INVESTIGATION OF LITHIUM DISTRIBUTION IN THE SOL OF T-11M TOKAMAK WITH LITHIUM LIMITER

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Introduction. The problem of protection of the tokamak first wall (including limiter and divertor surface) against plasma fluxes by means of liquid metal becomes more and more important [1]. The liquid lithium stabilized by capillary-porous structure is one of materials which can be used for creation of protective self-restoring layer on the intra-vessel elements of the -reactor [1,2]. However, nowadays we lack some experimental data important for use of Lithium in reactor-scale devices. Particularly, the processes of Lithium migration during plasma discharge are not studied experimentally well enough. This paper presents the results of experimental studies of Lithium flux distribution in a scrape-off layer (SOL) in T-11M tokamak, obtained during experiments with Lithium limiter. The physical model explaining obtained distribution is discussed. On the basis of this model quantitative estimations of lithium flux to the limiter (the return flux) and to elements of the vessel are performed.

The experiment and diagnostics. Experiments were performed on T-11M tokamak [2] in an ohmic mode (I_p=70kA, B_t=1.2Tl). Two limiters were used: Lithium limiter (main limiter) located at fixed radius of 17.5cm, and auxiliary graphite limiter, which position varied from 19cm to 25cm. The cross-section of the vacuum vessel containing limiters and diagnostics is presented on fig.1. By means of optical diagnostics (Li I spectral line detectors) the intensities of spectral lines of neutral Lithium in the vicinity of Li limiter and auxiliary C-limiter were measured simultaneously. The optical detectors being used for spectral line intensity measurement consist of lens, photodiode and preamplifier. In front of each detector there were installed narrow-band optical interference filter, with the maximum transparency being

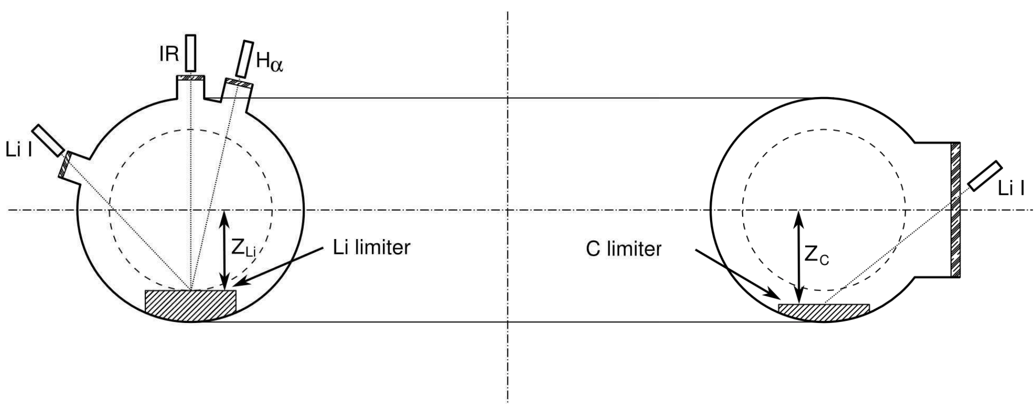

Fig.1. *The experiment arrangement on T-11M tokamak and optical diagnostics.*

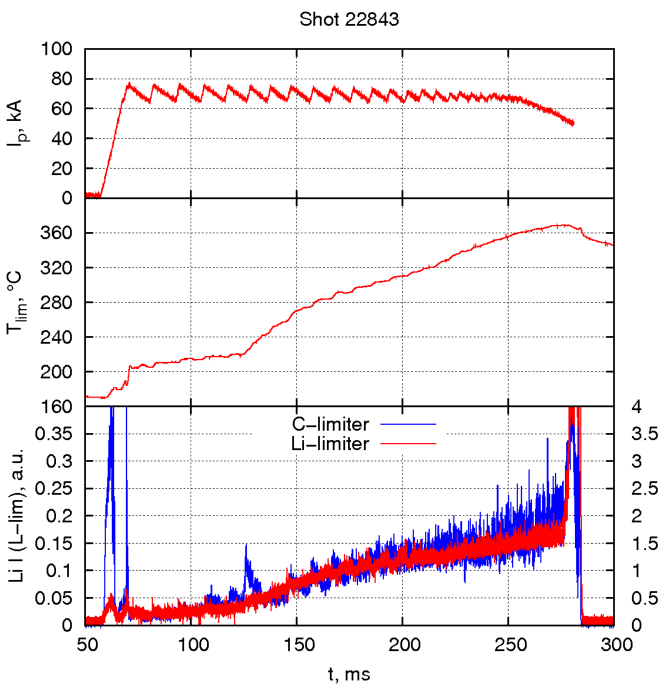

Fig.2. *The behavior of signals during a tokamak discharge: Ip-plasma current, T_{lim} - limiter surface temperature and LiI - intensities from C and Li limiteres.*

