EXTENDING SERPENT2/SUBCHANFLOW COUPLING FOR DEPLETION CALCULATION CURRENT STATUS AND CHALLENGES

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Presentation Outline

- Motivations and Objectives
- Serpent and SubChanFlow Overview
- General Coupling Approach
- Extended Depletion Algorithm
- Extended Coupling Demonstration:
  - Test Case Description.
  - Test Case Modelling.
  - Power Profile, Fuel Temperature Distribution and Xe-135 Concentration.
  - Total Xe-135 Convergence Behavior.
  - K_{eff} Convergence Assessment.
  - Memory Demand.
- Summary

Motivations and Objectives

- **Motivations:**
  - Having a high-fidelity tool for a more accurate estimation of:
    - Fuel pellet isotopic inventory.
    - Decay heat sources.
    - Fuel pellet power profile during fuel depletion.
    - Local safety parameters during operation lifetime of reactor core.

- **Objectives:**
  - Extending the current coupling to include TH feedback during depletion calculation following the Stochastic Implicit Euler (SIE) method with TH feedback.
  - Testing the new implementation against a mini-PWR-liked FA.
  - Highlighting the bottlenecks to perform full core pin-by-pin depletion calculation with TH feedback.

Serpent and SubChanFlow Overview

- **Serpent:**
  - A reactor physics dedicated Monte Carlo Code developed at VTT.
  - Has a built-in Doppler Broadening routine that result in an accurate temp. modeling.
  - Can accurately represent S(α,β) thermal scattering data at any selected temp.
  - Version 2.1.29 was used in this study.

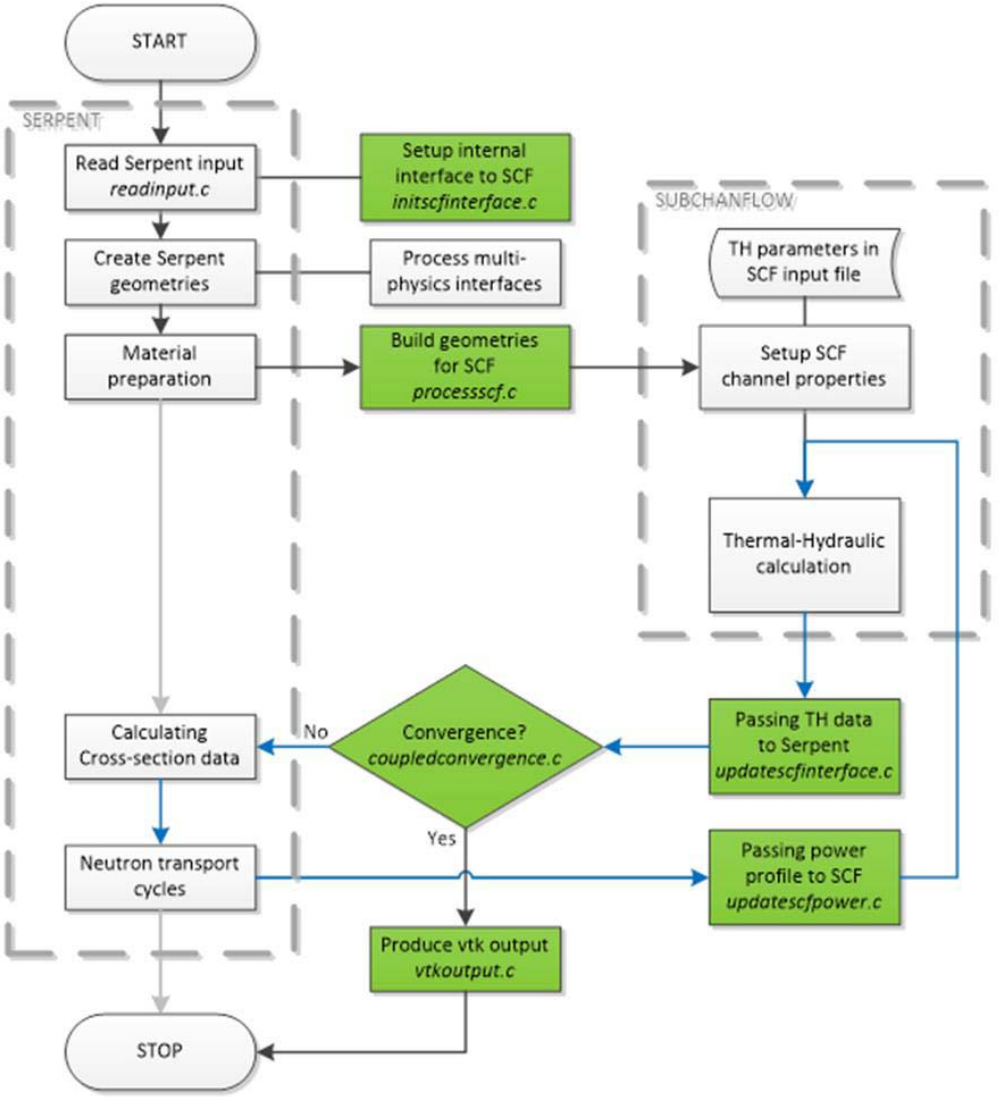
- **SubChanFlow:**
  - A sub-channel thermal-hydraulics code developed by INR/KIT.
  - Can handle both rectangular and hexagonal geometries.
  - Available fluids: water, lead, lead-bismuth, sodium, helium, and air
  - Version 3.5 was used in this work.

