Karlsruhe Institute of Technology

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Advanced Numerical Simulation for Reactor Safety: The High Performance Monte Carlo (HPMC) Reactor Core Analysis Project

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Main goals:

- Improved coupling with thermal-hydraulics
- Optimised depletion calculations
- Time-dependent Monte Carlo codes
- Use of High Performance Computing techniques

HPMC Calculation Tools:

- SERPENT, MCNP
- SUBCHANFLOW (SCF)

www.fp7-hpmc.eu

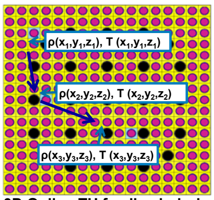
Coupled Codes:

- MCNP/SUBCHANFLOW
- SERPENT/SCF

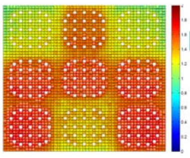
High Fidelity MC/TH Coupling: PWR 3x3 FA

MCNP/SUBCHANFLOW Simulations:

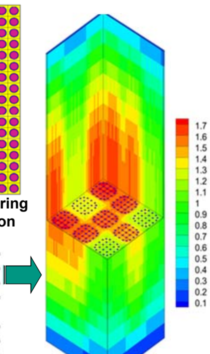
- Internal coupling
- Uniform convergence
- Stochastic approximation
- Optimised convergence acceleration
- On-the-fly T-interpolation of XS
- Variance reduction with an iterative flux-based Weight Window technique
- Accelerated tallying with custom written Collision Density and Track-length estimators
- Parallelisation of MCNP and SCF with hybrid MPI/OpenMP
- Utilization of HPC Blue Gene/Q



3D Online TH feedback during neutron history simulation



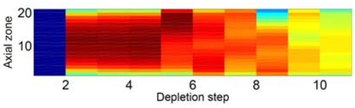
Weight window mesh and 2D power



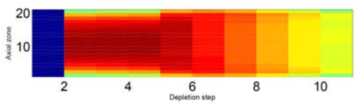
3D Rel. Power distribution

Optimal and stable Monte Carlo Depletion Integration

- Numerical instability of the commonly used predictor-corrector method was demonstrated in MC burnup calculations.
- New Stochastic Implicit Euler (SIE) based MC burnup scheme was suggested.
- The SIE-based scheme was proved to be stable for any time step length, which was also demonstrated on a PWR-FA MC burnup calculations

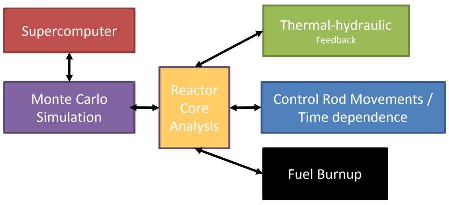


Spatial distribution of Xe-135 in a **conventional predictor-corrector based MC-burnup** calculation of a PWR-FA with 10.0 MWd/kgU step.



Spatial distribution of Xe-135 in a **SIE-based MC-burnup** calculation of a PWR-FA with 10.0 MWd/kgU step (same statistics in all calculations).

Main Elements of High Fidelity MC/TH Core Analysis

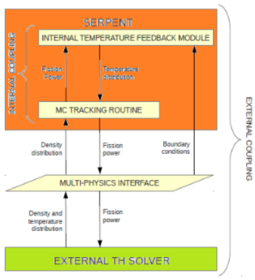


Time-dependent Monte Carlo Methods

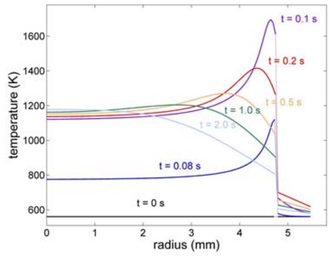
- **Goal:** develop Dynamic MC capable of dealing with time-dependent problems including thermal-hydraulic feedback for safety assessment
- **Major challenges in the statistics of predicted power as a function of time:**
  - The inherent statistics in the chain length of prompt neutrons
  - Large difference in lifetime of a prompt neutron chain (less than 1 ms)
  - Decay time of neutron precursors (0.1 to 100 s)
  - Control rod movement
  - Parallelisation of time intervals
- **Solution approach:**
  - Introduction of a new techniques to reduce the variance
  - Introduction of a new and accurate technique to deal with moving control rods or control rod banks
- **Status**: Developments for MCNP and SERPENT are not complete. Preliminary capability to describe prompt neutrons in testing phase, extensions for treatment of delay neutrons underway.

SERPENT-2 Multi-physics Capabilities

- Based on the combination of internal solvers and external coupling via a universal
- The internal modules are:
  - 1) The FINIX light-weight thermo-mechanical solver for steady-state and transient heat transfer at pin level.
  - 2) The COSY light-weight three-dimensional system / component scale thermal-hydraulics solver.
- The MP-interface is designed to pass state variables and power distributions between Serpent and external codes (CFD, system-scale TH, fuel performance)
- Universal and versatile scheme not limited to any particular code.
- Methods still under development, and the first results of coupled calculations are expected by the end of 2013.

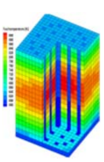


Multi-Physics Features of SERPENT 2

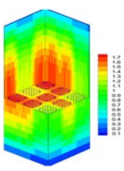


SERPEN2/FINIX: Temperature profile in a fuel pin after a reactivity transient

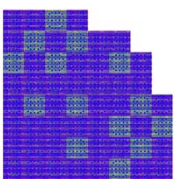
Medium and long term goals of HPMC: provide reference solutions for static and time-dependent deterministic codes (diffusion or transport) and analysis of safety cases (Transients)



PWR FA



PWR 3x3 FA Cluster

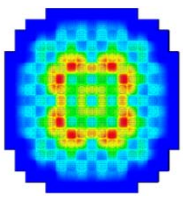


PWR ¼ Core (56 FAs)

Increasing complexity of the problems to be solved

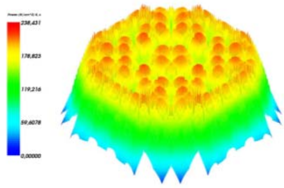
Need exp. data **or** MC reference solutions

Diffusion Solution + PPR



DYN3D-PPR: Pin power distribution in the core for the steady state conditions of the boron dilution benchmark

SP3 Transport Solution + TH



DYNSUB: Full core axially cumulated power density distribution [W/cm³]