Progress Towards ITER

24th Symposium on Fusion Engineering (SOFE)

Chicago, IL
June 27, 2011

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Director of the ITER Administration Department
for
ITER Organization
and
Domestic Agencies

The goal of ITER is to demonstrate the scientific and technological feasibility of fusion power for peaceful purposes.

- **ITER will make a major contribution to the physics basis for Demo.**
  - Plasma transport
  - MHD stability
  - Plasma boundary
  - α-particle physics

- **ITER will also make a major contribution to the technology basis for Demo.**
  - Plasma control
  - Superconducting coils
  - Vacuum vessel and in-vessel components
  - Remote handling
  - and many other areas….

ITER is Successfully Making the Transition from Design to Construction

- Going from developing requirements to detailed designs

- Going from R&D to large scale prototypes

- Going from prototypes to large scale manufacturing.

- Beginning construction!

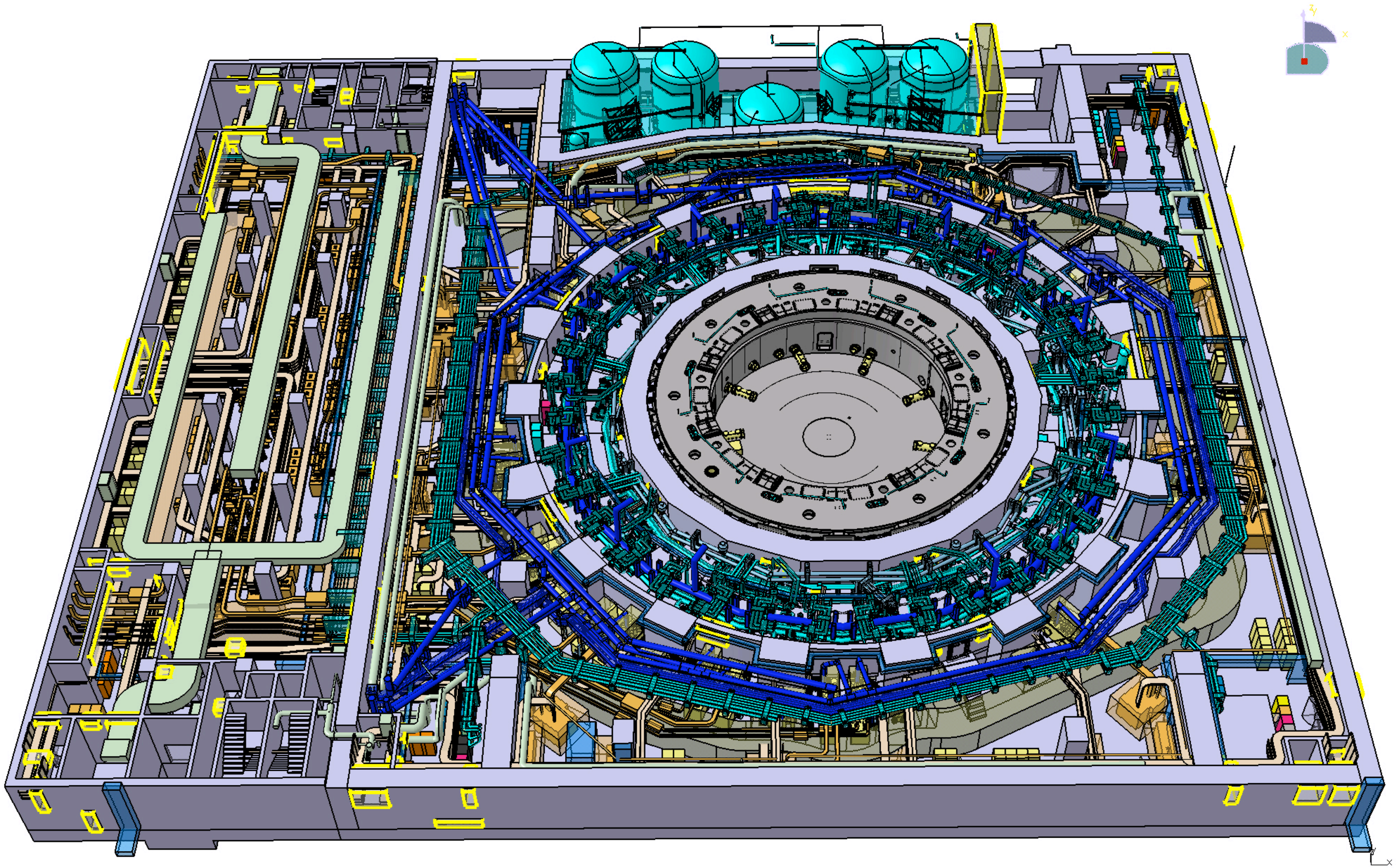
Construction of Buildings is Going Well

- **Poloidal Field Coil Winding Bldg.**
  – Ready 2011
- **Headquarters Bldg.**
  - Ready 2012

- **Excavation of the Tokamak Complex has recently been completed.**

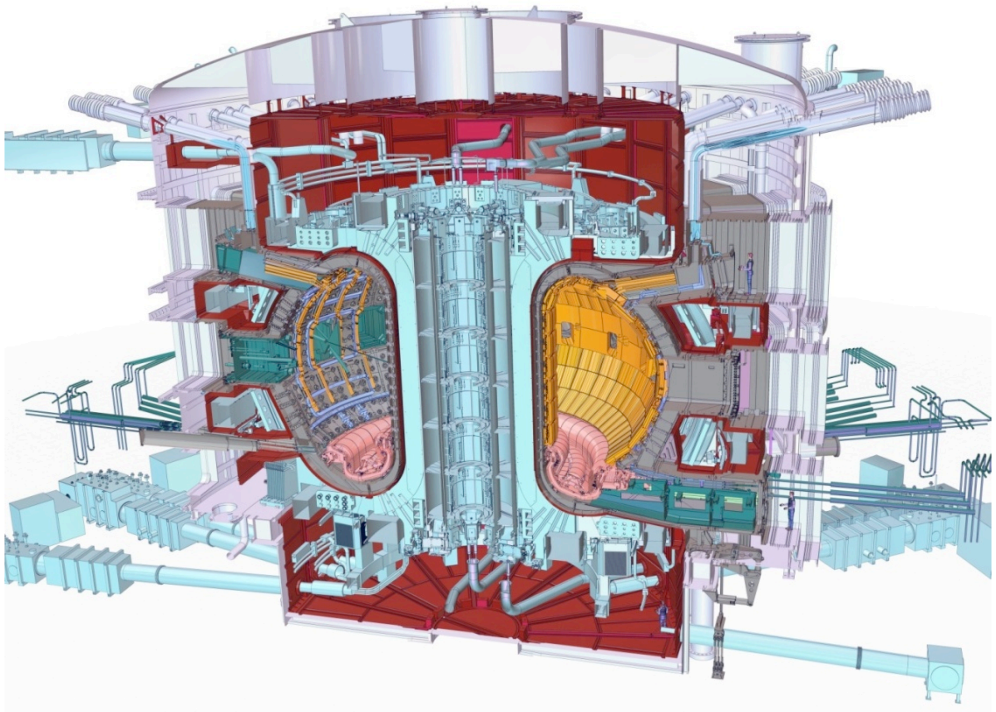
EUDA

Detailed Layout of the Diagnostic and Tokamak Building (B2 level)

