Simulation Study of the Radiation Efficiency of Different Impurity in Divertor Plasma

Shifeng Mao, Minyou Ye, Yifu Zhou

School of Nuclear Science and Technology, University of Science and Technology of China, Hefei, Anhui 230026, PR China

Email: sfmao@ustc.edu.cn

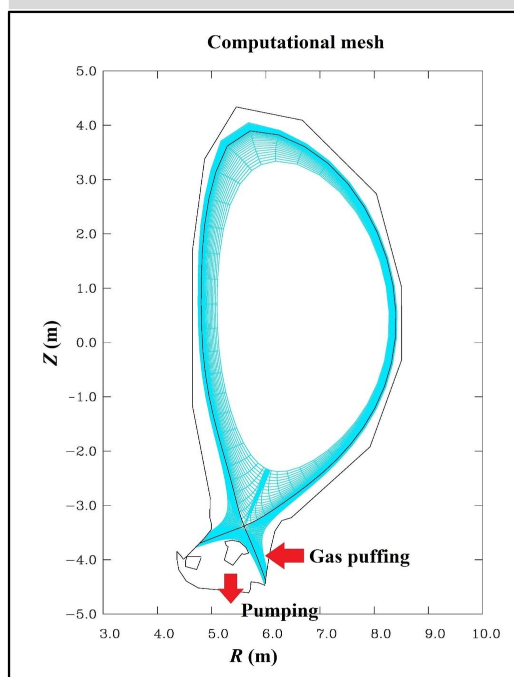
Abstract

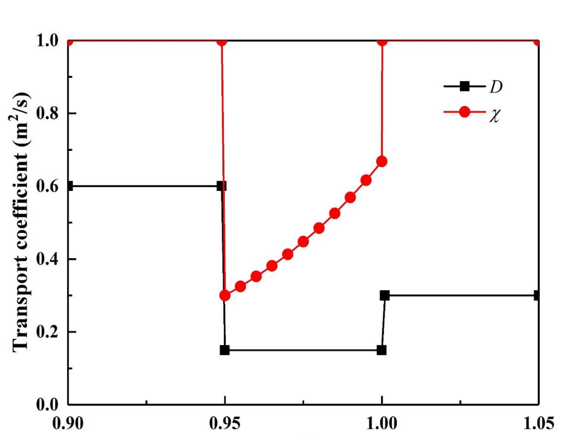
- Impurity seeding is necessary for future fusion reactor where no intrinsic radiative impurity exists.
- The radiative divertor with a high radiation fraction ~85% is simulated by seeding N/Ne/Ar for CFETR.
- The performances of different impurity species are compared and discussed.
- A modified Matthews's scaling law is attempted.

Background

- For CFETR, the fusion power would be ~1 GW[1], it is necessary to radiative the thermal power to a high fraction to avoid unacceptable heat flux onto divertor targets. Because full metal wall is considered to avoid tritium retention issue, radiative impurity seeding is necessary.
- On the other hand, too much impurity would cause degradation of the core plasma performance.
- Among the various consideration to have a high radiation power and low impurity concentration, the choice of a kind of suitable impurity species is of high attention.
- This work focuses on the influence on the radiative divertor performance of different impurity species.

Simulation Settings





Boundary conditions (ρ = 0.9):

- $P_e = P_i = 100$ MW
- $n_{D^+} = 6.0\times10^{19}$ to 1.0×10^{20} m^{-3}

Other settings:

- no sputtering
- no drifts
- recycling rate is 100%:

