Energy differential and displacement damage cross section of DT neutron induced reactions on fusion reactor materials

M. Rajput[1]*, R. Srinivasan[1], PV Subash[2], and S. Vala[1]
[1]*Institute for Plasma Research, HBNI, Gandhinagar, Gujarat, India*
[2]*ITER-INDIA, Institute for Plasma Research, HBNI, Gandhinagar, Gujarat, India*
*· * email: rajputmayank18@yahoo.in*

Introduction

All probable reaction channels such as (n,n'), (n,2n), (n,p), (n,α) and (n,d) are open for the interactions of DT neutrons of 14 MeV energy with the fusion reactor material. Evaluation of nuclear responses in reactor materials such as gas production per atom (GPA) and displacement per atom (DPA) requires gas production cross section (σ_{GPA}) and displacement damage cross section (σ_{DPA}) data. TALYS 1.8 has been used to calculate cross section data and recoil spectra for each reaction channel. In the cross-section and spectra calculations, Contribution from all possible reaction mechanism such as direct, pre-equilibrium, compound and multiple emission reaction mechanisms have been considered. Prediction of σ_{DPA} requires energy spectra (EDX) of recoil nuclei from each reaction channel. EDX of emitted charged particles have been predicted and compared with the existing evaluated and experimental data from IAEA data Libraries to select the best fitted nuclear models and parameters. Energy spectra of recoil nuclei for each reaction channel have been predicted using the appropriate nuclear models and parameters in TALYS code for incident neutrons of 0 to 15 MeV energy. Displacement cross section by NRT method which is used to optimize the appropriateness of the material in fusion reactor and ADSS based reactor. EDX data of recoils nuclei are used to predict the σ_{DPA} using the NRT approach. Total σ_{DPA} is predicted by adding the σ_{DPA} from each reaction channel. Predicted σ_{DPA} is compared with the existing database of $\sigma_{DPA,}$ prepared using the NJOY code. NJOY code uses energy spectra data from ENDF database. The predicted σ_{DPA} can be used to predict DPA using the neutron fluence on the material. EDX data of each reaction channels are calculated for all stable isotope of Cr (^{50}Cr, ^{52}Cr, ^{53}Cr, ^{54}Cr), and W (^{182}W, ^{183}W, ^{184}W, ^{186}W) and later used for the prediction of σ_{DPA} for natural elements.

Methodology and calculation methods

Calculation of σ_{DPA} requires energy spectra of recoil nuclei from each reaction channels. σ_{DPA} has been calculated in 3 steps and as follow: 1) selection of nucleal model for the energy differential cross-section (EDX), 2) calculation of recoil spectra of recoil nuclei from each reaction channel, 3) calculation of σ_{damage} using NRT method. For the cross-section calculations, TALYS-1.8 code has been used. For the calculations of EDX data, compound nuclear contribution (eq. 1), Preequilibrium contribution (Eq. 2) and direct reaction contribution have been considered [2].

$$\frac{d\sigma}{dE}=\sum_{j\pi}\sigma^{CN}(E_a)\,\frac{\sum_{l\pi}\Gamma_b(U,J,\pi,E,I,\pi)\,\rho_b(E,I,\pi)}{\Gamma(U,J,\pi)} \qquad (1)$$

$$\frac{d\sigma}{dE}=\sigma^{CF}\sum_{p_\pi=p_\pi^0}^{p_\pi^{eq}}\;\sum_{p_n=p_n^0}^{p_n^{eq}}\omega_k\,S_{pre} \qquad (2)$$

Direct like contribution such as pick up, knock on reactions have been solved with Kalbach method. σ_{damage} have been calculated using the NRT (Norren Robinson and Torren) approach [2] and given in formula,

$$\sigma_{damage}(E_n)_i=\int_{Ed}^{Tmax}\left(\frac{d\sigma}{dE}\right)_i\upsilon(T)_i\,dT \qquad (3)$$

$$T_{dam}=\frac{T}{1+k(3.4008\varepsilon^{1/6}+0.40244\varepsilon^{3/4}+\varepsilon)} \qquad (4)$$

$$k=\frac{0.079Z_R^{2/3}Z_L^{1/2}(A_R+A_L)^{3/2}}{(Z_R^{2/3}+Z_L^{2/3})^{3/4}A_R^{3/2}\,A_L^{3/2}} \qquad (5)$$

$$\varepsilon=\frac{T}{30.724Z_RZ_L(Z_R^{2/3}+Z_L^{2/3})^{1/2}}\;\frac{A_L}{(A_R+A_L)} \qquad (6)$$

Default nuclear models that come with TALYS code have been implemented for the calculation of (n.p), (n,2n), (n,n') and (n,gamma) reaction channels for Tungsten. For chromium, nuclear models have been adopted from Mayank et al [3].