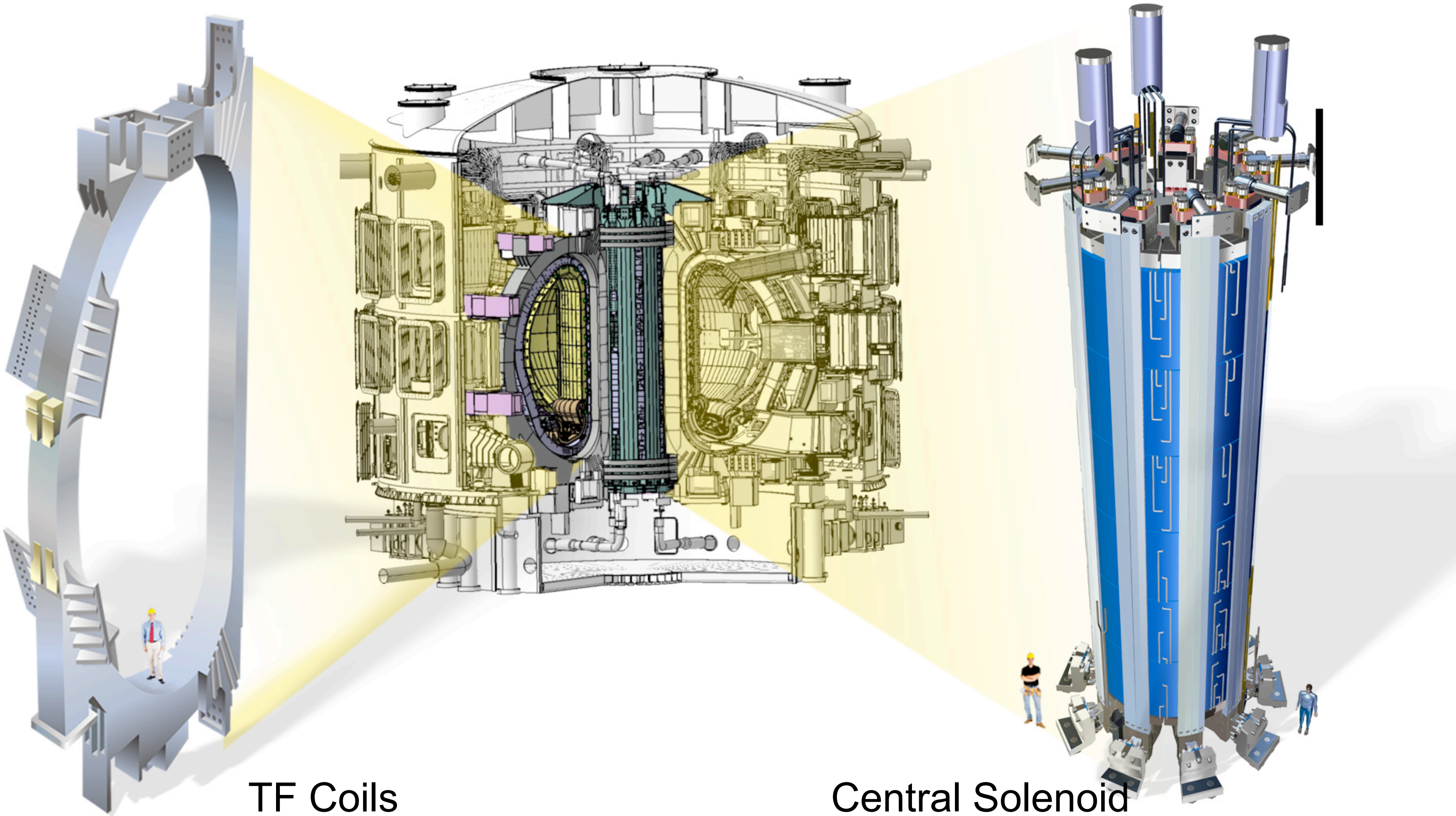


ITER is Addressing the Key Technical Challenges of the Tokamak

- ***Tokamak***
  - Large scale up of many systems
  - High quality high tech components
  - Tight tolerances
  - Manufacturing around the world
  - Highly integrated design
- ***Superconducting magnets***
  - Unprecedented magnet size
  - High field performance ~12T
  - Conductor and magnet manufacturing
- ***Vessel Systems***
  - Large size
  - Safety boundary
- ***Plasma facing components***
  - High heat flux
  - Plasma-Material Interactions
  - RH requirements



Unprecedented in Size and Performance



TF Coils
11.8 Tesla, 41 GJ
400 MN centering force

Central Solenoid
13 Tesla, 7 GJ
20 kV, 1.2 T/s

USDA

TF Coils Progress – Japan

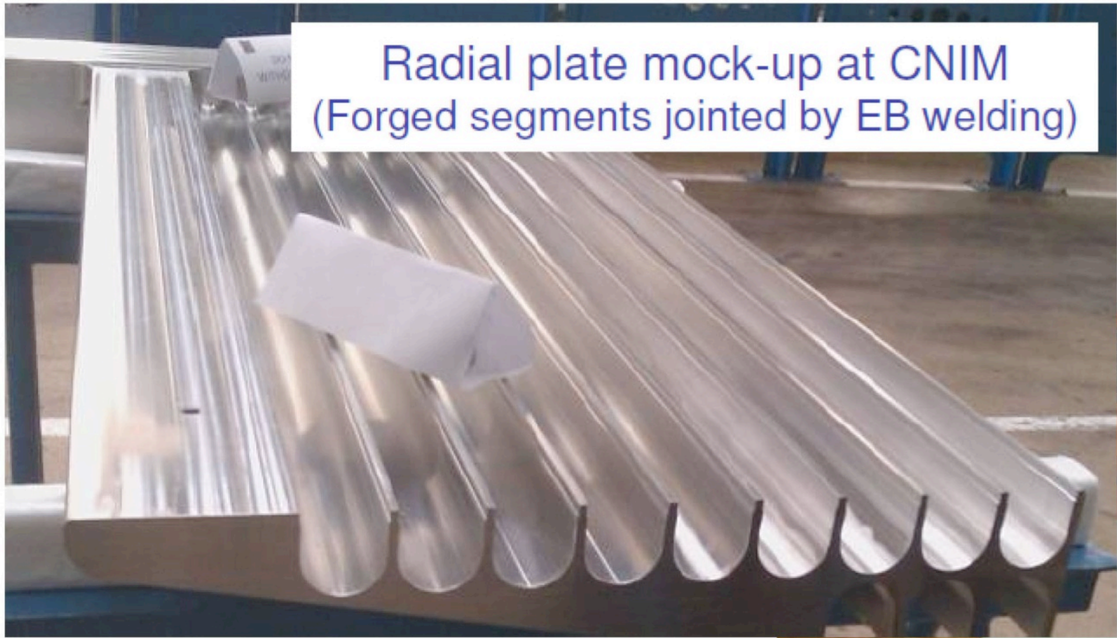
Completed one third scale 3-turn winding trials at Toshiba

Winding Support Jig

Winding & Bending Rollers

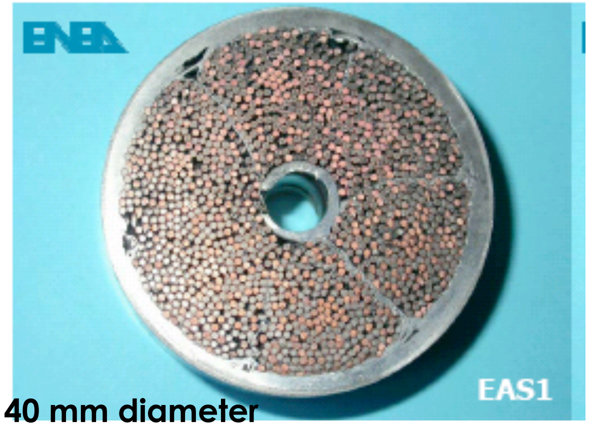
Photos: JAEA and Contractor Toshiba

TF Coils Progress – EU



Photos: F4E & Contractors SIMIC, CNIM and Le Creneau

TF Superconducting Strand Procurement Is Largest in History



40 mm diameter

ITER TF Conductor

More than 100 tons of TF strand registered in Database

Stepping up to 100 tons/year, an increase of two orders of magnitude from previous Nb_3Sn worldwide production rate

Mid-Joint for Feeder Busbar

Most material from JA, followed by KO, RF, EU and US

Feeder uses HTc superconductor

(YBaCuO)Achieved less than 5nΩ contact resistance on feeder for correction coils (CN).

