ИТЭР РФ
ITER RF

ROSATOM

Progress with the ITER project activity in Russia

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for RF ITER collaboration

Institution "Project center ITER (RF DA)

Fusion Energy Conference
International Atomic Energy Agency",
Saint Petersburg, Russia, 13-18 October 2014

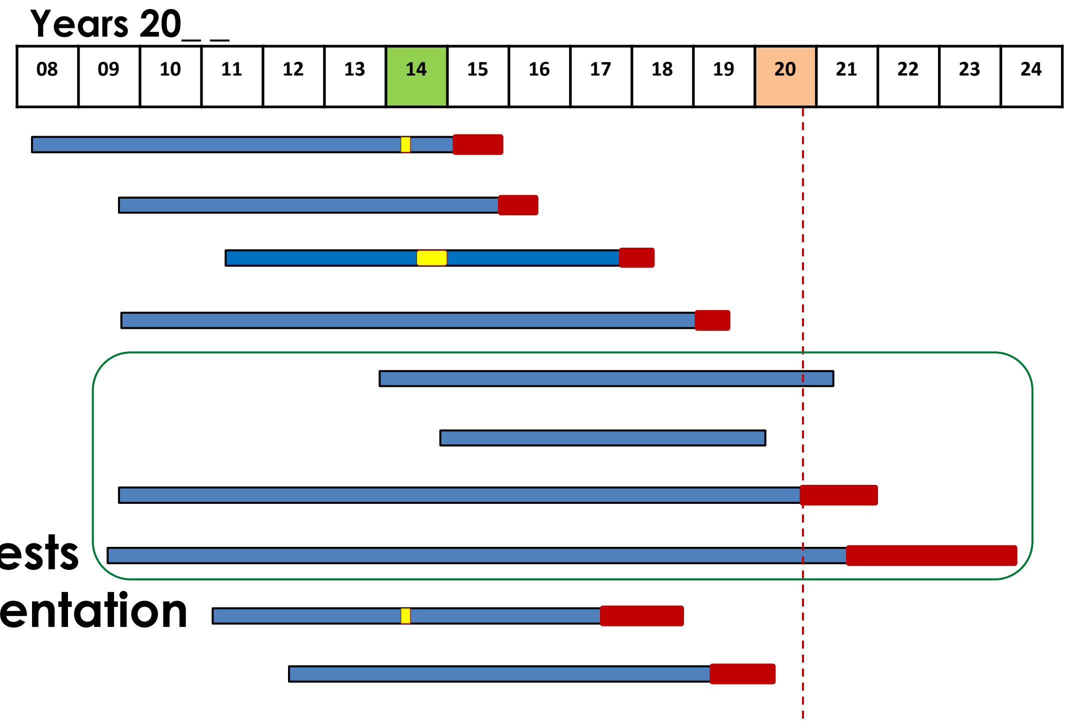
Schedule of RF obligations execution

- **Russian obligations in the ITER project consist of the development, manufacture, installation and puting into operation at the ITER site of 25 systems.**

- **At this stage Russian ITER domestic agency (RF DA) - Institution «Project center ITER» has signed with the ITER Organization 18 procurenment arrangements (PA) for manufacture and supply of the equipment for ITER.**

Manufacture of the signed PA systems and development of yet not signed PA systems is carrying out without critical delay from the schedule of ITER construction.

RFDA Procurements execution / Tokamak systems



1. **TF Conductors**
2. **PF Conductors**
3. **PF Magnet 1**
4. **Upper Ports**
5. **Blanket First Wall**
6. **Blanket Module Connectors**
7. **Dome divertor**
8. **Plasma Facing Component Tests**
9. **SN, FDU, DC Busbar & Instrumentation**
10. **EC Gyrotrons**

On-schedule
AWP Delayed

Assembly after FP

Last IPL delayed

Submitted – May 14

Baseline – Sep 12

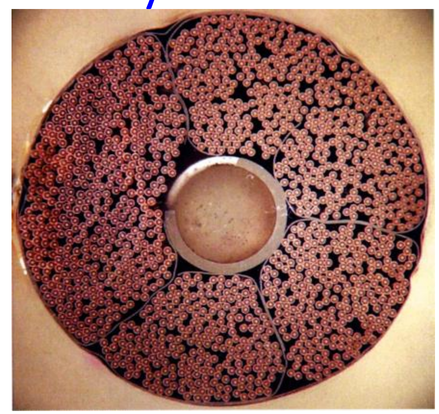
RF contribution to ITER Magnet System

Russian Federation contributes in ITER Magnet System by supplying both **TF and PF Cable In Conduit Conductors** (CICC):

- **28 unit lengths or more than 17 km of Nb_3Sn** based CICC for TF coils;
- **41 unit lengths or more than 23 km of NbTi** based cables for PF coils (Russia manufactures NbTi strand and cables only, while CICC manufacturing "Jacketing" is performed by F4E's contractor Criotec).

Multistage TF Cable contains 900 Nb_3Sn superconducting strand and 522 Copper strands

Cross-section of ITER TF CICC 43.7 mm in diameter



PF cable is pretty similar to TF except it is made only of 1440 NbTi superconducting strands

Cross-section of ITER PF 1&6 cable 38.3 mm in diameter (ss jacket 53.8×53.8 mm^2)

Manufacture of Nb_3Sn and NbTi superconductors is carrying out by cooperation of JSC "TVEL", JSC "Chepetsk Mechanical Plant", JSC VNIIKP, JSC "Bochvar Institute", FSI IPHE and National Research Center "Kurchatov Institute".

Bochvar Institute

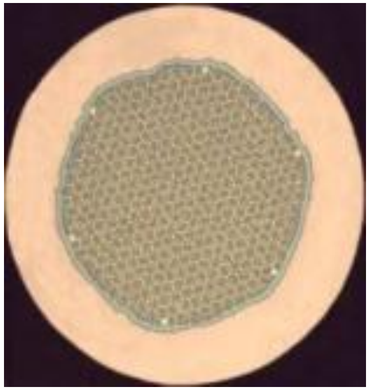
National Research Center "Kurchatov Institute"

Bochvar Institute

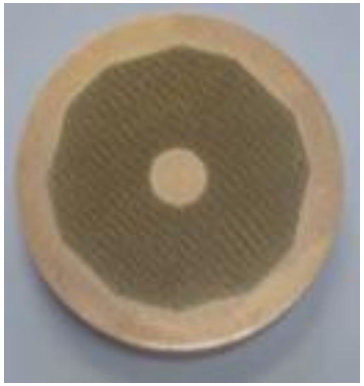
Superconducting strands manufacturing

- Manufacturing process and design of both Nb_3Sn and NbTi strands have been developed by **Bochvar Institute**. Bochvar Institute supervises the manufacturing process implementation at **ChMP** and have been nominated as RF-DA's Reference Lab.
- ChMP's Nb_3Sn and NbTi strand production cycle includes numerous activities starting from in-house producing of raw materials such as Nb and NbTi; and finishing with strand final acceptance tests at own cryogenic lab.
- The total amount of strands to be produced **by the end of 2014 is 99 tons of Nb_3Sn and 125 tons NbTi** for ITER purpose.

Workshop at ChMP, Glazov



Cross section of Nb_3Sn bronze route strand 0,82 mm in diameter



Cross section of NbTi strand 0,73 mm in diameter

Cable manufacturing

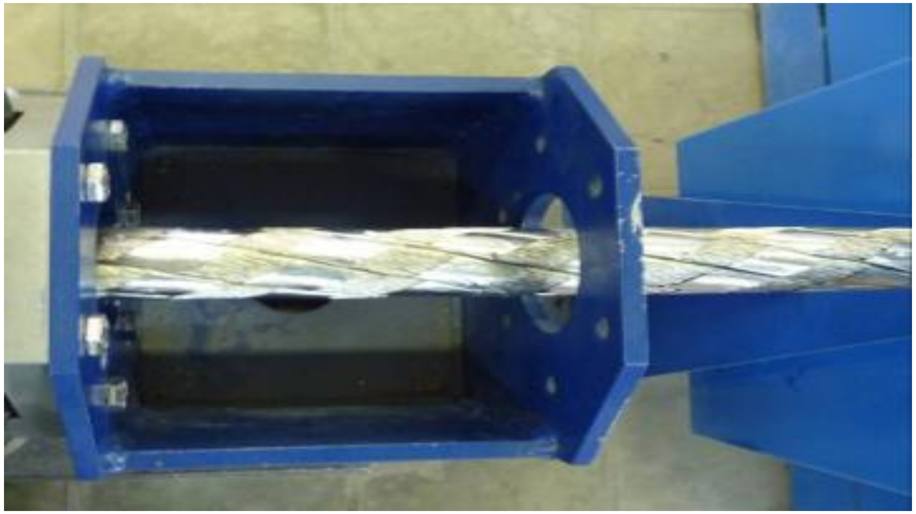
- Cabling facilities for TF and PF cables production are situated in at **Superconducting cables and wires division of JSC VNIIKP (Podolsk)**.

- JSC VNIIKP also produces cable components such as **central cooling spiral** for both TF and PF cables and performs **Cr and Ni plating** of Nb_3Sn and NbTi strands accordingly.

- JSC VNIIKP will produce more than **43 km of TF and PF cables by the end of 2015**.

- JSC VNIIKP's cabling production is appreciated by ITER community as one of **the most modern and well advanced.**

Final cabling stage at VNIIKP, Podolsk



Unwrapped cable

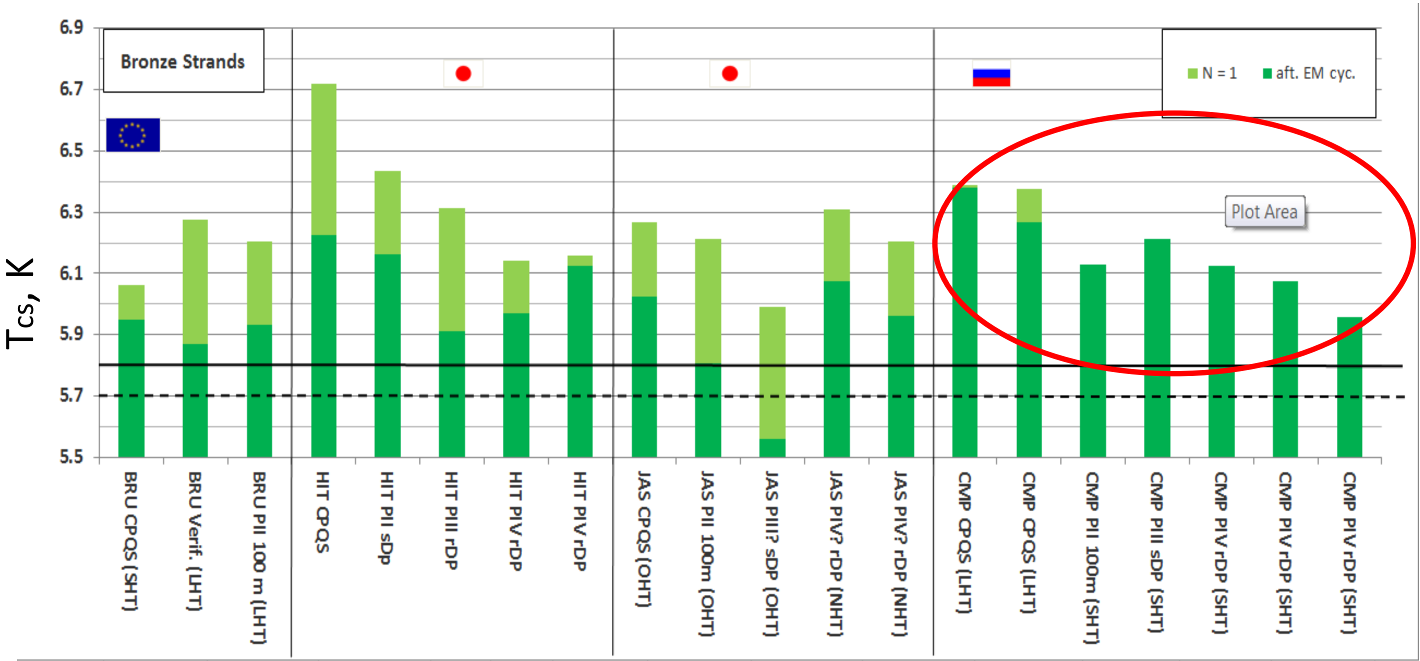
TF CICC manufacturing

- **TF CICC is producing by inserting cable into almost 800m stainless steel jacket and following compaction of the jacket onto the cable.**
- A new jacketing line was **established by VNIIKP in IPHE (Protvino)** specially for implementing ITER program.
- There is only TF CICC jacketing takes place in Russia and **by the end of 2015 about 18 km of TF CICC** will be produced.
- Completed TF CICCs are undergone **global leak test at NRC "Kurchatov Institute"** facility prior to shipping to TF coil manufacturer ASG (La Spezia, Italy).
- In order to confirm sufficiency of CICC performances for the ITER Magnet system **full-size samples of CICC are tested at** operating conditions in the **SULTAN test facility in Villigen, Switzerland**

Jacketing workshop, Protvino

Jacketing line in Protvino

RF and others bronze route based TF CICCs performances during EM cycling tests



- initial Tcs (before EM cycling);
- final Tcs (after EM cycling).

Courtesy of A. Devred, Challenges and Status of ITER Conductor Production (SuST, IOP) 27, No. 4, 044001, (2014).

- CICC performances are estimated by **current share temperature (Tcs)** parameter obtained during full-size sample test in the Sultan facility (Villigen, Switzerland);
- **RF TF CICC samples show good performances and their reproducibility, what indicates good QA/QC system implementation.**
- A peculiarity of RF TF CICC is an absence of degradation (difference between initial and final value of Tcs) versus EM cycling **due to unique strand layout and specific cabling procedure**.

Final tests in NRC "Kurchatov Institute" and transportation to EU

18 of 24 unit lengths of Nb_3Sn toroidal field conductor are manufactured and 16 of those ULs have been delivered to TF coil manufacturer ASG in La Spezia, Italy.

26 of 41 pieces of NbTi PF cables have been completed and 19 of them shipped to Criotec, Italy for the jacketing. **All superconductors will be supplied in 2015**

Tasks solved to implement Russia's contribution to Magnet System

Bochvar Institute

- **Nb_3Sn and NbTi strands production with a capacity up to 60 tons a year has been established at JSC Chepetsky Mechanical Plant (ChMP)** in Glazov, Udmurt republic. **The strands design and process had been developed by Bochvar Institute of Inorganic Materials (JSC VNIINM).**

- **Cabling facilities at JSC VNIIKP (Podolsk, Moscow region) have been upgraded to capacity of 10 km of cable a year.**

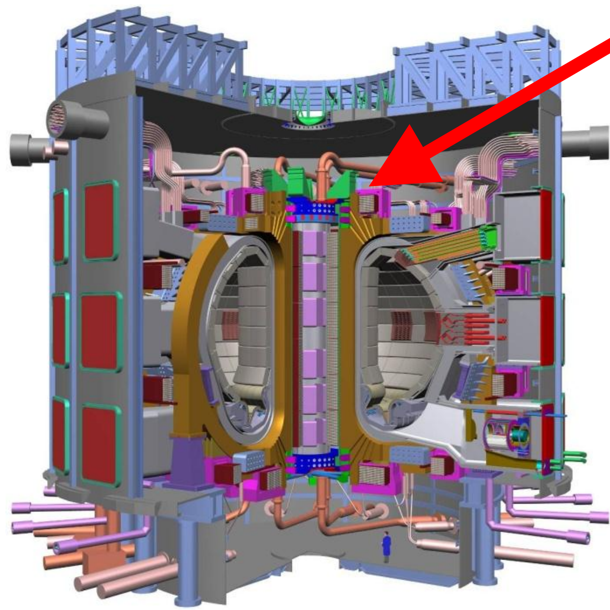
- **A jacketing line for producing up to 7 km of TF CICC a year** has been established by **JSC VNIIKP** in premises **of High Energy Physics Institute** (Protvino, Moscow region).

- **Global leak test facility has been upgraded in Kurchatov Institute (Moscow) for testing TF CICC.**

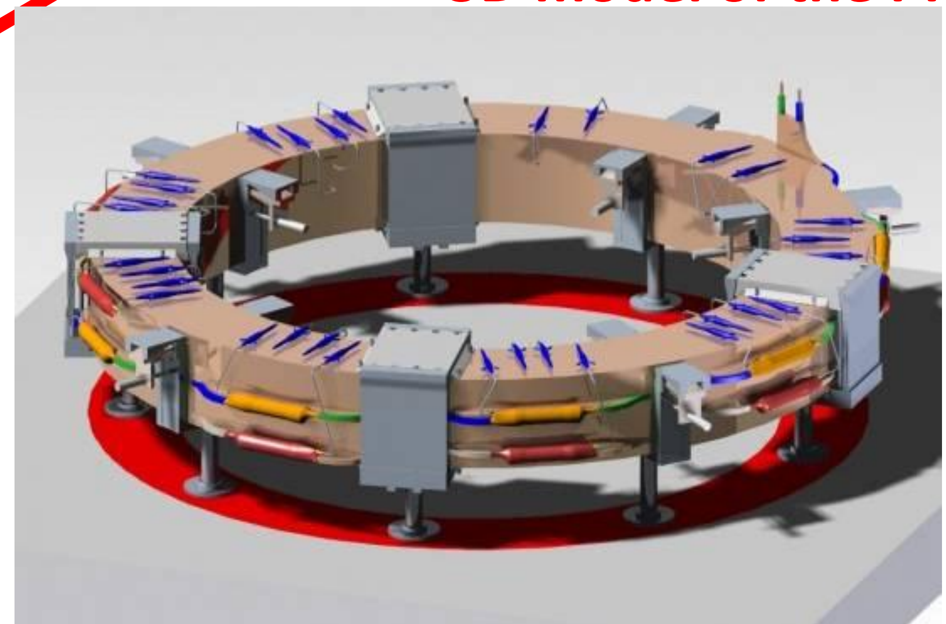
Existing manufacturing capacities are available for new projects demanding superconducting strands, cables or CICCs.

«D.V.Efremov Institute of Electrophysical Apparatus»

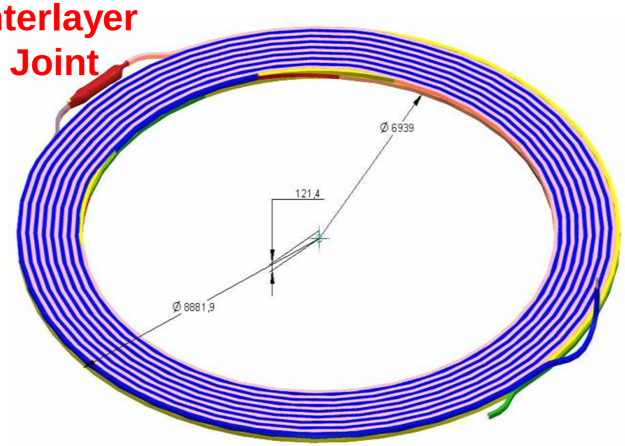
ITER PF1 coil



3D model of the PF1



Interlayer Joint



Dummy double pancake

PF1 coil engineering data

superconductor - NbTi

conduit material - SS 316L

Conductor unit length, m - 400

Number of unit lengths - 16

Number of DPs - 8

DP weight, ton - 16

Winding pack (WP) outer/inner diameters, mm - 8892/6928

WP cross section (width x height) , mm - 982x1007

WP weight, ton 131

Assembled PF1 coil weight, t - 193

Number of Turns Nr × Nz 15.54 × 16=248.6

Current per turn, kA - 48/41

Peak field, T - 6,4/6,5

Predicted inlet temperature, K -4,3-4,5

WP to ground (norm. oper.), kV - 14

WP to ground (fault scenario), kV - 28

«D.V.Efremov Institute of Electrophysical Apparatus»

PF-1 manufacture facility in shipping plant (Saint Petersburg)

Winding Line

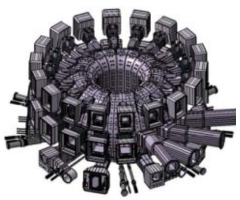
Assembling of Vacuum-pressure impregnation line

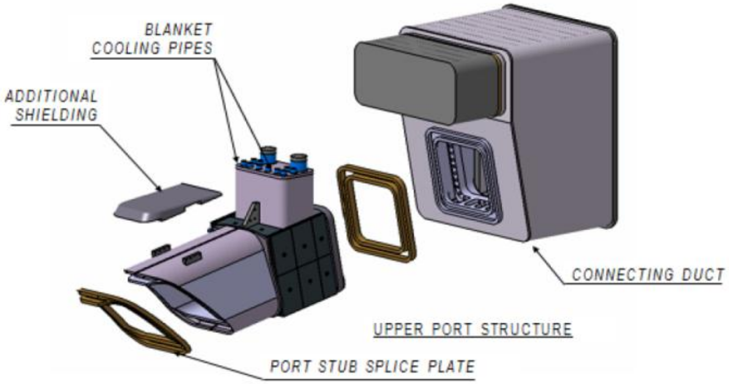
Vacuum-pressure impregnation vessel for one pancake

PF1 coil assembly plant on pantone

Upper Ports of the ITER Vacuum Vessel

NIIEFA



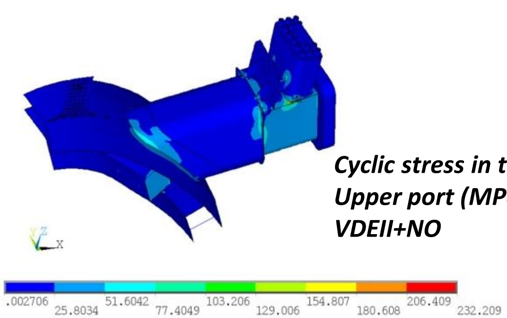


Upper Ports	9 central + 9 lateral
Materials	austenitic stainless steel 316L(N)-IG, 304L
Dimensions	7.2 x 3.7 x 2.8 m
Weight	34 ton x 19
High Vacuum	< 1e-7 Pa m^3/sec
Double wall Cooling water	2.6MPa (100/200^{o}C)

Port structure includes a Port Stub Extension (PSE) connected to the port stub integrated with the main vessel, and a port extension connected to the cryostat with a connecting duct.

PA 1.5.P2B.RF	2014	2015	2016	2017
Materials	■	■		
Manuf. Design	■	■		
Qualification	■	■		
Port Stub Extension	■	■		
Connecting Ducts		■	■	■
Sealing flanges		■	■	■

The Upper Ports belong to the Safety Important Class (SIC) components of ITER.
Build to requirements by RCC-MR2007
QC2 under surveillance by ANB: AIB Vinçotte International, Belgium



Cyclic stress in the VV Upper port (MPa). VDEII+NO

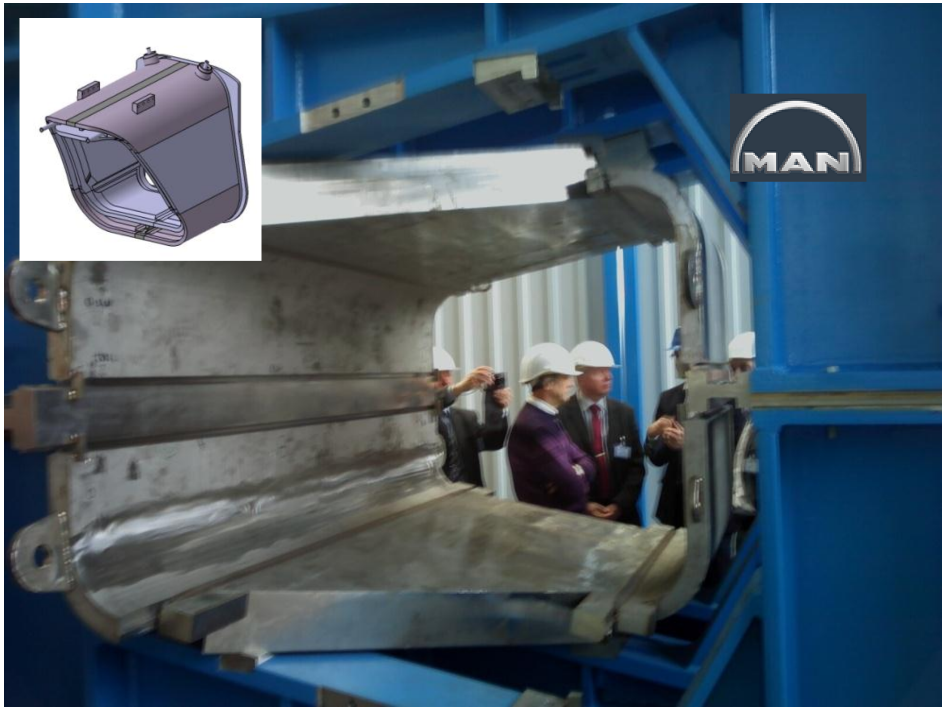
Full-scale mock-ups are manufactured at JSC "Izorskie zavodi" and JSC "ZIO Podolsk" (Russia)

Structural integrity of ITER VV Upper Ports is confirmed against P-type and S-type damage with regards to RCC-MR and ITER requirements in detailed ANSYS analysis by Efremov Institute (Russia).

