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Development of an object-oriented Serpent2-SUBCHANFLOW coupling and verification with Problem 6 of the VERA core physics benchmark

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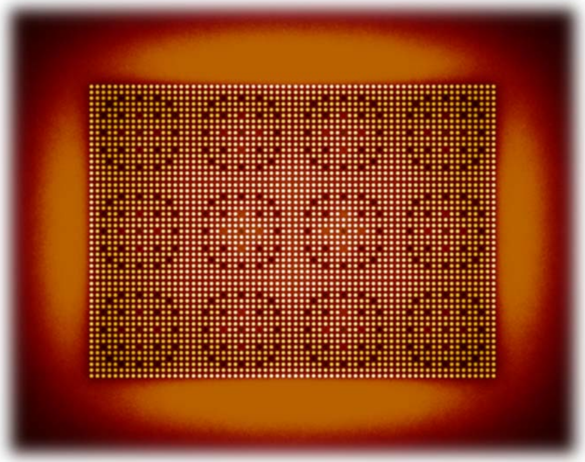

Presentation Overview

- Introduction & motivation
- McSAFE: high-fidelity multiphysics
- Serpent2-SUBCHANFLOW coupling
- Mesh-based feedback exchange
- Verification with Problem 6 of the VERA benchmark
- Conclusions & further work

1 – Introduction & motivation

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- ***Increasing effort*** to develop highly accurate multi-physics approaches for nuclear reactor analysis of complex phenomenology.
- ***Increasing demand*** from designers, operators, regulators and other stakeholders.
- Several projects around the world oriented to provide ***high-fidelity results*** → improvement of local phenomena calculation & provide reference solutions).
- Under this framework, the ***McSAFE*** project started in 2017 under Horizon 2020 (EU):

H2020 Mc SAFE High Performance Monte Carlo for Safety

McSAFE*: High –Performance* ***M****onte****c****arlo Methods for* ***SAFE****ty Demonstration:*

✓ ***Cooperation*** between code developers, methods developers and industry stakeholders.

✓ **12 partners** from **9 countries** around EU and an extended community of users around world.

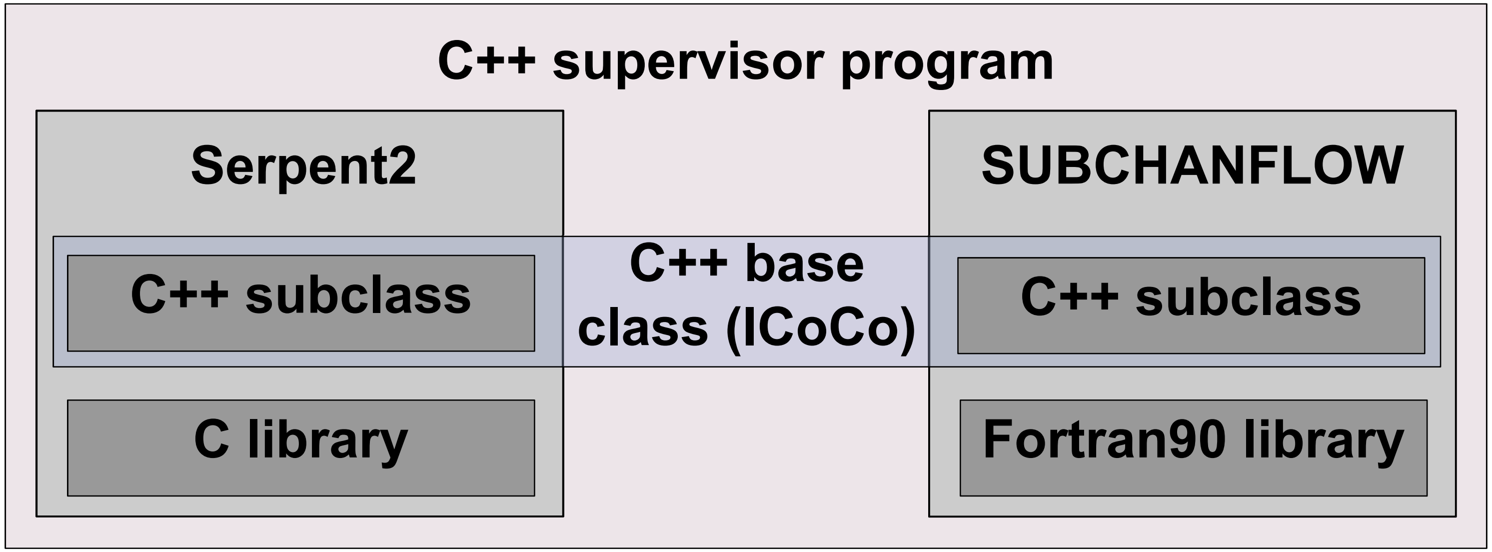
2 – McSAFE: high-fidelity multiphysics

- Move towards high fidelity multi-physics calculations using advanced codes and methodologies.
- High performance Monte Carlo (MC) codes to become valuable tools for core design, safety analysis and industry like applications for LWRs of gen II and III.
- ***Final scope***: NPP core level calculations including depletion and TH-feedback in a full scope approach (i.e. pin level):

➡ ***Develop a Serpent2-SUBCHANFLOW coupling scheme to be used in pin-by-pin steady-state and depletion calculations (towards full-core)***

