Measurement of cross section for ^{65}Cu(*n,p*)^{65}Ni nuclear reaction at 14.96 ± 0.03 MeV Neutron energy

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Introduction

Accurate cross-section data is imperative in various nuclear applications as nuclear reactor design, astrophysics, radiation protection and radiation therapies. Copper alloys are being considered for use as primary structural materials in fusion reactors as they are crucial for managing the intense heat and radiation produced in fusion environments [1]. Copper-based nanomaterials excel in wastewater treatment, making copper essential in electronics, construction, and environmental engineering. The nuclear data available for the ^{65}Cu(n,p)^{65}Ni reaction is sparse, posing difficulties in reliably predicting the reaction's behavior across varying neutron energy spectra. This limitation hinders accurate modeling and simulation, which are essential for applications requiring precise reaction rate assessments.

Furthermore, previous studies exhibit significant discrepancies in the cross-section values, with precise data lacking for various incident neutron energy ranges [2]. In the present study, an effort has been made to validate the accuracy of the existing nuclear data through the application of Neutron Activation Analysis (NAA).

The ^{65}Cu(n,p)^{65}Ni reaction (E_{th} = 1.376 MeV), induced by bombardment of incident neutrons , the produced ^{65}Ni ($\tau_{1/2}$ = 2.515 hr) is a radionuclide that has been extensively examined for its beta-emission properties and decay behavior, showing great promise in nuclear medicine.

Experimental Details

The experiment was performed at Neutron and Ion beam Irradiation Facility at the Institute for Plasma Research, Gujarat, India. The ^{3}H(d,n)^{4}He nuclear reaction was achieved by directing a 200 keV deuterium beam with a 2.5 mA beam current on a tritium-titanium target, producing the monoenergetic neutron beam of 14.96 ± 0.03 MeV neutron energy in forward direction. This beam was directed to interact sequentially with an Al foil-Cu pellet (thickness = 0.111 cm, purity = 99.5%) target placed at an angle of 0˚. The setup was shielded by a lead wall to minimize environmental radioactive contamination. The stable sample when exposed to the neutron beam, emits γ-rays at the characteristic 1115.53 keV energy. An Au-Si α-particle surface barrier detector was positioned at 135° from the neutron beam axis to detect the flux of α-particles. The emitted γ-rays were detected and quantified using a High-Purity Germanium (HPGe) detector having end cup size of 8.2 cm, energy resolution ≤ 2.1 keV at 1.33 MeV γ-ray energy. To minimize the coincidence summing effect, the sample was placed at distance of 3 cm in the detector. The HPGe detector was pre-calibrated using a ^{152}Eu point source ($\tau_{1/2}$ = 13.517 ± 0.014 y). The neutron flux [3] was monitored using the ^{27}Al(n,α)^{24}Na monitor reaction using the **Eq (1):**

$$<\Phi> = \frac{(C_m \lambda_m)}{(<\sigma_m> N \varepsilon_m I_m f_m)} \left(C_{attn} C_g\right)_m \qquad (1)$$

Here, m in subscript stands for monitor reaction, σ_m is the monitor reaction cross section (ENDF-B/VIII.0), C_m is the photo-peak counts of the γ-ray of the reaction products, I_m is the γ-ray

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abundance, ε_m is the efficiency for the characteristic γ-ray of radionuclide, C_{attn} is the γ-ray self-attenuation correction factor, C_g is the geometry correction factor for the monitor reaction, λ_m is the decay constant, f_m is time factor as mentioned in **Eq (2):**

$$f = (1 - \exp(-\lambda t_i))\exp(-\lambda t_c)\,(1 - \exp(-\lambda t_t)) \qquad (2)$$

where t_i is irradiation time, t_t is counting time, and t_c is cooling time. The neutron flux produced from ^{3}H(d,n)^{4}He reaction was 1.60×10^8 n/(cm^2.sec).

The spectrum averaged cross section was computed using **Eq (3)**:

$$< \sigma_r > = \frac{(C_r \lambda_r)}{(< \Phi > N \varepsilon_r I_r f_r)} \left(C_{attn} C_g\right)_r \qquad (3)$$

where *r* in subscript represents sample reaction.

Table 1: Spectroscopic Data of Reaction

Nuclear reaction	^{65}Cu(n,p)	^{27}Al(n,α)
Product Nucleus	^{65}Ni	^{24}Na
Half-Life (hr)	2.5175 (5)	14.9578 (12)
Eγ (keV)	1115.53	1368.63
Iγ (%)	15.43 (13)	99.99 (15)

Results and Discussion

The estimated cross-section value for the reaction ^{65}Cu(n,p)^{65}Ni is 0.0164 ± 0.0008 barns at 14.96 ± 0.03 MeV. The cross-section data is compared with Evaluated libraries [4], as ENDF/B-VIII.0, JEFF 3.3. The present data is closer to ENDF/B-VIII.0 near 14.96 ± 0.03 MeV neutron energy. The data is also compared with existing studies on the cross-section for the ^{65}Cu(n,p)^{65}Ni reaction from the EXFOR library [2]. The current results reveal a slight reduction in cross section value relative to earlier experimental and evaluated trends. This divergence stems from variations in measurement methodologies and detection techniques. **Fig (1)** demonstrates, measured experimental cross section and further revealed

better agreement with work reported by M. J. Depraz et.al [5]. However, the existing data shows large discrepancies in the Neutron energy range within 14-15 MeV. There is a profound need to perform experiments in this range to obtain more precise cross-section data.

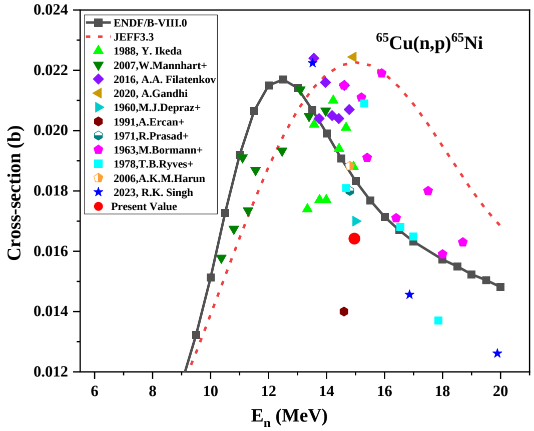

Fig (1): Experimental and Evaluated cross section for ^{65}Cu(n,p)^{65}Ni reaction.

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