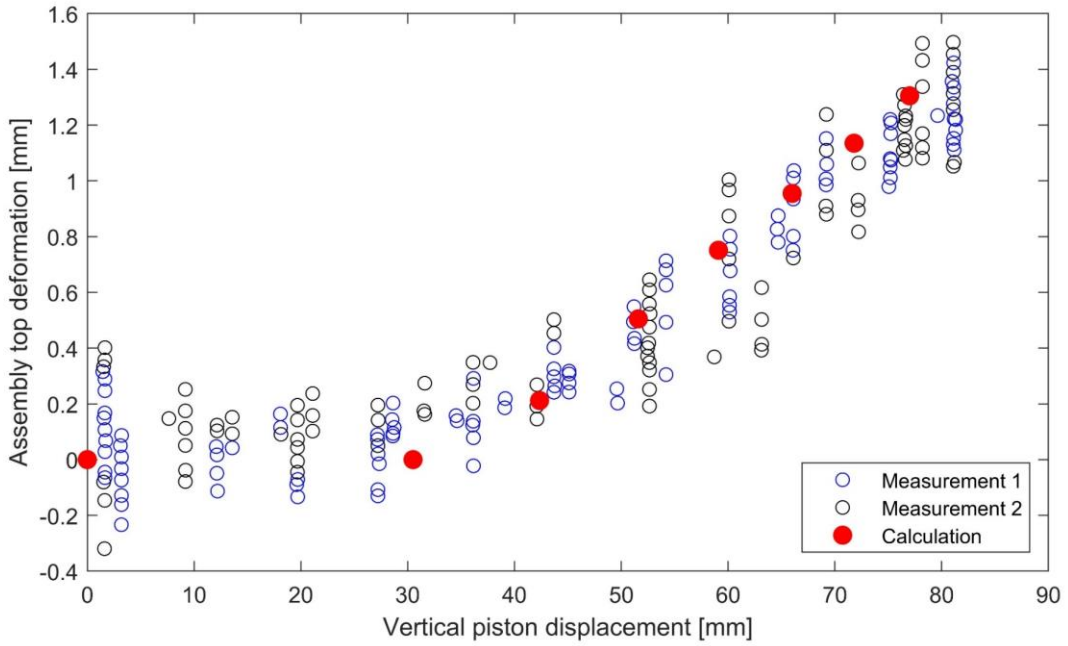
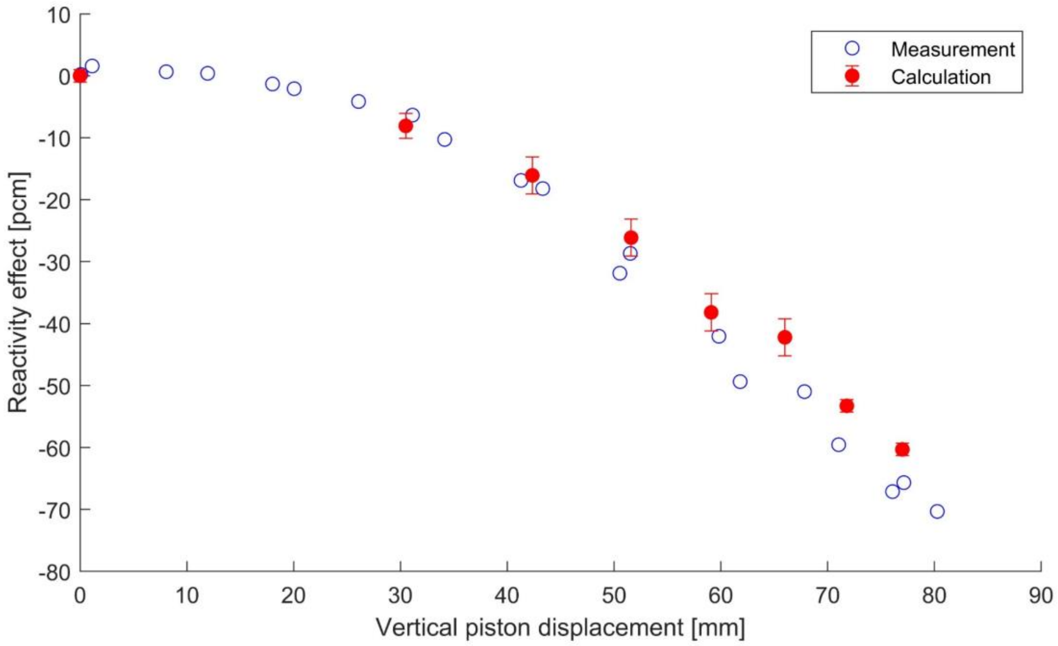
