

Monte Carlo simulation of helium atoms and ions in JT-60U W-shaped divertor

S. Suzuki, K. Shimizu, H. Kubo, T. Shirai*, A. Sakasai, T. Sugie and N. Asakura

Naka Fusion Research Establishment, Japan Atomic Energy Research Institute, Naka-machi, Naka-gun, Ibaraki 311-0193, Japan

**Tokai Research Establishment, Japan Atomic Energy Research Institute, Tokai-Mura, Naka-gun, Ibaraki 319-1195, Japan*

1. Introduction

Studies on the transport processes of helium atoms and ions in the divertor region are of great importance to control the helium ash exhaust of a fusion reactor. Some experimental studies have been made so far by injecting helium beams[1] and by puffing gases[2,3] into JT-60U plasmas. However, there have been few computer simulations of helium transport for actual divertor plasmas where many different processes take place. In this study we have analyzed the behavior of helium atoms and ions in JT-60U W-shaped divertor plasmas by using a two dimensional impurity transport code IMPMC[4].

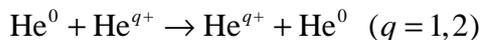
2. Computational method

The computer code IMPMC was developed for the simulation of transport processes of impurity ions in divertor plasmas by taking into account the effects due to Coulomb scattering, thermal force, friction force, and anomalous diffusion across the field line. In order to simulate the helium particle behaviour in the divertor region, however, it is required to simulate the transport of helium atoms and ions simultaneously, because atomic processes involving the helium atoms and ions affect the transport processes appreciably. As an initial condition, we postulate that the He^{2+} ions come into divertor plasma from core plasma and move about owing to interactions with the plasma. In the divertor region, the ions recombine to become neutral through interactions with the graphite wall and charge exchange collisions with the helium atoms. The neutrals thus produced are ionized again by collisions with electrons and helium ions, that is, recycling processes take place in the divertor plasma.

In the collision processes involving the helium atoms, the ionization by electron impacts is more dominant than any other processes. In order to take into account the effect of the ionization via metastable states, a recent collisional-radiative model[5] was employed. On the other hand, the excited He^+ ions decay quickly into the ground state, so that we take into

account only the ionization from the ground state with the rate constant adopted from Ref. [6].

The charge exchange processes between helium atoms and ions,



are taken into account also[7], because the cross sections are large in the energy range studied here. These processes produce fast helium atoms. The number of this reaction per unit volume per unit time depends on the helium atom density and ion density. However, these densities also depend on the number of the reactions. Therefore we used an iterative procedure to determine these densities self-consistently.

On the divertor plates, the helium ions accelerated by a sheath potential interact with the graphite wall. This interaction neutralizes the incident ions. The incident helium particles reflected or absorbed on the wall. Helium particles that got absorbed to the wall are assumed to be desorbed again at the wall temperature. The data on the particle reflection and energy reflection coefficients of the helium atoms incident on the graphite wall have been taken from Ref. [8].

In order to take into account the effect of energy transferred to slow helium atoms in elastic collisions with the hydrogen ions, the elastic and momentum transfer cross sections from Ref. [9] have been used.

We also have considered the recombination of helium ions in collisions with electrons and the charge exchange processes between helium ions and hydrogen atoms. However, the ion impact ionization was neglected because it is much less probable than the electron impact ionization in the energy range studied here.

3. Results and discussion

In the present study, we analysed an L-mode discharge ($B_T=3.5\text{T}$, $I_P=1.2\text{MA}$, $P_{\text{NB}}=4.5\text{MW}$, $\bar{n}_e=2.1 \times 10^{19} \text{ m}^{-3}$) where helium gas was puffed into a hydrogen plasma[3]. The plasma parameters were $n_e=2-4 \times 10^{19} \text{ m}^{-3}$ and $T_e=10-20\text{eV}$ at the inner divertor region, and $n_e=0.5-1 \times 10^{19} \text{ m}^{-3}$ and $T_e=30-40\text{eV}$ at the outer divertor region. The inner divertor plasma was detached in the narrow region around the separatrix. The electron density and temperature distributions used in this study were obtained from a calculation with a simple divertor code[10] that uses the Langmuir probe measurements. The averaged density of helium ions is taken to be 10% of the electron density.

