§9. Active Method of Impurity Control in LHD-type Reactor FFHR

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Impurity control is one of the crucial issues for Helical reactor, FFHR because of the lack of a neoclassical temperature “screening” effect, the expected large negative radial electric field and the large surface area (and therefore a large source of impurities) due to typically large aspect ratios. Since the level of tolerable metallic impurities in reactor plasma is strongly limited, the risk of accumulation must be controlled. A new technique for active impurity control in FFHR is proposed.

The Super Dense Core (SDC) discharges in LHD were chosen as a reference discharges for a Helical reactor. In this case the neoclassical theory predicts only the “ion root” and, since the dominant electron transport coefficient scales inversely proportional to temperature the thermal force is directed inwards and together with negative electric field can cause a strong impurity accumulation within the confinement time scale. However, effect of the centrifugal force due to a strong poloidal plasma rotation can mitigate the problem. The centrifugal force is directed outwards and it can retain high Z impurities at the edge, when their rotation energy exceeds the thermal energy of impurity ions. Calculations show, that the centrifugal force must be taken into account in the force balance, which determines the impurity radial distribution. However, in a Helical reactor the centrifugal force due to a moderate value of the poloidal Mach number seems to be insufficient to overcome the pulling effect of the electric field [1].

It was shown experimentally and confirmed in our calculations that the externally induced magnetic island at the plasma edge can protect intrinsic impurities from penetration in bulk plasma [2]. However, this method has, first, an undesirable effect in lowering the active plasma volume in reactor and, second, could be unreliable in case of a healing effect at high beta.

A new technique of bulk plasma “screening” from the penetration of intrinsic impurity ions, originating at the first wall of the FFHR, has been suggested [1]. By launching repetitively small pellets at the plasma edge the perturbation of density and temperature can capture the impurities and push them back into the scrape-off layer. The resulting effect is similar to that seen in ELMing H-mode tokamak plasmas. Calculations show that periodic plasma and energy outflow to the SOL changes the impurity behavior along the open magnetic field lines, where the conduction and convection alternate to enhance the efficiency of the impurity retention in the SOL. For the LHD case calculation gives the required pellet frequency and size to be about 10Hz, and 10^{21}/s, respectively. This amount of pellets, which should be injected continuously, are supplemental to the larger pellets needed to initiate the super dense core regime in a helical reactor and is not detrimental to the achievement of the internal diffusion barrier existence and furthermore do not deteriorate the confinement time. For the helical reactor it must be shown, that these small pellets pose no threat to ignition or the power loading.

Reference:

[1] Reported on Combined Meeting of Kinetic Theory in Stellarators and Coordinated Working Group, 2006, September 19-22, Kyoto.

[2] Yu.L.Igitkhanov, et. al., “Impurity Dynamics in Nonaxisymmetrc Plasmas.“ In: Fusion Science and Technology 50, 268-275, (2006)