ID: 1196

Disruption Mitigation in Tokamak Reactor via Reducing the Seed Electrons of Avalanche

V.Yu. Sergeev[1], B.V. Kuteev[2]
[1]Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia
[2]National Research Center "Kurchatov Institute", Moscow, Russia
V.Sergeev@spbstu.ru

MOTIVATION

- The current ITER DMS [1] will provide delivery of a moderate amount of impurities (Ne, Ar) reducing the thermal and electromagnetic loads during thermal TQ and current CQ quenches to appropriate for the device levels.
- DMS will use additionally massive D_2 injection for collisional suppression of the runaway avalanche during CQ [2]. This technology creates problems of technological systems (fueling, pumping etc.) in ITER after disruption.
- A novel approach for the seed control that might reduce the avalanche current in ITER below 1 MA without massive gas injection is proposed.

ESSENCE OF THE APPROACH

- Fig. 1 shows a schematic of the approach in case of using the tungsten rod 8 mm in diameter and 80 mm in length that crosses the plasma volume with the velocity of 0.8 km/s perpendicularly to the toroidal magnetic field.
- The W projectile is accelerated by a railgun. It reaches the plasma border and crosses the plasma size 4 m in equatorial plane within 5 ms duration.
- The projectile collects seed electrons falling on its surface and sequentially cleans from runaways crossed magnetic surfaces during flight.
- After crossing the plasma, the projectile enters a collector for utilization.

HOT-TAIL SEEDS and RA CURRENT GENERATION

- The seed current I_{seed} formed by hot-tail mechanism and the runaway avalanche current I_{RA} were evaluated as in [3] for the inductive ITER scenario parameters: R = 6.2 m, a = 2.0 m, k_{el} = 1.7, I_0 = 15 MA, B_t = 5.3 T, n_{e0} =10.5·10^{19} m^{-3}, T_{e0} = 22.7 keV.
- For the TQ scenario, it was assumed that a fast reconnection event occurs in the whole plasma volume. The plasma thermal energy is then lost during TQ due to both the injected impurity radiation and the electron heat diffusivity in stochastic magnetic fields.
- The key parameter within the hot-tail model implemented is the characteristic time of TQ close to $t_0 \cong$ 1 ms in ITER [1-3]. The inductive electric field was evaluated using Spitzer plasma resistivity and accounting for the current growth up to I = 22.5 MA after TQ [4] due to the fast reconnection.
- The seeds density $n_{ht} \cong 10^{13}$ m^{-3} and $I_{seed} = ecn_{ht}k_{el}\pi a^2 \cong$ 10 кA were estimated using Ref. [5]. Although there is a considerable uncertainty in predictions of the seed amount, the obtained in our analysis value I_{seed} = 10 кA is in the 10~100 kA range expected in ITER current design.
- For constant T_{eCQ} = 10 eV during CQ, the Ohmic decay time $\tau_{res} \cong$ 30 ms is in the range of 22~66 ms needed to ensure acceptable EM loads.
- Fig. 2 shows reduction of I_{RA} from 5 MA to acceptable for ITER level of 1 MA if the projectile collects 95% of the seed current I_{seed}.

