Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 23-24, 2019

McCARD Analysis for Pb-Bi-Zoned Accelerator Driven System at Kyoto University Critical Assembly

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1. Introduction

An accelerator driven system (ADS) has advantages in its unique safety characteristics and high flexibility of fuel compositions. Kyoto University Critical Assembly (KUCA) is a research reactor equipped with a pulsed neutron source producing 14 MeV neutrons from the D-T reaction and a fixed field alternating gradient (FFAG) accelerator for the 100 MeV proton spallation source. Recently an experimental benchmark conducted in the KUCA ADS system has been published for core configurations embedding solid lead-bismuth plates [1] (Pb-Bi benchmark hereafter). KUCA has been analyzed for static and kinetic parameters using Monte Carlo (MC) code because of its capabilities of using the continuous-energy cross section libraries and modeling the detailed geometry [2-3].

In this paper, neutronics parameters calculated by McCARD [4], the Seoul National University MC code, are compared with experimental results for the Pb-Bi benchmark. The McCARD calculations are conducted for KUCA ADS experiments using the Pb-Bi plates [1] with spallation neutrons generated by 100 MeV protons produced from the FFAG accelerator at the KUCA A-core. The prompt neutron decay constants and reaction rate distribution are calculated by McCARD and compared with experimental results.

2. Benchmark Modeling

Fuel assemblies use 93.3 wt% highly-enriched uranium (HEU) plates. Figures 1-3 show the fuel assemblies: type-F, type-f and type-16. Assemblies are divided into three parts: lower reflector, active core and upper reflector. Lower and upper reflector parts consist of polyethylene layers. Active core consists of HEU and polyethylene plates. Type-f assemblies has 30 times unit cells which consist of HEU and Pb-Bi plates.

Figure 4 shows the core configuration. The proton target is modeled as a Pb-Bi target where the 100 MeV protons are injected. The neutron source generated at Pb-Bi target is obtained from MCNPX2.6.0 [5] proton simulations [6]. The azimuthal angle distributions of the source are isotropic and polar angle bin are equally divided by 15˚. The calculation is conducted with 10,000,000 histories and lal150h libraries.

In reaction rate experiments, Indium wire (In-wire) is used. Its diameter is 1.0 mm and its length is 800 mm long.

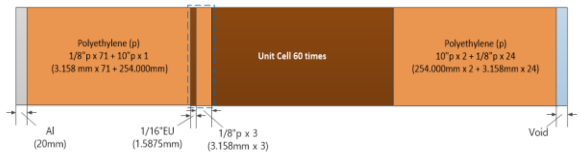

Fig. 1. Fall sideway of type-F assembly

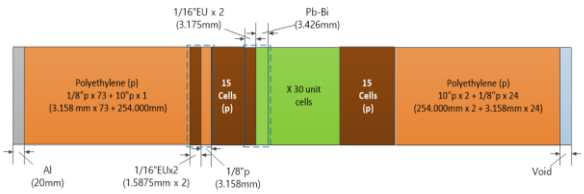

Fig. 2. Fall sideway of type-f assembly

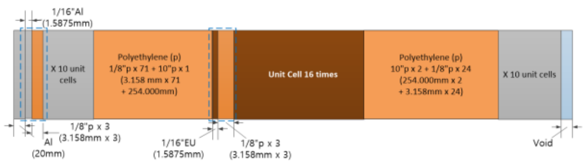

Fig. 3. Fall sideway of type-16 assembly

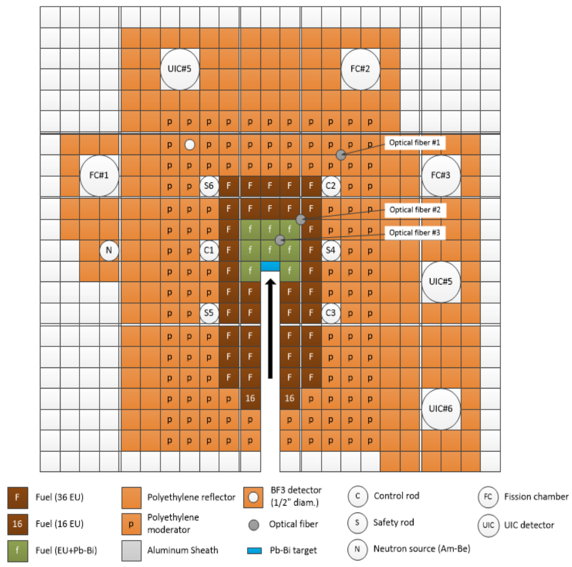

Fig. 4. Core configuration of ADS with 100 MeV protons

3. McCARD Analysis for Prompt Neutron Decay Constant

3.1 Alpha Experiment

Figure 5 shows subcritical core configurations by changing the control rod positions and the number of loaded fuel assemblies for which the pulsed neutron source experiments were conducted.

