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Detailergebnisse / Details

TEC Main Topic 2 — Confinement

Plasmas with a radiating plasma mantle to allow for acceptable power exhaust have been a main subject of investigation. While no experiments were conducted on the tokamak TEXTOR in Jülich because of the shut down to install the Dynamic Ergodic Divertor, extensive work has been done on JET in Abingdon, UK. To understand the impact of the radiating impurities on transport in the plasma core and the global confinement properties, transport modelling has been an important element in 2003 as described in this report.

Experiments and modelling on radiating plasmas at JET under EFDA

The experiments at JET, the world largest tokamak device, have been jointly conducted under the European Fusion Development Agreement (EFDA) by the various EURATOM-Associations. The Trilateral Euregio Cluster (TEC) is participating in these activities. One of the main subjects is the exploration of plasma regimes, where the power is exhausted from the plasma in form of radiation onto large wall areas by radiation of impurities. Thereby, excessive heat loads on plasma facing components can be reduced at locations where the magnetic field directs charged particles on relatively small areas.

Two aspects have been especially investigated during last years campaign: *the development of a radiative scenario at high density with good confinement which is realised by means of a sophisticated feedback system,* and *the investigation of the impact of the seeded impurities on turbulence driven transport in the confined plasma*. For the latter the comparison to results obtained on the medium sized TEXTOR device is of special importance.

The plasma regime chosen for the impurity seeding experiments has been the so-called *High confinement mode* (H-mode) where a transport barrier at the edge is formed and energy and particles are released in periodic, burst-like events (so called edge localised modes, ELMs). The ELMy H-mode is the reference scenario presently foreseen for the next step fusion experiment ITER.

The seeding of argon into such kind of plasma discharges allows to establish high energy confinement at high plasma densities (close to the operational density limit of tokamak discharges, the so-called Greenwald density) in combination with a radiating plasma mantle. Previous experiments have shown, that the energy confinement at the high plasma density is very sensitive to the external gas fuelling, a characteristic which is also seen in discharges with high energy confinement and high density in TEXTOR as described later on. This experience has led to the development of a dual feedback system for JET, where at the same time the fraction of the radiated power with respect to the total input power is controlled by the external argon fuelling rate and the energy confinement time expressed by the enhancement factor with respect to the H-mode scaling law H98(y,2) is controlled by the deuterium fuelling rate. Once the energy confinement starts to degrade, the D2-fuelling rate is reduced and vice versa. In this way the plasma density is determined by the effective particle confinement time at the given gas flow. Discharges with a radiating mantle are characterised by improved particle confinement with respect to un-seeded reference pulses, which explains the possibility to obtain highest plasma densities in excess of the empirical Greenwald density limit in the presence of the radiating impurities.

Fig. 1 shows an example of a high triangularity discharge in the JET tokamak with dual feedback on the radiated power fraction and the H98 factor. During the phase, where the feedback is active, simultaneously high density (density normalised to the empirical Greenwald density limit f_{Gwd}=1.15), good H-mode performance (energy confinement time normalised to the ELMy H-mode scaling, H98(y,2)=1) and a radiated power level f_{rad} = P_{rad}/P_{tot} = 60% could be realised under quasi-stationary conditions.

