Development of energy-control method for slowed-down ^{93}Zr beam

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The spallation reaction of the long-lived fission product (LLFP) in nuclear waste might be a key reaction for nuclear transmutation. The spallation cross sections for the LLFPs were measured on proton and deuteron targets via the inverse kinematics method using the RI beam with an energy of 185 MeV/u at RIBF.[1)] For the cross-section measurement at ∼100 MeV/u,[2,3)] the aluminum energy degrader was used to slow down the RI beam. At a lower energy such as 50 or 20 MeV/u, the inaccuracy of the energy-loss calculation becomes relatively larger. A new control method of the RI-beam energy was developed for quick and precise tuning.

The RI beam of ^{93}Zr was produced using a ^{238}U primary beam with 345 MeV/u impinging on a 7-mm Be target. The aluminum energy degraders were placed at foci F1 and F5, which were the momentum dispersive focal planes of the first and second stages of the BigRIPS separator. The thicknesses of the F1 and F5 degraders were 4 mm and 0.5 mm, respectively. The F1 slit was ±1 mm. A 90-mg/cm^2 carbon target was prepared supposing the spallation-reaction measurement. The goal energy at the center of the carbon target was 50 MeV/u, and the energy without the carbon target was expected to be 60 MeV/u using the energy-loss calculation in the target. The energy without the carbon target was measured to be 51.1 MeV/u by using the time of flight in the ZeroDegree spectrometer, as shown in Fig. 1. The magnetic rigidity $B\rho_{01}$ of the first dipole was increased by 1.24% based on the calculated relation between $B\rho_{01}$ and the energy in the ZeroDegree spectrometer. The magnetic rigidities of other dipoles were readjusted. The energy became 60.4 MeV/u, which was almost same as the goal energy of 60 MeV/u. Hence, $B\rho_{01}$ was changed again by −0.37% because the average of the energies with and without the carbon target, 53 MeV/u, was slightly large. The final energy average, 50.1 MeV/u, was remarkably close to the goal energy: it was obtained by averaging the peak energies of the two energy distributions as indicated by the red line in Fig. 1.

For the 20 MeV/u setting, the thickness of the F1 degrader was changed to 5 mm. Two energies with and without a CH_2 target with a 17-mg/cm^2 thickness were measured for an initial condition to obtain the average, which was 27.0 MeV/u, as shown in Fig. 2. An average energy of 20.2 MeV/u was successfully obtained after $B\rho_{01}$ was changed by −0.56%. The energy after the CH_2 target was 16.9 MeV/u and its width was 0.82 MeV/u (FWHM), which corresponds to 2.4% (FWHM) in momentum. The position and angle distributions on a secondary target were also optimized in a later experiment.[4)]

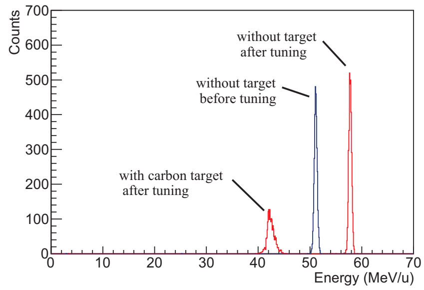

Fig. 1. Energy distributions of the ^{93}Zr beam before (blue) and after (red) the $B\rho$ tuning of dipoles in the BigRIPS separator. The goal energy at the center of the carbon target was 50 MeV/u, and 50.1 MeV/u was achieved.

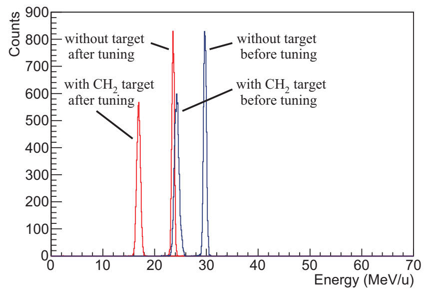

Fig. 2. Energy distributions before (blue) and after (red) the $B\rho$ tuning of dipoles for the 20 MeV/u setting of the ^{93}Zr beam.

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