# Development of Dynamic Boundary Density Model in *H*-mode Scenarios

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***Abstract***

Self-consistent simulations of deuterium and carbon density in H-mode scenarios are carried out using BALDUR 1.5D integrated predictive modelling code. The anomalous transport models Mixed Bohm/gyro-Bohm (Mixed B/gB) together with a dynamic boundary density model is used in these simulations. In this model, deuterium and carbon density at the boundary are assumed to be a large fraction of their line average density. It was found using the experimental data obtained from the latest public version of the International Pedestal Database (version 3.2) that the constants of proportion for deuterium and carbon density are 0.77 and 0.74, respectively. The developed density model is implemented in BALDUR code and used to provide density boundary condition in order to simulate the time evolution of temperature and density from JET tokamak. Statistical techniques, such as root mean square errors and offset values, are used to quantify the agreement between simulated profiles and experimental measurements.

***Keywords****:* Plasma, dynamic boundary density model, *H*-mode

## 1. Introduction

In the operation of tokamak, the divertor plates and other plasma facing component (PFC) materials get some interaction with hot plasma by ion backscattering, chemical and physical sputtering processes, which yield impurities into the plasma. In ITER, the critical level of impurity concentration is 4.0% for carbon, 0.1% for ion and 0.008% for tungsten with respect to the electron density [1]. The presence of these impurities can contribute to radiation loses and plasma fuel dilutions, which can decrease the performance of a tokamak. The impurity accumulation occurs when the radial density profile of an impurity evolves a stronger peaking than the profile of the main plasma ion, which is usually observed in the central part of the plasma inside a normalized radius $r/a < 0.5$ [2]. The impurity transport in the SOL region and the impurity penetration to the

core is one of the key issues in the edge plasma physics [3]. In the recent work, Leekhaphan P. *et al*.[4] had shown that the impurity accumulation in ITER standard type I ELMY *H*-mode depends sensitively on boundary conditions and impurity transport.

In this work, the hydrogenic is deuterium and impurity is carbon. The dynamic boundary density model is used to simulate the deuterium and carbon density profiles of plasma [5]. The deuterium and carbon density at the top of pedestal in this model is assumed to be a large fraction of its line averaged density, can be expressed as:

$$n_{D,ped} = C_C \cdot \bar{n}_D \quad (1)$$

$$n_{C,ped} = C_C \cdot \bar{n}_C \quad (2)$$

where $C_D$ and $C_C$ are the deuterium and carbon density constants while $\bar{n}_D$ and $\bar{n}_C$ are the deuterium and carbon line averaged density, respectively. The deuterium and carbon density constants are calibrated against experimental data obtained from the latest public version of the International Pedestal Database (version 3.2). The dynamic boundary density model is implemented in BALDUR code to provide boundary conditions for *H*-mode plasmas. In each BALDUR simulation, the core transport is the combination of anomalous transport called the Mixed Bohm/gyro-Bohm (Mixed B/gB) transport models. Simulations of *H*-mode plasmas in various plasma conditions are carried out. Statistical technique is used to quantify the agreement between simulations and experimental data.

## 2. Development of dynamic boundary density model

For the deuterium density constant, it can be analyzed from 68 experimental data points from three tokamaks: 36 TFTR discharges, 17 JET discharges and 15 DIII-D discharges. For the carbon density constant, 55 experimental data points from two tokamaks: 36 TFTR discharges and 19 JET discharges are analyzed. It is assumed that the deuterium and carbon density at the top of pedestal are large fraction of its line averaged density, called the C-value, which in the dynamic boundary density model can be found from the ratio of the density at the top of pedestal to its line average density. In the current models, the density at the top of pedestal is assumed that equally to the constant multiply with its line average density, this constant can be found by averaged C-value of all discharges. Figs. 1a) and 1b) show that the density at the top of pedestal from models compared with the experimental data for deuterium and carbon density, respectively. The root mean square (RMS) deviation is used to quantify the comparison the density at the top of pedestal between the predictions and the experiments.

It can be found that the deuterium and carbon density constants are 0.77 and 0.74, respectively. The RMS deviations for deuterium and carbon density are 22.89% and 19.84%, respectively.

