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Advances in Runaway Electron Control and Model Validation for ITER

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Measurements and modeling of runaway electron (RE) dissipation in DIII-D has resolved key experimental discrepancies and validated predictions for ITER, improving confidence that RE mitigation and avoidance can be predictively optimized without risking first-wall integrity. Energy-resolved measurements of hard X-ray (HXR) flux with a unique gamma-ray imaging (GRI) system demonstrate that anomalous dissipation of RE beams is strongest for low energy RE populations. Modeling including the self-consistent interaction of the RE population with RE-driven kinetic instabilities reproduces the enhanced dissipation and finds strong wave-particle interactions with the low energy RE population.
Novel spatio-temporally resolved HXR measurements using the GRI system have also validated RE distribution function (f_e) dependencies and observed the effect of phase-space attractors that pile up REs at a given energy. Increasing synchrotron damping shifts the high-energy f_e towards lower energy, though quantitatively observed synchrotron effects are larger than predicted. Increasing collisional damping shifts the full f_e to lower energy. f_e validation in both phase space and real space is further advanced by new synchrotron and bremsstrahlung emission synthetic diagnostics. These tools reproduce experimental images and can validate different pitch-angle distribution models.
Considering RE seed formation and final loss, a new method to experimentally estimate the RE seed current from pellet ablation rates reveals that the hot-tail generation mechanism significantly over-estimates RE seed production, while the Dreicer mechanism is insufficient to explain the observed seed. Model predictions of first wall Joule heating during the RE final loss are consistent with experiment at high ion charge (Z). Discrepancies are found at low Z, however, indicating some RE dissipation processes remain poorly understood. The above measurements and comparison with theory substantially improves confidence that model-based optimization of RE avoidance and mitigation can be achieved. This is essential to fully exploit ITER while avoiding RE-induced damage to the first-wall.

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