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Flipping Plasma Geometry at DIII-D Demonstrates Stable Pathway to Practical Fusion Energy

Using a reverse of the standard "D-shape" plasma cross-section leads to promising results that could solve several roadblocks to producing stable, high performance fusion plasmas needed for a power plant.

DENVER—Magnetic containment of hydrogen plasma is a leading approach to develop practical fusion energy. As plasmas consist of charged particles, they can be shaped into different geometries using magnetic fields. Devices known as tokamaks use powerful magnetic fields to contain hydrogen plasma in a toroidal, or donut-shaped, configuration at very high temperatures until fusion occurs.

Tokamaks must confine the high-temperature fuel plasma efficiently to maintain the temperatures needed to keep the fusion reaction going. However, the confining magnetic fields can develop instabilities that allow the plasma to escape and, in some cases, damage the containment vessel.

Future fusion power plants will need plasma configurations that prevent plasma from escaping confinement and potentially damaging the vessel walls. They will also need reliable approaches for managing the exhaust from the immense power generated in the plasma core.

One important element of tokamak operation is the shape of the magnetic fields. Most tokamaks use plasmas with variations on a basic "D"-shaped cross-section. Recent international research has explored the prospects of using magnetic configurations that use a reversed D shape, which places more of the plasma away from the center of the tokamak. Scientists refer to this approach as negative triangularity (NT), as shown in Figure 1.

It has long been thought that NT could solve the problem of managing plasma exhaust, circumventing one of fusion's most difficult obstacles. But NT was also believed to have poor stability that would limit its achievable fusion power output, thereby precluding its use in fusion power plants. Recently, work at the DIII-D National Fusion Facility in San Diego has demonstrated that NT stability may be suitable for practical power plant design.

In these experiments, researchers increased power input to the NT plasma to push the upper limits of possible plasma pressure. High pressures are vital for fusion power, but also a primary driver of instabilities that impact performance. Stable NT discharges were found for a certain combination of plasma currents and powers, and the final configurations were reproducible with fewer destructive instabilities compared to generic high-performance configurations.

The NT experiments demonstrated several other important accomplishments.

A specific type of instability called "edge localized modes," or ELMs, occurs at the edge of the confined plasma. ELMs are dangerous because they carry energy directly from the hot plasma core to the machine walls in periodic intense bursts. This makes them a significant concern for fusion power plants. One discovery of the DIII-D campaign was that NT can eliminate ELMs entirely while still maintaining robust, high-power conditions in the core (see Figure 2).

NT also shows significant promise for solving the power exhaust problem. During operation, impurities and by-products of the fusion reaction must be removed from the plasma on an ongoing basis. One leading approach is referred to as a "detached divertor," meaning that the hot plasma exhaust is prevented from directly contacting the divertor surfaces. The divertor can also be protected through injection of impurities at the plasma edge, but these impurities can interfere with the fusion reaction. In the NT experiments, researchers simultaneously achieved divertor detachment and an ELM-free plasma edge. They also demonstrated that NT plasmas are tolerant to impurity injection.

Because certain parameters of the plasma will need to be different in a power plant–size device, another set of experiments determined how plasma containment changed as these parameters were scaled toward power plant levels. The changes in containment in NT, compared to those in standard positive triangularity plasmas, were sometimes favorable and sometimes less favorable. However, as explorations of possible configurations of NT plasmas are just beginning, translating more advanced operation modes into NT may yield more favorable containment. Long thought to be impractical, NT may prove to be an important element for stable, economic operation of future fusion power plants.

Visit www.d3dfusion.org/2023campaign for more information.

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Abstracts

JO08.00003	Highlights from the DIII-D Negative Triangularity Campaign
Session	JO08: MFE: DIII-D Tokamak 2:00 PM–5:00 PM, Tuesday, October 31, 2023 Room: Grand Ballroom II
VI02.00001	Robust avoidance of edge localized modes alongside pedestal formation in negative triangularity plasmas
VI02.00002	Confinement Scaling and Rotation Dependence in DIII-D Negative Triangularity Plasmas
VI02.00003	Scrape-Off Layer characterization and detachment integration in Negative Triangularity discharges in DIII-D
VI02.00004	Scenario Development and MHD Stability of Negative Triangularity Plasmas in DIII-D
Session	VI02: MFE: Negative Triangularity 3:00 PM–5:00 PM, Thursday, November 2, 2023 Room: Plaza D/E

