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Energetic Particle Diagnostics for Magnetic Fusion Experiments[1]

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In magnetic confinement experiments, energetic ions are produced in fusion reactions, through acceleration by RF waves, and by ionization of injected neutral beams. The distribution function f that describes the energetic ion population is shaped by orbital effects, Coulomb collisions, atomic processes, and interactions with waves, resulting in a distribution function that has a complicated dependence on velocity $\vec{v}$, spatial position $\vec{r}$, and time t. The diagnostic challenge is to measure $f(\vec{v}, \vec{r}, t)$ in the harsh plasma environment. Many diagnostic techniques rely on emission from fusion reactions or from interaction with a probe neutral beam; unconfined energetic particles are also measured. In all cases, the measurement effectively averages over the variables that describe the distribution function. To understand these complicated averages, it is convenient to define an instrument function W that describes the diagnostic weighting in phase space; the measured signal is then the convolution of W and f over the phase space variables. In practice, measured signals from the various energetic-particle diagnostics often differ dramatically but qualitative differences are readily explained by differences in instrument function W. Owing to the complexity of W, quantitative comparisons with a theoretically predicted f require forward modeling. A relatively new spectroscopic technique dubbed fast-ion D-alpha (FIDA) provides valuable data at the DIII-D tokamak and the National Spherical Torus Experiment. In plasmas with weak MHD activity, FIDA measurements often compare well with theoretical predictions. Simulations employing the calculated distribution function during RF heating also match many features of the FIDA measurements. On the other hand, flattened fast-ion profiles observed during strong energetic-particle-driven instabilities are harder to explain theoretically.

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