Measurement of Neutrons Induced by 50 MeV/u Uranium Beams on Thin Graphite Target

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1. Introduction

The neutron production is major subject for the shielding calculation of particle accelerator facilities. At the 90 degree and 180 degree bending section of RAON accelerator which is being designed in Korea, secondary neutrons are always produced in the stripping process of uranium beam. The energy of uranium beam at bending section is 17.5 MeV/u and a few μm-thick graphite stripper will be used. To secure the result of shielding calculation, the experimental data to benchmark should be required, but the neutron production data by the uranium beam of intermediate and low energy is rare.

In this study, neutrons produced by 50 MeV/u uranium beams on thin graphite stripper were measured using the activation detectors. Activation detectors of Bi, Co, Al were used. Production yields of each neutron induced reaction were measured by γ-ray spectroscopy using HPGe detector. Neutron spectra at the position of each activation detector were obtained by the unfolding with SAND-II code. Measured results were compared with calculated data by the PHITS and FLUKA code.

2. Methods and Results

The graphite stripper is located at the E1 Room (Experimental 1) of RIBF. The incident uranium beam energy is 50 MeV/u and the charge state of uranium is 64+. After the stripping and charge selection using bending magnet and collimator, the charge state is changed to 86+. The graphite stripper has been used since 2015. The thickness of the graphite stripper is 70 μm. Activation detectors of Bi, Co and Al were installed at the outside of the stripper chamber. Angles respect to center of beam pipe are 15, 30, 45, 65.2 and 90 degrees.

Irradiation time was 62.5 hours. Absolute beam currents were measured using the Faraday cup. The systematic error of the Faraday cup is 20%. The beam current variation was recorded using beam profile monitor and monitored by neutron area monitor. Fig. 1 shows the plan view of the E1 room, and position of the stripper and Faraday cup. The Faraday cup, FC-M04, and beam profile monitor, PP-M04, are installed at the upstream of the stripper, and FC-M11 and PP-H12 are installed after the charge selecting magnet. The beam current profile during the irradiation is shown in Fig. 2. The uranium beam current was assumed as 18193 enA (1.77E+12 pps) which is the mean value of the FC-M04.

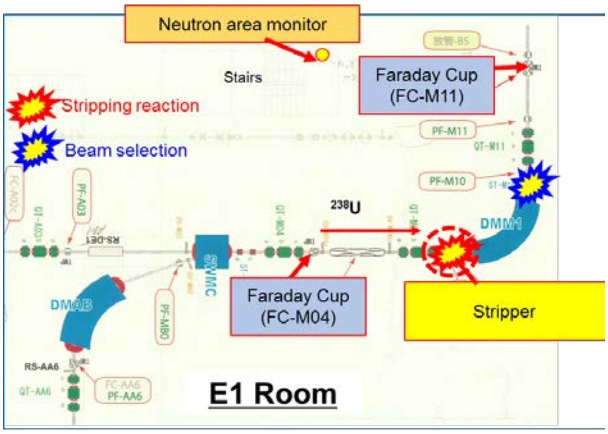

Fig. 1. Plan view of the E1 room of RIBF.

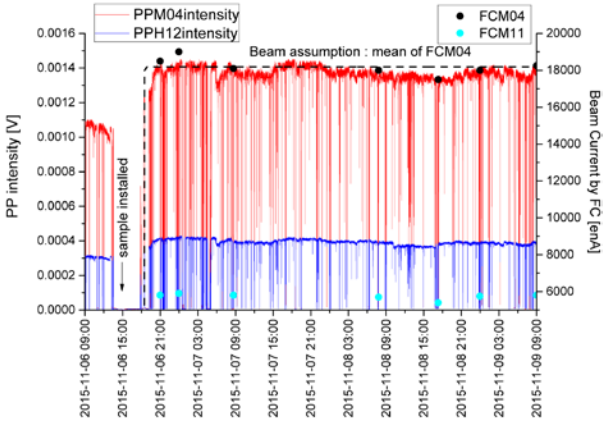

Fig. 2. Beam current profile of upstream and downstream of the graphite charge stripper during irradiation.

The γ-ray spectra of each activation detector after the irradiation were measured using the HPGe detector (CANBERRA GC2019). The net area of full-energy peak was obtained using the HyperGam software [1]. The peak efficiency, considering the self-absorption in thick activation detector was determined using MCNP code [2].

The cross-section of interested reactions is shown in Fig. 3. The threshold energy of available Bi reaction is above 20 MeV. To extend the neutron spectra to lower energy region, we used production yields from Bi and Al for the spectrum unfolding. We used the Co for cross-check. Its minimum threshold energy is above 0.3 MeV in case of (n,p) reaction.

