Production yields of ^{165}Er and ^{169}Yb via 24-MeV deuteron induced reactions

Y. Shigekawa,[*1] A. Nambu,[*1] Y. Kumakura,[*2] and H. Haba[*1]

The use of Auger electrons for cancer therapy has been widely investigated owing to their higher linear energy transfer than β^- particles. ^{165}Er ($T_{1/2}$ = 10.4 h) and ^{169}Yb ($T_{1/2}$ = 32.0 d), which decay purely via electron capture (EC), are promising candidates for targeted radionuclide therapy using Auger electrons.[1,2] Moreover, the decay of ^{169}Yb accompanies the emission of cascade γ-rays potentially applicable to nuclear-medicine imaging that can prove the local chemical environment.[3] In order to perform nuclear-medicine studies with ^{165}Er and ^{169}Yb, we need to produce >1 GBq of ^{165}Er and >100 MBq of ^{169}Yb and chemically purify them without adding carriers. The production cross sections for these isotopes were reported for the ^{165}Ho$(d,2n)^{165}$Er[4,5] and ^{169}Tm$(d,2n)^{169}$Yb reactions.[6–8] In this study, we confirmed the production yields of ^{165}Er and ^{169}Yb via 24-MeV deuteron induced reactions using thick target foils to determine the irradiation conditions to obtain sufficient radioactivity for nuclear-medicine studies.

We irradiated ^{165}Ho and ^{169}Tm targets with a 23.9-MeV deuteron beam at the RIKEN AVF cyclotron. The ^{165}Ho target consisted of four ^{165}Ho foils (10 × 10 mm, 219.9 mg/cm^2, purity 99.9%) and was irradiated with an average beam intensity of 102 nA for 30 min. The ^{169}Tm target consisted of nine ^{169}Tm foils (8×8 mm, 94.5 mg/cm^2, purity 99%) and was irradiated with an average beam intensity of 105 nA for 3 h. After irradiation, γ-ray spectroscopy was performed using high-purity Ge detectors.

The radioactivity of ^{169}Yb was determined with the γ peaks of 177.2 and 307.7 keV. For ^{165}Er, no-γ rays are emitted; thus, the-X rays of Ho emitted after the EC decay were used to quantify ^{165}Er. The X-rays of Ho (46.7, 47.5, 53.7, 53.9, and 55.3 keV) were observed as three peaks in the γ-ray spectra. The peak corresponding to the 53.7- and 53.9-keV X-rays was useful to quantify ^{165}Er because the other X-rays overlap with the Er X-rays emitted from ^{166}Ho ($T_{1/2} = 26.8$ h) produced in the ^{165}Ho$(d,p)^{166}$Ho reaction. The count rate for the peak of the 53.7- and 53.9-keV X-rays was obtained by fitting a Gaussian function to each dataset. The X-ray count rate as a function of the elapsed time decreased with the half-life of ^{165}Er (10.4 h), meaning that interference from radioactive impurities was negligibly small. To determine the radioactivity of ^{165}Er, the self-absorption of X-rays by the thick Ho foils was corrected using the γ-ray measurements for the two sides of each foil and a database of the X-ray absorption coefficients.[9]

The cross sections of ^{165}Er and ^{169}Yb (Figs. 1 and 2) are almost consistent with those of previous studies.[4–8] The total radioactivity of ^{165}Er at the end of bombardment (EOB) was 19.7(12) MBq, and the impurity was 3.2(3) MBq of ^{166}Ho. The total radioactivity of ^{169}Yb at the EOB was 2.06(3) MBq, and the impurities were 0.071(1) MBq of ^{168}Tm and 0.16(3) MBq of ^{167}Tm. Hence, the thick target yields for ^{165}Er and ^{169}Yb were determined to be 390(24) and 6.58(14) MBq/μAh, respectively. Via irradiation

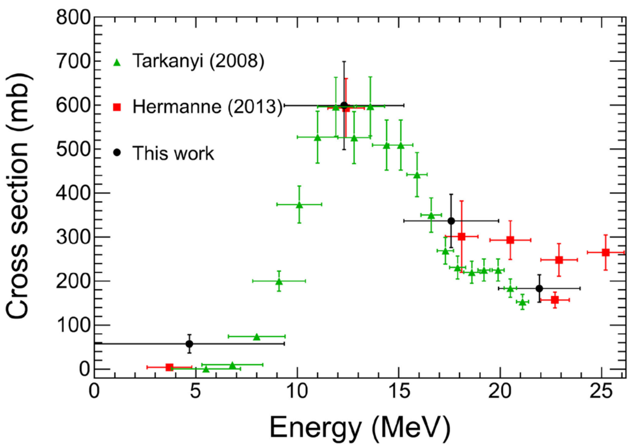

Fig. 1. Excitation function of the ^{165}Ho$(d,2n)^{165}$Er reaction measured in this work. The values measured in previous studies[4,5] are also shown for comparison.

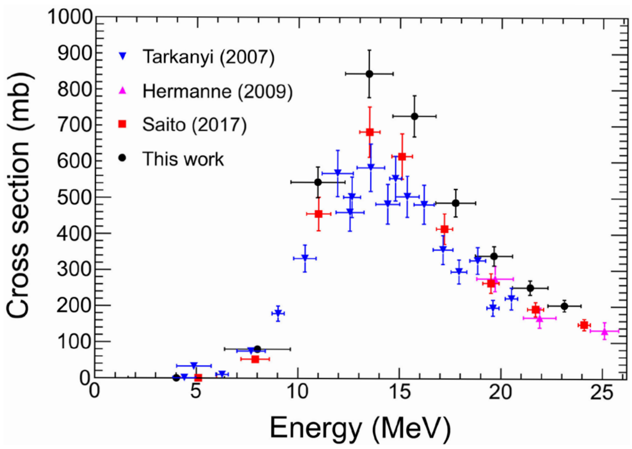

Fig. 2. Excitation function of the ^{169}Tm$(d,2n)^{169}$Yb reaction measured in this work. The values measured in previous studies[6–8] are also shown for comparison.

*1 RIKEN Nishina Center
*2 Faculty of Medicine, Saitama Medical University

with a 5-μA deuteron beam, we will be able to produce 1 GBq of ^{165}Ho in 0.5 h and 100 MBq of ^{169}Yb in 3 h, which are sufficient for nuclear-medicine studies.

References
1) I. D. Silva *et al.*, Molecules **26**, 7513 (2021).
2) S. M. Qaim *et al.*, Radiochim. Acta **95**, 313 (2007).
3) K. Shimazoe *et al.*, Commun. Phys. **5**, 24 (2022).
4) F. Tarkanyi *et al.*, Nucl. Instrum. Methods Phys. Res. B **266**, 3529 (2008).
5) A. Hermanne *et al.*, Nucl. Instrum. Methods Phys. Res. B **311**, 102 (2013).
6) F. Tarkanyi *et al.*, Appl. Radiat. Isot. **65**, 663 (2007).
7) A. Hermanne *et al.*, Nucl. Instrum. Methods Phys. Res. B **267**, 727 (2009).
8) M. Saito *et al.*, Appl. Radiat. Isot. **125**, 23 (2017).
9) M. J. Berger *et al.*, XCOM: Photon Cross Section Database (version 1.5), National Institute of Standards and Technology, Gaithersburg, MD (2010).