Estimation of SOL/Divertor Plasma Heating by Electron Cyclotron Radiation from Core Plasma in ITER

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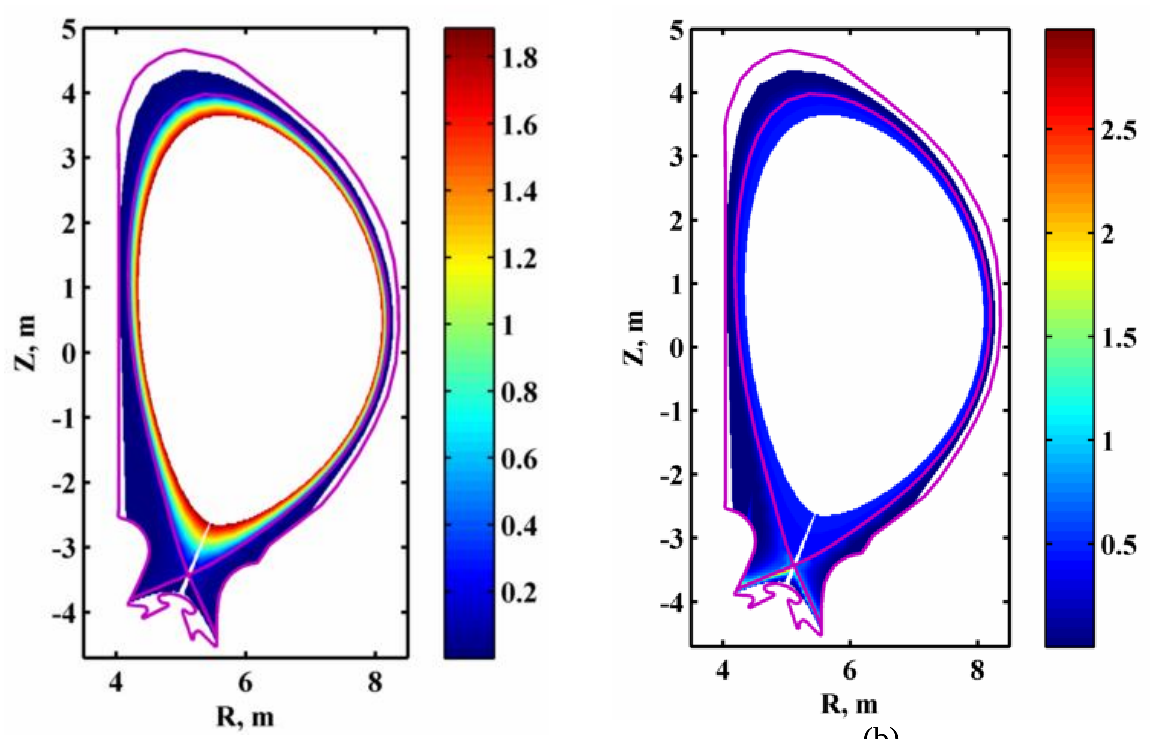
1. Introduction. Coupling of the plasma located inside the separatrix (the core plasma) with that outside (SOL and divertor plasma) is usually taken into account via an exchange of boundary conditions (at the separatrix) between the transport codes for respective parts of plasma. In ITER tokamak, this pertains to the Automated System for Transport Analyses (ASTRA) [1] and the SOLPS4.3 [2] code. Since the mean free path (m.f.p.) of neutral atoms in ITER plasma is rather short and the intensity of the electron cyclotron (EC) waves with m.f.p. comparable with the minor radius of the plasma column is high [3]-[5], the EC radiation emitted by the core plasma could contribute to nonlocal coupling of the core and the SOL+divertor plasmas. Recent calculations [6] of the local electron energy balance for parameters needed for the steady-state operation of ITER [7] were based on a self-consistent model employing 1D transport and 2D equilibrium models (1.5D approximation). That modeling included calculation of the electron cyclotron radiation (ECR) power density profile using the CYNEQ code [4],[6],[8] incorporated into the ASTRA framework. However, modeling [6] did not allow for the absorption of the EC waves in the SOL+divertor region, despite the total power of EC radiation (on the top of the ECRH/ECCD power) in the vacuum vessel can amount, in the regime [7], to as much as ~30 MW.

