Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

A Study of Neutronics Effects of the Spacer Grids in a Typical PWR via Monte Carlo Calculation

Tran Xuan Bach[1] and Nam Zin Cho[*]

KINS-KAIST Master Program
Korea Advanced Institute of Science and Technology (KAIST)
291 Daehak-ro, Yuseong-gu, Daejeon, Korea 305-701
[*]nzcho@kaist.ac.kr

1. Introduction

The Monte Carlo method has practically no limitation in describing geometry and is capable to solve continuous-energy problems. For higher accuracy in the neutronics analysis, the continuous-energy Monte Carlo calculation with detailed description of geometry is demanded.

In practical neutronics analysis, the spacer grids which support fuel rods are not explicitly described, but they are homogenized with coolant. However, the effects of neglecting or simplifying the spacer grids are not reported in the literature to the best of our knowledge.

In this paper, to investigate the effects of spacer grids in neutronics analysis, a detailed description of spacer grids is added to the KAIST benchmark problem 1B. Then, the effective multiplication factor, spatial distributions of neutron flux, and its energy spectrum are obtained for the two cases (with and without spacer grids). Numerical results show that the effects of spacer grids are not negligible.

2. Test Problem and Modeling of Spacer Grid

In this section, the geometry of the test problem and the way to model the spacer grids are described.

2.1 Test Problem without Spacer Grids

The test problem used for the analysis in this paper is a modified version of the KAIST benchmark problem 1B in which MOX fuel is loaded into a small PWR core as shown in Fig. 1.

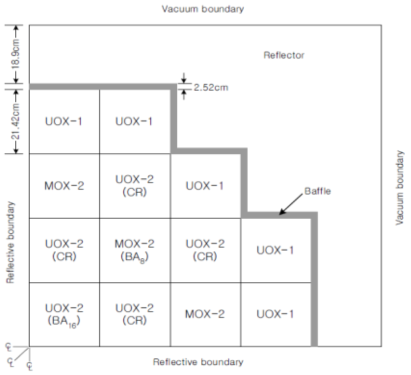

Fig. 1. Horizontal cut of KAIST benchmark problem 1B [1]

This benchmark problem was modified by adding upper and lower structure materials to the active core region. Using MCNP5 [2], the geometry of the test problem without spacer grids is built as in Figs. 2 and 3.

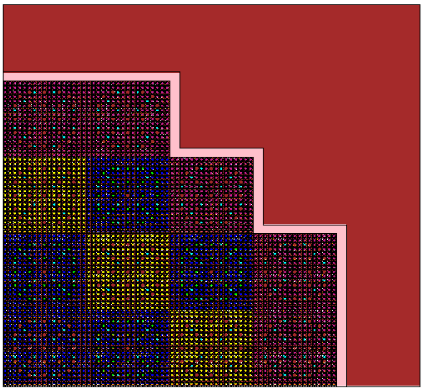

Fig. 2. Horizontal cut of the test problem without spacer grids (colored by material)

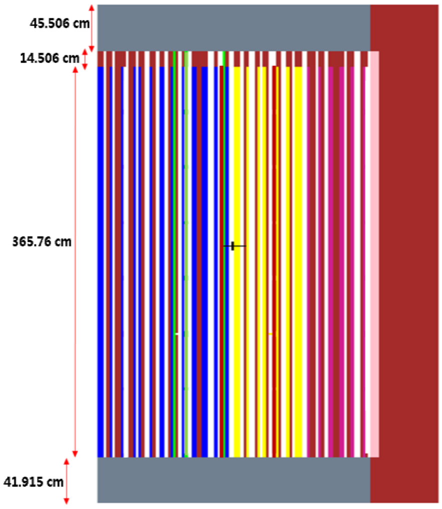

Fig. 3. Vertical cut of the test problem without spacer grids (colored by material)

2.2 Modeling of Spacer Grids

Fig. 4 from Ref. 3 shows the typical geometry of a spacer grid in PWR. For simplicity in describing the geometry by MCNP5, the shape of the spacer grid is simplified with mass preservation as in Fig. 5.

