§8. Assessment of Impurity Concentration in the Helical Reactor FFHR and Development of the Integrated TASK 3D Code

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Impurity control is one of the crucial issues for the Helical reactor, FFHR, which being an extension of the non-axisymmetric LHD configuration towards the reactor parameters, has much higher power and must be protected from possible impurity accumulation in the core region. There are several concerns with regard to impurity contamination in helical reactor plasmas due to the large surface area of the large aspect ratio helical systems, the lack of a neoclassical temperature screening effect and the large negative electric field in the helical reactor, where the "ion root" of operation is usually envisaged.

The concentration of impurities in the FFHR has been started by evaluating the sputtering of divertor plates, then the dynamics of impurities in the SOL region was modeled and, finally, the impurity distribution in the bulk plasma by using the stellarator impurity code SIT was estimated. This concentration has been eventually compared with the fatal levels, which prohibit ignition.

The impurity yield was evaluated by averaging over the distribution function of incident ions, accelerated in the sheath [1]. The incident ion flux was estimated using the confinement time and the average plasma density value, envisage for reactor. The sheath potential in the presence of secondary electron emission (SEE) and charged impurity ions has been taken into account to evaluate sputtering of the plate. It was found that impurity ions increase whereas the SEE decrease the potential drop at the plate. For materials such as tungsten with a high electron emissivity the effect of SEE prevails over the effect of sputtering and leads to a substantial decrease of the potential drop. The sputtering (and self-sputtering) of tungsten starts to be significant at some critical electron temperature (which depends on the level of impurity recycling at the target).

Impurity distribution in the SOL region has been evaluated by using the momentum and particle balance equations along the magnetic field line. In 1D approximation the balance of several forces (pressure, electric field, thermal and friction forces) determine the actual impurity localization along the magnetic field lines. It is shown, that the impurity density in Z_j charge state scales at the separatrix position as the plasma temperature with some power k_j :

$$n_{j,sep} / n_{j,plate} \cong \left(T_{sep} / T_{plate} \right)^{k_j}$$

where

$$k_j \approx -1 + 2\left(\frac{\overline{Z_j}^2}{Z_{eff}} - \overline{Z_j} \right) + const. \frac{\overline{Z_j}^2}{1+\sqrt{2}Z_0}(1-\eta) \qquad Z_0 \equiv \sum_j n_j Z_j^2 / n_e$$

η is the ratio of friction force to thermal force and

$$n_{z,plate} = \Gamma_z / V_z \cong \left\langle S_{sputtering} \cdot \Gamma_{pl}^i \right\rangle$$

The plasma temperature in the SOL scales along B as:

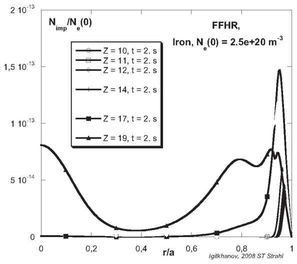
$$T(s) = (T_{sep}^{7/2} - T_*^{7/2} \cdot (s/L)^2)^{2/7}$$

where $T_*,[keV] = 8.54 \cdot 10^{-3} \cdot \left(q_{//}[MW/m^2] \cdot L[m] \right)$ and $T_{sep}^{7/2} = T_*^{7/2} + T_{pl}^{7/2}$. The density scales as:

$$n(s) = n_{sep} \frac{T_{sep}}{2T(s)} \cdot \left(1 + \sqrt{1 - \frac{T(s)}{T_{pl}} \cdot \left(\frac{s}{L} \right)^2} \right)$$

For impurities in low charge state the electric field is dominate (two first terms in expression of k_j), whereas for high charge state – thermal and friction forces, being proportional to Z^2, mainly determine the localization [2]. The averaged over the SOL impurity distribution of each charge state was treated as a source term in the SIT code for the bulk plasma.

The SIT code includes a heliotron specific neoclassical transport description together with the radial electric field solver [3]. Calculations show, that impurities in the reactor plasmas accumulate at the centre due to strong negative radial electric field, unless magnetic islands protecting them from penetration. Below has shown the radial distribution of Fe in the FFHR2m2 case. We estimate the level of impurity ions which are growing up at the centre during the energy confinement time. These concentrations were compared with the fatal ones, extinguishing reactor. Calculations show that for the FFH reactor with the SDC type profiles, the expected impurity concentrations remains well below the fatal values:



	Be	C	Ne	Fe	W
Fatal fraction,%	0.14	0.07	0.025	0.0027	0.0007
Calculated fraction,%	0.08	0.057	0.089	0.0015	0.0005

Integration of the stellarator impurity transport Code SIT into the modular structure of the TASK Code has been started. The SIT code has a modular structure, which includes neoclassical transport and the electric field solvers, working in series. These modules are prepared for implementation into the TASK structure.

[1] V.Abramov, Yu. Igitkhanov et. al., Journal of Nuclear Materials 162-164 (1989) 462-466

[2] Yu. Igitkhanov, Contribution Plasma Phys. 28 1988 4/5 477

[3] Yu.L.Igitkhanov et., al.Fusion Science and Technology 50, 268-275, (2006)