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Improved screening effect of seeded high-Z impurity through SOL plasma flow enhanced by additional low-Z impurity injection

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Abstract

Numerical simulations by the integrated divertor code SONIC show that the screening effect on the seeded high-*Z* impurity in the SOL plasma is improved through the enhancement of plasma flow induced by additional low-*Z* impurity injection. A single impurity injection of Ar into a steady-state high-beta plasma of JT-60SA results in a high Ar density at the top of SOL plasma, leading to an increase of core Ar density. This issue can be solved with even a small Ne seeding, which reduces Ar density in the SOL and the core plasmas. This is mainly caused by the enhanced friction force due to the higher D+ parallel flow towards the inner divertor, which is originated from the strong Ne radiation around X-point. We show that the line emission of Ne^{7+} has a key role for the generation of higher D^+ parallel flow.

Divertor power handling by impurity seeding

One of the issues towards ITER and DEMO is divertor power handling

Radiation cooling of impurity has important role

- **Intrinsic impurities** generated from wall/divertor plate: W, Be, C
- **Extrinsic Seeding impurities**: N, Ne, Ar

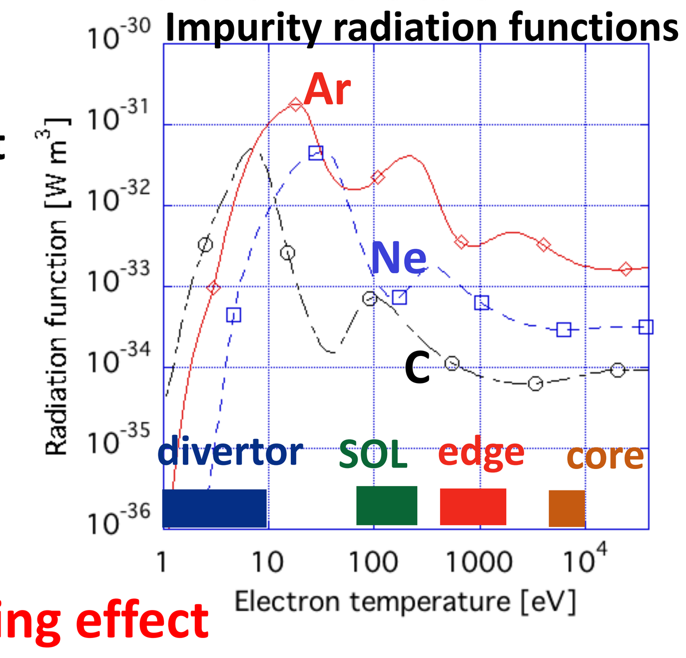
Radiation cooling in Divertor/SOL/Edge
- Reduces divetor heat load

Impurity accumulation in the core
- Harmful to the core performance (dilution/radiation)

Ar: radiative in Div./SOL/Edge; high charge/ radiative in the core

Ne: radiative in Div.; larger seeding rate than Ar required -> dilution in the core

To establish control method of impurity transport in the SOL/divertor is necessary

