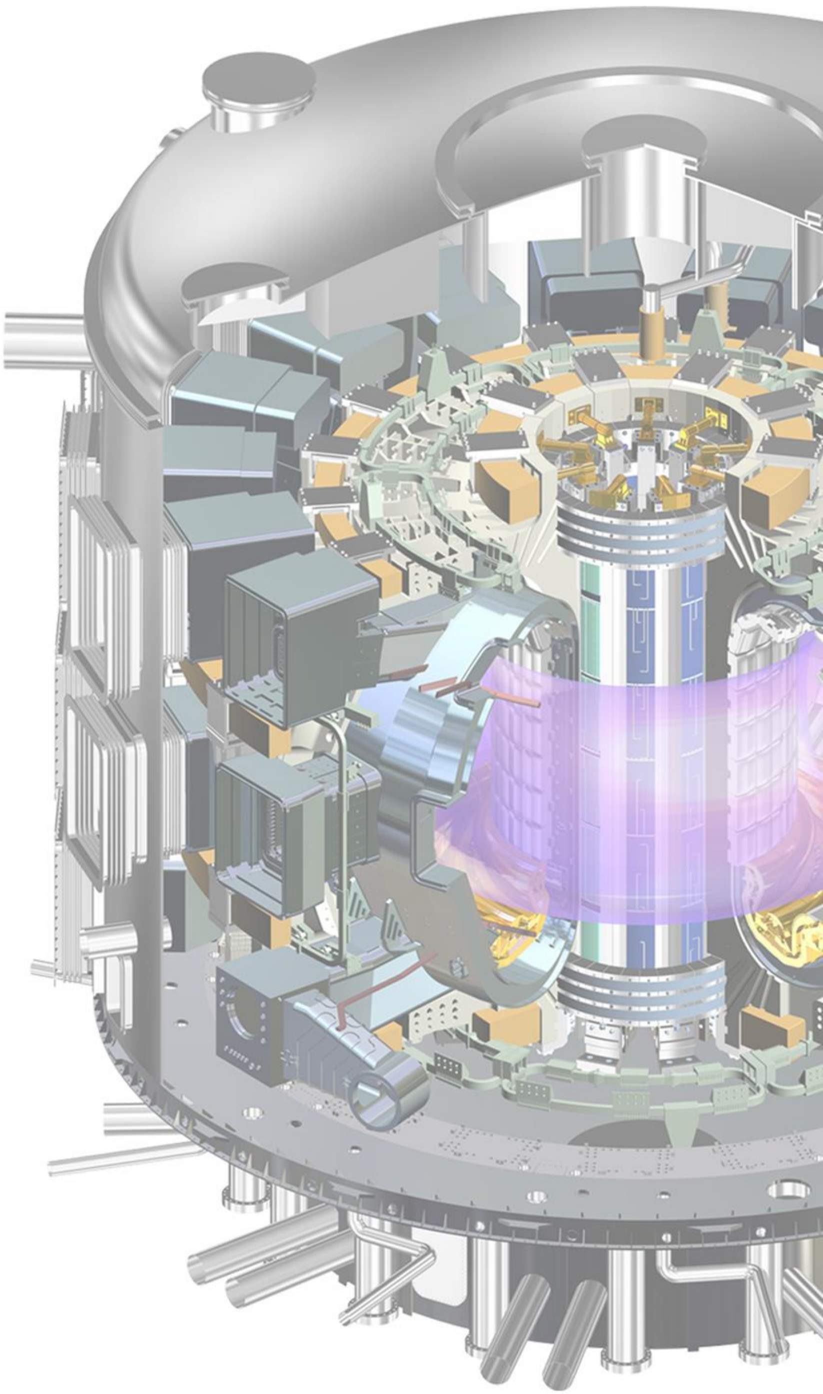
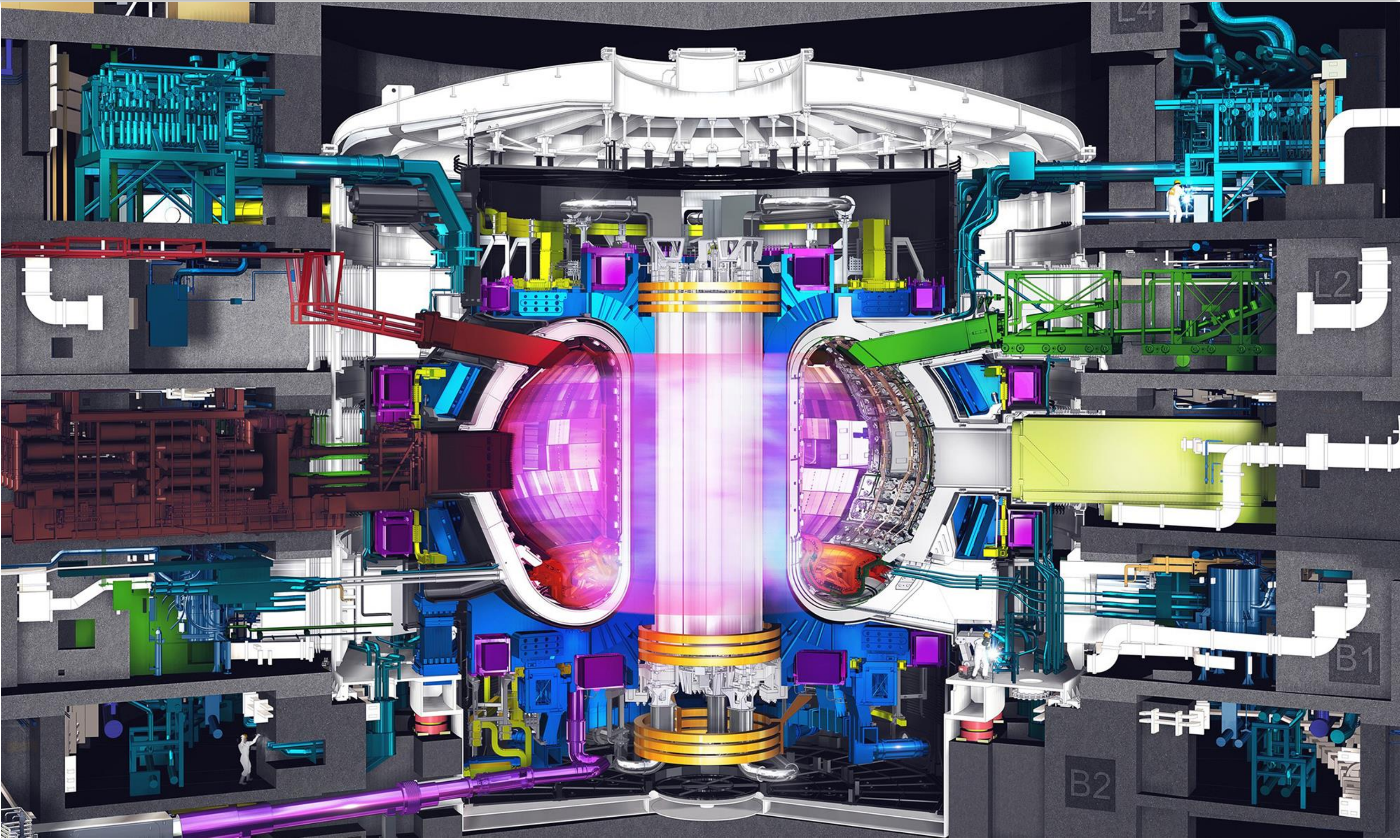
ITER Project Progress

Graeme Murdoch
Non-Nuclear Systems Division Director
US ITER Project Office

Fusion Energy Sciences Advisory Committee
March 12-13, 2015



ITER Tokamak Core



International perspective

ITER Council has acted on the latest Management Assessment:

- Bernard Bigot accepted DG position on March 05, 2015
- Bigot's action plan endorsed by ITER council
- Key points:
  - Project reorganization with emphasis on highly integrated Central Team & Domestic Agencies
  - Clear lines of authority; streamlined upper management
  - Executive Project board
  - Project Teams
  - Fully functional organization by December 2015

Site Progress

Photo: ITER Organization April 2014

Panoramic view of ITER site

Photo: ITER Organization March 2015

Tokamak Complex floor

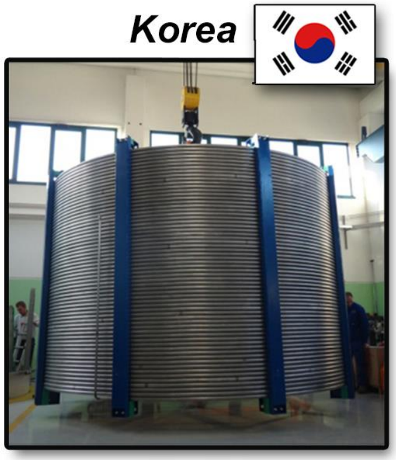
Photo: ITER Organization February 2015

Assembly Hall under construction

Fabrication of ITER Components by Global Partners is Underway

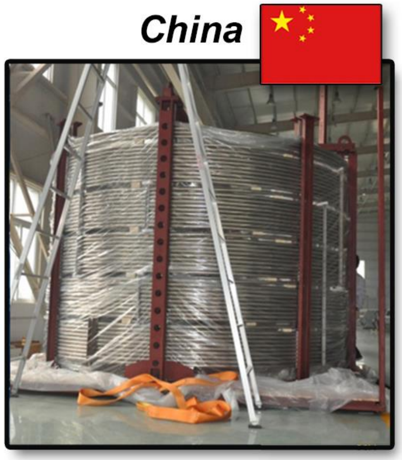
Toroidal Field conductor is in production around the world

Korea

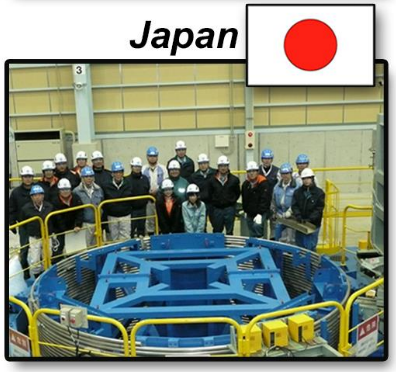


Russia

China



Japan

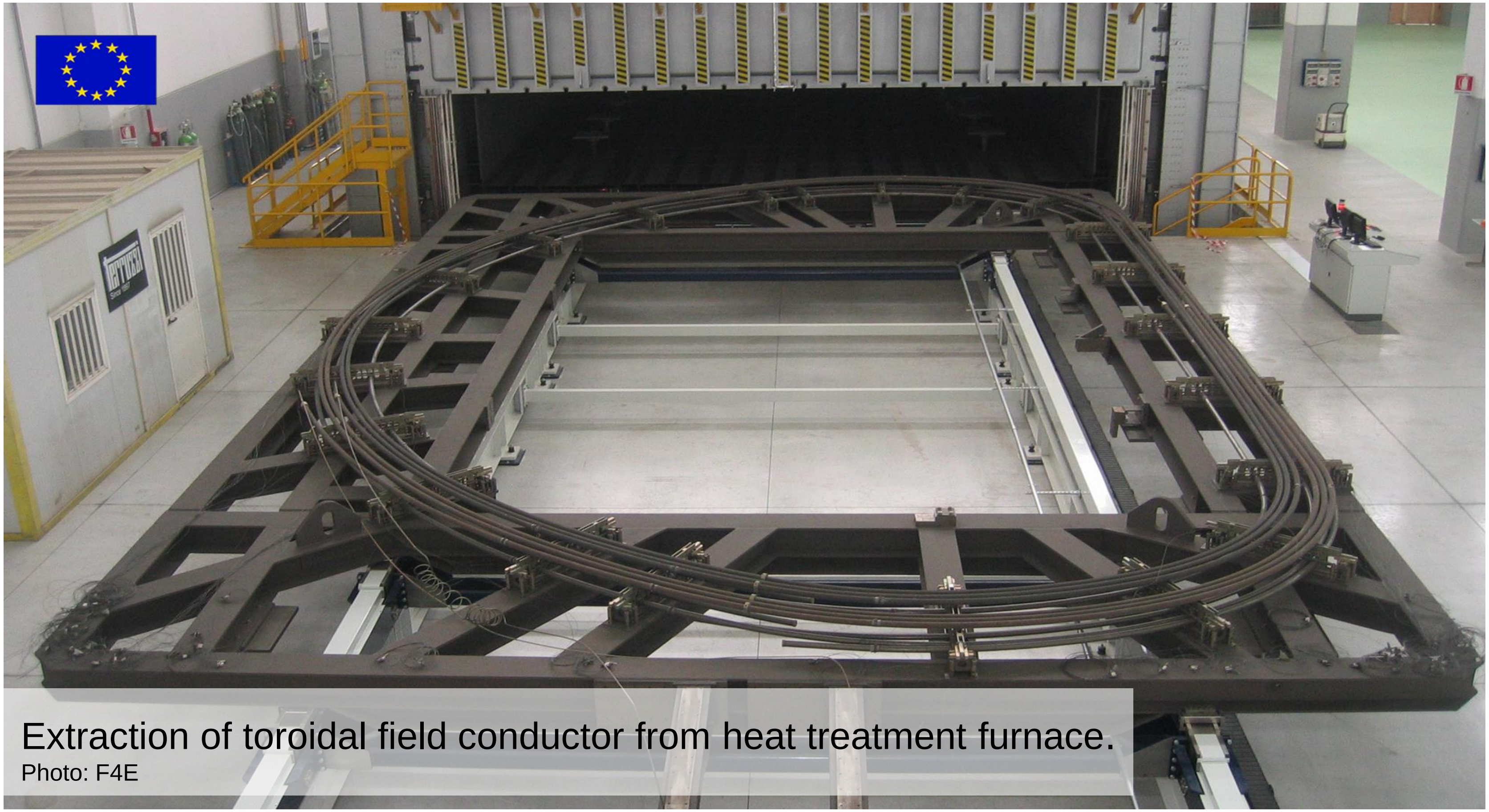


EU

United States

- **Sample toroidal field (TF) conductor has been produced by the six responsible Domestic Agencies**
- **Japan has completed production**
- **Russia will complete production in March 2015**
- **US will complete fabrication in 2016**

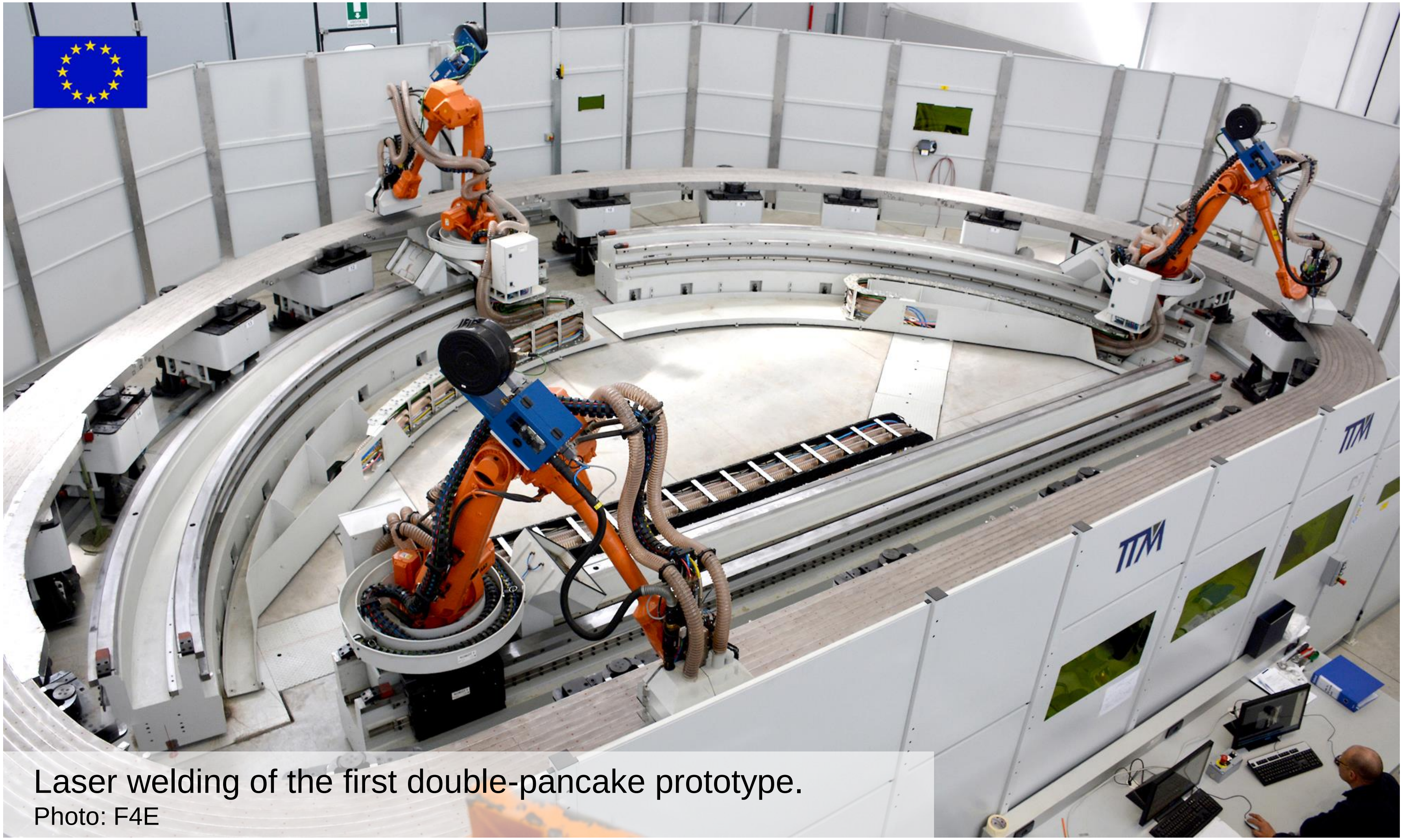
TF manufacturing processes have been proven in Europe



Extraction of toroidal field conductor from heat treatment furnace.
Photo: F4E

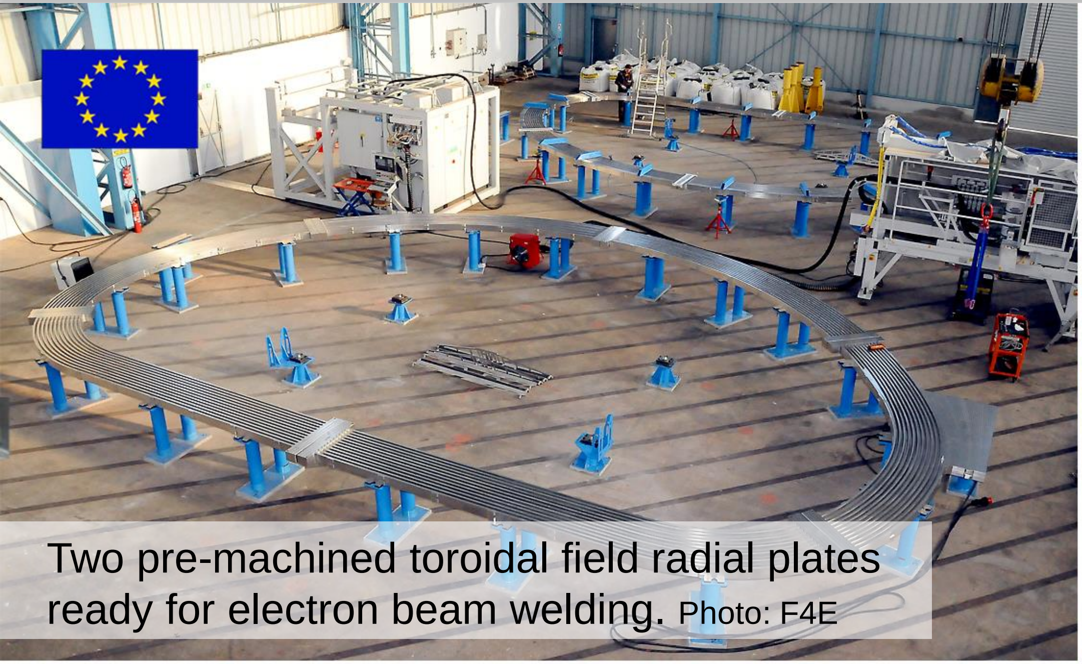
Europe has completed manufacture of all of its strand for the toroidal field coil conductor.

