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MODELING OF ASDEX UPGRADE DETACHED DIVERTOR WITH RADIATING X-POINT BY SOLPS-ITER

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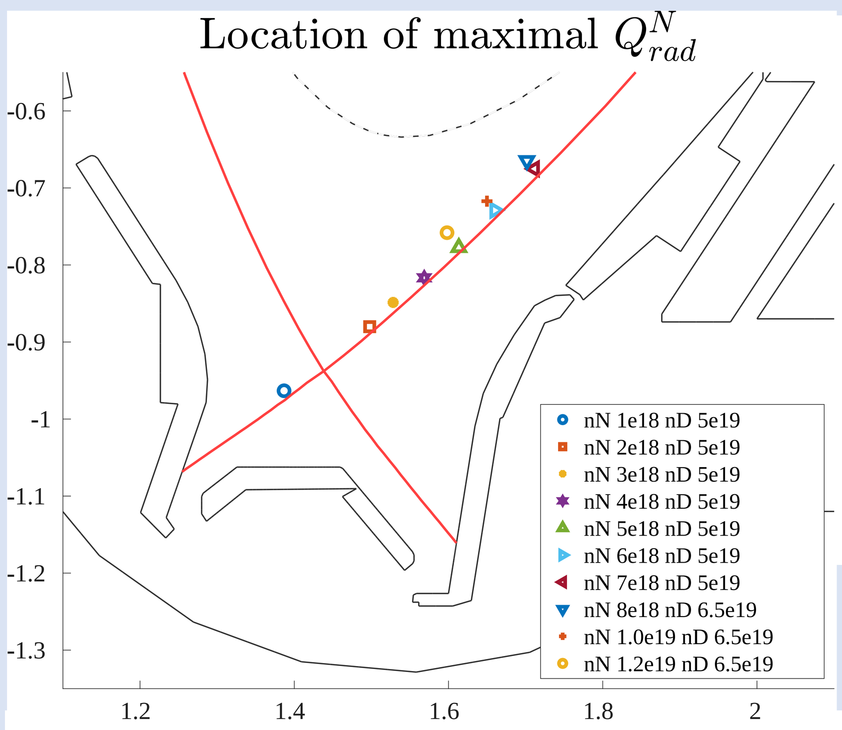
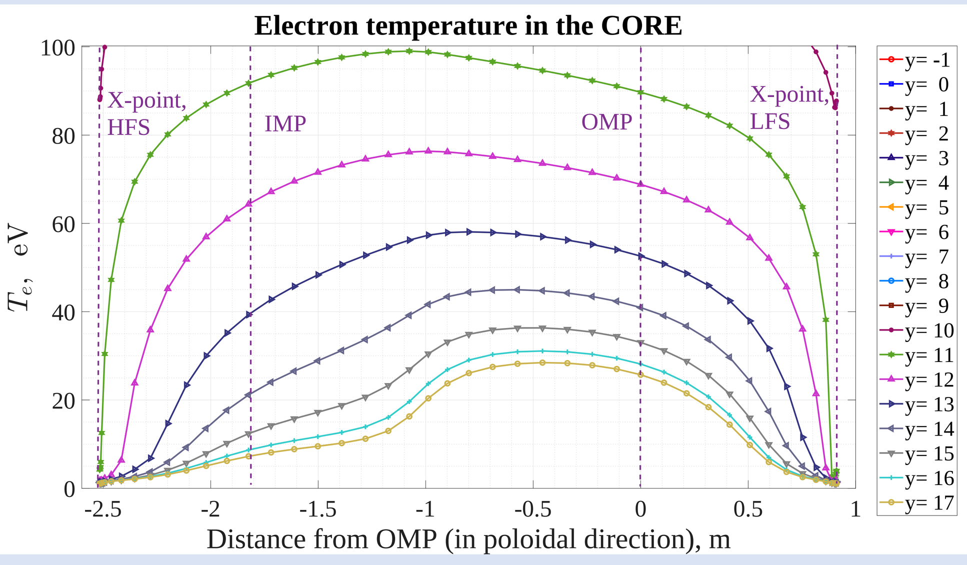
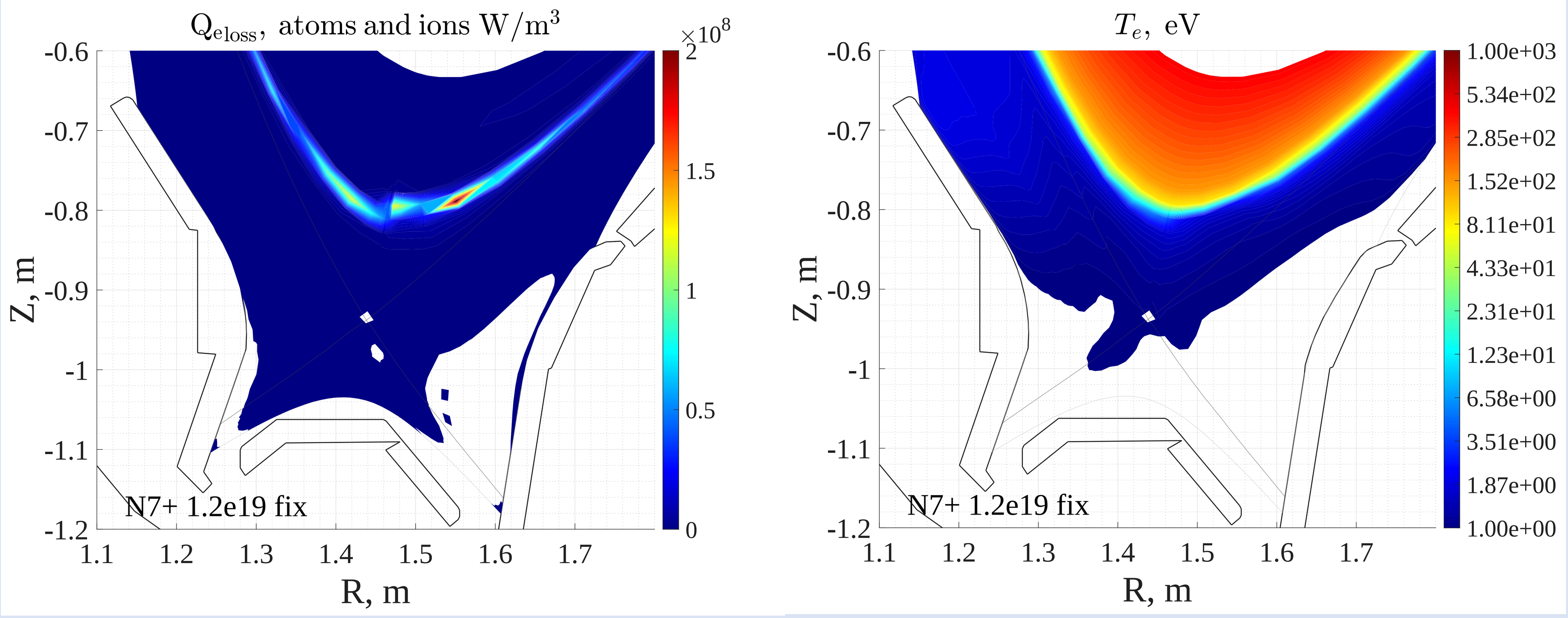
ABSTRACT

