H2020

McSAFE

High Performance Monte Carlo for Safety

Coupling TRANSURANUS with Monte Carlo and subchannel codes for pin-by-pin depletion in LWR

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McSAFE EU H2020 project

- Objectives:
  - Improve the prediction of local safety parameters through high-fidelity.
  - Develop multiphysics tools based on Monte Carlo particle transport, subchannel thermalhydraulics and fuel-performance analysis.
  - Solve steady-state, depletion and transient problems.
  - Optimize the codes for massive problems such as full-core burnup.
  - Validate with PWR and VVER plant data.
- Participants:
  - KIT (SUBCHANFLOW).
  - JRC, HZDR (TRANSURANUS).
  - VTT (Serpent2).
  - CEA (Tripoli), DNC (MCNP), AMEC (MONK), NRI, KTH.
  - EKK, CEZ, EdF.
- Continuation of the NURESAFE and HPMC projects.

Serpent2-SCF-TU

- Codes:
  - Serpent2: continuous-energy Monte Carlo particle transport.
  - SUBCHANFLOW: MATRA- (COBRA-) based subchannel code.
  - TRANSURANUS.
- Objectives:
  - Perform fully coupled pin-by-pin depletion calculations.
  - Optimize the system for High Performance Computing (HPC).
  - Develop a suitable modelling approach (pin-by-pin, hot channel) for full-core.
  - Validate with PWR and VVER experimental data from the industry partners.
- Coupling approach:
  - Pin-level feedback, fully coupled calculation scheme.
  - TRANSURANUS replaces the rod solver of SUBCHANFLOW.
  - Object-oriented design.
  - Mesh-based (geometry agnostic) field exchange.
  - Pre- and post-processing capabilities for PWR and VVER reactors.

Object-oriented coupling

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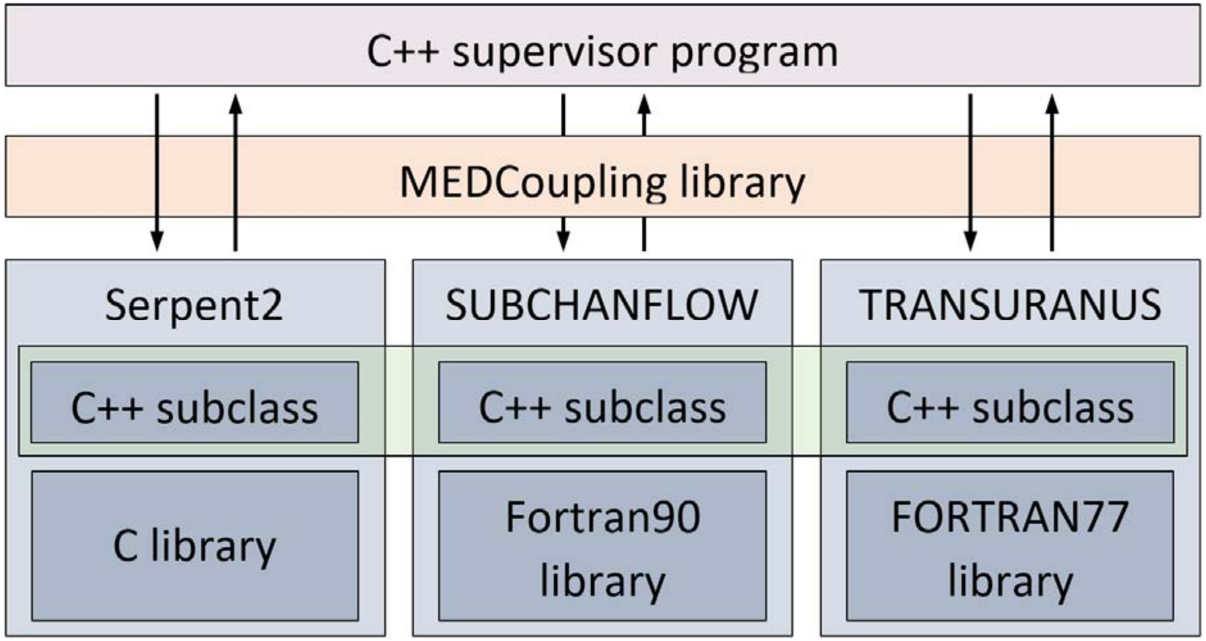
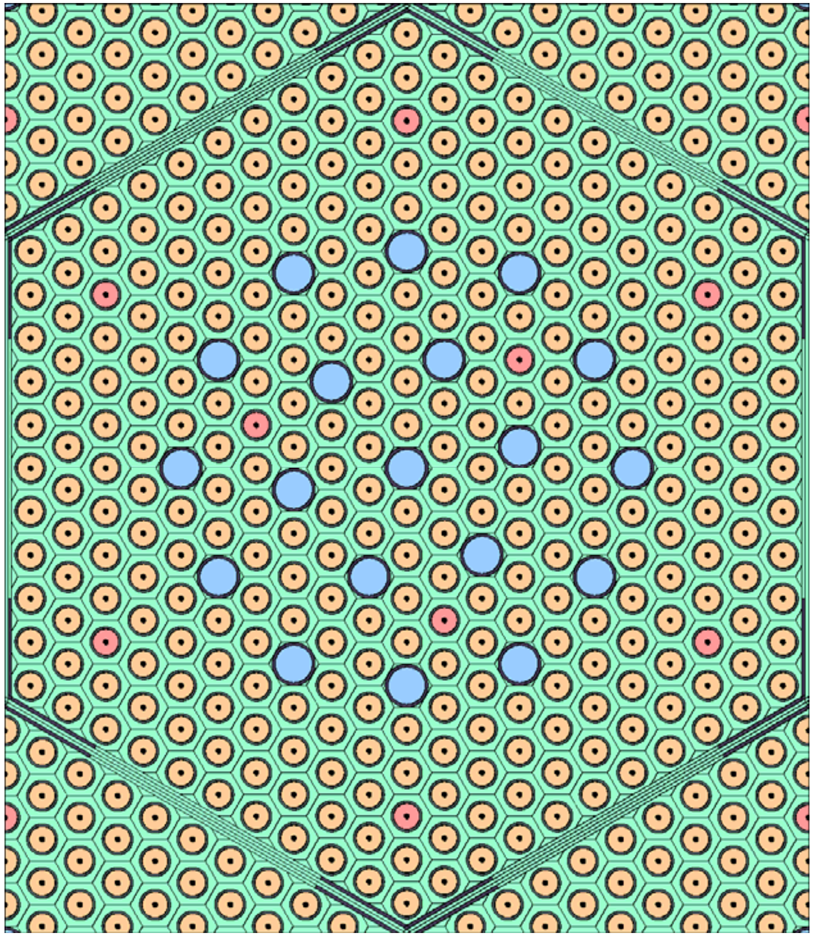
- Object-oriented design:

