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Tokamak with Reactor Technologies Concept

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Concept of a tokamak with reactor technologies (TRT) is developed to facilitate fast and economically sound transition to the pure fusion reactor as well as to the fusion neutron source (FNS) for the hybrid fusion-fission system. Well controllable steady - state operation and reliable power and particle control in a reactor relevant conditions are principal plasma physics problems to be resolved on the way to both fusion reactor and FNS. Finding optimal solutions to them determines the mission of TRT. To explore wide variety of technically feasible proposals to achieve these goals the experiments should be performed in low activation conditions, i.e. mostly with H and D plasmas. However tritium trace experiments are also foreseen for the TRT research program.

TRT concept also includes development of the technical solutions for the electromagnetic system based on the high temperature superconductors (HTS) in combination with low temperature superconductors (LTS) with gradual increase of the HTS portion in subsequent modernizations; plasma facing elements with use of liquid lithium; advanced divertor; heating and CD systems including EC, NNB and IC; remote handling and remote control systems; reactor relevant diagnostics, tritium complex.

Development of the fusion –fission hybrid system based on the tokamak as the FNS is considered to be one of the principal goals of Russian fusion research program. Basic requirements for the FNS to be attractive for industrial fission fuel breeding or suitable for post-combusting of long-lived transuranic radionuclides in a hybrid system are to provide several tenth of MW of fusion power at relatively low gain factor Q~1 with neutron flux to the wall of ≥0.2 MW/m2. FNS should operate continuously (steady –state) or in pulsed regime with neutron production pulse duration, Δt, to pause ratio exceeding 80%. Thus requirements on power loads on the plasma facing elements in FNS are significantly less stringent compared to the pure fusion reactor.

Fast progress in HTS technology opens new high field operation domain for tokamaks. Along with technical advantages of HTS for implementation in tokamak magnets, higher field allows more compact design of FNS at lower capital cost. At the present TRT design is focused on the relatively compact R/a = 2.15/0.57 tokamak with Bt=8T provided with HTS (REBCO) toroidal field coils and poloidal field coils based on LTS Nb3Sn (for central solenoid) and Nb-Ti conductors. It is recognized that operation of the HTS magnet in high magnetic field is reliable at rather low temperature. Thus requirements for the TRT cryoplant are assumed to be similar for LTS, HTS or LTS+HTS variants of its electromagnetic system. It allows staged upgrades of TRT as HTS technology and manufactory progresses.

Non inductive current drive (CD) and integrated control of plasma parameters profiles are commonly recognized necessary conditions for achievement of steady-state operation. TRT auxiliary systems include 20 (30) MW NNBI, 10 (20) MW EC (230GHz) and 10 (0) MW IC (helicons). 3 NB ports in equatorial plane allow tangential injection (Rtarget≈R0-a/2) of 20-30MW neutral beams with energy of 300-500keV providing CD of about 30% of plasma current. Conceptual design of the EC power sources for 230GHz is in progress to be used at magnetic field Bt=8T. Decision on implementing IC CD system depends on the success of the dedicated future experiments on the existing tokamaks and constructed T-15MD [Ref.1].

Even more severe restriction limiting pulse duration can originate from plasma –wall interaction and accumulation of the erosion products at the tokamak first wall [Ref.2]. This restriction is called in [Ref.2] PH/S limit, which gives for the maximum achieved pulse length in existing tokamaks scaling Δt ~ 1/(PH/S)1.7. Here PH is a heating power in MW and S is a FW surface in m2. Auxiliary systems of TRT with up to 40MW of total heating power enable exploring an extensive range of PH/S values covering foreseen power densities from FNS to DEMO. Research plan to overcome PH/S limit with gradual increase of the Li percentage in tokamak and experiments with various constructions of the divertor is considered.

Analysis of the TRT discharge scenarios demonstrates that plasma current of 4MA can be driven during more than 100s with ~ 50% of bootstrap, 30% NBCD and 10% ECCD at plasma density of ne~2.0*1020m-3. For lower plasma current and plasma densities stationary non inductive CD regime can be established. Then the discharge length is limited by the operation time of the auxiliary systems. Synergetic effects in simultaneous use of EC and NBI systems were examined in development Heating/CD algorithms with controllable plasma profiles.