General Coupling Approach

- **Internal coupling.**
- **Power relaxed according to:**

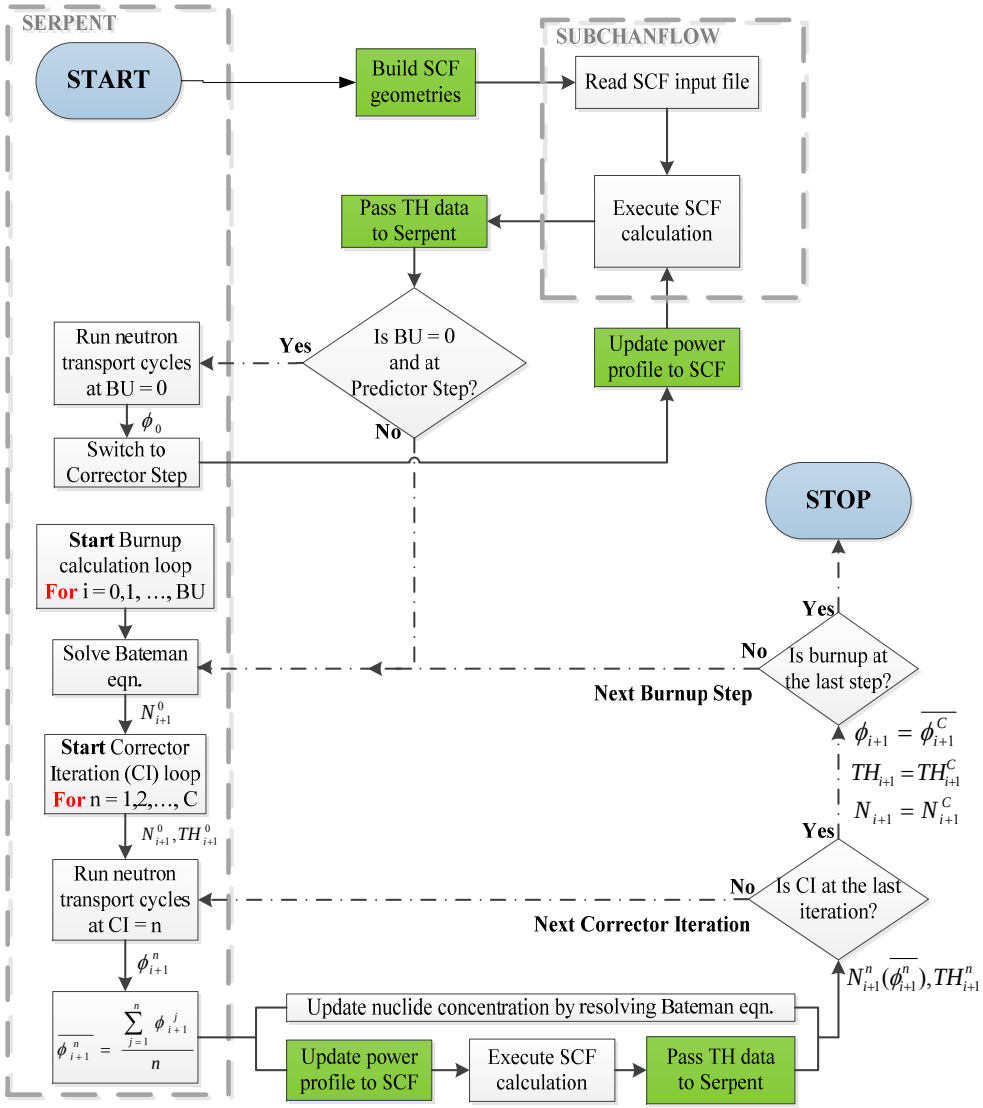
$$\phi^n = \frac{1}{n}\sum_{i=1}^{n}\phi^i$$

- **Convergence criteria is set for:**
  - Δk_{eff}
  - l^2-norm for Doppler temperature.
  - l^2-norm for Moderator density.



