RESEARCH AT THE KURCHATOV INSTITUTE IN SUPPORT OF THE CREATION OF A HYBRID FUSION-FISSION SYSTEM

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1. INTRODUCTION

Combining nuclear fusion and fission reactions in a single design allows achieving fundamentally new characteristics and parameters of nuclear power systems. Over the past few years, the National Research Center “Kurchatov Institute” has been working on the feasibility and creation of a pilot industrial hybrid reactor facility (PIHRF) for the integrated commissioning of fusion and nuclear technologies [1-3]. Such a facility could produce fuel isotopes for both fusion (tritium, if necessary) and nuclear (^{233}U) reactors. It is assumed that such a facility containing a hybrid blanket, based on a steady-state tokamak with a DT fusion power of more than 30 MW (this corresponds to the generation of ~ $1\cdot10^{19}$ neutrons/s) and a fission power of up to 500 MW.

2. WORK PERFORMED AND RESULTS

Until recent time, a small-sized compact fusion neutron source (FNS-C) (R ~ 0.5 m, A = 1.6, $V_{pl} \leq 2.5$ m^3) with a fusion power of 3 MW, corresponding to the generation of ~ 10^{18} n/s, was being developed for testing materials and components of hybrid systems. However, the successful launch, start of operation and first encouraging results of the T-15MD tokamak, it was decided to create a FNS built using the technologies and solutions adopted during the design and construction of the T-15MD tokamak, but taking into account its adaptation to the tasks of a fusion neutron source. Thus, at present, the main goal of the work being performed is R & D to justify the development of an experimental prototype of a fusion neutron source (TIN-1) on the scale of the T-15MD tokamak in support of the PIHRF, the construction of which is a common goal. At the present stage, the goal is to develop and validate the technology for the production, extraction and purification of ^{233}U from the working material of the blanket containing the natural isotope ^{232}Th, as well as to assess the possibility of transferring the developed technologies and achieved results to the project for the creation of the PIHRF. This paper presents the latest (2024-2025) TIN-1 facility project development results.

In 2024, system studies were conducted to determine and analyze the parameters of the designed TIN-1 facility with a "warm" magnetic system (MS) based on copper alloy. The basic parameters were similar to those of the T-15MD tokamak - R_0 = 1.48 m, B_{t0} = 2 T, I_P = 2 MA, A = 2.2. The parameters during the system analysis varied within the range of R_0 = 1.2-1.8 m, B_{t0} = 1-5 T, I_P = 1-5 MA, Δt_{pulse} = 1-500 s. The experience of tritium experiments at the JET facility was taken into account during the system analysis. As a result, the facility with the parameters R_0 = 1.725 m, A = 2.5, B_{t0} = 3 T, I_{pl} = 2.1 MA was selected as the preferred option for TIN-1 facility. The total power consumption P_{sum} from the network was estimated at 200 MW, and the average neutron flux to the first wall was Nn~10^{12} cm^{-2}s^{-1}. The limitation of the plasma current plateau duration in this variant (10 s) is due to the heating of the solenoid and the flux reserve in it.

The efficiency of neutral injection into the plasma of the designed TIN-1 facility was analyzed within the T-15MD tokamak geometry. To analyze the efficiency of neutral injection and study the two-component plasma of FNS facility (of any geometry), it is necessary to use a comprehensive approach that takes into account all beam losses during its formation and transportation to the plasma, as well as its "transfer" in the plasma - in the form of generation of fast ion current and increased reactivity of fast ions. For this purpose, it is possible to use models that combine a statistical description of the beam with analytical methods for calculating particle trajectories, as is done in the BTR-BTOR model [5]. With an increase in the injection energy from 60 to 120 keV, the neutron yield increases approximately 3 times. With an injection power of 8 MW, the neutron yield on the beam is expected to be 1.3×10^{17} (60 keV) and 4.2×10^{17} (120 keV) at a plasma electron temperature of 5 keV. Increasing the plasma temperature to 10 keV leads to an increase in the neutron yield by 15-20%, but at the same time the intensity of neutron yield in reactions between thermal ions increases by an order of magnitude, which makes operating regimes with high plasma temperatures the most attractive for FNS facilities.

