Hydrogen isotopes distribution modeling by "FC-FNS" code in fuel systems of fusion neutron source DEMO-FNS

Abstract

Fusion neutron source is promising for research, testing of structural materials of future fusion and fusion reactors, utilization of nuclear waste, fuel production and control of subcritical nuclear systems. Tokamak is one of the most promising systems for the creation of fusion neutron source with a power output exceeding 10 MW. The maintenance of plasma in a tokamak requires the injection of a fuel mixture containing hydrogen isotopes (deuterium and tritium) into the vacuum chamber, as well as its subsequent pumping out and processing. To simulate hydrogen isotopes fluxes in fuel systems of FNS, a FC electronic model has been created and continues its development. We are representative the electronic model changes, the calculations carried out for the project of a fusion neutron source DEMO-FNS for different T/fraction in plasma are presented.

Fusion-fusion system. Fusion Neutron Source

The concept of the hybrid/fusion-fusion reactor (combining nuclear and thermonuclear fuels) is the basis for a tokamak-based fusion neutron source (FNS). An essential difference of a hybrid reactor compared to a fusion reactor is a much smaller required fusion power for operation, since the total energy release of a fusion reactor takes place in a subcritical blanket due to fusion reaction sustained by neutrons from the plasma. As a result, the requirements to plasma parameters become less severe, which leads to less stress on the structural and functional elements of the facility.

Fueling systems

Fuel systems (FS) are an extremely important part of FNS and must ensure the cycle circulation and storage of fusion fuels (deuterium and tritium), as well as the reprocessing of the fuel mixture in all thermonuclear reactor systems. The breeding of tritium, the amount of which will increase due to thermonuclear burn-out and fission, is planned to be carried out in the Blanket Module. To maintain the stationary operation regime of the FNS, an uncontrolled operation mode of components is required.

Three scenarios of NBI gas supply system

To ensure a useful output power of the plasma beams and heating, it is planned to use neutral atomic beams (NAB), providing steady-state mode (by consecutive injection and regeneration modes). The beam injectors are connected to the vacuum vessel by ducts, with the hot gas can inject into injectors and, as a result, they are also gas consumers and NBI gas supply system is a part of FNS. We consider the gas beam neutralizer.

New prerequisites for FC systems. Fuel isotopic composition change...

For the operation of pellet injectors (PDI), a relatively pure (T:D = 1:9) isotopic mixture is required!!

Therefore, we need to provide a procedure for separating the gas mixture to produce tritium in an amount sufficient for PDI – it is necessary to change the original concept (using a gas mixture with the same isotopic composition as the fuel mixture).

By GCS is not possible to compensate for the particle fluxes lost from the plasma (due to low efficiency). In this case, the deuteron fraction in the FC systems will increase (relative to the plasma composition).

The solution is pellet injectors using deuterium injection (separately from tritium). In this case, it is possible to completely compensate the “plasma mode” i.e. create a stationary (without deuterium) DT plasma composition.

Therefore, it is necessary to simulate the fuel circulation in the FC system, taking into account the fuel isotopic composition dynamics monitoring.

Simulation for fusion neutron source DEMO-FNS

Modeling hydrogen isotopes flows and inventories in fuel systems

To simulate hydrogen isotopes flows and inventories in the DEMO-FNS fuel systems, the FC electronic model-FNS is used. To take into account new approaches to the FNS, the electronic model will be further developed.

The T/fraction change in the plasma and fuel systems of the FC system is influenced by the fuel isotopic composition.

The fraction of tritium in the plasma is equal to 1.

D and T are separated in the FC system.

FC simplified schematic

Conclusion

FC-electronic model of DEMO-FNS FC is used for hydrogen isotopes distribution and inventories simulation in fuel systems of a fusion neutron source based on a stationary tokamak with a power of fusion of 10-50 MW developed at the National Research Center "Kurchatov Institute".

• DEMO-FNS FC electronic model-FNS was significantly modified.
• By analysis we selected a scenario (for NB injection systems) which a tritium-containing mixture flux from NB will be pumped to FC when the DT ratio decreases.
• We are modifying a fuel mixture: circulation systems are in the cycle in the plasma, T fraction is pumped to FC with a change the T fraction in the plasma.
• We can analyze the fuel isotopic composition in successive fuel circulation (from plasma to the storage-injection systems) for different injection modes. This allows to select the injection modes which will obtain plasma composition with a given isotopic composition of fuel.
• We calculated T:atom dependence of the scenario and T/D ratio in plasma.
• T isotope ratio is calculated by FC-FNS electronic model of DEMO-FNS fuel system. At the same time, the least accurate calculation were made for a cycle operation mode (including ISS). A rough estimate did not give a significant error with relatively small flows, but substantial growth gives an overestimated T/atom content.

It has been shown that a significant change in the isotopic composition of the fuel mixture occurs during the injection into the plasma and isotopic recombination system (T should increase). In DEMO-FNS fuel systems, this effect is more significant.

An important step forward was the beginning of fuel mixtures in the FC systems of the DEMO-FNS cycle simulation cycles. At the same time, we controlled the fuel composition in the key FC systems and believe that subsequent systems will receive a gas mixture with the current composition. We also consider the fuel flow into the reprocessing (taking into account T and D losses compensation in the plasma and FC). Thus, it is possible to observe the plasma isotopic composition dynamics with a slight fuel mixture in several successive fuel circulation (from the plasma to the storage – injection systems for different injection modes).