$$\Delta^{*}\Psi + r^{2} p'_{\Psi} + FF'_{\Psi} = 0$$

Status of Upgrading Project of Tokamak T-15

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INTRODUCTION

- **The basic strategic directions of the efforts in controlled fusion research in the Russian Federation are the support and participation in the ITER project and the participation in the development of the demonstration fusion reactor DEMO as pure thermonuclear energy sources.**

- **Besides ITER and DEMO, researches and developments on controlled fusion within the next few years can be used for the needs of atomic power engineering.**

- **The development and creation of fusion neutron sources (FNS) for solving problems in atomic power engineering are parallel efforts.**

- **The Tokamak T-15 upgrade project is the initial technical base for creating industrial FNS.**

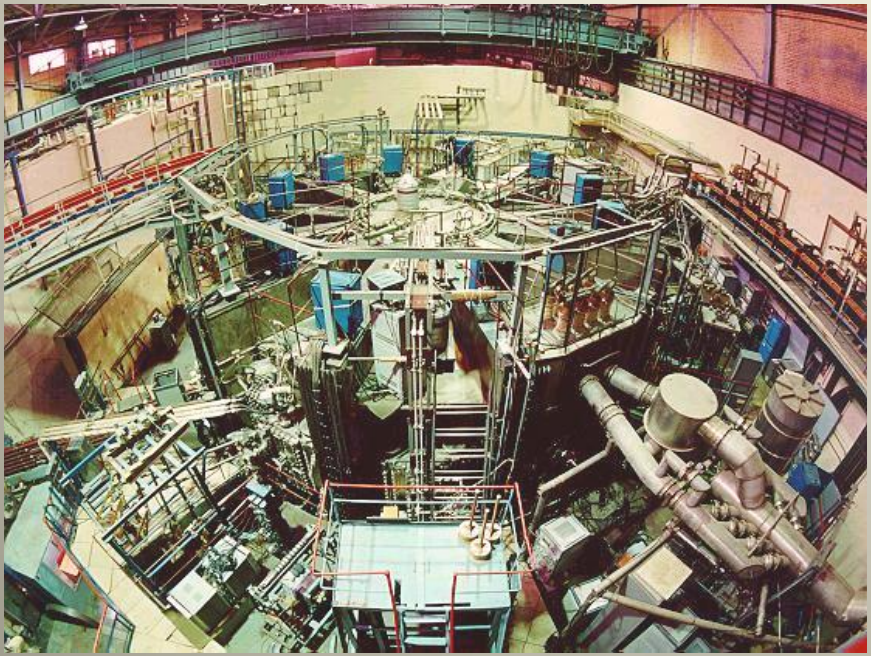
Goals and Main Parameters of Tokamak T-15 UPGRADE

Experimental study program on tokamak T-15 upgrade includes decision of the following tasks:

- the obtaining of physical and technological data for FNS creation;
- possibility of achieving the high values of beta as way to the reduction of fusion reactor cost;
- control by the current and pressure profiles;
- study of the possibility of the realization of high beta and plasma density in steady-state discharge with the completely non- inductive current;
- on-line control of stability, equilibrium, heating and confinement of high-temperature plasma; study of plasma interaction with different materials, including graphite, tungsten and lithium;
- as the hydrogen prototype of FNS the tokamak T -15 upgrade will be used as the test bed, on which will be mastered such systems, as the stationary injectors of neutral particles, ICR, ECR and LH plasma heating systems, will test materials and the technologies of the first wall and divertor.