- In the SOLPS-ITER simulations of the intensively seeded AUG discharges the confined plasma goes into the radiation collapse as a certain threshold in seeding rate is exceeded. It is possible to achieve radiating X-point regime with prescribing the impurity content.
- X-point behaves as an energy sink similarly to the the divertor in the conventional regime.
- The formation of an electric potential peak above the X-point is observed in the simulations, and the corresponding E × B drift flux appears to give the largest contribution to the main ion and impurity fluxes.

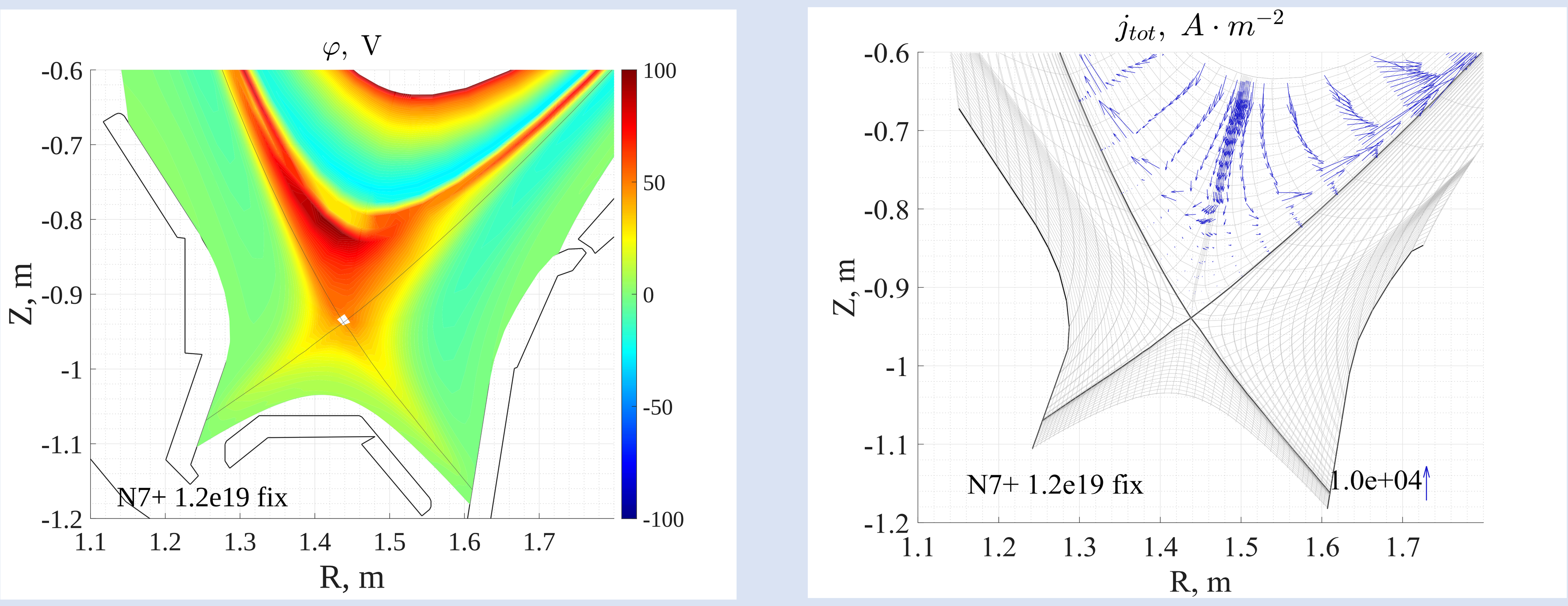




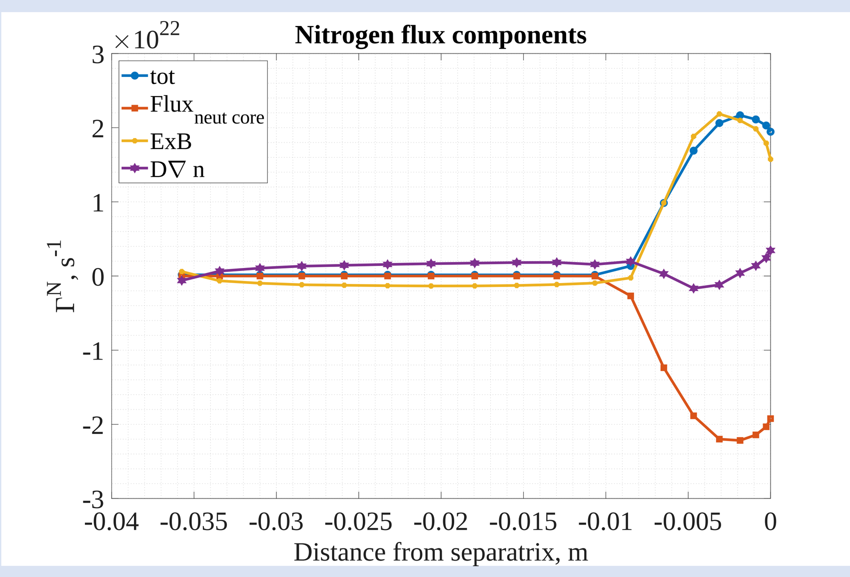
Poloidal Te profiles along different flux surfaces. y=-1 labels innermost one, y=17 labels LCFS (on computational mesh)



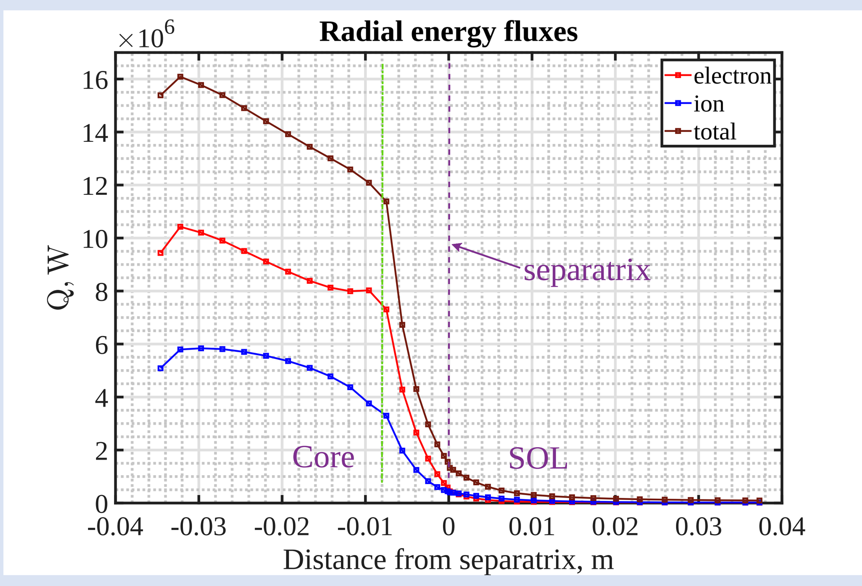
2D profiles of electron energy losses on inelastic collisions and T_e for the case with maximal fixed nitrogen content



