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

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Manganese serves as an important component of ferritic steels and aluminum alloys used in nuclear facilities.[1,2] Investigating its behavior under irradiation holds significant importance. The isotopes produced from manganese irradiated by protons have various applications. For instance, ^{51}Cr ($T_{1/2}$ = 27.7 d) decays via electron capture, emitting 320-keV γ rays, and can be utilized as a medical radioisotope to label red blood cells.[3] Additionally, ^{54}Mn ($T_{1/2}$ = 312.2 d) decays through electron capture, emitting a single γ ray of 834.8 keV, and finds an application as a standard for calibrating γ-ray detectors.[4]

As manganese is a monoisotopic element, cross-section measurements for ^{55}Mn do not require additional isotope enrichment. In this work, we measured the proton-induced reactions on ^{55}Mn up to 30 MeV, comparing our findings with previous studies in the EXFOR library[5] and those predicted by the TALYS model available in the TENDL-2021 library.[6]

We adopted the well-established stacked-foil activation technique and high-resolution γ-ray spectrometry for this study. The stacked target comprised foils of natural titanium, natural aluminum, and manganin alloy. All folis were bought from Nilaco Corp., Japan. The manganin consists of manganese, copper, and nickel. The elemental composition ratios (Mn 12.5%, Cu 85.2%, Ni 2.2%) were analysed by a scanning electron microscope with an energy dispersive X-ray spectrometer (Hitachi TM4000 Plus II). ^{nat}Ti foils (99.6% purity) were employed for the ^{nat}Ti$(p,x)^{48}$V monitor reaction. ^{27}Al foils (99% purity) were interleaved to collect recoiled products. The target comprises seventeen sets of Mn-Mn-Ti-Ti-Al foils. The loss recoiled from the second foils was assumed to be compensated by that from the first foils. Only γ spectra from every second Mn and Ti foil were measured.

The thicknesses were derived from the average weight and size of the original foils. The foils were cut into squares of 8 × 8 mm to fit a target holder. The target holder also served as a Faraday cup. The stacked target was irradiated for 20 min with a 30-MeV proton beam using the AVF cyclotron at RIKEN. The average beam current was 182 nA, with a primary energy of 30.1 ± 0.1 MeV. We calculated the energy degradation within the stacked target using stopping powers obtained via the SRIM code.[7]

The γ rays emitted from the foils were detected in four rounds 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 18.4 h–121 d, and the associated dead time was less than 3.6%.

The cross sections of the ^{nat}Ti$(p,x)^{48}$V monitor reaction were derived and compared with the recommended values of IAEA.[8] According to the comparison, the foil thickness and initial beam energy was corrected by +1% and −0.1 MeV, respectively.

The production cross sections of ^{51}Cr, ^{54}Mn, and ^{52g}Mn, were determined using the 320.0824-keV (I_γ = 9.91%), 834.848-keV (I_γ = 99.976%), and 935.538-keV (I_γ = 94.5%) γ lines, respectively. The derived cross sections of ^{52g}Mn were discarded due to iron contamination unmeasurable in our elemental analysis. Fig. 1 shows our result of ^{54}Mn, compared with the previously published data and the predicted values of TENDL-2021.[6] While some published experimental values align with ours, our result demonstrates strong consistency with the values provided by TENDL-2021.

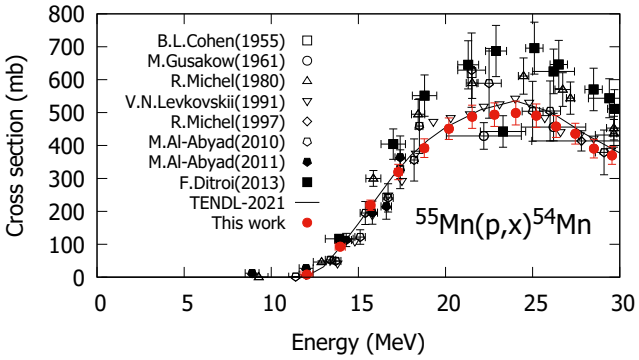

Fig. 1. Cross sections of the ^{55}Mn$(p,x)^{54}$Mn reaction compared with the previous studies found in the EXFOR library[5] and the TENDL-2021 values.[6]

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