Measurement of the neutron capture cross-section of ^{238}U at E_n = 5.9 MeV using activation technique

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Introduction

Most of the reactors operating in the world are light water reactors (PWR and BWR) or heavy water reactors (HWR), which are based on enriched or natural uranium as a fuel. Recently, the significant effort has been aimed at generating nuclear power based on the concept of fast reactor and advanced heavy water reactor (AHWR) [1] to fulfill the increased demand of power production. In AWHR, ^{232}Th-^{233}U in the oxide form is used as the primary fuel, whereas in the fast reactor ^{238}U-^{239}Pu in the form of carbide is used as the primary fuel. The ^{239}Pu is first generated in a research reactor from ^{238}U(n, γ)^{239}U nuclear reaction and by successive two beta decays. Then the fissile material ^{239}Pu along with ^{238}U is used as a fuel in the fast reactor for nuclear power generation. The ^{238}U is used as the breeding material to regenerate the fissile material ^{239}Pu. In the fast reactor, there is a fast neutron spectrum. Thus, for the production of ^{239}Pu, it is necessary to have knowledge about ^{238}U(n, γ)^{239}U reaction cross-section at various neutron energies. This is because the production of fissile nucleus ^{239}Pu depends on the ^{238}U(n, γ) reaction cross-section, which is required with an accuracy of 1-2 % for predicting the dynamical behavior of complex arrangements in the fast reactor [1] safely. Thus, the ^{238}U(n, γ) reaction cross-section at higher neutron energy has a strong impact on the performance and safety assessment for the fast reactor [1].

In the present work, we have determined the ^{238}U(n, γ)^{239}U reaction cross-section at average neutron energy of 5.9±0.3 MeV using the neutron beam from the ^{7}Li(p, n) reaction and by the standard activation technique followed by off-line γ-ray spectrometry. The theoretical value of cross-sections for this reaction was also estimated from 1 MeV to 20 MeV, using the TALYS-1.4 [2] computer code. The cross-section measured in the present work have been compared with the EXFOR database [3] and also with the theoretical cross-sections obtained using the Talys-1.4 computer code.

Experimental Details

The experiment was performed using the 14UD BARC-TIFR Pelletron facility at Mumbai, India, main line at 6 m height above the analysing magnet. About 0.7 g of natural U metal foil (~ 29.3 mg/cm^2) of area 1.0 cm^2 doubly wrapped with 0.025 mm thick Al foil was irradiated for 15 hours at 5.9 MeV quasi mono energetic neutrons by using ^{7}Li(n, p) reaction of 8 MeV proton beam. The lithium foil was made up of natural lithium with thickness of 3.7 mg/cm^2, sandwiched between two tantalum foils of different thickness. The proton current during irradiation was 250 nA. The sample was mounted at zero degree with respect to the beam direction at a distance of 2.1 cm from the location of the Ta–Li–Ta stack. After irradiation and sufficient cooling, the γ-rays of fission product (^{97}Zr) or reaction product (^{239}Np) from the irradiated U sample were counted in an energy and efficiency calibrated 80 c.c. HPGe detector coupled to a PC-based 4K channel analyser. The energy and efficiency calibration of the detector system was done by using standard ^{152}Eu and ^{133}Ba γ-ray sources. Table-I gives the details of the nuclear spectroscopic decay data [4] used in the present work.

Table 1: Nuclear spectroscopic decay data

Nuclide	Half-Life	γ-ray energy (keV)	γ-ray abundance (%)
^{239}U	23.45 m	74.7	49.2
^{239}Np	2.35 d	103.4	22.2
^{97}Zr	16.74 h	743.4	93.0

From the observed photo-peak activity (A_{obs}) for 743.4 keV γ-line of ^{97}Zr the neutron flux (Φ) of 3 x 10^6 n / cm^2-s was obtained by using Eq.1 [1]. Eq.1 can be used for estimating σ when Φ is known or vice versa.

$$A_{obs}(CL/LT) = N\sigma_f\, Y \Phi a\varepsilon(1-e^{-\lambda t})e^{-\lambda T}(1-e^{-\lambda CL})/\lambda \quad (1)$$

where, A_{obs}, λ, N, a, ε , Φ, t, T, CL, LT, σ_f and Y are observer activity, decay constant, number of atoms of the isotope of the element, gamma ray abundance, efficiency of the detector , neutron flux, irradiation time, cooling time, clock time, counting time, fission cross-section of ^{238}U and cumulative yield of the fission product ^{97}Zr respectively.

The neutrons from ^{7}Li(p, n) reaction are not mono-energetic at the high energy side, and their energy spectra were obtained from literature as shown in ref. [1]. The average energy of neutrons under quasi mono-energetic peak is 5.9±0.3 MeV for 8 MeV protons after removing the tail of the neutron spectrum.

Results and discussion

For ^{238}U(n, γ) reaction, the theoretically estimated and measured cross-section obtained in the present work, along with a few literature cross-sections are given in Fig.1. The present experimental ^{238}U(n, γ) cross-sections are within the range of evaluated data of ENDF/B-VII.1, JENDL-4.0 and JEFF-3.1. However, the evaluated values from CENDL-3.1 are not in agreement with the present experimental value.

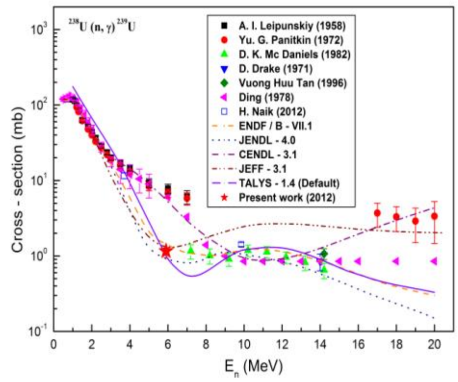

Fig.1. Plot of the $^{238}U(n, \gamma)^{239}U$ reaction Cross-Sections as a function of neutron energies.

In order to examine this aspect, the ^{238}U(n, γ) reaction cross-sections from the present work and similar data from EXFOR [3] are plotted in Fig.1. In view of this the ^{238}U(n, γ) reaction cross-sections were also calculated theoretically using the TALYS 1.4 computer code [2] and was found to be in good agreement with the experimental data, which shows the correctness of the present approach.

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