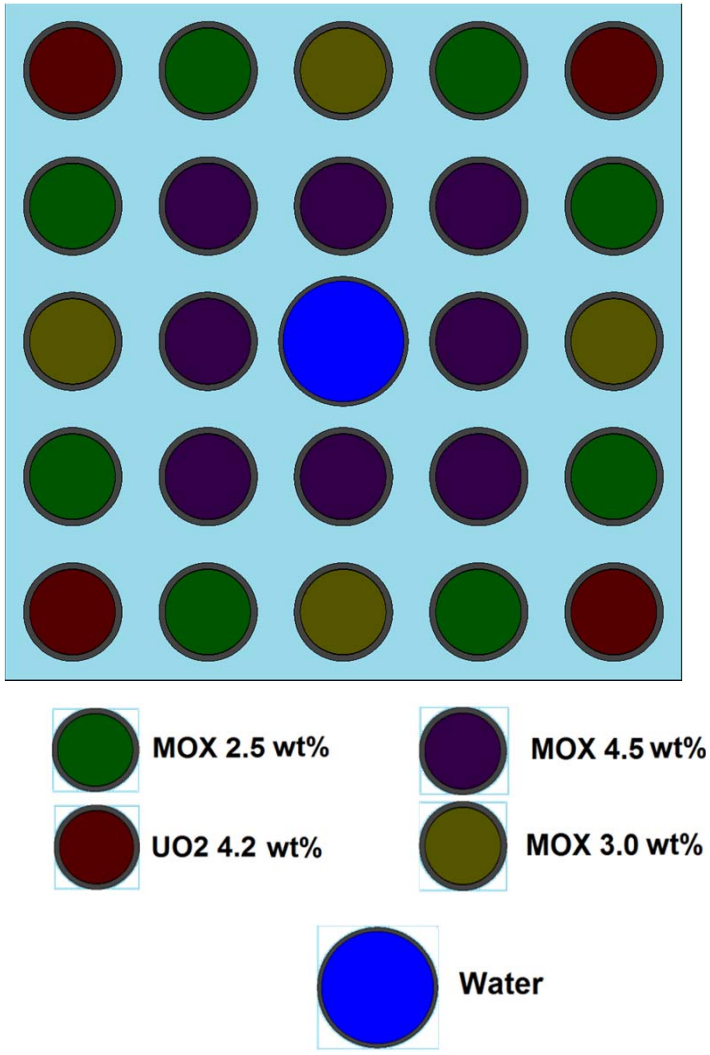
Extended Depletion Algorithm

- **Based on:**
  - J. Dufek et al., "*Derivation of a stable coupling scheme for Monte Carlo burnup calculations with the thermal-hydraulic feedback*," *Ann. Nucl. Energy*, vol. 62, pp. 260–263, 2013