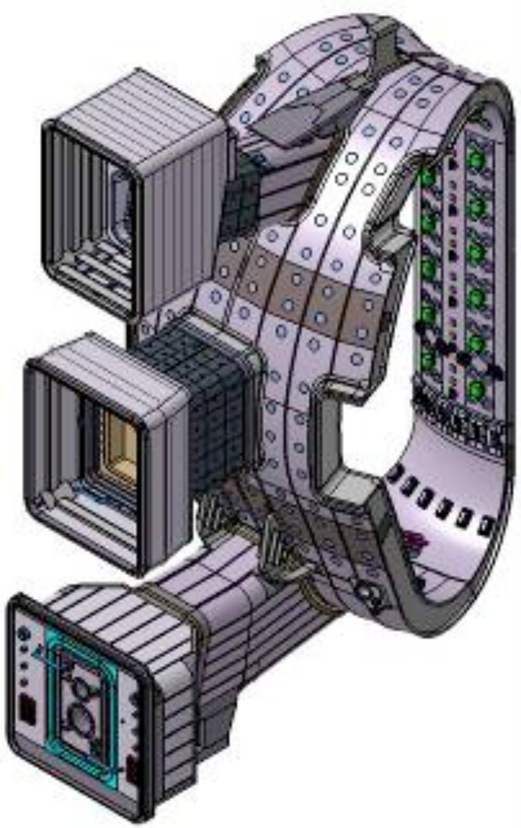
Test Results from Central Solenoid (CS) Conductor Are Being Reviewed

- **Tests conducted at Sultan facility indicated larger than expected degradation due to cyclic and thermal cycling of CS conductor and one TF sample.**
  - Some cyclic degradation in large Nb_3Sn conductors is expected, understood and is included in the design.
  - Some of this may be due to the non-uniformity of the field in Sultan, which is not present in a coil.
- **A program is in place to understand the degradation:**
  - Further analysis of the samples with poor performance.
  - Evaluate whether the cause is poor sample preparation.
  - Possibly increase performance of CS conductor.
    - Decide in October how to proceed.
- **IO assessment is that the TF conductor is acceptable.**
- **CS insert coil should be manufactured and tested.**

Vacuum Vessel Is the First Safety Barrier and Must Withstand Disruption Loads

Facts

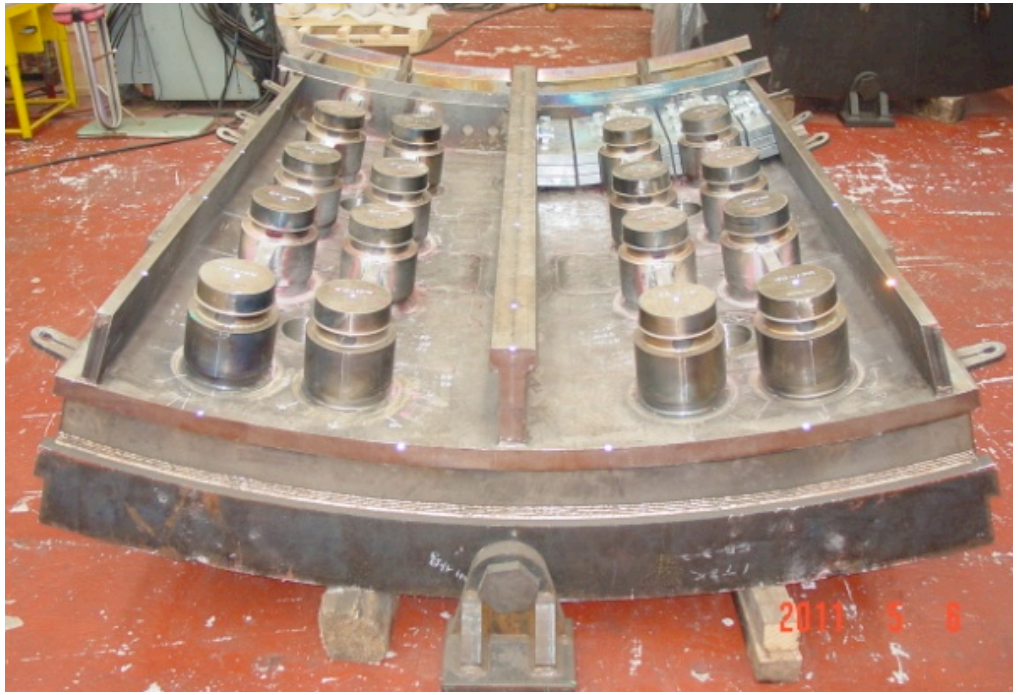
- SS 316 L(N)-IG
- ~5300 tons (VV, ports, shielding only)
- 19.4 m (63 ft) torus outer diameter
- 11.3 m (37 ft) torus height



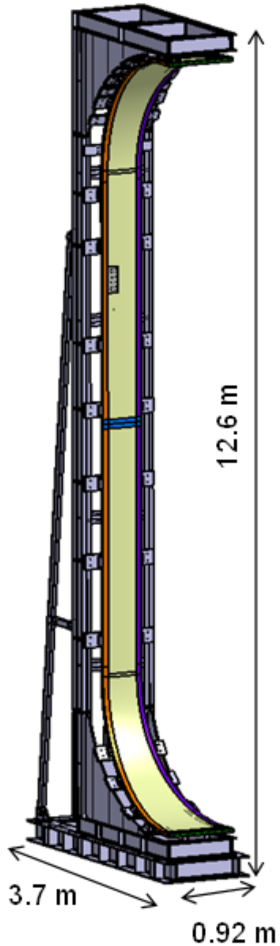
Status

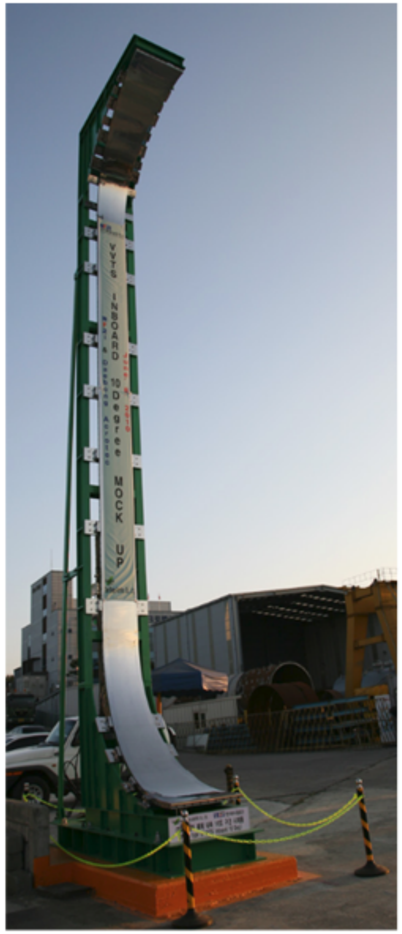
- VV sector and port Procurement Arrangements signed (EU, KO, IN, & RF)
- KO - VV & port contract awarded to Hyundai Heavy Industries
- EU - VV contract awarded