Here we prove the validity of this approximation via calculating the EC power deposited in the SOL+divertor plasma and estimating the possible impact of this absorption upon the in-vessel EC intensity, using the data from the SOL+divertor plasma modeling with the SOLPS4.3 code [2].

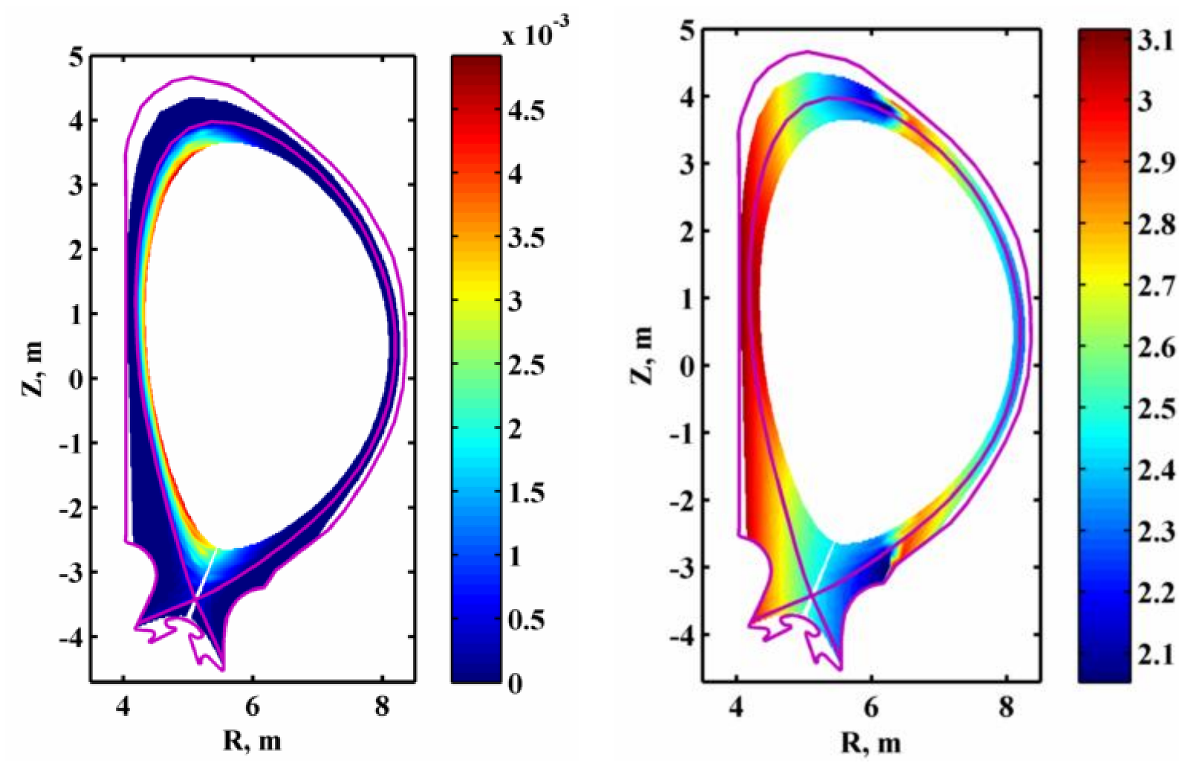
2. SOL/Divertor plasma heating by ECR. The calculations of SOL/divertor plasma heating by ECR were carried out with the use of the CYNEQ code [4] for the conditions of the core plasma in the ITER steady-state scenario [7] where the ECR power is higher and various conditions in the SOL+divertor plasmas (runs 1511, 1514 and 1635 of the SOLPS4.3 code [2]). The results for the conditions of the run 1511 are shown in Figs. 1-4. Similar results are obtained with the edge data from the other SOLPS4.3 runs.

Similar to the core plasma, in the SOL and divertor the ECR intensity is assumed to be isotropic.



(a) (b)

Figure 1. (a) Electron temperature, $T_e(R,Z)$ [keV] and (b) density, $n_e(R,Z)$ [10^{20} m^{-3}] profiles in the SOL and divertor region in ITER simulated with SOLPS4.3 [2] (run 1511).