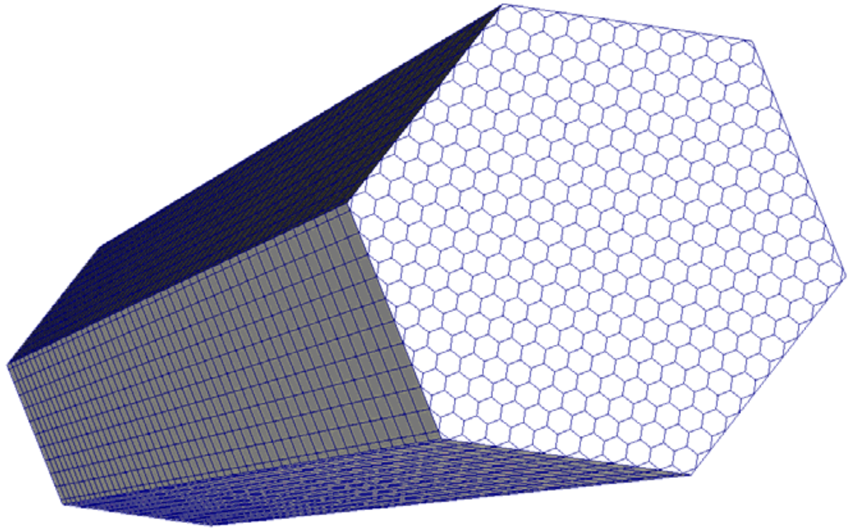


- Advantages:
  - The codes are kept completely separate and maintainability is enhanced.
  - Suitable model for collaborative development projects.
  - The coupling through the supervisor is flexible and somehow generic.

