Helium-Hydrogen generation arising from the ^{55}Fe(n,x) reaction and its impact on fusion reactor

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Introduction

At present stainless steel (SS) is the prominent candidate as structural material for upcoming experimental fusion reactor. Iron, nickel, chromium are the main elements present in SS (Table-1) [1]. Hundred tons of stainless steel will be used for different components of a fusion reactor (cryostat ~ 3800 tons stainless steel, vacuum vessel ~ 5000 tons etc). Iron based (SS) alloys are used in blanket shield modules, thin walled pipes, cooling manifolds, divertor body, cooling pipes, divertor support, fastening components of the fusion reactor [2]. Natural iron (Fe) has 5.845% ^{54}Fe, (91.754% ^{56}Fe, 2.119% ^{57}Fe and 0.282% ^{58}Fe. However irradiation onto the alloys of Fe, Ni, Cr in fusion environment will produce long-lived radioactive isotopes, which lead to difficult radioactive waste disposal problem. ^{55}Fe ($t_{1/2}$ = 2.73 years) is one of unstable radio-nuclide which is produced in large quantities inside the fusion reactor via the reactions ^{56}Fe(n,2n)^{55}Fe, ^{54}Fe(n, γ) ^{55}Fe and ^{58}Ni(n,α) ^{55}Fe [3, 4].

In order to design the fusion reactor components neutron induced reaction (n,p) & (n,α) on the generated ^{55}Fe to be studied. Detail study of ^{55}Fe(n,p) reaction cross-section has been performed earlier [5]. The present study describes the hydrogen and helium production from ^{55}Fe(n,p) and ^{55}Fe(n,α) reactions and its impact on fusion reactor. However it is not recognized earlier that the ^{55}Fe(n,p) & ^{55}Fe(n,α) reaction will also generate significant amount of hydrogen and helium gases inside the fusion reactor and result in significant displacement damage.

Table-1.

Element	% of element in SS	Concentration (mg of elements per kg of steel)
Cr	16-18	1.8×10^5
Fe	65-72	6.3×10^5
Ni	10-14	1.4×10^5
Mo	2-3	2×10^4

Amount of ^{55}Fe produced in fusion reactor

The major pathways for the production of ^{55}Fe in fusion reactor environment are ^{56}Fe(n,2n)^{55}Fe, ^{54}Fe(n, γ) ^{55}Fe, and ^{58}Ni(n,α) ^{55}Fe. The production pathways of ^{55}Fe together with their percentage contribution at different neutron energies (0.257 eV, 148.54 eV, 37.587KeV, 14.734 MeV) as obtained from Activation code- European Activation System (EASY) is shown in Table-2 [4]. Fe-55 is the primary dominant nuclide at different neutron energies. The excitation function of all of these reactions are shown in Fig.1. The amount of ^{55}Fe formed inside the fusion reactor has been calculated by using Monte Carlo calculations [6]. Variety of neutron spectra in 175 energy group (VITAMIN-J) has been used at the time of calculations.

Calculated hydrogen and helium generation

The ^{55}Fe(n,p) and ^{55}Fe(n,α) having the Q values 1.014 MeV and 3.583 MeV respectively are very exothermic, producing charged particles which lead to radiation damage. In order to assess the importance of enhanced hydrogen production from iron, calculations are performed for various neutron spectra of interest in fusion reactor at different locations [7]. In our calculations, the production of helium or hydrogen from the two step iron reaction ^{56}Fe(n,2n) ^{55}Fe(n, p or α) reaction is given by

$$\frac{N(X)}{N_0(N_i)} = 91.745\ \sigma_X\{\sigma_\gamma(1 - e^{-\sigma_T\varphi t}) - \sigma_T(1 - e^{-\sigma_T\varphi t})\}/\sigma_T(\sigma_\gamma - \sigma_T)$$

Where N(x) = atoms of H or He, $N_0(N_i)$ = initial atoms of Fe, 91.745 is the abundance of ^{56}Fe,
σ_X= spectral cross-section for p or α from ^{55}Fe,
σ_γ= cross section for ^{56}Fe(n,2n),
σ_T= total absorption cross section for ^{55}Fe, and
φt= the total neutron fluence

Conclusion

The total amount of Fe-55 produced inside the fusion reactor has been calculated with MCNP calculations, which takes into account all the channels from which it is produced. Furthermore, fast and low energy neutrons present in fusion reactor will produce significant amount of helium and hydrogen by interaction with Fe-55. This aspect has to be taken into account while calculating the displacement per atom (dpa) in first wall and other structural material in fusion blanket.

Table-2

Nuclide	$T_{1/2}$	Pathways	0.257 eV	148.54 eV	37.587 keV	14.734 MeV
Fe55	2.73 y	Fe54(n,γ) Fe55	100	100	100	98.8
		Fe56(n,2n) Fe55	100	100	100	97.5
		Ni58(n,α) Fe-55				

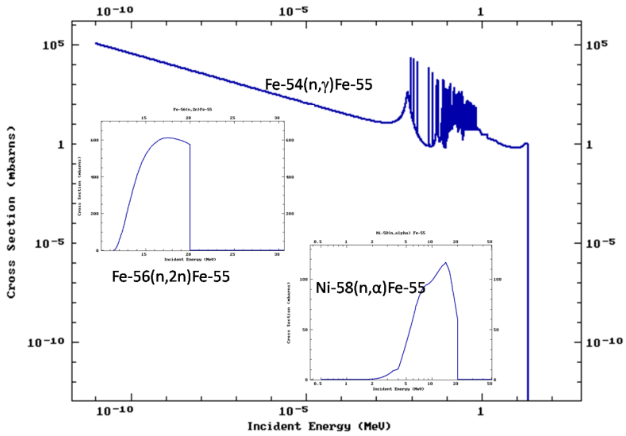

Fig.1- Excitation function of ^{56}Fe(n,2n)^{55}Fe, ^{54}Fe(n, γ) ^{55}Fe and ^{58}Ni(n,α) ^{55}Fe

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