Runaway Electron Threshold Discrepancy in Tokamaks

R. G. Granetz, Plasma Science and Fusion Center, MIT, Cambridge, MA 02139

Request submission to Panel Topic A

No oral presentation

The proposed scheme for mitigating disruption-generated runaway electrons (RE's) on ITER is to rapidly raise the electron density enough to collisionally damp their growth. Runaways are accelerated by the toroidal electric field, and they are decelerated by Coulomb collisions with background electrons, AND POSSIBLY BY OTHER ENERGY LOSS MECHANISMS. Coulomb collisional damping is well-understand from first principles, and that is probably why the proposed ITER RE mitigation scheme relies on it alone. CONSIDERING ONLY COLLISIONAL DAMPING, electrons will runaway when the acceleration by the toroidal electric field is greater than the collisional drag on the background electrons. This Coulomb drag is essentially proportional to density. Thus for any given electron density, there is a minimum electric field, Ecrit, required to generate and sustain runaways [Connor Hastie 1975]. Conversely, for any given E-field, there is a maximum density at which runaways can be sustained. At densities above this threshold, runaways cannot be generated, and any runaways that already exist will be suppressed. Again, this assumes that the only RE energy loss mechanism is collisional damping. If there are other energy loss mechanisms in play, the actual threshold conditions between growth and decay of RE's will occur at a density that is lower than the Connor-Hastie value.

During the current quench of ITER disruptions (dI/dt = 15 MA/50 ms), toroidal voltage is inductively generated (V = - L dI/dt), and the electric field can get up to 38 V/m. The density of the Connor-Hastie RE threshold for this value of E_{crit} is 4-5 × 10^{22} m^{-3} [Rosenbluth Putvinski 1997], which is hundreds of times higher than the nominal ITER operating density. Experiments in present-day machines have not been able to achieve this density with massive gas injection (MGI). Furthermore, even if this density could be achieved in ITER on the desired short timescale, it would have severe consequences for the cryogenic, pumping, and tritium-handling systems. So the question arises, "Is the Rosenbluth density really required to mitigate runaways on ITER?" The MHD ITPA group is currently studying this issue. As a first step, we looked for published measurements on the threshold conditions (electric field and density) for RE's. Unfortunately, we couldn't find any empirical data on this. So the MHD ITPA group has been conducting a well-defined joint experiment to measure the threshold E-field and density on a number of fusion devices. The details are in [Granetz et al 2014], but the results to date indicate that there is at least a factor of 5 discrepancy with the Connor-Hastie formulation. This implies that there are other RE loss mechanisms that dominate over collisional damping, at least in the regime that the joint experiments were carried out in. In order to have reproducible conditions and good diagnostic measurements, the threshold experiments have been carried out during the nearly steady quiescent conditions of the current flattop by running low-density discharges.

So I can think of at least two specific questions that could be addressed by theory:

1) Several RE energy loss mechanisms could conceivably be invoked to explain the observed discrepancy, such as drift orbit losses, synchrotron emission, stochastic losses due to B-field fluctuations, scattering in velocity space by relativistic beam instabilities, etcetera. Which ones are plausible? Remember that the measurements were done in quiescent plasmas, not during disruptions, so MHD fluctuations are not likely to be large. Note that some theory work is already being done on this; see for example [Stahl et al 2015].

2) During disruptions on ITER, the E-field will be roughly two orders of magnitude higher than in the ITPA threshold study. In addition, the avalanche (i.e. knock-on) RE generation mechanism will be much larger than in the ITPA study. Will the results from this study be applicable to ITER disruptions? Will other energy loss mechanisms, such as those listed above, be even more dominant over collisions during ITER disruptions? This would imply that it would not be necessary to get the Rosenbluth density in order to suppress runaways on ITER.

References

[Connor Hastie 1975]: J.W. Connor, R.J. Hastie, “Relativistic limitations on runaway electrons”, Nucl. Fusion **15** (1975) 415-424.

[Rosenbluth Putvinski 1997]: M.N. Rosenbluth, S.V. Putvinski, “Theory for avalanche of runaway electrons in tokamak”, Nucl. Fusion **47** (1997) 1355-1362

[Granetz et al 2014]: R.S. Granetz, B. Esposito, J. H. Kim, R. Koslowski, M. Lehnen, J. R. Martin-Solis, C. Paz-Soldan, T. Rhee, J. C. Wesley, L. Zeng, and ITPA MHD Group, “An ITPA joint experiment to study runaway electron generation and suppression”, Phys. Plasmas **21** (2014) 07250

[Stahl et al 2015]: A. Stahl, E. Hirvijoki, J. Decker, O. Embreus, T. Fulop, “Effective Critical Electric Field for Runaway-Electron Generation”, Phys. Rev. Lett. **114** (2015) 115002