§47. Particle Balance Modeling in CPD and QUEST

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It is widely recognized that core plasma density control is a key to the successful operation of steady-state magnetic fusion reactors. In particular, high-performance core confinement is known to favor reduced edge recycling, as has recently been reviewed by Hirooka [1]. A variety of wall conditioning techniques have been used to reduce edge recycling. However, it is also true that the efficacy of wall conditioning has a finite lifetime because plasma-facing surfaces will be saturated with trapped particles.

In our previous work on CPD [2], it was demonstrated that a Li-gettered rotating drum installed as a poloidal limiter can maintain reduced edge recycling of hydrogen as well as oxygen impurities, and hence improved plasma performance. Particle balance modeling has been done on CPD to predict the core density behavior in QUEST.

The model used in the present work is essentially the same as those used for LHD [3] and TRIAM-1M [4], but has been modified in such a way that an extra hydrogen reservoir is added as a "2nd wall" to incorporate the effect of Li-gettering. The modeling equations are as follows:

$$\frac{dN_{core}}{dt} = -\frac{N_{core}}{\tau_{core}} + \eta\left(\frac{N_{core}}{\tau_{core}} + \alpha\frac{<\sigma v>_{CX-1}}{2V_{gas}}N_{core}N_{gas}\right)\left(R_{ef}^{MS} + R_{e}^{MS}\right) + \beta\frac{<\sigma v>_{CX-2}}{2V_{gas}}N_{gas}N_{SOL}$$

$$+\left(\frac{N_{SOL}}{\tau_{SOL}} + \beta\frac{<\sigma v>_{CX-2}}{2V_{gas}}N_{gas}N_{SOL}\right)\left(R_{ef}\,{}^{ref}f_{core} + R_{e}\,{}^{re}f_{core}\right) + f_{core}\Phi_{fuel}^{DT} \qquad (1)$$

$$\frac{dN_{SOL}}{dt} = -\frac{N_{SOL}}{\tau_{SOL}^{DT}} + (1-\eta)\frac{N_{core}}{\tau_{core}^{DT}} - \left(\alpha\frac{<\sigma v>_{CX-1}}{V_{gas}} - \gamma\frac{<\sigma v>_{ion}}{V_{SOL}}\right)N_{gas}N_{SOL}$$

$$+\left(\frac{N_{SOL}}{\tau_{SOL}} + \beta\frac{<\sigma v>_{CX-2}}{2V_{gas}}N_{gas}N_{SOL}\right)\left\{R_{e}\,{}^{re}f_{SOL} + R_{ef}(1-{}^{ref}f_{core})\right\} + f_{SOL}\Phi_{fuel} \qquad (2)$$

$$\frac{dN_{gas}}{dt} = -S_{pump}N_{gas} - \gamma\frac{<\sigma v>_{ion}}{V_{SOL}}N_{gas}N_{SOL} + \left(\frac{N_{SOL}}{\tau_{SOL}} + \beta\frac{<\sigma v>_{CX-2}}{2V_{gas}}N_{gas}N_{SOL}\right)\left\{(R_{e}(1-{}^{re}f_{SOL}\right.$$

$$\left.-{}^{re}f_{core}) - \gamma_1 Y_{H\to Fe}\right\} - \eta\left(\frac{N_{core}}{\tau_{core}} + \alpha\frac{<\sigma v>_{CX-1}}{2V_{gas}}N_{core}N_{gas}\right)\gamma_2 Y_{H\to Li} + (1-f_{core}-f_{SOL})\Phi_{fuel} \qquad (3)$$

$$\frac{dN_{1st-wall}}{dt} = \left(\frac{N_{SOL}}{\tau_{SOL}} + \beta\frac{<\sigma v>_{CX-2}}{2V_{gas}}N_{gas}N_{SOL}\right)\left(1 - R_{e} - R_{ef} + \gamma_1 Y_{H\to Fe}\right) \qquad (4)$$

$$\frac{dN_{MS-wall}}{dt} = \eta\left(\frac{N_{core}}{\tau_{core}} + \alpha\frac{<\sigma v>_{CX-1}}{2V_{gas}}N_{core}N_{gas}\right)\left(1 - R_{ef}^{MS} - R_{e}^{MS} + \gamma_2 Y_{H\to Li}\right) \qquad (5)$$

The sum of these equations is rather simple as follows:

$$\frac{dN_{total}}{dt} = \Phi_{fuel} - S_{pump}N_{gas} \qquad (6)$$

Using all the experimental parameters and data taken from CPD, the time evolutions of hydrogen reservoir inventories have been calculated. The hydrogen fluxes to the 1st wall and 2nd wall (i.e. Li-gettered limiter) during the flat-top period are calculated to be about 4 x 10^{15} 1/s/cm^2 and 1.5 x 10^{18} 1/s/cm^2, respectively. The plasma densities in the core, SOL and gas phase, shown in Fig. 1, have been found to be in good agreement with experimental data.

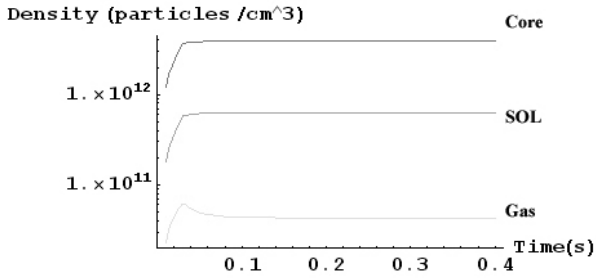

Fig. 1 Particle densities in the core, SOL and gas phase.

The hydrogen inventories predicted by the model are shown in Fig. 2. Recognize that the inventory in the 1st wall reaches a steady state level whereas the one in the 2nd wall continuously increases due to Li-gettering effects.

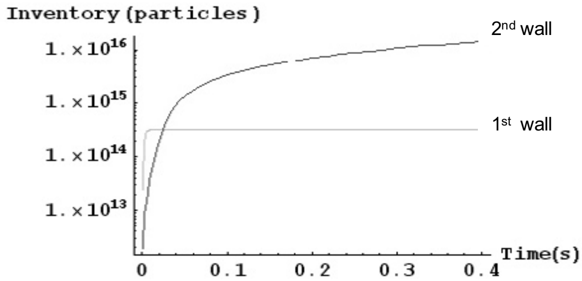

Fig. 2 Hydrogen inventories in the 1st and 2nd walls in CPD.

Core density behavior has been predicted for a long pulse of 3s, assuming possible recycling coefficients for the 2nd wall, as shown in Fig. 3. Notice that the core density can sensitively be affected the wall recycling coefficient.

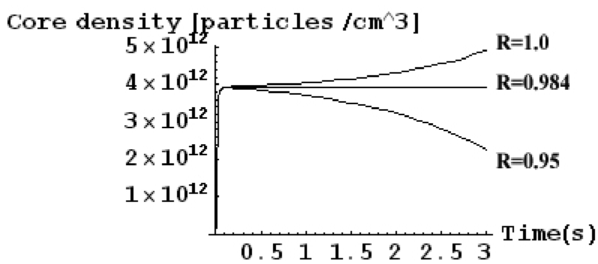

Fig. 3 Effects of wall recycling on the core plasma density.

[1] Hirooka, Y. "A review of plasma-wall boundary effects on core confinement and lithium applications to boundary control "(to be published in Fusion Eng. & Design (2010).
[2] Hirooka, Y. et al., J. Nucl. Mater. **390-391** (2009)502.
[3] Hirooka, Y. et al., J. Nucl. Mater. **290-293**(2001)423.
[4] Hirooka, Y. et al., J. Nucl. Mater. **313-316**(2003)588.