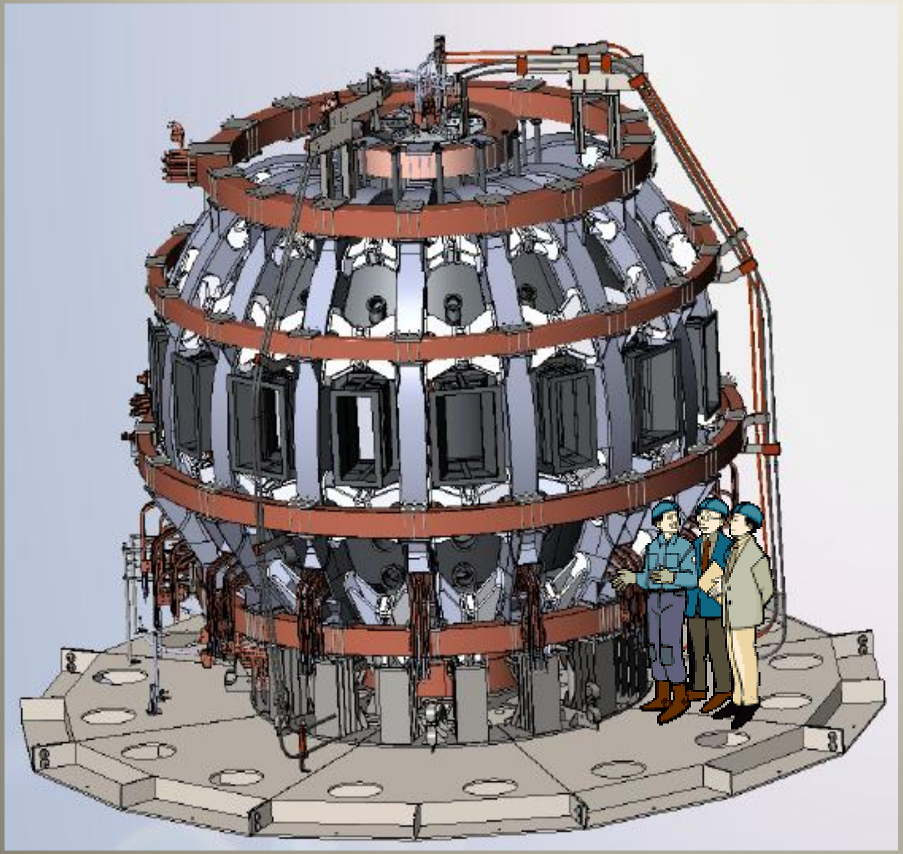
The tokamak T-15 upgrading is carrying out within the Federal Target Programme "Nuclear energy-technologies of new generation for period 2010 - 2015 and to the prospect until 2021"

Tokamak-15 (1988-1995)



