Development of test particle module for impurity transport in BOUT++ framework*

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Long-pulse steady state operation is the major goal of the current fusion devices, while impurity accumulation in the core plasma can significantly impact on fusion plasma performance through radiation losses and dilution of fuel. The impurity also plays an important role for efficiency of RF heating and the achievement of divertor heat flux control via large volumetric power losses (dissipation) in radiative divertor and detached divertor operations. However, the physics process of impurity generation, migration and transport is not fully understood.

Based upon a well-known Hamiltonian guiding center equation of motion by Littlejohn, Boozer, White and others [1,2,3], a new test particle-in-cell (PIC) module is developed in the BOUT++ framework to study the impurity production, transport and migration. A shifted circular JET like equilibria is used to simulate the impurity transport and confinement under the influence of the turbulence and ELM fields. The PIC module is implemented in field aligned coordinate for circular geometry and cylindrical coordinate for divertor geometry, and uses the RK4 time advance scheme. The trapped and passing particle orbits width and the squeezing factor of the radial electron field effect correctly verified in comparison with the analytical theory. Our simulation results show that the turbulent $\boldsymbol{E} \times \boldsymbol{B}$ drift can cause the impurity particles spreading cross magnetic flux surface, and transport the impurities into the core of tokamaks. To study the effects of the RF sheath electric field and the perturbed electric field on the impurity transport, we first make comparisons on the impurity convection flux with analytical results, showing a good agreement. Then we perform simulations with impurity ion sources at the RF limiter at the outside mid-plane as a model of RF sputtering to map out the impurity spatial distribution across the magnetic separatrix and migration pattern on the boundary wall surface. Using the perturbed electric field from our BOUT++ nonlinear ELM simulation, the transport of the impurities in different phase of ELMs are discussed.

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