Measurement of thermal neutron capture cross sections of $^{139}La(n,\gamma)^{140}La$ and $^{140}Ce(n,\gamma)^{141}Ce$ using Am-Be neutron source

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Introduction

Neutron capture cross sections in thermal and epithermal energies can be measured experimentally by activation method using reactor neutron beam or D-T neutron beam. In the present experiment, an Am-Be neutron source facility is used to measure the thermal capture cross sections of ^{139}La and ^{140}Ce. Both the isotopes are fission products in nuclear reactors. The neutron capture of ^{139}La is used to measure operating power distribution by activation gamma measurements after reactor shutdown. A Cd-cut off method is used to eliminate the contribution from epithermal neutrons. The thermal cross sections were estimated with reference to ^{55}Mn sample.

Materials and methods

La_2O_3 and CeO_2 samples in powder form procured from Star Rare Earth Ltd were used for the thermal capture cross section measurements. The powder samples were made into circular packets of diameter 12 mm. Activation foils of Mn(83%)-Cu having diameter 12 mm procured from Shieldwerx with purity 99.9% were used as reference. The weights of the samples used in the calculations are listed in Table.1. The samples were irradiated with and without Cd cover. This Cd-cut off method is used to subtract the contribution from epithermal neutrons (>0.5eV). All the samples were irradiated at the Am-Be neutron physics laboratory available at Manipal Centre for Natural Sciences. The samples were irradiated in the experimental channel where the thermal neutrons are maximum (≈ 5 ×10^3 n/cm^2/s) for 15-30 days. The induced activity in each foil after irradiation were counted using a well shielded and pre calibrated 30% HPGe (Bruker Baltic) detector having an energy resolution of 0.25% at 1.33MeV. Nuclear data of selected samples are listed in Table 1. The area under each of the gamma peaks (C) of interest are used to estimate the reaction rates using Eq.1

Table.1. Nuclear Data of the selected isotopes

Foil	Half life	Gamma Energy (keV)	Weight (g)
^{55}Mn	2.58 h	846.8	0.05
^{139}La	1.658 d	1596.5	0.5
^{140}Ce	32.58 d	145.5	1.0

$$R = \frac{C\lambda_c}{(1-e^{-\lambda t_{irr}})(e^{-\lambda t_d})(1-e^{-\lambda t_c})}\frac{M}{N_A\theta\varepsilon\gamma m}f \quad (1)$$

where λ is the decay constant in s^{-1},t_{irr} is the irradiation duration, t_d is the delay time, t_c is the counting time, ε is efficiency of the detector, γ is gamma yield, N_A is Avogadro's number, θ is the isotopic abundance, f is the gamma attenuation, m is the weight of the target and M is the atomic mass.

Later, thermal cross section of the sample ($\sigma_{0,S}$) is estimated with respect to the monitor cross section $\sigma_{0,Rf}$ (13.41b) as shown in Eq.2

$$\sigma_{0,S} = \frac{\left(R-\frac{R_{Cd}}{F_{Cd}}\right)_S}{\left(R-\frac{R_{Cd}}{F_{Cd}}\right)_{Rf}}\frac{g_{Rf}}{g_S}\sigma_{0,Rf} \quad (2)$$

Reaction rates with and without Cd cover are represented by R and R_{Cd} respectively and the difference between them corresponds to the reaction rate due to thermal neutrons. The sample and monitor are represented by the subscripts S and Rf respectively. Deviation in the cross section from 1/υ behavior is represented by Westcott g-factor g_{Rf} and g_S. F_{Cd} in Equation (2) is cadmium transmission factor which accounts for the specific count rate

difference due to cadmium cover. The thermal self shielding correction factors for the samples as well as for the reference are 0.99 and hence neglected the same in the present estimation.

Results and Discussions

Thermal neutron capture cross sections of ^{139}La and ^{140}Ce are estimated with respect to that of ^{55}Mn(n,γ)^{56}Mn. The estimated values are 9.27±0.29 and 0.48±0.02 respectively. A comparison of the present studies with respect to few of the previous reported values are given in Table 2 and other evaluated data can be found in Ref [1]. More measurement data are available in EXFOR database [2]. Various parameters affecting the uncertainty of the data are counting statistics (2-5%), detector efficiency (2-4%), sample mass (0.5-1%), nuclear data (cross section (0.1-0.9%) and reference cross section (0.37%)

Table.2: Thermal neutron capture cross sections of ^{139}La and ^{140}Ce .

	Reference	Thermal cross section(b)
^{139}La(n,γ)^{140}La	Present work	9.27±0.29
	Nguyen, V.D[3]	9.16±0.36
	Farina,F et al[4]	9.25±0.04
	Heft, R.E[5]	9.18±0.05
	Mughabghab, S.F [6]	9.04±0.04
	EAF-2010[7]	8.94
^{140}Ce(n,γ)^{141}Ce	Present work	0.48±0.02
	Torrel,S [8]	0.510±0.02
	Heft, R.E[5]	0.582±0.005
	Katcoff,S[9]	0.310±0.07
	Mughabghab, S.F [6]	0.580±0.02
	EAF-2010[7]	0.575

The present results in the case ^{139}La are in good agreement within the uncertainty with various evaluations and experimental measurements [7]. This indicates the accuracy of adopted experimental methodology. As it is evident from Table 2, the reported experimental cross sections of ^{140}Ce have a wide spread between 0.31 -0.58 b. Thermal neutron capture cross section of ^{140}Ce measured in the present work is in agreement with the recently reported data and is within the band mentioned before. However the evaluations which are predated to the recent measurements are different from the current estimate by approximately 17%.

Conclusions

Thermal neutron capture cross sections of ^{139}La(n,γ)^{140}La and ^{140}Ce(n,γ)^{141}Ce are estimated with respect to that of ^{55}Mn(n,γ)^{56}Mn using Cd-cut off method. The measured value for ^{139}La is 9.27±0.29 b and is in agreement within the uncertainty with the evaluated data as well as measurements. Even though, the measured data from the present measurement of ^{140}Ce (0.48±0.02 b) is different from the two evaluations, it is in agreement with the recent measurement of Torrel, 2012 [8]. The above observation suggests the requirement of more measurements for thermal capture cross sections of ^{140}Ce. In addition, requirement of updated evaluations can also be suggested taking into account recently available data including the present measurements.

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