Mesh-based feedback

- Serpent2:

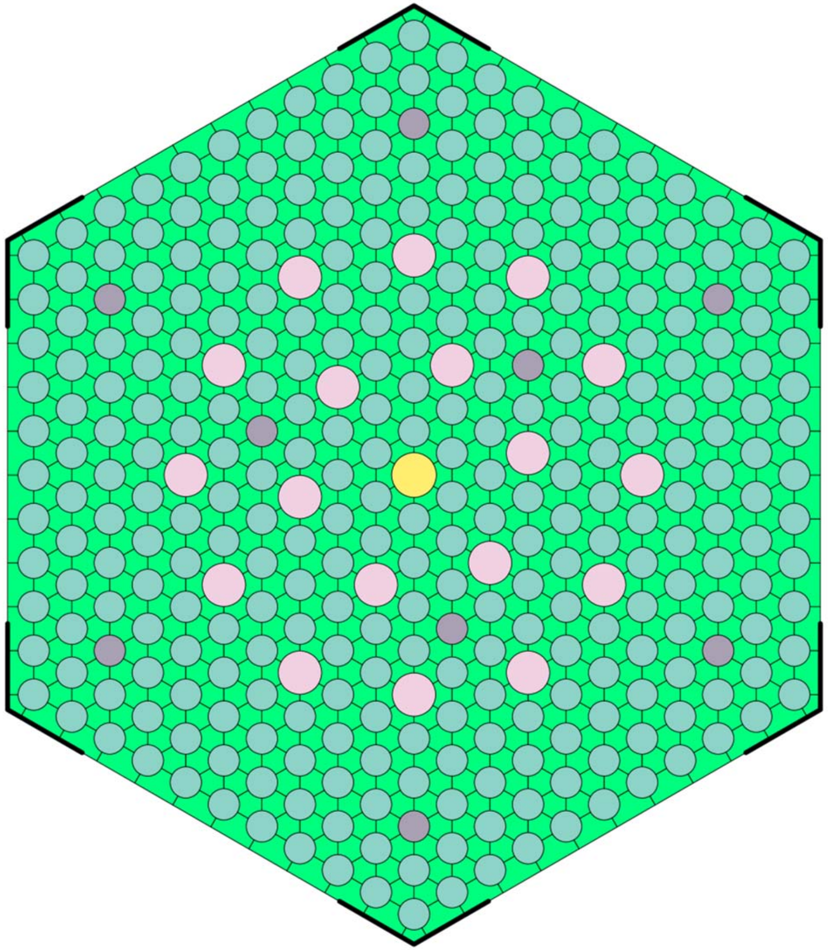


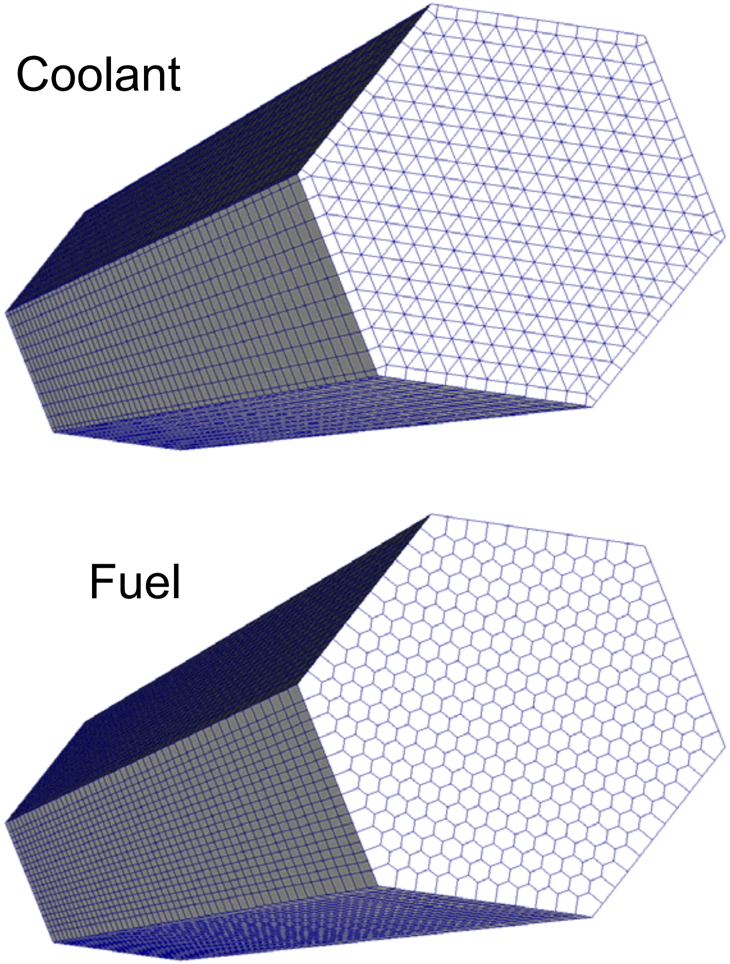


Multiphysics interfaces:
- Superimposed meshes.
- Not linked directly to the tracking geometry.
- Define temperatures and densities and tally power.

