The first wall and divertor sputtering in the ITER

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Abstract

Beryllium fluxes into the ITER tokamak plasma due to sputtering of the first wall by D and T atoms leaving the plasma were estimated. The flux of beryllium atoms entering the plasma was calculated to be $6.5 \cdot 10^{17}$ atoms$\cdot$s$^{-1}\cdot$m^{-2}. The concentration of beryllium impurities can be 2.5–4.2% of the mean ion plasma density. Such a high content of beryllium ions in the region close to the separatrix can lead to significant sputtering of the divertor with multiply charged beryllium ions. The proposed model allows estimation of the flux of sputtered tungsten atoms into the near divertor plasma.

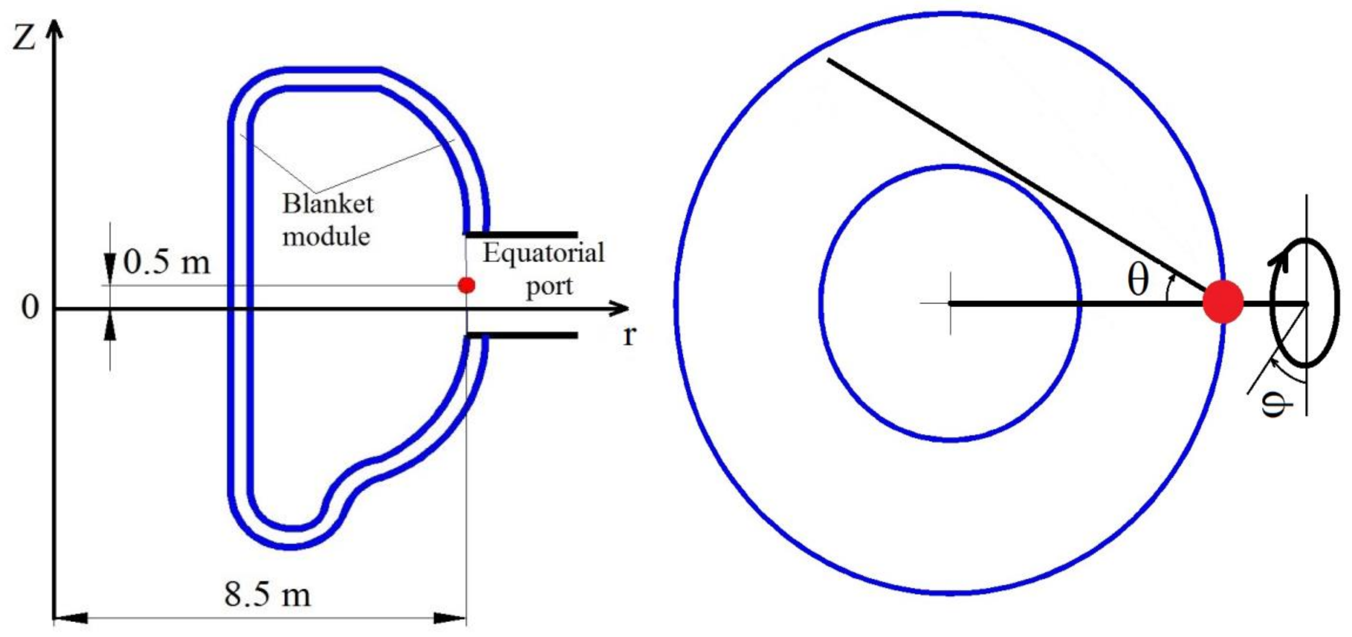

Fig. 1. The geometry scheme for calculating energy spectra of particles with the DOUBLE-MC code [1]. The observation point is indicated by the red circle.