3 – Serpent2-SUBCHANFLOW coupling

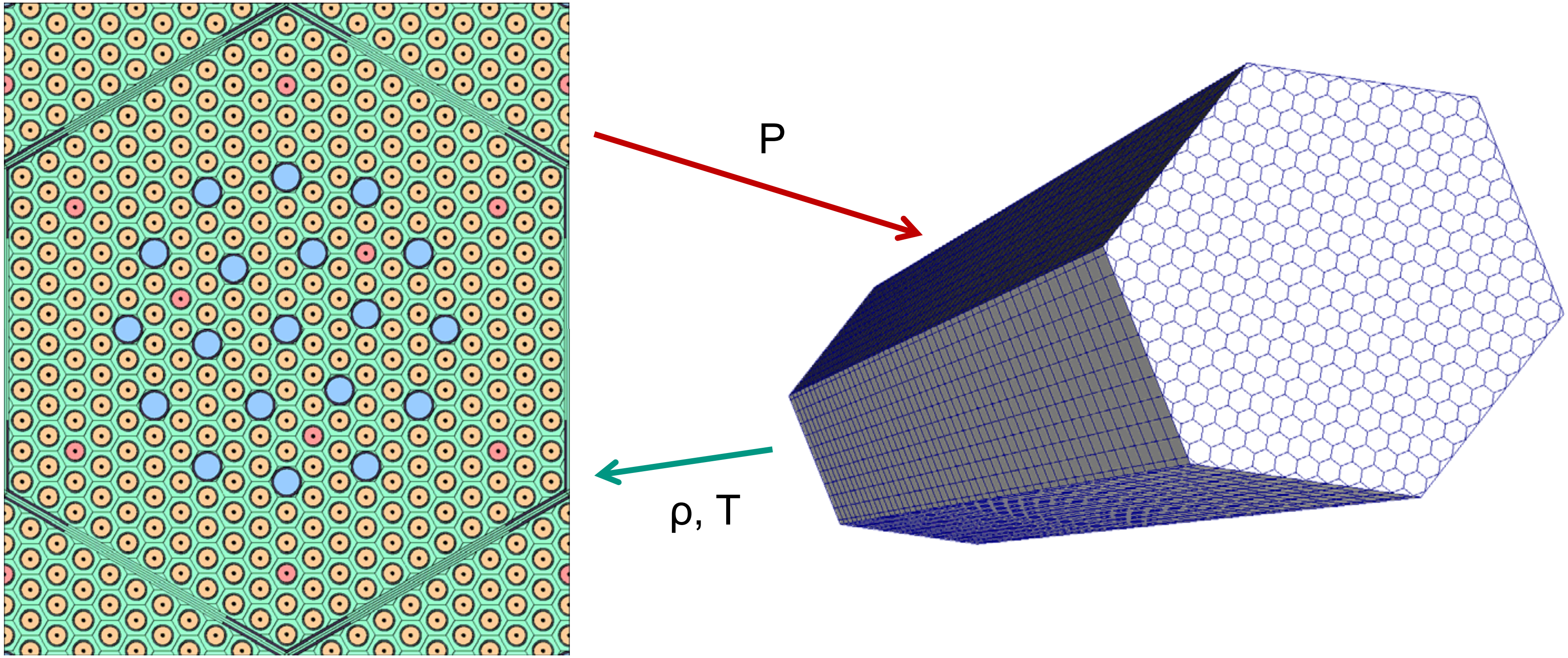
- Serpent2: continuous-energy Monte Carlo particle transport.
- SUBCHANFLOW: COBRA-based subchannel thermalhydraulics.
- Object-oriented design:



  - `Problem` base class (ICoCo): generic multiphysics interface.
  - Enhanced flexibility, maintainability and code reusability.
  - Experimental implementation strategy.
- Backup strategy: master-slave coupling (proven, reliable and efficient).

