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Can Materials Survive a Fusion Power Plant? DIII-D Puts Them to the Test

Researchers use the DIII-D National Fusion Facility as a test platform for evaluating tungsten alloys and ceramics under conditions relevant to fusion pilot plants.

CHICAGO—One of the biggest challenges facing fusion energy may be finding materials tough enough to survive inside a commercial fusion power plant. As part of a new study, researchers at the DIII-D National Fusion Facility tested 14 advanced materials under some of the intense heat and plasma conditions expected inside a fusion reactor. The findings identified several promising candidates that could help scientists develop longer-lasting components, an important step toward building fusion power plants that can operate reliably for extended periods.

"Producing fusion energy is only part of the challenge. We also have to build a machine that can withstand these extreme conditions day after day," said Rob Kolasinski, R&D materials scientist at Sandia National Laboratories. "By testing these materials in DIII-D, we can begin to understand which approaches have the greatest potential and what still needs to be improved."

Scientists have known for decades that fusion power plants will require materials capable of withstanding extraordinary conditions. Components surrounding the plasma will be repeatedly exposed to intense heat and high-energy particles that can weaken, erode, or damage them over time.

For more than two decades, tungsten has been considered a leading choice for surfaces that come into direct contact with fusion plasmas because of its ability to withstand extremely high temperatures. While tungsten is expected to meet the needs of many near-term fusion devices, research suggests conventional tungsten could become more vulnerable to damage over the long operating lifetime of a commercial power plant.

That has created a push to develop new forms of tungsten, along with entirely different materials, that could perform better over time. DIII-D provides an important bridge between conventional laboratory testing and the more complex conditions these materials could face in a fusion device.

A team from Sandia National Laboratories, Stony Brook University, Northwestern University, Oak Ridge National Laboratory, and General Atomics tested advanced tungsten alloys and a class of extremely heat-resistant materials known as ultra-high-temperature ceramics. Many had already performed well in laboratory experiments, but

smaller-scale facilities cannot reproduce the combination of heat and plasma exposure found inside a fusion device.