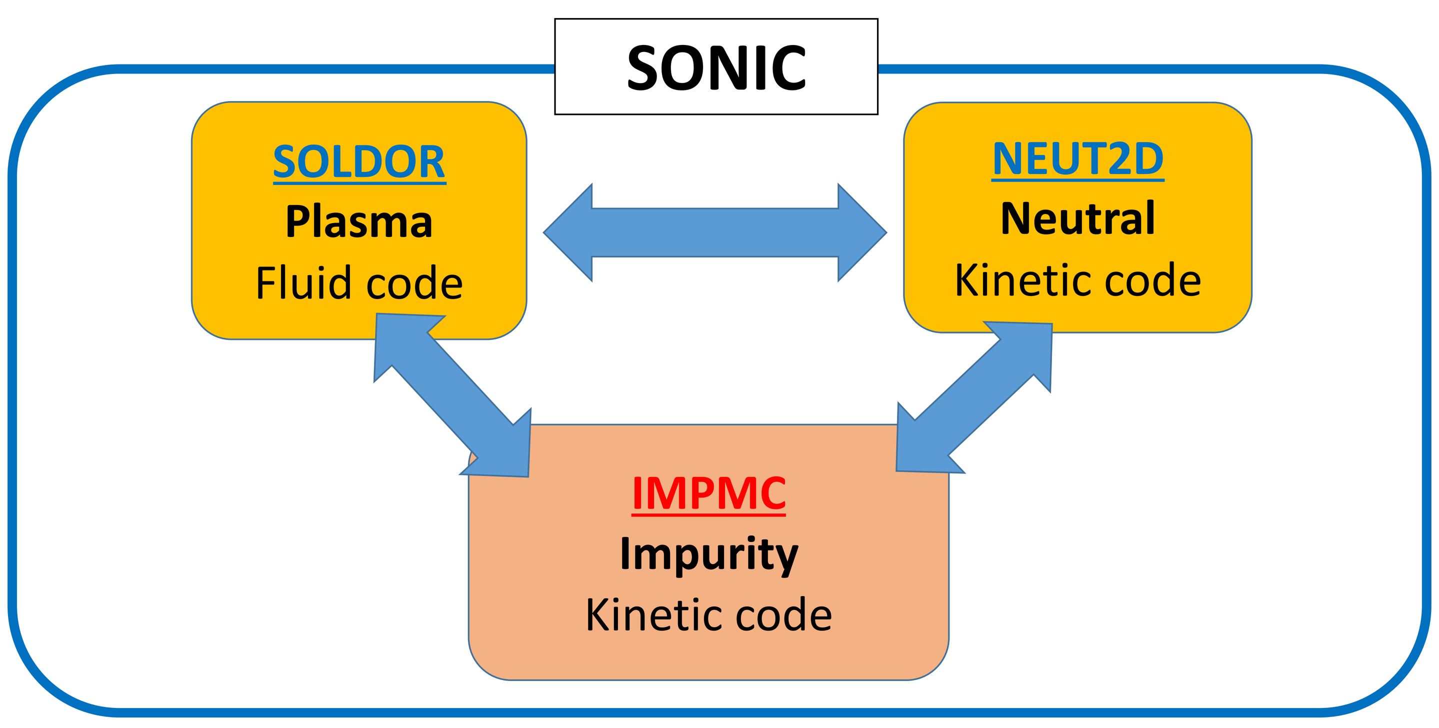


One of the possible seeding strategies is mixed-impurity seeding

-> Different radiation characteristics of each species
Is it possible to control impurity transport?

Aim: Study mixed-impurity (Ar + Ne) seeding effect
- e.g. plasma-impurity interaction, impurity transport processes, etc.

Integrated SOL/divertor transport code SONIC [1]



Self-consistently computes transport processes of plasma, neutral and impurity

SONIC computes impurity transport kinetically by IMPMC code

Kinetic effects of impurity can be considered (i.e. detailed Coulomb collision processes, plasma-wall interactions, etc.)

SONIC is applied to JT-60SA steady state high-beta plasma with Ar-only and Ar+Ne mixed impurity seeding simulations

Calculation conditions

Input parameters

P_{out} = 23 MW

Γ_{ion} = 2.8 x10^{21} s^{-1} (from NBI),

Γ_{puff}^{osol} = 4.25 x 10^{21} s^{-1} (8.5 Pa m^3/s)