Parameter	Value
R, m	2,43
a,m	0.7
B_t (Nb_3Sn), T	3.6
I_p, MA	1.0

Tokamak T-15 upgrade

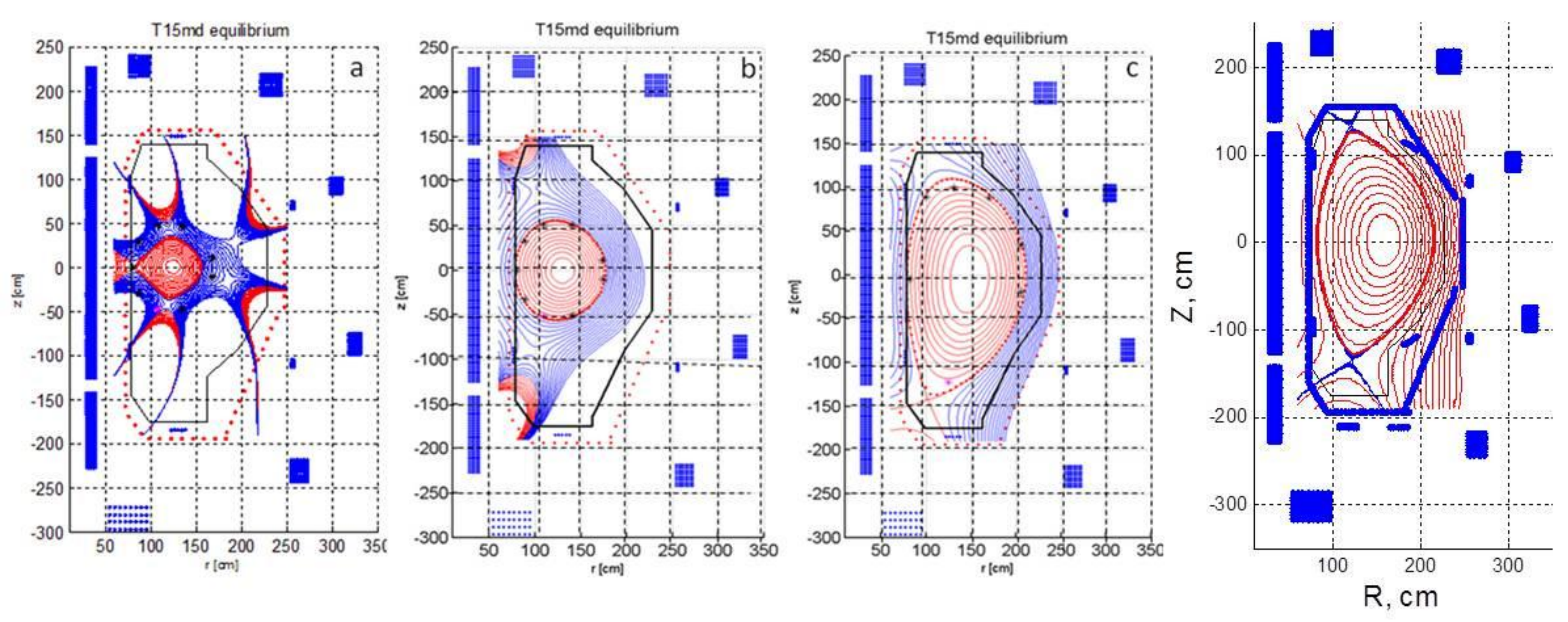


Main parameters

Major radius of torus R, m	1.48
Aspect ratio	2.2
Plasma current I_P, MA	2.0
Elongation, k	1.9
Plasma configuration	SN,DN
Discharge pulse duration, s	10
Toroidal magnetic field at plasma axis, T	2
Magnetic flux swing in central solenoid, Wb	6
Neutral beam injection power, MW	6
ECR heating power, MW	7
ICR heating power, MW	6
LH heating power, MW	4

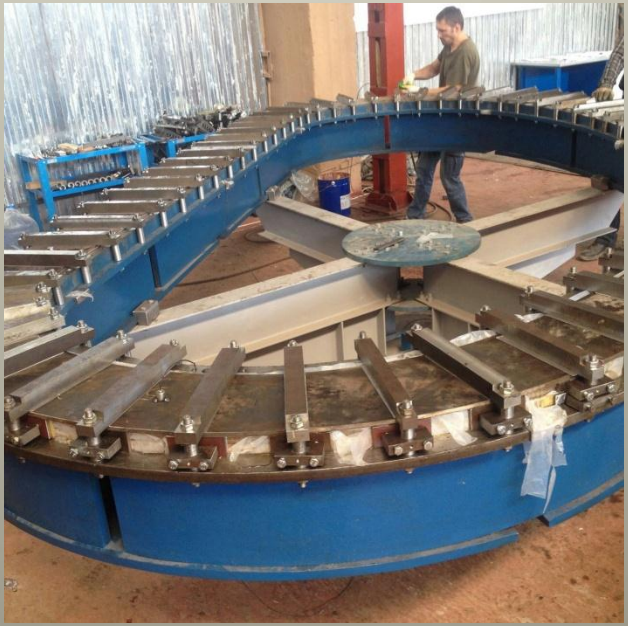
STATUS of MAGNET SYSTEM

- At the present time, the magnet system (MS) of the tokamak T-15 upgrade is being manufactured.
- MS should obtain and confine of the hot plasma in the different divertor configurations.
- MS includes the toroidal winding, central solenoid, poloidal field coils and horizontal field coils.

