Evidence of enhanced impurity screening with higher plasma density in the island divertor in W7-X

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Direct experimental evidence for screening of carbon impurities sourced by surface erosion was found in the island divertor of Wendelstein 7-X (W7-X). This specific stellarator divertor concept is being qualified as a potential divertor solution for a future steady-state stellarator reactor. The impurity handling capability is of key importance, because significant impurity contamination in the confined plasma is detrimental for high performance operation. In experiment it was shown that the screening of carbon becomes more efficient towards higher plasma density, which is in qualitative agreement with numerical modeling using the EMC3-EIRENE code \cite{1}.

These results were obtained by experimentally quantifying and comparing the scaling of the carbon source from the divertor and the carbon concentration/density in the confined plasma with plasma density. A line integrated density scan from 4E19m\textsuperscript{-3} to 8E19m\textsuperscript{-3} was performed in the attached standard divertor configuration, corresponding to separatrix densities of around 1E19m\textsuperscript{-3} to about 3E19m\textsuperscript{-3}. The radiated power at each density level remained below 33\% of the total 4.5MW input ECRH heating power. To measure the carbon particle source, a divertor camera outfitted with a 2nm FWHM C\textsc{II} (514.3nm, 2s\textsuperscript{1}2p\textsuperscript{1}3p\textsuperscript{1}4P_{5.5} \rightarrow 2s\textsuperscript{1}2p\textsuperscript{1}3s\textsuperscript{1}4P_{5.5}) filter was used in combination with ionization per photon coefficients (S/XBs). The C\textsc{II} line emission was concentrated at the strike line, and therefore the S/XBs were determined using electron temperature and density information from the divertor Langmuir Probes situated in this region. For the confined carbon content, Charge eXchange Recombination Spectroscopy (CXRS) was used to provide C\textsuperscript{6+} concentration profiles from the 529.3nm line radiation. It was found that as the density was increased, the carbon source showed a small increasing trend, but within error bars of the calculation. At the same time, the C\textsuperscript{6+} concentration profile is flat over the range of the measurement (normalized radius from 0 to 0.8) and shows a decrease from about 2\% down to about 0.7\% at the highest density. This corresponds to a C\textsuperscript{6+} density decrease from about 6E17m\textsuperscript{3} to about 4E17m\textsuperscript{3}. These C\textsuperscript{6+} concentrations are consistent with \(Z_{\text{eff}}\), which is reduced from 1.5 to 1.2. Thus, even for a constant carbon source with increasing density, the reduced concentrations/densities in the confined plasma provide evidence for enhanced impurity screening at higher densities. This favorable scaling of the impurity screening capacity of the island divertor with density is a key finding for the high density, stationary operation of W7-X foreseen for 2021.

\cite{1} Y. Feng et al, \textit{Plasma Phys. Control. Fusion} \textbf{53} (2011) 024009

This work was supported in part by the U.S. Department of Energy under grants DE-SC00013911, DE-SC00014210, and DE-AC02-09CH11466 and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053.