

# 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  $E_{\text{tor}}$  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  $\tau_r$ , which is typically of the order of seconds in present tokamaks. From the Faraday EM equation,  $E_{\text{tor}}$  is proportional to the time derivative of the poloidal magnetic field, which, from the Ampere equation is proportional to the toroidal current. Thus,  $E_{\text{tor}}$  rapidly increases due to rapid temperature drops, to prevent change in the toroidal current faster than  $\tau_r$ . In simulations with KPRAD [2] of neon pellet injection into a DIII-D shot,  $T_e$  drops from 2 keV to 10 eV in 0.1 msec and  $Z_{\text{eff}}$  increases 1 to 4, giving that  $E_{\text{tor}}$  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  $\tau_r$  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  $E_{\text{tor}}$  on time-scales of order  $\tau_r$ , applies an iterative technique for the  $E_{\text{tor}}$  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  $T_e$  drop.

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[1] R.W. Harvey and M. McCoy, "The CQL3D Fokker Planck Code", [www.compxco.com/cql3d.html](http://www.compxco.com/cql3d.html).

[2] D.G. Whyte, T.E. Evans et al., Proc. 24th EPS Conf., Berchtesgaden, Germany (1997).

[3] R.W. Harvey, V.S. Chan, S.C. Chiu, T.E. Evans, M.N. Rosenbluth, and D.G. Whyte, Phys. Plasmas 7, 4590 (2000).

[4] K. Kupfer R.W. Harvey, et. al., PoP 3, 3644 (1996).

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