Mesh-based feedback

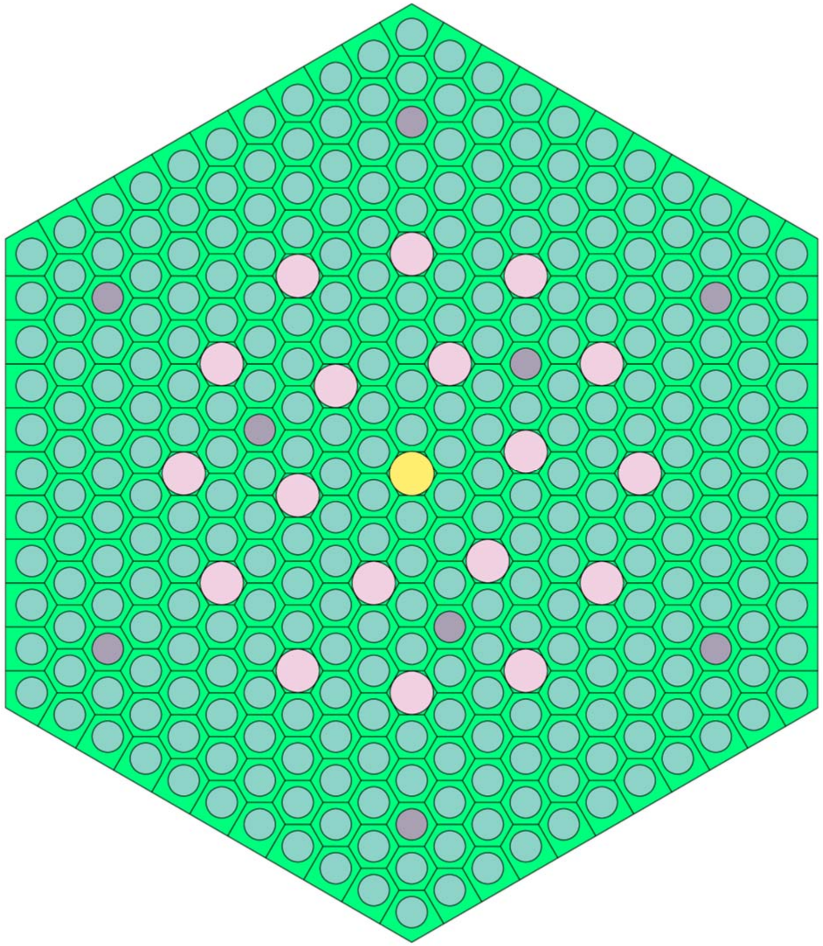
- SUBCHANFLOW:

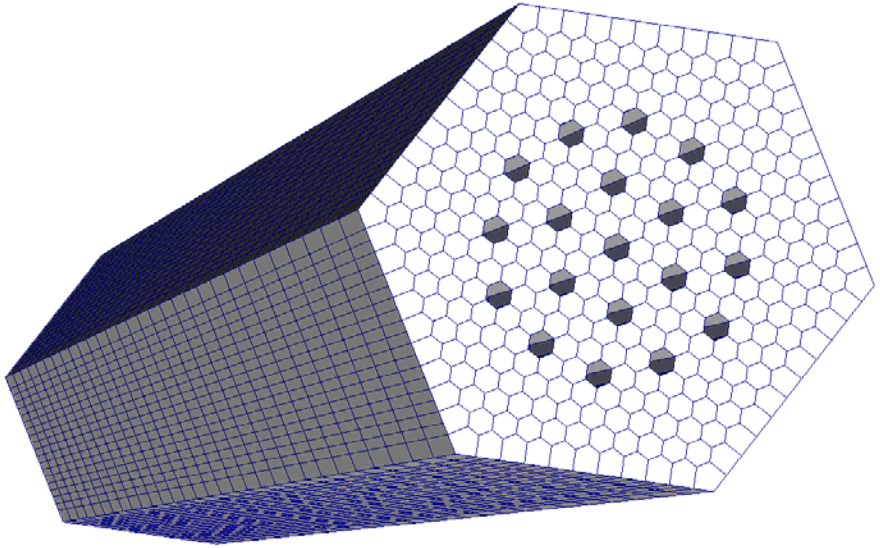




Mesh-based feedback

- TRANSURANUS:

