Development of DEMO-FNS Hybrid Facility and Its Integration in Russian Nuclear Fuel Cycle

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Abstract: Development of a fusion-fission hybrid facility based on superconducting conventional tokamak DEMO-FNS runs in Russia since 2013. The main design goal is to reach the technical feasibility and outline prospects of industrial hybrid technologies providing the production of neutrons, fuel nuclides, tritium, high-temperature heat, electricity and subcritical transmutation in Fusion-Fission Hybrid Systems. The facility should operate in a steady-state mode at the fusion power of 40 MW and fission reactions of 400 MW. Major tokamak parameters are the following: major radius R=3.2 m, minor radius a=1.0 m, elongation 2.1, triangularity 0.5. The design provides the neutron wall loading of ~0.2 MW/m², the lifetime neutron fluence of ~2 MWA/m², with the surface area of the active cores and tritium breeding blanket ~100 m². Core plasma modelling showed that the neutron yield ~10¹⁹ n/s is maximal if the tritium/deuterium density ratio is 1.5-2.3. The design of the electromagnetic system (EMS) defined its basic parameters, accounting for the coils strength and stability, and identified the most problematic nodes in the toroidal field coils and the central solenoid. The EMS generates toroidal, poloidal and correcting magnetic fields necessary for the plasma shaping and confinement inside the vacuum vessel. EMC consists of eighteen superconducting toroidal field coils, eight poloidal field coils, five sections of a central solenoid, correction coils, in-vessel coils for vertical plasma control. Supporting structures, the thermal shield, and the cryostat maintain its operation. EMS operates with the pulse duration of up to 5000 hours at the plasma current up to 5 MA. The vacuum vessel (VV) is an all-welded two-layer toroidal shell placed inside the EMS. The free space between the vessel shells is filled with water and boron steel plates, which form the neutron protection of the EMS. The VV-volume is 265 m³, its mass with manifolds is 1800 tons. The nuclear blanket of DEMO-FNS facility was designed to provide functions of minor actinides transmutation, tritium production and enrichment of spent nuclear fuel. The vertical overloading of the subcritical active cores with MA was chosen as prospective. Analysis of the device neutronics and the hybrid blanket thermal-hydraulic characteristics has been performed for the system with functions covering transmutation of minor actinides, production of tritium and enrichment of spent nuclear fuel. A study of FNS facilities role in the Russian closed nuclear fuel cycle was performed. It showed that during ~100 years of operation three FNS facilities with fission power of 3 GW controlled by fusion neutron source with power of 40 MW can burn 98 tons of minor actinides and 198 tons of Pu-239 can be produced for startup loading of 20 fast reactors. Instead of Pu-239, up to 25 kg of tritium per year may be produced for startup of fusion reactors using blocks with lithium orthosilicate instead of fissile breeder blankets.

Keywords: fusion-fission hybrid system, conventional tokamak, superconducting electromagnetic system, two-layer vacuum vessel, subcritical active cores, nuclear fuel cycle

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