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# Neutron Productions from thin Be target irradiated by 50 MeV/u $^{238}$U beam

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Neutrons generated from thin beryllium target by 50 MeV/u $^{238}$U beam were measured using activation analysis at 15, 30, 45, and 90 degrees from the beam direction. A 0.085 mm-thick Be stripper of RIBF was used as the neutron generating target. Activation detectors of bismuth, cobalt, and aluminum were placed out of the stripper chamber. The threshold reactions of $^{209}$Bi(n, xn)$^{210-x}$Bi(x=4~8), $^{59}$Co(n, xn)$^{60-x}$CO(x=2~5), $^{59}$Co(n, 2nα)$^{54}$Mn, $^{27}$Al(n, α)$^{24}$Na, and $^{27}$Al(n,2nα)$^{22}$Na were applied to measure the production rates of radionuclides. The neutron spectra were obtained using an unfolding method with the SAND-II code. All of production rates and neutron spectra were compared with the calculated results using Monte Carlo codes, the PHITS and the FLUKA. The FLUKA results showed better agreement with the measurements than the PHITS. The discrepancy between the measurements and the calculations were discussed.

***KEYWORDS: $^{238}$U beam, Be, Activation analysis, Neutron spectrum***

## I. Introduction

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

The interesting energy of 238U beam is lower than 100 MeV/u because another group had already performed similar study using 345 MeV/u at RIBF[1)]. The produced neutrons were measured when 50 MeV/u $^{238}$U beam hit thin Be using activation analysis. The production rate of radionuclides were compared with the Monte Carlo calculation and neutron spectra were also obtained using the unfolding method.

## II. Material and Method

### 1. Experiments

The charge stripper chamber was chosen as the experimental station as shown in figure 1. The produced neutrons were measured when 50 MeV/u $^{238}$U beam hit thin Be stripper (0.085 mm) 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. The samples have a diameter of 2 cm (or 2.5x2.5 cm2) and a thickness of 5 mm (or 2 mm). We chose four different emission angles (15, 30, 45, and 90 degrees) of neutron productions as shown in Fig. 1. The irradiation of 238U beam was done during normal operation for the other experiments at the RIBF target station. The beam intensity of $^{238}$U ions was monitored by a phase probe (PPM04) and calibrated by the current of Faraday cup (FCM04). The gamma-rays from activated samples were measured using an HPGe detector and analyzed using HYPEGAM[2)] software. Radionuclide yields in the samples were obtained. The gamma spectroscopy system was calibrated using multi-lines standard source and verified by the MCNPX simulation[3)].

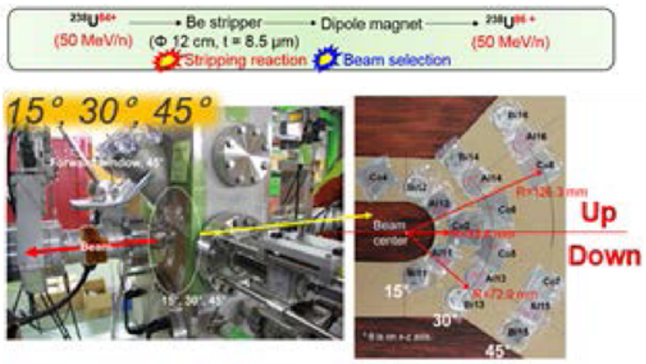


**Figure 1: Experimental setup at a charge stripper chamber and the arrangement of activation samples at the forward direction. (Charge stripping process is described up)**

### 2. Monte Carlo calculation and unfolding

Monte Carlo codes FLUKA[4)], version 2c.0, PHITS[5)], version 2.64, and MCNPX, version 2.7 were used to simulate this experiment. The radionuclide yields in Bi, CO, and Al samples were estimated using the FLUKA or the PHITS and activation code, DCHAIN[5)], version 2001. The flux and energy distribution of all kinds of particles produced from Be stripper target were estimated. In figure 2, the part of calculated PHITS results, fluence distribution of neutrons and nucleus including 238U ions, were presented. All devices and real geometry were considered in this simulation in order to figure out the contribution of those to sample activation, especially a big dipole magnet downstream of the stripper chamber.

The energy distributions of produced neutrons were calculated by the unfolding method. The SAND-II code[6)] was applied for several threshold reactions of Bi, Co, and Al elements. The measured data were compared with the results simulated using the FLUKA, and the PHITS.