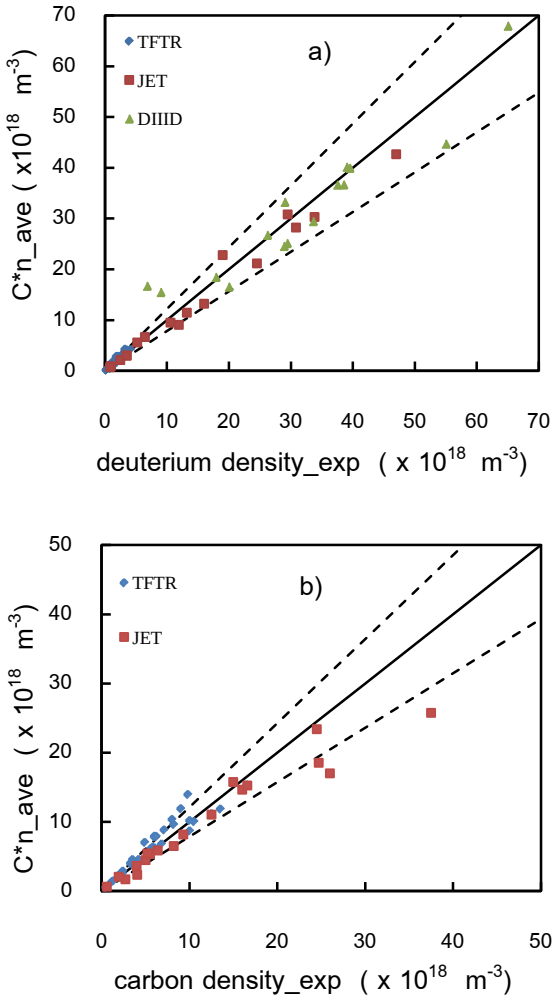


**Fig. 1** The density at the top of pedestal from model compare with the experimental data for a) deuterium density (68 discharges) b) carbon density (55 discharges).

### 3. Simulation and discussion

The simulations are carried out using 1.5D BALDUR integrated predictive modeling code with the Mixed Bohm/gyro-Bohm (Mixed B/gB) transport models. The deuterium and carbon influxes have strong line-averaged density dependence [6], $\Gamma = a\overline{n}^{\beta}$. It is assumed here that $\beta = 1$ and the constant "$a$" of the proportion is equal to 3.27, note that the value of this constant was found by comparing with the experimental data from JET discharge 35156. In this work, the BALDUR code with the boundary density models is used to simulate 5 discharges from JET tokamak and compare these simulation results in H-mode scenarios with the experimental data. For these simulated density profiles are shown in Fig 2. It can be seen that the electron, deuterium and carbon density somewhat agreement with the experimental data discharge 35156. For the other discharges, most of the carbon density tends to be lower than that of the experimental data.

The statistical analysis such as the relative root mean square (RMS) deviation and the relative offset are used to quantify the comparison between simulation and experiment, both are computed based on the difference between simulation profiles and experimental data. The RMS deviation of each quantity $X\,(n_e, n_{deu}, n_C)$ is defined as

$$\sigma_x = \sqrt{\frac{1}{N}\sum_{j=1}^{N}\left(\frac{X_j^{sim} - X_j^{exp}}{X_{max}^{exp}}\right)}$$

where $X_j^{sim}$ and $X_j^{exp}$ are the $j^{th}$ data point of the simulation and experimental profiles, respectively, while $X_{max}^{exp}$ is the maximum data point of the experimental profile of $X$ as a function of radius which has $N$ total points. For the relative offset of each quantity $X\,(n_e, n_{deu}, n_C)$ is defined as

$$f = \frac{1}{N}\sum_{j=1}^{N}\left(\frac{X_j^{sim} - X_j^{exp}}{X_{max}^{exp}}\right)$$

