Determination of ^{53}Mn(n,xp) cross sections using surrogate reaction ratio method

Ramandeep Gandhi[1],* B. K. Nayak[1,2], S. V. Suryanarayana[1], A. Pal[1], G. Mohanto[1], Sukanya De[1], A. Parihari[1], A. Kundu[1], P. C. Rout[1,2], S. Santra[1,2], K. Mahata[1,2], B. Srinivasan[1], E. T. Mirgule[1], and J. Pandey[4]
[1]*Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai 400085, INDIA*
[2]*Homi Bhabha National Institute, Anushaktinagar, Mumbai 400094, INDIA*
[3]*Inter University Accelerator Centre, New Delhi 110067, INDIA and*
[4]*Department of Physics, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand 263145, INDIA*

Introduction

Nuclear reaction cross sections data are important for a variety of nuclear physics applications in the areas of nuclear energy and national security. Not all relevant data can be directly measured in the laboratory or easily determined by calculations. The deuterium-tritium (D-T) reaction has been identified as the most efficient for fusion devices. 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 of the reactor. Due to succesive neutron capture, various long lived radio-nuclides are produced in the structural materials during opration of the reactor.^{53}Mn($T_{1/2} = 3.74\times 10^6$ y), ^{55}Fe($T_{1/2} = 2.73$ y), ^{60}Fe($T_{1/2} = 1.5 \times 10^6$ y), ^{60}Co($T_{1/2} = 5.27$ y), ^{59}Ni($T_{1/2} = 7.6 \times 10^4$ y) and ^{63}Ni($T_{1/2} = 100.1$ y) are some of the long lived radio-nuclei produced in the mass region 50-60. Fusion neutronics studies have been done so far considering only the stable isotopes of structural materials (Cr, Fe, and Ni) [1–3]. In order to quantify the damage during the operation of the reactor and to understand overall neutronics of a fusion reactor, the experimental data on (n,xp) and (n,x) cross-sections with these long-lived radionuclei are very important.

Out of unstable radio-nuclei mentioned above ^{53}Mn is produced during reactor operation predominantly via ^{54}Fe(n,np), ^{54}Fe(n,d) and ^{54}Fe(n,2n)^{53}Fe(β^+) [4]. The ^{53}Mn produced will lead to hydrogen(H) and helium(He) production through (n,xp) and (n,xα) reactions. Due to unavailability of a ^{53}Mn target in nature, direct measurement of (n,xp) and (n,xα) cross-sections are extremely difficult. As of now, there is no experimental data on (n,xp) and (n,xα) cross-sections for ^{53}Mn is availbale in literature. In present work we have determined ^{53}Mn(n,xp) cross sections using surrogate reaction ratio method similar to our recent work [5].

Experimental details and Data Analysis

Measurements were carried out at BARC-TIFR Pelletron accelerator facility at Mumbai. Natural Cr (abundance ^{52}Cr ≈ 84%) of thickness ≈ 578 μg/cm^2 and ^{59}Co (abundance ≈ 100%) of thickness ≈ 500 μg/cm^2 were bombarded by ^{6}Li beams at incident energies of $E_{\rm lab}$ = 33.0 MeV and 40.5 MeV, respectively. The projectile like fragments(PLFs) were identified by silicon surface barrier (SSB) ΔE-E telescope with thicknesses of $\Delta E \approx 150$ μm and E ≈ 1 mm, mounted at 25°. Evaporated particles (e.g., p, d, t, and α) from the compound nuclei ^{54}Mn* and ^{61}Ni* in coincidence with the PLF(α) were detected by 2 Si strip detector telescopes (S1 and S2),with thicknesses of $\Delta E \approx 150$ μm and E ≈ 1 mm, mounted at backward angles 120° and 150°. The time correlation between

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*Electronic address: `ramangandhipu@gmail.com` light charged particles and decay particles (p) were recorded through a time to amplitude converter (TAC). Surrogate reactions investigated in the present experiment, the compound nuclei (CN) formed, and corresponding equivalent neutron induced reactions are given in Table below.

