Calculation of (n,α) reaction cross-sections and examination of Weisskopf-Ewing approximation for (n,α) reactions

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Introduction

Out of the many neutron-induced reactions that take place inside a fusion reactor, the ones that produce gaseous elements like hydrogen and helium are of utmost importance for the study of the structural integrity of reactor materials. Hydrogen and helium gas production occurs mainly through (n, xp) and (n, xα) reactions. These reactions are induced on the different walls of the fusion reactor mainly first wall, structural, blanket materials and other. The production of hydrogen and helium leads to other processes such as atomic displacements and transmutations which can produce microstructural defects and modify physical properties of the materials. The materials suitable for the reactor structures are stainless steel with Cr, Fe, and Ni as main constituents in SS316(LN)-IG (Fe $\sim$ 65%, Ni $\sim$ 12%, Cr $\sim$ 17%). As the neutrons continuously coming from plasma interact with the various walls of the reactor made up of SS, there will be generation of various long-lived, short-lived radio-nuclides like ^{55}Fe ($T_{1/2}$= 2.737 years), ^{59}Ni ($T_{1/2}$= 7.6×10^4 years) and many others inside reactor environment. The neutrons coming from plasma interacts with various long-lived radionuclides already generated in reactor environment during its operation, such types of reactions are called second generation reaction. The cross sections of the neutron induced reaction of various radionuclides are not measured and studied till now. So, there is a large gap in the nuclear data library. In the past few years, surrogate method has been used for the cross-section measurement. The surrogate method assumes that the reaction takes place through the compound nucleus mechanism only, but at high energies pre-equilibrium and direct reactions channel also occur. Present study explores the surrogate reaction method by determining the validity of Weisskopf-Ewing approximation for (n,α) reaction on ^{56}Fe reaction.

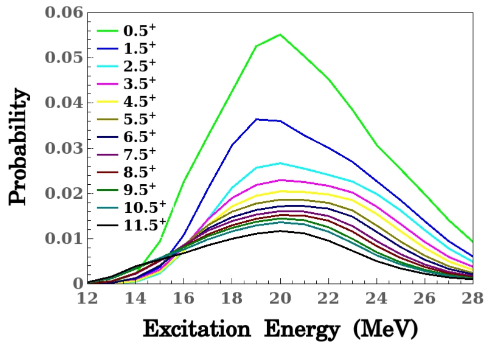

FIG. 1: Spin-dependent alpha decay probabilities of ^{57}Fe compound nuclei as a function of compound nucleus excitation energy for positive parity states.

Materials and methods

A surrogate experiment is mostly concerned about experimentally determining the specific decay probability of a desired compound nucleus formed in a surrogate reaction. We have

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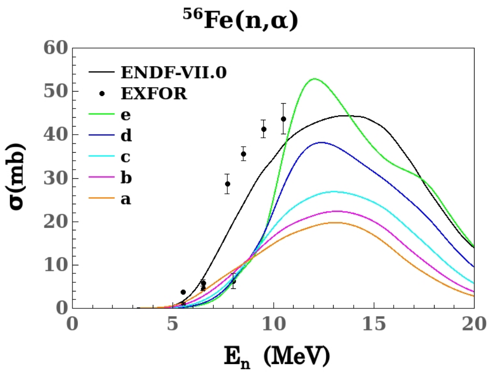

FIG. 2: ^{56}Fe(n,α) cross sections corresponding to different schematic distributions derived by assuming the validity of the Weisskopf-Ewing approximation.

produced the experimental cross-section data from EXFOR, with TALYS using best y parameter. For positive and negative parity states of ^{57}Fe , spin-dependent alpha decay probabilities were calculated using TALYS. Then we considered five energy independent schematic spin distributions a, b, c, d, e which are centered around 1.5, 3.5, 5.5, 7.5, 9.5 respectively. The alpha decay probabilities as measured in the surrogate experiment can be simulated as

$$P_{\delta\chi}(E_{ex}) = \sum_{J\pi} F_{\delta}^{CN}(E_{ex}, J, \pi) G_{\chi}^{CN}(E_{ex}, J, \pi)$$

where $F_{\delta}^{CN}(E_{ex}, J, \pi)$ is the probability of the formation of the compound nucleus, excitation energy E_{ex} in a specific spin-parity state (J, π) and $G_{\chi}^{CN}(E_{ex}, J, \pi)$ is the alpha branching ratio of the compound nucleus in that state. Assuming that W.E. is valid then the desired cross-section for a reaction with entrance channel β and exit channel χ can be calculated as -

$$\sigma_{\beta\chi}(E_{ex}) = \sigma_{\beta}^{CN}(E_{ex}) P_{\delta\chi}^{CN}(E_{ex})$$

following the Weisskopf-Ewing approximation.

Results and Discussion

For the validity of the Weisskopf-Ewing approximation, the spin-parity-dependent alpha decay probabilities for the compound nuclei under consideration are calculated which are shown in FIG. 1. It is observed in this figure that the α decay probabilities are highly dependent on the spin of the compound nucleus, hence the Weisskopf-Ewing approximation is not valid. The surrogate results corresponding to each schematic distribution a,b,c,d,e has been calculated individually and we have studied the effect of difference in the spin-parity distribution of the compound nucleus. The trends of the results is similar to the trend of the results for neutron energies below 14 MeV but for the neutron energies greater than 14 MeV the trend of the simulated results is different than the desired cross-sections, as shown in Fig.2. This is because surrogate method donot consider the pre-equilibrium emission.

Summary and Conclusion

It is concluded that the surrogate reaction method relying solely on the Weisskopf-Ewing approximation is not sufficient for determining the (n,α) cross sections and further development of the surrogate technique is required. It will be interesting to check whether SRM can reduce the effect of spin-dependence of the α decay probabilities.

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