Large Scale Mockups of Vacuum Vessel and Thermal Shield



Inboard segment of a VV sector





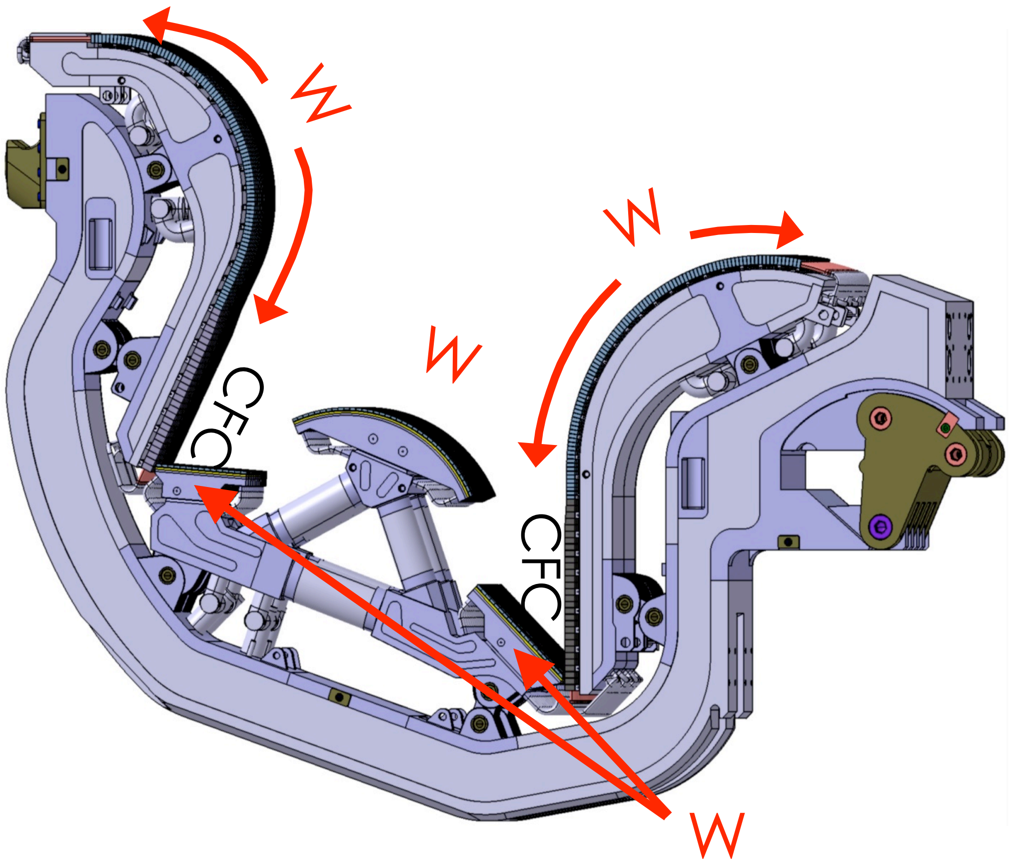
Korean Domestic Agency is verifying the manufacturing design and fabrication methods

KODA

Divertor PFC Materials Choice

Non-active phase (H, He):
CFC at the strike points, W on the baffles

All-W from the start of D operations



Rationale:

- Carbon easier to learn with
- No melting → easier to test ELM and disruption mitigation strategies before nuclear phase
- T-retention expected to be too high in DT phase with CFC targets

Divertor Qualification Prototypes

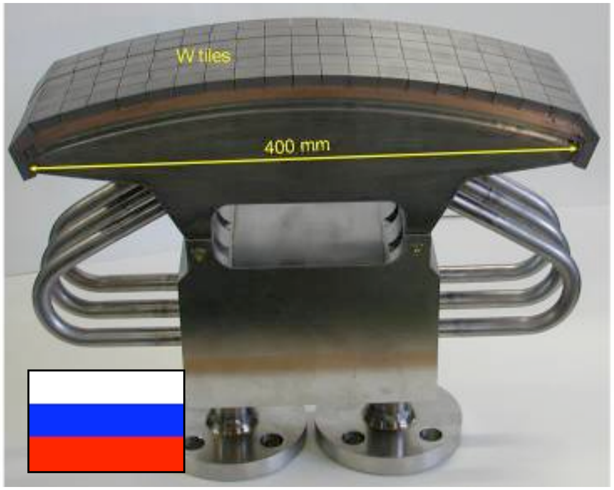
CFC Armoured Areas

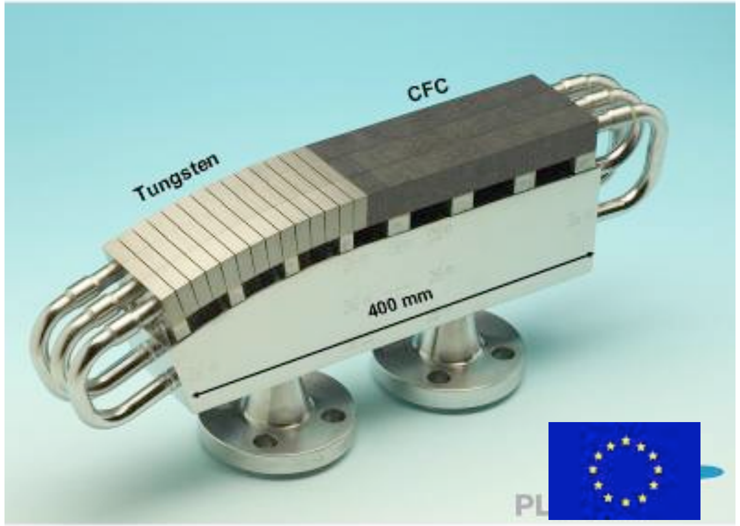
1000 cycles at 10 MW/m^2
1000 cycles at 20 MW/m^2

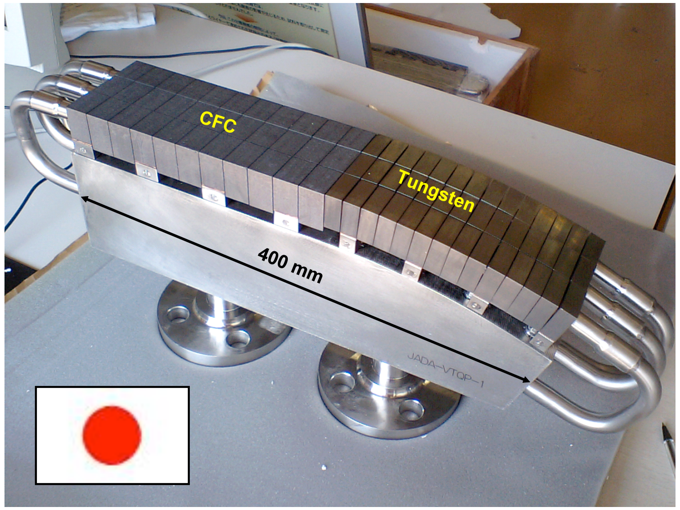
W Armoured Areas

1000 cycles at 3 MW/m^2
1000 cycles at 5 MW/m^2

All 3 Domestic Agencies have been qualified.



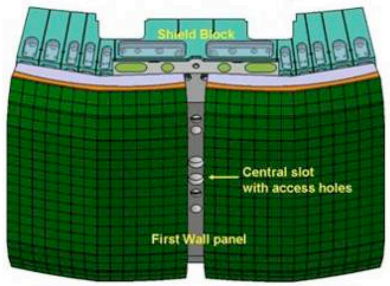


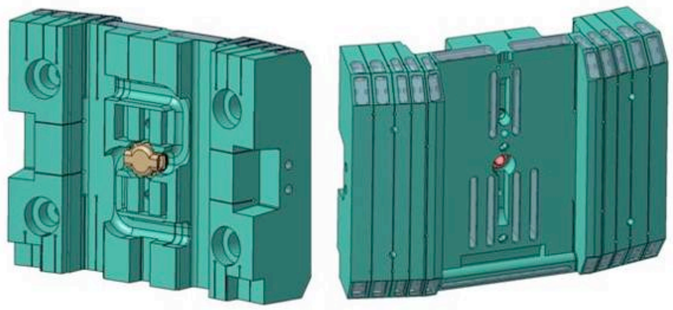


Blanket Shield Module and First Wall Panels Have Been Redesigned for Remote Maintenance

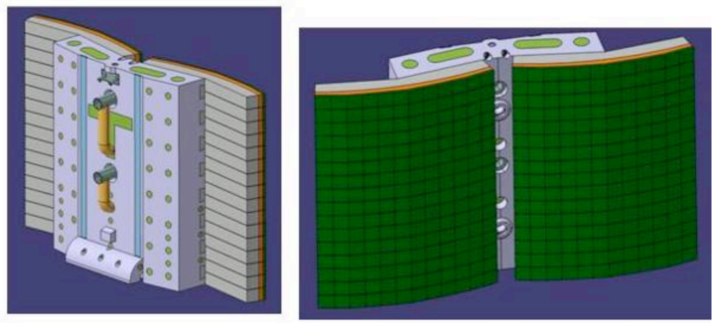
Facts:

- 440 blanket modules
- ~4 tons each
- 18 poloidal rows
- 18 or 36 toroidal rows
- ~40 different modules
- Mass: 1530 tons





