Neutron Radiation Damage Study of Proposed Plasma Facing Material Using Recoil Spectra of residual Nuclei

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Introduction

During service, plasma-facing components in every fusion devices are exposed to intense fast neutron flux which originates from the fusion reactions taking place in the fuel. These fast neutrons are capable to displace the atoms from their stable positions in the crystalline lattice and thus create a lattice defects. Due to these defects, the microstructure of plasma-facing materials (PFM) changes and as a result, characteristics of material may also change. In order to improve working ability of PFM and to develop new material which can be used as a PFM with high working efficiency, it is necessary to understand the plasma wall interactions [1]. PFM which are currently in use or under consideration, are lithium (Li), beryllium (Be), carbon (C), molybdenum (Mo) and tungsten (W) etc. All probable neutron induced reaction channels such as (n,n'), (n,2n), (n,p) and (n,α) are likely to be happen at 14.6 MeV energy. These reaction channels yield energetic ejectiles along with the recoil nucleus. Recoil nuclei from different reaction channels act as a primary knock on atoms (PKA)[2]. A complete description of all process in plasma edge is an extremely challenging task which requires theoretical predictions, experimental observations and computational codes [1]. In the present work, energy spectra of recoils or PKA have been studied for ^{6,7}Li,^{9}Be, ^{12,13}C, ^{98}Mo,^{184}W correspond to reaction channels (n,n'), (n,2n),(n,p)and (n,α).To see the effect of 14.6 MeV neutrons on PFM,TALYS 1.9 has been used to calculate recoil spectra for each reaction channel. Along with PKA spectra, we have seen the average recoil energy versus incident neutron energy behavior for different channels.

Calculations of Recoil using nuclear model calculations

In fusion reactor, neutrons are produced by D-T and D-D reactions and these neutrons interact with materials using for constructing first wall, blanket and diverter etc. and as a result secondary neutrons, gamma rays and charged particles are created and target nuclei are knock-on. The charged particles and knock-on nuclides move in the material in short range and lose their kinetic energy by changing into thermal energy. The neutrons and γ rays travel in the target materials in longer range than the charged particles and also change their energy in thermal energy. In the present study, TALYS 1.9 and recent version of EMPIRE codes are used for generating the recoil spectra of the daughter nuclei from different neutron induced reaction. For each reaction channels both the recoil matrices of the primary (heavy) residual and secondary emitted particle such as n, α-particle and proton are calculated. In TALYS, there are two methods to calculate recoil energy: (a) Exact approach, (b)Approximative approach. In the exact approach, each excitation energy bin of the population of each residual nucleus is described by a full distribution of kinetic recoil energies. As an approximation, each excitation energy bin of the population of each residual nucleus is described by average kinetic recoil energy [2]. Calculation of nuclear recoils basically needed for energy balance. Recoil spectra are calculated taking into account correlation between the excitation energy of the nucleus and the emission energy of the ejectile. In order to do so, recoil energies are followed throughout the de-excitation cascade. A recoil spectrum is ascribing to each excitation energy bin for each nucleus involved in the decay chain [3]. The calculation of the energy distribution of residual and emitted particles resulting from nuclear reaction is an important input to the modeling of radiation damage in materials [4]. The recoiling species or primary knock-on atom (PKA), can induced cascades of atomic displacements leading to the accumulation of structural damage. The recoil energy of residue can be calculated with the help of following expression:

$$\frac{d\sigma(e_r,E_r)}{de_r}=\int_0^{\infty}\int_0^{\Pi}\delta(e_r - e_r(e_p,\theta))\left[\frac{d\sigma(e_p,E_p)}{de_p}\right]_n\left[\frac{d\sigma(\Delta e,E_r,\theta)}{d(\Delta e)}\right]\sin(\theta)d\theta de_p$$

Where, $\left[\frac{d\sigma(\Delta e,E_r,\theta)}{d(\Delta e)}\right]=\frac{m_r}{m_{ejc}}\frac{d\sigma(\varepsilon,E_r)}{d\varepsilon}$,

$\Delta e=\frac{m_{rejc}}{m_r}\varepsilon$,

$e_r(e_p,\theta) = \Delta e + e_p + 2\sqrt{\Delta e.e_p}\cos(\theta)$,

ε = ejectile emission energy; E = excitation energy; Δe = recoil kick energy; e = nucleus recoil energy; m_{ejc} = mass of ejectile; m_r = mass of recoil; $\frac{d\sigma(e,E)}{de}$ = recoil spectrum at excitation energy E; θ= angle between the momentum of the parent and the recoil kick; r and p subscripts are used to mark residuals and parent nuclei respectively.

Result and Discussion

Reaction channels such as (n,n'), (n,2n), (n,p)and (n,α) produce different PKA spectra of different atomic number, mass and energy. The calculated value of recoil energy cross-section for ^{98}Mo corresponding to different reaction channels are shown in Fig.1.In the case of ^{98}Mo, (n,n'), (n,2n), (n,p) and (n,α) reaction channels yield ^{98}Mo, ^{97}Mo, ^{98}Nb, ^{95}Zr recoil nuclei (Fig. 1). From graph, it is clear that (n,n') and (n,2n) reaction channels has high probability to produce damage. In the case of ^{9}Be, we got three reaction channels (n,n'), (n,p), (n,t) and their corresponding products are ^{9}Be,^{9}Li, ^{7}Li. Similarly, ^{184}W, ^{183}W, ^{184}Ta , ^{181}Hf are yielded from (n,n'), (n,2n), (n,p) and (n,α) reaction channels in ^{184}W. In the case of ^{6}Li and ^{7}Li, we got only two reaction channels which are (n,n') and (n,γ). ^{6}Li yields ^{6}Li and ^{7}Li corresponding to the (n,n') and (n,γ) reaction channels while ^{7}Li yield ^{7}Li and

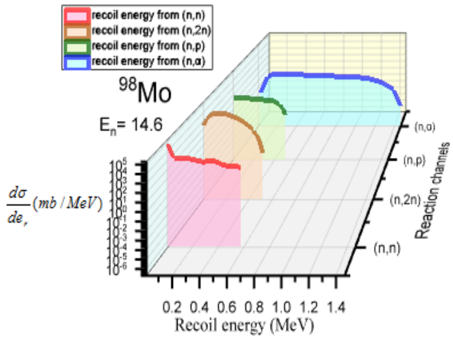

Fig. 1- 3D plot of recoil energy cross-section for ^{98}Mo corresponding to multiple reaction channels

^{8}Li corresponding to the (n,n') and (n,γ) reaction channels. In the case of ^{12}C, we got (n, n'), (n,p), (n,α) reaction channels and the corresponding products are ^{12}C, ^{12}B, ^{9}Be. In the case of ^{13}C, (n,n'), (n,p), (n,np), (n,α) reaction channels yield ^{13}C, ^{13}B, ^{12}B, ^{10}Be respectively. Average recoil energy versus incident neutron energy behavior for different channels will also be discussed.

Conclusion

In the present study, PKA data for all major reaction channels have been calculated using TALYS-1.9. From all the graphs, it is clear that the major contributor of displacement damage are (n,n') and (n,2n) reaction channels. However charged particle reaction such as (n,p) and (n,α) lead to very high recoil energies determined mainly by the masses of the target and product nuclei.

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