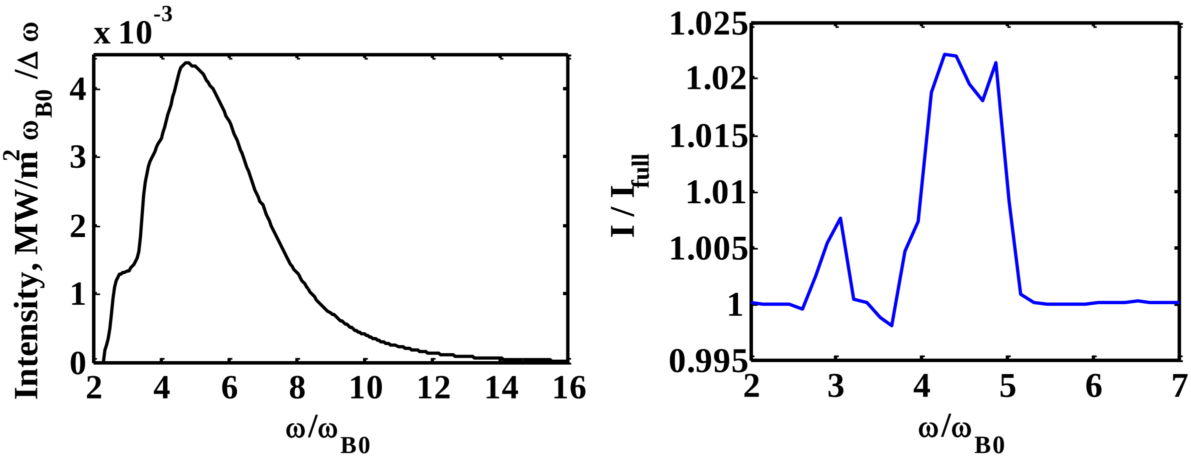
(a) (b)

Figure 2. (a) Density of the absorbed ECR power [MW/m^3], predicted by CYNEQ in the SOL and divertor region for the conditions of the run 1511 (Fig. 1) in the ITER steady-state scenario [7]. (b) Average frequency of the absorbed ECR power from Fig. 2(a), see Eq. (1).

Spectral characteristics of the absorbed ECR power is illustrated with Figure 2(b) for the average frequency of the absorbed ECR, defined by the relation:

$$\tilde{\omega}_{\text{eff}} = \left[\sum_{\zeta=E,O} \int \tilde{\omega} I_{\zeta}(\tilde{\omega}) \kappa_{\zeta}(\vec{r}, \tilde{\omega}) d\tilde{\omega}\right]\left[\sum_{\zeta=E,O} \int I_{\zeta}(\tilde{\omega}) \kappa_{\zeta}(\vec{r}, \tilde{\omega}) d\tilde{\omega}\right]^{-1}, \quad \tilde{\omega} = \frac{\omega}{\omega_{B0}}, \tag{1}$$

where I is the intensity of radiation escaping from the core plasma, ς denotes the wave mode (O – ordinary, E – extraordinary), κ is the absorption coefficient and ω_{B0} the fundamental EC frequency with respect to the magnetic field B_0 at the plasma center. The scale of the optical thickness of the divertor plasma is shown in Fig. 5.



(a) (b)

Figure 3. (a) Intensity of outgoing radiation for the ITER steady-state scenario [7]. (b) Ratio of intensity of the outgoing radiation in [7], I, calculated by CYNEQ neglecting the SOL and divertor regions (figure 3(a)) to the refined intensity, I_{full}, which takes into account the ECR absorption in the SOL+divertor region.

