MODELLING OF WALL PUMPING, FUELLING AND ASSOCIATED DENSITY BEHAVIOUR IN TOKAMAKS

M. Sugihara, G. Federici, C. Grisolia*, Ph. Ghendrih*, T. Loarer*, H. Nakamura,
Yu. Igitkhanov, G. Janeschitz, G.W.Pacher**, H.D. Pacher***, D.E. Post
ITER Joint Central Team, Joint Work Site, D-85748 Garching, Germany
** Association EURATOM-CEA sur la fusion, C.E. Cadarache, France*
***Centre canadien de fusion magnétique, Varennes, Québec, Canada*
****The NET Team , D-85748 Garching, Germany*

Introduction

Material surfaces surrounding the plasma in Tokamaks play an important role on the transient plasma density and particle balance. In fusion reactors like ITER, pumping and fuelling by walls will also affect the overall DT fuel particle balance and determine the amount of radioactive tritium in the walls. A dynamic model of the plasma and walls has been developed, which solves a time dependent coupled system of equations for 0-D plasma densities and surface and bulk concentrations for representative walls. The wall model includes both metallic and non-metallic materials. The model is applied to the density behaviour and fuelling characteristics of a long pulse discharge and transient density experiments between different configurations in Tore Supra and JT-60 . The goal is to understand the governing processes for the wall and to identify their dependencies upon the various design parameters such as operational conditions, material properties, discharge history and wall conditions.

2. Wall and Particle Balance Models and Equations

Wall and particle balance models are extension of the existing models so far developed in various groups, e.g., [1]. Five representative wall regions are considered; (1) First wall near gas puff port, (2) General first wall, (3) Limiter, (4) Divertor plate, (5) Divertor side wall.

Balance equations in implantation layer

Schematics of particle balance in each wall is shown in Fig. 1. Balance equation for the particles implanted in this layer , particles desorbed from this layer by diffusion/recombination, and particles diffusing into bulk of the wall is expressed as

$$\frac{d}{dt}N_j = \left(\Gamma_j^{in}\right) - \left(\Gamma_j^{out}\right) + A_j\left(D_j \frac{\partial}{\partial x} C_j\right)_{x=\delta} \tag{1.1}$$

where N_j is the total particles stored in the implantation layer of the wall (j), $C_j(x)$ is the particle concentration (concentration is assumed constant in this layer, width δ). Γ_j^{in} is influx to each wall (j). Particle flux on the limiter and divertor plate Γ_j^{in} is determined by $\Gamma_j^{in}=N_p / \tau_p$. Here N_p, τ_p are total plasma particles and the particle confinement time including the recycling, respectively. Flux amplification is considered by appropriate choice of τ_p. For limiter configuration, Γ_j^{in} on the first wall is determined by some fraction of the influx on the limiter, e.g., 0.15 [1]. For divertor configuration, Γ_j^{in} on the first wall and divertor side wall are determined by the neutral density in divertor and main plasma region, respectively. Desorbed flux from the layer Γ_j^{out} is determined by the desorption model. In the case of CFC based materials; $\Gamma_j^{out} = (N_j / N_{j,max})\Gamma_j^{in}$, where $N_{j,max}$ is maximum absorbable particles. In the case of metal wall (e.g., Be, W), $\Gamma_j^{out} = 2k_r^j (N_j)^2 / A_j \delta^2$, where k_r^j is recombination coefficient.

Diffusion into bulk materials

$$\frac{\partial}{\partial t} C_j(x) = D_j \frac{\partial^2}{\partial x^2} C_j(x) \qquad (1.2)$$

Particle balance model in plasma

$$\frac{d}{dt} N_p = \left(\Gamma_{puff}\right) - \sum_j \frac{d}{dt} N_j - \Gamma_{NET}^{co} - \Gamma_{pump} \qquad (1.3)$$

Codeposition of hydrogen

$$\Gamma_{NET}^{co} = \left[Y_D \Gamma_j^{in} - \frac{Y_D \Gamma_j^{in} f_r}{1 - f_r Y_{ss}} (1 - Y_{ss}) \right] \frac{N_j}{N_{j,\max}} \qquad (1.4)$$

where Y_D, Y_{ss}, f_r are the coefficients for hydrogen and self-sputtering and return fraction of sputtered atoms [2]. Codeposition is considered only for limiter and divertor plate. Eqs (1.1)-(1.3) are simultaneously solved with initial values adjusted for each of the problems considered.

