VENUS-2 Benchmark Problem Analysis with HELIOS-1.9

Hyeon-Jun Jeong, Jiwon Choe, Deokjung Lee*
Ulsan National Institute of Science and Technology, UNIST-gil 50, Eonyang-eup, Ulju-gun, Ulsan, 689-798, Korea
**Corresponding author: deokjung@unist.ac.kr*

1. Introduction

The computation of the VENUS-2 benchmark problem is one of the established methods to verify the accuracy of numerical core analysis. Since there are reliable results of benchmark data from the OECD/NEA report of the VENUS-2 MOX benchmark problem, by comparing benchmark results users can identify the credibility of code [1]. In this paper, the solution of the VENUS-2 benchmark problem from HELIOS 1.9 using the ENDF/B-VI library(NJOY91.13) is compared with the result from HELIOS 1.7 with consideration of the MCNP-4B result as reference data [2]. The comparison contains the results of pin cell calculation, assembly calculation, and core calculation. The eigenvalues from those are considered by comparing the results from other codes.

2. Methods and Results

In this section the result of calculations for the VENUS-2 benchmark problem are described. There are three types of calculation; pin-cell calculation, assembly calculation, and total core calculation. The calculation using HELIOS 1.9 utilizes the Current Coupling Collision Probability (CCCP) method. For pin cell calculations the geometry is just discretized, but from assembly calculations the current coupling methods between structures are considered to examine the proper level of performance and efficiency [3].

2-1 Pin-Cell Calculation

The VENUS-2 MOX core has 3 types of fuel pins: 3.3 w/o UO_2 pin, 4.0 w/o UO_2 pin, and MOX pin. Each k_{eff} value of the pin cells was computed on reflective condition.

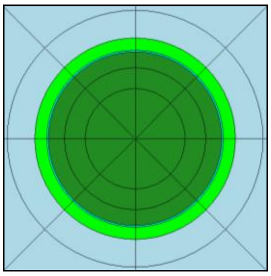

Fig. 1. Pin cell discretization method

The discretization method is shown in Fig 1 [2]. Each area of fuel has equal area, and the void gap between fuel and cladding was also treated in the geometry. The moderator region is divided into two sections of equal area. The flux shape can be more accurate by this discretization.

Tables I~III show the results of pin cell calculations by 47 group HELIOS 1.9, by MCNP-4B as referance data, by 45 group HELIOS 1.7, and by 44g NEWT [2]. The results from MCNP-4B are considered as reference data. In the case of 3.3 w/o UO_2 the result from HELIOS 1.9 shows a difference from MCNP lower than 100 pcm, but in other cases the differences are from 278 to 332 pcm. Generally HELIOS 1.9 shows the most credible results.

Table I: 3.3% UO_2 pin cell calculation (k_{eff}) and the difference from MCNP-4B

Code	k_{eff}	Difference (pcm)
MCNP-4B	1.40670	
HELIOS 1.9	1.40741	71
HELIOS 1.7	1.40691	21
NEWT	1.40424	-246

Table II: 4.0% UO_2 pin cell calculation (k_{eff}) and the difference from MCNP-4B

Code	k_{eff}	Difference (pcm)
MCNP-4B	1.33775	
HELIOS 1.9	1.34053	278
HELIOS 1.7	1.34189	414
NEWT	1.33259	-516

Table III: MOX pin-cell calculation (k_{eff}) and the difference from MCNP-4B

Code	k_{eff}	Difference (pcm)
MCNP-4B	1.25769	
HELIOS 1.9	1.26101	332
HELIOS 1.7	1.26332	563
NEWT	1.25435	-334

2.2 Assembly Calculation

Three assembly types used in the total core are shown in Fig 2~4 [2]. The UOX assembly contains 190 3.3% UO_2 pins, 10 Pyrex rods, an inner baffle, and a central hole. The MOX assembly contains 105 4.0% UO_2 pins and 120 MOX pins. Finally, the MOX-Reflector assembly contains 105 4.0% UO_2 pins, 120 MOX pins, an outer baffle, and a reflector. The assembly calculation performance of HELIOS-1.9 was evaluated by comparison of the results with the other codes. In calculation of MOX-Reflector, every reflector and baffle cell was discretized into 5x5 regions to get more accurate flux. The calculation was done on a reflective, inflow transport correction condition [4].

