# Estimate of (n, p) Cross-section for Unstable Nuclide $^{53}$Mn

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## Introduction

$^{53}$Mn is one of the long-lived radionuclides (decay by electron capture) having half life of $3.74\times10^6$ year, produced inside the fusion reactor, due to transmutation of stable isotopes of Stainless Steel (SS) present in the structural materials **[1,2].** Due to its longer half life and as primary nuclide (isotopes having percentage contribution ≥50%) it interacts with neutrons inside the reactor and give rise to different nuclear reactions depending on the neutron energy and reaction Q values. Neutrons emitted in a D-T fusion reactor ($D+T\rightarrow n+\alpha+17.6$ MeV) are of 14.1 MeV energy, however inside the fusion reactor the energy of the neutrons degrades due to interactions with various reactor materials resulting in a neutron spectrum with energy from eV to MeV range. From neutronics point of view, it is therefore important to study the nuclear reactions such as $^{53}$Mn(n,p), $^{53}$Mn(n,α), $^{53}$Mn(n,d) and $^{53}$Mn(n,t). The (n,p) (n, α) and (n,d) reactions can cause the production of hydrogen, helium and deuterium gases while (n,t) is important for production of tritium ($^3$H; $T_{½}$=12.33 year) inside the fusion reactor **[3].** The (n,p) and (n,α) reactions are more critical because He/H deposit at different locations inside the reactor can degrade the integrity of the materials.

$^{55}$Mn is the only one stable isotope found in nature with abundance 100%. $^{53}$Mn is radioactive and is produced during the operation of the fusion reactor through different pathways given by $^{54}$Fe(n,np), $^{54}$Fe(n,2n)$^{53}$Fe($\beta^+$), $^{54}$Fe(n,d) **[4].** Neutron induced cross-section measurements by direct neutron activation method is not feasible because $^{53}$Mn target cannot be made and therefore, one needs indirect methods to estimate these cross sections.

## Experimental Details

Recently measurement of $^{55}$Fe(n,p) reaction cross-section has been carried out using surrogate technique. In this method, the transfer reaction $^{52}$Cr($^6$Li,d)$^{56}$Fe* is measured which is the surrogate of the desired reaction $^{55}$Fe(n,p) **[5]** leading to same compound system $^{56}$Fe*. In the experiment, the deuteron (PLF) was detected in coincidence with protons coming as evaporation from $^{56}$Fe*. It is observed that in the same experiment, another PLF α-channel is also present given by transfer reaction $^{52}$Cr($^6$Li,α)$^{54}$Mn*. This is the surrogate of the $^{53}$Mn(n,p) reaction. In this paper, this surrogate reaction has been studied to measure $^{53}$Mn(n,p) reaction cross-section by using nuclear reaction modular codes EMPIRE and TALYS **[6]** and compare the values with systematics **[7],** and evaluated data libraries **[8].** Table-1 shows the calculation for all isotopes of Fe and Mn. Comparison of the calculated cross-sections with available evaluated data libraries and systematics has been shown in Fig.1 for $^{53}$Mn(n,p). The experimental data is under analysis to determine the $^{53}$Mn(n,p) reaction cross-section data by measuring the alpha (PLF) in singles and alpha and proton (evaporation from $^{54}$Mn*) in coincidence. Transfer reaction $^{45}$Sc($^6$Li,α)$^{47}$Ti* has been chosen as surrogate of the known (for which experimental data is available) $^{46}$Ti(n,p) reaction, which is the reference reaction for both the above desired reaction ( i.e. $^{55}$Fe(n,p) and $^{53}$Mn(n,p) ) to be used in the surrogate ratio method. All the detailed information about three reactions, $^{6}$Li+$^{52}$Cr→d+$^{56}$Fe* [surrogate of $^{55}$Fe(n,p)], $^{6}$Li+$^{52}$Cr→α+$^{54}$Mn* [surrogate of $^{53}$Mn(n,p)] and $^{6}$Li+$^{45}$Sc→α+$^{47}$Ti*[surrogate of $^{46}$Ti(n,p), also known as reference reaction in the present experiment] will be presented.

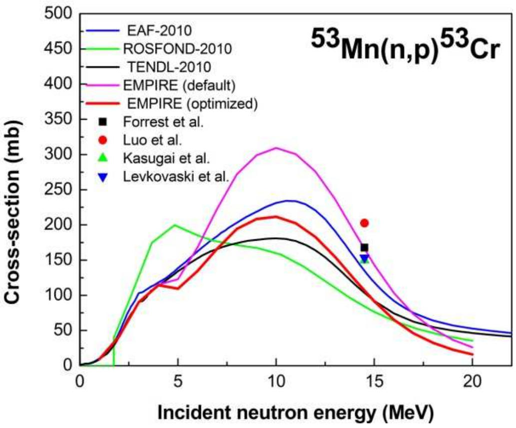

**Fig.1** (color online) Comparison of calculated excitation function of $^{53}$Mn(n,p) with systematics and evaluated data files.

## References

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**TABLE 1-** Comparison of Nuclear model calculations and semi-empirical formula (Forrest, 1986) for **Fe** and **Mn** cross-section at 14.5 MeV

| **Reaction** | **Model Calculations (mb)** | | **Semi-emp.[7] formula (S) (mb )** | **Exp. data [11] (E) (mb)** | **Deviation** | | |
|---|---|---|---|---|---|---|---|
| | EMPIRE (C1) | TALYS (C2) | | | (C1- E) / E | (C2- E) / E | (S- E) / E |
| $^{54}$Fe(n,p) | 301 | 295 | 355 | 315±10 | -0.044 | -0.063 | 0.126 |
| **$^{55}$Fe(n,p)**<br>our experiment | 217 | 198 | 190 | 189±15<br>our measurement | 0.148 | .047 | .0052 |
| $^{56}$Fe(n,p) | 106 | 112 | 101 | 108±3 | -0.019 | 0.037 | -0.065 |
| $^{57}$Fe(n,p) | 58 | 61 | 54 | 80±10 | -0.275 | 0.238 | 0.325 |
| **$^{53}$Mn(n,p)** | 106.57 | 103.31 | 167.79 | Exp.data analysis in progress | | | |
| $^{55}$Mn(n,p) | 34.79 | 26.91 | 45.30 | 63 | -0.447 | -0.573 | -0.280 |