US ITER Project Progress

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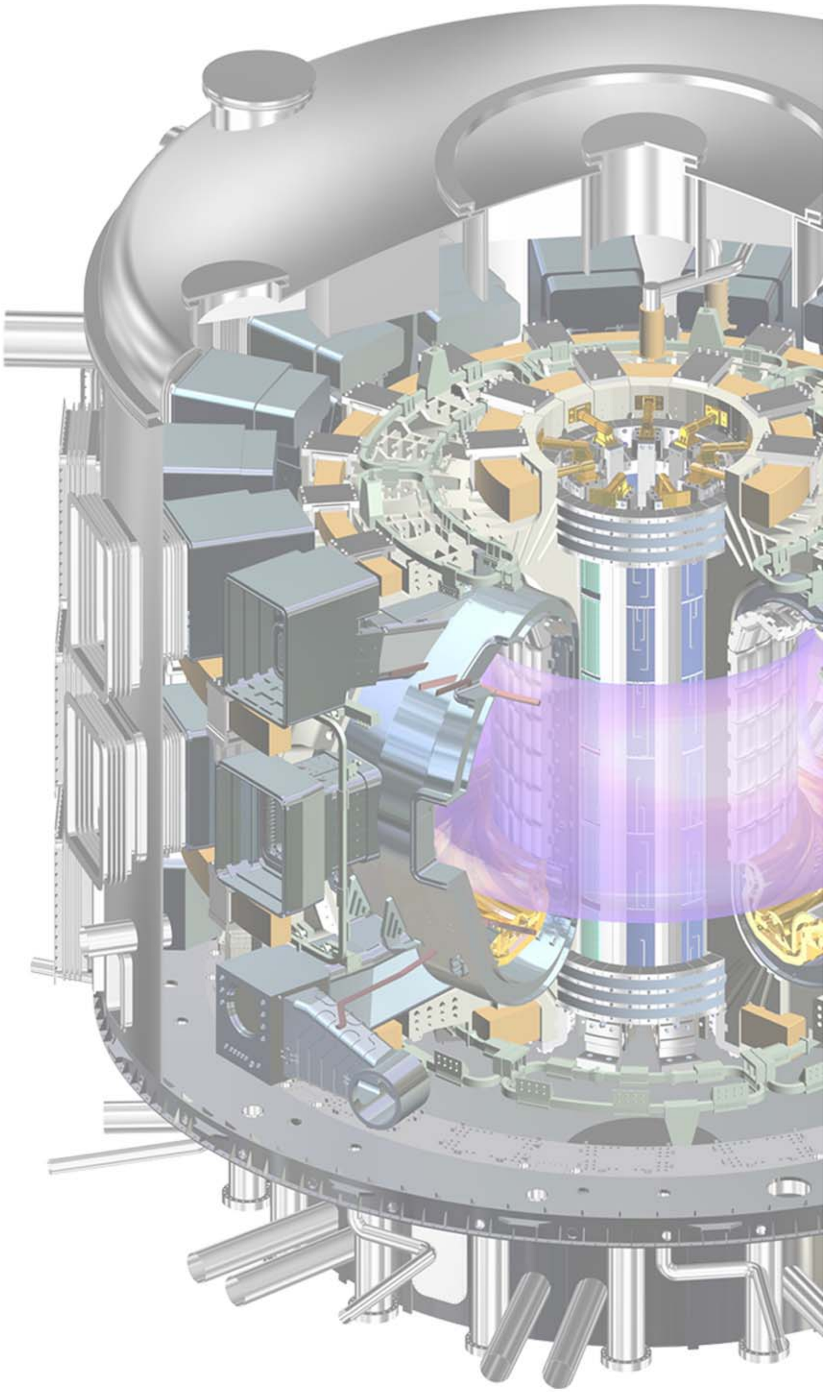
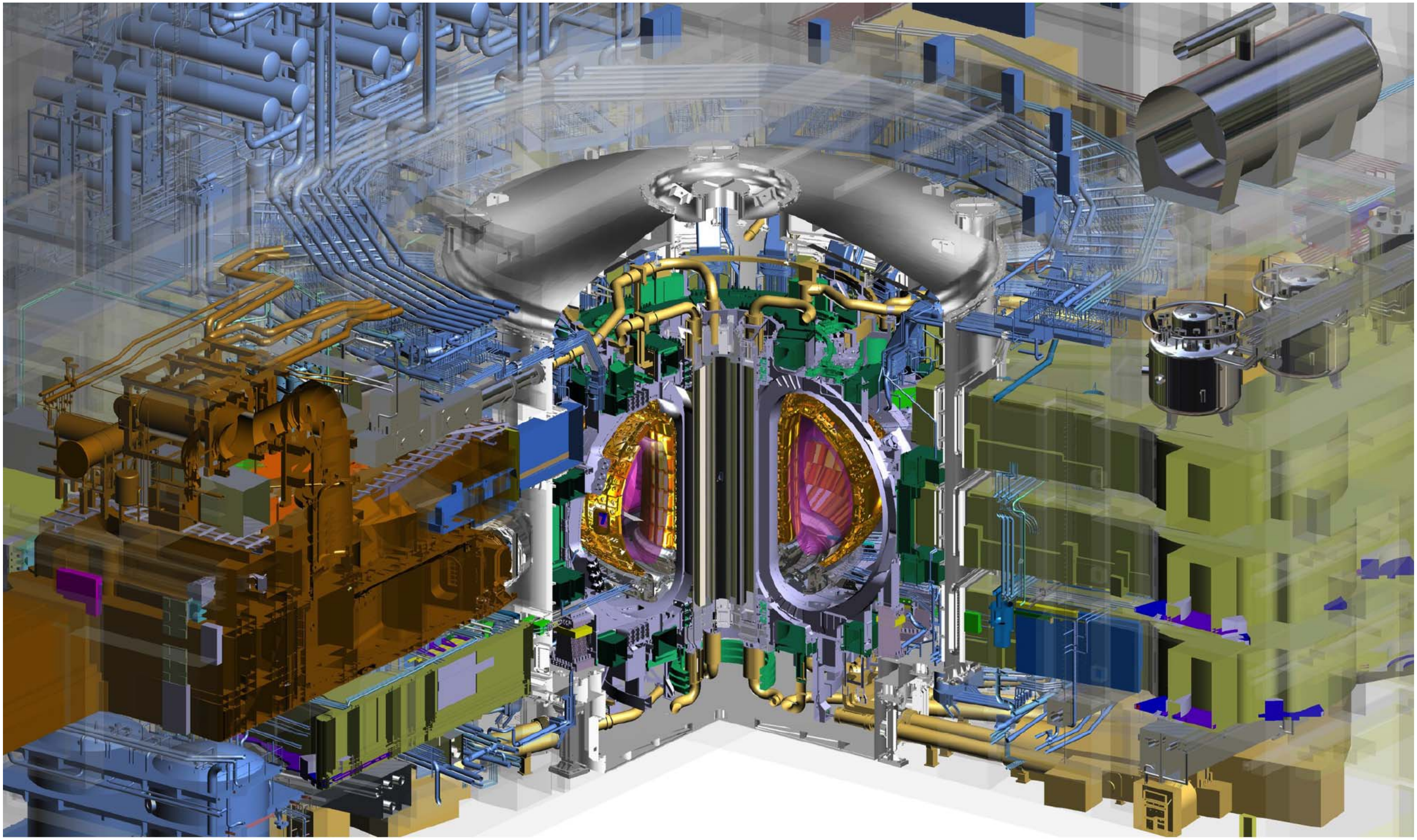
Fusion Energy Sciences Advisory Committee

September 23, 2014



ITER Tokamak Core in Building



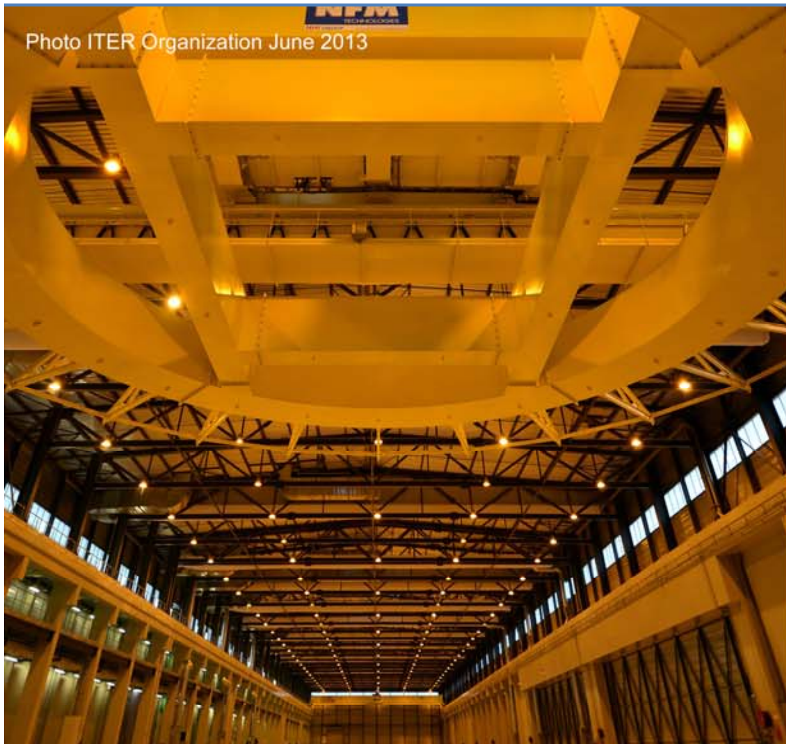
Site Progress

Recent Activities

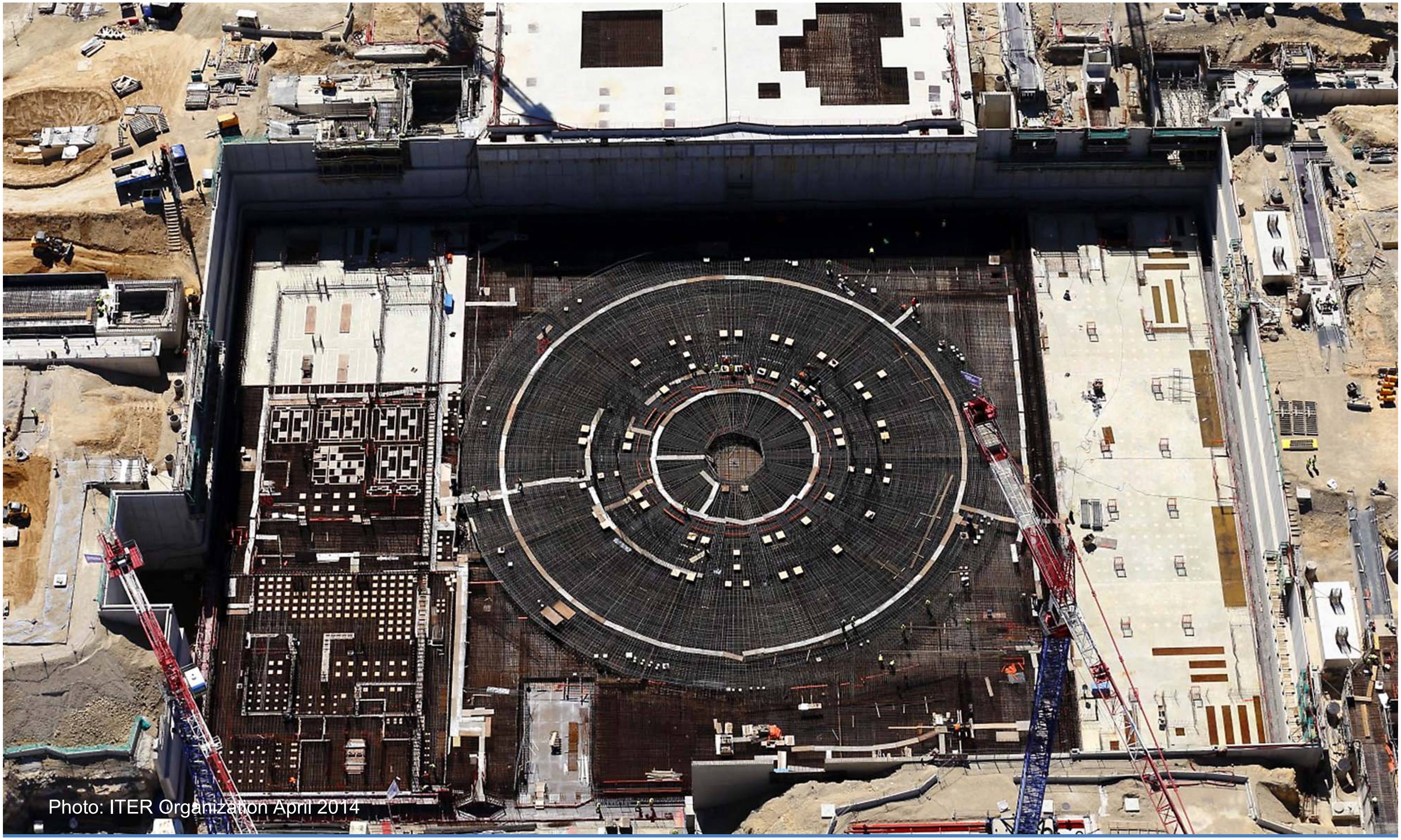
Cryostat Workshop (India)


Photo: ITER Organization April 2014

Poloidal Field Coil Winding Facility (EU)

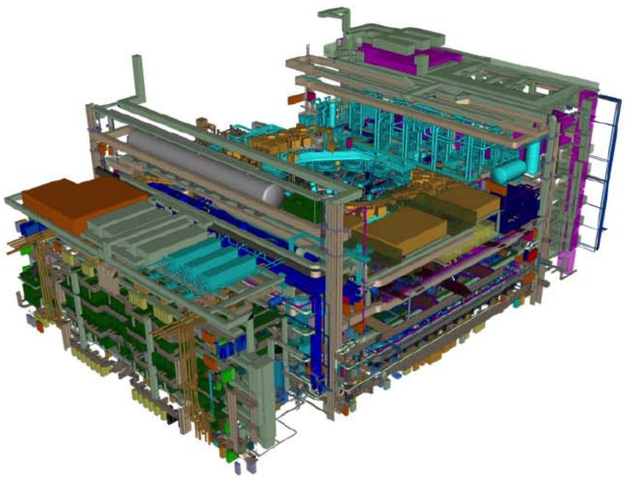


Tokamak Pit

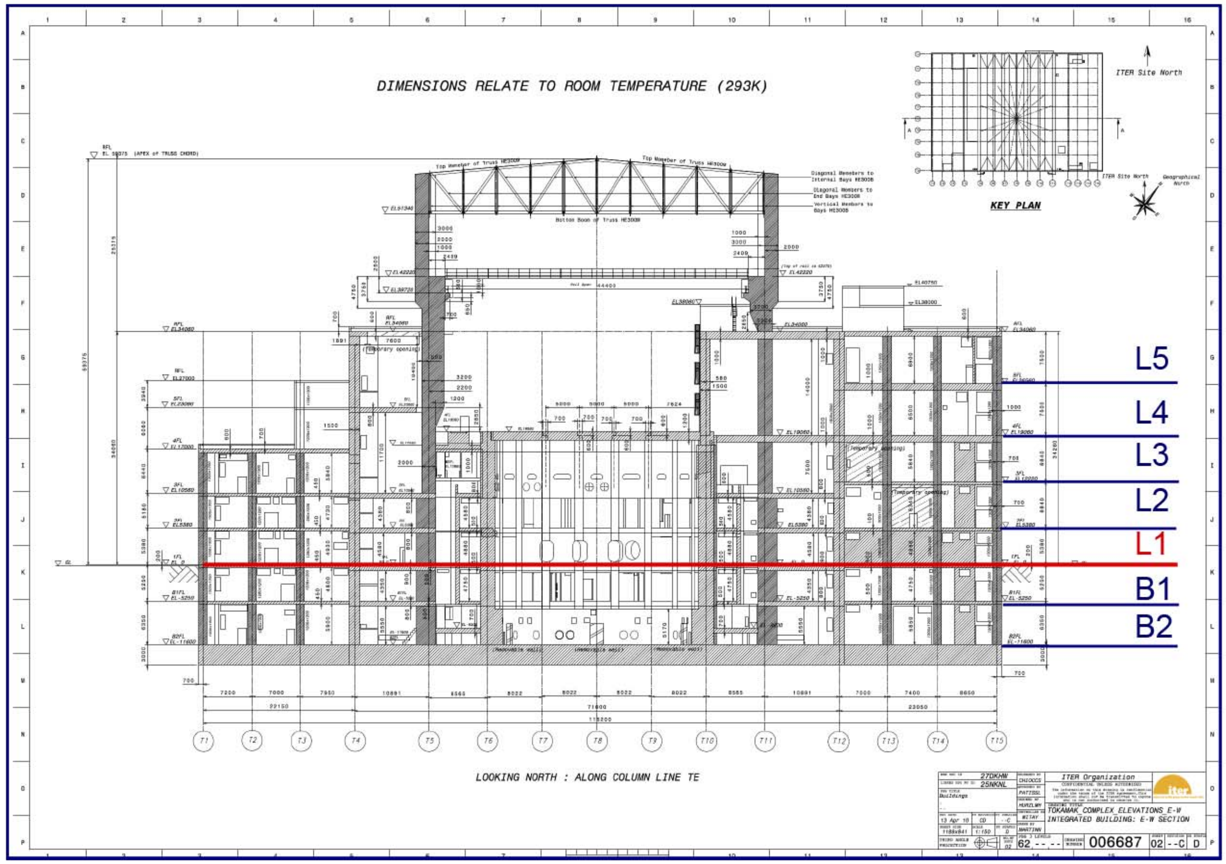


Where is the B2 Slab?

The ITER Tokamak Building is Defined by Levels



Re-bar for B2 Slab



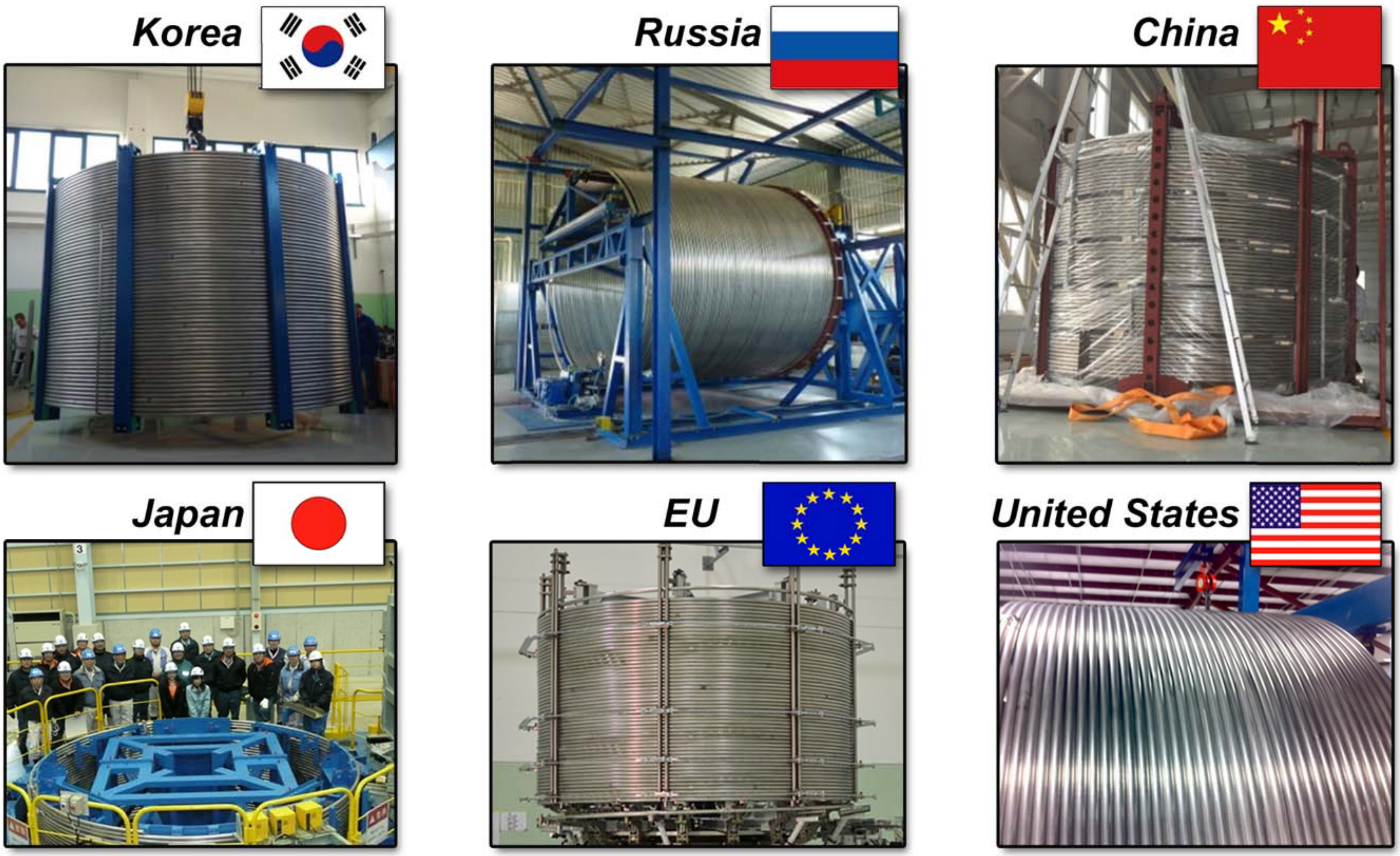
Tokamak Complex Floor (B2 Slab)

Tokamak Complex Floor (B2 Slab)

Tokamak Complex Floor (B2 Slab)

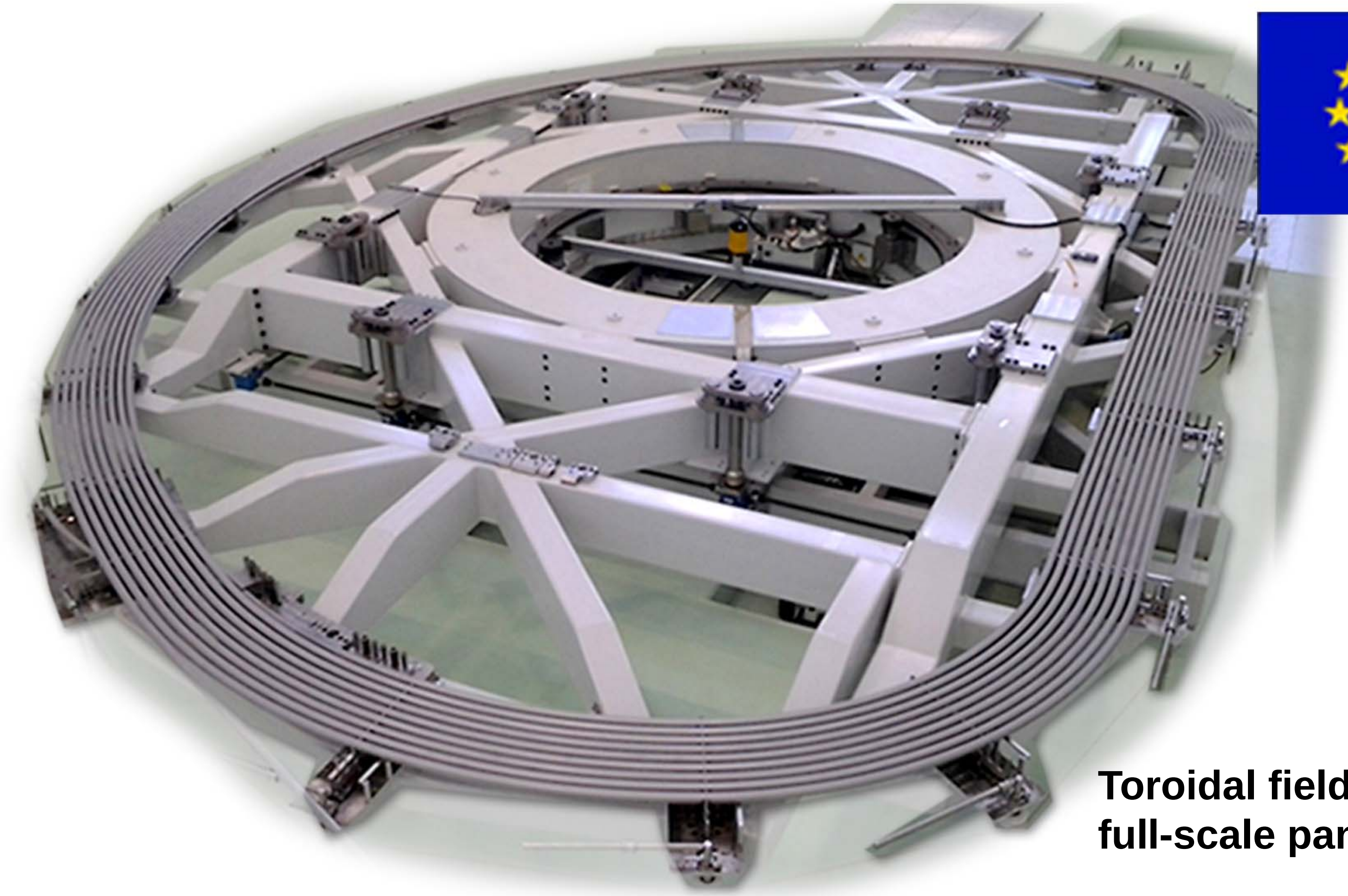
Fabrication of ITER Components by Global Partners is Underway

FY 2014 Partner Achievements



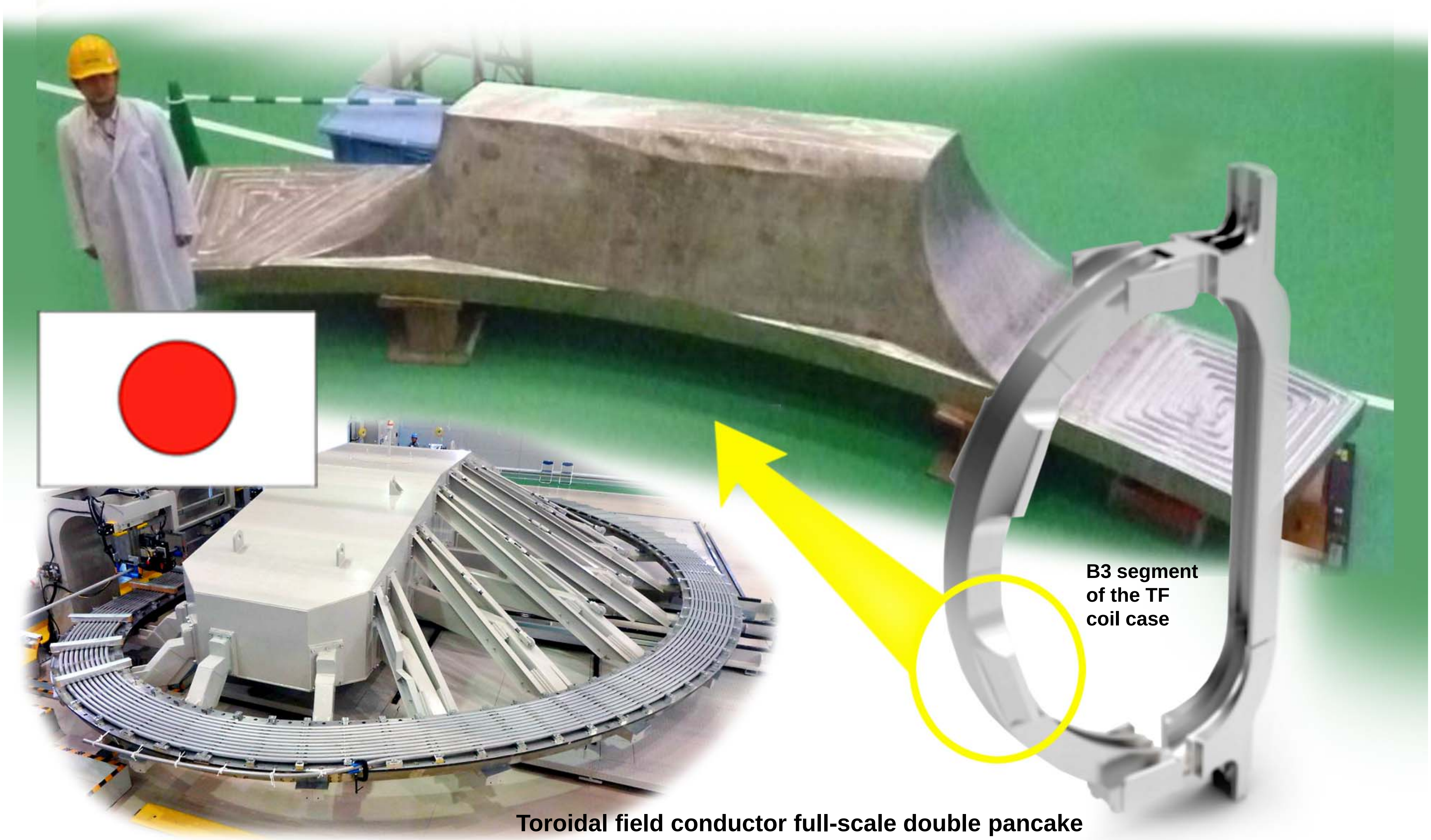
Sample toroidal field conductor has been produced by the six responsible Domestic Agencies.

