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Progress of High-Performance Steady-State Plasma and Critical PWI Issue in LHD

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An ultra-long-pulse plasma with a duration time of 48 min, a line-averaged electron density of 1.2x10^19 m^-3, and electron and ion temperatures (Te, Ti) of 2 keV has been achieved by the averaged heating power (P_ECH+ICH) of 1.2 MW for helium plasma. The heating energy injected into plasma reached 3.36 GJ, which is a new world record in toroidal plasmas. Three types of ICRF antennas were installed at different toroidal sections in order to avoid local hot spots around each ICRF antenna. In the ultra-long pulse plasma, the spike frequency of the line intensity for the carbon spectrum began to increase after 600 sec, and the divertor temperature was almost saturated at 460 °C. Many flashes are observed with a monitor TV camera which views mostly outside of LCFS and the divertor region. Both the frequency and intensity are increased as the discharge time goes on, which suggest that large sizes of carbon mixed-material layers on divertor region (domes and divertor plates) are ejected into the plasma.
A large amount of mixed-material layers, consisting mainly of carbon (> 90%) and iron impurities, are formed over a wide surface area of the plasma facing surface (PFS). Carbon impurity originally from the divertor region and iron impurity from the first wall by physical sputtering are deposited on the PFS. Comparing the mixed-material layers on divertor region with deposition layer on the stainless steel specimen installed at the equivalent position of the first wall surface with the expose time of ~ 1000 sec for steady-state discharges, these composition were consistent with each other. Since such layers are hard and brittle, deposition layers are easily removed as a flake. Plasma termination may be caused by exfoliation of the mixed-material layers. The mixed-material deposition layer can easily retain helium particles, and these trapped particles are released even below 400 K. The amount of trapped particles in it is proportional to the thickness of the mixed-material layers. Since such amount of He trapped particles was 100 times as large as that of plasma and neutral particles in the vacuum vessel, the release of He could not be negligible in wall-temperature increasing phase. Control of the growth rate of mixed-material layers will be critical issue in steady-state devices and long-term plasma operation such as a fusion reactor.

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