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Self-consistent runaway beam formation in 3D magnetic fields during radiation-driven disruptions

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We report new simulations that predict three-dimensional (3D) spatial profiles of runaway electrons (REs) throughout the whole evolution of disruption plasmas using a nonlinear reduced MHD code including a runaway beam model. Both the RE generation mechanisms relevant to mitigated disruption scenario for D-T activation phase in ITER and the convective transport of REs due to disruptive MHD instabilities during thermal quench (TQ), such as reconnection, magnetic islands, and their overlapping, are taking into account. In our approach, REs are expressed as the advection of beam density with the zero-orbit width model, and electron runaway is taken into account as source models that account for the parametric dependence of runaway rates in the velocity space for Dreicer generation, hot-tail generation, and intrinsic high-energy electron sources (due to tritium decay and the Compton scattering of gamma rays). The range of the validity is checked via the comparison to Fokker-Planck and orbit-following simulations. The developed simulation code EXTREM is a powerful tool for studying the physical mechanisms of RE generation in the presence of disruptive MHD instabilities and those of subsequent avalanche growth. We here perform a long-term simulation of radiation-driven disruption over the avalanche timescale for the ITER 15 MA parameter with noble gas and deuterium injection. During TQ MHD instabilities, overlapping of multi-n tearing modes and subsequent m/n=1/1 mode, where the latter causes the disruption of the central electron temperature profile, are shown to play a dominant role in mixing of REs in partially-destroyed magnetic fields. The resultant seed current profile localized in the region with the safety factor around unity is inherited by the avalanche growth, and the final RE profile and the net RE generation becomes significantly different from those predicted by the conventional 1D modeling without MHD effects. The sensitivity of the results for different initial q profiles and the impurity injection condition is investigated. In particular, the effectiveness of Ar/Ne + deuterium mixture injection for RE suppression is addressed over the parameter ranges relevant to disruption mitigation scenarios in ITER.

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