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Observation of Fast Penetration of Impurities into the Plasma Core During the Disruptions at T-11M Tokamak

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Introduction

In the present work the results of continued studies of fast (υ > 10 km/s) penetration of impurities into the plasma core during the disruptions and other MHD activity related events are submitted [1]. These well-known phenomena [2,3] were not studied in detail yet, due to spontaneous appearance of disruption and technical difficulties to identify the process of impurity penetration. However, the main negative disruptions sequences, i.e. current crash and runaway electron acceleration, definitely result from this process. Therefore it seems to be quite reasonable to get more detailed data concerning its dynamics.

Experimental

Recently developed Multichannel Radiation Losses Measuring System (MRLMS) based on vacuum pinhole camera with 16-channel AXUV-16ELO Si photodiode array have been used providing fast measurements of UV and soft X-ray radiation power with ~ 2µsec temporal resolution [1,4]. According to estimations for the disruptions at T-11M (general parameters: $n_e = (0.5...5)\cdot 10^{19} m^{-3}$, τ = 10...100 µsec, T_e = 20...200 eV) with rail Li limiter installed at the bottom of the vessel, the main component of penetrating Li impurity should be in the form of Li^{+1} and Li^{+2} ions [5].

Similar to [1], the tangential direction (touching toroidal axis) of the detector field-of-view (FOV) with vertical orientation of FOV plane have been chosen, contrary to traditional poloidal directions of view chords (Fig. 1). It provides an opportunity to watch the vertical diameter of poloidal plane in the vicinity of Li limiter being the main source of impurities during the disruptions. This FOV setup eliminates the necessity of Abel inversion procedure for the reconstruction of fast transverse evolution of emitting profile. Some improvements of the system were developed in comparison to [1]. I.e. the number of channels coupled to fast ADC was increased to 11, FOV plane was shifted to the center of Li limiter (touching toroidal axis), and spatial resolution was narrowed to 3 cm (vertical) $\times$ 5 cm (horizontal) dimensions in the limiter plane.

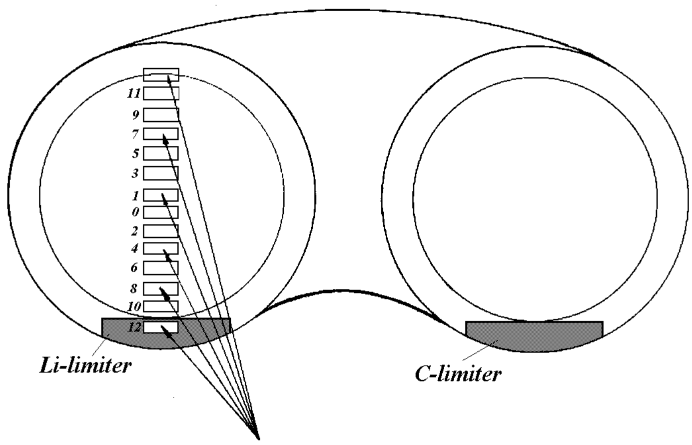

Fig. 1. AXUV photodiode array FOV setup: arrows detector view directions. Li or C limiter.

Results and discussions

Lower traces on Fig. 2 represent typical evolution of the vertical profile of UV emission beginning from the bottom (limiter edge) to the upper plasma edge during various MHD activities: A and A* - minor disruptions, B- major disruption. Upper trace corresponds to pick up coil signal indicating the amplitude of MHD activities. It could be clearly seen that impurities do not penetrate into the plasma core during low-level MHD activities, but it occurs during the major disruption, obviously resulting to current crash.

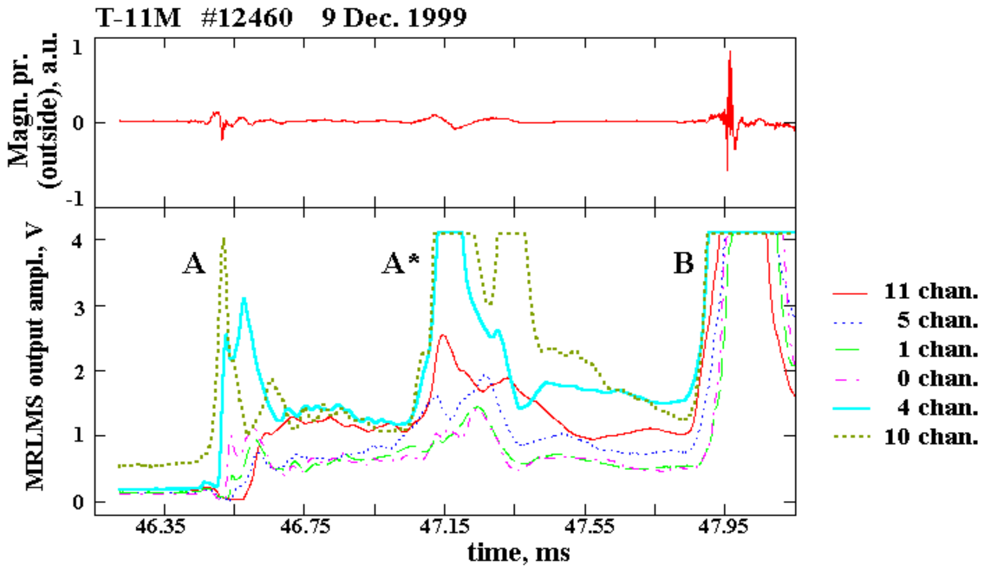

Fig. 2. Traces of 5 MRLMS channels during the minor (A, A) and major (B) disruptions.*