located at the line of neutral lithium (Li I) λ =670.8nm; the filter passband is about 5 nm. The angular diagram of Li I detectors sensitivity was wide enough to detect light from the whole area of Li I radiation near the limiters. The behavior of signals from these detectors is presented on fig.2. Note that intensity of Li I spectral line from the area of C-limiter is proportional to intensity of LI I emission from the area of Li limiter. It is known that the intensity of spectral line of neutrals in tokamak conditions is approximately proportional to their flux into the plasma. In this case, the graphite limiter was used as a probe, on which surface Li ions undergo recombination, capture and subsequent desorption substantially due to ion sputtering. Such process is called impurity recycling, implying the proportionality of fluxes to and from the surface. Since the intensity of neutral atom spectral line is proportional to the flux of neutrals into the plasma, the distribution of lithium in a SOL can be obtained by measuring the Li I spectral line intensity on the C-limiter surface as a function of its position. To eliminate the influence of instability of lithium flux from the lithium limiter (a source of lithium), these data were normalized by the intensity of Li I spectral line from the surface of lithium limiter, which is proportional to the flux of neutral Lithium from its surface. These results are presented on fig.3. During the experiment, the position of Li limiter was fixed (Z_{Li}=17.5cm), as well as other plasma parameters that can significantly influence the transport of Li (plasma current, density, plasma axis position).

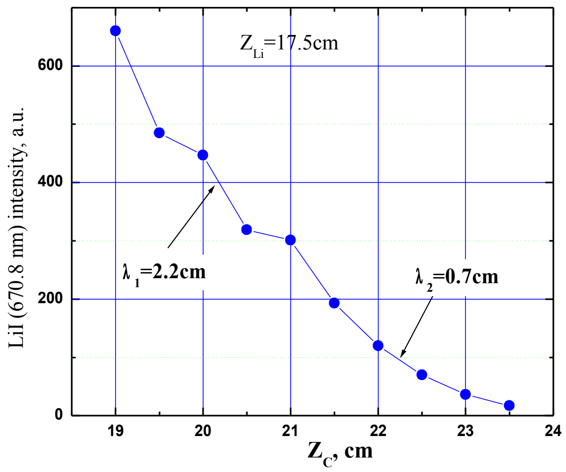

Fig.3. *The Lithium flux radial distribution in a SOL plasma of T-11M tokamak.*

Results and discussion. To perform the analysis of the data obtained, it is convenient to present it in a logarithmic scale (fig.4). It is clear from this figure than the radial distribution of lithium flux

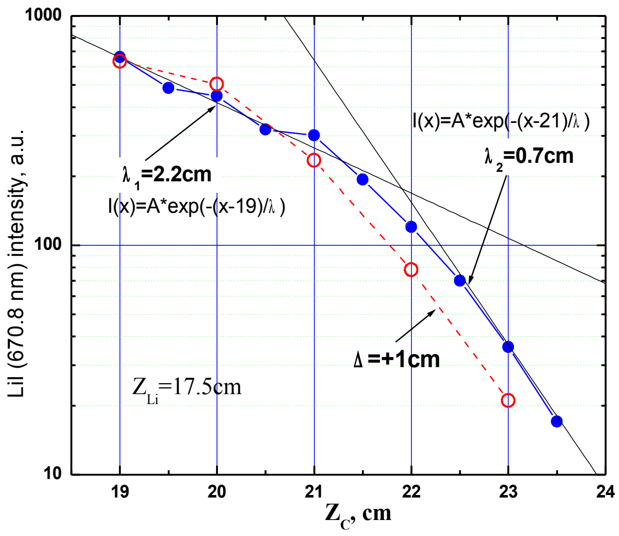

Fig.4. *The radial distribution of lithium flux cannot be approximated by one exponential fit.*

cannot be approximated by one exponential fit. However it can be adequately approximated by two different exponential dependencies at different ranges of radius, with different characteristic lengths λ_1=2.2cm and λ_2=0.7cm. The smaller length corresponds to region close to the wall of the vacuum vessel. In order to explain this behavior, we can assume presence of another "limiter" in a SOL. Actually, there is an ICRH antenna in the T-11M vessel located 90^O from the lithium limiter. The edge of the antenna is located 22cm from the plasma axis, which approximately corresponds to the radius of transition from one exponential fit to another (fig.4.) Thus, the decrease of characteristic length of lithium flux distribution occurs due to reduction of length of magnetic force line in the "shadow" of the HF antenna. To verify this hypothesis, the same experiment was performed with plasma column axis being displaced 1cm outwards. The results of this experiment are presented on fig.4. (red points, dotted line). It is obvious that the position of transition from one exponent to another has been displaced to the smaller radius (~21.5cm), and characteristic lengths λ_1 and λ_2 stayed unchanged, exactly as we expected.

