The tungsten target erosion and W impurity transport during external impurity seeding

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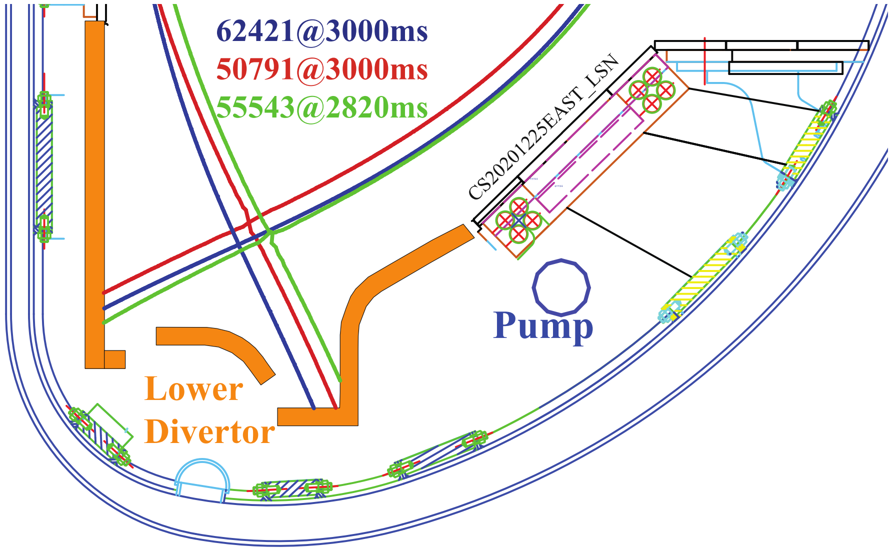
Background and motivation

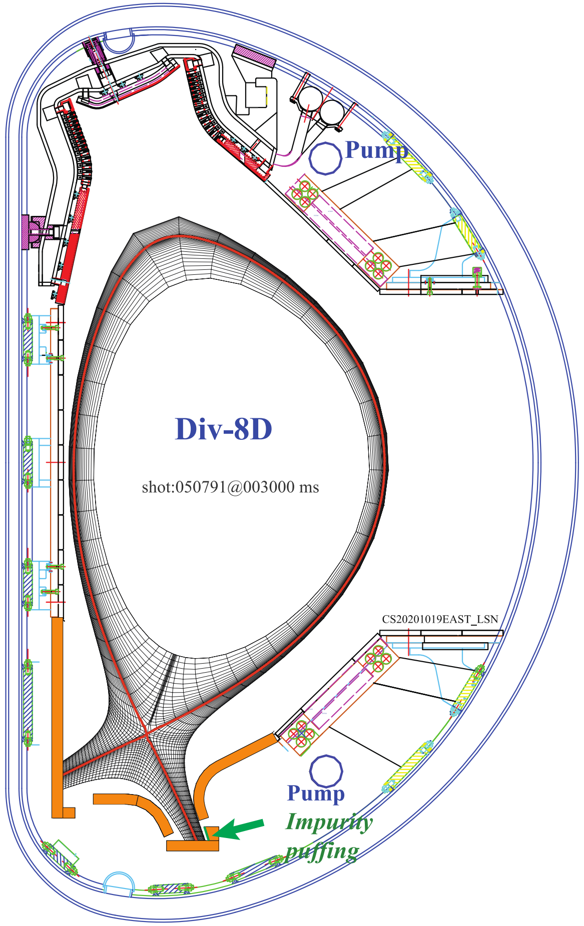
- Tungsten (W) has been chosen as the divertor plasma-facing materials (PFMs) for ITER.
- To solve the power exhaust problem, EAST will upgrade its lower divertor to use W material.
- The W target erosion and W impurity accumulation is the key issue.



Divertor requirements:

- **Heat flux to the target < 10 MW/m^2**
- **T_e< 10 eV includes the far SOL at the target**
- **W impurity control and efficient particle removal**

The SOLPS and DIVIMP are applied to the modeling



Tungsten PFM is used

SOLPS

➢ P_{SOL}= 4.0MW

Simulation species:

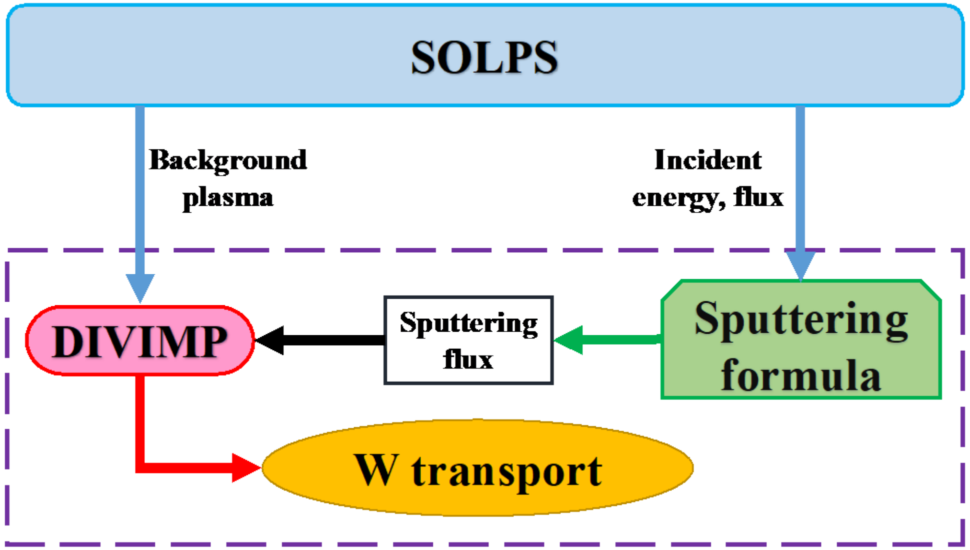
D^0, D^+, Ar^0- Ar^{18+}/Ne^0-Ne^{10+}

Radial transport coefficients:

D= 0.3 m^2/s

χ = 1.0 m^2/s

Drifts are not included by default.