Upper Ports of the ITER Vacuum Vessel

NIIEFA

Manufacturing of the Upper Ports is **started at MAN Diesel & Turbo SE, Deggendorf, Germany** with technologies/documents preparation, detailed manufacturing design, material cutting, NDT testing, and mock-ups for welding and forming.



At **MDT**, Welding Eng. Werner Konig is discussing results of the full-scale mockup of the Upper Ports inner shell structure with Alexander Alekseev, head of ITER's Tokamak Directorate (centre right) and Technical Coordinator Evgeny Kuzmin (Efremov institute, Russia)
UP Mockup to demonstrate tolerances of the PSE inner surface (to be within +4/-2 mm) and the double wall (to be within ±2 mm)

Forming Qualification of 60mm plates incl. heat treatment at comp. Koenig in Siegen, Germany

Manufacturing of jigs/turning devices for the Upper Ports assembly at MDT

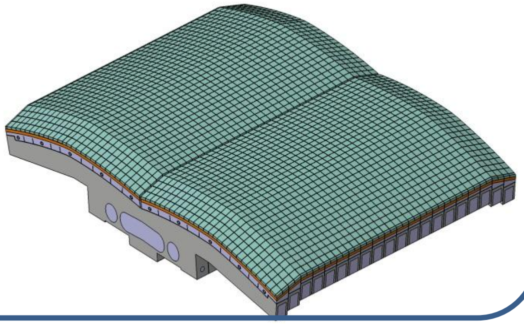
Tasks for manufacturing and testing of High Heat Flux (HHF) components in

NIIEFA

First Wall (FW) Panels (40% -Enhanced Heat Flux)

N = 179 Be-armored panels

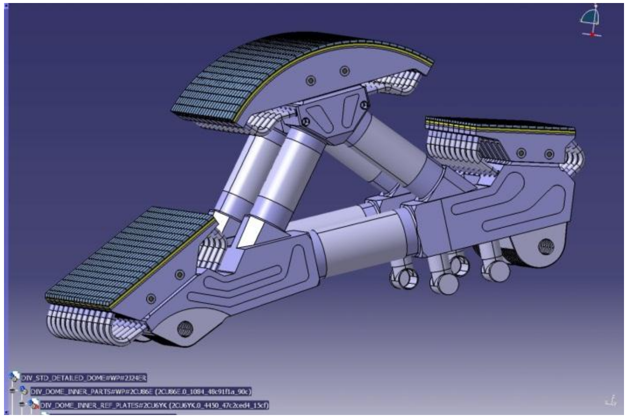
Each: (0.4x1.5x1.0) m, 0.8 t



Divertor Dome (100%)

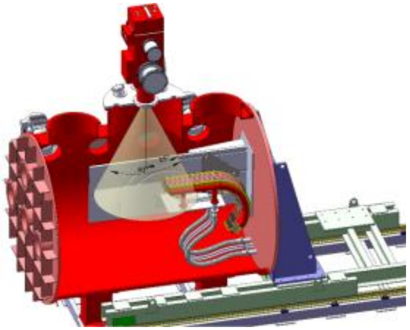
N= 60 W-armored assemblies

each: (0.8x0.6x1.6) m, 1 t



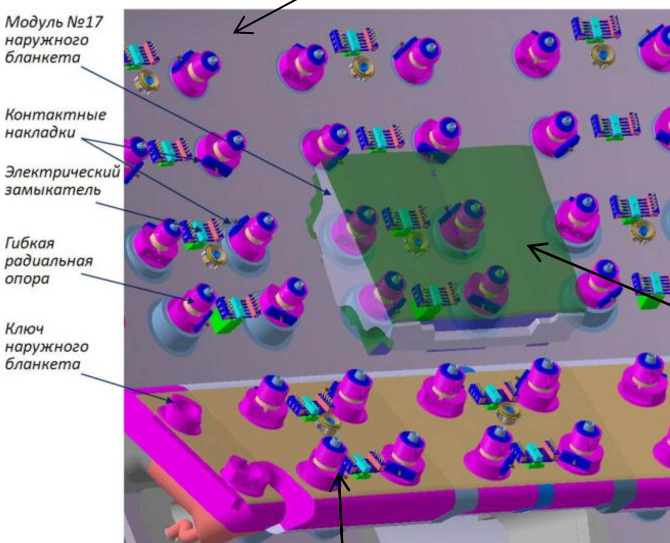
HHF testing of divertor (100%)

20% of all divertor PFU will be HHF tested



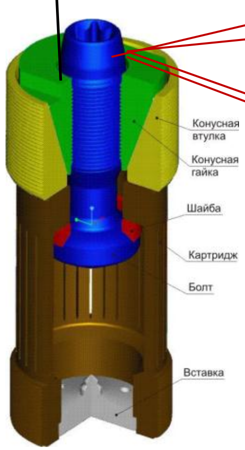
Blanket Module Connectors and First Wall Panels

Vacuum Vessel

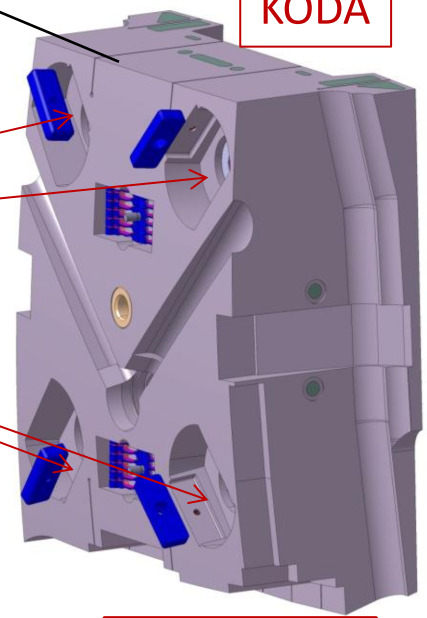


- The FW panel comprises a beryllium armour surface joined to a CuCrZr heat sink and supported by a stainless steel structure. **FW panel size is up to 2 m wide, 1.4 m tall and mass - 900 kg.**
- **The Shield Block is a large stainless steel component up to 2 m wide, 1.3 m tall and 0.5m thick, its maximum mass is of the order 4000 kg.**

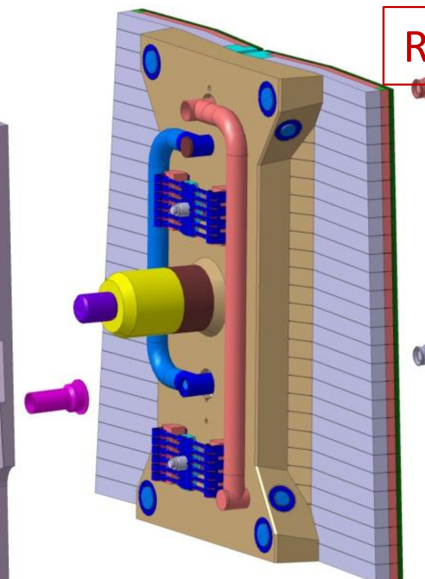
RFDA



KODA



RFDA



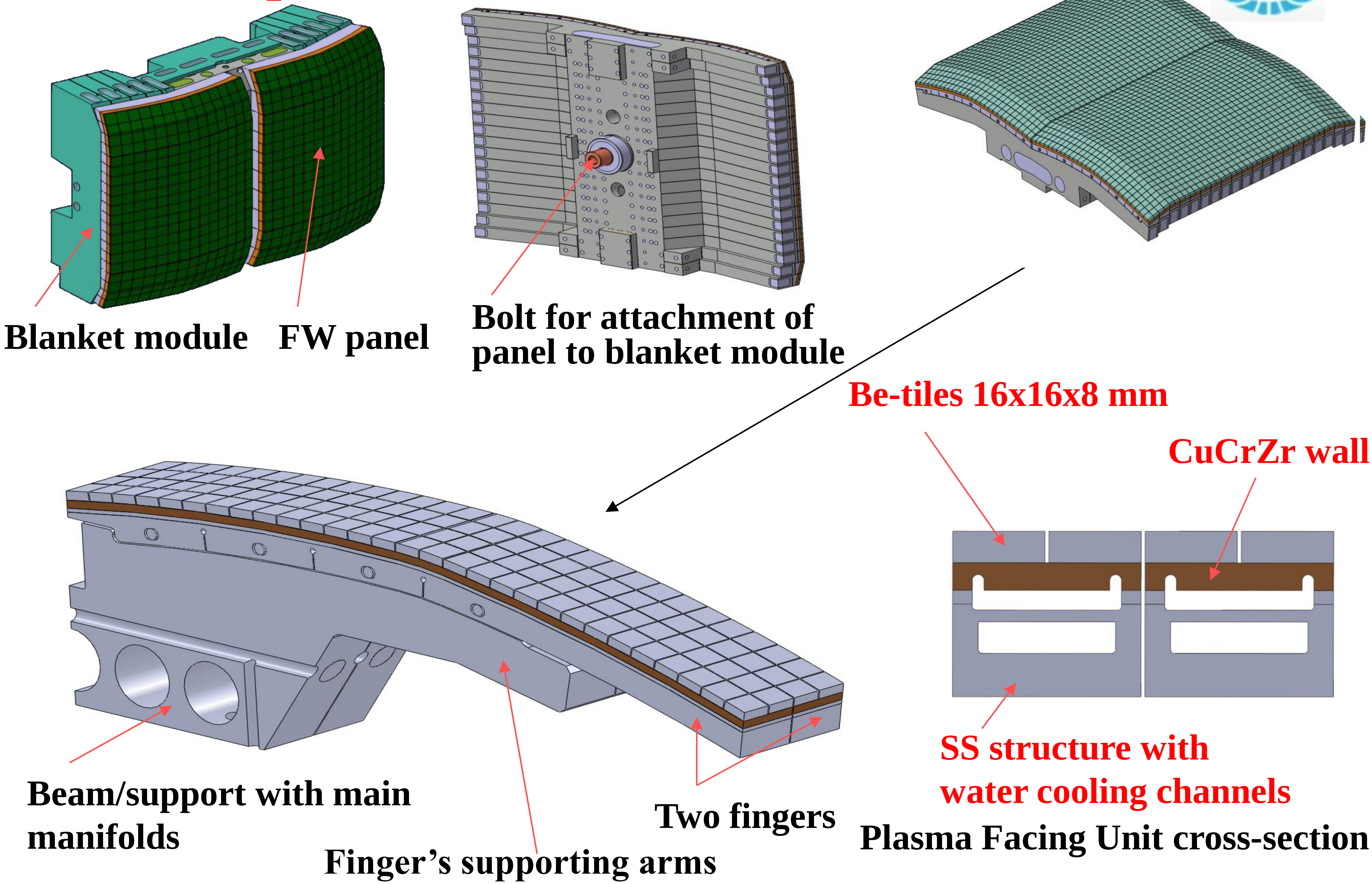
Shield Block Connectors = 1760

Shield Blocks

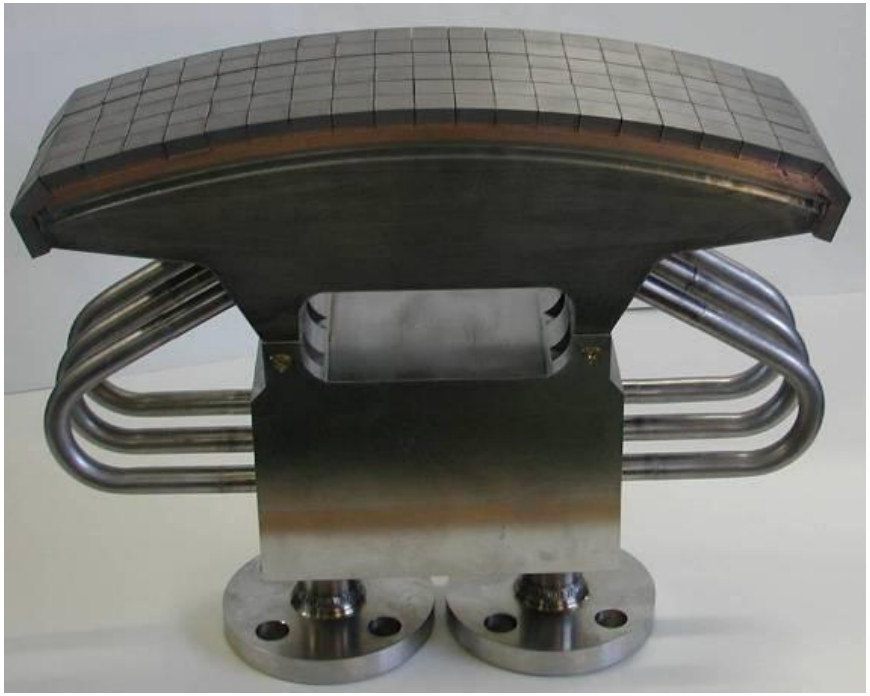
First Wall panels = 179

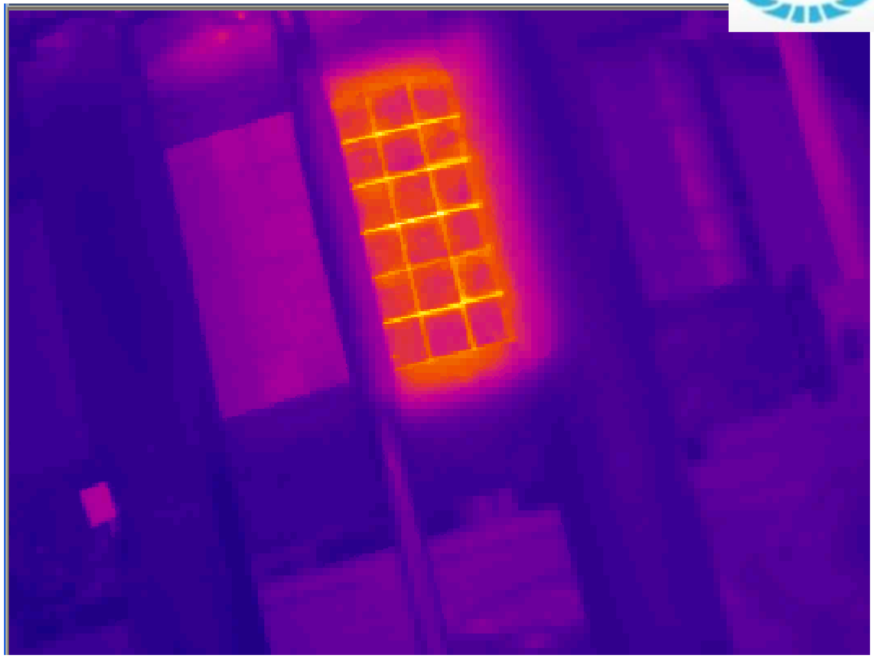
First wall panel

NIIEFA



НИКИЭТ им.Н.А.Доллежаля





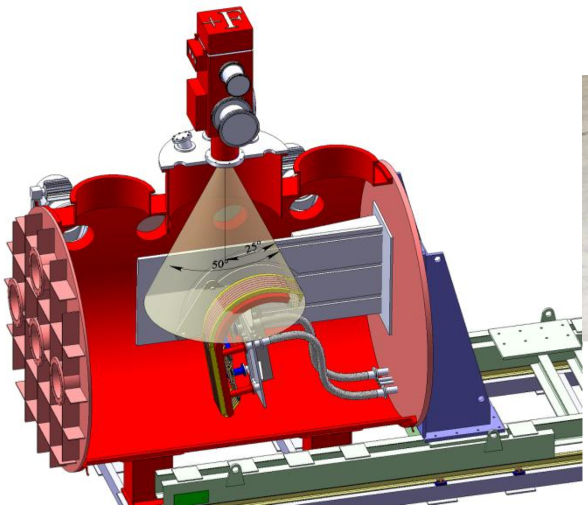
NIIEFA

Water cooling parameters	Surface thermal loading parameters
V = 5 m/s T in=125°C P in=3.2 MPa	1000 cycles at 5 MW/m^2 – OK - ITER specification 500 cycles at 8 MW/m^2 – OK 326 cycles at 10 MW/m^2 – water leak

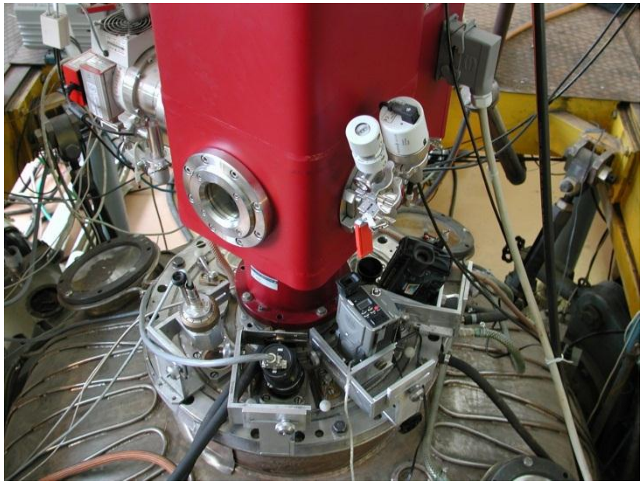
Successful qualification testing of Divertor Dome medium size mockups

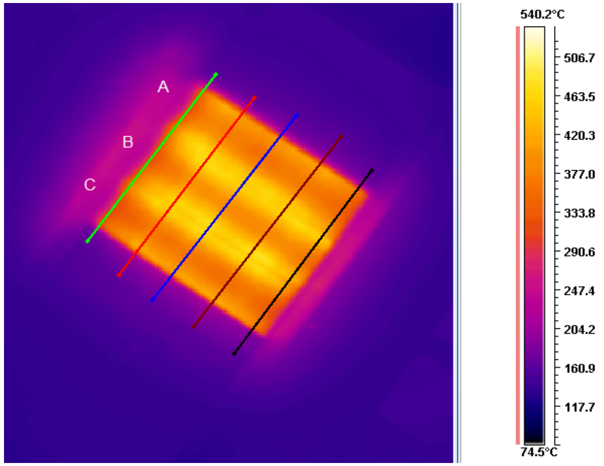
Heat flux testing of Plasma Facing Unit (PFU) during manufacturing

NIIEFA

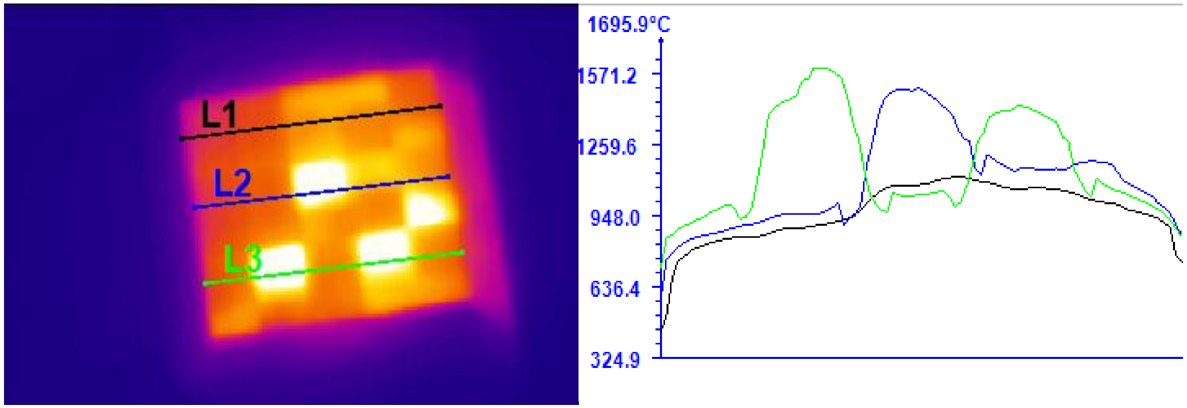


PFU of Dome to be HHF tested before assembling





IR-picture of mockup with qualitative joints



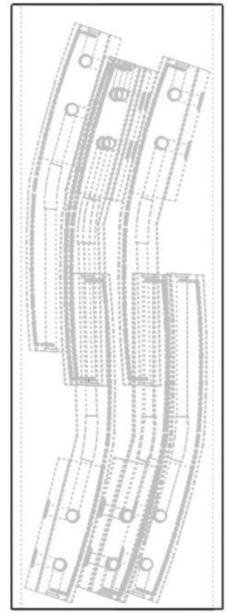
IR picture and surface temperature variation for mockup with defects

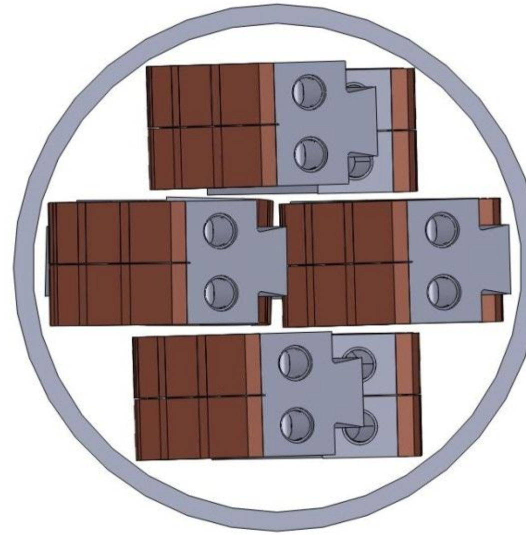
Manufacturing sector of HHF/PFC department in

- In-door area (with pilot plant PFC-area)   ≥ 3000 m^2
- Readiness to serial production   – end of 2016
- Annual turnover ~20 M$ in a peak
- Staff: 60-70 operators and assistants

–

HIPping of finger's CuCrZr-SS structure





HIP- machine

D_{in} =380 mm, L_{in} =1200 mm

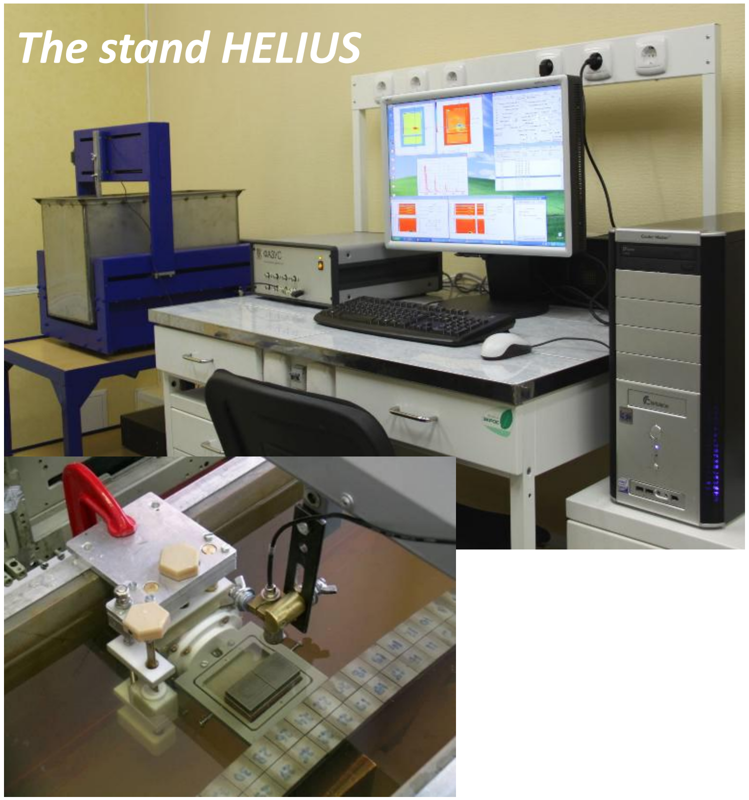
P≤150 MPA

T≤1250 C

Several fingers (4-8) in one heat

Ultrasonic equipment for non destructive tests of ITER plasma facing components in

(laboratory type-left, industrial type –right)



Small-scale flaw detector
(500*300*300mm)
FAZUS 2007

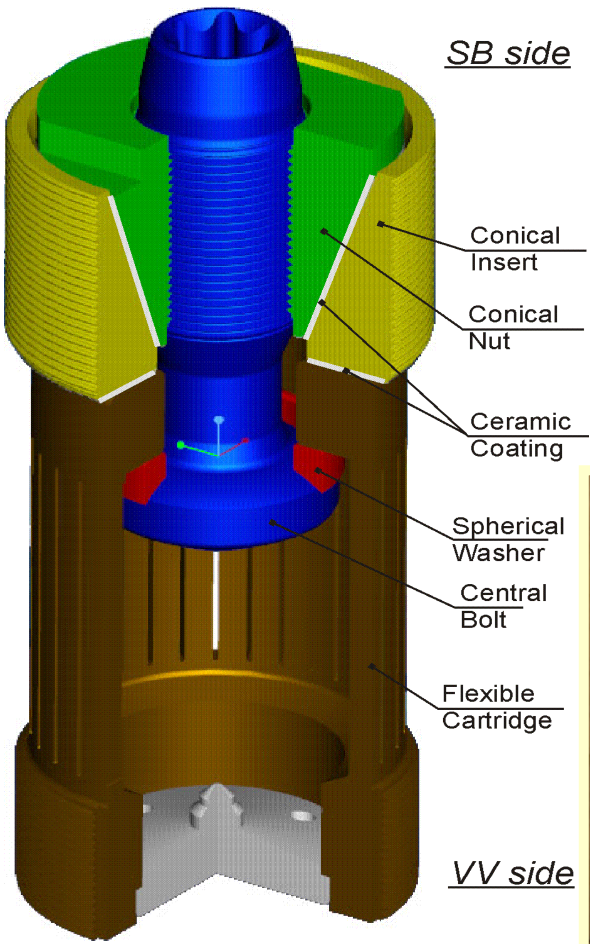
Factory flaw detector
(2000*1500*1000mm)
FAZUS 2010

