*34th EPS Conference on Plasma Phys. Warsaw, 2 - 6 July 2007 ECA Vol.**31F**, P-4.039 (2007)*

Preliminary numerical simulations of highly radiative JET plasmas

S. Glowacz[1], W. Fundamenski[2], R. Zagórski[1], G.Corrigan[2], J. Rzadkiewicz[1,3]
and JET-EFDA Contributors*

[1]*Institute of Plasma Physic and Laser Microfusion, EUROATOM Association, Poland*

[2]*Euratom/UKAEA Fusion Association, Culham Science Centre, Abingdon, 0X14 3DB, UK*

[3]*Soltan Institute for Nuclear Studies, 05-400 Otwock-Swierk, Poland*

1. Introduction

The reduction of the power load to divertor target plates to a level compatible with the present day materials is a critical issue for future fusion reactors. To this end, power exhaust by radiation due to intrinsic (eroded) and extrinsic (seeded) impurities is beneficial, since it distributes the radiated power, P_{rad}, over a wide surface area, thereby reducing the power load on the divertor plates. The radiation is described in terms of the radiative fraction, f_{rad}, defined as the ratio of the radiated and input powers, (e.g. in the ITER reference scenario f_{rad} ~ 75% is required). Recent JET experiments with nitrogen seeding show that it is possible to achieve such high levels of radiation (f_{rad} > 90%) in Type-III ELMy H-mode discharges [1].

In this paper we present numerical simulations of the edge plasma in highly radiative JET discharges by means of the EDGE2D/NIMBUS [2] codes. The EDGE2D code is based on the Braginskii fluid equations implemented to describe SOL plasma transport in parallel and perpendicular directions to the magnetic surfaces. It solves the equations on a numerical mesh based on an EFIT-reconstruction of the actual plasma equilibrium. The trajectories of hydrogen and impurity neutrals are calculated with the Monte-Carlo module NIMBUS. The two codes are then coupled and a steady-state solution is obtained iteratively.

The above codes were used to investigate two nitrogen-seeded Type-III ELMy H-mode discharges on JET (pulses #68490 and #69353), which were characterised by high level of radiation (f_{rad} ~ 75%). Specifically, the influence of seeded (N) impurities, i.e. the nitrogen injection rate and its location (top vs. divertor), on power loads in the divertor, were studied, as was the interplay between seeded (N) and eroded (C) impurities.

As expected, simulations indicate that seeded impurities strongly enhance plasma radiation in the SOL. The level of seeded impurity radiation becomes comparable to that by intrinsive impurities for a nitrogen puff rate of γ_{puff} ~$3*10^{21}$ atoms/sec. Moreover,

---

* See the Appendix of M.L.Watkins et al., Fusion Energy 2006 (Proc. 21st Int. Conf. Chengdu, 2006) IAEA, (2006)

simulations indicate that more than 70% of power entering the SOL can be removed by total (seeded + intrinsic) impurity radiation, particularly in the higher density case.

2. The comparison with the experimental data

The total radiation for shots #68490 ($P_{in}^{\exp} = 15.3MW$, $\Gamma_{N}^{\exp} = 7.3 \cdot 10^{22} s^{-1}$) and #69353 ($P_{in}^{\exp} = 21.2MW$, $\Gamma_{N}^{\exp} = 18.4 \cdot 10^{22} s^{-1}$) were obtained by means of bolometry technique.

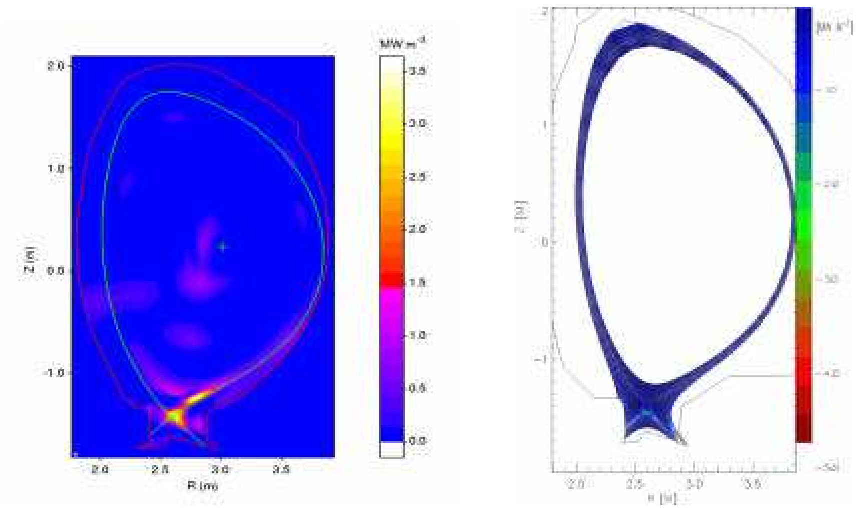

Fig.1 Distribution of total radiation power obtained for shot #68490 at time 57.1s averaged over 100ms (on the left) and calculated distribution of carbon radiation power for the shot #68490 (P_{in}=15MW, Γ_N=1.75*$10^{22}$$s^{-1}$)