## III. Results and Discussion

The radionuclide production rates of Bi, Co and Al samples were measured for different angles, 15, 30, 45, and 90 degrees as shown in figure 2. The rate of Bi samples are presented in figure 3. The angular distribution of production rate regenerated well the theoretical trend. The comparison between the measured and the calculated data by two codes showed reasonable agreements but the PHITS results underestimated more than the FLUKA results relatively.

All neutron-induced reactions of Bi, Co, and Al samples have each threshold energy. The neutron spectra above 10 MeV were obtained from the production yields of each reactions through the unfolding process7). The contamination of neutron energy spectrum by surrounding devices except of the Be stripper target was found as very small at the energy range higher than 20 MeV. The calculated spectra using the FLUKA had good agreements with the unfolded one for every emission angle. Figure 4 shows one spectra. However the PHITS results showed big discrepancy. The reason of the discrepancy has been discussed at present. The different physics model of two codes at the energy range has been reviewed.

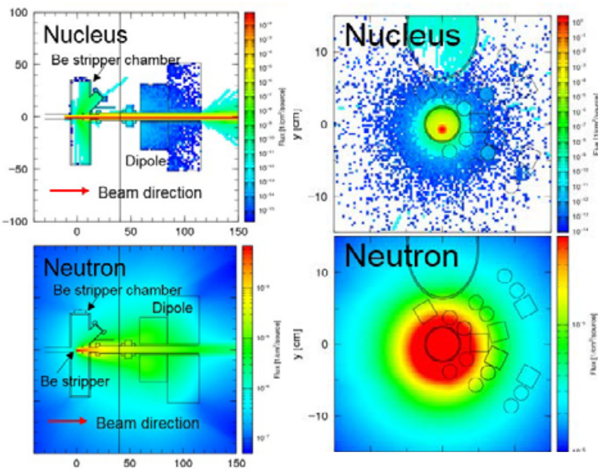


**Figure 2**: **Fluence Distribution of nucleus (up) and neutrons (down) at stripping reaction area.**

## IV. Conclusion

These experimental results are very important to compensate the fact that there is no proved data below about 300 MeV/u for benchmarking 238U induced neutron production. The enhanced analysis is ongoing to confirm the discrepancy between the PHITS and the FLUKA results or with the experimental results.

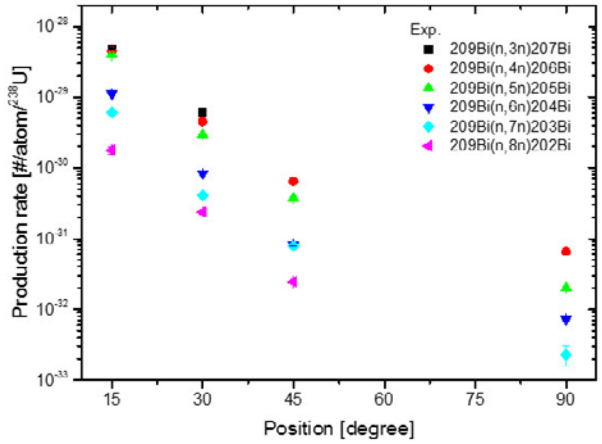


**Figure 3**: **Angular distribution of radionuclide yields in Bi samples.**

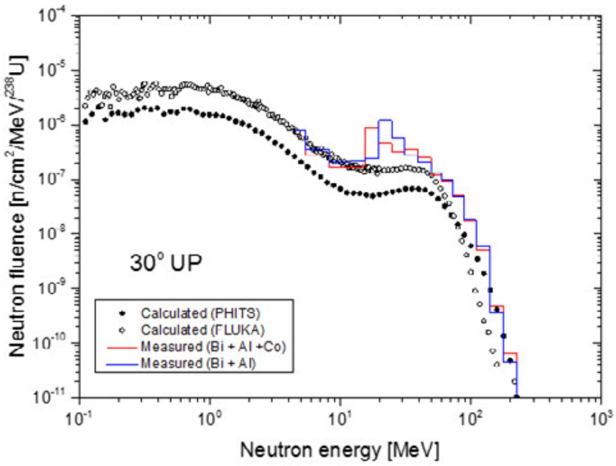


**Figure 4**: **Differential neutron yields from thin Be target by 50 Mev/u $^{238}$U beam at 30 degree: comparison of the measured using two or three elements with resulted calculated by PHITS and FLUKA.**

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