Flexible Supports for the Blanket Modules

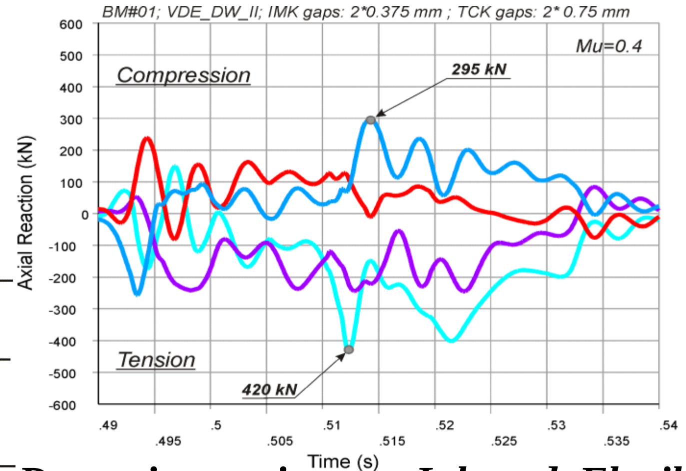
PA signature - 01.12.2014

Fabrication, test, delivery 07.11.2016 - 30.01.2020

2209 pieces in total



Flexible Support Assembly



Dynamic reactions on Inboard Flexible

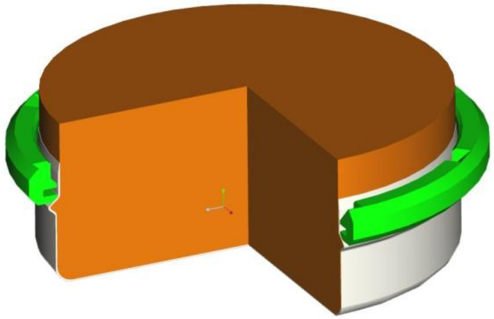
6 Test Samples Studied at 500-1000 kN up 12000 cycles

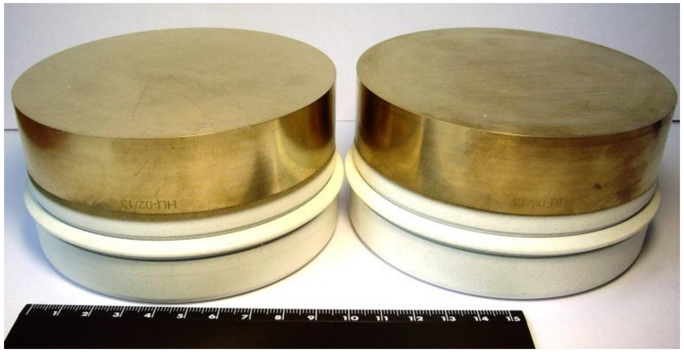
Instron 8806 (2,5 MN, up to 1 Hz)

Parts after cyclic test

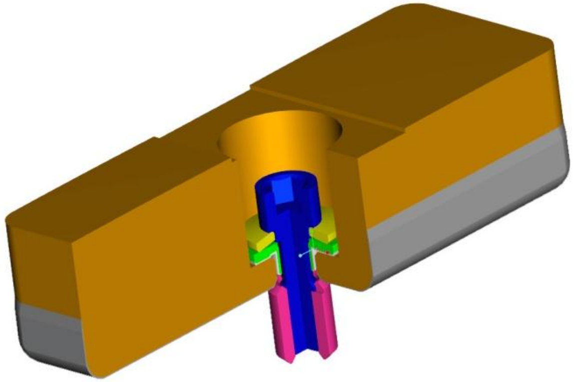
Pads with Ceramic Insulation

2561 pieces in total





Cylindrical pad



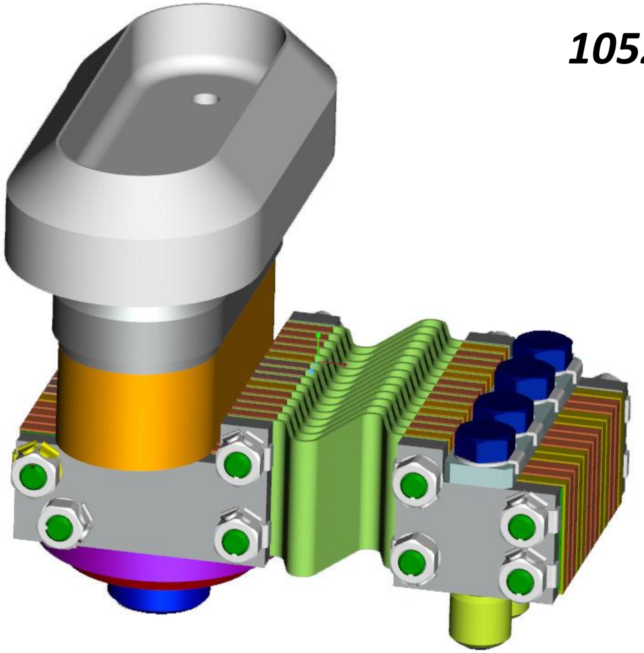
Rectangular pad

Test samples

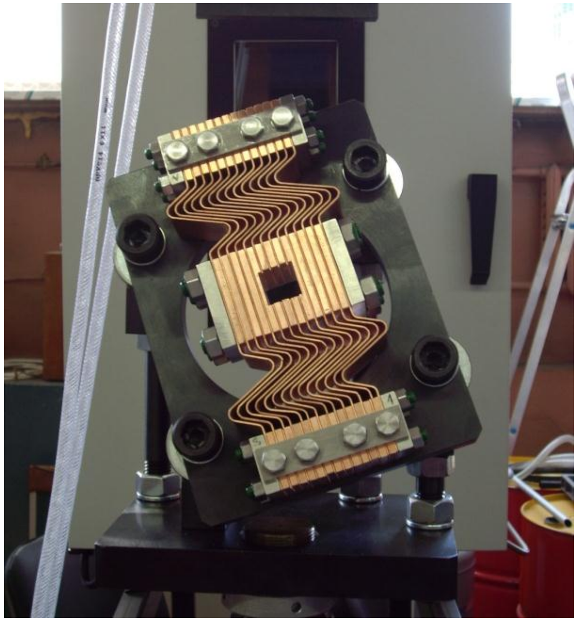
Cyclic test facility at Instron 8806

Electrical Strap Connector

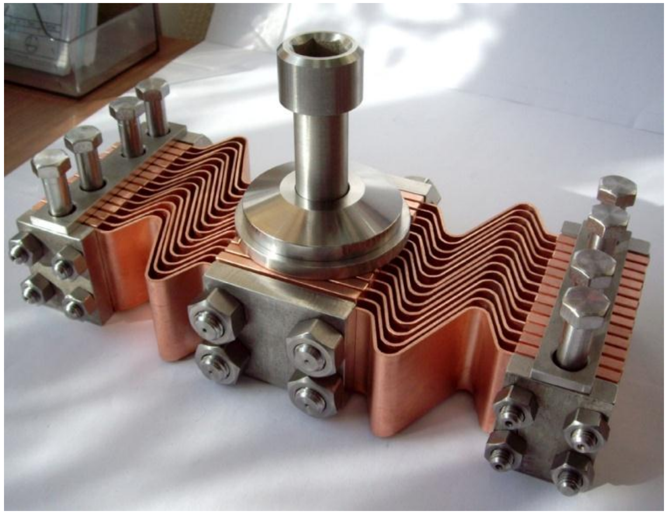
1052 pieces in total



Design by February 2014



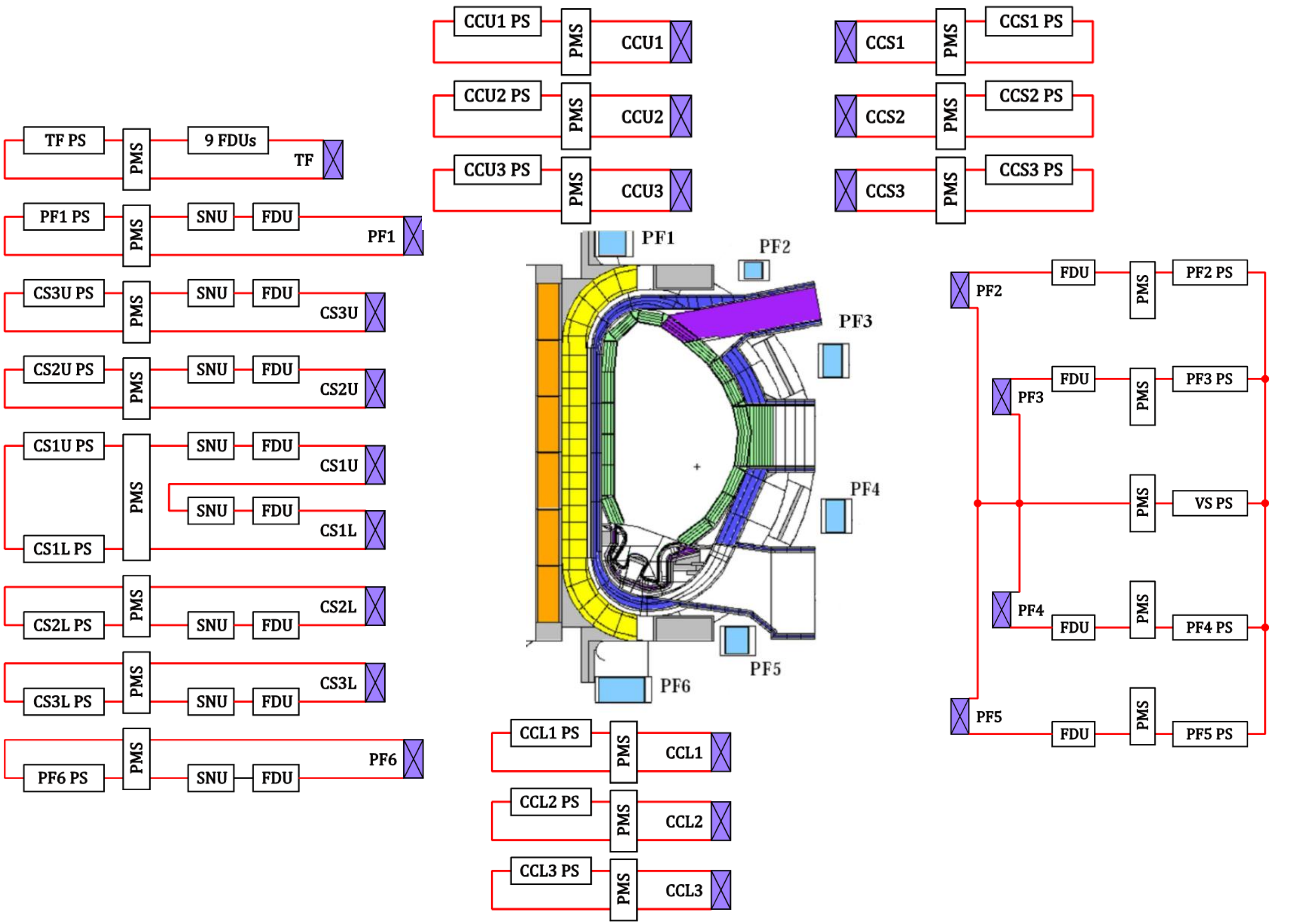
Cyclic Test of ESC at Instron 8802 (250 kN, 15 Hz)



Test Sample by March 2013

Bimetal pedestal of ESC

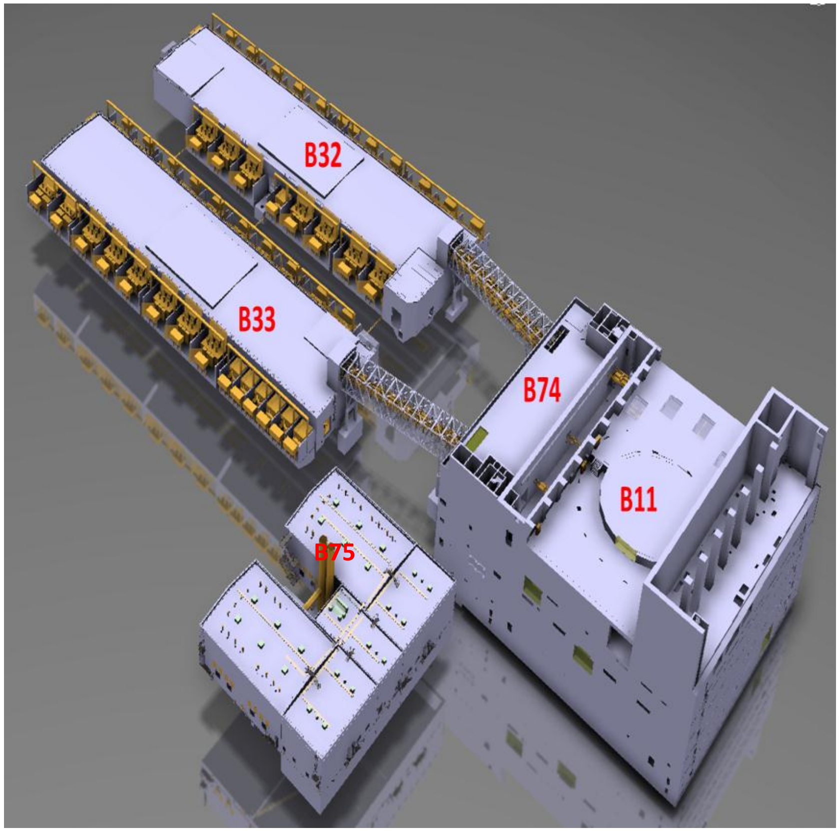
Diagram for Coil Power Supply System (CPSS)

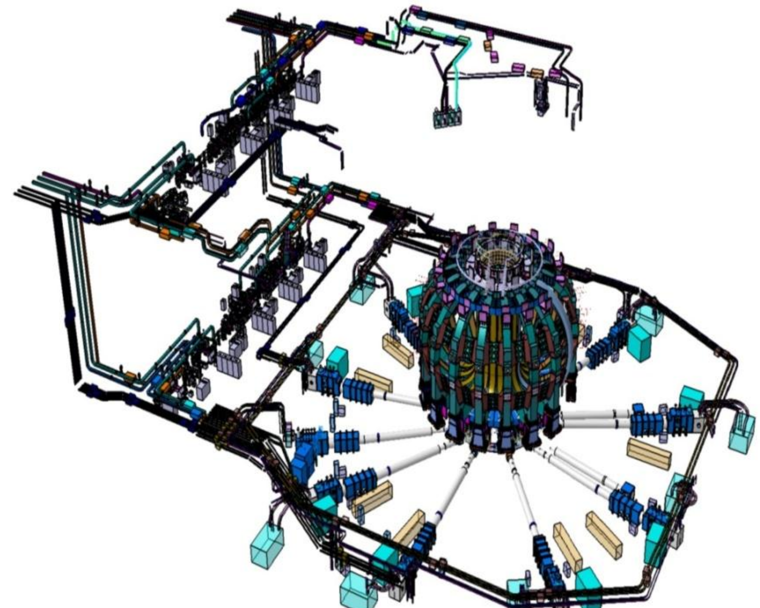


Equipment subject to designing and manufacturing

ELEMENTS OF THE EQUIPMENT	QUANTITY
➢ **SWITCHGEAR** • **Fast-responding switching devices for SNU** • **Protective devices with explosive drive (for FDU and SNU)** • **Thyristor switches and alligators** • **Disconnectors, grounders**	More than 140 devices of different types
➢ **POWER ABSORBING RESISTORS** • **Resistors for SNU** • **Resistors for FDU**	18 GJ/50 sections 50 GJ / 800 sections
➢ **BUSBARS SYSTEM** • **Aluminium busbars (with supports)** • **Flexible copper links for thermo compensation** • **Copper bars for devices connection**	 4500 m 2850 pieces. 400 m
➢ **Power coaxial cables**	40 км
➢ **The system of current and windings voltage measurement**	more than 100 sensors
➢ **Control racks**	~ 70 pieces

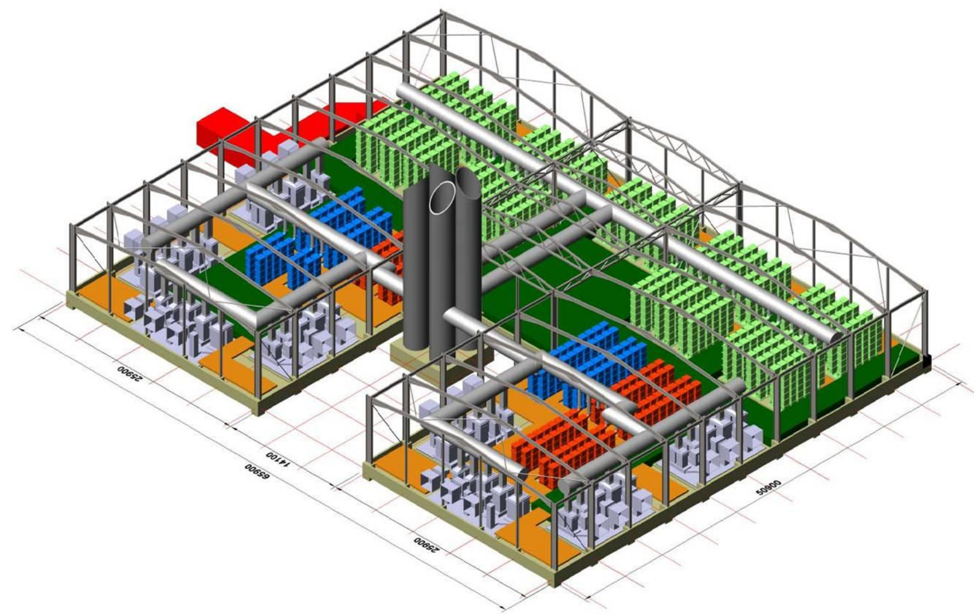
Location of the CPSS equipment and busbars





DC busbars and equipment in the Tokamak complex

Buildings housing the CPSS equipment and busbars



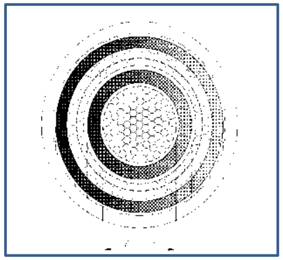
Building B75 for Power Discharge Resistors

MAIN COMPONENTS

Components to be designed and manufactured by Subcontractors

SWG - main Circuit Breaker
SIEMENS AG, Germany

DC Current Commutation Devices

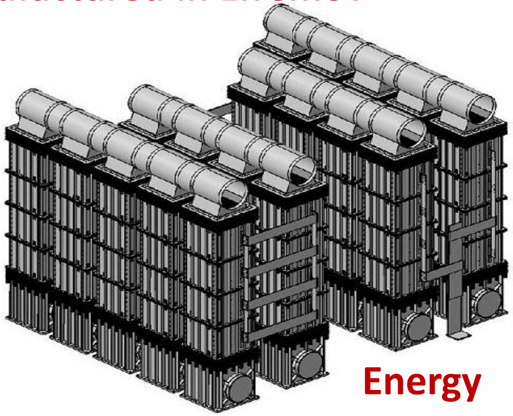


Power Cables

Main Supplier RDTCI SEVCABEL, Russia

- **Manufacture & routine tests - JCT “Sevcabel”**
- **Type Tests (electric) “STC UES”**
- **Type Tests (flame) “Electrosert”**

Components to be designed and manufactured in Efremov



Energy Discharge Resistors

PB - Pirobreaker (backup circuit breaker)

CPC
Counter Pulse Circuit

DC Busbars (build.11-B2)

2014 Activity: FDR, tests of the equipment prototypes, busbars and start serial manufacture

Gyrotrons for ITER

The main specifications of the gyrotrons for ITER:

Parameter	Specification
Nominal output power	≥ 0.96 MW at MOU output
Nominal frequency	170±0.3 GHz (TBD) including initial transient phase
Pulse length	400/1000/3600 sec (TBD)
RF power generation efficiency	≥ 50 % (with collector potential depression)
Gaussian content	> 95 % at output waveguide (63.5 mmϕ) of MOU
Power modulation	1 kHz (cathode); 5 kHz (anode)

The gyrotron prototypes for ITER showed parameters corresponding to ITER requirements.

Main results			Institution/Company
1 MW / 55 % / 800 s	and	0.8 MW / 57 % / 3600 s	JAEA/Toshiba, Japan
1 MW / 53 % / 1000 s	**and**	**1.2 MW / 53 % / 100 s**	**IAP/GYCOM, Russia**

Now the main part of activity is enhancement of reliability and integration in ITER EC system

GYCOM

Russian 170 GHz ITER Gyrotron. Design features.

Gyrotron cavity designed for **$TE_{25.10.1}$ mode** with specific wall loading **$2 kW/cm^2$ at 1MW**

Diode type electron gun forms the electron beam with optimal size, up to **50A / 70-80kV**

Synthesized Built-in quasi-optical converter**. Gaussian mode content over 95% at stray radiation less than 5%**

Main output window is based on **CVD diamond disk of 106-mm diameter with 88-mm clear aperture.**

Relief window uses ceramics (BN or AlN) disk of 123-mm diameter to transmit 40 kW.

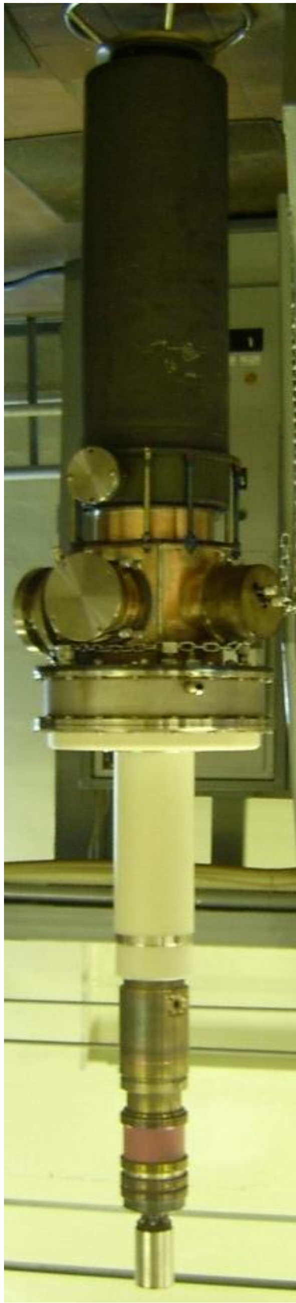
Depressed-collector with longitudinal beam sweeping is capable to withstand 1-MW electron beam. **Enhances gyrotron efficiency over 50%**.

DC break insulator upon cryomagnet top flange. C_8F_{20} fluorocarbon as a coolant .

LHe-free cryomagnet has a bore diameter of 160 mm.

Gyrotron inner surfaces are fabricated from copper with water cooling for CW operation.

Gyrotron total height is 2.7m. Gyrotron weight is about 300+ kg.