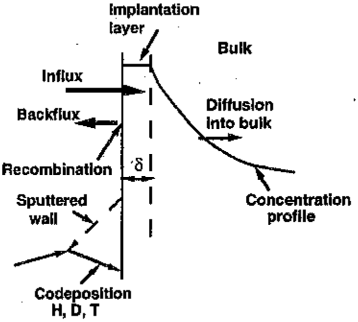

Fig. 1 Schematics of particle balance in wall.

3. Model Validations by Tore Supra and JT-60 Experiments

(1) Transition experiment from outboard limiter to inner wall in Tore Supra

Series of wall pumping experiments have been done in Tore Supra by using the transition from outer limiter to inner wall configuration without actual pumping system [3]. These shots have been performed with CFC wall materials after long hours of wall conditioning. We have selected two shots #5070 and 5080 from this series. First, initial particle contents in the walls are adjusted to obtain reasonable fit to #5070 experiment. Then, the initial contents for #5080 are somewhat increased to obtain a reasonable fit to #5080 with fixing other simulation conditions. Results of simulations are shown in Fig. 2. Fit is reasonably good only by adjusting the initial particle content in the walls. In the simulation, the increase of initial particle content between these shots are $N_0(\#5080) - N_0(\#5070) = 1.28 \times 10^{21}$ (p), where N_0 is the total initial particle content in the walls. This increment is much smaller than the total particles injected into the torus during these 10 shots, which are estimated as 2×10^{22} (p). This is consistent with the previous finding in Tore Supra [3], which concluded some reduction mechanisms of the wall-absorbed particles. By simple examination, it is shown that the particle diffusion into the bulk materials is too small to explain this reduction, unless wall temperature is very high (>1000 °K

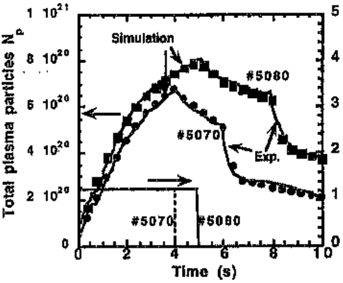

Fig. 2 Experimental density behaviour (solid lines) and simulation (closed circle, square).

is required for diffusion to be effective), which is unlikely in the experiments. Thus, most likely mechanisms for this reduction are either thermal desorption between shots (≈900 s) or surface diffusion to other part of the wall, which are not directly exposed by the particle. These speculations still need further confirmation by further detailed study. Another necessary adjustment in the simulation is τ_p. Here, $\tau_p \approx 90$ ms during gas puffing is needed and 480 ms for the rest of the period for both shots. This confinement time is consistent with that obtained by detailed study of the density decay after transition in [3]. This adjustment of τ_p need further investigation. One possible interpretation is that during density ramp-up with strong gas-puffing, density profile is flat and the flux amplification is generally high and during the density decay phase after gas-puff is stopped, density profile tends to shrink.

(2) Transition experiment from inboard limiter to outer divertor in JT-60

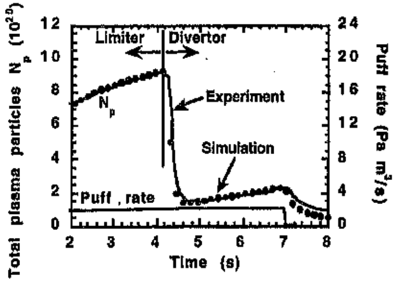

Fig. 3 Experiments (solid line) and simulation result (closed circles) for the density behaviour during limiter, transition and divertor phases in JT-60.