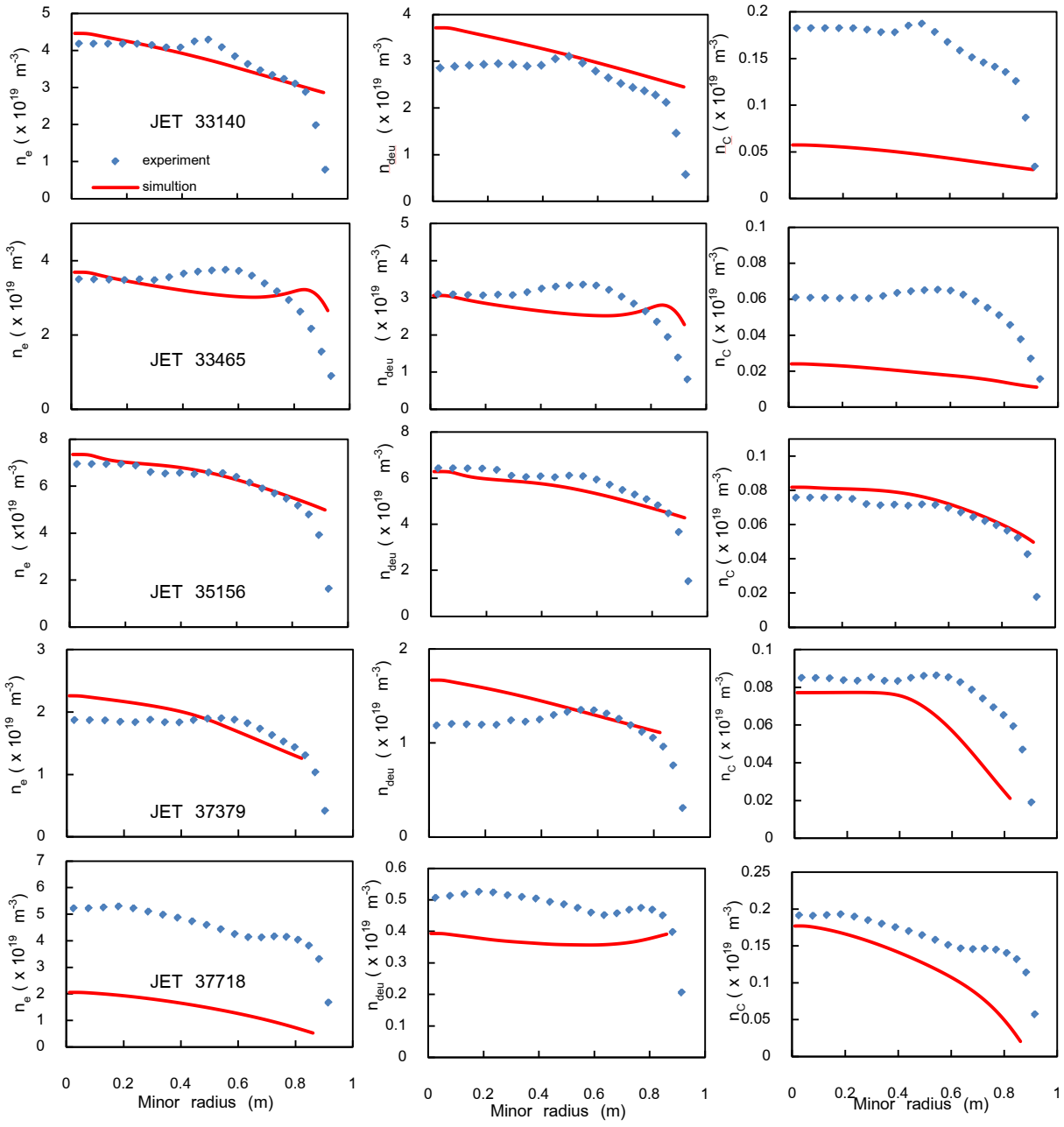


**Fig. 2** Simulation results of electron, deuterium and carbon density from 5 discharges of JET tokamak compared with the experimental data.

Beside density profiles, in these simulations get the temperature profiles both of electron temperature ($T_e$) and ion temperature ($T_i$). All of the temperature profiles are shown in Fig. 3, it can be seen that both of the simulation temperature profiles match equally well with the experimental data, except discharge 37718 which has simulated ion temperature lower than that of the experimental data.