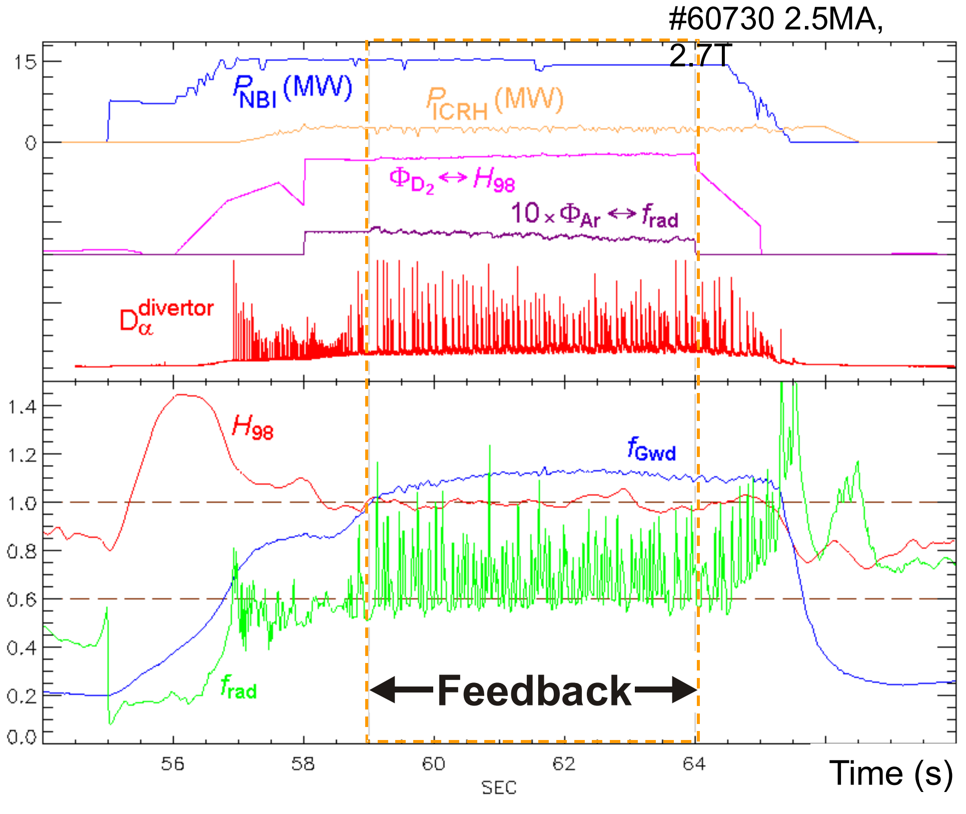


***Fig. 1**: Time traces of global plasma parameters in a JET discharge with dual feedback control of the radiated power fraction and the normalized energy confinement time.*

In parallel to the development of the experimental discharge scenario with the feedback scheme mentioned above much effort has been spent to improve the modelling tools which allow to study the physical mechanisms in impurity seeded, high density H-mode discharges. For this purpose the RITM code has been extended to predict the transport reduction in the edge barrier region of the H-mode plasma. In addition to the transport caused by unstable drift waves owing to ion temperature gradient, dissipative trapped electron and drift resistive ballooning modes, transport related to drift Alfvén modes have been incorporated. This transport model allows to predict the transition between L- and H-mode in dependence of the power flow to the separatrix. Fig. 2 illustrates the capability of the code to predict the formation of an edge pedestal by depicting the temperature at the top of the edge barrier and the normalised pressure gradient as a function of the heating power for the discharge scenario shown in Fig. 1. Note, that the power required to establish the barrier corresponds fairly well with the experimental threshold for the power flow to the separatrix of 9 MW for the discharge conditions under consideration, if we take into account that 25% of the total input power is radiated from the confined volume.