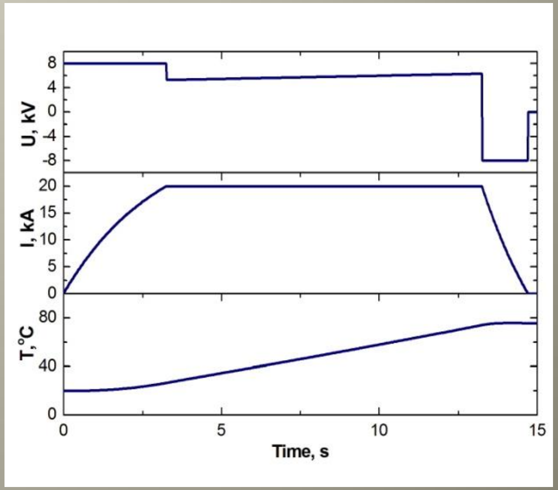


STATUS of MAGNET SYSTEM
Toroidal Winding

- **The toroidal winding consists of 16 D-shaped coils forming the arched structure.**
- **The toroidal magnetic field at the plasma axis is 2 T.**
- **The level of ripples at the outboard plasma boundary is approximately 0.8 %.**
- **Each TF coil has 50 turns that are wound by a hollow conductor made of silver (15%)-copper alloy with dimensions 22.5mm × 32 mm and ∅10.5 mm ID.**

Coils at the plant in Bryansk

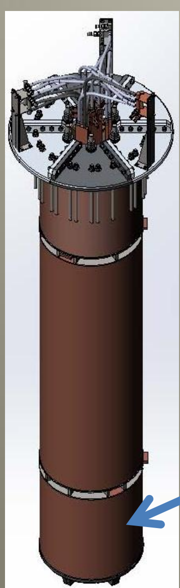


Scenarios for the applied voltage to the winding, the current through the winding and the calculated curve of the conductor temperature.

STATUS of MAGNET SYSTEM

Central Solenoid

- The central solenoid consists of three separated coils (of 151, 449 and 151 turns).
- Each coil is wound with two parallel hollow conductors of trapezoidal form (dimensions are 14.8 x15.5 × 20 mm^2 with ∅8 mm ID), made of silver-copper alloy.
- The magnetic flux swing in the central solenoid Ψcs is approximately 6 Wb (I_{cs} = ± 40 kA).
- The current scenario in the central coil is provided by four thyristor convertors (± 40 kA, 4 kV), and the scenarios in the upper and lower coils are provided by eight thyristor convertors (± 40 kA, 2 kV for each coil) to generate loop voltage 10 V for gas breakdown.



The lower coil winding process

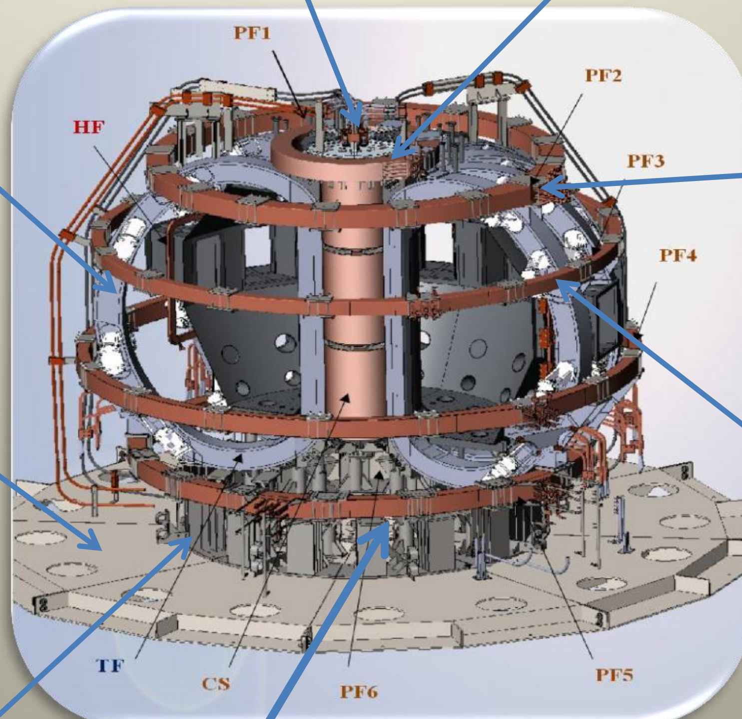
STATUS of MAGNET SYSTEM

Poloidal Field Coils

❑ PF coils are placed outside the toroidal winding and are fastened to the TF coil cases.
❑ All coils are wound by hollow copper conductor and cooled by distilled water.
❑ Each PF coil is fed by an independent current source.
❑ At present, the five of six poloidal coils (PF1, 2, 3,4, 6) have been manufactured and tested.

