# Production cross sections of $^{47}$Sc via proton-induced reactions on calcium

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Scandium radionuclides can be used for theranostics, a combination of therapeutics and diagnosis.[1)] $^{43}$Sc ($T_{1/2}$ = 3.89 h) and $^{44g}$Sc ($T_{1/2}$ = 3.97 h) are positron emitters that are used in positron emission tomography (PET). $^{47}$Sc ($T_{1/2}$ = 3.35 d) decays with beta particle emissions that can be used for therapy. These radionuclides can be produced via charged-particle-induced reactions on calcium. Only a few experimental studies of each reaction were found with scattered cross sections in a literature survey. Therefore, we performed experiments to measure reliable cross sections of proton-, deuteron-[2)] and alpha-particle-induced reactions on natural calcium.[3)] The abundance of natural calcium is $^{40}$Ca: 96.941%, $^{42}$Ca: 0.647%, $^{43}$Ca: 0.135%, $^{44}$Ca: 2.086%, $^{46}$Ca: 0.004%, and $^{48}$Ca: 0.187%. In this report, we present the preliminary results of the proton-induced reactions on natural calcium for $^{47}$Sc production. $^{47}$Sc can be directly produced in the proton-induced reactions on $^{46,48}$Ca. However, the contribution of the $(p,\gamma)$ reaction on $^{46}$Ca is expected to be negligibly small owing to the extremely low abundance of $^{46}$Ca and tiny cross sections of the $(p,\gamma)$ reaction. Thus, the measured cross sections of the $^{nat}$Ca$(p,x)^{47}$Sc reaction can be converted to those on $^{48}$Ca enriched targets and vice versa.

We performed an experiment using a 30-MeV proton beam at the RIKEN AVF cyclotron. The stacked-foil activation technique and high-resolution gamma-ray spectrometry were employed.

Calcium targets were prepared from a calcium-fluoride ($CaF_2$) layer deposited on a high-purity $^{27}$Al backing foil (99.999% purity, Goodfellow Co. Ltd., UK). Additional foils of $^{nat}$Ti (99.5% purity, Nilaco Corp., Japan) and $^{27}$Al (>99% purity, Nilaco Corp., Japan) were used for the $^{nat}$Ti$(p,x)^{48}$V monitor reaction and beam-energy degradation, respectively. Based on size and weight measurements of each foil, average thicknesses of the $CaF_2$ layer, its $^{27}$Al backing, the $^{27}$Al degrader, and the $^{nat}$Ti monitor foils were derived as 0.148, 5.26, 27.3, and 2.30 mg/cm$^2$, respectively. The foils were then cut into a size of 8 × 8 mm to fit a target holder served as a Faraday cup. Each calcium target was composed of two $CaF_2$ layers sandwiched between the $^{27}$Al backing foils followed by a set of Ti-Ti-Al-Al foils. Eighteen calcium targets were stacked together in the target holder.

The stacked target was irradiated for 60 min with a 30.2 ± 0.1-MeV proton beam. The average beam intensity measured by the Faraday cup was 199 nA. The energy degradation of the beam in the stacked target was calculated using stopping powers derived from the SRIM code.[4)] The irradiated foils without chemical separation were subjected to gamma-ray spectrometry using a high-purity germanium detector. Nuclear data for determining the cross section were obtained from an online database, NuDat 3.0.[5)]

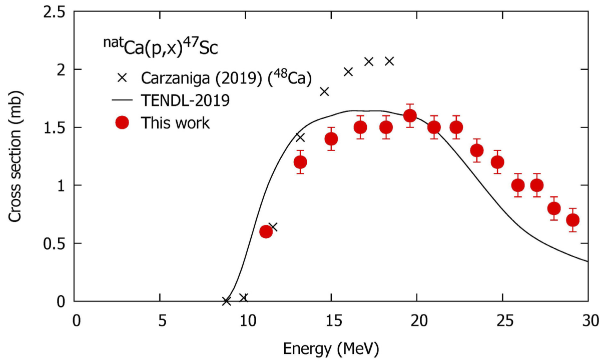


Fig. 1. Excitation function of the $^{nat}$Ca$(p,x)^{47}$Sc reaction in comparison with previously reported experimental data for $^{48}$Ca[3)] normalized to $^{nat}$Ca and TENDL-2019 values.[7)]

We derived cross sections of the $^{nat}$Ca$(p,x)^{47}$Sc reaction using a specific gamma line at 159.381 keV ($I_\gamma$ = 68.3%) emitted after the decay of $^{47}$Sc. The co-produced $^{47}$Ca ($T_{1/2}$ = 4.536 d) can also contribute to the production of $^{47}$Sc. Our preliminary result on $^{47}$Sc including the partial contribution from the $^{47}$Ca decay is shown in Fig. 1 in comparison with previous experimental data[6)] and TENDL-2019 values.[7)] The previously reported experimental data were normalized to those of $^{nat}$Ca for the comparison. Previous data are larger than our data around the peak. The TENDL-2019 values show a peak amplitude that is consistent with our data, while the peak position shifts to the lower energy region.

We continue to analyze the measured spectra in more details and to determine production cross sections of other scandium radioisotopes as well.

This work was partly supported by the Japan-Hungary Research Cooperative Program between JSPS and HAS, Grant number JPJSBP120193808 and NKM-43/2019.

References

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