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The in-situ diagnosis of plasma-wall interactions on magnetic fusion devices with accelerators[1]

ZACHARY HARTWIG, MIT Plasma Science and Fusion Center

We present the first in-situ, time-resolved measurements of low-Z isotope composition and deuterium retention over a large plasma-facing component (PFC) surface area in a magnetic fusion device. These critical measurements were made using a novel diagnostic technique based on the analysis of induced nuclear reactions from PFC surfaces on the Alcator C-Mod tokamak. Achieving an integrated understanding of plasma physics and materials science in magnetic fusion devices is severely hindered by a dearth of in-situ PFC surface diagnosis. Plasma-wall interactions, such as the erosion/redeposition of PFC material, the evolution of PFC surface isotope composition, and fusion fuel retention present significant plasma physics and materials science challenges for long pulse or steady-state devices. Our diagnostic uses a compact ($\sim$1 meter), high-current ($\sim$1 milliamp) radio-frequency quadrupole accelerator to inject $\sim$1 MeV deuterons into the vacuum vessel. We control the tokamak's magnetic fields – in between plasma shots – to steer the deuterons to PFC surfaces, where they induce high-Q nuclear reactions with low-Z isotopes in the first $\sim$10 microns of material. Analysis of the induced gamma and neutron energy spectra provides quantitative reconstruction of PFC surface conditions. This nondestructive, in-situ technique achieves PFC surface composition measurements with plasma shot-to-shot time resolution and 1 centimeter spatial resolution over large PFC areas.

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