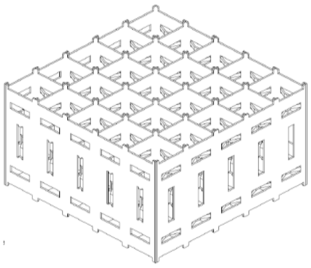

Fig. 4. Real geometry of a spacer grid

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[1] Permanent address: Vietnam Atomic Energy Agency, 113 Tran Duy Hung St., Cau Giay Dist., Hanoi, Vietnam

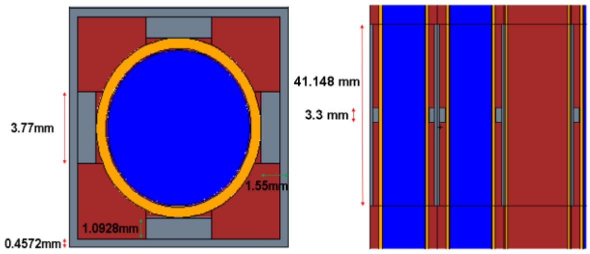

Fig. 5. Horizontal cut (left) and vertical cut (right) of the simplified spacer grid

Along the z-axis, there are two end spacer grids and six intermediate spacer grids in a typical PWR core [4], where their axial locations and material compositions are shown in Tables I and II, respectively. These spacer grids are added in the test problem shown in the previous section 2.1.

Table I. Geometrical specifications of spacer grids

	End Grids	Intermediate Grids
Number	2	6
Height (cm)	3.723	4.1148
Axial Locations (cm) (The center positions of spacer grids along the assembly length)	13.884 388.2	75.2 127.4 179.6 231.8 284.0 336.2

Table II. Material composition of spacer grids (Zircaloy-4)

Isotope	Atom density (10E+24 cm^{-3})	Isotope	Atom density (10E+24 cm^{-3})
Zr-90	2.18865E-02	Fe-54	8.68307E-06
Zr-91	4.77292E-03	Fe-56	1.36306E-04
Zr-92	7.29551E-03	Fe-57	3.14789E-06
Zr-94	7.39335E-03	Fe-58	4.18926E-07
Zr-96	1.19110E-03	Cr-50	3.30121E-06
Sn-112	4.68066E-06	Cr-52	6.36606E-05
Sn-114	3.18478E-06	Cr-53	7.21860E-06
Sn-115	1.64064E-06	Cr-54	1.79686E-06
Sn-116	7.01616E-05	Hf-174	3.54138E-09
Sn-117	3.70592E-05	Hf-176	1.16423E-07
Sn-118	1.16872E-04	Hf-177	4.11686E-07
Sn-119	4.14504E-05	Hf-178	6.03806E-07
Sn-120	1.57212E-04	Hf-179	3.01460E-07
Sn-122	2.23417E-05	Hf-180	7.76449E-07
Sn-124	2.79392E-05		

3. Numerical Results

By using MCNP5, multiplication factor, axial flux distribution, and neutron flux spectrum are obtained for the two cases. Case 1 is the test problem without spacer grids, and Case 2 is the test problem with spacer grids. For both cases, 300,000 histories/cycle, 300 inactive cycles, 300 active cycles are used.

As shown in Table III, Case 1 which does not include spacer grids shows higher multiplication factor by around 386 pcm. Since in Case 1, the water moderator fills the space taken by the spacer grids, it would have higher neutron population in thermal energy range.

Table III. Comparisons of multiplication factors

	Case 1	Case 2	Case 1 – Case 2
k_{eff}	0.90963	0.90577	0.00386
Sample standard deviation	0.00007	0.00007	N/A

Fig. 6 shows the axial power distributions in the center assembly for both cases. The axial power shape of Case 2 is not as smooth as that of Case 1. This is caused by the appearance of spacer grids along the length of assembly. At each point where moderator is replaced by a spacer grid, the neutron flux decreases and thus the location of the maximum axial power is also changed from z=188.73 (Case 1) to z=200.93 (Case 2), where the origin is set to the end of lower structure in the active core region.

Fig. 7 shows neutron flux spectra in the center assembly for Cases 1 and 2, while differences of the two spectra (Case 1 – Case 2) are shown in Fig. 8.

