Measurements of cross section of ^{160}Gd (n,2n)^{159}Gd reaction at energies of 10.72, 14.72 and 18.72 MeV

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Introduction

Neutron induced nuclear reaction cross sections are very important in nuclear reactor technology. Materials which are used in the reactors are under heavy irradiation of neutrons with different energies formed during fission and fusion reactions. Cross section data gives us the information about the probability of the reaction and estimation of reaction products. It is important to have cross section data at all different neutron energies for red waste management and the reactor safety. In addition to this, experimental data are useful to validate the theoretical nuclear reaction models. At higher energies (1 to 20 MeV) data are scarce for many reactions such as ^{160}Gd(n,2n)^{159}Gd and some reactions have no experimental data. Gadolinium(Gd) is a rare earth material which is used in the fission reactor because of very high neutron absorption cross section. Gadolinium as gadolinium nitrate is used as neutron poison in the moderator system for regulating and controlling the power generation of Pressurized Heavy Water Reactors (PHWR) [1]. In the present work cross sections for the reaction ^{160}Gd(n,2n)^{159}Gd have been measured experi-mentally using standard neutron activation analysis (NAA) technique. The cross sections were also calculated and comparted using nuclear modular codes: TALYS-1.8 [2] and EMPIRE-3.2.2 [3].

Experiment and Data analysis

The experiment was done at TIFR-BARC 14UD Pelletron facility, Mumbai, India. Neutrons were generated by ^{7}Li(p,n) reaction and samples were irradiated for production of sufficient activity of the desired isotopes. The energy of the protons was selected 13 MeV, 17 MeV and 21 MeV. After sufficient irradiation of the sample off-line gamma ray spectrometric technique was employed for the measurement of activity of the sample using HPGe detector. Indium foils were used for the neutron flux measurement. The HPGe detector was calibrated using ^{152}Eu multi-gamma ray source at different energies. The efficiency of detector was calculated at desired prominent gamma ray energy of ^{159}Gd by fitting the same data. Data for isotopic abundance, prominent gamma ray energy, half- life of the daughter nucleus, absolute gamma ray emission probability etc. are taken from the IAEA-Nuclear Data Service [4]. The spectroscopic data are given in the Table I.

Threshold Energy (MeV)	Half-life of daughter (hour)	Prominent gamma energy (keV)	I_γ (%)
7.50	18.479	363.543	11.78

Table 1: Spectroscopic data for reaction ^{160}Gd(n,2n)^{159}Gd

The (n,2n) reaction cross section was calculated using the following equation [5]:

$$\phi = \frac{A_\gamma \lambda (t_c/t_r)}{\sigma N I_\gamma \varepsilon (1-e^{-\lambda t_i})(1-e^{-\lambda tc}) e^{-\lambda t_w}} \qquad (1)$$

where,

$A_\gamma =$ number of detected gamma ray counts with the detector (here offline);

$\lambda =$ decay constant of the product nucleus(s^{-1});

t_c = counting time(s);
t_r = real time (clock time) (s);
t_i = irradiation time (s);
t_w = cooling time (s);
N = number of target atoms in the sample;
ϕ = incident neutron flux ($cm^{-2}\ s^{-1}$);
I_γ = absolute gamma ray emission probability (per decay);
ε = absolute efficiency (Full Energy Peak Efficiency) of the detector for the chosen gamma ray.

Neutron flux (ϕ) from monitor reaction was calculated using the same formula (1) for all three energies. ^{7}Li(p,n) reaction generates neutrons of main peak energy as well as low energy. The tailing correction was done to remove the contribution of neutrons generated at the tail region (of low energy) [4]. For the calculation of flux, cross sections data needed for monitor reaction ^{115}In(n,n') at various energies are taken from the EXFOR and ENDF [6 - 7] data libraries of IAEA-Nuclear data center.

Theoretical Calculations

Cross sections were calculated using nuclear reaction model code EMPIRE 3.2.2 [3] and nuclear reaction simulation code TALYS 1.8 [2]. Default values of the parameters were taken for the calculations. The data are compared with present experimental findings as shown in Figure I. Cross sections from EXFOR data library are also plotted for the comparison with the present work [6].

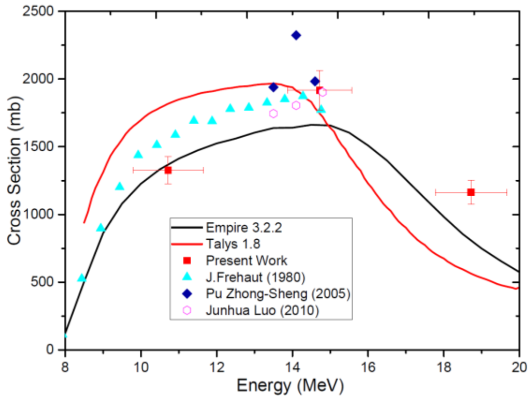

Figure 1: Comparison of present work with TALYS 1.8 [2], EMPIRE 3.2.2 [3] and EXFOR data

Results and Discussions

Cross sections for the reaction ^{160}Gd(n,2n)^{159}Gd at three different energies 10.72$\pm$0.95, 14.72$\pm$0.86 and 18.72$\pm$0.93 were measured experimentally with NAA technique. These measured cross sections are compared with theoretically calculated cross sections by EMPIRE 3.2.2 [3] and TALYS 1.8 [2]. At higher energies, both the theoretical predictions underestimate the present experimental results. The experimental measured cross sections at 10.72 MeV energy agrees with the calculation done with EMPIRE 3.2.2 [3] within experimental error. The present experimental result at 14.72 MeV gives better agreement with the previous EXFOR [6] data.

References

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