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A study of hydrogen isotopes fuel control by wall effect in magnetic fusion devices

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HIGHLIGHTS

- A particle balance model for the main plasma and wall inventory in magnetic fusion device has been represented.
- The dependence of incident particles energy on the wall has been considered in 10–300 eV for the sputtering yield and recycling coefficient.
- The effect of fueling methods on plasma density behavior has been studied.

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ABSTRACT

Determination of plasma density behavior in magnetic confinement system needs to study the plasma materials interaction in the facing components such as first wall, limiter and divertor. Recycling of hydrogen isotope is an effective parameter in plasma density rate and plasma fueling. Recycling coefficient over the long pulse operation, gets to the unity, so it has a significant effect on steady state in magnetic fusion devices. Typically, sputtered carbon atoms from the plasma facing components form hydrocarbons and they redeposit on the wall. In this case little rate of hydrogen loss occurs. In present work a zero dimensional particle equilibrium model has been represented to determine particles density rate in main plasma and wall inventory under recycling effect and codeposition of hydrogen in case of continues and discontinues fueling methods and effective parameters on the main plasma decay has been studied.

1. Introduction

Material selection is a key issue in design of magnetic fusion devices. Tokamaks like JET and ITER with long pulse operation [1–3] need to choose materials wisely in vacuum vessel, magnets, blankets and wall components. Plasma control and plasma interactions in a closed confined system, is one of the most important issues in design of the magnetic fusion devices [4,5]. As investigations proven plasma facing components and choice of materials, play a key role in particles control [6,7]. Attaining to the better steady state operation, study on particles recycling process in the fusion devices is very important issue [8,9]. High energetic deuterium tritium particles which escaped from confinement region make interaction with plasma facing components (PFCs). The wall acts as a sink for plasma charged particles, consequently incident particles reflect back to the plasma inventories by several such reflection and reemission processes [10]. As the result of this phenomenon, sputtering and recycling of particles from the wall surface takes place [11]. Codeposition as secondary phenomenon, as well as sputtering, is probably desired [12,13]. Imperfect confinement causes more density wasting away and wall load might be increased. In order to study the effective parameters on density decay and plasma wall interaction, some models based on deuterium tritium inventories has been represented [10,14]. In this paper we are going to utilize particle balance models to study wall effects on deuterium tritium fuel control. Find out density decay and wall erosion effective parameters help better designing of magnetic fusion devices.

2. Representing model

The particle balance modeling introduced for plasma materials interaction in magnetic fusion devices is based on particles reflection from the wall and hydrogen codeposition. Here, we have built model without the contribution of vacuum pumping and in future we are going to upgrade it. Typically particles recycling occur by reflection and reemission and here we assumed the yield of R for both of them. As the carbon atoms sputter from the wall surface, consequently hydrocarbon atoms form and redeposit to the wall.

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So in order to determine particles density in the main core and wall, we represent a zero dimensional modeling which is

$$\frac{dN_p}{dt} = f\Phi - \frac{N_p}{\tau_p} + R\left[(1-f)\Phi + \frac{N_p}{\tau_p}\right] \quad (1)$$

$$\frac{dN_w}{dt} = (1-R)\left[(1-f)\Phi + \frac{N_p}{\tau_p}\right] + \gamma Y_s\left[(1-f)\Phi + \frac{N_p}{\tau_p}\right] \quad (2)$$

where Φ is external hydrogen fueling rate in TorrL per second, f is the fueling efficiency, τ_p is particles confinement time, R is the recycling coefficient as a function of time and incident particles energy, Y_s is sputtering yield for normal incident deuterium tritium ion on carbon wall as a function of particles energy and γ is the codeposition probability of hydrogen atoms on the wall. Since some experimental data in sputtering yields is generated. The Bohdansky formula [15,16] can be as good as fit on these data for normal incident

$$Y_s = QS_n(\epsilon)\left(1-\left(\frac{E_{th}}{E}\right)^{2/3}\right)\left(1-\left(\frac{E_{th}}{E}\right)\right)^2 \quad (3)$$

which E_{th} is the threshold energy of sputtering, Q is the fitting parameter and S_n is the nuclear stopping power cross section based on Tomas-Fermi fitting formula as a function of an energy parameter ϵ

$$S_n(\epsilon) = \frac{3.441\sqrt{\epsilon}\log(\epsilon + 2.718)}{1 + 6.35\sqrt{\epsilon} + \epsilon(-1.708 + 6.882\sqrt{\epsilon})} \quad (4)$$

$$\epsilon = E\frac{M_2}{M_1+M_2}\frac{0.03254}{Z_1Z_2\left(Z_1^{2/3}+Z_2^{2/3}\right)^{1/2}} \quad (5)$$

where ϵ is reduced energy, M_1 and M_2 are incident and target atomic masses, respectively, Z_1 and Z_2 are incident and target atomic numbers, respectively, and E is particles incident energy. So the sputtering yield curve for deuterium and tritium energetic ions that leave confinement region to the carbon wall surface shown in Fig. 1. Because of little difference in rate, we considered the same value for deuterium and tritium sputtering rate.