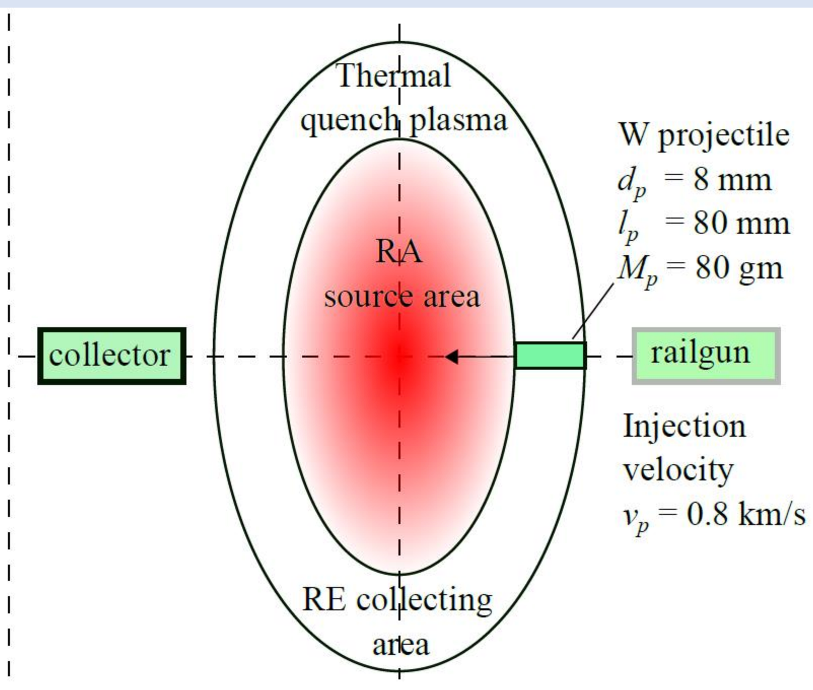

Fig.1. Schematic of the approach

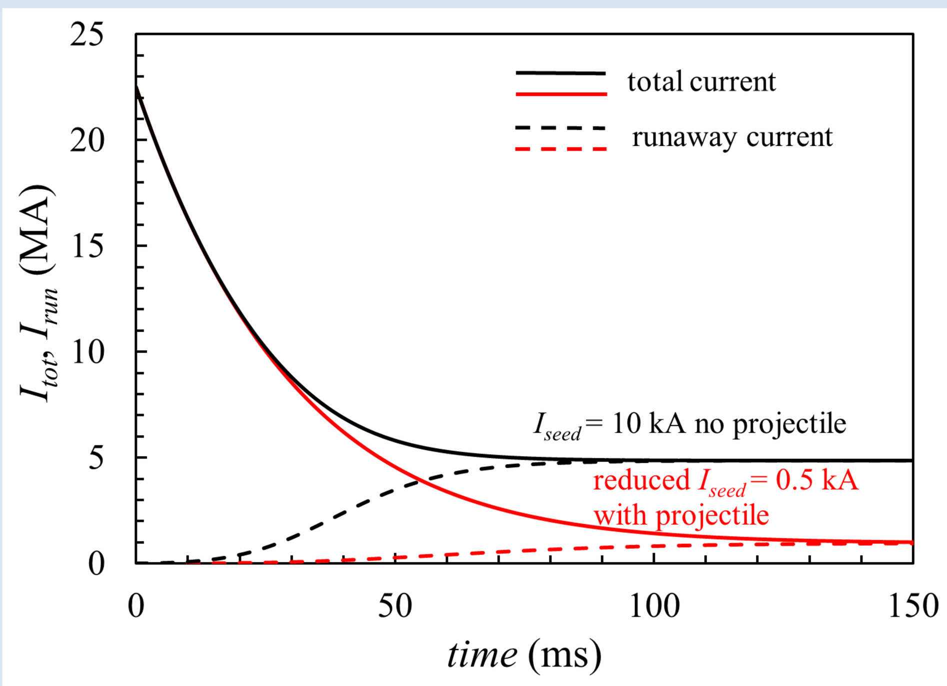

Fig.2. Currents in ITER disruption with and without projectile

PLASMA-PROJECTILE INTERACTION

- The choice of material and size of the projectile is governed by a combination of material properties. The high efficiency of RE deceleration that reduces the projectile size and mass as well as high melting and evaporation temperatures declining the projectile erosion are favorable.
- Fig. 3 shows dependencies of the path length L_{path} versus the RE energy. The W projectile diameter d_p = 8 mm captures RE with energy 25~50 MeV. Tungsten is the best material for termination of seeds and runaways.
- Collection efficiency (*CE*) of runaways by the projectile is shown in Fig.4. CE ≥ 95% is inside ≤ 0.5a for 4 crossings of the magnetic surface.
- The projectile heating during flight is acceptable for $T_{eCQ} \leq$ 50 eV (Fig. 5.).
- Options for the projectile injection are shown in Fig. 1 and Fig. 6. The tangential injection in the equatorial plane passing close to the region of a high magnetic field seems optimal (4 crossings, a simpler positioning due to the existing equatorial tokamak ports).
- Compactness of the railgun is provided by the toroidal field magnetic coil. The railgun with 600 kA current and 0.5 m length is capable to accelerate the 80 g W projectile up to 800 m/s during 0.8 ms.