In fig. 1(a) the calculated neutral helium density distribution in the divertor region with pumping from the inboard side in the private flux region is shown. The helium atoms are removed in the calculation when the atoms pass through the pumping slot. The helium atoms are produced when the helium ions hit the wall around the separatrix strike points as can be seen in this figure. In the upstream of the strike points, the helium atoms are ionized by the electron impact, so that the helium atom density become small. The helium atom

density in the private region where the electron density is low, is higher than that in the region of scrape-off layer. The helium atom density for the case without pumping is shown in fig. 1(b). The pumping effect is clearly seen around the inner divertor region [see figs. 1(a) and 1(b)]. The number of the charge exchange reaction between helium ions and atoms is 36% and 44% of the number of hitting the wall for figs. 1(a) and 1(b), respectively. The reason of this difference is attributed to the difference of neutral helium density in the divertor region.

To clarify the effect of the charge exchange reactions, the results of fig. 1(b) is recalculated without the charge exchange processes. They are shown in fig. 1(c). The neutral helium density in fig. 1(c) is higher than in fig. 1(b) in the divertor region. The charge exchange reaction transfers momentum from the fast helium ion to the slow helium atom by the exchange of nuclei, thus the number of the fast helium atoms that have the energy over several eV is relatively increased. Fast helium atoms are also produced by the reflection of the helium ions on the wall. However the fraction of reflected atoms is only 14% of total helium particle hits. The fast helium atoms quickly move away and are ionized in the scrape-off layer or in the core plasma. Therefore, the reduction of the helium atom density occurs. The number of helium atoms penetrating from the divertor region into the core plasma is 3.9% and 2.1% of the number of atoms that hit the wall for the conditions of figs. 1(b) and 1(c), respectively. This difference is attributed to the fact that the fast helium atoms which are produced by charge exchange reactions have a long mean free path.

The helium atom and ion flux on the divertor plates with and without the charge exchange processes is plotted in figs. 2(a)

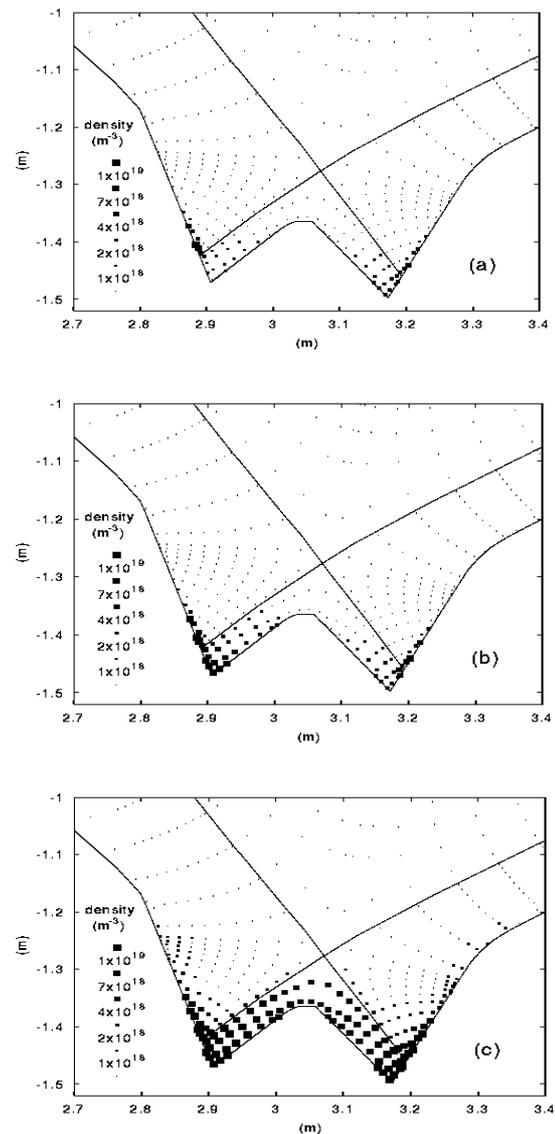


Fig. 1 The helium atom density distribution in the divertor region. (a): with pumping and charge exchange processes, (b): without pumping and with charge exchange processes, and (c): without pumping and charge exchange processes.

