Multi-physics simulations with TRIPOLI-4^R: coupling neutron transport with the CFD code TRUST/TrioCFD

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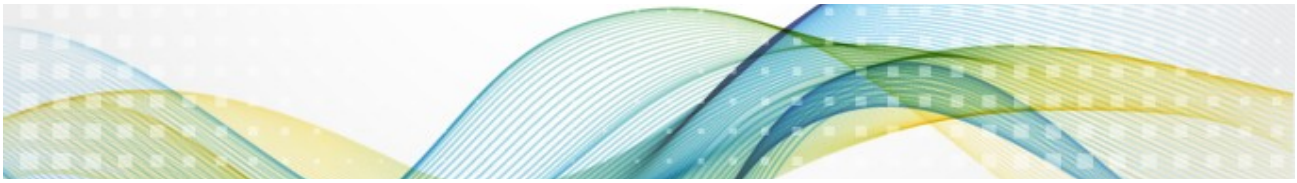
The coupling between neutron transport, fuel thermo-mechanics and thermal-hydraulics is key for the description of fundamental reactivity feedback mechanisms as the Doppler and moderator effects, which are the main counter-reactions responsible for reactor stability. Multi-physics problems in reactor physics, where neutron transport is coupled to other disciplines such as thermal-hydraulics or thermo-mechanics, have mostly been handled so far by deterministic codes. However, Monte Carlo simulation can provide reference solutions for neutron transport, in that it introduces very few approximations as compared to deterministic solvers: in this respect, there is a growing interest for Monte Carlo tools to provide reference multi-physics simulations for reactor physics.

Thermal-hydraulics simulations based on Computational Fluid Dynamics (CFD) finely model the physical exchanges, at the expense of high requirements of computation time and memory; this contrasts with the comparatively faster porous-media-based simulations. However, the computer time required by Monte Carlo simulations, especially in the non-stationary regime, might be even longer than for CFD. Memory requirements for CFD are even more stringent: a few million mesh cells may be required to model a single fuel pin-cell by using a CFD code. Another challenge in the coupling strategy between Monte Carlo and thermal-hydraulics lies in the choice of the algorithm for mapping physical quantities between the volumes of the geometry for Monte-Carlo neutron transport and the very fine spatial meshes of the CFD code.

For all these reasons, the application of Monte Carlo for multi-physics simulations in reactor physics has initially been developed with porous-media codes [1,2,3]. In order to improve the accuracy of thermal-hydraulics modeling, couplings with CFD codes have been recently considered [4,5,6]; however, further investigation is necessary to meet the different challenges listed above: computer time, memory handling and mapping between geometries.

In this work, we present the coupling between a CFD solver and the Monte-Carlo neutron-transport code TRIPOLI-4® [7]. This coupling was made possible by the implementation of a multi-physics interface for TRIPOLI-4. As an external CFD thermal-hydraulics code, we use TRUST/TrioCFD [8,9]. Data exchange between the two codes is performed using the MEDCoupling library [10,11]. As a demonstration, we simulate the stationary state of a PWR pin cell based on SPERT III E-core nuclear reactor [12]. The steady state is approached iteratively: temperatures in the fuel and the moderator computed by TRUST/TrioCFD are given as inputs to TRIPOLI-4 for the following calculation step. Similarly, power distributions computed by TRIPOLI-4 are fed to TRUST/TrioCFD. The iterations stop when appropriate convergence criteria are met. We compare uncoupled and coupled simulations in order to highlight the effects of thermal-hydraulics feedbacks on the neutron flux. This work, combined with uncoupled kinetic method described in [13] is a stepping stone towards the analysis of accidental transients with TRIPOLI-4. Full simulations of the kinetic behaviour of SPERT III E-core coupled with thermal-hydraulics will be considered for future work, in view of comparing simulation results with available experimental measurements.



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