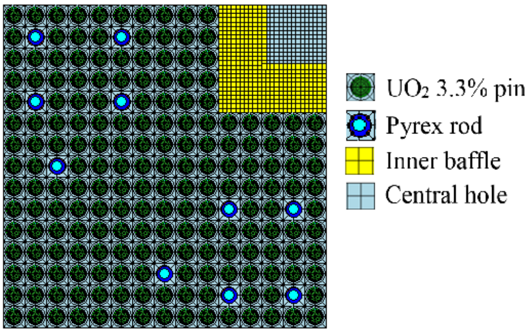

Fig. 2. UOX assembly layout

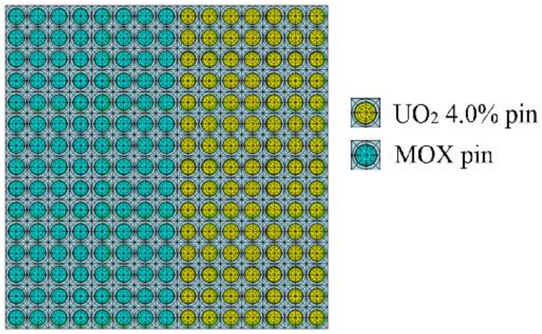

Fig. 3. MOX assembly layout

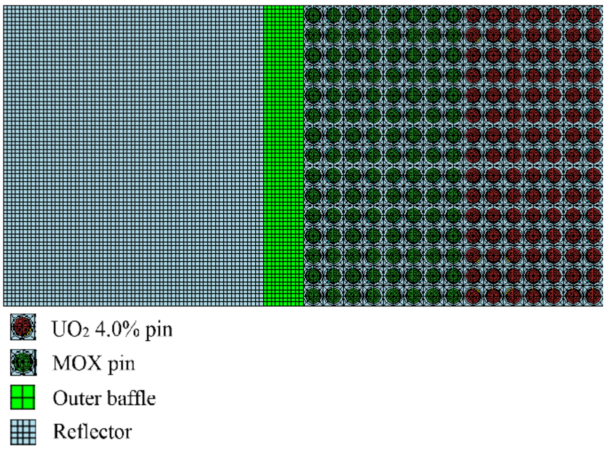

Fig. 4. MOX-reflector assembly layout

From assembly calculation, the way the interface current is divided between cell structures has an effect on the calculation result [3]. To couple the current, two discretization method are considered [5].

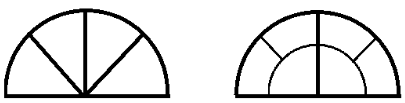

Fig. 5. Angular sectors for current coupling.

Three assembly types in Fig. 4 were tested to select the proper current coupling value. Tables IV-VI show the results have a tendency of inverse proportion between the accuracy and computation time. There are consistent rises of computation time when increasing the coupling orders to 11, but it does not guarantee more correct result than the cases for k=4. Therefore, the calculations for assemblies and core were on the condition of coupling order 4.

Table IV: UOX assembly calculation with two type of coupling order

Codes	MCNP-4B	HELIOS 1.9	
Coupling order		4	11
k_{eff}	1.17570	1.17563	1.17617
Difference (pcm)		-7	47

Table V: MOX assembly calculation with two type of coupling order

Codes	MCNP-4B	HELIOS 1.9	
Coupling order		4	11
k_{eff}	1.29459	1.29448	1.29470
Difference (pcm)		-11	11

Table VI: MOX-reflector assembly calculation with two type of coupling order

Codes	MCNP-4B	HELIOS 1.9	
Coupling order		4	11
k_{eff}	1.14882	1.15349	1.15301
Difference (pcm)		467	429

Tables VII-IX show the results of assembly calculations from HELIOS 1.9 and compared codes [2]. The result from MCNP-4B is considered as reference. In the case of UOX and MOX assemblies, the results from HELIOS 1.9 have differences of only 7 pcm and -11 pcm, respectively. There are quite large differences between the results from HELIOS 1.9 and those of 1.5 because the group library was upgraded from the 45 g to 47 g library. At the MOX-reflector calculation, the difference of k_{eff} from the MCNP-4B result is more than 400 pcm. Although HELIOS 1.9 gives reliable k_{eff} values on assemblies with no reflector environment, it seems to be less accurate in baffle-reflector condition.

Table VII: UOX assembly calculation results

Code	k_{eff}	Difference(pcm)
MCNP-4B	1.17570	
HELIOS 1.9	1.17563	-7
HELIOS 1.7	1.17502	-68
NEWT	1.17316	-254

Table VIII: MOX assembly calculation results

Code	k_{eff}	Difference (pcm)
MCNP-4B	1.29459	
HELIOS 1.9	1.29448	-11
HELIOS 1.7	1.29843	384
NEWT	1.2896[1]	-500

[1] Fix mistyped data as 1.12896 on reference [2].

