*35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008 ECA Vol.**32D**, P-4.004 (2008)*

LITHIATION OF THE FTU TOKAMAK
WITH A CRITICAL LEVEL OF LITHIUM INJECTION

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Introduction. The discovery of Li “shielding” phenomena is one of the most significant results of tokamak lithium experiments, which had demonstrated an accumulation of injected Li close to plasma boundary with quite slow penetration into the plasma core. The reason of this effect is not well understood yet, though it was clearly observed in early experiments on the TFTR [1], T-11M [2], CDX-U [3] and later on the FTU [4,5] as well.

The problem of heat sink in the fusion reactor could be much facilitated, if lithium shielding mechanism is universal. In this case the injected lithium ions will circulate between the Li emitter (limiter or divertor plate) and the collector (secondary limiter or the first wall) without significant accumulation in the plasma core, and provide the dissipation of main part of the scrape-off layer (SOL) energy to the vessel wall by Li non-coronal radiation.

The mechanism of heat sink by lithium radiation was observed in quasi steady-state modes of plasma discharges in the T-11M tokamak with high liquid Li limiter temperature (>400^{o}C) and boundary layer radiation up to 80% of the ohmic heating power P_{OH}. A limiter power load drops from the conventional 20-30% P_{OH} level to 3-5% P_{OH} in these modes [2].

However, an average radiation flux to the T-11M wall was quite low (<20 kW/m^2). In ITER-like reactor it should be 3-5 times higher. An average heat load of the FTU vessel wall is 40…50 kW/m^2 and Li experiments there provide a new information related to the properties of “radiative” lithium limiter at higher power load and in longer plasma shots.

Vessel wall conditioning (lithiation) and studies of lithium impurity influence on the plasma dynamics were the major goals of the FTU experiments with liquid lithium limiter (LLL) located deeply in “shadow” of Mo toroidal bumper limiter, close to the vessel wall.

However, during the LLL surface conditioning after a long exposure in open air some shots were performed with deeper insertion of LLL into the SOL, which resulted in extremely intensive Li efflux into the plasma down to disruption - so called “critical shots” and “critical level” of Li efflux. Therefore a proper analysis would be helpful for investigation of the behavior of Li “radiative” limiter in tokamak with high power load.

Experimental. A simplified scheme of the FTU lithium experiment [4,5] is shown in Fig.2. The LLL was installed in the lower vessel port. In lithiation shots, the LLL outer surface was located close to the vessel wall level and could be moved into (or out of) the SOL from shot to shot. The surface temperature of the LLL was measured during the shots by infrared (IR) sensor (FOTS) [6].

A visible plasma radiation was observed by CCD video camera (VC in Fig.2). UV Li-III line emission (13.4 – 13.7 nm) was monitored as an indicator of Li presence in the core plasma. A neutral Li atom emission from the LLL region was registered by optical multi-channel LiI analyzer (OMA) in the visible range. Total plasma radiation was measured by the bolometer array. Just two of them were used for the current analysis – horizontal channel B01 and vertical B21, both shifted 60^0 in toroidal direction from the LLL location port. Conditioning of the LLL was performed with plasma currents: 360 kA, 500 kA and 770 kA , respectively, with toroidal field B_T = 5.3 T.

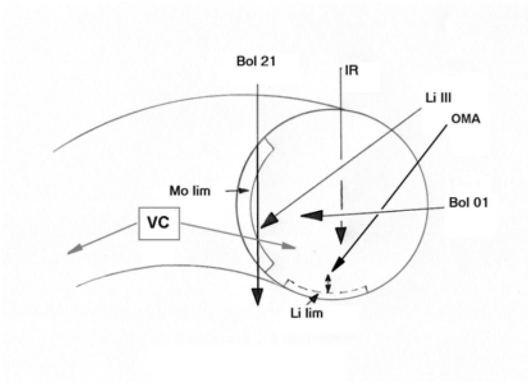

Fig.1. A simplified scheme of the FTU Li experiment: VC- CCD Camera, Bol 01 and Bol 21 – horizontal and vertical channels of the bolometer array, IR –infrared sensor for measurements of Li limiter surface temperature, OMA – optical multi-channel analyzer