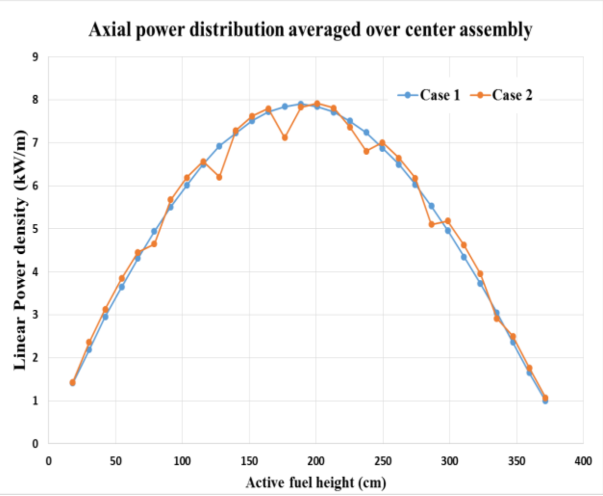

Fig 6. Axial power distribution in center assembly

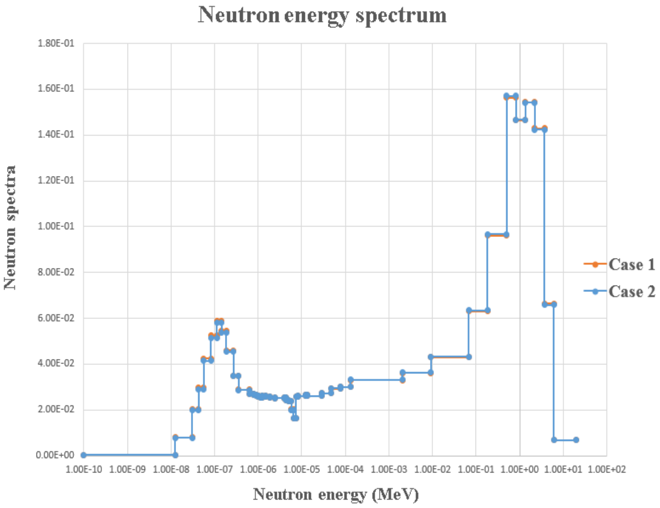

Fig. 7. Neutron flux spectra in center assembly for Cases 1 and 2

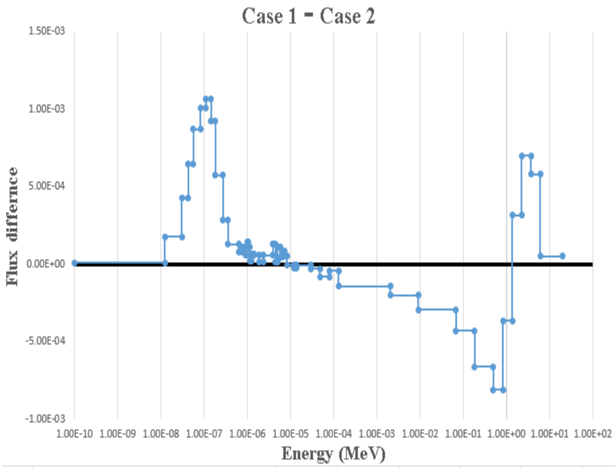

Fig. 8. Differences of neutron flux spectra between Case 1 and Case 2

From Fig. 8, Case 1 shows higher flux in thermal energy range, while in intermediate energy range, Case 2 shows higher flux. In the high energy range, Case 1 also shows higher flux. This is due to the fact that spacer grid material is not as efficient as coolant in moderating neutrons except for the high energy range. In the high energy range, Zr-90 which is the major isotope of spacer grid material (Zircaloy-4) has large inelastic scattering cross section in 1.5MeV-13MeV. Therefore, in the high-energy range, Case 2 shows lower flux spectrum.

4. Conclusions

In this paper, to investigate the effect of spacer grids, the spacer grid geometry is described in detail in the Monte Carlo calculation. In the numerical test, the two cases are compared in the context of a modified KAIST benchmark problem 1B. Case 1 does not have spacer grids, while the space is filled by coolant instead. Case 2 includes the spacer grids.

The multiplication factors of Cases 1 and 2 differ by about 380 pcm, which is not negligible. The location where the maximum axial flux occurs is also changed by about 12 cm. The difference in neutron flux spectra is also observed. Thus, the effect of the spacer grids should be considered in the whole-core reactor analysis.

In practice, the spacer grids are homogenized into coolant to consider its effect. As a further study, therefore, it would be worthwhile to investigate the differences between the homogenization and the explicit description of the spacer grids.

Acknowledgements

The first author (TXB) wishes to express thanks to YuGwon Jo of KAIST for his kind help during this work and to the Korean and Vietnamese governments for the financial support during his stay in Korea.

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[3] US NRC OECD Nuclear Energy Agency, OECD/NRC BENCHMARK based on NUPEC PWR Subchannel and Bundle Tests (PSBT), November 2010.

[4] Andrew T. Godfrey, “VERA Core Physics Benchmark Progression Problem Specifications - Revision 2,” March 29, 2013.