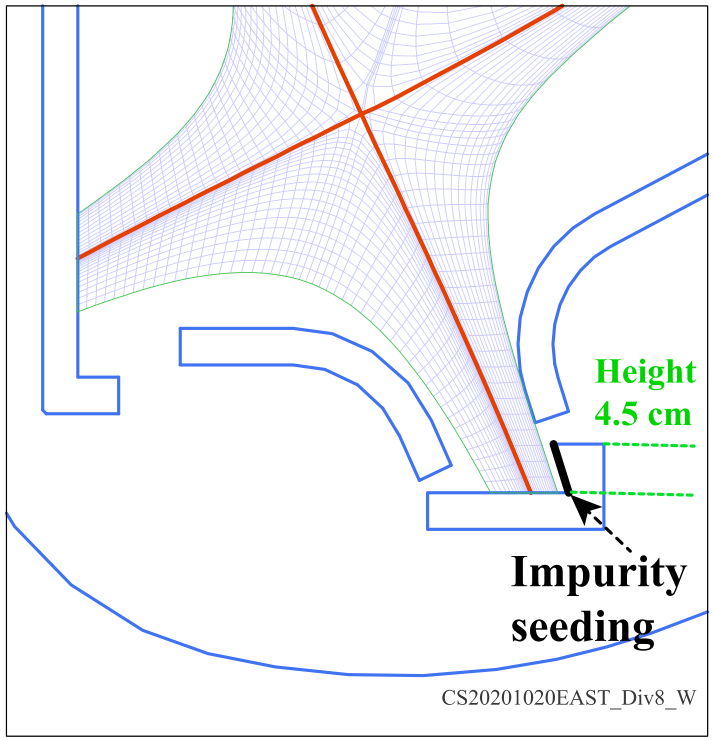


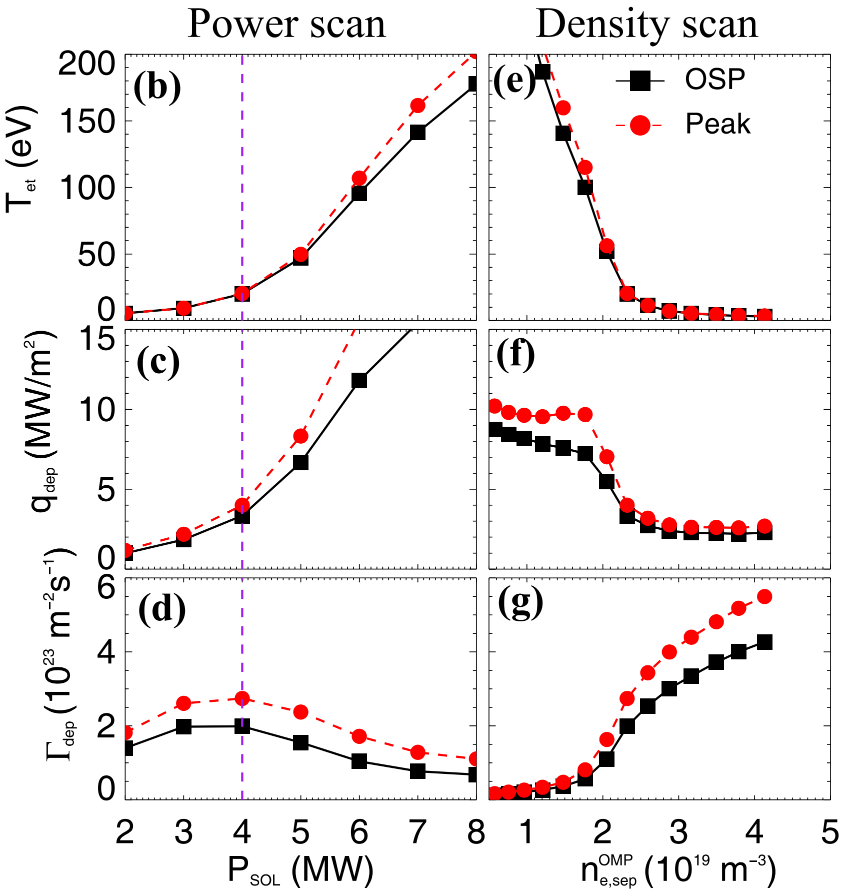
➢ Sang et al., Nucl. Fusion (2021)
➢ Zhou et al., Nucl. Mater. Energy (2020)

Tungsten divertor requires external impurity to enhance the power radiation

Pure D discharge

(a) Divertor 8D

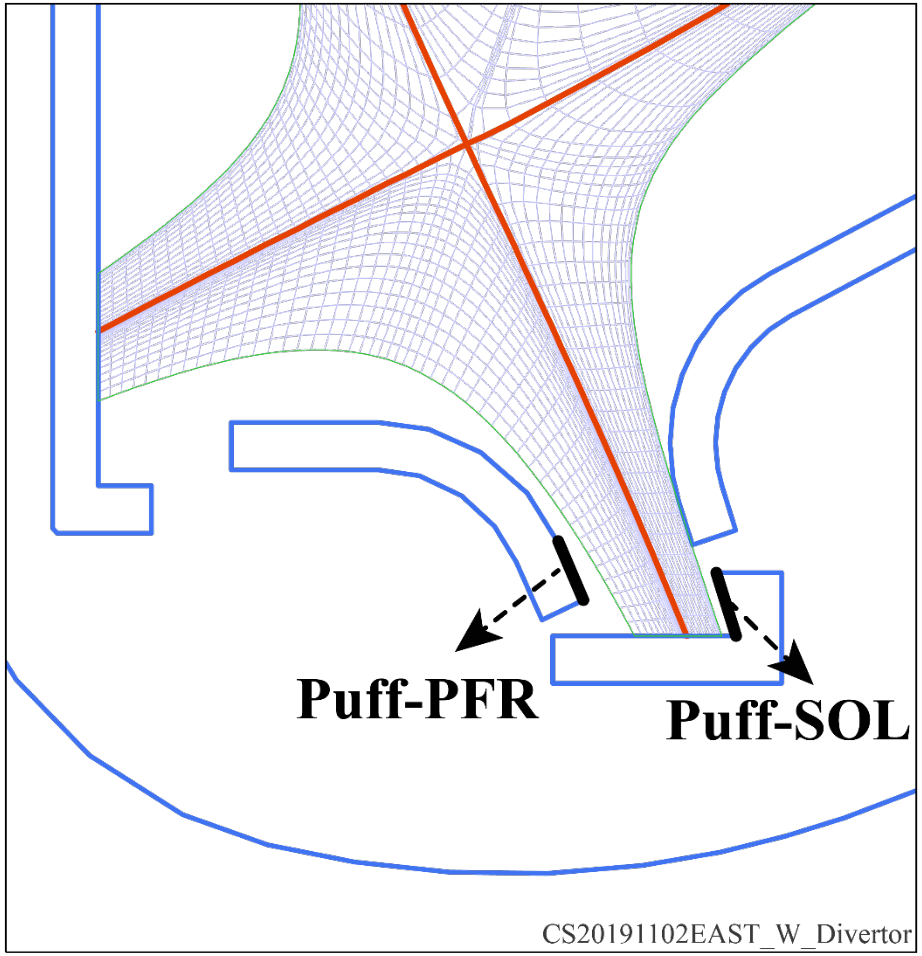




Power scan: maintaining $n_{D+,CEI}$ = 6.0e19 m^{-3}, high P_{SOL} makes it exceed the tolerance of W target easily

Density scan: fixing P_{SOL} =4MW, detachment is not observed even when $n_{e,sep}$ ~ 4e19 m^{-3}

