A BENCHMARK FOR COUPLED THERMOHYDRAULICS SYSTEM/ THREE-DIMENSIONAL NEUTRON KINETICS CORE MODELS

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1. Introduction

During the last years 3D neutron kinetics core models have been coupled to advanced thermohydraulics system codes. These coupled codes can be used for the analysis of the whole reactor system. Although the stand-alone versions of the 3D neutron kinetics core models and of the thermohydraulics system codes generally have a good verification and validation basis, there is a need for additional validation work. This especially concerns the interaction between the reactor core and the other components of a nuclear power plant (NPP). In the framework of the international „Atomic Energy Research“ (AER) association on VVER Reactor Physics and Reactor Safety, a benchmark for these code systems was defined.

2. Definition of the Benchmark

This benchmark is the first benchmark for coupled thermohydraulics system/3D hexagonal neutron kinetics core models. It was defined by the Institute of Safety Research of Forschungszentrum Rossendorf (FZR). The complete definition can be found in [1]. The reference plant for the definition of the benchmark is the VVER-440/213. The VVER-440/213 is a pressurized water reactor with six loops. The nominal power is 1375MW_{th}. The NPP has six horizontal steamgenerators and two turbines. The reactor core consists of 349 fuel assemblies with hexagonal cross section. In this benchmark the response of the reactor core to a perturbation coming from the secondary side of the NPP is to be investigated. The initiating event of the transient is a break of the main steam header at the end of the first fuel cycle during hot shutdown conditions with one control rod group stucking. Although the main application fields of such coupled code systems are accidents with asymmetrical perturbations, a nearly symmetrical main steam line break was chosen for this first benchmark for these codes. This assumption corresponds to the way: begin with a simple problem and then increase the complexity. This approach led to good results in the previous AER benchmarks.

The following control and safety systems were considered in the benchmark calculation: pressurizer heater, volume control system and high pressure injection system (HPIS) in the primary circuit and one feedwater pump in the secondary circuit. For the calculation each participant had to use own nuclear cross section data. A burnup calculation for the first loading of the core had to be performed by each code. The use of own data bases for the nuclear cross sections leads to the necessity to provide a reference value for some key parameter. It was decided to adjust the subcriticality at the beginning of the transient, so that all participants begin the calculation from the same subcriticality level.

The expected course of the transient is the following: The double ended break of the main steam header causes a depressurization of all six steamgenerators. The set points for the closure of the main steam isolation valves will not be reached, so that this depressurization will not be stopped. For this reason, the main coolant pumps remain in operation, too. The water level in the steamgenerators decreases and the one available feedwater pump begins to work. The secondary side temperature decreases together with the pressure along the saturation line. Pressure and temperature decrease lead to an increasing heat flux from the primary to secondary side. Coolant temperature and primary circuit pressure start to drop. Due to the negative moderator temperature feedback, a positive reactivity is inserted into the core, and the initial subcriticality can be compensated so that recriticality of the reactor is achieved. Due to the further overcooling of the primary circuit, the nuclear power can rise until reactivity compensation by fuel temperature increase. The pressure and temperature decrease in the primary circuit lead to an activation of the HPIS. The injection of highly-borated water terminates the power excursion.

3. Results

Five organizations from five different countries took part in the benchmark calculations. Solutions were received from Kurchatov Institute Moscow (Russia) with the code BIPR8/ATHLET, VTT Energy Espoo (Finland) with HEXTRAN/SMABRE, Nuclear Research Institute Rez (Czech Republic) with DYN3D/ATHLET, KFKI AEKI Budapest (Hungary) with KIKO3D/ATHLET and Forschungszentrum Rossendorf (Germany) with the code DYN3D/ATHLET.

Tab. 1: Comparison of Key Parameters

	DYN3D/ ATHLET	BIPR8/ ATHLET	HEXTRAN/ SMABRE	DYN3D/ ATHLET (Rez)	KIKO3D/ ATHLET
recriticality time [s]	48.8	80.4	66.0	56.9	58.2
recriticality temperature [^{o}C]	228.2	218.3	221.2	225.1	222.0
max. core power [MW]	685.7	547.4	534.0	657.6	585.9
integrated leak mass at 400s [t]	169.3	147.5	154.5	165.0	149.3
time of HPIS activation [s]	229.9	230.0	236.0	231.4	224.8
boron concentration at 400s [ppm]	95.5	68.1	129.5	109.5	149.1

All codes predicted the recriticality of the core due to overcooling, but at different times (Tab. 1). The corresponding recriticality temperatures were determined by stationary k_{eff}-calculations. For these calculations all boundary conditions were given, so that differences in the results are caused only by the different nuclear libraries used in the calculations. It can be seen, that the recriticality temperatures of the core range from 228.2^{o}C (DYN3D/ATHLET) to 218.3^{o}C (BIPR8/ATHLET). These differences in the nuclear data give the biggest contribution to the deviations in the predicted recriticality time.

