Determination of ^{58}Co(n,xp) cross sections using surrogate reaction ratio method

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Introduction

Neutron induced reaction cross sections are of primary importance for the design of advance reactor concepts such as ADS and fusion reactors. Inside a fusion reactor, high energy (14.1 MeV) neutrons are produced via D-T fusion that lead to various reactions. The neutron induced reactions that produce gaseous products such as hydrogen (H) and helium (He) through (n,xp) and (n,$x\alpha$) reactions, lead to swelling and embrittlement of structural materials (SS) of the reactor. There are numerous 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,$x\alpha$) cross sections with these radionuclei and SS are very important for safety and design analysis, and to understand overall neutronics of a fusion reactor [1–3]. ^{58}Co with half life $T_{1/2} = 70.86$ d is one of the important radionuclides produced in the fusion reactor. The ^{58}Ni(n,p), ^{60}Ni(n,t) and ^{61}Ni(n,nt) reactions are the major pathways that produce ^{58}Co in a typical fusion reactor [4]. Direct measurement of ^{58}Co(n,xp) cross sections is extremely difficult due to short half life of ^{58}Co target and these cross sections are not available in literature. In the present work ^{58}Co(n,xp) cross-sections have been measured experimentally using surrogate reaction ratio method and using known ^{60}Ni(n,xp) cross section values from the literature as reference [5].

Experimental details and data analysis

Measurements were carried out at BARC-TIFR Pelletron Accelerator Facility in Mumbai. Freshly prepared self-supporting targets ^{57}Fe (enriched) and ^{59}Co (abundance ≈ 100%), of thicknesses ≈ 850 μg/cm^2 and ≈ 500 μg/cm^2 were bombarded by ^{6}Li beams of energy $E_{\rm lab} = 37$ MeV and 33 MeV respectively. The surrogate reactions of interest, the compound nuclei (CN) formed, and corresponding equivalent neutron induced reactions for the present experiment are listed in Table I.

TABLE I: see text.

$E^{^6Li}_{beam}$ (MeV)	Surrogate reaction	CN	Equivalent neutron induced reaction
37	^{57}Fe(^{6}Li,α)^{59}Co*	^{59}Co*	^{58}Co(n,xp)
33	^{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 23° for identification of projectile like fragments (PLFs). Two large area Si strip detector telescopes (S1 and S2) were mounted at backward angles 120° and 150°, to detect evaporated particles (e.g., p, d, t, and α) from the

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compound nuclei ^{59}Co* and ^{61}Ni* in coincidence with the PLF (α). The time correlations between the PLFs detected in the T and the corresponding evaporation particles (from the residual CN) detected in detector S1 or S2, were recorded by Time to Amplitude Converter (TAC).

Two body kinematics is employed to obtain excitation energy spectra of compound systems ^{59}Co* and ^{61}Ni* produced in ^{57}Fe(^{6}Li,α) and ^{59}Co(^{6}Li,α) reactions respectively, without (N_α) and in coincidence with evaporated protons ($N_{\alpha,p}$). The compound systems ^{59}Co* and ^{61}Ni* are found to be populated at overlapping excitation energies. The proton evaporation probabilities ($\mathrm{P}_p^{CN}(E^*)$) for CN produced in the transfer reactions are obtained experimentally in excitation energy range of 22–27 MeV using the following relation:

$$\mathrm{P}_p^{CN}(E^*) = \frac{N_{\alpha,p}(E^*)}{N_\alpha(E^*)}. \tag{1}$$

Using these measured $\mathrm{P}_p^{CN}(E^*)$ values and the CN formation cross sections ($\sigma^{CN}(E^*)$) calculated from statistical model code TALYS-1.8, we have determined the ^{58}Co(n,xp) cross sections using following equation in excitation energy range of 22–27 MeV.

$$\frac{\sigma^{^{58}Co(n,xp)}(E^*)}{\sigma^{^{60}Ni(n,xp)}(E^*)} = \frac{\sigma^{CN}_{n+^{58}Co}(E^*)}{\sigma^{CN}_{n+^{60}Ni}(E^*)}\frac{\mathrm{P}_p^{^{59}Co}(E^*)}{\mathrm{P}_p^{^{61}Ni}(E^*)}. \tag{2}$$

The excitation energy range was then converted to equivalent neutron energy range of E_n = 11.7-16.8 MeV, using the expression $E_n = \frac{A+1}{A}(E^* - S_n)$, where A+1 (= 59). The hence determined cross sections for ^{58}Co(n,xp) reaction are shown in Fig. 1.

It is important to mention here that for our systems we have validated the applicability of SRM to determine the desired (n,xp) cross sections by satisfying following 3 conditions [6, 7], (1) the spin distributions in two compound nuclei ^{59}Co* and ^{61}Ni* populated by two surrogate reactions ^{57}Fe(^{6}Li,α) and ^{59}Co(^{6}Li,α) used in the SRM are found to be equivalent, (2) the difference of the representative spin values between the neutron-induced and surrogate reactions is not much larger than $10\hbar$, and (3) the weak Weisskopf-Ewing condition on J^π-by-J^π convergence of the branching ratios is satisfied for the present systems in the excitation energy range of E^*=22-27 MeV (convergence is of the order of 0.2-8.7%).

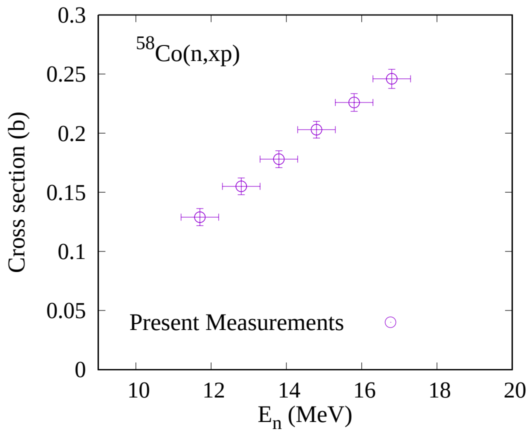

FIG. 1: The determined ^{58}Co(n,xp) reaction cross sections as a function of equivalent neutron energy (E_n)

Results

The ^{58}Co(n,xp) cross sections have been determined in equivalent neutron energy of 11.7-16.8 MeV, within the framework of the surrogate reaction ratio method.

References

[1] H. Iida et al., Nuclear Analysis Report (NAR), ITER Report, G 73, July 2004.
[2] R. A. Forrest, Fusion Eng. Des. **81**, 2006.
[3] Ramandeep Gandhi et al., Phys. Rev. C **100**, 054613 (2019).
[4] R. A. Forrest et al., Handbook of Activation Data Calculated Using EASY-2007.
[5] Jutta E. Escher et al., Rev. Mod. Phys. **84**, 353 (2012).
[6] Chiba and Iwamoto, Phys. Rev. C **81**, 044604 (2010).
[7] Ramandeep Gandhi et al., Phys. Rev. C **106**, 034609 (2022).