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Excitation functions of deuteron-induced nuclear reactions on erbium in the energy range of 4–24 MeV

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ABSTRACT

Excitation functions for the $^{nat}Er(d,x)^{163,165,166,167,168,170}Tm$ and $^{nat}Er(d,x)^{171}Er$ nuclear reactions were measured from the respective thresholds up to 24 MeV by using a stacked-foil activation technique combined with HPGe γ-ray spectrometry. Measured data show a partial agreement when compared with the available literature data, theoretical data extracted from the TENDL-2019 library, and predicted data by the model code EMPIRE-3.2.2. Estimated physical thick target yields of the reaction products show close values to the directly measured ones available in the literature. The deduced yield curves indicate that a typical irradiation (E_d = 15 MeV, I_d = 100 μA, t_{irr} = 72 h) of enriched ^{167}Er target by a low energy deuteron cyclotron is suitable to obtain more than a hundred GBq activity of ^{167}Tm with negligible impurity from ^{168}Tm. Measured data of $^{170}Er(d,p)^{171}Er$ reaction have great significance to improve the predicting capability of the model code.

1. Introduction

Currently, radionuclides find wide applications in various fields such as medicine, industry, and agriculture [1–3]. The production of radionuclides is performed via a number of processes, mostly by the use of particle accelerators and nuclear reactors. However, the production of radionuclides via the former process is still not well practiced. The nuclear reaction cross-sections play a key role in the optimization of production parameters for radionuclides of interest via the use of particle accelerators.

The present study concerns the measurement of production cross-sections of residual radionuclides via deuteron irradiation on natural erbium target in the energy range of 4–24 MeV. It is worth mentioning that erbium already has principal uses as a neutron-absorbing control rod in nuclear technology [4]. However, this rare earth metal can also be used as a potential material for the production of some medically important thulium and erbium radionuclides. For instance, among the several medically important lanthanide radionuclides, ^{167}Tm is largely used as a tracer for tumor and bone studies by using both the Anger/gamma camera and the rectilinear scanner [5–13]. Furthermore, its relatively long half-life ($T_{1/2}$ = 9.25 d) and emission of a low energy γ-ray (E_γ = 207.801 keV, I_γ = 42%) and Auger electrons (Auger L = 5.5 keV, 114%) make it suitable for applications in radiotherapy [14–16]. On the other hand, the suitable decay characteristics of ^{165}Er ($T_{1/2}$ = 10.36 h; EC + β^+ = 100%; 5.33 keV L-Auger line (65.6%)) without any accompanying gamma radiation make it promising for Auger-electron therapy [17]. The most convenient method for the direct production of ^{165}Er is the thermal neutron capture $^{164}Er(n,\gamma)$ reaction, but this results in a carrier-added and low specific activity ^{165}Er product. The use of $^{nat}Er(d,xn)^{165}Tm \rightarrow {}^{165}Er$ generator (indirect process) may be a suitable alternative to obtain high specific activity ^{165}Er. Therefore, the cross-section of ^{165}Tm is important due to its possible applications as a precursor for ^{165}Er production. Additionally, another erbium radionuclide, ^{171}Er ($T_{1/2}$ = 7.516 h; E_γ = 308.291 keV, I_γ = 64%) finds remarkable applications for the development and evaluation of pharmaceutical drug delivery systems via the well-known gamma scintigraphic technique [18–20]. The measured cross-sections for ^{171}Er also have great significance as a short-lived parent for producing medically important long-lived daughter ^{171}Tm ($T_{1/2}$ = 1.92 y) via the $^{170}Er(d,p)$ $^{171}Er \rightarrow {}^{171}Tm$ process.

It is important to note that considering the common drawbacks of the reactor production route (carrier added and low specific activity production), several authors [10,21–29] studied the production possibility of thulium and erbium radionuclides via light-charged particle-

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