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Magnetohydrodynamic Modeling of Shattered Pellet Injection and Runaway-Electron Dynamics

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Future tokamaks will require robust disruption mitigation to prevent machine damage from thermal loads, electromagnetic forces, and runaway-electron (RE) impact. The leading-candidate for this is shattered-pellet injection (SPI), which is being tested experimentally on several tokamaks and will be used on ITER. Verified, predictive models are needed to project the performance of these systems on future devices. We present an overview of disruption-mitigation and disruption-dynamics modeling performed with the M3D-C1, NIMROD, and MARS-F magnetohydrodynamics (MHD) codes. M3D-C1 and NIMROD have been coupled to a coronal non-equilibrium model for impurity ionization, recombination, and radiation along with a state-of-the-art model for pellet ablation. A 3D benchmark between M3D-C1 and NIMROD for an injected pellet in DIII-D has been improved due to a number of code enhancements. The codes agree on the peak radiated power as well as time scales for thermal quench, current quench, and onset of macroscopic MHD instability. Understanding of remaining discrepancies will be considered. The agreement found gives confidence in the ability of both codes to perform high-fidelity, predictive modeling for ITER and other future devices. M3D-C1 modeling has been performed for realistic SPI plumes based on JET experiments. Pure-neon and neon-deuterium pellets are considered, which vary in speed and shatter distribution due to the differing composition. Simulations with the velocities swapped show that at low speeds, the quench dynamics are similar for the two compositions, while at high speeds, the mixed pellet travels further into the plasma before complete thermal quench. These results show a competition of time scales between the traversal of the pellet and outside-in radiative collapse. Similar NIMROD modeling of JET finds that reducing viscosity increases MHD activity and decreases thermal quench time slightly. Initial results from KSTAR modeling with M3D-C1 and NIMROD will also be considered, with particular focus on comparing single versus dual, symmetric injection. In addition, validation of M3D-C1 and NIMROD DIII-D SPI modeling with experimental data and EFIT reconstructions during the early thermal quench will be considered. A coupling between NIMROD DIII-D SPI quench simulations and the Fokker-Planck CQL3D kinetic code has been established to simulate the production of REs and their radial transport. It is shown that without the radial transport, a large RE current is generated, up to 30% of the pre-pellet Ohmic current. However, when the radial transport is included in CQL3D, the RE current is reduced to undetectable levels, consistent with experiment. The MARS-F code has been updated with various modules capable of modeling RE loss due to 3D field perturbations (with REORBIT), runaway avalanche, and interactions between REs and MHD instabilities (MHD-RE hybrid). Important examples will be reported utilizing these new tools.

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