Test Case Description

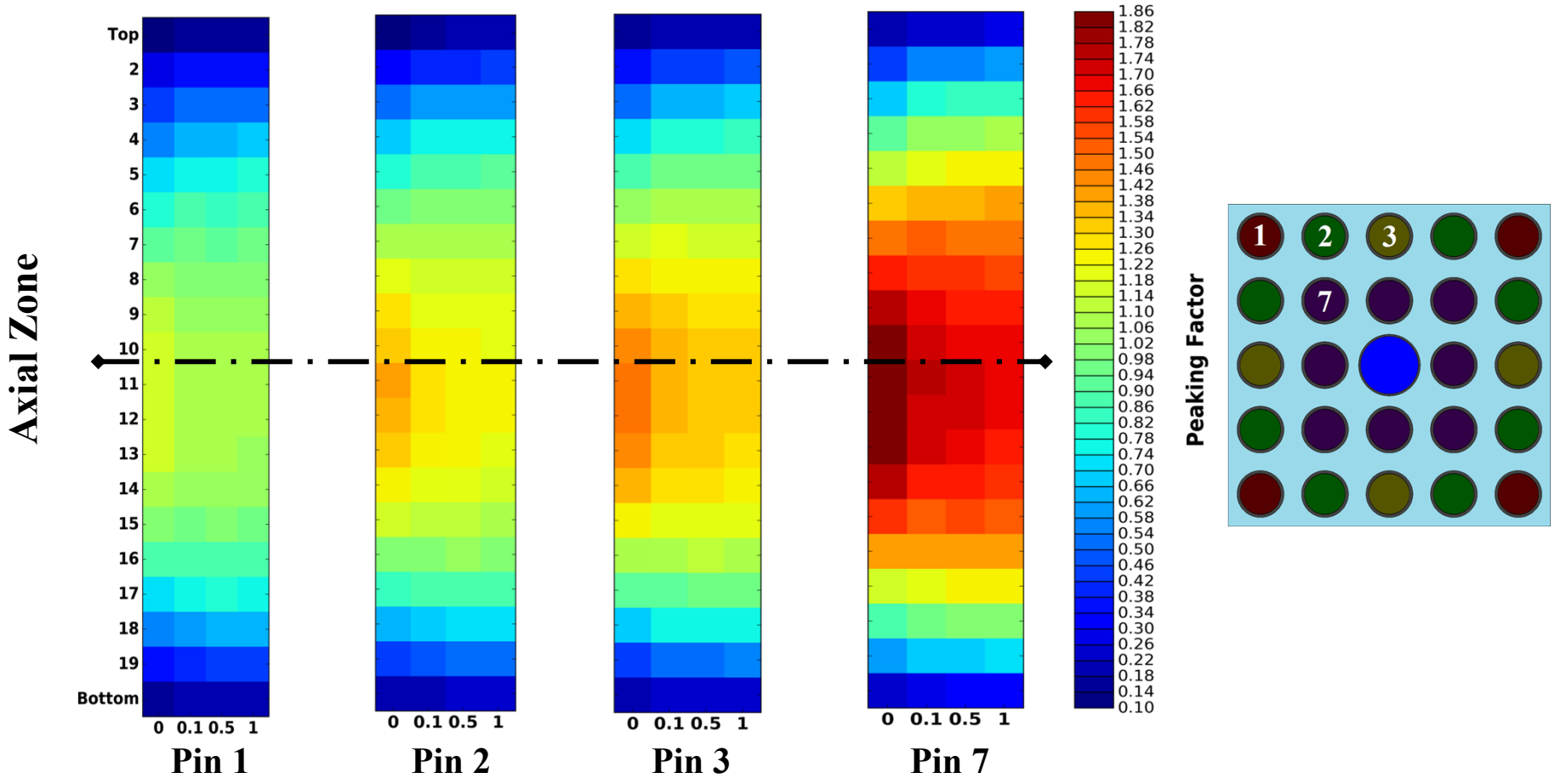
Quantity	Value
Power	1.576 MW_{th}
Mass flow rate	10.1 kg/s
Outlet pressure	15.5 MPa
Coolant inlet temperature	560 K
Boron concentration	0 ppm