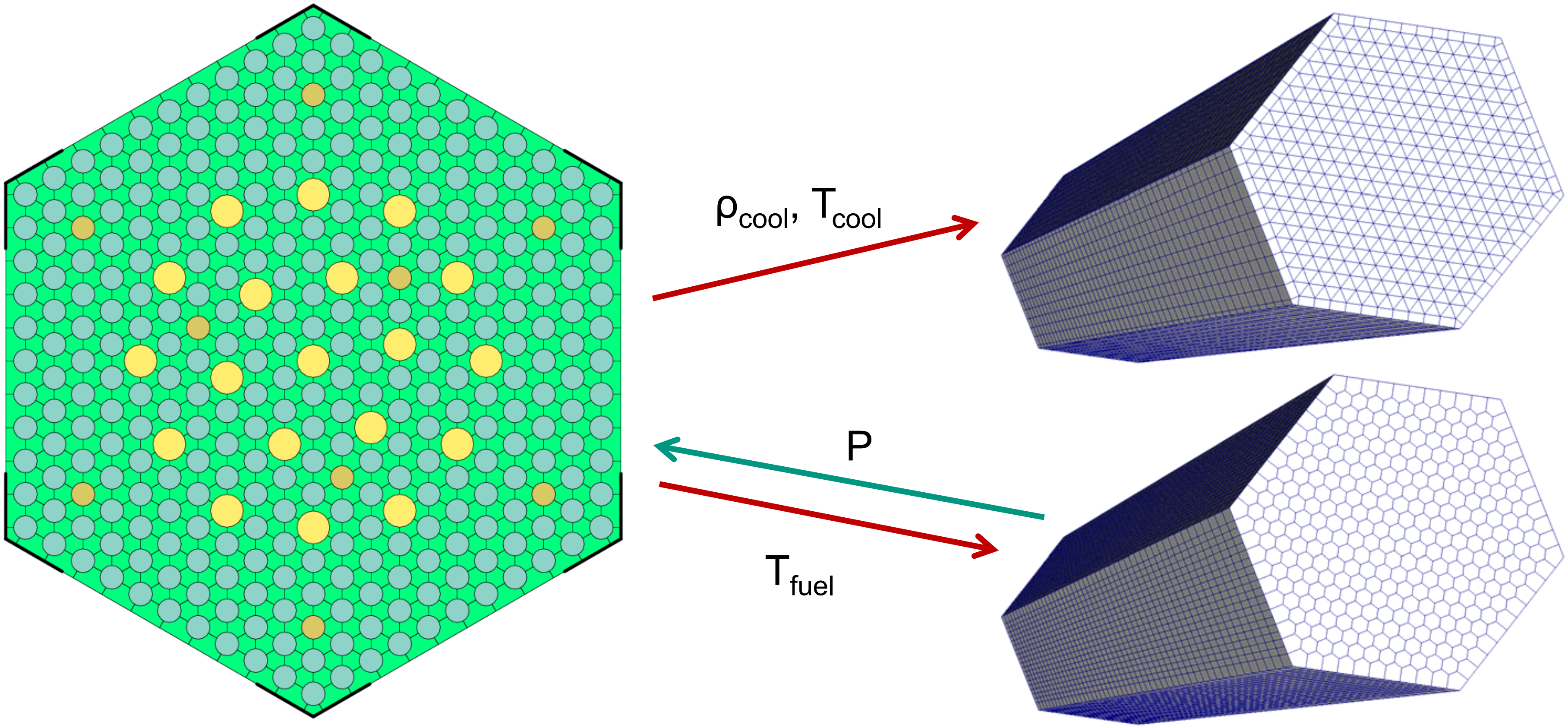
4 – Mesh-based feedback exchange (1)

- Serpent2:
  - Multiphysics interfaces based on superimposing meshes on the tracking geometry to set densities and temperatures and get power.
  - Internal (nested) meshes represented as (MEDCoupling) unstructured meshes for feedback exchange and interpolation.



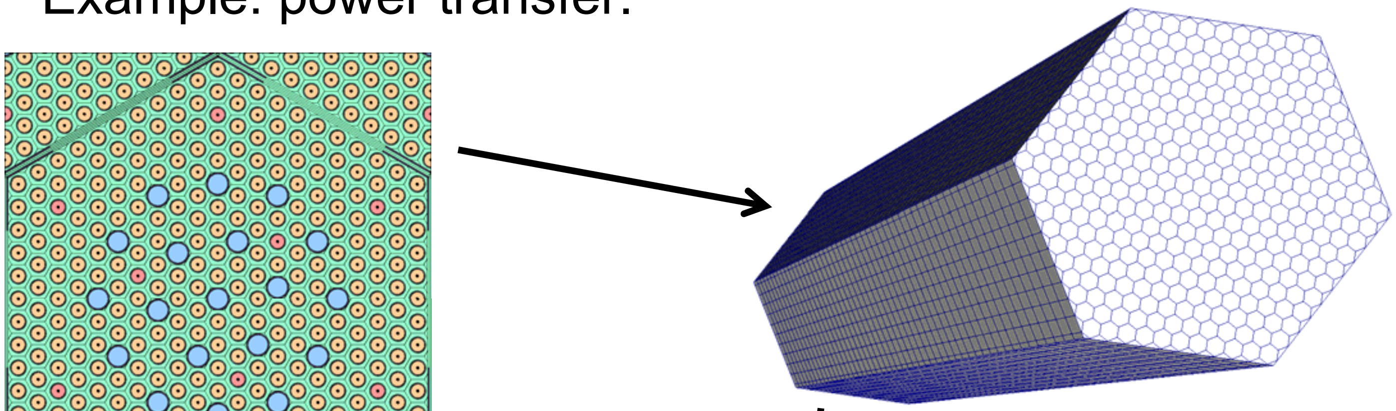
4 – Mesh-based feedback exchange (2)

