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Radial Displacement of Pellet Ablation Fuel in Tokamaks Due to the grad-B Effect[1]

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An apparent displacement of deposited pellet ablation substance toward the low-field or large-R side of the tokamak is observed during pellet injection from the low-field side, and it has been attributed to uncompensated ∇B and curvature drifts induced by the $1/R$ toroidal field variation. The effect was recently exploited in ASDEX-U during pellet injection from the high-field side in order to promote deeper fuel penetration. This presentation will discuss a self-consistent model that predicts the large-R velocity and transport distance. The particle source from an ablating pellet presents a significant disturbance to the plasma. Initially, an ablated "cloudlet" just separated from the pellet shadow is a toroidally localized, mildly diamagnetic (magnetic $\beta_{\rm c} < 0.1$) plasmoid, which will polarize and $E \times B$ drift towards the low-field side of the tokamak. Periodic cloud "disruptions," related to the formation of striations, breed a sequence of 20 to 30 discrete cloudlets along the trajectory of the pellet, with each cloudlet carrying off the ablated mass contained in the pellets ionized shielding channel at the moment of its birth. The cloudlets are assumed to have a cylindrical shape, with initial field-aligned profiles inherited from the shielding channel and sharp-boundary density and pressure profiles in the radial direction. The cloudlet expands along the field lines against the ambient backpressure, while it undergoes motion as a whole in the large-R direction. The rigid body motion is obtained from $\vec{B} \cdot \nabla \times$ of the momentum equation, while a combination of the parallel component of the momentum equation and the energy balance equation, in one-dimensional Lagrangian coordinates, expresses the parallel dynamics. The internal heat source comes from a kinetic treatment for partial absorption of the parallel heat flux carried by incident plasma electrons streaming through the cloudlet. The ∇B drift drive enters into in the large-R motion in the form of a toroidal drive integral, which depends on the cloudlet to ambient pressure ratio. In current tokamaks, parallel pressure relaxation cut soff the toroidal drive after the cloudlet has expanded to a length that is about 50 times its original half-length, or about 10 m, which is still smaller than the connection length $2\pi qR$. The ends of the cloudlet propagate outgoing shear Alfvén waves that damp out the large-R motion. The theory presented is in reasonable agreement with inside launched pellet experiments on DIII–D. The dependence of the penetration depth of the cloud with plasma parameters suggests that low-velocity inside launched pellets may provide a unique solution to the refueling problem in larger and hotter machines of the future.

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