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Influence of Neoclassical Effects on Runaway Electron Avalanche

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During tokamak disruptions, a large number of runaway electrons (REs) may strike localized areas of the first wall, posing significant risks of damaging the wall and the blanket. Careful analysis and effective mitigation of these REs is therefore important to the success of tokamak-based fusion reactors. Rapid growth of RE population can occur during disruptions through the so-called avalanche mechanism, the characterization of which is therefore essential to predicting the plateau RE current. However, existing theoretical frameworks for RE avalanche fail to self-consistently incorporate the collisional scattering and trapping effects, leading to deviations in estimating the RE avalanche growth rate. Furthermore, precise quantification of secondary runaway electron generation is vital for evaluating the portion of trapped REs during disruptions, which impacts the excitation of Alfvén waves. Building on Rosenbluth's avalanche theory [1], we developed a revised avalanche growth rate calculation method by solving the bounce-averaged electron kinetic equation and accounting for the distinct responses of passing and trapped electrons to electric fields with finite values of inverse aspect ratios. This approach integrates both collisional scattering and trapping effects. Validation through kinetic simulations using the kinetic RE simulation code DREAM [2] demonstrates that, our modified avalanche model agrees with simulation results across a wide range of aspect ratio values, while the original Rosenbluth model (considering only collisional scattering effects) and the Nilsson model (accounting solely for trapping effects [3]) align with simulations only in the large and small aspect ratio limits, respectively. These comparisons confirm the validity of our proposed corrections. This study establishes a theoretical foundation for more accurate estimations of runaway electron growth in tokamaks, and can be implemented in fluid-based RE simulation code such as DREAM and M3D-C1.

References
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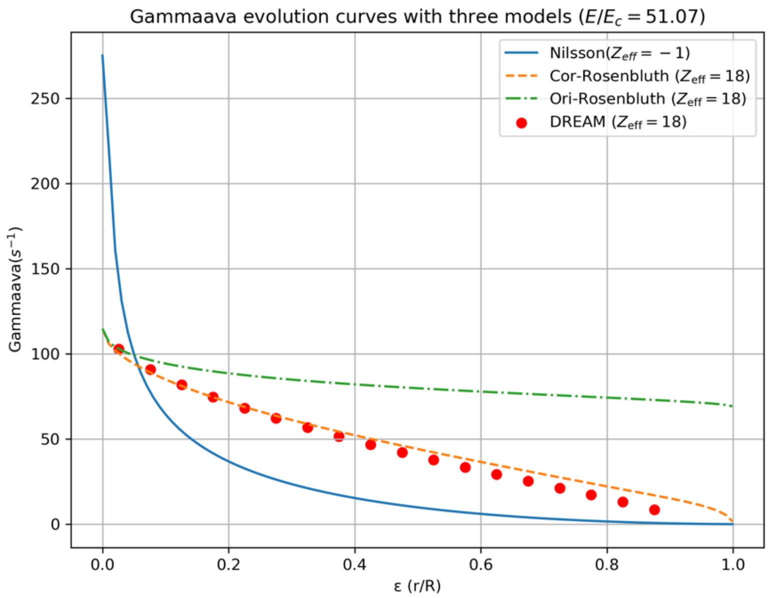

Figure 1 Gamma avalanche evolution curves for four models, Nilsson's model(blue)、Rosenbluth origin model(green dash)、Modified Rosenbluth model(red dash)、DREAM full kinetic simulation(red dot), Z_{eff} is effective nuclear charge number, E_c is the critical electric field.