FY 2014 Partner Achievements



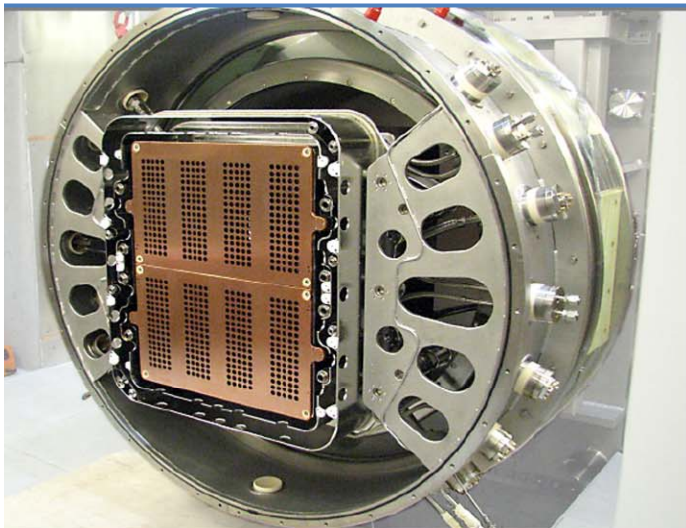
Toroidal field conductor full-scale pancake

FY 2014 Partner Achievements



Toroidal field conductor full-scale double pancake

FY 2014 Partner Achievements



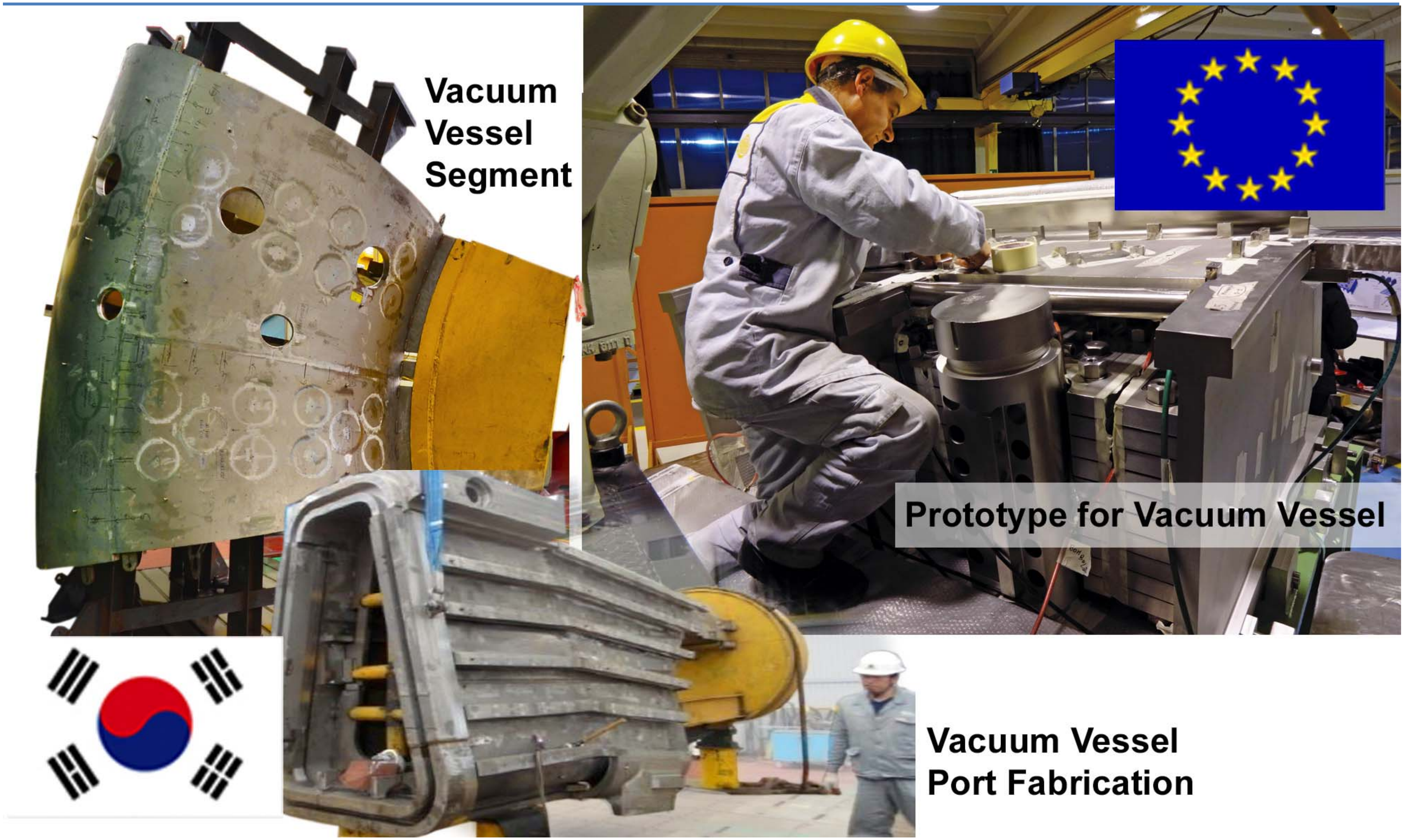
ELISE ion source at IPP,
Garching, Germany

Neutral beam injector test facility

Neutral beam injector test facility in Padova, Italy

Extraction grid power supply
in San Giorgio di Piano, Italy

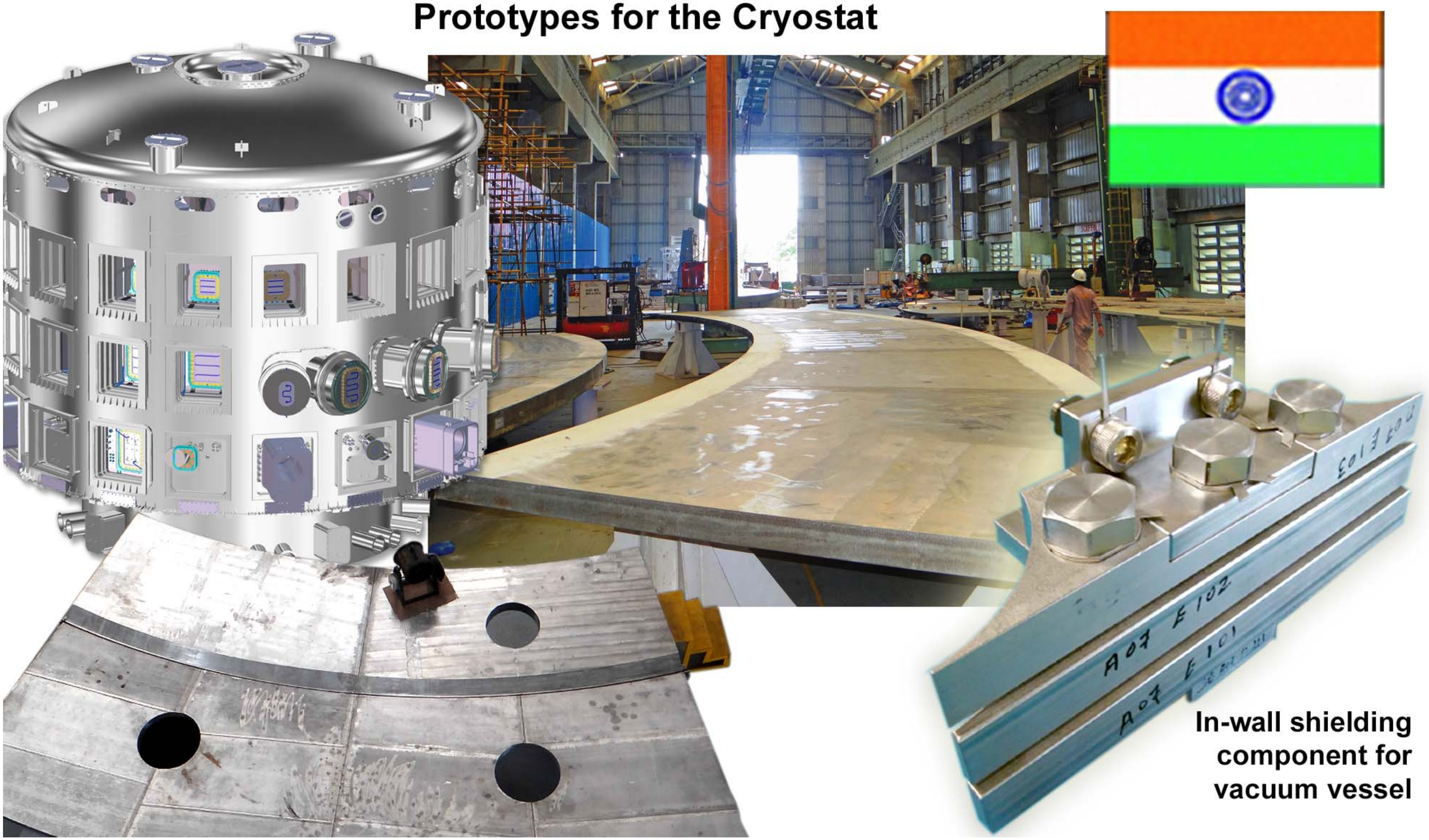
FY 2014 Partner Achievements



FY 2014 Partner Achievements

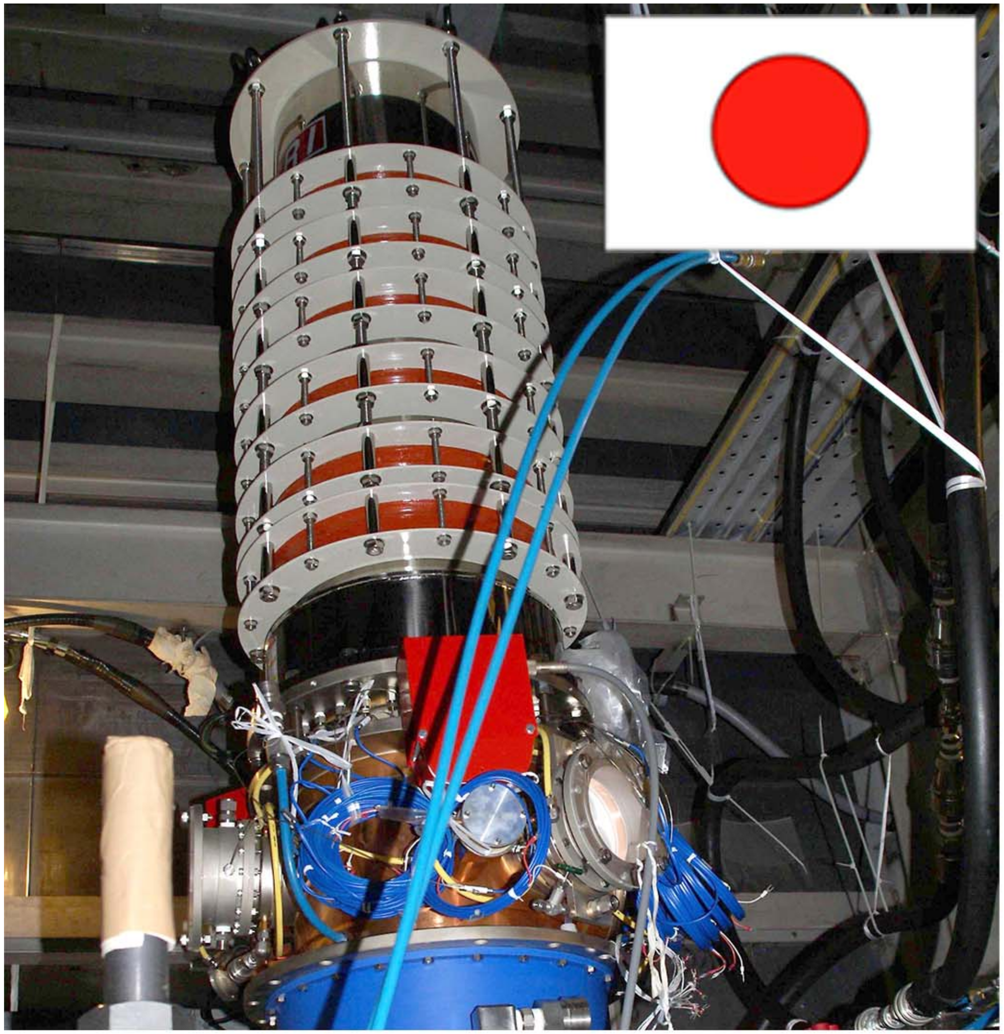
FY 2014 Partner Achievements

Prototypes for the Cryostat



In-wall shielding component for vacuum vessel

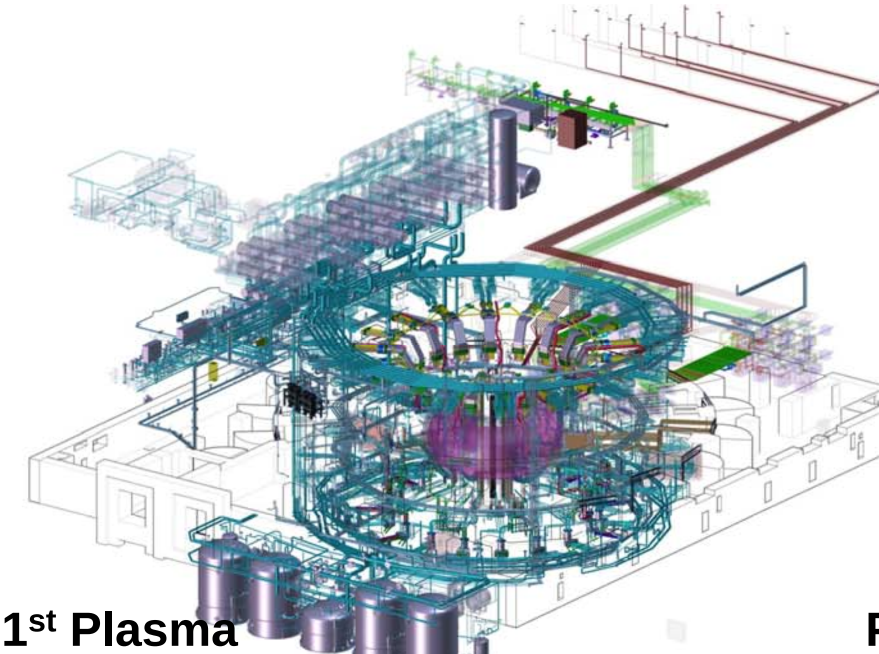
FY 2014 Partner Achievements



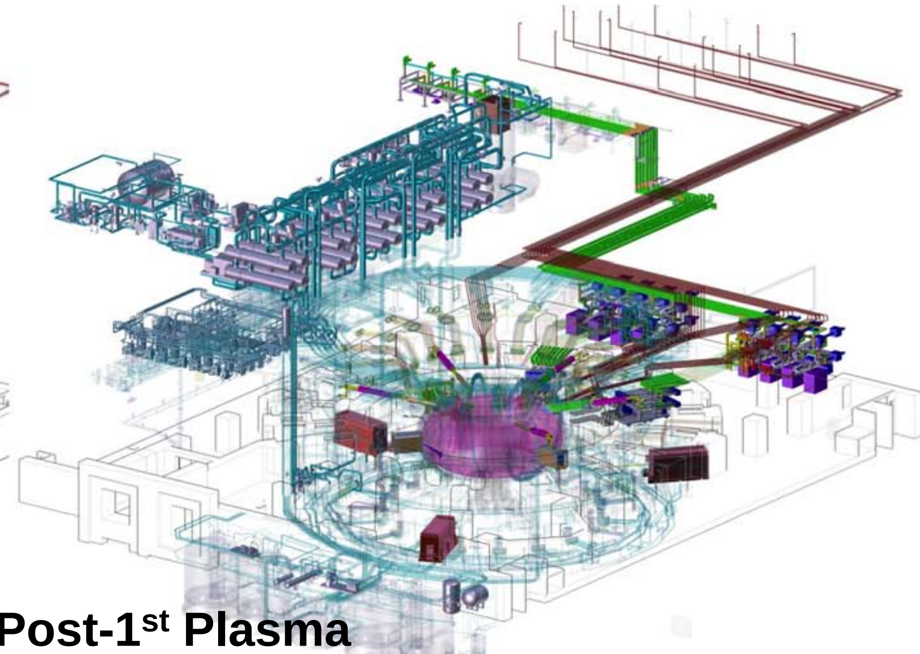
1MW gyrotrons for plasma heating & current drive and mode suppression

US FY14 Status and Achievements

Scope Delivered in 2 Phases
All Designs Completed Before 1st Plasma



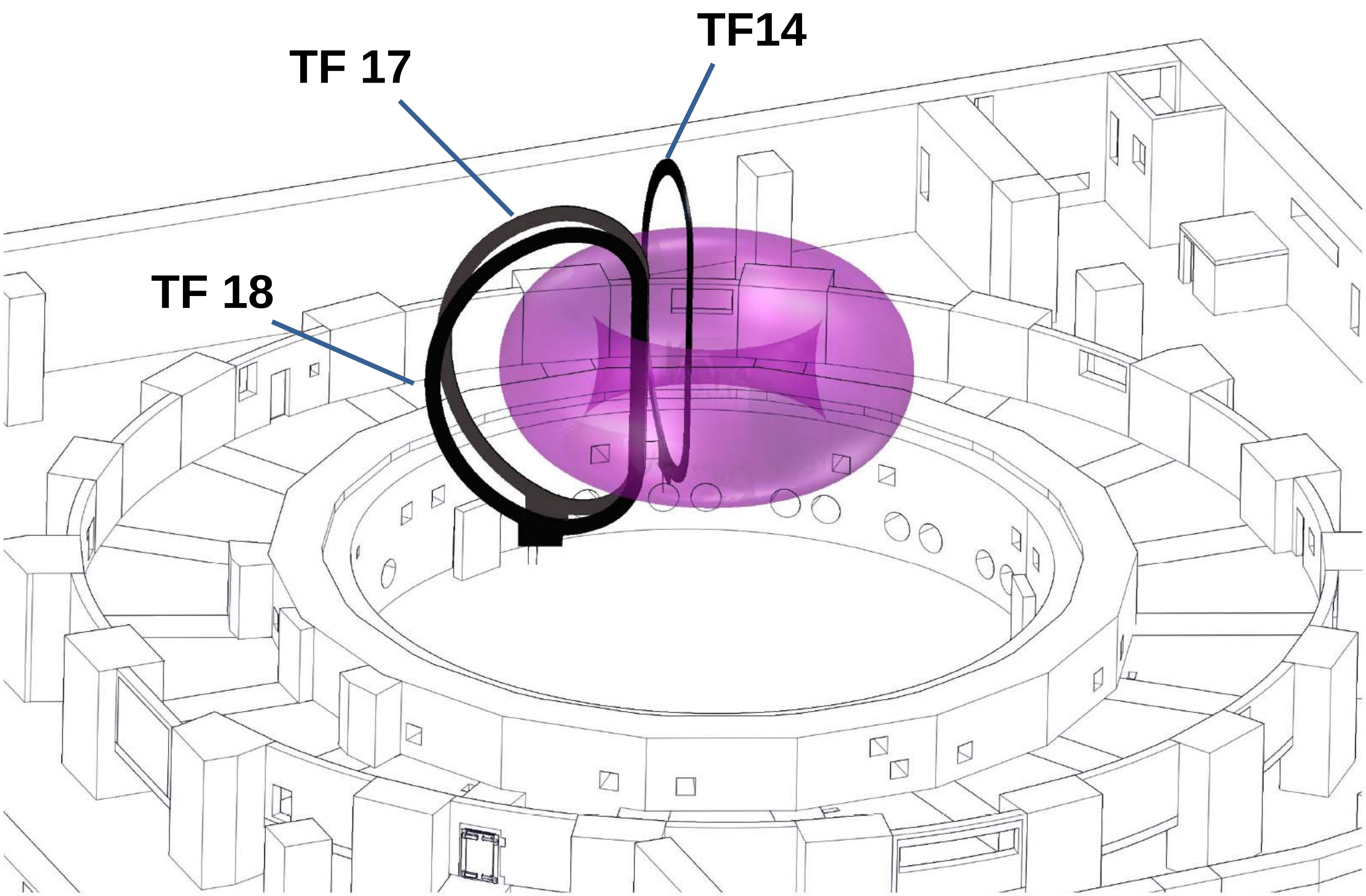
1st Plasma



Post-1st Plasma

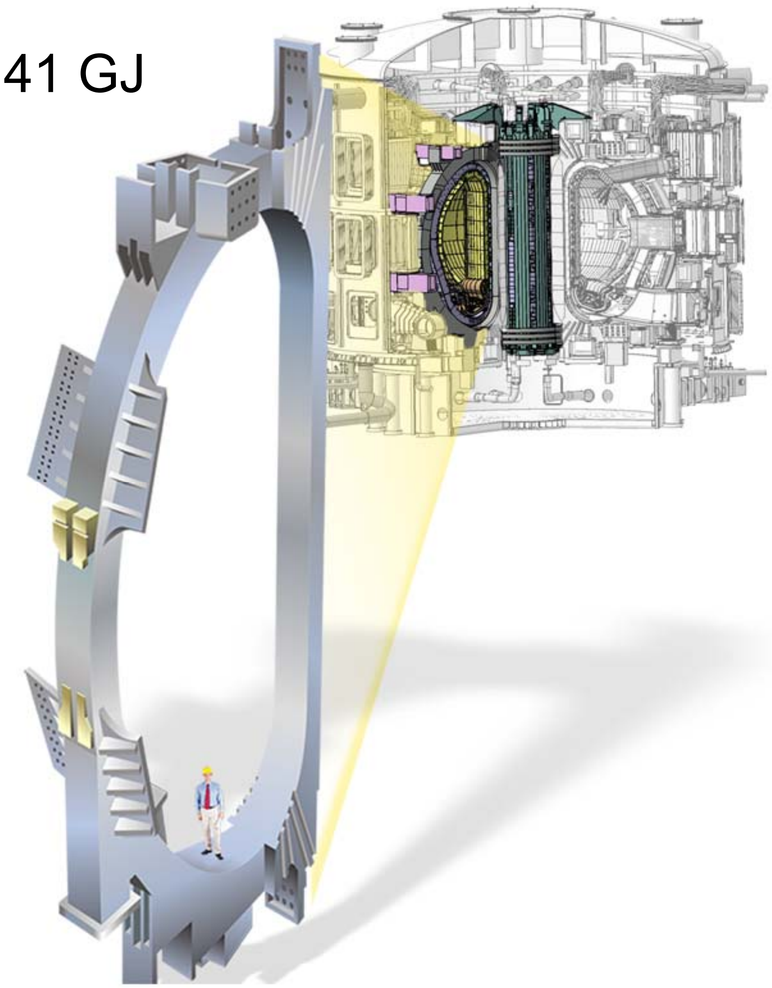
Delivered	Partial Production	Completion of Production	Full Production
• Central Solenoid • Toroidal field conductor • Steady-state electrical network	• Ion/electron cyclotron heating • Diagnostics • Roughing pumps • Pellet injection • Tokamak cooling water system • Vacuum auxiliary system	• Ion/electron cyclotron heating • Diagnostics • Roughing pumps • Pellet injection • Tokamak cooling water system • Vacuum auxiliary system	• Tokamak exhaust processing • Disruption mitigation