E^{6Li}_{beam} (MeV)	Surrogate reaction	CN (MeV)	Equivalent neutron induced reaction
33	^{52}Cr(^{6}Li,α)^{54}Mn*	^{54}Mn*	^{53}Mn(n,xp)
40.5	^{59}Co(^{6}Li,α)^{61}Ni*	^{61}Ni*	^{60}Ni(n,xp)

The compound systems ^{54}Mn* and ^{61}Ni* are found to be populated at overlapping excitation energies in the range of ≈ 17 - 25 MeV as shown in Fig.1. ^{53}Mn(n,xp) cross sections are determined using following relation:

$$\frac{\sigma^{^{53}Mn(n,xp)}(E^*)}{\sigma^{^{60}Ni(n,xp)}(E^*)} = \frac{\sigma^{CN}_{n+^{53}Mn}(E^*)}{\sigma^{CN}_{n+^{60}Ni}(E^*)} \frac{\mathrm{P}^{^{54}Mn}_{p}(E^*)}{\mathrm{P}^{^{61}Ni}_{p}(E^*)}. \quad (1)$$

Decay probabilities ($\mathrm{P}^{C.N}_{p}(E^*)$) are experimentally measured and compound nuclear formation cross-sections ($\sigma^{CN}(E^*)$) are calculated from TALYS-1.8 code. $\sigma^{^{60}Ni(n,xp)}(E^*)$ are taken from [5].

Results and Discussions

The ^{53}Mn(n,xp) cross sections in the excitation energy range of 17 - 25 MeV (in steps of 1 MeV bin) which correspond to equivalent neutron energy of 8.2 - 16.4 MeV have been determined within the framework of surrogate reaction ratio method. The present experimental cross sections of ^{53}Mn(n,xp) have been compared with data evaluation libraries EAF-2010, ROSFOND-2010, and JEFF-3.3 as shown in Fig.2. The experimental cross sections are found to be well explained by the results obtained from various data evaluation libraries like EAF-2010, ROSFOND-2010, and JEFF-3.3 in the equivalent neutron energy range measured in present study.

References

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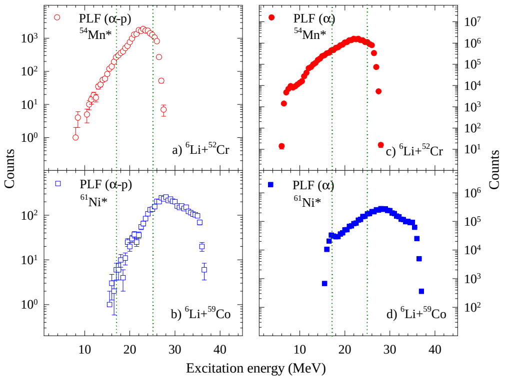

FIG. 1: Excitation energy spectra of the target-like fragments produced in ^{6}Li + ^{52}Cr and ^{6}Li + ^{59}Co reactions corresponding to PLF α with [(a), (b)] and without [(c), (d)] coincidence with evaporated protons.

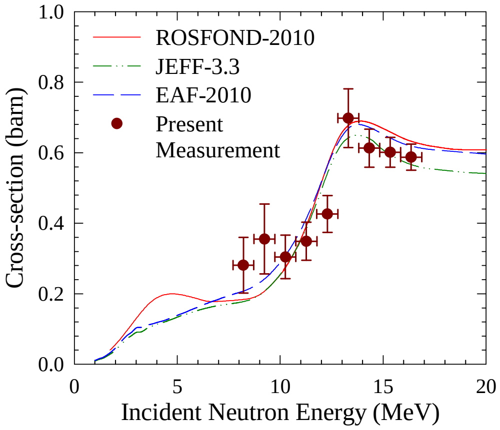

FIG. 2: The experimental ^{53}Mn(n,xp) cross sections as a function of equivalent neutron energy along with the ones from various nuclear data libraries.

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