Neutron nuclear data of (n, 2n) reaction for Sb Isotopes

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Introduction

In nuclear physics, nuclear structure and decay data of the different radioisotopes nuclei is widely applicable in the field of nuclear medicine and agriculture. This nuclear reaction data of different nuclei also used for the different theoretical nuclear model calculations [1]. In the present work from Neutron Activation Analysis techniques (NAA) the nuclear reaction ^{123}Sb(n, 2n)^{122}Sb produced ^{122}Sb ($\tau_{1/2} = 2.47\ day$) nuclei and this radionuclei were used for the studies of environmental contamination and food crops. The decommissioning of the light water nuclear reactors, this neutron induced activation reactions cross section data of Sb element is very important. Therefore, it is necessary to measure cross section data on Sb nuclei [2]. Antimony used in semiconductor devices diodes, infrared detectors and antimony alloy with lead to increase the hardness and mechanical strength of lead, this lead Antimony alloy used in the radiation shielding. Natural Antimony used in the startup of neutron source [3]. The γ-rays emitted by Sb-124 initiate the photodisintegration of Be source and this natural Antimony with Beryllium (Sb-Be) source produced monoenergetic neutrons with average energy 24 keV. In commercial nuclear reactors this Sb-Be neutron used as an external neutron source.

Experimental Details

The experiment was performed using 14UD BARC-TIFR Pelletron Linac accelerator facility Mumbai, India. The nuclear reaction ^{7}Li(p, n)^{7}Be was used for the production of the quasi-monoenergetic neutron beam in which protons incident on natural Lithium (Li) foil of thickness 8.0 mg/cm^2 and this lithium foil is sandwiched between the two Tantalum (Ta) foils of different thickness. The front Tantalum foil that is facing the proton beam was the thinnest and have thickness 4 mg/cm^2 the back tantalum foil of thickness 0.1mm was used to stop the proton beam. The Antimony (Sb) sample and flux monitor Aluminium (Al) were irradiated with neutron flux of the order of 10^7 to 10^6 n/cm^2.sec for 4 to 6 hours. The neutron irradiated activated samples emit γ-rays and these γ-rays counted with pre-calibrated 80 cm^3 HPGe detector coupled to a PC based 4096 multi-channel analyzer. The energy and efficiency calibration of the HPGe detector determined using the standard ^{152}Eu source. The energy resolution of the HPGe detector was 1.8 keV at 1408 keV. The neutron flux calculated from ^{27}Al(n, α)^{24}Mg nuclear reaction which used as a flux monitor. The neutron activation cross section calculated from the following equation,

$$\sigma = \frac{A\lambda\left(\frac{C_L}{L_T}\right)}{N\epsilon\varphi I_\gamma\left(1-e^{-\lambda t_{ir}}\right)\left(1-e^{-\lambda t_c}\right)e^{-\lambda t_w}} \qquad (1)$$

Where, A-total area under the gamma peak, λ-decay constant, N-number of target nuclei-$/cm^2$, ϵ-photo-peak efficiency of γ-rays, I_γ γ-ray transition probability, t_w cooling, t_c counting, t_{ir} irradiation time, φ neutron flux C_L and C_T are clock and live time. The necessary spectroscopic data for ^{27}Al(n, α)^{24}Mg, ^{121}Sb(n, 2n)^{120}Sb and ^{123}Sb(n, 2n)^{122}Sb nuclear reactions are given in the table-I.

Theoretical Calculation

The theoretical calculation of the ^{121}Sb(n, 2n)^{120}Sb and ^{123}Sb(n, 2n)^{122}Sb nuclear reaction was performed by the different statistical nuclear model codes Talys-1.9, Alice-2014 and EMPIRE-3.2 [4]. In Talys-1.9 nuclear code [5] different level density model from 1 to 6 are given and this model used for the computation of the reaction cross section. In EMPIRE-3.2 code default level density model used for cross section calculation and in Alice-2014 [8] Kataria-Ramamurty Shell dependent level density model used for reaction cross section calculation. In the present work, the cross section of ^{121}Sb(n, 2n)^{120}Sb and ^{123}Sb(n, 2n)^{122}Sb nuclear reaction measured by NAA techniques. This theoretical estimated data from Talys-1.9, Alice-2014 and EMPIRE-3.2 codes and experimentally measured ^{121}Sb(n, 2n)^{120}Sb and ^{123}Sb (n, 2n)^{122}Sb data in the present work from the equation (1) also compared with the different ENDF/B-VIII.0, JEFF-3.3, JENDL-4.0 and Tendl-2017 evaluated nuclear data library.