Toroidal Field Coil Conductor



Toroidal Field Coil

- Total Magnetic Energy of all TF Coils: 41 GJ
- Maximum Magnetic Field: 11.8 T
- Number of Coils: 18
- Total TF Coil Weight: 6540 t
- TF Coil Height: 16.5 m
- TF Coil Width: 9 m
- Operating Temperature: 5.7 K
- Current in 1 TF Coil: 9.11 MA
- Number of turns in 1 TF coil: 134



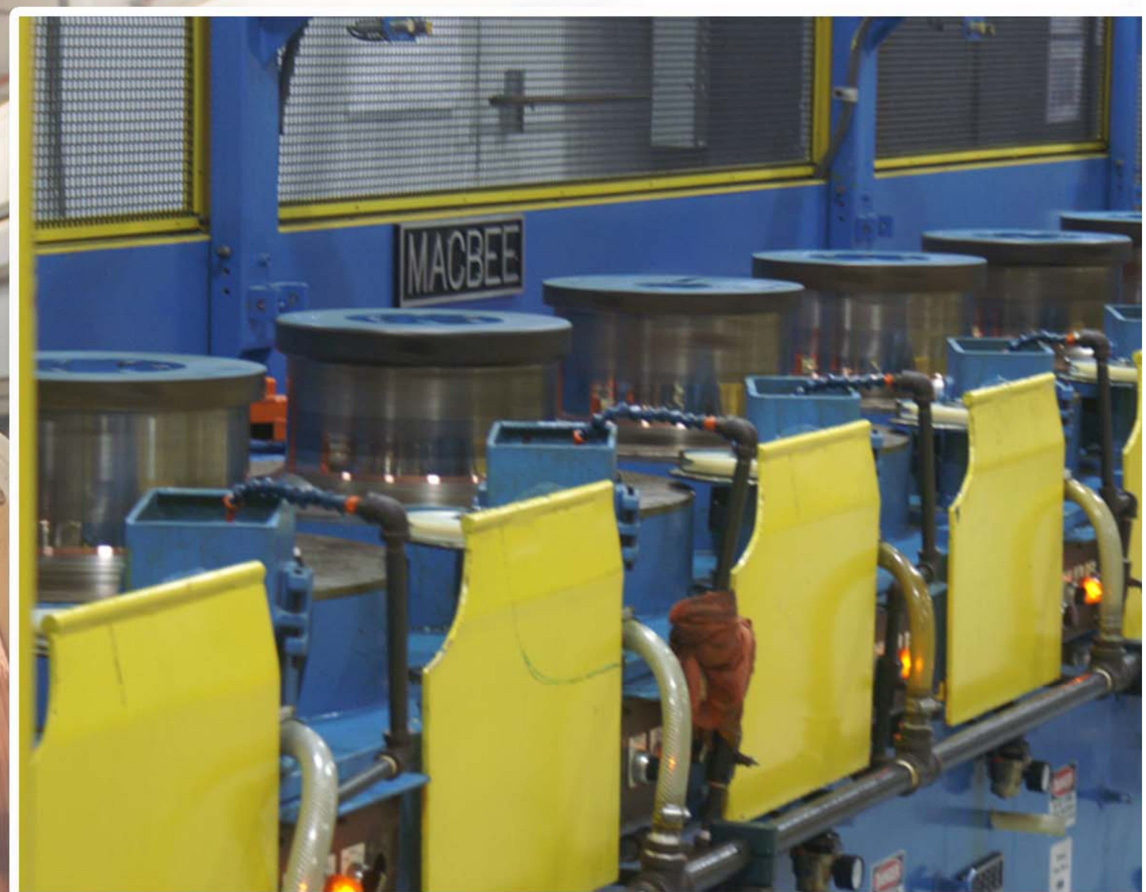
Toroidal Field Conductor
FY 14 Status

- US responsible for providing nine 800 m TF conductor unit lengths (8% of the total)
- Fabrication contracts
  - All of the superconducting strand (from OST and Luvata), jacket sections (e-Energy), and spiral core tubing have been provided
  - Remaining fabrication work is at NEWT for cabling the superconducting strand and HPM for integration (jacket assembly; cable insertion, compaction, and spooling; and testing)

800 m Dummy Spool shown in turn-over frame at HPM

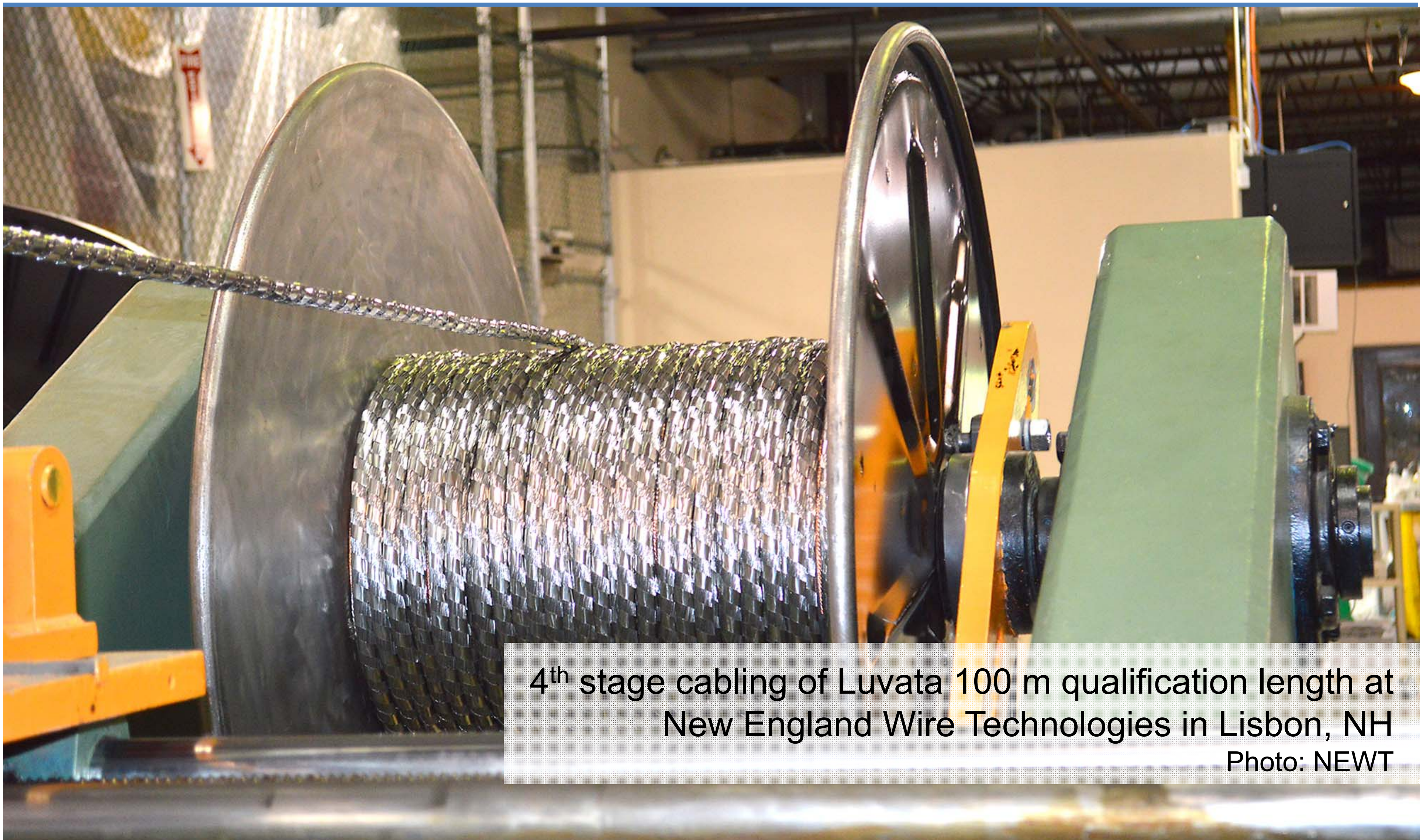
FY 2013 US Achievement:
Completion of Toroidal Field Strand

Production conductor strand at Luvata Waterbury Inc. in Newark, NJ



Production conductor strand at Oxford Superconducting Technology in Carteret, NJ

FY 2014 US Achievement:
Toroidal Field Cabling



4^{th} stage cabling of Luvata 100 m qualification length at New England Wire Technologies in Lisbon, NH
Photo: NEWT

FY 2014 US Achievement:

Toroidal Field Conductor Jacketing

High Performance Magnetics jacketing and integration facility in Tallahassee, Florida
Photo: US ITER

FY 2014 US Achievement:
Deliveries to EU Coil Winding Facility

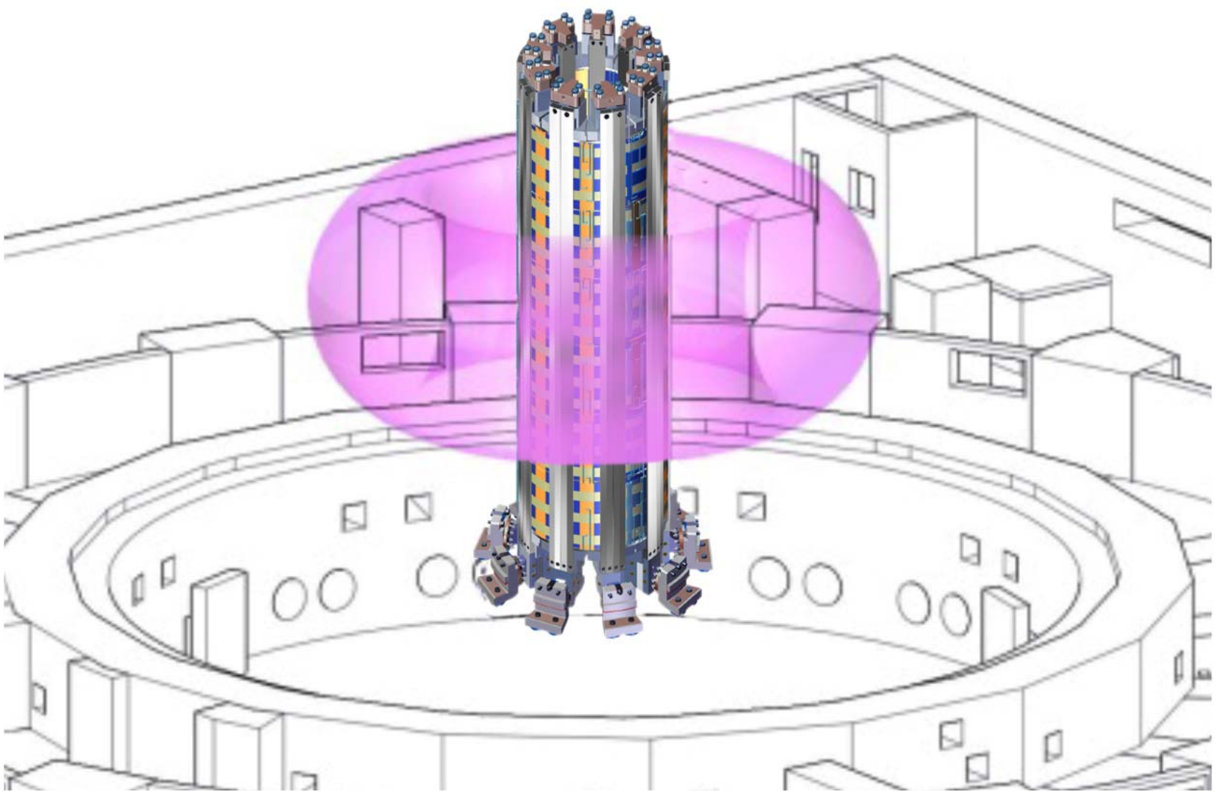
US TF 800 m Dummy Conductor and 100 m production conductor delivered to EU winding facility

US contribution includes over 4 miles of conductor, which is constructed from 40 tons (over 4000 miles) of niobium-tin superconducting strand

Truck arriving at ASG in Italy with US TF 800 m dummy conductor

US TF 800 m Dummy Conductor - Delivery at ASG in Italy

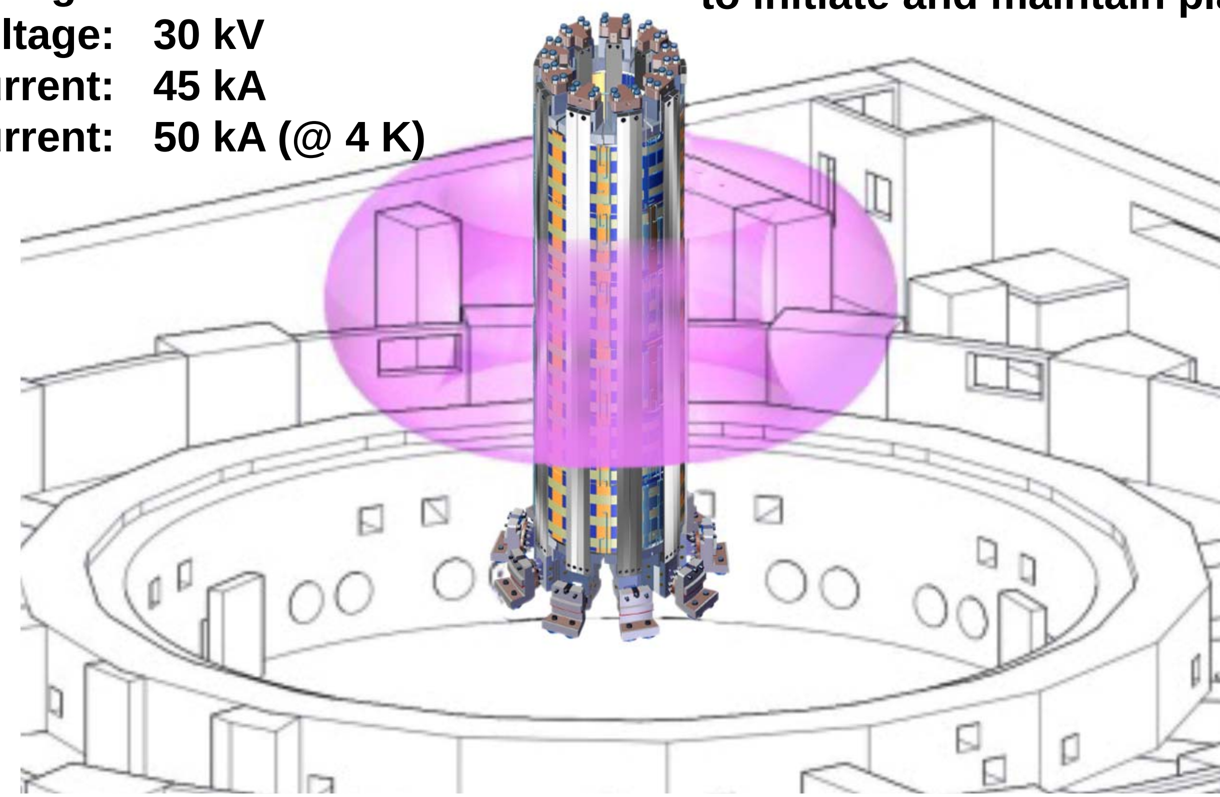
Central Solenoid



Central Solenoid

Coil Packs:	6 + 1 spare
Field Strength:	13 T
Operating Voltage:	14 kV
Test Voltage:	30 kV
Operating Current:	45 kA
Test Current:	50 kA (@ 4 K)

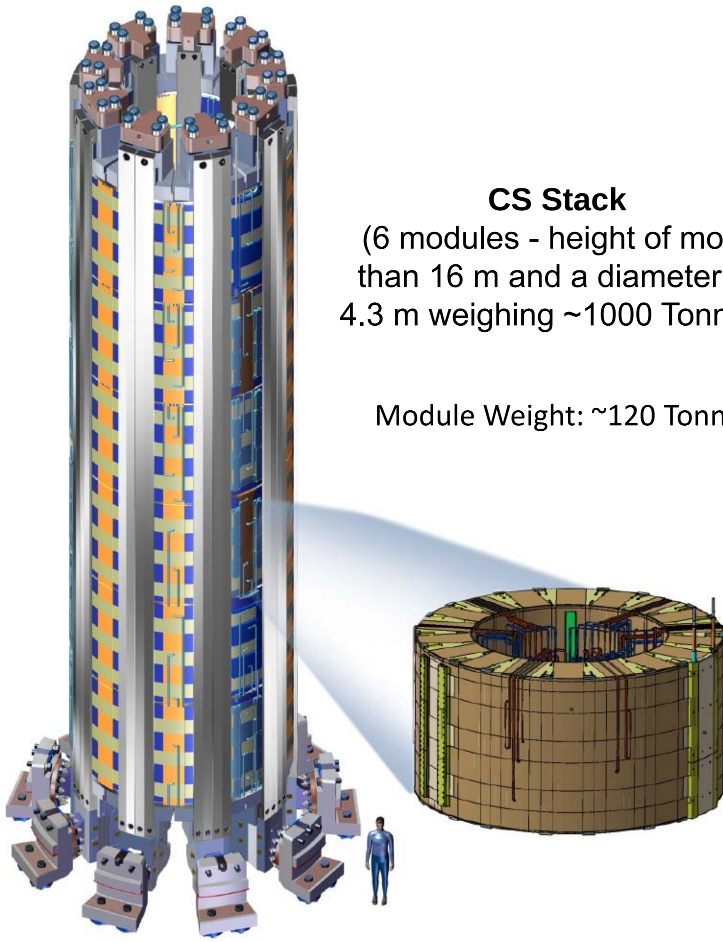
1,000 metric ton magnet induces the majority of magnetic flux charge needed to initiate and maintain plasma current



The most powerful pulsed superconducting electromagnet in history (5.5 Gigajoule stored energy capacity)

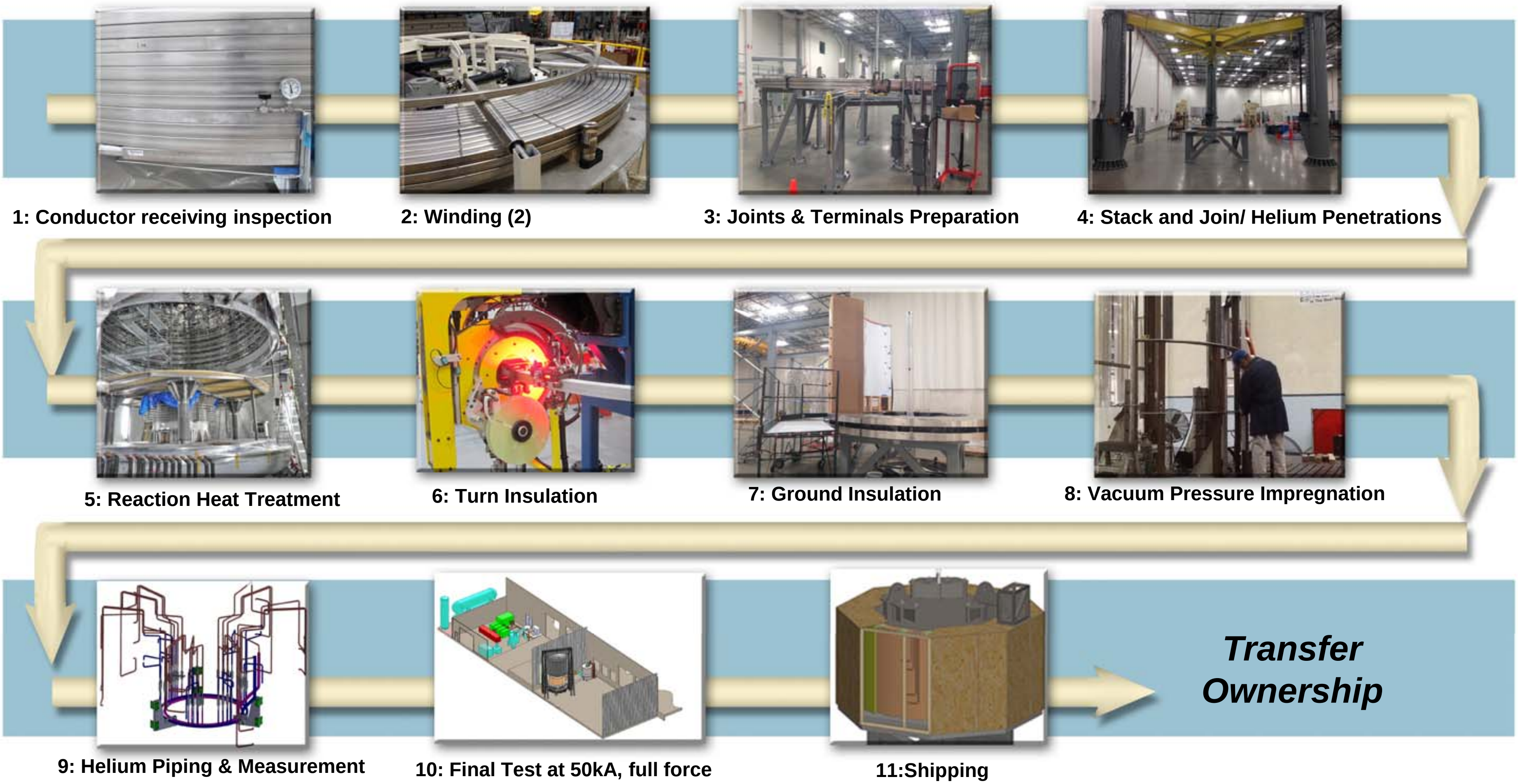
Central Solenoid (CS)
FY 14 Status

- Successful FDR in Nov 2013
- Completed design modifications based on FDR feedback
- Final 3D model submitted to IO
- Final design documentation (specifications, drawings, and analysis reports) being submitted for IO approval
- Completed Manufacturing Readiness Review (MRR) for winding station
- Began winding mock-up coil



FY 2014 US Achievement:

Module Tooling Stations are Being Installed at General Atomics



FY 2014 US Achievement:
1st Winding Station Installed

MRR Conducted in July 2014


De-spooler


Tractor drive and straighteners


Grit blast and cleaning


Forming head


300m double pancake coil on winding table with cleaning, grit blast and de-spooler stations behind

FY 2014 US Achievement:
Japanese Conductor Ready for Winding

Dummy conductor shown loaded on winding machine – in prep for mock-up winding

4 central solenoid active conductor spools and 1 dummy at General Atomics

FY 2014 Achievements

Mock-up Winding Has Begun

Conductor routed from de-spooler

Conductor routed through straightener

FY 2014 Achievements

Reaction Heat Treatment Furnace Installed

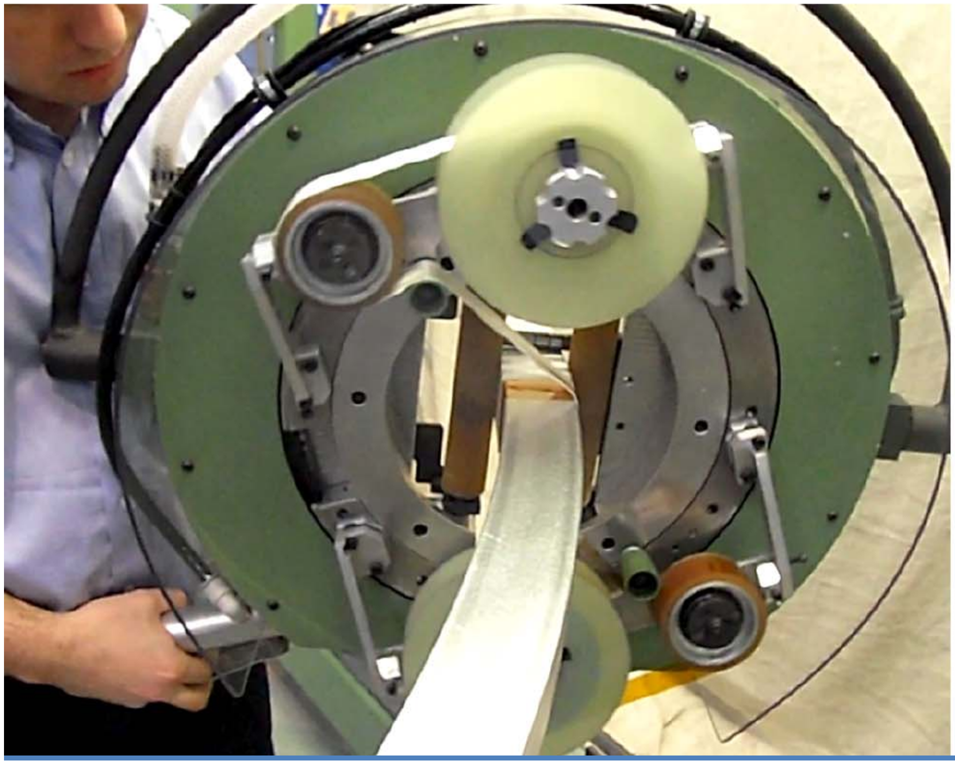
Specifications for heat treatment furnace:

- Height – 7 m
- Diameter – 5.56 m
- Weight – 132 Tonnes (including Module)
- Power 800 kW
- Medium – Argon
- Pressure – 1 x 10^{-2} mbar

Heat treatment furnace and associated equipment being installed at General Atomics.

