RADIATIVE INSTABILITIES IN W7-AS PLASMAS WITH HIGHLY RADIATING BOUNDARIES

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Introduction

In low radiation ATF (Advanced Toroidal Facility [1]) stellarator plasmas it was concluded that the lack of efficiency in the radial energy transfer to sustain the local energy balance in regions with enhanced losses leads to plasma collapse [2]. The Proctr code [3] was used to analyse NB heated ATF collapsing discharges with moderate radiation levels (Prad/Pin ≈ 30 %) finding that radiative instabilities near the plasma periphery may be the trigger mechanism. On the other hand, low to intermediate Z impurity injection is being considered as a suitable procedure to cool the plasma edge region and, therefore, protect divertor plates in high power fusion experiments from thermal overloads. Then, the dominant plasma contaminant must be the adequate in every device for radiative edge cooling purposes, since cooling rate profiles determine the local energy lost by radiation.

Nitrogen is widely considered as an appropriate impurity for those purposes because of its radiative properties and its capability to be sufficiently pumped by the wall, especially when no active pumping is available [4]. In particular, it is used in tokamaks [5] to get the so called detached plasmas.

Experimental

In a previous work [6], nitrogen was confirmed to be an adequate impurity to effectively cool the edge region of Wendelstein 7-AS stellarator (R = 2.0 m, a = 0.18 m, no active pumping capability). However, steady state complete detachment from the limiters could not be established due to the onset of a radiative instability at a radiation level of about 60 % of the heating power. Further nitrogen injection experiments have been performed in W7-AS stellarator with feedback control of the radiation levels, via VUV line emission (N IV, 765 A), to maintain the impurity concentration under the limit of radiative collapse [7].

For the present studies a series of net current free ECRH discharges are considered, with flat-top of 1.5 s, at B=2.5 T, Iota/2π=0.34, injected power about 430 kW and electron density $n_e = 10^{19}$ m^{-3}. Transport analysis have been done with the predictive transport code Proctr. Here we are presenting the results obtained for three representative discharges, with no N_2 injection, 1 % and 2.5 % N_2 concentrations, shots # 36770, 36780 and 36783, respectively. In Figure 1 time evolution of line density, plasma stored energy and radiated power are plotted for the three mentioned discharges. A fraction of about 60 % radiated power (measured from bolometry) is reached in discharge 36783 and the attempts to exceed this limit lead to a radiative instability and to feedback induced oscillations of the discharge parameters rather than to a collapse. Decreasing the nitrogen influx and, thus, the radiation level within the discharge duration leads to re-establishment of stationary conditions.

W7-AS is operated with two carbon limiters and so a moderate concentration of carbon is considered to be present in discharge 36770. The experimentally measured density profile is flat up to r/a=0.5, whereas the electron temperature profile is rather peaked for the three discharges.

Transport Analysis

To simulate the discharge dynamics the following experimental parameters have been used as inputs for Proctr: total radiated power, stored energy, heating power, line density, and the dominant species. Density is feed-back maintained with gas puffing plus limiter recycling. Power deposition is notably localized, according to [8]. The experimental electron temperature and density profiles have been used to benchmark the transport models chosen. The modelled temperature and density profiles can be seen in Figure 2, marked with the nitrogen concentration of the discharge.

In Figure 3 the radial profiles of loacal and integrated power electron balances are plotted for the three discharges in steady state regime, at time t = 700 ms. Again every plot is marked with the nitrogen concentration. It can be seen the very different behaviours of the radiated power profiles, depending on the nature and concentration of the impurity. In discharge 36770 carbon impurities are accumulated mainly at r/a = 0.6, and the radiation profile is rather flat. When about 1% of nitrogen is injected (discharge 36780) the global radiated power increases in the whole plasma column, mainly due to a small increase of Z_{eff}, but this increment is more pronounced at the edge, where the radiation profile becomes clearly peaked. For this nitrogen concentration only slight changes appear in plasma transport. Further nitrogen injection notably modifies the power balance at the outermost region of the plasma. Due to the strongly localized ECR absorption in these plasmas, almost no changes in the power deposition profile are seen because 100 % single pass absorption is reached, since the temperature is still high enough. Differences are found mainly in particle convection and in the power interchanged with ions by collisions. The edge radiation peak propagates inwards and increases in intensity. This nitrogen concentration somehow represents the maximum admissible limit beyond which a steady state discharge cannot be held.

Surpassing this limit leads to a sudden plasma contraction together with an accumulation of impurities in the plasma core. That is, a thermal collapse occurs. An artificial discharge has been modelled based on the data and transport parameters considered in discharge number 36783. Concentration of nitrogen, radiated power, and stored energy have been proportionally modified to provoke the appearance of radiative instabilities.