Poloidal coil winding process

STATUS of MAGNET SYSTEM

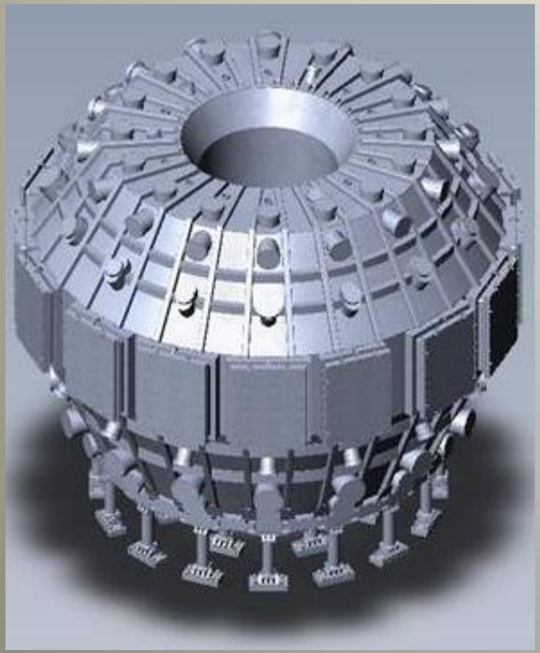


- ❑ **Manufacturing of poloidal coils will be completed in 2014**
- ❑ **Manufacturing of toroidal coils will be completed in 2015**

STATUS of Vacuum Vessel

Vacuum vessel consists of :

- ❑ toroidal shell made of a 321 stainless steel of 5 mm and 8 mm thick,
- ❑ horizontal and vertical ports, a carbon first wall,
- ❑ upper and lower divertors with water cooled graphite tiles,
- ❑ a passive turns covered by graphite tiles.



Parameter	Value
Diameter of outer cylinder, m	4.8
Diameter of inner cylinder, m	1.44
Height of the shell, m	3.49
Volume of chamber, m^3	47
Surface square faced to plasma, m^2	~150
Limiting vacuum, Pa	10^{-5}

- ❑ Vacuum tests of the vessel shell are planned to carry out in January, 2015
- ❑ Baking up to 220 ^{0}C – March, 2015
- ❑ Vacuum shell will be cut into three parts (one half and two quarters) for delivering to Kurchatov Institute
- ❑In-Vessel components will be manufactured in 2015

Parts of vessel at the plant in St-Petersburg

STATUS of ENGINEERING SYSTEMS

Vacuum Pumping System

- The high vacuum pumping of chamber is provided by four turbo molecular pumps with total productivity ~ 10 m^3/s (H_2) and by two cryogenic pumps with productivity 4 m^3/s (H_2) each.

- At present time the all vacuum pumping equipment was supplied and tested with using of a control system.

STATUS of ENGINEERING SYSTEMS

WATER COOLING SYSTEM

- The magnet system, in-vessel components, the turbo molecular pumps, equipment of auxiliary plasma heating systems are cooled by distilled water with pressure 0.5 MPa and 1.0 MPa.

- The total mass flow rate of distilled water is 2000 m^3/h and river water is 1500 m^3/h.

- The equipment for water cooling system was supplied and mounted. The part of equipment is used in real operation now.

STATUS of ENGINEERING SYSTEMS

POWER SUPPLY SYSTEM

- The large changes occur in the power supply system.

- Modernization of the substation 110 /10 kV should be completed in 2015.

- The new sixteen different thyristor convertors and transformers for power supply systems of the toroidal winding and the central solenoid will be supplied and mounted in 2015-2016.