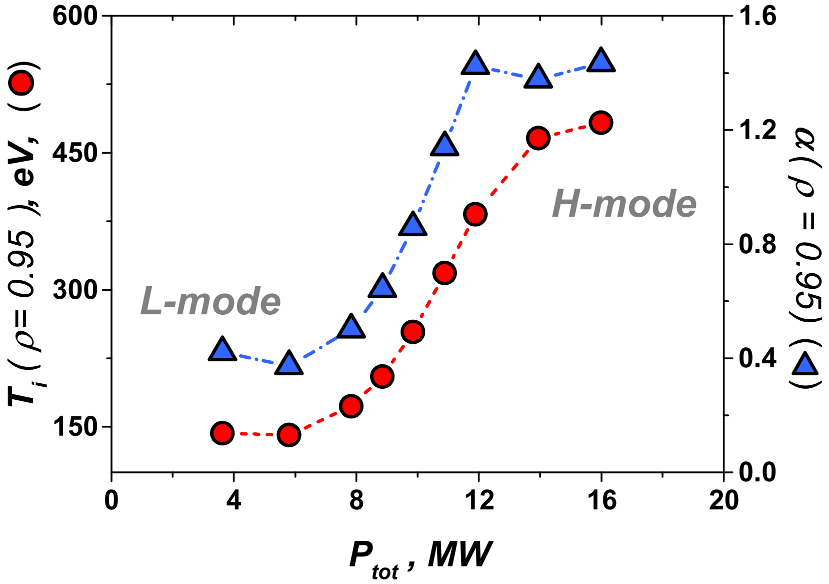


Fig. 2: *Normalised pressure gradient and ion temperature taken at $\rho = 0.95$ as a function of the total heating power.*

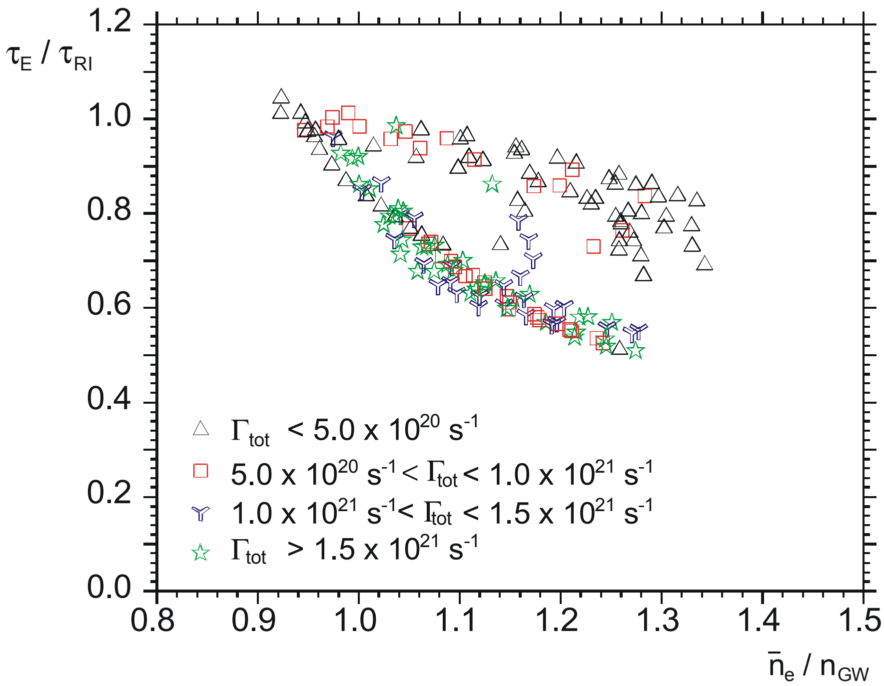
With this extended version of the RITM code, predictive and self-consistent modelling of the impact of argon on high density H-mode discharges from the magnetic axis to the separatrix has been performed. Fair agreement between modelling results and experimental data was obtained. It was found that in this plasma regime the injected impurities only weakly affect the background transport. In particular, a transition to a state with peaked density profiles and improved core confinement as observed in L-mode plasmas is hindered by the very flat q-profile in these H-mode plasmas.

Experiments and modelling on radiating plasmas at TEXTOR

In order to achieve high plasma density necessary in a future fusion reactor, puffing of neutral working gas is ordinarily applied in fusion devices. However, a too intensive gas puff normally leads to a confinement degradation. Prior to the shut down to install the Dynamic Ergodic Divertor, dedicated experiments had been performed to study *the effect of external gas injection on the global confinement properties of discharges with a radiating plasma mantle at high density*.