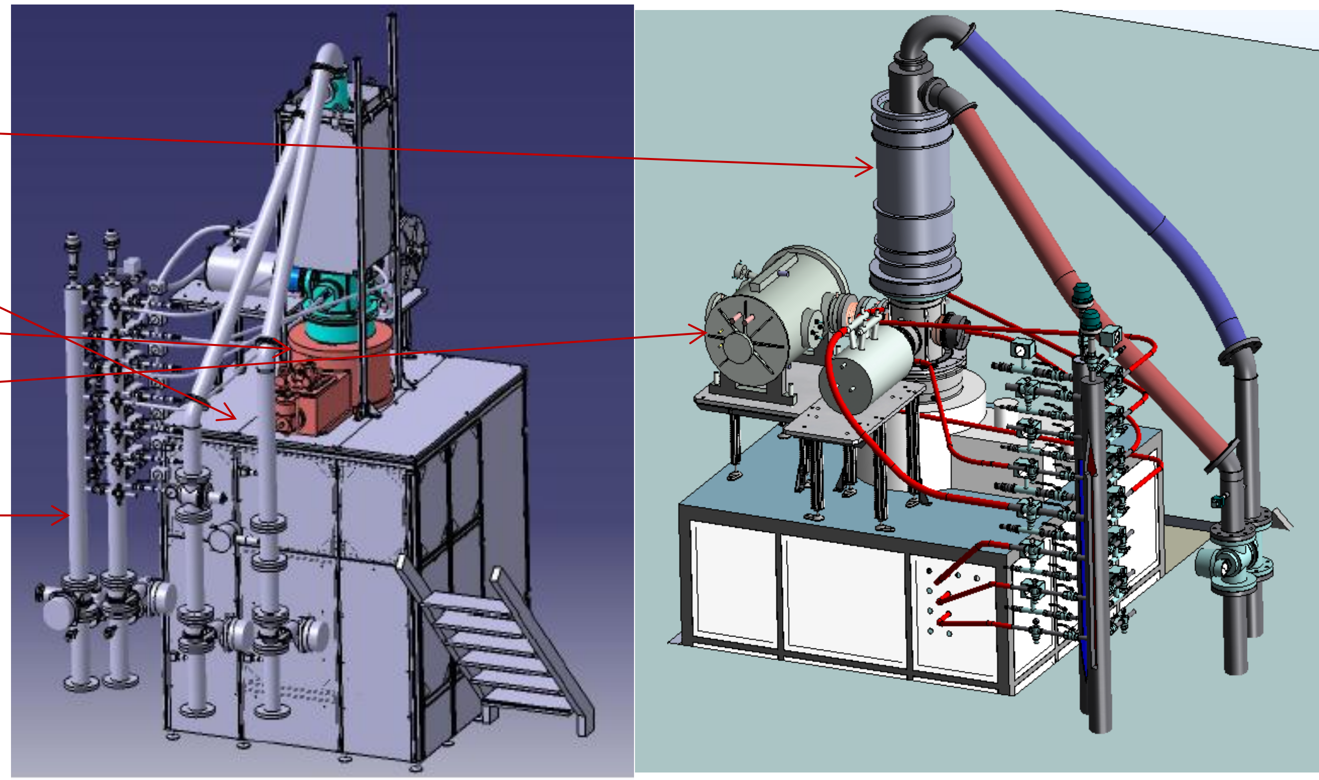
IAP RAS GYCOM NRC KI

Russia is to deliver 8 gyrotron sets to ITER:

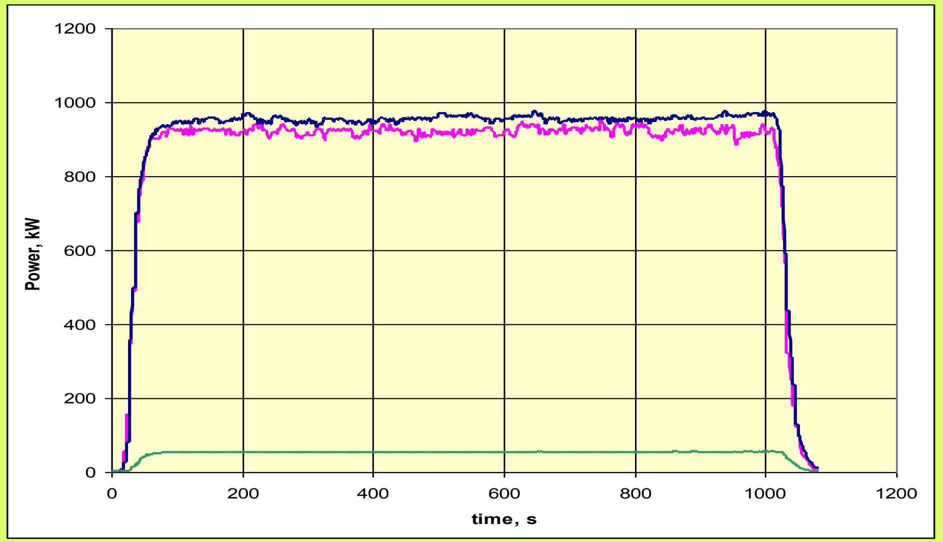
Gyrotron system

- Gyrotron
- Gyrotron support (oil tank)
- Magnet
- Microwave units (MOU, relief load)
- Water cooling system
- Auxiliary power supplies
- Local controller
- Cubicles for apparatus

3D drawing of gyrotron module installation on ITER site



Achievement of ITER relevant parameters with RF gyrotron



V-11: Power calorimetry in the 1MW/1000s pulse

In the last five years four gyrotron prototypes were fabricated and tested with CRYOMAGNETICS (USA) and JASTEC (Japan)

LHe–free magnets

all gyrotrons demonstrate similar output parameters

Summary of test results attained with V-10 and V-11 gyrotrons

Gyrotron	Beam voltage kV	Beam current A	Retarding voltage kV	Output power* kW	CPD efficiency %	Pulse duration Sec
V-10	71	34	30.5	~750	~54	1000
	71	34	30	~750	~54	600
V-10	71	45	30.5	~960	~53	578
	70	45	31.5	~960	~55	400
V-11	70	39.5	30	~850	~53	1000
	71.5	45	30	~990	~53	1000
	73	53	29.5	~1200	~52	100

* Power referred to MOU outlet (~ 0.95 of output power)

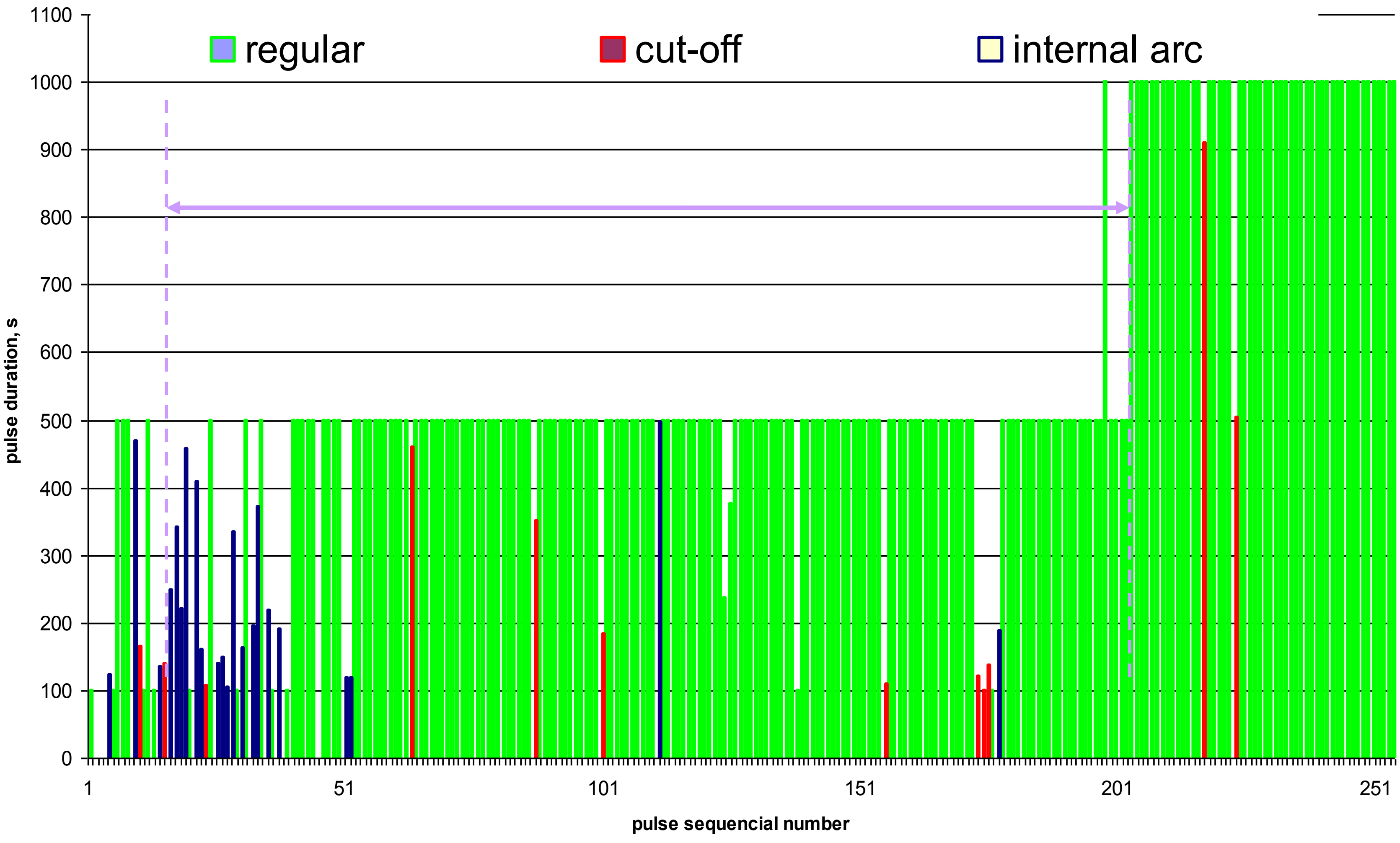
Now V-12 and V-14 are under tests in 1MW/1000 pulses

IAP RAS GYCOM NRC KI

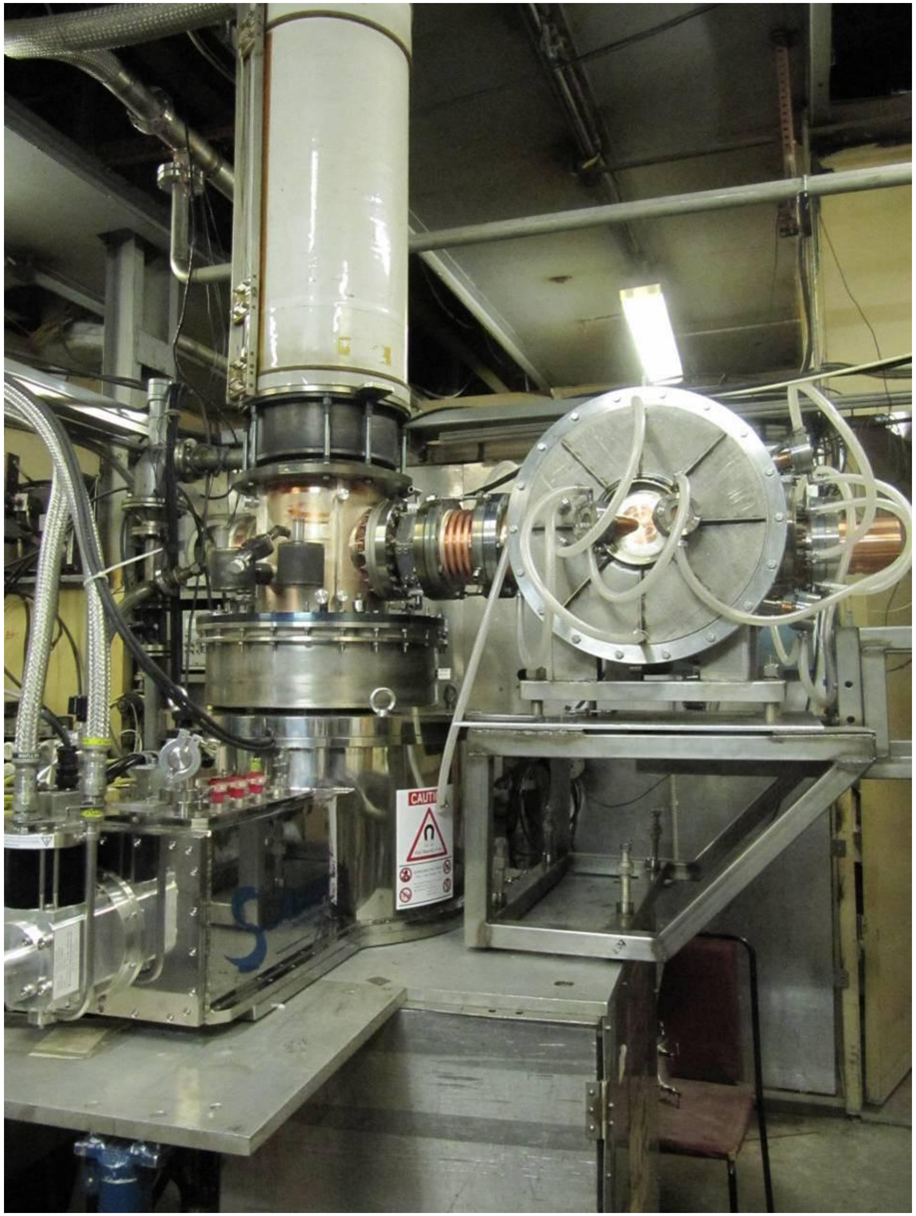
Gyrotron for ITER

Reliability > 95%

Gyrotron run test at 1MW output power with pulse duration 500s and 1000s (500s – 160 pulses, 1000s – 55 pulses)



Higher power gyrotrons



RF $TE_{28.12}$ long-pulse 1.5 MW gyrotron prototype in the test bench

Preliminary test successful:

✓ Over 2 MW with efficiency of ~34 % at 100 kV/60 A was achieved in the 100-μs gyrotron mock-up

✓ 1.75 MW and efficiency ~50 % pulse duration was achieved in the gyrotron prototype at 0.1 s

✓ **2.5s pulse duration at 1.5MW** output power has been attained at 92.3 kV/52 A

✓ Wave beam structure OK

Collector damage.

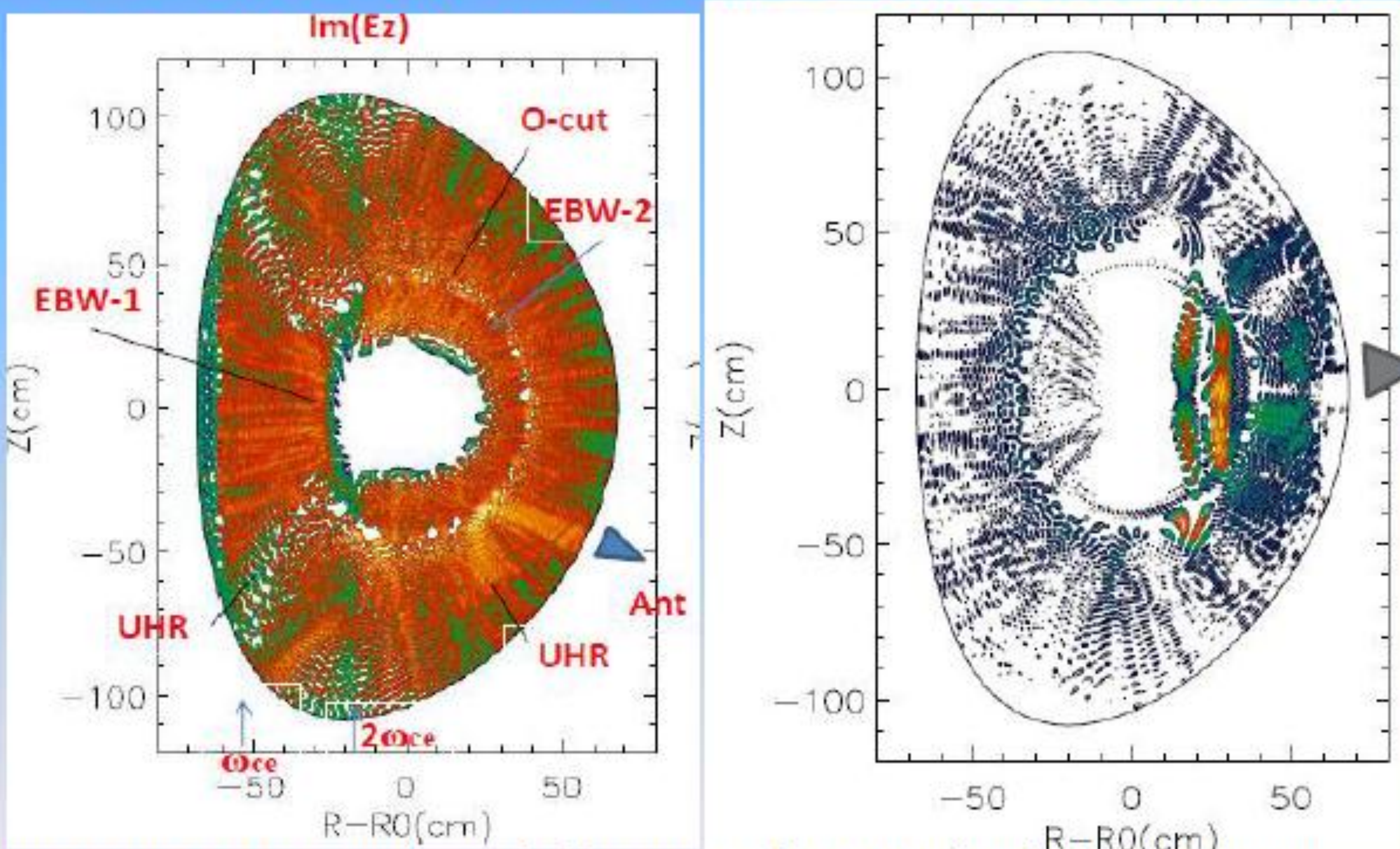
Test restart in Oct.2014.

Aim 1.5 MW/500 sec.

Result for today	Country
170 GHz/1.5MW/48%/ 2.5 sec	Russia
170 GHz/ 1.94 MW/43%/ 0.003 sec	EU
117 GHz/ 1.8 MW/ 41%/ 0.005 sec	US
77 GHz / 1.7-1.8 MW/ 1-2 sec	Japan

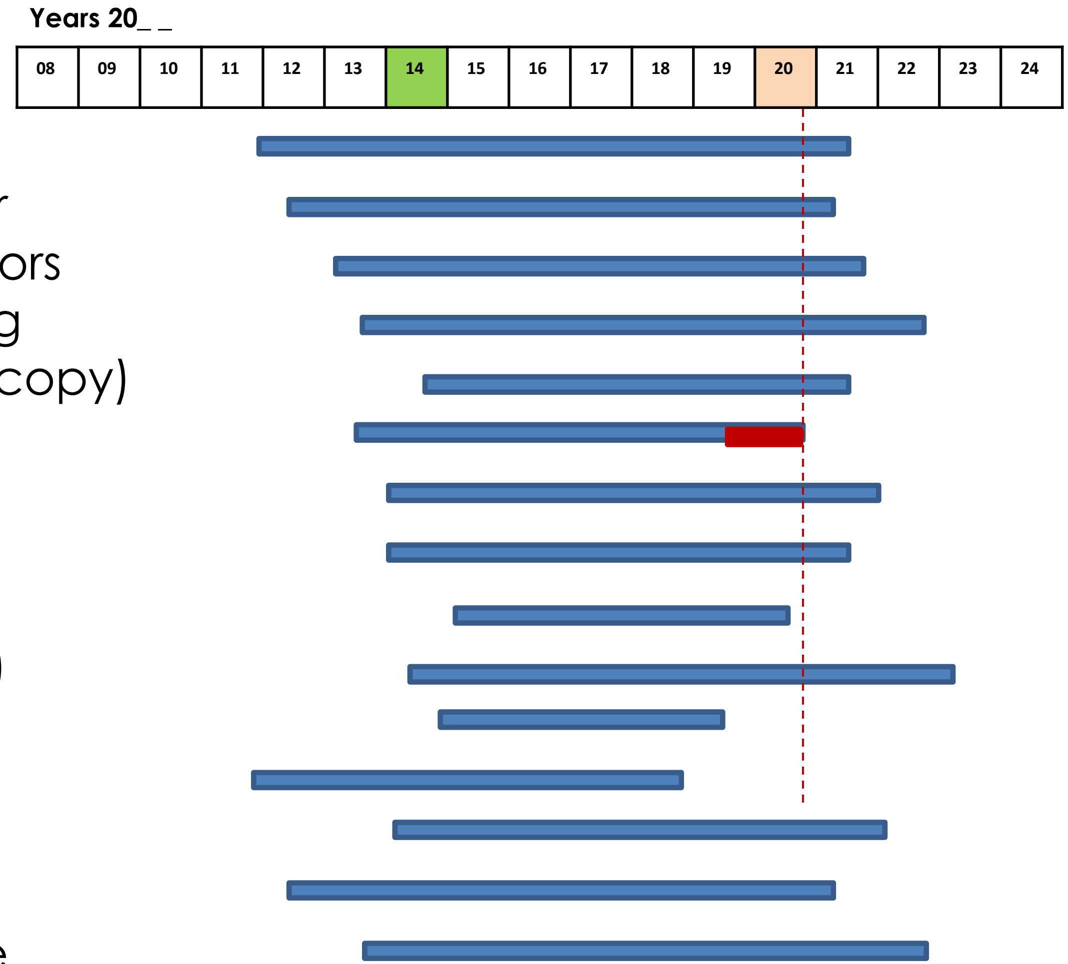
Development of Innovative ECRF scenario –

Helicons generation *via beating of two ECRF EBW waves in MAST-U (O2-left) and DIII-D (O1-right)* Vdovin V. TH/P3-36



Two O2 or O1 ECRF modes with δF = F1 –F2 (500 MHz) Helicons generation $N_{//}$=0.39. O1- Equatorial launch with FADIS waves combining. ITER relevant Helicons generation scenarios at 110 GHz and Ne=1.5 10^20 m-3 dense plasma

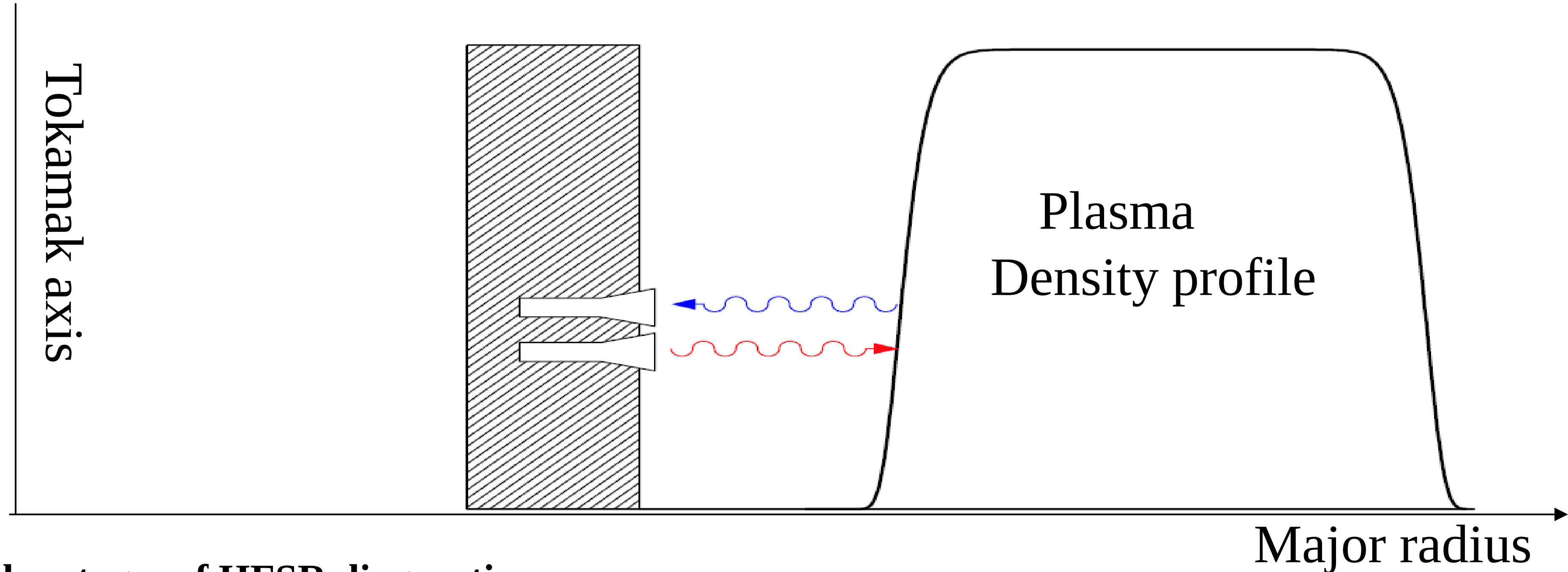
RFDA Procurements execution / Diagnostics



11. HFS Reflectometry
12. E8 Neutral Particle Analyzer
13. Divertor Neutron Flux Monitors
14. Divertor Thomson Scattering
15. H-Alpha (+ Visible Spectroscopy)
16. Equatorial Port Plug 11
17. Upper Port Plug 02
18. Upper Port Plug 08
19. Lower Port Structures 08
20. CXRS Based on DNB (Edge)
21. Vertical Neutron Camera
22. Port Plug Test Faciliy
23. Upper port Plug 07
24. Gamma spectroscopy
25. Laser Induced Fluorescense

