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** See annex of F. Romanelli et al, "Overview of JET Results", (Proc. 22nd IAEA Fusion Energy Conference, Geneva, Switzerland (2008)).*

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1. INTRODUCTION

This paper deals with the numerical simulation - made with the self-consistent COREDIV code [1] - of nitrogen seeded JET discharges and with the comparison to the experimental data. The JET discharges we refer to are characterized by $q_{95} = 2.6$ ($I_p = 3$MA), high density ($f_{GW} \sim 1$), high radiated fraction (frad ~ 0.8) and moderate confinement ($H_{98} \sim 0.75$). Although these JET discharges are type III ELMy H-mode, they lead to a power amplification factor Q in the range 6-10 when scaled to ITER [2] and therefore might be considered as representative in JET of an alternative ITER scenario at higher density, lower confinement and acceptable target load. The main features of the COREDIV code are described in [1], where it is shown that the code is capable to reproduce satisfactorily the experimental temperature and density profiles as well as the total radiated power, Prad, and the ionic effective charge, Z_{eff}. In this paper we focus on the analysis of some edge properties as the particle fluxes and the compatibility of Z_{eff} with the radiation properties of the impurities.

2. PARTICLE FLUXES AND DENSITIES

The energy transport coefficient profiles are given as input in COREDIV as they are deduced from the experimental energy content of the considered pulse. In the simulations here presented, the anomalous main particle diffusion coefficient is set to be proportional to the energy transport ($D_\perp = 0.25\ \chi_\perp$) as is the anomalous component of the impurity diffusivity (which includes also a neo-classical term). In the following, both the neo-classical and anomalous impurity pinch is set to zero. The main particle recycling coefficient is R = 0.975.

The simulated main particle fluxes are in the range $5\text{-}7\times10^{23}\ s^{-1}$ while the experimental ones are in the range $1.2\text{-}1.45\times10^{24}\ s^{-1}$ i.e. about a factor of two higher. The experimental fluxes are calculated using the absolutely calibrated spectroscopic signals and the ionization per photon (S/XB) = 30 and 15 for the outer and inner divertor, respectively [3]. Comparing simulation with experiment, one should consider the error in the absolute calibration and a certain degree of arbitrariness in the choice of the S/XB. Moreover, the boundary condition $Q^{div} = Q^{heat}\,(1-f_{rad}) = 8\ \Gamma_e T_e$(plate) implies that Te at the plates is about 6eV for $\Gamma_e = 6\times10^{23}\ s^{-1}$ when the typical value (calculated and experimental) of the power load Q^{div} = 5MW is used. Particle fluxes higher than that computed in COREDIV would lead to lower temperature at the plates, incompatible with the attached plasmas we are considering here (on this point, see also next section).

The simulated carbon fluxes are in the range $5.9 - 9\times10^{21}\ s^{-1}$ while the experimental ones are in the range $6.7\text{-}10\times10^{21}\ s^{-1}$(see Fig.1). Using the data from the KS3 JET diagnostic and the same S/XB used for the deuterium flux [4], from the CII line (λ = 515nm) we obtain carbon fluxes in the range $6.7\text{-}7.8\times10^{21}\ s^{-1}$ while using the CIII line (λ = 465nm) and the assumption made by Strachan [5], the carbon fluxes for these discharges are in the range $8.3\text{-}10\times10^{21}\ s^{-1}$.

In these high density, low temperature discharges the physical sputtering of carbon is of minor relevance, while chemical erosion is the dominant carbon release mechanism. We have given as an input in COREDIV the chemical erosion yield, which we have changed and adjusted from pulse to pulse (in the range 0.8-1.3 %) as well as the level of nitrogen puffing rate until the simulated Z_{eff} and the simulated nitrogen concentration become, simultaneously, similar to the measured values from bremsstrahlung and CXRS, respectively. We have compared the resulting simulated carbon fluxes with those predicted by the formula of Roth [6], in which chemical erosion yield is expressed as a decreasing function of the deuteron flux, multiplied by a numerical coefficient Y_{low}. The function with $Y_{low} = 0.16$ represents the best fit with the values of the yield we have given and, therefore, we have inserted in COREDIV the Roth formula with $Y_{low} = 0.16$ and we have made new runs with this input. All the simulated values shown and discussed in this paper refer to runs made with $Y_{low} = 0.16$. In figures 2 and 3 comparison is shown between simulated and experimental N2 concentration and Z_{eff} while, simultaneously, the simulated and experimental P_{rad} are in good agreement (not shown).