Discussion

Nitrogen injection has been demonstrated as a good procedure for edge cooling in W7-AS, provided that feed-back is used to maintain the plasma under the limit of radiative collapse. In spite of the high radiated power, energy confinement time is only slightly degraded in discharge 36783 as compared with the reference one. This fact is confirmed by the diminishing of the estimated heat conductivity in the bulk plasma. This result agrees with the one presented in [7].

When comparing these results with the ATF NB-heated discharges [2] a difference is found in the plasma behaviour. As was concluded there, the detailed radial profile of the electron thermal conductivity plays a key role to supply power to the place where is needed. In the plasmas studied here this term is not able to cure the local increase of power losses and so the plasma can only reacts by modifying convection and power transmission to ions, i. e., particle transport must be mainly involved. One possible reason for these diverse behaviours can be found in the plasma heating method, since NBI power deposition profile is wider than ECRH (for high electron density and temperature) and changes according to the evolution of plasma parameters, such as density and temperature, higher power density is available near the maximum radiative losses region. Another likely cause may be that the magnetic configuration, strong sheared in ATF torsatron and almost shearless in W7-AS helias, is the responsible of the different transport regimes that appear in the two devices.

To clarify this problem simulations of ECR heated ATF discharges are underway. In particular the formation of transport barriers is planned to be studied.

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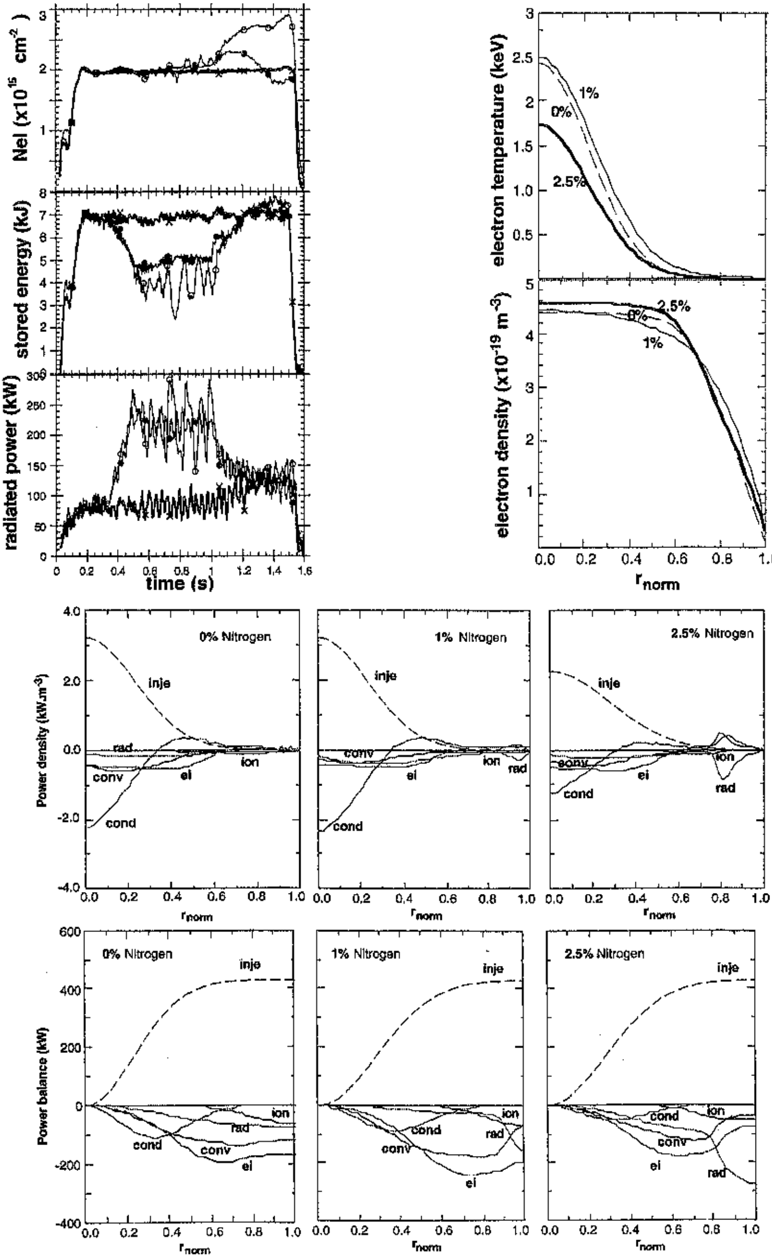

Nel (x10^15 cm^-2)
stored energy (kJ)
radiated power (kW)
time (s)
electron temperature (keV)
1%
0%
2.5%
electron density (x10^-19 m^-3)
2.5%
0%
1%
r_norm
0% Nitrogen
1% Nitrogen
2.5% Nitrogen
Power density (kW.m^-3)
inje
rad
conv
ei
ion
cond
Power balance (kW)