Measurement of cross section for the ^{94}Mo(n,p)^{94}Nb reaction using surrogate reaction ratio method

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Introduction

The neutron induced reaction cross-sections of the structural materials have critical importance from the point of view of neutron economy for advanced reactor designs specially for the choice of reactor grade materials. Materials inside a fusion reactor are exposed by high energy neutrons ∼ 14 MeV and for spallation neutrons in ADSs this can go upto ∼ 100 MeV. This high-energy neutron flux causes radiation defects to the surrounding materials by atomic displacement and nuclear transmutations. Many long-lived radionuclides are produced through neutron induced reactions such as (n,2n), (n,p), (n,α) etc. Apart from producing radioactive elements, (n,p) and (n,α) reactions cause damage to the material by producing gases like Hydrogen and Helium. Stainless steel (SS) is a widely used structural material in these facilities which has Molybdenum as one of its important composition. As of today, only limited data is available in the literature for direct experimental measurement of the ^{94}Mo(n,p)^{94}Nb cross section. In this study, we will present measurement carried out to obtain the cross-section of ^{94}Mo(n,p)^{94}Nb using surrogate ratio (SR) method [1–3]. The measurement was done through the reaction $^{93}\mathrm{Nb}(^{6}\mathrm{Li},\alpha)^{95}\mathrm{Mo}^{*}$ which is a surrogate reaction to n+ ^{94}Mo. For reference, ^{90}Zr(n,p)^{90}Y reaction was used which was measured in the same setup by using a similar surrogate reaction $^{89}\mathrm{Y}(^{6}\mathrm{Li},\alpha)^{91}\mathrm{Zr}^{*}$.

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Experimental Method

The experiment was carried out at BARC-TIFR Pelletron LINAC facility, Mumbai. Self-supporting ^{93}Nb and ^{89}Y targets (thickness ∼ 1 mg/cm^2) were bombarded with 40 MeV ^{6}Li beam. Four (ΔE-E) telescopes detectors (T1-T4), made of silicon surface barrier detectors, were placed around grazing angle (20°, 30°, 40°, 50°) to detect projectile like fragments (PLFs). Evaporated protons were detected at an angle of $140° - 160°$ with respect to the beam using two large area ΔE-E telescope detectors consisting of Si strip detectors. Energy calibration of the detectors was done using standard radioactive source of ^{229}Th as well as using ^{6}Li + ^{12}C reaction at energies 20 and 40 MeV. Figure 1 shows the energy calibration plot for one of the telescopes (T2).

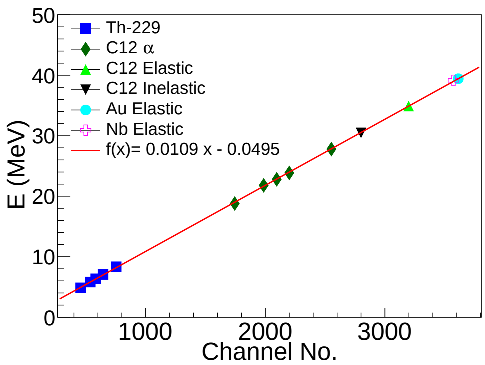

FIG. 1: Energy calibration plot of T2 telescope.

Result and Discussion

Two-dimensional plot of ΔE (energy loss in ΔE detector) vs. E_{total} (total energy) for tele-

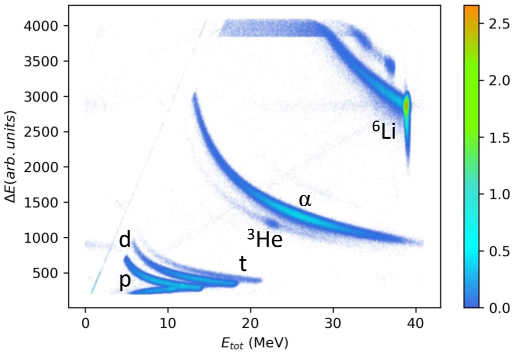

FIG. 2: Correlation plot of ΔE (energy loss) vs. $E_{\rm total}$ (total energy) for particles detected in telescope T2 at 30°.