Table IX: MOX-reflector assembly calculation results

Code	k_{eff}	Difference (pcm)
MCNP-4B	1.14882	
HELIOS 1.9	1.15349	467
HELIOS 1.7	1.15420	538
NEWT	1.14419	-463

2-3 2-D quarter Core calculation

The actual geometry of VENUS-2 contains a neutron pad, jacket, reactor vessel, and reactor room, but in this paper the configuration for geometry stops at the reflector and barrel. The shape of the barrel is approximated with many squares meshes, like block piling. Since HELIOS does not provide a solution for a 3-D core, only the 2-D core calculation results are compared.

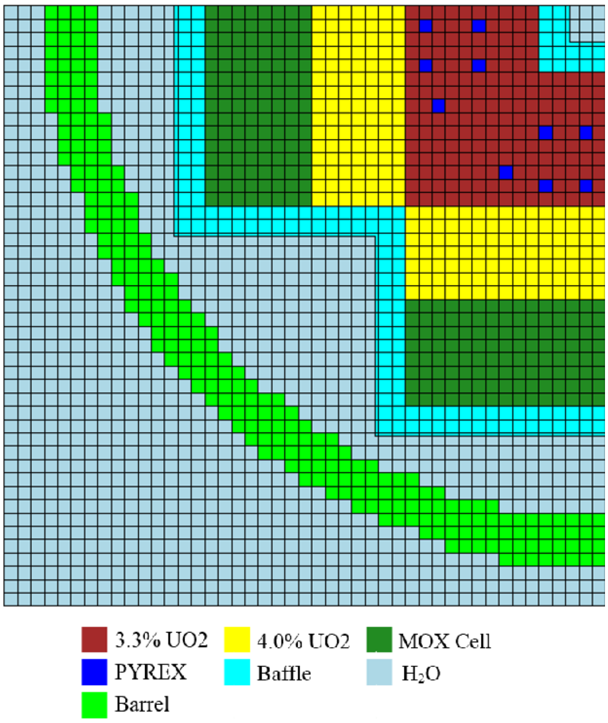

Fig. 6. VENUS-2 quarter core geometry for HELIOS-1.9.

Fig. 6 shows the geometry of 1/4 core model. Each cell for baffle, barrel, and reflector (H_2O) is divided into a 5x5 lattice structure. Each fuel cell is discretized with the shape of pin cell calculation. The structures outside the barrel are replaced by the reflector. The boundary condition for the right and upper side is reflective, for the left and bottom is vacuum.

The results of the VENUS-2 2-D core calculations from HELIOS 1.9, HELIOS 1.7, and MCNP-4B are shown in Table X

Table X: Results for 2-D core calculation

Code	k_{eff}	Difference (pcm)
MCNP-4B	1.08277	
HELIOS-1.9	1.09130	853
HELIOS-1.7	1.08901	624

The difference between the results from HELIOS-1.9 and MCNP-4B is 853 pcm. This result reconfirms the problem identified on the calculation for the MOX-reflector assembly. Although the difference is larger than that from HELIOS-1.7, they have a similar problem of inaccuracy in calculation for baffle-reflector condition.

3. Conclusions

As a numerical method, HELIOS 1.9 gives results which have good agreement with the results from MCNP-4B. In pin cell and assembly calculations the results range within about 500 pcm. In the case of UOX and MOX assemblies, the differences from the MCNP-4B results are about 10 pcm. However, there is some inaccuracy in baffle-reflector condition, and relatively large differences were found in the MOX-reflector assembly and core calculation. Although HELIOS 1.9 utilizes an inflow transport correction, it seems that it has a limited effect on the error in baffle-reflector condition.

REFERENCES

[1] B. C. Na, "Benchmark on the VENUS-2 MOX core Measurements," OECD/NEA report, NEA/NSC/DOC, 2000.
[2] Z. Zhong, T. J. Downar, H. G. Joo, J. Y. Cho, "Benchmark Analysis of the DeCART MOC Code with the VENUS-2 Critical Experiment," PHYSOR 2004 –The Physics of Fuel Cycles and Advanced Nuclear Systems: Global Developments Chicago, Illinois, April. 25-29, 2004.
[3] B. Ivanov, K. Ivanov, R. J. J. Stamm'ler, "Deterministic Two-Dimensional MOX Fuel Assembly Transport Calculations Without Spatial Hommogenization," PHYSOR 2002, Seoul, Korea, Octver 7-10, 2002
[4] HELIOS, HELIOS Program, Studsvik Scandpower, December. 2005.
[5] AURORA, USER MANUAL AURORA, Studsvik Scandpower, September. 2005.