Laser welding of TF cover plates has been characterized

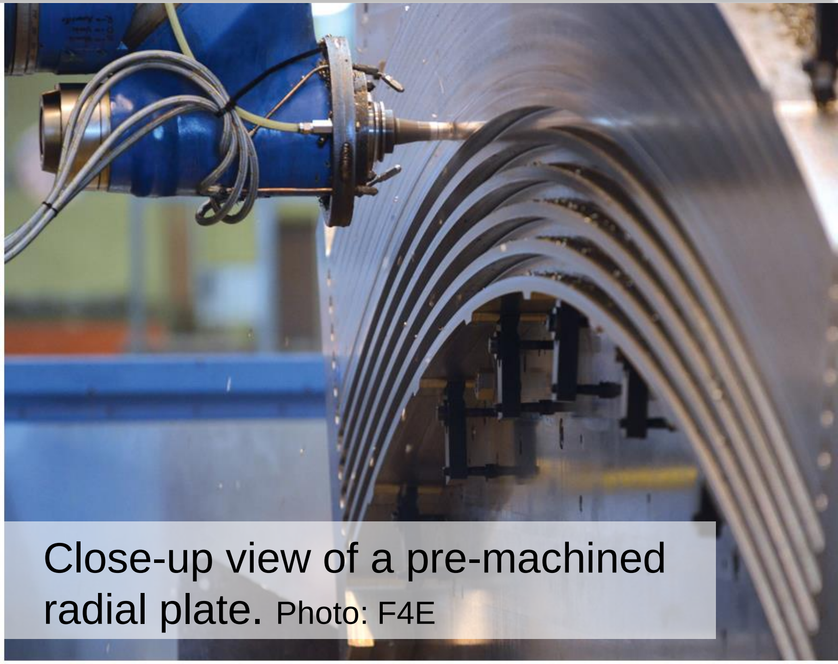


Laser welding of the first double-pancake prototype.
Photo: F4E

Machining of TF radial plates successfully completed



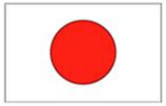
Two pre-machined toroidal field radial plates ready for electron beam welding. Photo: F4E



Close-up view of a pre-machined radial plate. Photo: F4E

The first radial plate during final machining. Photo: F4E

R&D support activities are yielding results in Japan

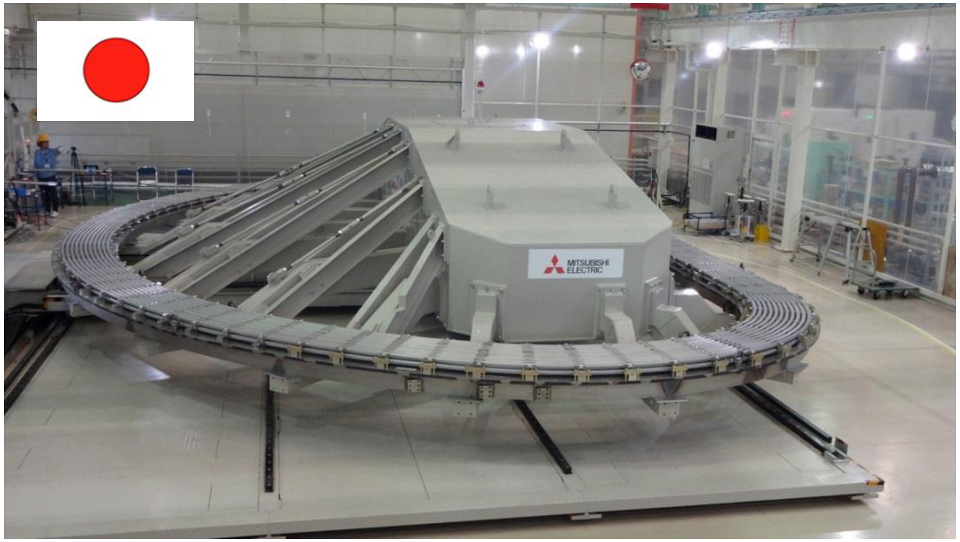


JADA delivered conductor for the central solenoid to the United States. Photo: US ITER

An ultra-compact DC 1.3 MV testing power supply for the neutral beam injection system. Photo: JA DA

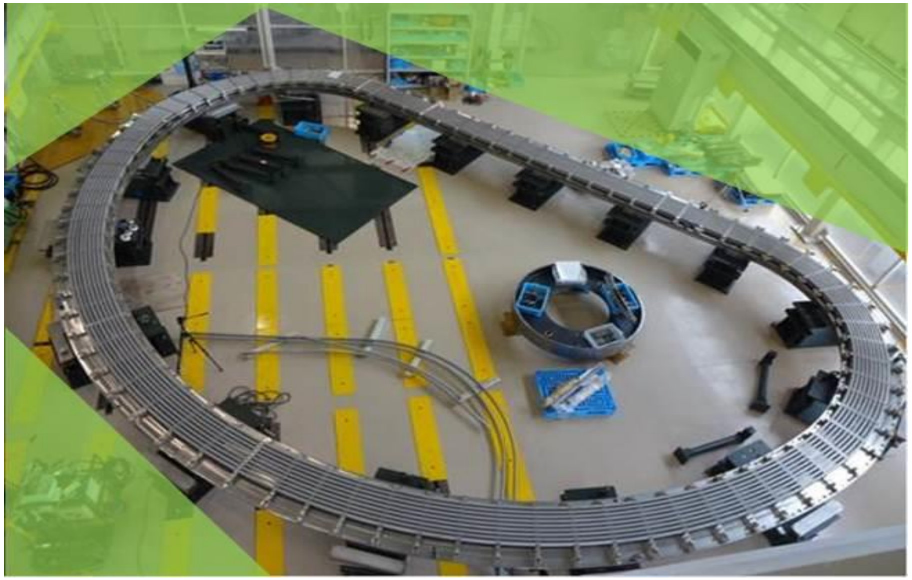
An advanced gyrotron design was manufactured which demonstrated 1 MW for >400 s. Photo: JA DA

Winding technology established and manufacture of TF coils is well underway in Japan



- JA DA have demonstrated winding technology for TF Coils using dummy conductors
- Production winding has started with 7 double pancakes completed

- Other JADA development activities:
  - TF coil structures
  - Diverter plasma-facing unit
  - Remote handling technology for ITER blanket
  - Diagnostics



Vacuum vessel fabrication is progressing well in Korea

Manufacturing of vacuum vessel sector 6 is on-going at HHI of Korea.

◄ Completion of welding of inter-modular and centering keys of inner shell of upper segment (PS2)

◄ Completion of forming of inner shell and machining of diverter rail, port stub corner, 4-pipe & IVV penetration of lower segment (PS4)

◄ Start welding after inner and outer jigs for inner shell of equatorial segment (PS3)

◄ Completion of inner and outer jigs for welding after forming of inner shell of inboard segment (PS1)

Equatorial and lower port fabrication is progressing well in Korea

Vacuum Vessel Equatorial and Lower Ports Manufacture Underway

LPSE Mock-up

Machining of Port Components

Inner shell welding

Welded Inner Shells

Poloidal field conductor and TF busbar have been produced in Russia

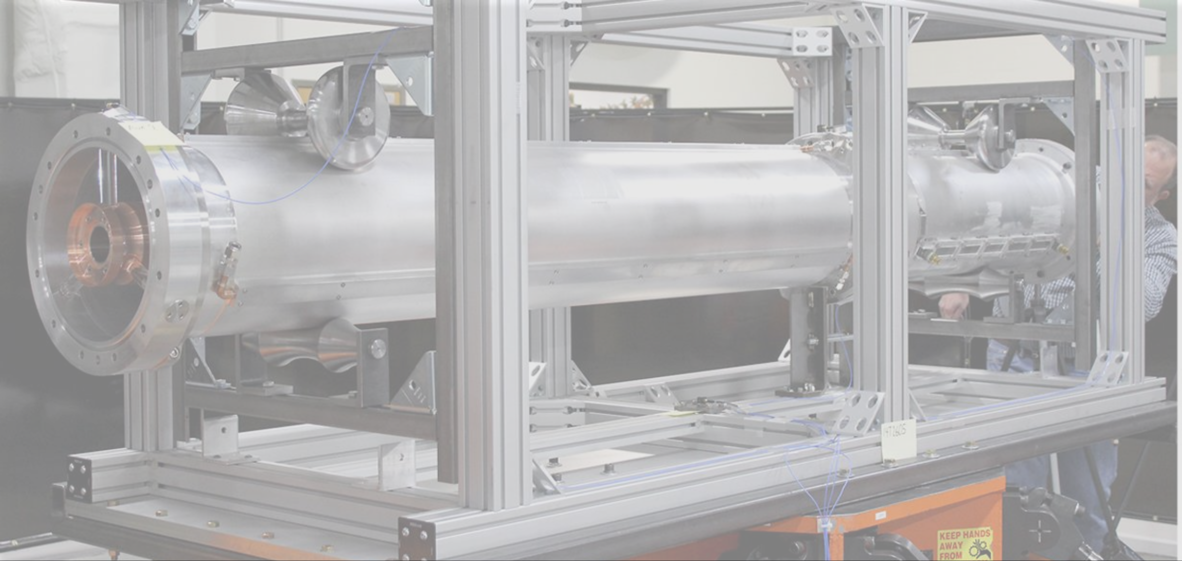
The first production lengths of conductor for poloidal field coil #1 have been manufactured. Jacketing and compaction were completed in Italy. Photo: ITER Organization

A prototype of the toroidal field busbar for the toroidal field magnet coils. Photo: ITER RF

Cryostat base and neutral beam dump components have been fabricated in India

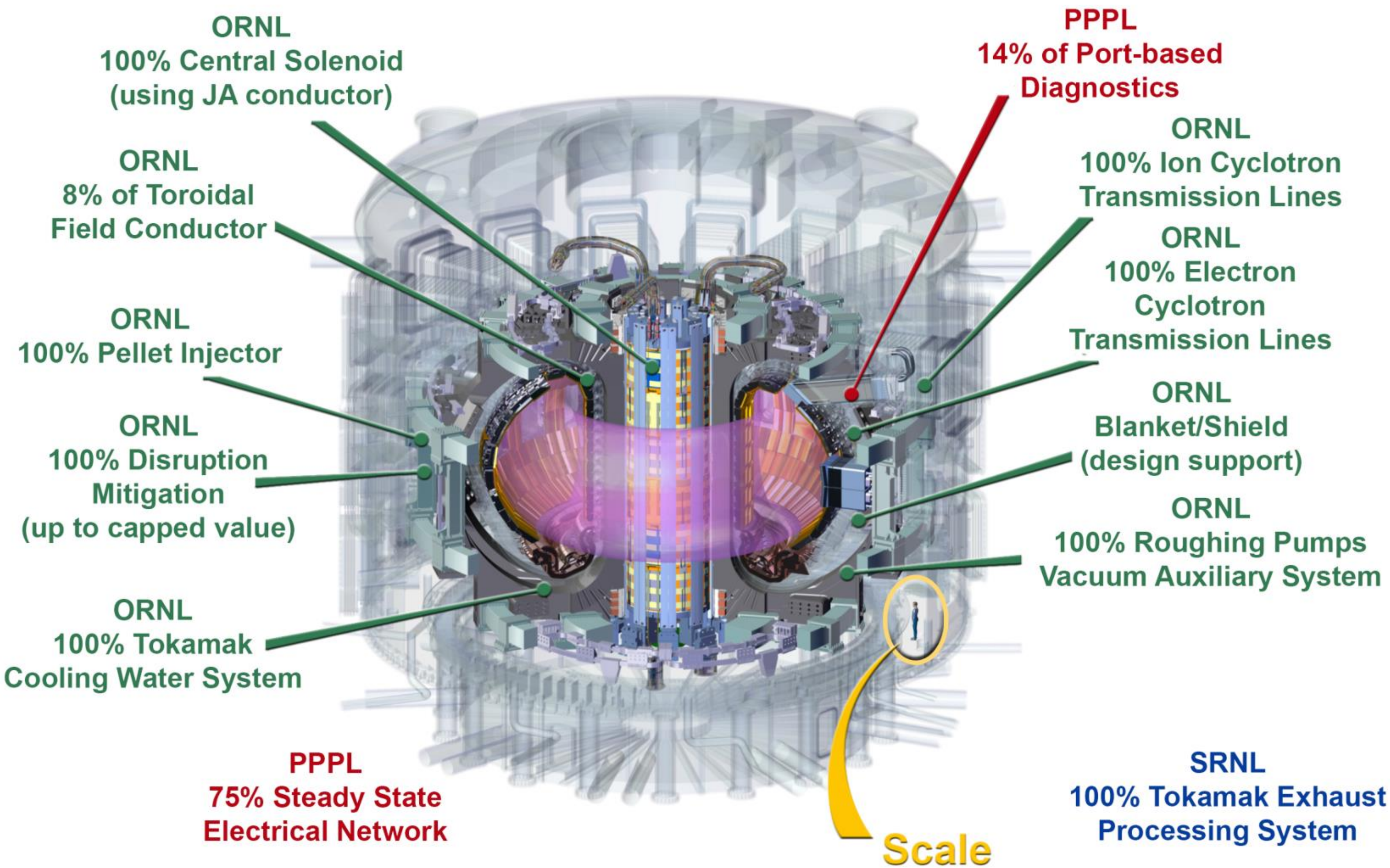
Cryostat base fabrication at Larsen & Toubro in Hazira, India (December 2014). Photo: ITER India

The SPIDER neutral beam dump component was delivered to the PRIMA neutral beam test bed in Padau, Italy. Photo: ITER Organization



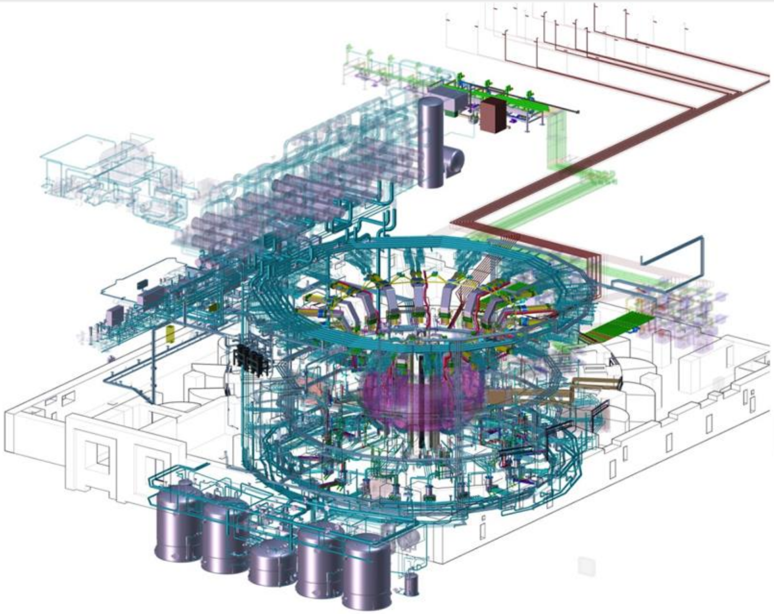
US FY 2014-15 Status and Achievements

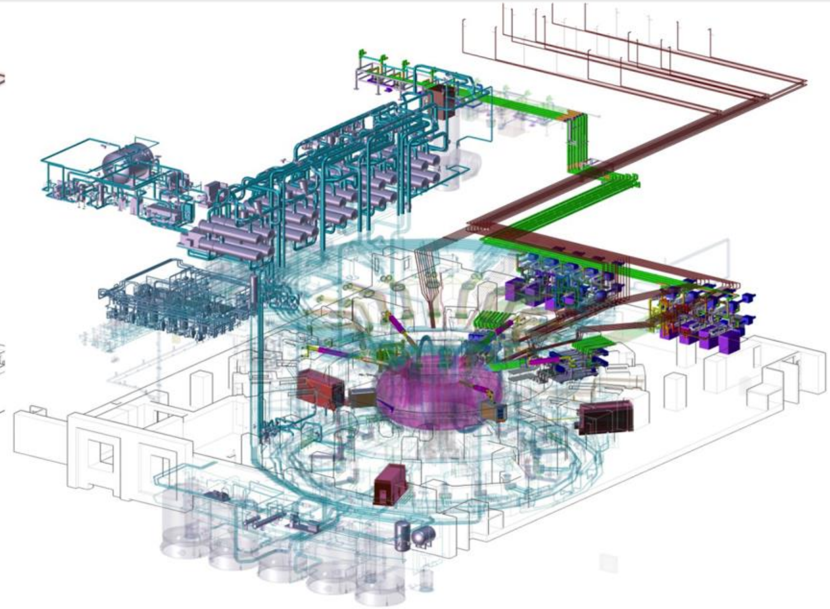
US Scope



ORNL: Oak Ridge National Laboratory PPPL: Princeton Plasma Physics Laboratory SRNL: Savannah River National Laboratory

US scope will be delivered in 2 Phases





1st Plasma

Post-1st Plasma

Full Production

- Central Solenoid
- Toroidal field conductor
- Steady-state electrical network

Partial Production / Completion of Production

- Ion/electron cyclotron heating
- Diagnostics
- Roughing pumps
- Pellet injection
- Tokamak cooling water system
- Vacuum auxiliary system