In these low edge temperature discharges N2 puffing does not lead to a significant change in the carbon flux, as experimentally observed. In COREDIV carbon sputtering caused by impinging nitrogen is not considered at this stage, but neglecting this carbon release mechanism does not imply a significant error. Indeed, considering that carbon self-sputtering (included in COREDIV) account for a few percent of the total carbon flux in these runs (this is due to the low edge temperature and to the low carbon concentration) and that the concentrations of C and N2 are similar (1-2 %), an error of the order of a few percent can reasonably be assumed for neglecting nitrogengraphite interaction.

3. RADIATED POWER AND ZEFF.

In the case the radiated power, P_{rad}, is emitted at the plasma edge by a dominant impurity of charge Z in a volume V with density ne and ionic charge Z_{eff}, the ratio $P_{rad}/(Z_{eff} -1)$ can be expressed in a first approximation as [7]: $P_{rad} / [(Z_{eff} -1)\, n_e^2] = (V / [Z^2 - Z]) * L_Z (T_e(edge))$ where L_z is the average cooling rate in the volume V at the average temperature Te. Assuming that for the discharges considered the local quantities P_{rad}, Z_{eff}, and ne are proportional to the global ones, we can plot the normalized cooling rates for the mixture C and N as a function of the (calculated) temperature at the target plates. The points of Fig.4, which show a dependence of the normalized cooling rates on the edge temperature and full compatibility between experiment and simulation, are constructed using the calculated and experimental global P_{rad}, Z_{eff} and line average density. With respect to the absolute value, using the typical numerically estimated local values near the x-point, we obtain an average cooling rate for the mixture nitrogen-carbon of the order of $L_{C\text{-}N}$ (av.) = 1×10^{-31} Wm^3, which is above the coronal model values both for carbon and nitrogen for the relevant range of temperatures.

DISCUSSION

The simplified geometry of the SOL in COREDIV does not allow to take into account carbon released from the wall, which has been shown in ref. [5] to enter the plasma core more easily than that released at the target. The related error is, however, minimized by two facts: first, in the experiments the carbon release from the wall is a small fraction of the total carbon flux [5] and, second, in COREDIV the ions produced at the target can be transported by thermal forces to the far SOL where they fuel the core with increased efficiency. In spite of the limitations caused by the uncertainties in the measurements as well as in the model, the results presented in this paper shown the capability of COREDIV of reproducing the main features of nitrogen seeded JET discharges.

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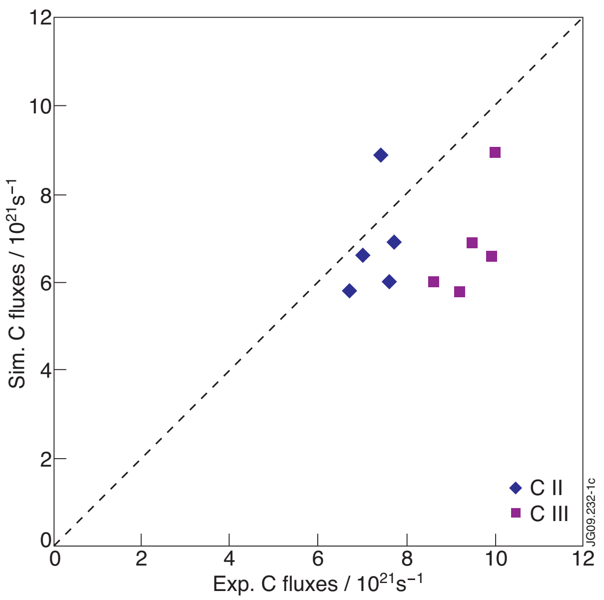

