*31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, P-4.152 (2004)*

Peculiarities of Radiative Loss Profiles and Radiation-Condensation Instability in the T-11M Tokamak Discharges with a Lithium Limiter

V.B. Lazarev, A.G. Alekseyev, E.A. Azizov, S.V. Mirnov, A.S. Prokhorov

TRINITI, Troitsk, Moscow region, 142190 Russian Federation

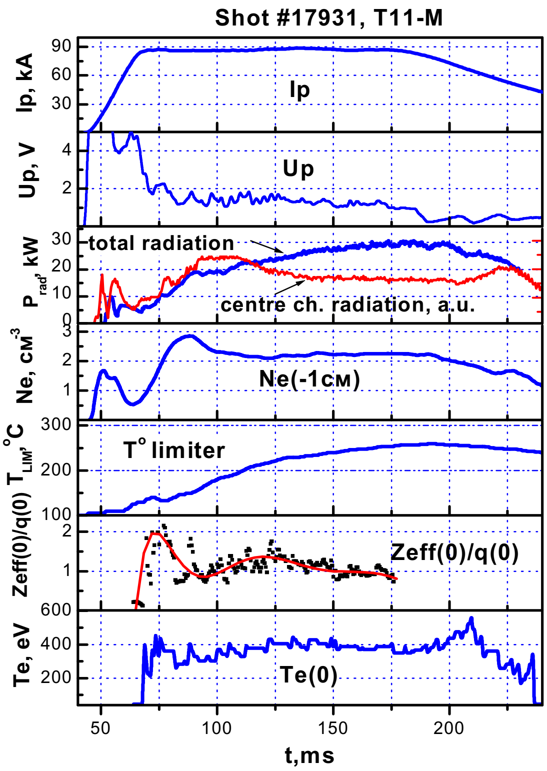

Fig.1. T-11M traces with a thin Li limiter.

In the last experiments on a tokamak T-11M with thin lithium limiter [1] the quasi-stationary thermal modes of the limiter operation were obtained (Fig.1). At rather low (90...100°C) starting temperature of the lithium capillary-porous structure (CPS), the plasma parameters were much better in comparison to the discharges with a graphite limiter. Using this limiter, it was possible to achieve a quasi-stationary mode of the discharge in deuterium at the plasma current $I_p \cong 90$ kA, shot duration ~0.2s with the stabilization of the main parameters at some certain level ($<n_e> \cong 2 \cdot 10^{19} m^{-3}$, $T_e \approx$ 400 eV, $\tau_E \approx 8$ ms, $T_{lim} \cong 260°C$, $P_{lim} \approx 10$ MW/m^2 – see Fig. 1). In this work the reason of this phenomena are considered which, as we have clarified, are related to the radial allocation of radiative losses in the plasma core.

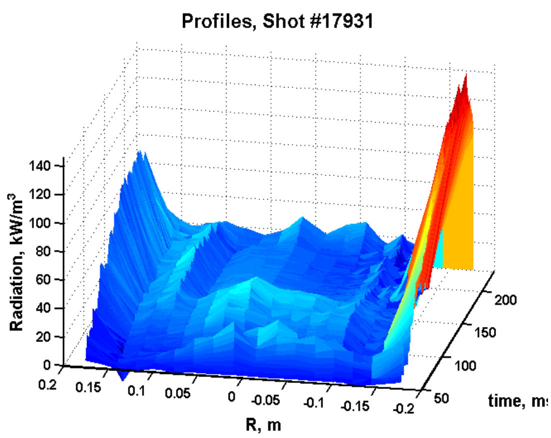

Fig. 2. The evolution of the plasma radiative loss profile with a Li limiter.

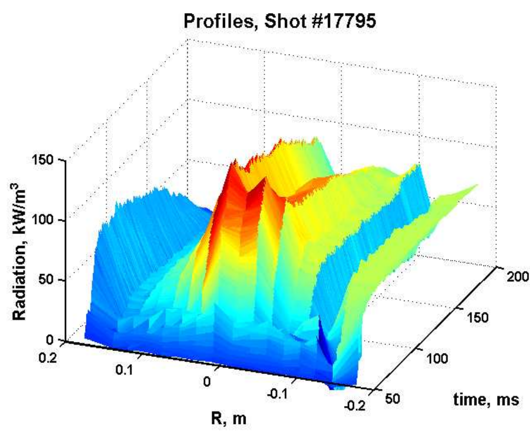

Fig. 3. The evolution of the plasma radiative loss profile with a graphite limiter.

