

## Measurement of the $^{115}\text{In}(n, 2n)^{114m}\text{In}$ reaction cross-section using the quasi-monoenergetic neutrons

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### Introduction

Indium (In) is being used over the years for the measurement of the neutron flux for the calculation of nuclear reaction cross-section data as the (n, n') and (n, 2n) reaction cross-sections of the  $^{113}\text{In}$  and  $^{115}\text{In}$  isotopes have significant values from threshold to 25 MeV neutron energies. The In isotopes also serve the purpose for the activation studies and dosimetry applications [1]. It can be seen from the compilation of the EXchange FORmat (EXFOR) [2] data library that, there is a numerous amount of cross-section data available for the  $^{115}\text{In}(n, 2n)^{114m}\text{In}$  reaction from threshold to 20 MeV neutron energies, that have large mutual discrepancies. Therefore, it is crucial to perform precise measurement of the cross-sections for different neutron-induced reactions for the In isotopes. The current work presents the measurement of the (n, 2n) reaction cross-section for the  $^{115}\text{In}$  isotope at average neutron energy of 20.12 MeV using the quasi-monoenergetic neutrons produced from the  $^7\text{Li}(p, n)$  reaction. The above mentioned reaction cross-section was also compared with literature data from taken EXFOR [2], ENDF-B/VIII.1 [3], JENDL-4.0 [4], and the theoretical model code TALYS-1.9 [5]. The different level density models (ld-model 1-6) included in the TALYS-1.9 model code were also tested for the better description

of the present and the literature data.

### Experimental Details

The experiment was performed using the 14UD Pelletron facility at Bhabha Atomic Research Centre-Tata Institute of Fundamental Research (BARC-TIFR) Mumbai, India, using the activation and following the off-line  $\gamma$ -ray spectroscopy. The neutrons of the desired energy were generated using the  $^7\text{Li}(p, n)$  ( $E_{th} = 1.88$  MeV) reaction with a proton beam of 22 MeV. A Lithium (Li) foil of thickness  $\approx 7$  mg/cm<sup>2</sup> was used in between the two Tantalum (Ta) foils of thicknesses  $\approx 3$  mg/cm<sup>2</sup> in front of the Li and  $\approx 0.1$  mm at the back of the Li to stop the proton beam. The In (sample) foil of thickness  $\approx 0.1$  mm was used together with the Aluminum (monitor) foil of similar thickness for the irradiation. The Ta-Li-Ta stack with the sample and monitors wrapped in a thin aluminum foils were then irradiated for about 5-6 hours at the 6 meter port of the main beam line of the Pelletron. The area of both the monitor and the sample foils were taken as  $1 \times 1$  cm<sup>2</sup> in order to avoid the area corrections in flux. After the irradiation, the samples were allowed to cool for a sufficient time to accumulate the high dose of radiation. The sample as well as the monitor were then counted using a pre-calibrated 80 cc single crystal HPGe detector coupled with a PC based 4K multi-channel analyzer. The energy and efficiency calibration of the detector was done by using a standard  $^{152}\text{Eu}$  source. The resolution of the detector system was measured as 1.88 keV during the counting.

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The dead time the detector was kept  $< 2\%$  by placing the samples at an appropriate distance from the detector head.

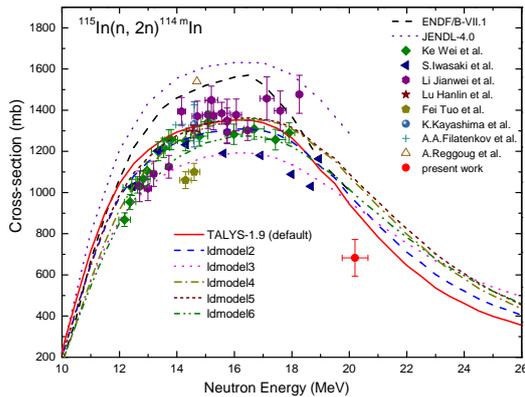


FIG. 1: Comparison of the present result with the literature data and the theoretical predictions using TALYS-1.9 [5] code.

### Data Analysis

A detailed discussion has been given elsewhere [6] for the generation of the neutron spectra using the  ${}^7\text{Li}(p, n){}^7\text{Be}$  reaction. The  ${}^{27}\text{Al}(n, \alpha){}^{24}\text{Na}$  reaction was used to evaluate the neutron flux. The decay statistics of the 1368.68 keV  $\gamma$ -line of the  ${}^{24}\text{Na}$  ( $t_{1/2} = 14.997$  hours) were used for the calculation of the neutron flux using the weighted  ${}^{27}\text{Al}(n, \alpha)$  reaction cross-sections from the ENDF-B/VII.1 [3] evaluated data library. Using the calculated neutron flux, the cross-section for the  ${}^{115}\text{In}(n, 2n)$  reaction has been calculated using the decay statistics ( $C_{obs}$ ) of the 190.27 keV  $\gamma$ -line of the  ${}^{114m}\text{In}$  ( $t_{1/2} = 49.51$  days) in the following relation,

$$\sigma_R = \frac{C_{obs}(C_L/L_T)\lambda(e^{\lambda T_c})}{N_0\epsilon I_\gamma \phi K(1 - e^{-\lambda T_i})(1 - e^{-\lambda T_{LT}})} \quad (1)$$

where all the symbols have their usual meanings. A tailing correction [6] was applied to the measured reaction cross-section to discard the contributions from the lower energy neutrons. The uncertainty in the present measurement was calculated using the error propagation method [7] and was found to be 12.8%.

### Result and Discussion

The cross-section for the  ${}^{115}\text{In}(n, 2n){}^{114m}\text{In}$  reaction at average neutron energy of  $20.12 \pm 0.45$  MeV was measured as  $682.9 \pm 88.4$  (mb). A comparison of the present result with the literature data from the EXFOR [2], theoretical code using the TALYS-1.9 [5] and the evaluated data from the JENDL-4.0 [4] library are plotted in Fig. 1. It can be seen from the figure that the measured cross-section is in agreement with the trend of the literature data. However, the present result shows a value lower than the TALYS-1.9 prediction. The different ldmodels from the TALYS-1.9 were also found to be successful in order to reproduce the reaction cross-section data and were found to fit the literature data to an acceptable degree. On the other hand, the ENDF-B/VII.1 and the JENDL-4.0 evaluated data libraries were also found in agreement with the literature data up to 20 MeV neutron energies.

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