FY 2014 Achievements
Turn Insulation Station Being Installed

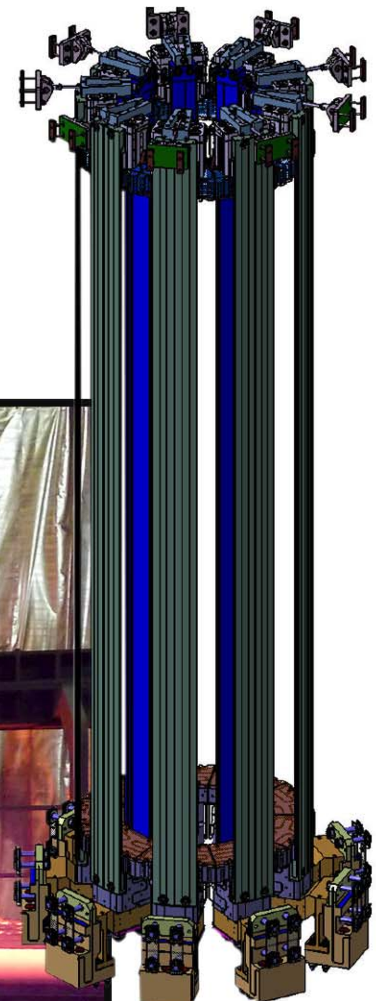
- Factory acceptance testing completed at vendors
- Units will be re-assembled and commissioned using mock hexapancake



Automated taping heads from Ridgeway have been delivered to GA.

Central Solenoid Structures
FY 14 Status

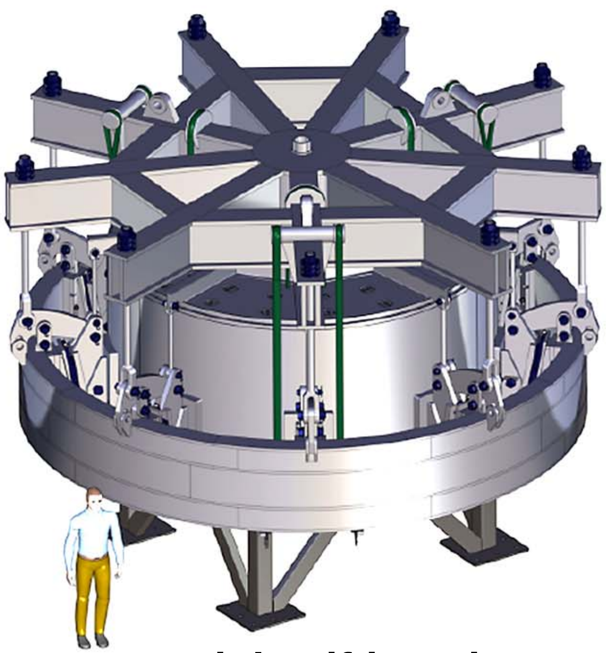
- Successful FDR in Nov 2013
- Placed first production contract with Peterson (Ogden, UT) for lower key blocks and isolation plates
- Issued RFP for tie-plate procurement

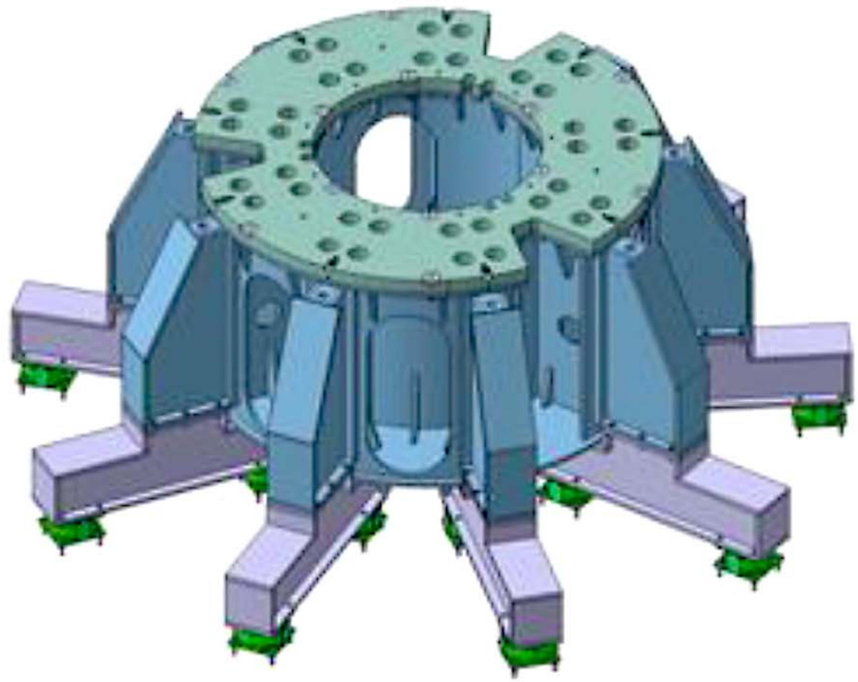
One piece tie-plate prototype forged at Kind LLC (Gummersbach, Germany)

Central Solenoid Assembly Tooling
FY 14 Status

- Completing the final design for the early need fixtures (assembly platform, module rotating fixture, and module lifting fixture)
- FDR for early need fixtures in September 2014

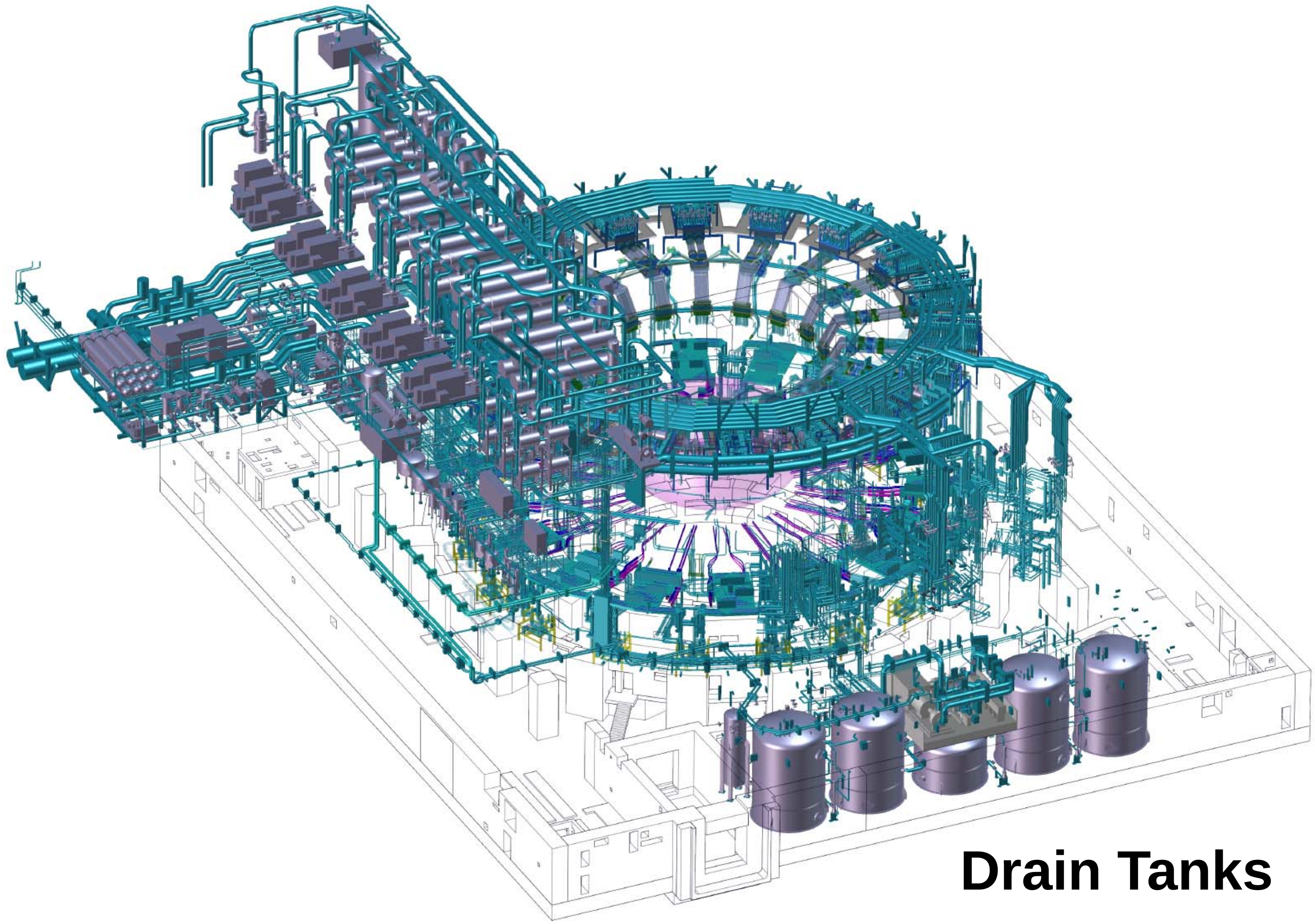


Module Lifting Fixture



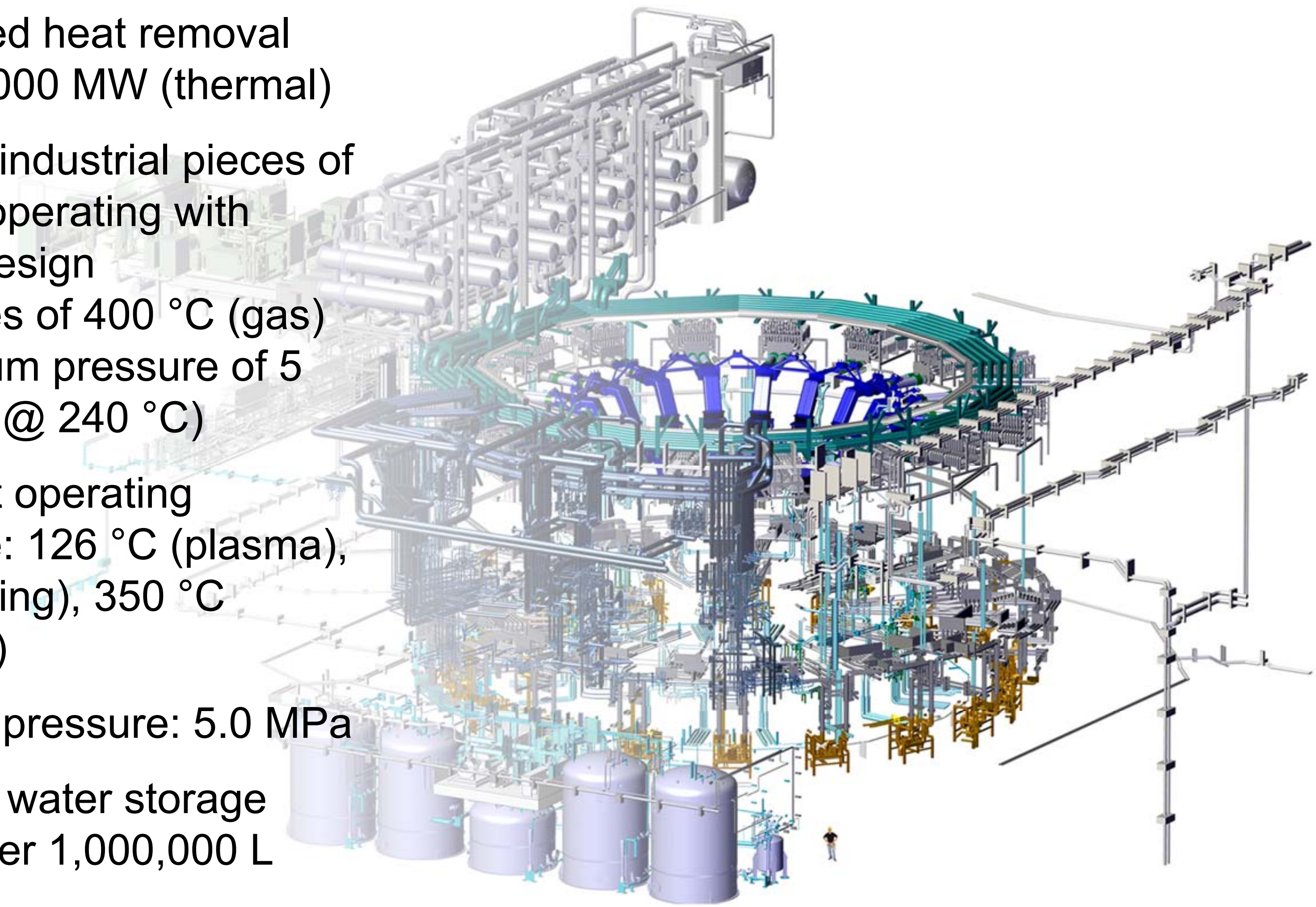
Assembly Platform

Tokamak Cooling Water System



Tokamak Cooling Water System

- Total installed heat removal capacity: 1,000 MW (thermal)
- 100+ major industrial pieces of equipment operating with maximum design temperatures of 400 °C (gas) and maximum pressure of 5 MPa (water @ 240 °C)
- Max coolant operating temperature: 126 °C (plasma), 240 °C (baking), 350 °C (gas baking)
- Max design pressure: 5.0 MPa
- Radioactive water storage capacity: over 1,000,000 L

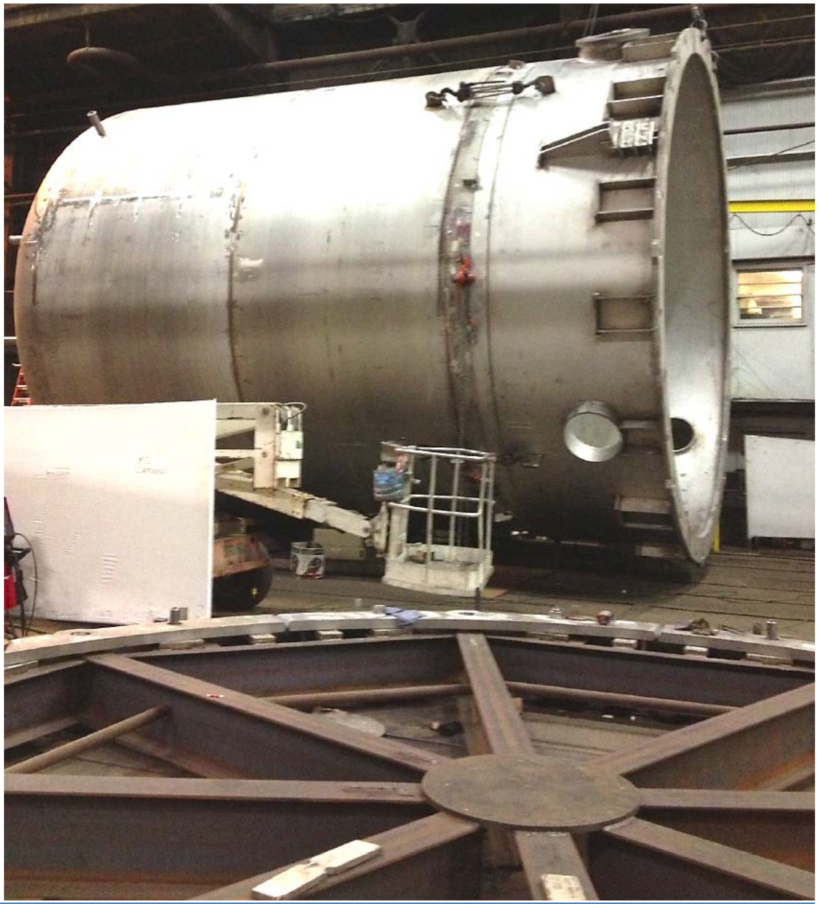


Tokamak Cooling Water System (TCWS)
FY 14 Status

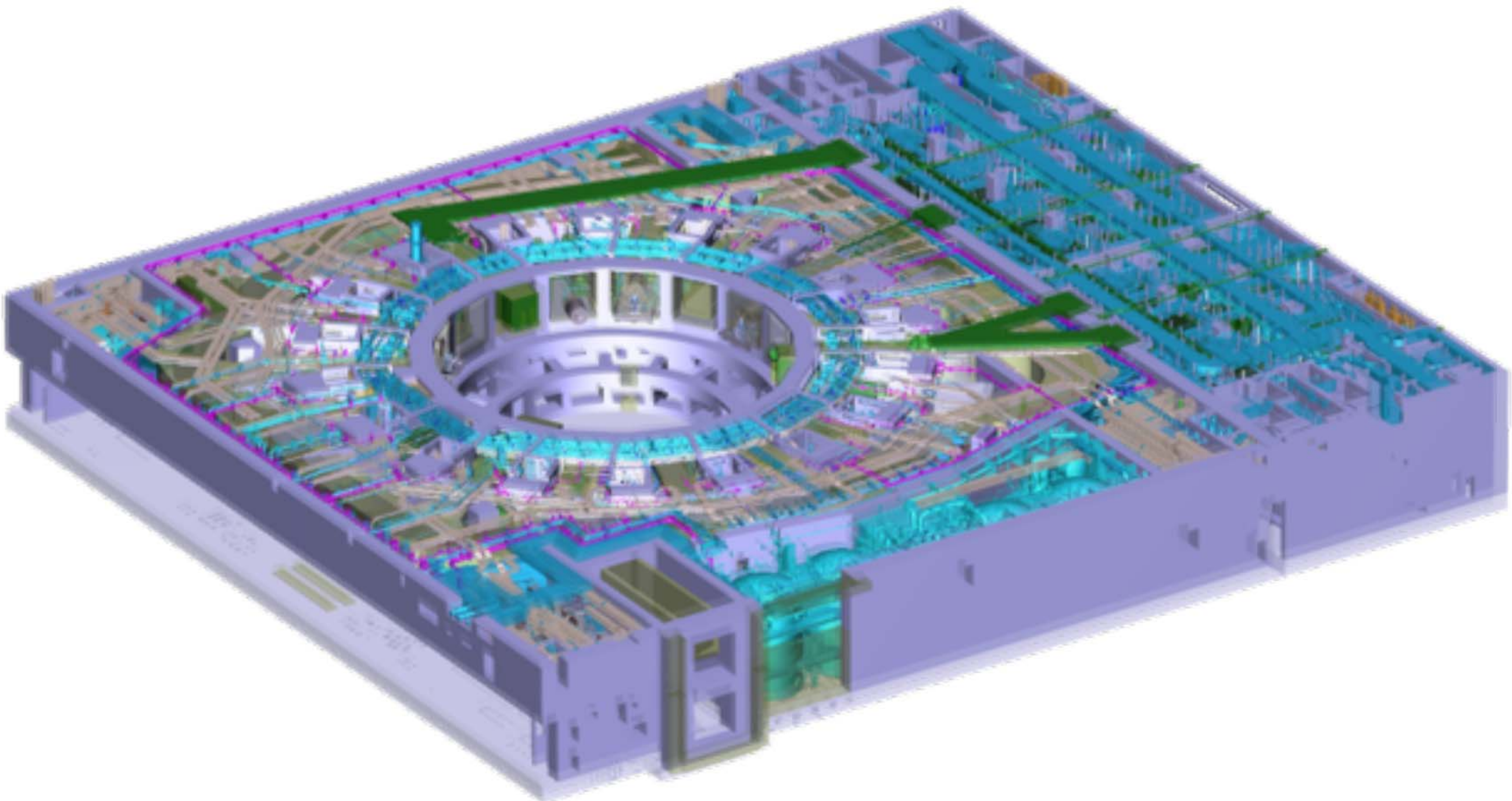
Configuration:
36 km (22 mi) of piping, ~230 pieces of equipment, safety important for the confinement of radioactivity

Status:
In fabrication: Drain tanks
In final design: Integrated system and equipment

Recent Achievements:
- Drain tank fabrication progressing and scheduled for completion in 2014
- First tank fabrication completes this month
- Shipment to the site in early 2015
- Arrangements between US ITER and the ITER Organization to complete the final TCWS design, and procure and pre-fabricate piping on behalf of US ITER

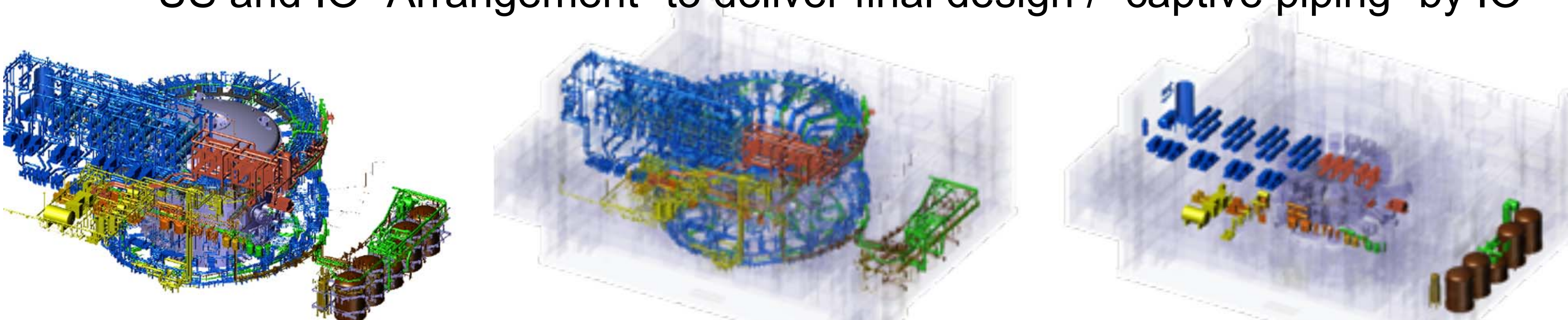


Drain Tanks in the Tokamak Building



TCWS Arrangement with IO for "Captive Piping"

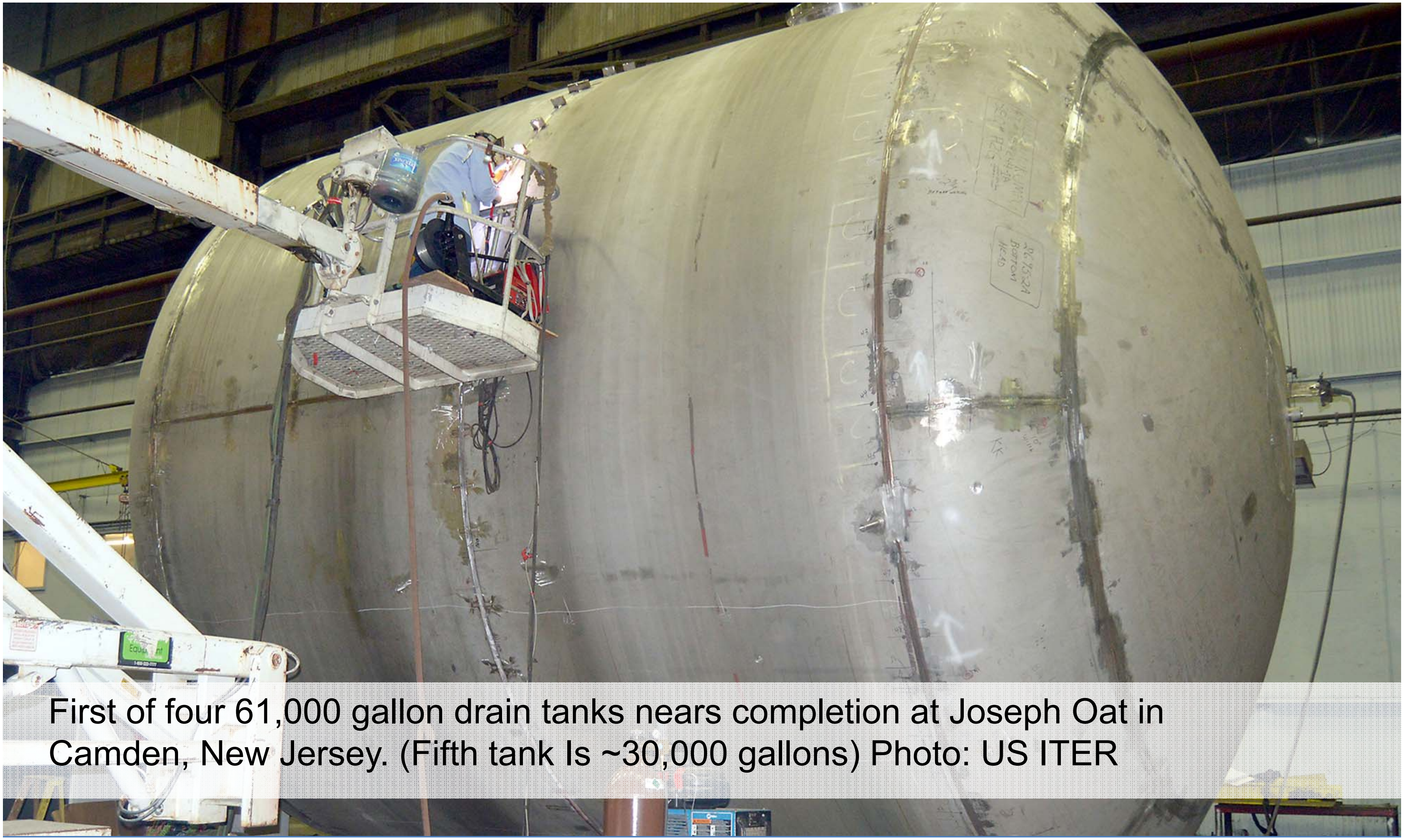
- US scope defined in PA
  - Piping and equipment design, configuration management, fabrication, and delivery
- "Captive piping" and 1st Plasma design effort is priority
- Ongoing "design optimization" efforts (heat exchanger example)
- US and IO "Arrangement" to deliver final design / "captive piping" by IO



Full System	+	**Design & Piping**	=	**Equipment**
Managed by USDA		Multiple (16) Contracts Managed by ITER IO Review by USDA		Fabrication Contract(s) Of 100+ major pieces managed by USDA

FY 2014 Achievements

Tokamak Cooling Water System



First of four 61,000 gallon drain tanks nears completion at Joseph Oat in Camden, New Jersey. (Fifth tank Is ~30,000 gallons) Photo: US ITER