Recycling coefficient for carbon surface versus incident particles energy always is between 1 and 0. As the incident particles energy increases, the recycling coefficient decreases. A suitable fitting function for particle recycling coefficient experimental data is

$$R(E) = \frac{A_1\ln(A_2\epsilon + 2.718)}{1 + A_3\epsilon^{A_4} + A_5\epsilon^{A_6}} \quad (6)$$

where ϵ is reduced energy which described in Eq. (5) and A_1 through A_6 are to be found in [17]. Reflection coefficient versus incident

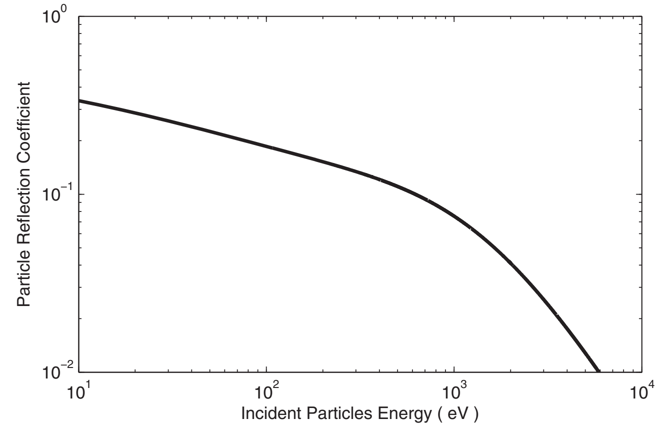

Fig. 2. Particles reflection coefficient versus incident particles energy on carbon wall.

particles energy on carbon wall is shown in Fig. 2. Additionally, the recycling coefficient in a constant energy of incident particles, varies over time. As the particles accumulating on the wall surface, recycled particles over incident particles rate increase and by long pulse operation raise to the unity. In this paper, for the simplicity we have considered that the particles recycling does only by reflection. An analytic formula according to TRIM calculations hve been represented by P. Mioduszewski [18], which the initial value of recycling coefficient R_0 assumed to be a constant value, here we have considered Eq. (6) as the energy dependence of the initial value of the recycling coefficient ($R_0(E)$):

$$R(E,t) = \frac{2}{\pi}\arctan(c\cdot t + R_0(E)) \quad (7)$$

by considering particles energy in Maxwellian distribution, almost we have particles in range of 10–300 eV energy which incident on the wall. Recycling coefficient over time in 10–300 eV incident particles energy is shown in Fig. 3.

Using gas puffing fuel injection for 0.2 s particle confinement, the simulation equations numerically have been solved in a hypothetic 20 s pulse operation. It is important to know that a spectrum of 10–300 eV particles energy facing the wall has been considered, so we have done two solutions for 10 eV and 300 eV energy. Any particles between these energies take place in this bound. As the result shown in Fig. 4, according to modeling, after part of a second, the main plasma particles raise to the steady state. The core plasma particles are affected by the energy but wall loaded particles not sound like this. By increasing the pulse length, the steady state interrupts and particle balance gets over. For wall particles

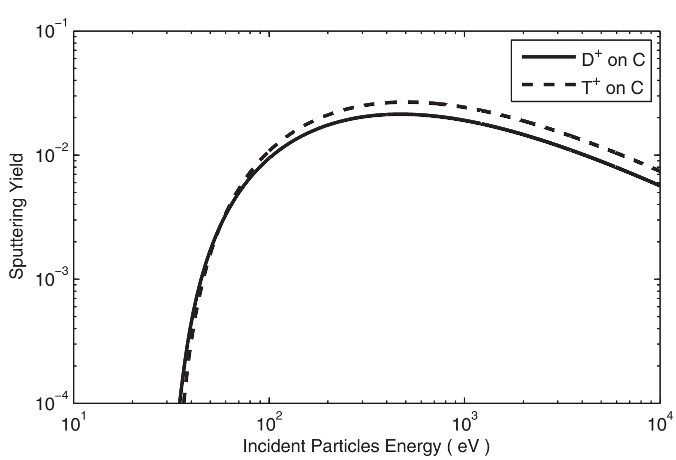

Fig. 1. Sputtering yield for deuterium and tritium ions incident on carbon wall surface.

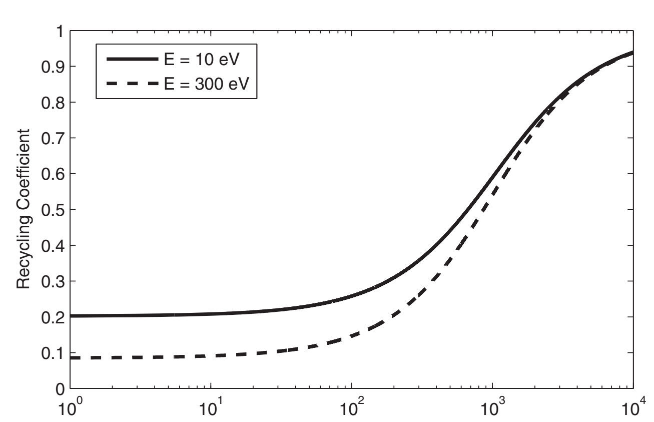

Fig. 3. Recycling coefficient over time in 10–300 eV incident particles energy.