PRODUCTION AND CONFINEMENT OF RUNAWAY ELECTRONS WITH IMPURITY "KILLER" PELLETS IN DIII-D*

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Recent experimental and theoretical impurity "Killer" Pellets (KPs) results have substantially enhanced our understanding of the physics involved in the mitigation of disruptions and the generation of runaway electrons. Experiments with cryogenic neon, argon and methane KPs have been carried out in DIII-D and an ablation/radiation model has been developed for the analysis of these experiments. The model is also used to predict the behavior of KPs in ITER. Our experimental results demonstrate that KPs reduce local VDE vessel forces by at least factor of four and divertor heat loads by a factor of two [1,2]. We also find that some KPs produce prompt runaway electron bursts which are often correlated with fast ablation spikes and large MHD events. In ITER KP induced runaways may result in processes which convert all of the plasma current into an energetic electron beam capable of damaging plasma facing components. Thus, a critical issue for assessing the viability of KP mitigation scenarios in ITER is understanding the details of runaway generation and confinement.

Theoretically, KP induced runaways may either be generated in a narrow skin layer immediately in front of the pellet or in the cold region behind the pellet $\rho \geq 0.5$. If runaways are generated behind the pellet, calculations show that they do not originate from the usual Dreicer acceleration mechanism where $E_{||}/E_{Dr} > 1$ but rather from a new type of dynamical process. A model describing the generation of runaways in this region has been developed. It includes two mechanisms originating from a rapid local cooling of the plasma electrons.

The first of these results from the development of a large radial ∇P_e across the flux surfaces intersecting the active pellet ablation zone. We have modeled argon KP experiments with the DIII–D KPRAD ablation/radiation code and find that T_e is reduced from 2500 eV to 30 eV within 20 μs on the $\rho = 0.5$ flux surface. Thomson scattering measurements, made 500 μs after the pellet reaches $\rho = 0.5$, confirm the KPRAD predictions. The pellet moves ~10 mm in 20 μs implying a $\nabla T_e \approx 2\text{-}3 \times 10^5$ eV/m. The corresponding n_e increase is quite modest, <50%, producing a large increase in ∇P_e. Based on estimates of ideal ballooning mode growth rates under these conditions *i.e.*, $\gamma > 5 \times 10^5\ s^{-1}$ one expects MHD modes to form in front of the pellet as it nears the high T_e plasma. Large MHD spikes observed during the pellet ablation phase match signatures expected for these instability. Our experimental results also show an increase in the central n_e and a complete loss of stored energy during the

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pellet ablation phase. These measurements are consistent with existence of MHD mixing which drives the pellet material into the core plasma. In the region behind the pellet, KPRAD predicts $E_{||} = \eta j_{||}$ of ~90 V/m assuming constant $j_{||}$ and $T_e \approx 30$ eV. The cold electrons in this region do not exceed the local Dreicer threshold *i.e.*, $E_{||}/E_{Dr} \approx 0.1$. On the other hand, less collisional keV electrons supplied by a mixing instability from in front of the pellet do exceed the local Dreicer threshold. Modeling results indicate that runaway bursts due to ∇P_e instabilities only occur inside $\rho \approx 0.65$ in typical DIII–D plasmas. We have confirmed these predictions experimentally.

A second mechanism for generating prompt runaways in the cold region results from modification of the Maxwellian nature of the electron distribution function (*i.e.*, a velocity space source involving electrons in the high energy wing of the distribution) and the rate at which these electrons cool compared to the thermal part of the distribution. We have calculated the electron cooling rate as a function of energy and used this data to estimate the runaway conversion rate at each flux surface [3]. In DIII–D the model predicts a runaway current density j_{re} ~75 kA/m^2 as the pellet crosses $\rho = 0.7$. During the rest of the pellet's flight ($0.7 \geq \rho \geq 0.5$) j_{re} increases linearly to ~95 kA/m^2. At $\rho = 0.5$ the runaway threshold energy is about eleven times T_e. We have independently verified this generation mechanism with the CQL3D Fokker-Planck code [4]. In addition, CQL3D predicts a complete conversion of the ohmic current to runaways with magnetic fluctuations neglected, but has shown that runaway generation is suppressed by magnetic turbulence losses at level $\delta b_p/b_T$ ~0.1% [4]. CQL3D is also being used to model avalanche runaway processes [5] in DIII–D and ITER. Our preliminary results indicate that KP induced runaways provide an efficient avalanching source during an ITER current quench but the inclusion of magnetic fluctuations significantly reduce the conversion and confinement process.

In order to evaluate a practical method of controlling runaway generation and to understand the role of magnetic fluctuations during KP injection, we have carried out a series of DIII–D experiments in which externally driven magnetic perturbations were applied. We found that externally applied, spatially static, magnetic perturbations resulted in a statistically significant reduction of the runaway current. The external coil set was used to drive a spectrum of n = 1, 2, and 3 modes with a flux surface averaged $\delta b_p/b_T = 2.5 \times 10^{-3}$ at the midplane separatrix. A simple analytic criterion for the suppression of runaways by stochastic magnetic field losses [6] implies that $\delta b_p/b_T$ perturbations exceeding 1.7×10^{-3} are sufficient to suppress runaways in DIII-D. Although this is consistent with the experiment results, our models need to account for the detailed mode structure of the magnetic perturbations. This work is currently in progress.

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