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Research at the Kurchatov Institute in support of the creation of a hybrid fusion-fission system

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ABSTRACT

•The NRC "Kurchatov Institute" is developing an experimental prototype of a thermonuclear neutron source (TIN-1) on the scale of the T-15MD tokamak, with the aim of using it in a pilot hybrid reactor facility to study the process of obtaining uranium-233 from natural thorium-232 by irradiating samples containing thorium-232 with a flow of thermonuclear neutrons. It is planned to develop preliminary and technical designs for the TIN-1 tokamak - a prototype thermonuclear neutron source, with geometric dimensions on the scale of the T-15MD tokamak.

BACKGROUND

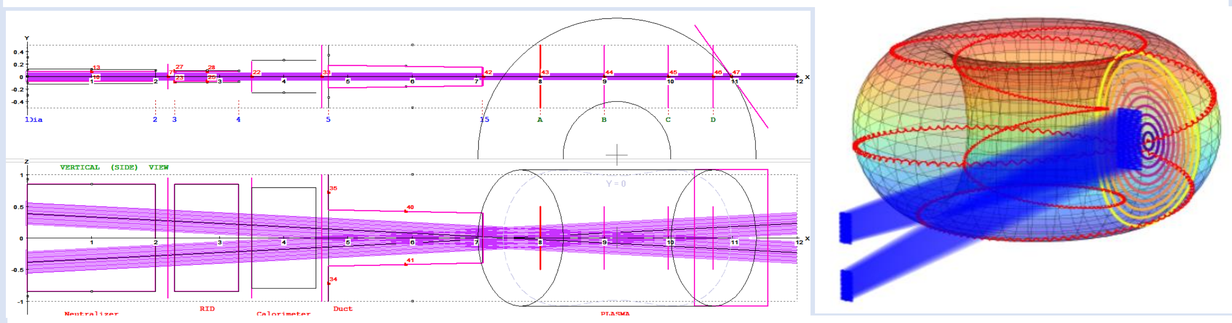
- In recent years, the Kurchatov Institute has been working to validate and develop a pilot hybrid reactor facility (PIHRF) for the integrated commissioning of fusion and nuclear technologies.
- Such a facility could produce fuel isotopes for both fusion (tritium, if necessary) and nuclear (U-233) reactors. The PIHRF, based on a stationary tokamak with a DT fusion power of over 30 MW (corresponding to the generation of ~1x10^{19} neutrons/s), would contain a hybrid blanket (fission power up to 500 MW). To develop nuclear and fusion fuel production technologies, the decision was made to design TIN-1.

SYSTEM ANALYSIS OF OPTIONS WITH "WARM" EMC

- In 2024-25, systems studies were conducted to determine and analyze the parameters of the TIN-1 facility with a "warm" copper alloy magnetic system. The baseline parameters were similar to those of the T-15MD:
- R_0 = 1.48 m, B_{t0} = 2 T, I_P = 2 MA, A = 2.2.
- The parameters for the systems analysis varied within the range of R_0 = 1.2-1.8 m, B_{t0} = 1-5 T, I_P = 1-5 MA, t_{pulse} = 1-500 s.
- The experience of the JET tritium experiments was taken into account during the systems analysis. As a result, a facility with parameters R_0 = 1.725 m, A = 2.5, B_{t0} = 3 T, I_{pl} = 2.1 MA was selected as the preferred TIN-1 option.
- The estimated total power consumption from the P_{sum} network was 200 MW, and the average neutron flux onto the first wall was Nn~10^{12} cm-2 s-1. The limitation on the plasma current plateau duration in this variant (10 s) is due to the heating of the solenoid and the flux reserve within it.

BEAM-PLASMA REGIME IN TIN-1

- The efficiency of neutral injection into the plasma of the TIN-1 tokamak was analyzed within the T-15MD geometry.

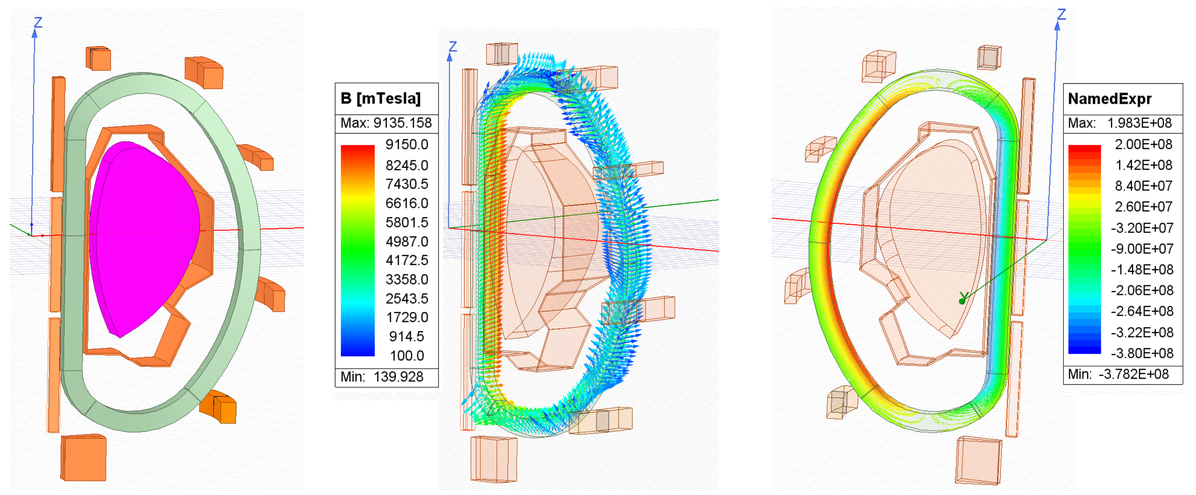


- Injection diagram (a) and beam and plasma model in the BTOR code (b).
- The magnetized ion trajectory is shown in red..

