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Transport and confinement in Wendelstein 7-X divertor plasmas

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After an initial limiter campaign (OP1.1), the Wendelstein 7-X experiment was upgraded with a so-called island divertor. This divertor concept makes use of the intrinsic resonant magnetic island chain at the plasma boundary. The divertor plates are toroidally discontinuous, but stellarator-symmetric (two per module) and are positioned to intersect each of the magnetic islands. The installed divertor is a test-unit and consists of uncooled carbon used for testing purposes in the first divertor operation phase (OP1.2), before the device will be upgraded with a fully cooled CFC divertor by the end of 2020 (OP2) [1].

In OP1.2, the island divertor was observed to have a strong impact on the plasma fueling. For helium plasmas with a particle recycling close to one, fueling could be controlled adequately and line-averaged densities of up to $8x10^{19}$ m^{-3} could be reached using strong ECRH with 2nd harmonic X-mode heating. Furthermore, by efficiently switching to 2nd harmonic O-mode heating [2], densities of more than $10x10^{19}$ m^{-3} could be achieved in helium. The fueling of hydrogen plasmas was more difficult to control under island divertor conditions and was accompanied by high radiation. At ECRH input powers of about 5 MW, a maximum density of $4x10^{19}$ m^{-3} could be achieved; higher densities were prevented by plasma terminating radiation collapse. Only with precisely timed pellet injection, densities on the order of $10x10^{19}$ m^{-3} were accomplished in hydrogen. Next to the plasma species, the fueling control was also influenced by the magnetic configuration, e.g. higher densities could be reached in the high-iota configuration compared with the standard configuration.

Density and power scans were carried out for helium and hydrogen for three different magnetic configurations: standard, narrow-mirror, and high-iota with the aim of studying first confinement effects in W7-X (with an average central ε_{eff} of 0.75%, 1.5% and 3.0% respectively).

Considering the plasma species, preliminary analysis suggests that, despite better fueling control in helium, the global energy confinement of helium plasmas seems lower than in hydrogen and diverges from the stellarator-specific energy confinement time scaling ISS04. Hydrogen plasmas are close to ISS04 values ranging between 50-200 ms with the majority being around 100 ms. The results, however, might be influenced by varying machine conditions and plasma purity. No significant difference could be observed for the global energy confinement time between the explored magnetic configurations. For the majority of the investigated plasmas with low density and temperature the total neoclassical energy flux is insufficient to explain the experimental flux under electron-root conditions. Only for high performance hydrogen experiments with pellet injection, the neoclassical energy flux becomes the dominant transport component. However, no clear conclusion can be drawn from the small number of pellet experiments at this time point. Meanwhile, gyrokinetic simulations are underway to assess turbulence transport effects.

Generally, high radiation fractions of 50% or higher were observed in most W7-X plasma experiments, in some cases even up to nearly 100%, complicating the confinement analysis. The 3D distribution and source of this radiation is as of yet still unclear. No significant high-Z impurities such as iron were observed, indicating that the radiation must have been caused by a number of lower-Z impurities, which is still under investigation. So far, boronization was not used in W7-X, but will be employed in the next campaign with the expectation of improved wall conditions.

References

[1] R.C. Wolf, et al., IEEE Trans. On Plasma Science 44, 1466 (2016)
[2] T. Stange, et al., EPJ Web of Conferences 157, 02008 (2017)