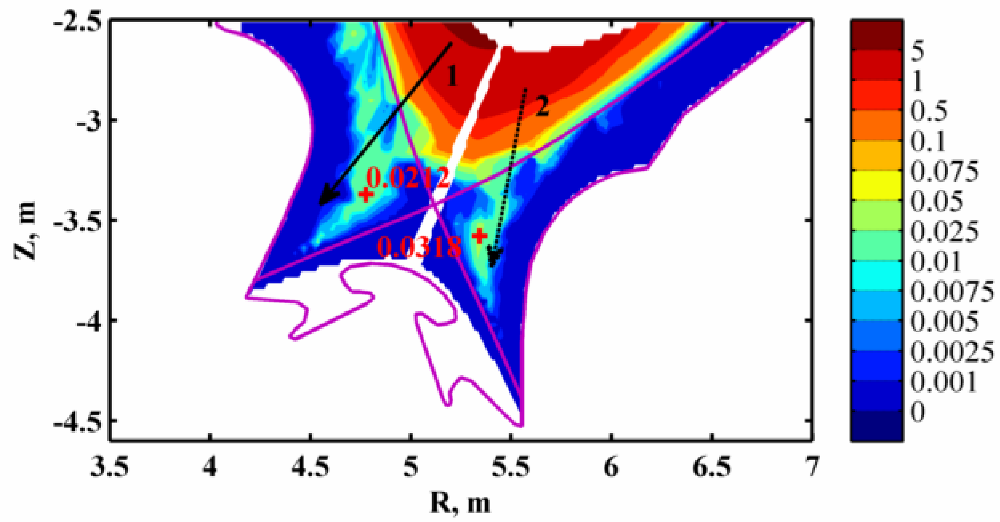


Figure 4. Ratio of the EC power losses, $P_{EC}(R,Z)$, to the total radiation losses, $P_{rad}(R,Z)$,. in the divertor. Points with cross-marker show local maxima of this ratio. Two ray paths (see Fig. 5) are shown by arrows.

3. Conclusions. The ECR power absorbed in the SOL+divertor plasma in steady-state regimes of the ITER operation is small (< 1%) compared to the total radiation losses. The strongest effect occurs at the high field side (HFS). Impact of the EC absorption in SOL+divertor plasma on the total EC power losses in these regimes is also small (< 0.5%). These effects do not affect the present coupling of the transport codes for the core and SOL+divertor plasmas (respectively, the ASTRA and SOLPS4.3 codes). The role of the ECR from the core plasma in the coupling of these codes should also be examined in the cases of transient events when rather hot plasma appears outside the separatrix, especially in the HFS region.

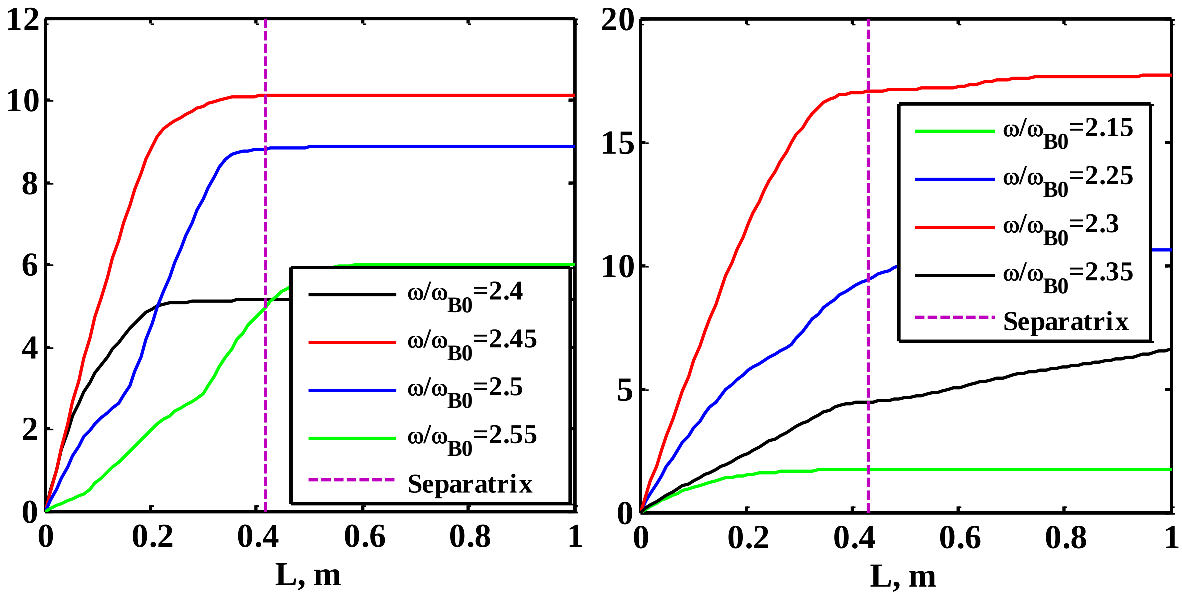


Figure 5. Typical optical thickness along the ray path L, from the core plasma through the separatrix towards the inner (left, ray 1 in Fig. 4) and outer (right, ray 2 in Fig. 4) divertor plates.

Acknowledgements. The work is supported by the RF State Corporation ROSATOM under the contract № H.4a.52.90.11.1085 in part of the NRC "Kurchatov Institute".

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