Investigation of Surrogate method for $^{55}Fe(n,p)^{55}Mn$ Reaction Cross-section Measurement

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Introduction

There are many short-lived isotopes present in fusion reactor environment whose neutron induced cross-sections cannot be determined either by conventional methods or have very contradictory results. These isotopes are quite important in the fusion reactor but non-availability of their neutron induced cross-sections introduces major uncertainty in the design of its components. The measurement of cross-sections of these nuclides is extremely difficult as they do not exist in nature. Surrogate method, which is an indirect way of determining cross-sections for nuclear reactions that proceed through a compound nucleus, is a promising method for neutron induced cross-section measurement on such nuclides. This method has an advantage that the target material required for the experiment is stable and the compound nucleus is formed via a charged particle interaction on the target nuclei.

In the present work we studied the feasibility of surrogate technique for the cross-section measurement of $^{55}Fe(n, p)^{55}Mn$. This reaction is very important in fusion environment as ^{55}Fe ($t_{1/2}$=2.73 years) is produced via $^{56}Fe(n,2n)^{55}Fe$ nuclear reaction with fast neutrons **[1,2].** It will be first time to use of surrogate method in fusion applications in this mass region.

Theoretical investigation of the 'DESIRED' Reaction mechanism

We studied several Possible Surrogate Reactions for the desired reaction of $^{55}Fe(n, p)^{55}Mn$. We selected $^{52}Cr(6Li, d)^{56}Fe^*$ as a possible reaction that matches with the desired reaction as discussed below.

The following conditions need to be satisfied for the measurement of desired reaction cross-section using surrogate method: (i) The surrogate method can only be used when the desired reaction takes place through a compound nucleus formation, (ii) spin and parity values should remain similar in Direct and Surrogate reaction routes (iii) Compound Nucleus Excitation Energy should be same in both desired reaction and surrogate reaction **[3].**

The excitation energy of the compound nucleus $^{56}Fe^*$ formed via $^{55}Fe(n, p)^{55}Mn$ at E_n~14 MeV and the $^{56}Fe^*$ formed via surrogate reaction $^{52}Cr(^6Li, d)^{56}Fe^*$ at E_{Li} ~33 MeV are same (E_{exc} of $^{56}Fe^*$ ~ 25 MeV).

According to the W-E approximation **[4],** the formula for compound nucleus reaction cross-section is simplified as (Applicable only at High Excitation Energy)

$$\sigma_{\alpha\gamma} = \sum_{J,\pi} \sigma_{\alpha}^{CN}(E_{ex,J,\pi})\ G_{\gamma}^{CN}(E_{ex,J,\pi}) \Rightarrow \sigma_{\alpha\gamma} = \sigma_{\alpha}^{CN}(E_{ex})\ G_{\gamma}^{CN}(E_{ex})$$

Where α and γ denote the relevant entrance and exit channels and G_{γ}^{CN} is decay probabilities for the different decay channels γ.

It is found that the pre-equilibrium contribution to $^{55}Fe(n, p)^{55}Mn$ reaction is ~ 17% whereas 83% takes place through compound nucleus formation at E_n~14MeV. Previous studies of neutron-induced charged-particle-producing reactions at 15 MeV in this mass region (A~ 50-60) have shown that proton and alpha particle emission proceeds largely through compound nuclear reactions, while (n,d) reaction is primarily direct **[5,6].**

Further, to check the feasibility of measurement of ^{55}Fe(n, p)^{55}Mn reaction cross-section using surrogate method, theoretical study has been performed using the nuclear reaction modular codes EMPIRE-3.1 **[7]** & TALYS-1.4 **[8].** Our calculations showed that all the above mentioned three conditions are satisfied for the surrogate reaction ^{52}Cr(^{6}Li,d)^{56}Fe*.So we can use the surrogate method to measure the ^{55}Fe(n, p)^{55}Mn cross-section at E_n ~9-14 MeV. Two methods (absolute and ratio method) can be employed involving stable target and projectile nuclei to estimate the compound nuclear cross sections for short lived target nuclei. Surrogate Ratio Method is of three types (External, Internal, Hybrid) which depends on the projectile target combination, entrance and exit channel in desired and surrogate reaction **[9,10,11].** For our case we will use Absolute method as well as External Surrogate Ratio Method (ESRM).

Experimental Plan

The mass and thickness of the Chromium -52 target calculated using SRIM-2008 monte-carlo code **[12]** is 93.82 μg and 121 μg/cm^2 respectively. Natural Cr consists of ^{52}Cr (83.78 %), ^{53}Cr (9.50 %), ^{54}Cr (2.36 %). These values have been obtained by demanding a negligible energy loss of lithium beam in the target.

We proposed an experiment which will be carried out at PLF, TIFR, Mumbai, where the cross section of ^{55}Fe(n, p)^{55}Mn reaction ($E_{n\,=}$ 9-14 MeV) will be measured by the surrogate reaction ^{52}Cr(^{6}Li, d)^{56}Fe* ($E_{(lab)}$ of ^{6}Li = 25 – 35 MeV) by employing particle identification technique using ΔE – E telescope method. The Silicon Surface Barrier (SSB) detectors will be used in the ΔE – E telescope. The size of ΔE detector will be around ~ 150 μm whereas E detector will be around ~ 2 mm. In the experiment, the evaporated protons will be detected in coincidence with deuterons.

Conclusions

It has been investigated that the measurement of cross-section of the desired reaction ^{55}Fe(n, p)^{55}Mn is possible through Surrogate method ^{52}Cr(^{6}Li, d)^{56}Fe*. Proposed surrogate reaction fulfils all the requirements of surrogate method.

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