S_{pump} = 50 m^3/s,

D = 0.3 m^2/s, $\chi_i = \chi_e = 1.0\ \mathrm{m^2/s}$

Seeding impurity

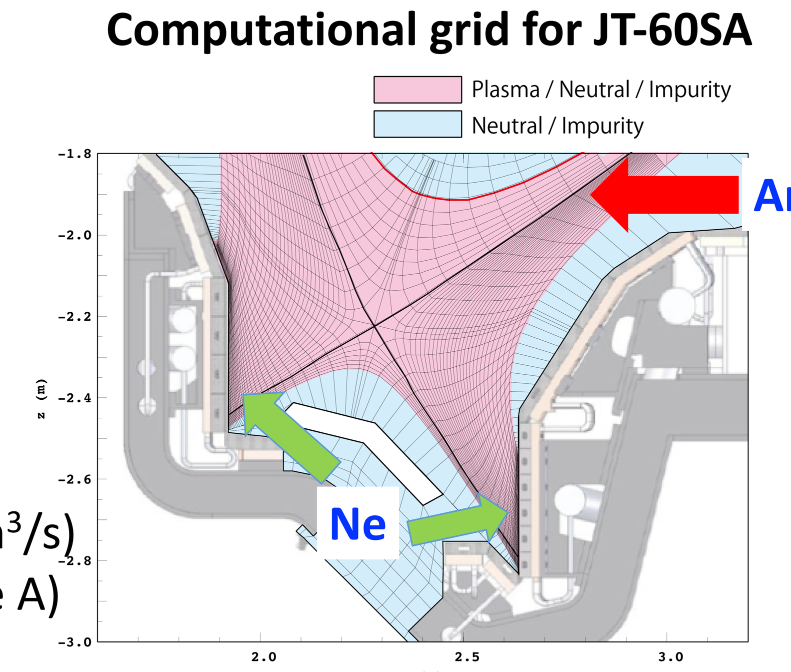
Case A: Ar (0.2 Pa m^3/s)

Case B: Ar (0.2 Pa m^3/s) + Ne (0.02 Pa m^3/s)
(Additional Ne seeding into Case A)

+ intrinsic C impurities (wall material)

C generation: Chemical sputtering, C self sputtering, Physical sputtering by D, Ar, Ne

