Contribution ID: **49** Type: **Oral**

Advances in Neutral Particle Control in the Closed Helical Divertor of LHD

Friday 31 October 2025 10:55 (20 minutes)

Control of particle recycling and neutral pressure in the divertor is a key challenge in sustaining high-performance, steady-state operation in fusion devices. This presentation highlights recent developments in the Large Helical Device (LHD), where a Closed Helical Divertor (CHD) with in-vessel pumping has been implemented to enhance neutral compression and control recycling.

The first part of the study presents the conceptual evolution, engineering realization, and experimental validation of the CHD. The integration of cryo-sorption and non-evaporable getter (NEG) pumps significantly improved neutral particle exhaust and reduced wall recycling, enabling flexible density control and sustained long-pulse operation. Fast ion gauges and EMC3-EIRENE simulations revealed more than a tenfold increase in divertor pressure with minimal impact on core plasma parameters.

The second part focuses on recent observations of ultra-high neutral pressures (up to 2.4 Pa) in inward-shifted magnetic configurations (Rax = 3.55 m). This regime is attributed to a newly identified near-wall condensation phenomenon, where recombination in a dense, low-temperature divertor plasma leads to a secondary neutral source. The resulting localized neutral buildup enhances divertor compression and leads to radiation detachment, observed via bolometry, spectroscopy, and high-speed imaging.

Together, these results demonstrate the viability of advanced divertor designs and localized neutral source phenomena as effective tools for achieving efficient particle exhaust and plasma edge control in stellarator reactors. These insights contribute to the development of reactor-relevant divertor concepts for future steady-state fusion power plants.

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Session Classification: Towards Integrated Scenarios for Exhaust

Track Classification: Towards Integrated Scenarios for Exhaust