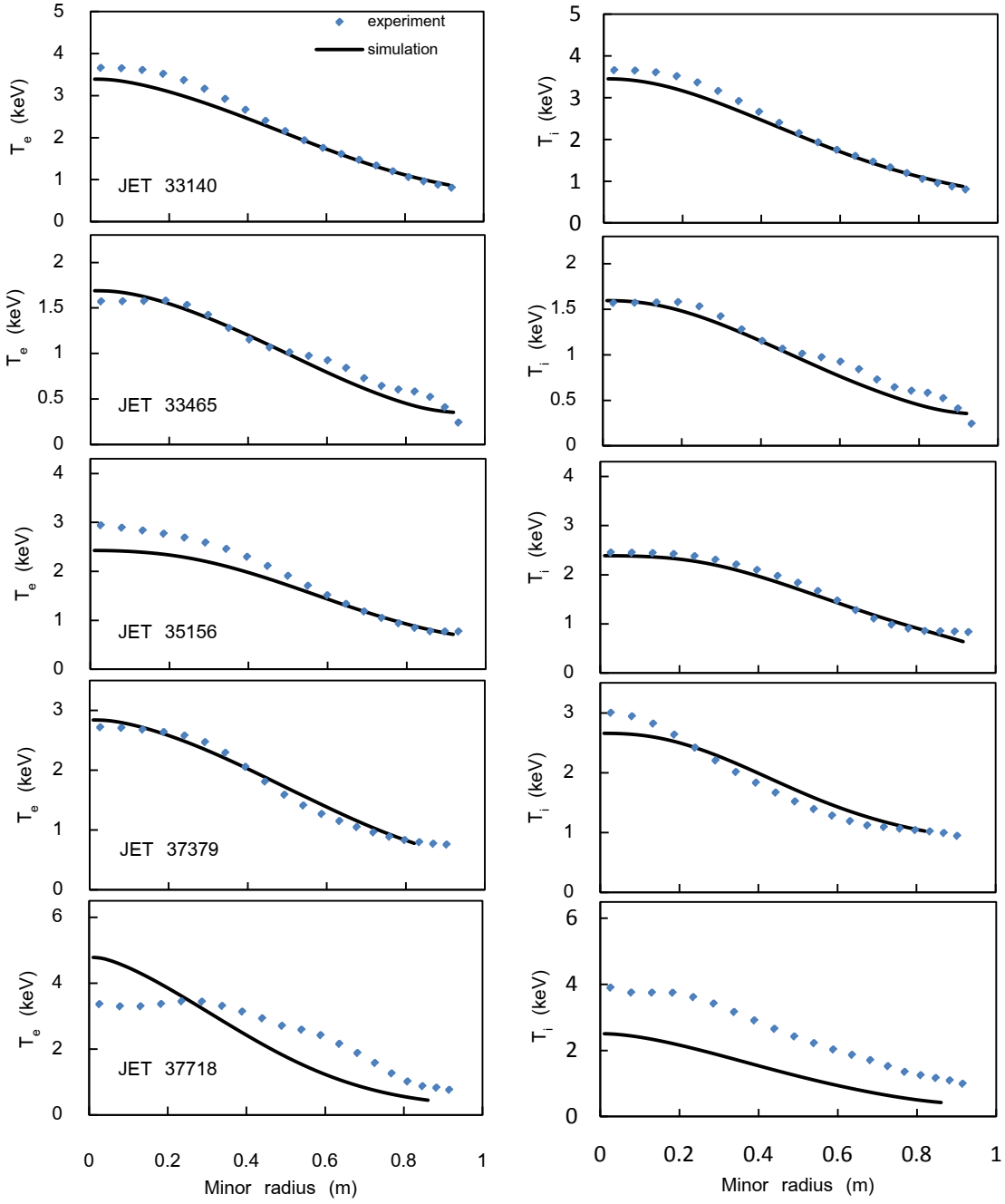


**Fig. 3** Simulation results of electron and temperature profiles from 5 discharges of JET tokamak compared with the experimental data.