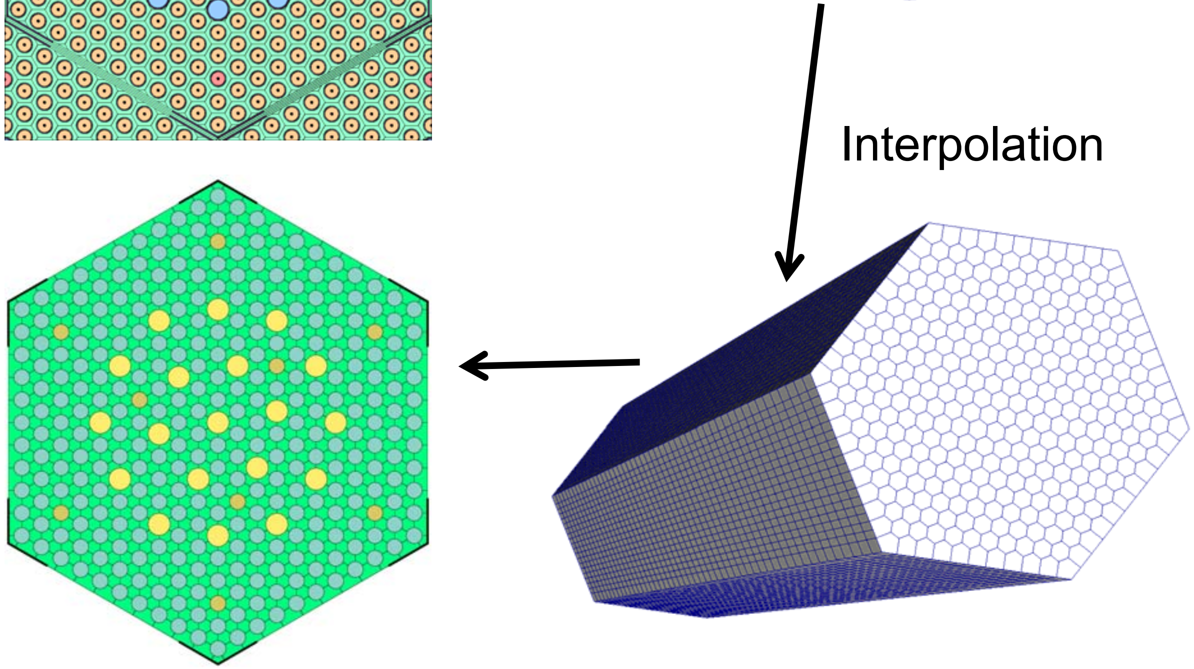
- SUBCHANFLOW:
  - Subchannel model defined by hydraulic parameters and connectivity.
  - Coolant and fuel (MEDCoupling) unstructured meshes define the channel and rod geometry for feedback exchange and interpolation.



4 – Mesh-based feedback exchange (3)

- Example: power transfer.



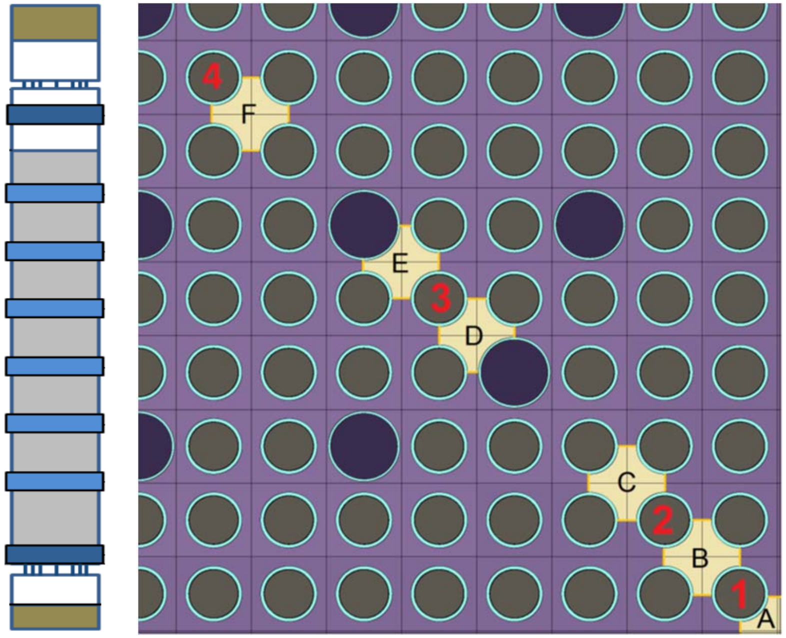


✓ Field transfer and interpolation handled by the supervisor.

✓ Interpolation done using MEDCoupling.

✓ Master-slave coupling: mappings generated with this strategy.

5 – Verification with VERA - Problem 6 (1)



- Multiplication factor:

Result	Keff	ΔKeff (pcm)
VERA-CS	1.16361	-
RMC-CTF	1.16239±0.00010	-90
MC21-CTF	1.16424±0.00003	47
MCNP6-CTF	1.16500±0.00006	103
Serpent2-SCF (OO)	1.16552±0.00003	141
Serpent2-SCF (MS)	1.16560±0.00003	147

- Pin-wise power, integrated axially:

