Investigation of dependence of lithium and hydrogen collection by collector target from temperature of target surface in emitter-collector system on T-11M tokamak

A.N. Shcherbak[1], S.V. Mirnov[1,3], A.S. Dzhurik[1], V.B. Lazarev[1], Ya.A. Vasina[3], V.G. Otroshchenko[1], A.V. Vertkov[2], M.Yu. Zharkov[2], I.E. Lyublinski[2,3]

[1]*SRC RF TRINITI, 108840, Russia, Moscow, Troitsk, Pushkovykh st., 12,*

[2]*JSC «Red Star», 113230, Russia, Moscow, Elektrolitny dr., 1A,*

[3]*NRNU MEPhI, 115409, Russia, Moscow, Kashirskoe sh.,* 31

1. Introduction

One of the key elements of the closed lithium loop concept [1] near the first wall of the steady-state fusion neutron source (FNS) [2] is a lithium collector for the collection of lithium “waste” and unused “fuel” (isotopes of hydrogen) for subsequent return to the plasma column. In figure 1, the principal scheme of the emitter-collector system of the steady-state closed lithium loop presents.

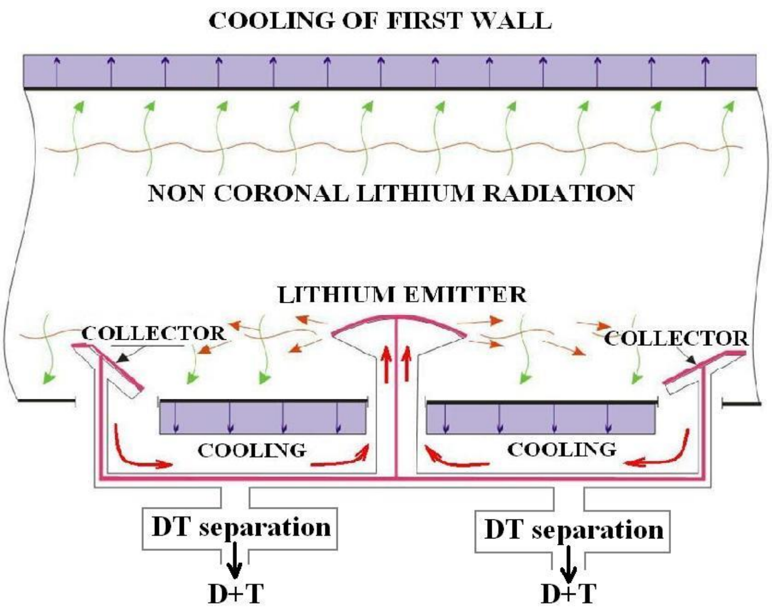

Figure 1 Closed loop of Li and fuel (D, T) circulation in emitter-collector scheme

An important feature of the lithium collector efficiency is the degree of trapping of the falling lithium ions flow on collector. For example, for a smooth metal collector of stainless steel in the case of cooling it with liquid nitrogen, this coefficient could be considered close to one, at least during the duration of exposure of 600 operating pulses of T-11M (it is equivalent to about 150 s of continuous operation of the collector). Under steady-state operating conditions, the collector target cooling with liquid nitrogen becomes unprofitable, and it should be ready for the transition to other ways of cooling and, respectively, to other working temperatures of lithium collectors surfaces.

Therefore, the question of the tolerance limit of surface temperature deviations from the cryogenic level is important in real conditions, when the collector surface has already covered with the active layer of the absorbed lithium. Thus, the first goal of this work was to study the efficiency of a metal coating as a collector with respect to the incident lithium and hydrogen ions, namely, the determining of the acceptable temperature range for lithium and hydrogen collection by the lithium target.

2. Experimental setup

Experiments were carried out on T-11M tokamak in typical discharges: I_p = 70 kA, B_T = 1.4 T, t = 200 ms, $n_e = 3 \cdot 10^{19}$ m^{-3}. A vertical lithium limiter of T-11M was used as a Li emitter, and a longitudinal lithium limiter was used as a Li collector. The movable collector target of stainless steel placed in the “shadow” of the vertical lithium limiter in the SOL zone at the distance of about 10 cm from the chamber wall was used as a lithium collector too. In such position, it played the role of the collector of lithium-hydrogen flow from the plasma column up to the first wall, which can be proposed for the future steady-state tokamak.

Two types of the collector target were investigated: a smooth collector target and the collector target, coated with capillary-porous system (CPS) [3]. Two kinds of experiments were conducted in parallel. The first experiment was consisted in the determining of the lithium collection by the collector target depending on the temperature. In addition, it was as follows: the exposure of the collector target in plasma shots, then the collector was removed from the chamber, and it was immersed in hot distilled water. The resulting solution was subsequently analyzed for lithium content. The second experiment was consisted in conducting a thermal desorption analysis (TDS), and it was carried out such as the first, but after exposure of the collector target, it was heated to 600°C, and hydrogen was analyzed by means of a mass spectrometer. TDS analysis was performed in the discharge chamber with reduced vacuum pumping efficiency. The exposure of the collector target was carried out under different temperatures and times of exposure.

3. Results and discussion

Figure 2 shows the dependence of hydrogen and lithium collection on the surface temperature of the smooth collector target during exposure in plasma discharges of the T-11M tokamak. It was noted that the intensive desorption of hydrogen begins after 360°C and ends at 500-550°C. This does not contradict the known laboratory results obtained on plasma simulators. The obvious degradation of hydrogen retention as the surface temperature of the smooth target rises. One explanation could be the loss of lithium on the surface of the target as it warms up.

