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Activation Cross Sections of $^{90}Zr(n, 2n)^{89}Zr$ Reaction in the Neutron Energy Range 14.10-14.71 MeV

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Abstract: The cross sections of $^{90}Zr(n, 2n)^{89}Zr$ reaction in the neutron energy range 14.10-14.71 MeV was measured by the activation technique. Neutrons were produced via $^{3}H(d, n)^{4}He$ reaction using solid tritium target at J-25 neutron generator. Activity of the reaction product was determined by measuring the gamma counts of the product nuclei using high resolution HPGe detector gamma ray spectrometry system. Neutron flux at each sample position was determined by using $^{27}Al(n, \alpha)^{24}Na$ monitor reaction. The measured cross section values along with the literature data were plotted as a function of neutron energy to get the excitation function of the reaction. A theoretical calculation was also performed to produce the excitation function of the investigated reaction using statistical code SINCROS-II.

Key words: Excitation function, neutron generator, resolution, neutron flux, gamma ray spectrometry system

INTRODUCTION

With the development of modern controlled fusion technique, the prospect of applying fusion reactor technique becomes more clear. Csikai[1] has recently reviewed that in D+T fusion almost 80% of the total energy is carried off by 14 MeV neutrons. For this reason, the accuracy of the cross section data at this energy is important for the prediction of reactor parameters such as tritium breeding, radiation damage, nuclear heating, calculation of the activation in materials to be used in fusion reactor and so on.

Zirconium is an important element in the field of the nuclear engineering. In the design of accelerator-driven system, ZrN is planned to be utilized as a main constituent of the nuclear fuel pellet, but till recently its cross section database, especially for neutron threshold reactions, was rather weak. A critical survey of the available literature reveals that some information of the reaction cross section of $^{90}Zr(n, 2n)^{89}Zr$ does existed[2-9]. But among them, there are large discrepancies. However, for more information and a better understanding on the field extensive research work is still inevitable. In view of the above consideration, we intend to carry out measurements of the excitation functions of the $^{90}Zr(n, 2n)^{89}Zr$ reaction in the energy range 14.10-14.71 MeV. The second aim was to compare the experimental data with the results of nuclear model calculations to be able to check the predictive power of the statistical model.

MATERIALS AND METHODS

High purity metallic zirconium foils were prepared nicely. Each zirconium foil was sandwiched by two aluminium flux monitor foils. The angular positions of the samples with respect to the direction of deuteron beam were 0°, 20°, 60° and 90°. The irradiation was carried out at J-25 neutron generator at the Institute of Nuclear Science and Technology, Atomic Energy Research Establishment, Savar, Dhaka and neutrons were produced via the $^{3}H(d,n)^{4}H$ reaction making use of the variation at neutron energy with the emission angle. The incident deuteron energy was 110 keV and the beam current was 120 μA. The neutron energy as a function of emission angle was determined by measuring the ratio of the ^{89}Zr to ^{92m}Nb specific activities induced both in Zr and Nb foils by (n, 2n) reactions[5]. During irradiation the relative changes of the neutron production as a function of time were monitored by means of a BF_3 long counter previously calibrated with a 1 mCi ^{252}Cf neutron source. The irradiation time was 3.5 h. The accurate neutron flux at each sample position was measured via monitor reaction $^{27}Al(n,\alpha)^{24}Na$ and the cross section data for the reaction as a function of neutron energy was taken from Vonach[10]. The flux passing through the sample was of the order of 10^6 neutron/cm^2/sec. After the irradiation, the radioactivity of the reaction product was measured by using a high resolution HPGe detector that was previously calibrated with a set of standard gamma ray

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Table 1: Decay data of nuclear reaction product ^{89}Zr

Nuclear reaction	Isotopic abundance of target nuclei (%)	Half life of the product nuclei	Gamma ray energy (keV)	Gamma ray intensity (%)
$^{90}Zr(n, 2n)^{89}Zr$	51.40	3.271 d	909.10	99.00

sources. Peak area analysis was done in a Canberra S-100 Multi Channel Analyzer (MCA) master board package based personal computer with the associated electronics.

The count rates at the end of irradiation were corrected for dead time loss, coincidence effects, detector efficiency and gamma transition intensities. Cross sections were calculated using the well-known activation formula. The reaction investigated and the decay data[4] of the product nuclei used in the cross section calculation are given in Table 1. The theoretical cross sections as a function of neutron energy were reproduced by the computer code SINCROS-II[11].

