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

H. Huang,[*1,*2] M. Aikawa,[*1,*2,*3] and H. Haba[*2]

^{51}Cr ($T_{1/2}$ = 27.8 d) decays through electron capture. It has been used to label the ethylenediaminetetraacetic acid (^{51}Cr-EDTA), whose blood clearance counting responds to the glomerular filtration rate.[1] It has also been used to label red blood cells as a tracer for measuring the of mass and volume of living systems.[2] This medical radionuclide is expected to be produced via charged-particle-induced reactions on neighbor elements. In this research, we focused on the proton-induced reaction on manganese. Manganese has only one stable isotope: ^{55}Mn. We found four former experimental data on the cross sections of the ^{55}Mn$(p,x)^{51}$Cr reaction in the literature survey.[3–6] However, they are scattered and not consistent with each other. Therefore, we performed an experiment to measure the cross sections of this reaction.

We conducted the experiment using a 30-MeV proton beam at the AVF cyclotron at RIKEN. We adopted the well-established stacked-foil activation technique, followed by high-resolution gamma-ray spectrometry to determine the excitation functions. The target consisted of manganin (Nilaco Corp., Japan), ^{nat}Ti (99.6% purity, Nilaco Corp., Japan) and ^{27}Al (>99% purity, Nilaco Corp., Japan) foils. Manganin is an alloy consisting of copper, manganese, and nickel. We analyzed the elemental ratio of the manganin foil using scanning electron microscopy with energy dispersive spectroscopy (Hitachi TM4000 Plus II). The measured mass ratios were 12.5%, 85.2% and 2.24% for Mn, Cu and Ni, respectively. 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 collect recoiled products. We measured the weight and size of these foils to obtain their average thicknesses. The foils were then cut into squares of 8 × 8 mm^2 to fit the size of a target holder, which also served as a Faraday cup. Seventeen sets of Mn-Mn-Ti-Ti-Al foils were stacked as the target.

The stacked target was irradiated for 20 min. The average intensity and primary energy of the beam were measured to be 182 nA and 30.1 MeV, respectively. Energy degradation in the stacked target was calculated using the stopping powers obtained using the SRIM code.[7] The gamma-ray spectrometry was performed using a high-purity germanium detector (ORTEC GEM30P4-70) and analyzed using the analysis software (SEIKO EG&G Gamma Studio). We assumed that the recoiled nuclides from the first foils compensate for the loss of the second foils. Only gamma spectra from second manganin and Ti foils were measured, The cooling times were from 18.4 to 52.8 h. The dead time was maintained below 3.6%. The cross sections of the ^{nat}Ti$(p,x)^{48}$V monitor reaction were derived and then compared with the recommended values of IAEA.[8] According to the comparison, the thicknesses of all the foils were corrected by +1%. The other parameters were adopted without any correction.

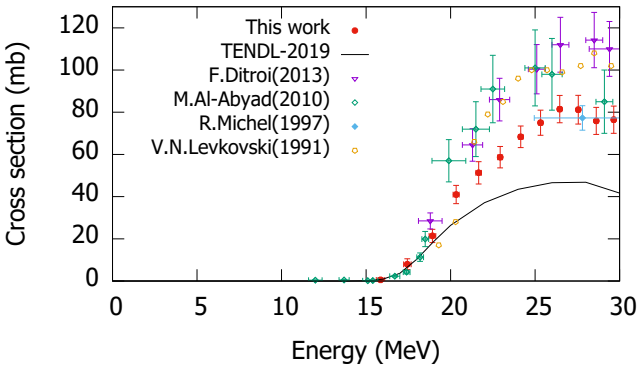

Fig. 1. Cross sections of the ^{55}Mn$(p,x)^{51}$Cr reaction with previous data[3–6] and TENDL-2019 values.[8]

The gamma line emitted from the decay of ^{51}Cr with an energy of 320.08 keV (I_γ = 9.91%) was measured to derive the cross sections of the ^{55}Mn$(p,x)^{51}$Cr reaction. We compared our data with previous experimental studies[3–6] and the theoretical values of TENDL-2019[9] in Fig. 1. Our data had fewer total uncertainties than former studies because the partial uncertainties of target thickness and beam intensity were smaller. The peak positions of previous experimental data were consistent with ours, whereas the amplitudes of some data were larger. The theoretical values of TENDL-2019 underestimated the experimental data.

*1 Graduate School of Biomedical Science and Engineering, Hokkaido University
*2 RIKEN Nishina Center
*3 Faculty of Science, Hokkaido University

References
1) S. J. Gray *et al.*, J. Clin. Investig. **29**, 1604 (1950).
2) A. A. Chaves *et al.*, Clinics (Sao Paulo) **65**, 607 (2010).
3) F. Ditroi *et al.*, Nucl. Instrum. Methods Phys. Res. B. **308**, 34 (2013).
4) M. Al-Abyad *et al.*, Appl. Radiat. Isot. **68**, 2393 (2010).
5) R. Michel *et al.*, Nucl. Instrum. Methods Phys. Res. B **129**, 153 (1997).
6) V. N. Levkovskii *et al.*, Radiat. Eff. **80**, 223 (1984).
7) J. F. Ziegler *et al.*, SRIM: the Stopping and Range of Ions in Matter (2008), `http://www.srim.org/` .
8) F. Tárkányi *et al.*, IAEA-TECDOC-1211 (2007).
9) A. J. Koning *et al.*, Nucl. Data Sheets **113**, 2841 (2012).