Measurement of Photo-neutron reaction Cross- Section of ^{93}Nb at end point bremsstrahlung energy of 10 MeV

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Photon-induced reaction cross section data are of importance for a variety of emerging applications such as radiation shielding design, radiation transport analyses, activation analyses and nuclear waste transmutations. The safety and reliability of a reactor largely depends on the cladding performance. The cladding tube is subjected to various thermal and multiaxial stress conditions inside the reactor. It was recognized that addition of Nb in Zr alloys improves the long term corrosion resistance and mechanical properties as well as retains a low neutron capture cross-section in the cladding, leading to extended fuel cycles with higher burn-ups [1]. In view of this, in the present work, (γ, n) reaction cross-section of ^{93}Nb with end point bremsstrahlung energy of 10 MeV by using off-line γ-ray spectrometric technique is determined.

The experiment was carried out using 10 MeV electron LINAC at EBC Kharghar, Navi Mumbai. Bremsstrahlung radiation was produced by impinging 10 MeV electron beam on 0.25 mm thick tantalum target. Natural Nb (0.04 g) and Au (0.0525 g) metal foils were wrapped separately with 0.025 mm thick super pure Al foil. The gold metal foil was used to measure the neutron flux. These target foils were placed below the tantalum foil on a suitable stand. It was then irradiated for 4 hours with end point bremsstrahlung energy of 10 MeV. The electron LINAC was operated at pulse mode with repetition rate (PRR) of 310 Hz, a pulse width of 10 μs and an average beam current of 33 mA The irradiated targets were cooled for 4 hours and assayed for γ-ray activity of the reaction products using pre-calibrated HPGe detector coupled to a PC based 4096 channel analyzer. The resolution of the detector system during counting was 2 keV at 1332 keV γ-line of ^{60}Co.

The observed photo peak areas (A_{obs}) of the γ-rays of nuclides of interest were calculated by subtracting the linear Compton background from their net peak areas. The photon flux based on the activity of 355.7 keV γ-line of ^{196}Au from ^{197}Au(γ, n) reaction was determined. The radionuclide ^{92}Nb^{m} was identified through an analysis of 934.4 keV, characteristic γ-lines [2]. The photo-peak activities (A_{obs}) of the respective nuclide are related to the photon flux (φ) by the equation,

$$A_{obs} = N\langle\sigma\rangle\varphi a\epsilon(1-e^{-\lambda t})e^{-\lambda T}(1-e^{-\lambda \Delta T})/\lambda \qquad (1)$$

Where N is the number of target atoms. $\langle\sigma\rangle$ is the average cross-section of ^{197}Au(γ, n) ^{196}Au reaction. 'a' is the branching intensity and ε is detection efficiency for the 355.7 and 934.4 keV γ-lines of the ^{196}Au and ^{92}Nb^{m}. 't' and T are the irradiation and cooling times whereas, CL and LT are the clock time and live time of counting, respectively. In the above equation, CL/LT term has been used for dead time correction.

The average cross-section ($\langle\sigma\rangle$) for ^{197}Au(γ, n) ^{196}Au reaction was calculated using the relation

$$\langle\sigma\rangle = \Sigma(\sigma\varphi) / \Sigma\varphi \qquad (2)$$

Where φ is photon flux for ^{197}Au(γ, n) reaction. The photon flux (φ) as a function of photon energy was calculated using EGS4 code [3].

The cross-sections given in Table 1 for ^{93}Nb(γ, n) ^{92}Nb reaction are based on the bremsstrahlung flux obtained from the flux-weighted ^{197}Au(γ, n)^{196}Au reaction cross-section data of mono-energetic photon [4] as well as from the mono-energetic data of TALYS [5].

In literature only one data is available for photo-neutron cross-section of ^{93}Nb(γ, n)^{92}Nb

reaction based on mono-energetic photon [6] using neutron counting method which is shown in Fig.1. It can be seen from Fig.1 that ^{93}Nb(γ, n)^{92}Nb reaction cross-section increases with photon energy up to 14-16 MeV and thereafter decreases up to 20 MeV. In order to examine this, the cross-section for ^{93}Nb(γ, n) ^{92}Nb reaction as a function of photon energy was also calculated theoretically using TALYS code 1.2 version. The (γ, n) reaction cross-section as a function of photon energy from TALYS calculation for ^{93}Nb is also plotted in Fig. 1. It can be seen from Fig.1 that the ^{93}Nb(γ, n)^{92}Nb reaction cross-section as a function of photon energy from TALYS 1.2 shows a similar structure within the available experimental data. However, the magnitude of the theoretical ^{93}Nb(γ, n)^{92}Nb reaction cross-section from TALYS is nearly half of the experimental data at peak position. The difference in magnitude is probably due to the use of the default parameters. The theoretical ^{93}Nb(γ, n)^{92}Nb reaction cross-section from TALYS also clearly shows the GDR effect.

The flux weighted average cross-section for ^{93}Nb(γ, n)^{92}Nb reaction was obtained from the literature using Eq. (2) The flux weighted average cross-section for ^{93}Nb(γ, n)^{92}Nb reaction from theoretical value of TALYS is also calculated and given in Table 1.

Table1. Cross-section of ^{93}Nb(γ, n)^{92}Nb in the end point bremsstrahlung energy of 10 MeV.

<σ> for ^{197}Au (γ, n) (mb) [Ref]	Flux(φ) x10^8 (Photons/ cm^2/s)	σ(mb) of ^{93}Nb(γ,n) at 10 MeV
38.65 [6]	13.649±0.22	4.923±0.12
55 [5]	9.592±0.155	6.993±0.17

It can be seen from the Table 1 that, the experimentally obtained ^{93}Nb(γ, n)^{92}Nb reaction cross-section based on 934.4 keV γ-line varies from 4.9-7.0 mb for end point bremsstrahlung energy of 10 MeV. The experimentally determined ^{93}Nb(γ, n) reaction cross-section at end point bremsstrahlung energy of 10 MeV were closer to the flux weighted value of TALYS (5.41 mb), whereas they are lower than the literature data (7.2 mb).

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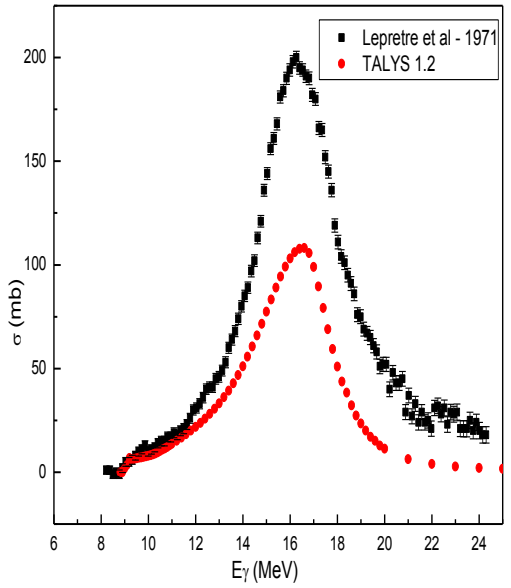

Fig.1 Plot of experimental and theoretical ^{93}Nb (γ, n)^{92}Nb reaction cross-section as a function of photon energy.

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