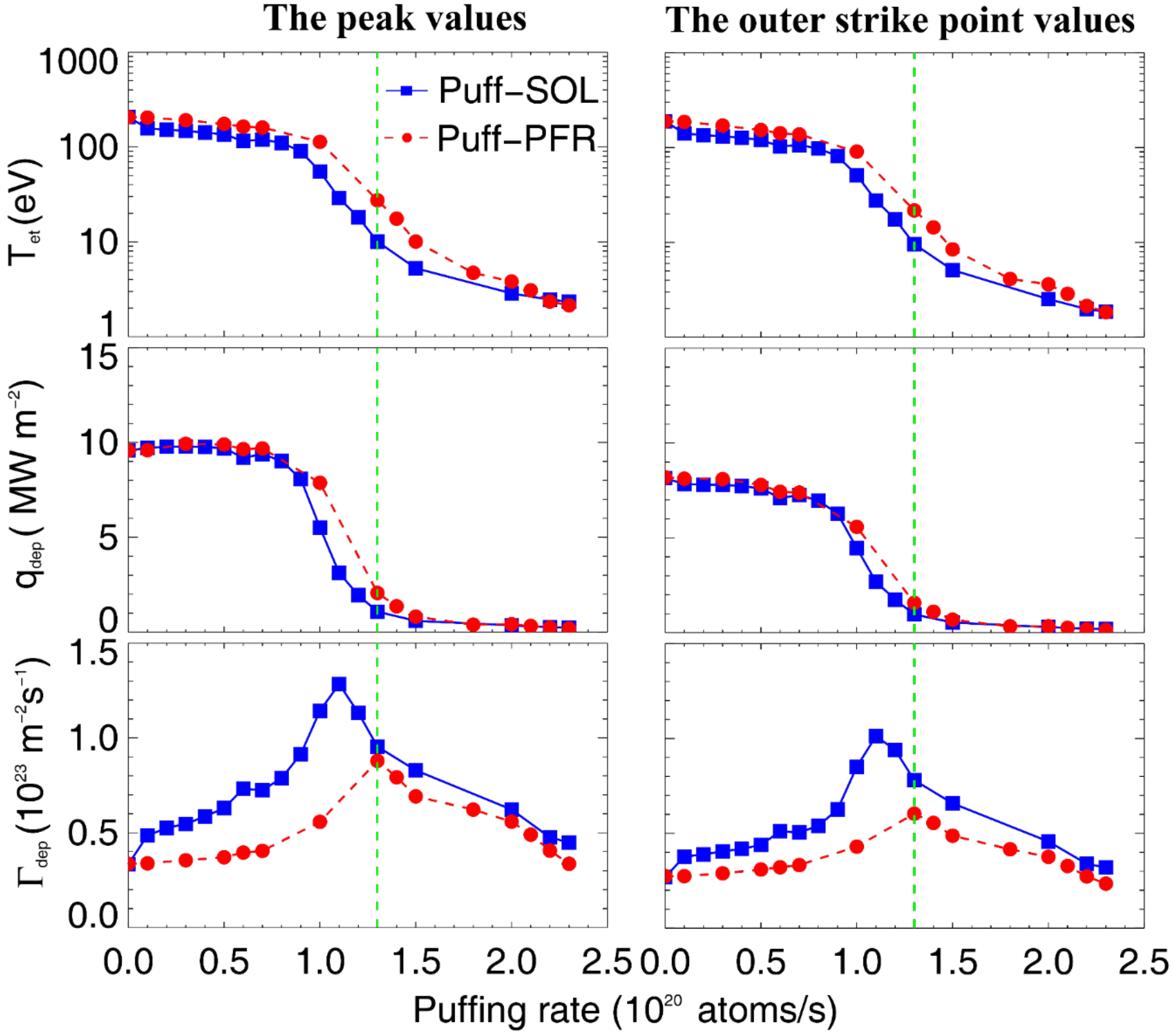
Investigation of the gas seeding location on the divertor/SOL plasma

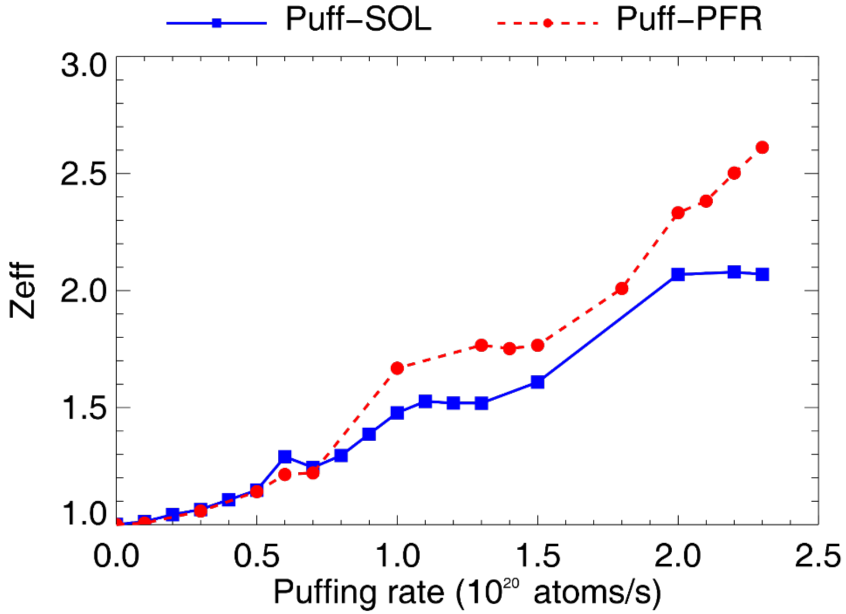


The divertor with W target material is simulated.

- **Two external impurity gas seeding locations are compared: puffing at SOL and PFR.**
- **The puffing rate scan with argon has been done.**
- **The power crossing the core-edge interface (CEI) P_{SOL} = 4 MW, n_{D+} at CEI is fixed to 4.5e19 m-3. ($ne_{sep,omp}$ ~ 1.5e19 m-3)**

The argon seeding scan shows difference between two puffing locations on the plasma