Test Case Modeling

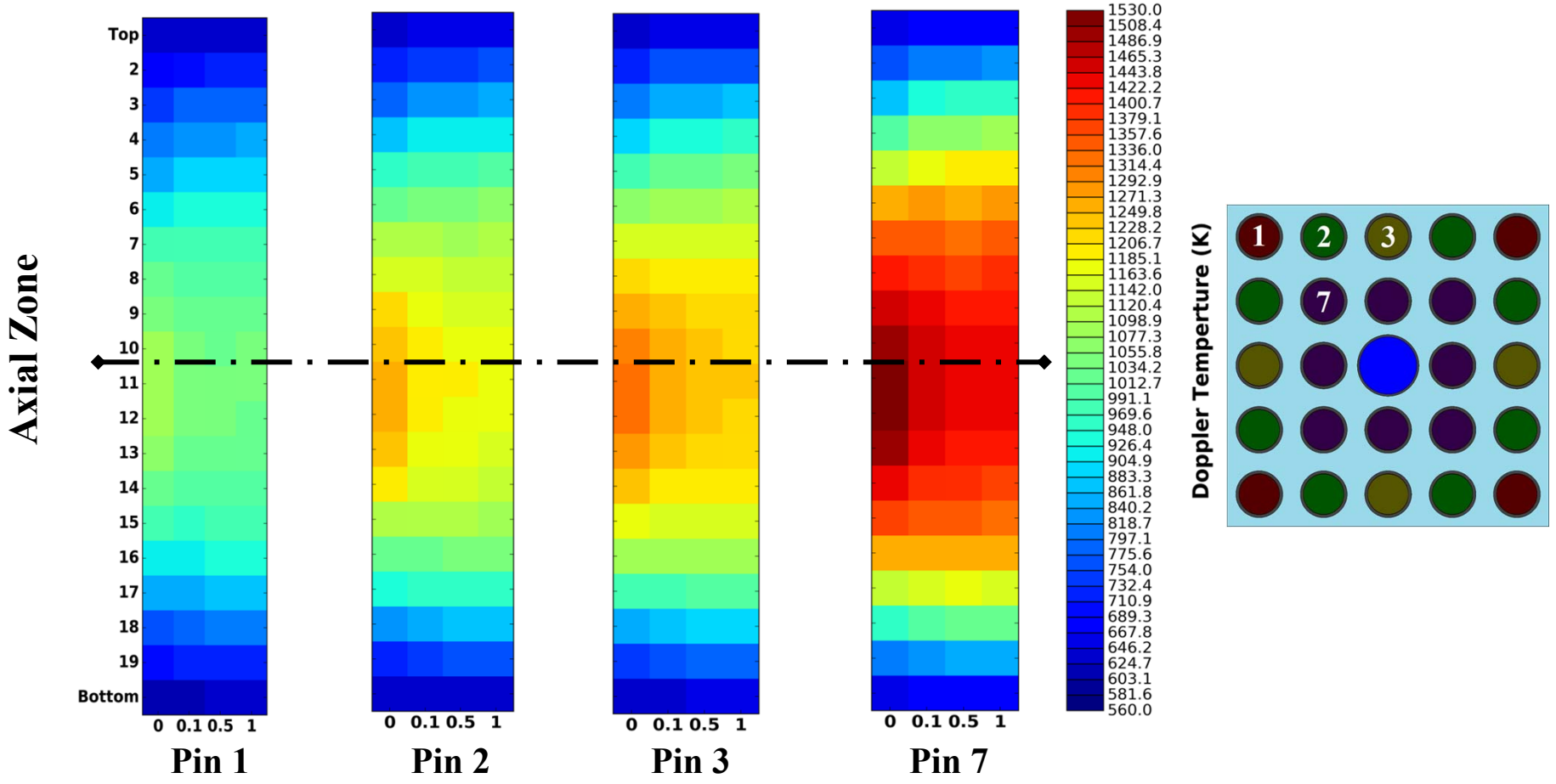
- **Boundary conditions:**
  - **Serpent:** Neutron flux radially reflective and axially black.
  - **SubChanFlow:** Coolant inlet temperature of 560 K and outlet pressure of 15.5 MPa.
- Pin-wise coupling of 20 axial meshes for the TH feedback.
- Each pin was discretized into 20 axial depletion zones, resulting into 480 depletion zones (i.e. 24 fuel pins x 20 axial depletion zones).
- Burnup calculation tracked 1334 nuclides (281 XS data + 1053 decay nuclides).
- Depletion steps: 0.1, 0.5, and 1.0 MWd/kgU.
- Several SIE iterations were performed: 2, 4, 8, 16, and 32 corrector iterations.

