Production of ^{45}Ti radioisotope by proton irradiation of natural scandium†

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Radioisotopes of titanium are frequently used in nuclear medicine due to their β^+ radiation and proper gamma emission.[1)] This study is focused on ^{45}Ti ($T_{1/2}$ = 3.08 h) as a promising metallic alternative for radio-labeling various proteins.[2)] Given that the target material is monoisotopic (^{45}Sc), the number of reaction channels and co-produced contaminating radioisotopes is limited, simplifying the result evaluation. Our experiments on scandium were performed in RIKEN, Wako, Japan, and ATOMKI, Debrecen, Hungary. In both locations, the well-established stacked foil technique combined with high-resolution gamma-ray spectrometry was employed. The newly obtained results contribute to clarifying inconsistencies in the literature regarding cross-section data of the proton-induced nuclear reactions for ^{45}Ti production, as well as for the co-produced other radio-isotopes. Comparison of the measured experimental data with the values of the theoretical calculation of nuclear reaction cross systems (TALYS)-based Evaluated Nuclear Data Library (TENDL-2021) online database[3)] supports ongoing improvements in theoretical nuclear reaction models.

Pure metal foils of ^{45}Sc ($0.1\times50\times50$ mm, 99.0% purity, Goodfellow UK), ^{nat}Ti ($0.005\times50\times50$ mm, 99.6% purity, Nilaco Japan and $0.1\times50\times50$ mm, 99.5% purity, Goodfellow UK), ^{nat}Mo ($0.15\times50\times50$ mm, 99.5% purity, Goodfellow UK) and ^{27}Al ($0.05\times300\times300$ mm, >99% purity, Nilaco Japan) were purchased for the two stacked targets. The thin ^{nat}Ti and ^{27}Al foils in the RIKEN experiment were used for the ^{nat}Ti$(p,x)^{48}$V monitor reaction and for recoil catchers, respectively. Mo and thick Ti foils were used both as monitor and catcher foils in the Debrecen experiments. Monitoring was performed using the ^{nat}Ti$(p,x)^{48}$V and the ^{nat}Mo$(p,x)^{96}$Tc on molybdenum. The lateral size and weight of each foil were measured to derive the average thickness. For the RIKEN experiment, the average thicknesses were 30.5 mg/cm^2 for ^{45}Sc, 2.25 mg/cm^2 for ^{nat}Ti, and 13.7 mg/cm^2 for ^{27}Al foils. For the ATOMKI experiment, the thicknesses were 30.95 mg/cm^2 for ^{45}Sc, 4.91 mg/cm^2 for ^{nat}Ti, and 12.24 mg/cm^2 for ^{nat}Mo. The foils were then cut into 10×10 mm pieces to fit into a target holder that also served as a Faraday cup. Twenty sets of Sc-Al-Ti-Ti-Al foils (100 foils in total) were stacked in the target holder at RIKEN. In the ATOMKI experiment, the particular element foils were doubled or tripled after each other to serve as recoil catchers and beam degraders, in addition to cross-section measurements and for monitoring purposes.

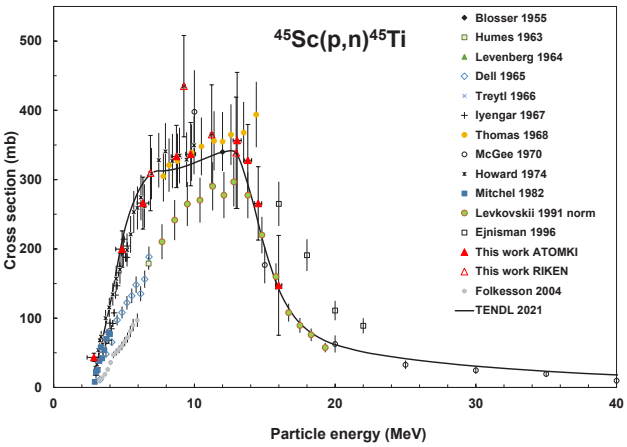

Fig. 1. Excitation function of the ^{45}Sc$(p,n)^{45}$Ti reaction compared with the literature data and the TENDL-2021 prediction.

The stacked target was irradiated with a 30.1 ± 0.1-MeV proton beam for 60 min in RIKEN and 18.0 ± 0.2 MeV proton beam for 60 min in ATOMKI. The initial beam energy was determined by the time-of-flight method in RIKEN and calculated from the cyclotron parameters in ATOMKI. The average beam intensity, based on charge collection by the Faraday-cup, was 203 nA in RIKEN and 120 nA in ATOMKI. Nuclear data for the gamma-ray spectrometry were retrieved from the online database, NuDat 3.0.[4)]

This study determined the activation cross section for the formation of ^{45}Ti. By irradiating Sc foils with proton beams, activation cross sections of ^{45,44}Ti and ^{44m,44g,43}Sc were determined. The cross sections of ^{45}Sc$(p,n)^{45}$Ti reaction have previously been measured by several laboratories. However, collecting the reported data revealed considerable scattered datasets (Fig. 1). Our two sets of results showed good agreement with each other in the overlapping region (except one point) and also with the TENDL-2021 prediction. Up to 4 MeV, almost all previously published results showed good agreement with each other and with the

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TENDL-2021 prediction.

Notably, our data are highly reliable because we used a well-established monitoring reaction. Consequently, our new results allow for assigning varying acceptance levels to the previously presented data.

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