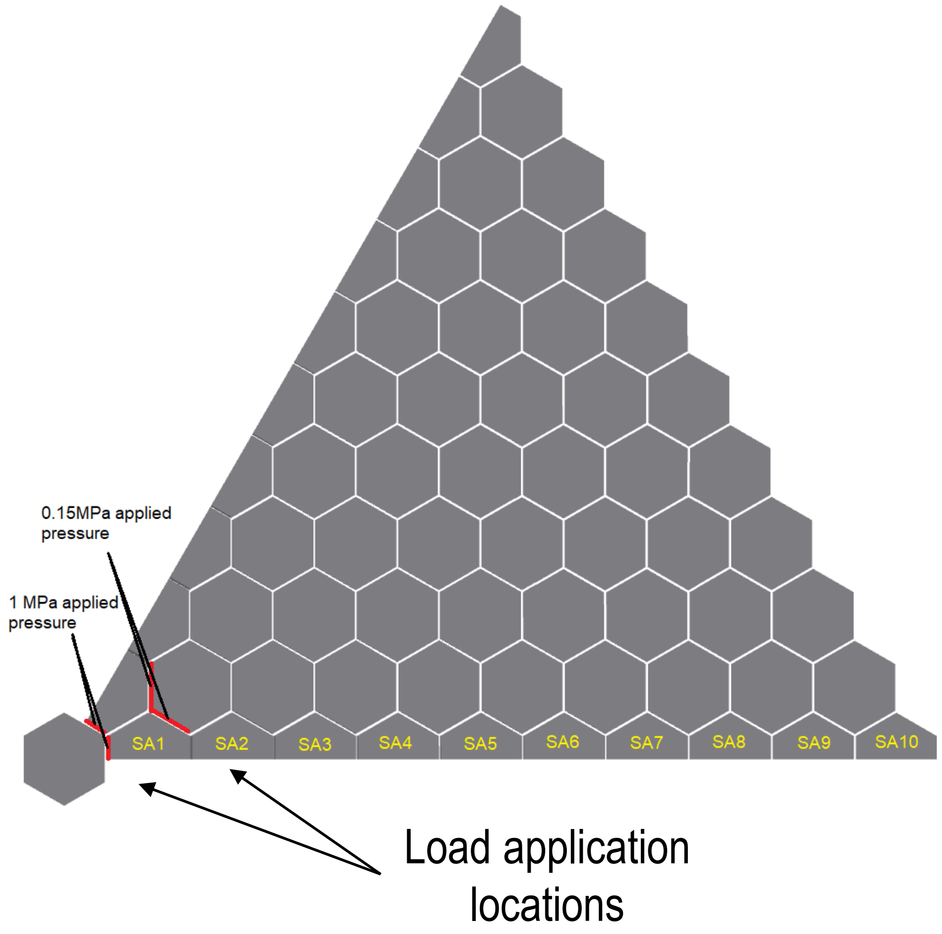