- Increasing the injection energy from 60 to 120 keV increases the neutron yield by approximately three times. At an injection power of 8 MW, the beam neutron yield will be 1.3x10^{17} (60 keV) and 4.2x10^{17} (120 keV) at a plasma electron temperature of 5 keV. Increasing the plasma temperature to 10 keV increases the neutron yield by 15-20%, but the intensity of neutron generation in reactions between thermal ions increases by an order of magnitude, making high-temperature plasma modes the most attractive for FNS facilities.

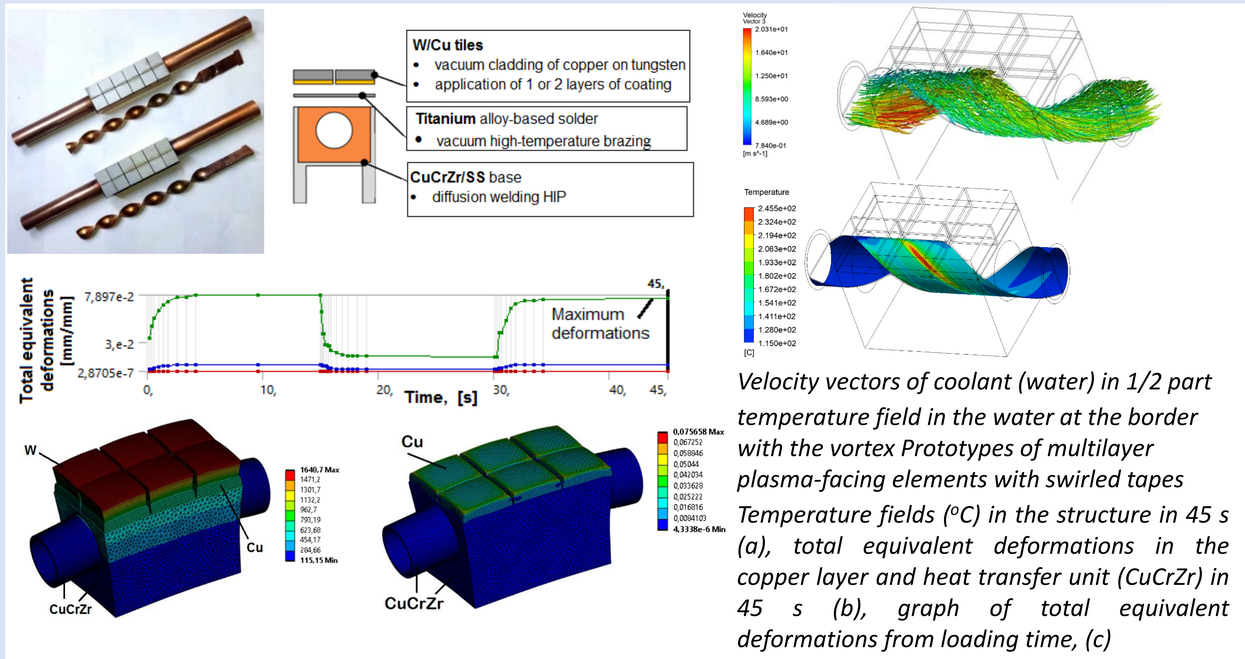
MAGNETIC FIELDS AND ELECTROMAGNETIC FORCES

Analysis of magnetic fields and electromagnetic forces in the TIN-1 coils were performed for both nominal and increased magnetic coil and plasma currents, compared to the T15MD facility. Both nominal (T-15MD) and increased unit sizes were considered. The analysis were performed using a finite element technique on a specially developed model.



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

CYCLIC LOADING ON A FW and DIVERTOR



Velocity vectors of coolant (water) in 1/2 part temperature field in the water at the border with the vortex Prototypes of multilayer plasma-facing elements with swirled tapes Temperature fields (°C) in the structure in 45 s (a), total equivalent deformations in the copper layer and heat transfer unit (CuCrZr) in 45 s (b), graph of total equivalent deformations from loading time, (c)

- Subsequent strength and cyclic analysis based on models of deformation approaches and fatigue experimental data of materials determined the number of cycles before the onset of local fractures or cracking. **For Cu, this number was 54 cycles.** Provided the copper substrate is intact and does not delaminate from adjacent elements, this number for CuCrZr is 10110 cycles, and for W, 291000 cycles.

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 were caried out. In 2025-2026, it is planned to analyze the designed TIN-1 facility with a cryoresistive magnetic system.

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