Shield Module

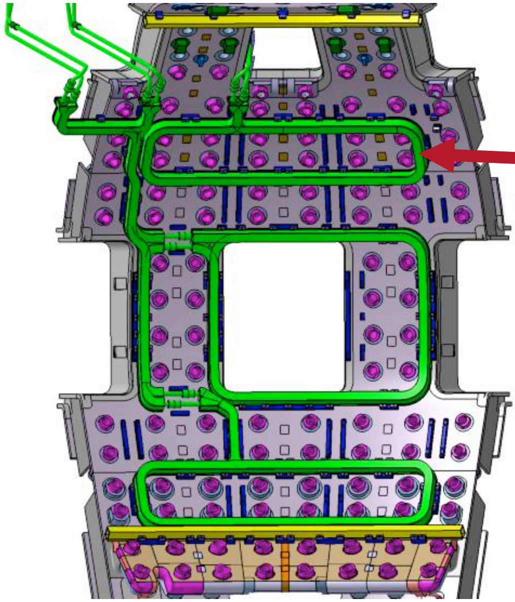


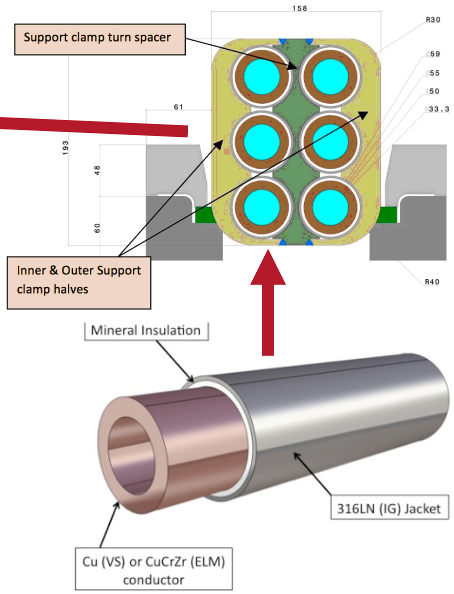
First Wall Panel

Technical Challenges:

- Large electromagnetic loads
- High heat flux ~ 5 MW/m^2
- Material bonding techniques
- Plasma-material interactions
- Integration with in-vessel coils, diagnostics and blanket manifold.
- Remote handling requirements

In-Vessel Coils for Vertical Stability and ELM Control Are Very Challenging





Conductor

Technical Challenges:

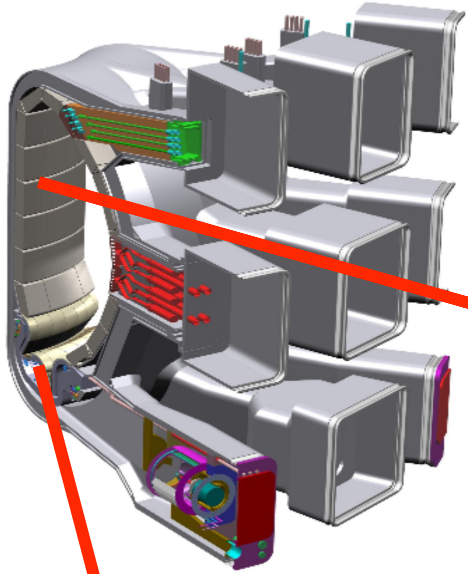
- High currents in neutron environment (~60 kA @ 2.3 kV)
- Scale up of conductor (26 to 59 mm diameter)
- Remote handling
- Very encouraging results from R&D program
  - Further work required.

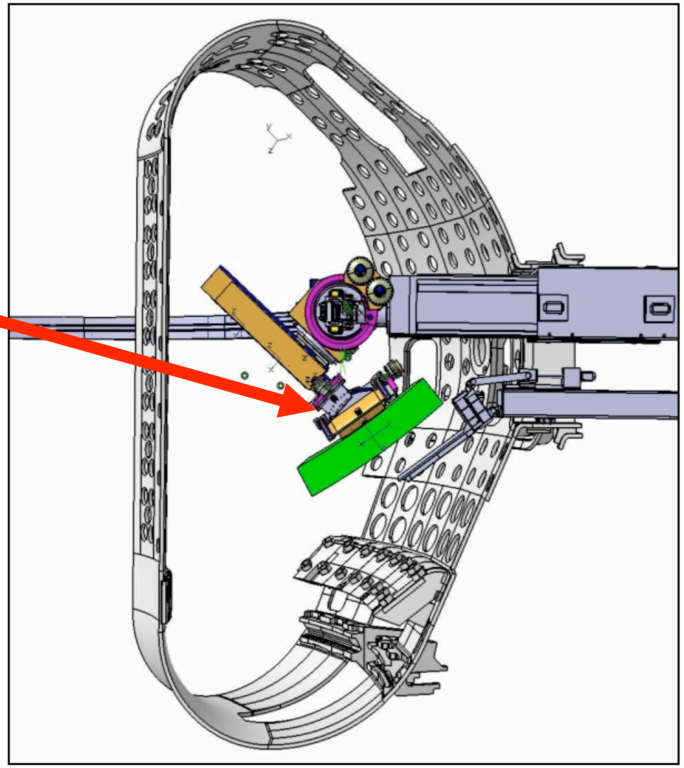
USDA

Stainless Steel Mineral Insulated Conductor R&D Results

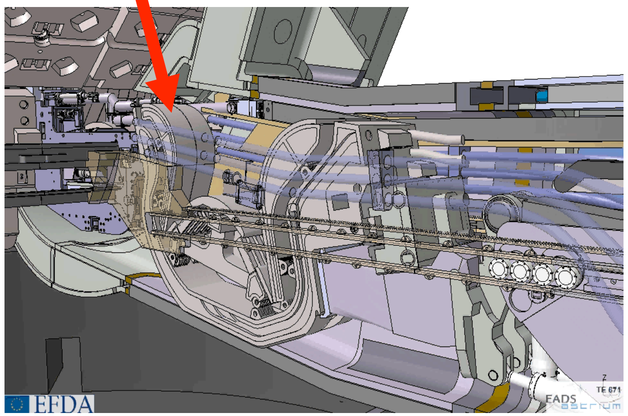
- **Conductor Development – feasibility demonstrated**
  - Electrical / mechanical testing of prototype conductors from two potential suppliers with favorable results
  - Hermetic seal for MgO insulation space determined to be an important requirement
- **Joining Development**
  - Techniques developed for brazing and welding
- **Remote Handling of Coil-Feeder Joints**
  - Joint RH process identified with RH-adaptable tools
  - Brazing/Welding chosen over bolting (emphasize reliability)
- **Flow Erosion/Corrosion Studies**
  - IVC flow velocity lower than FW/DIV by ~2X (5 vs. 10 m/s)