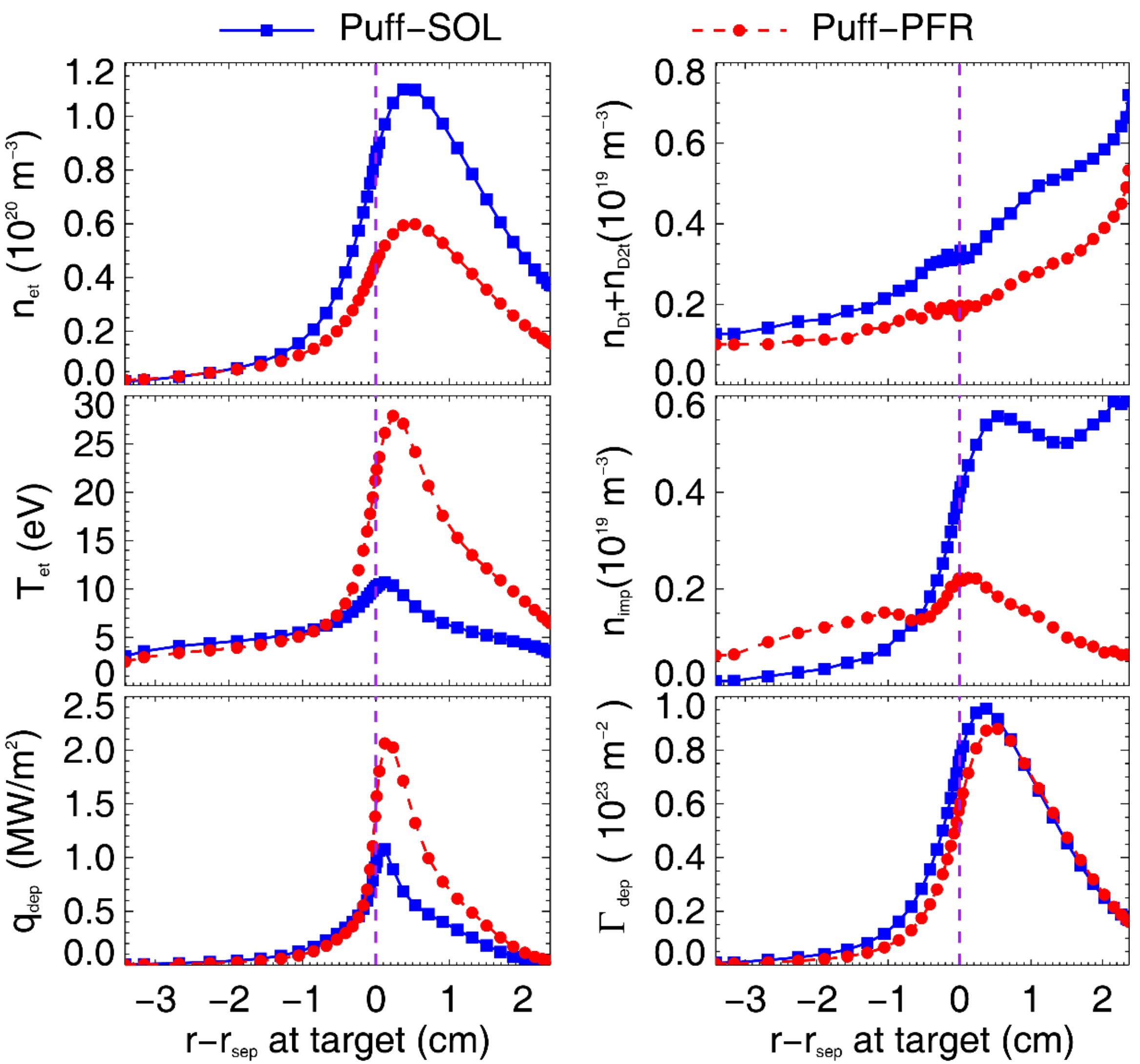


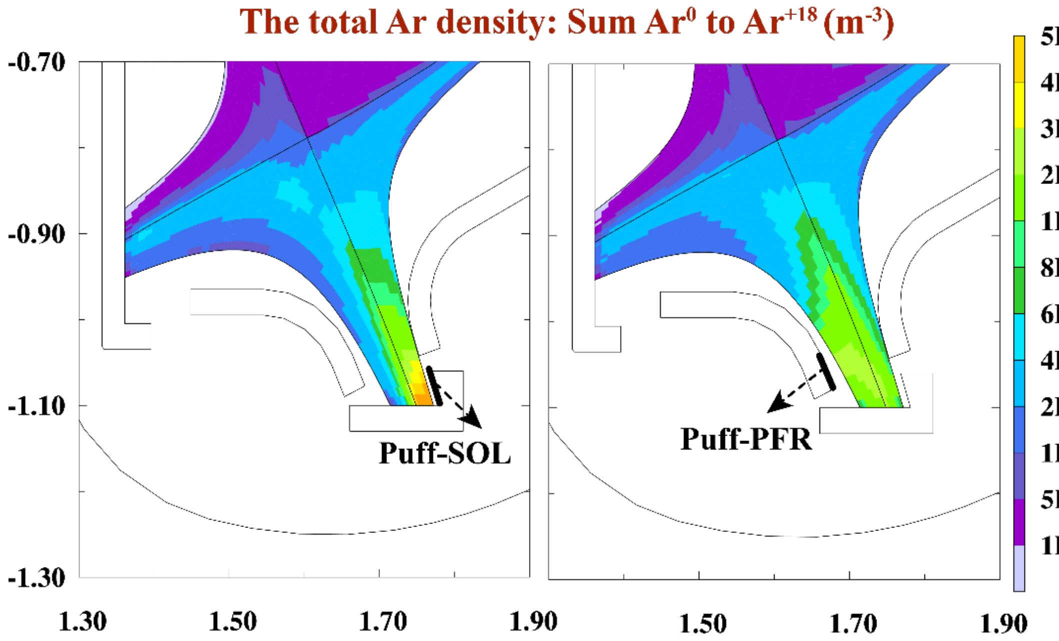


Argon seeding scan in two locations shows

- **Flux rollover: puffing at SOL achieves detachment with smaller seeding rate (1.1 vs 1.3e20 atoms/s).**
- **Zeff at the core edge: puffing at SOL has better impurity screening.**

The profiles at the outer target shows significant differences between two seeding locations

