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Plasma boundary as a key factor in toroidal magnetic confinement

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The energy confinement is the major parameter of the toroidal plasma which determines the size, magnetic field, plasma current, the external heating, the total fusion powers, and many other aspects of potential fusion reactors. Traditionally, the energy confinement is associated with the transport properties of the core plasma. Unfortunately, the reliance on the properties of the core transport is essentially exhausted. Its requirements for large size of burning plasma devices, the highest possible magnetic field and plasma current, big external heating power lead to difficult problems of disruptions, power extraction and very survival of the plasma facing components.

In reality, the confinement of the high-temperature plasma is much more sensitive to the boundary conditions, and specifically to recycling, which determines the rate of plasma edge cooling by the neutral atoms [1,2]. While the always turbulent core transport is uncontrollable, the recycling can be controlled and reduced to the level below 50 % by arranging the liquid lithium flow, in fact, creeping (1 cm/s, 0.1 mm thickness, 1 g/s flow rate). The key technology elements for it were recently invented and the first limiter, which implements the concept of continuously flowing liquid lithium (24/7FLiLi) was tested on EAST tokamak [3]. At present there are numerous experimental evidences of high sensitivity of confinement to the plasma boundary: H-mode with poloidal divertors, TFTR supershots with lithium conditioning, 4-fold enhancement of confinement on CDX-U [4] with plasma absorbing liquid lithium.

From the plasma physics point of view, the reduction of recycling below 50 % manifests the transition to a new, the best possible confinement regime, where the energy is lost only due to plasma diffusion [2] (radiation neglected). In its turn, the high edge and core plasma temperatures are determined exclusively by boundary conditions, i.e., by the ratio of the heating power to highly reduced particle flux from the plasma boundary. The thermal conduction in core (and anomaly of electrons) does not play any role in confinement. The plasma diffusion, if assessed realistically, is of the order of the ion neo-classical thermal conduction and sma This understanding implemented into a simple Reference Transport Model (RTF), described very well the energy confinement in CDX-U machine [4]. The DIII-D tokamak with RMP experiments (and then many others) confirmed the independence of the edge temperature on transport coefficients by demonstration that the magnetic perturbations cannot shake the edge pedestal electron temperature.

The entire plasma physics of the tokamaks is simplified dramatically in such a low recycling, called the Li Wall Fusion (LiWF), regime. First, the stabilization of the plasma edge was predicted [5] and confirmed in NSTX by suppression of ELMs by lithium conditioning. With flattened core temperature, there is no tendency for excitation of sawtooth oscillations and associated neo-classical tearing modes. The NBI can externally control the particle source in the core and the plasma pressure profile, thus, allowing for the control of the global MHD.

The expected ion-neoclassical core confinement could be sufficient for maintaining the plasma density by NBI. For the burning plasmas and fusion DEMO [6] this opens the opportunity for a new high-temperature/low-density LiWF regime where the fusion alpha particle energy is delivered to the side wall by synchrotron radiation of electrons, and only minor energy from NBI is directed to the divertor target plate. The implementation of such a LiWF regime also suggest a solution to severe problem of power extraction from the burning plasma.

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