On-schedule

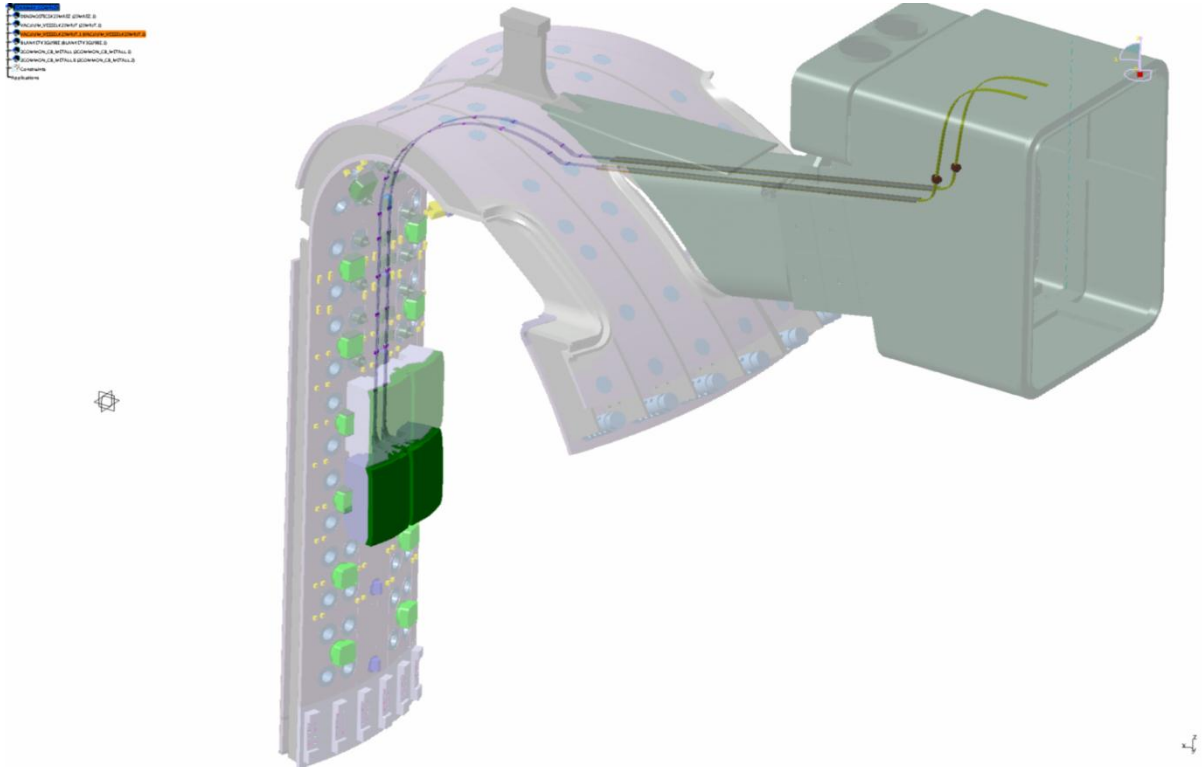
Principle of High Field Side Reflectometry (HFSR)



Advantages of HFSR diagnostic

1. **HFSR gives a valuable information about the plasma density profile and the turbulence, including the TAE modes exited by the thermonuclear alpha particles.**
2. **Not suffer much from the high neutron fluxes**
3. **Does not very sensitive to the high level of the redeposition of the sputtered materials**
4. **By probing plasma from High Field Side the access to the plasma core is possible even at the flat density profile**
5. **The strong reduction of the plasma turbulence at the HFS greatly increase the quality of the reflectometry measurements**

Diagnostic layout

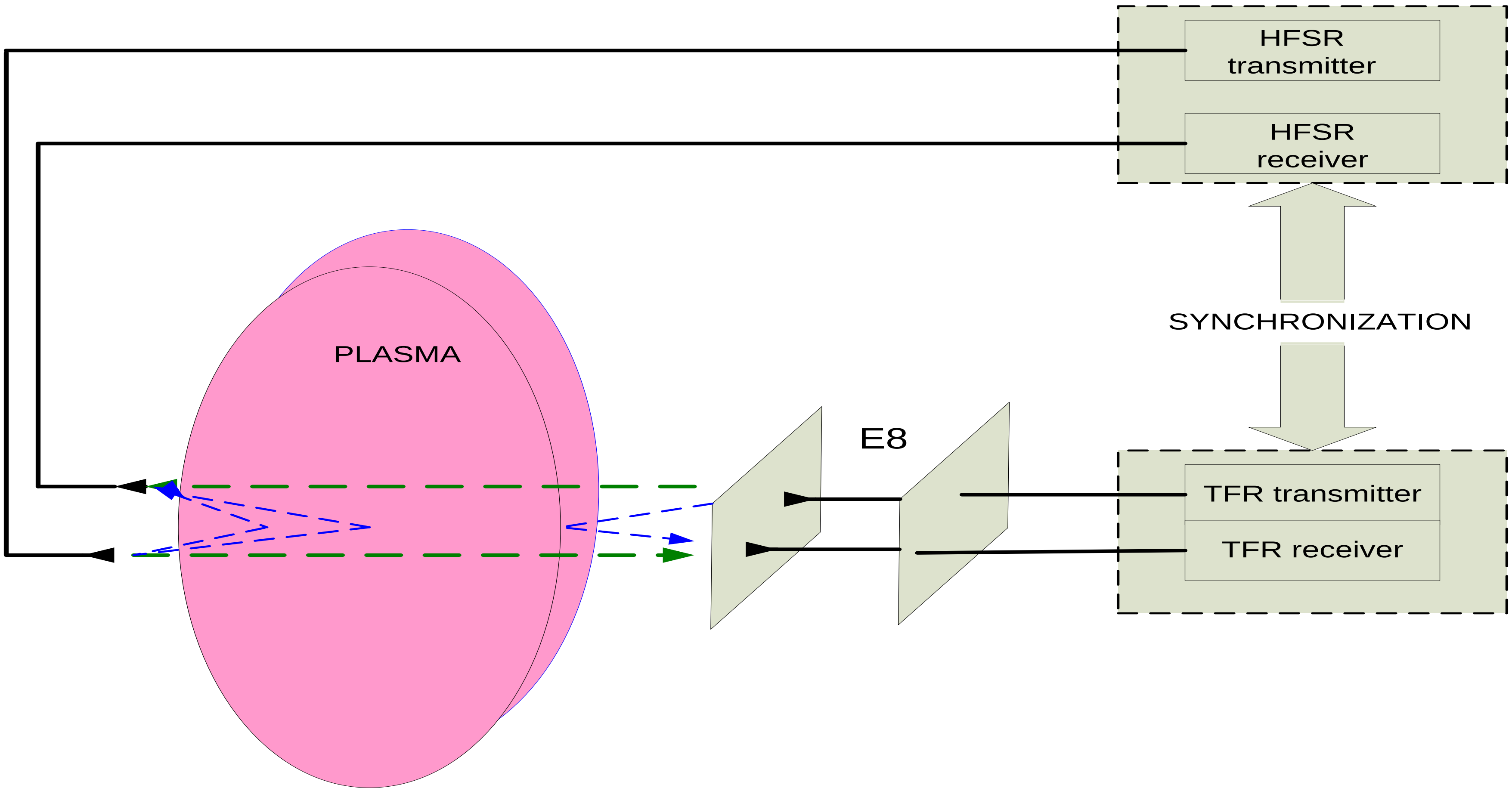


- **Antennae are placed at HFS equatorial plane in blanket gap in 8, 9 and 17 sectors**
- **In-vessel waveguide transmission lines go behind the blanket, along the vacuum vessel to the upper port.**

Serious challenges solved during diagnostic design

1. **Extremely wide range of the required frequency band from 12 to 140 GHz in two polarizations to be transmitted with low losses along the curved oversized waveguide.**
2. **Design of antenna with high efficiency in restricted area between blankets**
3. **Developing the system for coupling and decoupling up to 5 mm-wave bands in one waveguide**
4. **Application of the stainless steel waveguides with thin inner Cu layer**

Upgrade of HFSR diagnostic by microwave transmission (Time of Flight Refractometer (TFR))



By the use of microwave transmission
the local HFSR measurements (left blue dash lines) are complemented
by line integral TFR measurements (green arrows)
to provide line integrated electron density measurements.

Physical background of TFR

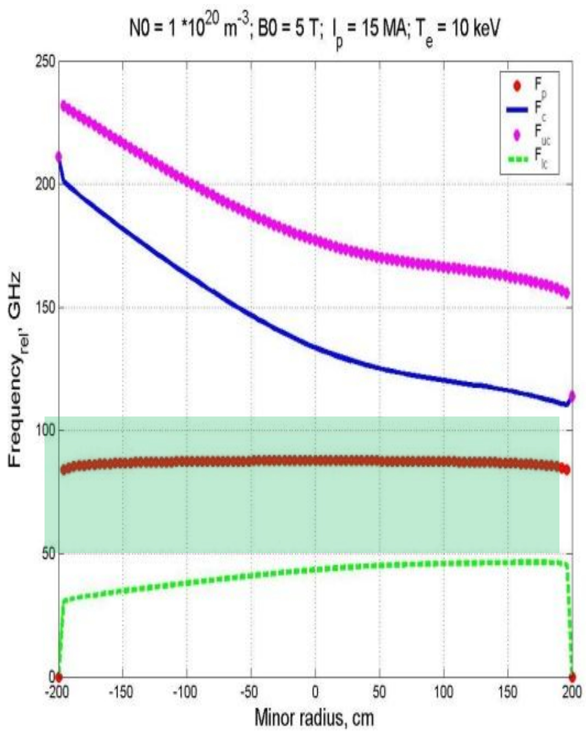
As a concept, TFR is a reflectometer ("delaymeter") operating in a "pass-through" mode.

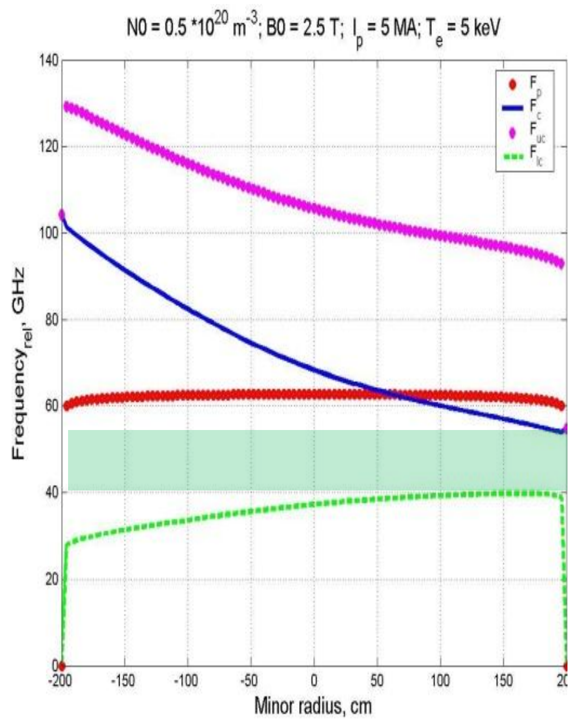
TFR information in contrast to interferometry **is free of fringe jumps**.

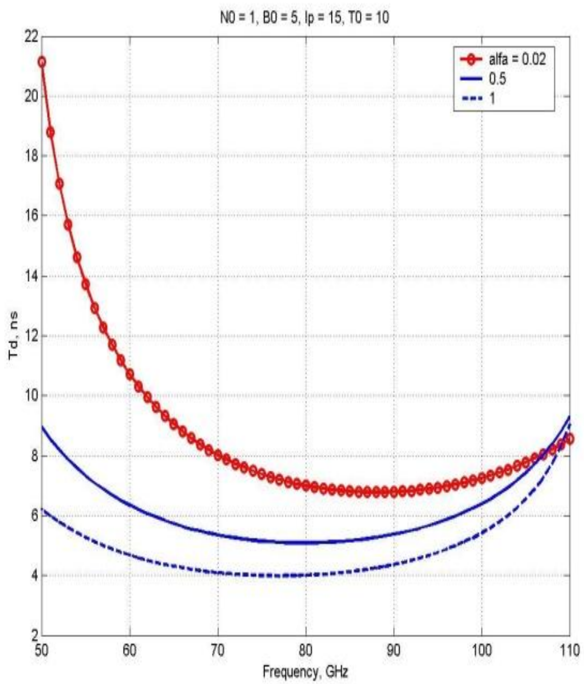
For X-mode the approximate formula for the group time delay can be written as [4]:

$$\tau_{gr,X} \approx k \cdot \frac{f^2 + f_c^{\ 2}}{(f^2 - f_c^{\ 2})^2} \cdot \int_l n(z)dz,$$

f_c – central electron cyclotron frequency, f – carrier frequency, l = 4·a for double pass probing in equatorial plane, a – radius of plasma, k – numerical factor, $f_p \ll f_c$, f.







TFR assessment and time delays for ITER main operating modes: green belts indicate frequency transparency windows – 50-110 GHz for full field and 40-55 GHz for half field

Advantages of combined HFSR + multi frequancy TFR system usage

- To provide line integral density measurements along HFSR direction of view for plasma control.

- Combining local and integral density measurements within a single system of equations greatly expands family of models of the density profiles
  (the "hollow" profiles also become possible to measure).

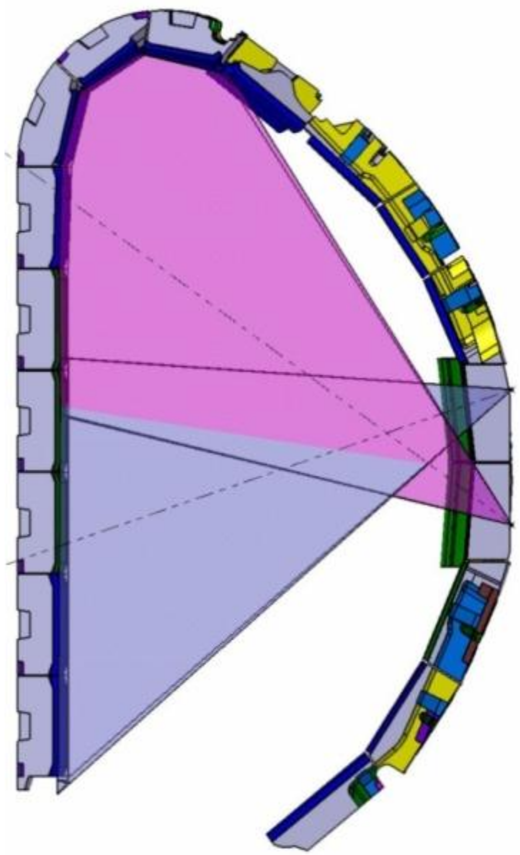
- Reliability of HFSR measurements during high level of density fluctuations is expected to be higher by adding multi frequency integral measurements

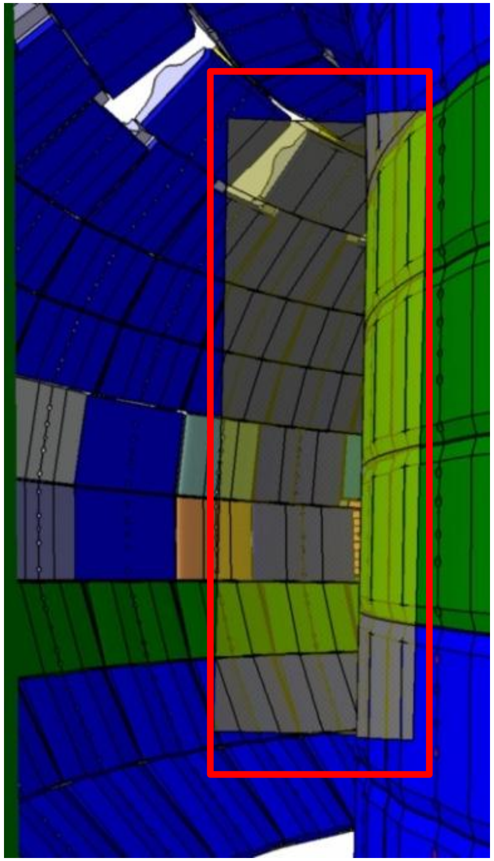
- Refractometry's concept was tested in T-11M, in T-10 and FTU in ITER-like configuration, with 1- frequency, and with 2 frequency instruments .

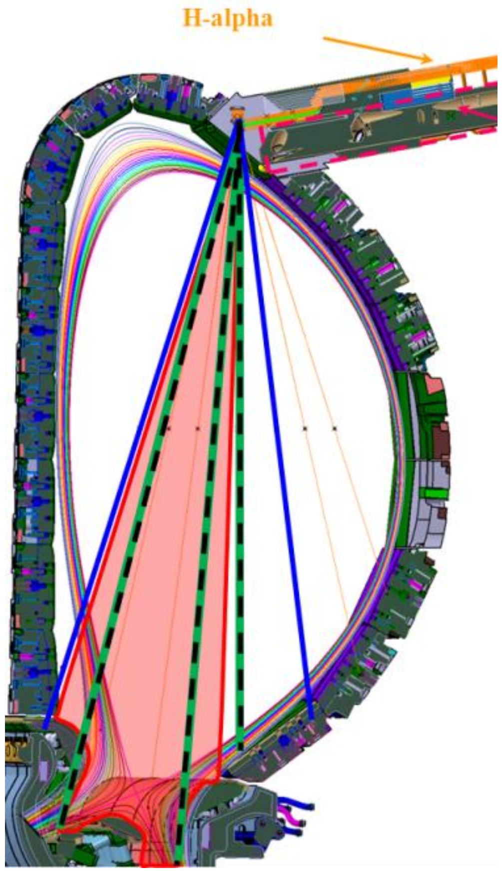
H_α and Visible Spectroscopy

4 optical channels in ITER

EP11 (2 ch.)	EP12 (1 ch.)	UPP02 (1 ch.)
2 poloidal views 43°×11°	tangential view 36×11°	divertor-view FOV 20×5°



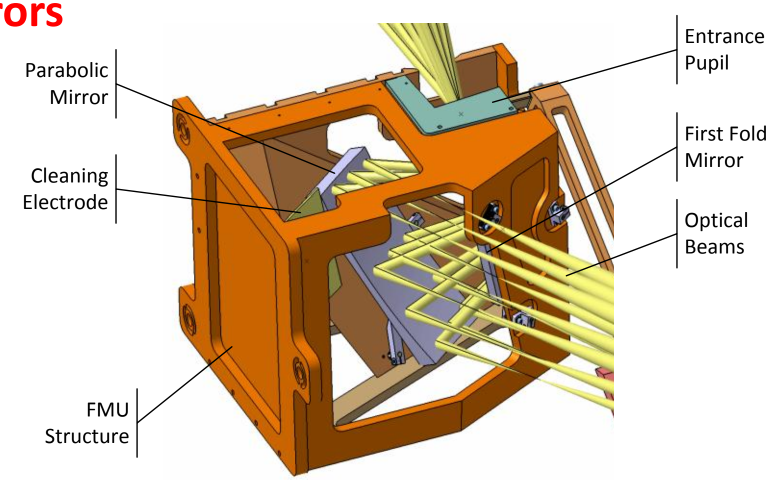


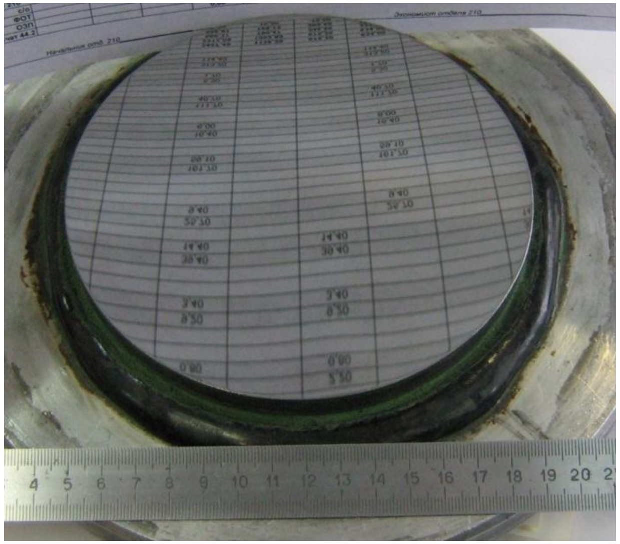


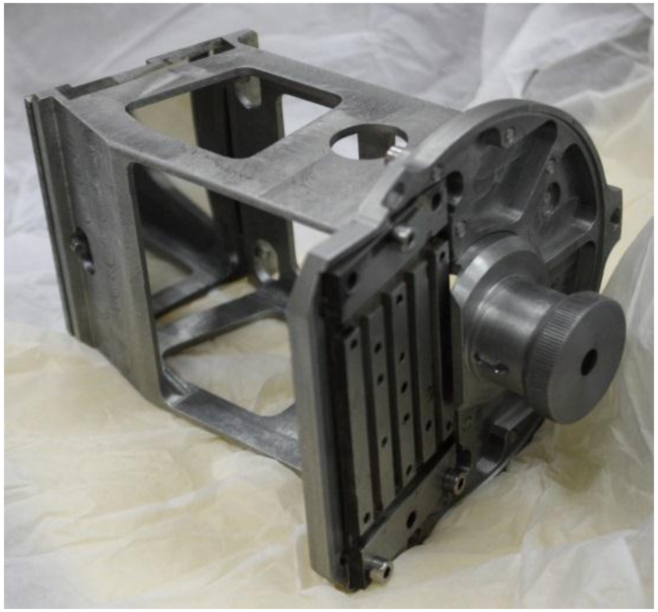
Hα and Visible Spectroscopy

Preliminary design and mock-ups of in-vessel units

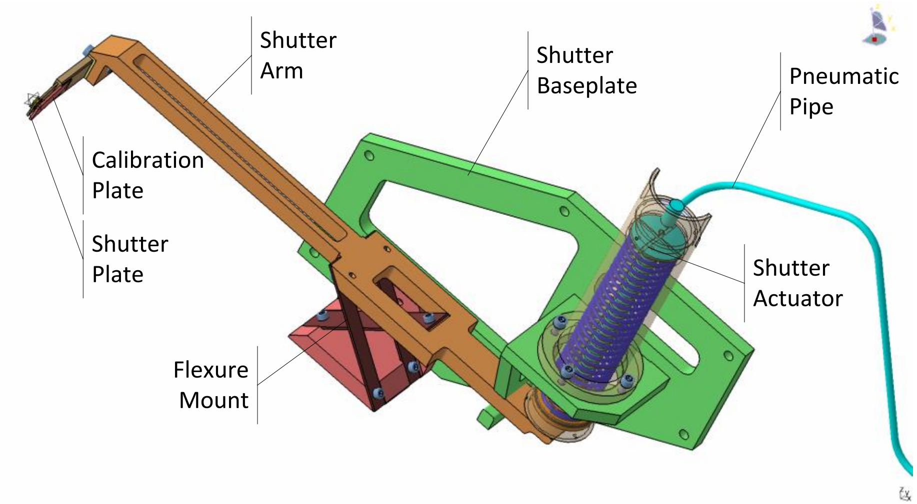
First Mirror Units with large single-crystal Mo mirrors



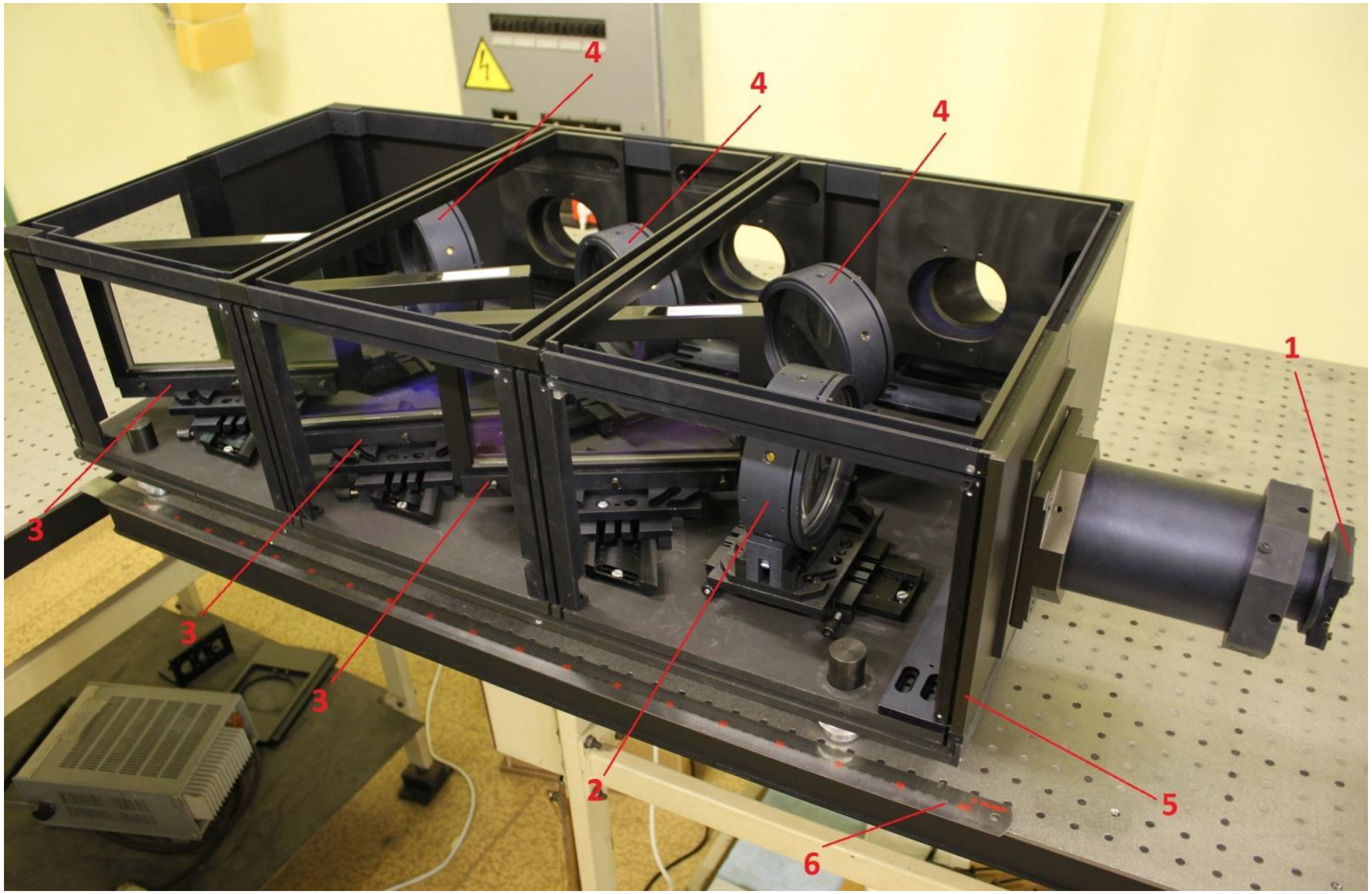




Shutter mechanism



High Etendue Spectrometer (HES) for three wavelength ranges simultaneous CXRS measurement in ITER