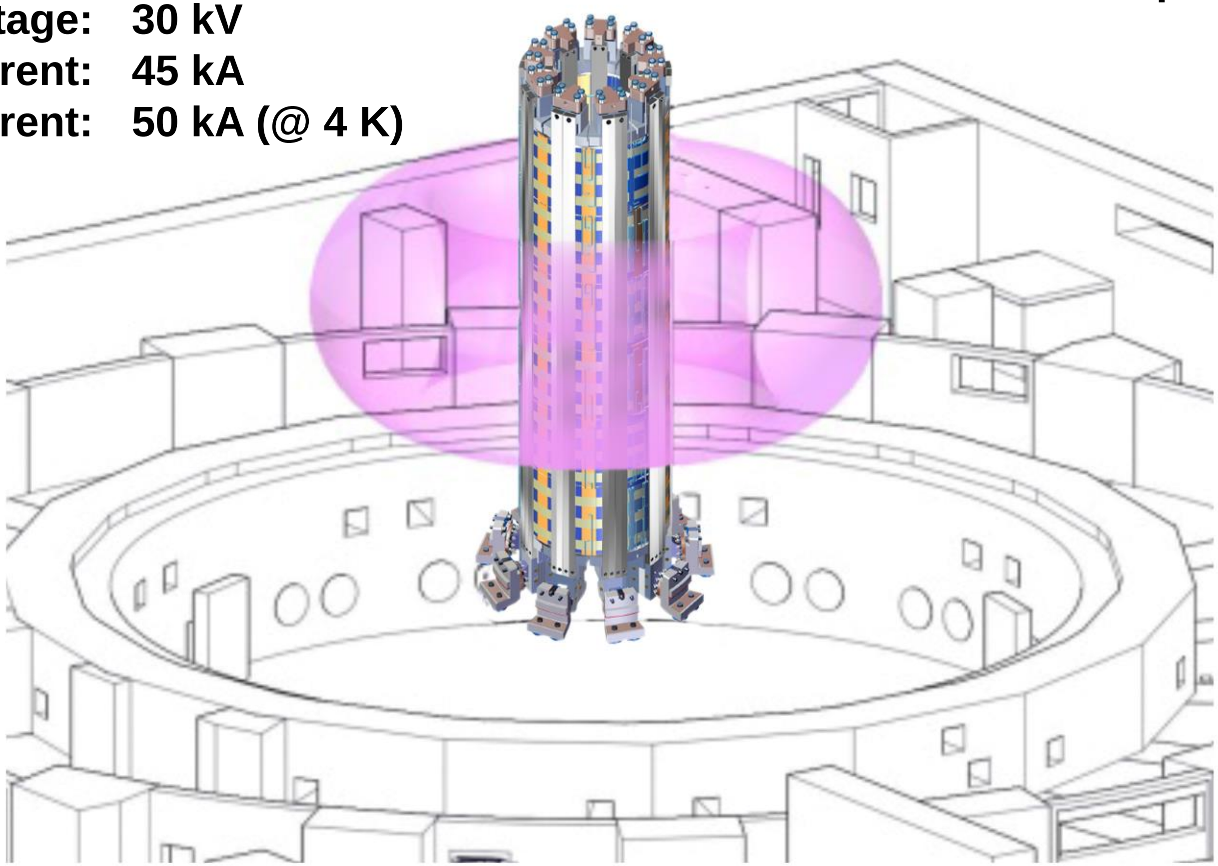
Full Production

- Tokamak exhaust processing
- Disruption mitigation

Central solenoid pulsed super-conducting electromagnet is now under manufacture

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



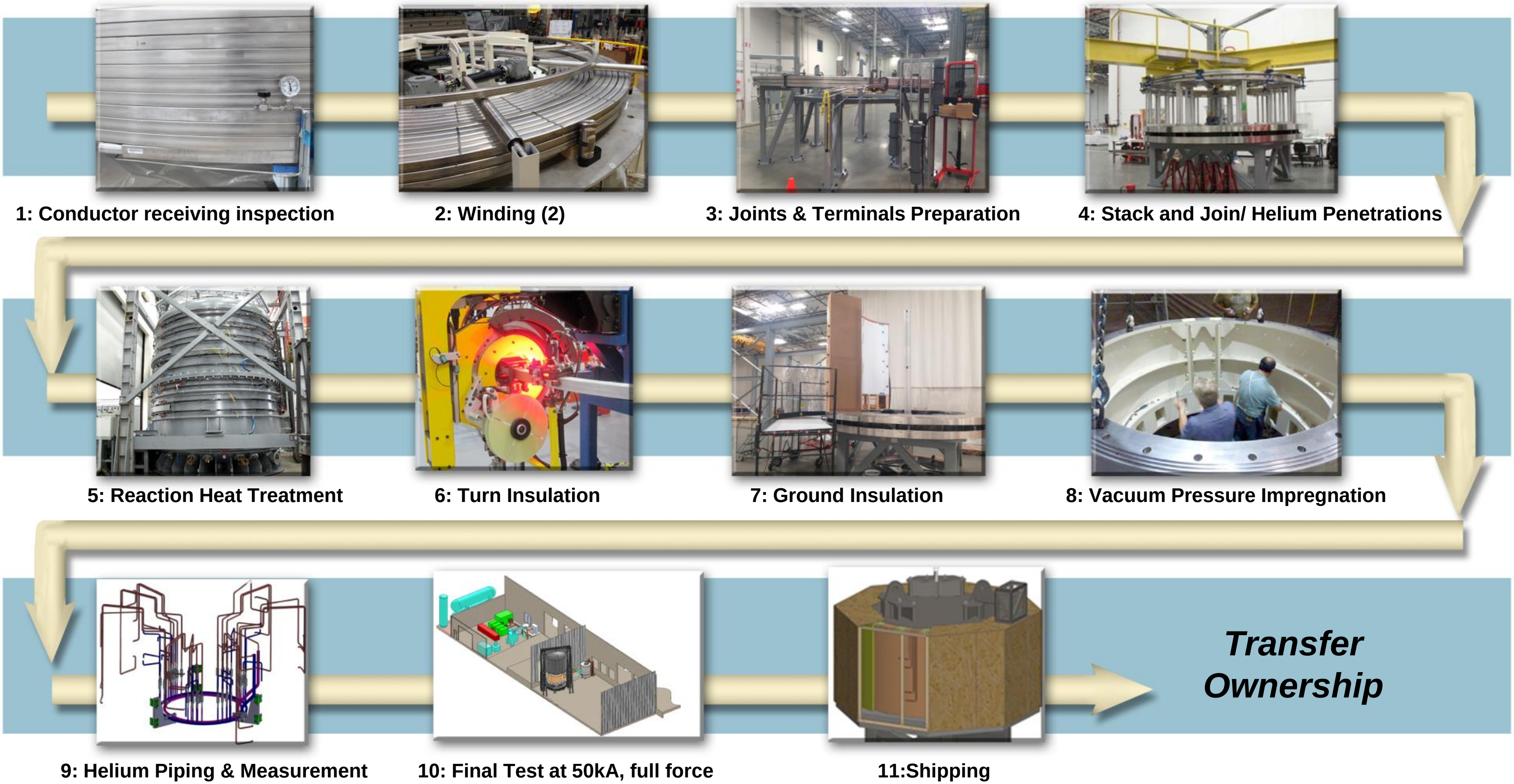
(5.5 Gigajoule stored energy capacity)

Central Solenoid modules fabrication preparation is well underway

Central solenoid fabrication facility ramping up at General Atomics in Poway, California

- 5 of 11 tooling stations in place
- 2 of 11 tooling stations in operation
- Mock-up coil winding completed

Module tooling stations are being installed and commissioned at General Atomics



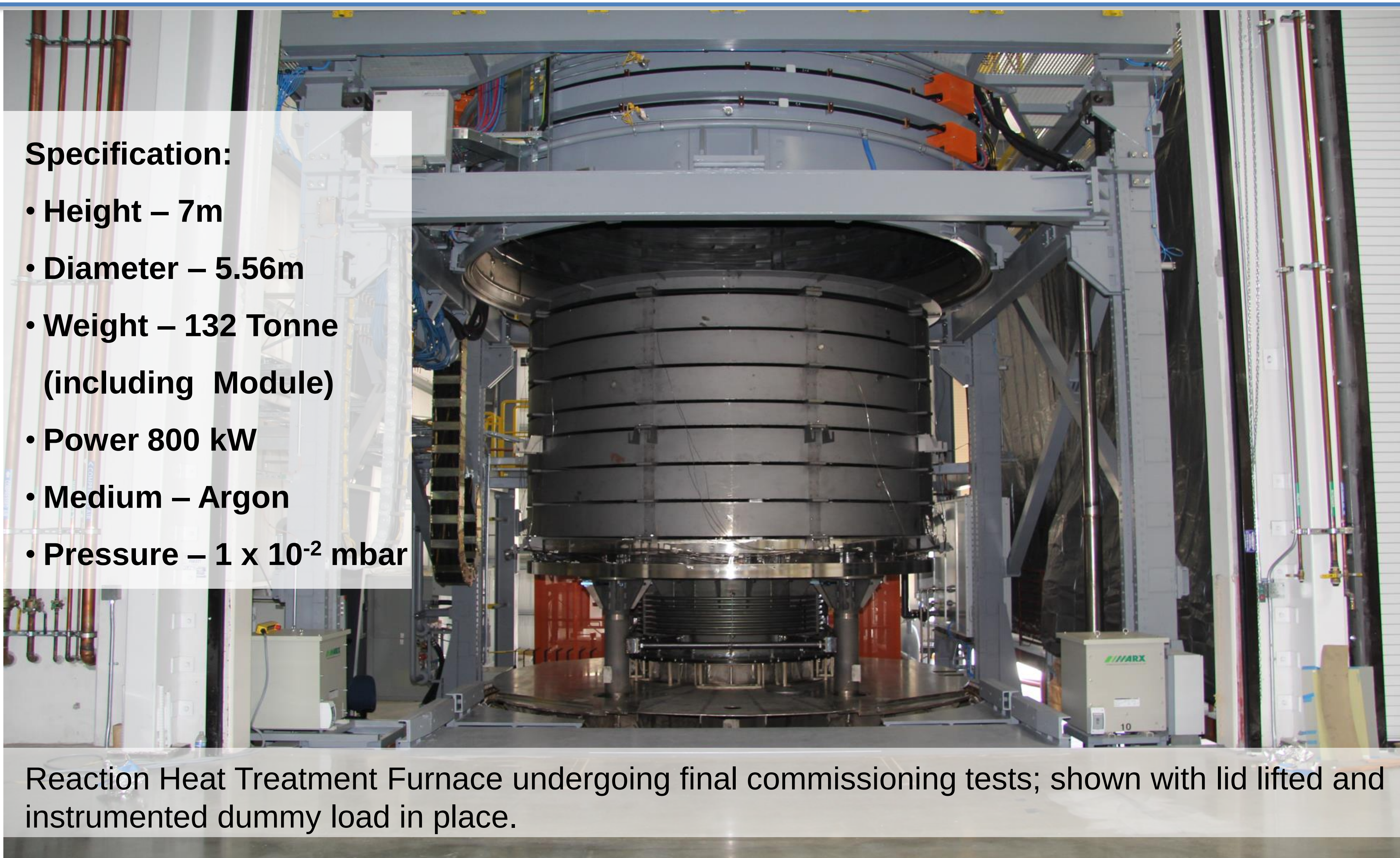
Central Solenoid mock-up coil winding successfully completed


Winding of the mock-up hexapancake.


Completed mock-up hexapancake.

Winding of the first production module will begin in March 2015.
Photos: GA

Reaction Heat Treatment Furnace is installed at GA

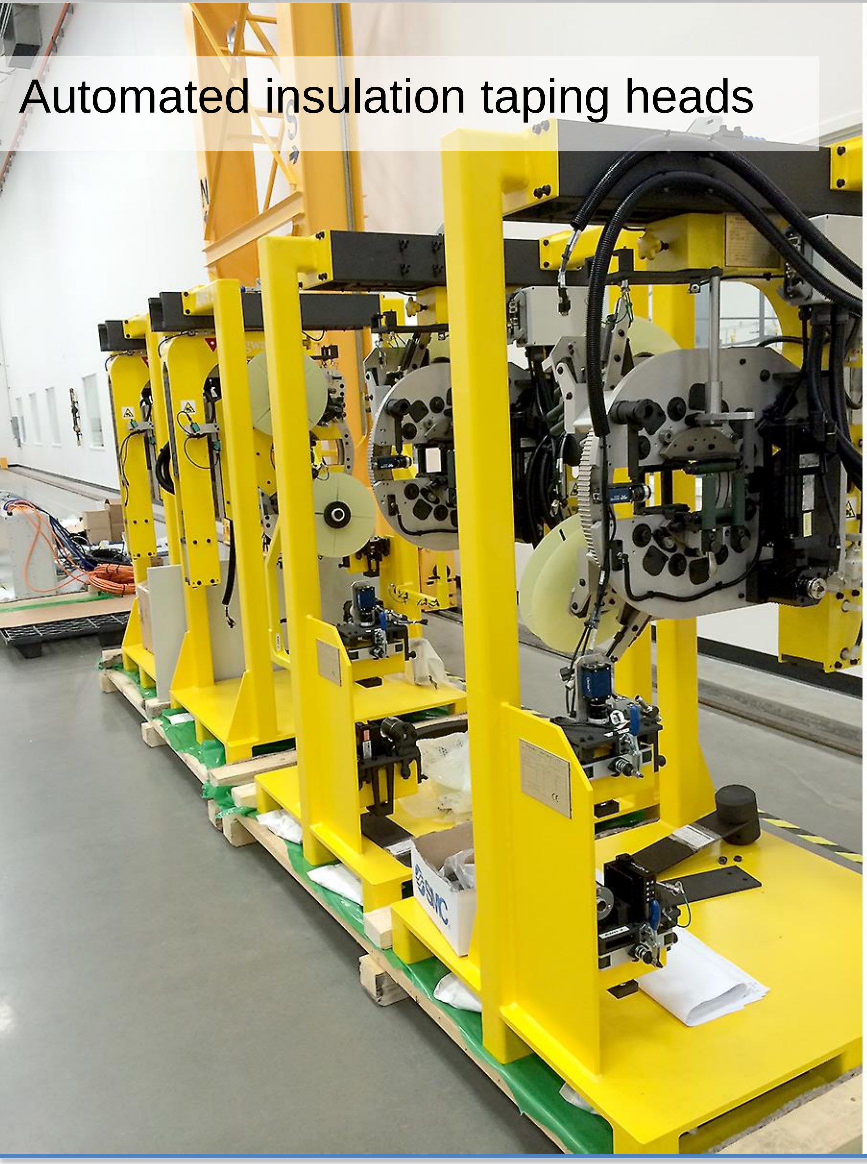


Specification:

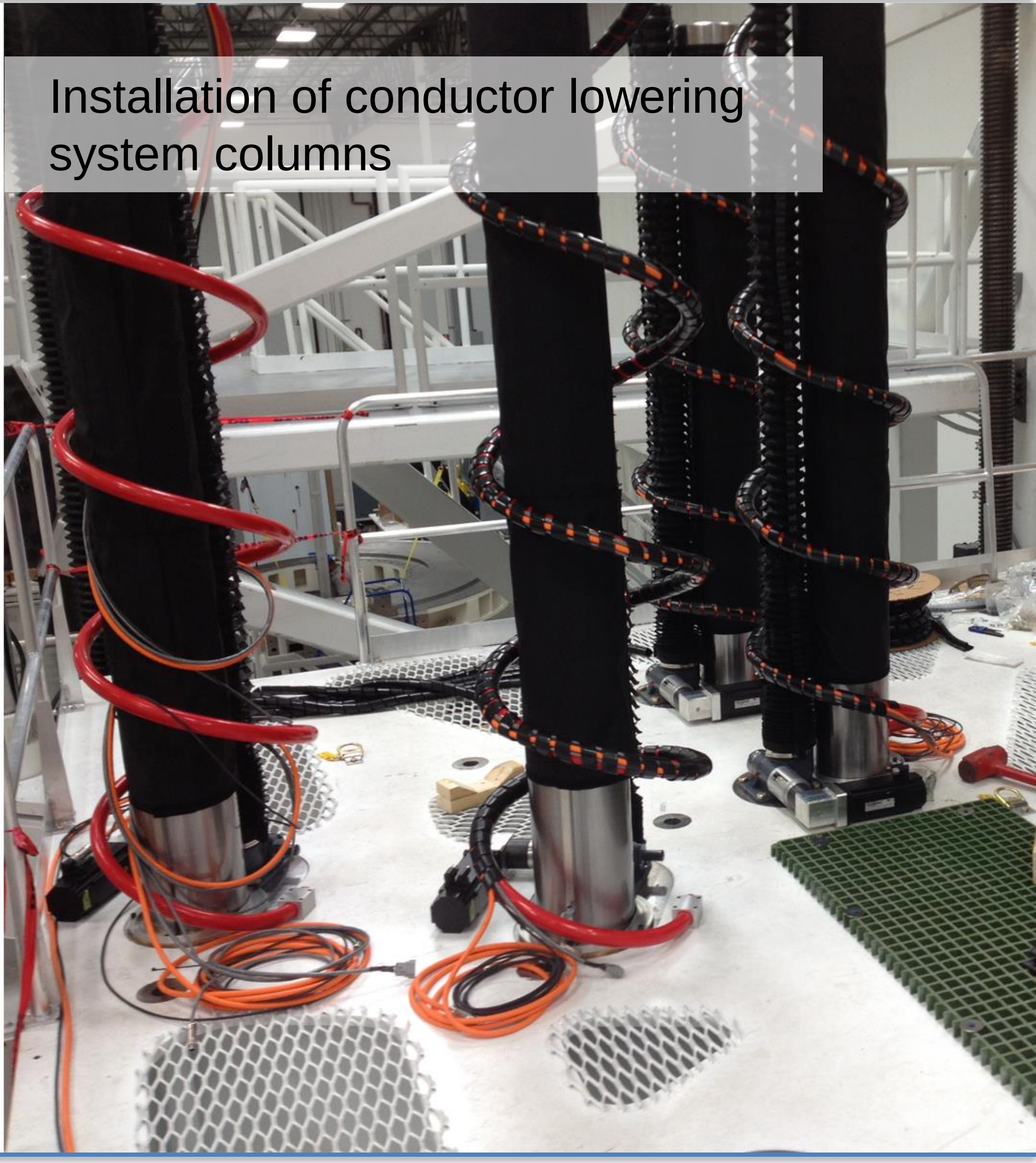
- **Height – 7m**
- **Diameter – 5.56m**
- **Weight – 132 Tonne (including Module)**
- **Power 800 kW**
- **Medium – Argon**
- **Pressure – 1 x 10^{-2} mbar**

Reaction Heat Treatment Furnace undergoing final commissioning tests; shown with lid lifted and instrumented dummy load in place.