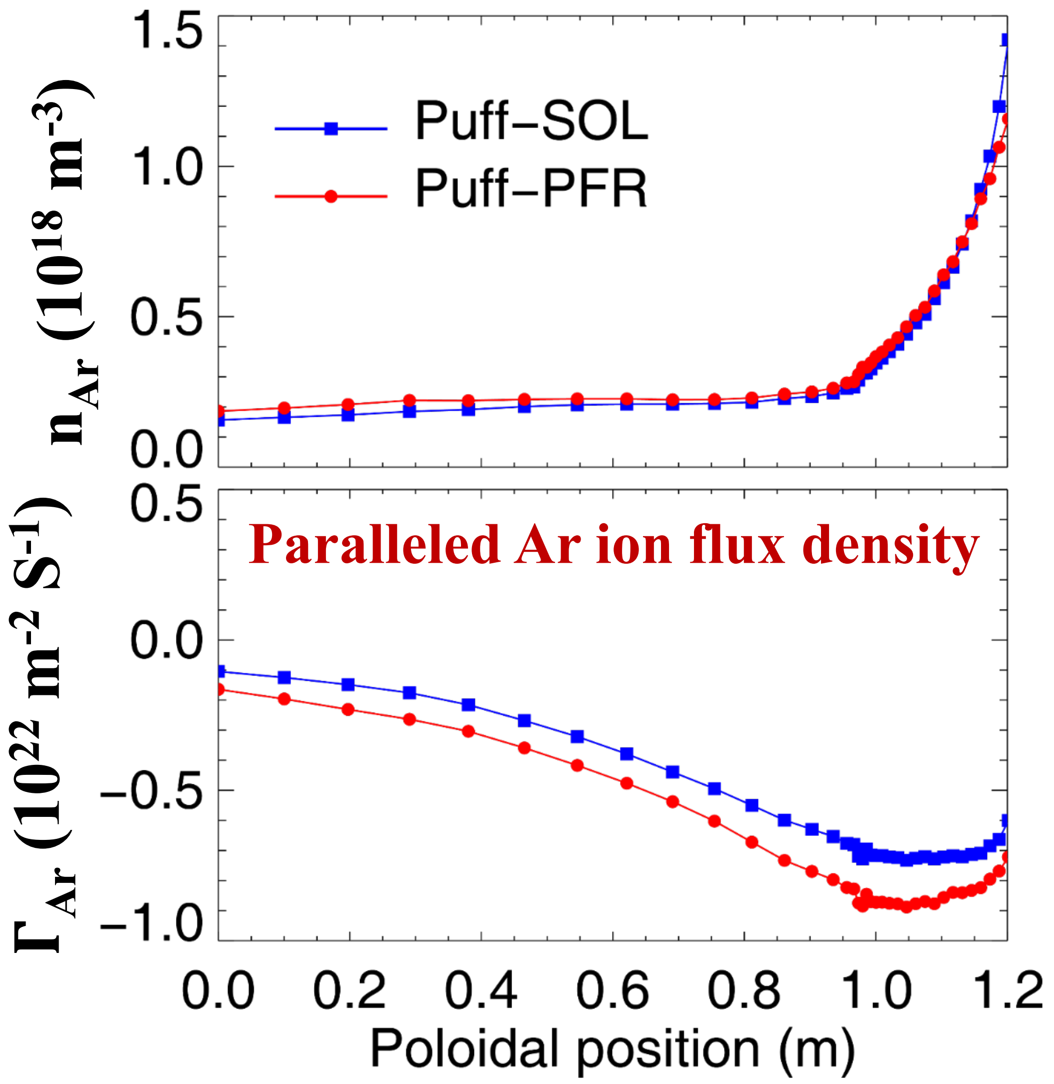


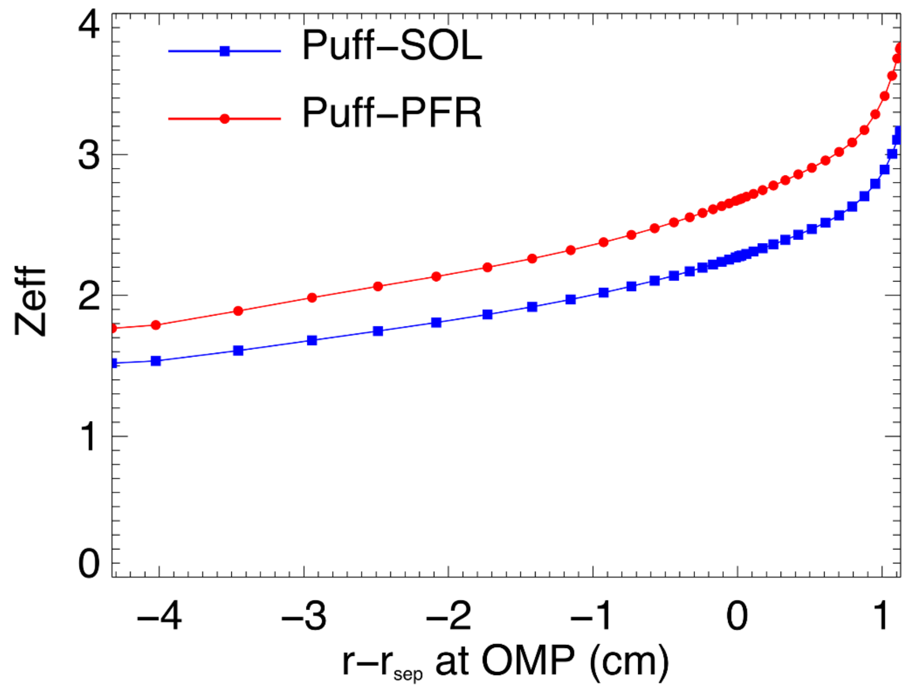


For the same Ar gas seeding rate (1.3e20 atoms/s)

- **Te and q of the seeding at SOL is much lower.**
- **The Ar impurity density are totally different.**

The smaller Ar ion flux from the outer target to the upstream reduces Zeff of puff-SOL case

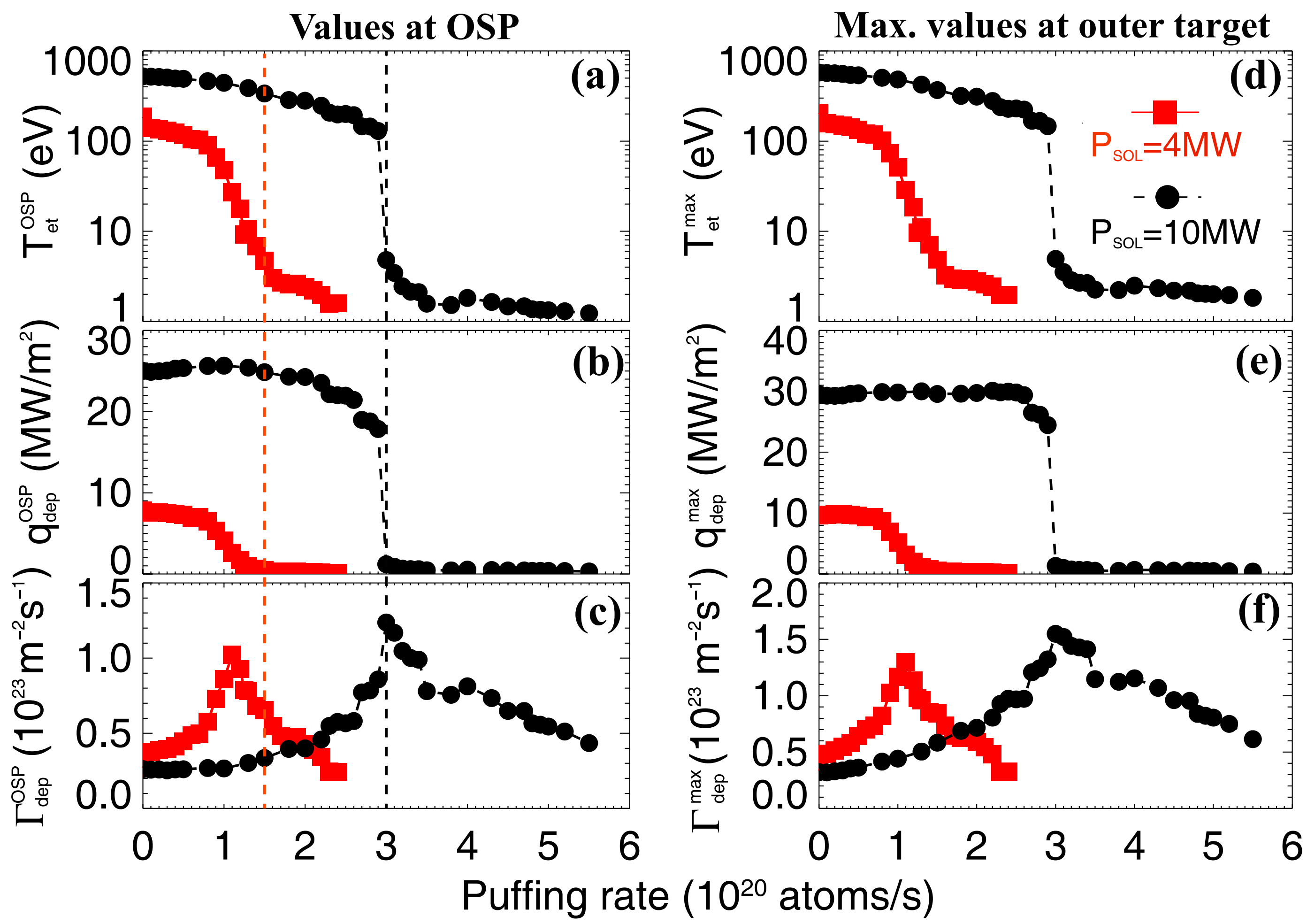




- **The direction of Ar flux at the SOL is from outer target to OMP (negative value).**
- **Puff-SOL case has smaller Ar ion flux, and better impurity screening.**