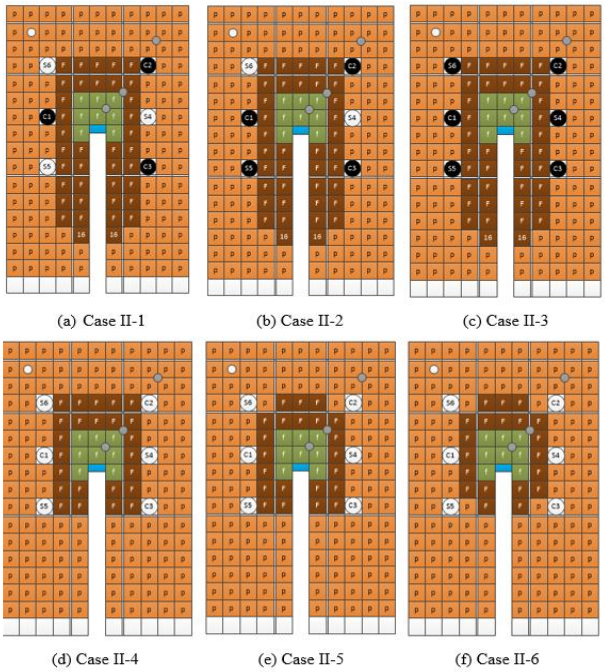

Fig. 5. Subcritical core configurations
(Black: Full-in, White: Full-out)

3.2 McCARD Calculation of Alpha

The prompt neutron decay constants (or α's) of the six subcritical configurations in Fig. 5 are calculated by the MC alpha-iteration method [7]. The McCARD alpha-static calculations are conducted with 1,000 iterations on 10,000 histories per iteration using JENDL-4.0 cross section libraries.

Table I. Alpha comparisons between McCARD calculations and experimental results

Case	k_{eff}	McCARD α-iteration	Least-squared fitting with PNS method		
			Fiber #1	Fiber #2	Fiber #3
II-1	0.99021 (0.00012)	380.0 (3.0)	398.0 (2.5)	326.8 (2.7)	494.5 (10.2)
II-2	0.98512 (0.00012)	497.0 (3.5)	506.7 (3.0)	452.6 (2.8)	685.4 (10.8)
II-3	0.97734 (0.00012)	668.8 (3.8)	672.6 (3.5)	631.9 (1.8)	1019.7 (8.3)
II-4	0.95556 (0.00012)	1034.9 (5.0)	982.5 (4.4)	971.3 (3.1)	1378.0 (18.4)
II-5	0.91088 (0.00012)	1789.6 (6.8)	1665.4 (8.7)	1680.7 (5.1)	1827.7 (22.8)
II-6	0.89725 (0.00011)	2010.9 (7.3)	1910.9 (7.4)	1930.7 (3.3)	2061.0 (37.8)

Table I shows comparisons of the McCARD alpha estimates with the measured values which are obtained by the slope fitting from the detector signals at three different locations. From the table, it is found that the McCARD estimates are within a 10% difference with averages over the detector results except Case II-3.

4. McCARD Analysis for Reaction Rate Distribution

4.1 Reaction Rates Experiment

Figure 6 shows subcritical core configurations with In-wire. The reaction rate distributions along In-wire are calculated for subcritical systems and compared with experimental results

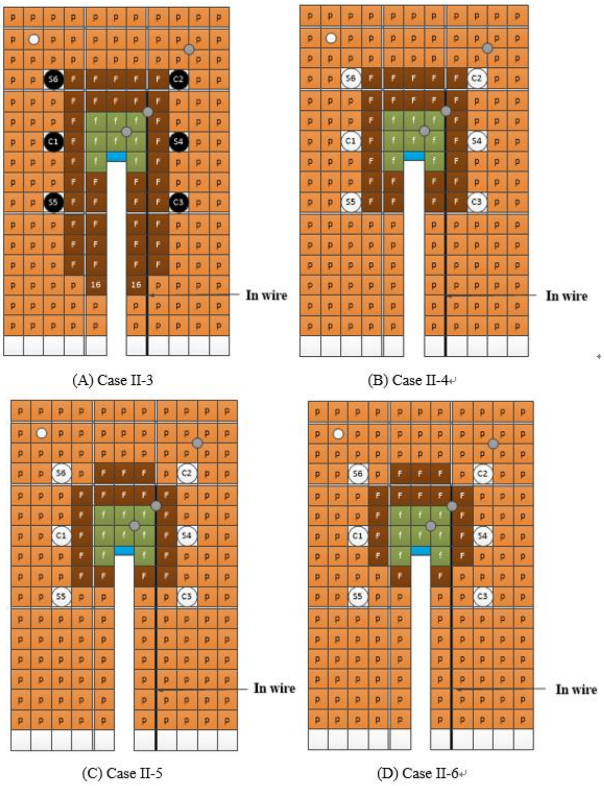

Fig. 6. Subcritical core configurations
(Black: Full-in, White: Full-out)

4.2 McCARD Calculation of Reaction Rates

The McCARD source mode calculations are conducted with 100,000,000 histories and JENDL-4.0 libraries. Reaction rates of $^{115}In(n, \gamma)^{116m}In$ are tallied and normalized to match the experimental results. Figures 7-10 show the comparison results between McCARD calculations and experimental results which were measured $^{115}In(n, \gamma)^{116m}In$ reaction rate by gamma-ray of 1097.3 keV. From the figures, the reaction rate distributions calculated by McCARD agree well with those from experiments within their 95% confidence intervals.