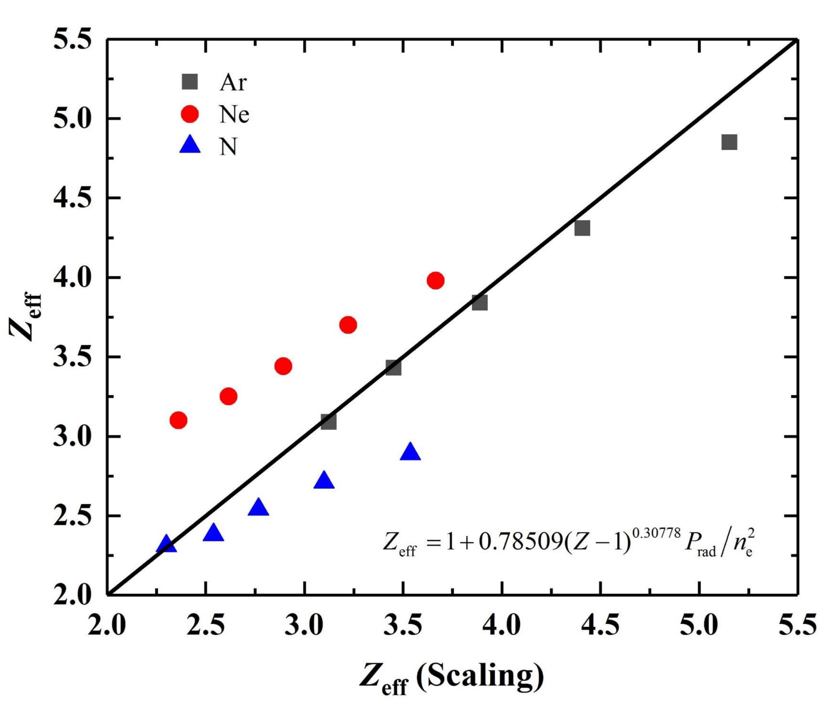
D_2 + impurity puffing

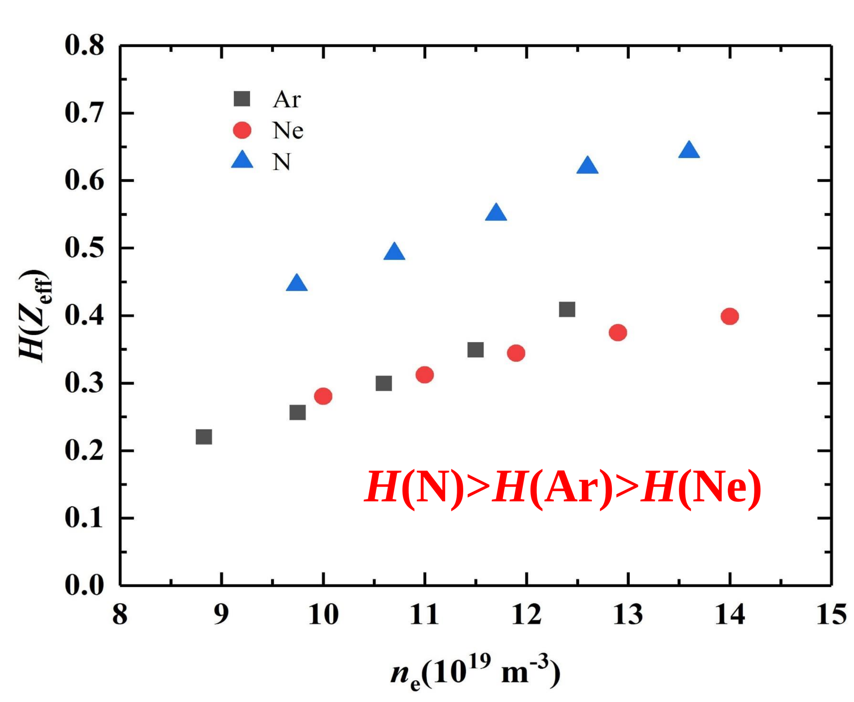
D_2 puffing rate fixed to 8.0 × 10^{22} s^{-1}