RESULTS AND DISCUSSION

The principal sources of uncertainty and their magnitudes involved in the gamma measurements are given in Table 2. The quoted uncertainties in the cross section values include both systematic and statistical errors. The Table 1 shows the isotopic abundance of target nuclei ^{90}Zr and half-life of the product nuclei ^{89}Zr are 51.40% and 3.271 d, respectively. The product isotope gives a gamma-ray peak at 909.10 keV energy with 99.00% intensity. The measured cross sections including errors obtained from the present investigated $^{90}Zr(n, 2n)^{89}Zr$ reaction in the neutron energy range 14.10-14.71 MeV are given in Table 3. The angular positions of the samples were 0°, 20°, 60° and 90° with respect to deuteron beam of 110 keV energy and 120 μA current. The neutron energies 14.71±0.11, 14.69±0.11, 14.41±0.08 and 14.10±0.04 MeV were determined at the angular positions 0°, 20°, 60° and 90°, respectively. The experimental cross-sections 814.35±70.62, 710.20±53.73, 758.07±51.67 and 638.86±42.53 mb were determined at the neutron energies 14.71±0.11, 14.69±0.11, 14.41±0.08 and 14.10±0.04 MeV, respectively (Table 3).

Table 2: Principal sources of systematic errors and their magnitudes

Sources of uncertainty	Magnitude (%)
Irradiation time	0.1
Irradiation geometry	0.5–1.5
Sample weight	0.3
Statistics of counting	1–4.3
Efficiency of the detector	1.5–3
Error in neutron flux determination	1.5–2.5
Neutron absorption and scattering within the sample	0.5
Neutron flux variation with time	0.5–1.5
Self absorption of gamma ray in sample	0.5
Gamma ray emission probability	0.5–1
Half life (decay constant)	0.5

Table 3: Measured cross section of the $^{90}Zr(n, 2n)^{89}Zr$ reaction

Emission angle	Corresponding neutron energy (MeV)	Measured cross section (mb)
0°	14.71±0.11	814.35±70.62
20°	14.69±0.11	710.20±53.73
60°	14.41±0.08	758.07±51.67
90°	14.10±0.04	638.86±42.53

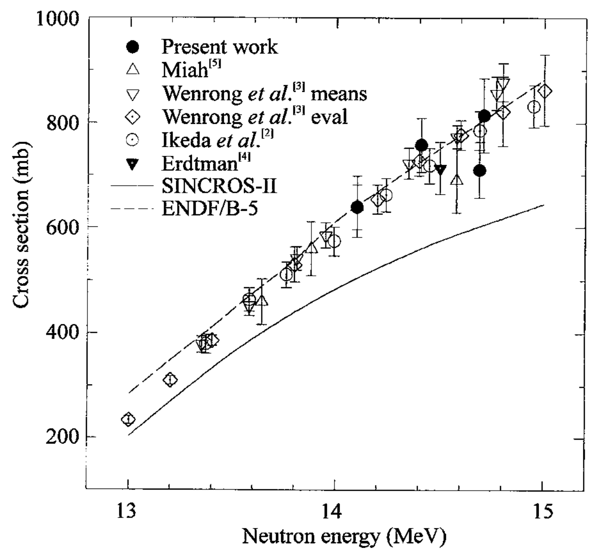

Fig. 1: The excitation function of $^{90}Zr(n, 2n)^{89}Zr$ reaction

Earlier studies[2-5,12] and the values obtained via model calculation with statistical code SINCROS-II are shown in Fig. 1 as a function of neutron energy. The large discrepancy in the nuclear model calculation using SINCROS-II code is observed for the investigated reaction. The model consists of a pure multi-step approach with the fixed global parameter set. It contains both statistical multi-step direct and statistical multi-step compound processes. The probable reason of large discrepancy in the cross section estimations via this code is that the compound nucleus formation cross-section is underestimated in SINCROS-II whereas direct reaction is overestimated. It is worth mentioning that the measured excitation function for $^{90}Zr(n, 2n)^{89}Zr$ reaction is in good agreement with the literature values. The present study introduces some newer data points to the existing literature and theoretical calculation.

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