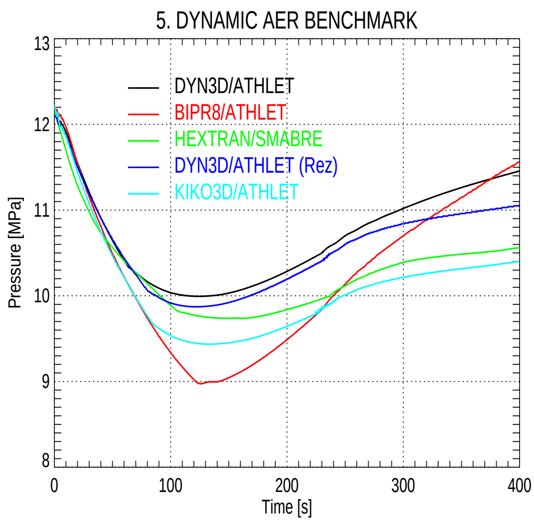

Fig. 1: Upper Plenum Pressure

Within the first 60s the thermohydraulic quantities in the primary circuit behave very similar in all calculations. Later on, the influence of the re-established power generation in the core after recriticality can be seen. The minimum pressure reached during the overcooling depends on the time of recriticality. In the later phase of the transient (after t=230s) the pressure is dominated by the volume control system and the beginning high pressure injection (Fig. 1).

Fig. 2 shows the behaviour of the core power. The time of remarkable power increase is in the interval from 62s (DYN3D/ATHLET) to 123s (BIPR8/ATHLET). The initial power peak can be seen only in two calculations (DYN3D/ATHLET, DYN3D/ATHLET (Rez)). The sudden power decrease after the beginning of the injection of highly-borated water by the HPIS can be observed in all calculations. The efficiency of the HPIS depends on the primary circuit pressure. Due to the differences in this pressure, the mass of highly-borated water injected by the HPIS differs in the calculations, too. This is expressed also in the boron concentration at core inlet at the end of the transient (Tab. 1). Four calculations show a consistence of the primary circuit pressure and the core inlet boron concentration. An analysis of the pressure behaviour in the BIPR8/ATHLET calculation showed, that the mass of injected highly-borated water should be in the range of the DYN3D/ATHLET and DYN3D/ATHLET (Rez) calculations. For this reason, the boron concentration should be about the same. However, the provided value is lower.

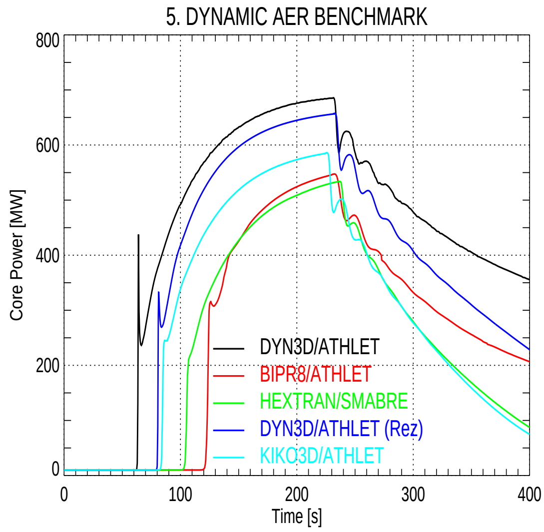

Fig. 2: Total Core Power

In section 2, it was stated, that the selected break causes a nearly symmetrical perturbation of the core. A small asymmetry is introduced by the connection of the pressurizer (to one loop). During the overcooling of the primary circuit the hot coolant coming down from the pressurizer affects the steamgenerator inlet collector temperature. For this reason, differences in the behav-

