Contribution ID: **462** Type: **Poster**

Generation of runaway electrons during the thermal quench in tokamaks

Wednesday, 19 October 2016 14:00 (4h 45m)

A consistent description of runaway electron (RE) generation in plasma disruptions remains an open physics issue. The possibility of the formation of high post-disruption RE currents raises safety-related concerns for large tokamaks, such as ITER. Although the avalanche mechanism of RE production is anticipated to be the dominant mechanism in ITER [M.N. Rosenbluth, S.V. Putvinski, Nucl. Fusion 37, 1355 (1997)], the avalanche multiplication of the runaways after the thermal quench still requires a seed RE current. The need for reliable prediction of the RE generation in ITER calls for additional attention to the primary (seed) population of the RE.

We present an advanced description of electron kinetics during impurity-dominated thermal quenches in tokamaks. A 2D Fokker-Planck equation for the hot electrons and a power balance equation for the bulk plasma are solved self-consistently, with impurity radiation as the dominant energy loss mechanism.

The post-thermal-quench (but pre-current-quench) RE density, energy and current are found for a broad range of initial plasma parameters (density, current density, temperature and impurity concentration), including those of interest for ITER.

We find that runaway formation is less efficient in plasmas with high pre-quench temperatures. In particular, we do not expect any significant runaway seed in a 10keV plasma with a density of 10ˆ20mˆ-3 when the amount of injected Argon is less than 5•10ˆ19mˆ-3, while in a 2keV plasma of the same density a significant RE population forms if 2•10ˆ19mˆ-3 of Argon is injected.

We also find that runaway production increases for heavier injection of impurities up to prompt conversion of the total pre-quench current into the runaway current in the case of abundant impurities. The mean kinetic energy of RE population is in this case limited to rather moderate values (sub-MeV), asymptotically approaching those of the near-threshold regime [P. Aleynikov and B. N. Breizman, Phys.Rev.Lett., 114,155001 (2015)].

We finally conclude that the non-uniformity of the plasma creates a possibility for the post-quench current to be carried by two distinct runaway populations (a sub-MeV and an ultra-relativistic).

Work supported by the ITER Contract No. ITER/CT/15/4300001178 and the U.S. Department of Energy Contract No. DEFG02-04ER54742.

Paper Number

TH/P4-2

Country or International Organization

Germany

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Session Classification: Poster 4

Track Classification: THW - Magnetic Confinement Theory and Modelling: Wave–plasma interactions; current drive; heating; energetic particles