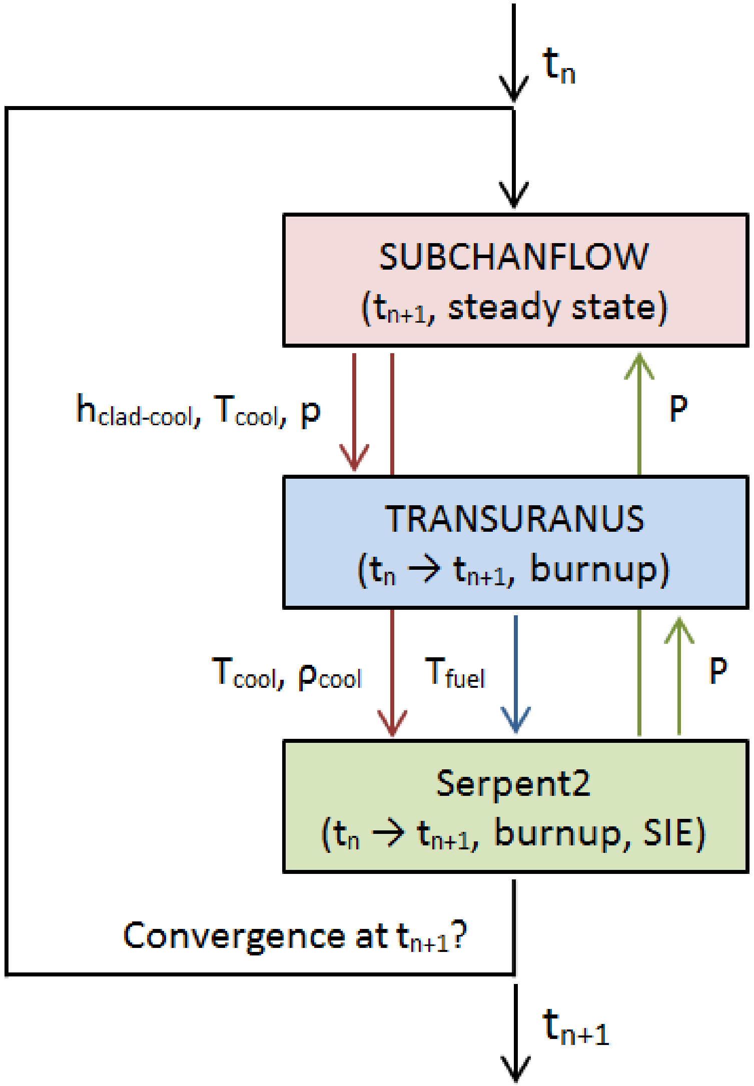




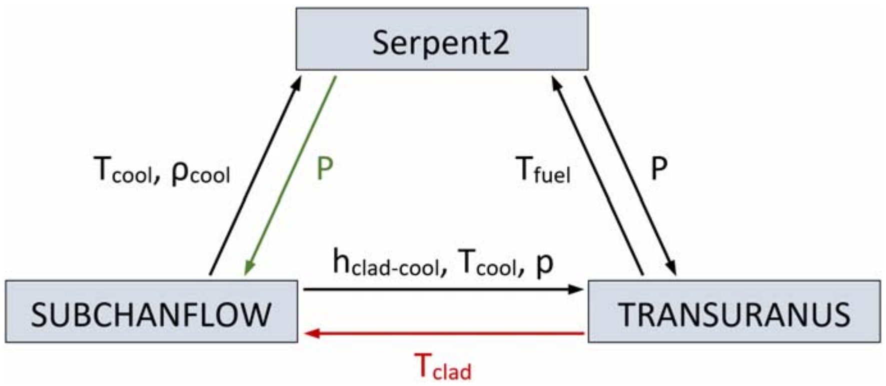
Multiphysics mesh:

- Used to gather results and set input variables.
- Contains only the fuel rods.

Calculation scheme



- Semi-implicit depletion scheme.
- Solution of the Bateman equations both in TU and Serpent2.
- The only Serpent2 data used in TU is the power distribution.
- The TU neutronic model is still used.
- SCF does not model the rods.



Developments on TRANSURANUS

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- No changes to the physical models.
- Code structure:
  - Kernel implemented as a library for flexible execution.
  - C++ wrapper to define the API used in the coupling scheme.
  - Support for multiple rods.
  - An unstructured mesh is used to gather results and handle input variables.
- Input:
  - Coolant boundary conditions ($h_{clad\text{-}cool}$, T_{cool}, p) from SUBCHANFLOW.
  - Linear heat rate from Serpent2.
- Output:
  - Fuel temperature to Serpent2.
  - Gap conductance, gap width, fission gas release (Xe, Kr, etc).
- Optimization:
  - MPI parallelization using domain decomposition.
  - Dynamic memory allocation (~12GB → ~1.5GB for a VVER-1000 fuel).