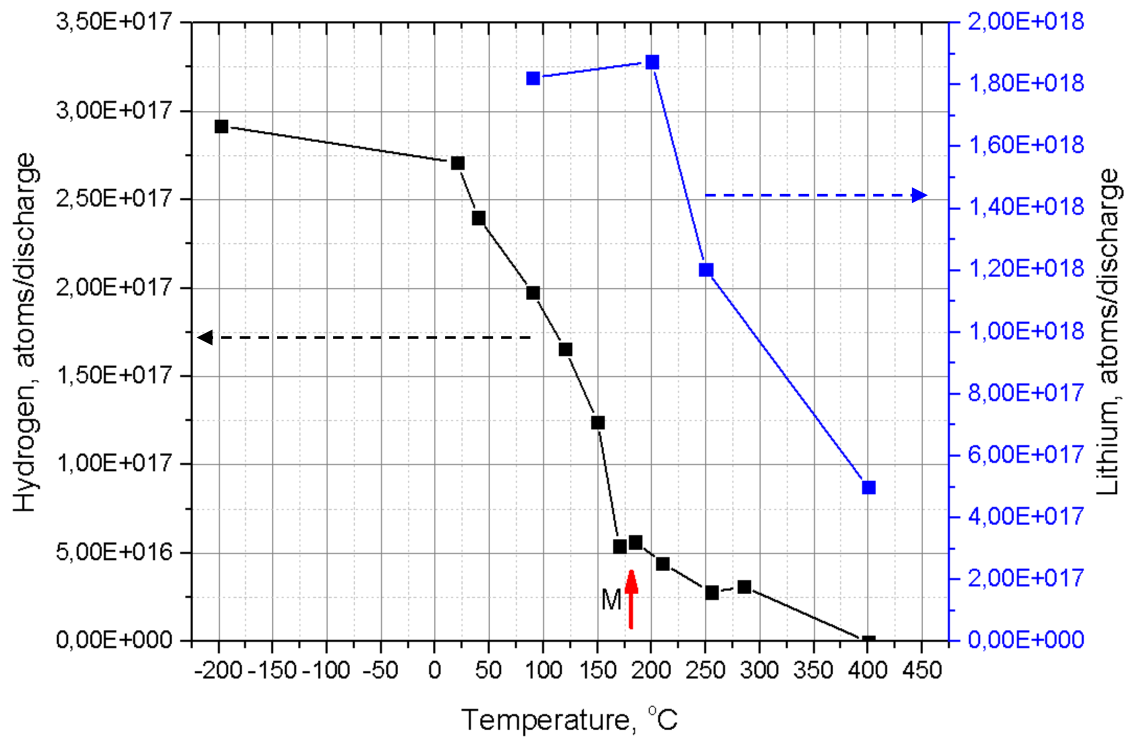

Figure 2 The dependence of hydrogen and lithium collection on the surface temperature of the collector target (black line – hydrogen, blue line – lithium)

At the same time up to 200°C, the collection of lithium trapped by the steel target remains practically unchanged, while the retention of trapped hydrogen decreases by almost an order of magnitude. At 400°C, the lithium content reduces by 4 times, while hydrogen is at the level of the measurement error. If we consider that the stainless steel target models the behavior of the wall of the discharge chamber, it can be assumed that at the temperature of about 300-400°C the reactor wall will act as a reflecting mirror with respect to the hydrogen isotope ions incident on it, that is, its tritium entrapment may be negligible.

The CPS target covered with lithium behaves in the same way with increasing target temperature. The amount of collected lithium is approximately 3-4 times higher than in the case of the smooth target. This may be because the effective target surface of the CPS target, in contact with the plasma, is approximately 4 times higher than in the case of the smooth target. Another important difference between the CPS target and the smooth one is that its TDS clearly reveals the presence of weakly bound hydrogen on its surface.

During experiments, it was found that the CPS collector target absorbs approximately 4 times more lithium than the smooth target, which is approximately proportional to the growth of its effective area. According to estimates, the total number of absorbed hydrogen atoms with respect to collected lithium atoms in the "optimal" temperature range from -200 to 50°C is about 22% for the CPS target, and about 10% for the smooth target.

4. Conclusions

In the paper, the dependences of lithium and hydrogen collection by the collector target of stainless steel on the surface temperature were investigated in the T-11M tokamak. In these studies the smooth collector target of stainless steel under lithium and hydrogen irradiation is the model of the first wall of the steady-state tokamak-reactor. Using method of thermodesorption spectroscopy it was found that the hydrogen absorption by lithium deposited on the target surface of both the CPS and the smooth target, depends substantially on their initial temperature. It was noted that the hydrogen absorption falls rapidly from a certain constant value in the temperature range -200 to 20°C, to 0.1 from the initial level as the temperature grows to lithium melting (180°C) and then continues to decrease practically to 0 (30 times) as the temperature grows to 300-400°C. At the same time, the collection of lithium absorbed by the target also reduces, but not more than 4 times, which could mean that walls of the tokamak-reactor discharge chamber, heated to 400°C, but still covered with residual lithium (or may be its chemical compounds), can play the role of a "mirror" in relation to the flux of hydrogen isotopes. This radically contradicts the prevailing view of lithium as an absolute absorber of all hydrogen isotopes at all reasonable temperatures by a lithium collector target, and can open up prospects for its use in the magnetic fusion.

Acknowledgements

Authors would like to thank the T-11M stuff for excellent experimental operations. This work was supported by ROSATOM Contract No. Н.4х.241.9Б.17.1008.

References

[1] S.V. Mirnov et al. J. Nucl. Mater. 390-391 (2009) 876

[2] S.V. Mirnov et al. Nucl. Fusion 55 (2015) 123015

[3] V.A. Evtikhin et al. Plasma Phys. Controlled Fusion 44 (2002) 95