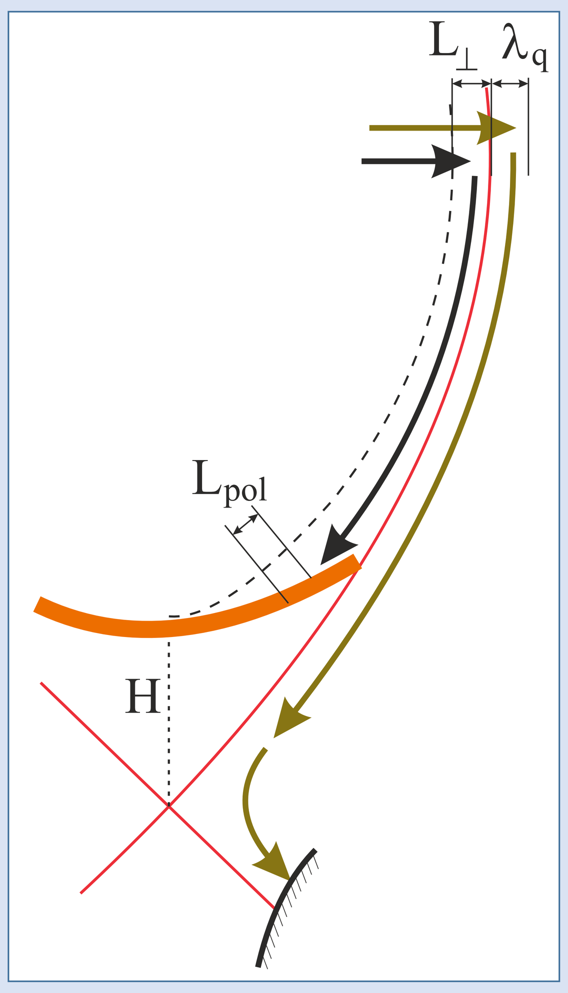
2D profiles of electric potential and current density for the case with maximal fixed nitrogen content.



Nitrogen radial fluxes, integrated over flux surfaces

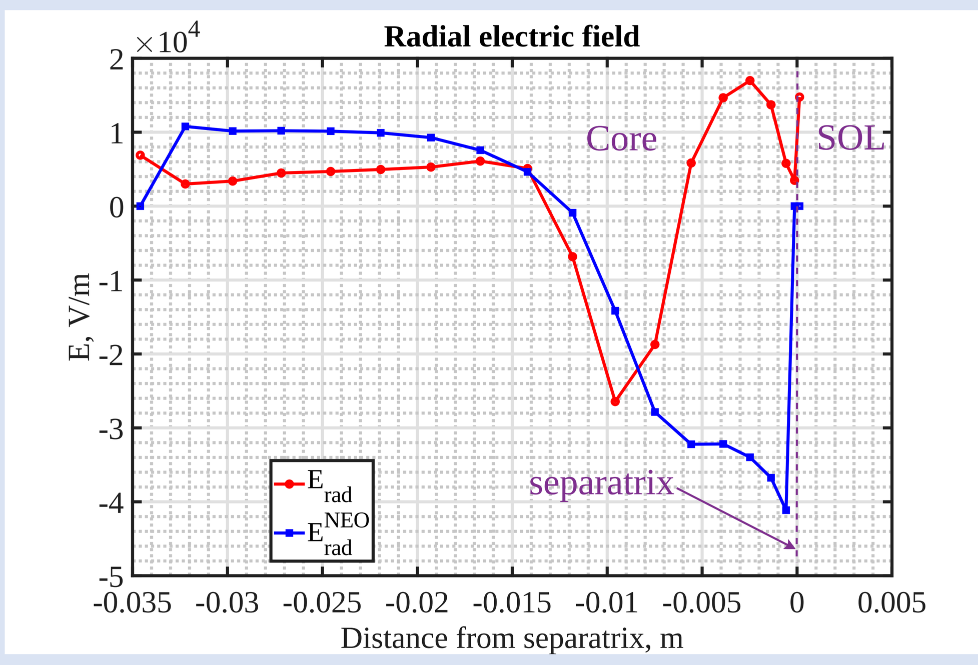


Net energy flux (power) through flux surfaces



Sketch of energy flow in regime with radiating X-point and in conventional regime

OMP radial electric field vs neoclassical formula.