Installation and commissioning is progressing on several tooling stations



Automated insulation taping heads

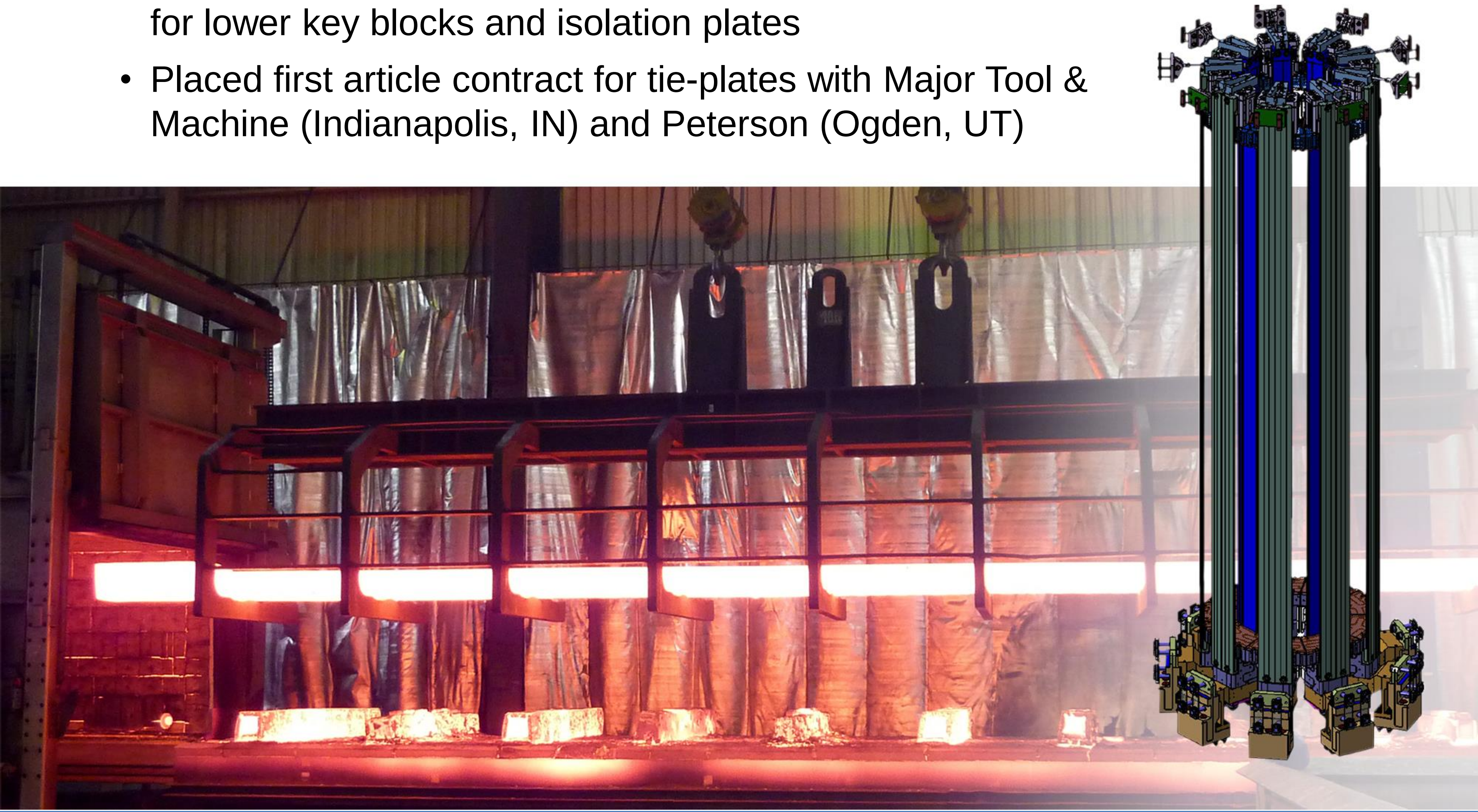


Installation of conductor lowering system columns

Turn insulation station has been assembled and is being commissioned

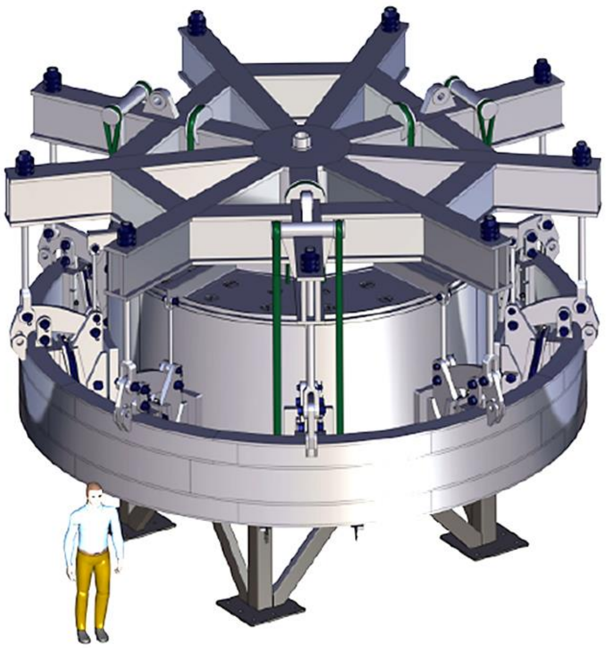
Central Solenoid structures are now in the manufacturing stage

- Placed first production contract with Peterson (Ogden, UT) for lower key blocks and isolation plates
- Placed first article contract for tie-plates with Major Tool & Machine (Indianapolis, IN) and Peterson (Ogden, UT)

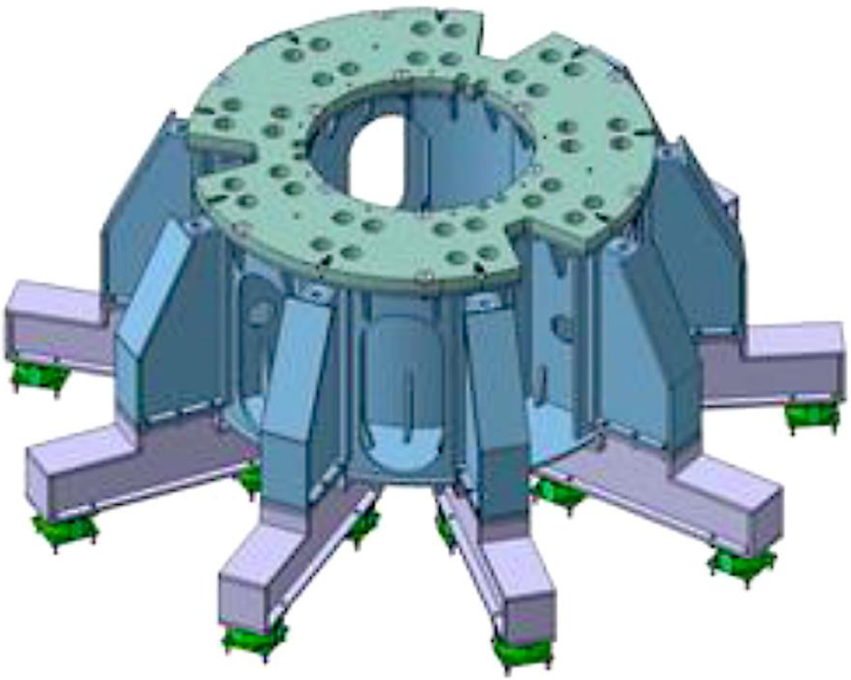


Central Solenoid assembly tooling (1st phase) has completed final design and is in the pre-procurement stage

- Final design review completed for the early need fixtures (assembly platform, module rotating fixture, and module lifting fixture)
- Award contracts for both fixtures this year
- Final design review for remaining fixture this year



Module Lifting Fixture

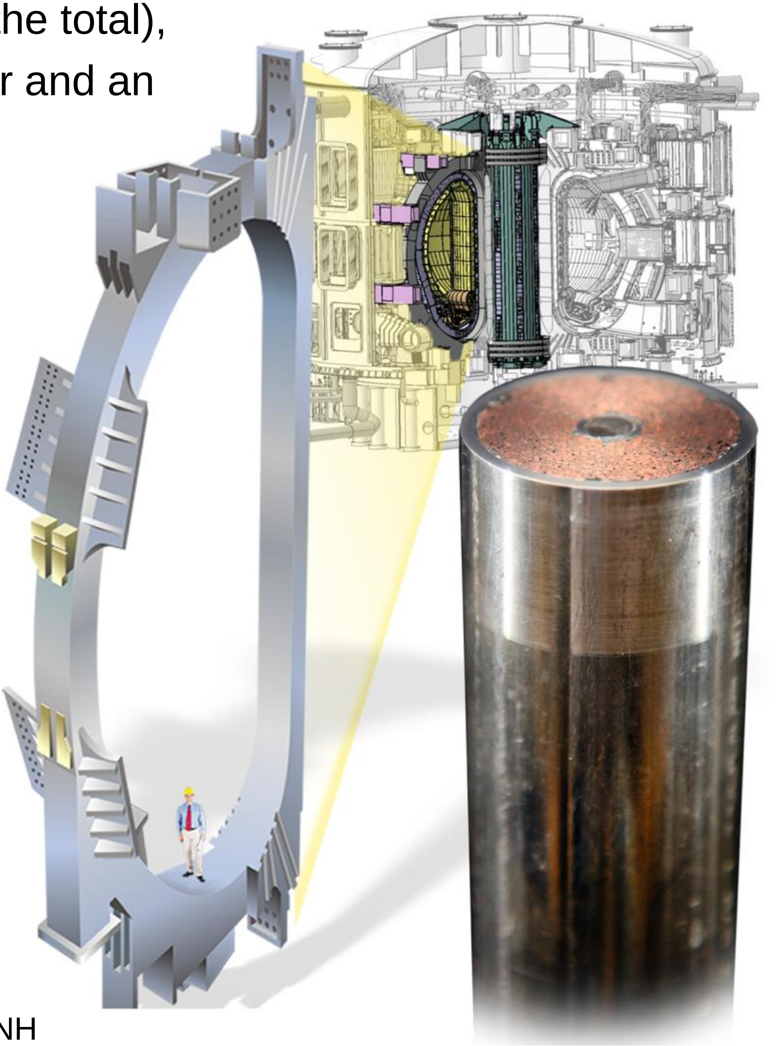


Assembly Platform

Cabling of TF conductor and deliveries to Europe of integrated conductor continue

- US is responsible for providing:
  - Nine 800 m TF conductor unit lengths (8% of the total),
  - Plus qualifying 100 m lengths for each supplier and an 800 m sample.

Production conductor cabled at New England Wire Technologies in Lisbon, NH



Three TF conductor shipments are scheduled in 2015

Completed Shipments:

US TF 800 m sample (dummy) conductor – *Delivered June 2014*

US TF 100 m active conductor (Oxford) – *Delivered July 2014*

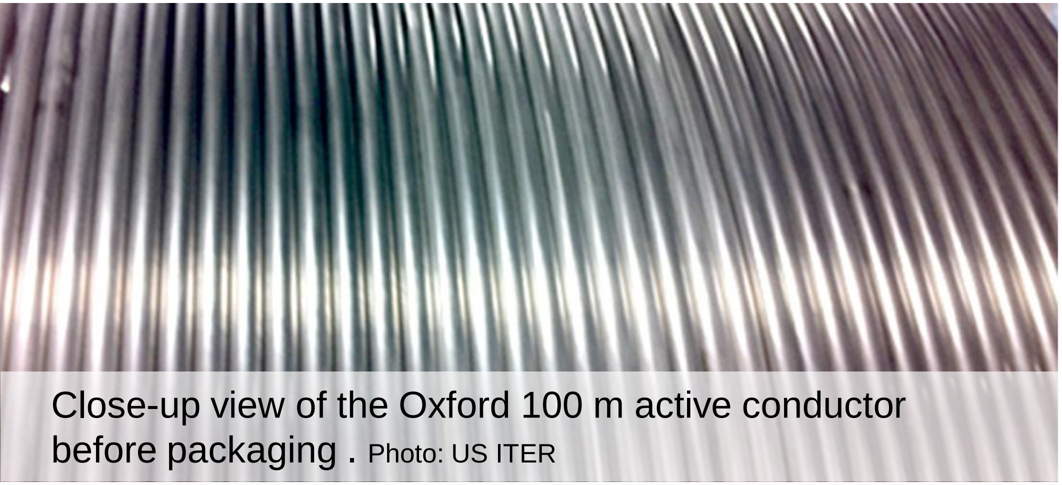
US TF 800 m production conductor (Oxford) – *Delivered January 2015*

Upcoming Shipments:

US TF 100 m active conductor (Luvata) – *April 2015*

US TF 800 m production conductor (Luvata) – *September/October 2015*

All TF shipments are scheduled to be completed in 2016

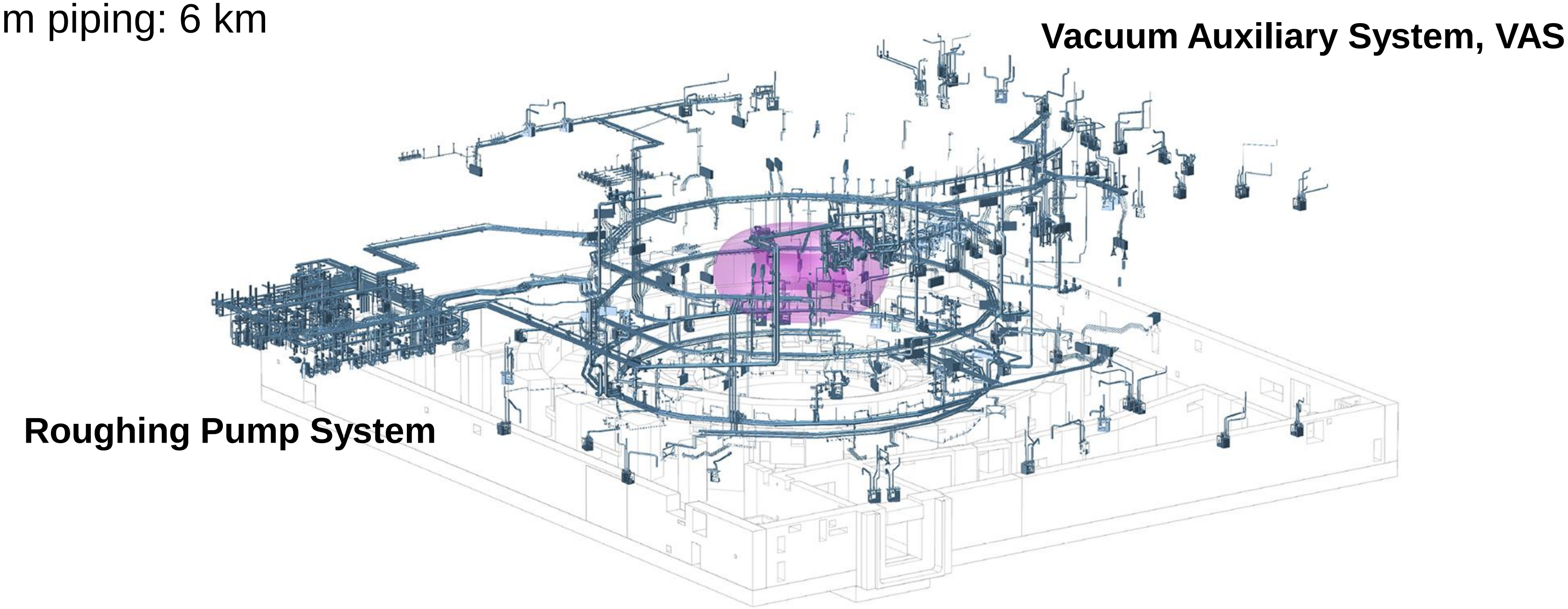


Close-up view of the Oxford 100 m active conductor before packaging . Photo: US ITER

The 800 m Oxford production conductor shown loaded on a vessel in Charleston, SC for shipment to the EU winding facility in La Spezia, Italy.
Photo: US ITER

Vacuum Auxiliary Systems and Roughing Pumps are progressing through design and into procurement

- 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



Cryogenic Viscous Compressor pump fabricated and pre-cryogenic testing completed

Manufacture of the prototype tritium compatible Cryogenic Viscous Compressor (CVC) was completed and is now being prepared for performance testing at the Cryogenic Test Facility at the Oak Ridge National Laboratory SNS facility.

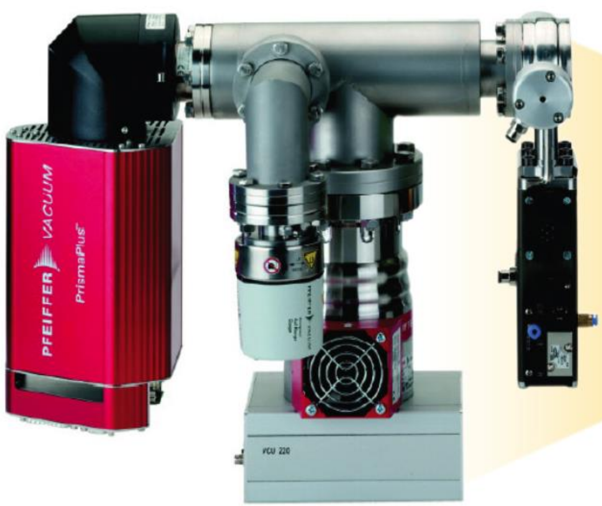
CVC Inner Core with multi layer insulation

CVC Inner Core with thermal shield

CVC assembly undergoing thermal cool down

US has already delivered vacuum equipment to the IO

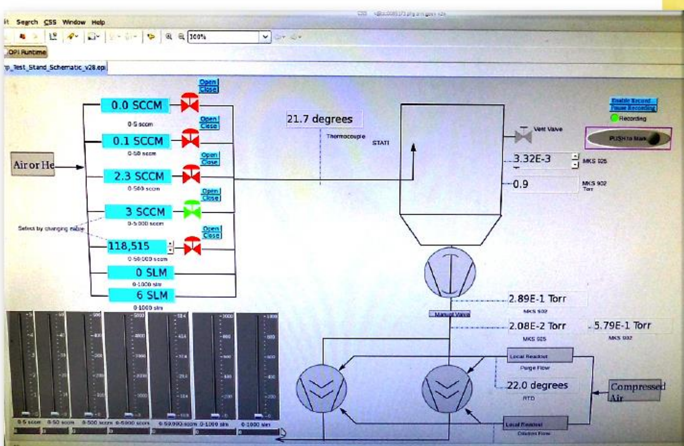
- Delivered Portable Residual Gas Analyzer Station (the 14th of 15 vacuum test components)
- VAS-01 Piping Procurement Centralization Arrangement signed; implementation underway at the IO