Results: steady state

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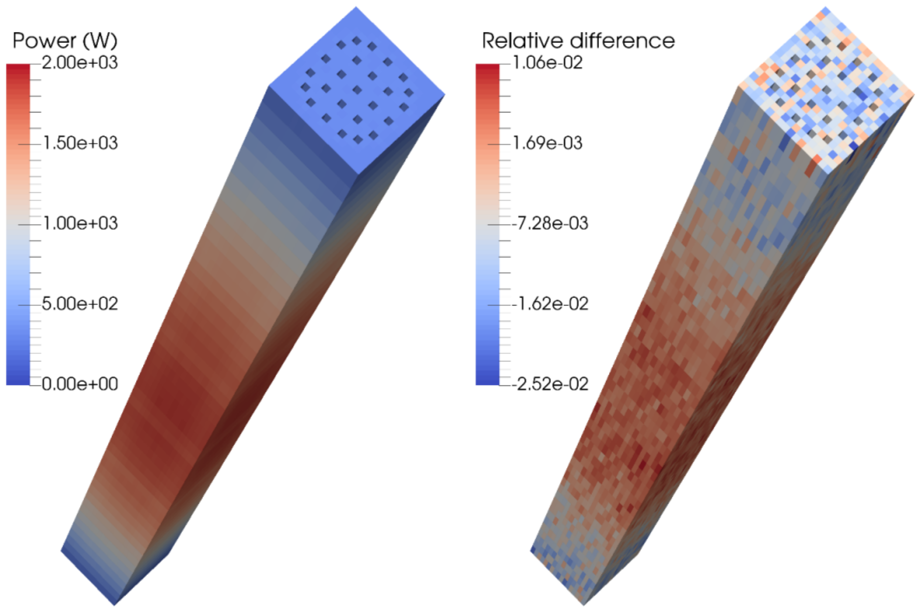
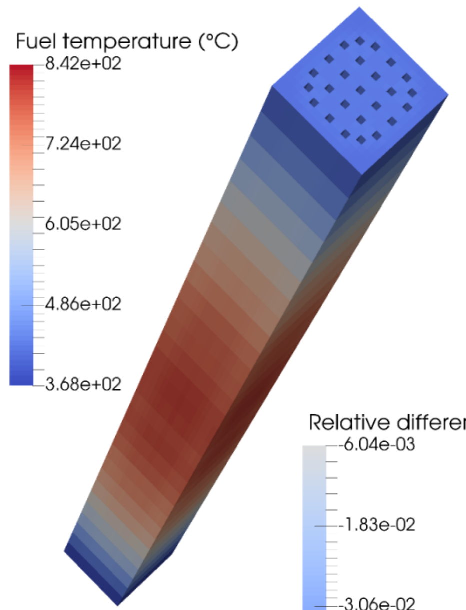
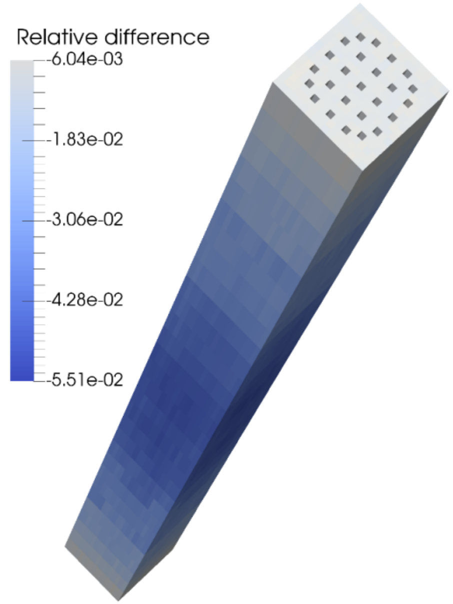
- PWR: VERA Benchmark Problem 6.