Global reactivity effect of the “flowering” simulation vs. measurement



Phenix transient analysis: Postulated scenario

- Core deformations due to pressure waves
  - 1 MPa pikes due to bubble collapse
  - Based on PSI ULOF simulation
- Loads applied to
  - SAs adjacent to the center
  - SA in the middle of second ring
  - Between fuel and SA tops
- Load duration = 30 msec
- Full simulation time = 210 msec
- Geometry snapshot at 15 time points



Phenix transient analysis: Analysis stages

- Generate geometry snapshots

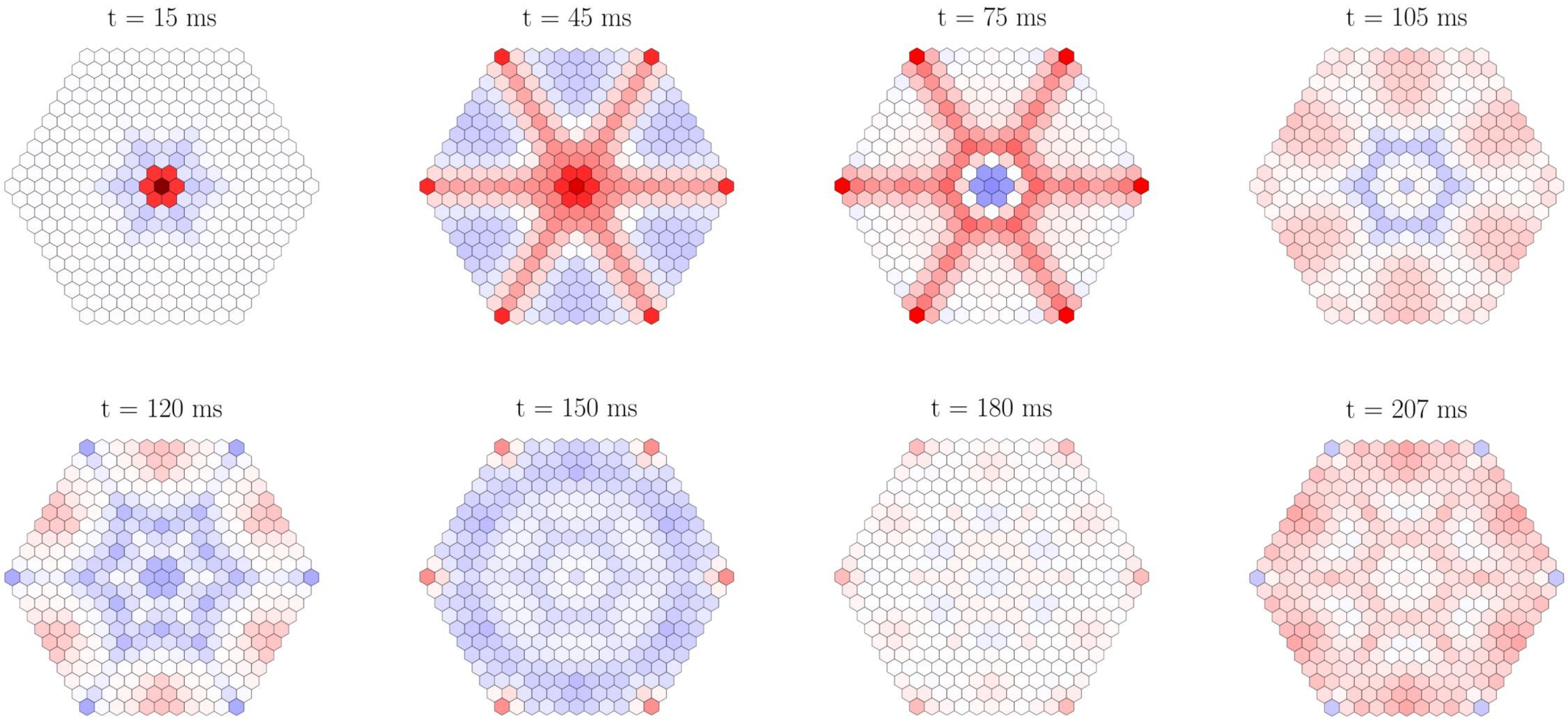
- Static Monte Carlo solution
  - CAD-based geometry models in Serpent
  - Set of static 3D calculations with geometry snapshots

- Static and dynamic DYN3D solution with 3D diffusion
  - Generate few-group XS using Serpent
  - **Set of static** 3D DYN3D calculations with geometry snapshots
  - **Single dynamic** 3D DYN3D calculation with dynamic geometry variation

- Dynamic TRACE solution with 0D NK
  - Incorporate new reactivity feedback in point kinetics
  - Transient calculations with system code TRACE