Figure 1: Carbon fluxes

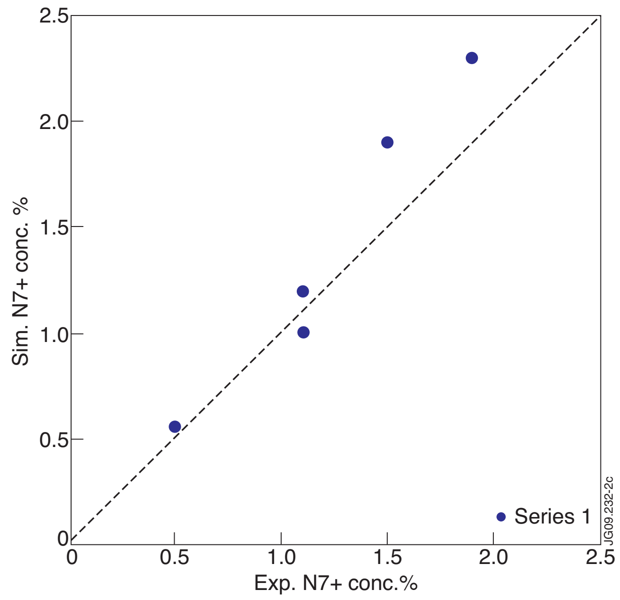

Figure 2: Nitrogen concentration

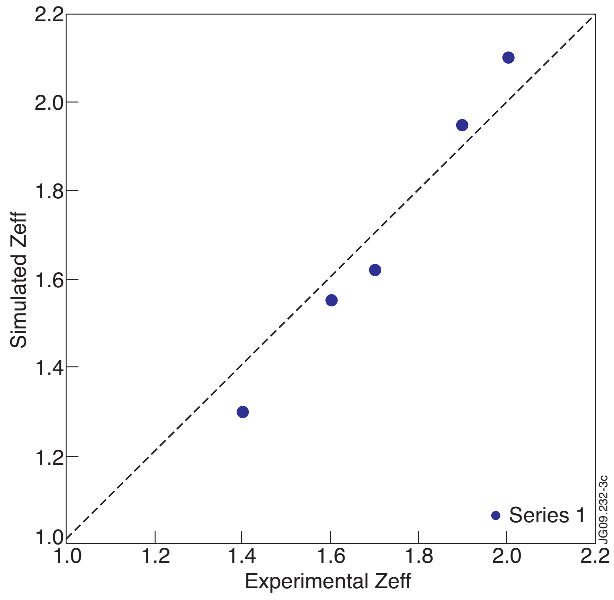

Figure 3: Z_{eff}

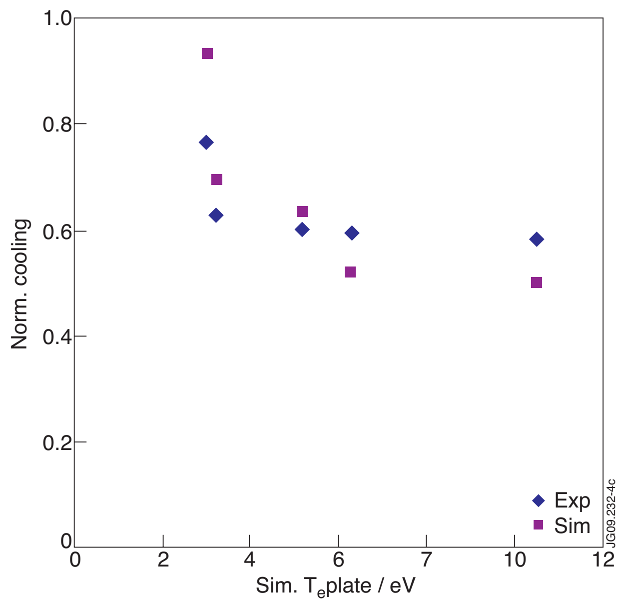

Figure 4: Cooling rates