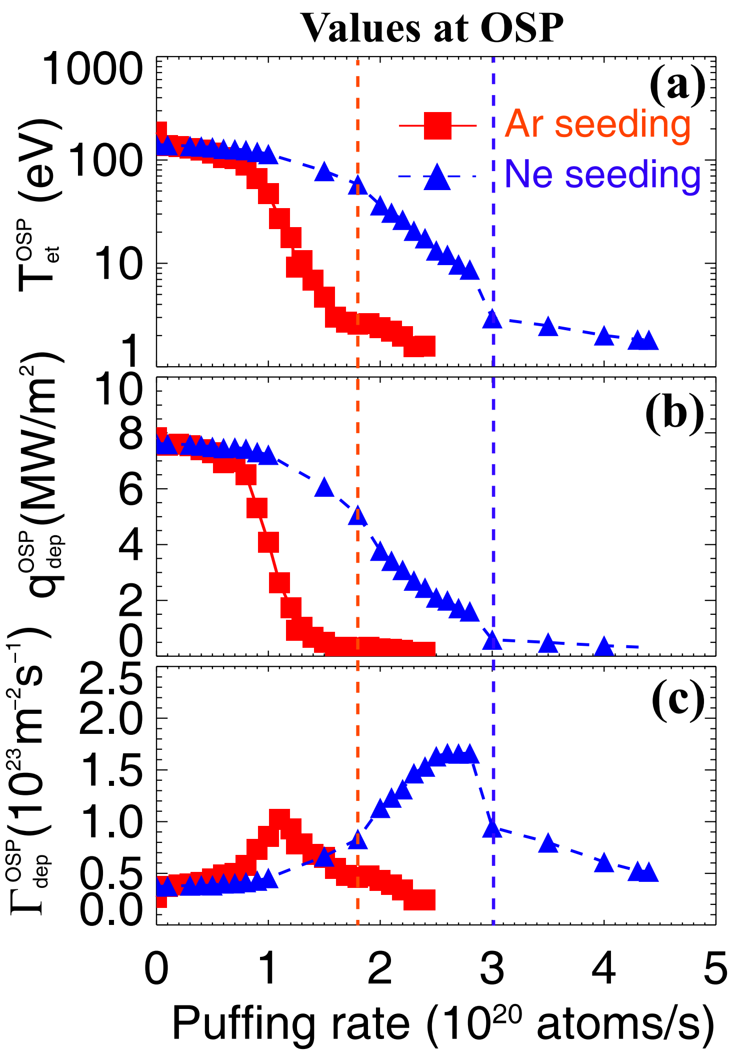
Larger P_{SOL} requires higher seeding rate to dissipate energy

Argon seeding at SOL



- Both T_{et} and q_{dep} fall first gradually, then remarkably.
- The sudden drop occurs at T_{et} ~ 130 eV, due to more than one order of magnitude increment of L_Z as T_e raises higher than ~ 130 eV.
- To reduce T_e at OSP below 5 eV, the required Ar seeding rate is 1.5 and 3.0×10^{20} argon atoms/s for P_{SOL} = 4 MW and 10 MW.

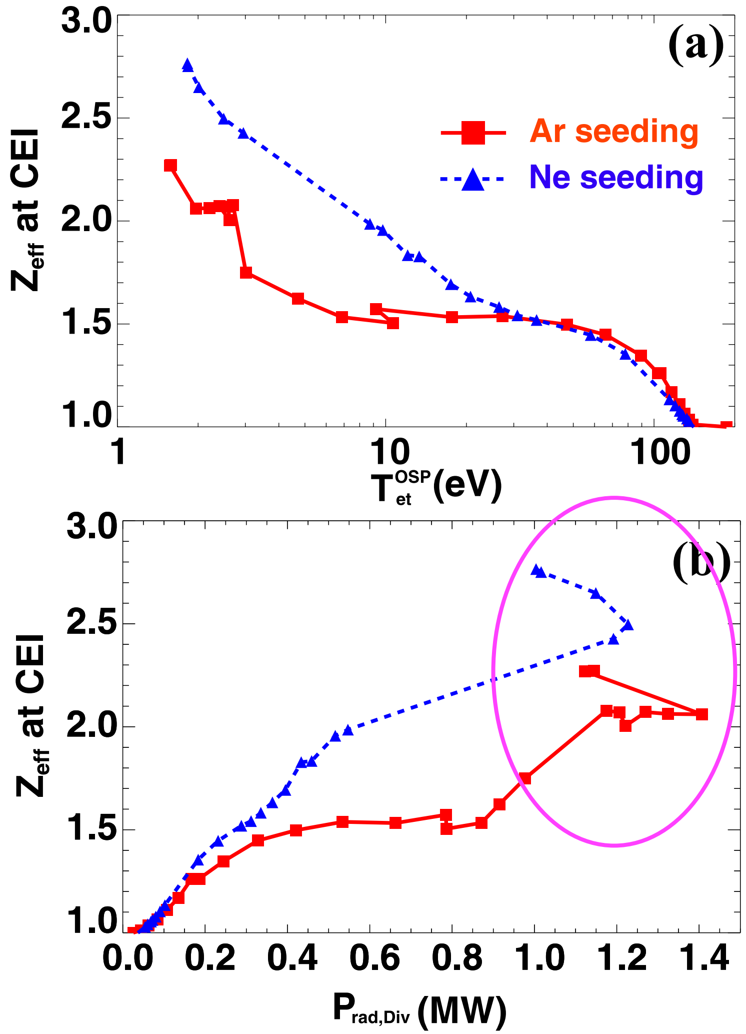
The comparison between Ne and Ar seeding rate scan shows significant difference on divertor plasma



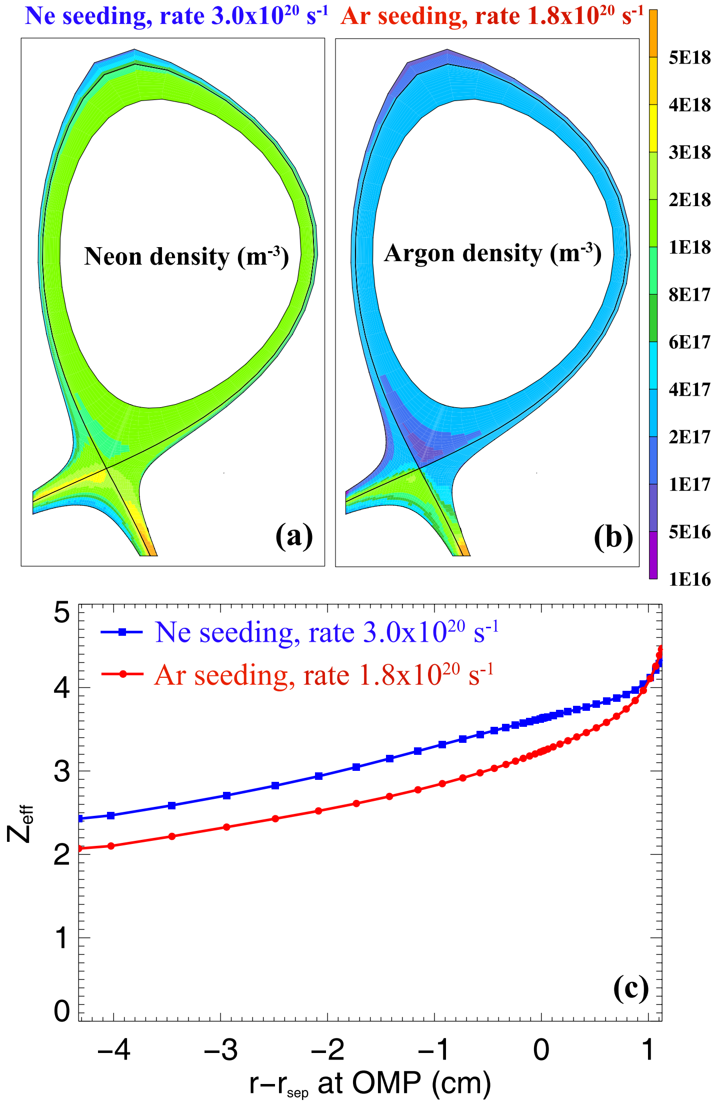
- **Detachment requires much smaller Argon seeding rate than that of neon. 1.1×10^{20} Ar atoms/s vs 2.6×10^{20} Ne atoms/s**
- **Argon has more power radiation efficiency than that of neon**

