§19. Stellarator Impurity STRAHL Code Development in NIFS

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The Stellarator Impurity Transport STRAHL code (SIT STRAHL) is an extended and upgraded version of the STRAHL impurity code [1]. It aims to calculate the evolution of impurity ions coming into a bulk stellarator plasma from the wall or due to pellet ablation. The code solves the system of continuity equations (averaged over the magnetic flux surfaces) for impurity ions of each charge state, coupled due to the ionization, charge-exchange and recombination. The code evaluates impurity behavior in the frame of the stellarator-specific neoclassical transport, which unlike the tokamak configuration is strongly dependent on magnetic topology and the radial electric field. In the case of a test impurity approximation, considered here, the radial electric field is evaluated from the ambipolarity condition in the background plasma and depends on neoclassical transport coefficients for electrons and ions. An analytical description [2, 3] of the neoclassical transport coefficient for the background plasmas (based on numerical results from the DKES code [4] and monoenergetic Monte Carlo simulations) was generalized to impurity ions of arbitrary mass and charge state and used in the code as a neoclassical transport model for impurities. The reduction of Pfirsch-Schlüter convection due to the radial electric field and its impact on impurity dynamics has been included. Calculations were performed for given plasma density and temperature profiles. However, the time variation of the background plasma can also be taken into account by incorporating the experimentally measured profiles into the ongoing calculation.

The SIT STRAHL code solves the set of coupled, time dependent, one-dimensional continuity equations for the impurity density n_j^I for each ionization state j of a given impurity species I, averaged over the magnetic surfaces, ψ:

$$\frac{\partial n_j^I}{\partial t}+\frac{1}{\sqrt{g}}\frac{\partial}{\partial x}(\sqrt{g}\Gamma_j^I)=S_j^I \quad ; \quad j=1,\ 2,\ ...,\ Z_I \qquad (1)$$

Here $g=\det|g_{ik}|$, $g_{ik}(\psi)$ are the metric coefficients, calculated from the equilibrium, the impurity flux Γ_j^I can be written as $\Gamma_j^I=-D_j^I\nabla n_j^I+n_j^I V_j^I$. In general, the radial diffusion coefficient $D_j^I=D_{1,j}^I+D_{an}^I$, and the convective velocity $V_j^I=V_{Ware}^I+V_{an}^I$ consist of a neoclassical and an anomalous term. Since in stellarators the Ware pinch can be neglected, the neoclassical impurity flux can be written as

$$\Gamma_j=-D\nabla n_j+n_j V_j$$

$$=-D_{1j}^I n_j\left\{\frac{n_j'}{n_j}-Z_j\frac{E_r}{T_j}+\left(\frac{D_{2j}^I}{D_{1j}^I}-\frac{3}{2}\right)\frac{T_j'}{T_j}\right\}$$

$$=-D_{1j}^I\nabla n_j+n_j\left\{D_{1j}^I Z_j\frac{E_r}{T_j}-D_{1j}^I\left(\frac{D_{2j}^I}{D_{1j}^I}-\frac{3}{2}\right)\frac{T_j'}{T_j}\right\}$$

$$=\Gamma^{diff}{}_j+\Gamma_j{}^{conv} \qquad (2)$$

The first term in equation (2) describes the impurity diffusion flux, whereas the remaining terms constitute the convective flux.

The Stellarator Impurity Transport STRAHL code can be used for diagnostic data analysis purposes, particularly as an interpretative tool in Tracer Encapsulated Solid Pellet (TESPEL) experiments on LHD [5]. The code calculates the evolution of density and emission in time and space of impurity ions coming from the wall or originating within the plasma due to pellet ablation. Under this condition the transport equations become stiff, which has required a considerable change in the numerical scheme. The radial electric field is evaluated from the ambipolarity condition and depends on neoclassical transport coefficients. An analytical description of the neoclassical transport coefficient for the background plasmas (based on numerical results from the DKES code and monoenergetic Monte Carlo simulations) was generalized to impurity ions of arbitrary mass and charge state and used in the code as a neoclassical transport model for impurities. The reduction of Pfirsch-Schlüter convection due to the radial electric field and its impact on impurity dynamics has been included. Calculations of the electric field and transport coefficients were included within the time dependent iterative loop. Various models of anomalous drift velocities and the diffusion coefficient were also included. Currently the calculations are performed for the given plasma density and temperature profiles. In the future this calculation will be also done in a self consistent manner. Because of its modular structure, the SIT STRAHL code can be easily incorporated into 1-D plasma transport codes like ASTRA or PROCTR.

References

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