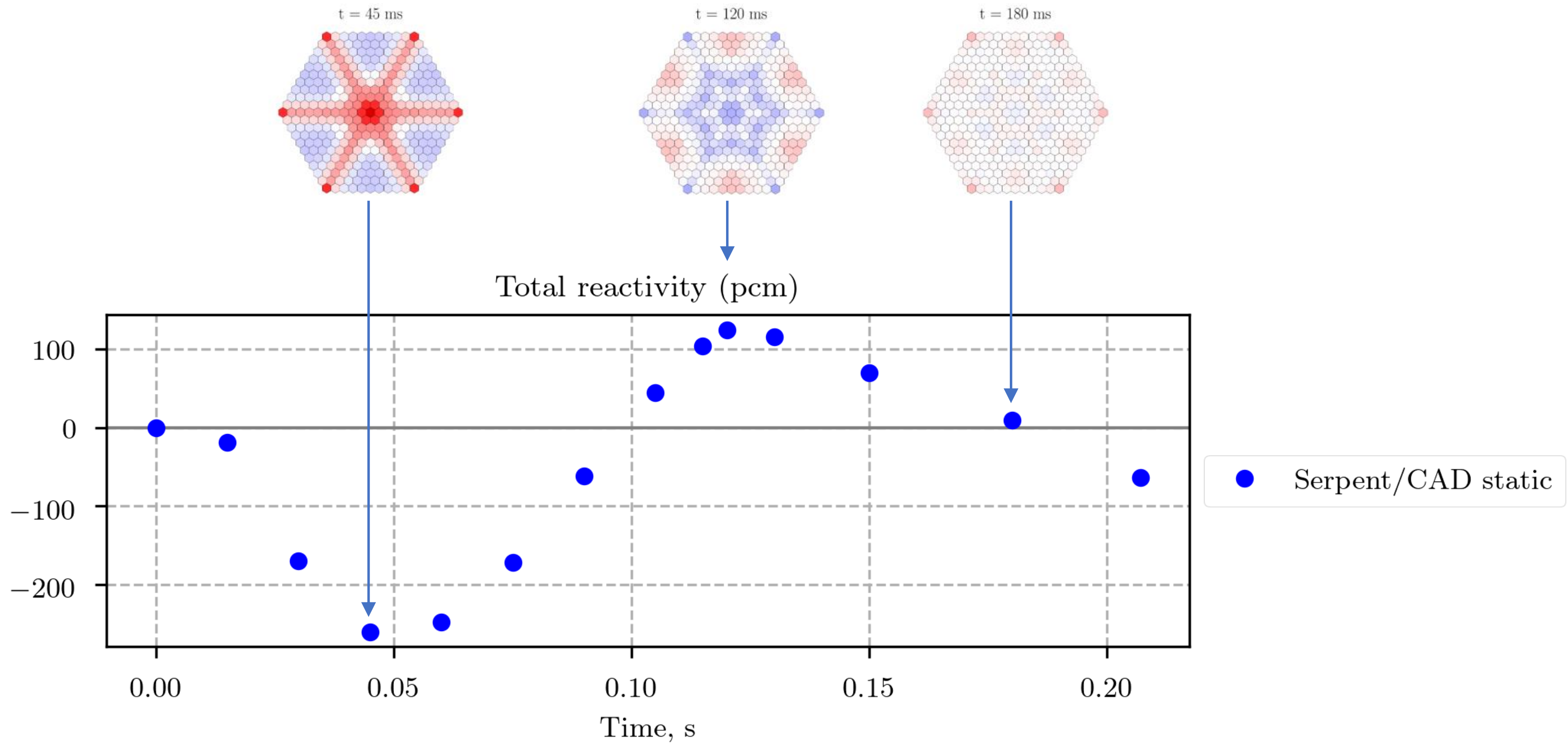
Selected snapshots of Phenix core geometry

- Averaged change of inter-assembly gap (red – expansion, blue – compaction)