- **Total power in the pulses will comprise 300 MVA.**

Information and Control System

The Central Control System that coordinates and controls the technological and fast problem-oriented subsystems has ITER-like structure and is based on Schneider Electric controllers, Wonder Ware software and NI platform.

At the present time the T-15 Data Center has been prepared, the assembling of equipment for the main systems was realized.

T-15 Data Center

Control room

38 working seats

Tele-conference room

Auxiliary Plasma Heating and Current Drive Systems

Installation will equipped with the auxiliary plasma heating and current drive (P aux = 15 - 20 MW) systems, including:

- **neutral beam injectors (3 co-injectors of 2 MW/ 60 keV H^0 each),**

- **electron cyclotron resonance heating (7 gyrotrons of 1.0 -1.5 MW each, f =112 GHz with a possibility both of second harmonic ECR and electron Bernstein wave heating),**

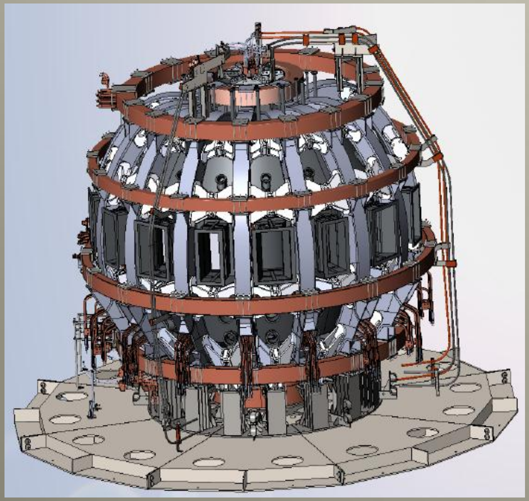
- **ion cyclotron resonance heating (3 antennas of 2 MW each including the possibility of the helicon wave generation),**

- **low hybrid heating and current drive (grill of 4 MW power, f=2.45 GHz).**

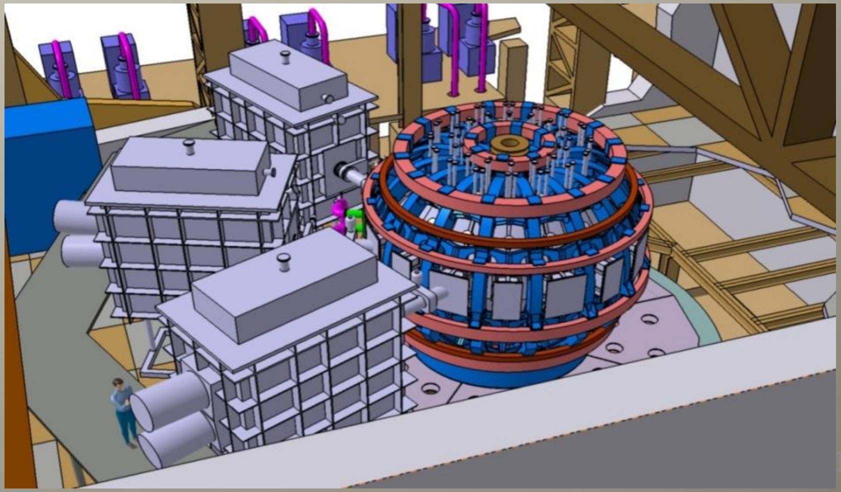
All auxiliary plasma heating and current drive systems will be introduced into operation during 2017-2021.

PLANS

- The time schedule for the tokamak T-15 upgrade introduction into operation is the following:
- 2015 – the completing of manufacturing of T-15 upgrade elements, the control assembling of the toroidal winding at the plant, delivering of the elements of the magnet system and vacuum vessel to the Kurchatov Institue, assembling and adjustment of engineering equipment (will be continued in 2016), disassembling of superconducting tokamak T-15;
- 2016 – T-15 upgrade assembling;
- **2017- Physical start-up.**



2018-2021



Thank you very much for your attention