Large space reserved in vacuum vessel for experiments with different variants of divertor. It is assumed that at the initial stage of operation TRT will work with ITER-like divertor. Then other options including the recent developments of the concept of the swept divertor target with a liquid metal interlayer between the moving armour and motionless heat-sink suggested in [Ref.3] should be explored at later stages of operation. Liquid Li protection of the plasma facing elements is one of the principal goals of TRT concept. Various variants of protection including lithium-filled capillary porous system (CPS) are discussed to accommodate the best achievements of the T-11M and T-10 lithium experiments as well as expected contribution from the T-15MD research program [Ref.1]. Simulations of plasma scenarios in TRT show wide operation domain to study reliable achievement of steady –state regimes in a reactor relevant conditions.

[Ref.1] P P Khvostenko et al., Tokamak T-15MD, this Conference
[Ref.2] S V Mirnov, Nucl. Fusion 59 (2019) 015001
[Ref.3] I V Mazul, Nucl. Fusion 56 (2016) 126009

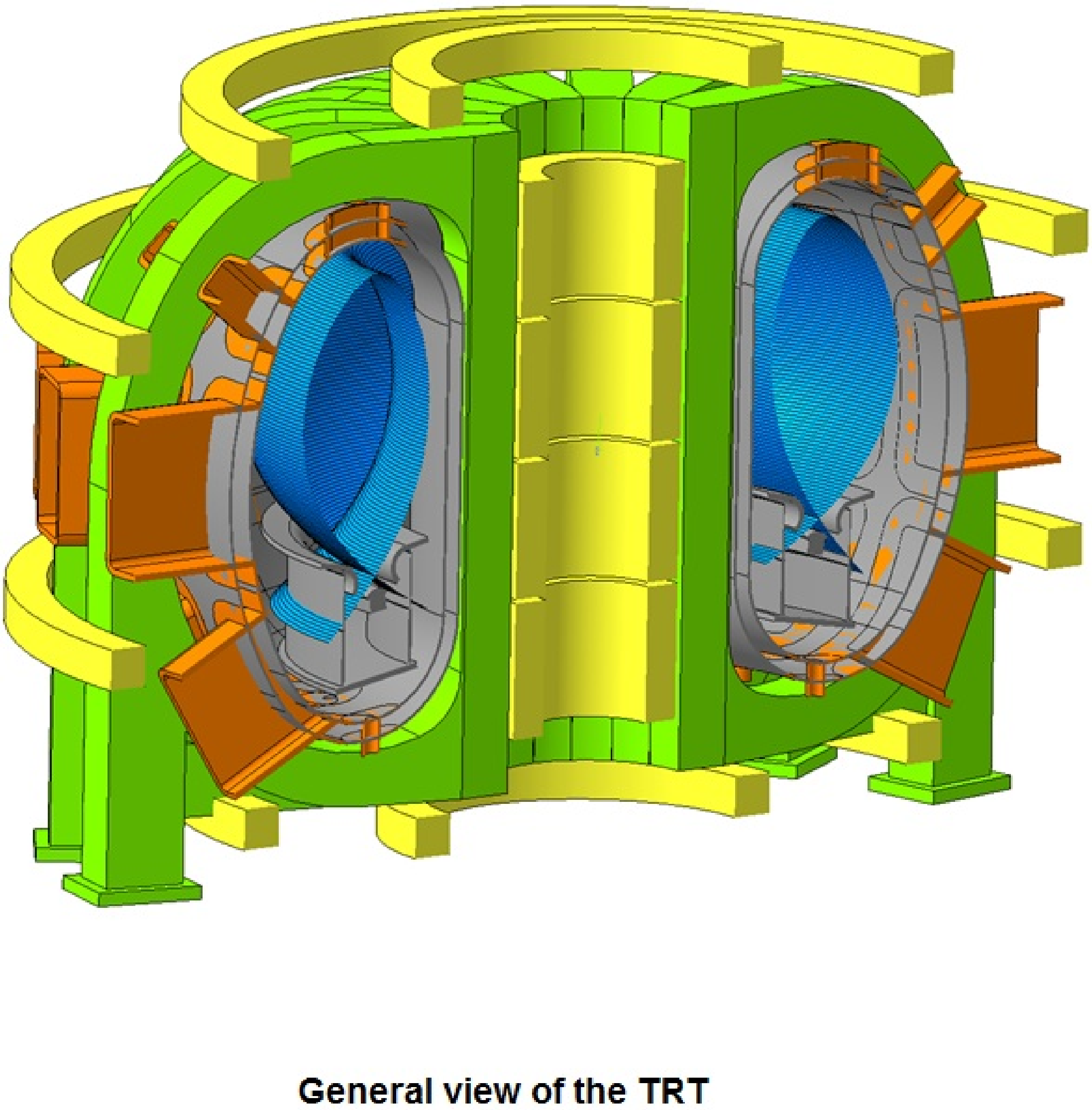

Figure 1: TRT general view

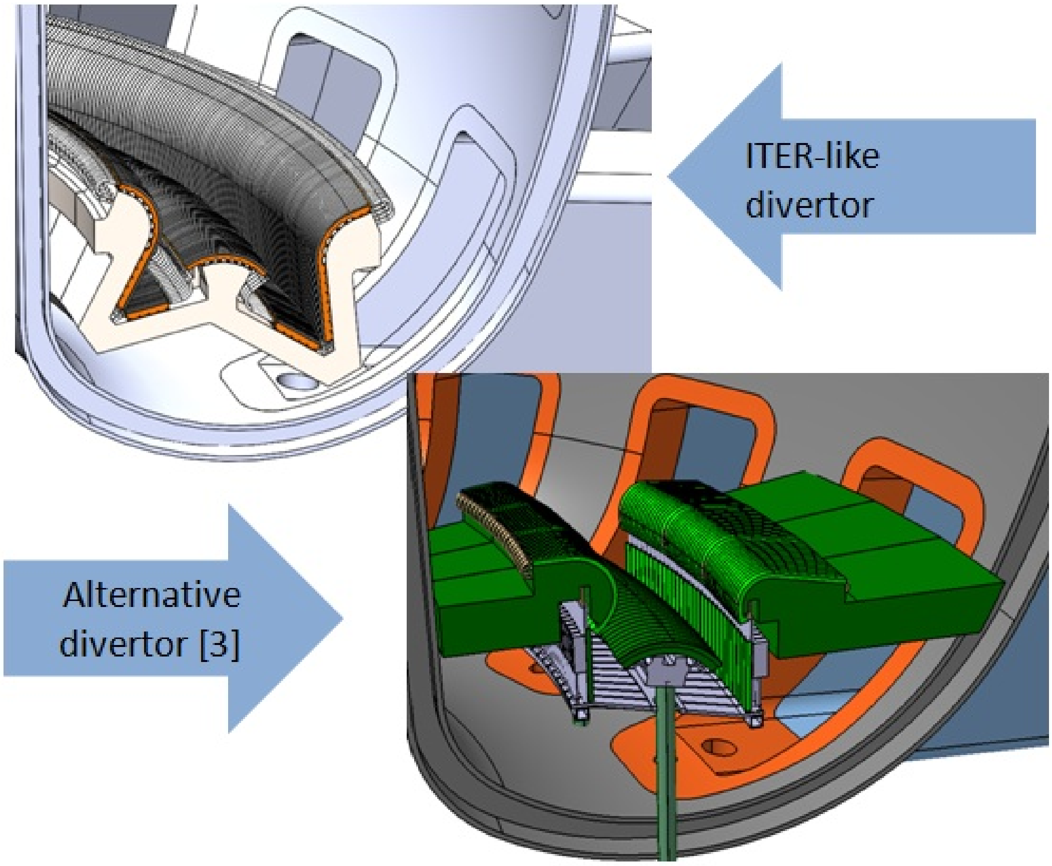

Figure 2: TRT divertor