In-Vessel Remote Handling Major Extension of JET Approach



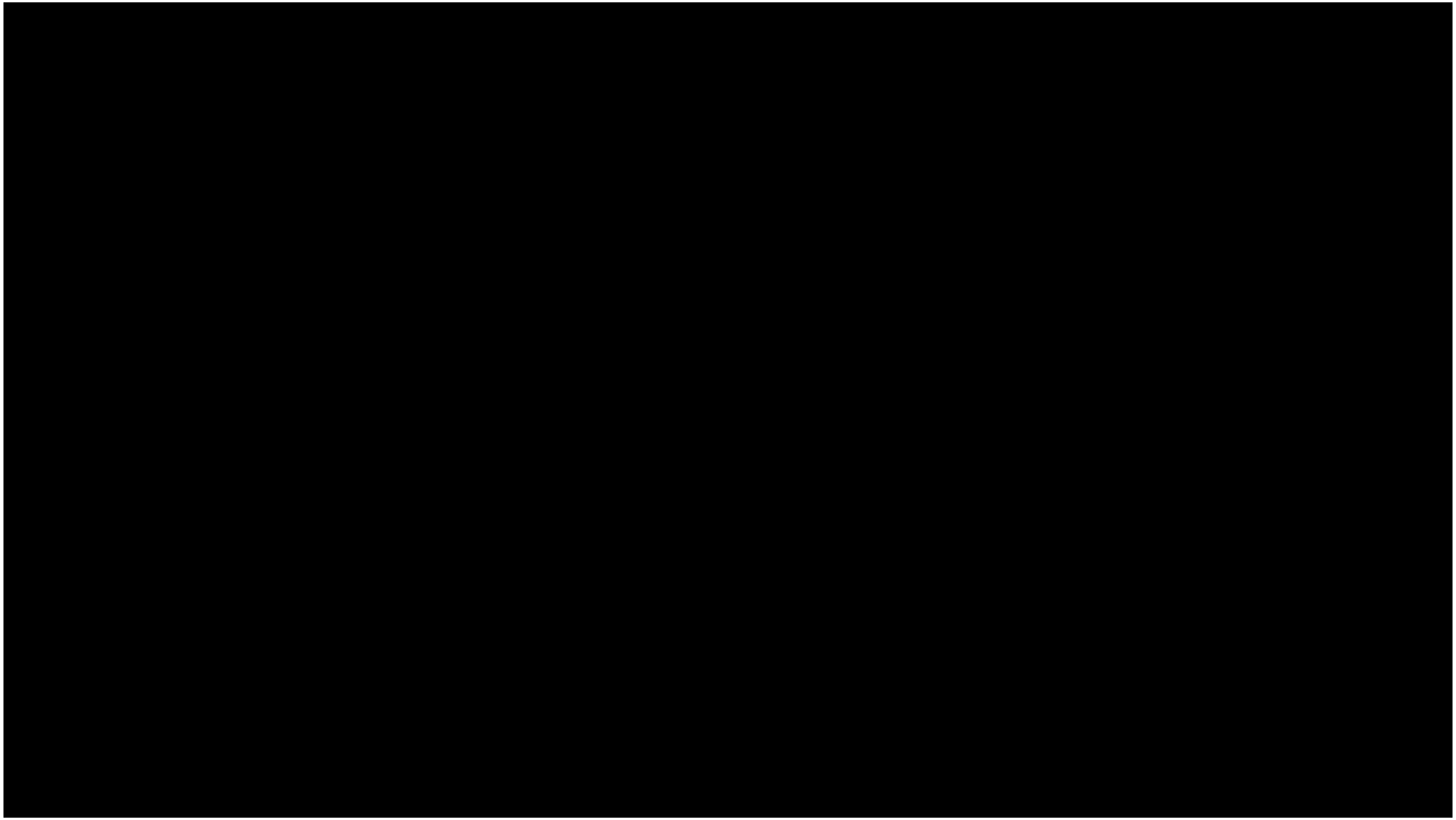


Blanket Module Handling ~4.5 ton

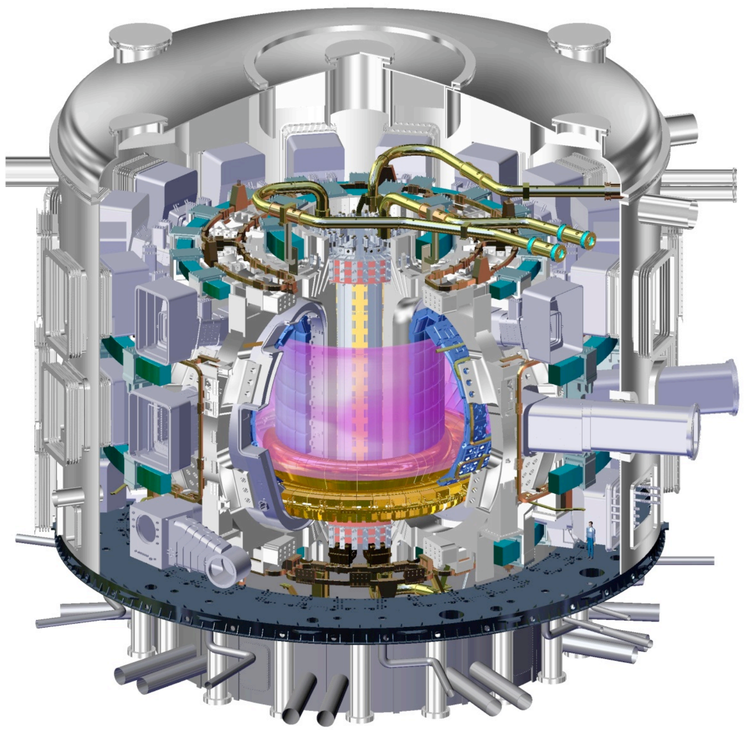


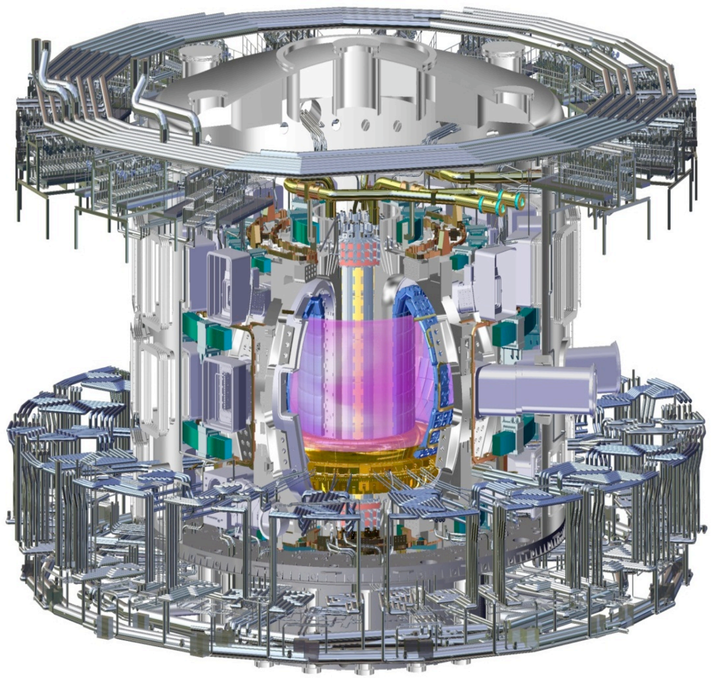
Divertor Cassette Handling ~9 ton

Mock-up Test Sequence of Divertor Cassette Remote Handling Removal in Finland



Tokamak Component Water Cooling System Has Interfaces with 27 Other Systems





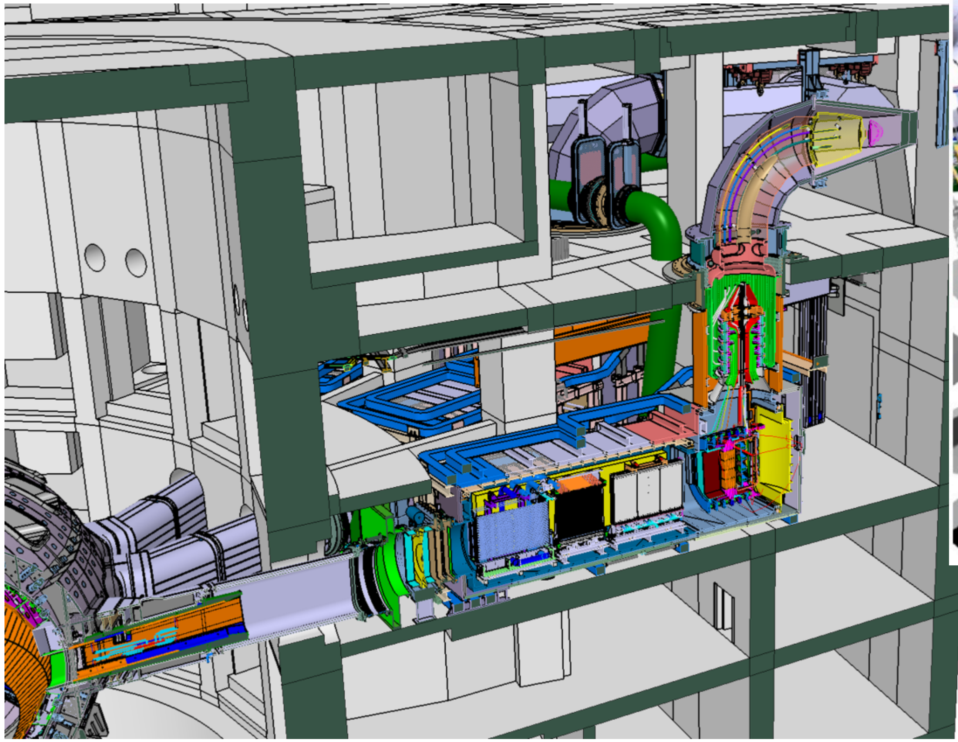
- Without water cooling system

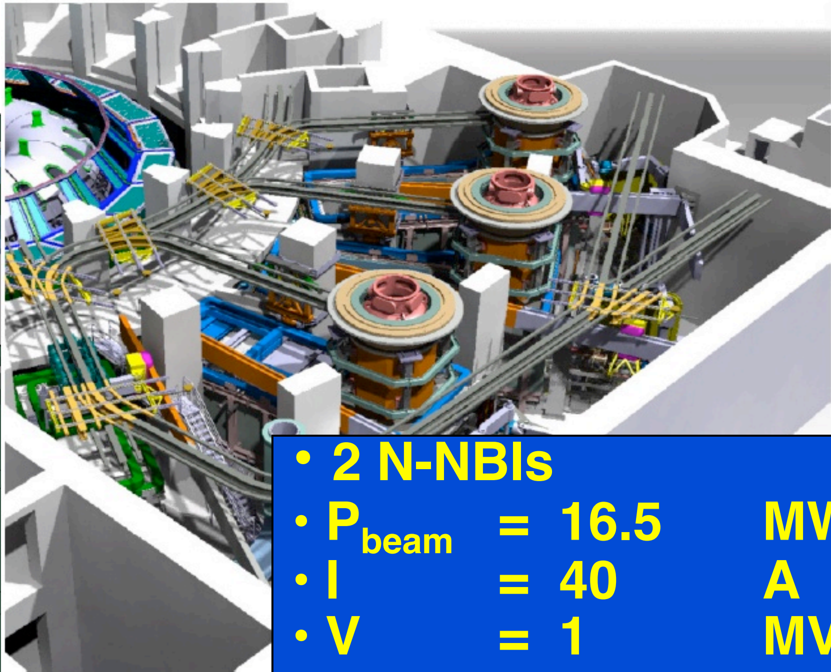
With water cooling system

