Activation cross sections of deuteron-induced reactions on ^{nat}Re

M. Aikawa,[*1,*2] Y. Toyoeda,[*3,*2] G. Damdinsuren,[*4,*2] S. Ebata,[*5,*2] H. Haba,[*2] S. Takács,[*6,*2] F. Ditrói,[*6,*2] and Z. Szücs[*6,*2]

The ground states of ^{186}Re ($T_{1/2}$ = 3.7186 d) and ^{188}Re ($T_{1/2}$ = 17.003 h) decay with the emission of β^- particles and γ rays. Both rhenium radionuclides can be used for theranostics, which combines therapy and diagnosis.[1,2] The radionuclides can be produced through neutron-capture reactions on rhenium and charged-particle-induced reactions on tungsten and rhenium targets. The possible production reactions should be investigated for practical use. In this work, we focused on the deuteron-induced reactions on rhenium. In a literature survey, we found only two experimental studies of cross sections[3,4] and their data were largely scattered. Therefore, we performed an experiment to measure the cross sections of the reactions.

In the experiment a 24-MeV deuteron beam delivered from the RIKEN AVF cyclotron was used to irradiate the stacked target. We adopted well-established methods, such as stacked-foil activation technique and off-line high-resolution γ-ray spectrometry.

The stacked target consisted of thin and pure metallic foils of ^{nat}Re ($0.0125\times50\times50$ mm, 99.98% purity, Goodfellow Co., Ltd., UK) and ^{nat}Ti ($0.005 \times 50 \times 100$ mm, 99.6% purity, Nilaco Corp., Japan). The ^{nat}Ti foils were interleaved for the ^{nat}Ti$(d,x)^{48}$V monitor reaction. The lateral size and weight of each foil were measured. The average thicknesses of the ^{nat}Re and ^{nat}Ti foils were found to be 24.9 and 2.24 mg/cm^2, respectively. The original foils were then cut into a size of 8×8 mm. Sixteen sets of Re-Re-Ti-Ti foils were stacked in a target holder.

The target was irradiated with a 24-MeV deuteron beam for 1 h. The initial beam energy was determined by the time-of-flight method. The average beam intensity determined using the charge collected by the Faraday cup was 105 nA. The beam energy at each foil was calculated using stopping powers derived from the SRIM code.[5]

γ-ray spectra of irradiated foils were measured using a high-purity germanium detector and dedicated software. The associated dead time was less than 4.4%.

Cross sections of the ^{nat}Ti$(d,x)^{48}$V monitor reaction were derived. The cross sections using the measured beam parameters and target thicknesses agreed well with the IAEA recommended values,[6] as shown in Fig. 1. The measured parameters were adopted without any correction to determine cross sections of the reaction on the Re targets.

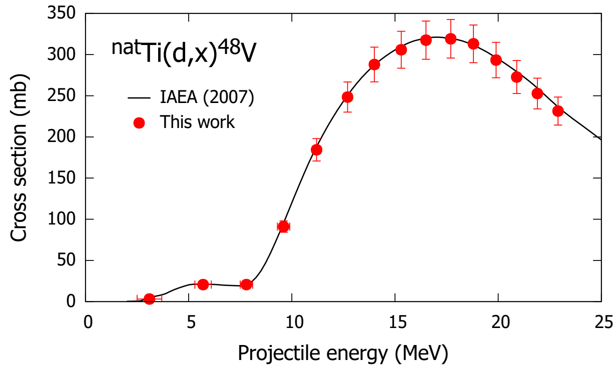

Fig. 1. Cross sections of the ^{nat}Ti$(d,x)^{48}$V monitor reaction with the IAEA recommended values.[7]

The cross sections of the ^{nat}Re$(d,x)^{188g}$Re reaction were determined using the γ line at 155.044 keV (I_γ = 15.49%). The preliminary result is shown in Fig. 2 with the literature data[3,4] and the TENDL-2019 values.[7] The data of Natowitz *et al.*[4] using ^{187}Re enriched targets were normalized to those using ^{nat}Re targets. The normalized data are consistent with our result, while the data by Ditroi *et al.*[3] are higher. The TENDL-2019 values are lower than all experimental data.

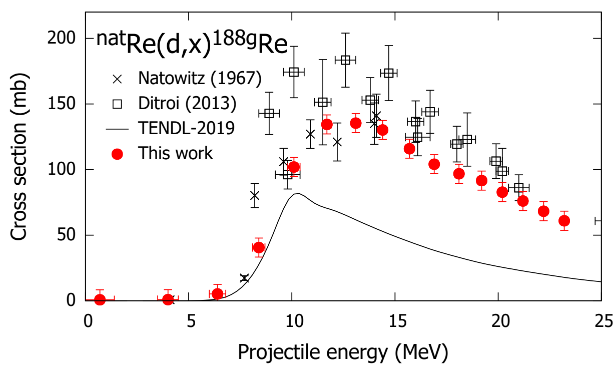

Fig. 2. Measured cross sections of the ^{nat}Re$(d,x)^{188g}$Re reaction with the literature data[3,4] and the TENDL-2021 values.[7] The literature data on enriched ^{187}Re[4] were normalized to those on ^{nat}Re.

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

References
1) A. M. Denis-Bacelar *et al.*, Eur. J. Nucl. Med. Mol. Imaging **44**, 620 (2017).
2) I. G. Finlay *et al.*, Lancet Oncol. **6**, 392 (2005).
3) F. Ditroi *et al.*, Nucl. Instrum. Methods Phys. Res. B **296**, 92 (2013).
4) J. B. Natowitz *et al.*, Phys. Rev. **155**, 1352 (1967).
5) J. F. Ziegler *et al.*, Nucl. Instrum. Methods Phys. Res. B **268**, 1818 (2010).
6) F. Tárkányi *et al.*, IAEA-TECDOC-1211 (2007).
7) A. J. Koning *et al.*, Nucl. Data Sheets **155**, 1 (2019).