Anomalous behavior of (n,α), (n,p) cross-section for ^{55}Fe and ^{59}Ni with low energy neutrons

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Introduction

Nickel, iron and chromium are the main constituents of stainless steel which will be present in large quantities in fusion reactors. Natural iron (Fe) has 5.845% ^{54}Fe, 91.754% ^{56}Fe, 2.119% ^{57}Fe and 0.282% ^{58}Fe and natural nickel has 68.007% ^{58}Ni, 26.223% ^{60}Ni, 1.1399% ^{61}Ni, 3.6345% ^{62}Ni, and 0.925% ^{64}Ni. ^{59}Ni and ^{55}Fe are unstable and long-lived radionuclides produced inside the fusion reactor during its operation [1, 2]. The major pathways for the production of these isotopes are ^{58}Ni(n,γ)^{59}Ni reaction for ^{59}Ni and ^{56}Fe(n,2n)^{55}Fe, ^{54}Fe(n,γ)^{55}Fe, ^{58}Ni(n, α)^{55}Fe reactions for ^{55}Fe [3].

The important helium and hydrogen production reactions of ^{59}Ni and ^{55}Fe lead to the swelling and embrittlement of the structural and wall materials as helium and hydrogen accumulate at different locations inside the fusion reactor. The production and retention of helium and hydrogen in stainless steel was thought to be well predicted by combination of fast neutrons (n, He), (n, H) reactions. But some of the nuclides show that the (n, p) and (n, α) cross-section are much higher even at low energy neutrons than for the fast neutrons [4,5]. Considerable interest in the helium and hydrogen production cross-sections for ^{59}Ni and ^{55}Fe radioactive isotopes has been developed because of the anomalous behavior of these reactions at lower energy neutrons.

It is observed that those isotopes which have (n,α) or (n,p) cross-sections at thermal neutron energies, lie on the proton rich side of the line of stability of the chart of the nuclides. Furthermore, it is observed that these isotopes have a large positive Q value for the reaction of interest as shown in Table-1 [6].

The objective of the present work is to study ^{55}Fe(n,p) ^{59}Ni(n,p), ^{55}Fe(n,α), and ^{59}Ni(n,α) reactions from the point of view of the prolific source of helium and hydrogen production not only at fast neutrons energy but also at lower energy. These reactions cannot be neglected at lower energy due to its very high cross-sections for He/H production inside the fusion reactor. A typical neutron spectrum at the first wall (FW) is shown in Fig.1.

Table-1.

Isotopes	T ½ (year)	(n,α) Helium reaction		(n,p) hydrogen reaction	
		Q (MeV)	$\sigma_{thermal}$ (b)	Q (MeV)	$\sigma_{thermal}$ (b)
^{59}Ni	7.6×10^5	5.096	12.0	1.855	1.96
^{55}Fe	2.73	3.584	0.011	1.014	-----

These cross sections have been estimated using Hauser –Feshbach formalism and for different optical model potentials. Energetics of all the above reactions has been also studied.

Present status of ^{59}Ni(n,α) ^{59}Ni(n,p) and ^{55}Fe(n,α) ^{55}Fe(n,p) reaction cross-section

There are very older measurement on ^{59}Ni(n,α and n,p) given by Harvey et al.[7], and Mcdonald et al [8] at 0.025 eV. Evaluated cross-section data file([TENDL, ENDF, JEFF, EAF)] [9] shows a very large discrepancy at lower energy as shown in Fig.2 & 3 for ^{59}Ni(n,α) and ^{55}Fe(n,α) reaction. Recently Liu et al. [10] determined the ^{55}Fe(n,α) cross-section at 0.025 eV having value 27 mb. There is no experimental measurement for ^{55}Fe(n,p) reaction till date. Experimental data are not available for all the above mentioned reactions in the whole energy range and evaluated data are also not reliable due to the large difference in their cross-section values. Thus, this will create a serious problem in the estimation of total helium and hydrogen production inside the fusion reactor, which lead to difficult radioactive waste disposal problem. So the proper and accurate understanding should be very much required for such type of cross-section on long-lived radionuclides, which are there for a very long time inside the reactor. The present paper is an effort in this direction.

Conclusion

From the study it is clear that the contribution of ^{59}Ni(n,α), ^{59}Ni(n,p) and ^{55}Fe(n,α), ^{55}Fe(n,p) reaction cross-section are quite higher at lower energies (eV) compare to higher energy(i.e, 14 MeV) and the available evaluated data file shows a very large discrepancy. Therefore revision of latest available nuclear data libraries for these reactions are very much needed in order to make better prediction.

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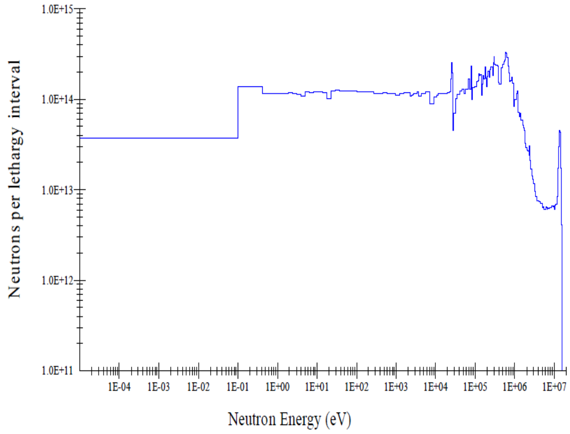

Fig.1. Typical neutron spectrum inside a fusion reactor

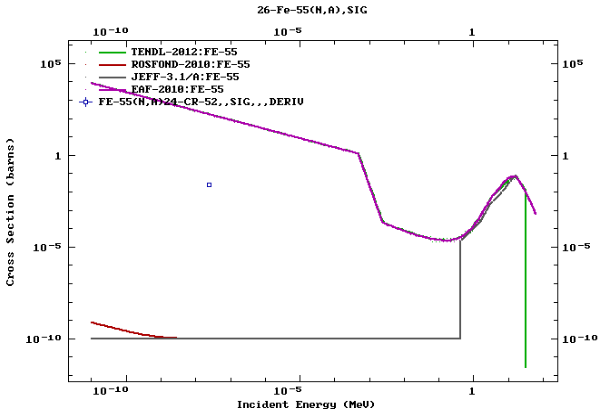

Fig.2. Cross-section of ^{55}Fe(n,α) reaction

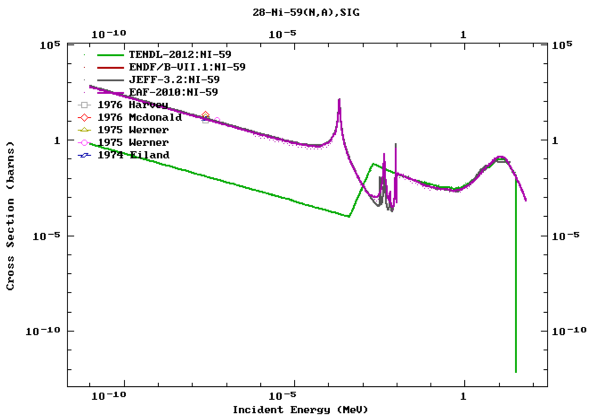

Fig.3. Cross-section of ^{59}Ni(n,α) reaction