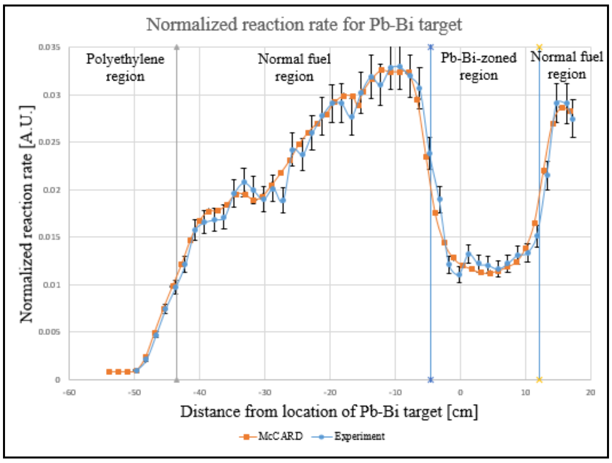

Fig. 7. Comparison between McCARD calculation and experimental results of $^{115}In(n,\gamma)^{116m}In$ reaction rate distributions for Case II-3

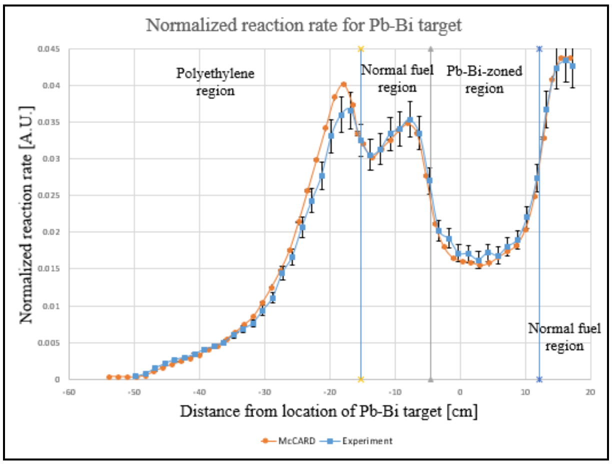

Fig. 8. Comparison between McCARD calculation and experimental results of $^{115}In(n,\gamma)^{116m}In$ reaction rate distributions for Case II-4

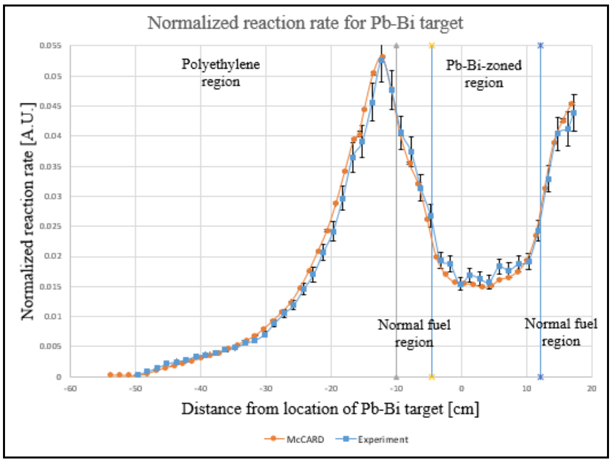

Fig. 9. Comparison between McCARD calculation and experimental results of $^{115}In(n,\gamma)^{116m}In$ reaction rate distributions for Case II-5

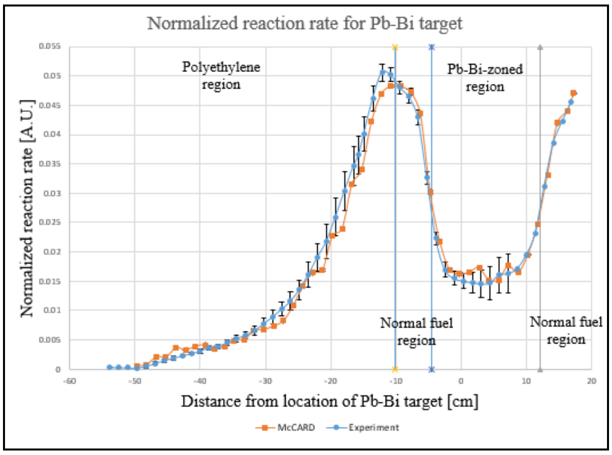

Fig. 10. Comparison between McCARD calculation and experimental results of $^{115}In(n,\gamma)^{116m}In$ reaction rate distributions for Case II-6

5. Conclusion

The KUCA experiments on prompt neutron decay constants and reaction rate distributions for the Pb-Bi benchmark are analyzed by McCARD. Alpha calculated by the McCARD alpha-iteration method is compared with experimental results of PNS regression analysis. Reaction rate distributions of In-wire are calculated by McCARD and they agree well with those from experiments within their 95% confidence intervals.

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