TABLE-I Spectroscopic Data of Reaction

Nuclear Reaction	E_{th} MeV	Half-life	E_γ keV	I_γ (%)
^{121}Sb(n,2n)^{120}Sb	9.331	15.89 m	1171.3	1.7
^{123}Sb(n,2n)^{122}Sb	9.033	2.7238 d	564.12	71
^{27}Al (n, α)^{24}Na	3.47	14.99 hours	1368.6	99.9

Results and Discussion

In present work, we have measured cross sections for ^{121}Sb(n, 2n)^{120}Sb and ^{123}Sb(n, 2n)^{122}Sb nuclear reactions using the neutron activation analysis techniques. This measured (n, 2n) cross section data compared with EXFOR [6], ENDF [7] and with different codes calculations. The ^{123}Sb(n, 2n)^{122}Sb nuclear cross section is higher compared to M. Bormann (1968) [6] and matched with the S. K. Ghori EXFOR data (1980) [6] as shown in the fig-1. In low energies region Empire-3.2 default and Talys-1.9 ldmodel 2 gives better agreement with experimentally measured cross section and in the higher energy region Talys-1.9 ldmodel 1 gives better result. Similarly in the ^{121}Sb(n, 2n)^{120}Sb reaction cross section measurement the calculation from Alice-2014 code shows better agreement with present experimentally measured data as shown in the fig-2.

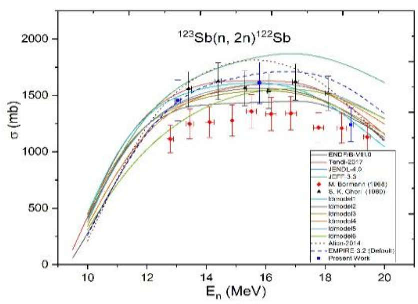

Fig-1 Plot of the experimentally and evaluated cross section for ^{123}Sb(n, 2n)^{122}Sb nuclear reaction from 10 to 20 MeV neutron energies.

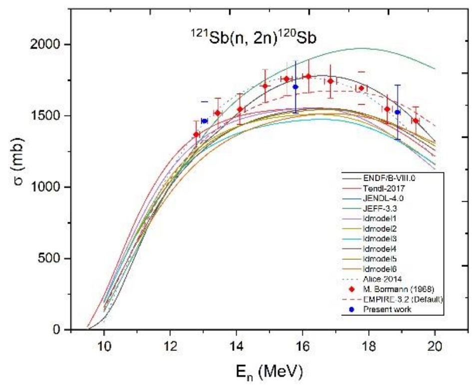

Fig-2 Plot of the experimentally and evaluated cross section for ^{121}Sb(n, 2n)^{120}Sb nuclear reaction from 10 to 20 MeV neutron energies.

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References

[1] Keiichi Shibata, Journal of Nuclear Science and Technology, 2014 Vol. 51, No. 4, 425–436.

[2] Milad Enferadi and Mahdi Sadeghi Nuclear Technology & Radiation Protection: Year 2011, Vol. 26, No. 1, pp. 58-63.

[3] T. Bücherl, N. Kardjilov, Ch. Lierse von Gostomski, and E. Calzada IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 52, NO. 1, FEBRUARY 2005

[4] M. Herman, EMPIRE-3.2.2 (IAEA, Vienna-, Austria, 2002).

[5] A. J. Koning, TALYS-1.9, the Netherlands, CEA, France (2004).

[6] EXFOR, Experimental Nuclear Reaction Data https://www-nds.iaea.org/exfor/exfor.htm

[7] ENDF, Evaluated Nuclear Reaction Data https://www-nds.iaea.org/exfor/endf.htm

[8] M. Blann, A. A. Konobeev, W. B. Wilson, S. G. Mashnik Alice-2014 code.