GA–A26688

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APRIL 2010

GENERAL ATOMICS

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This is a preprint of a paper to be presented at the 23rd IAEA Fusion Energy Conference, October 11–16, 2010 in Daejon, Republic of Korea and to be published in Proceedings.

*Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA
†University of California-San Diego, La Jolla, California, USA

Work supported in part by
the U.S. Department of Energy
under DE-AC05-00OR22725, DE-FC02-04ER54698
and DE-FG02-07ER54917

GENERAL ATOMICS ATOMICS PROJECT 30200
APRIL 2010

Novel rapid shutdown strategies for mitigating runaway electrons (RE) generated in ITER disruptions have been recently tested in DIII-D. Both major and vertical displacement disruptions in ITER are predicted to generate multi-MeV RE beams that could potentially damage the machine. Thus the mitigation of REs is critical for the reliability of ITER. Based on studies that have shown that particle assimilation during massive gas injection (MGI) is only effective during the thermal quench, new particle delivery techniques have been developed and tested. The injection of shattered D_2 pellets has improved the delivery of neutrals to the plasma core during the thermal quench with record electron densities of $9x10^{21}$ m^{-3} achieved locally. In addition, n=3 RMP fields applied during disruptions with MGI have been shown to deconfine runaway electrons, potentially reducing the particle delivery requirements. New diagnostics for characterizing REs have also been developed and are being used to obtain a better understanding of RE generation and transport.

Several new injection schemes have been developed and tested on DIII-D for delivering sufficient particle inventory to reach the theoretically predicted density n_{crit}~$5\times10^{22}m^{-3}$ [1,2] to be required for collisional suppression of the RE avalanche in ITER. These include multi-valve massive gas injection, shattered pellet injection (SPI), and shell pellet injection (SHPI). The multi-valve MGI differs from the typical single valve scheme in that several fast valves inject simultaneously instead of one by itself. This method achieved a density of 0.15 n_{crit} instead of the typical 0.04 n_{crit} value for a single valve. SPI involves injecting a large cylindrical cryogenic pellet (15 mm x 20 mm) that is shattered against metal plates before entering the plasma. SHPI involves injecting a thin polystyrene shell containing a payload of boron powder or argon gas. Both SPI and SHPI were tested in ITER relevant DIII-D plasmas (H mode lower single null plasma) in 2009.

During rapid plasma shutdowns induced by deuterium SPI, direct penetration of the injected particles into the core of the plasma was observed during the thermal quench (TQ), both by fast bolometry and by visible imaging (as is shown in Fig. 1). This is a major improvement when compared to the typical MGI case where injected particles are stopped at the edge of the plasma during the TQ. The direct deposition resulted in record levels of local electron density (up to $9x10^{21}$ m^{-3}) deep in the core during the TQ.

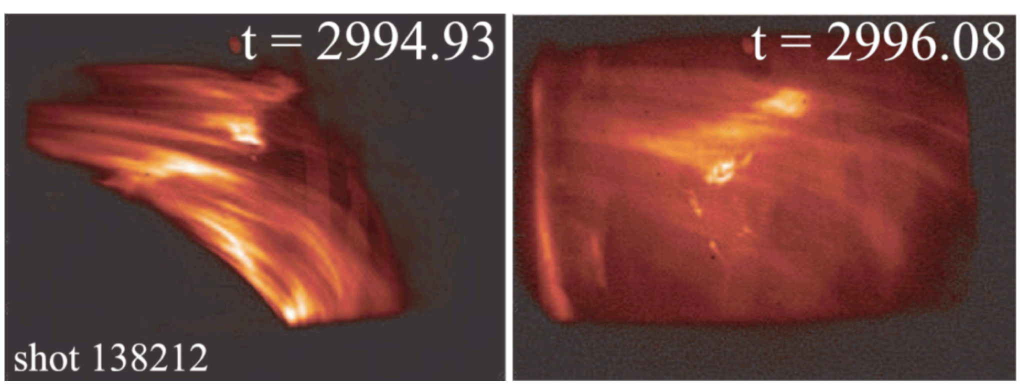

Fig. 1. Visible images of D_2 SPI from a tangential viewing fast camera showing direct penetration of D_2 ice fragments deep into the plasma core.

SHPI was first attempted on DIII-D using small (D = 2 mm) shells. The small SHPI successfully demonstrated core deposition of boron powder and argon gas payloads in agreement with ablation calculations [3]. Subsequent experiments using 1 cm diameter shells containing enough boron powder to reach n_{crit} were carried out. However the ablation rate of these larger shells was lower than expected, and thus the payload was not released, indicating the need for thinner shells for future experiments.

Other strategies were also developed in an attempt to deconfine the REs harmlessly. The primary methods tested were to apply non-axisymmetric magnetic perturbations to increase edge magnetic field ergodicity and deconfine REs prior to avalanching, and to apply poloidal field feedback control to hold REs away from the vessel walls. Preliminary results indicate some increased RE losses when an n=3 magnetic perturbation (dB/B ~ 0.5%) is applied. First attempts on RE position feedback control have shown promising results.

The studies discussed here were complemented by new REs diagnostic capabilities. A new array of bismuth germanate (BGO) scintillators using various levels of gamma shielding provided localization of the RE-wall interaction and a measurement of the average energy of the REs when they interact with the wall. Another measurement of the REs energy was carried out using absolutely calibrated visible synchrotron imaging. This diagnostic provided a measurement of the maximum energy of the electron population in the RE beam as well as showing the location of strong RE beams in the vacuum vessel. These diagnostics showed that the REs reach energies in the 10-30 MeV range roughly consistent with 0-D loop voltage integration. The BGO array also showed that the deconfinement of RE occurs in 3 different phases: the prompt RE losses observed at the TQ, the diffusive losses observed during the slow RE decay and the late RE losses at the end of the slow decay (as is shown in Fig. 2).

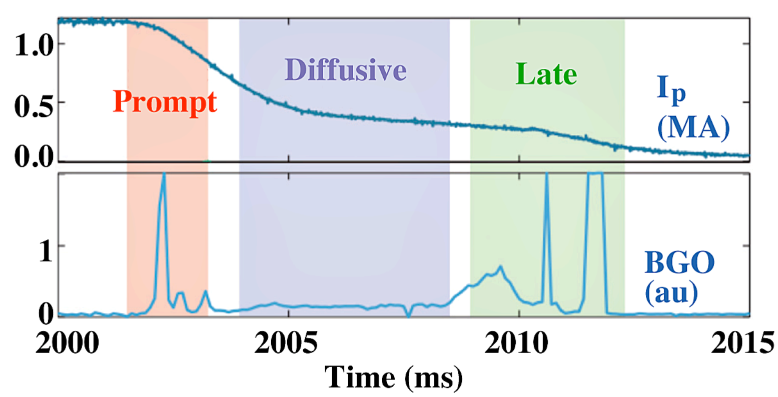

Fig. 2. Gamma emission generated by the RE hitting the wall during the current quench showing the 3 phases of RE deconfinement.

This work was supported by the US Department of Energy under DE-AC05-00OR22725, DE-FC02-04ER54698, and DE-FG02-07ER54917.

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