Impurity (N/Ne/Ar) rates adjusted to achieve **a radiation fraction ~85%**

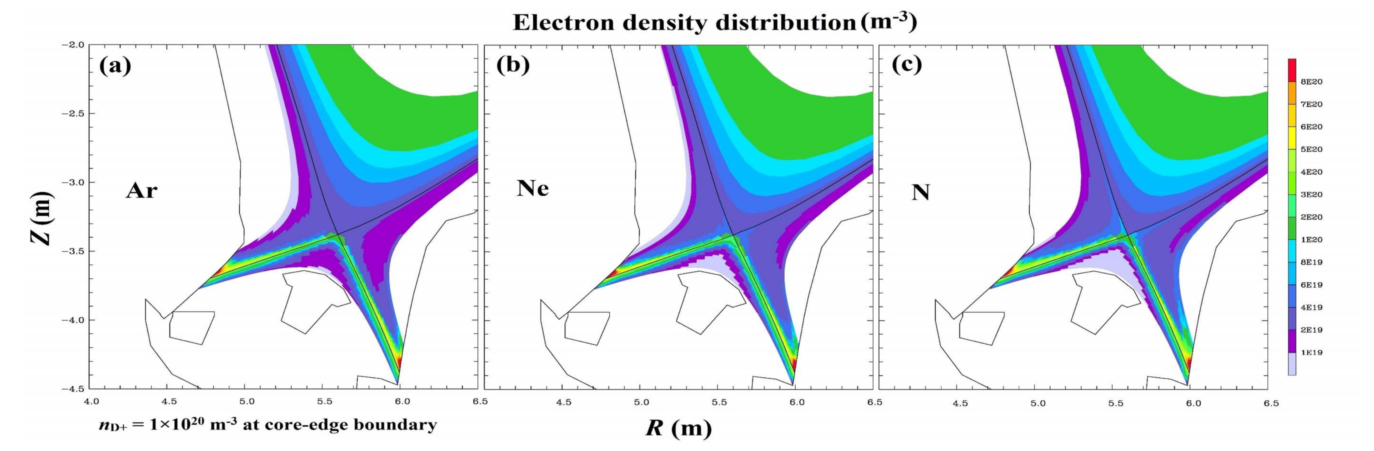
Results and discussions

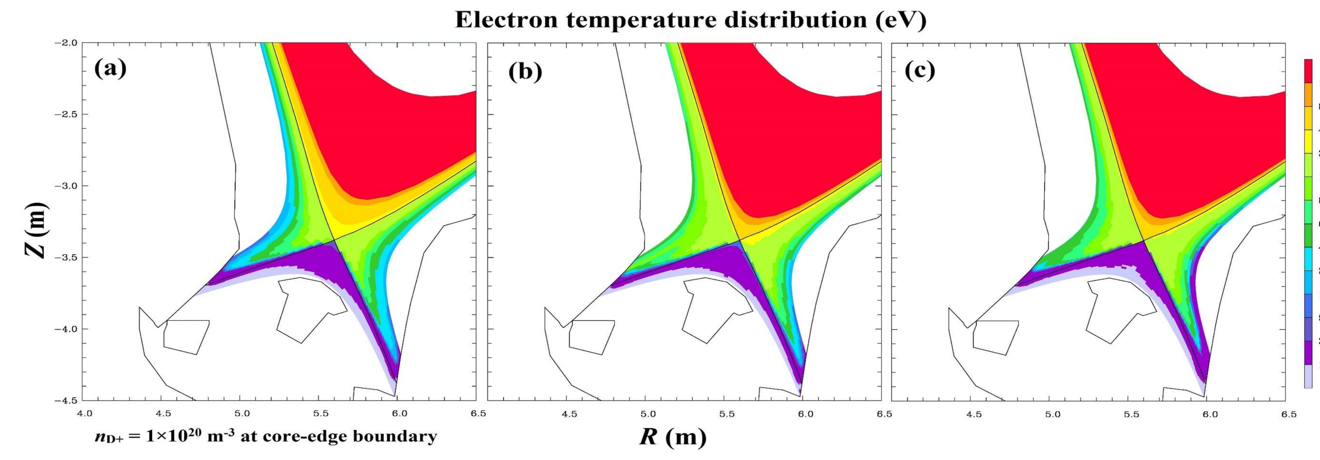
- Simulated Z_{eff} is fitted according to the Matthews' law[2]. Obviously difference can be seen for different impurity species.
- The radiative efficiency $H(Z_{eff})=f_{rad}/(Z_{eff}-1)$ is calculated to compare the performance of three different impurity species.