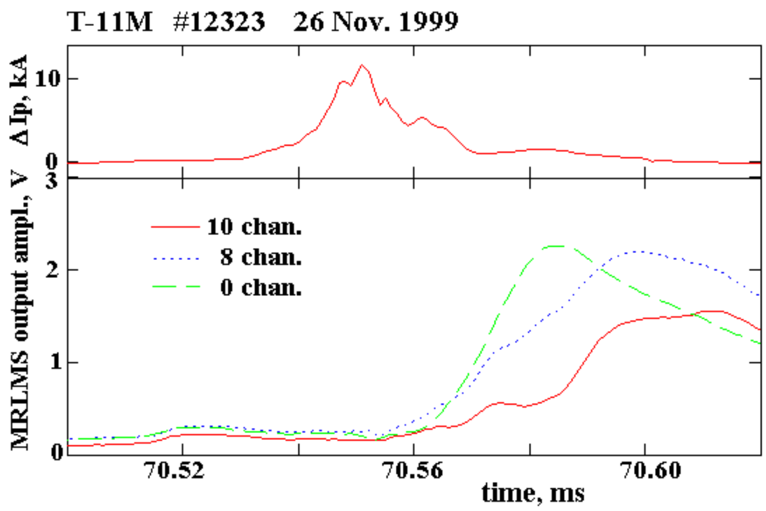

Fig. 3. Evolution of UV emission detected by central and peripheral channels during the disruption with graphite limiter.

In order to exclude the influence of direct plasma wall interactions on the results obtained, comparative tests were performed with similar shot scenario but using graphite limiter instead of Li one, installed at the opposite poloidal plane (Fig.3). Much lower increase of signal of central channels were observed in this case with ~30 μsec delay in comparison to previous one. This delay approximately corresponds to toroidal motion of impurities from graphite limiter to detector FOV. That means the effect of plasma-wall interactions on MRLMS response in general could be neglected, except occasional peripheral events.

One of the exceptional shots is shown at Fig.4 representing in grayscale the evolution of vertical emission profile during the disruption. Image brightness follows UV intensity. Lower detector view FOV partially covers the shadow of the limiter. It could be clearly seen that limiter edge is the primary source of impurities at the beginning of disruption. Rising front of UV emission (marked by arrow **A**) is propagating to the center. Vertical component of its velocity reaches the value 3 10 km/sec. Plasma-wall direct contact watched by lower and upper detectors (arrow **B**) begins when the impurities are almost reaching the core.

