Disruption runaway electrons generation and mitigation attempts in STEP

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Introduction

- Generation of Runaway Electrons (REs) during plasma disruptions and their impact on the plasma facing components is of great concern for ITER and future reactors, such as STEP (Spherical Tokamak for Energy Production).
- With flat-top plasma current of 20 MA or more, STEP is expected to be in the seed-insensitive regime of avalanche multiplication, i.e., any runaway seed would quickly generate a large runaway beam during unmitigated disruption current quenches (as in ITER and SPARC).
- Using the code DREAM [1], we model RE generation during STEP unmitigated and mitigated disruptions.

DREAM inputs

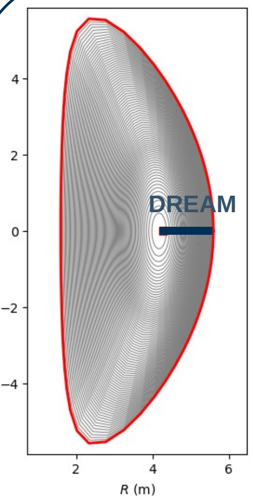

Fig. 1: STEP equilibrium modelled in DREAM, shaping effects included

DREAM (Disruption and Runaway Electron Analysis Model) is designed to simulate RE generation during tokamak disruptions.

Includes advanced rates for RE generation mechanisms: Dreicer, Hot-tail, tritium decay, Compton scattering, avalanche.

DREAM 1D grid constructed using:

- Free-boundary equilibrium from FIESTA.

- Plasma profiles from JETTO (n_e, T_e, $j_{||}$).

- I_p = 19.7 MA, B_T = 3.2 T, κ = 2.8

- $n_{e,0}$ ~ 1.5e20 m^{-3}, $T_{e,0}$ = 18 keV

Unmitigated disruptions

- We tested the assumptions for the prescribed thermal quench phase (duration, final electron temperature) in a reasonable physical range, but also the wall time, the plasma-wall distance, and shaping effects.
- Overall, all STEP unmitigated disruptions generate more than 10 MA of runaway current (up to full conversion).
- Hot-tail generation of runaways is found to be the dominant primary generation mechanism, and the avalanche multiplication factor is confirmed to be extremely high.

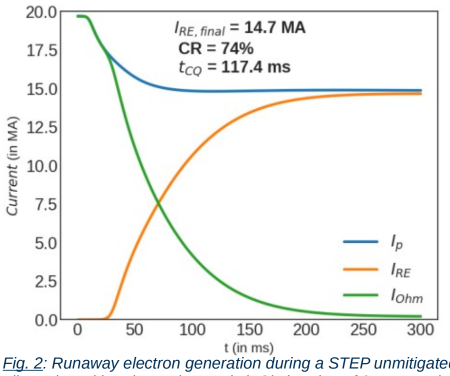

Fig. 2: Runaway electron generation during a STEP unmitigated disruption with a thermal quench (TQ) duration of 3.4 ms and a post-TQ electron temperature of 10 eV

Runaway avoidance

- Mitigation using idealized impurity injection of Argon and D_2 has then been modelled, with a self-consistent temperature evolution.
- Transport during the TQ is imposed by choosing dB/B (Rechester-Rosenbluth)
- Different dB/B transport assumptions tested, including runaway transport during the TQ.
- No injection scenario allows to avoid runaways while respecting the other constraints of disruption mitigation (20 ms < CQ time < 150ms, f_{rad} > 90%), in contrast with results for a earlier and smaller STEP concept [2].

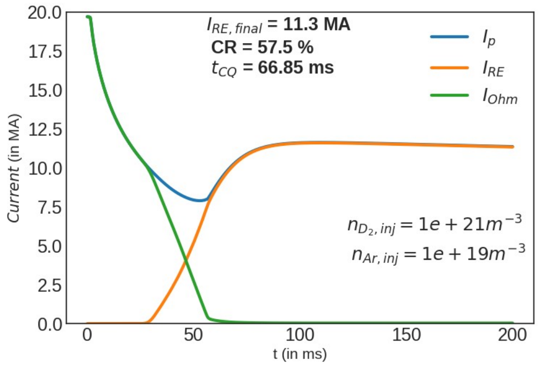

Fig. 3: Runaway electron generation during a STEP mitigated disruption with Argon and D_2 impurity injections (t_{TQ} = 1.8 ms, f_{rad} = 82%)

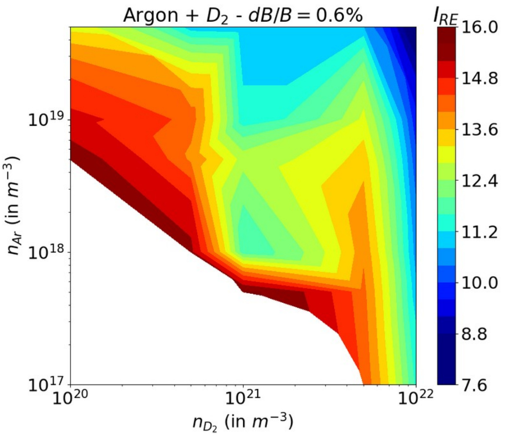

Fig. 4: Runaway electron generation during STEP mitigated disruptions – Scan in Argon and D_2 injected quantities

Conclusion & Future work

- Idealised impurity injection of Argon + D2 and Neon + D2 (not shown) in STEP can mitigate some of the disruption effects (radiating the thermal energy, controlling the CQ duration), but fail to mitigate fully the generation of REs.
- Next steps include using DREAM SPI model, including a better model for MHD losses during disruptions (i.e., DREAM + JOREK) and studying and optimizing the mitigation of runaway electrons beams with the D_2+MHD scheme, as was proven successful in JET [3], TCV, ASDEX Upgrade and DIII-D.
- Additional mitigation methods, such as active 3D fields and the effect of a passive runaway electrons mitigation coil will also be investigated.

1] M. Hoppe, et al., 2021, Computer Physics Communications 268, 108098.
[2] E. Berger, et al., Submitted to Journal of Plasma Physics – arxiv link
[3] C. Reux, et al., 2021, Physical Review Letters 126, 175001