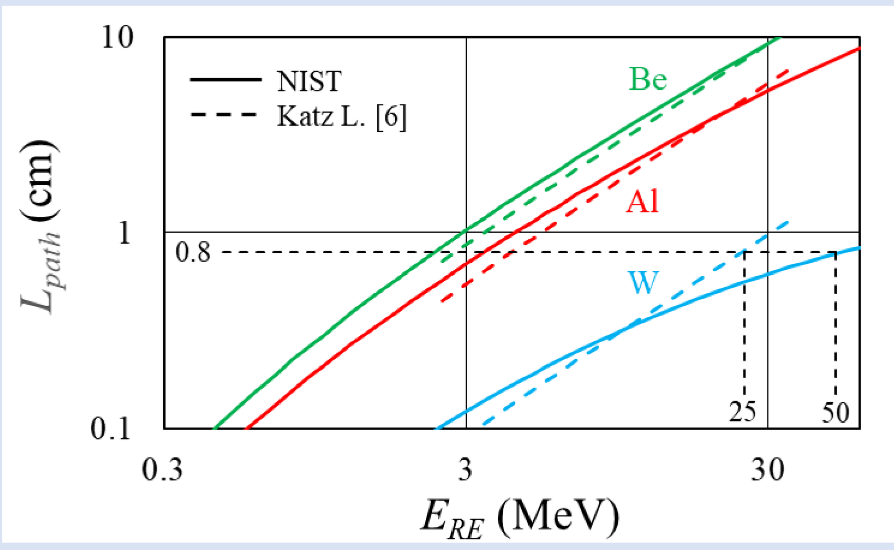

Fig.3. RE path length via RE energy

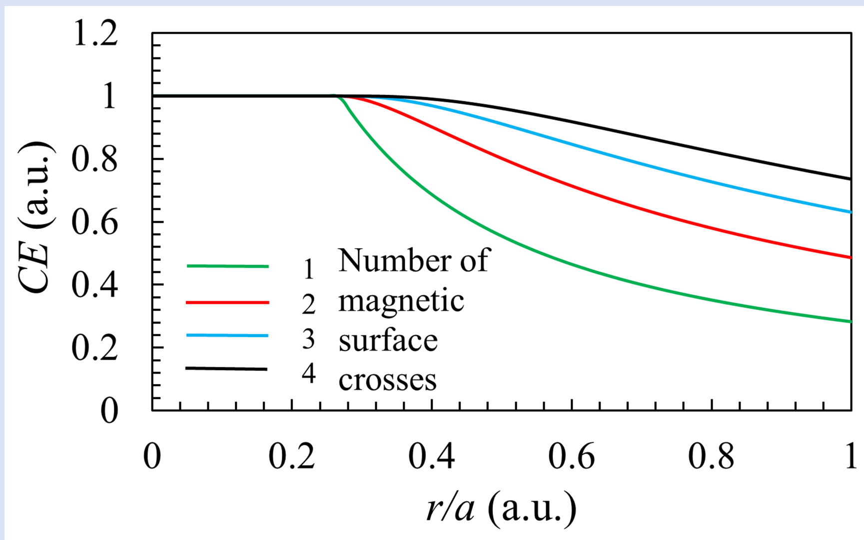

Fig.4. RE Collection efficiency

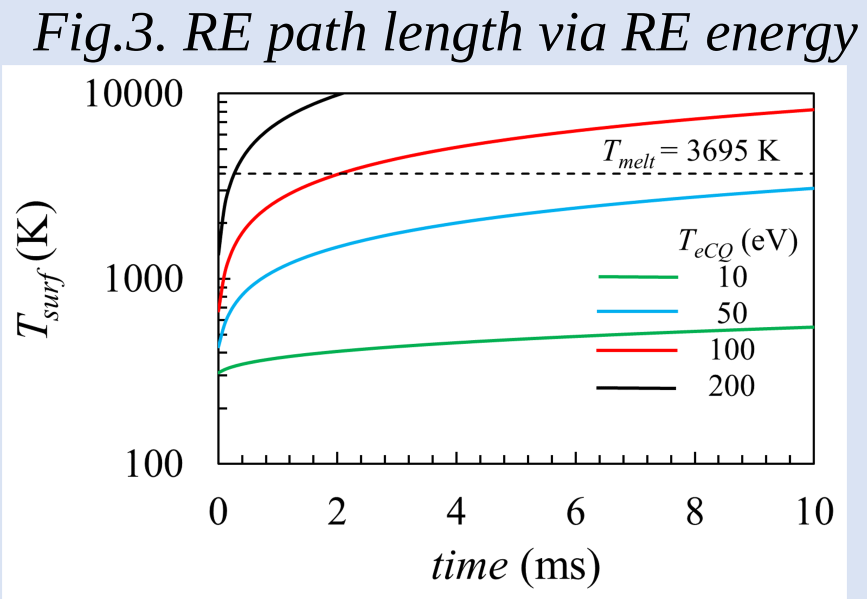

Fig.5. Heating during projectile flight

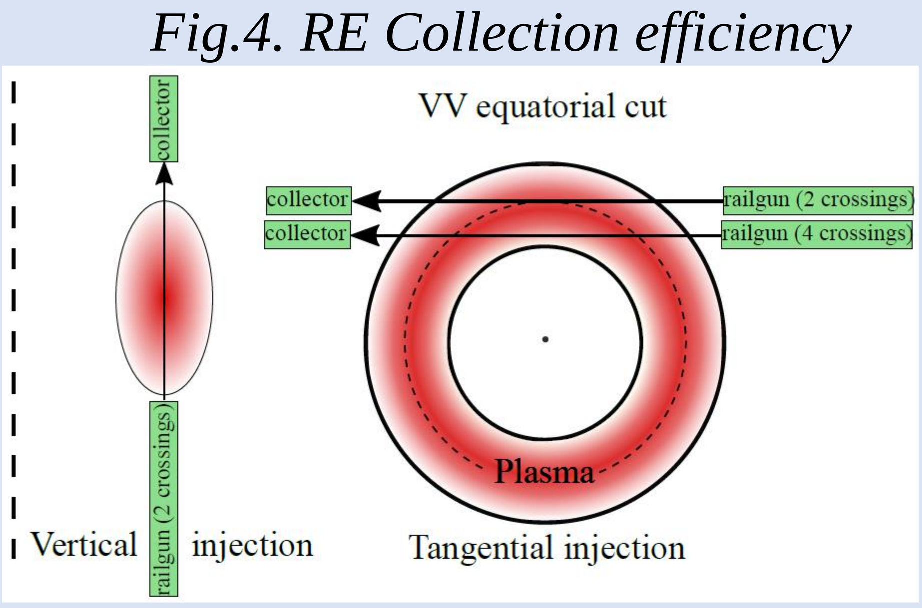

Fig.6. Projectile injection options

SUMMARY

- A novel approach is proposed for enforce the ITER DMS by the W projectile injection just after TQ instead of the massive D_2 injection. This cancellation significantly reduces problems of technological systems (fueling, pumping etc.) in ITER after disruption.
- The collection of seeds and runaways by the tungsten projectile injected, might reduce the avalanche current in ITER below 1 MA.
- The projectile surface temperature can be below the melting threshold of tungsten during the flight time for CQ plasma temperature less than 50 eV.
- Railgun using the tokamak toroidal magnetic field is the optimal projectile accelerator.

REFERENCES

[1] Lehnen M. et. al. *J. Nucl. Mater.* **463** (2015) 39
[2] Martin-Solis J.R., Loarte A., Lehnen M. *Nuclear Fusion* **57** (2017) 066025
[3] Breizman B.N et. al. *Nucl. Fusion* **59** (2019) 08300
[4] Boozer A.H. *Phys. Plasmas* **23** (2016) 082514
[5] Smith H.M., Verwichte E. *Phys. Plasmas* **15** (2008) 072502
[6] Katz L., Penfold A.S. *Reviews of Modern Physics* **24** 1(1952) 28