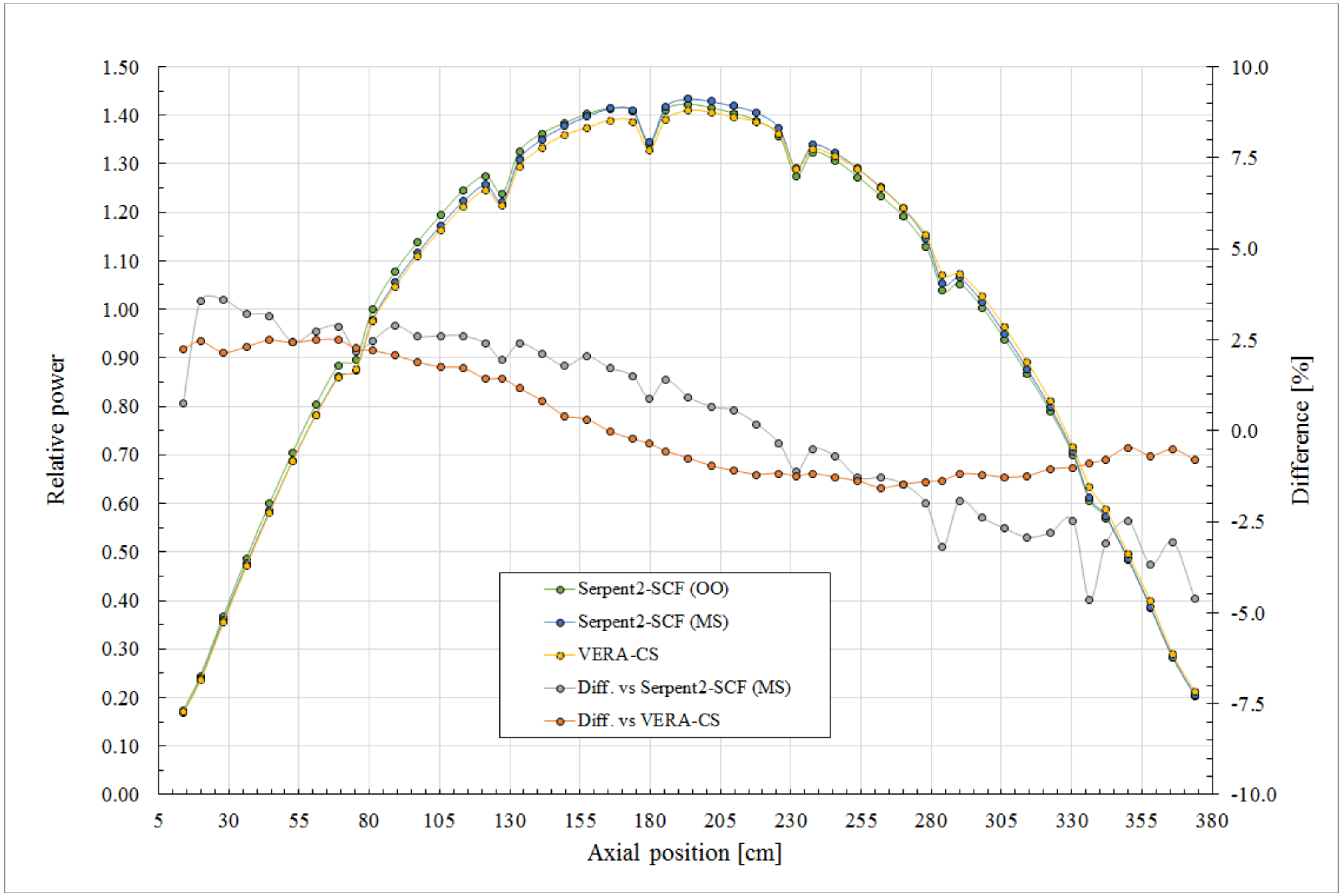
	1.0355 1.0345 -0.0010	1.0357 1.0348 -0.0009		1.0342 1.0335 -0.0007	1.0311 1.0303 -0.0008		1.0114 1.0112 -0.0002	0.9764 0.9781 0.0017
1.0355 1.0334 -0.0021	1.0096 1.0077 -0.0019	1.0100 1.0076 -0.0024	1.0359 1.0355 -0.0004	1.0088 1.0070 -0.0018	1.0057 1.0045 -0.0012	1.0252 1.0240 -0.0012	0.9890 0.9873 -0.0017	0.9730 0.9748 0.0018
1.0355 1.0340 -0.0015	1.0100 1.0088 -0.0012	1.0102 1.0092 -0.0010	1.0371 1.0355 -0.0016	1.0110 1.0077 -0.0033	1.0090 1.0085 -0.0005	1.0265 1.0273 0.0008	0.9890 0.9894 0.0004	0.9724 0.9743 0.0019
	1.0359 1.0344 -0.0015	1.0371 1.0361 -0.0010		1.0436 1.0438 0.0002	1.0436 1.0430 -0.0006		1.0115 1.0116 0.0001	0.9740 0.9748 0.0008
1.0342 1.0334 -0.0008	1.0088 1.0061 -0.0027	1.0110 1.0092 -0.0018	1.0436 1.0418 -0.0018	1.0328 1.0308 -0.0020	1.0509 1.0494 -0.0015	1.0363 1.0347 -0.0016	0.9842 0.9831 -0.0011	0.9654 0.9669 0.0015
1.0311 1.0303 -0.0008	1.0057 1.0035 -0.0022	1.0090 1.0090 0.0000	1.0436 1.0416 -0.0020	1.0509 1.0466 -0.0043		1.0169 1.0149 -0.0020	0.9649 0.9661 0.0012	0.9560 0.9566 0.0006
	1.0252 1.0240 -0.0012	1.0265 1.0266 0.0001		1.0363 1.0324 -0.0039	1.0169 1.0180 0.0011	0.9743 0.9755 0.0012	0.9488 0.9515 0.0027	0.9473 0.9505 0.0032
1.0114 1.0111 -0.0003	0.9890 0.9875 -0.0015	0.9890 0.9888 -0.0002	1.0115 1.0110 -0.0005	0.9842 0.9840 -0.0002	0.9649 0.9660 0.0011	0.9488 0.9507 0.0019	0.9403 0.9413 0.0010	0.9434 0.9453 0.0019
0.9764 0.9792 0.0028	0.9730 0.9732 0.0002	0.9724 0.9737 0.0013	0.9740 0.9729 -0.0011	0.9654 0.9668 0.0014	0.9560 0.9590 0.0030	0.9473 0.9505 0.0032	0.9434 0.9454 0.0020	0.9493 0.9533 0.0040

