Measurement of ^{90}Zr (n,p) ^{90}Y^{m} reaction cross-section at 7.3 MeV neutron energy

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Nuclear data on neutron induced reaction cross-section of Zr and Nb are important from reactor point of view. This is because Zircolly is an important cladding material of nuclear fuel in reactor and has very low (n,γ) activation cross-section. Natural Zirconium has an isotopic abundance of ^{90}Zr (51.45 %), ^{91}Zr (11.22 %), ^{92}Zr (17.15 %), ^{94}Zr (17.38 %) and ^{96}Zr(2.80 %). The energy of neutrons in a reactor varies from 0 to 10 MeV [1]. Thus, there is a possibilities of different nuclear reaction such as (n,γ), (n,n'), (n,p) and (n,α) etc. to occur in spite of very low (n,γ) reaction. In the present work we have determined (n, p) reaction cross-section of ^{90}Zr with average E_n of 7.3 MeV by using off-line γ-ray spectrometric technique.

The experiment was carried out at BARC-TIFR Pelletron facility at TIFR, Mumbai. Natural Zr (0.1694 gm) having 2.5 % Nb and natural U (0.9917 gm) metal foil were wrapped separately with 0.025 mm thick super pure Al foil. The uranium metal foil was used to measure the neutron flux. These samples were irradiated for 4 hours with average neutron energy of 7.3 MeV from ^{7}Li (p,n) ^{7}Be reaction of 12 MeV proton beam at the 6 meter height main line of Pelletron facility. The proton current during irradiation was 400 nA. After two hours of cooling, the irradiated Zr and U samples were mounted on two Perspex plate and taken for γ-ray counting. The ^{90}Y^{m} from ^{90}Zr(n,p) reaction has half life of 3.19 h with γ-line of 202.47 keV and 479.5 keV [2] and the fission products from ^{238}U have varying half-lives [1]. In view of this, the irradiated Zr and U on Perspex plate were counted alternately for their γ-ray activity using pre-calibrated 45 cc HPGe detector coupled to a PC-based 4K MCA. The resolution of the detector system during counting was 2 keV at 1332 keV γ-line of ^{60}Co.

The observed photo-peak area (A_{obs}) for 479.5 keV of ^{90}Y^{m} and for different γ-lines of fission products (e.g. 743.3 keV of ^{97}Zr) were obtained from their total peak area after subtracting the linear background due to Compton effects. From the A_{obs} of a particular fission products (e.g. ^{97}Zr), neutron flux (φ) was obtained using decay equation [1]

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

where N is the number of atoms of the isotope of the element and σ is the fission cross-section of ^{238}U. Y is the cumulative yield of ^{97}Zr. 'ϵ' is the detector efficiency, which was determined by using ^{152}Eu source. 'a' is the γ-ray abundance and λ is the decay constant of the product nuclide. 't', T and ΔT are irradiation, cooling and counting time respectively.

In the present experiment the proton beam of energy 12.0 MeV was bombarded on Li target to produce neutrons. The neutrons produced in ^{7}Li(p,n) reaction with 12 MeV proton beam are not mono-energetic. Thus the neutron spectrum, obtained by using EMPIRE-2.19 [3], has a peak at 8.8 MeV with tailing towards lower energy. The flux-weighted average neutron energy was calculated to be 7.3 MeV. The yield of ^{97}Zr from ^{238}U (n,f) at 7.3 MeV from ref. [4] was used for the calculation of neutron flux. Thus the yield of ^{97}Zr from ^{238}U (n,f) at 7.3 MeV (1.5-7.7 MeV) from ref. [4] was used for the calculation of neutron flux. This is justified because the yields of ^{97}Zr in ^{238}U (n,f) vary marginally from 5.36 %

at 1.5 MeV to 5.62 % at 7.7 MeV [4]. From the observed activity (A_{obs}) of ^{97}Zr and its yield (Y) at 7.3 MeV in equation (1), the neutron flux was obtained to be 1.8×10^{7} n cm^{-2} s^{-1}. Using A_{obs} of ^{90}Y^{m}, Y=1 and other terms in the above equation, (n,p) reaction cross-section (σ) of ^{90}Zr was obtained as 0.0021±0.0004 barn, which is given in Table 1 along with EXFOR [5] for comparison.

Table 1. ^{90}Zr (n, p) ^{90}Y^{m} reaction cross-section in barns at 7.3 MeV neutron energy

Present work	EXFOR	TALYS
0.0021±0.0004	0.0014-0.0025	0.0025 (0.0021)

The experimentally obtained ^{90}Zr (n,p) cross section (0.0021±0.0004 barn) was found to be in agreement with the EXFOR data [5] given for the energy range of 7.16-8.9 MeV. The ^{90}Zr (n,p) ^{90}Y^{m} reaction cross-section was also calculated using TALYS 1.0 [6]. We obtain a theoretical value of 0.0025 barn at mono-energetic neutron energy of 7.3 MeV using TALYS, which is given in Table 1. It was found that theoretical value is slightly higher than the experimental value obtained from present work as well as from EXFOR [5]. This is because the value from TALYS is obtained for mono-energetic neutron as shown by line in Fig. 1. The experimental data from present work is obtained for the average neutron energy of 7.3 MeV, which is shown filled square in Fig. 1 In view of this the flux-weighted value from TALYS was also calculated and given in the bracket of Table 1. The flux weighted ^{90}Zr (n,p) ^{90}Y^{m} reaction cross-section calculated by TALYS, which is in excellent agreement with the experimental value and shows the correctness of present approach.

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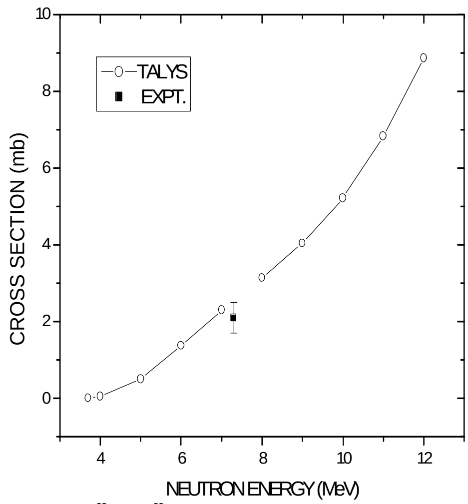

Fig.1. ^{90}Zr(n,p)^{90m}Y reaction cross-section vs. neutron energy.

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