^{56}Fe (n, p) ^{56}Mn Reaction cross-section measurement at neutron energy 7.3 MeV

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Structural materials such as stainless steel, zirconium and aluminum are important from reactor point of view. This is because they are used as cladding material of nuclear fuel in reactor. Besides this, in reactor stainless steel is used as the calandria vessel and pipe lines of secondary coolant circuit. In stainless steel natural iron is a primary component with isotopic composition of ^{54}Fe (5.845 %), ^{56}Fe (91.754 %), ^{57}Fe (2.119 %), ^{58}Fe (0.282 %). In reactor there is a broad neutron spectrum of energy ranging from 0 to 10 MeV [1]. Therefore different nuclear reactions such as (n, γ), (n, n'), (n, p) and (n, α) etc. occur based on the energy of neutron and isotopic composition of iron. In view of this, in the present work we have determined the (n, p) reaction cross-section of ^{56}Fe with average neutron energy of 7.3 MeV by using off-line gamma ray spectrometric technique.

In the experiment, 0.172 gm of natural Fe with ^{56}Fe of 91.754 % and 0.9917 gm natural uranium were wrapped separately with 0.025 mm thick aluminum foil. The uranium metal foil was used to measure the neutron flux. Both the samples were irradiated for 4 h with neutron from ^{7}Li (p, n) reaction of 12 MeV proton beam in the 6 meter height main line at BARC-TIFR Pelletron facility. The proton current during irradiation was 400 nA with 6.05 MV terminal voltage. After 2 hours of cooling the irradiated iron and uranium samples were mounted on two different Perspex plate and taken for γ-ray counting. ^{56}Mn from ^{56}Fe (n, p) have a $T_{1/2}$ of 2.58 h with characteristic γ-line of 846.7 keV whereas, fission products from ^{238}U (n,f) have varying half-lives [2]. In view of this, the irradiated Fe and U on Perspex plate were counted for suitable time alternately for their gamma ray activity, using pre-calibrated 45 cc HPGe detector coupled to a PC-based 4K MCA. The resolution of the detector system was 2 keV at 1332 keV γ-line of ^{60}Co.

The observed photo-peak area (A_{obs}) for 846.7 keV of ^{56}Mn 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 observed A_{obs} of a particular fission product (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 fission yield of ^{97}Zr. 'ϵ' is the detector efficiency, which was obtained by using standard ^{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. Thus the yield of ^{97}Zr from ^{238}U (n, f) at 7.32 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 neutron energy [4]. From the A_{obs} of ^{97}Zr, its yield (Y) at 7.3 MeV and other terms in the above equation, neutron flux was obtained to be 1.8×10^{7} n/ cm^{2}-s. Then using A_{obs} of ^{56}Mn and other terms in the above equation, (n, p) reaction cross-section (σ) of ^{56}Mn was calculated, which is found to be 0.033±0.004 barn. This value along with the data from EXFOR [5] is given in Table-1 for comparison.

Table 1. ^{56}Fe (n, p) reaction cross-section (barns) at 7.3 MeV neutron energy

Present work	EXFOR	TALYS
0.033±0.004	0.031 to 0.044	0.041 (0.036)

The experimentally obtained (n, p) reaction cross-section of ^{56}Fe (0.033±0.004 barn) from the present experiment is in good agreement with EXFOR data [5] within the neutron energy range of 7-8 MeV. The ^{56}Fe (n,p) reaction cross-section was also calculated using TALYS 1.0 [6] and plotted in Fig. 1 shown in lines, along with the value from present work (filled square). TALYS value of 0.041 barns at mono-energetic neutron energy of 7.3 MeV is also given in Table 1, which was found to be slightly higher than the experimental value obtained from present work as well as from literature. This is because the value obtained from TALYS [6] is for mono-energetic neutron. In view of that the flux weighted theoretical ^{56}Fe (n, p) ^{56}Mn reaction cross-section was also calculated and given in the bracket of Table 1. The flux-weighted value of 0.036 barns was found to be in good agreement with the experimental value.

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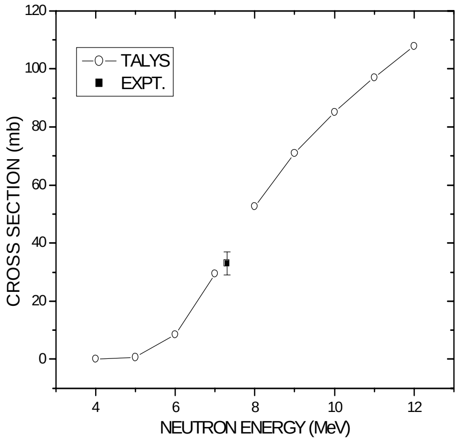

Fig. 1. ^{56}Fe(n,p)^{56}Mn reaction cross-section vs. neutron energy.

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