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Runaway mitigation and safe termination during startup and disruptions

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Runaway electrons of MeV and higher energies can dominate the plasma current during ITER startup and the current quench phase of a major disruption. The plasma regime spans from reasonably low-density and high-temperature (startup) to high-density and low-temperature (disruption mitigated by high-Z impurities), and somewhere in between (disruption mitigation by low-Z injection). Here we describe the recent physics findings informing how runaways can be managed in these diverse situations. The first result is on how runaway-induced wave instabilities, particularly the slow-X modes as opposed to the whistler waves, can efficiently transfer the plasma current from high-energy runaways to suprathermal electrons, during which relativistic runaways can even reverse their direction with respect to the magnetic field. These findings come from fully-kinetic simulations that remove the shackle of quasilinear formulation previously reported in the literature, and the physics is of interest to warm plasmas during ITER startup or in reheated plasmas during a current quench. The second result is on the standard ITER scenario of high-Z impurity mitigated disruption in which runaway dissipation and transport loss are greatly enhanced by high-Z impurities while plasma column scrapes off against the first wall during a vertical displacement event (VDE). The runaway loss pattern on the first wall, as the result of both collisional transport and VDE scrape-off, is of particular interest in assessing the wall tolerance for the runaway impact. A hybrid model that couples quasi-static MHD with drift-kinetic runaway electrons has been simulated to account for the ITER VDE dynamics with the full kinetic physics of runaway dissipation and transport loss, as well as the scrape-off process. The third result is on the use of solid tungsten particulates for standoff termination of the relativistic runaway electrons. The idea is that instead of having the runaways scrape-off against the wall, one can place a cloud of tungsten particulates in front of the first wall to be impacted by the VDE, so runaways can terminate on these solid particulates. This is similar to the previous dust shield concept for divertors, but the new twist is that the tungsten particulates can facilitate safe termination by both runaway energy attenuation and effective pitch angle scattering, which can alter the runaway orbits (e.g. from passing to trapped) for broader deposition pattern on the first wall. Here we will show both effects by the tungsten particulates via MCNP calculations. The fourth result is on the feasibility of doing away with thermal quench mitigation by radiative cooling. The idea is to inject enough amount of hydrogen that the plasma would be dilutionally cooled to be collisional for open field line transport, but still warm enough that the inductive electric field from $E_\parallel = \eta j_\parallel$ stays below the avalanche threshold electric field if not the Connor-Hastie critical field. Interestingly, MHD simulations with Braginskii transport coefficients are supposed to be theoretically sound for such a mitigated collisional plasma. Here we will show the most up-to-date PIXIE3D simulations that establish comparable TQ and CQ time scales in such mitigation scenario.

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