Depth δ of the LLL outer surface insertion into the SOL was a very critical parameter. The LLL location was reckoned from the extrapolated surface of the vessel wall with an accuracy ±1cm. A first visible lithium glow in the LLL region was registered during the discharge by the VC if the LLL location was δ = 0.5 cm above the vessel wall. During the "critical" shots the depth δ was increased up to 1.5 cm value with clear lithiation effect – a rapid increase of D_2 puffing.

The Li line intensity rise up shot by shot probably as result of lithium surface cleaning and lithium collection in chamber. In the last three shots (##29860-68) a total Li emission increased twice more. The shot duration shortened gradually from 1.7 to 1 sec and finished by the disruptions. Obviously, a critical level of Li injection had been obtained. Fig. 2 show the proper waveforms of Li-III emission before (#29857) and after (#29867) the LLL deep insertion (δ = 1.5 cm). The last test shot #29869 was performed without LLL plasma contact with pushed it deep down into the port. In this test shot #29869 the highest plasma performance was obtained. As shown in Fig.2, Li-III line emission in this shot had a maximum at the initial stage of a discharge and decreased gradually during ~0.5 sec.

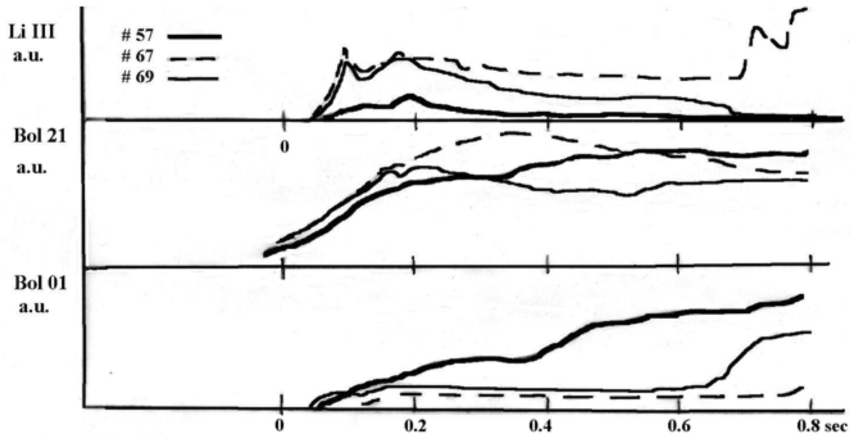

Fig.2. Waveforms of Li-III emission and horizontal B01 and vertical B21 bolometer signals for the shots: #29857 (w/o Li), #29867 (w Li), #29869 (after Li)

The powerful Li injection into the tokamak vessel in critical shots (##29867) resulted in the decrease of horizontal bolometer signal (B01, Fig.2) and same increase of vertical bolometer signal (B21, Fig. 2) had been observed. That means a loss of radiation profile symmetry and a vertical shift of radiation profile maximum from the center of a plasma column. This assumption is supported by the VC images (Fig. 3). In the shot with low depth of the LLL insertion, major part of visible emission is commonly localized near an ordinary Mo limiter lower edge. But in the discharge with deep LLL insertion, a bright annular region was formed in the lower part of vacuum vessel. Finally, a decrease of Li-III intensity in the

