Measurement and estimation of 14.77 MeV neutron induced nuclear reactions for Gadolinium and Erbium isotopes

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Introduction

The EXFOR database does not contain cross-sectional data for numerous neutron-induced reactions involving rare earth elements. The reaction cross sections are important for nuclear physics studies. Gadolinium has six stable isotopes ^{154}Gd,^{155}Gd, ^{156}Gd, ^{157}Gd, ^{158}Gd and ^{160}Gd and erbium too has six stable isotopes ^{162}Er, ^{164}Er, ^{166}Er, ^{167}Er, ^{168}Er and ^{170}Er. The ^{162}Er nuclei studied in this work is a p-nuclei, which is important for nuclear astrophysics. The ^{159}Gd isotope has importance in nuclear medical physics such as radio-imaging.

In the present work, we have reported the cross section of ^{160}Gd(n,2n)^{159}Gd, ^{162}Er(n,2n)^{161}Er and ^{167}Er(n,p)^{167}Ho nuclear reactions induced by 14.77 MeV energy neutrons. The measured cross sections are compared with the available literature data and evaluated data. The theoretical model calculations are performed with TALYS 1.96 nuclear code. The cross sections are calculated by optimizing various models available in the code and the parameters which reproduced the experimental cross sections are reported.

Experimental Details

The samples were created by using pure Gd_2O_3 and Er_2O_3 powders, each with a purity of 99.99%. In the preparation of each sample, precisely 1 gram of powder was measured with a microbalance that offered an accuracy of 10 micrograms. This powder was then enveloped in a polyethylene sheet, shaping it into a cuboid measuring 1x1 cm. The samples were then covered in Al foil weighing 0.3 g for monitoring the neutron flux. The irradiations with 14.77 MeV neutrons were performed at the 14 MeV neutron generator in the Department of Physics at Savitribai Phule Pune University, Pune, India. The neutron generator typically yields a flux of approximately ~10^8 n/cm^2-s. During these irradiations, the samples were maintained at an angle of 0^o degrees in relation to the incident deuterium ion beam.

Following the respective irradiations, the samples were transferred to the gamma spectrometry lab for assessing the induced radioactivity. To diminish the activity of short-lived isotopes, a cooling period was observed. Gamma spectrometry was performed using a pre-calibrated p-type HPGe detector, enclosed in a lead shielding. This detector has an energy resolution of 1.5 keV at the 1.33 MeV gamma peak and a relative efficiency of 30%. **Table 1** provides comprehensive information on the experimental data, including the threshold energy for the reactions. For our study, we extracted nuclear spectroscopic data for the relevant isotopes from the ENSDF library, as described in Table 2.

Table 1. Experimental details:

Reaction	t_1	t_2	t_3	E_{th}
^{160}Gd(n,2n)^{159}Gd	3600	8100	5400	7.49
^{162}Er(n,2n)^{161}Er	3600	660	7200	9.26
^{167}Er(n,p)^{167}Ho	3600	660	7200	0.288

Table 2. Nuclear spectroscopic data:

Nuclide	$T_{1/2}$	Decay	Eγ (keV)
^{159}Gd	18.4 h	β- (100 %)	363.5 (11.78%)
^{161}Er	3.2 h	ec β+ (100 %)	826.6 (64%)
^{167}Ho	3.1 h	β- (100 %)	346.5 (57%)
^{24}Na	14.9 h	β- (100 %)	1368.6 (99.99%)

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Data Analysis:

The observed activity within the samples was adjusted to account for self-absorption and the true coincidence summing effect. We computed a total correction factor, F_S, by multiplying these two correction factors together.

The neutron induced cross-sections of the reactions was measured using the activation Eq. (1):

$$\sigma_s = \sigma_m \frac{F_S C_S M_m a_m A_S \epsilon_m I_{\gamma m} f_{\lambda S}}{F_m C_m M_S a_S A_m \epsilon_S I_{\gamma S} f_{\lambda m}} \qquad (1)$$

Where, the subscript S and m corresponds to parameters belonging to sample and monitor reaction of aluminum respectively. σ is the reaction cross-section for a nuclear reaction, F is total correction factor for activity induced, C is counts under gamma peak, M is the mass of the samples, a is isotopic abundance, A is atomic mass, ε is detector efficiency at corresponding energies, I_γ is gamma peak intensity and f_λ is timing factor given in Eq. (2).

$$f_\lambda = \frac{\lambda}{(1-e^{-\lambda t_1})e^{-\lambda t_2}(1-e^{-\lambda t_3})} \qquad (2)$$

Where, λ is the decay constant, t_1, t_2 and t_3 are the irradiation, cooling and counting time respectively used for the samples. The uncertainty in the measurements was determined by standard error propagation.

Nuclear Model Calculations

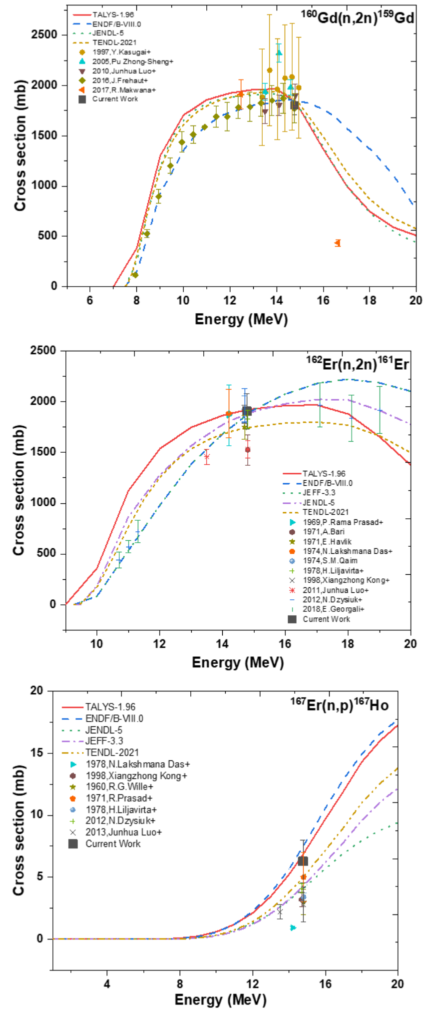
The optimized TALYS 1.96 curve for neutron induced reactions was calculated using Hauser-Feshbach mechanism with level density from Goriely's tables, analytical transition rates in the two-component exciton model for calculating pre-equilibrium contribution, Generalized Lorentzian of Kopecky and Uhl for gamma strength function and the nucleon-nucleus optical model potentials given by KD globalOMP model.

Results And Discussion

The cross section for the $^{160}Gd(n,2n)^{159}Gd$, $^{162}Er(n,2n)^{161}Er$ and $^{167}Er(n,p)^{167}Ho$ reactions are measured at 14.77 MeV energy neutrons. The results are compared with the available literature data from the EXFOR database, the evaluated nuclear data libraries ENDF/B.-VIII.0, JEFF-3.3, JENDL-5 and TENDL-2021 and theoretical calculations performed with TALYS 1.96 code.

Table 3: Measured reaction cross sections

Reaction	Measured (mb)	Talys
$^{160}Gd(n,2n)^{159}Gd$	1803.78 ± 92.14	1837.61
$^{162}Er(n,2n)^{161}Er$	1906.38 ± 177.35	1920.83
$^{167}Er(n,p)^{167}Ho$	6.29 ± 1.71	6.83



Figures 1-3 Experimentally measured cross sections compared with evaluated and literature data.

References

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