There exist analytical expressions [3-5] for characteristic length of plasma density decay in a scrape-off layer: $\lambda_n = \sqrt{LD_\perp / C_s}$, where L is the length of a magnetic force line, C_s - ion sound speed, $D_\perp$- transversal diffusion coefficient. These expressions are derived from the continuity equation for a particle flux [5]. Obviously, we can also obtain similar expressions for lithium component of the plasma. Using expression for length of magnetic force line in a tokamak with rail limiter [4] L=2πR/α, where - α is a poloidal angle covered by the limiter (for the lithium limiter α=1/6, R=0.7м), it is possible to calculate a transversal diffusion coefficient from experimental results. The value obtained $D_\perp \approx 0.7 \cdot m^2/s$ appears to be close to Bohm value $D_B = kT_e/16eB \approx 1 m^2/s$. Supposing that $D_\perp/C_s$ is a constant, we obtain that $\lambda_1/\lambda_2 = (L_1/L_2)^{1/2}$, therefore, supposing that L_1=L=2πR/α ≈ 26m, we conclude that $L_2 \approx$2.5m. The obtained lengths of the magnetic force line, L_1 and L_2, correspond to the geometrical position

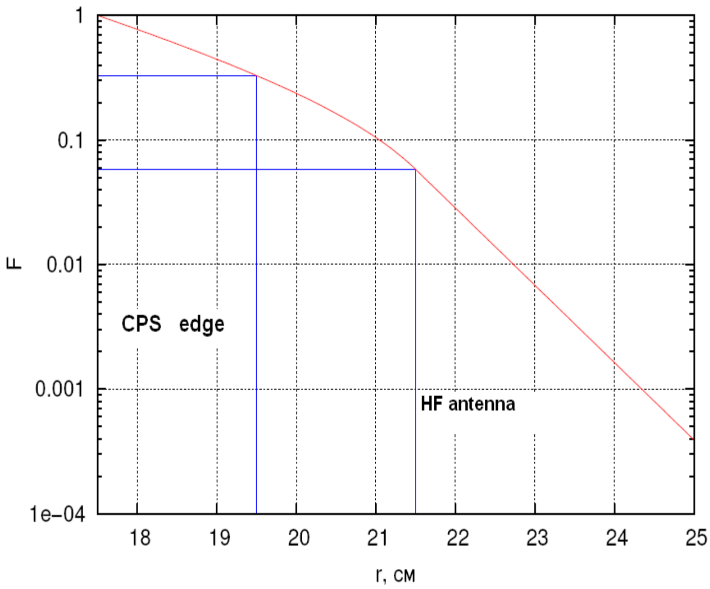

***Fig.5.** The radial distribution function of losses F(r) for Lithium ions in the T-11M SOL.*

of the antenna and the limiter: L_1 equals approximately to six turns of the force line, L_2 – approximately one turn. Thus, we can conclude that in the process of walls lithization is substantially caused by abnormal transversal diffusion of lithium ions. As a first approximation, we can consider simple quantitative model of the processes of lithium transport in a scrape-off layer. Supposing that the «coefficient of adherence» for lithium is close to 1, we can integrate radial distribution of lithium (fig.4) and obtain the function of losses F(r) (fig.5), which value equals to the portion of lithium being deposited inside the radius of r. From this function one can conclude that the portion of Li ions being returned to the active zone of limiter (liquid metal) and participating in circulation is about 60% for this limiter (it equals to (1-F (r))), about 30% of lithium is deposited on the basement of the limiter, 10% is deposited on the protective plates of ICRH antenna, and only about 0.05% is deposited on the walls.

Conclusions. The radial distribution of lithium fluxes in the SOL region of lithium limiter has been investigated. The data obtained show that the lithium flux distribution is controlled by abnormal transversal diffusion of lithium ions. The diffusion model, which explains the behavior of spatial distribution of lithium, is proposed and verified. It takes into account the influence of "shadow" of ICRH antenna and geometry of magnetic surfaces in the SOL. Quantitative estimations of circulation and migration of lithium in the tokamak vessel are performed. **This work was supported by the Russian Foundation for Basic Research. Number of the project: 07-02-13513.**

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