Activation cross sections of alpha-particle-induced reactions on natural calcium

M. Aikawa,[*1,*2] Y. Hanada,[*3,*2] D. Ichinkhorloo,[*4,*2] H. Haba,[*2] S. Takács,[*5] F. Ditrói,[*5] and Z. Szűcs[*5]

We focused on the production of the therapeutic radionuclide ^{47}Sc ($T_{1/2}$ = 3.3492 d) via alpha-particle-induced reactions on calcium. Owing to the relatively small abundance of ^{46}Ca (0.004%) and ^{48}Ca (0.187%) in natural calcium, the dominant route for ^{47}Sc production is the reaction on ^{44}Ca (2.086%). Only one experimental study was found in a literature survey,[1)] and therefore, we performed an experiment to obtain the cross sections of the ^{nat}Ca$(\alpha, x)^{47}$Sc reaction. The production cross sections of ^{46,44m,44g,43}Sc and ^{47}Ca were also determined.

The experiment was conducted with a 29-MeV alpha-particle beam at the RIKEN AVF cyclotron. Stacked-foil activation technique and high-resolution gamma-ray spectrometry were used in the experiment. Calcium-fluoride (CaF_2) deposited on a high-purity ^{27}Al backing foil (99.999% purity, Goodfellow Co. Ltd., UK) was used as the calcium target. In addition, two metallic foils of ^{nat}Ti (99.5% purity) for the ^{nat}Ti$(\alpha, x)^{51}$Cr monitor reaction and ^{27}Al (>99% purity) to catch recoiled products were purchased from Nilaco Corp., Japan. The measured average thicknesses of the ^{27}Al backing, ^{27}Al catcher and ^{nat}Ti monitor foils were 2.57, 1.50 and 2.30 mg/cm^2, respectively. The thickness of the CaF_2 layer was 0.135 mg/cm^2, as derived from the measured deposited area and net weight of CaF_2. Thickness uncertainties were estimated to be 5% for the CaF_2 layer and 1% for the other foils. All foils were cut into a size of 10 × 10 mm^2 to fit a target holder. Each calcium target consisted of two CaF_2 layers sandwiched with the ^{27}Al backing foils. Twelve calcium targets and seven sets of the ^{nat}Ti monitor and ^{27}Al catcher foils were stacked together in the target holder.

The stacked target was irradiated for 30 min with an alpha-particle beam. The measured average beam intensity and energy were 175 nA and 29.0 ± 0.2 MeV, respectively. The energy degradation in the stacked target was calculated using stopping powers obtained from the SRIM code.[2)]

The high-resolution gamma-ray spectrometry using a high-purity germanium detector was performed without chemical separation. The calcium targets were measured five times with cooling times from 3.2 h to 77.0 d and dead times below 2.1%.

The derived cross sections of the ^{nat}Ti$(\alpha, x)^{51}$Cr monitor reaction were compared with the IAEA recommended values.[3)] The comparison results indicated that the beam intensity and thicknesses of both ^{27}Al backing and catcher foils were corrected within the uncertainties by +5.6% and −1%, respectively. The measured thicknesses of the ^{nat}Ti monitor foil and the CaF_2 layer were adopted without any correction.

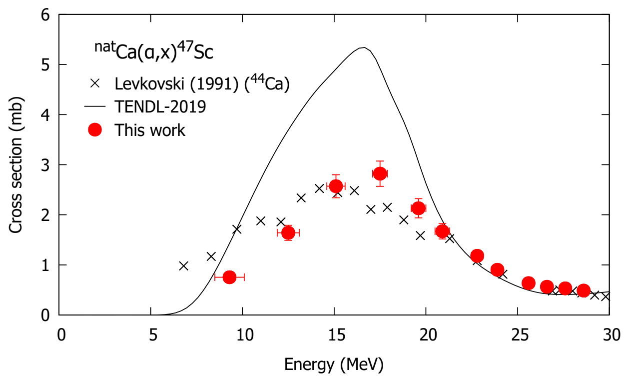

Fig. 1. Excitation function of the ^{nat}Ca$(\alpha, x)^{47}$Sc reaction in comparison with normalized data from the previous study[1)] and TENDL-2019 values.[4)]

^{47}Sc can be produced directly from the ^{44}Ca$(\alpha, p)^{47}$Sc reaction and indirectly from the decay of the co-produced parents, ^{47}Ca and ^{47}K. The indirect contribution was negligible because the co-produced parents can be formed only from the lower-abundant isotopes, ^{46}Ca and ^{48}Ca. The gamma line at 159.381 keV (I_γ = 68.3%) from the ^{47}Sc decay was measured after cooling times of 1.2–2.8 d. The derived cross sections of the ^{nat}Ca$(\alpha, x)^{47}$Sc reaction are shown in Fig. 1 in comparison with the experimental data studied earlier[3)] and the theoretical values provided in the TENDL-2019 library.[4)] The previous data of the ^{44}Ca$(\alpha, x)^{47}$Sc reaction are normalized to those using natural calcium targets. The peak of the previous data shifts to the low-energy region. The TENDL-2019 calculation largely overestimates the excitation function.

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

References

1) V. N. Levkovski, *Cross Sections of Medium Mass Nuclide Activation (A = 40–100) by medium energy protons and alpha particles (E = 10–50 MeV)* (Inter-Vesi, Moscow, USSR, 1991).
2) J. F. Ziegler *et al.*, Nucl. Instrum. Methods Phys. Res. B **268**, 1818 (2010).
3) A. Hermanne *et al.*, Nucl. Data Sheets **148**, 338 (2018).
4) A. J. Koning *et al.*, Nucl. Data Sheets **155**, 1 (2019).

*1 Faculty of Science, Hokkaido University
*2 RIKEN Nishina Center
*3 Graduate School of Biomedical Science and Engineering, Hokkaido University
*4 Nuclear Research Center, National University of Mongolia
*5 Institute for Nuclear Research (ATOMKI)