VERA-CS
Serpent2-SCF (OO)
Diff. vs VERA-CS

1.055
0.935

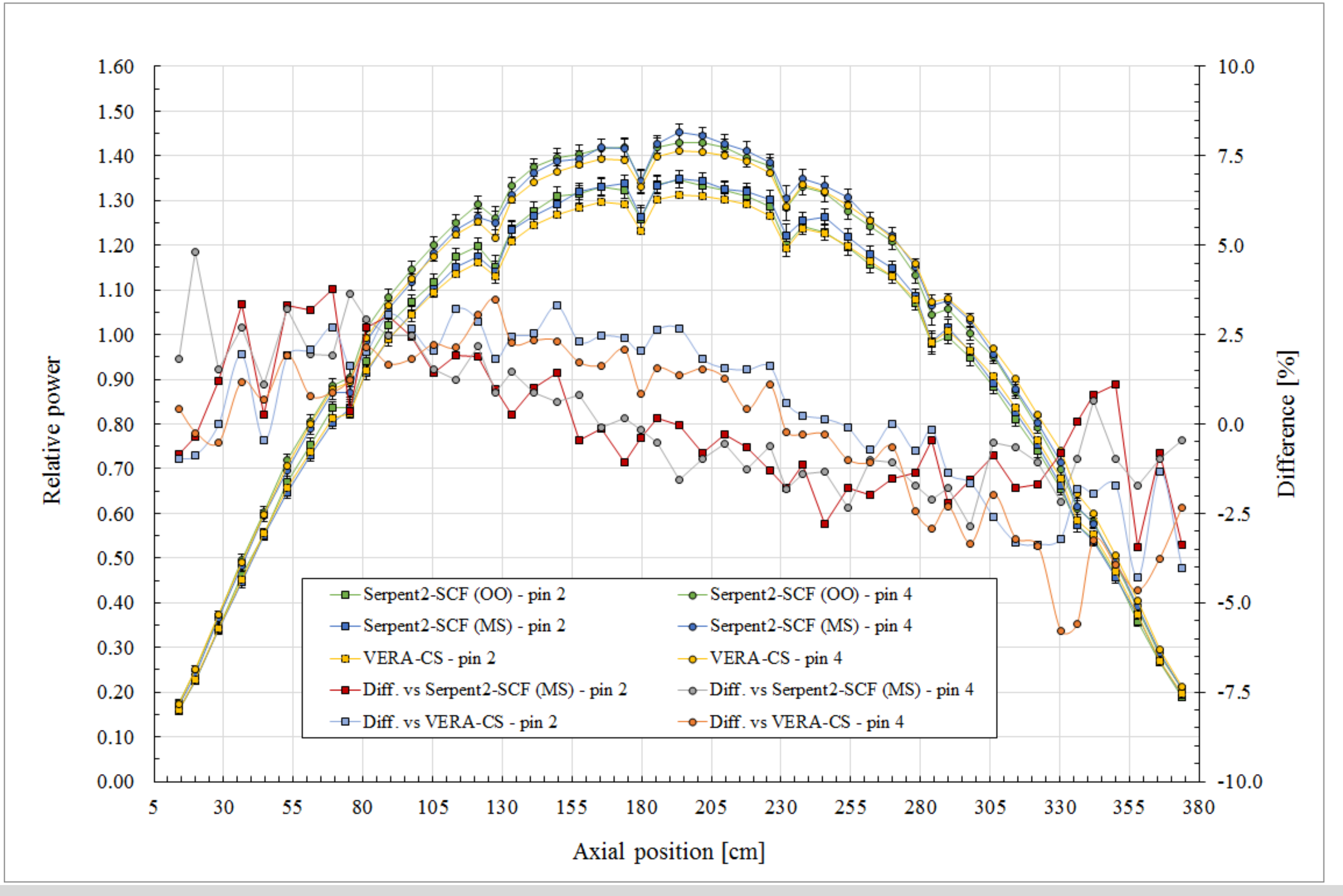
5 – Verification with VERA - Problem 6 (2)

- Axial power profile, integrated pin-wise:



