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Integrated two-dimensional quasilinear modeling of fast ion relaxation in tokamaks[1]

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An integrated, quasilinear analysis framework to quantify the losses of fast ions in tokamaks that is both fast and comprehensive has been realized through the development of the Resonance Broadened Quasilinear (RBQ) code. It formulates the 2D quasilinear diffusive beam ion relaxation in action variables (i.e., in both the canonical toroidal momentum and the unperturbed particle kinetic energy) via a generalized alternating direction implicit method. Since the success of next-generation fusion devices relies on their ability to confine fusion alpha particle products long enough to for them to transfer a substantial fraction of their energies to the reacting thermal particles via collisions, it is essential to develop efficient and robust capabilities to predict the level of energetic ion losses in tokamak experiments. The RBQ model is analytically constructed from first principles and is designed to efficiently evolve amplitudes of several interacting Alfvén modes, in regimes of both overlapping and isolated resonances, while self-consistently relaxing the fast ion distribution function in the presence of collisions and turbulence. The developed framework employs realistic eigenstructures, mode damping rates and wave-particle interaction matrices. Rigorous verification exercises have been undertaken in limiting cases in which there exist analytical solutions for single mode saturation levels. The quasilinear simulation output provide unprecedented mapping of fast ion flows and are useful in informing phase-space engineering solutions for neutral-beam-driven instabilities. The simulations are integrated with TRANSP with the calculated neutron loss rate, yielding reasonable quantitative agreement compared with measurements from DIII-D, which suggests that the integrated model is a promising predictor of fast ion confinement in scenario development studies.

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