Benchmark Analysis of the NUREC Code with OECD/NEA and U.S.NRC PWR MOX/UO_2 Control Rod Ejection Problem

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1. Introduction

The NUREC code has been developed based on the refined AFEN method for the analysis of LWR cores with mixed-oxide (MOX) fuel [1]. The code was verified against the NEACRP-L336 MOX benchmark problem and the experimental data of YeongKwang Unit 3&4. The transient calculation capability of the code was also tested against the NEACRP-L335 rod ejection problem proposed by Finnemann [2]. However, the core in the rod ejection problem was composed of only UO_2 fuels.

In this paper, the NUREC code was verified against the OECD/NEA and U.S.NRC PWR MOX/UO_2 control rod ejection problem [3] which was proposed recently by comparing its results with those of the U.S.NRC PARC code. This benchmark problem employed many characteristics of the NEACRP-L335 rod ejection problem but some complexities were added to model a rod ejection accident in a core fueled partially with weapons grade MOX.

Some subroutines of the NUREC code were modified to model the transient initiated by a rod ejection in a core loaded with MOX fuels. They include subroutines for reading the cross sections, interpolating the cross sections, treating the delayed neutron fractions, and treating the thermal conductivity of the fuel.

2. The Benchmark Problem

The core of the OECD/NEA and U.S.NRC PWR MOX/UO_2 control rod ejection problem consists of 141 UO_2 fuel assemblies and 52 MOX fuel assemblies. The core was designed based on a three-batch equilibrium cycle and no MOX assemblies are loaded at the control rod positions.

A complete set of macroscopic cross sections and kinetic parameters are defined for each assembly in a table form as a function of the moderator density, fuel temperature, and soluble boron concentration. The delayed neutron fraction is given as assembly-wise to take it into account that the delayed neutron fraction in the MOX fuel is significantly smaller than that in the UO_2 fuel. The thermal properties of UO_2 fuel and cladding material used in the NEACRP-L335 problem were employed and the thermal conductivity of MOX fuel pellet is given as 10% smaller than that of the UO_2 fuel.

The benchmark problem consists of the following four parts :

Part 1 : 2-D core with fixed TH condition
Part 2 : 3-D core with HFP condition
Part 3 : 3-D core with HZP condition
Part 4 : 3-D core with transient initiated by rod ejection

In part 1, the TH condition is given at the core temperature of 560K, the moderator density of 752.06kg/m^3, and the soluble boron of 1000ppm. HFP in part 2 corresponds to the all rods out (ARO) state, the core power of 100% rated power (3565MW), the core pressure of 15.5MPa, and the inlet coolant temperature of 560K. HZP in part 3 corresponds to the all control banks in and all shutdown banks out state, the core power of 10^{-4}% rated power, the core pressure of 15.5MPa, and the inlet coolant temperature of 560K. In part 4, the rod was assumed to be fully ejected in 0.1 seconds.

3. Results

To verify the accuracy of the NUREC code, its 4-nodes-per-assembly calculation results were compared with a reference solution. The PARCS results were taken as a reference in the comparison.

Table 1 shows the results in part 1, 2, and 3. All the parameters from the NUREC code are almost identical to those from the PARCS code. There are relatively large discrepancies between the results of the two codes for the part 2 HFP status, in which the thermal hydraulic feedback is important. The discrepancies are mainly due to the fact that the NUREC code uses the COBRA code for the thermal hydraulic calculation while the PARCS code uses its own thermal hydraulic calculation routines. However, the results are still close to each other.

Figure 1 shows the axial power shape in the part 2 and 3. The axial power shapes from the NUREC and the PARCS codes are practically identical.

Figure 2 shows the core power excursion during the transient. The results of the NUREC and the PARCS code using an assembly-wise delayed neutron fraction agree well each other. However, the peak time and the peak power are much earlier and higher than the others in case where the core average delayed neutron fraction is used. It is due to the fact that the delayed neutron fraction of the assembly at which the rod is ejected is underestimated if the core average delayed neutron fraction is used instead of that of the UO_2 fuel. It is well known that the power excursion of that assembly plays an important role in the power excursion of the whole core. Underestimation of the delayed neutron fraction at that assembly leads to an earlier and higher power peak at that assembly and consequently an earlier and higher peak in the power excursion of the whole core. It was also found that a smaller thermal conductivity of the MOX fuel has almost no effect on the results.

