Cross Section Measurement of ^{nat}Ni(α,xp)^{61}Cu Reaction: Implications for Reactor Safety and Secondary Particle Production

Swapna Balakrishnan[1],* M M Musthafa[1], Midhun C V[1], Gokul Das H [1], Vafiya Thaslim T T[1], F S Shana[1], Najmunnisa T[1], Rijin N T[2], S Ghugre[3], S Dasgupta[4], and J Datta[4]

[1] *Department of Physics , University of Calicut, Malappuram, 673635, Kerala, India*
[2] *Department of Physics , Jain University, Banglore, 560069, Karnataka, India*
[3] *UGC-DAE-Consortium for Scientific Research, Kolkata, 700098, India and*
[4] *Analytical Chemistry Division , BARC-VECC, Kolkata, 700064, West Bengal, India*

Introduction

The radiation-induced transmutation reactions, hydrogen and helium bubble formation in the reactor structural materials must be analysed for understanding the structural stability of reactors. Stainless steels with Fe, Ni and Cr as main constituents (SS316 composed of Fe∼65%, Ni∼14%, Cr∼17%) are frequently used as reactor structural materials. Moreover, a class of nickel-based alloys has become prominent in Gen IV reactor systems due to their outstanding temperature sensitivity and corrosion resistance [1].
In fusion reactor environment there is high fluence neutrons, and their interaction with structural material will cause (n,p) and (n,α) channels [2] . In fission reactors, there will be a production of alpha as a result of ternary fission. The reactor structure will interact with energetic particles inside the reactor, resulting in the production of secondary charged particles and will lead to degradation of structural stability.

The experimental cross section data available for ^{nat}Ni(α,xp) in the IAEA-EXFOR [3] library is compared with the cross sections available in evaluated nuclear data library TENDL-2023, as shown in FIG. 1. Literature data shows significant cross section discrepancies across energy ranges, despite using the same stacked foil activation method. As a result, we decided to investigate the alpha-induced reaction on natural nickel, focussing primarily on the residue ^{61}Cu, because its production leads to an increase in proton yield.

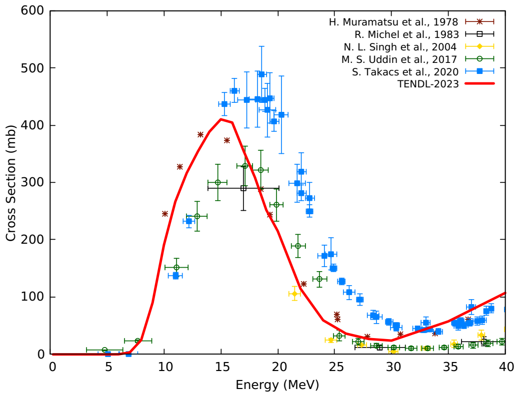

FIG. 1: Comparison of data from evaluated nuclear data library-TENDL-2023, with Previous experimental data sets taken from EXFOR.

Experimental Setup and Data Analysis

The experiment was performed at the K-130 Cyclotron facility, VECC, Kolkata, India. Natural nickel foils (∼45 mg/cm^2) were prepared by rolling. Two separate stacks were irradiated with 30 MeV and 40 MeV alpha beams at a current of ∼100 nA. The stopping ranges of alpha particles through the stacks were simulated using the SRIM code for both energy configurations.
After irradiation, the evaporation residues formed in the α + ^{nat}Ni were identified by all the characteristic γ-rays and the gamma-ray

*Electronic address: swapnabalakrishnan@uoc.ac.in

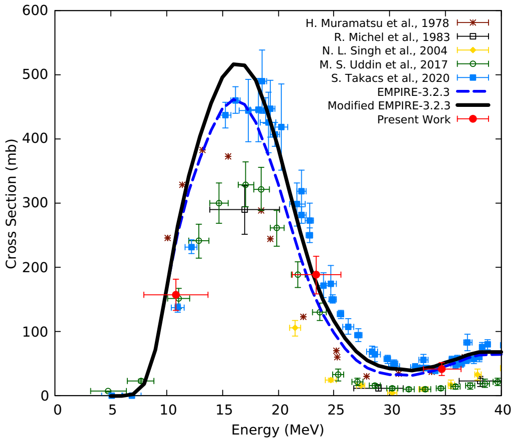

FIG. 2: Comparison of experimental cross sections with EMPIRE-3.2.3 predictions, including modifications accounting for the production cross section of ^{61}Zn.

activity of the residue was investigated using the HPGe detector (CANBERRA). The energy and efficiency calibration of the detector were done using a standard ^{152}Eu source. The spectrum was analysed using IUAC data acquisition and analysis software CANDLE.

The cross section calculation was done using the activation equation.

$$\sigma(E) = \frac{C_\gamma \lambda e^{\lambda t_{cool}}}{N\phi I_\gamma \varepsilon_\gamma (1 - e^{-\lambda t_{irrad}})(1 - e^{-\lambda t_{count}})} \quad (1)$$

where C_γ is the net counts under the photopeak of the radionuclide, λ is decay constant of the radioisotope (in s^{-1}), N is the number of target atoms per cm^2 , ϕ is the beam flux (particles/s), ϵ_γ is the absolute efficiency of the detector at the measured gamma ray, I_γ is the absolute intensity of the measured gamma ray, t_{irrad} , t_{cool} and t_{count} are the irradiation time, cooling time and counting time (in s) respectively.

Results and Discussion

The experimentally obtained cross section presented here agrees well with the experimental data available in IAEA EXFOR [3] (FIG. 2). The nuclear reaction code EMPIRE-3.2.3 is used to optimize experimental data. Different level density models available in EMPIRE-3.2.3 have been used in simulations, out of which the Gilbert-Cameron nuclear level density model is found to be reproducing the experimental data up to some extent. The production of ^{61}Cu involves both direct and indirect pathways. The direct pathway is through the ^{nat}Ni(α, xp) reaction. Indirectly, ^{61}Cu is generated via $\beta+$ decay of ^{61}Zn, which itself is formed predominantly from ^{58}Ni(α,n) (Q-Value =-9.53 MeV) and ^{60}Ni(α,3n) (Q-Value =-29.91 MeV) reactions. Incorporating the production probability of ^{61}Zn into computational models with optimized parameters improves their agreement with experimental data to some extent, as illustrated in FIG. 2.

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