Measurement of ^{76}Se(n,2n)^{75}Se reaction cross section with detailed uncertainty analysis at 14 MeV neutron energy

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Introduction

Selenium (Se) is a grey non-metal found to occur in nature as seven stable isotopes. The isotopic abundance for ^{76}Se is 9.37 ± 0.29 % in a natural Se sample. ^{75}Se decays by electron capture with a half-life 119.78 ± 0.05 days. Weeks et al. [1] explored the use of ^{75}Se as a potential gamma source for brachytherapy. In literature, only a few previous works for ^{76}Se(n,2n)^{75}Se reaction cross section have been reported in the experimental exchange format (EXFOR) database [2]. Only two of the reported experimental measurements were carried out with a high purity germanium (HPGe) detector and the sources of error in the experimental parameters were not adequately reported. In light of the various differences arising in the previous reported data, the re-measurement of ^{76}Se(n,2n)^{75}Se reaction cross section has been carried out in the present work.

Experimental details

Samples of Se (99.99 %) powder of natural isotopic abundance were prepared by packing 2 gm sample in polythene vials. The samples were sandwiched between two aluminium (Al) foils totally 0.285 gm and the sample size was 10 mm × 10 mm with a thickness 1 mm. The samples were irradiated at the 14MeV Neutron Generator facility [3], Department of Physics, Savitribai Phule Pune University, Pune, India. The 14 MeV neutron beam was produced by bombarding 150 ± 1 keV D^+ ions on an 8 Ci TiT (titanium-tritide) solid target. The neutron energy was 14.77 ± 0.17 MeV determined by kinematics at the sample position. The neutron flux during irradiation was found to be 10^8 n/cm^2/s with Al foil activation. After irradiation for an hour, the samples were transferred to the counting room. After a sufficient cooling time, the induced gamma activity of the irradiated samples was measured with a pre-calibrated lead-shielded Ortec HPGe detector having 30% relative efficiency and 1.5 keV energy resolution at 1.33 MeV gamma energy. The decay details used in the data analysis for the present work are provided in Table 1. The irradiation time, cooling time and counting time for the present work are 3690 secs, 83268 secs and 3616 secs respectively.

Table 1: Decay details for sample and reference monitor reactions.

Product Nuclei	Half-life	Eγ (keV)	Iγ (%)
^{75}Se	119.78 ± 0.05 d	136	58.5 ± 0.4
^{24}Na	14.997 ± 0.12 hr	1368.626	99.9936 ± 0.0015

Data analysis

The cross section was determined using the neutron activation equation

$$\sigma_s = \sigma_{Al} \frac{\varepsilon_{Al}\, C_s\, a_{Al}\, A_s\, M_{Al}\, I_{\gamma Al}\, f_{Al}\, F_s}{\varepsilon_s\, C_{Al}\, a_s\, A_{Al}\, M_s\, I_{\gamma s}\, f_s\, F_{Al}} \quad (1)$$

here, the sample reaction parameters and the monitor reaction parameters are referred to with the subscript *s* and *Al* respectively. ε is the detector efficiency, *C* is the photo peak counts, *a* is the isotopic abundance, *A* is the atomic mass, M is the mass, $I\gamma$ is the branching ratio of γ-ray taken from Ref. [4] and *f* is the timing factor. The timing factor *f* is given by

$$f = \frac{\left(1 - e^{-\lambda t_1}\right)\left(e^{-\lambda t_2}\right)\left(1 - e^{-\lambda t_3}\right)}{\lambda} \quad (2)$$

where, λ is the decay constant, t_1 is the irradiation time, t_2 is the cooling time and t_3 is the counting time. The correction factor (*F*) due to the coincidence summing effects (f_c) and the gamma ray self-attenuation (f_a) is given by $F = f_c \times f_a$. The information related to the HPGe detector calibration, detection efficiency curve and

uncertainty, coincidence summing effects and self-attenuation can be found in our previous work [5]. The uncertainty in the detector efficiencies was reduced by adopting $\eta_{Al,s} = \frac{\varepsilon_{Al}}{\varepsilon_s}$ where $\eta_{Al,x}$ is the detection efficiency ratio of monitor product (ε_{Al}) to the sample product (ε_s). The details about total uncertainty propagation can be found in Section 3.3 of Ref. [6]. The partial uncertainties in the parameters of equation 1 is listed in Table 2. The total error (%) is the square root of the quadrature sum of the fractional uncertainties (%).

Table 2: The fractional uncertainties (%) in different parameters.

parameter	fractional uncertainy (%)
C_s	7.4236
C_{Al}	0.8967
$I_{\gamma s}$	0.6838
$I_{\gamma Al}$	0.0015
$\eta_{Al,s}$	1.3771
$f_{\lambda s}$	0.0415
$f_{\lambda Al}$	0.0092
M_s	0.0247
M_{Al}	0.05
a_s	3.0949
σ_{Al}	2.4443
Total	**8.4816**

Results and Discussions

Fig. 1 shows the present result with normalized literature data [2], default statistical model calculations of TALYS-1.96 [7] and EMPIRE [8] nuclear codes. The measured cross section of ^{76}Se(n,2n)^{75}Se reaction was found to be 1.1055 ± 0.0938 barns at 14.77 ± 0.17 MeV neutron energy. The present result is in good agreement with the data reported in Refs. [9,10] within experimental uncertainty and TALYS-1.96 default calculations. The present study lists the various sources of uncertainty and the total uncertainty in the present measurement is 8.5%. The details about uncertainty quantification will be presented during the conference.

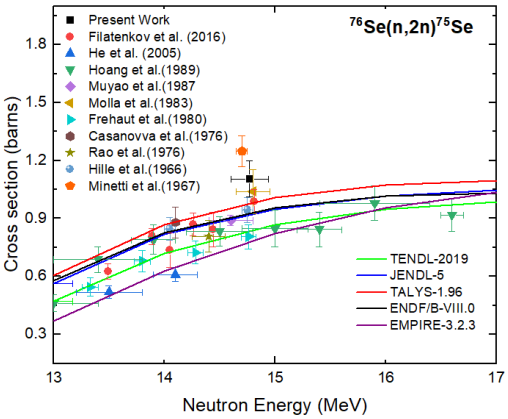

Fig. 1 Experimental result for ^{76}Se(n,2n)^{75}Se reaction.

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