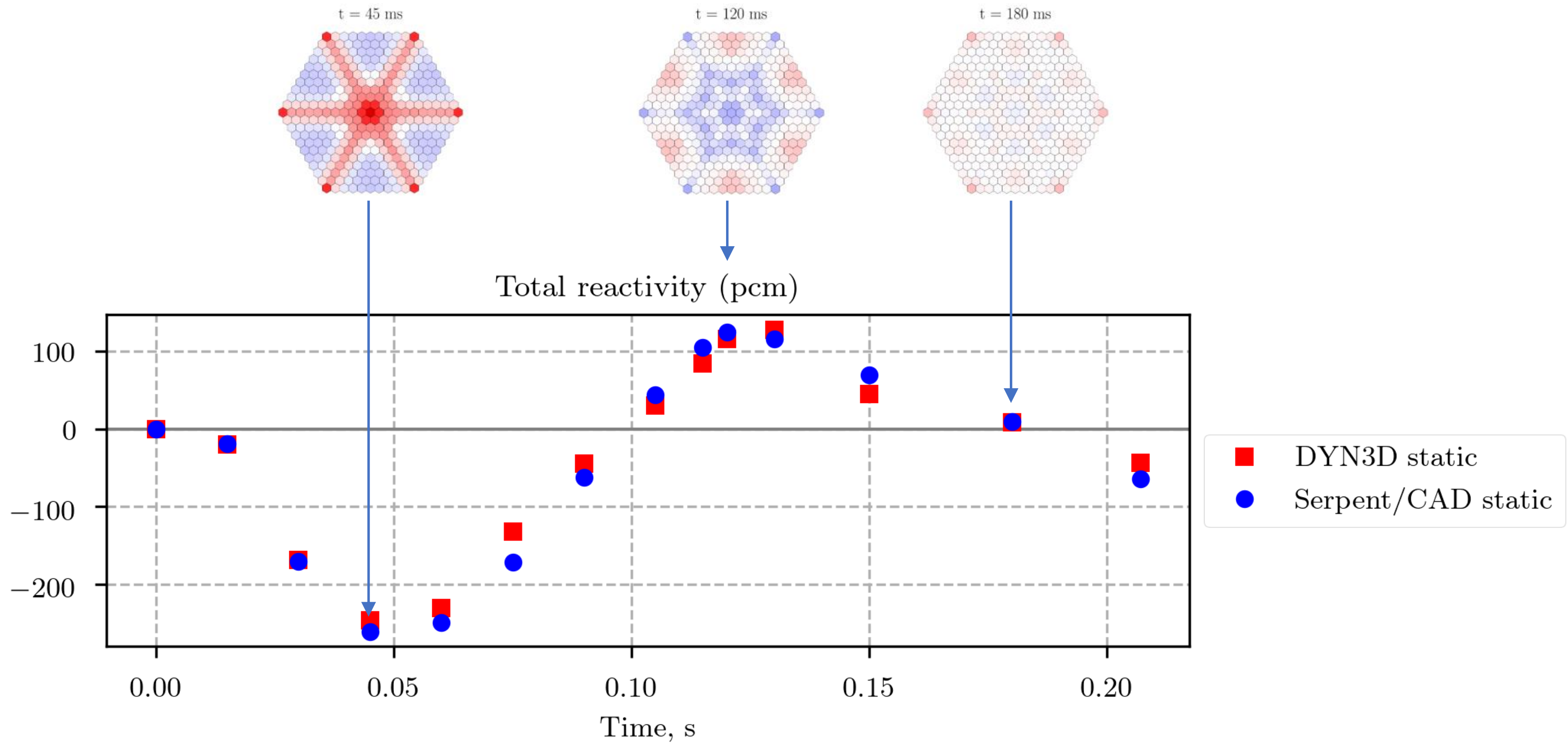
Phenix core deformation: Static Serpent solution

- Detailed CAD models for deformed geometries
- Static neutronic calculations for 14 geometry snapshots