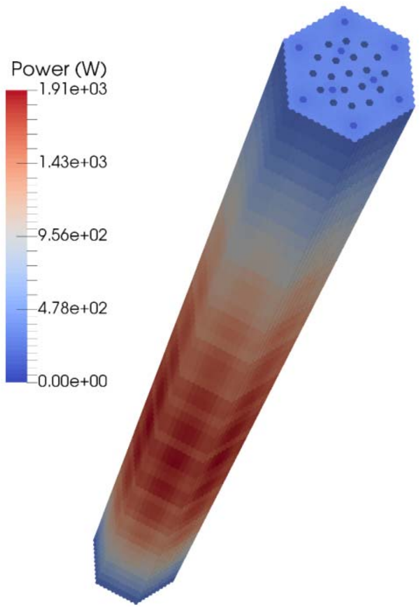


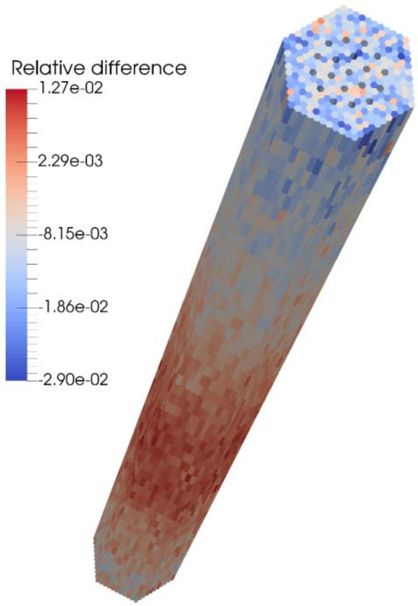
Difference: Serpent-SCF-TU – Serpent-SCF

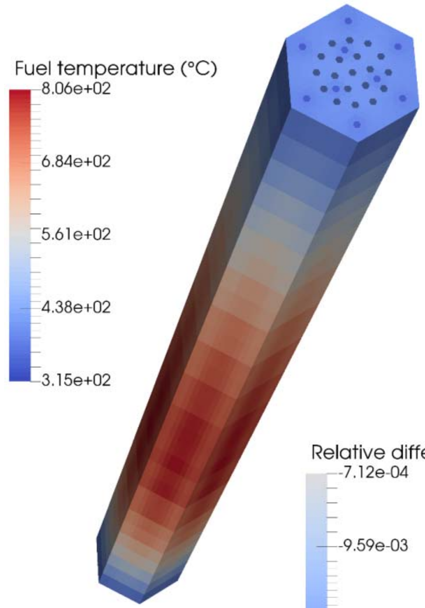
Field	Maximum difference	Average difference
Power (W)	19.83 (2.52%)	5.24 (0.48%)
Coolant density (kg/m³)	6.08 (0.89%)	1.06 (0.15%)
Coolant temperature (°C)	2.31 (0.39%)	0.42 (0.07%)
Fuel temperature (°C)	46.36 (5.51%)	24.22 (3.36%)

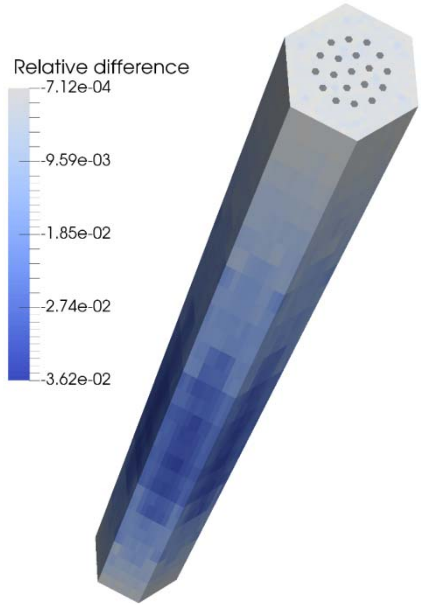
Results: steady state

- VVER: 30AV5 VVER-1000 fuel-assembly type.







