§42. Modeling of Particle Balance in Steady State Plasma Confinement Device: TRIAM-1M

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Over the past two decades most of the “sub-critical, i.e., Q<1” fusion experiments have been successfully conducted using large tokamaks such as TFTR and JET. Also, the construction site for ITER (for the International Thermonuclear Experimental Reactor), intended to exceed the energy breakeven, i.e., Q=1, has recently been decided to be Cadarache. Although ITER is planned to be operated in the long pulse mode, the pulse duration is limited to ~500 seconds due to the OH capacity. Interestingly in this regard, recent operation experiences with the TRIAM-1M tokamak have demonstrated that it often takes hours of continuous plasma interactions for wall components to reach their respective thermal equilibria [2]. Therefore, one predicts that the ITER pulse length is not sufficiently long for all the in-vessel components to reach steady state temperatures, in which case gas recycling dynamics unavoidably affect edge characteristics, and hence the core plasma performance during the course of pulse discharge. Clearly, not all the technical issues associated with steady state operation will be resolved by the ITER program as it is planned.

Among these remaining issues, particle balance and its control are critical in achieving true steady state because they can affect the overall reactor performance significantly as to fuel economy and related on-site radiation safety, lifetime of the plasma-facing components and core plasma stability. Though it has not been addressed until now, well-regulated fusion power generation probably would require solomonic control over particle balance because local plasma behavior is not quite at steady state due to the facts that core fueling tends to be discontinuous, particularly if it is done by pellet injection, and edge energy bursts due to ELMs is generally high-frequency but not truly continuous, etc. Responses to these operation “kick-backs” from plasma-facing components are yet to be explored in ITER and fusion devices beyond it towards the end of the 21st century.

To understand the particle balance behavior in steady state devices, a zero-dimension, four-reservoir (core, SOL, gas, wall) particle balance model has been applied to analyze the data taken from TRIAM-1M with the emphasis on interpretation of the wall pumping effects observed in long-pulse limiter discharges heated by LHCD.

The particle balance model equations used are:

$$\frac{dN_{core}}{dt}=-\frac{N_{core}}{\tau_{core}}+\alpha_1\frac{<\sigma v>_{cx1}}{2V_{gas}}N_{gas}N_{SOL}-\alpha_2\frac{<\sigma v>_{cx2}}{V_{gas}}N_{gas}N_{core}+(\frac{N_{SOL}}{\tau_{SOL}}$$
$$+\alpha_1\frac{<\sigma v>_{cx1}}{2V_{gas}}N_{gas}N_{SOL}+\alpha_2\frac{<\sigma v>_{cx2}}{V_{gas}}N_{gas}N_{core})(R_e{}^{re}f_{core}+R_{ef}{}^{ref}f_{core})+f_{core}\Phi_{ext} \tag{1}$$

$$\frac{dN_{SOL}}{dt}=-\frac{N_{SOL}}{\tau_{SOL}}+\frac{N_{core}}{\tau_{core}}-\alpha_1\frac{<\sigma v>_{cx1}}{V_{gas}}N_{gas}N_{SOL}+\beta\frac{<\sigma v>_{ion}}{V_{SOL}}N_{gas}N_{SOL}+(\frac{N_{SOL}}{\tau_{SOL}}$$
$$+\alpha_1\frac{<\sigma v>_{cx1}}{2V_{gas}}N_{gas}N_{SOL}+\alpha_2\frac{<\sigma v>_{cx2}}{V_{gas}}N_{gas}N_{core})\{R_e{}^{re}f_{SOL}+R_{ef}(1-{}^{ref}f_{core})\}+f_{SOL}\Phi_{ext} \tag{2}$$

$$\frac{dN_{gas}}{dt}=-S_{pump}N_{gas}-\beta\frac{<\sigma v>_{ion}}{V_{SOL}}N_{gas}N_{SOL}+(\frac{N_{SOL}}{\tau_{SOL}}+\alpha_1\frac{<\sigma v>_{cx1}}{2V_{gas}}N_{gas}N_{SOL}$$
$$+\alpha_2\frac{<\sigma v>_{cx2}}{V_{gas}}N_{gas}N_{core})(R_e(1-{}^{re}f_{SOL}-{}^{re}f_{core})-\gamma(Y_{sput}\frac{N_{SOL}}{\tau_{SOL}}+Y_{sput-1}\alpha_1\frac{<\sigma v>_{cx1}}{2V_{gas}}N_{gas}N_{SOL}$$
$$+Y_{sput-2}\alpha_2\frac{<\sigma v>_{cx2}}{V_{gas}}N_{gas}N_{core})+(1-f_{core}-f_{SOL})\Phi_{ext} \tag{3}$$

$$\frac{dN_{wall}}{dt}=(\frac{N_{SOL}}{\tau_{SOL}}+\alpha_1\frac{<\sigma v>_{cx1}}{2V_{gas}}N_{gas}N_{SOL}+\alpha_2\frac{<\sigma v>_{cx2}}{V_{gas}}N_{gas}N_{core})(1-R_e-R_{ef})$$
$$+\gamma(Y_{sput}\frac{N_{SOL}}{\tau_{SOL}}+Y_{sput-1}\alpha_1\frac{<\sigma v>_{cx1}}{2V_{gas}}N_{gas}N_{SOL}+Y_{sput-2}\alpha_2\frac{<\sigma v>_{cx2}}{V_{gas}}N_{gas}N_{core}) \tag{4}$$

,where N_{core}, N_{SOL}, N_{gas}, N_{wall} are the particle inventories in the core, SOL, gas, and wall, respectively, α_1, α_2, β, are adjusting parameters to express degrees of separation between the SOL and gas regions. All other symbols have their usual meanings. Results obtained are shown in Fig. 1, showing reasonably good agreement between the experimental data and model predictions.

The next step is to apply this particle balance model to analyze the data taken from experiments in which some of the wall components are acting as neutral gas sources due to the thermal degassing effect in addition to the usual gas-puff fueling.

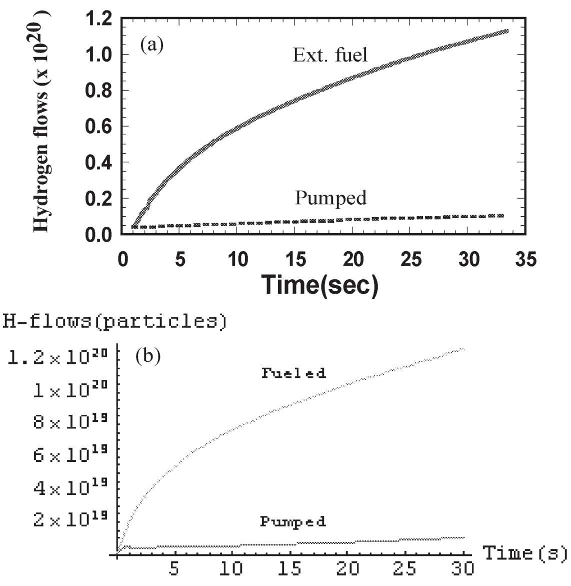

Fig. 1 A comparison between the experimental data (a) and model predictions (b) for the particles gain by external fueling and the loss due to active pumping.