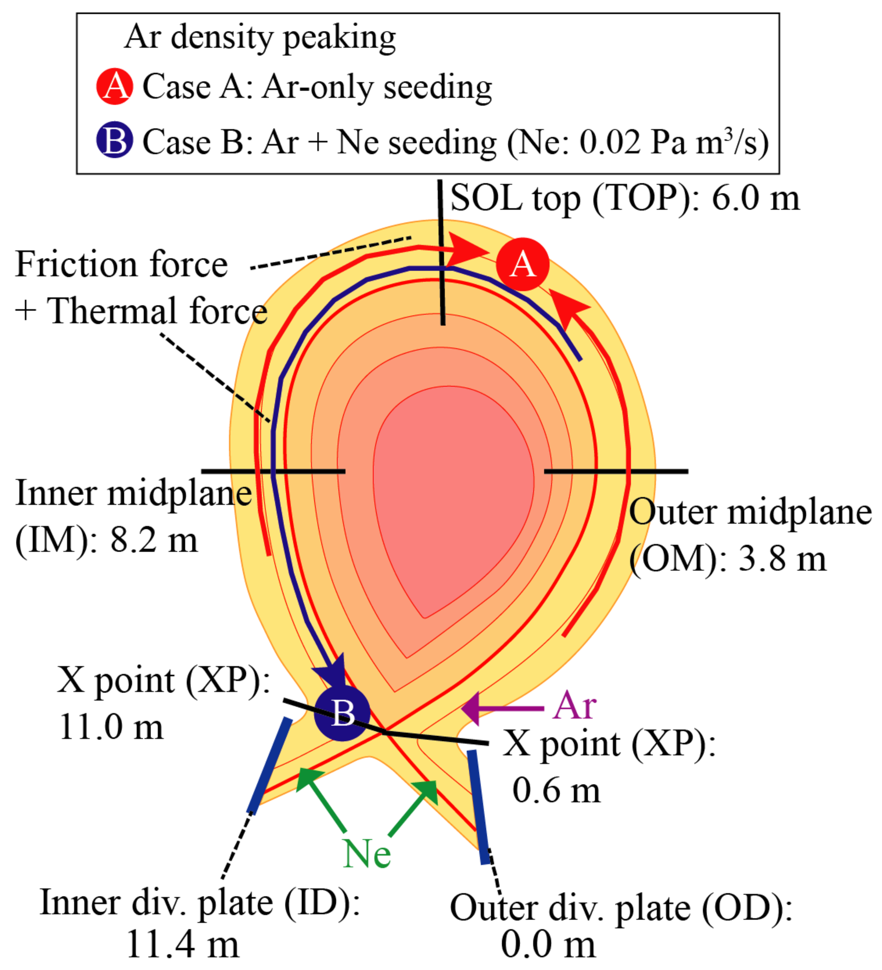
Computational grid for JT-60SA



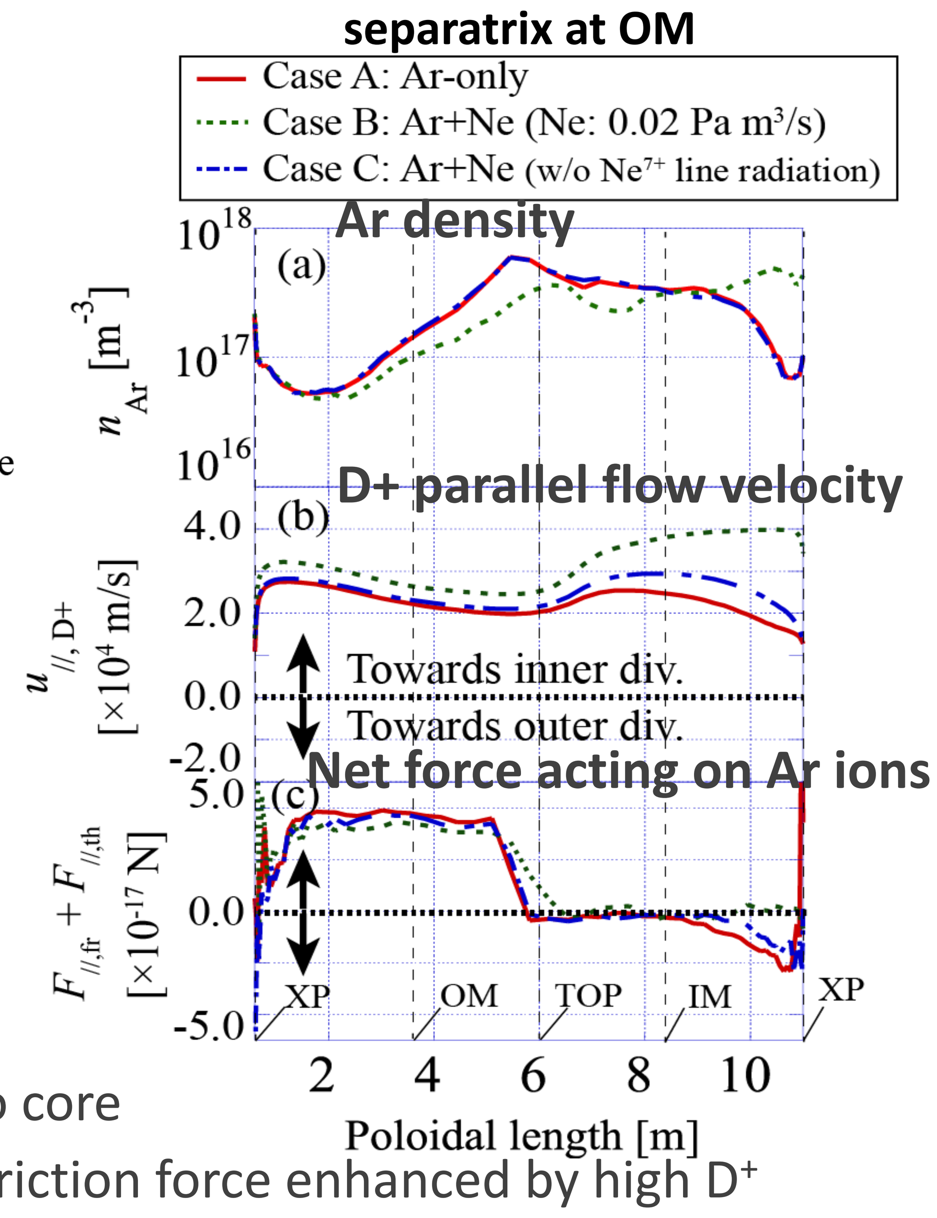
Results

Additional Ne seeding into Ar-seeded plasma results in low Ar density at SOL top -> low Ar density in core