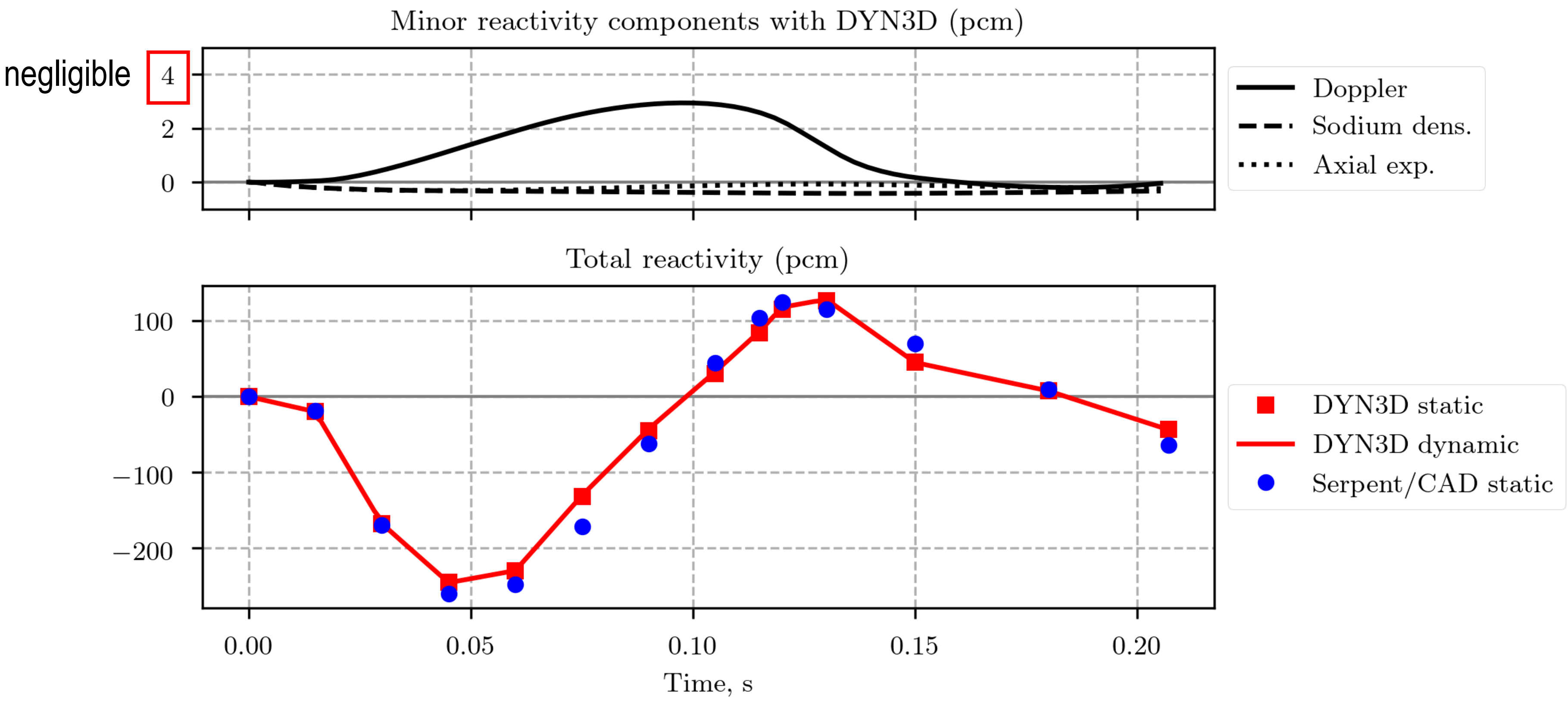
Phenix core deformation: Static DYN3D solution

- Few group XS with Serpent
- Deformation of each node by Coordinate Transformation Method