Affiliation

National Research Center “Kurchatov Institute”

Country or International Organization

Russia

Authors: Dr KONOVALOV, Sergey (National Research Center ”Kurchatov Institute”); Dr BONDARCHUK, Eduard (Joint Stock Company “D.V.Efremov Institute of Electrophysical Apparatus”, St Petersburg, Russia); Dr KRASILNIKOV, Anatoliy (Institution ”Project Center ITER”, Moscow, Russia); Dr RODIN, Igor (Joint Stock Company “D.V.Efremov Institute of Electrophysical Apparatus”, St Petersburg, Russia); Dr KHAIRUTDINOV, Rustam (National Research Centre “Kurchatov Institute”, Moscow, Russia); LUKASH, Victor (NRC Kurchatov Institute); Mr LEONOV, Vladimir (NRC “Kurchatov Institute”); KUKUSHKIN, Andrei (NRC Kurchatov Institute); LYUBLINSKI, Igor (JSC ”Red Star”); MAZUL, Igor (Efremov Institute); Dr MINEEV, Anatolij (Efremov Scientific Research Institute of Electrophysical Apparatus); VERTKOV, Alexey (JSC “Red Star”); VYSOTSKY, Vitaly (Russian Scientific R&D Cable Institute); Dr LELEKHOV, Sergey (Institution ”Project Center ITER”, Moscow, Russia); Dr SYTNIKOV, Victor (”R&D Center FGC UES”, JSC, Moscow, Russia)

Presenter: Dr KONOVALOV, Sergey (National Research Center ”Kurchatov Institute”)

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