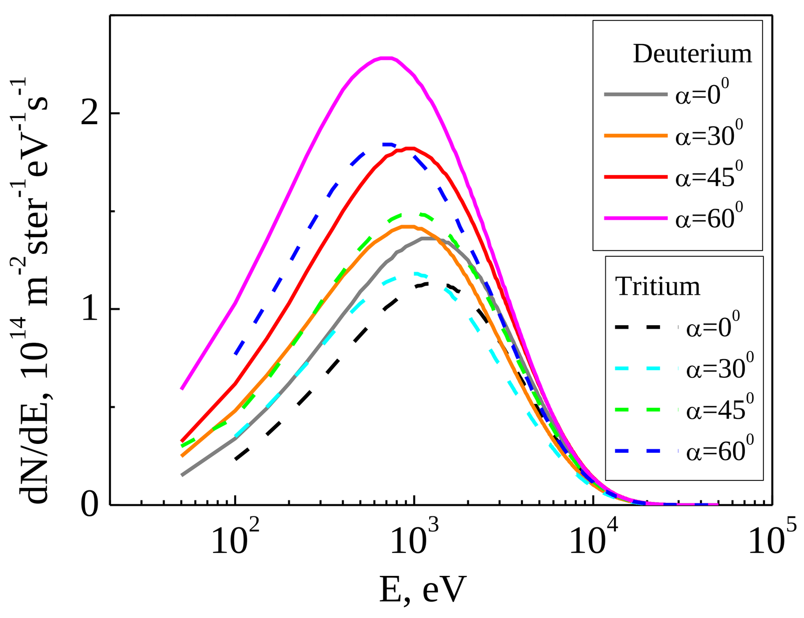

Fig. 2. Typical energy spectrum dN/dE of deuterium and tritium atoms bombarding the tokamak first wall.
θ is the angle of incidence relative to the surface normal, φ=0°. The spectra were obtained by us using the DOUBLE-MC code [1].

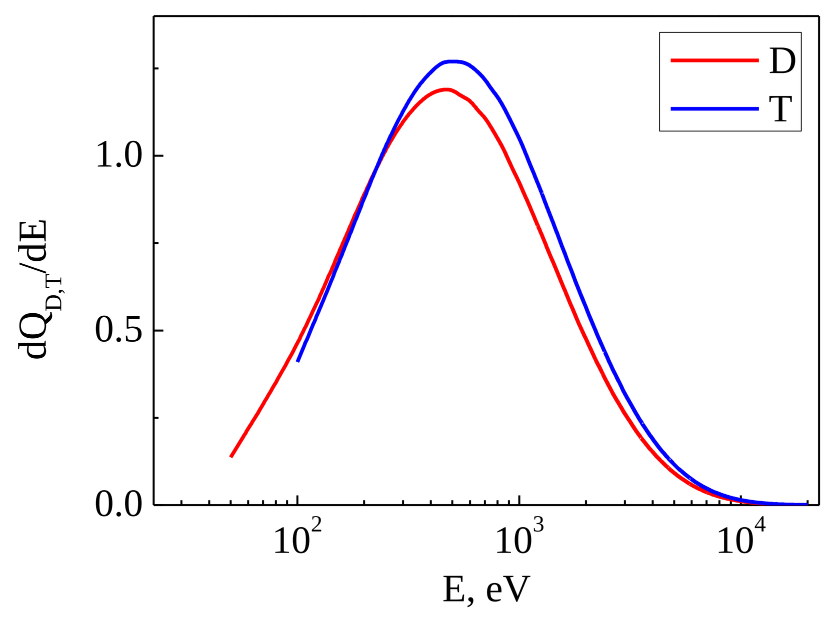

Fig. 3. D and T relative contributions to the wall sputtering as a function of projectile energies.

