Low recycling concept of tokamak fusion

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The talk explains a new approach to tokamak fusion instead of present, complicated and essentially exhausted.

It is evident now that after two unlucky attempts in the mid 1990s to achieve the breakeven $Q_{DT} = 1$, tokamak fusion has lost its momentum. The root reason of stagnation is in reliance on 63 year old high recycling regime in which the plasma edge is continuously cooled down by neutrals from the walls. This intense cooling leads to peaked plasma temperature profiles, requires large external heating power, and causes numerous problems: turbulent thermal conduction, low energy confinement, unreliable stability, big problem of power extraction, etc. Associated complicated plasma-surface interaction (PSI) contributes significantly to plasma unpredictability and disruptivity, both unacceptable for fusion energy.

Invented in 2012 technology of Continuously Flowing Liquid Lithium (24/7-FLiLi), which is being tested for a while on EAST, allows to develop a tokamak divertor with recycling reduced to 50 %. Its implemention would dramatically suppress plasma edge cooling and will keep plasma edge as hot as the core. At the same time, NBI enables direct plasma core fueling by energetic ions. With a proper size of tokamak (JET is an example) NBI would be sufficient to maintain plasma density at fusion relevant high temperatures.

The combination of plasma pumping by FLiLi and core fueling by NBI constitutes a new, high performance regime, called LiWF (Lithium Wall Fusion) with an order of magnitude better confinement relative to presently achievable. At high edge temperature, the Scrape off Layer (SoL) becomes collisionless and representing a flux of energetic particles rather than plasma. Such SoL is much simpler than the present PSI. Plasma stability is expected exceptional (no sawteeth, no triggering NTM, q-profile corresponds to second stability of ballooning modes). Thermal conduction looses its importance.

The important property of LiWF regime is that the tokamak plasma becomes simple, predictable, and controllable what is invaluable for burning plasmas. This gives a chance for disruption avoidance, which is impossible in the present very complicated high recycling plasma.

New plasma regimes with highly enhanced confinement lead to a new concept of tokamak fusion. Thus, LiWF challenges the reliance on α-particle heating, the pillar of magnetic fusion. Presently, the key assumption is that the power from fusion α-particles goes to electrons and then to ions: $P_\alpha \rightarrow P_e \rightarrow P_i$, automatically requiring electron temperature be higher than that of ions, $T_e > T_i$. In all tokamaks this was a bad confinement regime. In contrast, in the LiWF-regime $P_\alpha \rightarrow P_e \rightarrow P_{radiation}$, thus keeping $T_e < T_i$ and reducing the load to the divertor plates by fusion P_α. This and numerous other properties makes LiWF feasible and practical for DEMO. Note that 24/7-FLiLi pumps out D and T from plasma and delivers them to outside the vessel dissolved in liquid lithium. This makes it uniquely compatible with Real Time Tritium Recuperation.

The JET tokamak, if 24/7-FLiLi divertor would be installed in JET for the next DT campaign, could demonstrate $Q_{DT} > 5$ and, probably even 10 using 4 MW 120 keV NBI. This would conclude the prolonged plasma physics phase of tokamak research as a success of the program, which otherwise has lost its realistic vision of further progress and hopeless.

Behind this scientific phase, which should prepare a reliable plasma regime, the lasting future burning plasma requires solving the important next step problems. The most evident is helium pumping compatible with the low recycling regime. New schemes, utilizing properties of ionized helium, should be developed. The high $Q_{DT} \simeq 10$ in LiWF regime corresponds to $\simeq$10 % tritium burn up, thus, emphasizing the role of helium pumping. Also, the regime leaves some residual bombardment of side walls by energetic charge exchange atoms from the SoL. Besides JET, MAST, LHD stellarator, EAST can contribute to resolving the next step issues and open the way to $P_{DT} = 100 - 200$ MW tokamak DEMO.

The talk also presents an assessment of the expected EAST performance in LiWF regime based on the same model as was used recently for JET[1]. The principal design components of 50 % recycling divertor will be outlined.

[1] **L.E. Zakharov.** "On a burning plasma low recycling regime with $P_{DT} = 23 - 26$ MW, $Q_{DT} = 5-7$ in a JET-like tokamak". Nucl. Fusion **59** 096008 (2019)