scope T2 is shown in Figure 2. It can be seen that different charged particles (p, d, t, α) are well separated and can be identified. The coincidence data was measured between evaporated proton and α-particles. After selecting only α-particles from these spectra, the excitation energy of target-like fragments were obtained. Excitation energy spectra for singles PLF (α) from ^{95}Mo* and ^{91}Zr* compound nuclei are shown in Figures 3(a,c) and the energy spectra for coincident events between α and p are shown in Figures 3(b,d). The overlapping excitation energies of compound systems ^{95}Mo* and ^{91}Zr* are found to be in the range of $\approx 15-30$ MeV. The proton decay probabilities from ^{95}Mo* and ^{91}Zr* are obtained using the relation

$$P_p^{\rm CN}(E^*) = \frac{N_{\alpha,p}(E^*)}{N_\alpha(E^*} \quad (1)$$

where, $N_\alpha(E^*)$ and $N_{\alpha,p}(E^*)$ denote the singles (α) and coincidence (between PLFα and evaporated p) counts, at an excitation energy of E^*. The cross section of ^{94}Mo(n,p) and ^{90}Zr(n,p) denoted as $\sigma^{^{94}{\rm Mo}(n,p)}$, and $\sigma^{^{90}{\rm Zr}(n,p)}$, respectively follows the relation

$$\frac{\sigma^{^{94}{\rm Mo}(n,p)}(E^*)}{\sigma^{^{90}{\rm Zr}(n,p)}(E^*)} = \frac{\sigma^{\rm CN}_{n+^{94}{\rm Mo}}(E^*)}{\sigma^{\rm CN}_{n+^{90}{\rm Zr}}(E^*)}\frac{P_p^{^{95}{\rm Mo}}(E^*)}{P_p^{^{91}{\rm Zr}}(E^*)} \quad (2)$$

The value of $\sigma^{^{90}{\rm Zr}(n,p)}(E^*)$ was taken from

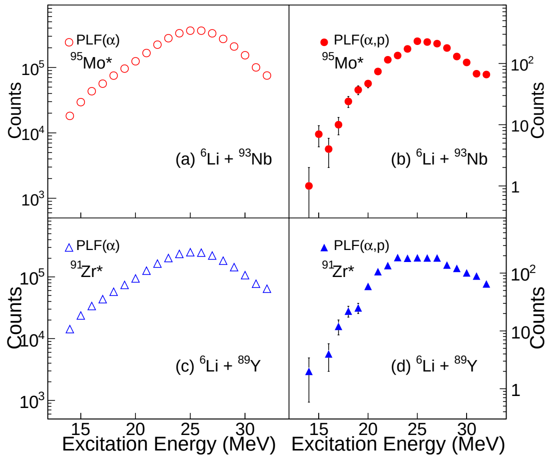

FIG. 3: Excitation energy spectra for target like fragments produced in reactions ^{6}Li+^{93}Nb, ^{89}Y. Figures (a) and (c) show counts for the singles α-particle events. Figures (b) and (d) show the coincident events between PLF α-particles and evaporated protons for ^{6}Li+^{93}Nb, ^{89}Y, respectively.

ENDF VIII evaluation which reproduces the available experimental data in EXFOR very well. The capture cross sections $\sigma^{\rm CN}_{n+^{94}{\rm Mo}}(E^*)$ and $\sigma^{\rm CN}_{n+^{94}{\rm Mo}}(E^*)$ are calculated using the statistical model code TALYS-1.8 [4]. From the excitation energy E^*, the equivalent neutron energy E_n can be obtained using the expression $E_n = \frac{A+1}{A}(E^* - S_n)$. Here, A is the mass number of the reacting nucleus and S_n is the neutron separation energy of the compound nucleus. Analysis is in progress to extract the cross section of ^{94}Mo(n,p)^{94}Nb as a function of E_n.

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References

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