Cross sections of ^{155}Tb and ^{156}Tb via α-particle induced reactions on ^{nart}Eu

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^{155}Tb ($T_{1/2}$ = 5.32 d, EC = 100%), which emits low-energy γ rays (87 and 105 keV), is expected to be useful for single photon emission computed tomography (SPECT), which will be combined with cancer therapies by the radioisotopes of rare-earth elements (*e.g.*, ^{177}Lu, ^{149}Tb, and ^{161}Tb).[1)] Moreover, ^{155}Tb is expected to be applicable to imaging using cascade γ rays that can prove the local chemical environment.[2)] In previous studies, ^{155}Tb has been produced through proton-induced spallation followed by on-line mass separation at CERN[3)] and proton-induced reactions on ^{155}Gd and ^{156}Gd targets.[1)] The latter method can be adopted at small cyclotrons; however, there are certain problems such as chemical separation of ^{155}Tb from a bulk amount of the Gd target being challenging and the enrichment levels of the normally available ^{155}Gd and ^{156}Gd not being very high (∼93%), which limited the radionuclidic purity of ^{155}Tb to ∼93%.[1)] To overcome these problems, we aim to produce ^{155}Tb through ^{153}Eu$(\alpha, 2n)^{155}$Tb reaction. The advantage of this method is that the chemical separation of ^{155}Tb from Eu is considerably easier than that from Gd because Eu can be reduced from 3+ to 2+ in aqueous conditions.[4)] Moreover, ^{153}Eu with an enrichment level of >99% is commercially available, potentially improving the radionuclidic purity. The primary radionuclidic impurity in this method would be ^{156}Tb ($T_{1/2}$ = 5.35 d) produced in the ^{153}Eu$(\alpha, n)^{156}$Tb reaction. In this study, we measured the production cross sections of ^{155}Tb and ^{156}Tb via the α-particle induced reactions on $^{\rm nart}$Eu, which have never been reported thus far.

We prepared 16 pieces of ^{nat}Eu targets (^{153}Eu 52%, ^{151}Eu 48%; 0.60–0.85 mg/cm^2) on thin ^{27}Al foils (Al$_{\rm a}$, 2.95 mg/cm^2, 99.999% purity) using the electrodeposition method. Before the deposition, we added an ^{88}Y tracer to the ^{nat}Eu solution to monitor the deposition yields and determine the thickness of each ^{nat}Eu target. We used ^{nat}Ti foils (2.35-mg/cm^2, 99.6% purity) for the ^{nat}Ti$(\alpha, x)^{51}$Cr monitor reaction and thick ^{27}Al foils (Al$_{\rm b}$, 13.13 mg/cm^2, >99% purity) as energy degraders. We stacked 5 sets of Al$_{\rm a}$Eu-Al$_{\rm a}$Ti-Ti-Al$_{\rm b}$ and 11 sets of Al$_{\rm a}$Eu-Al$_{\rm a}$Ti-Ti onto a target holder. We irradiated the target with an α-particle beam of 50.9(1) MeV at the RIKEN AVF cyclotron. The average beam current was 100 particle nA, and the irradiation time was 1 hour. Following irradiation, γ-ray spectroscopy of each foil was performed using high-purity Ge detectors. The cross sections of ^{51}Cr, ^{155}Tb, and ^{156}Tb were determined from the γ rays of 320, 105, and 534 keV, respectively. The energy degradation of the beam was calculated using the stopping powers from the SRIM code.[5)] Here, we assumed the chemical composition of ^{nat}Eu to be Eu(OH)$_3$ among the probable compositions (Eu$_2$O$_3$, Eu(OH)$_3$ or Eu(NO)$_3$) This is because the SEM-EDX measurements of an Eu-deposited sample exhibited an atom ratio of Eu:O = 1:3.1(4), whereas the X-ray peak of N was not clearly observed.

The cross sections of the ^{nat}Ti$(\alpha, x)^{51}$Cr reaction are shown in Fig. 1 with the IAEA recommended values.[6)] For the best agreement between the measured and recommended values, we corrected the thickness of the Ala foils and the beam current within their uncertainties (3% and 7%, respectively). The cross sections for the ^{153}Eu$(\alpha, 2n)^{155}$Tb and ^{153}Eu$(\alpha, n)^{156}$Tb reactions are shown in Figs. 2(a) and 2(b), respectively, with the TENDL-2019 values.[7)] The peak height of the measured cross sections for ^{155}Tb is similar to

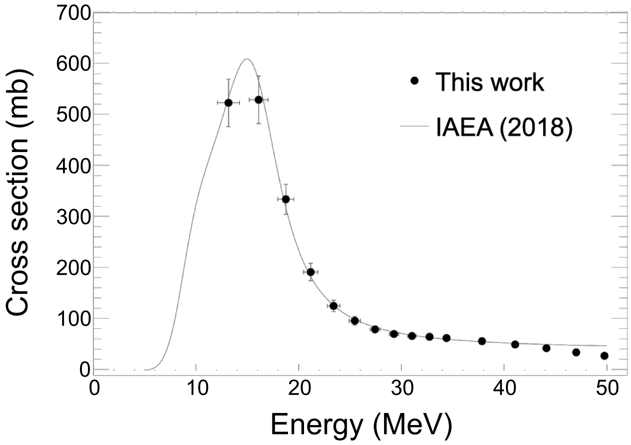

Fig. 1. Cross sections of the ^{nat}Ti$(\alpha, x)^{51}$Cr monitor reaction along with the IAEA recommended values.[6)]

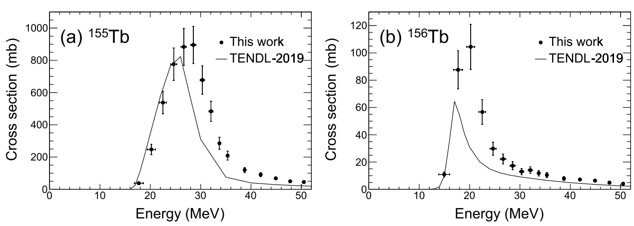

Fig. 2. Measured cross sections of the (a) ^{153}Eu$(\alpha, 2n)^{155}$Tb and (b) ^{153}Eu$(\alpha, n)^{156}$Tb reactions in comparison with the TENDL-2019 values.[7)]

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the TENDL-2019 values, whereas the peak position is slightly larger. The cross sections measured for ^{156}Tb were clearly higher than the TENDL-2019 values. The maximum cross section of ^{155}Tb is 900(120) mb at 28.5(5) MeV, which is sufficiently high for the large-scale production. If we irradiate an ^{153}Eu$_2$O$_3$ target (35-mg/cm^2) with a 30-MeV α beam (energy in the target: 26.3–30.0 MeV), which is less than the threshold of the production of ^{153}Tb ($T_{1/2}$ = 2.34 d), the production yield of ^{155}Tb is estimated to be 3.2(4) MBq/particle μAh and the radioactivity ratio of ^{156}Tb to ^{155}Tb is $\sim$2%, which is better than the case for the Gd targets ($\sim$7%).[1] If we use 90 mg/cm^2 of the ^{153}Eu$_2$O$_3$ target, the yield of ^{155}Tb can be increased to 6.2(8) MBq/particle μAh, although the ratio of ^{156}Tb to ^{155}Tb is increased to $\sim$7%.

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