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Overview of first Wendelstein 7-X high-performance operation with island divertor

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The optimized superconducting stellarator device Wendelstein 7-X restarted operation after the assembly of a graphite heat shield and an inertially cooled island divertor. This paper reports on results from the first high-performance plasma operation. Plasma densities of $1-4\cdot10^{19}\,\mathrm{m}^{-3}$ with electron temperature $5-10\,\mathrm{keV}$ were routinely achieved with hydrogen gas fuelling, eventually terminated by a radiative collapse. Up to $1.4\cdot10^{20}\,\mathrm{m}^{-3}$ plasma density was reached with repetitive hydrogen pellet injection. Here, the ions are indirectly heated, and at a density of $8\cdot10^{19}\,\mathrm{m}^{-3}$ temperatures $T_e\simeq T_i=3.4\,\mathrm{keV}$ were accomplished, which corresponds to $nT\tau_E=6.4\cdot10^{19}\,\mathrm{keVs/m}$ with peak diamagnetic energy $1.1\,\mathrm{MJ}$. Stable $25\,\mathrm{s}$ long-pulse helium discharges with $2-3\,\mathrm{MW}$ ECRH power and up to $75\,\mathrm{MJ}$ injected energy were created routinely for equilibrium and divertor load studies, with plasma densities around $5\cdot10^{19}\,\mathrm{m}^{-3}$ and $5\,\mathrm{keV}$ electron temperature. The divertor heat loads remained far below the limits. The O/C impurity concentration ratio has decreased in comparison to the previous limiter operation and no intrinsic impurity accumulation along with high edge radiation were observed in stationary plasmas. During pellet-fuelled hydrogen discharges, full detachment was observed with divertor target heat flux reduction by more than $\times10$. Both X2 and O2 mode ECRH schemes were applied and electron cyclotron current drive (ECCD) experiments were conducted. During co-ECCD injection experiments with axial currents up to $13\,\mathrm{kA}$, frequent fast crashes were observed mainly in the core electron temperature, suggesting a fast magnetic reconnection mechanism. The radial electric field measured with (Doppler) and correlation reflectometry changes sign at the plasma edge from $+10\ldots+20\,\mathrm{kV/m}$ to $-10\ldots-5\,\mathrm{kV/m}$, fairly independent of discharge parameters and heating power. Edge and scrape-off layer turbulence was measured with both Langmuir probes and reflectometer diagnostics. Core turbulence was measured with a phase contrast imaging diagnostic and different levels of broad band turbulence as well as coherent Alfvén mode activity were observed.

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