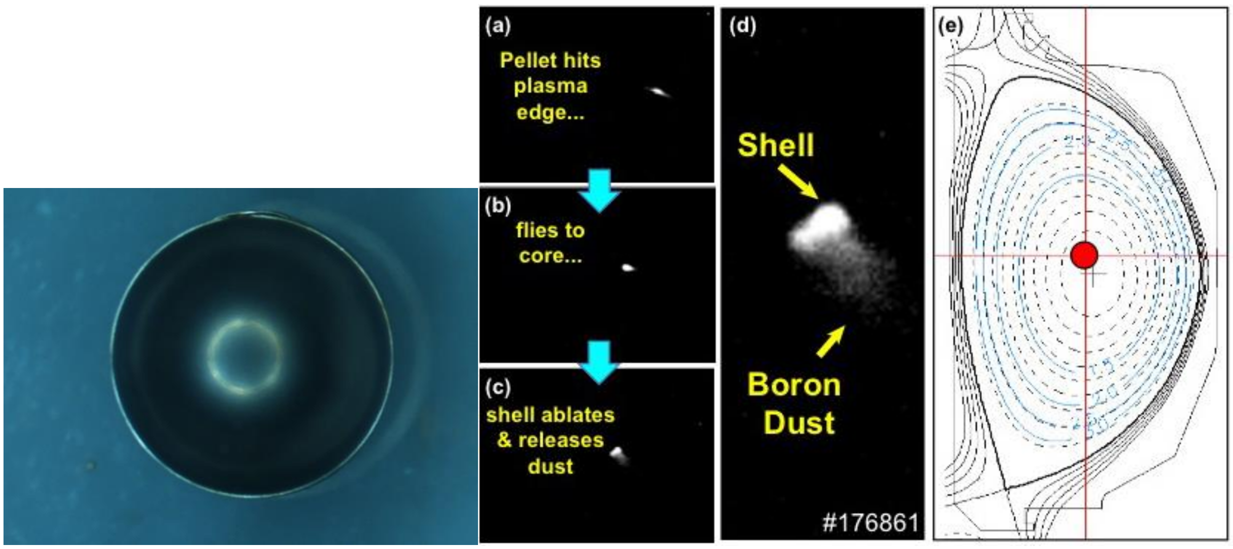
January 2019

Disruption Mitigation through Shell Pellet Impurity Injection

Thin-walled diamond shells carrying payloads of boron dust demonstrate effective “inside-out” mitigation of tokamak disruptions



Left: X-ray image of 3.6mm-diameter, 40μm-thick, 30mg B-filled diamond shell. Right: Visible imaging of (a) shell pellet hitting low-field-side boundary of plasma, (b) continuing through plasma toward core, (c) ablating and releasing boron dust in core. (d) Expanded view of (c), highlighting shell and dust. (e) Plasma cross-section with red dot indicating pellet location at time of dust release in (c). Injection velocity ≈ 230 m/s. *Image courtesy of ...*

The Science

When instabilities cause magnetically confined tokamak plasmas to lose confinement (a “disruption”), the rapid, concentrated release of the plasma’s stored energy can damage the tokamak wall and surrounding structure. This energy release takes the form of heat that vaporizes or melts plasma-facing materials, large electrical currents that can produce damaging forces in the walls, and the formation of high-energy “runaway” electron beams that can cause intense localized damage.

Disruption mitigation is a major focus of current fusion research. The process is analogous in some ways to the airbags in a car: While they cannot prevent a collision, they can dissipate the impact energy in safe fashion. Likewise, plasma disruption mitigation methods seek to quench the stored energy in way that lessens the risk to the tokamak.

Disruption mitigation involves injecting impurities into the plasma which then radiate the plasma energy evenly around the tokamak as light. One challenge is that methods such as massive gas injection have difficulty reaching the plasma core (where most of the plasma thermal energy is stored) before instabilities that release the plasma energy occur. What has been needed is a way to get impurities into the core, which researchers hope can provide “inside-out” radiative cooling of the plasma, as well as high impurity assimilation and suppression of runaway electron production.

A team of researchers at the DIII-D tokamak have developed a method of impurity injection involving thin-walled diamond shells carrying a payload of boron dust. Initial experiments have demonstrated that shell pellets fired into the core at around 200m/s can deposit boron dust impurities deep in the plasma core where they are most effective. The diamond shells gradually ablate in the plasma without causing a disruption before releasing the dust at the magnetic axis.

The Impact

Disruption mitigation is of particular concern for future devices like ITER because their much more energetic plasma carries greater risks of damaging the surrounding tokamak structure. Safely mitigating disruptions in ITER will be essential for reliable operation.

The large size and high temperatures of ITER or a future tokamak reactor will require more complex methods to inject shell pellets than initially demonstrated on DIII-D, but the DIII-D team is working on improved shell designs that will provide larger quantities of impurity dust as well as allow penetration into a reactor core at accessible injection velocities.

Summary

By encapsulating boron impurities in thin-walled diamond shells, DIII-D researchers have demonstrated “inside-out” disruption mitigation when the pellets are fired into the plasma core. The shells gradually ablate as they travel through the plasma until they reach the plasma core and deposit their payload.

Future work is aimed at creating more sophisticated shell designs that can carry larger payloads and penetrate reactor-class plasmas.

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Funding

This work was supported by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences, using the DIII-D National Fusion Facility, a DOE Office of Science user facility, under Award DE-FC02-04ER54698.

Publications

N.W. Eidietis *et al*, "First demonstration of disruption mitigation using shell pellets for core impurity deposition on DIII-D", 60th Annual Meeting of the APS Division of Plasma Physics (Portland, November 2018) UO5.00005

Related Links

DIII-D Home Page: https://fusion.gat.com/global/diii-d/home