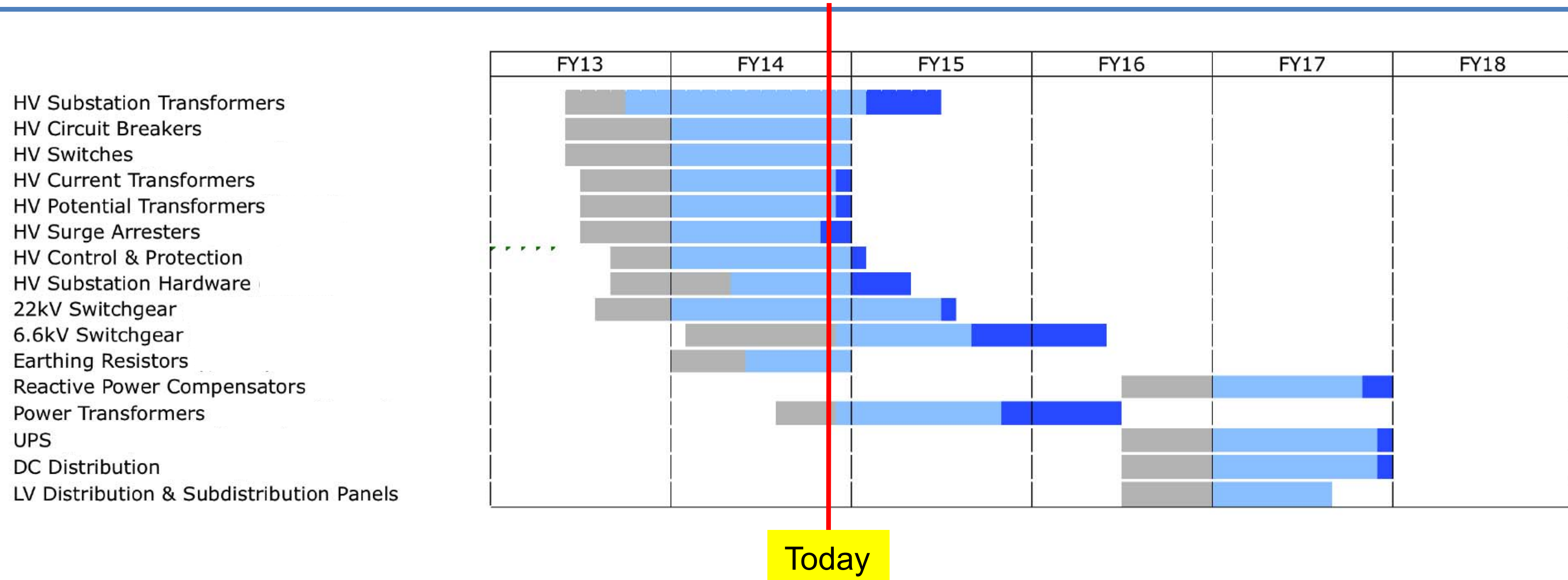
Steady State Electrical Network

4 power feeds:

- 2 at 6.6 kV distribution
- 2 at 22 kV distribution

Standards: International Electrotechnical Commission standards for 50Hz operation

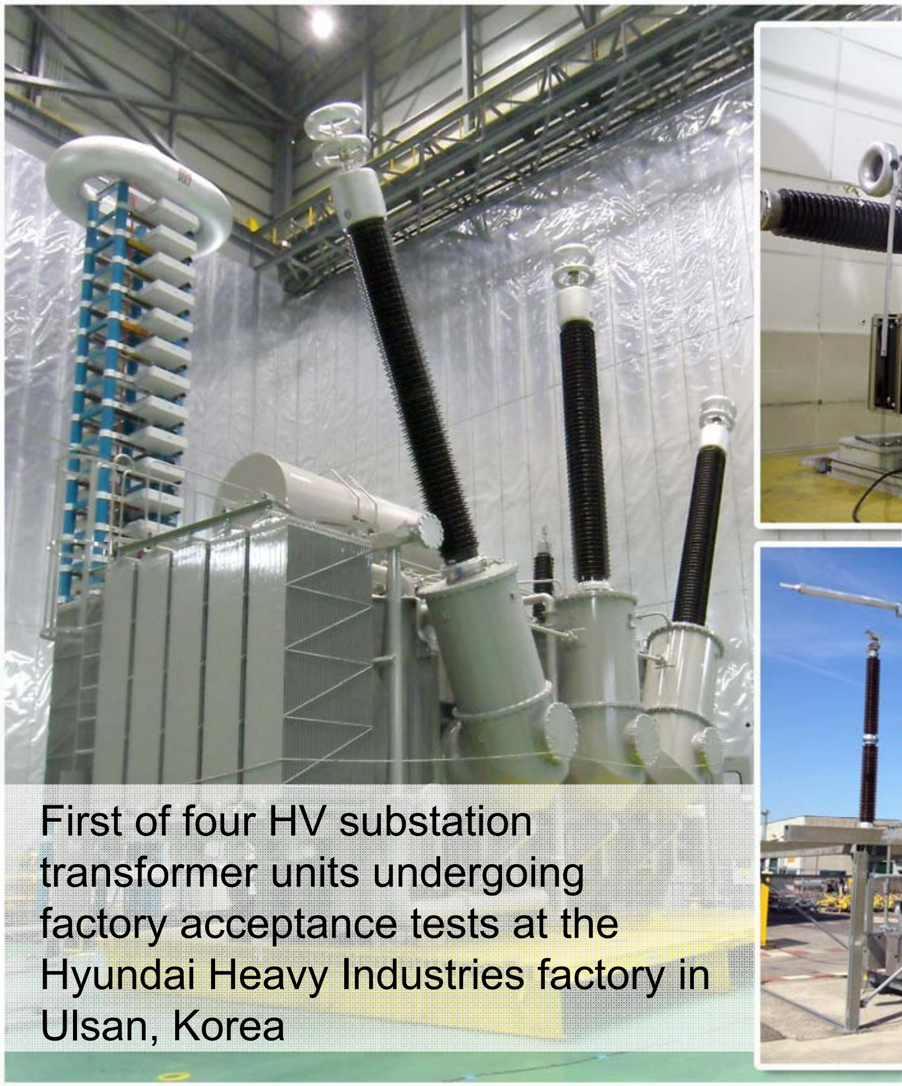
Steady State Electrical Network (SSEN)
FY 14 Status



- 11 of 16 procurement have been awarded
- Deliveries have started; 400kV HV Substation delivery dates based substation construction starting 10/1/14 and energization on 10/1/15, others to support timeline of commissioning of ITER subsystems
- Remaining procurements timed to avoid contract awards in FY15
- All shipments will be completed by the end of FY17

FY 2014 US Achievements:

Steady State Electrical Network



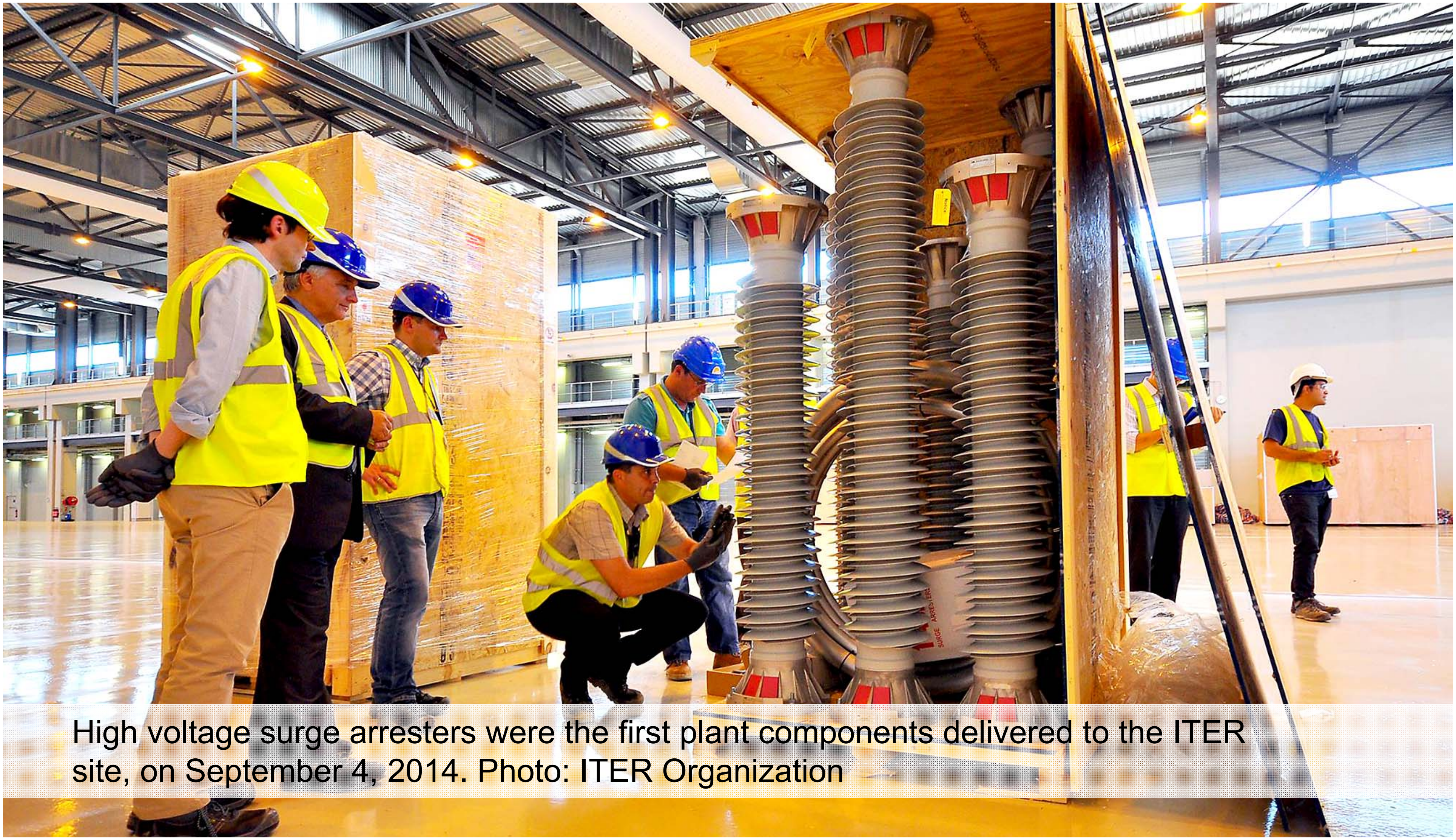
First of four HV substation transformer units undergoing factory acceptance tests at the Hyundai Heavy Industries factory in Ulsan, Korea

One of four sets of 400kV, 3-phase HV circuit breakers undergoing factory acceptance test at Alstom SAS, Villeurbane, France

One of four 400kV, 3-phase HV disconnect switches undergoing factory acceptance tests of the Alstom SpA factory in Noventa di Piave, Italy

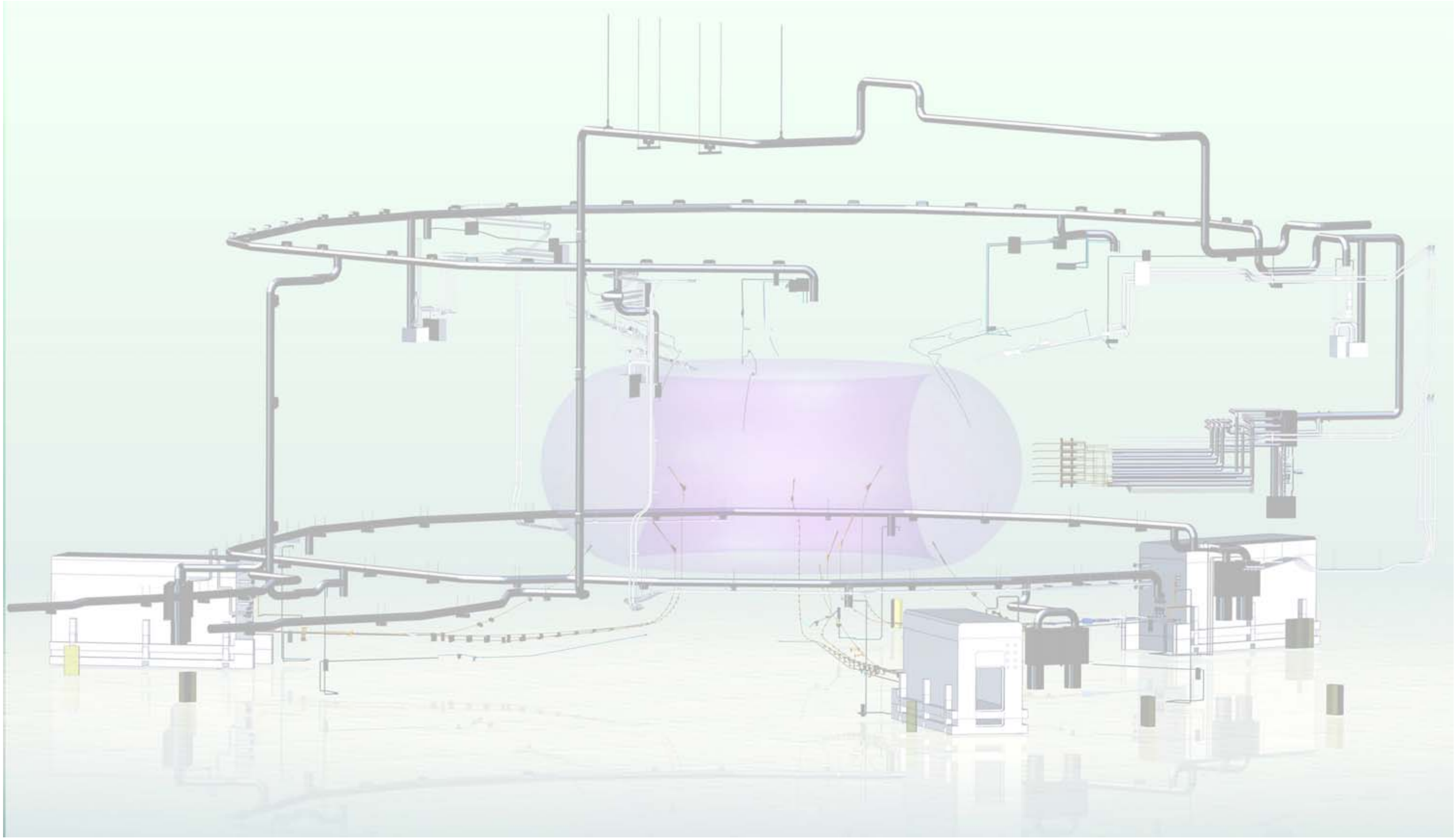
FY 2014 US Achievements:

Steady State Electrical Network

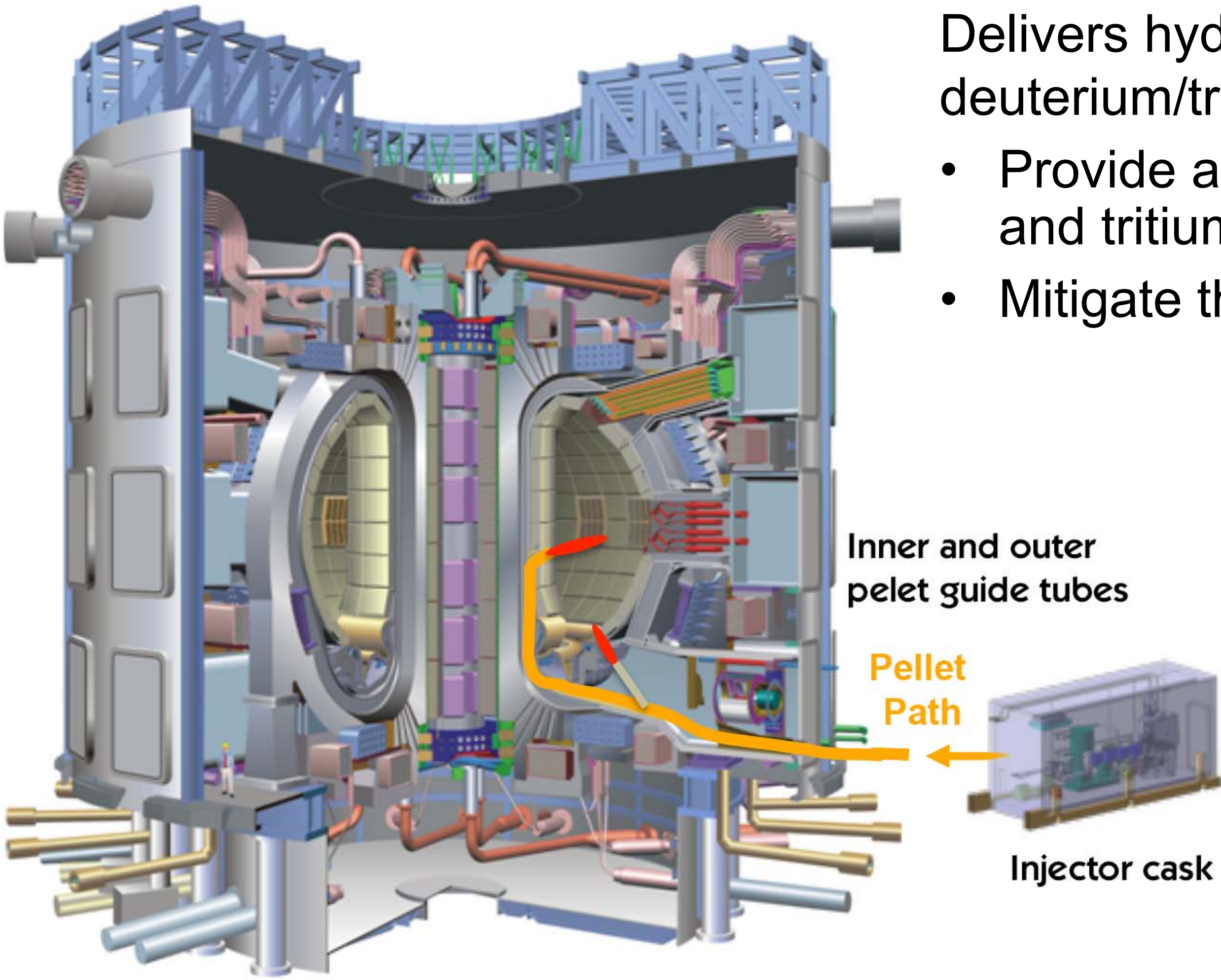


High voltage surge arresters were the first plant components delivered to the ITER site, on September 4, 2014. Photo: ITER Organization

Pellet Injection and Disruption Mitigation Systems



Pellet Fueling and Pellet Pacing



Delivers hydrogen, deuterium and deuterium/tritium pellets to:

- Provide a steady supply of deuterium and tritium fuel
- Mitigate the impact of ELMs

Configuration:

- Two pellet injection casks with dual injectors in each cask
- Guide tubes to inner and outer wall locations
- Guide tube selector to route pellets as needed

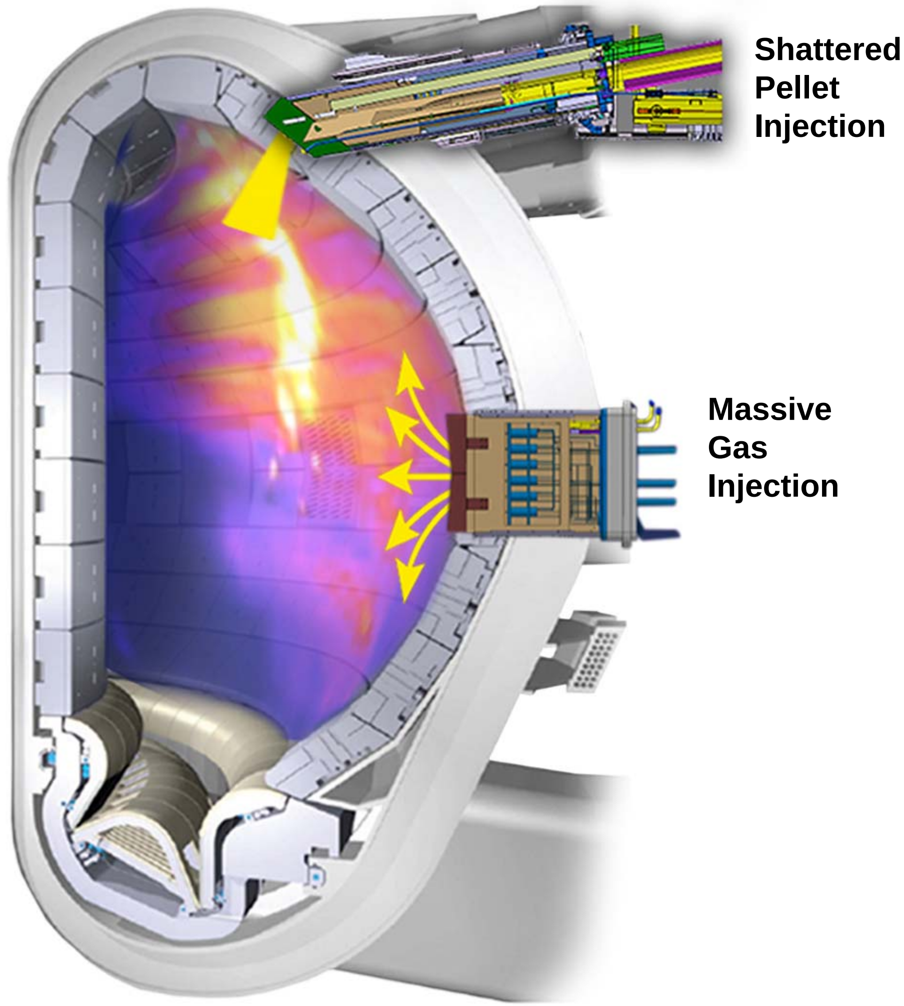
Disruption Mitigation System

Requirements:

- Rapid plasma thermal quench to mitigate localized heat loads (response time ~10 ms)
- Plasma current quench to mitigate mechanical loads (response time ~200 ms)
- Suppress or dissipate runaway electron current (response time ~500 ms)

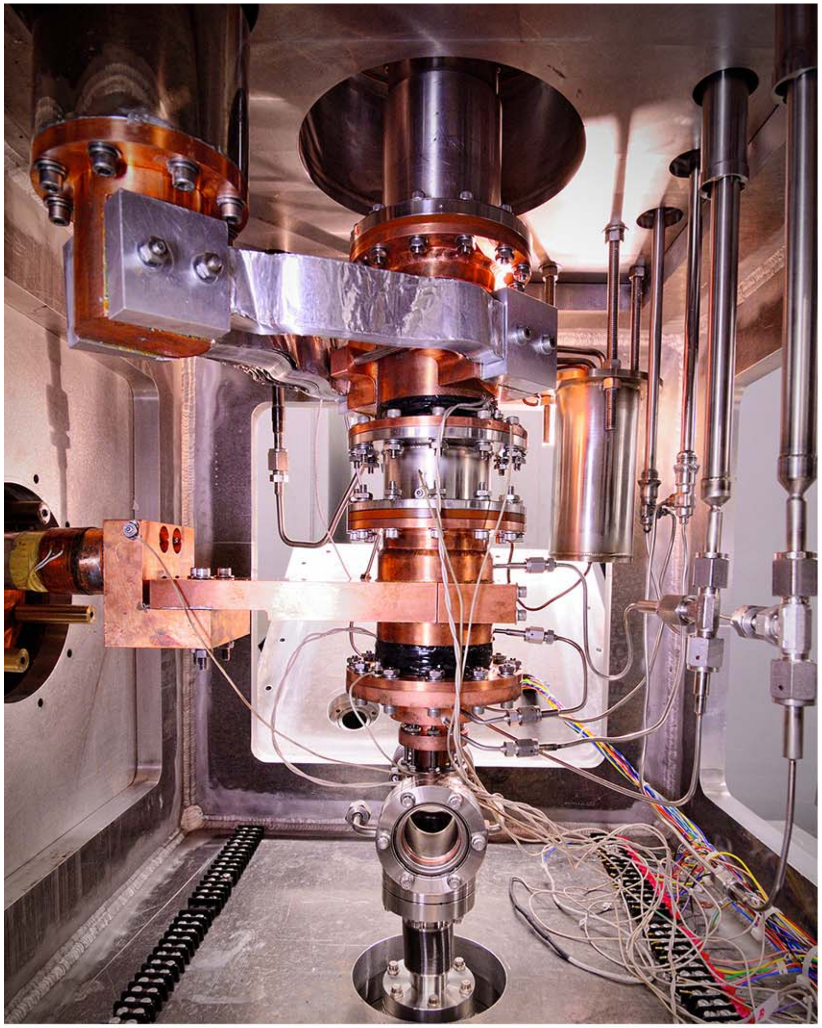
Configuration:

- Shattered pellet injector (SPI) located in upper port cell with pellet shattered near plasma edge
- SPI has multiple barrels for redundancy and injection adjustment
- Massive gas injection (MGI) valves located in equatorial port cell

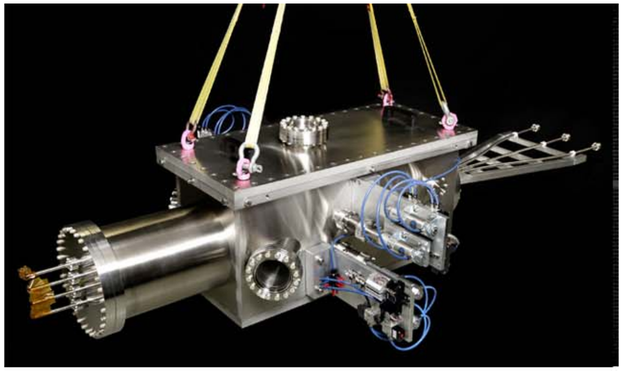


FY 2014 US Achievements

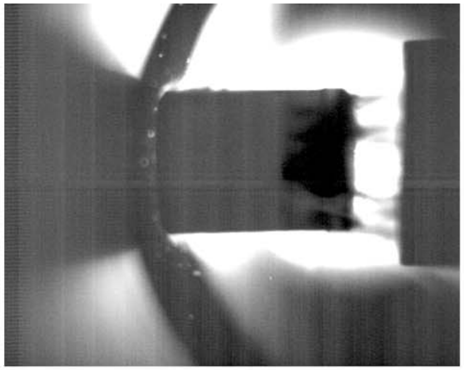
Pellet Injection and Disruption Mitigation