The calculation of magnetic fields and electromagnetic forces in the designed TIN-1 facility coils was performed with both nominal and increased values currents of magnetic coil and plasma currents in comparison with the T-15MD tokamak. The nominal (T-15MD) and increased dimensions of the facility were also considered. The calculations were performed using a finite element code on a specially created model (Fig. 1a). The calculation results are presented in Fig. 1b and 1c.

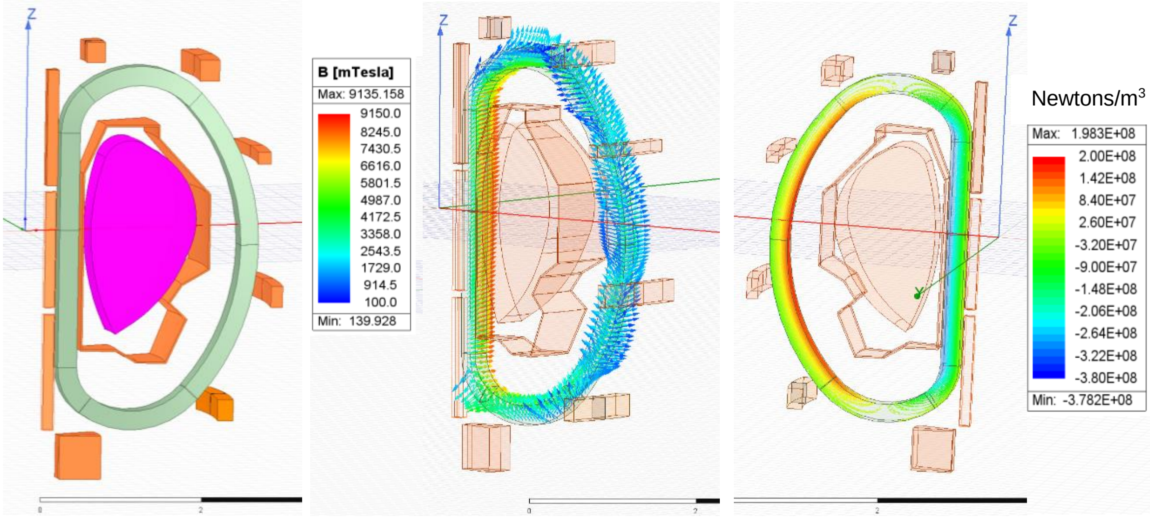

Fig. 1. Finite element model (a), magnetic field induction (b), radial volume forces (c) for the TIN-1 toroidal coil.

Materials Science: a new approach to studying the evolution of helium (monatomic gas) and hydrogen (diatomic gas) bubbles by the Ostwald ripening (OR) mechanism under annealing is proposed. An asymptotic analysis is performed describing the evolution of helium bubbles by the OR mechanism at early and later stages of the process. The results of this analysis were compared with the corresponding data from experimental studies of metals and alloys pre-implanted with helium, used in structural elements of both fission and fusion reactors. Comparison of these theoretical assessments and experiments showed good agreement.

Other works performed: two- and three-dimensional models of designed TIN-1 facility for neutron calculations were created; the possibility of using thorium in nuclear power engineering was analyzed; possible variants of TIN-1 facility thorium blankets were determined.

3. CONCLUSION

R & D activities are being performed in NRC “Kurchatov Institute” of an experimental prototype of a fusion neutron source (TIN-1) on the scale of the T-15MD tokamak in support of the pilot industrial hybrid reactor facility. System analyses of designed TIN-1 facility based on “warm” MS was caried out. In 2025, it is planned to analyze the designed TIN-1 facility with a cryoresistive magnetic system.

ACKNOWLEDGEMENT

The work was carried out in accordance with the Russian Federation state assignment of the National Research Center "Kurchatov Institute".

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