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MOTIVATION

- On ASDEX Upgrade, after the outer target fully detaches, with further increase of the impurity seeding rate the tokamak plasma moves to a new regime, which is characterized by the presence of a radiating spot in the confinement region above the X-point.
- The radiated power inside the separatrix might exceed 3/4 of the total discharge power, and therefore regimes with radiating spot above the X-point seem to be suitable for machines like DEMO, CFETR and beyond.
- This regime is not yet understood. There were some SOLPS5.0 simulations without drifts, but inclusion drifts in modelling changes flows significantly.
- Results of simulation with drifts fully turned on are presented in this paper.

APPROACHING RADIATING X-POINT REGIME

MODELING SETUP

The modeling cases presented here and below are based on ASDEX Upgrade shot #28903, where an H-mode deuterium plasma was seeded with nitrogen. E×B drifts, diamagnetic drifts, and currents are fully turned on in all modeling cases

HIGH SEEDING RATE CASES

In maximal achievable seeding rate detachment everywhere along the target except in the far SOL wing was achieved, but amount of radiated power in core is small. Further increasing of seeding rate leads to radiative collapse, because atoms goes to the core region instead of pump. It appears that it is not enough of incoming power to ionize all atoms.

CASES WITH FIXED PARTICLE CONTENT

Particle content in the system was fixed rather than fueling/seeding and pumping. The scan in nitrogen particle content is performed, thus modeling the feedback. With such an approach a stable solution with radiating spot in the confined region above the X-point is achieved. With increasing nitrogen density and power, the location of the radiation loss maximum moves from the inner SOL towards the OMP along the separatrix and then shifts back down and simultaneously inside the confined region

OUTCOME FOR CASE WITH MAXIMAL ACHIEVABLE N CONTENT

- Both targets are in full detachment. Zone of low T_e (1-2 eV) appears in the confined region above the X-point and is separated from hot plasma by the radiating mantle of bow-like shape. Poloidal width of this radiating mantle is estimated assuming that all available parallel heat flux is spent here, and L_{pol} appears to be about 2.4 cm.

$$\frac{B_x}{B}\frac{1}{h_x}\frac{d}{dx}\left(\frac{T_u^{\frac{7}{2}}k_0}{qR}\right) = n_e n_N R_N(n_e, T_e) \quad \Rightarrow \quad L_{pol} = \frac{T_u^{\frac{7}{2}}k_0 B_{pol}}{qRn_e^{(max)}n_N^{(max)}R_N^{(max)}B}$$

R_N is a radiation loss function for N, T_u is upstream (OMP) electron temperature, maximal (along flux surface) values of ne, nN and RN should be taken inside radiating mantle,

$$k_0 = 3(4\pi\varepsilon_0)^2/4\sqrt{2\pi m_e}e^4\Lambda$$

- The incoming power of about 15 MW is spent almost entirely in the confined region, and only 2 MW crosses the separatrix. Power flux decay length is of the order of λ_q (2-3 mm)

$$L_\perp = qR\sqrt{\frac{m_e\nu_{ei}\chi_e^{AN}}{T_u}}$$

- Electrostatic potential hill above the X-point in the confined region appears, which corresponds to strong poloidal eclectic field. Such strong E-field is required to drive the Pfirsch-Schlüter current through the cold plasma of low electrical conductivity.
- The consequence of the potential maximum is a vortex E × B drift flow which appears to give the major contribution to the main ion and impurity fluxes in the vicinity of the X-point.
- Parallel velocity perturbation, which is caused by heat sink and particle source, affects significantly the radial electric field, which deviates from neoclassical expression and even might become positive.
- Simulations can reproduce most of features of the regime with radiating spot above the X-point except Z_{eff}, which is significantly bigger than in experiment.

CONCLUSIONS

- To achieve regimes with a radiating spot above the X-point, it appears to be necessary to prescribe particle content in the system. The stable solution is obtained with up to 90% of discharge power radiated away from inside the separatrix.
- Strong electric field is required to drive Pfirsch-Schlüter currents through this cold highly resistive plasma zone.
- Consequently, an electrostatic potential hill forms in the cold zone above the X-point, leading to large E × B drift flows of main ions and impurity.
- The radial electric field deviates significantly from what is given by the neoclassical expression, which might affect the turbulence suppression