Schematic view of Ar density and net force



Ar density/D+ flow/ net force distributions plotted along flux tube 0.8 mm outside separatrix at OM

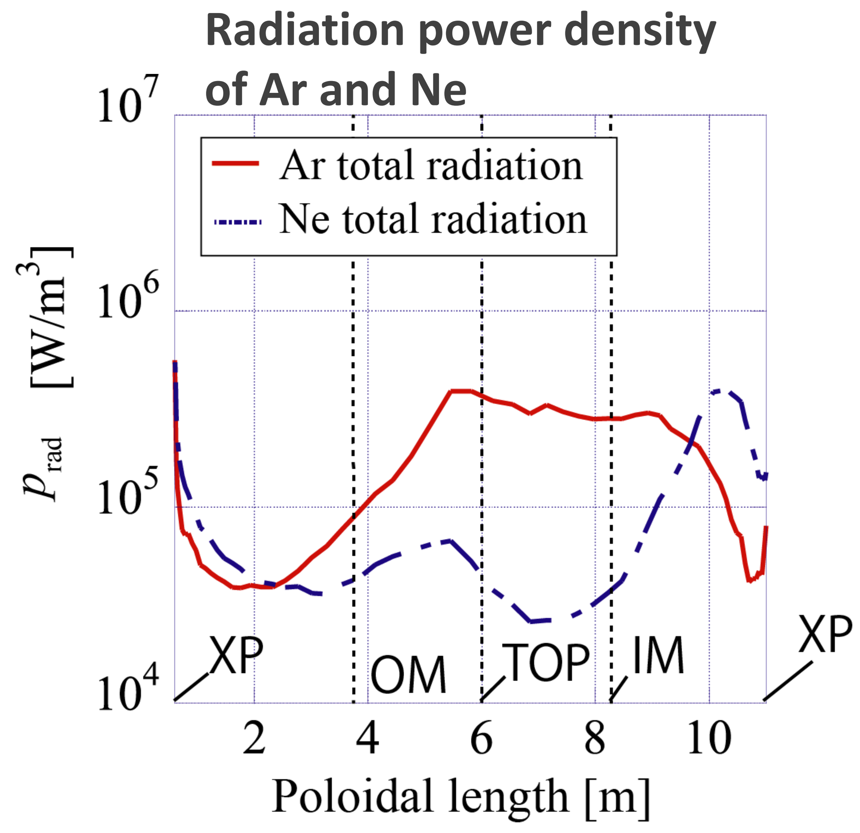


Case A: high Ar density in SOL top by thermal force
-> main source of Ar ions into core