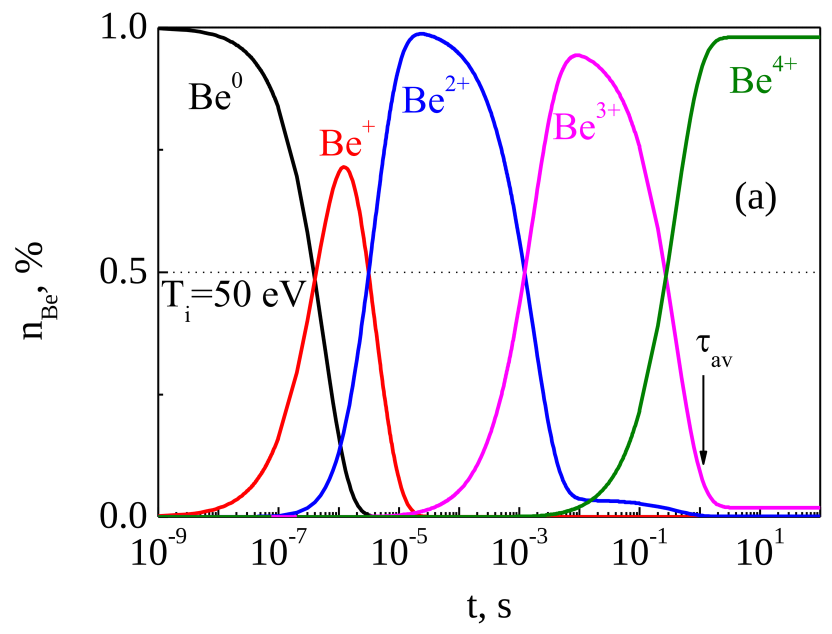

Fig. 4a. The time dependencies of beryllium fractions with different z for T_e of 50 eV (a).

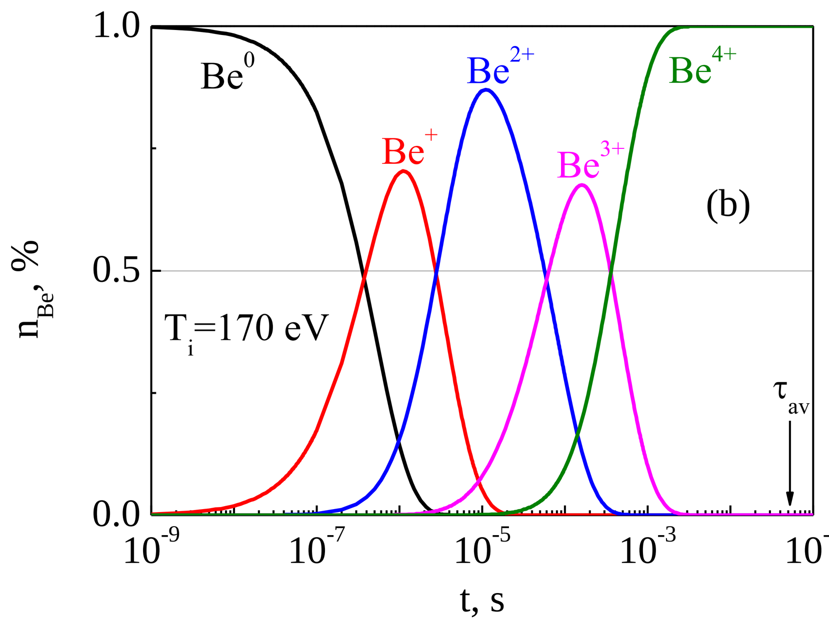

Fig. 4b. The time dependencies of beryllium fractions with different z for T_e of 170 eV (b).

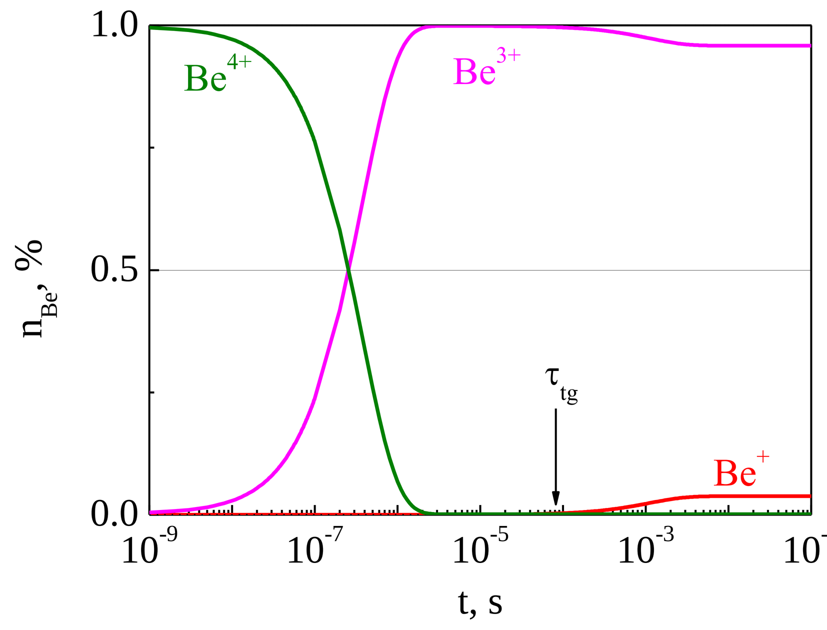

Fig. 5. The time dependencies of beryllium fractions with different z at T_e 170 eV after passing through the gas-plasma target near divertor. The target pressure was 10 Pa, the target thickness was 5 cm. The time of flight through the gas target τ_{tg} is indicated by arrow.

