From tokamaks to toga device with lithium plasma environment and eliminated PSI

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In June 2024, the toga device has been invented (USPTO patent pending 63/8333,065) as implementation of Li Wall Fusion (LiWF) concept as the overdue upgrade to the Shafranov-Artcimovich tokamak [1] by extending its plasma vacuum chamber with a lower chamber containing the heat-sinks for the power extraction through the Scrape off Layer (SoL). Standing for "Tokamak Great Again", toga embodies the driving idea that the tokamak plasma, fueled by NBI, should see only Li without touching it, while all Plasma Surface Interaction (PSI) with both Z>3, Z=3 materials is eliminated. The toga design arranges the driven by gravity slow Creeping Liquid Lithium (24/7-CLiLi) layer along the all inner-sidewalls and actively cooled heat-sinks as a continuous flow loop connecting the vessel interior with an external reservoir for LiLi, which is, thus, accessible for reprocessing. In the plasma chamber, 24/7-CLiLi absorbs secondary Charge Exchange (Cx) atoms from NBI, while unavoidable, but controlled, Li evaporation from the heat-sink surface is directed to the inner walls of the lower chamber avoiding the penetration to the plasma chamber.

The toga approach reduces plasma-ions cooling factor $R^{cooling}$ (replacing the recycling coefficient) to the residual level of $R^{cooling}$=0.1-0.2 determined by small, controlled lithium evaporation and by negligible sputtering of Li layer by the secondary Cx atoms from the plasma.

In combination with the energetic NBI fueling right to the plasma core, the suppression of plasma edge cooling leads to the plasma edge ion T_i and electron T_e temperatures comparable with their core values [2,3]:

$5T_i^{edge} \approx (1- R^{cooling})(P_i^{ext} - P_{i\to e})/\Gamma_{NBI}$, $P_{i\to e} = P_{NBI}/E_{NBI}$

$5T_e^{edge} \approx (P_e^{ext} + P_{i\to e})/\Gamma_{NBI}$, determined by the total powers P_i^{ext}, P_e^{ext} to ions and electrons (including heating from NBI, ECRH, etc, minus radiation), power exchange $P_{i\to e}$ between ion and electrons in the core, and by the NBI particle flux Γ_{NBI}. The role of thermal conductivity is highly reduced. Instead, the energy losses are determined by particle diffusion (i.e. by the best confined component), thus establishing the best possible energy confinement regime. With plasma edge temperature of 10-40 keV, the SoL is collisionless and represents a self-consistent flow of energetic particles while being much simpler than if it was plasma.

The elimination of PSI in the toga plasma regime, eliminates also the main source of tokamak plasma unpredictability and disruptivity, which is significantly determined by the current density at the plasma edge right in front of SoL. In the present high recycling regime SoL is unpredictable. Moreover, the toga MHD stability can be described by the ideal MHD stability model with tis stability operational space.

The toga invention breaks several long-standing dogmas regarding tokamak fusion. (a) The 24/7-CLiLi is the only material, safe and predictable, which can prevent accumulation of tritium in the future burning plasma devices. (b) NBI fueling, which is impossible for the high recycling regimes, is possible for toga which has no concerns with secondary Cx NBI atoms bombarding the 24/7-CLiLi. (c) Because the same LiLi stabilizes the Edge Localized Modes (ELM), the He ash pumping from the burning plasma might be feasible from the properly modified, but not discussed here, toga chamber. The present research version of Toga targets the stable plasma regime with pumping by Li and fueling by NBI to address the apparent remaining research issue with convective energy transfer across the plasma boundary and accumulating design data for future pumping of He.

In 1961, L.A. Artcimovich said: "The problem of controlled thermonuclear fusion, in terms of its difficulty, has left behind all other scientific and technical problems generated by the successes of natural science in the 20th century." In the 1970s, another view was expressed by A.I. Morozov "Fusion is too simple for me to be interesting compared to plasma propulsion". Elimination of PSI and suppression of core thermal conduction by invention of toga, i.e., the best device for confinement of the high temperature plasma, essentially confirms the validity of the Morozov views. Toga converts the presently complicated magnetic fusion problem into a difficult but well formulated physics research problem.

The fusion enabling technology of 24/7-CLiLi, unrelated to words "tritium", "neutron", or even "tokamak", as well as to government nuclear regulations, is well suitable for development by a private business under the Li fire-code. All other tokamak basic science, technology and operational experience from the 20th century is applicable for toga. In 2024, the highly enhanced NBI capture has been discovered on LTX-β (PPPL) using a small Li doping of hydrogen plasma. Just 10 % plasma dilution by Li ($Z_{eff} < 1.5$) reduces the mean free path of the 60 keV hydrogen or 120/180 keV deuterium/tritium NBI (relevant to the burning plasma) by a factor of 2.5, thus opening the opportunity of using these standard NBI energies in middle size tokamaks without fear of the shine-through. In its turn, this effect will allow the middle size toga devices to eliminate uncontrolled PSI and disruptions by using NBI together with supersonic gas or pellet injection for fueling. Such middle size devices can provide fast progress in toga development toward the burning plasma and ignition.

References

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