- Numerical mesh remains regular and fixed



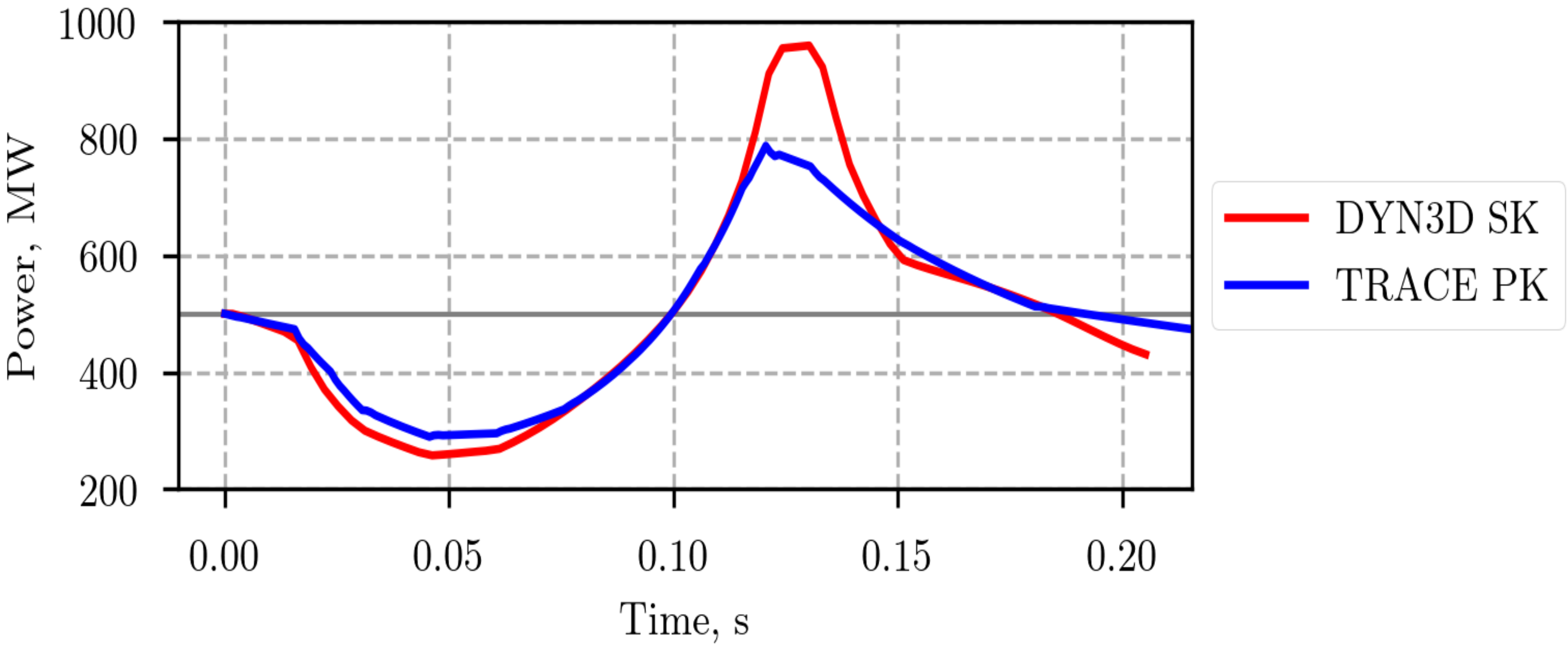
Phenix core deformation: Dynamic DYN3D solution