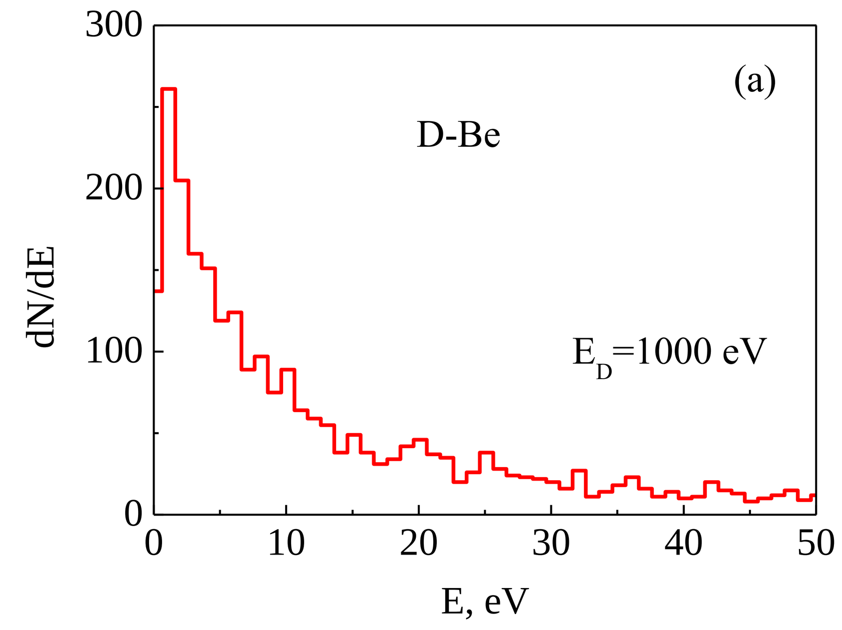

Fig. 6a. A typical SRIM [2] energy spectrum of sputtered atoms: a) Be target bombarded by D atoms with initial energy of 1000 eV.

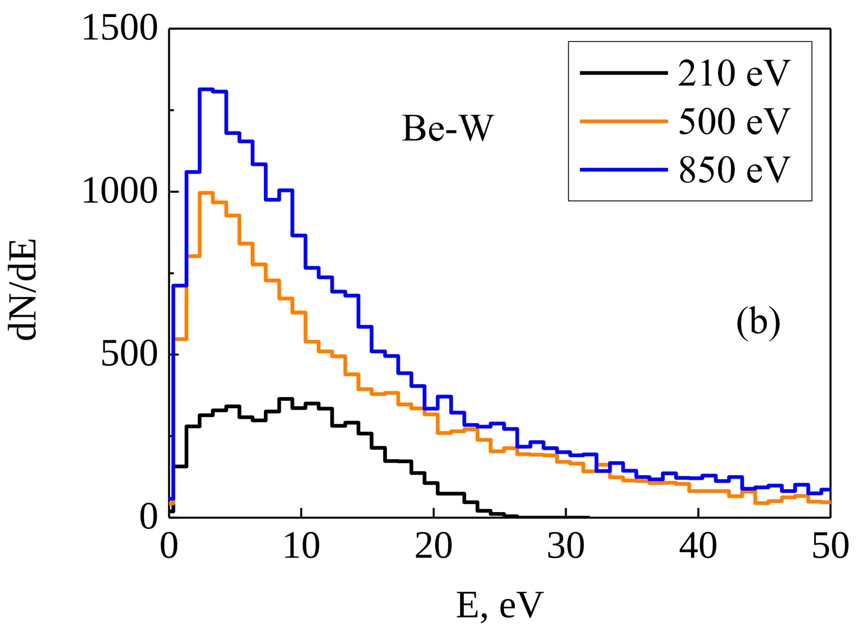

Fig. 6b. A typical SRIM energy spectrum of sputtered atoms: b) W target sputtered by Be ions with initial energies of 210, 500 and 850 eV, respectively.