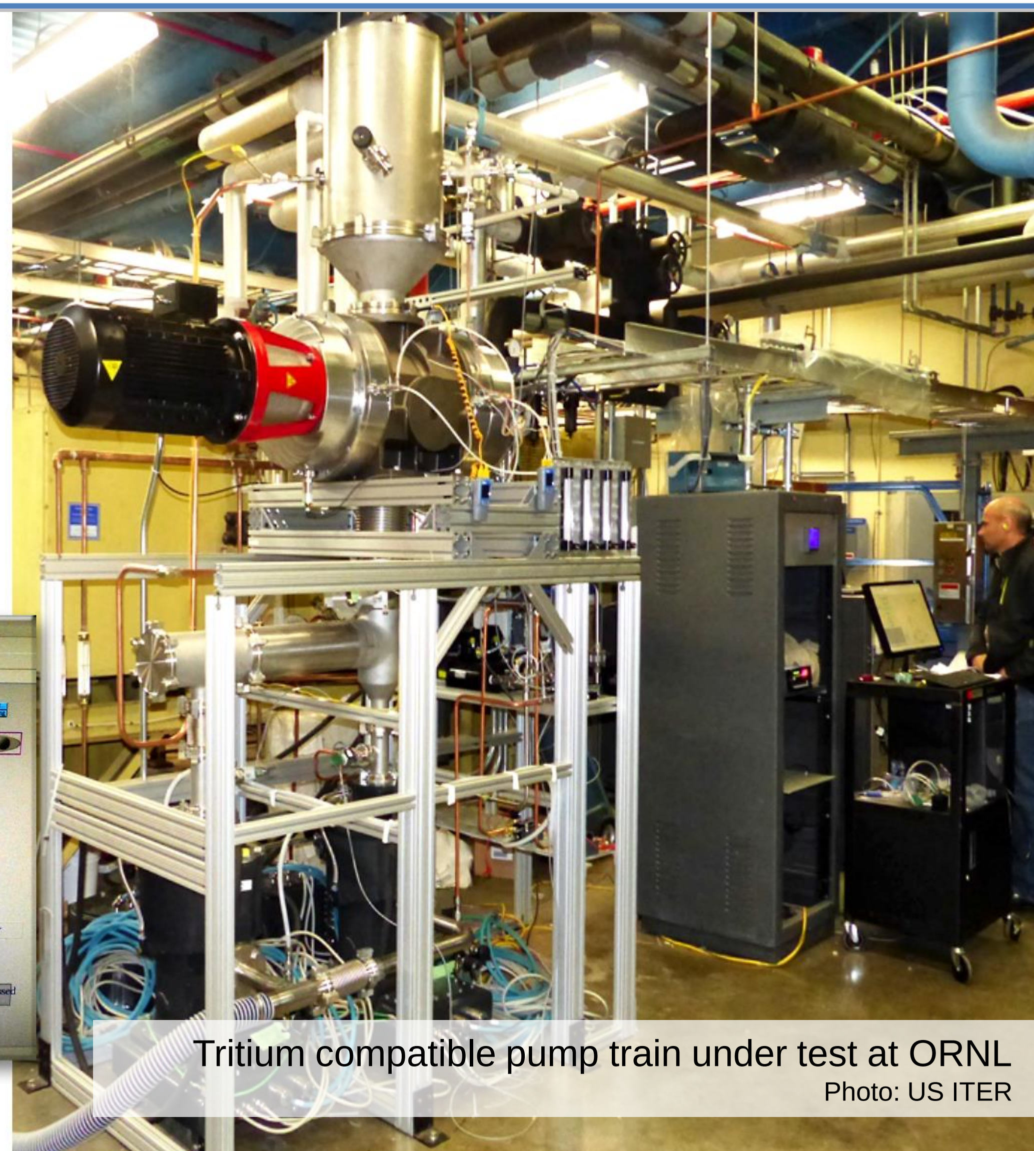
Portable Residual Gas Analyzer Station

Roughing pump testing was successfully completed at ORNL

- Testing of prototype tritium compatible roots and screw pump train completed at ORNL
- Results show good light gas (He) pumping performance
- Pumps to be delivered to IO early in 2015



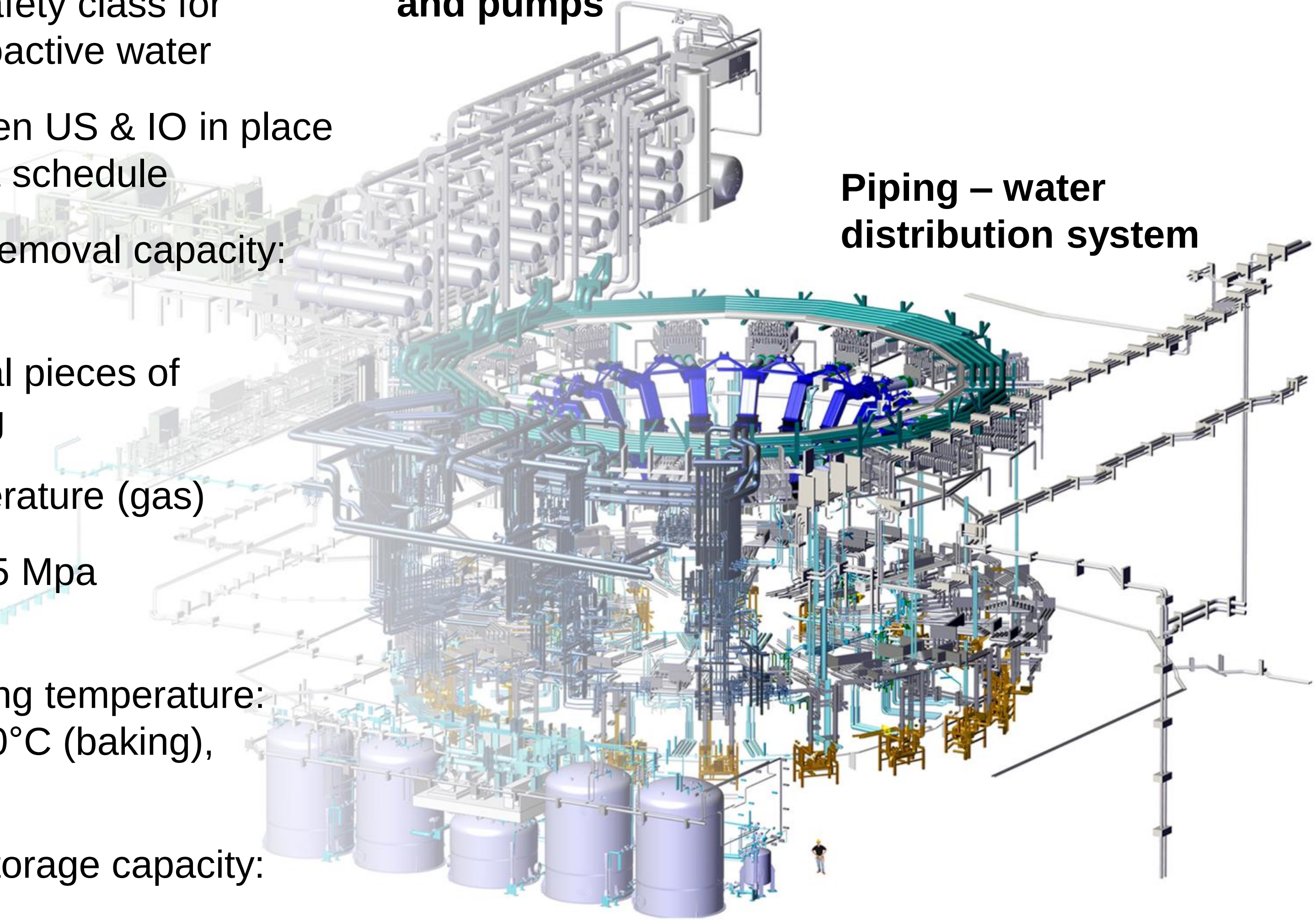
Data acquisition and control interface for roots and screw pump train



Tritium compatible pump train under test at ORNL
Photo: US ITER

Tokamak Cooling Water System (TCWS) design being optimized

- Nuclear system – safety class for confinement of radioactive water
- Arrangement between US & IO in place to optimize design & schedule
- Total installed heat removal capacity: 1,000 MW (thermal)
- 100+ major industrial pieces of equipment operating
- 400°C design temperature (gas)
- Design pressure of 5 Mpa (water @ 240°C)
- Max coolant operating temperature: 125°C (plasma), 240°C (baking), 350°C (gas baking)
- Radioactive water storage capacity: over 1,000,000 L



TCWS drain tanks are under manufacture at Joseph Oat Company

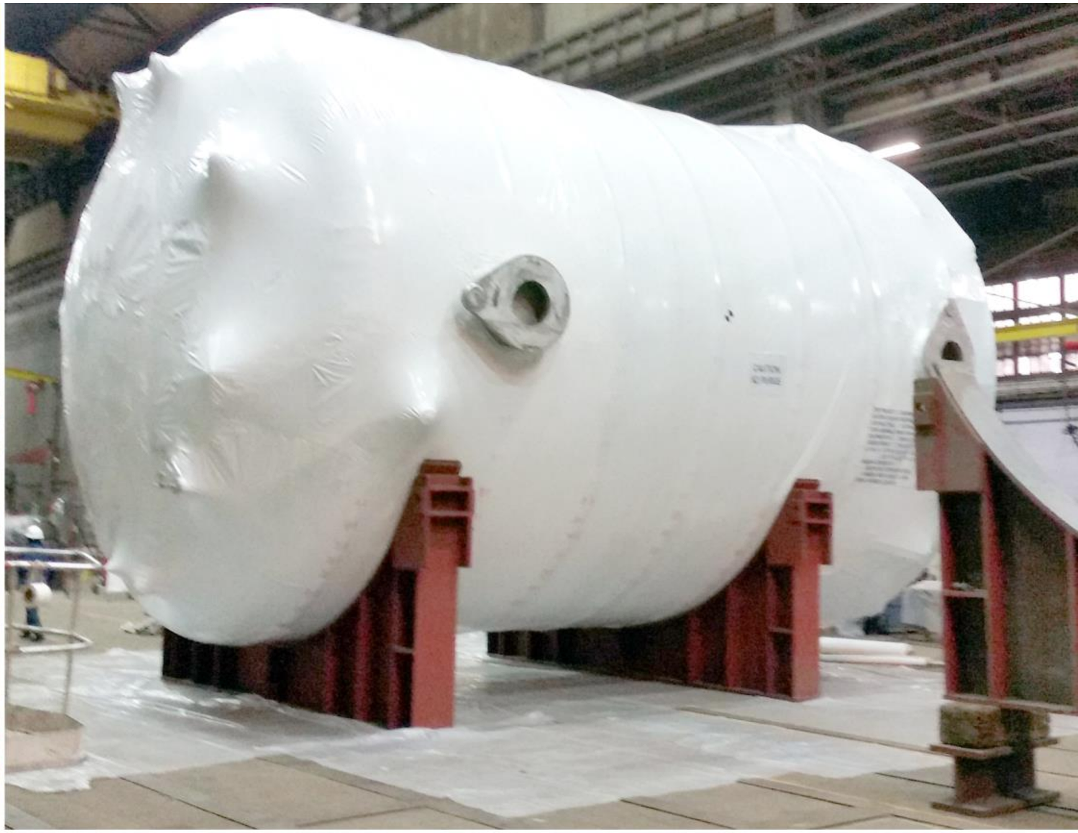
Joseph Oat Company, Camden, NJ is completing fabrication of drain tanks (four 61,000 gallon drain tanks and one ~30,000 gallon tank). At left, a completed tank undergoes a lifting test. At right, tanks in earlier stages of fabrication.

Photo: US ITER

First two drain tanks are ready for shipment to the IO

All (5) drain tanks scheduled to be delivered by April 2015

First shipment due to leave Joseph Oat Corporation in Camden, NJ in March.

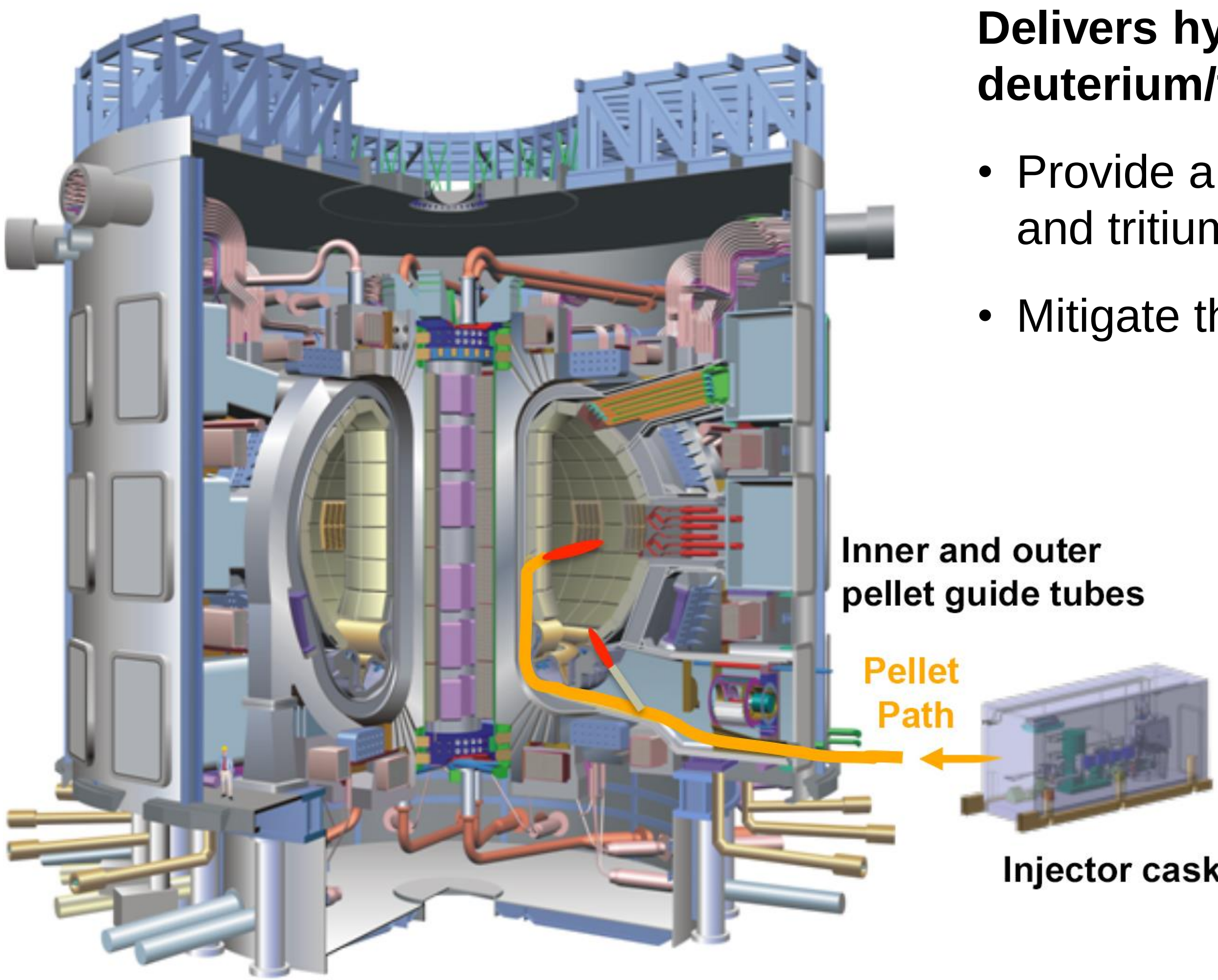


A 61,000 gallon drain tank (left) is part of the first shipment. Each drain tank will be shrink-wrapped for shipment (right).
Photo: US ITER

Pellet fueling and pellet pacing development activities are progressing

Delivers hydrogen, deuterium and deuterium/tritium pellets to:

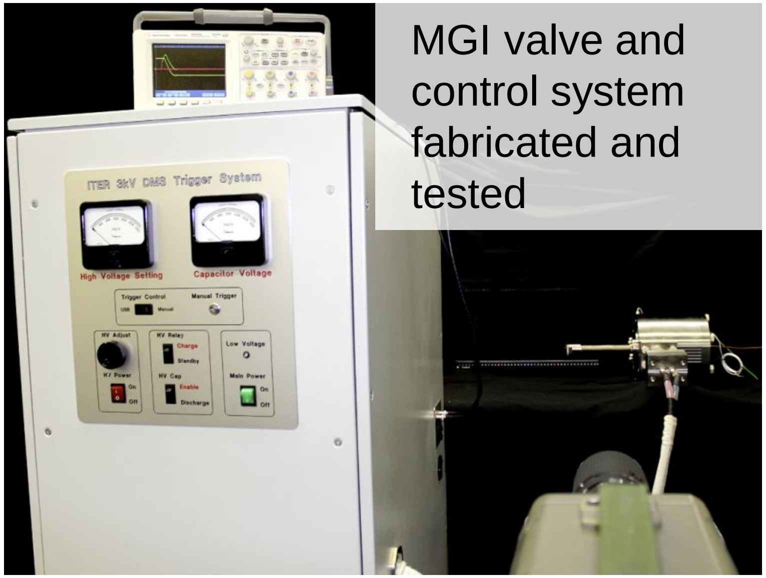
- Provide a steady supply of deuterium and tritium fuel
- Mitigate the impact of ELMs



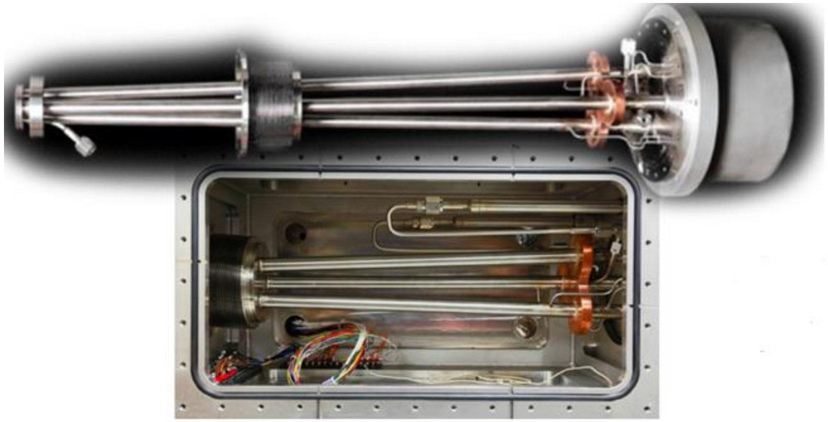
Configuration:

- 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

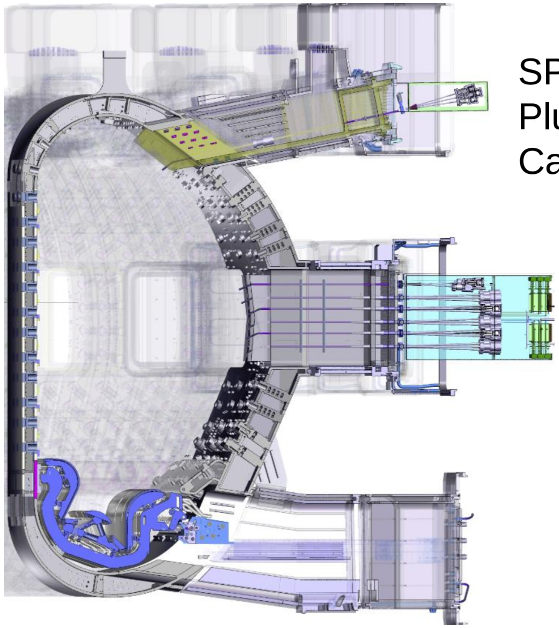
Disruption mitigation development hardware is now in testing



MGI valve and control system fabricated and tested



Three Barrel Pellet Unit for large pellet studies



SPI Upper Port Plug with MGI Capabilities

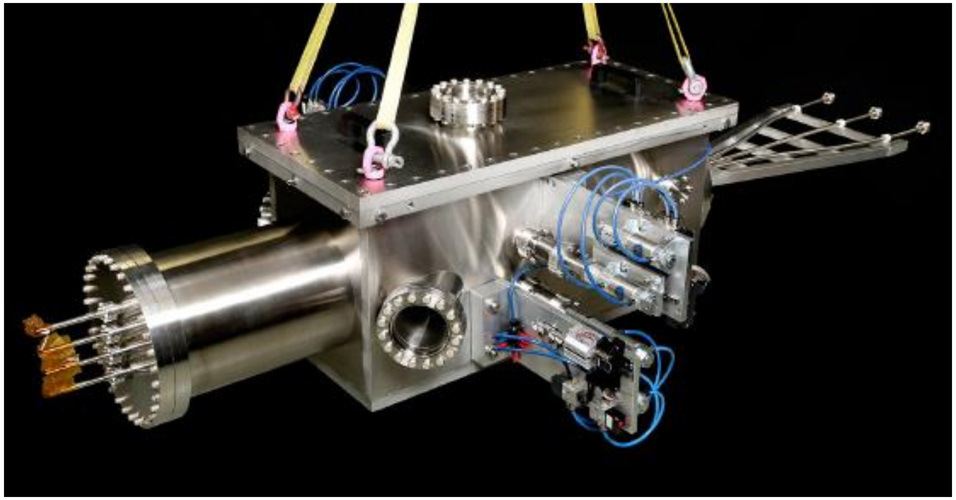
SPI Equatorial Port Plug with MGI Capabilities