1 – entrance slit

2 – collimator lens

3 – “blue”, “green” and “red” gratings

4 – camera lenses

5 – spectrometer body ;

6 – “1-meter” rule

Spectral ranges: 468±5 nm, 529±5 nm and 656 ±6 nm

40 - 50 % grating efficiency for the working spectral ranges

Magnification (in horizontal and vertical direction) = 1

Image plane size: 25 x 25 mm

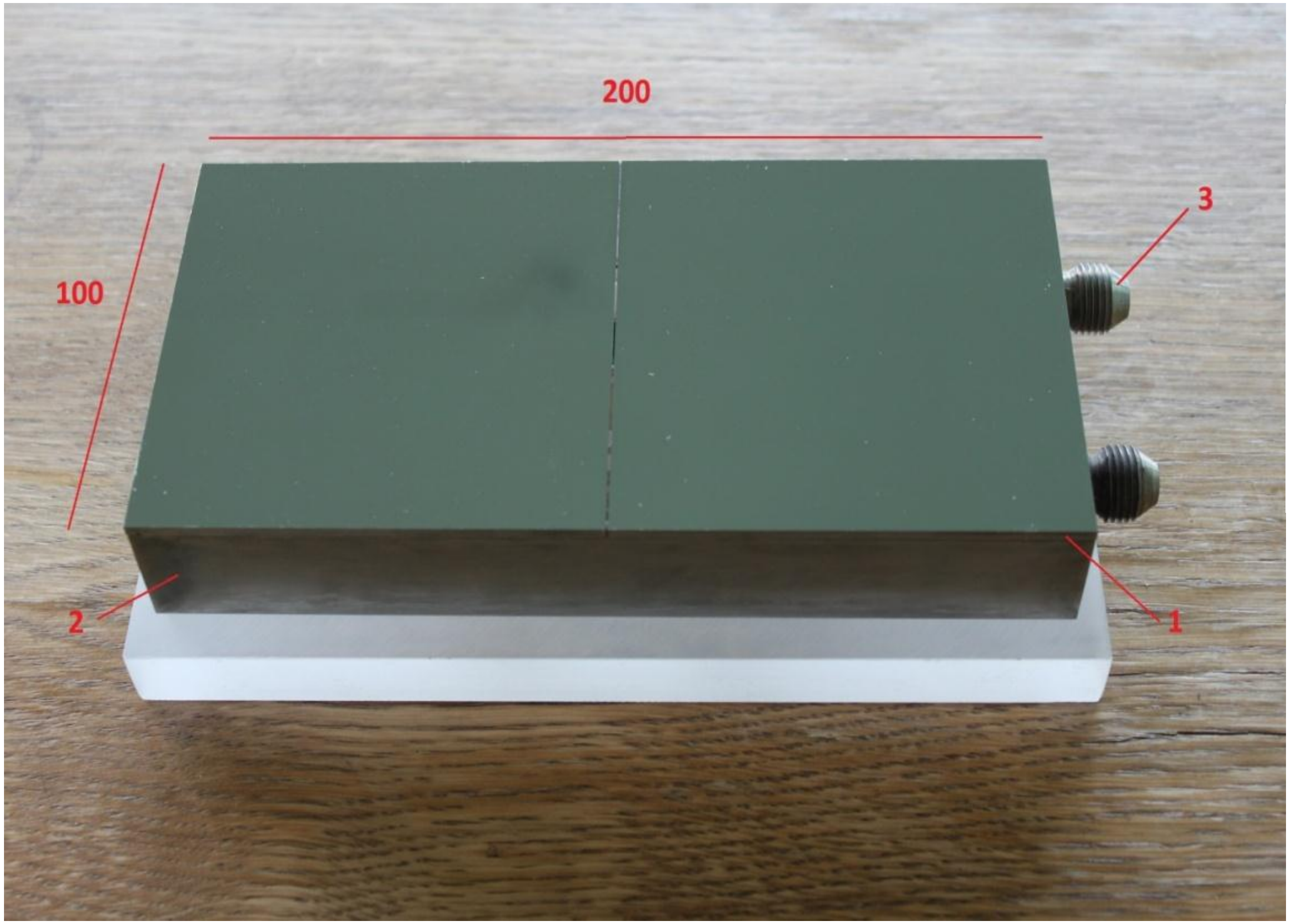
Linear dispersion: 3.4 ; 3.8 and 5.0 A^0/mm,

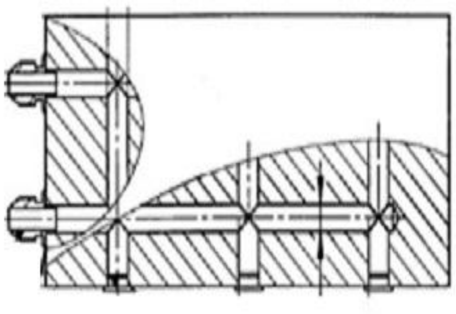
F-number = 3 Stigmatic image

Entrance slit height: up to 25 mm

Max. spectral resolution ~ 0.15 A^0

First single crystal Mo mirror full-scale prototype with water cooling





1 – Mo single crystal layer (4 mm thickness) ;

2 – Mo polycrystal base

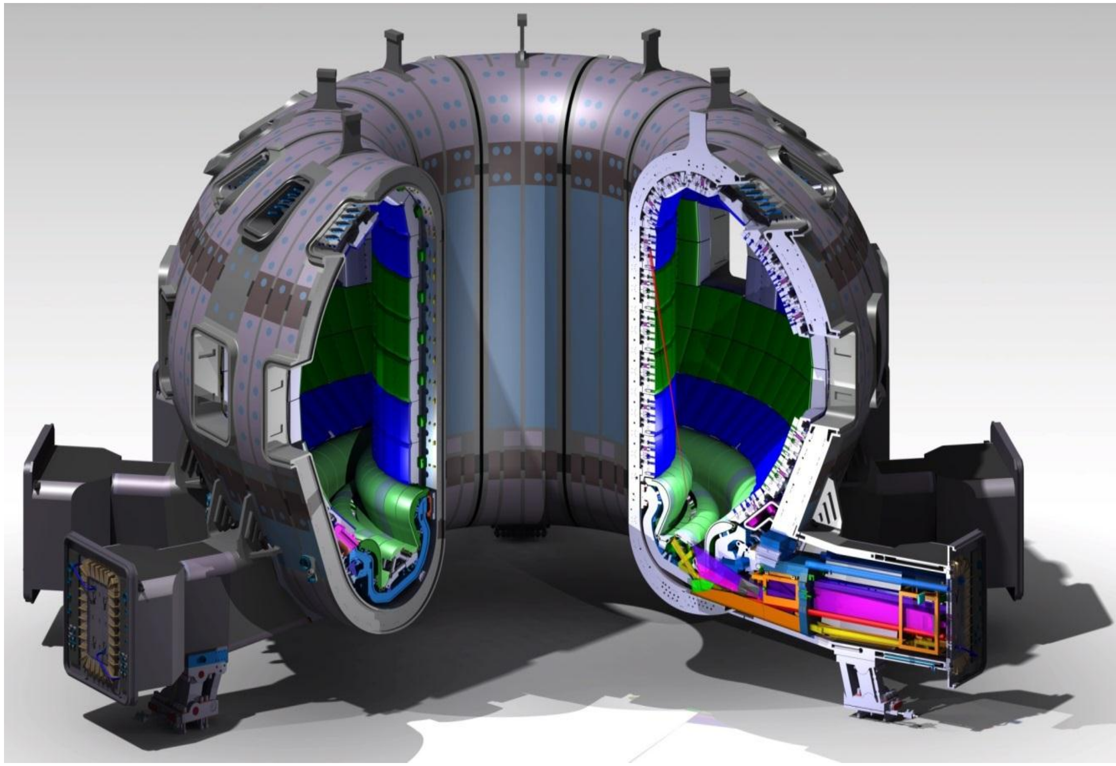
3 – water pipe

Tests in vacuum vessel under a water pressure (up to 4 MPa) and water temperature (up to 200 ^{0}C) will be made at 2014

Divertor Thomson scattering
(Divertor port #8)

Parameter	Range	Time resolution	Accuracy
T_e n_e	1-200 eV 0.3-1 eV 10^{19} -10^{21} m^{-3}	20 ms/50 Hz	20% 0.2 eV 20%

Procurement Arrangement was signed in August 2013



Main tasks

- **Calibration**
- **First mirror problem**
- **Laser systems**
- **Spectral analytical equipment**

Prototyping and tests

- **Spectral Analytical Equipment**
  Filter polychromator 5-200 eV
  Grating polychromator 0.3-200 eV

- **Laser system**

Diagnostic Nd:YAG 1.0645μm (2 J, 3 ns, 50Hz)

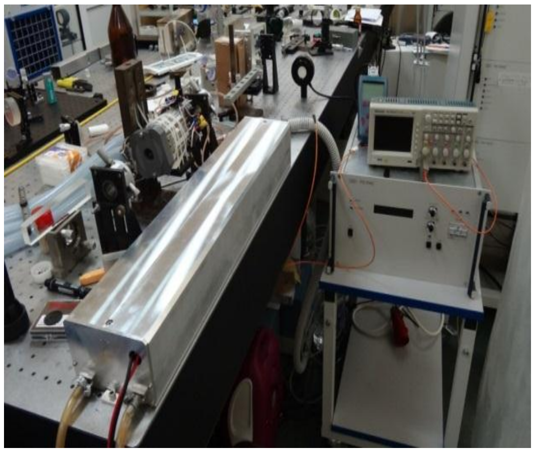
(2014) Calibration Nd:YLF laser 1.047 μm (2J, 10ns, 5Hz)

(2014) Calibration Nd:YAG laser 0.946 μm (0.1J, 10ns, 100 Hz)

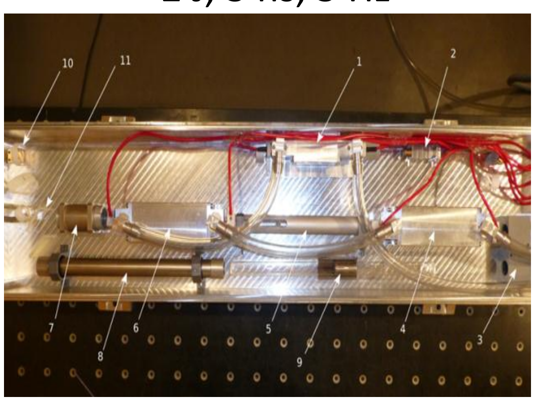
Divertor Thomson scattering

Lasers for calibration

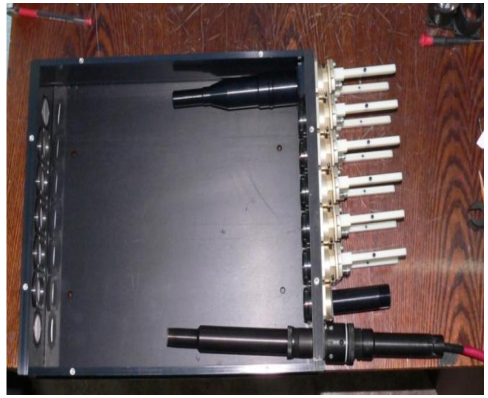
Nd:YAG 946 nm
80 mJ, 15ns, 50 Hz



Nd:YLF 1047 nm
2 J, 3 ns, 5 Hz

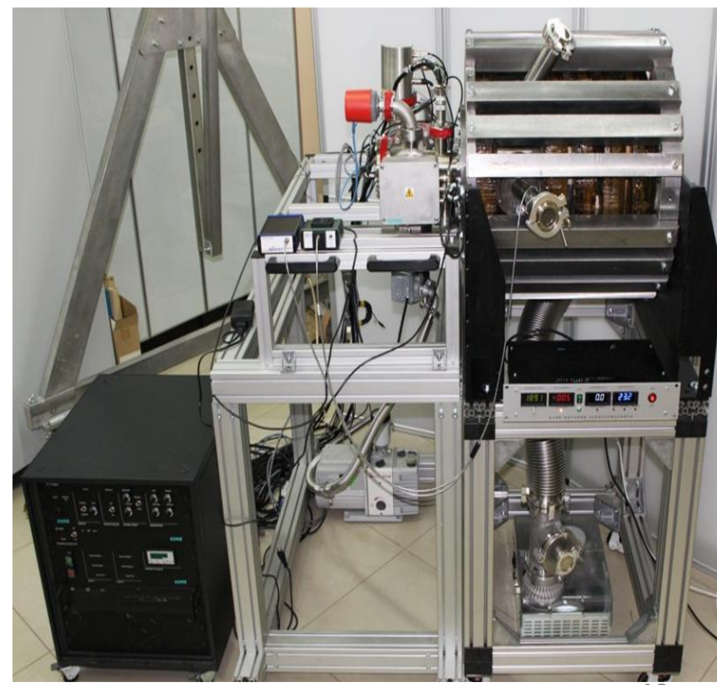


Filter polychromator



Fiber bundle

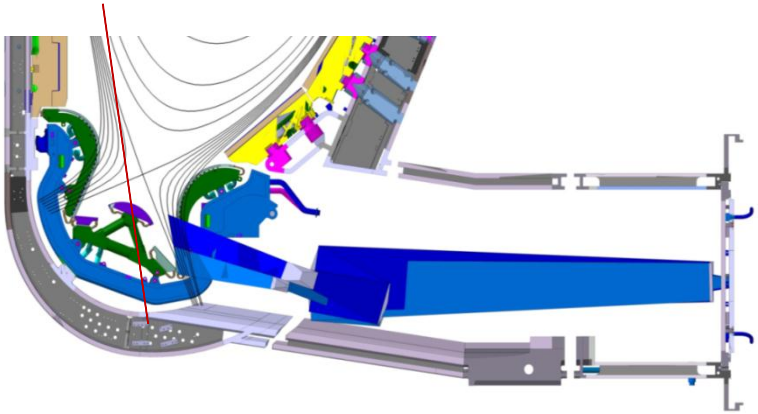
Test benchmark for RF mirror cleaning

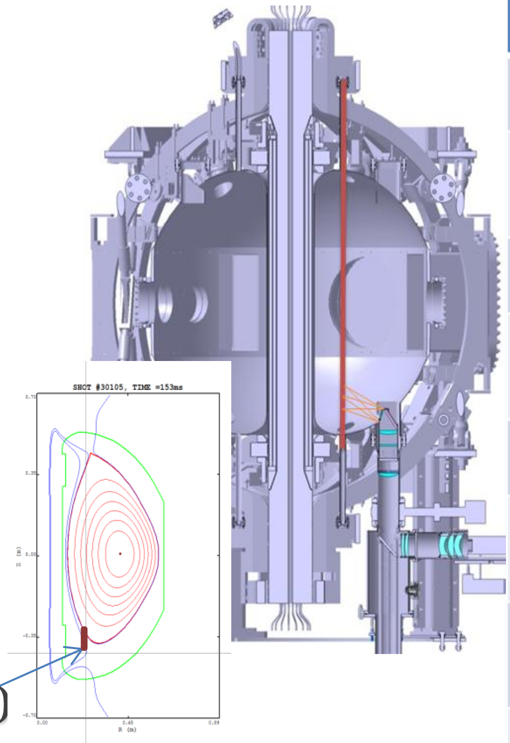


Divertor Thomson scattering 2014 plan

Experiments on Globus-M tokamak

Preparing Preliminary Design Review March 2015





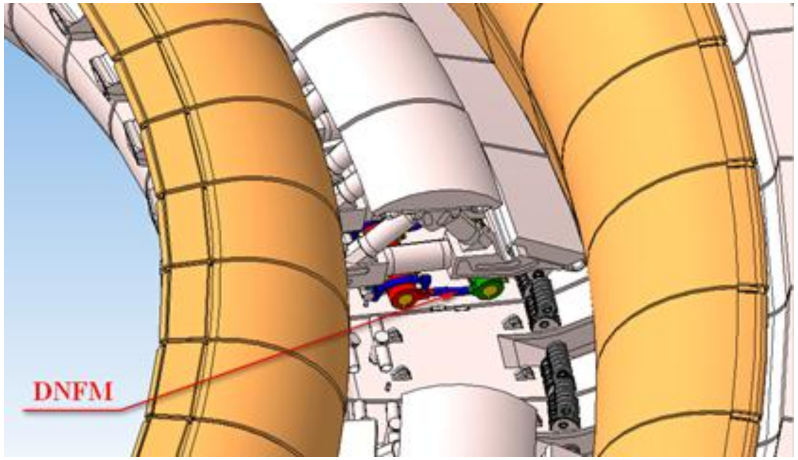
Parameter	Globus-M	ITER
Major laser λ_{01}, nm	1064	1064
Calibration laser λ_{02}, nm	1047	1047, 946
Scattering length, L, мм	5,8	30 (25)
Field angle, Ω, sr	0,019	0,00265 (0,00353)
Transmission, T	30 %	40%
L·Ω·T	0,033	0,032 (0,035)
n_e range , m^{-3}	$3 \cdot 10^{19}$ – $0.1 \cdot 10^{19}$	10^{22} – 10^{19}
T_e range, eV	10-400	0,3-200

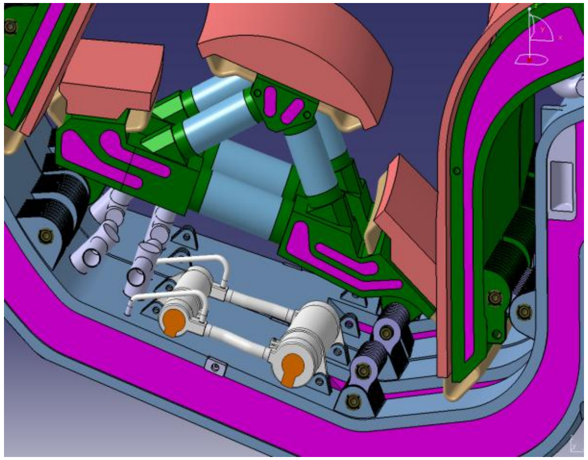
Mock-ups and tests

- Mock-up Divertor TS in Globus-M (chord)
- Piezoactuator for operation in ITER VV
- Laser for calibration 0.946 μm, 1 J, 50 Hz, 15 ns
- Inner frame of the Front Diagnostic Rack
- RF cleaning discharge
- Large scale SiC mirrors

Diagnostic for ITER Fusion Power Control

(Divertor Neutron Flux Monitor – direct method of Fusion Power measurements)



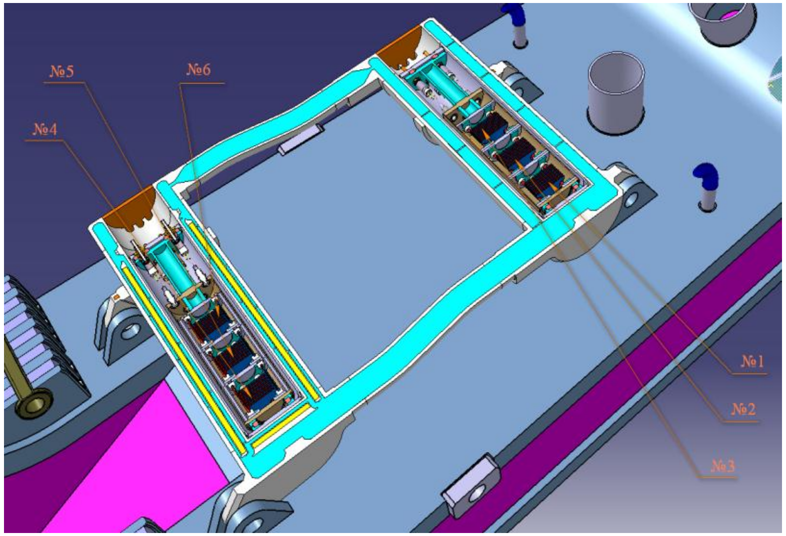


Extreme operating conditions at the ITER Divertor zone:

- magnetic field (up to 6T);
- nuclear heating (~ 1W/cm^3);
- thermal load (50 kW/m^2).

Measurement requirements:

- dynamic range 1:10^7;
- temporal resolution 1 ms;
- uncertainties < 10%;
- absolute calibration.



Set of fission chambers (U-235 & U-238) with active cooling/moderator system

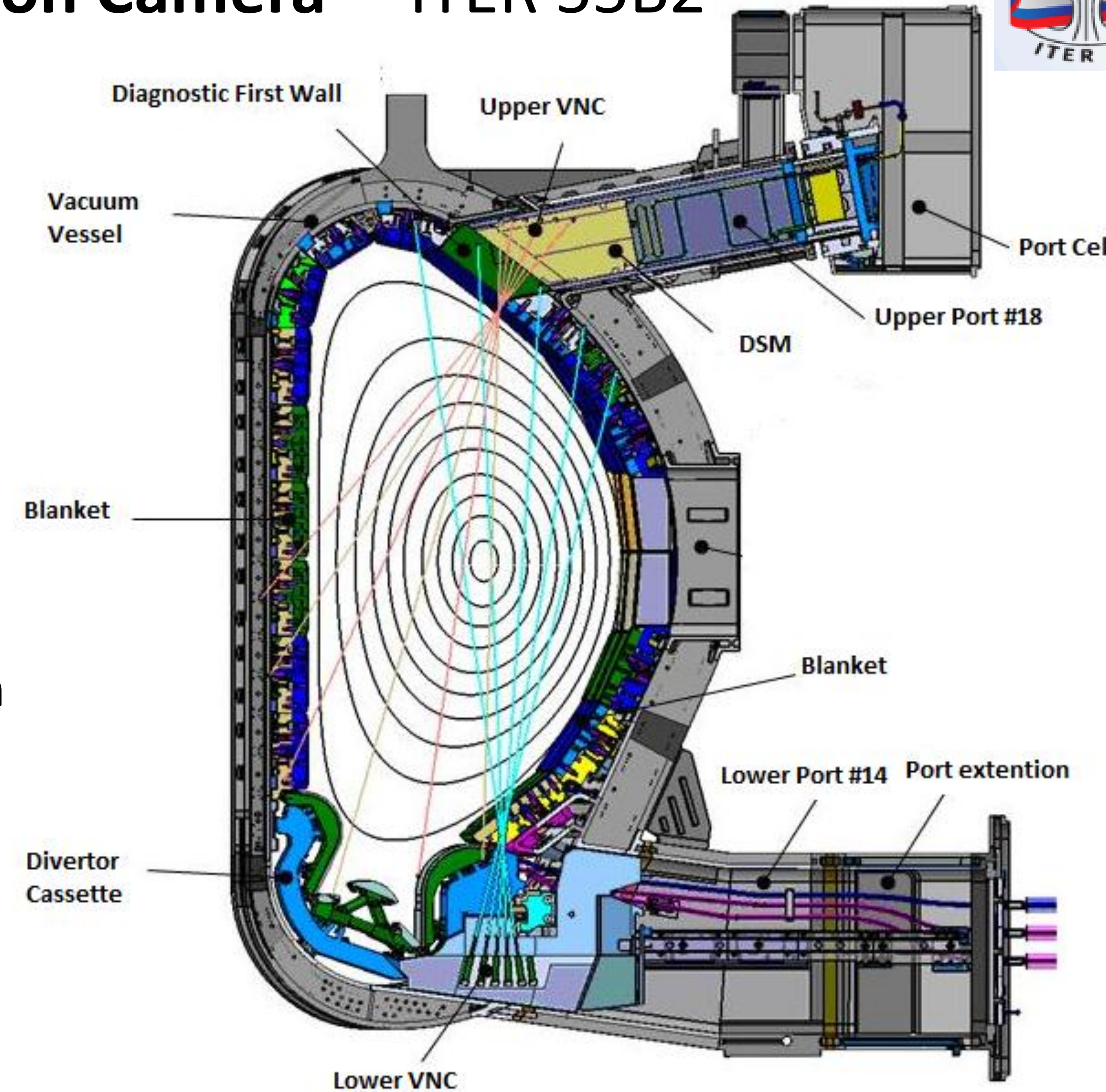
Design of fission chamber with plane electrode system

✓ **All six fission chambers are identical in the construction.**

✓ **Wide range fission chambers with U-235 are used to detect thermal neutron flux.**

✓ **Fission chambers with highly depleted U-238 (99.999%) are used for direct fusion neutron flux measurements.**

