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Collisional generation of runaway electron seed distributions leading to sub-criticality, avalanche, or fast transfer

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Well before ITER operations begin, we must have a comprehensive understanding of the potential for runaway electron generation, as well as methods for their control and mitigation, as the destructive potential to the plasma facing components is severely intolerable. This makes for a unique situation in requiring an assessment based on plasma theory and computation well before validation experiments can be performed.

Among the most important questions given a thermal collapse event is that of how many seed electrons are available for runaway acceleration and the avalanche process. Seed electrons remain with a kinetic energy above the critical energy for runaway after a thermal quench, either natural or induced. The expected seed generation is a critical question that needs to be addressed, and new methods are now available to do so. The most important source of seed electrons is the high-energy tail of the pre-thermal-quench Maxwellian. This high energy tail can be lost in two ways: (1) collisional drag on cold electrons or (2) loss to the walls if all the magnetic surfaces within the plasma are destroyed.

In this study, we use the kinetic equation for electrons and ions to investigate how different cooling scenarios lead to different seed distributions. Given any initial distribution, we study their subsequent avalanche and acceleration to runaway with Adjoint and test particle methods [Chang Liu, Dylan P. Brennan, Amitava Bhattacharjee and Allen H. Boozer, Phys. Plasmas 23, 010702 (2016)]. This method gives an accurate calculation of the runaway threshold by including the collisional drag of background electrons (assuming they are Maxwellian), pitch angle scattering, and synchrotron and Bremsstrahlung radiation. A resulting probability to runaway is determined in phase space, which has a sharp transition, such that electrons with energy above this transition become highly likely to runaway. Summing the electrons above this threshold determines the number of seed electrons N_s. When N_s exceeds the number of relativistic electrons needed to produce the entire equilibrium current, fast transfer to runaway current is possible. Alternatively, N_s can be small enough that the runaway process is too slow to cause any significant runaway population on the experimental timescale. Between these limits, the avalanche process determines the runaway population.

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Primary author: BRENNAN, Dylan (Princeton Plasma Physics Laboratory)

Co-authors: BOOZER, Allen (Columbia University); BHATTACHARJEE, Amitava (Princeton Plasma Physics Laboratory); LIU, Chang (Princeton Plasma Physics Laboratory); HIRVIJOKI, Eero (Princeton Plasma Physics

Laboratory)

Presenter: BRENNAN, Dylan (Princeton Plasma Physics Laboratory)

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