and 2(b), respectively. Two strong peaks of He^+ ions near the strike points are found in these figures. The He^+ ions are produced from the ionization of helium atoms around the separatrix. Since the ionization rate of He^+ ions is 0.01 to 0.1 times that of helium atoms in the energy range 10-100eV, most He^+ ions return to the divertor plate before the ionization in the scrape-off layer. The helium atom flux on the dome seen in both figures is due to the generation of helium atoms in vicinity of the strike points. The increased helium atom flux around the strike points in fig. 2(a) is due to charge exchange processes just above the strike points where both the helium atom and ion densities are high.

In summary, the helium transport in the divertor plasma is simulated by taking into account various atomic processes. A reduction in the helium atom density by the pumping is found. The charge exchange reactions between helium atom and ion causes the decrease of the helium atom density in divertor region and increase of the helium atom flux around the strike points.

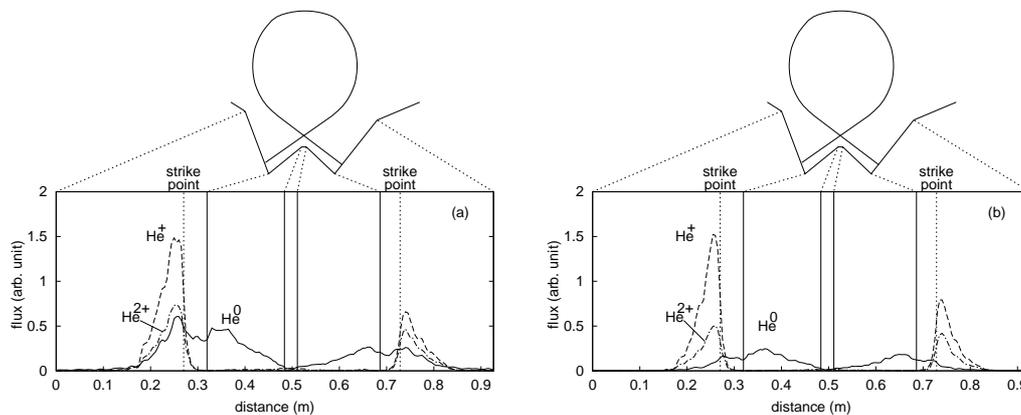


Fig. 2 The flux of He^0 , He^+ , and He^{2+} on the divertor plates without pumping. (a): with the charge exchange processes, and (b): without the charge exchange processes.

References

- [1] A. Sakasai *et al*, J. Nucl. Mater. 266-269, 312 (1999).
- [2] H. Kubo *et al*, JAERI-Research 97-047, 118 (1997) (Naka, Japan).
- [3] H. Kubo *et al*, Proceedings of 1998 ICPP & 25th EPS CCFPP, P1.031, Praha.
- [4] K. Shimizu *et al*, J. Nucl. Mater. 220-222, 410 (1995).
- [5] M. Goto and T. Fujimoto, NIFS-DATA-43, National Institute for Fusion Science, Japan (1997).
- [6] R. K. Janev *et al*, Elementary Processes in Hydrogen-Helium Plasmas (Springer-Verlag, New York, 1987).
- [7] R. Ito *et al*, JAERI-M 93-117 (1993).
- [8] W. Eckstein, IPP-Report 9/117, Max-Planck-Institute für Plasmaphysik, Germany (1998).
- [9] P. S. Krstic and D. R. Schultz, Atomic and Plasma-Material Interaction data for Fusion vol.8 (1998).
- [10] K. Shimizu *et al*, J. Nucl. Mater. 196-198, 476 (1992).