Determination of thermal neutron capture cross-section of ^{94}Zr

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Introduction

Zirconium is an important and major component of the structural materials used in traditional and advanced nuclear reactors. Because of its very low absorption cross-sections of thermal neutrons and resistance to corrosion, ninety percent of zirconium produced is frequently used as cladding of fuel rods, calandria vessel and pipe lines of secondary coolant circuit in nuclear reactors in the form of zircolly. The literature available in IAEA-EXFOR [1] indicates that most of the thermal neutron activations cross-sections for zirconium isotopes were made in reactors with neutron spectra and therefore were not precise thermal cross-section measurements. Motivated by these requirements, the thermal neutron activation reaction cross-section for ^{94}Zr(n,γ)^{95}Zr was determined using activation and off-line γ-ray spectrometric technique. For determination of "thermal neutron" activation cross-section of ^{94}Zr, thermal column of swimming pool type APSARA reactor was utilized.

Experimental Method

A known amount (0.3268 gm) of natural Zr metal foil (17.38% ^{94}Zr) of thickness about 1 mm and neutron flux monitor Au metal foil (0.0215 gm) were wrapped separately with 0.025 mm thick super pure aluminum foil and doubly sealed with alkathene bags. These samples were kept inside an irradiation capsule made of polypropylene. The capsule containing samples were doubly resealed with alkathene and were taken for irradiation. These samples were irradiated in the thermal column of swimming pool type APSARA reactor for the period of 6 hours and 30 minutes. After sufficient cooling, the irradiated Zr and Au samples along with Al wrapper were mounted on two different Perspex plates and taken for γ-ray spectrometry. Radioactivity in the irradiated Zr and Au samples were measured using energy and efficiency calibrated 80 cm^3 high-purity germanium (HPGe) detector coupled to a PC based 4K multi-channel analyzer in live-time mode. The efficiency of the detector was 20 % with energy resolution of 1.8 keV FWHM at 1332.0 keV peak of ^{60}Co.

Calculations

The neutron flux was calculated using Au monitor. The photo-peak activity of 411.8 KeV γ-lines of ^{198}Au from ^{197}Au(n, γ)^{198}Au reaction was used for flux determination. The observed photo peak activity (A_{obs}) of γ-lines was related to neutron flux (Φ) with the relation as given below,

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

Where, N is the number of target atoms and σ is the reaction cross-section. 'a' is the branching intensity of the γ-lines and ε is its detection efficiency of the detector system. λ is the decay constant of the product nuclide. t, T and ΔT are irradiation, cooling and counting time respectively. The observed photo-peak activities of 411.8 keV of ^{198}Au and 756 keV of ^{95}Zr lines were obtained using PHAST peak fitting program. The ^{197}Au(n,γ) reaction cross-sections (σ) value from literature [2], was used in Eq. (1) to determine the neutron flux, which was $1.105x10^8$ n cm^{-2} sec^{-1}. The nuclear spectroscopic data such as half-life, γ-ray energy, branching intensity were taken from ref. [3]

The ^{94}Zr(n,γ)^{95}Zr reaction cross-sections was determined from the observed photo-peak activity of 756 keV γ-line of ^{95}Zr, which has a half-life of 64.02 days, using equation (1) and given in Table 1. The overall uncertainty in the measured cross-section has contributions from both random and systematic errors.

Table1. The ^{94}Zr(n,γ)^{95}Zr reaction cross-section in barns at thermal neutron energy

Present work	EXFOR	ENDF/B-VII
0.051±0.0037	0.047- 0.075	0.049

Results and Discussion

It is seen from Table 1 that the experimental data for ^{94}Zr(n,γ)^{95}Zr reactions at thermal neutron energy (0.0253 eV) from literature available in IAEA-EXFOR database has a wide range from 0.047-0.075 barns. The present measured data is well within this range of experimental data. It is also seen from Table 1 that the our experimentally determined cross-sections values for the ^{94}Zr(n,γ)^{95}Zr is in very close agreement with the evaluated data from ENDF/B-VII, which indicates our excellent measurement of the neutron reaction cross-sections using activation technique followed by off-line γ-ray spectrometric technique. The ^{94}Zr(n,γ)^{95}Zr reaction cross-section from present work at thermal neutron energy and at 2.45 MeV from our earlier work [4] are plotted in fig. 1 along with EXFOR data and TALYS 1.2 [5] for comparison. From the fig 1, it is clear that ^{94}Zr(n,γ)^{95}Zr reaction cross-section decreases with increase of neutron energy in MeV region due to opening other reaction channels such as (n, p), (n, α) and (n,2n) etc.

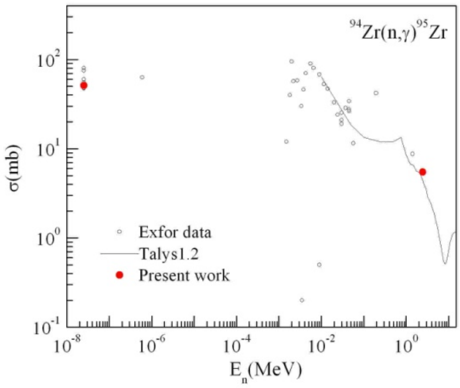

Fig.1. ^{94}Zr(n,γ)^{95}Zr reaction cross-section vs. neutron energy.

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