- Being designed and procured by US Domestic Agency

Development of Negative-Neutral Beam Injection Systems Is a Major Effort

- 100kV ion source test bed (beg. 2014)
- Full size HNB injector test bed (2017)





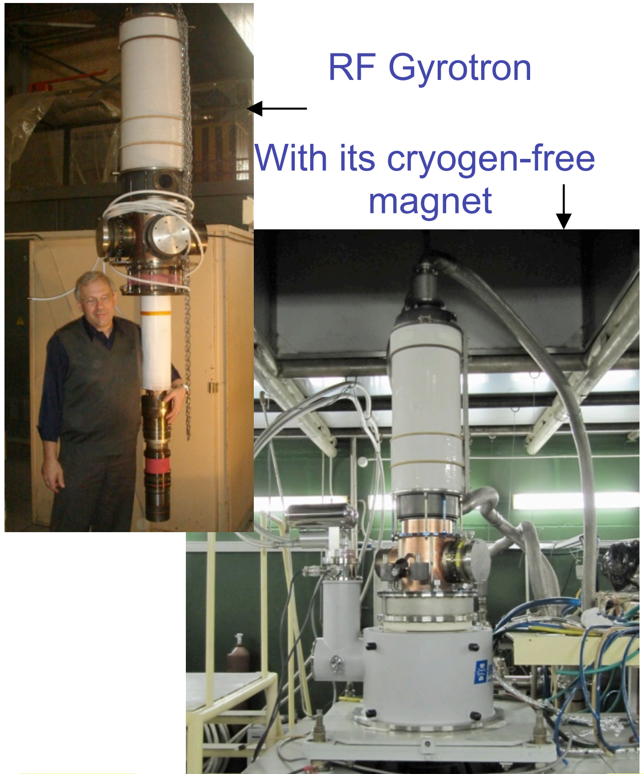
- 2 N-NBIs
- P_{beam} = 16.5 MW
- I = 40 A
- V = 1 MV
- T_{pulse} = 3600 s

60 GJ to be delivered to the plasma by each beam

•1MeV neutrals implies negative ions for efficient neutralisation (60%)

EUDA & JADA

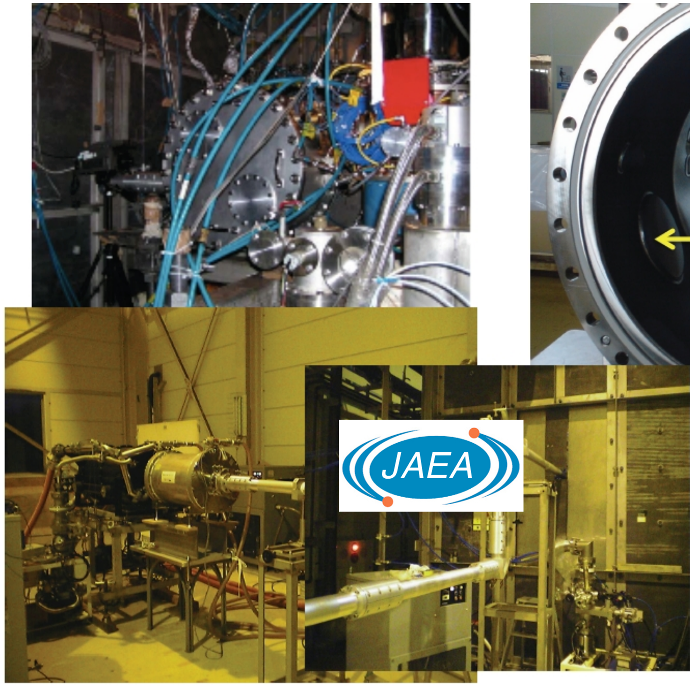
Good Progress in Gyrotron Development for Electron Cyclotron H&CD System