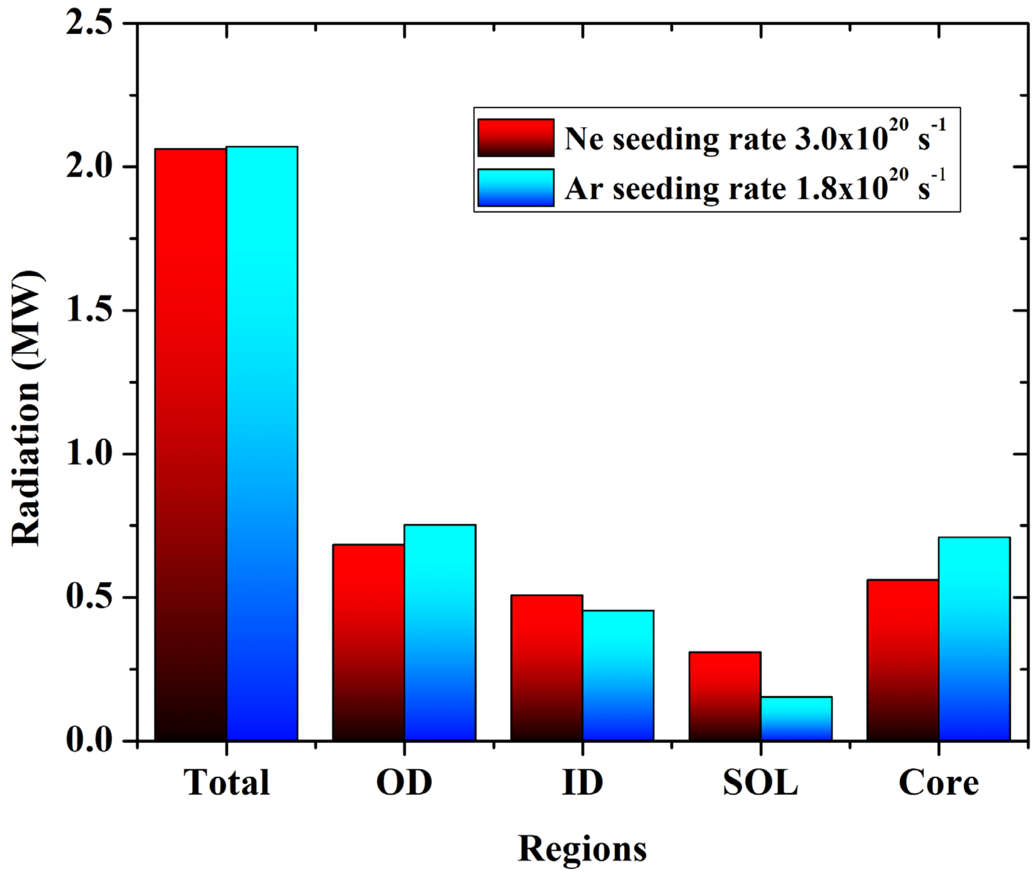
T_{et}^{OSP} and $P_{rad,Div}$ are used to represent divertor condition, Z_{eff} represents the influence on the core plasma.

- **Smaller T_{et}^{OSP} corresponds to larger Z_{eff}.**
- **When T_{et}^{OSP} < 20 eV, Ne seeding leads to larger Z_{eff} than Ar seeding with same T_{et}^{OSP}**



For similar total power radiation, the Ar seeding has smaller Zeff in the core than that of the Ne seeding

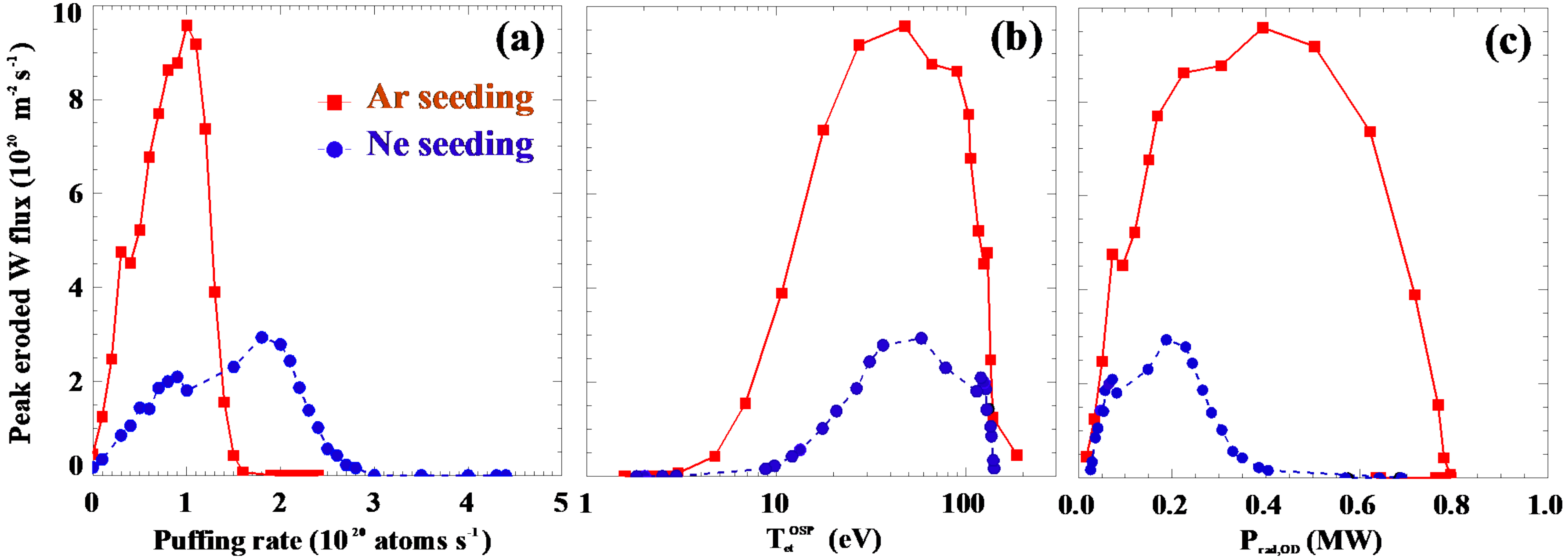




Power radiation efficiency in the core of the Ar is much higher than Ne

- ➢ **Neon seeding rate is much higher than that of Ar seeding.**
- ➢ **Neon density in the core is much higher than that of Ar**
- ➢ **Core radiation by Ar is little higher than that of Ne seeding**