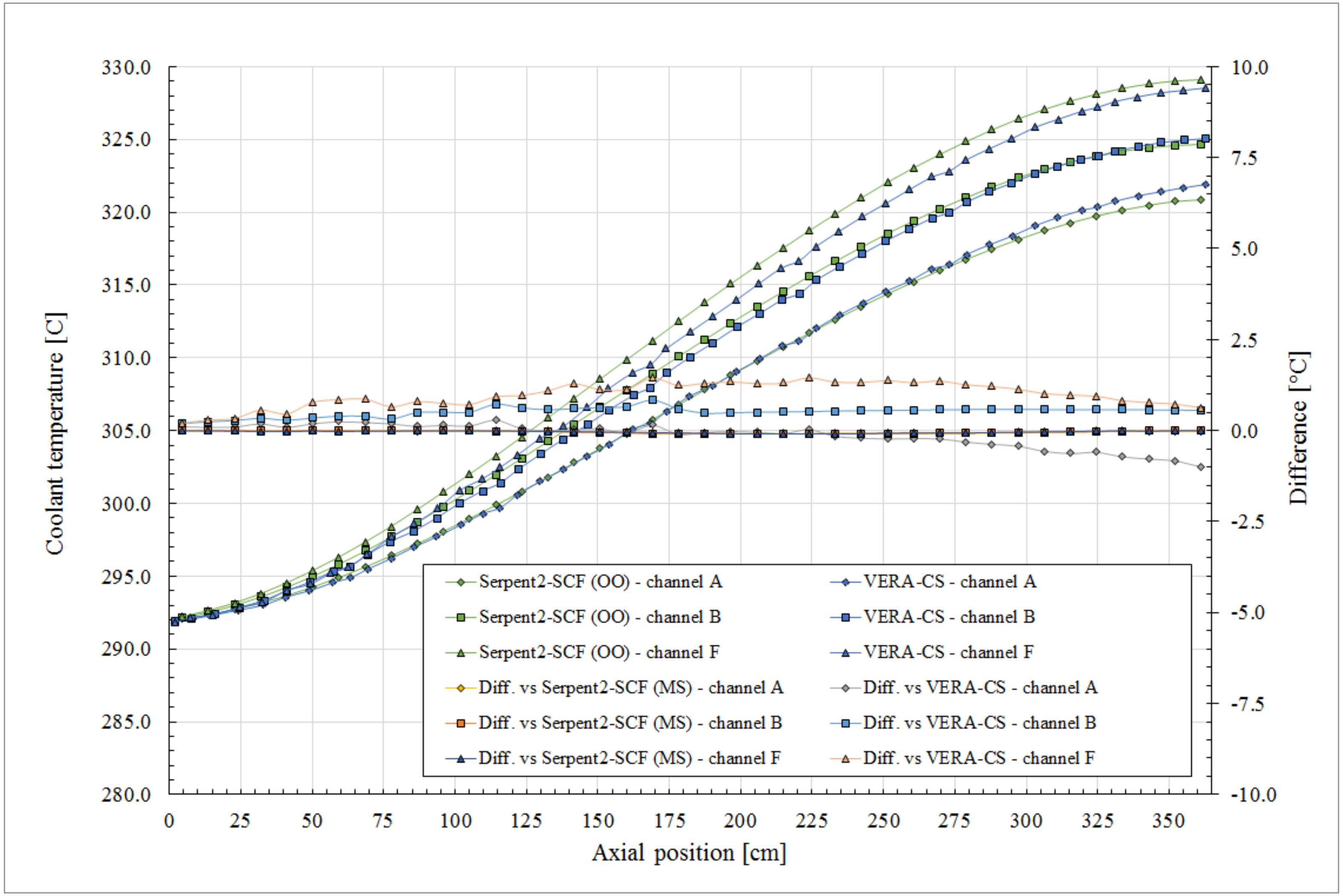
5 – Verification with VERA - Problem 6 (3)

- Axial power profile, for pins 2 and 4:



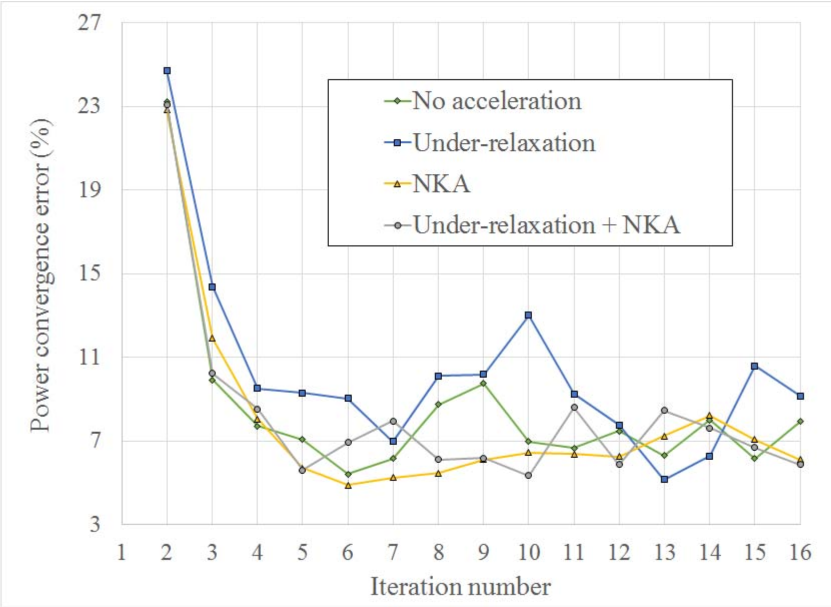
5 – Verification with VERA - Problem 6 (4)