System Configuration Selected
(SPI units outside of port plug w/ MGI capabilities)

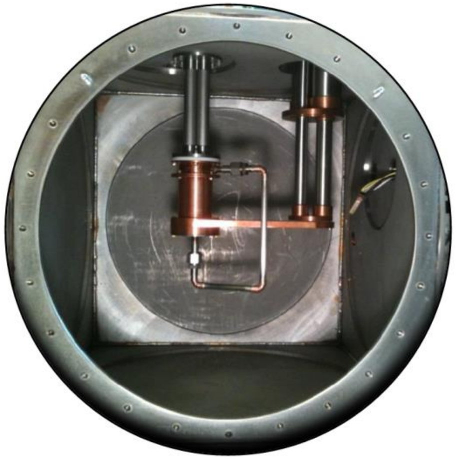
FY15 plan:

- Complete testing of large pellet equipment at ORNL
- Develop fast valves for SPI
- Complete testing of MGI flyer plate fast valve at full design pressure at ORNL

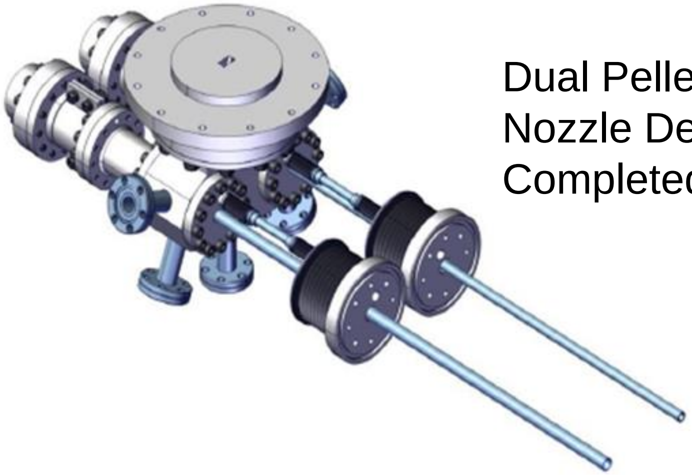
Pellet Injection development hardware is now under testing



Pellet Selector Designed, Built and Tested



Washington State University Twin Screw Extruder successfully extrudes hydrogen

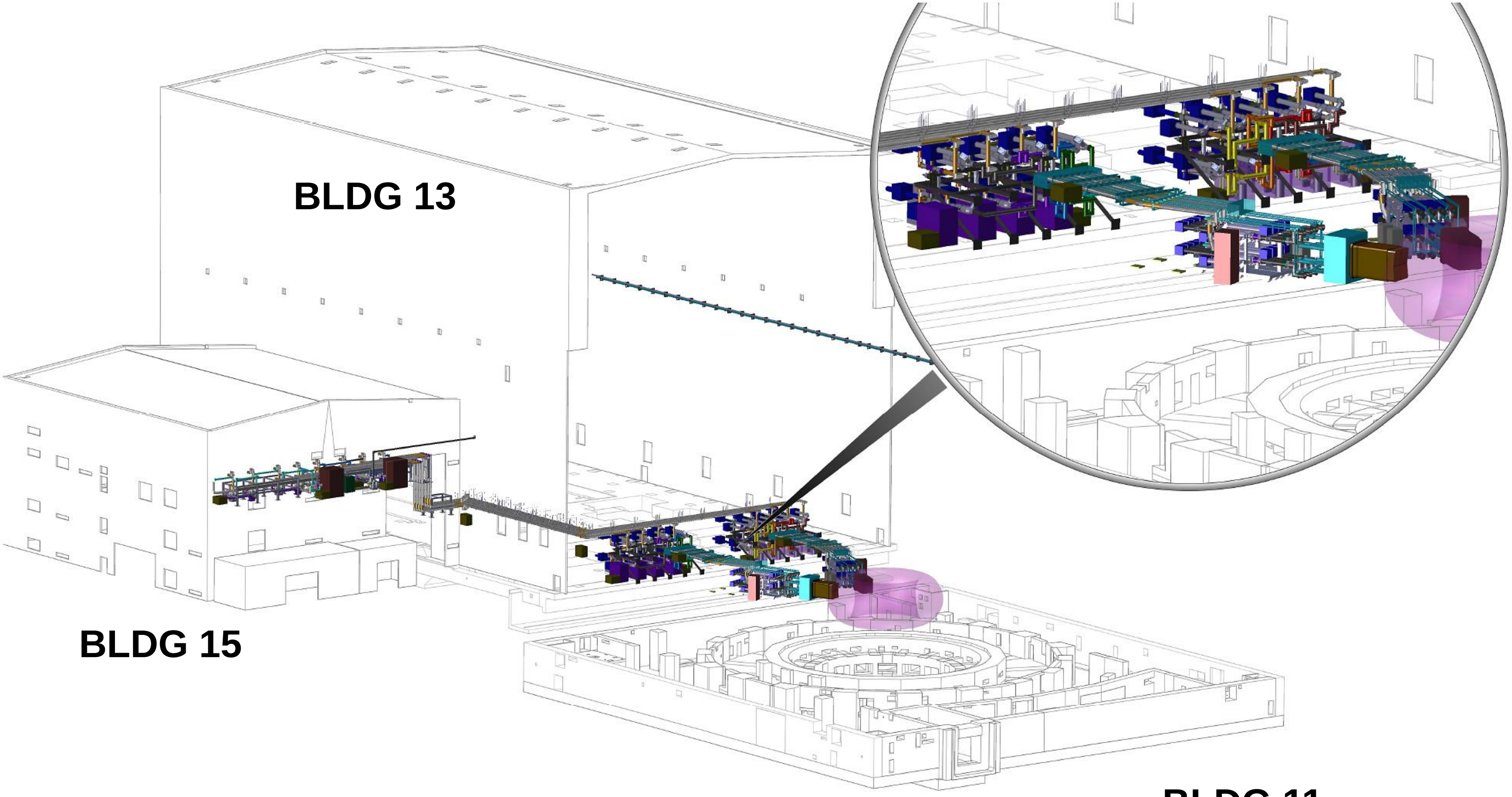


Dual Pellet Gun Nozzle Design Completed

FY15 plan:

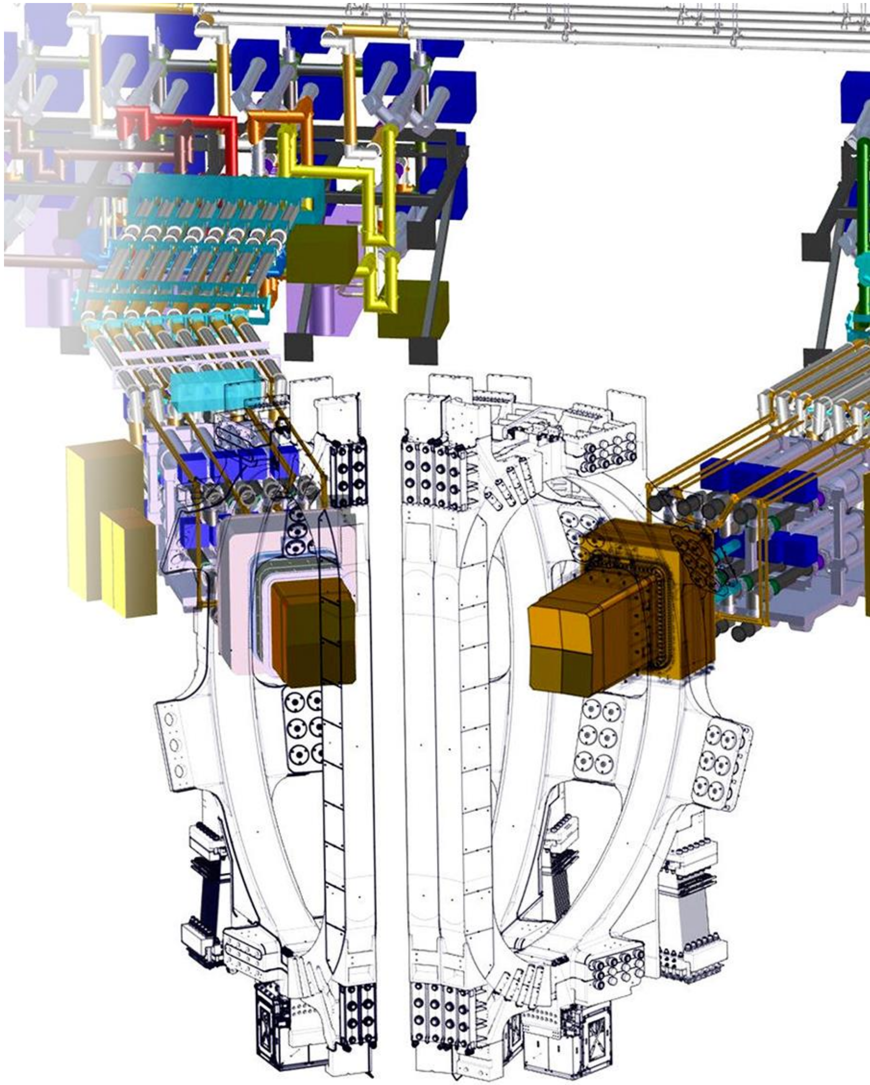
- Complete PDR of pellet injection flight tubes
- Successfully operate twin screw extruder in ORNL
- Design fuel recirculation loop and prove concept in lab

Ion cyclotron transmission lines and matching system are in the design and development stage



Ion cyclotron transmission lines have to transmit an unprecedented amount of sustained power

- 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 system



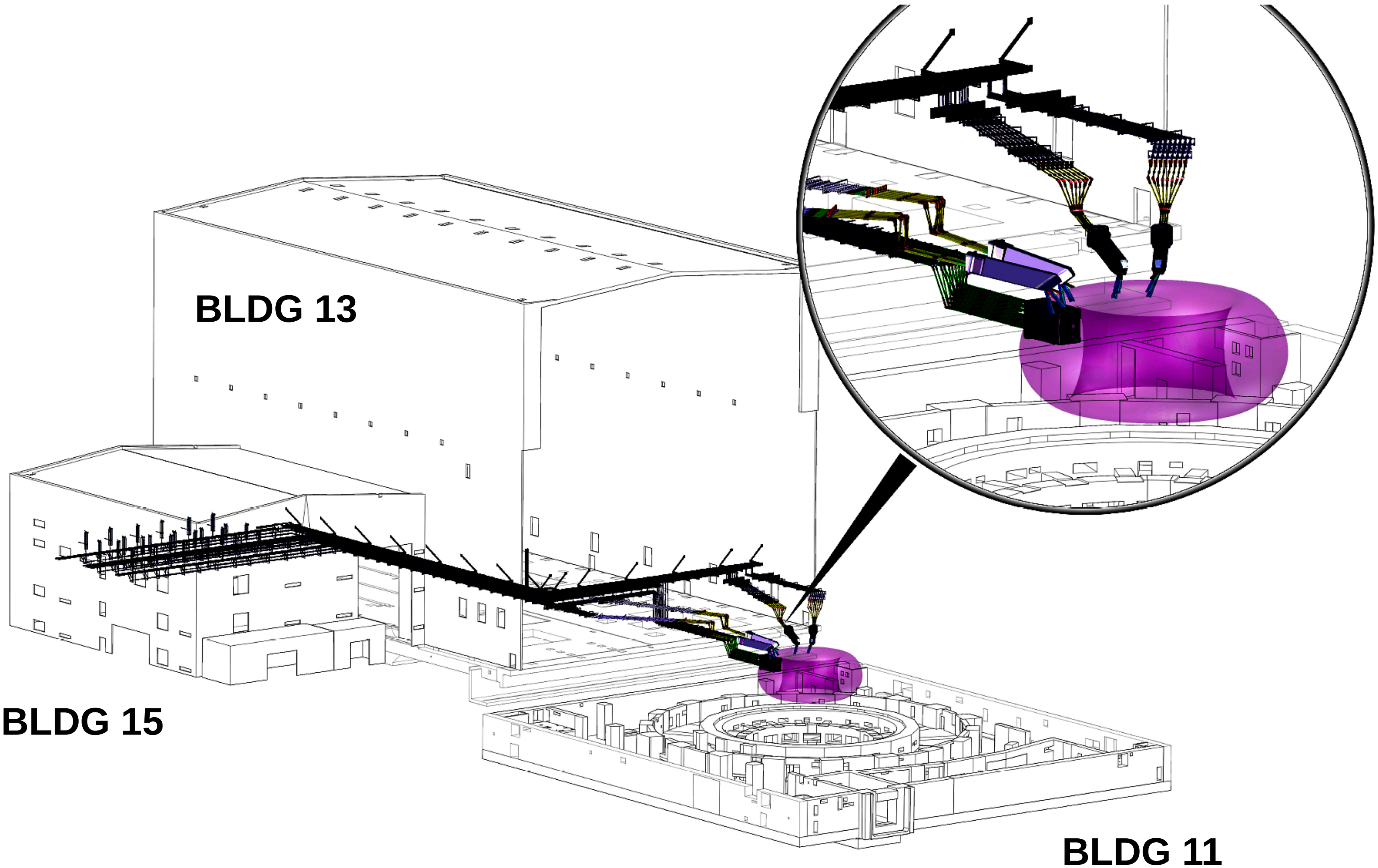
Ion cyclotron transmission lines have undergone testing

Prototype transmission line undergoes seismic testing on a shake table in Oak Ridge
Photo: US ITER

Further testing of ion cyclotron components will be completed this year

- Pressurized blower for gas cooling system
- Assembly Bellows to allow components to be installed without precision field-cut work.
- Rotary joint to reduce stress on transmission line from thermal expansion.
- Flexible joint to accommodate movement of the antennal from disruptions.

Electron cyclotron system transmission lines are in the design and development stage

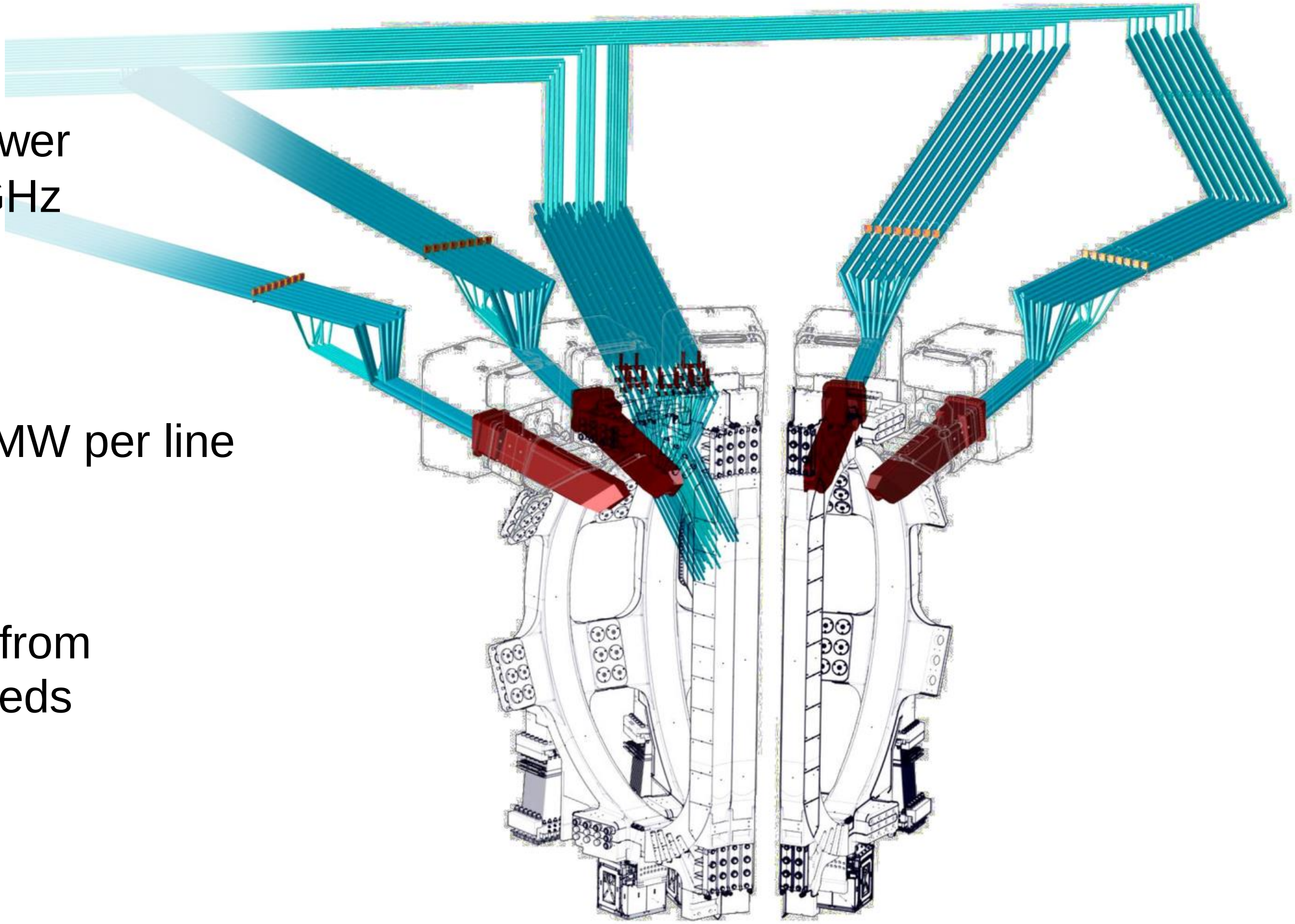


Electron cyclotron transmission lines must transmit high sustained power

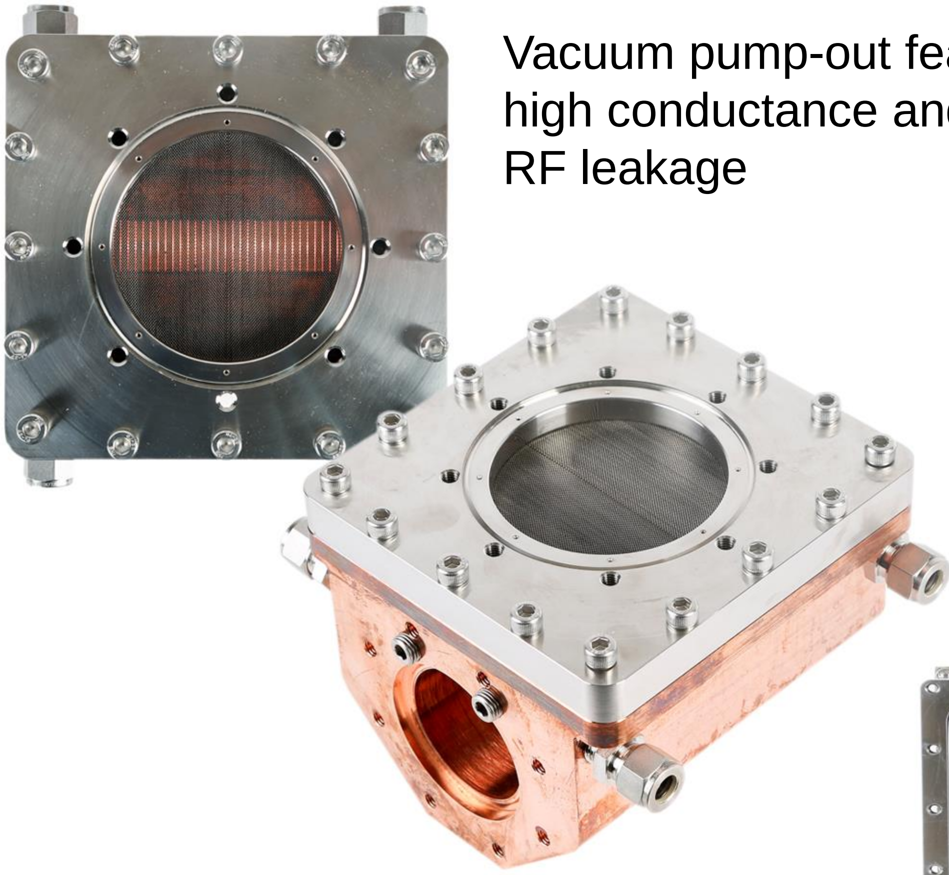
- Provide efficient power transfer from 170 GHz gyrotron sources to launchers