Detailed spectroscopic studies have revealed clear indications that intense gas injection leads to the formation of a cold and dens plasma cloud at the injection zone. This process is facilitated by localised recycling owing to the local cooling of the plasma and results in a significant amplification of the neutral influx. The global energy confinement at densities well above the empirical Greenwald density limit is found to be closely correlated with the total localised neutral influx as indicated in Fig. 3.

Furthermore, the isotope effect of the fuelling gas on the overall plasma performance had been studied. It has been found that the degradation takes place at lower external fuelling rates in the case of hydrogen compared to deuterium injection for a given plasma density. This fact has been explained by a stronger decrease of the effective plasma charge Z_{eff} during the hydrogen puffing. Within the core plasma the reduction of Z_{eff} during the hydrogen puff leads to a decrease of the collision frequency and a proportional increase of the transport driven by unstable drift waves (here the dissipative trapped electron mode). This hypothesis has been supported by self-consistent modelling with the RITM code.



***<u>Fig. 3</u>:** Global energy confinement time as a function of normalized density in discharges with a radiating plasma boundary using the total neutral influx to the injection zone as a parameter (including the localized recycling flux).*

Transport processes at the plasma edge

The 2D multi-fluid code TECXY was used to study the impact of the Dynamic Ergodic Divertor on the formation of MARFEs in TEXTOR. The increase of the effective transport coefficients in the stochastic magnetic field have been calculated according to a model prescribing optimal paths, which leads to analytical formulae involving the field line diffusion coefficient and the Kolmogorov length. According to the calculations, the increased heat conductivities from DED transport tend to weaken the MARFEs, whereas the increased diffusion and radial convection via enhanced recycling rather tend to feed and strengthen the MARFEs, in particular by enhanced sputtering of carbon impurities. Thus, in the presence of carbon no MARFE stabilisation has been found. However, the plasma core is found to be more efficiently screened from carbon impurities owing to their rapid outward convection.

Study of self-organized-criticality (SOC) behaviour of edge plasma fluctuations in TEXTOR

In recent years, to understand the widely found non-diffusive transport behaviour characterized by long-range time and spatial dependencies in fusion plasmas, models based on self-organized criticality (SOC) were proposed suggesting the existence of avalanche-like transport propagating from the plasma core towards the edge. The concept of SOC brings together the ideas of self-organization of nonlinear dynamical systems with the often observed near-critical behaviour of many natural phenomena, which exhibit remarkable spatial and temporal self-similarities and long-range correlations. In such systems, scale lengths can be described by fractal geometry and time scales that lead to a 1/f-like power-law frequency dependence of the spectrum.

To deepen our understanding on these issues, we have studied the SOC-relevant properties on the fluctuation data in ohmic discharges and edge biasing experiments on TEXTOR. The results are as follows: For the normal ohmic heated plasmas, the floating potential and also the density fluctuations exhibit an f^{-1} power-law dependence in their spectra. The autocorrelation function displays slowly decaying long tails, the rescaled range (R/S) analysis shows Hurst parameters well larger than 0.5, indicating an existence of long-range correlations at all measured locations, and a radial propagation of avalanche events is manifested in the edge plasma region.

All these results are consistent with SOC behaviour and plasma transport mechanisms based on avalanches. During the edge biasing experiments, where an edge radial electric field E_r and thus an E_r x B flow shear is generated, the Hurst parameters are substantially enhanced in the negative E_r shear region and in the scrape-off layer as well. Nevertheless, it is found that the local turbulence is well de-correlated by the E_r x B velocity shear in the negative E_r shear zone, being consistent with theoretical predictions. The increase of long-range dependence and concomitant decrease of local de-correlation time of turbulence in the negative E_r shear region appear to support the statements given by Carreras et al. that "*The dynamics governing the de-correlation of the local fluctuations and the long-range time dependencies are probably different, one being the de- correlation of the turbulence and the other being the de- correlation of the transport events (avalanches)*".