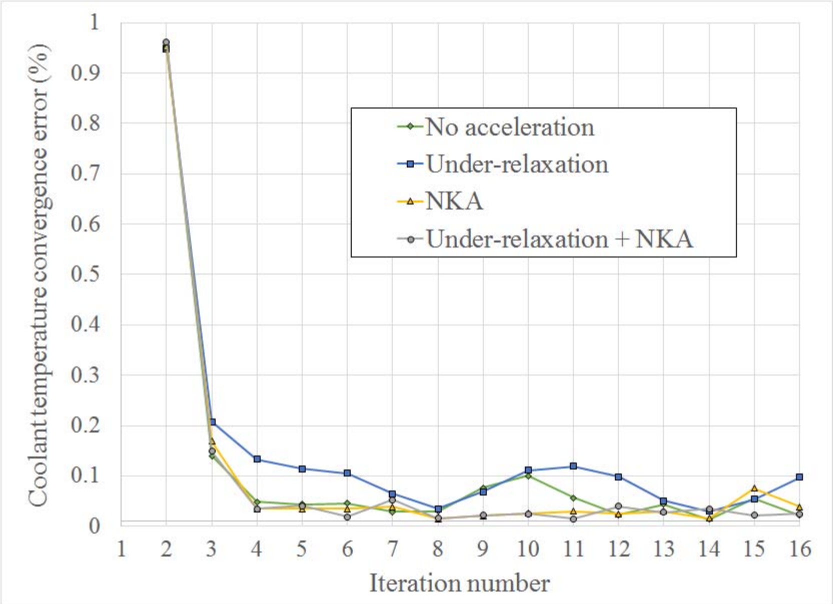
- Axial coolant temperature profiles, for channels A, B and F:



5 – Verification with VERA - Problem 6 (5)

- Performance and convergence:
  - No significant overhead between the object-oriented and master-stave approaches.
  - Relatively small gain from using acceleration methods.
  - MC uncertainty quickly reached.

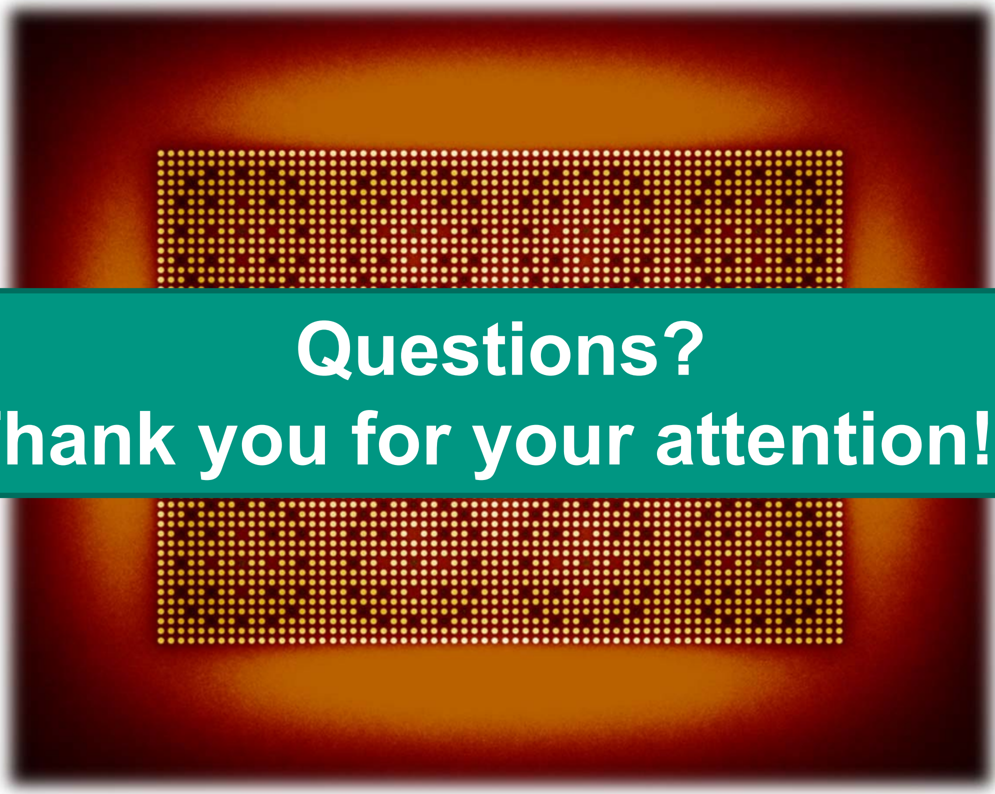




6 – Conclusions and further work

- Object-oriented Serpent2-SUBCHANFLOW coupling:
  - Enhanced flexibility, maintainability and code reusability.
  - Suitable for cooperation within the McSAFE project.
  - Successful verification with Problem 6 of the VERA benchmark.
  - No overhead observed with respect to the master-slave approach.
  - Geometry agnostic capabilities assessed (VVER, PWR, etc.)

  (see to paper ANE 135 “***Serpent2-SUBCHANFLOW pin-by-pin modelling capabilities for VVER geometries*** **” – M García et al.**)
- Further work:
  - Towards full-core depletion:
    - Memory bottleneck → Collision-based Domain Decomposition (CDD).
    - Speedup optimization with CDD.
  - Coupling with TRANSURANUS (fuel-performance).
  - Validation with VVER-1000 and Konvoi PWR plant data.



Questions?

Thank you for your attention!!!

Serpent2-SCF VERA FA model