Activation cross sections of proton-induced reactions on praseodymium up to 30 MeV†

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The medical radionuclide ^{140}Nd ($T_{1/2}$ = 3.37 d) is expected to be used as a ^{140}Nd/^{140}Pr in-vivo generator for positron emission tomography (PET).[1] It can be produced via charged-particle-induced reactions. Among the possible production reactions, we focused on the proton-induced reaction of ^{141}Pr. A survey revealed three experimental studies of the reaction for ^{140}Nd production.[2–4] However, the experimental cross sections in the literature are largely scattered. Therefore, we performed an experiment to obtain the cross sections of the ^{141}Pr$(p, 2n)^{140}$Nd reaction up to 30 MeV. The production cross sections of $^{141, 139m}$Nd and ^{139}Ce were also determined.

We conducted an experiment using a 30-MeV proton beam at the AVF cyclotron in RIKEN. We adopted the stacked-foil activation technique and high-resolution gamma-ray spectrometry to determine the excitation functions. The target consisted of pure metallic thin foils of ^{141}Pr (99% purity), ^{nat}Ti (99.5% purity), and ^{27}Al (>99% purity), which were purchased from Nilaco Corp., Japan. The ^{nat}Ti foil was used for the ^{nat}Ti$(p, x)^{48}$V monitor reaction to assess beam parameters and target thicknesses. The ^{27}Al foil was interleaved to catch recoiled products. The side lengths and weight of each foil were measured to obtain the average thicknesses. The measured thicknesses of the two ^{141}Pr, ^{nat}Ti and ^{27}Al foils were 68.6 and 68.5 mg/cm^2, 9.1 mg/cm^2, and 2.2 mg/cm^2, respectively. The large foils were cut into small pieces of 8 × 8 mm^2 to fit a target holder. Eighteen sets of the Pr-Al-Ti-Ti-Al foils were stacked in the target holder, which served as a Faraday cup.

The stacked target was irradiated with a proton beam for 15 min. The average intensity and primary energy of the beam were measured to be 201 nA and 30.2 MeV, respectively. Energy degradation in the stacked target was calculated using stopping powers obtained from the SRIM code.[5]

Gamma-ray spectrometry was performed using a high-purity germanium detector. Each ^{141}Pr foil was measured together with the next ^{27}Al foil that caught the recoiled products. The ^{141}Pr foils were measured 3–9 times to assess the decay curves of the products. The cooling times were from 1.7 h to 31.9 d, and the dead time was maintained below 7.5%.

Cross sections of the ^{nat}Ti$(p, x)^{48}$V monitor reaction were derived for comparison with the IAEA recommended values.[6] Based on the comparison, the thicknesses of the ^{141}Pr foils and the beam intensity were corrected by +2% and −7% within the uncertainties. The measured thicknesses of ^{nat}Ti and ^{27}Al were used without any correction.

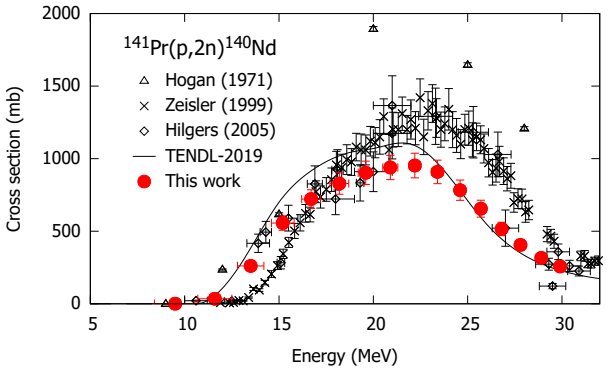

Fig. 1. Cross sections of the ^{141}Pr$(p, 2n)^{140}$Nd reaction with the previous data[2–4] and the TENDL-2019 values.[7]

^{140}Nd has the ground state ($T_{1/2}$ = 3.37 d) and the metastable state at 2.221 MeV ($T_{1/2}$ = 0.60 ms). The isomer fully decays to the ground state via the IT transition (IT: 100%). Because there are no measurable gamma lines from ^{140}Nd, gamma rays with the decay of ^{140}Pr ($T_{1/2}$ = 3.39 min) were instead measured under secular equilibrium with the decay of ^{140}Nd. Direct production of ^{140}Pr during irradiation was negligible because the cooling times were much longer than its half-life. We measured the gamma line at 511 keV (I_γ = 102%) emitted from the irradiated foils, which were sandwiched between copper plates to force positron annihilation. The result is compared with those of the previous studies[2–4] and the TENDL-2019 values[7] in Fig. 1. Our excitation function is largely different from those of the previous studies. The TENDL-2019 values slightly overestimate our experimental data below 23 MeV.

References
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† Condensed from the article in Nucl. Instrum. Methods Phys. Res. B **508**, 29 (2021)

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