Contribution ID: **23** Type: **Contributed Oral**

KORC Modeling of Wall Heating by Avalanche Runaway Electrons During a Final Loss Event in DIII-D

Tuesday, 19 July 2022 15:05 (25 minutes)

This work extends the recent modeling of runaway electron (RE) mitigation in Ref. {1} by including an avalanche RE source {2} in the Kinetic Orbit Runaway electrons Code (KORC). Our main finding is that REs produced by the avalanche source are the primary contributor to transient high heat loads observed at plasma-facing component (PFC) surfaces as shown in Fig. 1. The magnitude of the calculated heating is comparable to that for DIII-D graphite tile ablation as described in Ref. {3}, and qualitative features of the simulated PFC surface heating agree with infrared imaging of the first wall tiles in DIII-D only when the avalanche source is included.

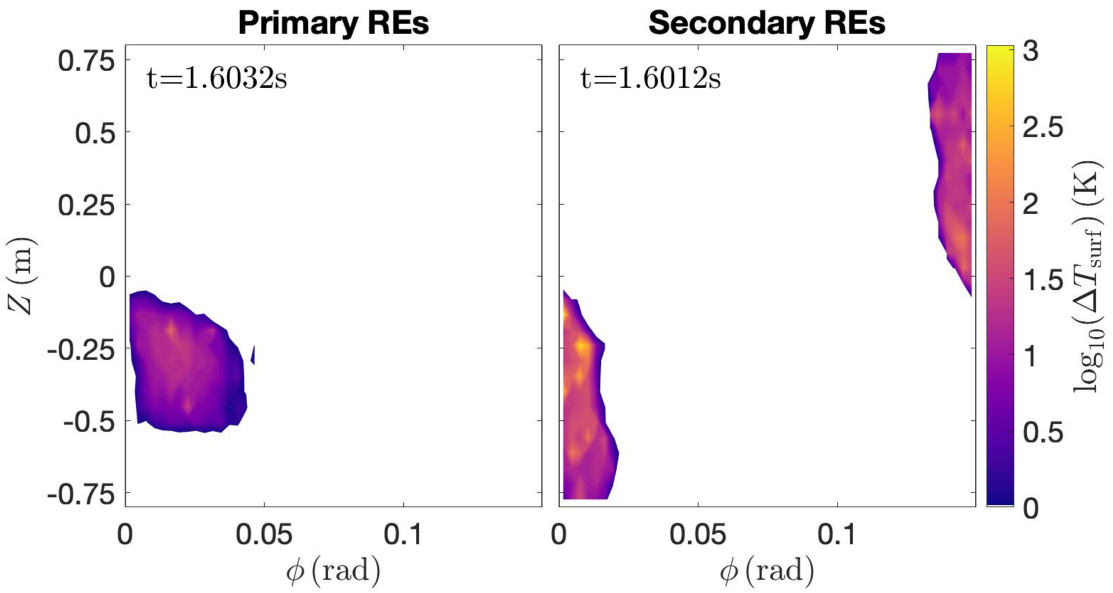

Figure 1: Maximum change in PFC tile surface temperature due to primary (left plot) and secondary (right plot) REs averaged over all simulated tiles. Secondary REs are the dominant contribution to transiently large PFC surface heating, while primary REs provide lower levels of sustained heating.

We model DIII-D discharge 177031, where a RE beam undergoes a rapid final loss event. As the beam advects into the inner wall, a large toroidal electric field is induced in a region where magnetic surfaces connect to the wall. The drift orbit effects of high energy, primary REs allow them to remain confined in this open field region where the large electric fields increase secondary RE generation by the avalanche source. Lower energy, secondary REs have negligible drift orbit effects, causing them to be rapidly deconfined and deposit their energy shallowly into the PFCs because the energy deposition length scales with energy as shown by the green trace in Fig. 2. Furthermore, because the distribution of secondary REs generated by the avalanche source scales inversely with energy, lower energy REs provide the dominant contribution to PFC surface heating as shown by the blue trace in Fig. 2.

