Spallation reaction study of ^{136}Xe on proton, deuteron and carbon

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Spallation reactions have been attracting considerable interest for their usefulness in the fundamental research to produce unstable nuclei[1)] as well as in applications to transmute nuclear waste in accelerator-driven systems (ADS).[2)] For these two purposes, it is important to have a comprehensive understanding of the spallation reaction mechanism both experimentally and theoretically. ^{136}Xe is a good candidate for both the fields. For the fundamental research, fragmentation and/or spallation of ^{136}Xe is well known to be one of the power tools to access unstable nuclei. On the other hand, ^{136}Xe is a stable isotope neighboring the long-lived fission product ^{137}Cs, whose spallation reaction has been studied recently for nuclear waste transmutation.[3)] The experimental data of ^{136}Xe will be a good benchmark for the theoretical calculations of ^{137}Cs. The comparison between the reaction of ^{136}Xe and ^{137}Cs is critical for checking the validity of the model calculation and clarifying the reaction mechanism. Several experiments have been performed for spallation reactions of ^{136}Xe at reaction energies of 500 AMeV[4)] and 1000 AMeV.[5)] In the present work, the proton-, deuteron-, and carbon-induced reactions of ^{136}Xe at 168 AMeV have been studied.

The experiment was performed using BigRIPS and ZeroDegree spectrometer.The setup was the same as the one for ^{137}Cs.[3)] The average intensity of the ^{136}Xe beams was 2.6×10^3 particles per second.

The isotopic distributions of the cross sections obtained in the present work are plotted in Fig. 1. In general, the cross sections on carbon (σ_C) are similar to the ones on deuteron (σ_d). The Cs isotopes in Fig. 1(a) are produced by charge-exchange reactions ($\Delta Z = +1$). In this channel, both σ_C and σ_d are smaller than the cross sections on proton (σ_p). This behavior of the charge-exchange reaction is consistent with the studies of ^{137}Cs and ^{90}Sr at 185 AMeV.[3)] For the Xe isotopes, σ_d is similar to σ_p; both are larger than σ_C. For the I and Te isotopes, σ_d and σ_C becomes larger than σ_p, especially in the neutron-deficient side. Such cross-section differences may be caused by the deposited energy. Deuteron and carbon have more nucleons than proton leading to the deposition of a higher energy relative to proton. This enables a large evaporation of nucleons.

The EPAX[6)] calculations are plotted in Fig. 1, in order to compare them with the experimental results. For both carbon and deuteron, EPAX calculations underestimate the cross sections, especially in the neutron-deficient side for the Xe, I, and Te isotopes. In the case of proton, EPAX was found to underestimate the cross sections by for the Xe and I isotopes. For the Te isotopes, EPAX overestimated the cross sections in the neutron-deficient side. For the cross sections on proton, the differences between the EPAX calculations and experimental results are similar to the ones observed in the reactions of ^{137}Cs.[3)]

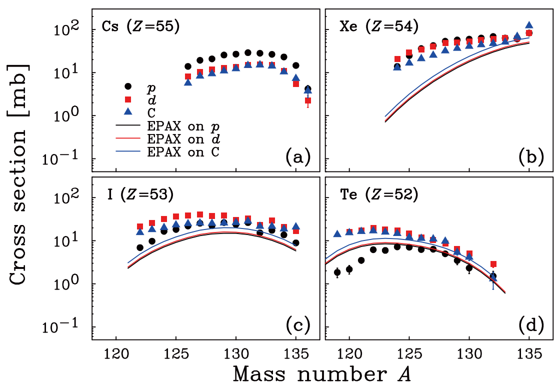

Fig. 1. Isotopic distribution of the cross sections for products from cesium element to tellurium element produced in the reaction ^{136}Xe + p(circle), ^{136}Xe + d(square), and ^{136}Xe + C(triangle) at 168 AMeV. EPAX calculations are displayed for comparison. The error bar shows the statistical uncertainties.

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