Twin-screw pellet extruder



Pellet guide tube selector test unit



Deuterium-neon pellet formation testing

3-barrel unit prototype for disruption mitigation

FY 2014 US Achievements

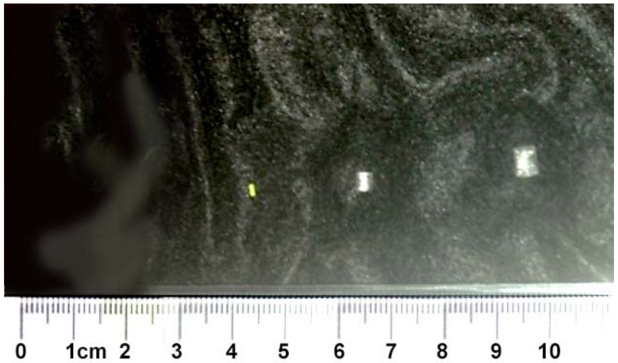
Pellet Fueling and Pellet Pacing

Status:

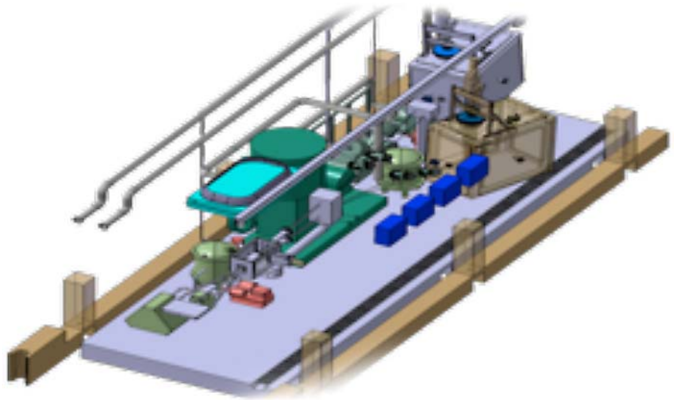
In design: Prototype extruder, pellet cutter and gas gun; fuel recirculation loop; propellant recirculation loop; guide tube selector

Recent Achievements:

- Fabrication of test articles for extruder
- Fabrication and acceptance test of guide tube selector
- Long-term reliability tests of tritium compatible piston pump for recirculation loop
- Demonstration, on DIII-D, of pellet ELM pacing at 12 X natural rate and associated 12 X reduction in ELM intensity



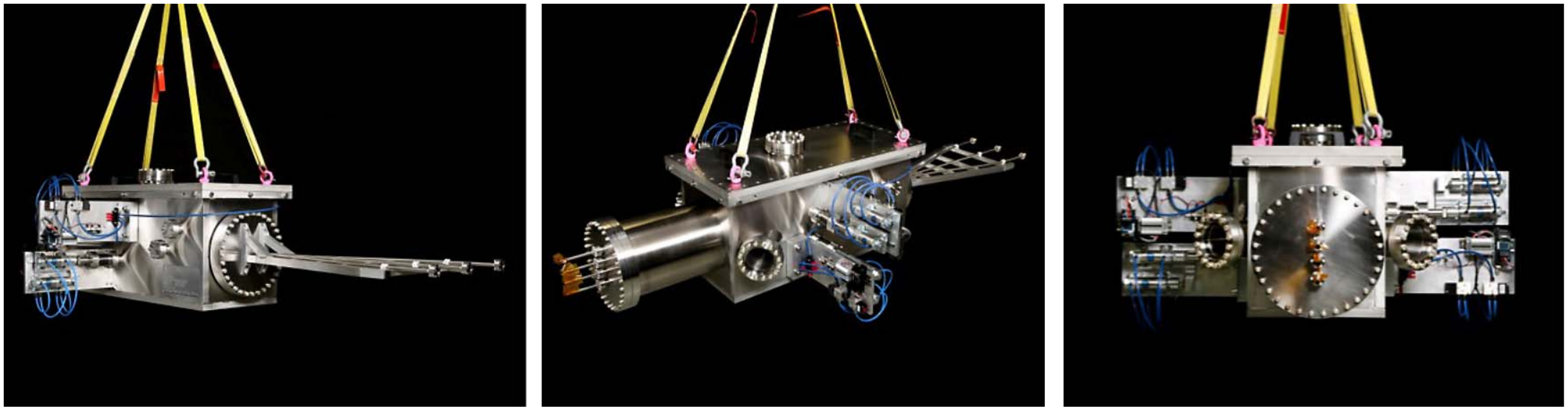
Small pellets fro ELM pacing and larger pellets for D/T fueling



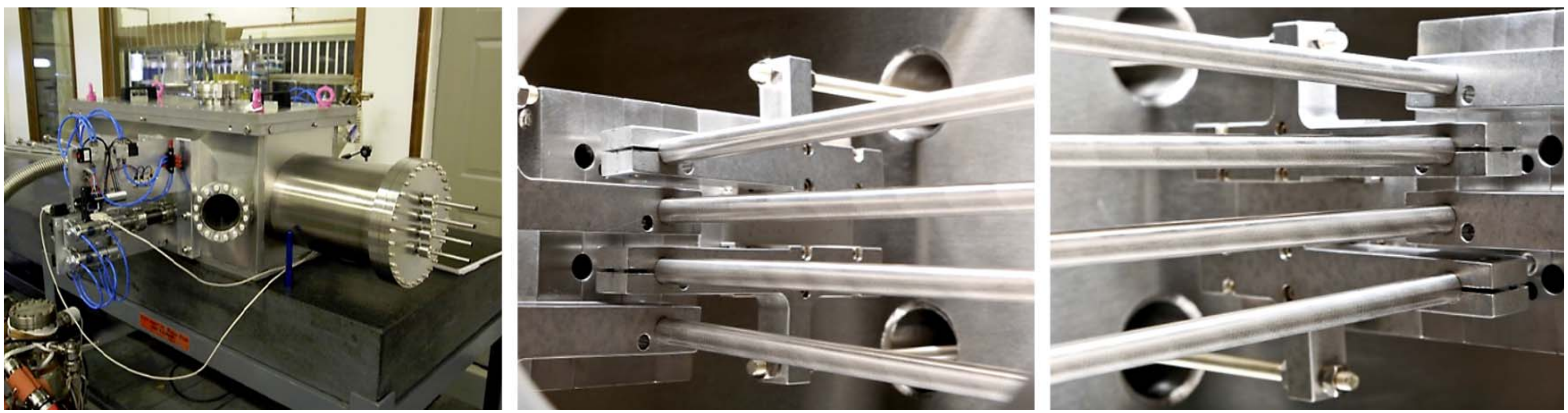
Equipment located in cask for frozen pellet formation, acceleration and recycling of deuterium and tritium gasses.

FY 2014 US Achievements

Fabrication and Acceptance Test of Guide Tube Selector



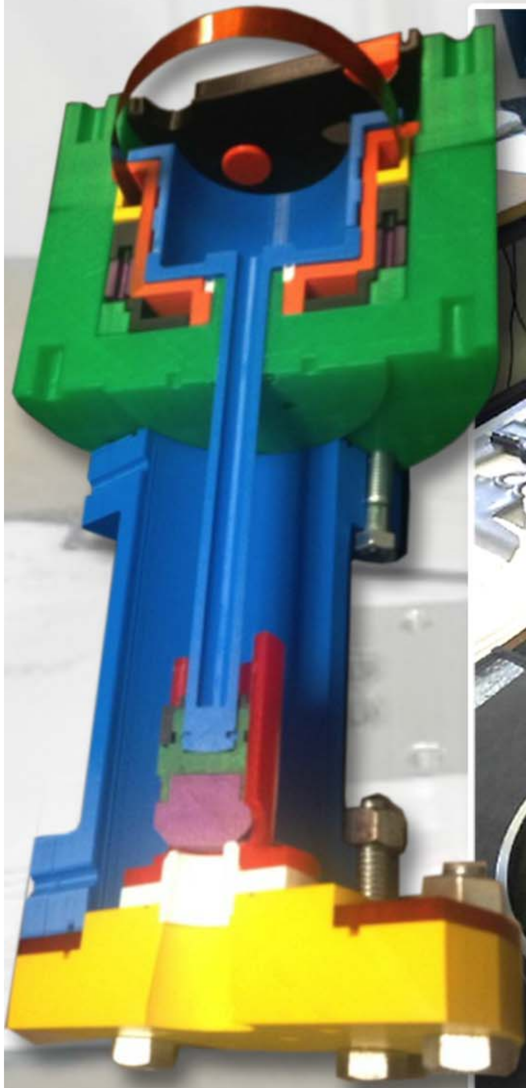
Pellet guide tube selector with internal views of actuators for routing pellets for multiple inputs to multiple outputs



Operation demonstrated at vendor site. Selector shipped to ORNL for pellet tests

FY 2014 US Achievements

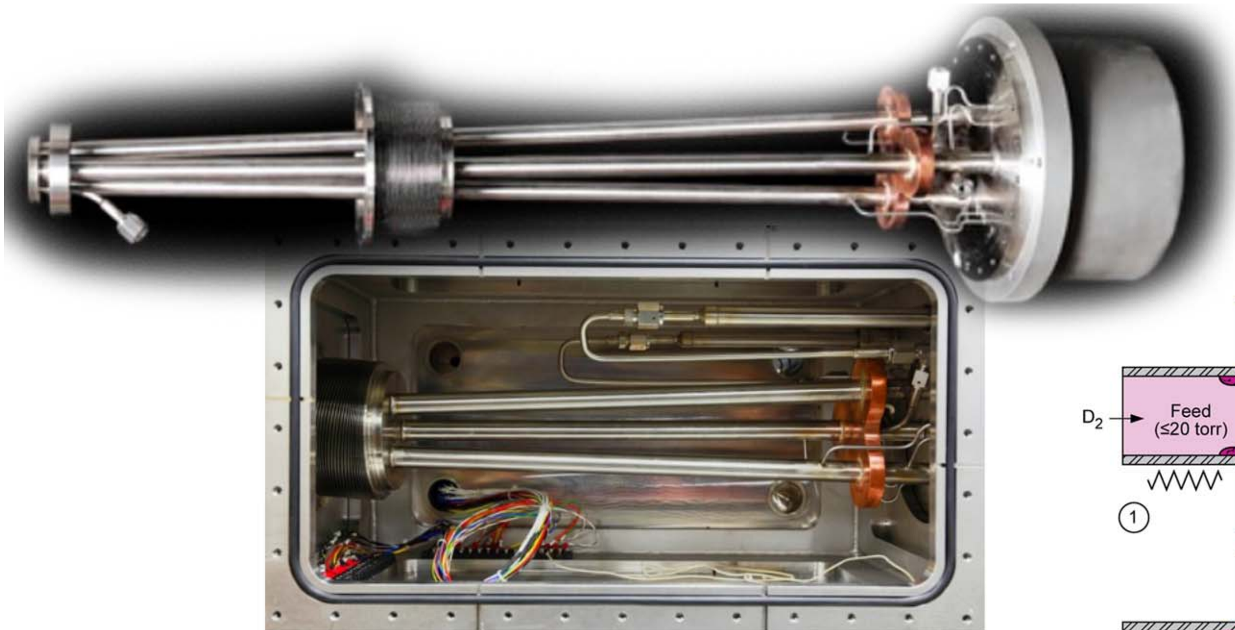
Massive Gas Injection Valve Prototype

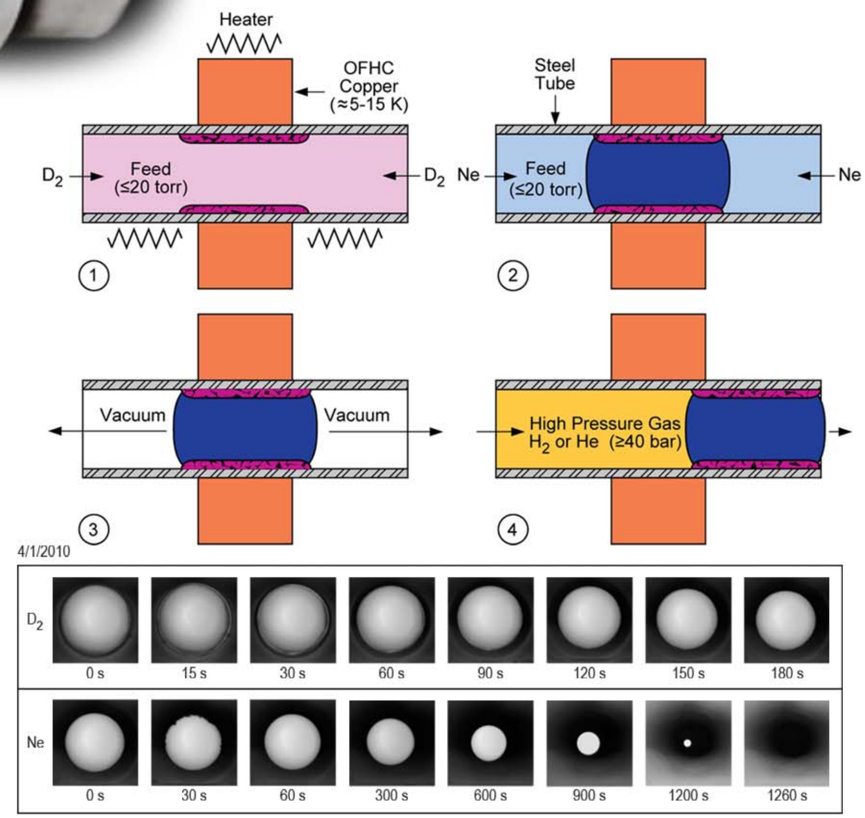


Valve based on a design used on JET but modified for ITER tokamak environment and injection rate requirements.

Modified valve uses flyer plate to achieve fast opening time and incorporates T compatible components

Shattered Pellet Injection 3-Barrel Testing

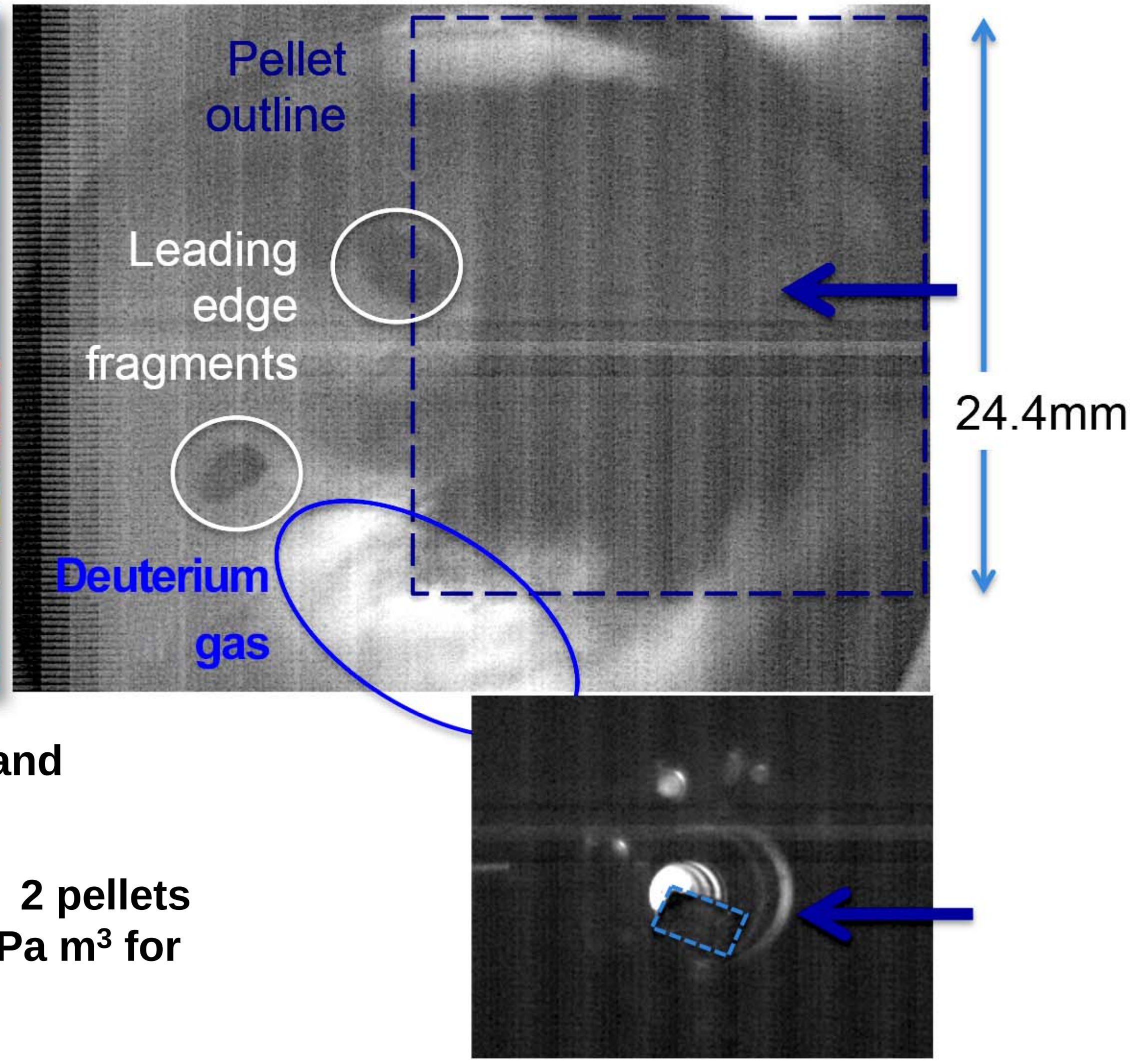




- **Barrel diameter increased to 25 mm (from 16 mm diameter) in order to study scaling of freezing/forming**
- **Larger size will reduce the number of barrels needed for Disruption Mitigation System.**

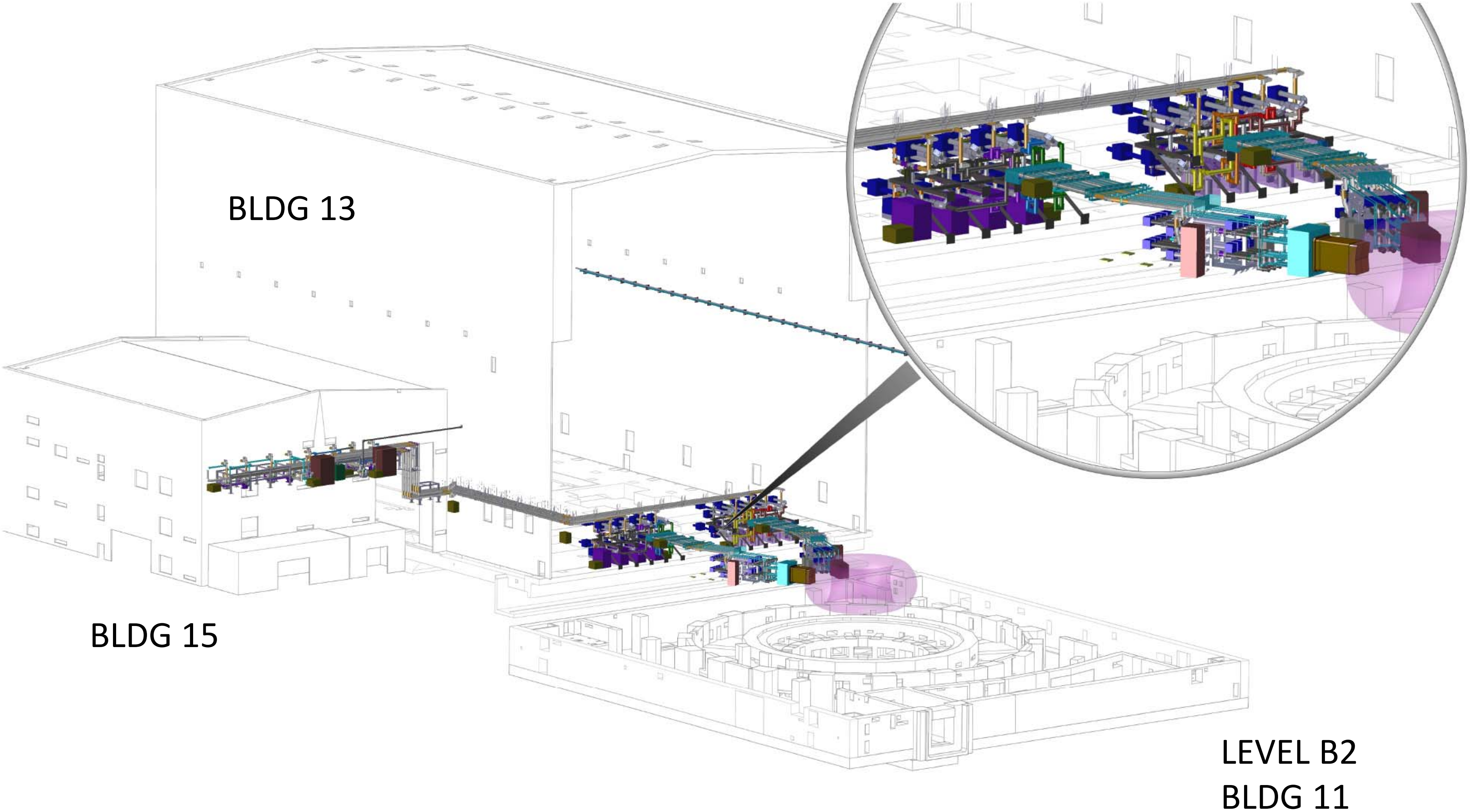
FY 2014 US Achievements

Deuterium Pellets Formed and Accelerated from Three 25 mm Barrels



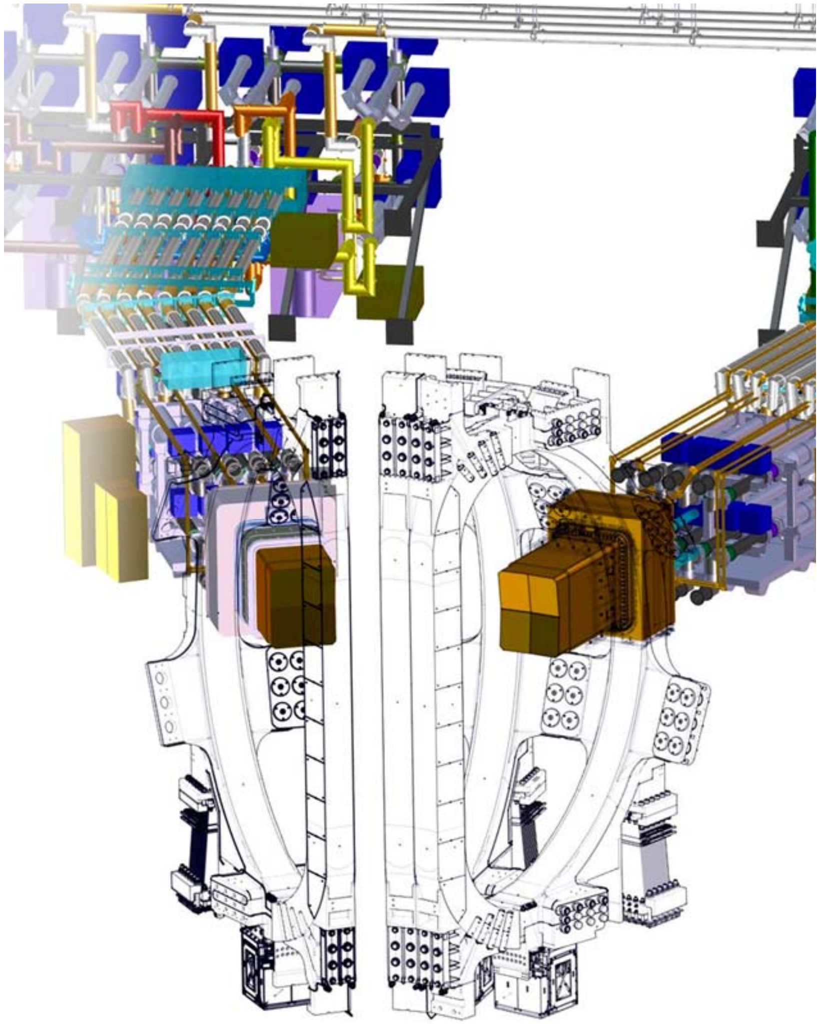
- **3 ea. ~ 25 mm pellets formed and accelerated to 330 m/s**
- **1.5 kPa m^3 of deuterium each. 2 pellets exceed the requirement of 2 kPa m^3 for thermal mitigation**

Ion Cyclotron System Transmission Lines



Ion Cyclotron System Transmission Lines

- Provide efficient transfer of 24 MW 40–55 MHz RF power from sources to plasma antennas using coaxial line and load tolerant matching/tuning
- Transmit up to 6 MW per line for up to 1 hour
- Total of 1.5 km of line connects 8 sources to 16 antenna feeds
- Two 8-channel matching networks weighing 27 t each
- Two 8-channel pre-matching networks weighing 14 t each
- Maximum losses: 2.5% of source power in the transmission line system, 10% in the matching syste