- Transmit up to 1.5 MW per line for 1 hour

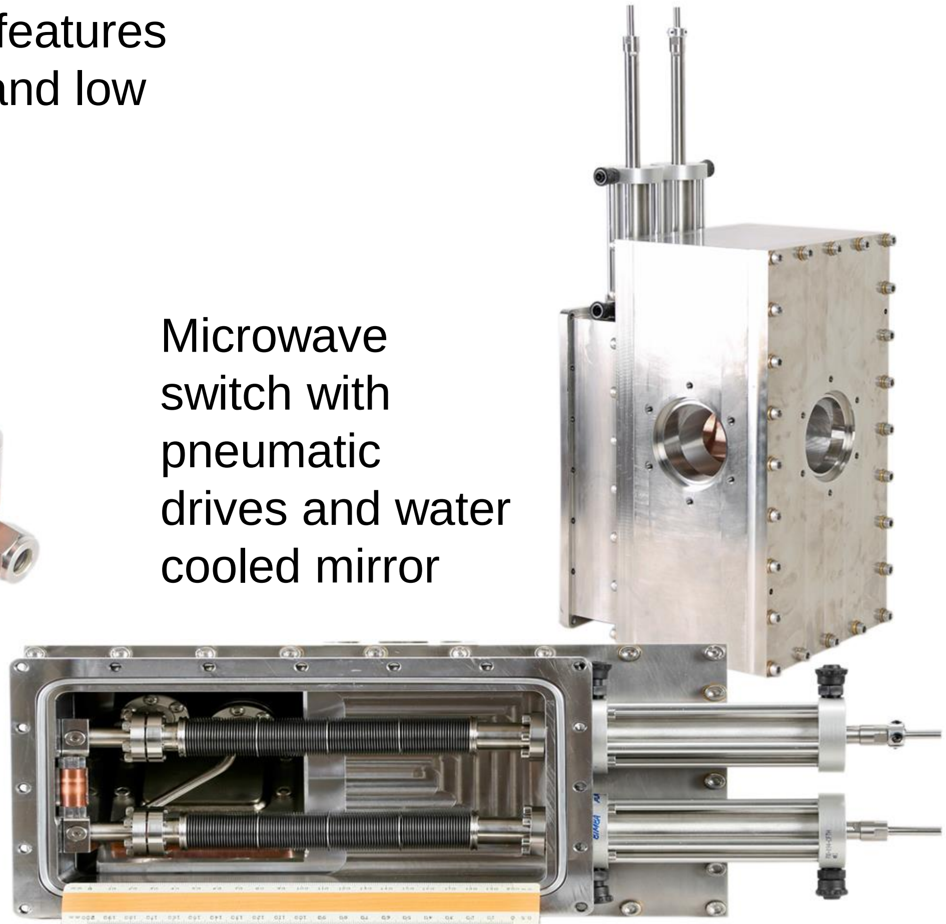
- Transmission lines from 24 sources to 56 feeds



Electron cyclotron development components have been designed, manufactured and tested at ORNL



Vacuum pump-out features high conductance and low RF leakage

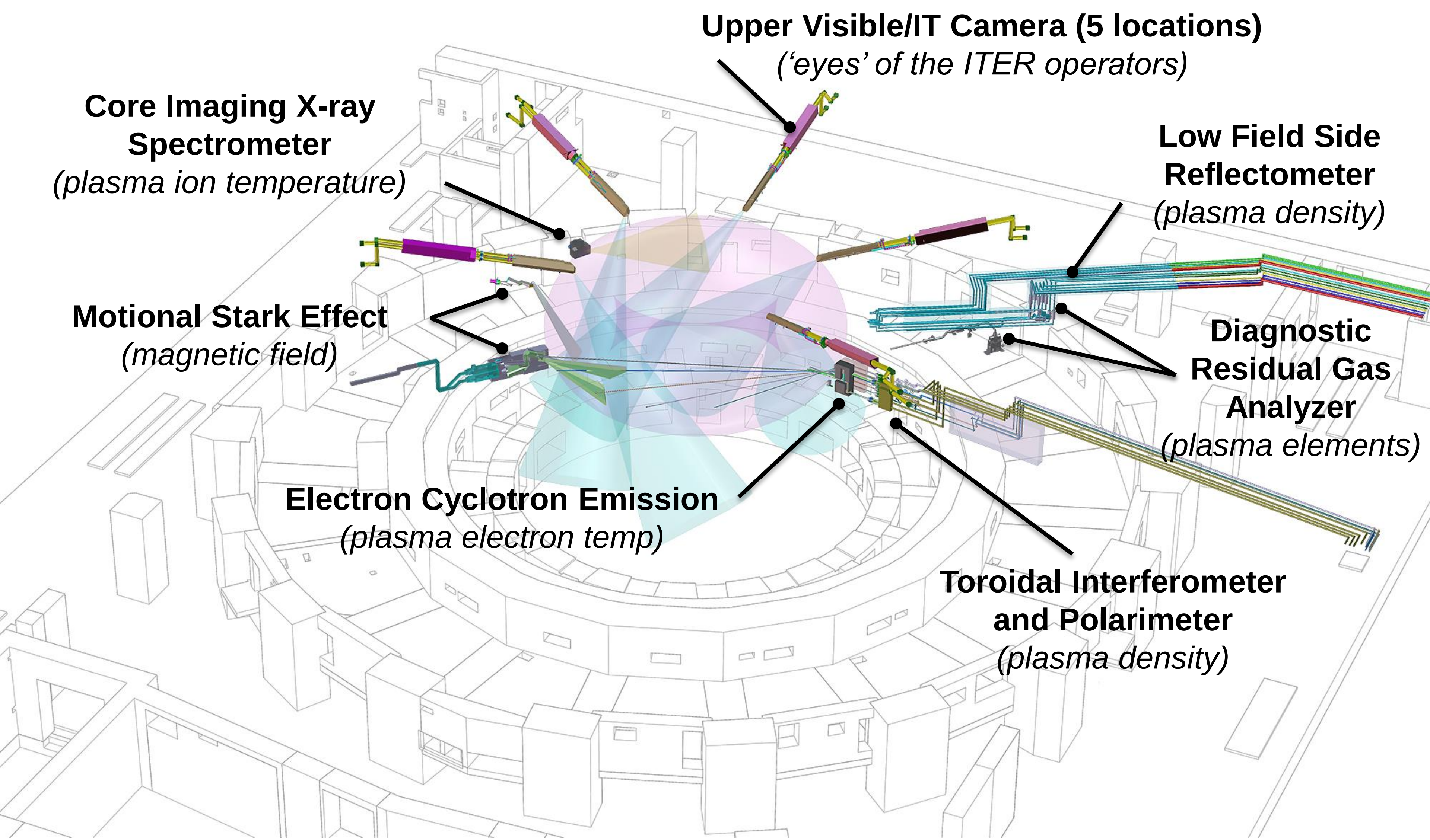


Microwave switch with pneumatic drives and water cooled mirror

Further manufacture and testing of electron cyclotron components will be completed this year

- Work with vendor to establish a full process for high precision (straightness) corrugated waveguide manufacturing. - 4 kilometers needed
- High power tests of Proof-of-Concept components
  - Water-cooled waveguide switch
  - Vacuum pump out section
  - Gyrotron commissioning load
  - Thermal expansion section
  - Procure a pair of waveguide polarization control miter bends

Six diagnostic instruments are in the preliminary design phase and one at final design



Four diagnostics port plugs are in preliminary design

Upper Port Plug 14

EQ Wide Angle View Visible/IR Cameras – US

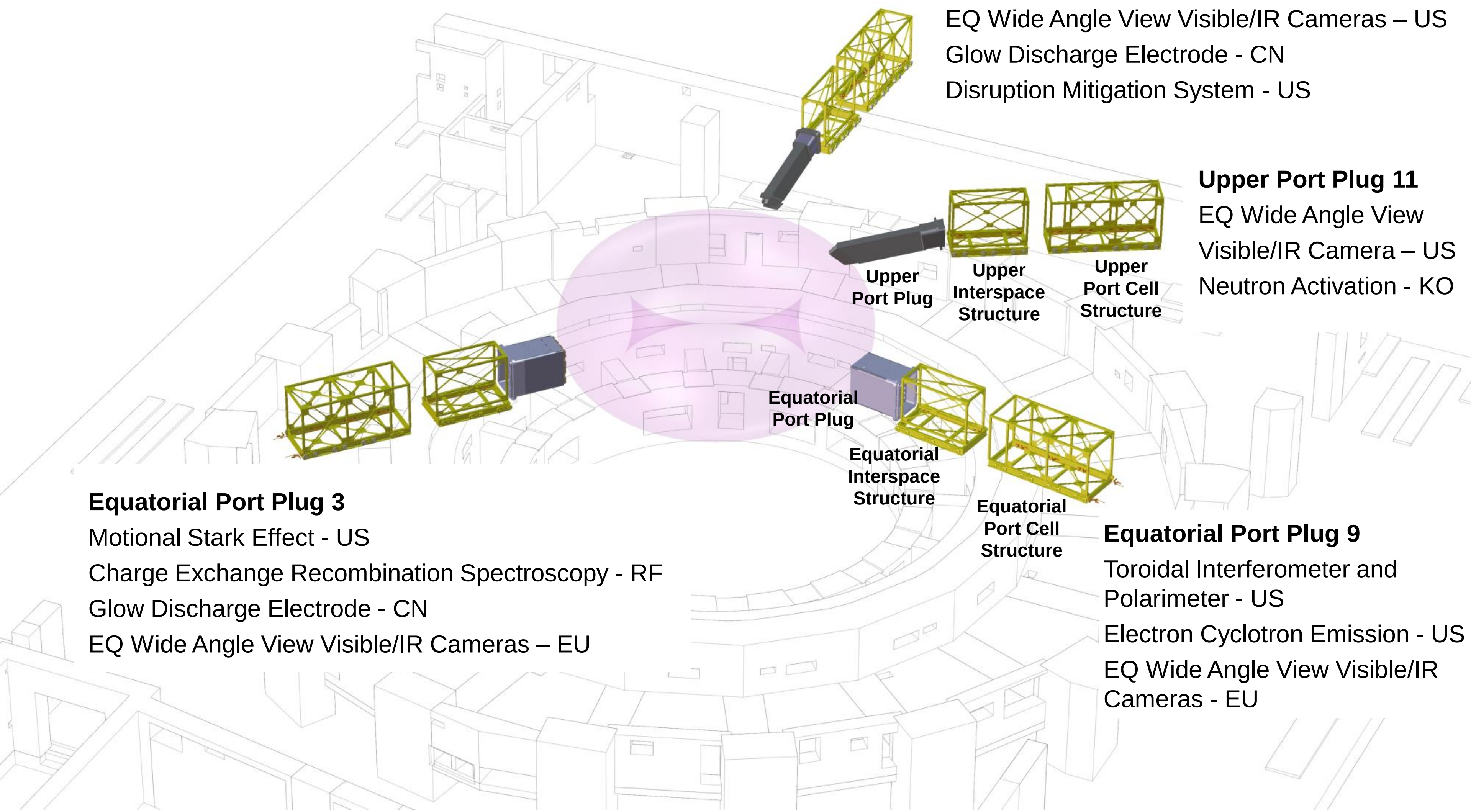
Glow Discharge Electrode - CN

Disruption Mitigation System - US

Upper Port Plug 11

EQ Wide Angle View Visible/IR Camera – US

Neutron Activation - KO



Equatorial Port Plug 3

Motional Stark Effect - US

Charge Exchange Recombination Spectroscopy - RF

Glow Discharge Electrode - CN

EQ Wide Angle View Visible/IR Cameras – EU

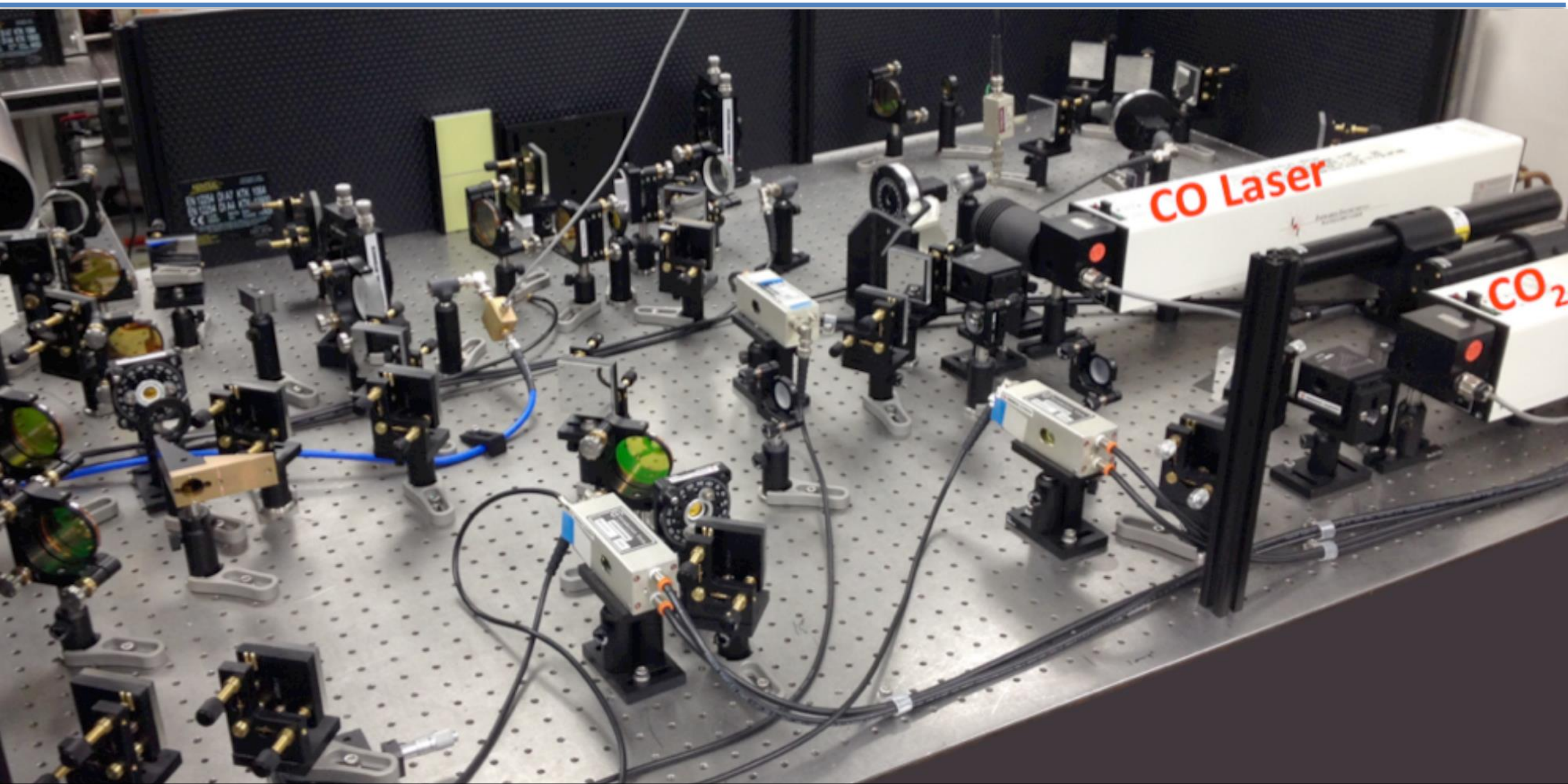
Equatorial Port Plug 9

Toroidal Interferometer and Polarimeter - US

Electron Cyclotron Emission - US

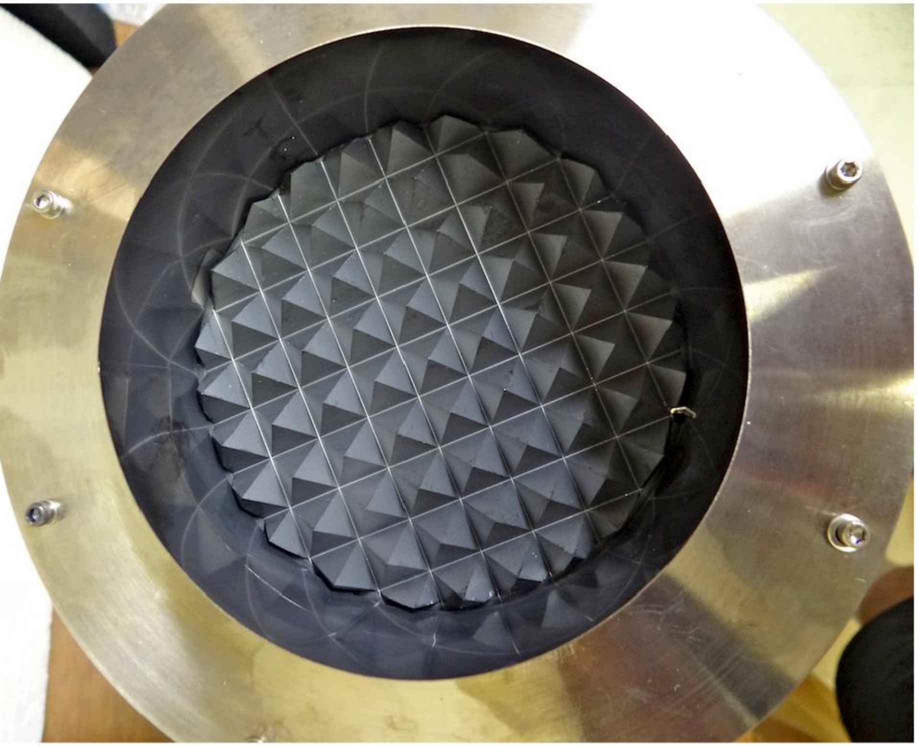
EQ Wide Angle View Visible/IR Cameras - EU