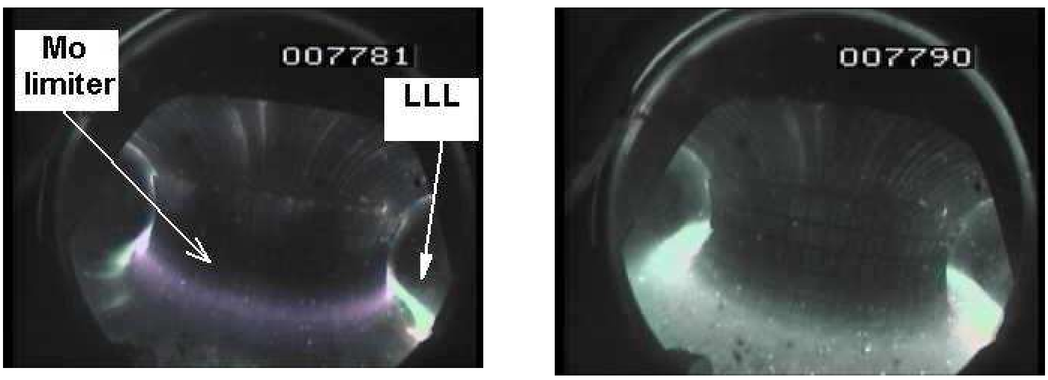

Fig.3 VC pictures of visible light glow w/o high level Li injection (left) and with him (right).

test shot #29869 (Fig. 2), and a recovery of B01 response is observed, which means some recovery of the radiation symmetry. Some important conclusions concerning the influence of intensive Li injection into the FTU plasma could be derived.

Conclusions. The first important result of these experiments with enhanced lithium injection is a spatial redistribution of plasma radiation profile, which looks like a development of "radiative" toroidal Li limiter at the bottom of vacuum vessel. This "radiative" limiter transforms and re-radiates the plasma energy flux to the tokamak vessel surface and decreases the heat loading of an ordinary Mo limiter.

The level of B01 signal indicates the heavy ion emission from the Mo limiter resulting from the Mo limiter bombardment by hot plasma. The LLL plays a role of main Li emitter in this case. The recovery of B01 signal after pushing down of the LLL far from plasma (Fig.2, #29869) supports this conclusion. But the LLL is not a single source of Li emission. Main Mo limiter and, perhaps, some part of the vessel wall play a role of secondary Li source of lithium, absorbed in the previous shots. The characteristic time of Li ions traveling between the Mo limiter and the vessel wall (Fig. 2) is ~0.5 s. In this case, a major part of the vessel wall plays a role of lithium collector.

The loss of axial symmetry of plasma radiation profile (both in θ and φ directions) do not permit the use of conventional method of total radiation estimations in the most interesting FTU shots with enhanced lithium injection. The last Li shot with almost axial symmetry of radiation was #29860. The radiation level increased up to 45% P_{OH} in this shot. In the next shots, an asymmetry of radiation profile had been developed together with the increase of Li emission. One could suppose that the main part of convective and conductive plasma energy fluxes to the vessel wall and to the Mo limiter were transformed into Li non-coronal radiation in these shots. Unfortunately, no direct measurements of plasma energy fluxes are available. Finally, the total power of Li-assisted radiation in these shots could be evaluated by 50- 100% fraction of P_{OH}.

Acknowledgements. The authors are grateful for help and valuable discussion with Dr. Smeulders P.P.L.A., and would like to thank the FTU operation team for professional work.

REFERENCES

[1] Mansfield D.K. et al. Phys. Plasmas. 3 (1996), 1892.
[2] Mirnov S.V., Azizov E.A., Evtikhin V.A. Plasma Phys. and Contr. Fus. 48 (2006), 821.
[3] Majeski R, Kaita R et al . 20th IAEA Conf. on Fus. Energy Vilamoura, (2004), EX/P5-24.
[4] Apicella M.L., Mazzitelly G. et al. Fus. Eng. Des. 75-79 (2005), 351.
[5] Apicella M.L., et al. Int. Conf. PSI in Contr. Fus. Dev. May 2006, Hefei, P.R. China.
[6] Alekseev A.G., et al, 33d EPS Conf. Plasma Phys.& Contr. Fus., Rome, June 19-23, 2006.