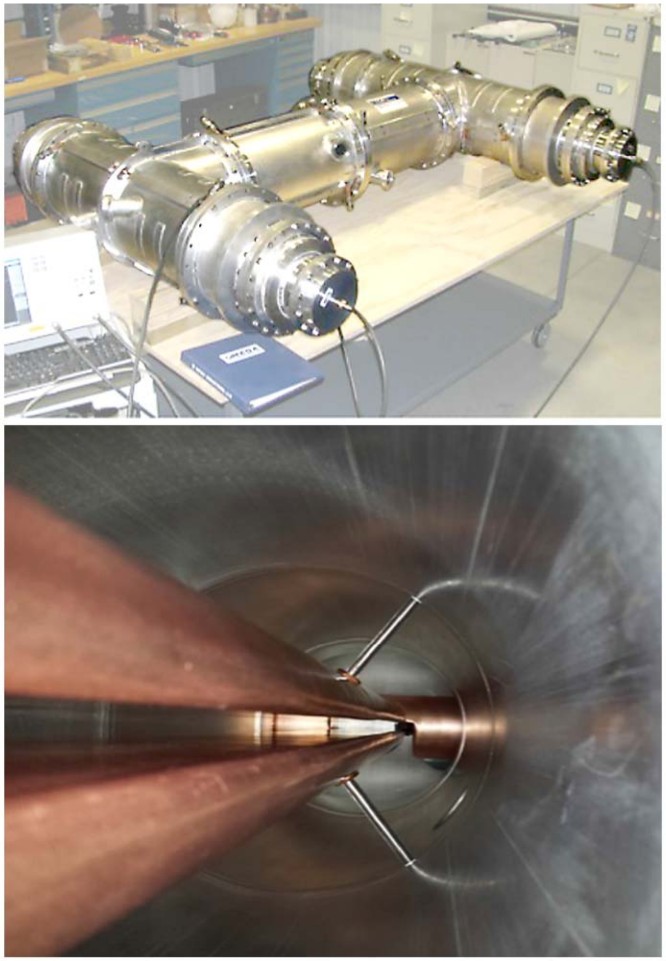


Ion Cyclotron System Transmission Line and Matching System Status

Status:

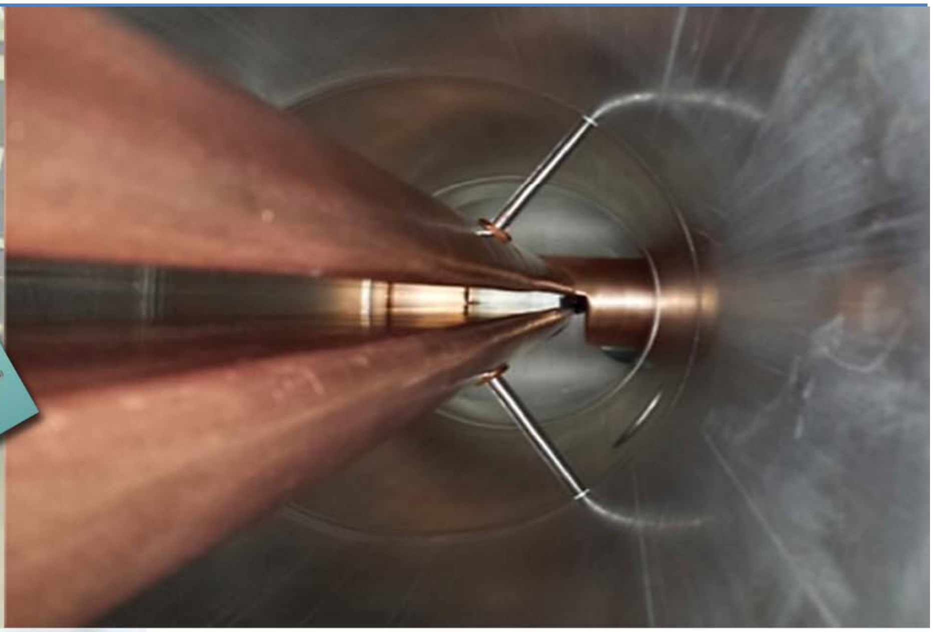
In design: Transmission line components, tuning components, gas cooling system, instrumentation and control

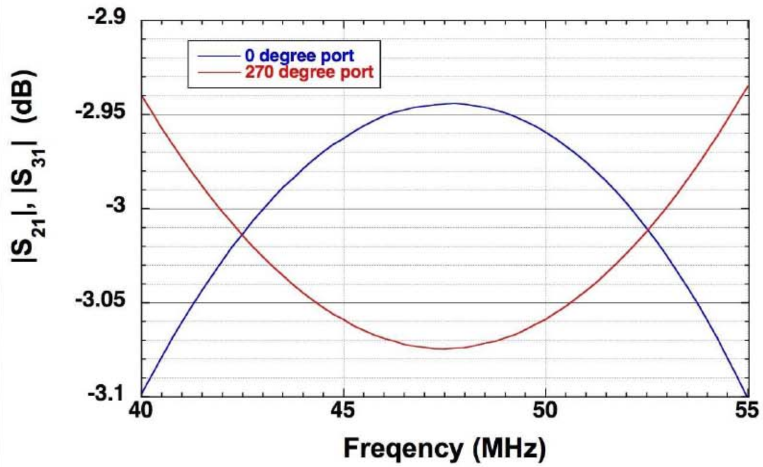
- Successful cooling of inner conductors with circulating air at 3-atmosphere pressure
- High-power (6 MW), high-voltage (40 kV), long-pulse (1 hour) tests of 2 candidate straight transmission lines
- High-voltage (40 kV), long-pulse (1 hour) tests of 3 candidate gas barriers
- Fabrication and performance verification test of 50/50 hybrid power splitter. The power splitter enables passive tolerance to plasma ELM events



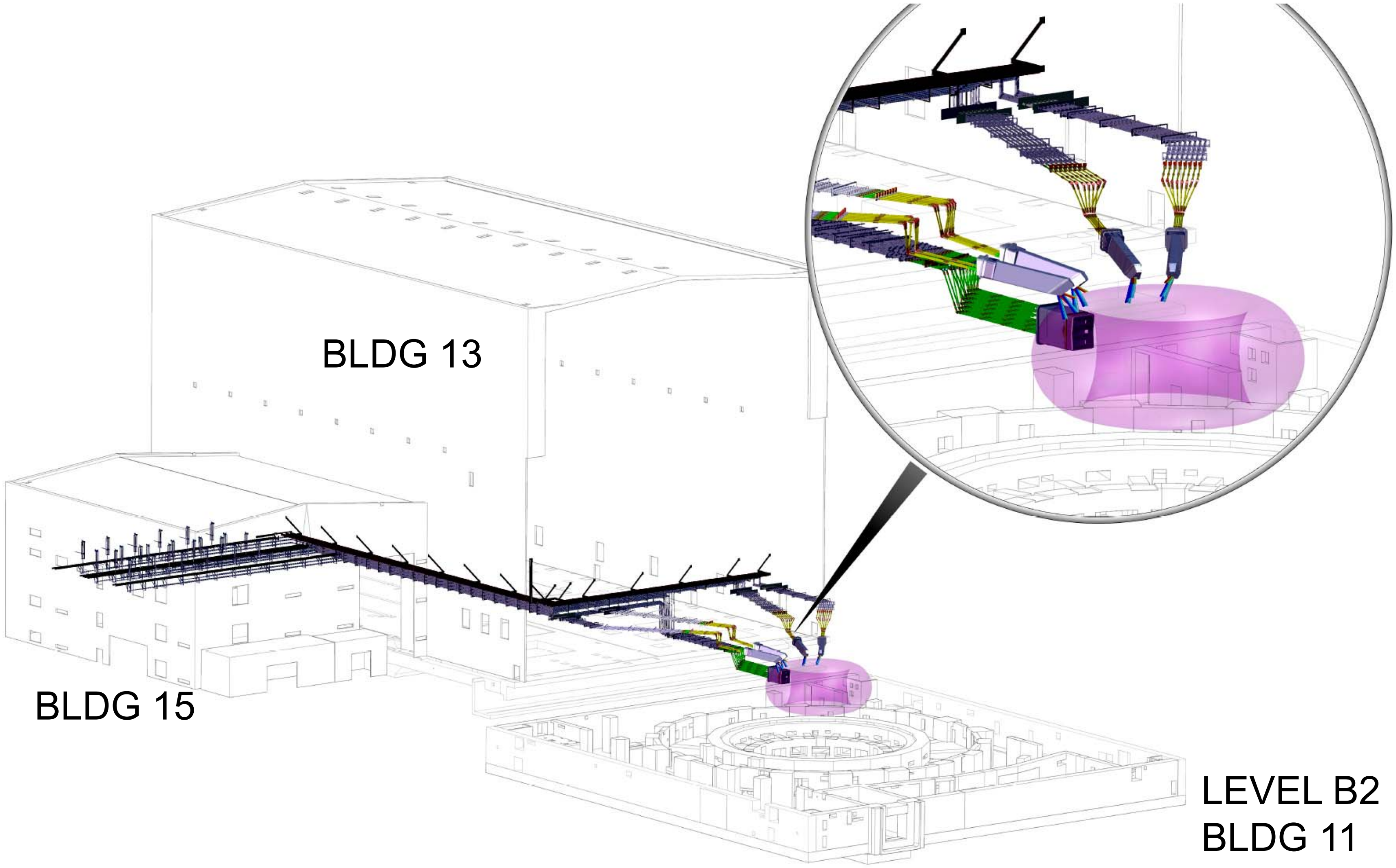
Four-port 50/50 Power splitter on the test bench. Internal view of outer conductor (Al) and inner conductors (CU) of the power splitter (Mega Industries, Portland, Maine)

Milestone Completed: 3 dB Hybrid Splitter Component Qualification Test



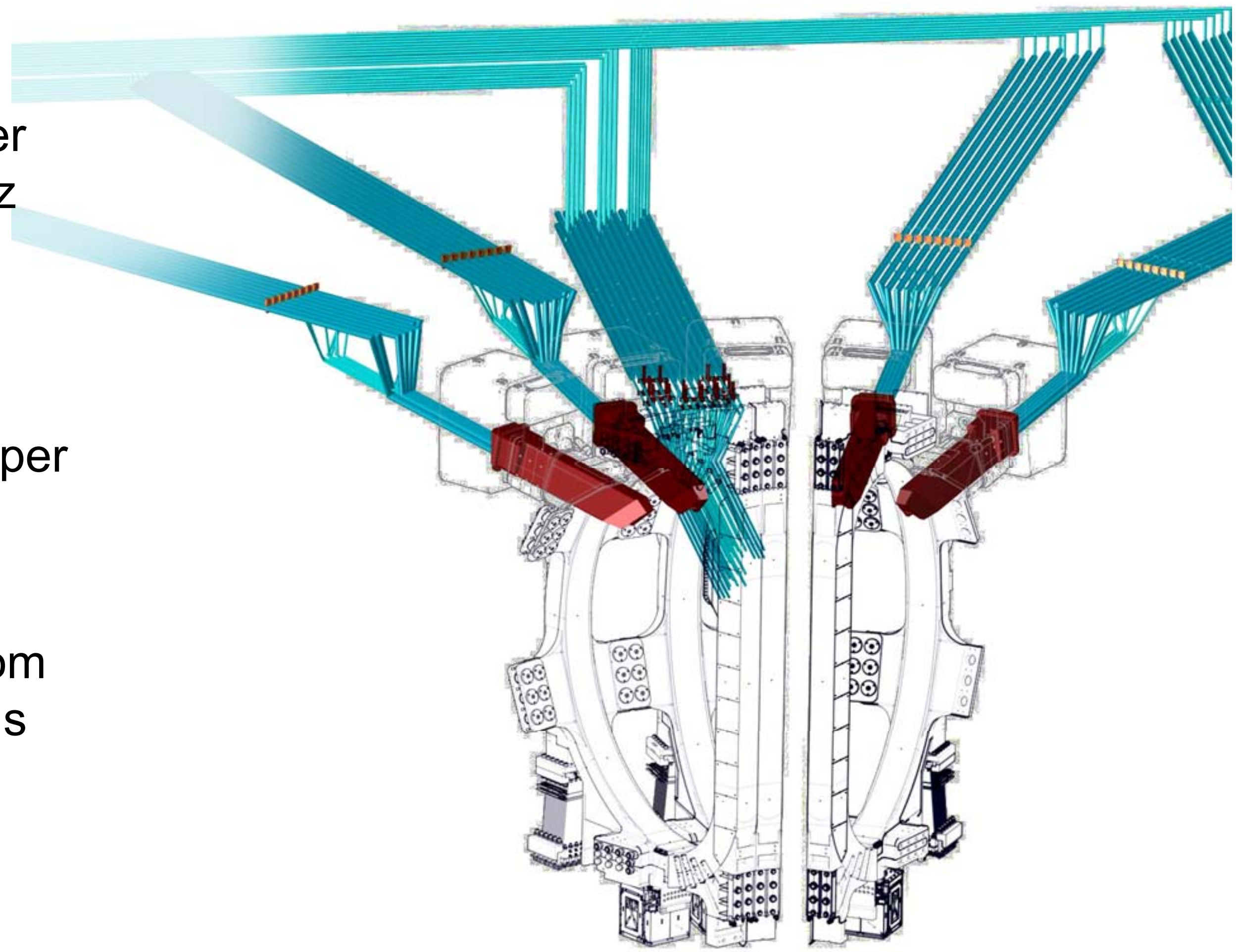


Electron Cyclotron System Transmission Lines



Electron Cyclotron System Transmission Lines

- Provide efficient power transfer from 170 GHz gyrotron sources to launchers
- Transmit up to 2 MW per line for 1 hour
- Transmission lines from 24 sources to 56 feeds



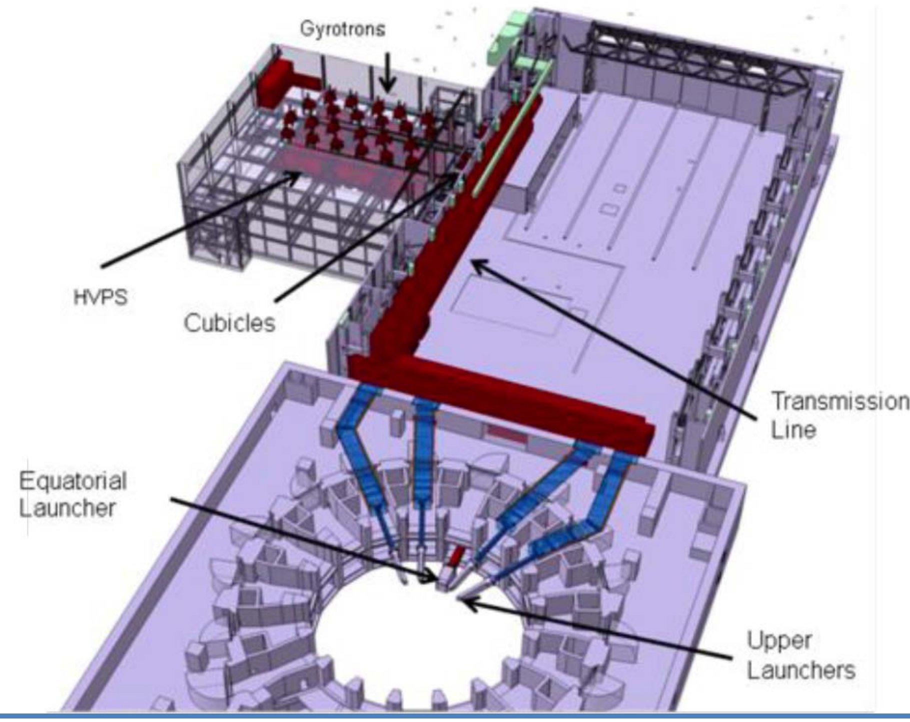
Electron Cyclotron System Transmission Lines
FY 14 Status

Design Progress: Transmission Line Movement

TL will move due to:
- Thermal expansion
- Building movements due to external loads

TL and Support system must be designed to accommodate these movements
- During Operations
  - Minimize extent of WG bending
  - Use Expansion Units to avoid WG bending
  - WG must move axially through supports
- Non–Operational conditions
  - Expansion units to take up some building movements
  - WG bends at building interfaces

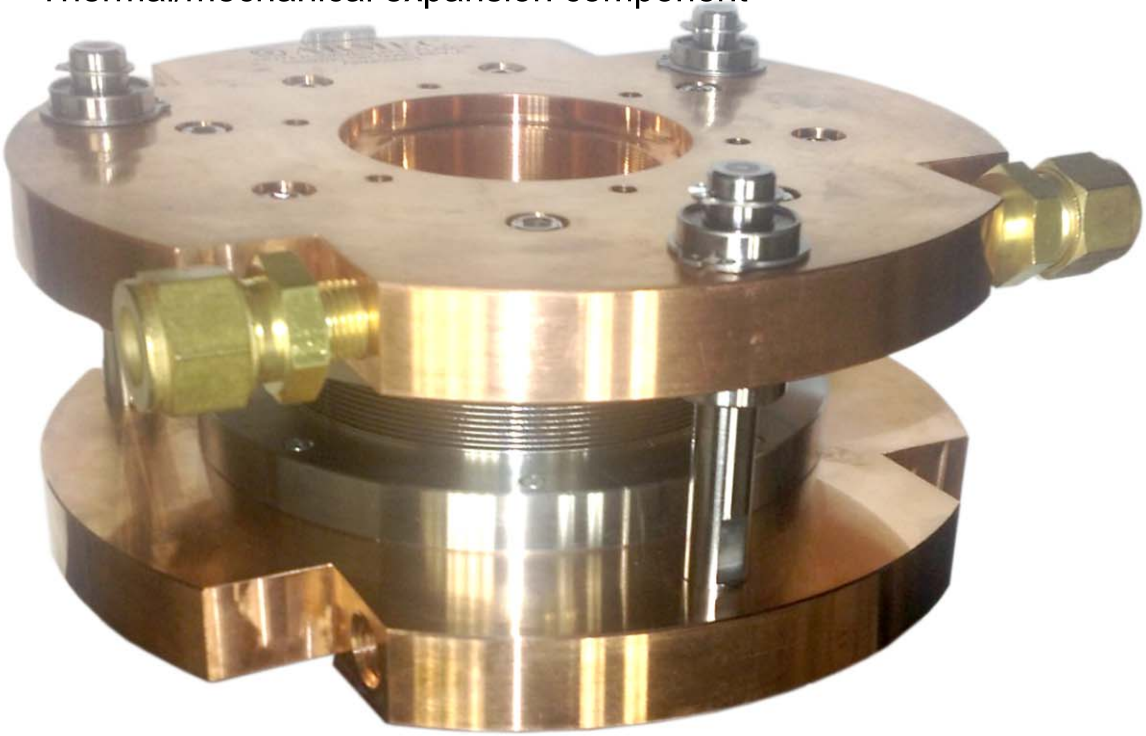
Wind loads on Assembly and RF buildings can cause buildings to move/sway by more than 10 mm

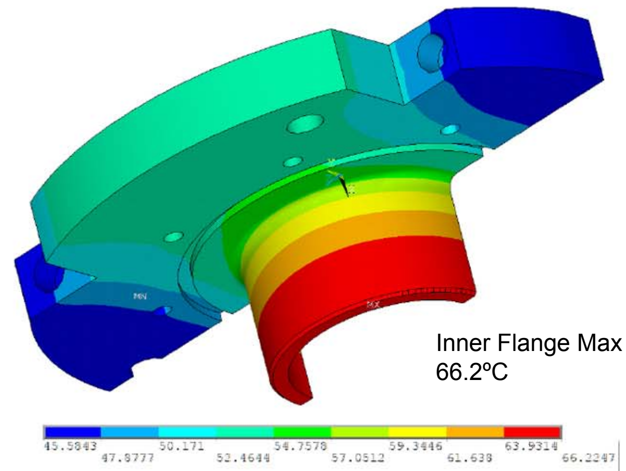


FY 2014 Achievement
30% Final Design Intermediate Design Review

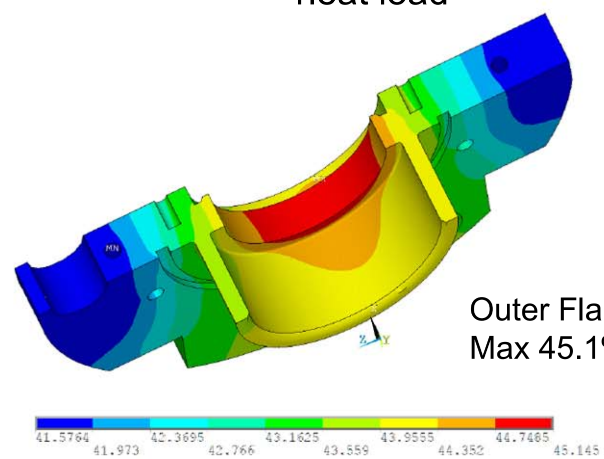
Modeling of in-line thermal/mechanical expansion compensation ECH transmission line component