Results and discussions

EDX data of different ejectiles have been predicted and presented in fig. 1 & 2 for the ^{52}Cr and ^{186}W using the TALYS code. For ^{52}Cr, neutrons of 0-15 MeV energy, protons of 0-9 MeV, alpha particles of 0-14 MeV and gamma of 0-20 MeV were observed in the calculations. For ^{186}W, neutrons of 0-12 MeV, protons of 0-5 MeV and gammas of 0-18 MeV have been observed in the calculations. Energy spectrum of recoils have been calculated from the EDX of different ejectiles. Energetic recoil nucleus act as the Primary Knock on Atoms (PKA) and initiate damage in the reactor materials. Displacement cross section have been calculated using the recoils spectrum, calculated with TALYS code for the 14 MeV incident neutron. Contribution to the total displacement cross section from different reaction channels have also been calculated and presented in table. 1

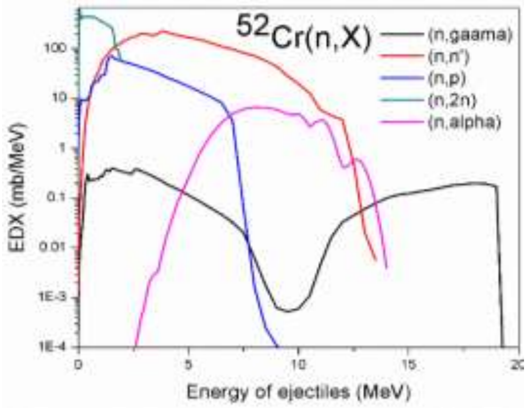

Fig. 1 EDX of ejectiles from ^{52}Cr for different ejectiles at 14 MeV neutron energy

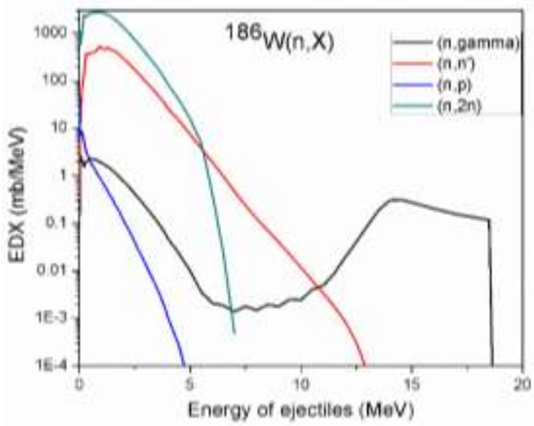

Fig. 2 EDX of ejectiles from ^{186}W at 14 MeV neutron energy

Table 1: σ_{DPA} of ^{184}W, ^{52}Cr at 14 MeV neutron energy

	σ_{DPA} (barn)	**n,n'**	**n,2n**	**n,p**	**n,α**
^{52}Cr	5020	3680	791	354	191
^{186}W	1100	410	688	0.9	-

Major contribution to the total σ_{DPA} are from (n,n') and (n,2n) reaction channels. Calculations of displacement cross section of neutron induced reactions on the first wall materials of ITER machine such as W, Cr, etc is planned for 0-14 MeV neutrons. Calculated displacement cross section will be compared with the data calculated from NJOY code.

Summery

Displacement cross section by NRT method require the energy spectrum of recoils (PKA) from each reaction channels. Recoil spectra have been evaluated using TALYS for each ejectiles (n,p,α,gamma) and later used in the NRT approach. σ_{DPA} have been predicted at 14 MeV neutron energy for ^{52}Cr and ^{186}W. Calculation of σ_{DPA} have also been carried out for other stable isotopes of chromium and tungsten from 0 to 14 MeV neutron energy.

References

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[3] Mayank et al, Indian J Phys DOI 10.1007/s12648-017-1079-y