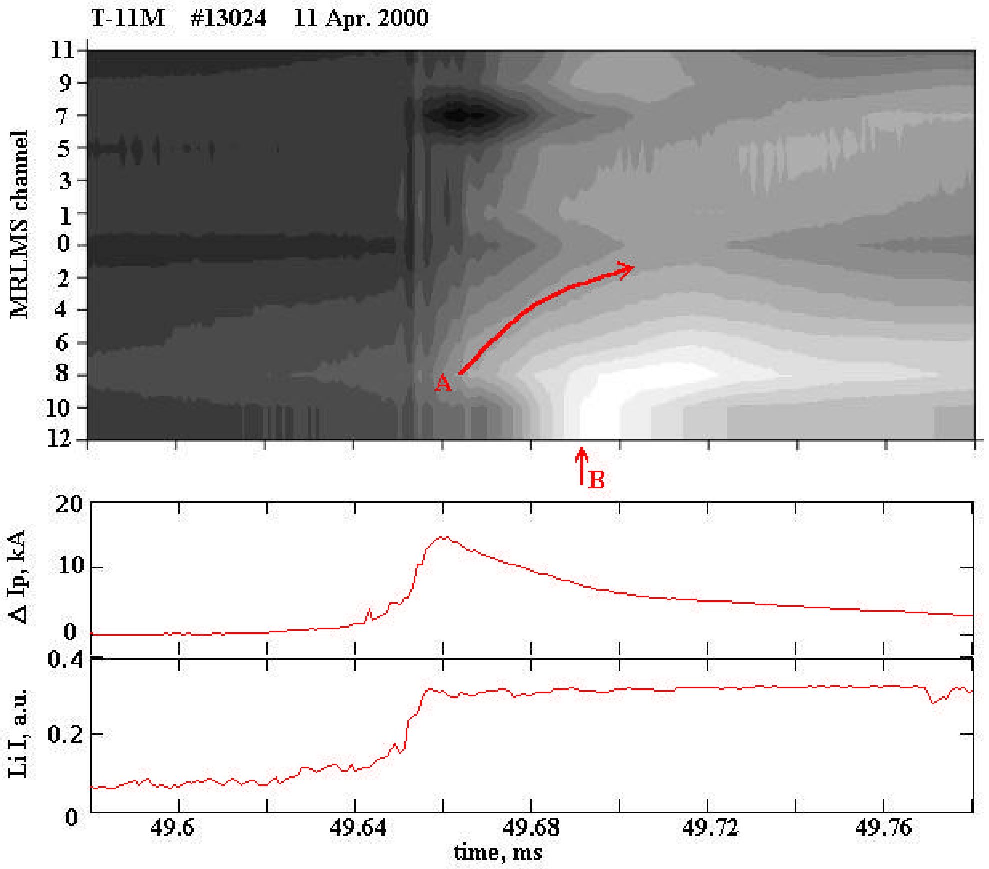

*Fig. 4. Evolution of UV radiation profile with plasma-wall interaction: **A**   front of impurity penetration into the core, **B**   start of plasma-wall interaction, an upper dark spot could be m=3 magnetic island. Lower traces   positive plasma current pulse and Li-I emission (saturated) from Li limiter region.*

A number of similar results confirm a conclusion that Li limiter is the main source of impurities at least 30 μsec after the start of major disruption. The vertical component of UV emission is propagated with the rate up to 90 km/sec. This is result of impurity penetration into the plasma core. It could be obviously related to the evolution of some MHD activity and, in particular, to generation of positive current pulse during major disruption.

However, some violations of such simple correlation could occur if the disruption starts preceded the lock-mode development. One of such events is presented on Fig. 5. In this case extra-fast breakthrough penetration of impurities into the core began at primary phase of current ramp-up with low level of MHD activity. It signifies that an absolute level of helical disturbance could be more important than their transformation.

The analysis of MHD disturbances shows that the process of impurity penetration is most effective if the X-point of magnetic islands is located at the limiter side. Therefore it could be supposed that general mechanism of impurity penetration includes the capture of cold vacuum bubbles . Low magnetic shear along the motion trace of such a bubble is well-known condition for this capture process [6]. But it could be easily shown that evolution of helical disturbances during the disruption results to the local decrease of magnetic shear and even to the creation of positive magnetic islands [7].

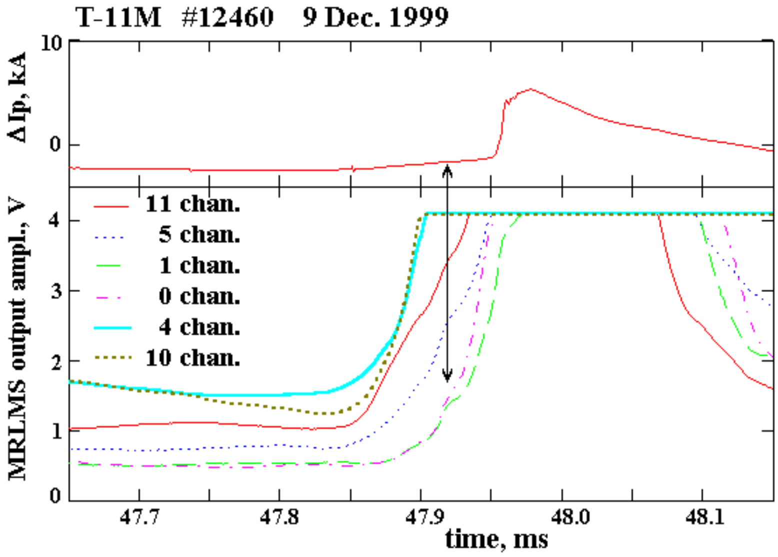

Fig. 5. Impurity penetration into the plasma core prior to main positive current pulse in the case of pronounced lock-mode before the major disruption.

Conclusions

1. Improved Multichannel Radiation Losses Measuring System (MRLMS) provided the detailed observation of recently discovered process of fast Li impurity penetration into the plasma core during the disruptions at T-11M tokamak.
2. Impurity penetration process exhibits quite complicated structure of UV emission profile evolution. Vertical component of penetration front rate can reach the value 90 km/sec.
3. Rail Li limiter being generally the main source of impurities, considerable contribution could result from the direct plasma-wall interactions in some particular cases. It can be explained in terms of helical disturbance of plasma edge.
4. Impurity penetration depth during low-level MHD activities (pre-disruptions or minor disruptions) is limited by peripheral plasma regions, besides the exceptional cases of pronounced lock-modes.
5. The observed peculiarities of impurity penetration could be explained in terms of convectional transport of vacuum bubbles along the trajectories with locally lowered magnetic shear in the vicinity of magnetic island separatrixes.

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