Activation cross sections of deuteron-induced reactions on natural rhenium†

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Rhenium radioisotopes are used in diagnosis and therapy in nuclear medicine.[1)] Such rhenium radionuclides can be produced by charged-particle-induced reactions on elements neighboring to rhenium. The best reaction to produce enough amounts of the rhenium radionuclides and suppress co-produced impurities should be found among the reactions. We have already studied the α-particle-induced reactions on natural tungsten.[2)] This study presents the deuteron-induced reactions on natural rhenium. Natural rhenium has two stable isotopes: ^{185}Re (37.40%) and ^{187}Re (62.60%). In a literature survey, it was found that only two experimental studies of the reactions.[3,4)] The literature data are scarce and scattered. Therefore, new experiments to determine reliable cross sections were required.

An experiment was conducted at the RIKEN AVF cyclotron. The stacked-foil activation technique and γ-ray spectrometry were used. The target comprised thin metallic foils of ^{nat}Re and ^{nat}Ti. The measured thicknesses of the ^{nat}Re and ^{nat}Ti foils were 24.9 and 2.24 mg/cm^2, respectively. Sixteen sets of Re-Re-Ti-Ti foils were stacked in a target holder, which also served as a Faraday cup.

The stacked target was irradiated with a deuteron beam for 60 min. The initial beam energy, determined by the time-of-flight method,[5)] was 23.8 MeV. The average beam current, determined by collecting charge on the Faraday cup, was 105 nA. The beam energy degradation in the stacked target was estimated using stopping powers derived from the SRIM code.[6)]

γ rays emitted from the irradiated foils were measured using an HPGe detector. The spectra of every second foil of the same element pair in the stack were measured, while considering compensation for the recoiled reaction products.

Cross sections of the ^{nat}Ti$(d,x)^{48}$V monitor reaction were used to adjust experimental parameters, such as target thicknesses and beam parameters. The derived cross sections for the monitor reaction agreed well with the IAEA recommended values. The measured parameters were adopted without any correction for the following data analysis.

Production cross sections of ^{185,183m,183g}Os and ^{188g,186g,184m,184g,183g}Re were determined in this work. ^{188g}Re ($T_{1/2}$ = 17.003 h) can be formed by the ^{187}Re$(d,p)^{188g}$Re reaction. The γ line at 155 keV (I_γ = 15.49%) was used for cross section determination. The meta-stable state ^{188m}Re ($T_{1/2}$ = 18.59 min) decayed to the ground state (IT 100%) during the cooling time longer than 4 hours. The self-absorption[7)] of the 155-keV γ rays was 1.9%.

Figure 1 shows the cumulative cross sections of the ^{nat}Re$(d,x)^{188g}$Re reaction using the self-absorption-corrected net counts. The result is compared with the literature data[3,4)] and the TENDL-2021 values.[8)] The literature data using ^{187}Re enriched targets[3)] were normalized to those using the ^{nat}Re targets. The renormalized data are consistent with our result. The other data[4)] are larger than ours. The TENDL-2021 values underestimate the experimental data above 12 MeV.

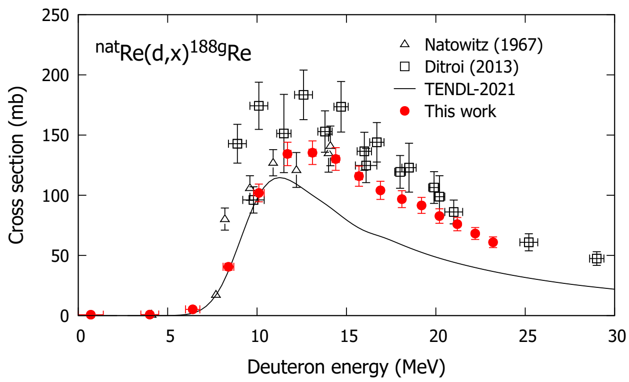

Fig. 1. Cumulative cross sections of the ^{nat}Re$(d,x)^{188g}$Re reaction with the literature data[3,4)] and theoretical calculation in the TENDL-2021 library.[7)]

Activation cross sections of deuteron-induced reactions on natural rhenium were determined up to 23.2 MeV at the RIKEN AVF cyclotron. The results are expected to contribute to nuclear medicine.

References
1) Q. Qi *et al.*, Molecules **28**, 2733 (2023).
2) N. Ukon *et al.*, Nucl. Instrum. Methods Phys. Res. B **539**, 95 (2023).
3) J. B. Natowitz *et al.*, Phys. Rev. **155**, 1352 (1967).
4) F. Ditrói *et al.*, Nucl. Instrum. Methods Phys. Res. B **296**, 92 (2013).
5) T. Watanabe *et al.*, Proc. 5th Int. Part. Accel. Conf. (IPAC2014), (2014), p. 3566.
6) J. F. Ziegler *et al.*, Nucl. Instrum. Methods Phys. Res. B **268**, 1818 (2010).
7) Z. B. Alfassi *et al.*, Appl. Radiat. Isot. **67**, 240 (2009).
8) A. J. Koning *et al.*, Nucl. Data Sheets **155**, 1 (2019).

† Condensed from the article in Nucl. Instrum. Methods Phys. Res. B **543**, 165093 (2023)

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DOI:10.34448/RIKEN.APR.57-015