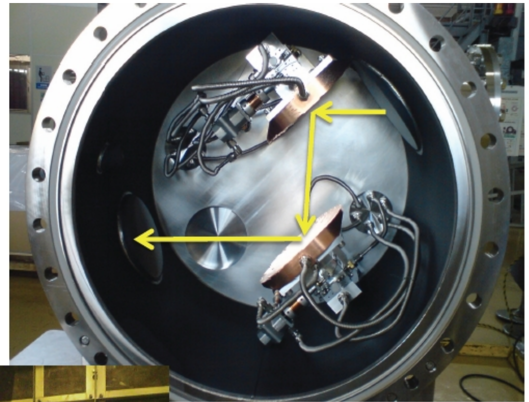


RF Gyrotron

With its cryogen-free magnet

IAP RAS GYCOM INF





Matching Optics Unit

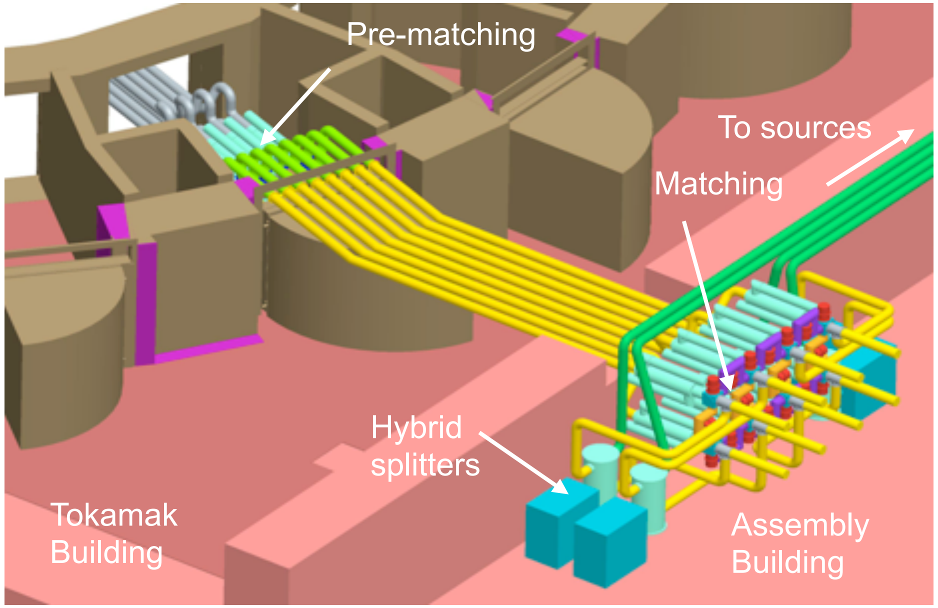
JA Gyrotron test bed

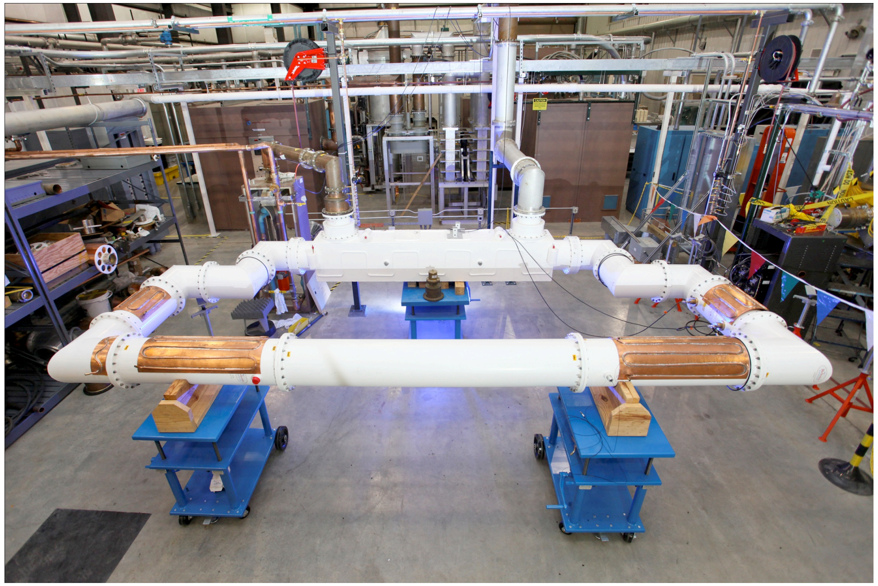
Evacuated Transmission Line

- **HV power supplies (60kV, 100A) and (50kV, <1A) (EU, IN)**
- **Evacuated waveguide components (US, EU, JA)**
- **Cooling manifold systems (JA, EU, RF, IN, US)**
- **Control systems (JA, EU, RF, IN, US)**

Alternate ICH Matching System Has Improved Maintenance

- **Enabled by novel phase shifter design**
- **Much more space for components**
- **Easier access to capacitors, etc. for maintenance**
- **Reduced technical risk**





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Port Plugs Contain Several Diagnostics

High fluxes onto plasma-facing mirrors

- Nuclear radiation - 0.5 MW / m^2

- Heat, neutrals and ion

Mirror/waveguide labyrinths for shielding

- Extensive neutronics analysis

Some systems cannot use labyrinths

- X-ray camera, spectroscopy

- Neutron and gamma cameras

Some systems require vacuum extensions

- VUV spectroscopy

- Neutral particle analyzer

High electromagnetic disruption loads

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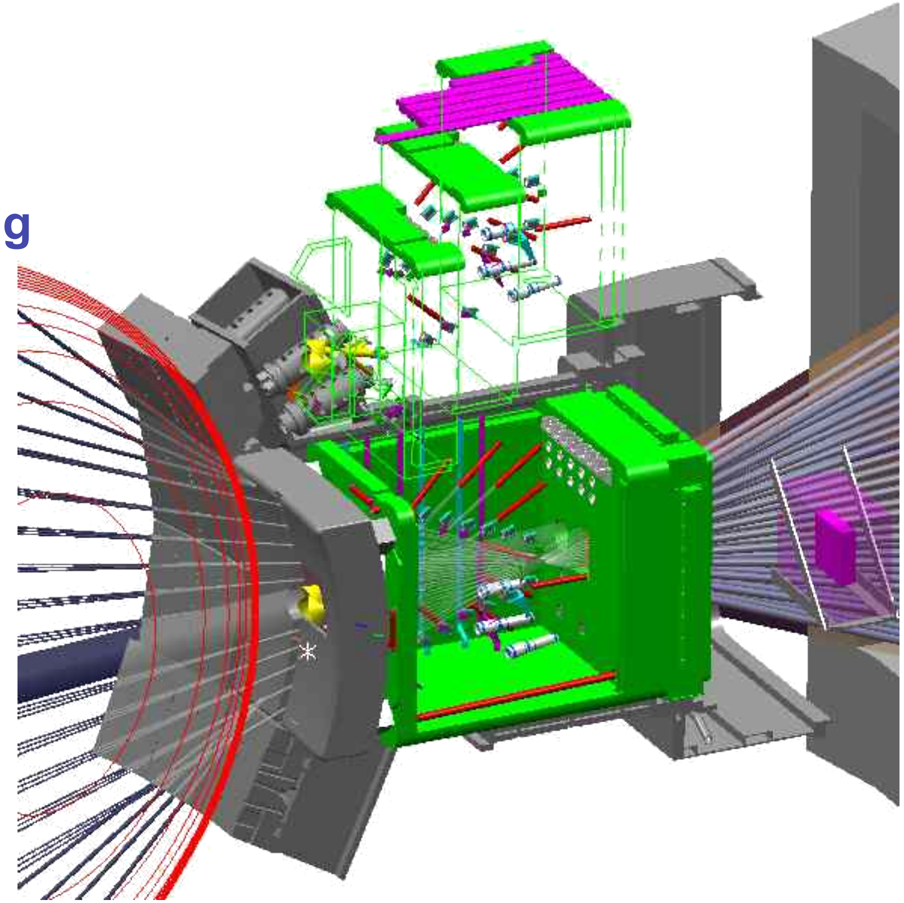

USDA

Tritium Breeding Blanket Testing is an Important Element in the ITER Mission

- **Up to six mock-ups of tritium breeding blanket systems (TBS), will be tested in three equatorial ports of ITER.**

- **The TBS testing has to demonstrate that**
  - Tritium can be produced and extracted at a rate that extrapolates to tritium consumption in the plasma
  - Heat can be extracted from the blanket at temperatures high enough for efficient electricity generation.

- **Successful TBS experiments in ITER would represent an important step on the path to fusion energy development.**

ITER Licensing Process is Well Underway

- **In December 2010, the ITER safety files were formally accepted by the French Authorities.**
  - Enables technical evaluation by the Nuclear Safety Regulator (ASN) as well as the public evaluation of the files;
- **A kick-off meeting was held at ASN in Paris to launch the "Groupe Permanent", a formal independent group.**
  - A final meeting of this group is foreseen for November 2011;
- **In April the IO received the formal positive acceptance of the French Environmental Authority of the ITER files.**
  - The last step to be achieved before the formal launching of the so-called Public Enquiry (Enquête Publique);
- **The Public Enquiry will be conducted from June 15 to July 20.**
  - Everybody in the nearby communities can provide comments about the ITER project.

Impact of Tohoku-Kantoh Earthquake and Tsunami in Japan is Being Evaluated

- **Fact finding delegation went to Japan in May, led by Rem Haange.**
  - Discussions are underway with Japan to assess the impact
- **Several key test facilities were damaged.**
- **Industry, responsible for the TF and CS conductor and coil procurement arrangements, had relatively minor damage.**
  - Impacts associated with electricity shortage.
  - Possible impacts associated with higher priority activities in Japan.
- **Task group has been set up to evaluate the options to minimize the schedule delay.**

ITER Provides an Opportunity to Address Key Technology Issues for Demo

- **The large size and unique requirements of ITER have presented many technical challenges for the design and manufacturing.**
- **ITER design, R&D, and prototype manufacturing activities are addressing these challenges.**
- **Construction has begun on key elements!**
- **ITER is developing key components necessary for the development of fusion.**