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Unraveling how Tungsten Armor Erodes in Tokamaks during Intense Plasma Bursts

New high-resolution measurements of tungsten walls in tokamaks may provide insight into how to better protect the armor material

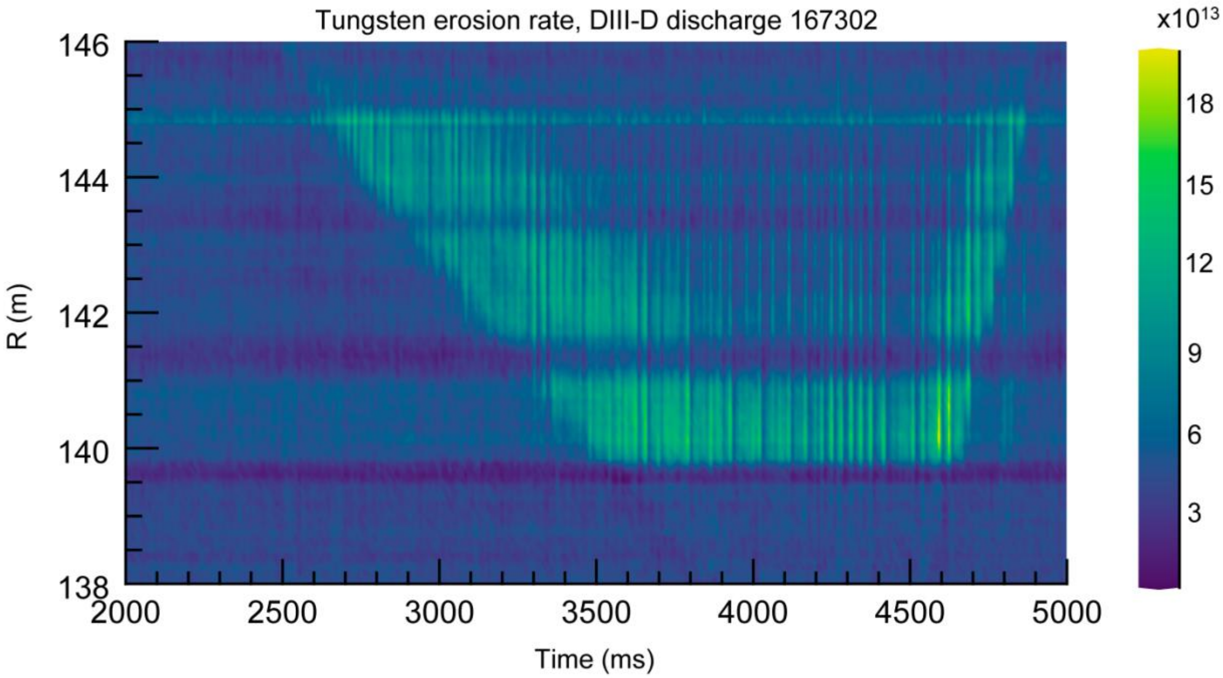

Image courtesy of Tyler Abrams

Measurements of the intensity of the line radiation emitted by tungsten atoms eroding from the region of highest heat and plasma flux on the tokamak wall, known as the divertor. The x-axis shows how the tungsten erosion rate changes in time, including periodic spikes in erosion during plasma instabilities known as edge localized modes. The y-axis displays how the tungsten erosion rate changes as the plasma contact point moves across the divertor surface.

The Science

A new model was developed for how large, periodic bursts of plasma known as edge localized modes (ELMs) erode the tungsten-armored region of the tokamak wall, known as the divertor. This model predicted that most of the plasma hitting the wall during ELMs will actually be low-energy particles that re-circulate, or "recycle" many times in the divertor region and do not cause much erosion of the tungsten armor. New measurements conducted on the DIII-D experimental fusion device agree well with these predictions and indicate that if trace amounts of carbon impurities are present in the plasma, they can cause just as much tungsten erosion as the main deuterium fuel.

The Impact

This new model provides insight into the long-standing question of how much erosion of the fusion reactor wall will occur during periodic edge plasma bursts known as ELMs. While it has been known that the plasma must be manipulated to a state where the ELM bursts are relatively small, this research provides new understanding into how small these plasma bursts must become to reduce the erosion rate of the tungsten wall armor below an acceptable level.

Summary

Large, periodic burst of plasma known as edge localized modes (ELMs) tend to occur near the edge region of high confinement plasma in fusion devices, which causes large amounts of tungsten to erode from the armor region of the tokamak wall known as the divertor. A refined model for how energetic ions stream out from the confined plasma and strike the divertor surface during ELMs was developed. This model predicts that most of the plasma density near the tokamak wall should actually be comprised of relatively low-energy particles that re-circulate, or "recycle" in the divertor region and do not cause much erosion of the tungsten armor. New experiments were conducted on the DIII-D experimental fusion device to test these predictions. Measurements from these experiments were consistent with the conclusion that only the energetic particles originating from the confined plasma region erode the tungsten armor, and the "recycling" particles do not damage the tungsten material. Both the hydrogen fuel and carbon impurities expelled from the plasma were observed to cause roughly equal amounts of tungsten erosion. New simulations were also performed to extrapolate how fast the tungsten armor will erode in ITER, and it was found that nearly all the damage to the armor will be done by the deuterium and tritium fuel ions because they will be very energetic in ITER, while the expected levels of beryllium impurity will not cause much erosion of the tungsten divertor. These results suggest that erosion of the tungsten armor may be reduced during ELMs in future fusion devices by maximizing the concentration of recycling particles near the wall while simultaneously minimizing the intensity of the ELM burst from the confined plasma.

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Publications

T. Abrams et al., "Experimental validation of a model for particle recycling and tungsten erosion during ELMs in the DIII-D divertor." *Nucl. Mater. Energy* 17 (2018) 164-173.

T. Abrams et al., "Impact of ELM control techniques on tungsten sputtering in the DIII-D divertor and extrapolations to ITER." *Phys. Plasmas* 26 (2019) 062504.