Progress in modeling the D/T component flows in fueling system of controlled fusion reactor by SOLPS+ASTRA+FC-FNS codes

Sergey Ananyev (NRC “Kurchatov Institute”)
Andrei Kukushkin, Boris IVANOV, Boris Kuteev, Maxim Nurgaliev

Fuel systems for a fusion neutron source (FNS), a fusion reactor (FNS), or fusion-fission hybrid systems (FFHS) based on a tokamak should supply DT fuel to maintain stationary fusion in the plasma and remove excess particles from the divertor regions. Fuel cycle systems (FC) must provide gas evacuation from the vacuum chamber, preliminary purification of and hydrogen extraction from impurity gases, additional purification of chemically bound hydrogen isotopes, and hydrogen isotope separation to the required concentration level. These systems must contain the hydrogen isotope inventory and provide the conditions for fusion burning, plasma heating, and current drive (by fast atom beam injection), as well as residual gas detritiation and waste processing. The particle fluxes in the FC are determined, first of all, by ensuring (by the injection system) the requirements for the plasma core parameters, as well as by the fluxes in the pumping system, coming from the vacuum chamber (divertor area). Thus, the simulation of the FC systems and calculation of the particle flux should be coupled to a core and divertor plasma model. For integrated modeling of the core and divertor plasma, it was proposed to use coupling of the ASTRA and SOLPS4.3 codes - an approach developed earlier for the ITER project. In this approach, the one-dimensional modeling of the plasma core by the ASTRA code is supplemented by the boundary conditions and constraints represented in the form of scalings obtained from the two-dimensional modeling of the edge plasma using the SOLPS4.3 code. This results in an efficient algorithm that provides a simultaneous description of the plasma regions with strongly differing timescales and makes it possible to calculate the parameters of the plasma core that are consistent with the constraints for the divertor (heat loads, gas flows). In the Russian Federation, to simulate the hydrogen isotope fluxes in the FC systems of a fusion neutron source based on a tokamak, the “FC-FNS” code was created. The processes in the FC mentioned above are modeled together with the tritium breeding in a blanket. An approach was proposed to simulate processes in the FC together with the core and divertor plasma. The developed approach has been applied to simulate the FC for the DEMO-FNS and FNS-ST project in the presence of feedback between the pumping and injection systems, taking into account the change in the isotopic composition of the core and divertor (edge) plasmas. A further development is the inclusion of ions instead of electrons in the particle transport equations in ASTRA. This makes it possible to more accurately estimate the ions partial retention times from different sources (NBI, pellets, and gas injection, recycling). The report describes the developed one-dimensional model used in the “FC-FNS” code for particle fluxes calculating in the FC, as well as the fuel component fluxes for DEMO-FNS and FNS-ST projects, obtained with this model. Various scenarios of the gas supply for the heating injection system were simulated, enabling injection of beams with different isotope composition. The effect of pellet injection (from HFS for core plasma fueling and from LFS for ELM pacemaking/stimulation) on D- and T-particle fluxes in FC systems was also considered. It is shown that for convective ELMs, the flux of particles from the plasma increases, which must be compensated by pellets injection. This results in increased flows through FC systems (up to an order of magnitude for some systems). Tritium inventory in DEMO-FNS FC systems should be up to 500 g and from 100 to 200 g for FNS-ST. The developed approach can be applied to simulate the fuel cycle system parameters in DEMOs projects.