Disruption Mitigation Using High-Pressure Noble Gas Injection on DIII–D*

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Experiments on DIII–D have demonstrated that the impact of disruptions on first wall or in-vessel components can be greatly reduced by the injection of noble gas by a high pressure gas jet. Modeling indicates this technique extrapolates well to burning plasma experiments. A viable solution on the issue of disruption mitigation must be developed as tokamak fusion research approaches the realization of burning plasmas. In-vessel components are damaged by three disruption effects: divertor surface melting/ablation by plasma heating, mechanical stresses from halo currents, and the amplification of relativistic electrons (runaway electrons) that eventually are lost into, and damage the wall. Since the magnitude of the damage increases with the plasma energy density and device size, in future burning plasma experiments the damage caused by a single disruption may necessitate the halt of further operation and the costly replacement of internal components. Disruption mitigation is intended to be the last resort for safe plasma termination; triggered if avoidance of the disruption by active detection and plasma control fails. Recent experiments on the DIII–D tokamak have demonstrated a technique that mitigates simultaneously all three disruption effects.

A high-pressure jet of a noble gas (neon or argon) is injected into the plasma (Fig. 1). The gas jet is found to penetrate to the central plasma at the gas sound speed (300–500 m/s) (Fig. 2). The high gas density (>10^{24} m^{-3}) and pressure (>20 kPa) of the jet, which exceeds the plasma pressure, allows it to penetrate. The deposited jet increases the atom/ion content of the

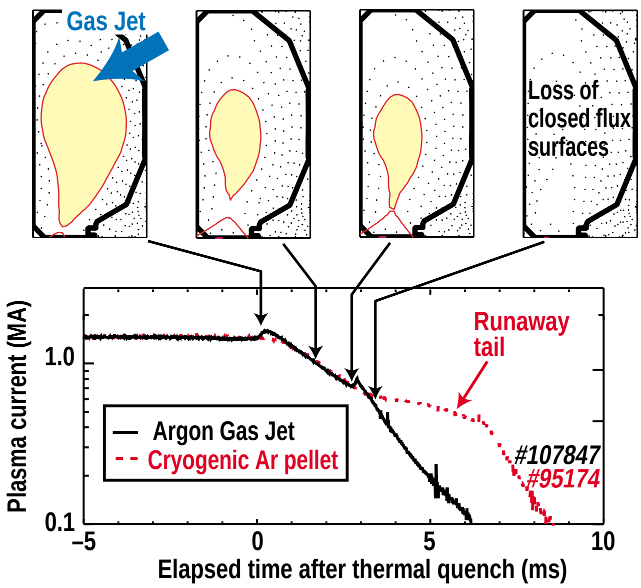

Fig. 1. Time traces of total plasma current during argon high pressure gas injection on DIII–D. Argon cyrogenic pellet injection results in a confined runaway electron tail, that is not present with the gas jet. Magnetic reconstructions during current quench show plasma remains centered in vessel.

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plasma by a factor of 50 in several milliseconds. As a result, the plasma energy is dissipated uniformly by UV radiation from the injected impurity species to the entire wall. The conducted heat flux to the divertor is found to be only ~2%–3% of the stored kinetic energy of the plasma, compared to 20%–40% found for natural, non-mitigated disruptions. The resulting plasma is also extremely cold and resistive, resulting in a rapid current quench with the plasma remaining well centered in the vessel, effectively reducing halo currents (Fig. 1). A practical implication for DIII–D was the observation that the initial phase of subsequent plasma discharges was much cleaner after a mitigated disruption than after a non-mitigated disruption - presumably from the reduced ablation damage of the carbon walls. Preliminary work on active disruption avoidance and mitigation triggers will be presented.

Runaway electrons are contolled by gas jet injection on DIII–D. This is in contrast to mitigation attempts with argon cryogenic pellet injection that were found to create significant a runaway electron tail during the current quench (Fig. 1). The gas jet suppresses runaway production because of the large neutral density of gas present in the plasma volume; these neutrals are not present in the pellet case. Neutrals increase the collisional drag for runaway electrons while the accelerating parallel electric field remains nearly constant due to lack of further ionization by the very cold plasma. Thus the Dreicer criterion can be broken and runaways are damped, suppressing runaway electron amplification by the avlanching process. We present modeling results that indicate a modest increase in the DIII–D gas jet pressure and volume will be sufficient for the gas jet to penetrate the plasma and to suppress runaways in large-scale burning plasma devices, where the problem of runaway amplification is severe.

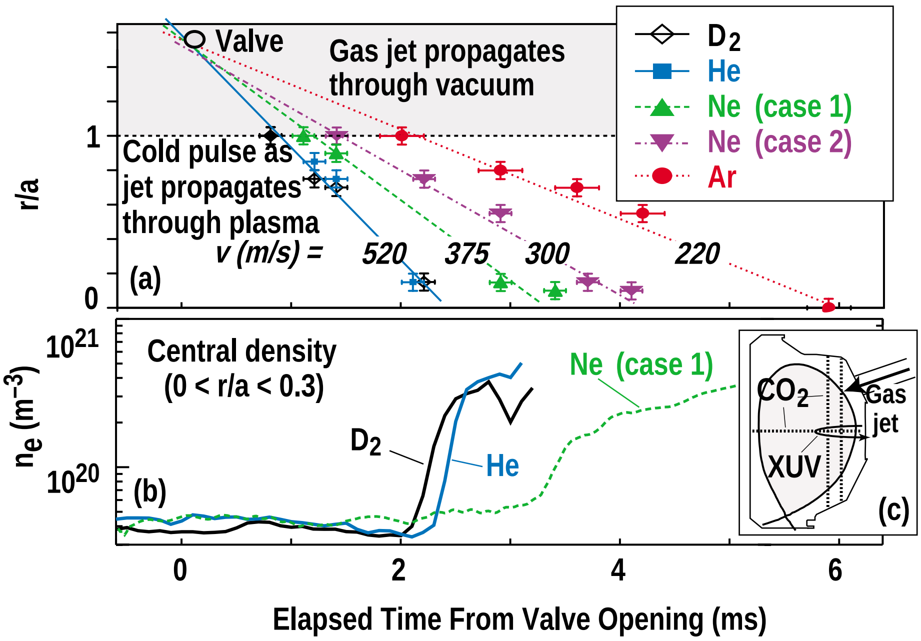

Fig. 2. The high pressure gas jet penetrates to the core plasma at approximately sonic velocity (a) Cold pulse propagates through plasma (b) Corresponding central n_e rise (c) target plasma shape, and diagnostic chords.

High-pressure noble gas injection appears to be a robust and simple method to mitigate simultaneously the principal damaging effect of disruptions in tokamaks. Heat pulses to the divertor and mechanical loading due to halo current are both greatly reduced. Runaway electrons can be suppressed through neutral damping. Based on physical models benchmarked against the DIII–D experimental data, it appears that this technique extrapolates favorably to burning plasma experiments. The design flexibility and operational reliability of next-step tokamaks is positively affected by the ability to mitigate disruptions reliably.