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Runaway Electron Generation During Tokamak Disruptions

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Tokamak disruptions have been the subject of extensive research due to the myriad of multiphysics issues present as well as the threat they pose to reactor-scale tokamak devices [1,2]. These events, which correspond to the sudden release of nearly all of the device's magnetic and thermal energy, are capable of causing significant damage to the confinement vessel via thermal and electromagnetic loads, or via the formation of a large population of runaway electrons. This last issue has recently attracted significant attention due to the large gaps in our understanding of the physical mechanisms responsible for the generation and evolution of runaway electrons during tokamak disruptions. This presentation will examine several of these gaps with particular emphasis on scaling to reactor-scale devices.

While avoiding runaway electron formation remains the most attractive scenario for a disruption mitigation system, identifying the precise criteria for runaway avoidance incorporating essential collisional and radiative processes along with spatial transport has remained elusive. This is due to the complexity of the MHD fields present during the thermal quench phase of a tokamak disruption, which results in large uncertainties in the transport of energetic electrons, and thus the size of the initial, or "seed" population of runaway electrons. Due to this uncertainty, our focus in this presentation will be to determine the efficiency through which a given seed can be amplified under conditions characteristic of a tokamak disruption. The physical mechanism underlying this amplification process, is due to large-angle collisions between pre-existing runaway electrons and low energy electrons. During these events, low energy electrons may be scattered to sufficiently high energy to run away, thus increasing the number of runaway electrons. Of particular interest will be to identify the efficiency of avalanche amplification in the limit of the large inductive electric fields that are expected during a tokamak disruption. It is found that in the presence of large inductive electric fields, the efficiency of avalanche amplification is modified in two important respects. The first arises when a significant number of partially ionized impurities are present. In this scenario the efficiency of avalanche amplification is substantially increased for sufficiently large electric fields [3,4], allowing for even a modest number of seed runaway electrons to be exponentiated into a large runaway electron population. In addition, for the limit of a strong inductive electric field, it is found that the physics of how tokamak geometry impacts runaway generation processes is qualitatively modified compared to the more commonly studied limit of weak inductive electric fields [5]. This modification leads to the efficiency of avalanche amplification being increased at mid radius in comparison to the more commonly studied limit of weak inductive electric fields, thus substantially modifying the number and profile of the final runaway electron population. Ongoing work is devoted toward applying these results to the self-consistent description of seed formation in a disrupting plasma, with a specific emphasis on investigating implications of these results for reactor-scale plasmas.

References

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