Modeling of Phenix End-of-Life control rod withdrawal benchmark with DYN3D SFR version

E. Nikitin, E. Fridman

The reactor dynamics code DYN3D is currently under extension for Sodium cooled Fast Reactor applications. The control rod withdrawal benchmark from the Phenix End-of-Life experiments was selected for verification and validation purposes. This report presents some selected results to demonstrate the feasibility of using DYN3D for steady-state Sodium cooled Fast Reactor analyses.

The Phenix End-of-Life (EOL) control rod (CR) withdrawal benchmark[1] was selected for verification and validation (V&V) purposes of Sodium cooled Fast Reactor (SFR) version of nodal diffusion code DYN3D.[2]

BENCHMARK DESCRIPTION. The benchmark comprises several code-to-code comparisons and a few experimental measurements on the Phenix EOL core. The latter is divided into two parts: the off-power tests and on-power tests. During the off-power (~50 kW) tests, the CR S-curves were measured for the CRs #1 and #4 with the balancing method. At the on-power tests, four different critical steady-states were achieved by shifting the CRs #1 and #4 (see Fig. 1). In the center part of the core, thermocouples have been positioned above each sub-assembly to measure the outlet sodium temperature distributions. During the experiments the total mass flowrate remained constant; therefore the radial power distribution can be calculated and can be compared with the calculations. Further details on the experiments are available in literature.[1] It should be noted that the core description provided by benchmark specification has some deficiencies, which means that only averaged distributions of materials, temperatures, burnup and sodium flow rates are available.

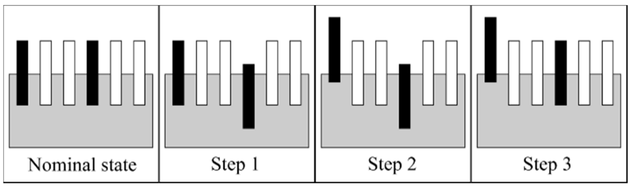

Fig. 1: Schematic overview on different CR positions.

CALCULATION METHODOLOGY. The full core nodal diffusion solutions of the benchmark were calculated with DYN3D. The homogenized few-group cross sections (XS) required by DYN3D were generated using the Monte Carlo (MC) code Serpent.[3] For further improvement of the nodal diffusion solution, Superhomogenization factors were used on CRs, first row of blankets and inside reflectors. Additionally, Serpent was also used to calculate the full core MC reference solutions for code-to-code comparisons. A more detailed description on the XS methodology and SPH method for realistic SFR cores can be found in literature.[4, 5]

RESULTS ON THE CR S-CURVES. The CR S-curves were calculated with both DYN3D and Serpent codes. The balancing method was reproduced with an iterative criticality search routine by using the movement of the compensation rod. A very good agreement was achieved between DYN3D and Serpent solutions. Compared to the experiment, DYN3D achieved a good agreement and overpredicted the CR worth by 119 and 70 pcm for CRs #1 and #4, respectively.

RESULTS ON THE ON-POWER TESTS. All steps of the CR-shift test were calculated with DYN3D. The obtained reactivity values are higher by ~800 pcm, which is still in a very good agreement with Serpent reference and the results of the benchmark participants. In the radial power prediction high discrepancies can be observed (e.g. in Fig. 2) between DYN3D and the experiment. This is the same difference that can be observed by other participants who used the same averaged core description (e.g. CEA ave. results in Fig. 2). The discrepancies can be explained by the lack of modeling details, since CEA, using their same code and a detailed core model, could reproduce the measured power in a better agreement (see Fig. 2 CEA det.).

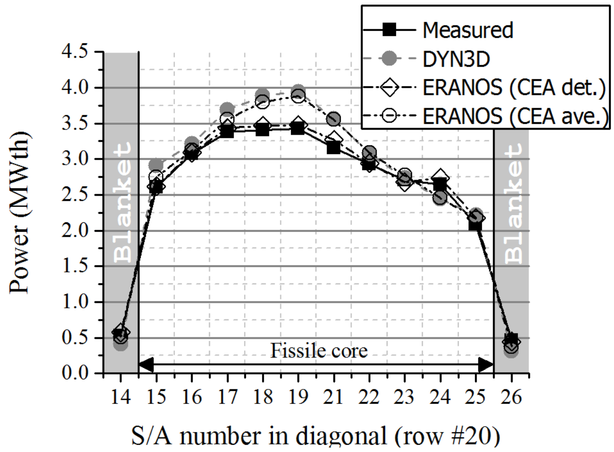

Fig. 2: Radial power distribution along the core diagonal at Step 2.

CONCLUSIONS. The SFR version of DYN3D was used to calculate the Phenix EOL CR withdrawal benchmark. The results were in a very good agreement compared to the MC reference solution in general. A good agreement was observed at the calculation of CR S-curves compared to the measurements. The CR-shift test calculations were in good agreement with other benchmark participants, but high discrepancies were observed compared to the experiment due to the averaged core modeling.

[1] International Atomic Energy Agency (2014) *Benchmark Analyses on the Control Rod Withdrawal Tests Performed during the PHÉNIX End-of-Life Experiments*, IAEA-TECDOC-1742. Vienna, Austria.
[2] Rohde, U. *et al.* (2016) *Prog. Nucl. Energy* **89**, 170–190.
[3] Leppänen, J. *et al.* (2015) *Ann. Nucl. Energy* **82**, 142–150.
[4] Nikitin, E. *et al.* (2015) *Ann. Nucl. Energy* **75**, 492–497.
[5] Nikitin, E. *et al.* (2015) *Ann. Nucl. Energy* **85** 544–551.