Demonstration of the Extended Coupling
Power Profile



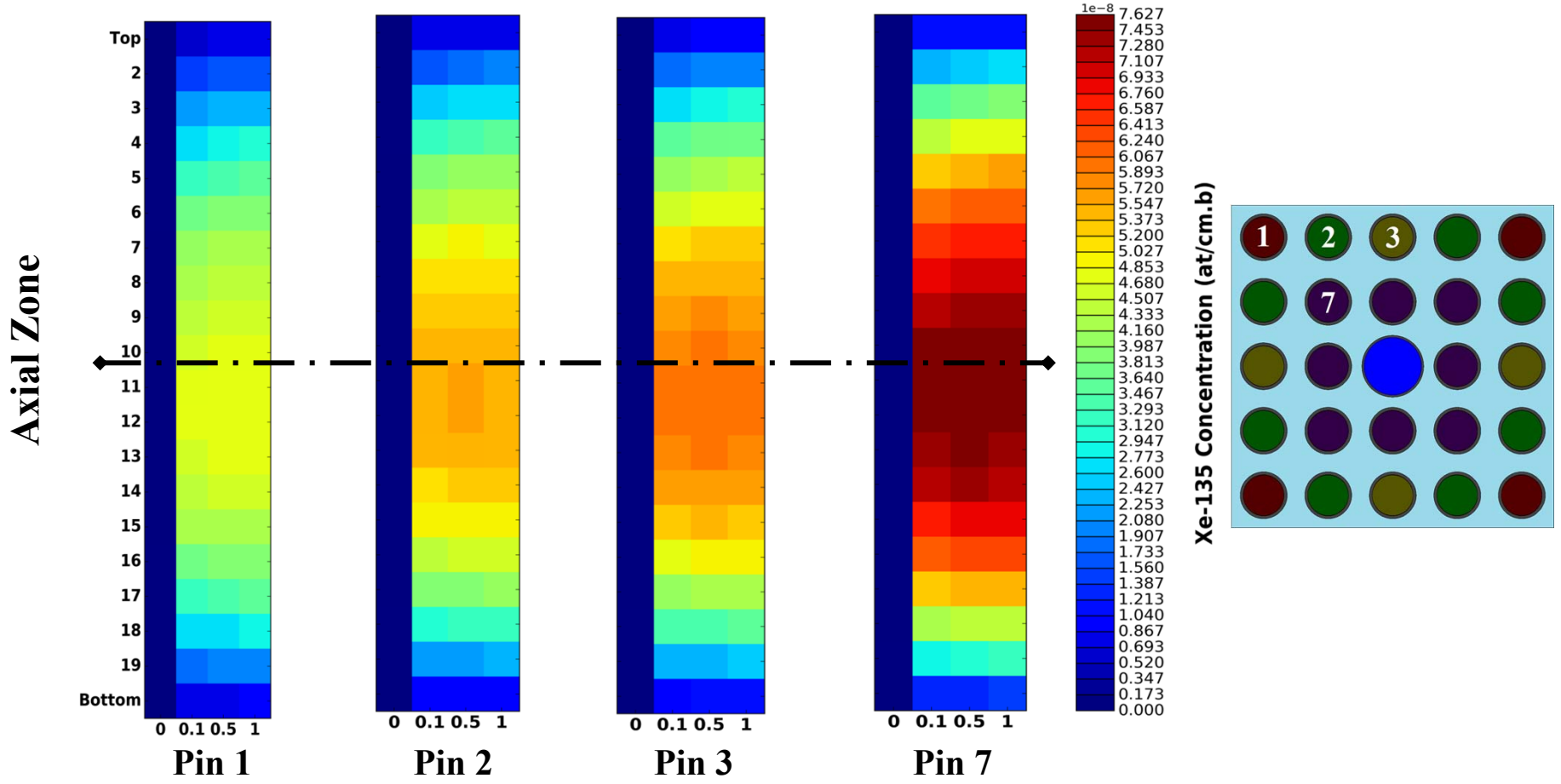
With 16 corrector iterations

Demonstration of the Extended Coupling
Doppler Temperature Profile



With 16 corrector iterations

Demonstration of the Extended Coupling
Xe-135 Distribution

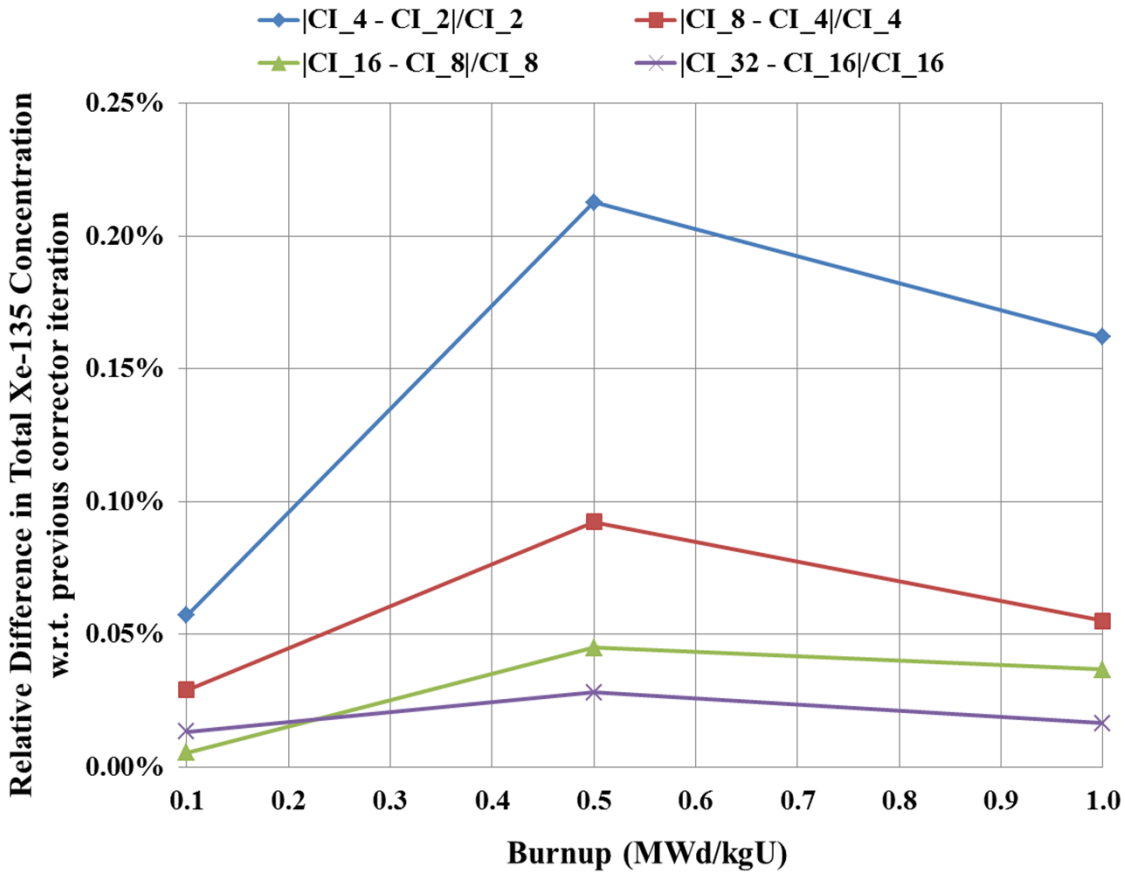


With 16 corrector iterations

Convergence behavior of the relative change in total Xe-135 concentration

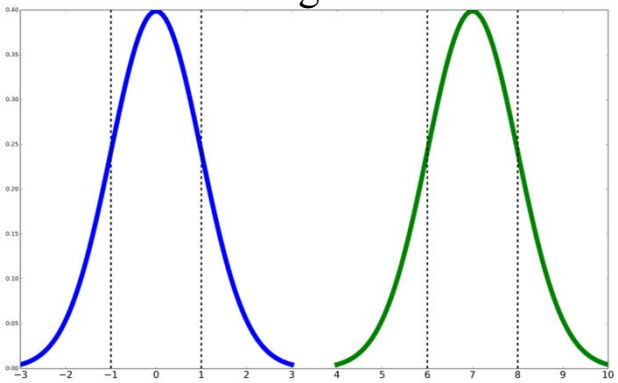
- Instead of using fixed value of the maximum SIE iterations, the maximum relative change of total Xe-135 concentration could be defined as:

$$\Delta N_{Xe135} = \frac{\left| N_{Xe135}^{n} - N_{Xe135}^{n-1} \right|}{N_{Xe135}^{n-1}} \leq \epsilon_{N_{Xe135}}$$