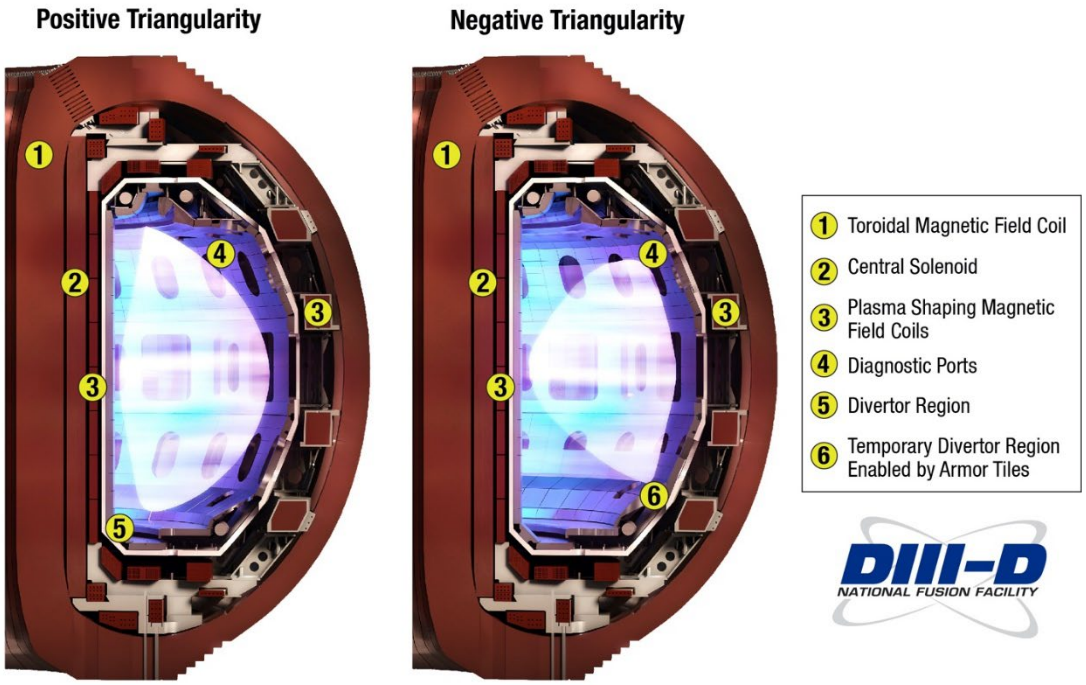

Figure 1. This side-by-side comparison shows a standard plasma configuration, known as positive triangularity, and a plasma created as part of the negative triangularity campaign at the DIII-D National Fusion Facility. Additional armor tiles were installed to enable a temporary divertor region.

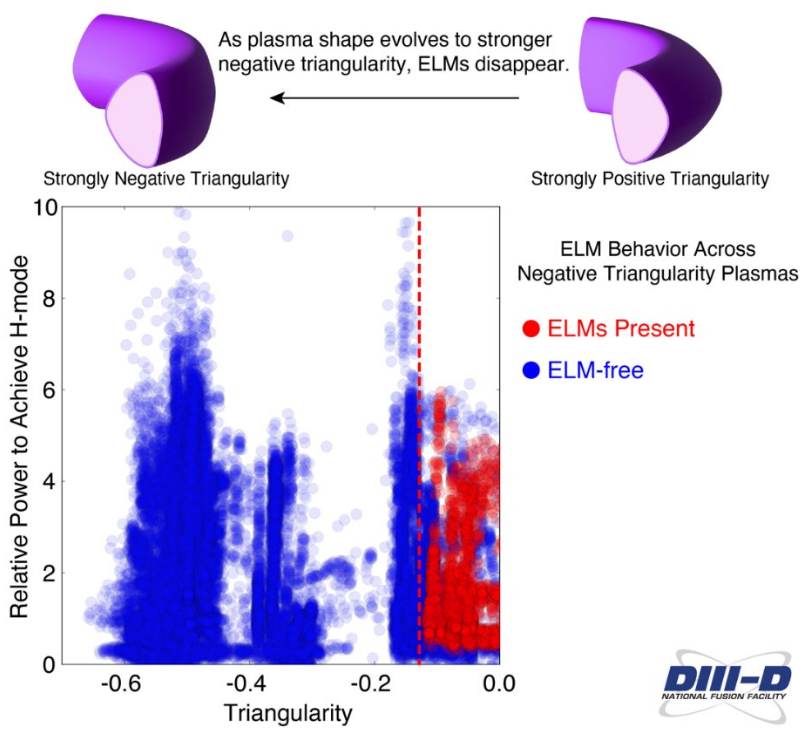

Figure 2. As the plasma shape is pushed to a more extreme level of negative triangularity, the undesirable edge localized modes (ELMs) cease to appear in high-performance (H-mode) conditions. This natural avoidance of ELMs is highly desirable for a reactor.