Measurements of secondary neutrons produced from thin Be and C by 50 MeV/u ^{238}U beam

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Neutron production is one of the important subjects for shielding calculation of particle accelerator facilities, such as RIBF/RIKEN. However, the number of high-energy heavy ion accelerators in the world is small. The accuracy of shielding calculations of such facilities has been studied until now. In particular, the information of neutron production is very rare if the accelerated particles are heavy ions such as uranium. The neutron production yields were measured using a 50 MeV/u ^{238}U beam of RIBF for the shielding design of the Rare Isotope Science Project (RISP) ion accelerator in Korea.

In this study, the interesting energy of the ^{238}U beam is lower than 100 MeV/u because another group had already performed a similar study using an energy of 345 MeV/u at RIBF[1]. The charge-stripper chamber was chosen as the experimental station as shown in Fig. 1. The produced neutrons were measured when the 50 MeV/u ^{238}U beam hit the thin Be stripper or C stripper target in the chamber. For this measurement, the activation analysis was applied using Bi, Co, and Al samples, which were attached on the outer surface of the stripper chamber. We chose four different emission angles of neutron productions as shown in Fig. 1. The gamma rays from activated samples were measured using an HPGe detector and analyzed using HYPEGAM[2] software. The beam intensity of ^{238}U was monitored by a phase probe (PPM04) and calibrated by the current of a Faraday cup (FCM04).

The radionuclide yields were calculated using the gamma-ray spectra and well-known reaction cross-sections of Bi, Co, and Al with high-energy neutrons. The energy distributions of the produced neutrons were calculated using the unfolding method. The SAND-II code[3] was applied.

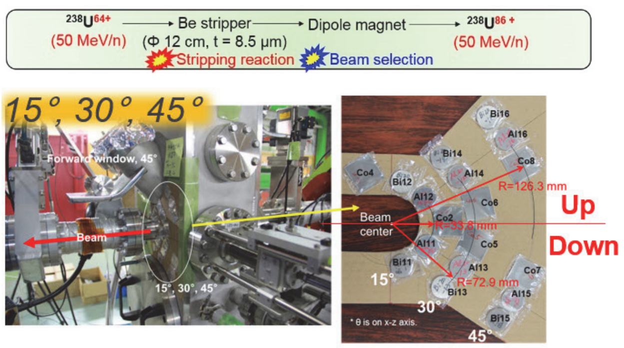

Fig. 1. Experimental setup at the charge-stripper chamber and the arrangement of activation samples in the forward direction. (Charge stripping process is described above)

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In this study, the entire experimental process was simulated using two Monte Carlo codes, PHITS[4] and FLUKA[5]. The spatial distribution of neutron fluence, one of the important results, was calculated using PHITS as shown in Fig. 2. The radionuclide production rates[6] of Bi samples were measured for different angles, 15°, 30°, 45°, and 90° as shown in Fig. 2. The angular distribution of the production rate was regenerated in good agreement with the theoretical trend. The comparison between the measured and calculated data by the two codes showed reasonable agreements, but the PHITS results were a greater underestimation relative to the FLUKA results.

Each neutron-induced reaction of Bi, Co, and Al samples has its own threshold energy. The neutron spectra above 10 MeV were obtained from the production yields of each reaction through the unfolding process[6]. The spectra calculated using FLUKA were in a good agreement with the unfolded one for every emission angle. However, the PHITS results showed a large discrepancy. The reason for the discrepancy has been reviewed carefully. The different physics models of two codes used in this energy range has been supposed as the first candidate reason.

These experimental results are very important to compensate for the fact that no proven data exist below approximately 300 MeV/u for benchmarking ^{238}U induced neutron production. The enhanced analysis is ongoing to confirm the discrepancy between the PHITS and FLUKA results or between the calculated results and experimental data.

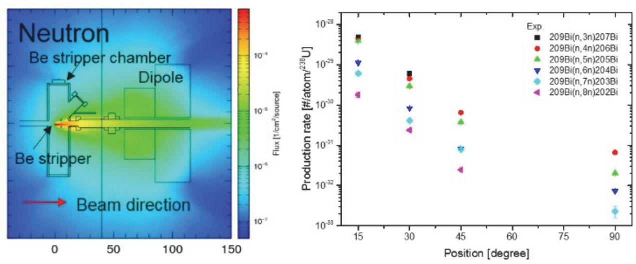

Fig. 2. Distribution of neutron fluence in the reaction area (left) and angular distribution of radionuclide yields in Bi samples (right).

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