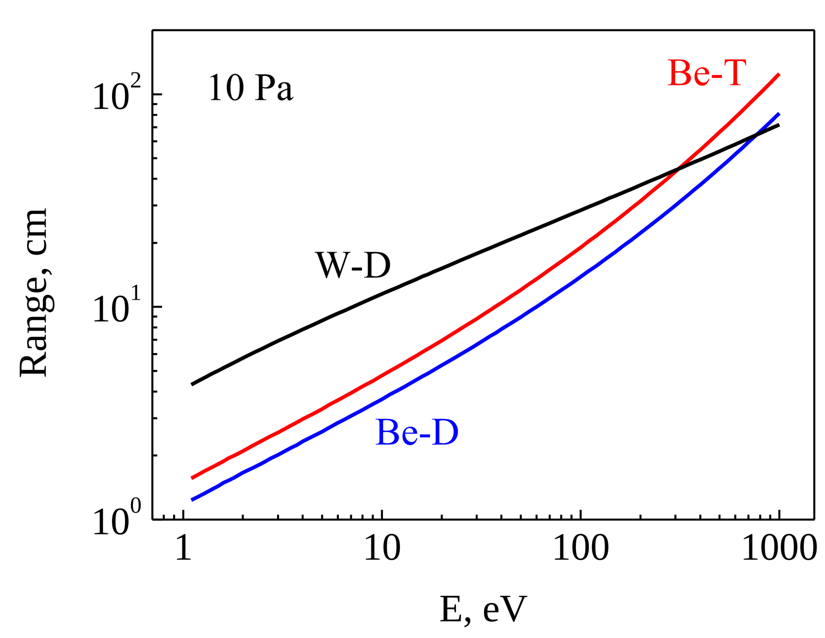

Fig. 7. Projected ranges of Be and W atoms in the target at the gas pressure of 10 Pa versus the atom initial energy.

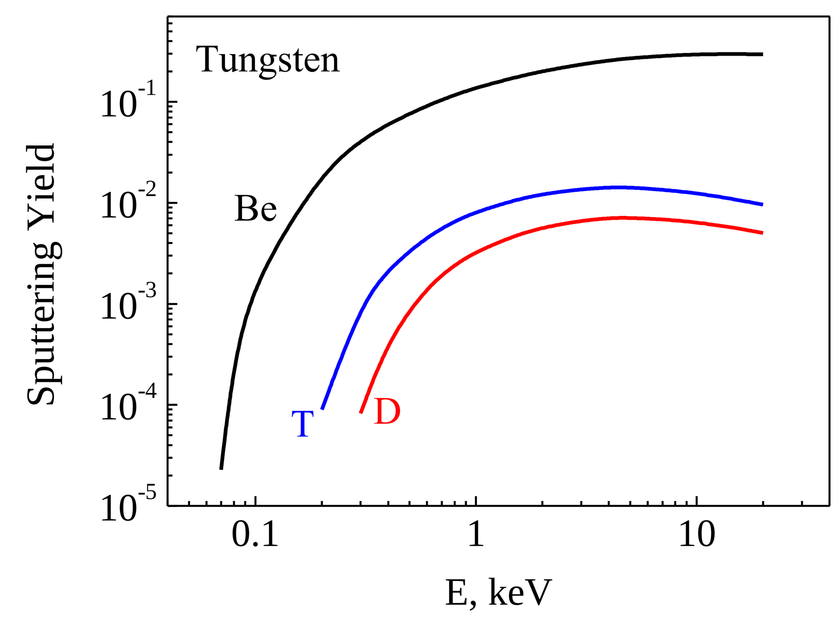

Fig. 8. Sputtering coefficient of the tungsten target depending on the energy of the bombarding D, T and Be atoms.

