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多種不純物入射シミュレーションに向けたSONICコードの拡張
Extension of SONIC code toward mixed-impurity seeding capability

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The JT-60SA tokamak is now being constructed and is expected to ignite the first plasma at 2020 and to perform ITER-supporting and -complementing experiments from 2023 under various operation scenarios. One of the underlying operation scenarios is the high-beta operation under full non-inductive current drive conditions (steady-state high-beta operation) [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-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. The impurity-impurity interaction such as the physical sputtering of C by Ne and Ar bombardment has been also implemented. The effects of seeding mixture of Ne and Ar in JT-60SA steady-state high-beta operation scenario is demonstrated by means of the extended version of SONIC.

The following steps are set to discuss the effects of additional Ne seeding taking the Ar seeding case [5] as a reference; (i) the parametric survey of the Ne seeding rate (0.01 – 0.1 Pa m^3/s) with other parameters kept the same as ref. [5], and (ii) the exploration of the D_2 gas puff and the seeding rate of impurities which satisfies the target parameters of the scenario (the electron density at the separatrix $n_{e,sep}$~1.7×10^{19} m^{-3}, and the divertor heat load q_{div}<10 MW/m^2). In step (i), the radiation more localized in the divertor region can be seen as the Ne seeding rate increases. In addition, the electron and D$^+$ densities at the outer midplane are reduced compared to the Ar seeding case. The Ne+Ar seeding is effective to obtain radiative divertor operation with keeping the upstream electron density lower than the Ar-only seeding case. In step(ii), a set of parameters which satisfies the target parameters of the scenario have been achieved (Ar seeding rate: 0.1 Pa m^3/s, Ne seeding rate: 0.1 Pa m^3/s, and D_2 puff rate: 10.0 Pa m^3/s). Figure 1 shows the 2D radiation power density distributions of each impurity species. In Ne+Ar case, the fuel purity at the edge (n_{D^+}/n_e) become highest among Ar-only, Ne-only, and Ar+Ne cases (n_{D^+}/n_e~ 0.79, 0.77, and 0.83 in each case, respectively), which is good for the core performance improvement. In addition, the Ar radiation power in the edge is reduced from 1.1MW (Ar-only case) to 0.6 MW (Ne+Ar case). Therefore, the Ar radiation in the core is possibly reduced in Ne+Ar case.

References

[1] JT-60SA Research Plan
(http://www.jt60sa.org/pdfs/JT-60SA_Res_Plan.pdf)
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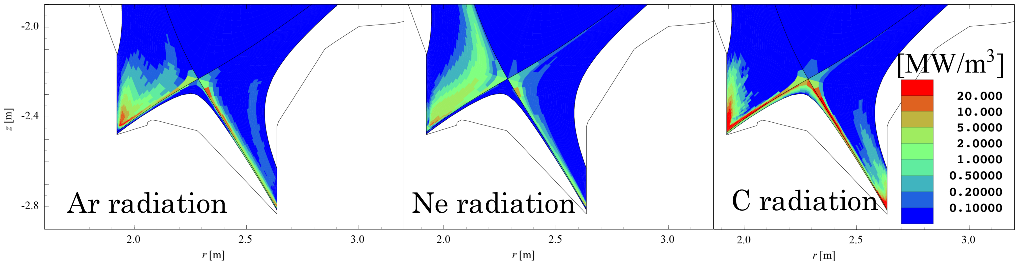

Fig. 1 Spatial distribution of the radiation power density in the Ne+Ar mixed seeding case calculated by the extended SONIC code.