Study of radiated power asymmetries in Spherical Tokamak Advanced Reactor (STAR)

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Investigating radiated power and its potential asymmetries in fusion plasmas is of utmost importance to understand the effect of undesired impurities, such as metals, in the present devices, or also desired impurities, such as noble gasses, to purposefully radiate a large fraction of power in future devices. These studies are especially important for high Z impurities which play a crucial role in future generation fusion pilot plants (FPPs).

In this work, we have investigated 2D distributions of impurity densities and radiated power asymmetries caused due to both plasma rotation and the cooling rate dependence on temperature profile, for the cases of Spherical Tokamak Advanced Reactor (STAR) FPP design scenarios [1] and experimental NSTX plasmas, both being low aspect ratio tokamak concepts. Self-consistent calculations of two-dimensional electron, main ion, and impurity ion densities are carried out using one-dimensional input density, temperature, and rotation profiles. In the case of NSTX, discharges with high rotation of ~170 km/s, measured with charge exchange recombination spectroscopy, have been investigated. Rotation-induced charge separation, leading to an electrostatic potential, is calculated iteratively using carbon as the main intrinsic impurity, while testing other higher Z impurities and imposing the quasi-neutrality condition [2]. Strong 2D asymmetry in the core radiated power has been observed due to centrifugal forces. The STAR design, being much larger (R= 4 m), is projected to have a much lower rotation, and is shown to have a low rotation-induced asymmetries in the case of intrinsic W on the order of a few percent between the low field and high field sides as shown in Fig. 1. However, another effect not due to rotation but to the dependence of impurity cooling rates on temperature can lead to radiation peaking off-axis, near the plasma edge. As shown in Fig. 2, this effect is noticeable for Ar in NSTX and for Xe in the much higher temperature projected for STAR ($T_{e,0}$~32 keV). Further, synchrotron radiation is found to be crucial component of power loss mechanisms for reactor-scale fusion devices. These effects must be taken into account for critical power exhaust solutions in large future fusion devices where deliberate radiation of power from the core or edge is desirable using noble gases [3].

References:

[1] J. Menard et al. 29th IAEA Fusion Energy Conference (2023)

[2] L. Delgado-Aparicio et al., Rev. Sci. Instrum. 85, 11D859 (2014)

[3] K. Shah et al. under review in PPCF

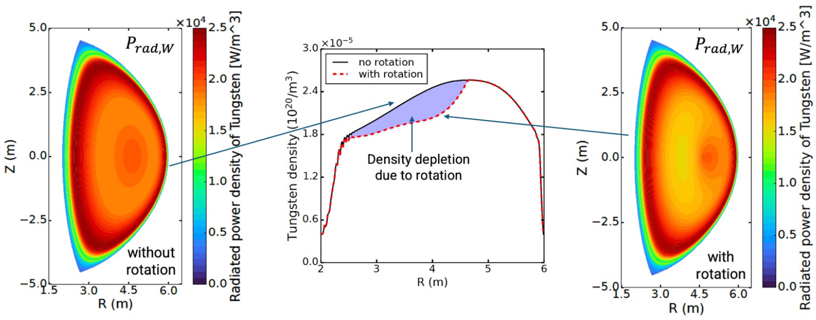

Figure 1: Synthetic 2D radiated power density profiles of W in STAR without (left) and with (right) centrifugal effects. W density depletion due to the rotation shown by the shaded region in the 1D mid-plane profile in the center.

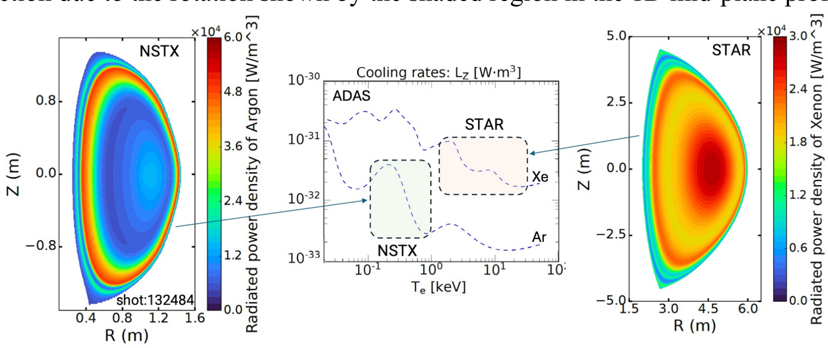

Figure 2: Synthetic 2D radiated power density profiles for Ar in NSTX shot 132484 (left) and Xe in STAR (right) showing off axis distribution due to temperature dependence of cooling rates shown by the shaded region in the center.