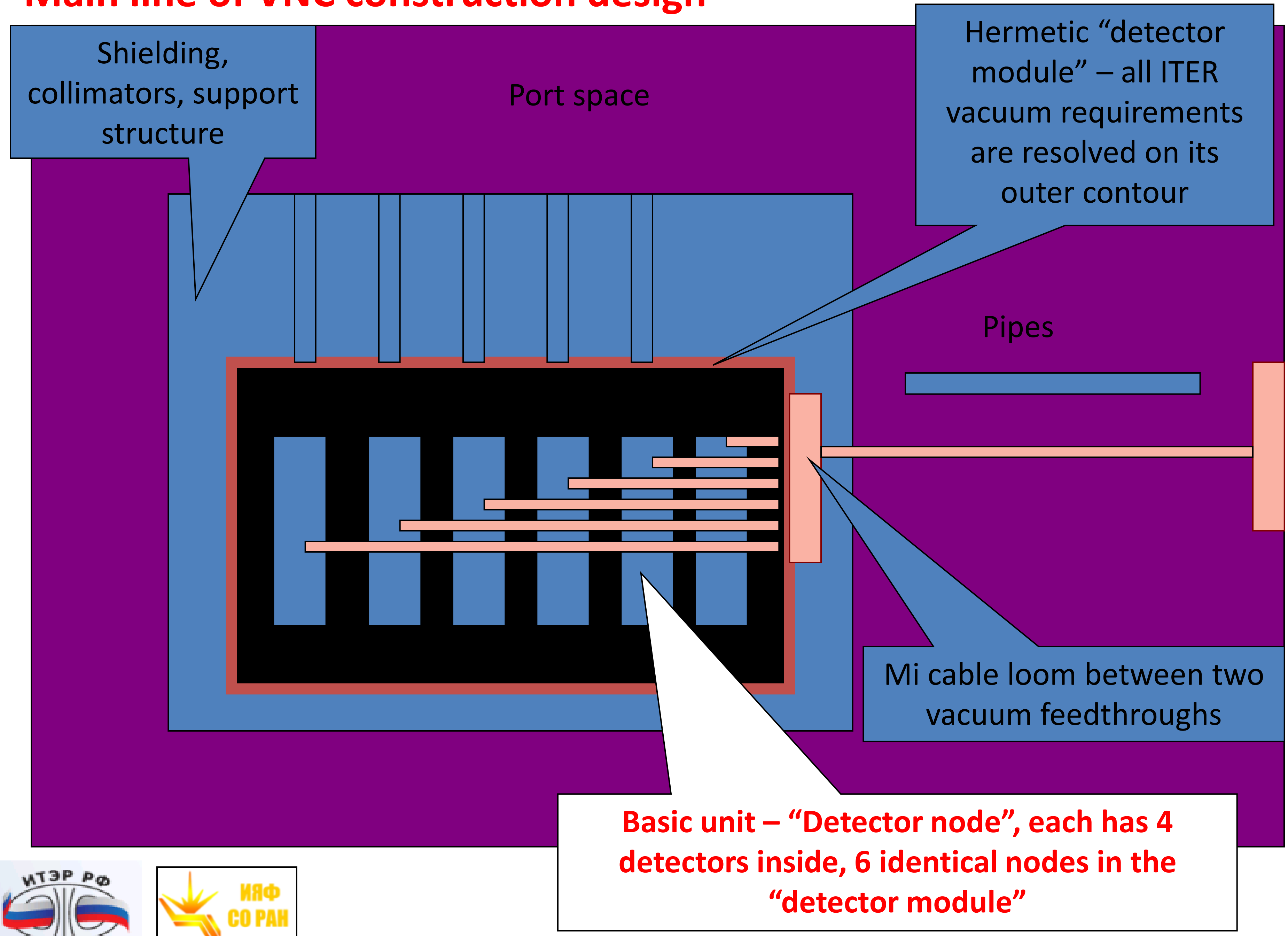
Vertical Neutron Camera   ITER 55B2



CDR - in July 2014

PA - to be signed in December 2014

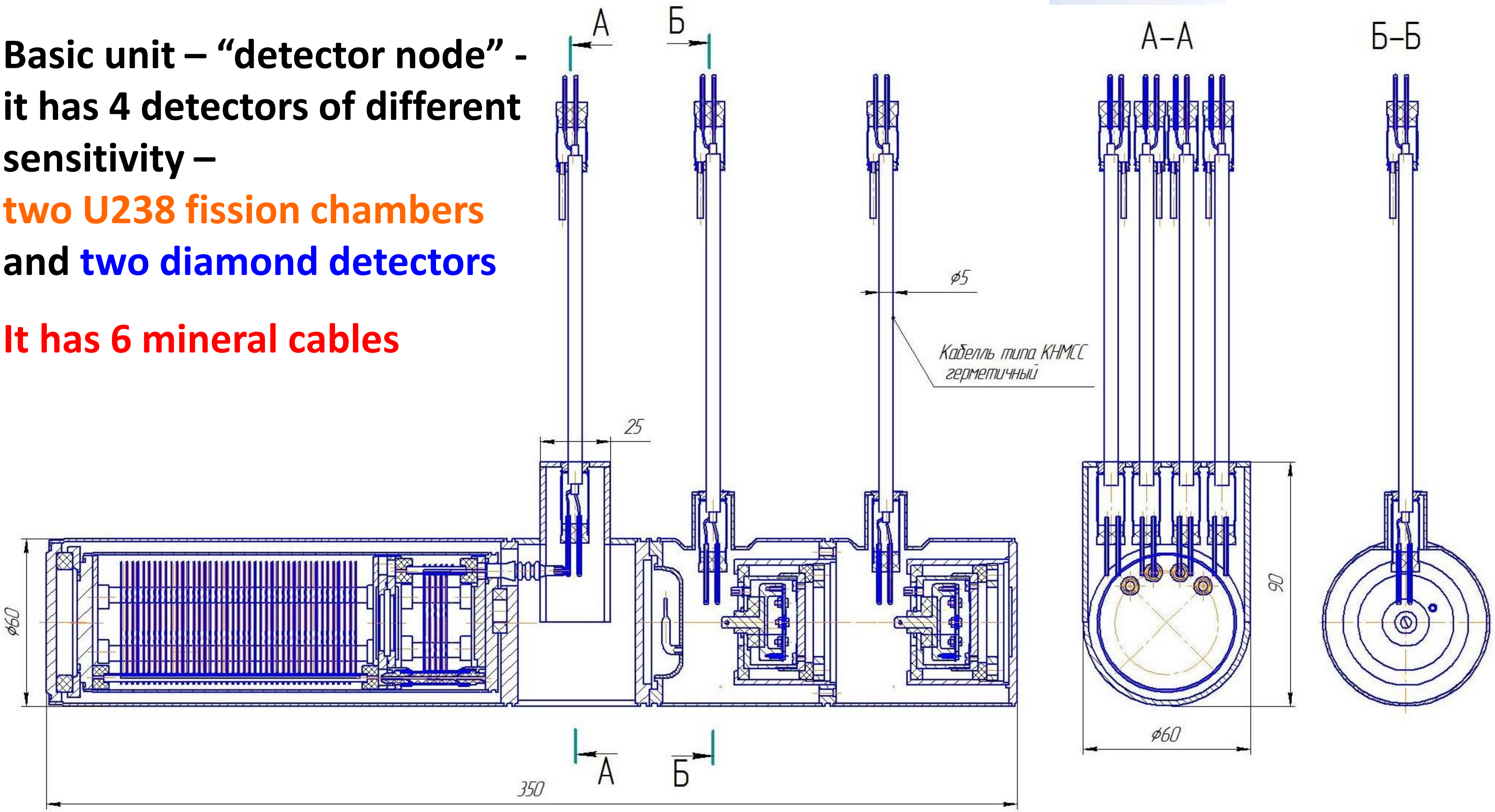
Main line of VNC construction design



Vertical Neutron Camera detector node

Basic unit – “detector node” - it has 4 detectors of different sensitivity –
two U238 fission chambers
and two diamond detectors

It has 6 mineral cables



Dimensions – diameter 60mm, length 350mm

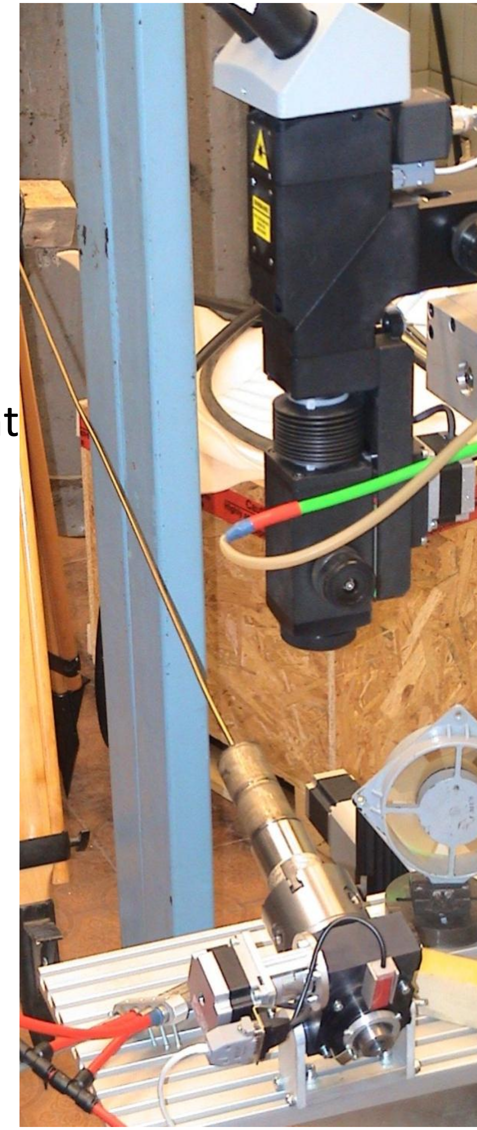
New technological lab for diamond detector production in and

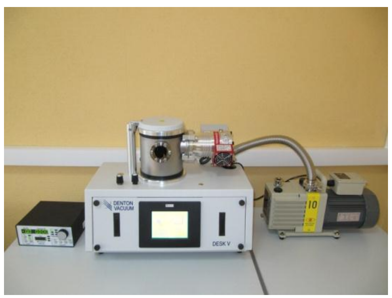
Laser cutting

Annealing

Chemical cleaning

Plasma treatment





Contact deposition

Gold wire microwelding

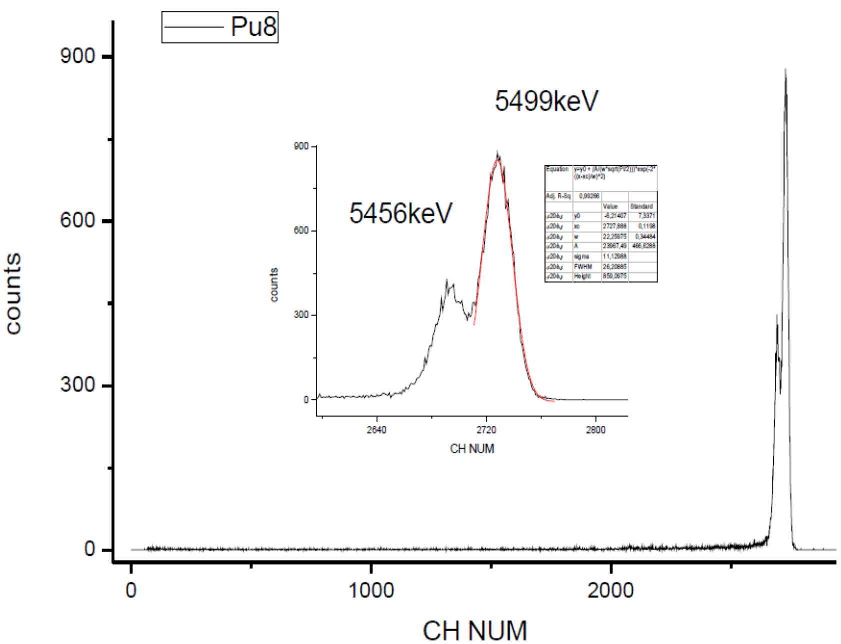
Analytical equipment: electron microscope, AFM, etc.

Diamond detector

Diamond detectors and spectrometers of ionizing radiation (α, β, γ, neutron) with high resolution

Diamond detectors successfully used at TFTR, JT-60U, JET, LHD

Diamond detector with triaxial mineral cable for the operation in the reactor conditions

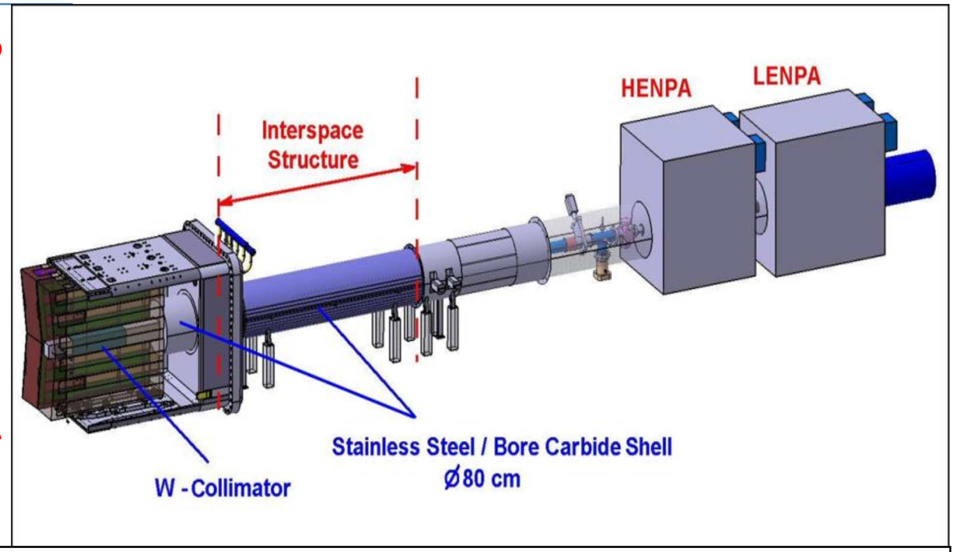


Measurement of the thin structure of Pu-238 alpha spectrum by CVD diamond detector. Energy resolution -better than 0.4%

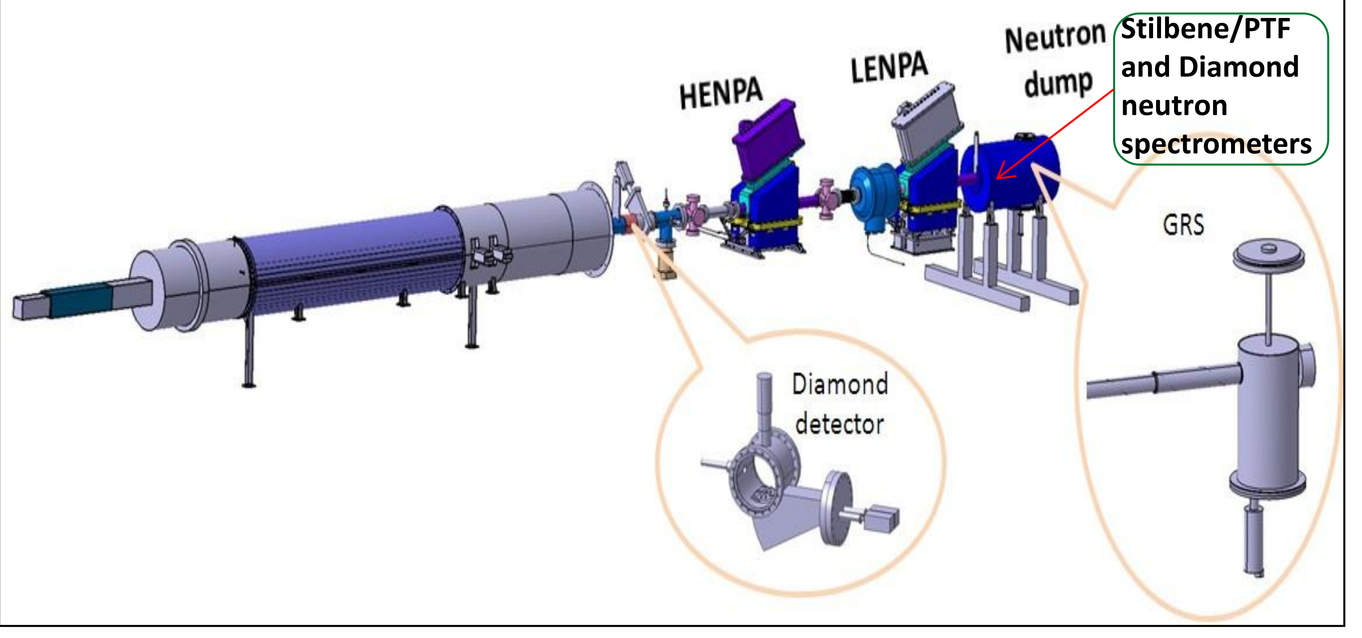
Electronic module and preamplifier, capable to operate with cable of 200 m length (used in the JET experiments)

Complex of Neutral Particle Analyzers

- Main role – measurement of isotopic ratio n_T/n_D (tritium/deuterium) in the center and on the periphery of plasma column
- Supplementary role – measurement of ion temperature and alpha-particle distribution function
- Consists of two neutral particle analyzers HENPA (0.2 – 2 Mev) и LENPA (10 – 200 keV)



- Includes also diamond fast atom/DT neutron spectrometer and also Stilbene/PTF and Diamond DD/DT neutron and gamma spectrometer (GRS)



- Situated in equatorial port 11
- Total weight about 50t

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Diamond fast atom / DT neutron spectrometers

- **Diamond detectors** have been successfully applied **for neutron, fast unconfined ion and fast charge-exchange atom spectrometry** at most large tokamak **TFTR, JT-60U, TORE SUPRA, NSTX, JET and stellarator LHD.**

- Two diamond spectrometers: **DNPS - diamond neutral particle spectrometer and DNS – diamond neutron spectrometer** will be installed inside atom flight tube between plasma and HEMPA and behind LEMPA in neutron dump, respectively.
- **DNPS** includes **four diamond detectors** different in the aperture and the size of diamonds (Ø3 mm and Ø8 mm, may vary) and therefore have different sensitivities to provide wide range of the counting rates.
- DNPS with digital signal processing will provide **maximum count rate 10^6** and **lower limit of measured atom energy 50-100 keV.**

- The main purposes of the **DNPS as a charge-exchange atom spectrometer** for ITER are:

  - To measure **time and energy resolved flux of neutral particles** and **plasma ion temperature**;

  - Investigation of **the dynamic of fast ion energy and spatial distributions** during NBI, ICRH and various plasma instabilities;

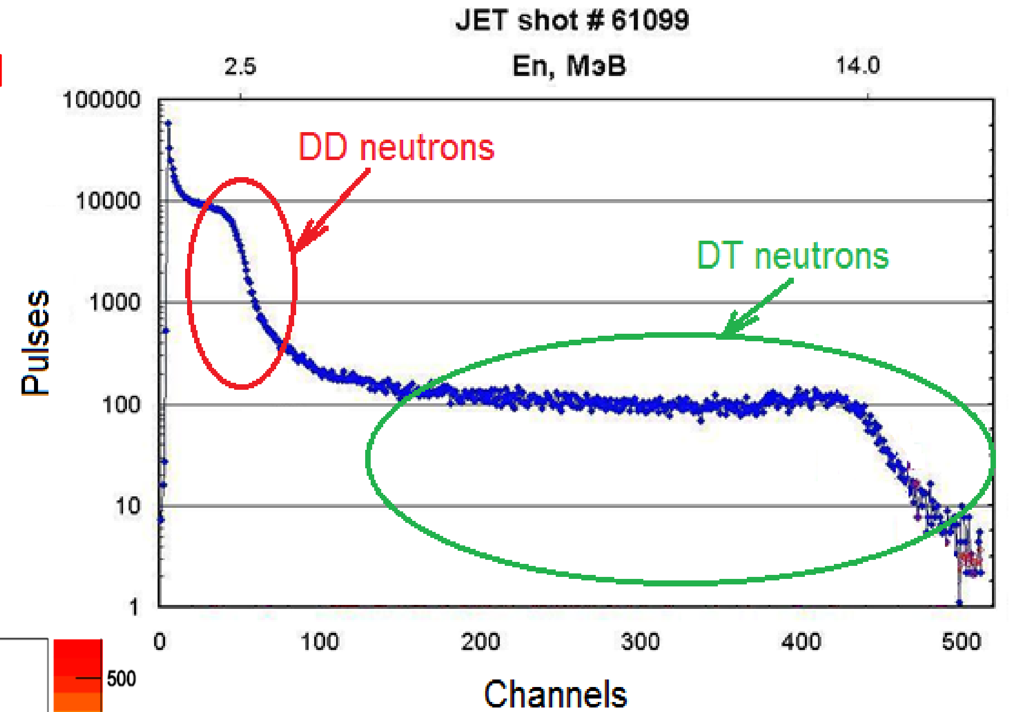
Operating at DT plasma phase **DNPS** and **DNS** will measure DT neutron energy distributions in wide energy range around 14 MeV with energy resolution <100 keV, at the counting rates of 10^6 cps (flux 10^{10} n/cm^{2}s) time resolution of 20 ms is achievable with 10% statistical accuracy.

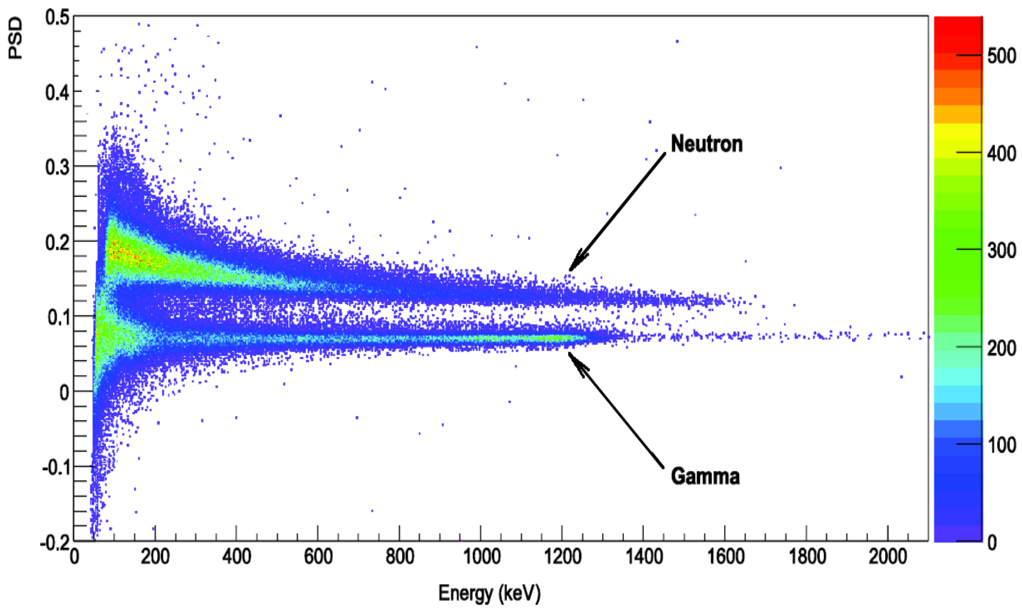
This provides **ion temperature measurements of the deuterium-tritium plasma** and data **for fast deuterium and tritium energy distributions studies**. They will also provide the **neutron flux monitoring.**

Stilbene neutron spectrometer for simultaneous DD and DT neutron flux measurement

- Stilbene or Paraterphenyl organic crystal scintillator for neutron and gamma-ray spectrometry

- High detection efficiency (1-10%)
- Scintillation fast response (4 ns)
- Good energy resolution (4-8%)
- Digital signal processing
- Pulse shape discrimination





- Simultaneous DD&DT neutron measurements
- Evaluation of nT/nD ratio in the plasma core and cross calibration with NPA data
- Fusion neutron spectra analysis and ion temperature evaluation in the plasma core
- Dynamic of total neutron flux

Gamma-ray Spectrometer in the NPA system

Gamma Ray Spectrometer will support NPA measurements of

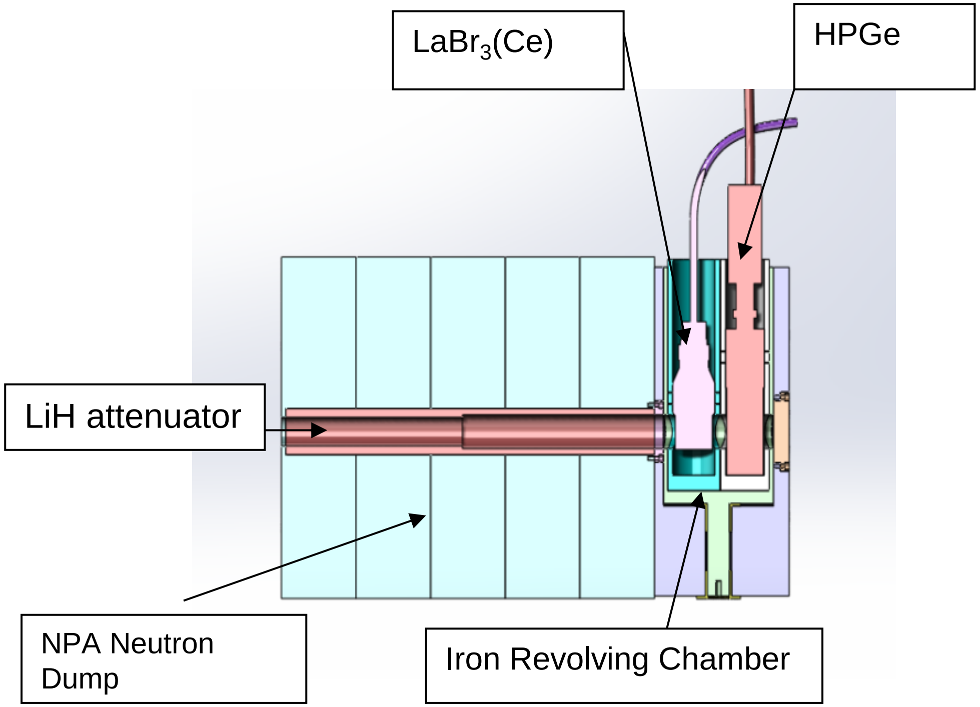
- **fuel ratio nT/nD,**
- **energy spectrum of fast ions and confined alpha-particles in 1.7-3.5 MeV range**
- **ion temperature T_i**

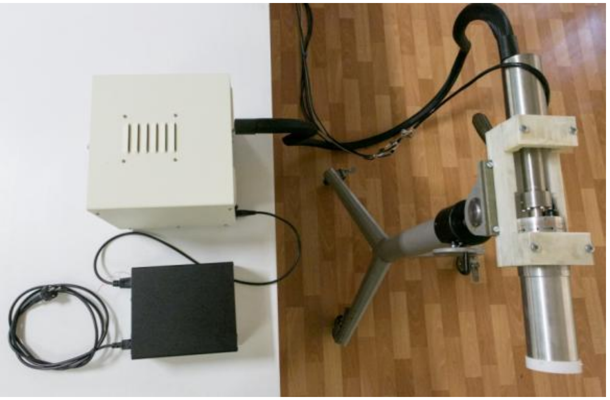
and also provides

- **maximum energy of runaway electrons**

Ø76x76 mm

$LaBr_3$(Ce) detector





HPGe detector

Scheme of installation of GRS elements in the NPA neutron dump

Neutron generator for in-situ calibration

Compact intensive neutron generator NG-24 recently has been developed in VNIIA

Neutron source is a sealed tube.