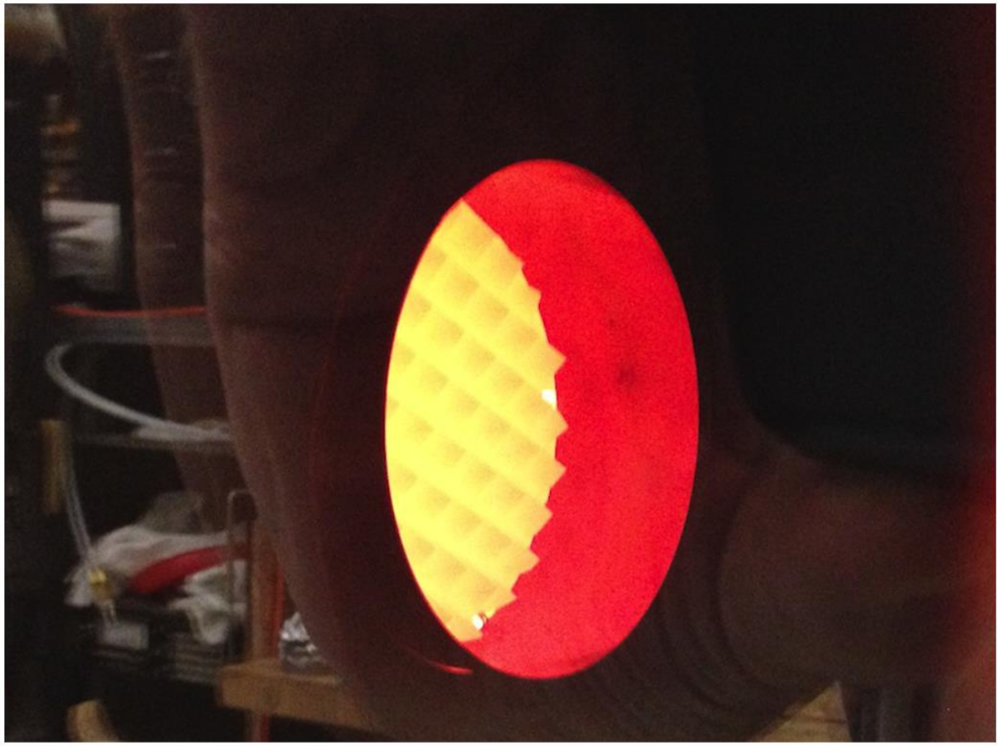
Optics testing for the TIP diagnostic is underway at GA



This complex optical table assembly is part of the Toroidal Interferometer and Polarimeter (TIP) diagnostic development at General Atomics in San Diego. The two lasers are injected in to ITER and the return signal is measured to determine the density of the plasma.
Photo: General Atomics

Diagnostics development and testing is being carried out at UT

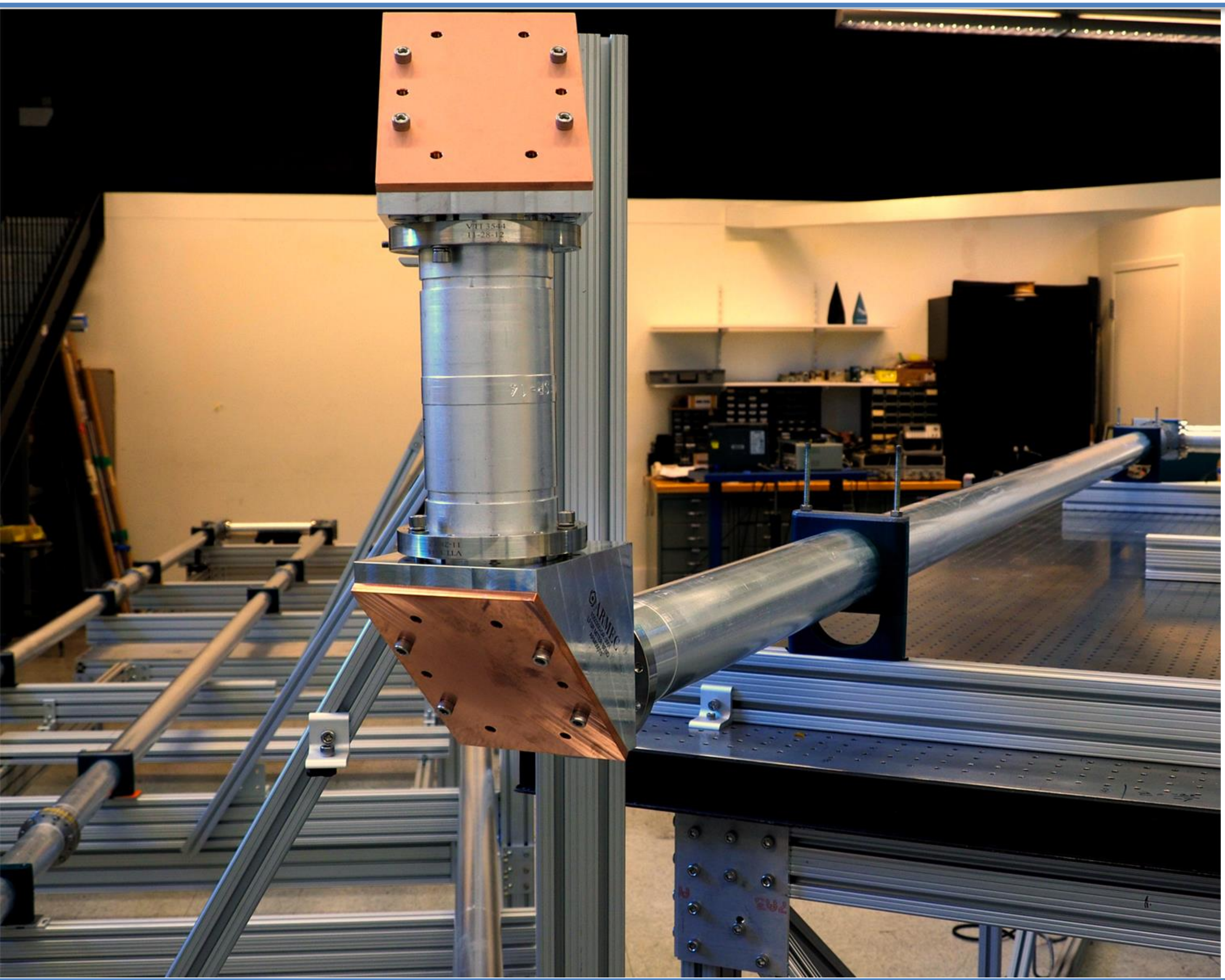




The Electron Cyclotron Emission (ECE) diagnostic contains a device used to calibrate the system. A Silicon Carbide disc is machined in a special way to have a pyramid pattern, shown on the left. This disc is then heated to well over 800°C. The right hand photo shows the calibration disc glowing red-hot while in use.

Photo: University of Texas

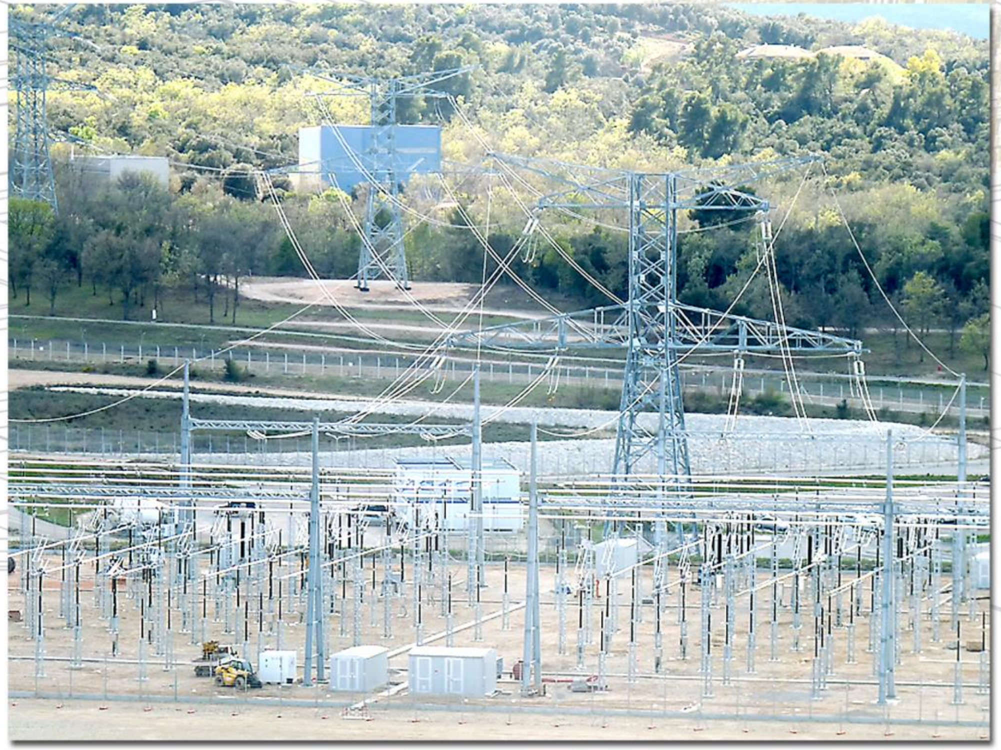
Low-field-side reflectometer test stand at UCLA



A test stand for the low-field-side reflectometer at UCLA mimics an ITER-like waveguide route; the copper material is part of a 30 degree miter bend. ORNL designed and fabricated the waveguide.

Photo: UCLA

Steady state electrical network is in the manufacture and delivery stage



Provides power to all steady state loads of the ITER facility including Tokamak Cooling Water System (largest load) and Cryoplant

Total load ~ 120 MW during plasma operations

Input power received from 400kV French grid and distributed throughout ITER facility at 22kV

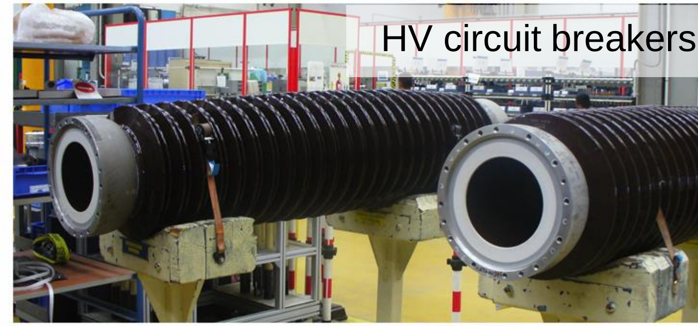
Individual loads are fed via local power centers at 6.6kV and 400V

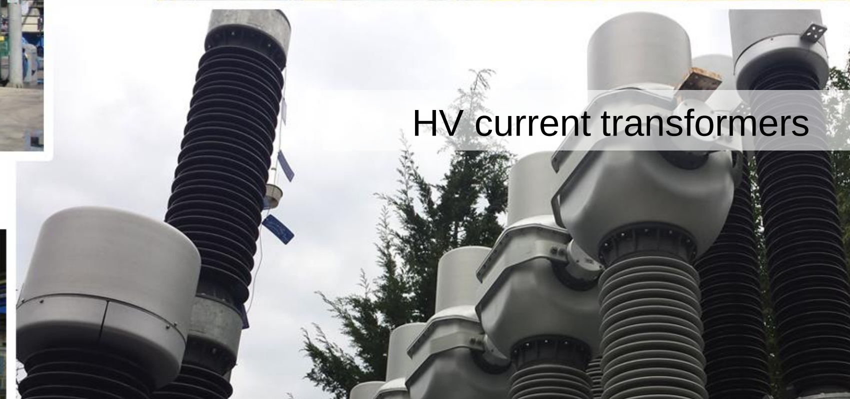
All equipment must comply with International Electrotechnical Commission (IEC) standards and be compatible with 50Hz operation

SSEN deliveries completed in the last year


HV substation hardware


HV switches


HV circuit breakers


HV current transformers


UPS batteries

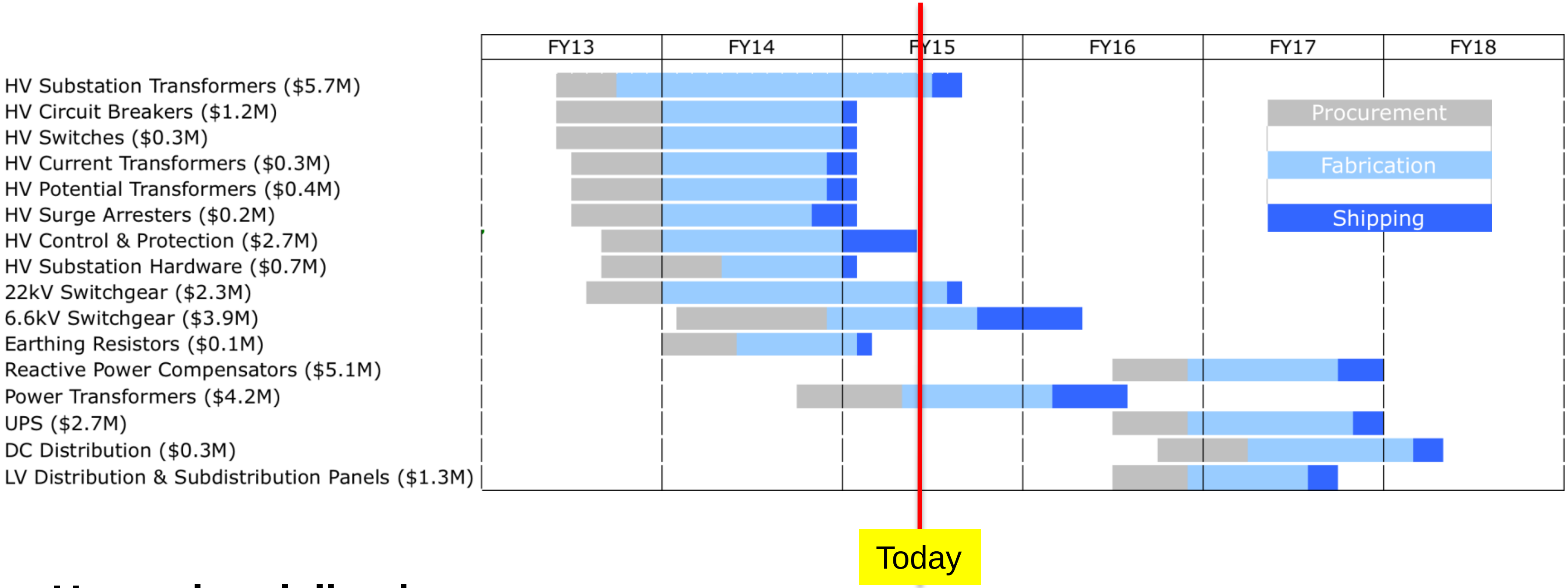

HV control and protection

Earthing resistors

US delivered the first "highly exceptional load" to ITER site

The main body of a HV substation transformer being unloaded at Fos-sur-Mer, France. The transformer was delivered to the ITER site on January 14, 2015
Photo: ITER Organization

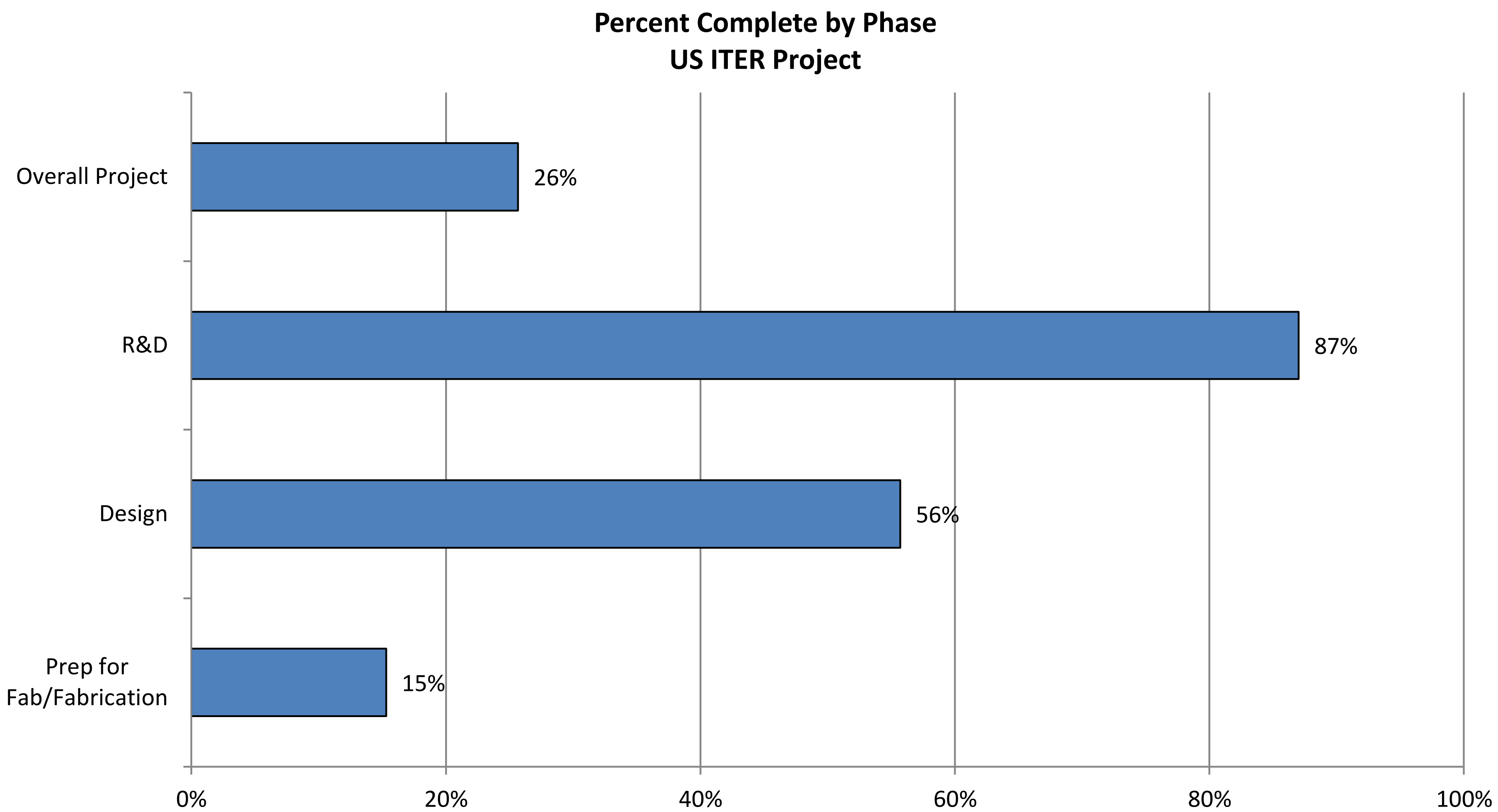
Deliveries of SSEN components will continue this year



Upcoming deliveries:

- HV substation transformers (lots 2,3,4): April 2015
- 22 kV switchgear (lots 1,2): April 2015
- 6.6 kV switchgear (lot 1): June 2015

US ITER progress by phase



Summary of US accomplishments

- ~2/3 (by value) of US hardware systems in final design or beyond
- Fabrication underway for critical-pacing items
  - TCWS drain tanks
  - Central Solenoid (CS) mock-up coil
  - CS structure components (lower key block, tie plates)
  - TF conductor
  - Steady State Electrical Network (SSEN) components
- Key hardware deliveries on-going - ~4% of total planned deliveries complete
  - TF Conductor
  - SSEN components

The US was the 1st ITER member to deliver a "highly exceptional load" and component hardware to the ITER site