Activation cross sections of deuteron-induced reactions on natural gadolinium up to 24 MeV[†]

D. Ichinkhorloo,[*1,*2] M. Aikawa,[*1,*3,*4] Ts. Zolbadral,[*2,*3,*4] Y. Komori,[*3] and H. Haba[*3]

Terbium (Tb) and gadolinium (Gd) radionuclides can be used for medical applications. For example, ^{161}Tb ($T_{1/2} = 6.89$ d) can be used for targeted β^- radionuclide therapy.[1)] The production cross sections of the radionuclide are important nuclear data in terms of practical use. The radionuclide can be produced via charged-particle-induced reactions on ^{nat}Gd, of which can yield the compositions as follows: ^{152}Gd (0.2%), ^{154}Gd (2.2%), ^{155}Gd (14.8%), ^{156}Gd (20.5%), ^{157}Gd (15.7%), ^{158}Gd (24.8%), and ^{160}Gd (21.8%). In this study, we focused on the deuteron-induced reactions on ^{nat}Gd. In the literature survey, only two experimental studies of the cross sections were found.[2,3)] However, the experimental data show a discrepancy between them. Therefore, we performed to measure cross sections of the deuteron-induced reaction on ^{nat}Gd. The result was compared with the literature data[2,3)] and the TENDL-2021 values.[4)]

The experiment to determine the activation cross sections was conducted at the RIKEN AVF cyclotron. The stacked-foil activation technique and the high-resolution γ-ray spectrometry were adopted. The stacked target comprised foils cut from ^{nat}Gd ($0.025 \times 50 \times 100$ mm, 99.9% purity, Nilaco Corp., Japan) and ^{nat}Ti foils ($0.005 \times 50 \times 100$ mm, 99.6% purity, Nilaco Corp., Japan). The thicknesses of the ^{nat}Gd and ^{nat}Ti foils were derived from the measured size and weight and found to be 25.3 and 2.34 mg/cm^2, respectively. ^{nat}Ti foils were used for the ^{nat}Ti$(d,x)^{48}$V monitor reaction to assess the beam parameters and target thicknesses. The foils were cut into a size of 8×8 mm and stacked into a target holder that served as a Faraday cup.

The stacked target was irradiated with a deuteron beam for 60 min. The average beam intensity measured by the Faraday cup was 98.1 nA. The beam energy measured by the time-of-flight method[5)] was 24.1 MeV. Further, the energy degradation in the stacked target was calculated using the target thicknesses and stopping powers derived from the SRIM code.[6)]

The γ rays emitted from each irradiated foil were measured using a high-resolution HPGe detector (ORTEC GMX30P4-70) and the dedicated software (SEIKO EG&G Gamma Studio). The spectra of each foil were measured four times with different cooling time and distance. The associated dead time was less than 6.3%. Comparisons indicated that the beam intensity was corrected by +6.5% within its uncertainty (7%).

† Condensed from the article in Nucl. Instrum. Methods Phys. Res. B **536**, 30 (2023)

*1 Faculty of Science, Hokkaido University
*2 Nuclear Research Center, National University of Mongolia
*3 RIKEN Nishina Center
*4 Graduate School of Biomedical Science and Engineering, Hokkaido University

The cross sections of the ^{nat}Ti$(d,x)^{48}$V monitor reaction, beam energy and measured foil thicknesses were adopted without any correction. The cross sections using the corrected parameters were consistent with the recommended values.

The cross sections of the ^{nat}Gd$(d,x)^{161}$Tb reaction were derived using the γ line at 74.57 keV ($I_\gamma = 10.2\%$). The self-absorption of the low-energy γ line in each ^{nat}Gd foil was estimated as 9.5%. The measurements were performed following a cooling time of 39–42 d. The co-produced parent ^{161}Gd ($T_{1/2} = 3.66$ min) decayed during the cooling time.

The cumulative cross sections are shown in Fig. 1 with the literature data[2,3)] and the TENDL-2021 values.[5)] Both experimental data were consistent our data below 12 MeV with deviations observed above 12 MeV. The TENDL-2021 values were smaller than the experimental data.

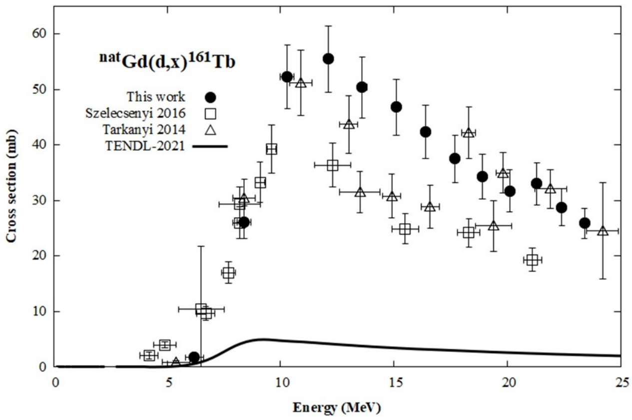

Fig. 1. Excitation function of the ^{nat}Gd$(d,x)^{161}$Tb reaction with the previous data[2,3)] and the TENDL-2021 data.[4)]

In addition to ^{161}Tb, we also determined the production cross sections of $^{153,\,154m1,\,154m2,\,155,\,156,\,160}$Tb and $^{153,\,159}$Gd. The cross sections are almost consistent with the experimental data studied earlier. The results are expected to contribute to development of theoretical model calculation and nuclear medicine.

References

1) C. Müller *et al.*, J. Nucl. Med. **53**, 1951 (2012).
2) F. Szelecsényi *et al.*, J. Radioanal. Nucl. Chem. **307**, 1877 (2016).
3) F. Tárkányi *et al.*, Appl. Radiat. Isot. **83**, 25 (2014).
4) A. J. Koning *et al.*, Nucl. Data Sheets **155**, 1 (2019).
5) T. Watanabe *et al.*, Proc. 5th Int. Part. Accel. Conf. (IPAC 2014) (2014), p. 3566.
6) J. F. Ziegler *et al.*, SRIM: the Stopping and Range of Ions in Matter, `http://www.srim.org`.
7) A. Hermanne *et al.*, Nucl. Data Sheets. **148**, 338 (2018).