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Time-Dependent Runaway Simulations: Ampere-Faraday Equations Implemented in CQL3D

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The runaway electron distributions driven by a large toroidal electric field Etor induced by the drop in the temperature profile due to disruption or pellets are comprehensively simulated by the 3D Fokker-Planck solver CQL3D [1], recently coupled to the Ampere-Faraday (A-F) equations. The evolution of the toroidal current in a plasma occurs on a resistive time scale tr, which is typically of the order of seconds in present tokamaks. From the Faraday EM equation, Etor is proportional to the time derivative of the poloidal magnetic field, which, from the Ampere equation is proportional to the toroidal current. Thus, Etor rapidly increases due to rapid temperature drops, to prevent change in the toroidal current faster than tr. In simulations with KPRAD [2] of neon pellet injection into a DIII-D shot, Te drops from 2 keV to 10 eV in 0.1 msec and Zeff increases 1 to 4, giving that Etor increases 3500X to 0.8 V/cm. As described in [3], this places much of the tail electron distribution beyond the Dreicer runaway velocity, giving so-called "hot-tail runaways" which for a time are the dominant source of runaways, more so than the knockon source. In this prior calculation, performed for a single flux surface, the toroidal current density is held constant, on the basis that tr is large. Most of the initial current can be converted to runaway current, which is then dangerous, particularly for ITER. The A-F model recently implemented in CQL3D, taking into account the time-development of the full-plasma-width Etor on time-scales of order tr, applies an iterative technique for the Etor previously developed for a different application [4], maintaining the implicit-in-time evolution of CQL3D. The degree of runaway current formation is reduced in A-F augmented CQL3D, but the basic mechanism of "hot-tail runaways" [3] remains a dominant contribution to the runaway electrons at early times after the Te drop.
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Primary author: Dr HARVEY, R.W. (Bob) (UsCompX)

Co-authors: Dr FOREST, C.B. (UsUWisMad); Dr LAO, L.L. (UsGA); Dr PARKS, P.B. (UsGA); Dr PETROV, Yu.V. (UsCompX)

Presenter: Dr HARVEY, R.W. (Bob) (UsCompX)

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