Prodution cross sections of ^{169}Yb and ^{167,168,170}Tm isotopes in deuteron-induced reactions on ^{169}Tm†

M. Saito,[*1,*2] M. Aikawa,[*1,*2] Y. Komori,[*2] H. Haba,[*2] and S. Takács[*3]

The ^{169}Yb ($T_{1/2}$ = 32.018 d, EC = 100%) radionuclide is an Auger electron and X-ray emitter, making it suitable for brachytherapy.[1,2] Previously measured experimental cross-section data suggest that the deuteron-induced reaction on ^{169}Tm[3–5] is one of the best candidates for the production of high-specific-activity ^{169}Yb owing to the large cross sections of the (d,2n) reaction and 100% natural abundance of the target ^{169}Tm. However, the available experimental cross-section data of the ^{169}Tm(d,2n)^{169}Yb reaction have relatively large uncertainties and are scattered; therefore, the excitation function is not defined properly. We report cross-section data of the ^{169}Tm(d,2n)^{169}Yb reaction using pure, thin metallic thulium foils as the target material to reduce the uncertainty of the experimental data.

The excitation functions of the deuteron-induced reactions on ^{169}Tm were measured by using the stacked-foil activation method and high-resolution γ-ray spectrometry of the irradiated target foils. The ^{169}Tm metallic target foils (purity: 99%, Goodfellow, UK) were stacked with ^{nat}Ti (purity: 99.9%, Goodfellow, UK) and ^{27}Al foils (purity: >99.95%, Nilaco, Japan) for monitoring the beam parameters and for degrading the beam energy. The average thicknesses of Tm, Ti, and Al foils were determined by measuring the surface area and the weight of larger pieces of the foils and were found to be 28.65, 4.95, and 13.44 mg/cm^2, respectively. The irradiation was performed at the AVF cyclotron of the RIKEN RI Beam Factory. The stacked target was irradiated for 75 min with a 24.36-MeV deuteron beam having an average intensity of 135.6 nA, which was measured by a Faraday cup. The incident beam energy was measured by the time-of-flight method using plastic scintillator monitors.[6] The beam-energy degradation in the stacked target was calculated using the SRIM code available online.[7] The γ-ray spectra of the activated foils were measured by HPGe detectors. Nuclear decay data were taken from the online NuDat 2.7 database.[8]

The excitation function of the ^{169}Tm(d,2n)^{169}Yb reaction was derived from the γ-line at 177.21-keV (22.28%), as shown in Fig. 1, together with the previously measured experimental data,[3–5] and the result of the TALYS calculation.[9] Our peak energy is in good agreement with the previous data[3–5] although the cross sections are slightly higher. In addition to ^{169}Yb, we have measured the production cross sections of ^{167,168,170}Tm. The measured data of Tm isotopes are not included in this report owing to the space limitation, but all data are available in Appl. Radiat. Isot. 125, 23 (2017). The present results for the Tm isotope production show good agreements with the previous data in general.

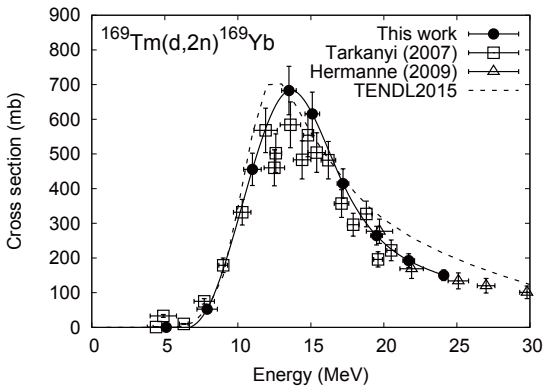

Fig. 1. Excitation function of the ^{169}Tm(d,2n)^{169}Yb reaction. The solid curve shows a spline fit over the experimental data. The result is compared with the previous experimental data[3–5] and TENDL-2015.[9]

In summary, we determined the cross sections of the deuteron-induced reactions on ^{169}Tm to produce ^{169}Yb and ^{167,168,170}Tm by using the stacked-foil activation method and γ-ray spectrometry. The thin metallic Tm foils with Ti and Al foils were irradiated by a 24.36-MeV deuteron beam. The obtained excitation functions were compared with previous experimental data, and good agreements were found in general. The excitation function of the ^{169}Tm(d,p)^{170}Tm reaction is reported for the first time.

References
1) F.H. DeLand *et al.*, J. Nucl. Med. **12**, 683 (1971).
2) G. Lymperopoulou *et al.*, Med. Phys. **33**, 4583 (2006).
3) F. Tárkányi *et al.*, Appl. Radiat. Isot. **65**, 663 (2007).
4) A. Hermanne *et al.*, Nucl. Instrum. Methods B **267**, 727 (2009).
5) A. Hermanne *et al.*, Nucl. Instrum. Methods B **383**, 81 (2016).
6) T. Watanabe *et al.*, Proc. 5th Int. Part. Accel. Conf. (IPAC2014), (2014), p.3566.
7) SRIM: the Stopping and Range of Ions in Matter, `http://www.srim.org/`.
8) National Nuclear Data Center: the NuDat 2 database, `http://www.nndc.bnl.gov/nudat2/`.
9) A. J. Koning *et al.*, Nucl. Data Sheets **113**, 2841 (2012).

† Condensed from the article in Appl. Radiat. Isot. **125**, 23 (2017)

*1 Graduate School of Science, Hokkaido University
*2 RIKEN Nishina Center
*3 MTA ATOMKI, Hungarian Academy of Sciences