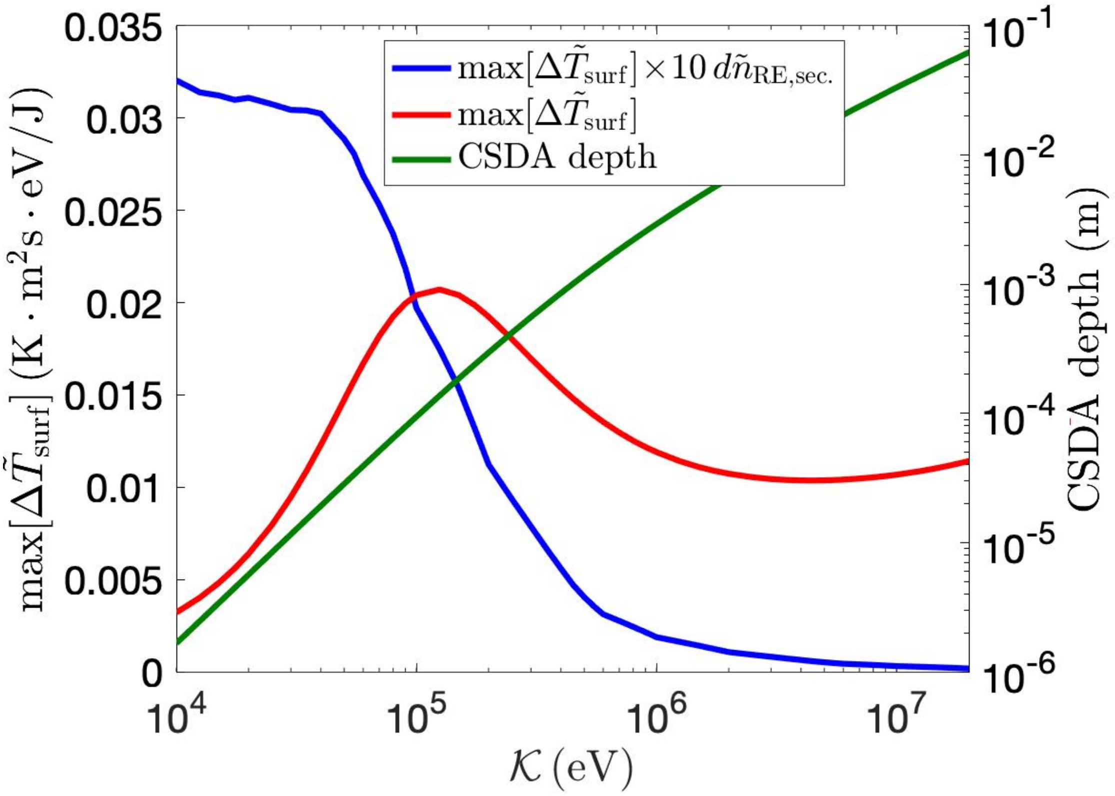

Figure 2: Energy dependence of deposition length scale from ESTAR database (green trace), single particle change in surface temperature (red trace), and avalanche distribution change in surface temperature (blue trace).

The KORC simulations presented in this work evolve a distribution of tracer RE guiding center (GC) orbits using a time series of axisymmetric experimental reconstructions of the electromagnetic fields, ignoring contributions from non-axisymmetric MHD modes. Fokker-Planck and large-angle collisions with the effects of partially-ionized impurities are employed assuming uniform and constant plasma and impurity profiles with magnitudes inferred from experimental observations. To calculate the PFC surface heating due to RE deposition, we have generalized the 1D analytic model from Ref. {4} to include the energy dependence of the deposition length scale. We have approximated the angle of incidence of deposition using the GC angle of incidence, pitch angle, and a randomized gyrophase constrained by the deposition geometry.

{1} Beidler et al., Phys. Plasmas 27, 112507 (2020)
{2} Aleynikov et al., IAEA FEC Paper TH/P3-38 (2014)
{3} Luxon, Nucl. Fusion 42, 614-633 (2002)
{4} Martín-Solís et al., Nucl. Fusion 54, 083027 (2014)

*This work is supported by the US DOE under contracts DE-AC05-00OR22725, DE-FC02-04ER54698, and DE-AC02-05CH11231.

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Session Classification: Disruption Consequences

Track Classification: Consequences