RELAP5-3D with PHISICS Neutronics, Part 3 – Depletion Thermo-Hydraulic Benchmark

Cristian Rabiti, Francesco Lodi, Andrea Alfonsi

October, 2013

As a conclusion of the newsletter series on the PHISICS RELAP5-3D coupling a results of a coupled simulation will be presented. The case presented involves several steady state analyses (coupled neutronics and thermo-hydraulics) and a coupled TH depletion for the first cycle of a PWR core.

The Benchmark

Benchmark Description

A clean start up core for a PWR is considered. The geometrical data are the following: 15x15 assemblies, 17 different types of assemblies originated by combination of 3 different enrichments, a burnable absorber and 4 control rod banks.

The following values will be calculated:

- Hot Zero Power (HZP):
  - Critical Boron and Boron worth
  - Control rod banks worth
- Cycle length

Benchmark Modeling

First of all, an eight-energy group microscopic homogenized cross section set of libraries has been generated. The library structure is reported in the following table.

Table 1 Benchmark Model Structure

	Hot Full Power	Hot Zero Power
Number of libraries	64	64
Number of energy groups	8	8
Tabulation points as a function of Boron concentration	4	3
Tabulation points as function of fuel temperature	2	3
Tabulation points as a function of moderator density	2	4
Tabulation points as a function of control rod position	4	NA
Tabulation points as a function of burn up	NA	3
Total number of tabulation points	64	108
Isotope number	~300	~300
		(~200 depleted)
Total number of point-wise cross sections used	9,830,400	16,588,800

The spatial geometry was discretized using 9 depletion zones per assembly with 32 axial layers leading to 64,800 regions depleted independently. The RELAP5-3D model was limited to only the power plant core with one channel per assembly. The simulation has been performed using 128 computer cores.

Results

For the computation of the cycle length, 35 depletion steps were used. Each depletion step, as explained above, involves several iterations between RELAP5-3D and PHISICS to re-equilibrate the TH field with the power distribution, as altered by the depletion, and to re-assess the boron concentration. Total calculation time was less than one day on 100 cores. Computational time was almost equally split between PHISICS and RELAP5-3D.

Table 2 summarizes the results for the above reported figure of merits.

Table 2 Figures of Merit

	Calculated	Reference	Error
Critical Boron HZP	1172	1150	1.93%
Boron Worth HZP	-11.27	-11.24	0.29%
Control rod worth bank D HZP	647.5	645	0.39%
Control rod worth bank C HZP (D+C)*	1188	1045	13.67%
Control rod worth bank B HZP (D+C+B)*	1048	1116	6.05%
Control rod worth bank a HZP (D+C+B+A)*	1219.27	1090	11.86%
Cycle length	332	332	0%

*Reference configuration

While results reported in the above table are satisfactory overall, there could be some concern about the evaluation of the control rod worth on bank insertions subsequent to the first one. The reason for this large discrepancy, a confirmation is pending new results, seems to be due to the generation process of the cross section that was based on a super homogenization approach performed for a core without control rod insertion. It is somehow expected that the more control rod are inserted, the less effective is the super homogenization approach used.

Figure 1 shows the time evolution of the critical boron comparing the evolution of a depletion simulation without any thermal feedback and the one used to generate the data shown above. The simulation without thermal feedback ends 4 day earlier that the one with RELAP5-3D. A large difference is also detectable in the initial part of the simulation where the one without thermal feedback exhibit a lower feedback in the initial days of the core life as expected.

Conclusion

First take away from this simulation is that cases of this complexity are nowadays affordable and, as a consequence, there is no need to use lower level of accuracy in treating the neutronic response of core in transient analysis or do not integrate thermal feedback in fuel cycle analysis.

Second important conclusion is that the RELAP5-3D PHISICS has proven to be capable to handle a simulation that is currently at least at the state of the art and numbers validate the approach and the coupled codes.

In the future a better super homogenization approach should lead to even more accurate results and also the second cycle (after reload/reshuffling) will be analyzed.

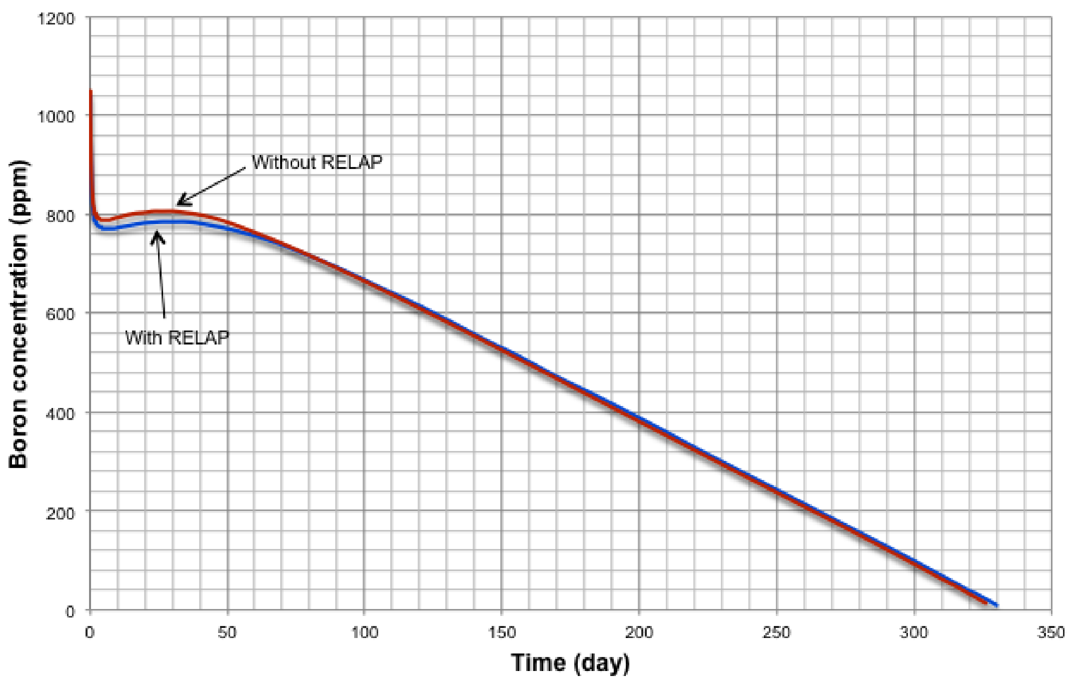

Figure 1: Critical Boron evolution