Table 1. Comparison of the results for part 1, 2, and 3

Part	Parameter	Reference (PARCS)	NUREC
1 ARO	k_{eff}	1.06379	1.06378
	RMS Power Error (%)	-	0.09
	Rod (A,1) Worth (pcm)	187	187
	Rod (A,3) Worth (pcm)	162	162
	Rod (A,5) Worth (pcm)	103	103
	Rod (A,7) Worth (pcm)	60	60
	Rod (B,6) Worth (pcm)	79	79
	Rod (C,3) Worth (pcm)	138	138
	Rod (C,7) Worth (pcm)	58	58
	Rod (D,6) Worth (pcm)	77	77
	Rod (E,5) Worth (pcm)	73	73
	Rod (E,7) Worth (pcm)	31	31
1 ARI	k_{eff}	0.99154	0.99153
	RMS Power Error (%)	-	0.13
	Rod (A,1) Worth (pcm)	833	833
	Rod (A,3) Worth (pcm)	873	873
	Rod (A,5) Worth (pcm)	400	400
	Rod (A,7) Worth (pcm)	55	55
	Rod (B,6) Worth (pcm)	150	150
	Rod (C,3) Worth (pcm)	1121	1121
	Rod (C,7) Worth (pcm)	77	77
	Rod (D,6) Worth (pcm)	286	286
	Rod (E,5) Worth (pcm)	245	245
	Rod (E,7) Worth (pcm)	20	20
2	Critical boron (ppm)	1679.3	1683.3
	RMS Power Error (%)	-	0.39
3	Critical boron (ppm)	1340.7	1342.7
	Core Average β(pcm)	579.4	575.6
	RMS Power Error (%)	-	0.12

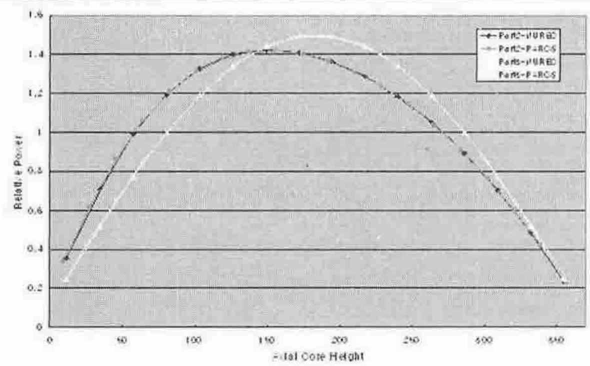

Figure 1. Comparison of axial power shape in part 2 and 3

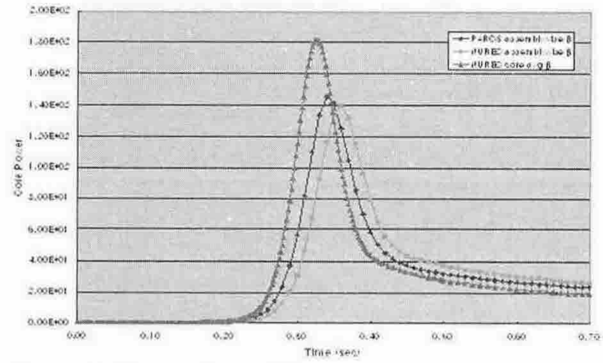

Figure 2. Comparison of the power excursion during a transient

4. Conclusion

The NUREC code was modified to model the transient initiated by a rod ejection in a core loaded with MOX fuels and was verified against the OECD/NEA and U.S.NRC PWR MOX/UO_2 control rod ejection problem by comparing its results with those of the PARC code. The results of the NUREC code agree well with those of the PARCS code. It was found that a proper treatment of the delayed neutron fraction is very important in the rod ejection transient analysis in a core partially fueled with MOX.

Acknowledgements

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REFERENCES

[1] J. W. Yoo, Jaeman Noh, Hyung Kook Joo, "Development of MOX Fueled Core Analysis Code Based on the Refined Analytic Function Expansion Nodal Method," Proceedings of the Korean nuclear society autumn meeting, Yongpyong, Korea, October, 2003.

[2] H. Finnemann, A. Galati, "NEACRP 3-D LWR Core Transient Benchmark," NEACRP-L335, October 1991.

[3] Tomasz Kozlowski and Thomas J. Downar, "OECD/NEA and U.S. NRC PWR MOX/UO2 Core Transient Benchmark,", December 2003.
(https://engineering.purdue.edu/PARCS/MOX_Benchmark/Benchmark_Description/mox_bench_spec.pdf)