Determination of ^{62}Cu(n,xp) cross sections using hybrid surrogate ratio approach

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Introduction

Nuclear reaction cross sections data is of utmost importance for the design of advance reactor concepts such as ADS and fusion reactors. High energy (14.1 MeV) neutrons produced via D-T fusion inside a fusion reactor lead to various reactions. The neutron induced reactions that produce gaseous products such as hydrogen(H) and helium(He) through (n,xp) and (n,xα) reactions, lead to swelling and embrittlement of structural materials (SS) of the reactor. There are many many short and long lived radio-nuclides produced, by exposure of high energy neutrons on SS via transmutation reactions. The experimental data on (n,xp) and (n,xα) cross sections with these radionuclei and SS are very important for safety and design analysis, and to understand overall neutronics of a fusion reactor [1–4]. The nuclide ^{62}Cu with half life $T_{1/2} = 9.67$ min is one of them. In a typical fusion reactor, ^{62}Cu is produced via ^{63}Cu(n,2n), ^{65}Cu(n,3n)^{63}Cu(n,2n), ^{64}Zn(n,d)^{63}Cu(n,2n) and ^{64}Zn(n,2n)^{63}Zn(β^+)^{63}Cu(n,2n) reactions [3]. Due to short half life of ^{62}Cu target, direct measurement of ^{62}Cu(n,xp) cross sections is extremely difficult and these cross sections are not available in literature. In the present work ^{62}Cu(n,xp) cross-sections have been measured experimentally using hybrid surrogate ratio approach (HSR) and using known ^{60}Ni(n,xp) cross section values from the literature as reference [5].

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Experimental details and data analysis

Measurements were carried out at BARC-TIFR Pelletron Accelerator Facility in Mumbai by bombarding freshly prepared self-supporting target of ^{59}Co (abundance $\approx$ 100%) of thickness $\approx$ 500 μg/cm^2 by bombarding ^{6}Li beams of energy $E_{\rm lab} = 40.5$ MeV. For the present experiment, the surrogate reactions of interest, the compound nuclei (CN) formed, and corresponding equivalent neutron induced reactions are listed in Table I.

TABLE I: see text.

$E^{^6Li}_{beam}$ (MeV)	Surrogate reaction	CN	Equivalent neutron induced reaction
40.5	^{59}Co(^{6}Li,d)^{63}Cu*	^{63}Cu*	^{62}Cu(n,xp)
40.5	^{59}Co(^{6}Li,α)^{61}Ni*	^{61}Ni*	^{60}Ni(n,xp)

A silicon surface barrier (SSB) $\Delta E - E$ detector telescope (T) was mounted at 25° for identification of projectile like fragments (PLFs). Two large area Si strip detector telescopes (S1 and S2) each having an angular opening of ∼16° were mounted at backward angles 120° and 150°, to detect evaporated particles (e.g., p, d, t, and α) from the compound nuclei ^{63}Cu* and ^{61}Ni* in coincidence with the PLF (d and α). The time correlations between the PLFs detected in the T and the corresponding decay particles (from the residual CN) detected in detector S1 or S2, were recorded by Time to Amplitude Converter (TAC).

Excitation energy (E^*) spectra of compound systems ^{63}Cu* and ^{61}Ni* produced in

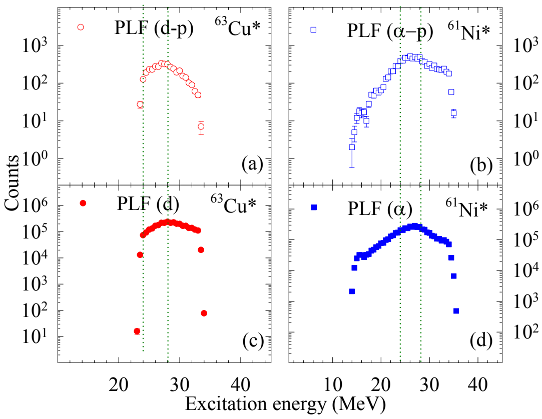

FIG. 1: Excitation energy spectra for ^{63}Cu* and ^{61}Ni*, with and without coincidence of evaporated protons (see text).

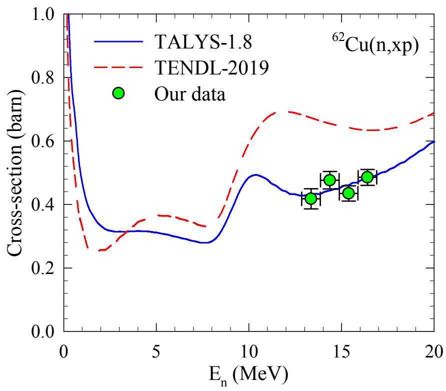

FIG. 2: The measured ^{62}Cu(n,xp) cross sections have been compared with predictions of TALYS-1.8 code and TENDL-2019 evaluation (see text).

^{59}Co(^{6}Li,d) and ^{59}Co(^{6}Li,α) reactions respectively with and without coincidence of evaporated protons are shown in Figs. 1[(a) and (b)], and Figs. 1[(c) and (d)]. The CN ^{63}Cu* and ^{61}Ni* are found to be populated at overlapping excitation energies. The evaporation proton spectrum from the CN ^{63}Cu* at E^* =28 MeV has also been observed and compared well with the PACE4 predictions, confirming their compound nuclear evaporation nature. We have determined the ^{62}Cu(n,xp) cross sections for region between dotted lines (in excitation energy range of 24 - 27 MeV) of above Fig. using Eq. (1).

$$\frac{\sigma^{62Cu(n,xp)}(E^*)}{\sigma^{60Ni(n,xp)}(E^*)} = \frac{\sigma^{CN}_{n+^{62}Cu}(E^*)}{\sigma^{CN}_{n+^{60}Ni}(E^*)}\frac{\mathrm{P}_p^{63Cu}(E^*)}{\mathrm{P}_p^{61Ni}(E^*)}. \quad (1)$$

The CN formation cross sections ($\sigma^{CN}(E^*)$) are calculated from statistical model code TALYS-1.8 and the proton decay probabilities ($\mathrm{P}_p^{CN}(E^*)$) for CN produced in the transfer reactions are obtained experimentally using the following relation:

$$\mathrm{P}_p^{CN}(E^*) = \frac{N_{d/\alpha,p}(E^*)}{N_{d/\alpha}(E^*)}. \quad (2)$$

Results and Discussions

The ^{62}Cu(n,xp) cross sections have been determined within the framework of hybrid surrogate ratio approach in excitation energy range of 24 - 27 MeV (in steps of 1 MeV bin) which correspond to equivalent neutron energy of 13.4 - 16.4 MeV. We have compared measured ^{62}Cu(n,xp) cross sections with available data evaluation library TENDL-2019 and the statistical model calculations using code TALYS-1.8 as shown in Fig. 2. The experimental cross sections compare reasonably well with the predictions of the TALYS-1.8 code, whereas the data evaluation library TENDL-2019 over-predicts the experimental data. The observed discrepancy between TENDL-2019 evaluation and measured ^{62}Cu(n,xp) cross sections demands the need of new evaluations and revisit the TENDL-2019 evaluation for this reaction.

References

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