- 3D kinetics + TH feedback
- Reactivity fully driven by deformation
- Very good agreement between DYN3D and Serpent/CAD



Phenix core deformation: 0D vs. 3D kinetics

- Good agreement between TRACE with point-kinetics vs. DYN3D with 3D kinetics



Summary

- Core deformation due to pressure waves
  - Modeling of core deformations is performed
  - Application to the Phenix and ESFR cores

- Reactivity effects due to core deformation
  - Established methodology for assessment of reactivity effects
  - Both 0D and 3D kinetics
  - Verification on the Phenix core

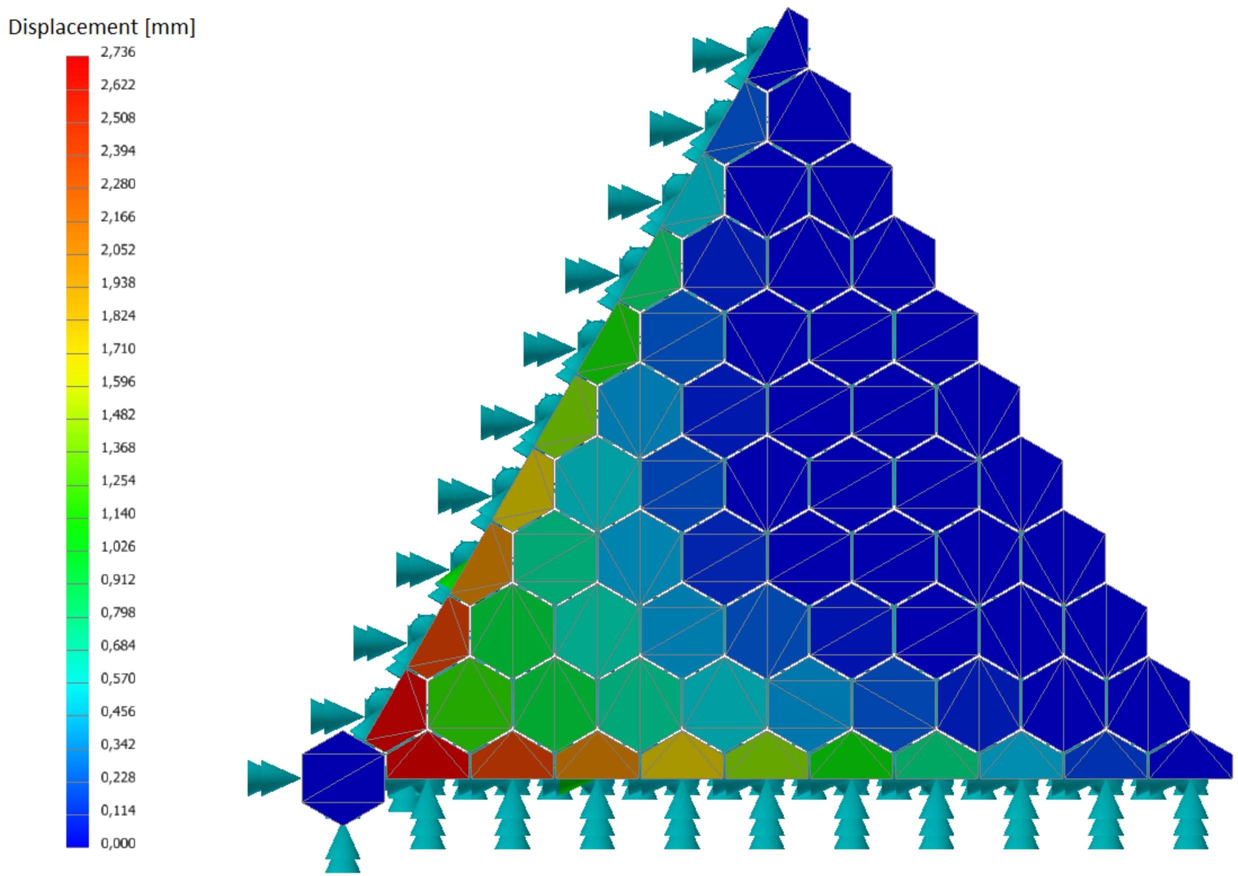
Acknowledgment

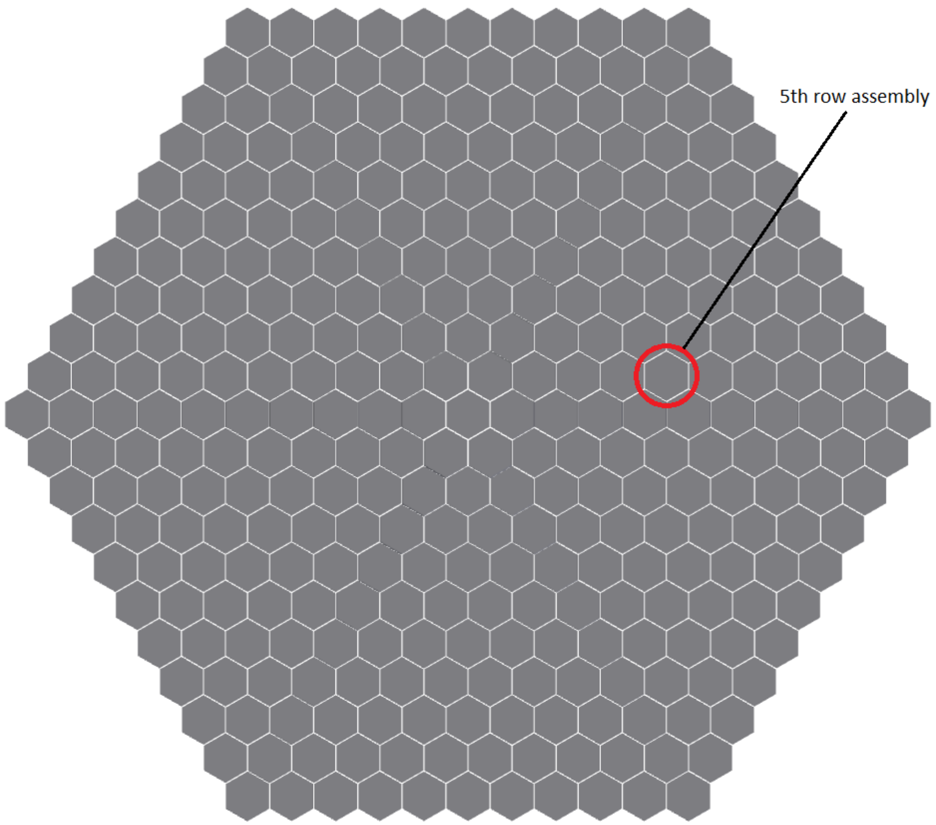
- HZDR
  - Evgeny Nikitin
  - Alexander Ponomarev

- PSI
  - Janos Bodi
  - Konstantin Mikityuk

Thank you!

Validation using Phenix “flowering” tests





Homogeneous Phenix core model