Measurement of ^{54}Mn(n, xp) cross section using Surrogate Ratio Method

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Introduction

Nuclear data are of importance in advancing nuclear technology, particularly in the design and operation of fission power plants, fusion devices, and particle accelerators. In fusion reactors, the intense flux of high-energy neutrons generated by the D+T reaction plays a vital role. These neutrons interact with structural materials, inducing various nuclear reactions that result in atomic displacement within the materials, leading to the generation and accumulation of radiation defects. These effects alter the physical properties of the materials over time. Particularly, the production of gaseous elements like hydrogen (H) and helium (He) is primarily driven by (n, xp) and (n, xα) reactions on the first wall, structural, and blanket materials of the fusion reactor. Additionally, the high neutron flux leads to the creation of both short-lived and long-lived radionuclides through transmutation reactions with the stainless steel compositions (Fe, Ni, Mn, Cr, Co and Nb)[1]. The ^{54}Mn isotope ($t_{1/2}$ = 312.1 days) is one of the unstable radio-nuclei produced during the operation of reactor through major pathways such as ^{55}Mn(n, 2n), ^{54}Fe(n, p), ^{58}Ni(n, pα) and ^{56}Fe(n, np) reactions.

There are no experimental cross section data available for ^{54}Mn(n, xp) reactions. As the ^{54}Mn target is radio-nuclide, direct measurement of (n, xp) reaction cross section is difficult and to overcome this problem, Surrogate Ratio Method (SRM) technique is used in this study to obtain the ^{54}Mn(n, xp) cross section.

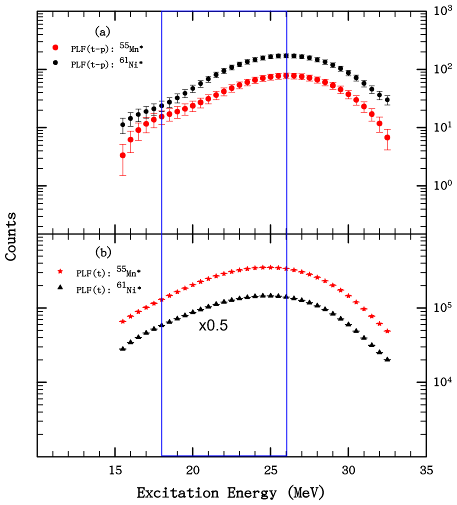

FIG. 1: Excitation energy spectra for ^{55}Mn* and ^{61}Ni*, with and without coincidence between PLF (triton) and evaporated protons.

Experimental Details

The experiment was conducted at the BARC-TIFR Pelletron Accelerator Facility in Mumbai by bombarding a ^{7}Li beam onto a freshly prepared, enriched, and self-supported ^{51}V target of thickness $\approx 790\mu$g/cm^2 and ^{57}Fe target of thickness $\approx 570\mu$g/cm^2 at a beam energy of E_{lab} = 34 MeV and 36 MeV respectively. In this work, the surrogate reactions of interest and equivalent neutron reactions are listed in Table I. Two Silicon Surface Barrier (SSB) and two Strip telescopes were used at

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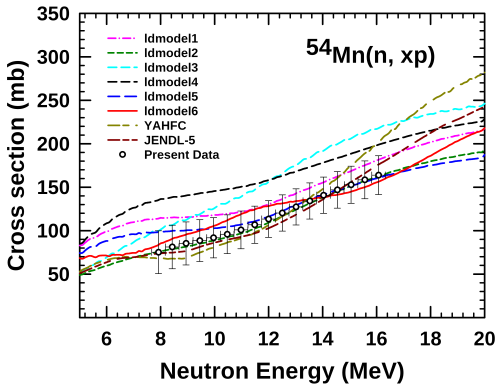

FIG. 2: The experimental cross sections for the ^{54}Mn(n, xp) reactions have been compared with YAHFC (ver-3.66) calculations , JENDL-5 evaluated results, and TALYS-1.96 predictions using different level-density models and default parameters.

forward angles, covering 15° to 75°, to detect the Projectile-Like Fragments (PLFs). Additionally, two Strip Telescopes were used at backward angles of 160° to detect evaporated particles from the compound nuclei (^{55}Mn* and ^{61}Ni*) in coincidence with the PLFs.

TABLE I: Surrogate reactions and their corresponding equivalent neutron-induced reactions.

$E^{7\text{Li}}_{\text{beam}}$ (MeV)	Surrogate reactions	CN	Equivalent reaction
34	^{51}V(^{7}Li, t)	^{55}Mn*	^{54}Mn(n, xp)
36	^{57}Fe(^{7}Li, t)	^{61}Ni*	^{60}Ni(n, xp)

Data Analysis

The energy calibration of the SSB telescopes and the strip telescopes was performed using the reaction ^{12}C(^{7}Li, α)^{15}N, measured at an incident laboratory energy of E_{lab} = 24 MeV. The known excited states of ^{15}N* were used for calibration. The excitation energy of the compound nucleus (^{55}Mn* and ^{61}Ni*) populated by the Surrogate reactions ^{51}V(^{7}Li, t) and ^{57}Fe(^{7}Li, t) were measured by the triton energy spectrum from the forward detectors. The excitation energy spectra with and without coincidence PLF (triton) and evaporated proton are shown in Fig.1.(a) and Fig.1.(b) respectively. The present ^{54}Mn(n, xp) cross sections were measured for excitation energy region between blue lines shown in Fig. 1 (a) and (b) (18 - 26 MeV) using the following equations.

$$\frac{\sigma^{^{54}\text{Mn}(n,xp)}(E_x)}{\sigma^{^{60}\text{Ni}(n,xp)}(E_x)} = \frac{\sigma^{\text{CN}}_{n+^{54}\text{Mn}}(E_x)}{\sigma^{\text{CN}}_{n+^{60}\text{Ni}}(E_x)} \frac{P^{^{55}\text{Mn}^*}_{xp}(E_x)}{P^{^{61}\text{Ni}^*}_{xp}(E_x)} \tag{1}$$

Where, the CN formation cross sections ($\sigma^{CN}(E_x)$) are calculated from statistical model code PACE4 and the proton decay probabilities ($P^{CN}_p(E_x)$) are obtained experimentally using the following relation.

$$P^{CN}_{xp}(E_x) = \frac{N_{t,p}(E_x)}{N_t(E_x)} \tag{2}$$

Where, N_t and $N_{t,p}$ are the triton singles and triton-proton coincidence counts at E_x, respectively. The cross sections shown in Fig.2 include only the statistical errors. The reference reaction ^{60}Ni(n, xp) cross sections were taken from the JENDL-4 library.

Results and Discussion

The experimental cross sections of the ^{54}Mn(n, xp) reaction are obtained using the SRM technique in the neutron energy range of 8 to 16 MeV. Theoretical calculations were done using TALYS-1.96 and YAHFC with different level density models. The experimental results compared well with the TALYS models: ldmodel 1, 2, 5, and 6 and results from YAHFC code. Additionally, the JENDL-5 library shows good agreement with the experimental results.

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References

[1] Ramanadeep Gandhi *et.al.*, Phys. Rev. C**106**, 034609 (2022).