Plasma radiative loss profile was measured by 16-channel AXUV detector array [3], installed vertically in the tangential port of T-11M tokamak [4] thus providing the toroidal view direction. The device is able to monitor the variations of plasma emission profile in a wide spectral range with the total frame time 200μsec and the spatial resolution ~2cm. The recovery of radiative loss profile was performed by the numerical procedure similar to Abel inversion adapted for the toroidal geometry [4]. The results are presented in a Fig.2 for the discharge with the lithium limiter and in the Fig.3 - for the discharge with the graphite one. The line averaged plasma density in both discharges was approximately equal $\langle n_e \rangle \sim 2.2 \cdot 10^{19}\ m^{-3}$, as well as the total power of radiative losses. The comparative analysis of radiative loss profiles in these two discharges reveals the considerable difference (Fig.2, Fig.3). In the case of a graphite limiter the radiative losses are concentrated at the plasma centre (Fig.3), and in the case of a lithium one the most part of radiative losses (more than 70%) are located at the plasma edge (Fig.2). It should be emphasized, that the total plasma radiative losses and densities in both cases are approximately equal (Fig. 4). In spite of this fact, the intensity of the most undesirable radiation from the plasma centre in lithium discharge is 3-5 times (Fig. 5) suppressed in comparison to the discharges with the graphite limiter. The radiative cooling

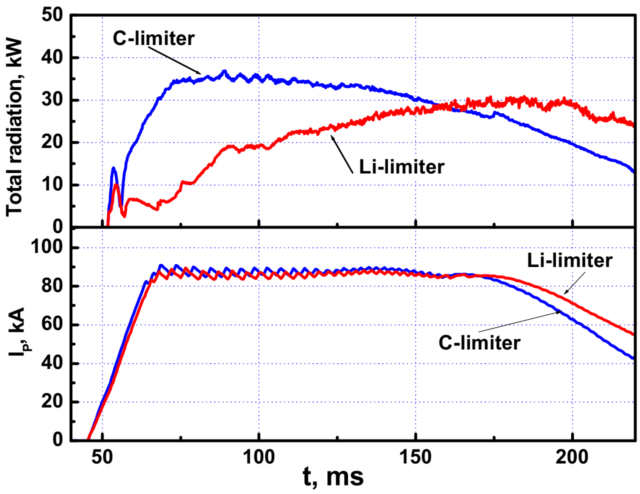

Fig.4. Total plasma radiative losses in two different discharges with Li and graphite limiters with the identical average plasma density $\langle n_e \rangle \sim 2.2 \cdot 10^{19} m^{-3}$.

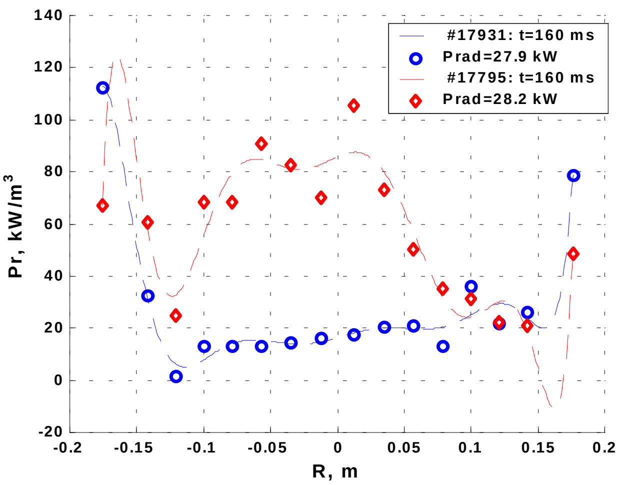

Fig.5. The radiative loss profiles at the moment t = 160 ms, the average plasma density $\langle n_e \rangle \sim 2.2 \cdot 10^{19} m^{-3}$ for both cases. Red points-C limiter, blue points -Li limiter.

of the centre decrees of Ohmic heating efficiency. The ~20% drop of Ohmic heating efficiency of the plasma centre for graphite discharges was approximately twice more than that for lithium ones (~10%). The electron temperature for the lithium discharge was $T_e(0) \approx 400$ eV (Fig.1), and a bit lower - for the graphite one $T_e(0) \approx 350$eV at a somewhat higher Ohmic power. The lower-Z_{eff} plasma in Li-limiter discharges seems to be the most probable reason of this effect. The lithium concentration at plasma centre estimated from the measured parameter $Z_{eff}/q(0) \approx 1.1$ for shots with relatively low limiter starting temperature (~250°C) is about 5%. The absolute value of radiative losses on the plasma axis was ~20 kW/m^3 in the lithium shots, rising up to ~120 kW/m^3 on the plasma edge. The results obtained experimentally confirm the earlier guess [2] that in the discharges with lithium limiter, the hot plasma core is enclosed within a strong radiating Li ion shell (see Fig.2). It should be noted also, that the growth of radiative losses at the plasma edge is quite helpful in the quasi-stationary tokamak discharges, providing the redistribution of a thermal loading from a limiter to the whole vacuum vessel.