In these experiment, with gas puff injection (inner divertor), the measured level of radiation for the shots #68490 and #69353 was $f_{rad}^{\exp} \approx 80\%$ and $f_{rad}^{\exp} \approx 74\%$, respectively. Such levels of radiation are obtained from calculations for smaller nitrogen puff rates. Since in the experiment impurity injection was placed in the fixed toroidal position the experimental puff rates do not exactly correspond to those appearing in the EDGE2D code. Fig.1 shows the measured distribution of energy radiation for the shot #68490. The calculated energy, distributions in contrast to the experimental results, shows no increased radiation near the X-point. This seems to be due to attenuation of impurity transport by the friction force. In our simulations seeded and sputtered impurities remain and radiate mostly in the divertor region.

3. The impact of the plasma parameters on the radiation properties of the edge plasma

Without the externally seeded impurities edge plasma can exhaust significant part of the power flowing from the core. Our calculations performed for two JET shots showed that atomic processes connected with hydrogen and carbon atoms can result in the level of radiation of ~40% for $n_S = 3 \cdot 10^{19} m^{-3}$ and ~25% for $n_S = 1.5 \cdot 10^{19} m^{-3}$ ass. Fig.2 demonstrates the impact of externally seeded impurities on the total radiation from the edge plasma for the density on the separatix $n_S = 3 \cdot 10^{19} m^{-3}$ and $n_S = 1.5 \cdot 10^{19} m^{-3}$. For $n_S = 3 \cdot 10^{19} m^{-3}$ at high puff rates ($\gamma_{puff} \geq 2 \cdot 10^{22} s^{-1}$) more than the 80% of input energy is radiated in the boundary region. In this case major part of radiation (>50%) is due to nitrogen ions. For $n_S = 1{,}5 \cdot 10^{19} m^{-3}$ more than 60% of input energy is radiated when $\gamma_{puff} \geq 1.75 \cdot 10^{22} s^{-1}$; nitrogen radiation constitutes more than 40% in this case. Somewhat surprisingly, simulations that the radiation of externally seeded impurities (nitrogen) has only a small effect on hydrogen and carbon radiation (the cause of this effect needs further investigation).

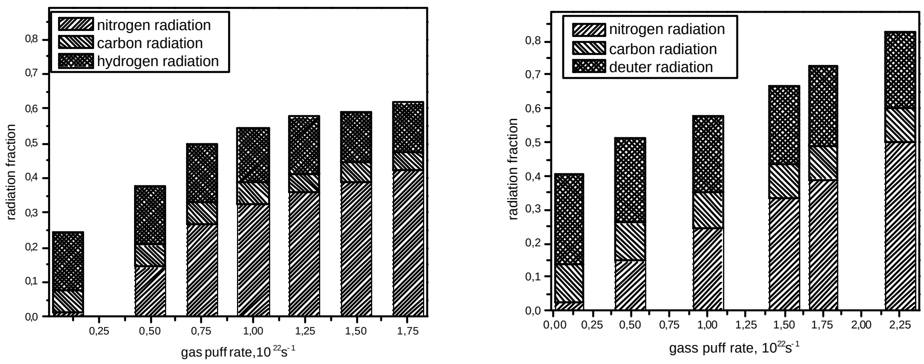

Fig.2 Calculated radiation fraction for n_S=1.5*$10^{19}m^{-3}$ (left) and n_S=3*$10^{19}m^{-3}$ (right); P_{in}=15MW, #68490.

The above effect is difficult to understand, since the target temperature decrease associated by increased nitrogen radiation should reduce carbon sputtering from the divertor plates and reduce the radiation of carbon in the edge region. The temperatures obtained on the divertor plates indicate that the chemical sputtering prevails; but even in this case, carbon content should depend on the temperature in divertor region (see Fig.3).