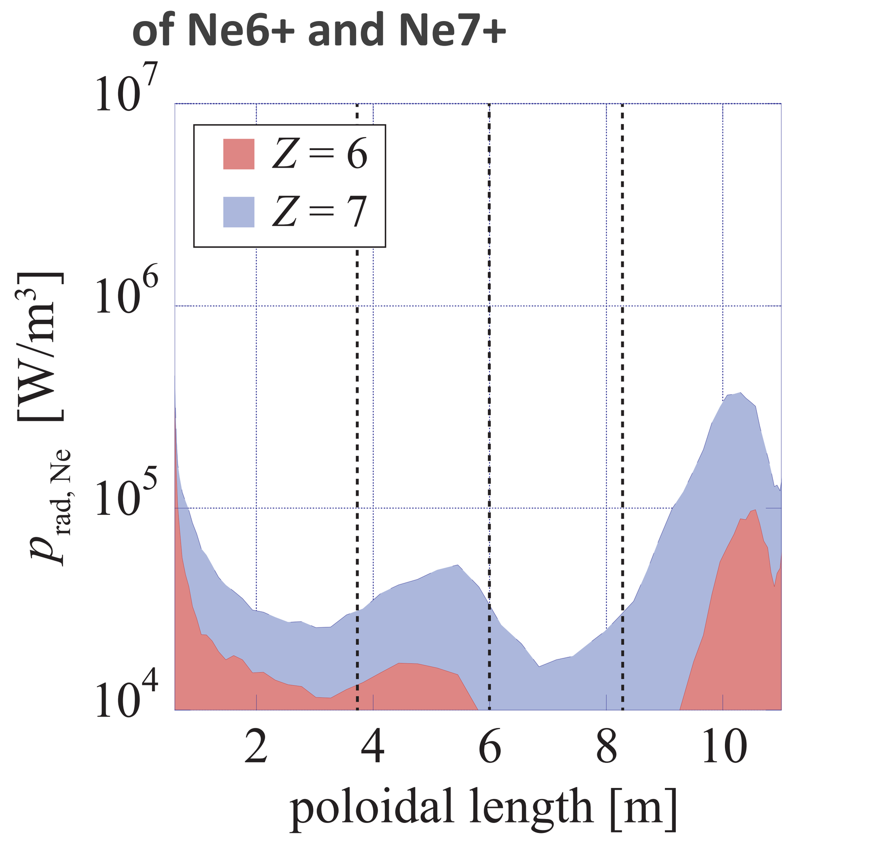
Case B: low Ar density in SOL top by friction force enhanced by high D^+ parallel flow towards inner divertor region

Mechanism of D+ flow acceleration can possibly be explained by analysis of Ne behaviour

Radiation power density of Ar and Ne



Stacked line radiation power density of Ne6+ and Ne7+



High Ne radiation power in HFS side near X-point (mainly line radiation of Ne^{7+})

Additional calculation without line radiation of Ne^{7+} is carried out (Case C)

- High D^+ flow cannot be seen: Ne^{7+} has a key role for low Ar density in top of SOL
- Importance of Ne^{7+} line radiation is consistent with spectroscopic/bolometric observation in JT-60U Ar+Ne seeding experiment [2,3].

Time-dependent analysis by SONIC is ongoing to reveal mechanism of D^+ flow acceleration by Ne seeding

Conclusion

Numerical simulations of SONIC shows that Impurity transport control in SOL could be possible by mixed-impurity seeding

Ar-only seeding: high Ar density in SOL top (due to thermal force)

Ar+Ne seeding: low Ar density in SOL top (due to friction force)

- Friction force is enhanced by high D+ parallel flow towards inner divertor region by Ne radiation (Key: Ne^{7+} line radiation)

Detailed results are shown and discussed in ref. [4]

Future Work

- Time-dependent analysis of Ar+Ne mixed seeding (ongoing)
- Comparison between SONIC simulation and JT-60U experiment

References

[1] Kawashima H. *et al* 2006 *Plasma Fusion Res.* **1** 031, [2] Asakura N. *et al* 2009 *Nucl. Fusion* **49** 115010, [3] Nakano T. *et al* 2015 *J. Nucl. Mater.* **463** 555, [4] Yamoto S. *et al* 2020 Plasma Phys. Contrl. Fus. **62** 045006.