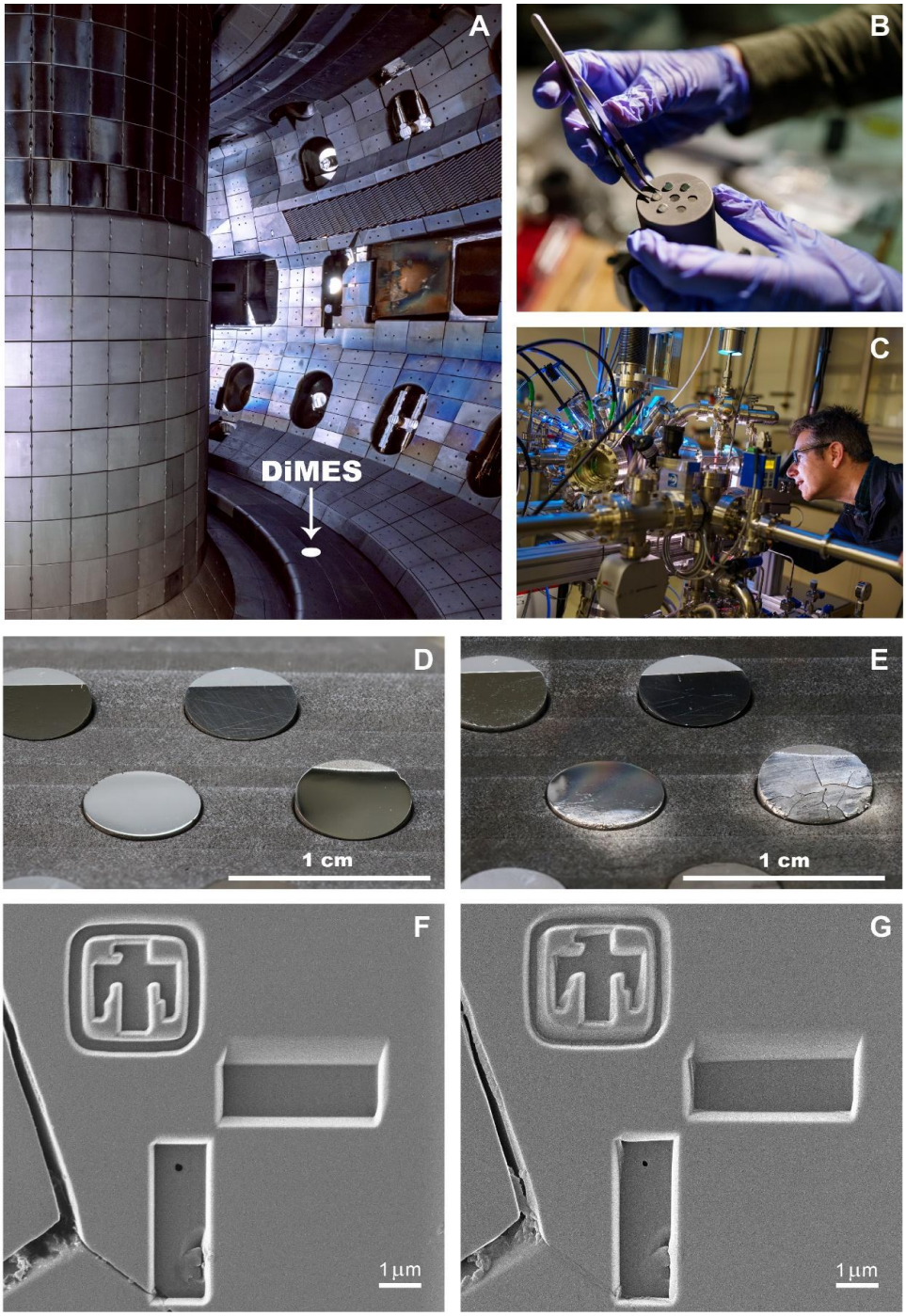


Figure 1: The DIII-D Divertor Materials Evaluation System (DiMES) allows researchers to evaluate how novel materials survive plasma exposure and impact plasma behavior. DiMES samples are loaded into a graphite head (B), exposed in the tokamak (A), and then evaluated after retrieval (C). Comparison before and after exposure allows scientists to identify visual changes, such as melting and cracking (D, E), and microscopic changes, such as erosion (F, G). (B, C) Images courtesy of Craig Fritz. Image C features Rob Kolasinski.

Using DIII-D's Divertor Materials Evaluation System (DiMES), the team placed samples directly in the divertor, the region of the machine that receives some of the highest heat and particle loads from the plasma, during plasma operations (Figure 1). The samples were exposed during multiple plasma experiments and reached temperatures above 2,500ºC (more than 4,500ºF).

"Overall, the advanced tungsten alloys and ceramic materials performed reasonably well under these demanding conditions," Kolasinski said. "We did see some localized melting and erosion, and those results are just as valuable because they show us where the weaknesses are and how these materials can be improved for future use."

The experiments also revealed changes that are difficult to identify through conventional laboratory testing alone, including surface erosion, roughening, and early changes to the internal structure. The results give researchers a clearer picture of the trade-offs among different materials and can help guide future improvements to their composition and microscopic structure.

While these advanced materials are still at an earlier stage of development than conventional tungsten, the findings suggest ultra-high-temperature ceramics and advanced tungsten alloys may have greater long-term potential in a fusion reactor environment.

"As fusion moves closer to practical energy production, we have to solve more than the physics of the plasma," Kolasinski said. "Thankfully, we have a facility like DIII-D that gives us a unique opportunity to test those materials in realistic conditions and learn what it will take to make them ready for the future."

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Abstract

RI01/1 Evaluating the Performance of Advanced Tungsten Alloys and Ultra-High Temperature Ceramics under Reactor-Relevant Plasma Exposure

Session CI02: Impurity Transport, Tungsten, and Radiative Exhaust
9:30 AM–12:30 PM, Friday, November 6, 2026
Room: Hilton Chicago, International North, Second Floor