In JT-60, transition experiments have been done from the inboard limiter to the outer divertor with TiC coated wall [4]. Gas puff of 2 Pam^3/s was constantly injected up to 7 seconds. During transition, density decreases very rapidly due to large pumping by the divertor plate and side wall. Fuelling efficiency during the divertor phase is half of the limiter phase. Whole of these characteristic features of density behaviour are target of simulation. In order to model the particle flux on the first wall and divertor side wall, we will use the experimental results for the neutral density n_0 both in the main plasma and divertor regions as a function of main plasma density, which scales as $<n_e>^2$ [4]. The particle flux on each wall is evaluated by $\Gamma^{in}=n_0 v_0 S_j$, where v_0, S_j are neutral velocity and wall area of (j), respectively. Result is shown in Fig. 3, where τ_p is set ≈ 80 ms throughout whole phase of the discharge. After the transition, divertor plate is saturated within ≈ 0.5 s, so that this choice of τ_p does not affect the result since the wall absorption is dominated by the first wall and side wall. Density decay after gas-puff stop is slightly slower in the experiment. This discrepancy could also be improved by reduced neutral pressure due to longer τ_p.

(3) Long pulse operation in Tore Supra

In Tore Supra, long pulse operation has been done with LHCD [5]. Plasma density has been maintained almost constant even under the continuous gas fuelling with no pumping, so that the walls absorb all of the fuelled particles. For these long pulse discharges, it is expected that some continuous absorbing mechanisms should be necessary, since the surface will be saturated during the discharge. Thus, we examine following mechanisms. (1) Enhanced diffusion into the bulk of the wall as suggested in [6], (2) Enhanced codeposition of hydrogen.

We examine the time evolution of total puffed particles when the density behaviour is reproduced. Fig. 4 shows the results for total puffed particles with and w/o appropriate enhancement of the diffusion coefficient. By choosing the appropriate initial particle content, it is possible to match the total puffed particles at the end of the discharge. However, the global time behaviour is convex upward in time, which reflect the saturation character in surface trapping. This can not been seen for a short pulse discharge (≤ 10 - 20 s), which indicate the importance of long pulse (≥ 60 s) to identify dominant effect by walls. Another mechanism of enhanced codeposition of hydrogen could also reproduce the experimental result. Required enhancement, however, are fairly large ($f_r < 0.3$ and large flux amplification τ_p<10 ms), which needs further study in experiment.

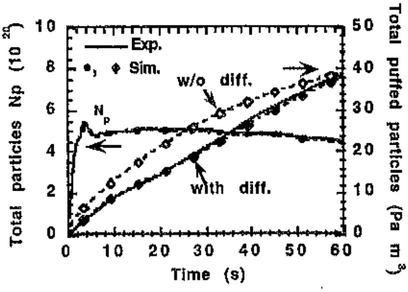

Fig. 4 Time evolution of total puffed particles for three different initial particle content in the walls when total particle (density) is matched with experiment.

Conclusions and Future R&D Needs

Dynamic wall particle interaction model is developed and applied to the experiments. The model can reproduce the density behaviour with large wall reservoir in transient experiments as well as constant wall up-take mechanisms, such as diffusion, codeposition in long pulse discharge. In addition to the wall modelling, it is identified that the modelling of the particle flux on each wall region are also important to reproduce the experimental results. This will be done by coupling the core plasma transport code with some sophisticated divertor/edge plasma models. Dedicated particle balance experiments under well controlled and diagnosed wall and plasma conditions are also essential to further develop and improve the model.

Acknowledgements

This report has been prepared as an account of work performed under the Agreement among the European Atomic Energy Community, the Government of Japan, the Government of the Russian Federation, and the Government of the United States of America on Cooperation in the EDA for ITER under the auspices of the International Atomic Energy Agency .

References

[1] J.K.Ehrenberg, JET-P(95)18.

[2] G. Federici, C.H.Wu, J. Nuclear Materials 207 (1993) 62.

[3] C. Grisolia et al., J. Nuclear Materials 196-198 (1992) 281.

[4] H. Nakamura et al., JAERI-M86-175 (1986).

[5] D. Van Houtte and Equipe Tore Supra, Nuclear Fusion 33 (1993) 137.

[6] C. Grisolia et al., Proceedings of 20th EPS, Lisboa (1993) II-595.