Excitation functions for production of Nb and Ta isotopes in the (d,x) reactions on ^{nat}Zr and ^{nat}Hf up to 24 MeV

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The isotopes ^{95g}Nb ($T_{1/2}$ = 34.991 d) and ^{179}Ta ($T_{1/2}$ = 1.82 y) are useful radiotracers for the basic studies of the element 105, Db. We have investigated the production of these radiotracers by the activation of ^{nat}Zr and ^{nat}Hf with a 14-MeV proton beam supplied by the RIKEN AVF cyclotron.[1)] From the AVF cyclotron, a deuteron beam is also available.[2,3)] Activation by the deuteron beam is one of the widely used and well-studied methods to produce the radiotracers. However, the production cross sections of ^{95g}Nb by the (d,x) reaction are scanty compared to those of the (p,x) reactions. Furthermore, the cross sections of ^{179}Ta in the (d,x) reaction have not been reported. In this work, we measured the excitation functions for the production of ^{95g}Nb and ^{179}Ta as well as other isotopes in the (d,x) reactions on ^{nat}Zr and ^{nat}Hf.

The excitation functions were measured with a stacked-foil technique. For the measurement of the cross sections of Nb isotopes, thin foils of ^{nat}Zr (20 μm thickness), ^{nat}Ti (20 μm thickness), and ^{nat}Ta (20 μm and 10 μm thickness) were stacked alternately and used as a target. The ^{nat}Ti foils were used to determine the beam energy and intensity by measuring the excitation function of the ^{nat}Ti$(d,x)^{48}$V reaction, and the ^{nat}Ta foils were also used as the energy degrader. For measurement of the cross sections of Ta isotopes, thin foils of ^{nat}Hf (25 μm thickness) and ^{nat}Ti (20 μm thickness) were stacked alternately. The size of all the foils was 15 × 15 mm^2. Both stacks were irradiated by the 24-MeV deuteron beam supplied by the AVF cyclotron for 30 min. The beam was collimated to a diameter of 9 mm, and the average beam currents were 0.48 μA and 046 μA for the Zr/Ti/Ta and Hf/Ti stacks, respectively. After irradiation and proper cooling, γ- and X-rays of each foil were measured by the Ge detectors.

The production cross sections were derived by the well-known activation formula.[4)] The beam energies in the individual target foils were calculated with the SRIM-2008 program.[5)] The experimental data were compared with the cross section data culculated by the TALYS-1.4 code.[6)]

The cross sections of ^{90g,91m,92m,95m,95g,96}Nb, ^{95,97}Zr, and ^{87m,87g,88}Y were measured in the ^{nat}Zr(d,x) reactions, whereas the production cross sections of ^{175,176,178,179,180g}Ta and ^{175,179m2,180m,181}Hf were measured in the ^{nat}Hf(d,x) reactions. Figure 1(a) shows the excitation function of the ^{nat}Zr$(d,x)^{95m+g}$Nb reaction. In Fig. 1(a), the cross sections reported by Gonchar et al.[7)], those reported by Tárkányi et al.,[8)] and those calculated by the TALYS code[6)] are compared. The data reported by Gonchar et al.[7)] and Tárkányi et al.[8)] show a similar shape of the excitation function with a systematically higher magnitude. The TALYS code also indicates a similar shape of the excitation function but lower values than the measured ones. The cross sections of the ^{nat}Hf$(d,x)^{179}$Ta reaction were measured for the first time, as shown in Fig. 1(b). The measured excitation function exhibits the maximum cross section of 489 ± 50 mb at 21.1 ± 0.4 MeV. Again, the calculated cross sections by TALYS indicate lower values, though the shape of the excitation function is similar.

Thick-target yields of ^{95m,g}Nb and ^{179}Ta were deduced from the measured cross sections and the stopping power given by the SRIM-2008 program.[5)] The deduced yields for beam energies up to 24 MeV were 1.3, 0.40, and 0.21 MBq/(μA·h) for ^{95m}Nb, ^{95g}Nb, and ^{179}Ta, respectively.

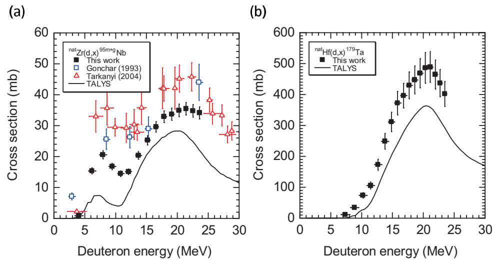

Fig. 1. Excitation functions of (a) ^{nat}Zr$(d,x)^{95m+g}$Nb reaction and (b) ^{nat}Hf$(d,x)^{179}$Ta reaction.

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