Fig. 4 shows the measured production yields from Bi, Al detector. The production yields of $^{209}Bi(n, 4n)^{206}Bi$ reaction at 13° angle is most high. When angles respect

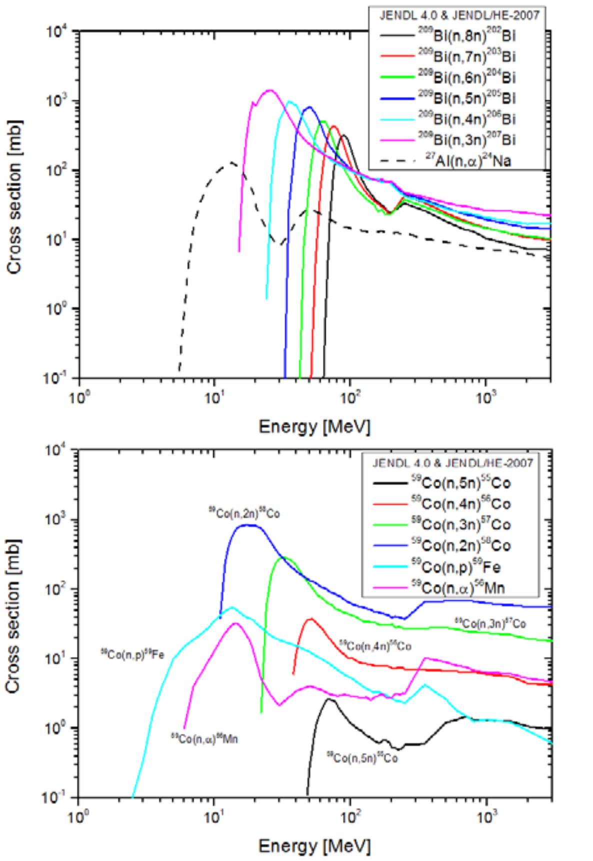

Fig. 3. Cross-section of the activation analysis from JENDL-4.0 (below 20 MeV) and JENDL/HE-2007 (above 20 MeV).

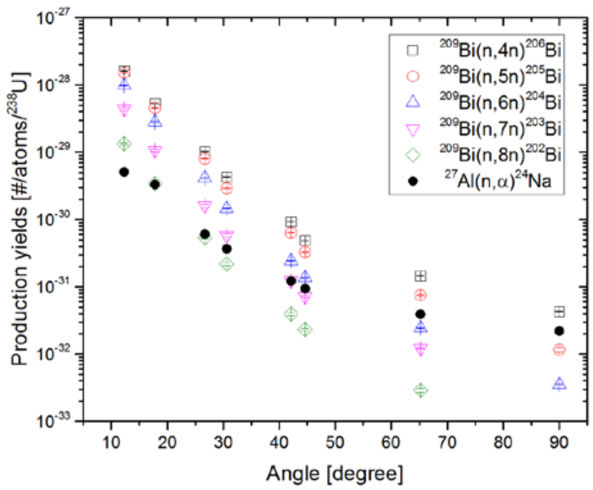

Fig. 4. Measured production yields of Bi(n,xn) and Al(n,α) reactions..

to the beam-axis is increased, the production yields of (n,xn) reaction decreased rapidly than (n, α) reaction. It means that the high-energy neutron above 20 MeV decreased more.

Examples of the unfolded neutron spectra are shown in Fig. 5. At the 30 degree respect to the beam-axis, FLUKA [3] result is similar with measured spectrum. At the 90 degree, which is related to the bulk shielding, PHITS [4] and FLUKA results are similar with measured spectrum.

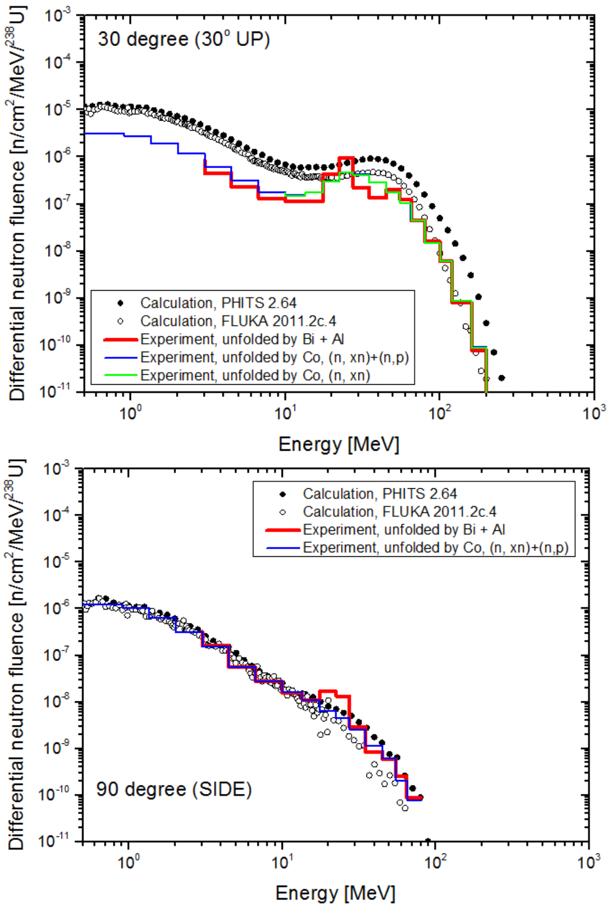

Fig. 5. Neutron spectra at different emission angle.

3. Conclusions

Neutron production from thin graphite by 50 MeV/n uranium beam was observed successfully by activation analysis with several elements which have threshold reaction cross-section with high energy neutrons. Experimental results were compared with calculation data by PHITS and FLUKA code. Some discrepancies between the calculations data and experimental results were found but might be acceptable. These results can compensate lacks of experimental data which are needed for benchmarking study.

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