MARS-GCR / CAPP Coupled Calculation of Reactivity Feedback Transients for the OECD/NEA PBMR-400 Benchmark

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1. Introduction

The OECD/NEA has lunched a benchmark problem program on a neutronics/ thermal-hydraulic (T-H) coupled calculation for the PBMR-400 to test the existing analysis methods for high temperature gas-cooled reactors (HTGRs) and to develop more accurate and efficient tools to analyze the neutronics and thermal-hydraulic behaviour for the design and safety evaluations of the PBMR-400 [1]. There are three cases for the steady state phase (Phase I) and six cases for the transient state phase (Phase II) in the benchmark.

In the previous works [2,3], by using the coupled code system with CAPP [3] and MARS-GCR [4] for a neutronics and T-H calculations respectively, we performed three steady state calculations which are the neutronics standalone, T-H standalone and neutronics / T-H coupled calculations that will be used as the initial condition of the cases in the transient state. Recently, however, the problem specification such as a graphite thermal conductivity has been modified by the OECD/NEA for a more realistic transient behaviour and so we have performed new calculations for two exercises in the steady state phase (T-H standalone and coupled steady) and the new coupled steady state result has been used for the initial condition of the transient problems. Among various transient cases, we have performed three selected transient cases, which are the reactivity insertions by a TCRW (total control rod withdrawal) and a TCRE (total control rod ejection), and a cold helium inflow transient.

2. Methods and Results

2.1 Model Description and Steady State Results

For a precise neutronics calculation, each material zone in the CAPP analysis model is divided into 5 x 5 sub-meshes, while the meshes in the r-z map of MARS-GCR corresponds to the material zone defined in the problem specification. Current coupling scheme is identical to a dynamic link library (DLL) technique in the previous works [2,3].

As described above, the thermal conductivity of graphite in all the regions was changed from 20 W/m-K to 26 W/m-K by the OECD/NEA. The comparisons of the old and new results for the T-H standalone (Exe-2) and the coupled calculation (Exe-3) are summarized in Table 1.

Table 1. Comparison of T-H & netronics parameters

Parameters	Exe-2		Exe-3	
	old	new	old	new
He outlet temperature (℃)	899.2	899.1	899.2	899.1
Δ P in pebble bed (kPa)	285.1	285.2	284.8	284.7
Avg. fuel temperature (℃)	819	808	818	806
Max. fuel temperature(℃)	1020	1000	1017	994
k_{eff}	-	-	0.99265	0.99645

It is found, from the above table, that there are little differences between the old and new results except for the average and maximum fuel temperatures dependent on a material thermal conductivity. The average fuel temperature decreases as the graphite thermal conductivity increases.

For the neutronics calculation results, as the average fuel temperature decreases, the effective multiplication factor, k_{eff}, increases by 380 pcm when compared with the result of the old calculation. Figure 1 shows the power density profile comparison of the T-H standalone case and the coupled steady state. It is also found that the power density profiles from given data and the coupled steady calculation are very close to each other.

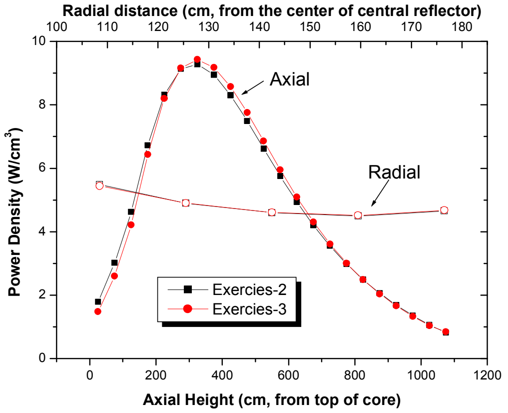

Figure 1. Comparison of averaged power density

2.2 Transient Calculation Results

Coupled transient cases have been performed by using the MARS-GCR/CAPP code. Two cases are the reactivity insertion transients by a total control rod withdrawal (TR-5a) and ejection (TR-5b). The remaining case is the cold helium inflow transient (TR-6). The results of the coupled steady state were used as the initial conditions for all the transients. The boundary conditions for each transient are summarized in Table 2.

