Isotopic production of high-radiotoxic nuclide ^{90}Sr via proton- and deuteron-induced reactions[†]

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The processing of spent fuels from nuclear power plants is a worldwide problem. The by-products of the reprocessing of spent fuels are high-level radioactive wastes, which contain minor actinides and fission products. In this study, we focus on ^{90}Sr, which is the most radiotoxic nuclide in fission products.[1] There is a strong desire to develop nuclear transmutation technology using accelerator facilities to reduce these harmful nuclides. The simplest method is to irradiate the radioactive waste with a neutron beam. However, it is not well known how much and into which nuclide ^{90}Sr is transmuted in this reaction. Therefore, it is essential to study the reaction cross sections to each nuclide from ^{90}Sr in advance. From this perspective, the inverse kinematics, *i.e.*, incident ^{90}Sr beam on light-particle targets, is an effective method for identifying reaction products in the forward direction.

The experiment was performed at RIBF. A secondary beam including ^{90}Sr was produced by the in-flight fission of ^{238}U at 345 MeV/nucleon on a 3-mm-thick ^{9}Be production target, selected and identified event-by-event using the TOF-$B\rho$-ΔE method.[2] Beam particles at 104 MeV/nucleon bombarded CH_2, CD_2, and C reaction targets placed at the entrance of ZDS. The residual nuclei produced in reactions were identified in ZDS with the same method as BigRIPS. Because the momentum acceptance of ZDS is limited to ±3%, the experiment was conducted using five different momentum settings ($\Delta(B\rho)/B\rho = -9, -6, -3, 0$, and $+3\%$) for each target to accept a wide range of the mass-to-charge ratio A/Q. The reaction cross sections were deduced from the number of incident ^{90}Sr nuclides, the number of residual particles of each species, and the thickness of the target. The backgrounds of carbon from CH_2 and CD_2 targets and beam-line materials were subtracted using empty and carbon target runs.

The data points above 1 mb were obtained with good statistics. These were compared with the calculations using the Particle and Heavy Ion Transport code System (PHITS),[3] as shown in Fig. 1. The Liège Intranuclear Cascade model (INCL4.6) and the Generalized Evaporation Model (GEM) were employed in the calculations. It is observed that the calculation results were overestimated around the mass number of the projectile. Few-nucleon removal reactions are not interpreted properly in INCL because momentum distributions of the nuclear surface are treated in a semiclassical way.[4] In addition, even-odd staggering effects appeared excessively for nuclides produced by emitting many nucleons. This may be controlled to some extent by considering the competition between particle and γ-ray emissions, as well as the discrete energy levels, in the GEM.

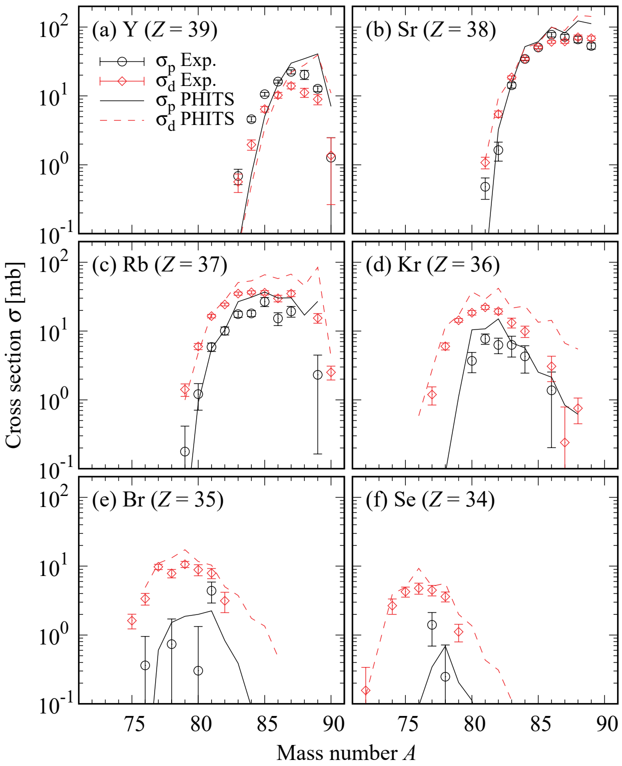

Fig. 1. Isotopic-production cross sections of proton- (circles) and deuteron-induced (diamonds) reactions and those obtained from the PHITS calculations (proton for solid and deuteron for dotted lines).

In the lower energy deuteron-induced reaction, it has been observed that the initial reaction mechanism changes drastically due to the breakup into proton and neutron during the reaction.[5] Thus, we would also like to obtain the reaction data for ^{90}Sr in the near future.

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