Thermal/mechanical expansion component



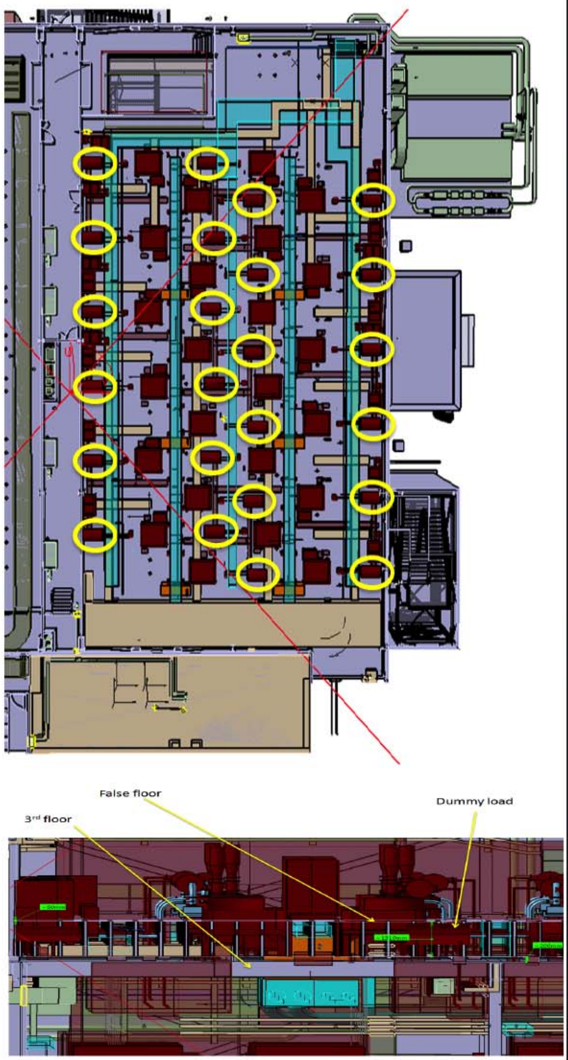


Temperature profile with 5,000 W/m heat load

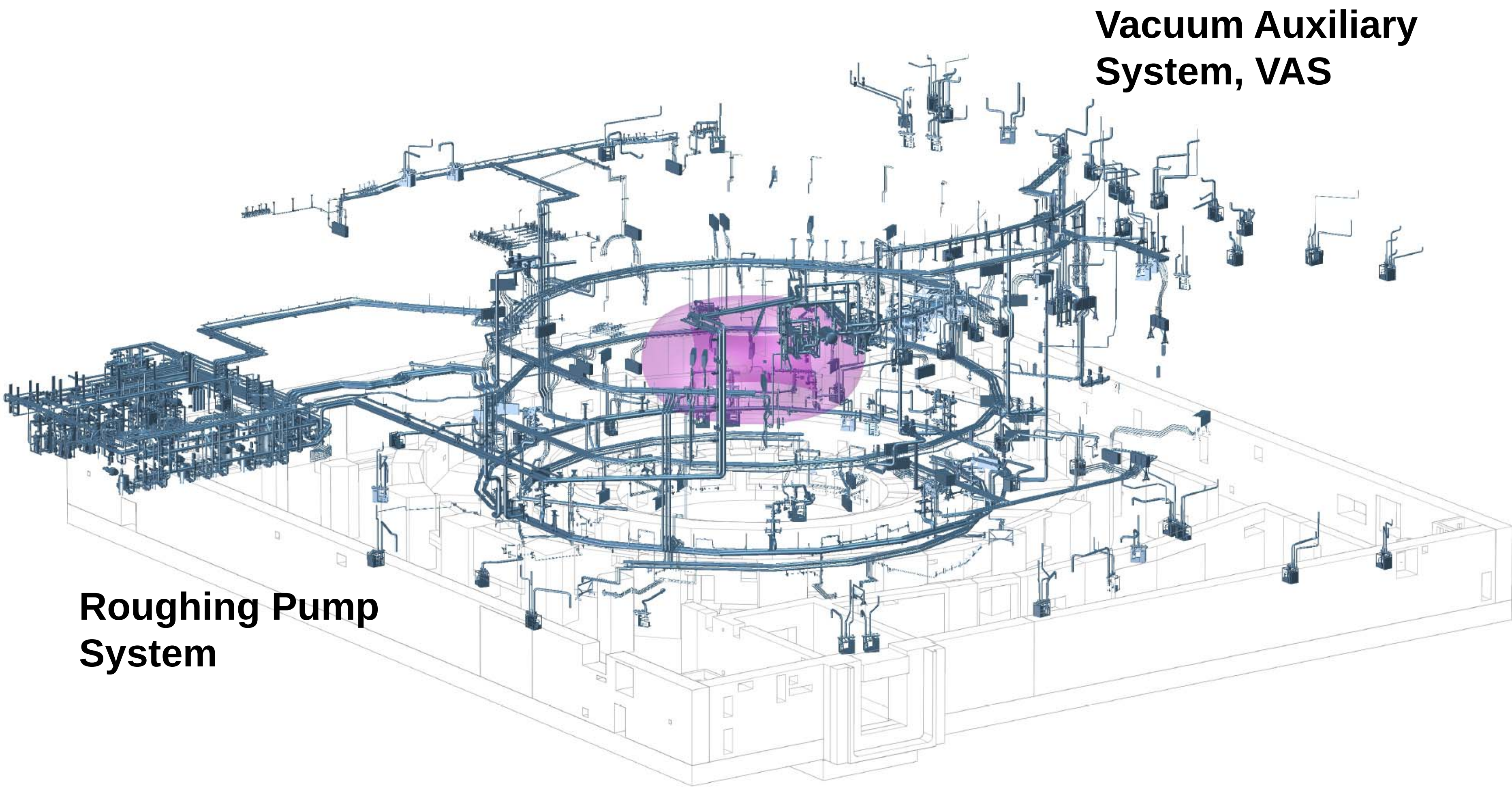


FY 2014 Achievement

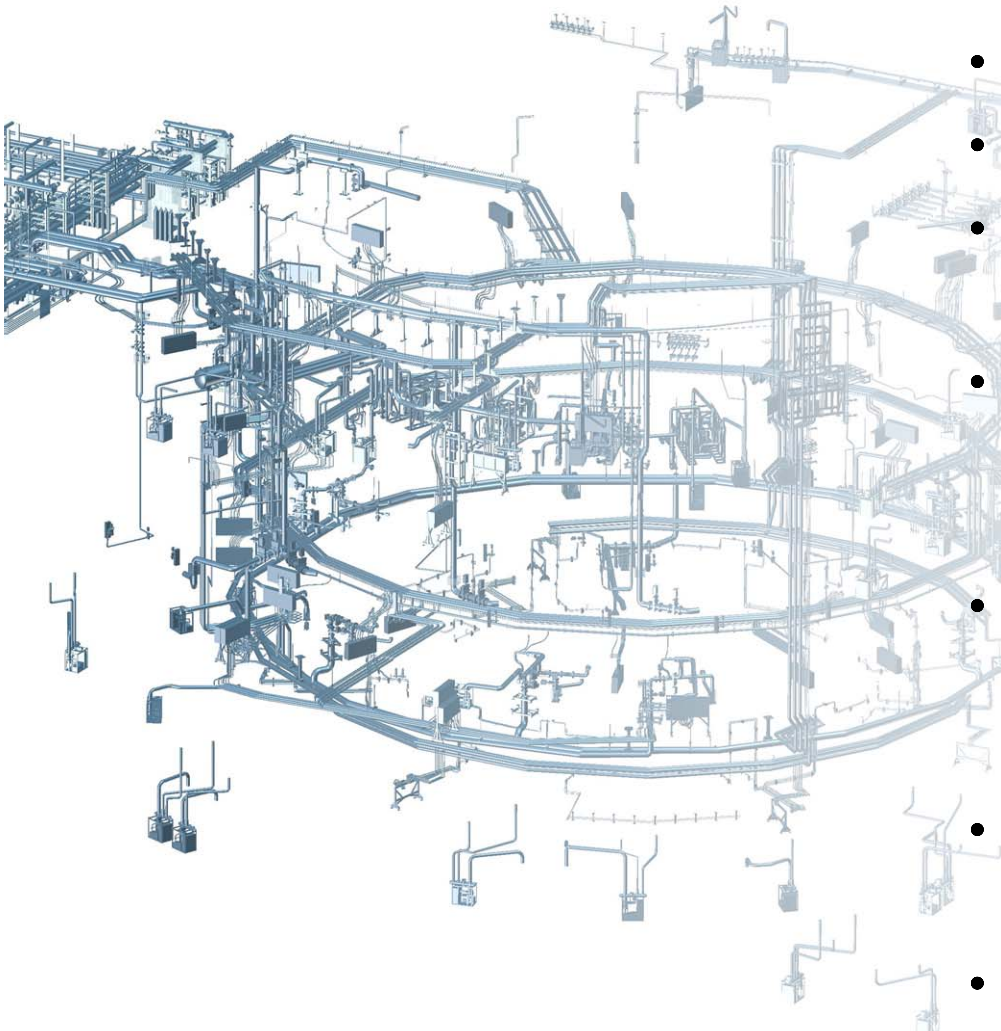
Completed Conditioning Power Load SOW



Vacuum Auxiliary System and Roughing Pumps



Vacuum Auxiliary System and Roughing Pumps



- Tokamak vacuum volume: 1330 m^3
- Cryostat vacuum volume: 8500 m^3
- Neutral beam injectors' volume: 8600 m^3
- Vacuum system performance: 105 Pa to 10 Pa in 24 hours, operating pressure 1 x 10^{-4} Pa
- Roughing pumps: 400+ vacuum pumps utilizing 10 different technologies
- Service vacuum system: >1500 clients
- Vacuum piping: 6 km

Roughing Pump System

FY 14 Status (1)

- The Roughing Pump System (RPS) achievements for FY14 consist of providing tritium compatible vacuum pump development support via the two Task Arrangements in effect.
- Successful manufacture and testing of the prototype tritium compatible roots and screw pumps
- Testing is underway at present at ORNL

Tritium compatible screw pumps in test stand at ORNL

Roughing Pump System
FY 14 Status (2)

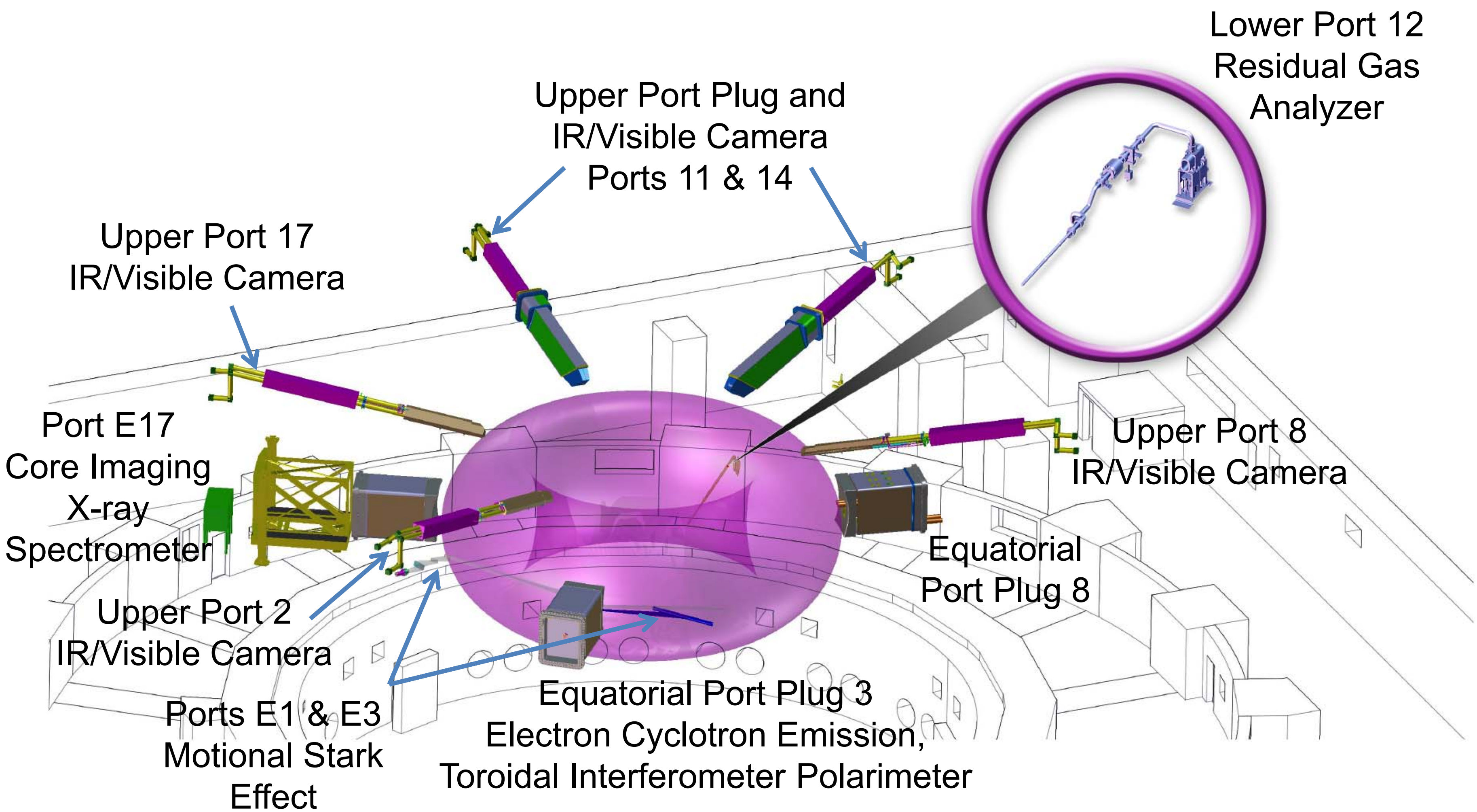
Manufacture of the prototype tritium compatible Cryogenic Viscous Compressor (CVC) is being completed at Major Tool and Machine, Indianapolis, IN

CVC assembly undergoing vacuum leak testing

Inner CVC core

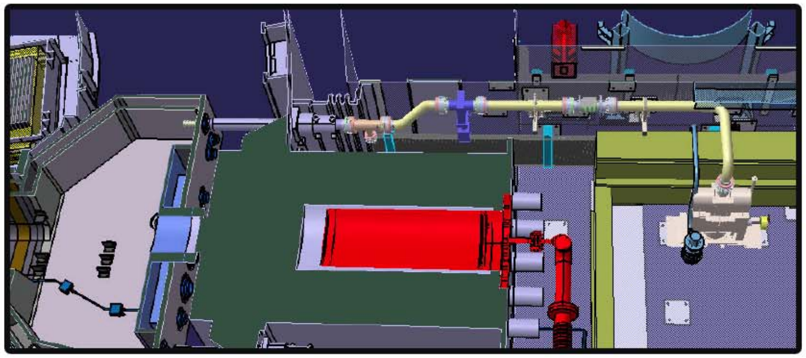
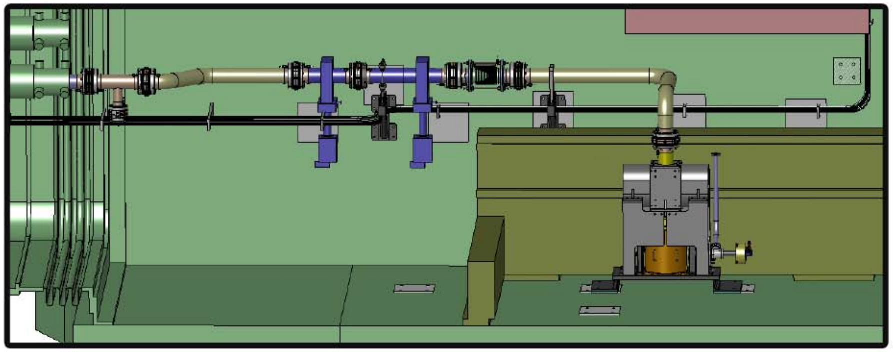
Multilayer insulation film surrounds the CVC core

Diagnostics



Diagnostics
FY 14 Status

- USIPO is responsibility for 14% of port based diagnostic systems, including integration of four diagnostics port plugs and seven instrumentation systems; achievements include:
  - Completed FDR of the Diverter Residual Gas Analyzer (DRGA) Sampling Tube
  - Awarded Subcontract for Low Field Side Reflectometer (LFSR) Physics Design
  - Awarded Subcontract for Electron Cyclotron Emission (ECE) Design
  - Awarded Subcontract for Upper Camera Design
  - Pending award - subcontract for Toroidal Interferometer/Polarimeter (TIP) Design

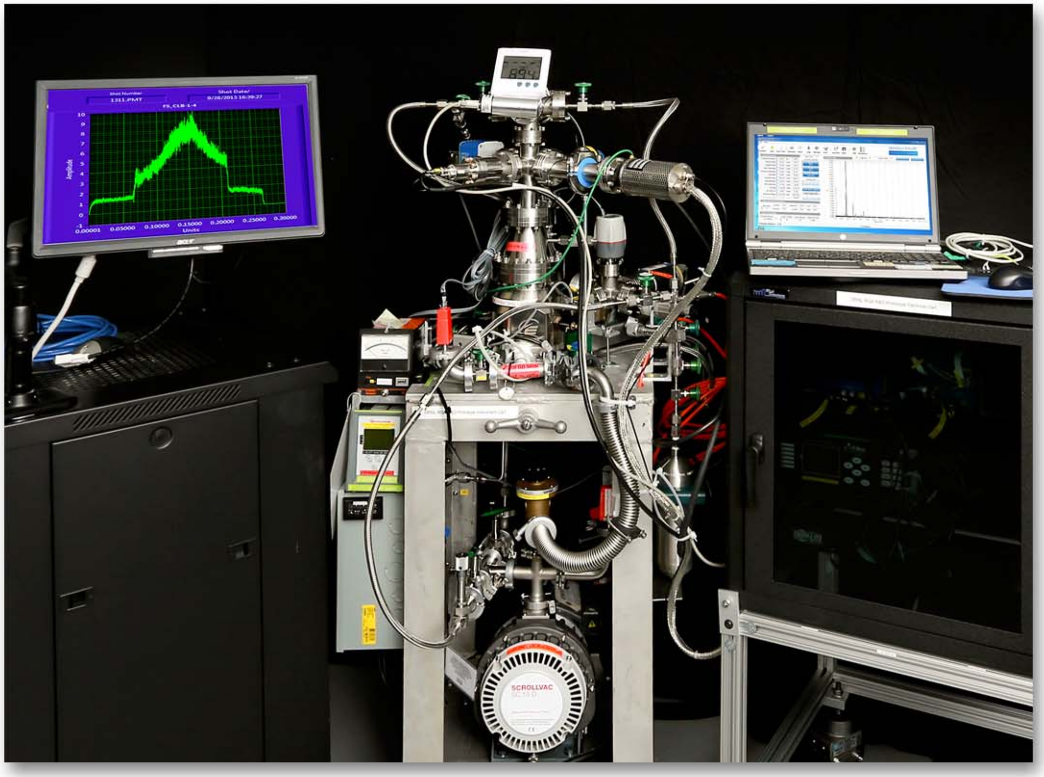



3-D CAD Model of RGA Diagnostic

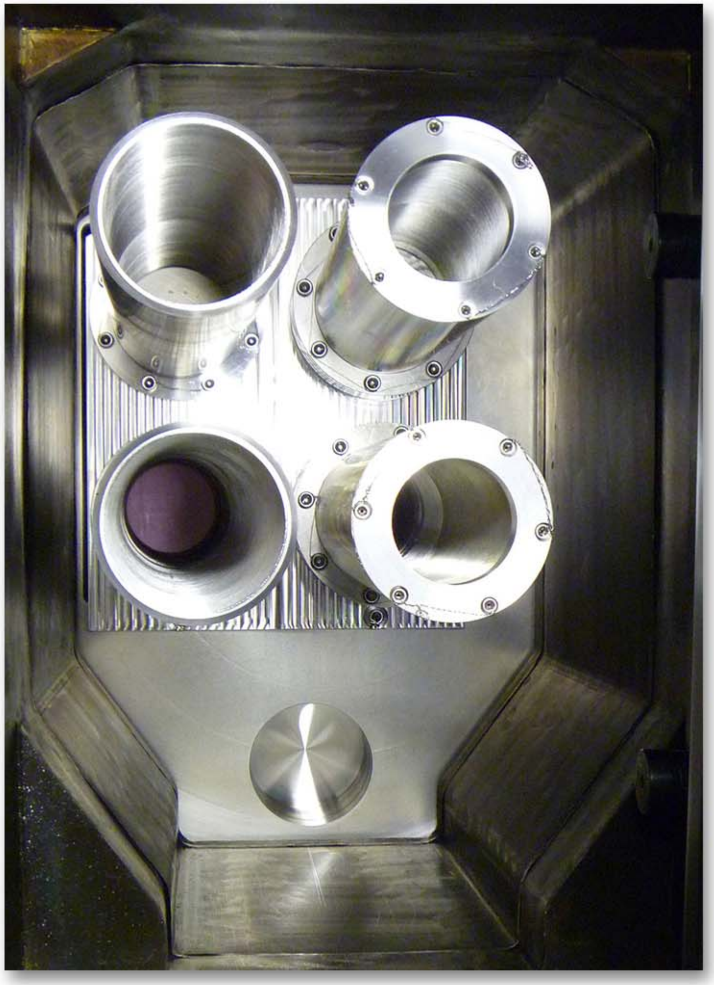
Diagnostics

FY 14 Status

The residual gas analyzer and part of the low-field side reflectometer will be installed for 1st Plasma.



Diagnostic residual gas analyzer in development at ORNL.
Photo: US ITER/ORNL



Prototype antenna for the low-field side reflectometer installed on DIII-D.
Photo: US ITER/ORNL

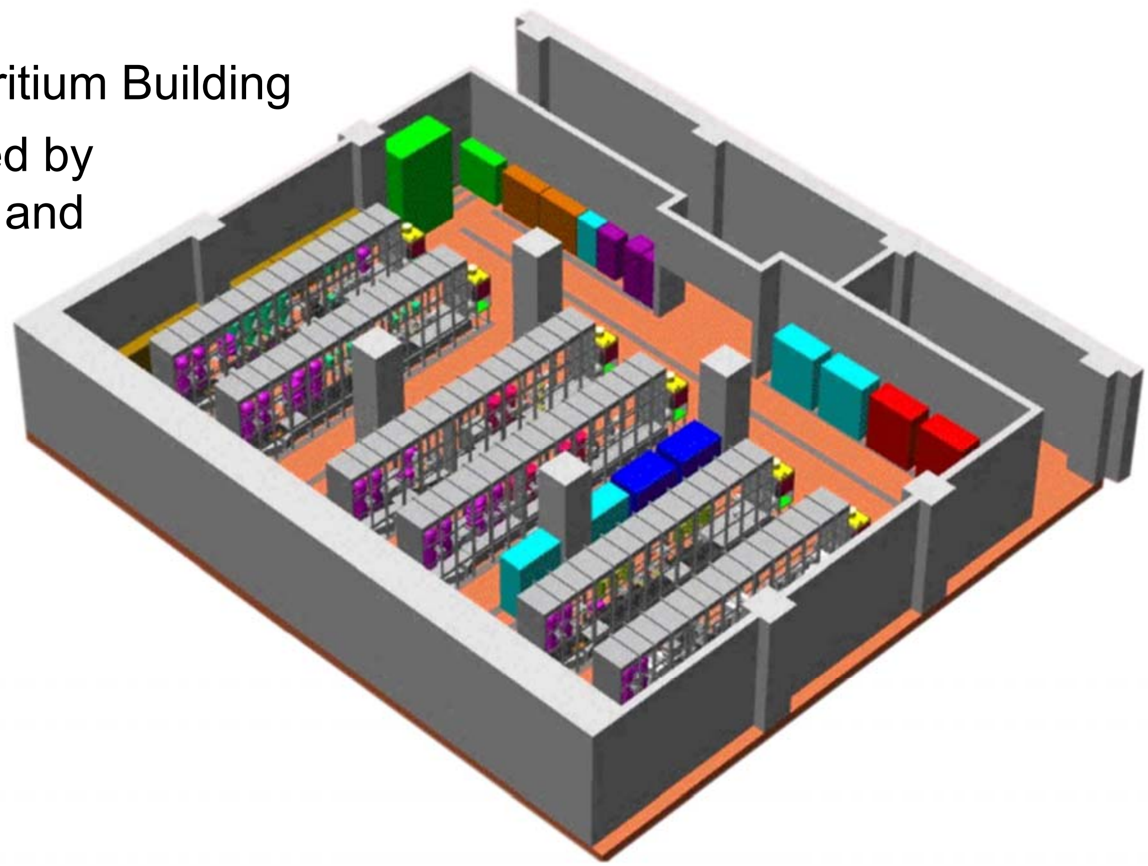
Diagnostics Design Status

System	Procurement Arrangement	Design Phase
Upper Port 11	✔	**PD**
Upper Port 14	✔	**PD**
Equatorial Port 3	imminent	**PD**
Equatorial Port 9	✔	**PD**
Upper Visible/IR Cameras	✔	**PD**
Low Field Side Reflectometer	✔	**PD**
Motional Stark Effect Diagnostic	imminent	**PD**
Electron Cyclotron Emission	✔	**PD**
Residual Gas Analyzer	✔	**FD**
Toroidal Interferometer/Polarimeter	✔	**PD**
Core Imaging X-ray Spectrometer	imminent	**PD**

Tokamak Exhaust Processing

Configuration:

- TEP equipment located in Tritium Building
- Tritium Confinement provided by nitrogen inerted gloveboxes and Tritium Building
- Gamma Decay Tanks located on separate floor



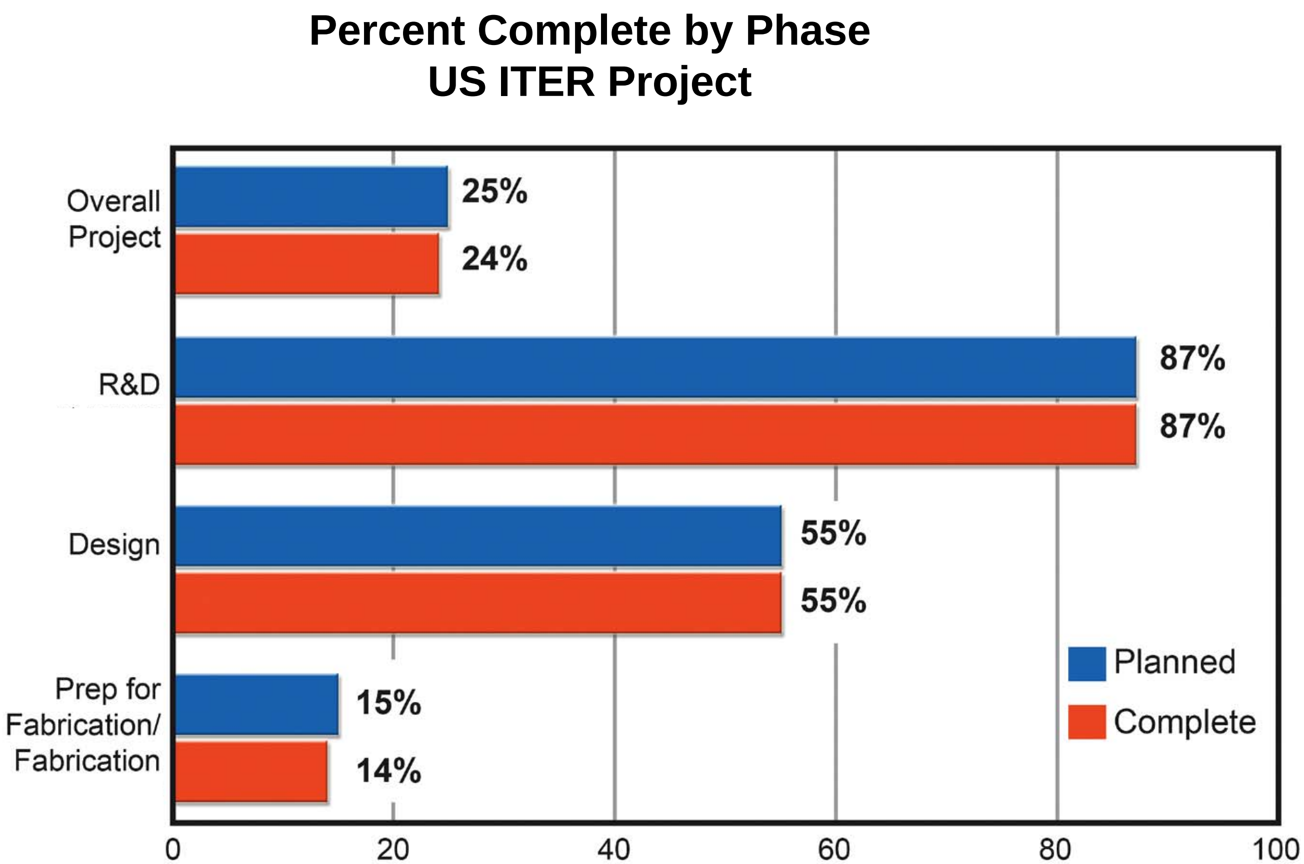
Status:

- In preliminary design
- TEP required for DT Plasma

Some Current Technical Challenges

Tokamak Cooling Water System	• **Finalize 1st Plasma scope and requirements**, including role in N^{16} gamma dose reduction • Oversight of IO as TCWS designer and piping manufacturer • Design changes that implement design optimization (i.e., Heat Exchanger options)
Ion and Electron Cyclotron Heating Systems	**Building interfaces** for penetrations through Tokamak Building wall and Port Cell wall for transmission line, services and cabling especially meeting fire requirements
Diagnostics	Meeting **radiation shielding** requirements in the port plugs while simultaneously satisfying diagnostic measurement requirements and weight limits.

Summary:
Project Execution Well Underway!



R&D - 87% complete
> 100 prototypes/first articles under development

Significant information gained:
- Technical feasibility
- Manufacturing issues
- Cost and time to fabricate

Design - 55% complete

Prep for fab/fabrication – 14% complete

Summary:
5 Hardware Systems in Fabrication

TF Conductor
- All strand complete
- 1st conductor (of 7) fabricated and undergoing leak testing
- 2 production cables are complete and jacketing of 1st cable is underway
- **All deliveries will be complete in 2016**

CS Modules fabrication
- 5 spools of JA conductor received
- Tooling stations being installed
- Mock-up coil fabrication started
- Winding of 1st module to begin in 2014

Tokamak Cooling Water System (TCWS) drain tanks
- All 5 tanks ready for shipment by end of 2014

Steady State Electric Network (SSEN)
- 11 fabrication contracts in process
- **All deliveries will be complete in 2017**

Vacuum Auxiliary
- 15 of 16 components for test stand complete

Summary:

Design, Contracts, Fabrication, Deliveries

Design well underway
~2/3 (by value) of US Hardware systems in final design or beyond

Contracts are in place
~1/2 (by value and number) of planned contracts have been awarded

Fabrication underway for critical-pacing items

Key hardware deliveries on-going

At the end of FY16:

- Only one PA remaining
- Design >80% complete
- 28% of US Hardware Deliveries needed for 1st Plasma will be complete
- One US Hardware contribution will be complete in FY16 (TF)