Table 2. Boundary conditions for each transient case

Conditions	Transient Cases		
	TR-5a	TR-5b	TR-6

Distance of rod withdrawal (cm)	200	200	-
Rod withdrawal rate (cm/s)	1	2000	-
Deviation of inlet He temp. (℃)	-	-	±50
Change rate of He temp. (℃/s)	-	-	5

Figure 2 shows the results of TR-5a. Reactor power increases initially with reactivity insertion by the TCRW, and then decreases as fuel temperature increases. Combined feedback effects from the rod withdrawal and fuel temperature changes cause the reactor power to oscillate till the end of the rod withdrawal. Once the rod withdrawal terminates, the reactor power reaches a maximum level of 188% and suddenly drops by negative temperature feedback. After this time, the reactor power as well as the fuel temperature becomes stable and increases slowly due to Xenon decay.

Figure 3 shows the results of TR-5b. In this case, the reactor power excursion initially occurs and reaches the maximum value of 24,000% due to the largest reactivity insertion rate. The reactor power, however, soon decreases drastically to several hundreds percents of full power as the fuel temperature increases. The fuel temperature also increases rapidly from the beginning of transient, becomes stable and finally slowly decreases as the reactor power decreases. The fuel temperature exceeds 1600℃ and reaches the maximum value of 1780℃.

Figure 4 shows the results of TR-6. In this case, a positive reactivity by the cold helium inflow is inserted very slowly. As a result, the reactor power and fuel temperature increase slowly during the cold helium flow injection. When the inlet helium temperature returns to a nominal value at 300 seconds, the reactor power and fuel temperature decrease to the vicinity of initial level.

From a comparison of our results and the TINTE preliminary results [5], it is found that the overall trends of the results are very similar to each other but there are delayed responses of both the reactor power and fuel temperature in our results for the case of TR-6. These delayed responses can be explained by a slower temperature change in the core top than in the coolant inlet region.

3. Conclusion

The T/H-Neutronics coupled steady state and transient calculations for the PBMR-400 OECD/NEA benchmark problem have been performed with MARS-GCR/CAPP. It seems that the reactivity feedback effects from the transient calculations are comparable to the preliminary results of TINTE from the PBMR. It is necessary, however, to compare them with the results from all the participants for a more quantitative analysis.

ACKNOWLEDGEMENTS

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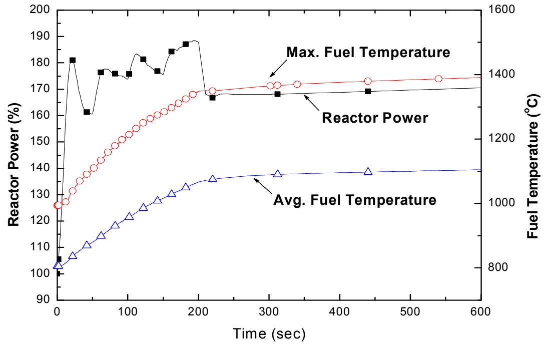

Figure 2. Reactor power and fuel temperature (TR-5a)

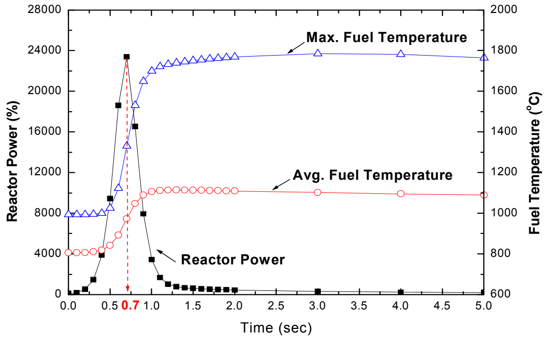

Figure 3. Reactor power and fuel temperature (TR-5b)

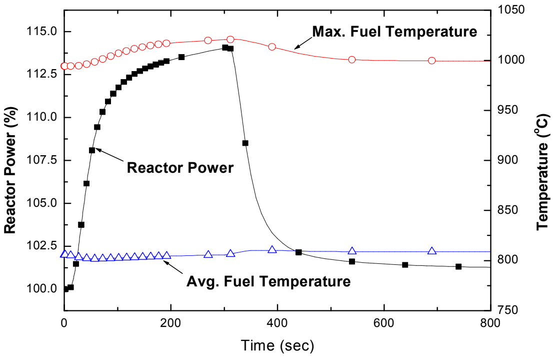

Figure 4. Reactor power and fuel temperature (TR-6)