HPC in the McSAFE EU project

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Introduction

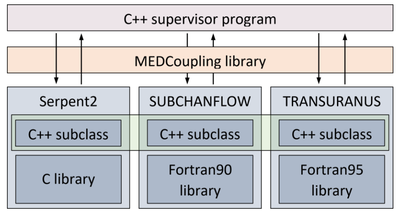
High-fidelity multiphysics for Light Water Reactor (LWR) analysis:

The EU Horizon 2020 McSAFE project is focused on the development, optimization and validation of cutting-edge tools for safety analysis of Light Water Reactors (LWR). The simulation tools considered are:

- *Serpent 2: Monte Carlo neutron transport for steady-state, burnup and transient calculations.*
- *SUBCHANFLOW: subchannel thermalhydraulics.*
- *TRANSURANUS: fuel-performance analysis*.

Serpent-SCF-TU coupling system:

Serpent, SCF and TU are integrated using an object-oriented approach, with the calculation scheme implemented in an independent supervisor program. The feedback exchange between codes is based on unstructured meshes using the MEDCoupling library.

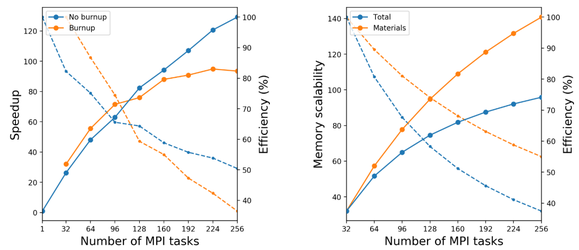


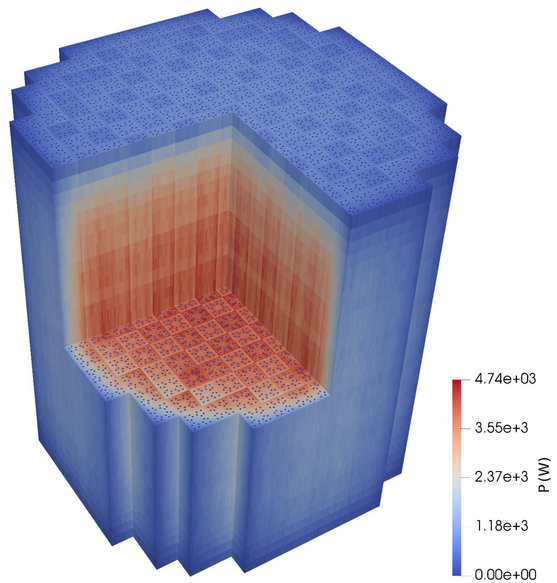
Collision-based Domain Decomposition:

Burnup problems take up to a few TB of RAM to store compositions, cross sections and reaction rates, and the traditional domain-replication method used in Monte Carlo transport has no memory scalability. To solve this, a Collision-based Domain Decomposition (CDD) scheme was implemented in Serpent 2 [3]. CDD is based on decomposing burnable materials in domains (MPI tasks), reducing the in-node memory demand, and modifying the particle tracking algorithm to account for neutrons frying across-domains.

Depletion

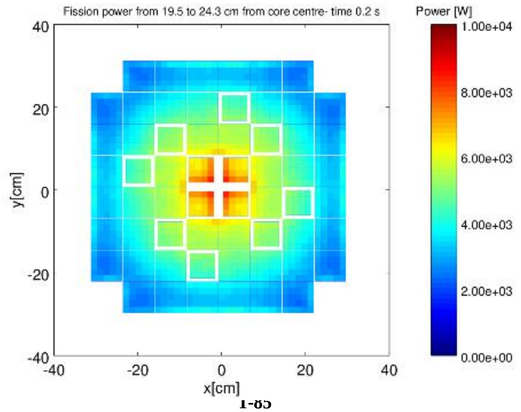
Full-core pin-by-pin burnup calculations based on Monte Carlo neutron transport coupled with subchannel thermalhydraulic and fuel-performance analysis involve huge computational requirements, both in terms of runtime and of memory demand. These type of calculations were validated with experimental data from VVER-1000 and Pre-Konvoi PWR reactors. The statistical accuracy of the simulation is bounded by runtime.

