

Further Development of High-Fidelity Reactor Simulator DYNSUB

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Abstract:

The availability of relatively cheap, large-scale parallel computers has triggered the development of high-fidelity reactor simulation tools for nuclear reactor design, optimization and safety analysis in academia. These are intended to replace Best-Estimate (BE) methods in future. While no truly high-fidelity multi-physics tool exists so far, most on-going efforts concentrate on increasing both the spatial resolution and on improving the accuracy of coupled neutron physics and thermal-hydraulic codes. These coupled code systems may rely both on deterministic and Monte Carlo methods to solve the neutron transport problem. Thermal-hydraulics is tackled using sub-channel programs or computational fluid dynamics.

One such multi-physics tool developed at the Karlsruhe Institute of Technology (KIT) is the deterministic coupled code DYNSUB, an internal coupling of the 3D reactor simulator DYN3D developed by Helmholtz Zentrum Dresden Rossendorf (HZDR) and the sub-channel code SUBCHANFLOW developed at KIT. Recently, DYNSUB has been optimized in terms of its numerical behaviour. Solution algorithms have been adapted to ensure the conservation of physical quantities of interest, to improve efficiency and to guarantee numerical stability. Both DYN3D and SUBCHANFLOW were originally serially implemented. Consequently, computational bottlenecks in DYNSUB were identified and parallelized for shared memory architectures using the API OpenMP. In addition to the numerical optimization, the physical models in DYNSUB were extended. On the one hand, the capability to track the concentration of chemical shims in the reactor coolant and time-dependent thermal-hydraulic boundary conditions were added. On the other hand, new possible parameterizations of incident neutron cross sections were enabled to improve the quality of the reactor kinetics solution. DYNSUB uses pre-generated multi-dimensional few-group effective incident neutron cross section tables to describe materials in the reactor core and their interaction with the neutron population. The generation of such effective cross sections introduces homogenization errors into the simulation. Generalized Equivalence Theory (GET) and Selengut-type interface discontinuity factors (IDF) and super-homogenization (SPH) factors were considered to reduce these homogenization errors.

Due to the optimization efforts and extension of physical models included, for the first time, it was possible to analyse selected safety cases for a Westinghouse pressurized water reactor (PWR) resolving the core at a 1cm scale, i.e. radially at fuel pin level. Here, a hot zero power (HZP) rod ejection accident (REA) scenario is presented.

With this study, DYNSUB principle applicability for light water reactor (LWR) safety analysis was proven. However, observed execution times of several days were found to be too long for a routine application of DYNSUB. Further numerical improvements are necessary to make DYNSUB a daily-routine multi-physics tool.

Miriam Daeubler:

After receiving a degree in physics from the Technical University of Munich, I came to the Karlsruhe Institute of Technology in May 2012. I work at the Institute for Neutron Physics and Reactor Technology and mainly concentrate on developing numerical simulation tools to perform nuclear reactor safety analyses. My PhD is supervised by my head of institute, Prof. R. Stieglitz. I intend to finish my PhD in early 2015.

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