Activation cross sections of deuteron-induced reactions on ^{nat}Cr up to 24 MeV†

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Many radioisotopes are used for medical applications. ^{51}Cr ($T_{1/2}$ = 27.8 d) decays through the electron capture process with the emission of 320-keV γ rays. The radionuclide is used to label red blood cells.[1] Another medical radionuclide ^{52g}Mn ($T_{1/2}$ = 5.591 d), decays via the electron capture and positron emission processes. The emitted positrons can be used for imaging of positron emission tomography (PET).[2] Further, ^{48}V ($T_{1/2}$ = 15.97 d) can be used for tumor imaging.[3] Among the possible reactions to produce the medical radionuclides, we focused on the deuteron-induced reaction on ^{nat}Cr. The reactions are also related to the effects on the anti-corrosion coating of chromium and the iron-chromium alloy in fusion reactors.[4] Reliable experimental and evaluated excitation functions of the reactions are required. Therefore, we aim to obtain a new set of experimental data for the reactions up to 24 MeV.

We adopted the well-established stacked-foil activation technique and high-resolution γ-ray spectrometry. The stacked target comprised foils of nickel-chromium (NiCr) alloy (99.9% purity, Goodfellow Co., Ltd., UK), ^{nat}Ti (99.6% purity, Nilaco Corp., Japan), and ^{27}Al (>99% purity, Nilaco Corp., Japan). The ^{nat}Ti foil was used for the ^{nat}Ti$(d,x)^{48}$V monitor reaction. ^{27}Al foil was interleaved to collect recoiled products. The average foil thicknesses were derived from their measured weight and size. We analyzed the elemental ratio of the NiCr alloy foil (Cr 21.5%, Ni 76.7%, Mn 1.7%) by a scanning electron microscope with an energy dispersive X-ray spectrometer (Hitachi TM4000 Plus II). The original foils were cut into squares of 8 × 8 mm to fit a target holder. Thirteen sets of NiCr-NiCr-Al-Ti-Ti-Al foils were stacked as the target. In addition, the loss recoiled from the second foils was assumed to be compensated by that from the first foils. Only γ spectra from each second foil were measured.

The stacked target was irradiated for 30 min using a 24-MeV deuteron beam at the AVF cyclotron at RIKEN. The average intensity and primary energy of the beam were measured as 105 nA and 24.0 ± 0.1 MeV, respectively. Energy degradation in the stacked target was calculated using stopping powers obtained by the SRIM code.[5]

The γ rays emitted from the foils were detected seven times using a high-purity germanium detector (ORTEC GEM30P4-70). To assess the radionuclides with different half-lives, the measurements were performed with cooling times of 1 h–32 d, and the associated dead time was less than 5.2%.

The cross sections of the ^{nat}Ti$(d,x)^{48}$V monitor reaction were derived and compared with the recommended values of International Atomic Energy Agency.[6] According to the comparison, the beam intensity was decreased by 1.1% within the uncertainty (5%). The other parameters, such as primary beam energy and target thicknesses, were adopted without correction.

The production cross sections of ^{52g}Mn were determined using the 935.544-keV γ line (I_γ = 94.5%), following a cooling time of 1.8 d. The short-lived isomer ^{52m}Mn ($T_{1/2}$ = 21.1 min) decayed to ^{52g}Mn via isomeric transition, with a branching ratio of 1.78%. Consequently, the derived cross sections were cumulative. Our result was consistent with the recent studies while slightly smaller than the others (Fig. 1). The predicted values in the TENDL-2019 library[8] are larger than the experimental data at the peak between 15–20 MeV.

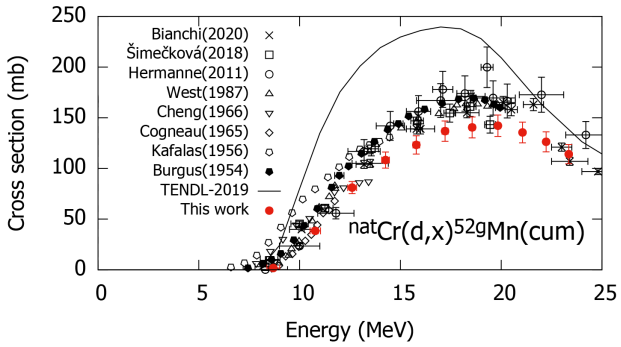

Fig. 1. Cumulative cross sections of the ^{nat}Cr$(d,x)^{52g}$Mn reaction compared with those in previous studies found in the EXFOR library[7] and the TENDL-2019 values.[8]

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