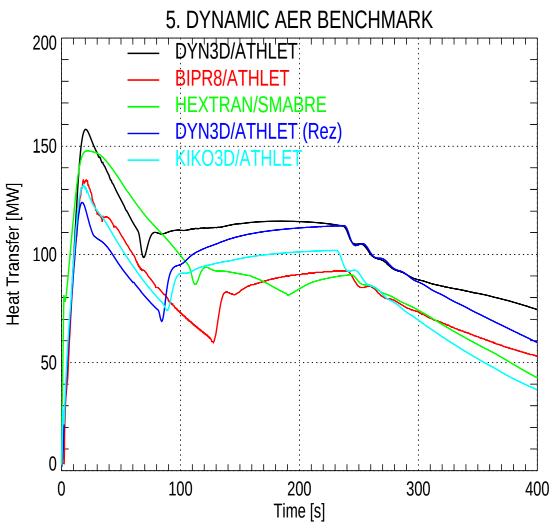

Fig. 3: Heat Transfer in the Steamgenerator of the Loop with the Pressurizer

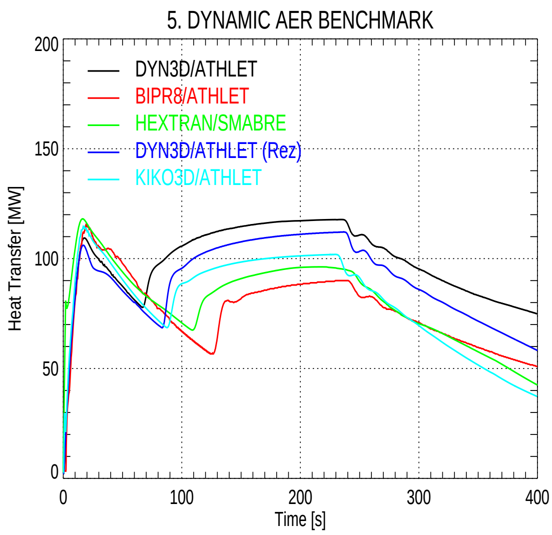

Fig. 4: Averaged Heat Transfer in the Steamgenerators of the Loops without the Pressurizer

iour of the loops were expected. Therefore, results for the loop with the pressurizer and averaged over all remaining loops were requested. Fig. 3 and 4 show the heat transfer from the primary to secondary side of the steamgenerators. A direct comparison of the values of one calculation reveals the expected differences in the behaviour of the loops with and without pressurizer. Two calculations (DYN3D/ATHLET and HEXTRAN/SMABRE) provide much higher values of this difference. This is obviously connected with the higher number of loops modeled in the calculations. The influence of the pressurizer is not distributed over several loops like in a calculation with two 3-fold loops (BIPR8/ATHLET, DYN3D/ATHLET (Rez), KIKO3D/ATHLET).

4. Conclusions

A short overview of the results of the first international benchmark for coupled thermohydraulics system/three-dimensional neutron kinetics core models is presented. The complete comparison can be found in [2].

All codes predicted the recriticality of the core due to overcooling, but at different times. Until the time of beginning of remarkable power generation in the core, all effects in the primary circuit observed in the calculations are dominated by the thermohydraulic modules of the codes. The depressurization of the secondary side caused by the break of the main steam header, the heat transfer from the primary to secondary side with the overcooling of the primary circuit are described in good agreement by all codes. The corresponding parameters show a very similar behaviour in all calculations. The recriticality temperature differs by 10K. These differences are caused by the use of different nuclear data libraries. The different nuclear data have an important influence on the further course of the transient. It seems, that this is the main reason for the differences between the solutions.

The realization of such benchmark calculations is very helpful, because different physical models and data can be compared. They contribute to minimize the user effects, too. But all in all it can be stated, that this very complex and complicated benchmark problem was solved by all participants in a very good manner. The considerable experience in calculations of both 3D neutron kinetics core and thermohydraulics NPP behaviour of the reactor type selected for this benchmark was a very good basis for the realization of the benchmark.

References

[1] S. Kliem (1997), Definition of the fifth dynamic AER benchmark problem - a benchmark for coupled thermohydraulic system/ three-dimensional hexagonal neutron kinetic core models, Proceedings of the 7th Symposium of AER (pp. 429-438), Budapest, KFKI Atomic Energy Research Institute

[2] S. Kliem (1998), Comparison of the results of the fifth dynamic AER benchmark - a benchmark for coupled thermohydraulic system/3D hexagonal neutron kinetic core models, Proceedings of the 8th Symposium of AER (pp. 429-469), Budapest, KFKI Atomic Energy Research Institute

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