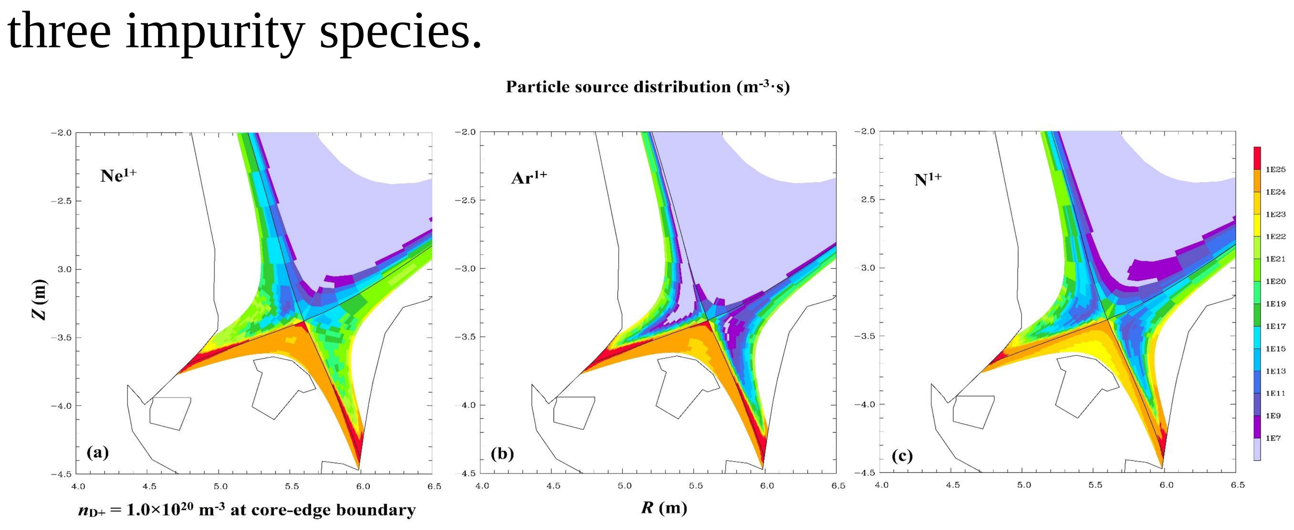


- The background plasmas are similar for along the separatrix, while for the low Z impurity the far SOL region is colder and denser. (below the $n_{D+} = 1.0\times10^{20}$ m^{-3} cases are used for discussion)





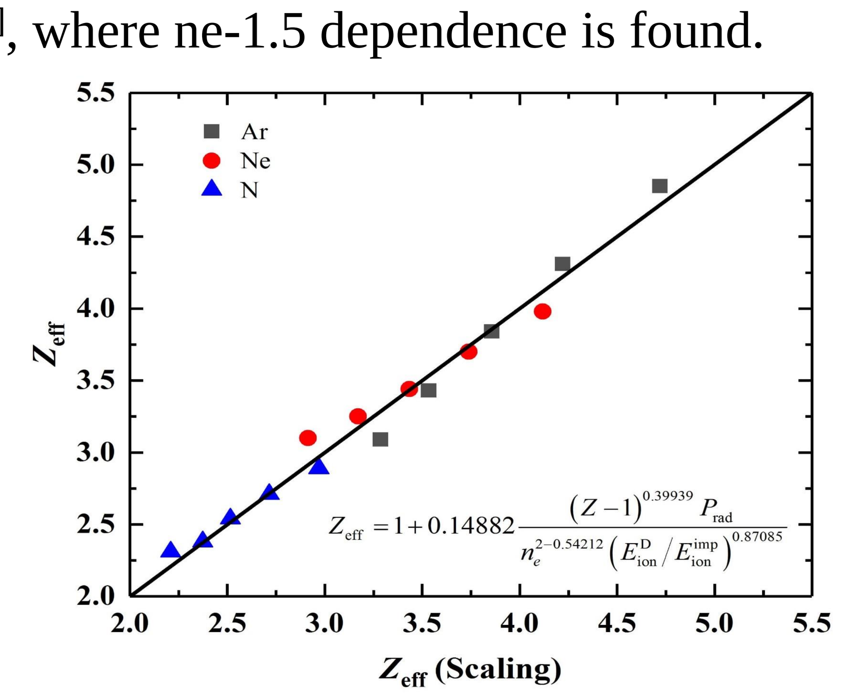
- With in the plasma background, the expansion of the ionization source distribution to the upstream near the separatrix is in the order of Ne, Ar and N.
- The depth of the ionization is in the same order with the ionization potential for the three impurity species.



- By using DIVIMP code, the absorption time is simulated. The result shows that the better performance is related to a lower absorption time. It implies that the impurity with lower ionization potential would have larger non-coronal effect.

Impurity species	Ar	Ne	N
Ionization potential (eV)	15.8	21.6	14.6
Neutron velocity (m/s)	432	611	732
Ionization length (m)	1.632	6.721	0.295
Ionization time (s)	3.78×10^{-3}	1.10×10^{-2}	4.03×10^{-4}
Absorption time (s)	4.28×10^{-3}	1.27×10^{-2}	4.35×10^{-4}

- Considering the influence of limited $n_e\tau$, a modified Matthews' scaling law is assumed. The n_e dependence is in good agreement with the experimental scaling for JET[3], where ne-1.5 dependence is found.



Conclusions

- Nitrogen will cause least fuel dilution with a fixed radiation fraction f_{rad} ~ 85% (there are potential drawbacks of increasing tritium retention with tungsten PFCs and the formation of ammonia), while Ne cause higher Z_{eff} than Ar.
- The difference in the performance is related to the ionization potential of impurity species, i.e. the higher ionization potential, the deeper ionization source, and the less non-coronal effect.
- A modified Matthews' scaling law is brought out $Z_{eff}=1+C(Z-1)^{\alpha}P_{rad}\big/n_e^{2-\beta}\left(E_{ion}^{D}/E_{ion}^{imp}\right)^{\gamma}$

References

[1] Y.X. Wan, et al., Nucl. Fusion 57 (2017) 102009.
[2] G. F. Matthews et al, J. Nucl. Mater. 241-243 (1997) 450.
[3] J. Rapp et al., J. Nucl. Mater. 390-391 (2009) 238.