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Radiative divertor experiments with Ne, N, and Kr seeding in LHD

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This paper reports divertor heat load patterns and plasma responses observed in the Ne, N, and Kr seeding experiments in LHD.
The previous study showed that the edge stochastic magnetic field layer in LHD, where Te changes from ~30eV at the divertor legs to 300-500eV at the LCFS, provides the main radiation contribution rather than the divertor legs. Understanding and control of impurity radiation in this layer is, therefore, prerequisite for detachment operation in future helical devices. The magnetic field structure of LHD has 10 field periods in toroidal direction, and thus uniform heat load reduction in toroidal direction is important.
With Ne seeding, simultaneous reduction of the divertor heat load at all toroidal sections is not always successful, despite an increase in radiated power. Rather, at specific sections the heat load even increases after Ne seeding. The asymmetry lasts for 0.2sec, which is much longer than the transport time of charged impurity particles in one toroidal turn, and then the high heat load returns. The "specific sections"are not a simple function of distance from the impurity puff location, and change depending on the heating power and on the ne. After the Ne seeding Te at the divertor plates, measured by Langmuir probes, decreases down to 5-10eV at all sections. On the other hand, ne is found to increase at the "specific sections"with the increased heat load. Further increase of the Ne seeding level aiming at symmetric heat load reduction fails with radiation collapse. The toroidal asymmetry is, however, effectively removed by the addition of Kr seeding prior to the Ne seeding. Kr emission remains very low until the Ne seeding, which then triggers Kr XIX to increase together with Ne VIII. Thereby, the divertor heat load decreases by a factor of ~2 in all toroidal sections. The reduction lasts for >1sec after the seeding. In this case, a clear decrease in Te at the stochastic layer is observed in the Thomson scattering measurements. Imaging bolometer measurements indicate a shift of the impurity radiation toward inner minor radii, i.e. around LCFS. Nevertheless, degradation of energy confinement time is limited to ~5% in the discharge. Kr seeding alone did not realize such operation. The results suggest a synergy effect between Ne and Kr. The relations between the magnetic field structure, radiation distribution, and the toroidal heat load pattern are under investigation.
N seeding discharges show stronger toroidal asymmetry than Ne seeding as expected, and also recovery of the divertor heat load after N seeding termination occurs very quickly, in several tens milliseconds. However, it is found that a slower seeding rate with a longer puff duration (>1sec) is effective to remove the toroidal asymmetry of the heat load. In this case, there is no significant degradation in the plasma stored energy observed.
These results suggest the importance of the mixture of impurity species as well as seeding rate to control the edge impurity radiation in the stochastic layer that appears in the 3D magnetic field structure of helical devices.

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