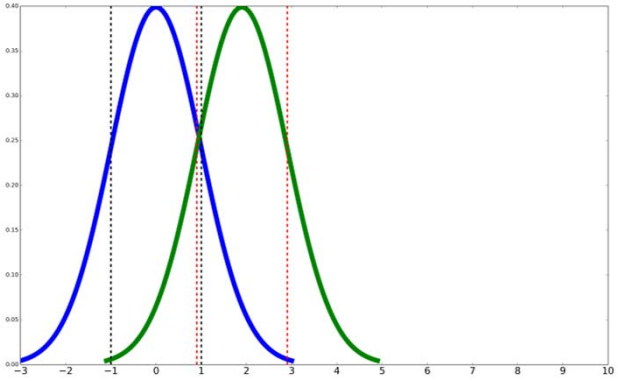


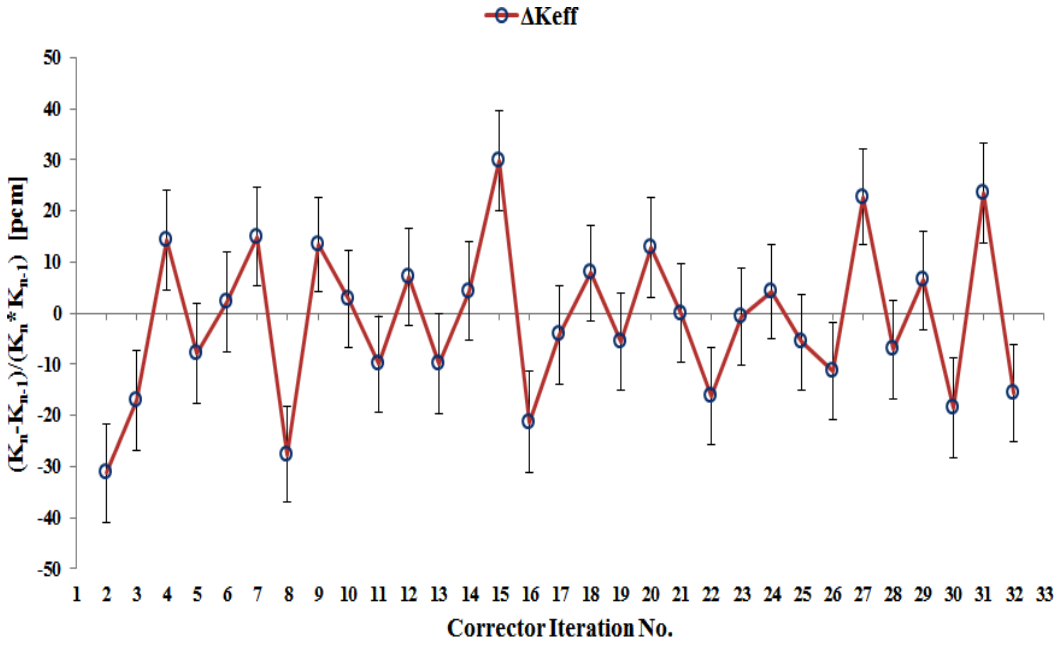
K_{eff} Convergence Assessment

Non-converged behavior



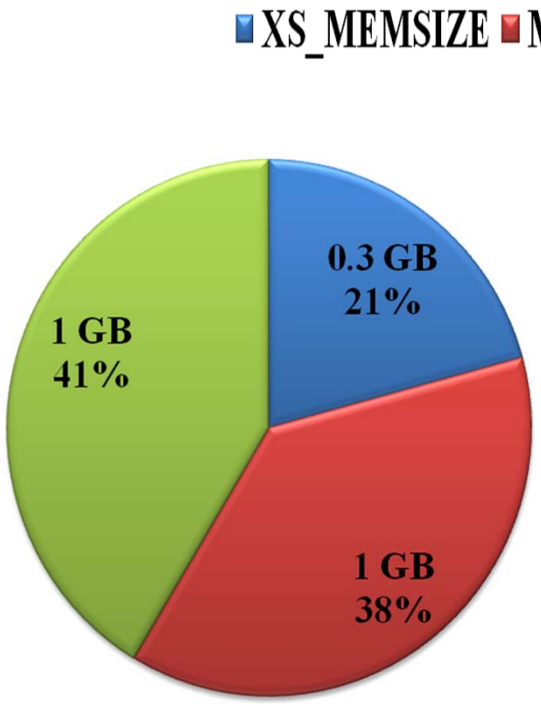
Within 1σ converged behavior



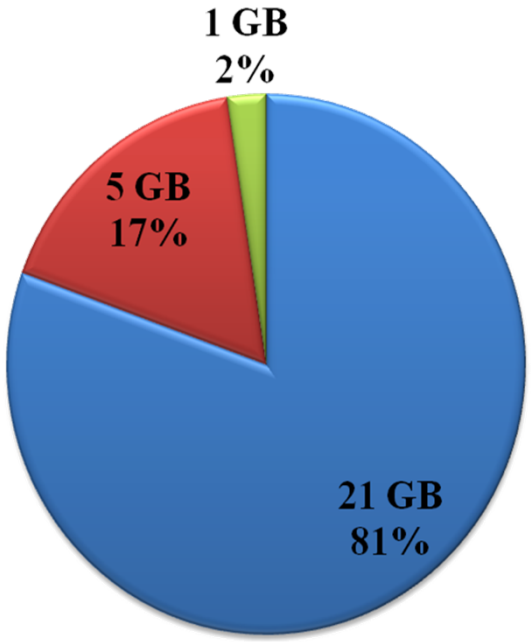


- A converged k_{eff} is reached when the Δk_{eff} is within 1σ of the associated statistical uncertainty.

Memory Footprint



Fresh Calculation



Depletion Calculation

- To simulate a large commercial PWR with 193 fuel assemblies of 17x17 arrays with 20 axial depletion segments per fuel pin, one can estimate memory demand to reach 50 TB.

Summary

- SSS2/SCF coupling has been extended for depletion calculation according to SIE method with thermal-hydraulics feedback.
- A proof-of-implementation was demonstrated on a 5x5 fuel pins test case.
- Area of improvement of the current work would involve:
  - **Problem:** Knowing beforehand the convergence behavior of Xe-135.
    - Suggestion: Number of SIE iterations should be based on a user defined max. relative change of total Xe-135 concentration rather than a fixed value.
  - **Problem:** SIE method with TH feedback did not involve any convergence checking between the neutronic and TH solvers.
    - Suggestion: An additional internal loop between Serpent and SubChanFlow could be added per SIE iteration. However, simulation time would increase so much.
  - **Problem:** Huge a mount of memory demand is needed to simulate practical cases.
    - Suggestion: Domain and Tally Data Decomposition.