Plasma edge instability at high lithium influx

At relatively low starting temperatures of lithium limiter (250…400ºC) the radiation of a plasma shell is monotonically increased according to the growth of lithium surface temperature of and related increase of neutral lithium influx into the plasma (Fig.2). The total power of radiative losses grows similarily, since the outer plasma layers give the major contribution (~70%) to the total losses. However, the behaviour qualitatively varies after the transition into the higher temperature range 500…600ºC, and oscillations of all plasma parameters observed at the plasma edge (Fig.6,7.). Their amplitude increase following the limiter surface temperature, and the latter itself begin to oscillate as well. The period of these oscillations are ~20 ms and rise and fall times, 2…3 ms and 15-

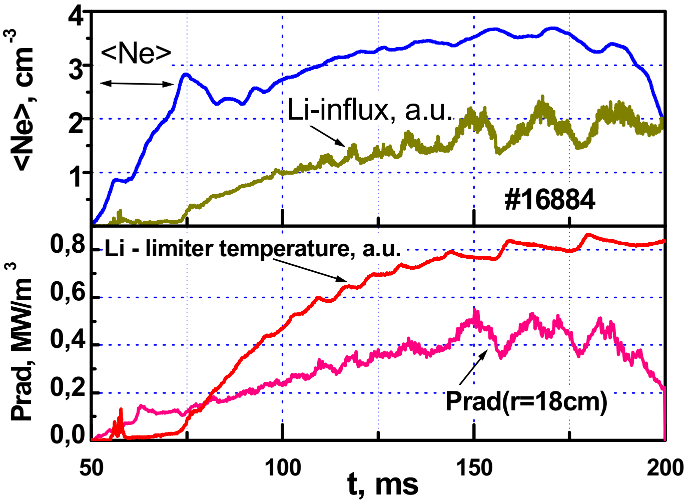

Fig. 6. Oscillations of the Li limiter surface temperature and other parameters caused by the instability at the plasma edge in the discharge with a Li limiter at high temperature ~600ºC.

18 ms respectively at the lithium temperature ~700ºC. The period of these oscillations is more at higher surface temperature. Although the nature of these oscillations is not completely clear, it is possible to assume, that they are caused by the high influx of neutral lithium into the peripheral plasma area resulting to its cooling. The estimated total influx of lithium atoms from the limiter is $\Gamma \sim 5 \cdot 10^{20} s^{-1}$. Normalizing this value by the area of the outer magnetic surface of a tokamak T-11M, the average influx density is about $\Gamma/S \sim 2 \cdot 10^{20} s^{-1}/m^2$. Very close value for a threshold of transition in a non-stationary mode, or threshold of "ionisation-condensation" instability with formation of MARFE-like region was calculated in [5], where the behaviour of lithium in SOL of the ITER-like "lithium tokamak" with the help of the two-dimensional numerical code was simulated. Both effects observed on the T-11M tokamak with lithium limiter. Namely:

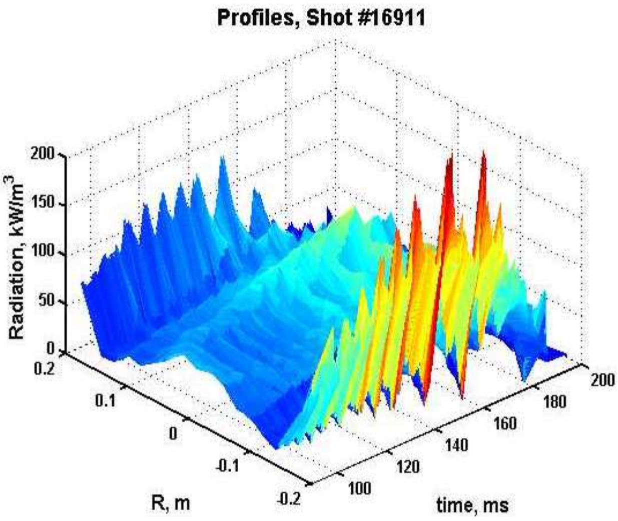

Fig. 7. The evolution of plasma radiative loss profile in the discharge with a "hot" Li limiter, temperature ~580ºC. Development of "ionisation-condensation" instability.

— formation of a screening radiative shell at Li influx level below $\Gamma/S \sim 2 \cdot 10^{20} s^{-1}/m^2$;

— development of "ionisation-condensation" instability at Li influx above this level.

These results are in a some agreement with the behaviour of lithium in the SOL region, predicted in reference [5]. An other significant result is that such high Li influx $\Gamma \sim 5 \cdot 10^{20} s^{-1}$ do not give any disruption and the "ionisation-condensation" instability gives only oscillations on the plasma edge.

References:

[1] Lazarev V.B. et al, Quasi-stationary tokamak experiment with thin liquid lithium limiter, 30th EPS Conference on Contr. Fusion and Plasma Phys., St. Petersburg, 7-11 July 2003 ECA Vol. 27A, P-3.162.

[2] Evtikhin V.A. et al, Experimental Study of the Tokamak plasma interaction with Lithium Capillary-Porous Systems ", 18th IAEA FEC, 2000, Sorrento, Italy, Exp 4/21.

[3] Alekseyev A., Perov G., Kurnosov A., et al, Fast Multichannel Plasma Radiation Loss Measuring System, Plasma Devices and Operations, 1999, v.7, pp. 139-147.

[4] Prokhorov A.S. et al, Plasma Physics Reports, Vol. 30, No. 2, 2004, pp. 136–142.

[5] Rognlien T.D., Rensink M.E., Interactions between liquid-vapor and edge plasmas, Journal of Nuclear Materials, 290-293 (2001), pp. 312-316.