The RMSE and offset from 5 discharges of JET are shown in Figs. 4 and 5, respectively. It shows that the RMSE of the electron density profiles vary from 11.91% to 59.86%, the deuterium density profiles vary from 11.42% to 22.35% and the carbon density profiles vary from 11.79% to 63.67%. For the RMSE of temperature profiles, the electron temperature vary from 3.67% to 24.99% and ion temperature vary from 4.14% to 31.37%. The offset values show that the electron and deuterium density somewhat agreement with the experiment. While

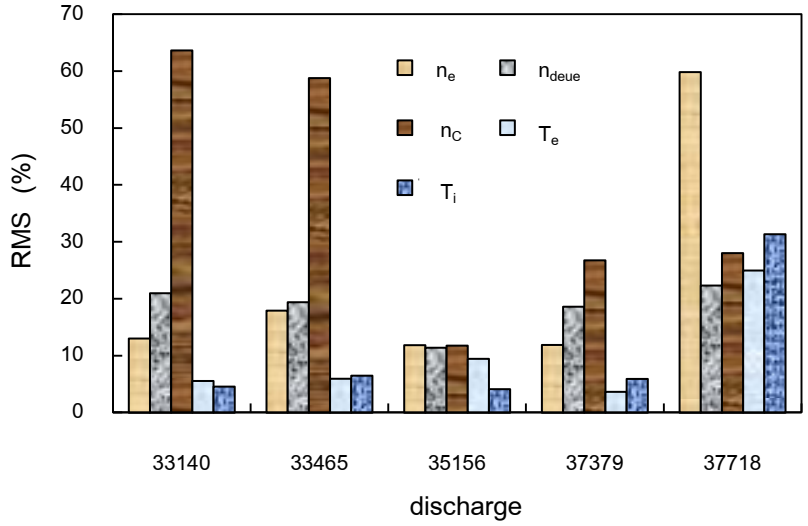


**Fig. 4** The RMSE (%) of simulation profiles for 5 discharges of JET

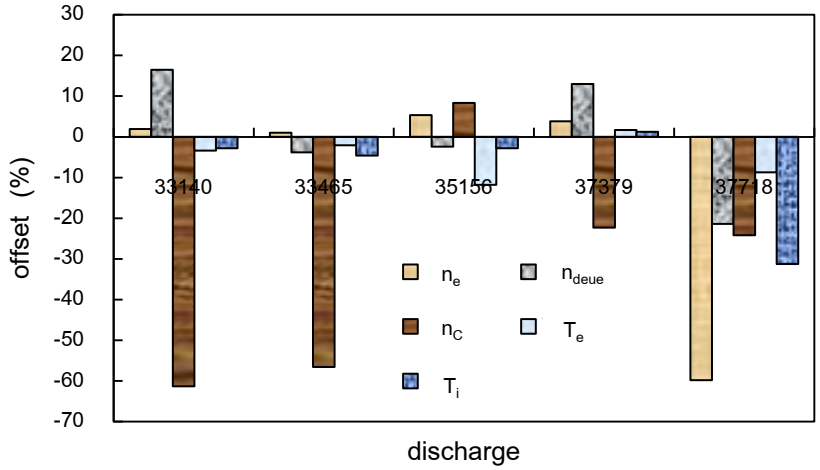


**Fig. 5** The offset (%) of simulation profiles for 5 discharges of JET

the carbon density profiles tend to lower than that of the experiment. For temperature profiles, most of all simulations are closely to the experiments.

## 4. Conclusions

The deuterium and carbon density constants in the dynamic boundary density model for predicting the density at the top of pedestal of deuterium and carbon profiles are 0.77 and 0.74, respectively. This model is used to implement in 1.5D BALDUR integrated predictive modeling code. The comparison of the simulation results in *H*-mode scenarios and experimental data show that this model somewhat agreement with the electron and deuterium density at the top of pedestal while the carbon density at the top of pedestal tend to be lower that of the experimental data. This dynamic boundary density is not affected to change the simulation of temperature profiles both of electron and ion temperature.

## 5. Acknowledgements

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## 6. Reference

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