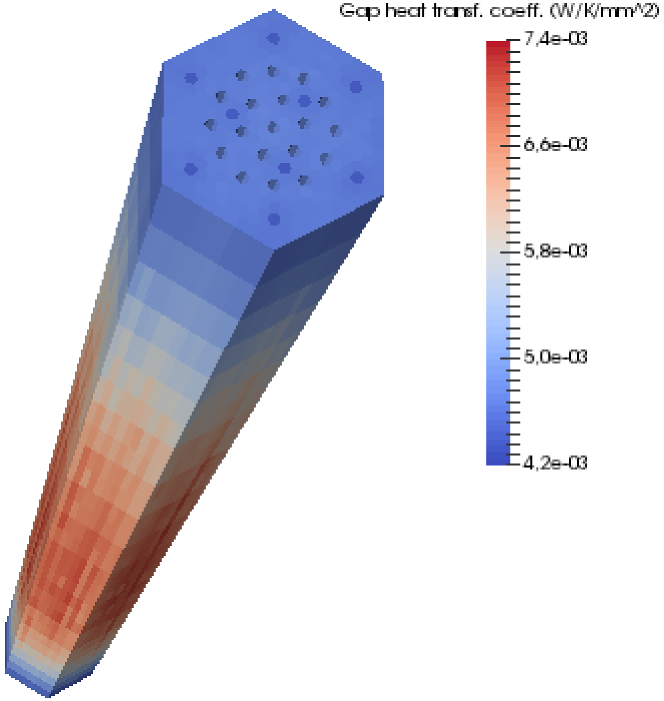


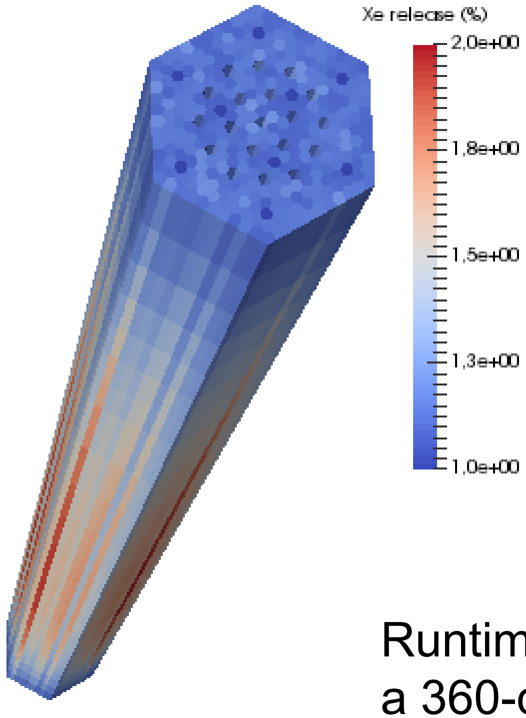
Difference: Serpent-SCF-TU – Serpent-SCF

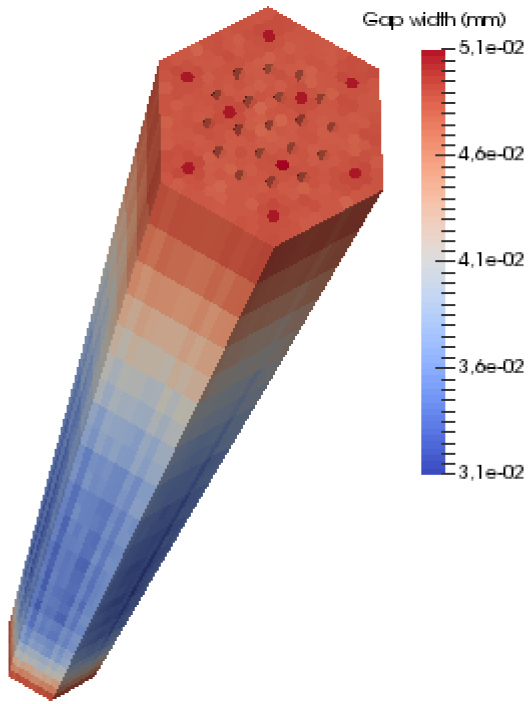
Field	Maximum difference	Average difference
Power (W)	22.12 (2.90%)	4.61 (0. 46%)
Coolant density (kg/m³)	0.43 (0.06%)	0.09 (0.01%)
Coolant temperature (°C)	0.17 (0.03%)	0.04 (0.01%)
Fuel temperature (°C)	28.86 (3.62%)	11.75 (1.73%)

Results: depletion

- VVER: 30AV5 VVER-1000 fuel-assembly type (t = 60 days).







Runtime: ~48hs in 40x20 cores for a 360-day cycle.

Open issues

- Neutronic feedback to TRANSURANUS:
  - Currently only the linear heat rate is used, the simples posible feedback.
  - Using power and flux radial profiles not feasible, at least not with the current modelling approach, i. e. having all pins in TRANSURANUS.
  - Other average parameters? Isotope compositions?
- Doppler feedback to Serpent2:
  - Currently volume averaging or empirical formulas are used.
  - Analysis of radial fuel temperature profiles in the near future.
- Modelling approach:
  - With the current approach we'd simulate ~60,000 rods for full-core cases!
  - Hot-channel methodology? Average pin for each fuel-assembly?
- Memory bottleneck for Serpent2 depletion:
  - A full core takes about 2TB for pin-by-pin depletion.
  - Domain decomposition in progress.

Conclusions

- Current status:
  - Three code coupling with pin-level feedback implemented.
  - Verification with single-fuel-assembly PWR and VVER steady-state cases.
  - Analysis of single-fuel-assembly depletion cases underway.
  - Optimization towards full-core capabilities in progress.
- Open issues:
  - Analysis of the TRANSURANUS side of the depletion scheme, including adding more neutronic feedbacks from Serpent2.
  - Analysis of the Doppler feedback to Serpent2.
  - Optimization of the modelling in TRANSURANUS (and the other codes).
- McSAFE user group open to new participants!

Questions? Comments?