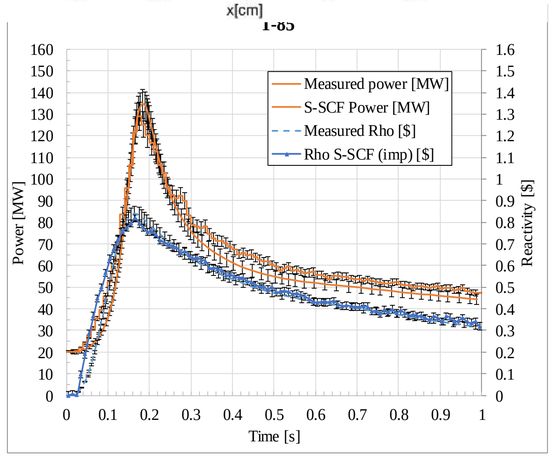




Transients

The analysis of transient scenarios using coupled Monte Carlo particle transport and subchannel thermalhydraulics represent a development beyond the state of the art in terms of high-fidelity multiphysics. Optimization and variance reduction techniques were developed and tested in relatively small problems [5], and the code system was validated using the SPERT-IIIE hot-full-power tests [6]. The validation calculations require about 6 hours in 1000 cores for one second of real time.





ForHLR II experience

Testing and optimization:

- *Testing up to 256 nodes (5,210 cores) using hybrid MPI/OpenMP execution, short runs (up to ~1h).*
- *Optimization of Serpent 2 domain decomposition:*
  - *Asynchronous MPI communications.*
  - *Different multithreading schemes (serialized, funneled) for MPI/OpenMP execution.*
  - *Buffering for particle transfers during tracking.*
  - *Termination control based on asynchronous and synchronous global reductions and a binary tree structure for communications.*

Production calculations:

- *Typically up to 64 nodes (1,280 cores) using hybrid MPI/OpenMP execution, long runs (up to 1 week, long queue).*
- *Full-core burnup problems need at least ~32 nodes to fit the data in memory.*

Related publications

1. M. García, et al., “A Serpent2-SUBCHANFLOW-TRANSURANUS coupling for pin-by-pin depletion calculations in Light Water Reactors”, Annals of Nuclear Energy, 139 (2020).
2. M. García, et al., “SERPENT2-SUBCHANFLOW-TRANSURANUS PIN-BY-PIN DEPLETION CALCULATIONS FOR A PWR FUEL ASSEMBLY”, PHYSOR2020 conference, Cambridge, UK (2020).
3. M. García, et al., “A Collision-based Domain Decomposition scheme for large-scale depletion with the Serpent 2 Monte Carlo code”, submitted to Annals of Nuclear Energy.
4. M. García, et al., “Validation of Serpent-SCF-TU full-core pin-by-pin burnup calculations using Pre-Konvoi PWR experimental data”, submitted to Nuclear Engineering and Design.
5. D. Ferraro, et al., “Serpent/SUBCHANFLOW pin-by-pin coupled transient calculations for a PWR minicore”, Annals of Nuclear Energy, 137 (2020).
6. D. Ferraro, et al., “Serpent/SUBCHANFLOW pin-by-pin coupled transient calculations for the SPERT-IIIE hot full power tests”, Annals of Nuclear Energy, 142 (2020).
7. D. Ferraro, et al., “SERPENT/SUBCHANFLOW COUPLED CALCULATIONS FOR A VVER CORE AT HOT FULL POWER”, PHYSOR2020 conference, Cambridge, UK (2020).
8. D. Ferraro, et al., “OECD/NRC PWR MOX/UO2 core transient benchmark pin-by-pin solutions using Serpent/SUBCHANFLOW”, Annals of Nuclear Energy, 147 (2020).