Activation cross sections of deuteron-induced reactions on praseodymium up to 24 MeV†

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The ^{140}Nd ($T_{1/2} = 3.37$ d) and ^{142}Pr ($T_{1/2} = 19.12$ h) radionuclides can be used for a ^{140}Nd/^{140}Pr in-vivo generator for positron emission tomography (PET)[1)] and for the treatment for arteriovenous malformations,[2)] respectively. We focused on the deuteron-induced reaction on the monoisotopic element ^{141}Pr among possible production reactions. In a literature survey, we found only two experimental studies on the ^{141}Pr$(d,3n)^{140}$Nd reaction, the experimental cross sections of which are scattered.[3,4)] Therefore, we conducted two experiments to measure the cross sections of this reaction. The production cross sections of ^{141,140}Nd, ^{142}Pr, and ^{141}Ce were determined up to 24 MeV.

Two independent experiments were conducted using 24-MeV deuteron beams at the RIKEN AVF cyclotron. The stacked-foil activation technique and high-resolution gamma-ray spectrometry were adopted for the experiments. For the stacked targets, two ^{141}Pr (99% purity), two ^{nat}Ti (99.6% purity), and one ^{27}Al (>99% purity) metal foils were purchased from Nilaco Corp., Japan. The measured thicknesses of the foils were 67.6 and 72.3 mg/cm^2 (^{141}Pr), 2.34 and 2.30 mg/cm^2 (^{nat}Ti), and 1.50 mg/cm^2 (^{27}Al). The first (#1) and second stacked targets (#2) were composed of ^{141}Pr and ^{nat}Ti and ^{141}Pr, ^{nat}Ti, and ^{27}Al, respectively. The ^{nat}Ti foils were interleaved for the ^{nat}Ti$(d,x)^{48}$V monitor reaction to assess beam parameters and target thicknesses. The ^{27}Al foils were used as catchers of the recoiled products and to address the variation in energy degradation. Nine sets of Pr-Ti-Ti (#1) and Pr-Al-Ti-Ti-Al foils (#2), which were cut into a size of 8 × 8 mm^2, were stacked into target folders served as Faraday cups.

Both stacked targets were irradiated with deuteron beams for 30 min. The average beam intensities measured by the Faraday cups were 107 (#1) and 110 nA (#2). The measured primary beam energies were 24.1 (#1) and 24.3 MeV (#2). The energy degradation of the beams in the stacked targets was calculated using stopping powers obtained from the SRIM code.[5)]

Gamma rays emitted from the irradiated foils were measured without chemical separation using a high-purity germanium detector. The ^{141}Pr foils with the following ^{27}Al foils were measured several times with a dead time below 5.2%.

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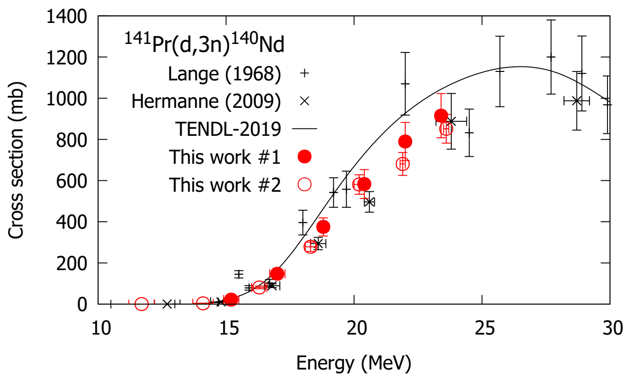

Fig. 1. Cross sections of the ^{141}Pr$(d,3n)^{140}$Nd reaction with the previous data[3,4)] and the TENDL-2019 values.[7)]

Cross sections of the ^{nat}Ti$(d,x)^{48}$V monitor reaction were derived to assess beam parameters and target thicknesses. A comparison with the IAEA recommended values[6)] indicated that the thicknesses of the ^{141}Pr foils were corrected by +1% within the uncertainties (2%). The other target thicknesses and beam parameters were adopted without any correction.

There are no gamma lines with the decay of ^{140}Nd ($T_{1/2} = 3.37$ d). Considering the secular equilibrium, the gamma lines at 1596.1 keV ($I_\gamma = 0.49\%$) and 511 keV ($I_\gamma = 102\%$) emitted with the decay of ^{140}Pr ($T_{1/2} = 3.39$ min) were measured instead. The directly produced ^{140}Pr decayed during the cooling times. The cross sections of the ^{141}Pr$(d,3n)^{140}$Nd reaction in the first experiment (#1) were deduced from the gamma line at 1596.1 keV, and those in the second experiment (#2) were determined from the gamma line at 511 keV. A comparison of the results with previous studies[3,4)] and TENDL-2019 values[7)] is shown in Fig. 1. Previous experimental data are scattered, but almost consistent with ours within the uncertainties. The TENDL-2019 values are slightly larger than our data.

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