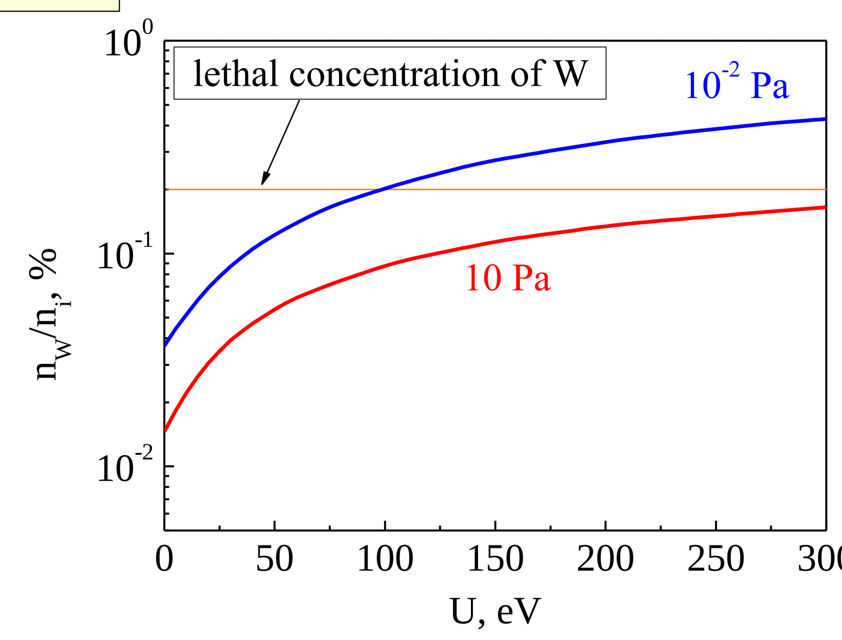

Fig. 9. Our estimates of the W concentration produced by the Be ion divertor sputtering at different plasma-wall potentials U. The ion temperature was T_i=170 eV. The lower curve corresponds to typical parameters of the gas target near the divertor.

CONCLUSIONS

The energy spectra of atoms of deuterium and tritium leaving the ITER plasma were calculated using the DOUBLE-MC code. By analyzing the existing experimental and calculated data on the sputtering coefficients of the beryllium target with hydrogen isotopes, we obtained the recommended curves for the sputtering coefficients for the cases of normal and oblique incidence. Calculation of the yields of beryllium atoms sputtered by fast D and T atoms leaving the plasma gives the following fluxes: $Q_D=2.97 \cdot 10^{17}$ atoms/(s$\cdot$m^2) for deuterium bombardment, $Q_T=3.54 \cdot 10^{17}$ atoms/(s$\cdot$m^2) for tritium bombardment, and $Q_\Sigma=6.54 \cdot 10^{17}$ atoms/(s$\cdot$m^2) in total. In the process of estimation, azimuthal anisotropy of the fluxes of atoms leaving the plasma was taken into account, which increased the beryllium flux by 15% compared to that in the isotropic case. Under the assumption that the confinement time is τ=3-5 seconds, this gives the mean beryllium concentration n_{Be}=2.5-4.2% of the plasma density.

The divertor sputtering depends on the ion temperature and charge distribution of beryllium ions on the separatrix. The analysis of the charge distribution dependence on the ion retention time on the separatrix shows that the coronal approximation cannot be reached at T_e=50 eV, while at T_e=170 eV plasma parameters are very close to those in the coronal equilibrium. For the Be fraction of 2-5%, the accelerated Be ions make a considerable contribution to the divertor material sputtering that exceeds the sputtering by D and T fluxes by 10-25 times.

Using SRIM, the energy spectra of sputtered atoms were calculated for two cases: a) when the Be wall is sputtered by fast D and T atoms and b) when the divertor tungsten plate is sputtered by Be ions of different initial energies. Analysis of sputtered atoms ranges led to the following conclusions: (a) Be atoms sputtered from the wall are able to reach the separatrix without absorption in the gas target everywhere except for the near-divertor region; (b) thermalized Be ions accelerated in the plasma-wall potential can reach the divertor with the probability higher than 73%; (c) the absorption of sputtered tungsten atoms in the gas target near the divertor plays an important role and reduces twice the flux of sputtered atoms. The concentration of tungsten released during the bombardment of the divertor by beryllium ions was estimated. It was revealed that the lethal concentration of tungsten in near-divertor plasma can be achieved at the Be concentration of 5% and ion temperatures at separatrix higher than 100 eV. The sputtered atoms can be ionized in the scrape-of-layer plasma.

Refrences

1. M.I. Mironov, F.V. Chernyshev, V.I. Afanasyev et al., Plasma Phys. Rep. 47 (2021) 18. – DOUBLE-MC code
2. Ziegler J.F., Biersack J.P. SRIM – http://www.srim.org.