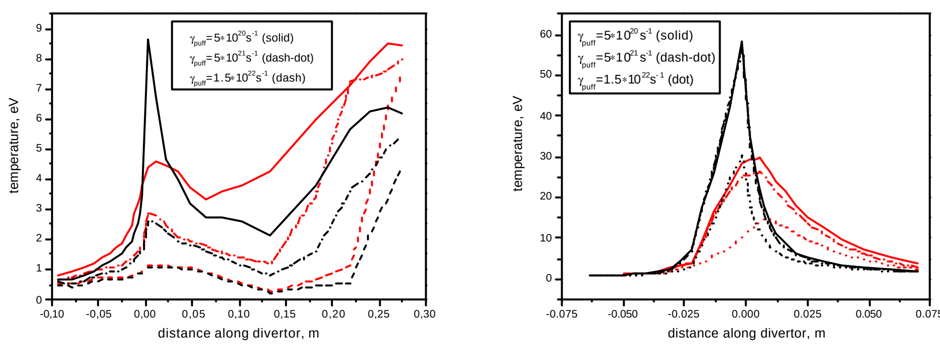

Fig.3 Electron (black) and ion (red) temperature profiles calculated along the inner divertor (left) and the outer divertor (right) plates for the numerical grid for the shot #68490; n=3*$10^{19}m^{-3}$, P_{in}=15MW.

Fig.4a shows hydrogenic, carbon and nitrogen radiative fractions as a function of nitrogen puff rate for both separatix densities considered in our calculations; Fig.4b shows the electron and ion temperatures on the first SOL ring at both targets as a function of nitrogen puff rate. Radiation of carbon remains on the level of about 10% for $n_S = 3\cdot 10^{19} m^{-3}$ and of about 6% for $n_S = 1.5\cdot 10^{19} m^{-3}$ almost independently on the nitrogen puff rate. While both targets are cooled by increasing nitrogen radiation, the inner target is cooled more rapidly and becomes detached when the rate of injection exceeds $7.5\cdot 10^{21} s^{-1}$ and the radiative fraction exceeds ~50%. However, the excessively high outer target temperature indicates that the assumed diffusivities of 1 m^2/s, do not accurately represent the experimental situation.

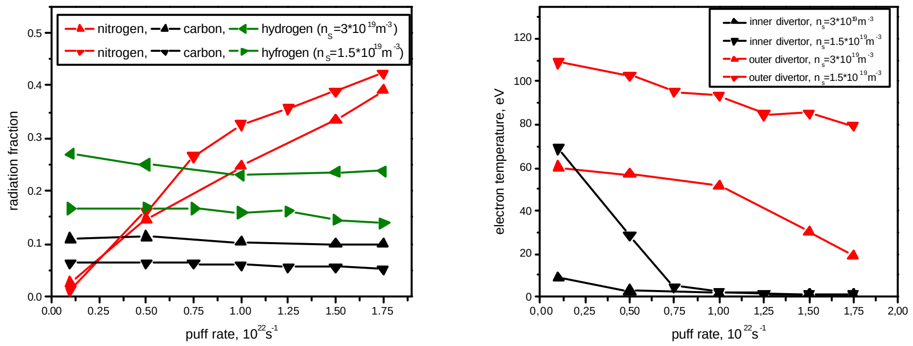

Fig.4 Radiation fraction of nitrogen and carbon (left) and electron temperatures on inner and outer divertor plates (right) as a function of nitrogen puff rates; P_{in}=15MW, shot #68490.

The impact of the gas puff position was studied at the fixed puff rate ($\gamma_{puff} = 5\cdot 10^{21} s^{-1}$) for shot #68490. With the gas puff located near the top of the machine, $f_{rad} \approx 63\%$ was found, whereas with the gas puff located in the private region, $f_{rad} \approx 80\%$ was obtained

4. Conclusions

Preliminary numerical simulations using the EDGE2D/NIMBUS codes indicate that nitrogen seeding can substantially increase the radiative fraction in JET discharges, to levels in excess of 80%, with more than half the radiation due to the seeded impurities. This results in cooling of both divertor targets and facilitates inner divertor target detachment. Future simulations will be dedicated to more accurate matching of experimental conditions, and the explanation of various trends observed in the Type-III ELMy H-mode experiments.

Acknowledgement

One of the authors (R.Zagórski) has been supported in years 2004-2007 by the grant 3T10B 00227 from the Polish Committee for Scientific Research.

References

[1] J.Rapp,et al., J. Nuclear Materials, **337-339** (2005) 826

[2] R. Simonini, *et al*, Contrib. Plasma Phys. **34**, 368 (1994)