# Fast electrons and the seeds of disruption

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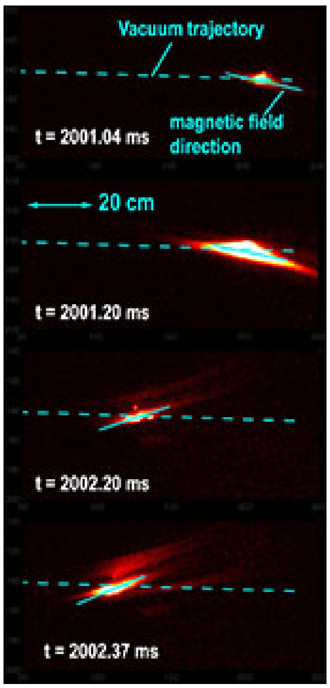


Neutral argon line emission from the ablation plume of a frozen argon ice pellet as it traverses the plasma of the DIII-D tokamak (t is the time in milliseconds (ms)). From the brightness of this ablation plume, it is possible to deduce the rate at which argon gas is boiling off the surface of the pellet and ultimately estimate the fast electron content of the plasma. Credit: U.S. Department of Energy

Measuring small fast electron populations hidden in a sea of colder "thermal" electrons in tokamak plasmas is very challenging. Why? The challenge comes from the fast electron signal being overwhelmed by thermal electron signal in most diagnostics. Physicists at the University of California-San Diego, with physicists from Oak Ridge National Lab and from General Atomics, have succeeded in measuring fast electron populations. They achieved this first-of-its-kind result by seeing the effect of the fast electrons on the ablation rate of small frozen argon pellets.

Tokamak disruptions, large instabilities that can occasionally terminate the entire plasma discharge, are a major concern of the tokamak concept for magnetic fusion energy. These disruptions can form large fast "runaway" electron beams that can cause unacceptably large localized reactor wall damage. These fast electron beams begin with tiny hard-to-measure fast electron "seeds." The seeds form at the start of disruptions. Observing these seeds is an important first step in predicting and avoiding fast electron damage to the vessel walls during tokamak disruptions.

Tokamak disruptions are large magnetohydrodynamic (MHD) instabilities that can occur, for example, if there is a rare and unforeseen failure in the plasma position control system which causes the plasma to touch the chamber walls. These instabilities cause wall material sputtering where the plasma touches the wall, and the resulting impurities then enter the plasma, causing an impurity "cold front" which moves into the plasma core.

At this cold front, the impurities radiate strongly, causing a rapid drop in plasma temperature. If the drop is fast enough, small fast electron seeds can form. These seeds can accelerate to relativistic (MeV+ level) energies and then amplify their numbers by the avalanche process (which also occurs in lightning, photomultiplier tubes, etc.), eventually forming large fast electron beams. Measuring the initial fast electron seeds is important for tokamaks to predict if and when large fast electron beams will form and how to avoid this.

Presently, predictions are made using two formulas: the Dreicer formula (which assumes constant temperature) and the hot tail formula (which assumes a very rapid temperature drop). In the DIII-D tokamak, scientists designed experiments to form intentional disruptions by firing small frozen argon ice pellets into plasma discharges. The hot plasma causes argon vapor to evaporate from the pellet surface, forming a cold front and disruption.

The rate at which argon evaporates (ablates) from the pellet surface is very sensitive to the number of fast electrons in the plasma; by careful analysis, it was possible to separate out the thermal and fast electron populations in the plasma during the intentional disruptions. The team found that the fast electron seed magnitudes were about 100x smaller than predicted by the hot tail formula but about 100x larger than predicted by the Dreicer formula. These experiments, therefore, clearly demonstrate a need for improved formulas or simulations to predict fast electrons seeds during disruptions.

**More information:** E.M. Hollmann et al. Use of Ar pellet ablation rate to estimate initial runaway electron seed population in DIII-D rapid shutdown experiments, *Nuclear Fusion* (2017). DOI: 10.1088/0029-5515/57/1/016008

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