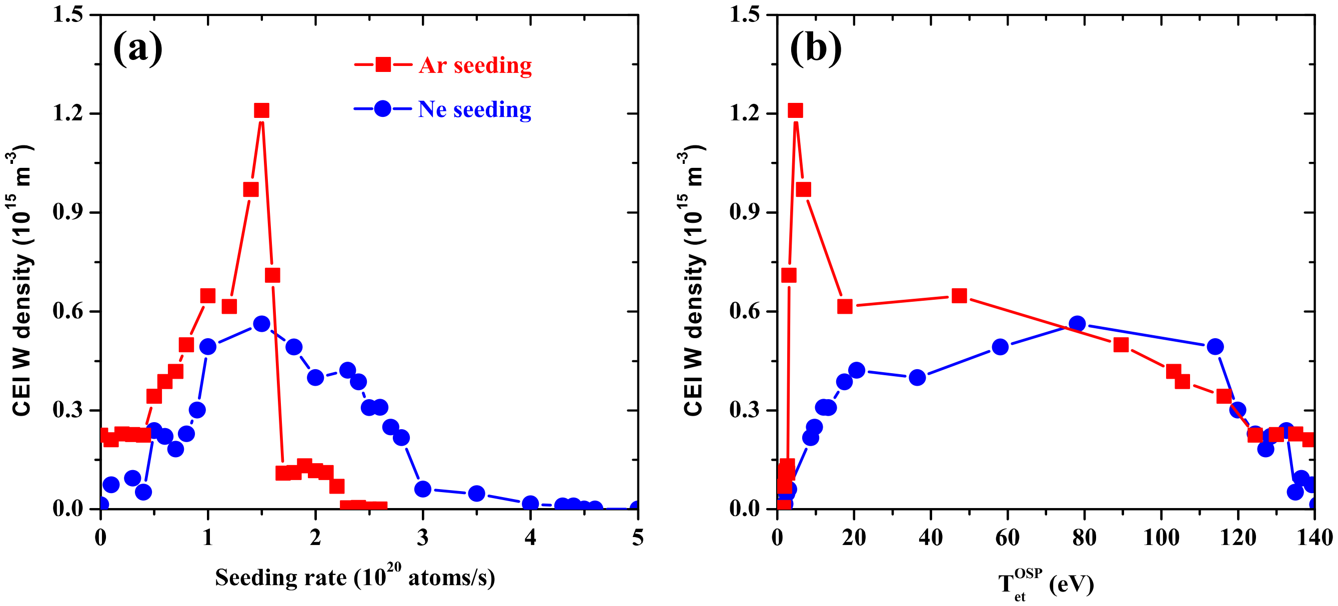
W divertor erosion shows the disadvantage of Ar seeding compared to Ne seeding

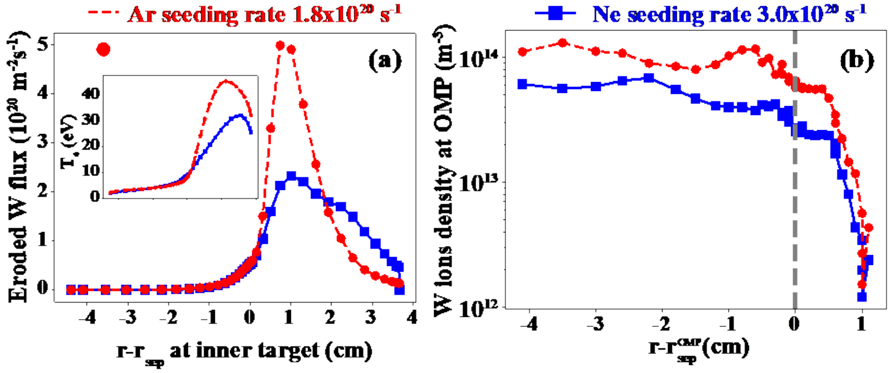


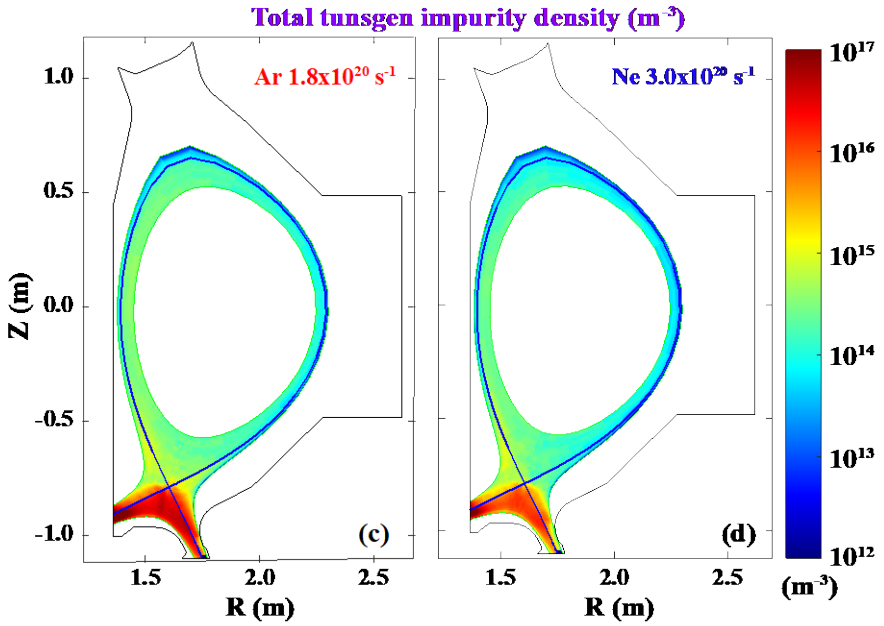
The correlations between the peak Γ_W at outer target and puffing rate, T_{et}^{OSP}, and $P_{rad,OD}$

- **As seeding rate increases, Γ_W first increases, then decreases.**
- **Much larger Γ_W with Ar than that with Ne for the same T_{et}^{OSP} or $P_{rad,OD}$.**
- **T_{et}^{OSP} < 10 eV with Ne or < 5 eV with Ar should be satisfied to eliminate W erosion**

Argon seeding leads to more W impurity accumulated in the core plasma region than Ne (DIVIMP modeling)







- Ar leads to higher W density in the core region than Ne with insufficient seeding rate (i.e. < 1.6×10^{20} argon atoms/s).
- For same T_{et}^{OSP}, Ar leads to more W impurity in the core.

Conclusions

1. Argon seeding at SOL location is better than seeding at PFR by considering the divertor power dissipation and impurity screening.
2. Larger P_{SOL} requires higher seeding rate to dissipate energy
3. The advantage of Ar impurity is the higher power radiation efficiency and better divertor impurity screening. While the disadvantage of Ar is the stronger core radiation.
4. Ar seeding causes more serious target erosion and core plasma contamination problem than that of Ne seeding.

Thanks for your attention!