Contribution ID: **122** Type: **Oral**

Impurity leakage mechanisms in the W7-X island divertor under experimentally relevant operational space

Tuesday, 8 November 2022 11:15 (20 minutes)

Optimization of divertor concepts for the 3D stellarator boundary is still only in its beginning stages. Multiple requirements must be satisfied for a properly functioning divertor, including optimized particle exhaust for density control, significant power exhaust to ensure the survival of plasma-facing components, and sufficient impurity retention in the scrape-off layer (SOL) to avoid undue contamination to the confined plasma. Impurity retention in the SOL serves two other important aspects of divertor operation: 1. For a given number of impurity particles, there is a greater concentration of impurities near the pumping area, allowing for efficient exhaust (critical for Helium ash removal) and 2. it provides a larger density of seeding impurities for a given puff rate in the SOL, where they more efficiently radiate, improving power exhaust. Thus, understanding the driving factors for impurity leakage in current stellarator divertor designs is an important step towards developing better optimization criteria for future stellarator reactor divertors.
The EMC3-Eirene code was utilized to study the dominating transport mechanisms for impurity leakage in the Wendelstein 7-X island divertor under experimentally relevant density operational space, in the absence of drifts. The results are consistent with previous work indicating a transition to friction force dominance over the majority of the island SOL, at separatrix densities below those that were typically achievable in the previous operational campaigns[1][2]. The suppression of the ion thermal force is so strong that no impurity neutrals ionize beyond the parallel impurity flow stagnation point. Therefore, parallel transport does not play any direct role in impurity leakage from the island SOL in the simulations. Rather, it was found that the impurity density at the last closed flux surface (LCFS) was strongly sensitive to the anomalous cross-field diffusion coefficient assumed, indicating that perpendicular transport plays a strong role in limiting the impurity retention of the island divertor[3]. The main location of impurity leakage via the perpendicular transport channel appears to be the island O-Point region. The impurity dwell time of this location is rather long, owing to the low internal island field line pitch in combination with impurity flow stagnation in this location. This provides enough time for the impurities to diffuse perpendicularly to the LCFS.
The results indicate the importance of the proximity of the island O-Point to impurity sources (plasma-surface interaction, seeding sources) in limiting the impurity retention of the island SOL. Such a result, if validated experimentally, provides valuable information for design of future island divertors. Additionally, the results indicate that experimental measurements of impurity retention may provide a useful constraint on the value of the assumed anomalous cross-field diffusion coefficient used in simulation. Further work is needed to quantify drift effects[4], which may impact the strength of the effects discussed here[5].

References

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Session Classification: SOL

Track Classification: Scrape-off Layer and Divertor Physics