Options of sealed tube	D-D or D-T neutrons
D-D neutron yield	10^9n/s
D-T neutron yield	10^{11}n/s
Sealed tube lifetime	300h

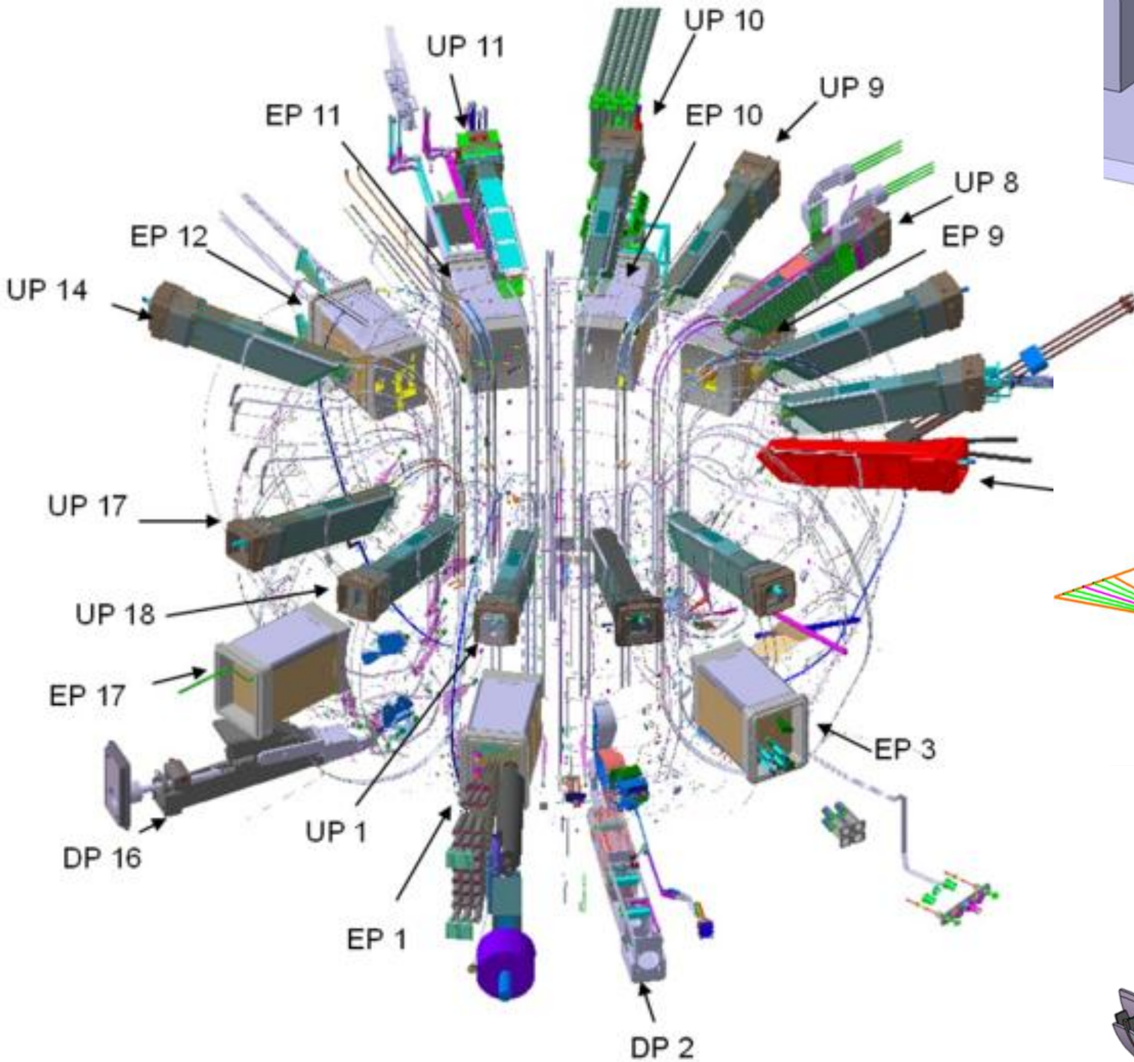
Sealed tube

NG-24 application for fast neutron therapy

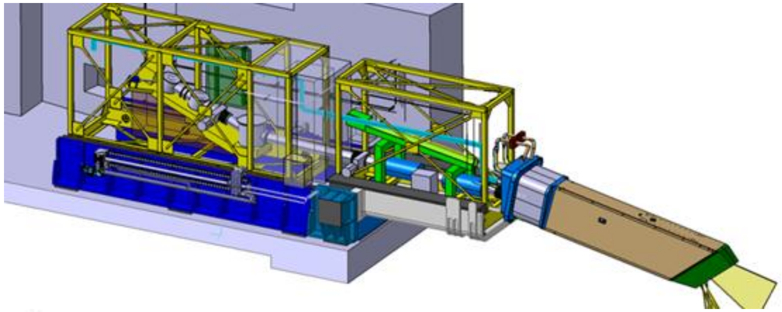
Neutron flux stability	5-7%
NG unit weight	200 kg
NG unit	ø400x1000мм

Port plugs and diagnostic integration

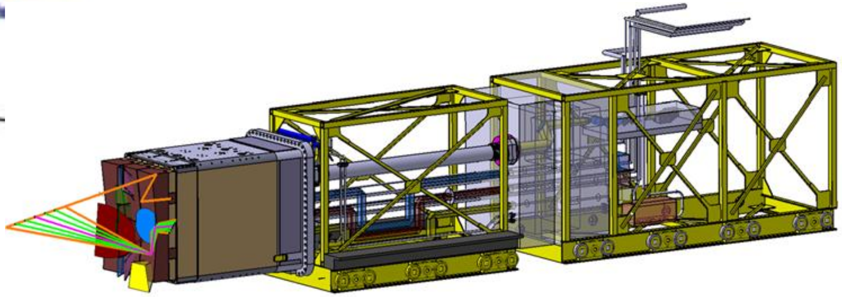
Budker Institute



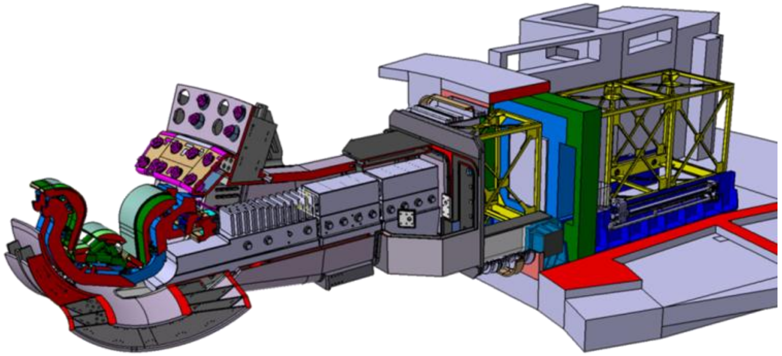
PBS 55: Diagnostic Systems



Upper Port Systems



Equatorial Port Systems



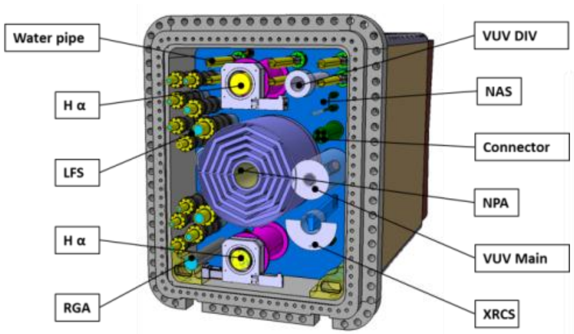
Lower Port Systems

Equatorial port plug 11

Equatorial Port plug
Size: L3420 x W1938 x H2390
Total weight (maxi): 45 tons

Port-cell Support Structure
Size: L6400 x W2300 x H3000
Total weight (maxi): 60 tons

EPP-11



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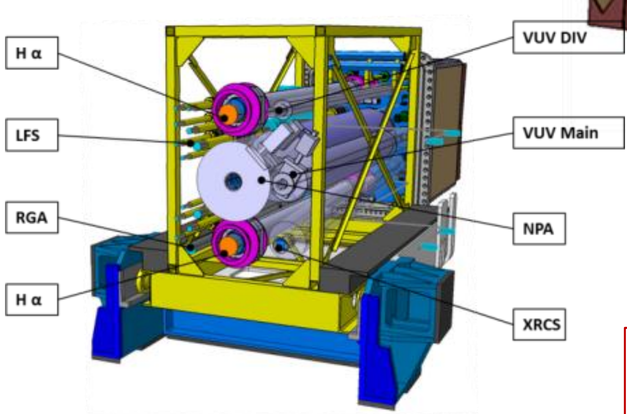
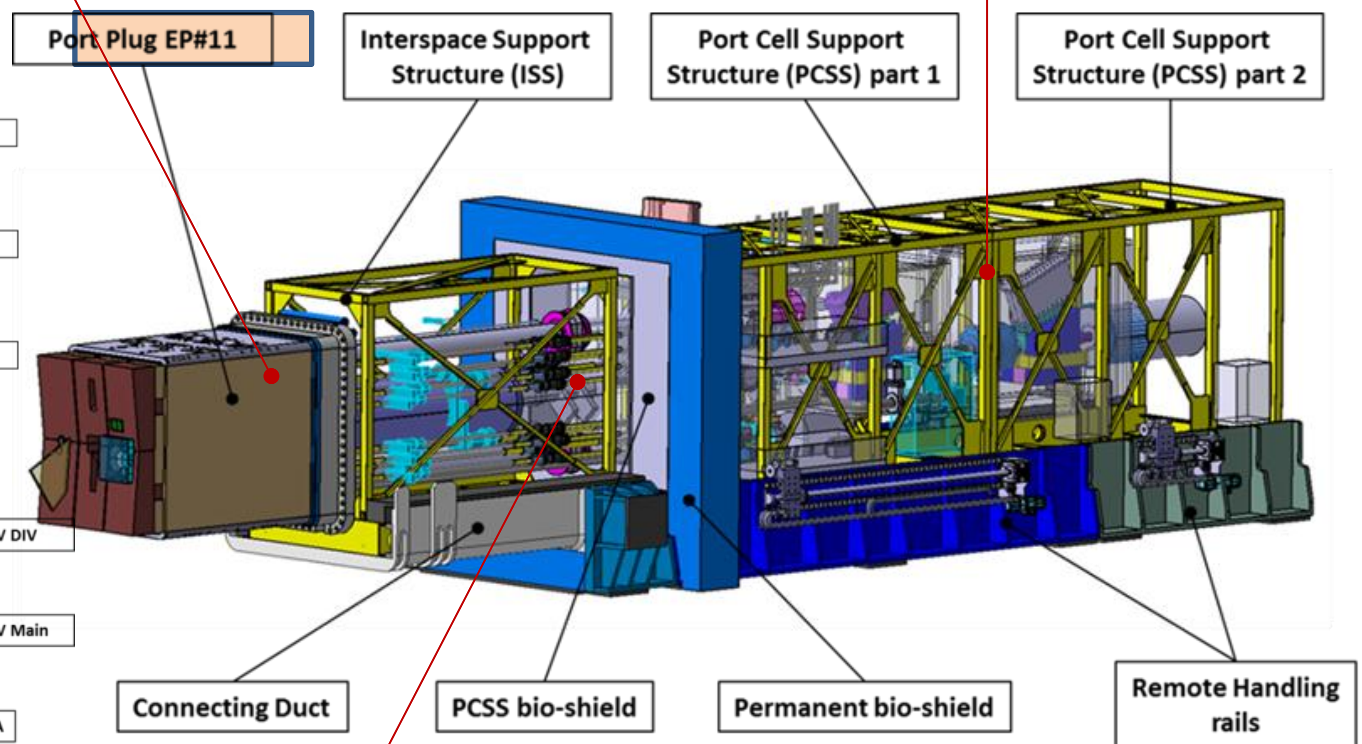
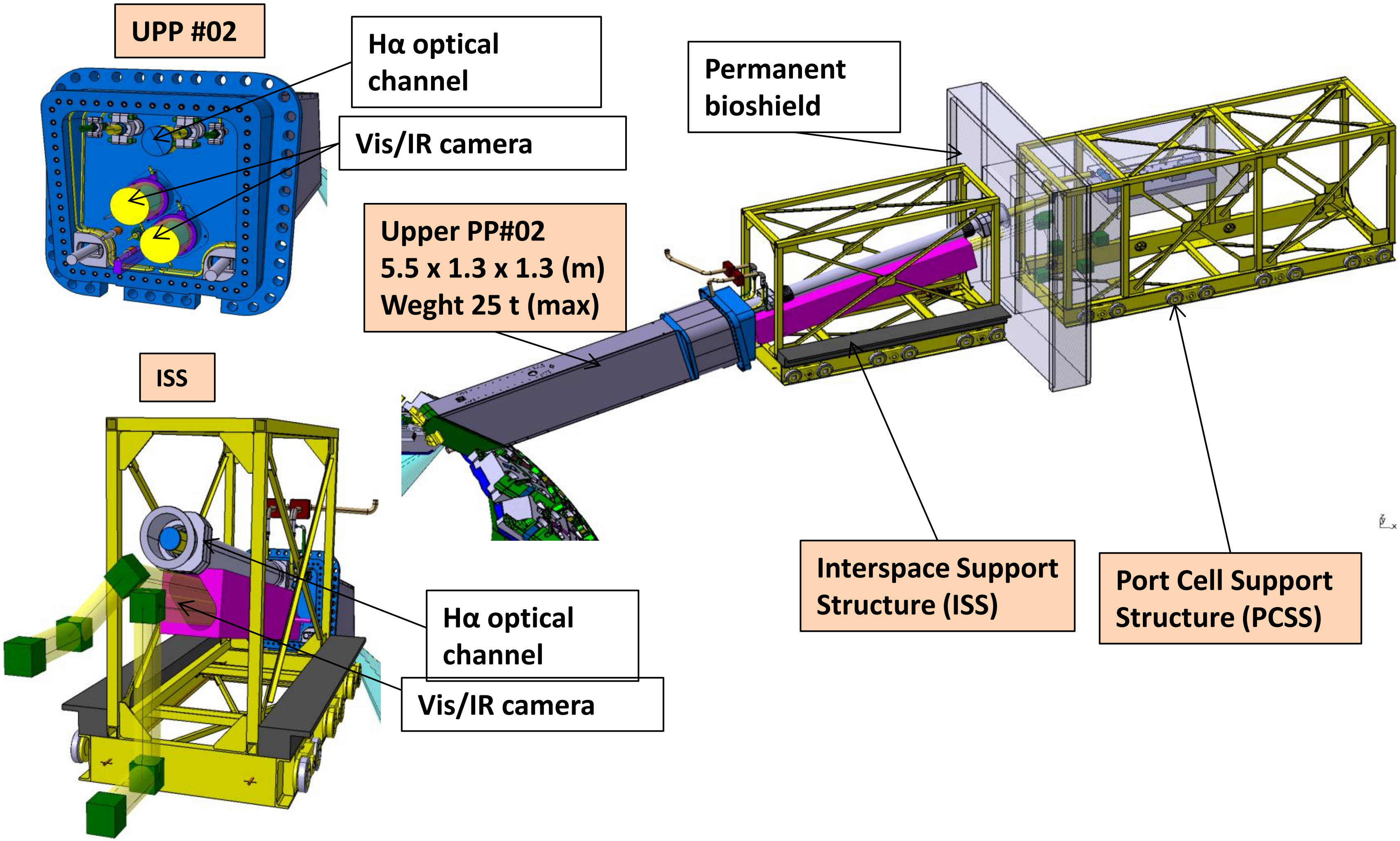




Interspace Support Structure
Size: : L3800 x W2300 x H3000
Total weight (maxi): 35 tons

Budker Institute

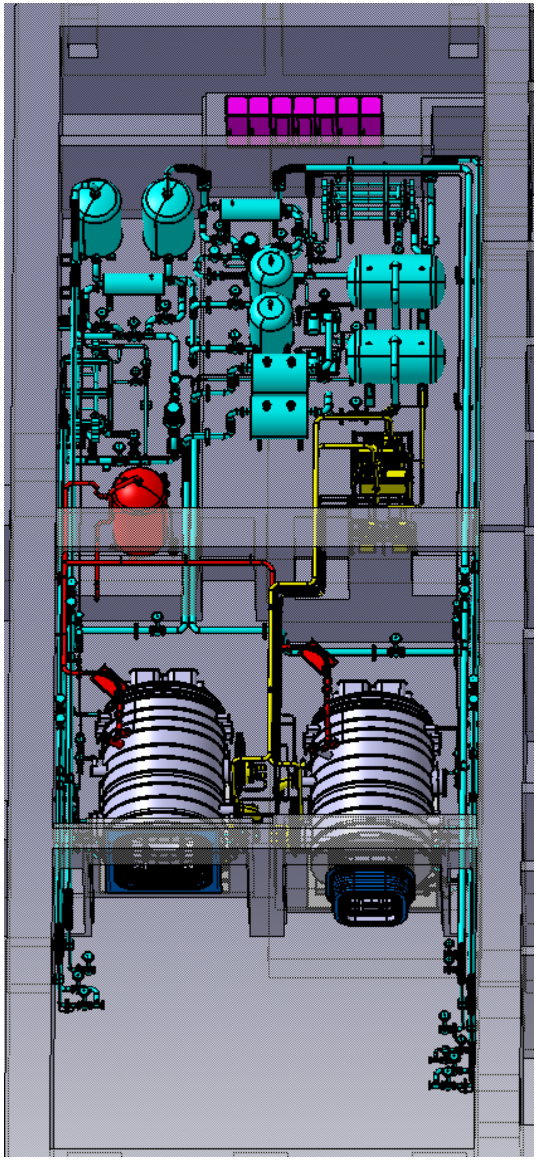
Upper Port Plug #02



Four Port Plug Test Facilities have to be manufactured : two of them for Hot Cell in ITER, one for EU DA in Spain, Barcelona, one for US DA in Princeton.ot

КРИОГЕНМАШ

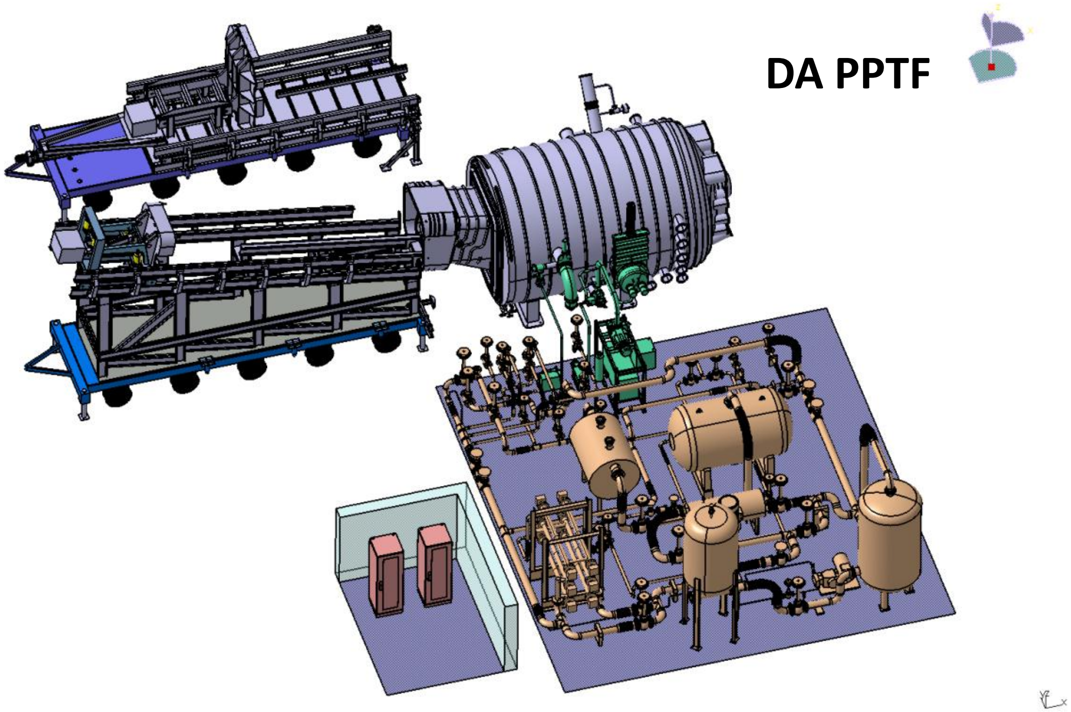
Hot Cell PPTF



After Preliminary design review (2013) and Final Design Review (2014) PPTFs become different for Hot Cell and Domestic agencies.

Hot Cell stand needs **non oil pumps implementation, tritium compatible equipment, only metal gaskets** (no rubber or elastomer). **Pressure suppression system appeared (marked red color)**. Test Tanks in Hot Cell have **shielding and bellows from radiation.** The way of sealing in Hot Cell - **welding**

DA PPTF



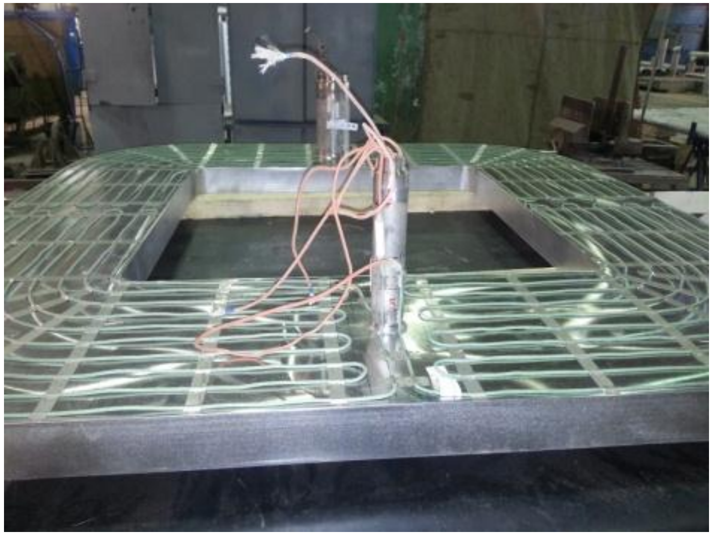
Port-plug test facility

КРИОГЕНМАШ

Mock-up

The mock-up was designed and manufactured for testing of three kinds of seal at temperature up to 240 C:

- elastomer;
- aluminum wire;
- HTMS sealing



Summary

- **RF scientific institutes and industries developed and manufacture the equipment without critical delay from the reference schedule.**
- **Management of nuclear safety and quality requirements by RFDA is performed in compliance with the French nuclear legislation.**
- **Design, manufacturing and testing of the ITER structures, systems and components are implemented in accordance with the requirements of recognized international and national codes and standards (ISO, EN, RCC-MR and ASME).**
- **The number of collaborations already established with the ITER partners and this activity will be supported by RF DA to increase efficiency and speed of ITER Project implementation.**

Thank you for attention.