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Extension of SONIC code toward mixed-impurity seeding capability

S. YAMOTO[1], K. HOSHINO[2], T. NAKANO[1], N. HAYASHI[1]
[1] National Institutes for Quantum and Radiological Science and Technology (QST),
[2] Faculty of Science and Technology, Keio University
e-mail (speaker): yamoto.shohei@qst.go.jp

The JT-60SA tokamak is now being constructed and is expected to ignite the first plasma at 2020 and to perform ITER-supporting experiments from 2023 under various operation scenarios. One of the underlying operation scenario is the high-beta operation under full non-inductive current drive conditions (scenario #5-1) [1]. The operation will take place with impurity seeding to reduce the heat load towards the divertors and with keeping the separatrix density low enough to match the core operation condition. On the other hand, the concentration of the impurities in the core causes a harmful effect to sustain the high-performance plasma by radiation cooling and dilution. Therefore, it is important to establish a method to control the impurity transport in the core and SOL/divertor regions.

So far, a favourable spatial distribution of radiation power has been achieved by Ne + Ar (mixed gas) seeding experiment in JT-60U, i.e. the radiated power is almost localized in the divertor region and as a consequence, better energy confinement than Ne-only and Ar-only cases has been achieved [2]. However, the interpretative and predictive simulation of such mixed gas seeding operation has not been performed. This is partly because the number of impurity species that the previous version of integrated divertor plasma transport code SONIC [3,4] could kinetically solve was limited to one. The issue has been essentially resolved by restructuring SONIC code with Multiple-Program Multiple-Data (MPMD) framework [5], which allows SONIC to calculate transport processes of two impurity species by a kinetic impurity transport code IMPMC. The extended SONIC code was applied to the analysis of the JT-60SA divertor plasma with two impurity species, i.e., the intrinsic C and seeded Ar gas impurities, and demonstrated the radiative divertor plasma scenario [5].

The purpose of this presentation is to examine the effects of different impurity seeding species in the JT-60U and JT-60SA divertor plasmas step-by-step in order to study the potential impurity seeding operation regime. Aiming for this purpose, the SONIC code has been further extended to handle three or more impurity species kinetically based on the MPMD framework mentioned above. Now the SONIC code is capable of calculating the mixed seeding impurities Ne + Ar and intrinsic C transport by IMPMC. In addition, IMPMC is extended to track W impurities regarding the future replacement of JT-60SA divertor material to W. The impurity-impurity interaction such as the physical sputtering of C by Ne and Ar bombardment has been also implemented. The code validation through the analysis of JT-60U mixed gas seeding experiment [2] will be presented.

Additionally, the effects of seeding various impurity species in JT-60SA operation is demonstrated by means of the extended version of SONIC. The following three impurity seeding cases are compared; (i) Ne, (ii) Ar , and (iii) the combination of Ne + Ar mixed gas. The intrinsic C sputtering/transport is also computed in each case. Except for the seeding impurity species, all other input parameters in the SONIC code kept the same as described in ref. [5]. In cases (i) and (ii), the Ar and Ne seeding rates are respectively set to be $0.15\ \mathrm{Pa\,m^3/s}$, and $0.35\ \mathrm{Pa\,m^3/s}$. These rates are adjusted to obtain desired divertor heat load $< 10\ \mathrm{MW/m^2}$ and separatrix electron density $1.7 \times 10^{19}\ \mathrm{m^{-3}}$ with keeping the total radiation power 12 MW in SOL/divertor regions.

Figure 1 shows the 2D radiation power density distributions for Ne and Ar seeding cases, respectively. The C radiation is also included. As seen from Fig. 1, the radiation power density distribution has been broadened especially in the inner divertor region in Ne seeding case compared to Ar seeding case. The C radiation distributions in both cases are very similar and therefore the difference is obviously due to the radiation of the seeded impurities. The following possible reasons will be discussed in the presentation; (a) the radiation of seeded Ne is enhanced due to higher seeding rate, (b) the difference of the transport processes between Ne and Ar in the divertor region, and (c) the difference of the sensitivity of the radiation function between Ne and Ar in the diveror plasma temperature regime. In addition to above discussion, mixture effects of Ar, Ne and C will be discussed. The effects of impurity distributions near the separatrix on the core accumulation will be also discussed.

References

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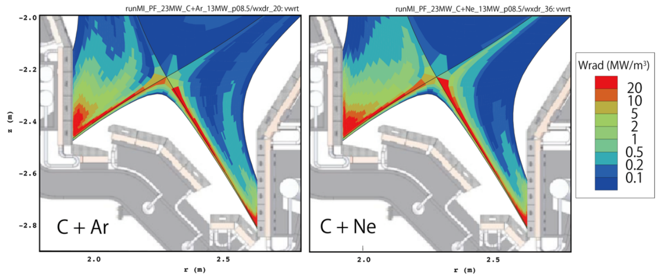

Fig. 1 Spatial distribution of the radiation power density calculated by the extended SONIC code. Left: Ar seeding case, Right: Ne seeding case