Report on Activities of US ITER Project

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for

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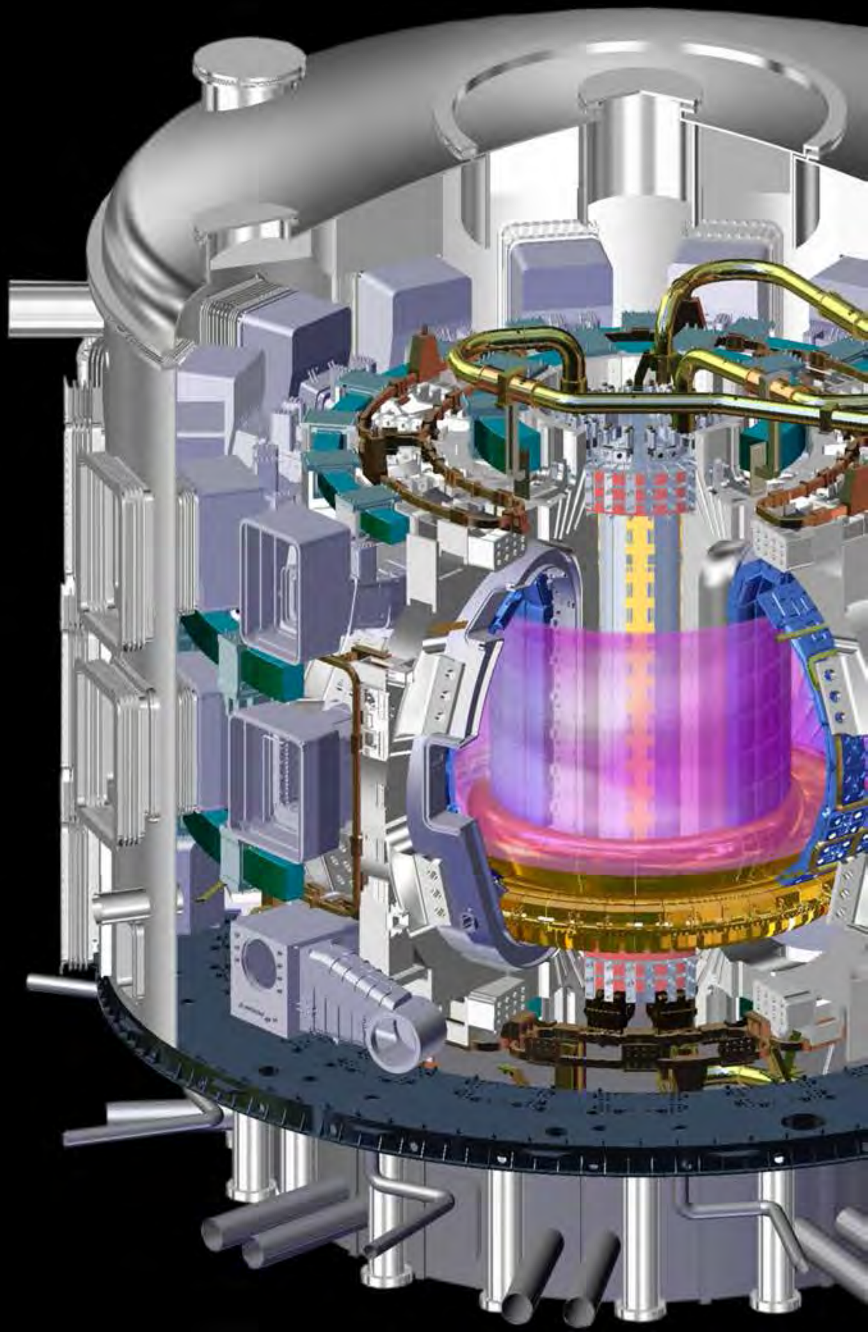
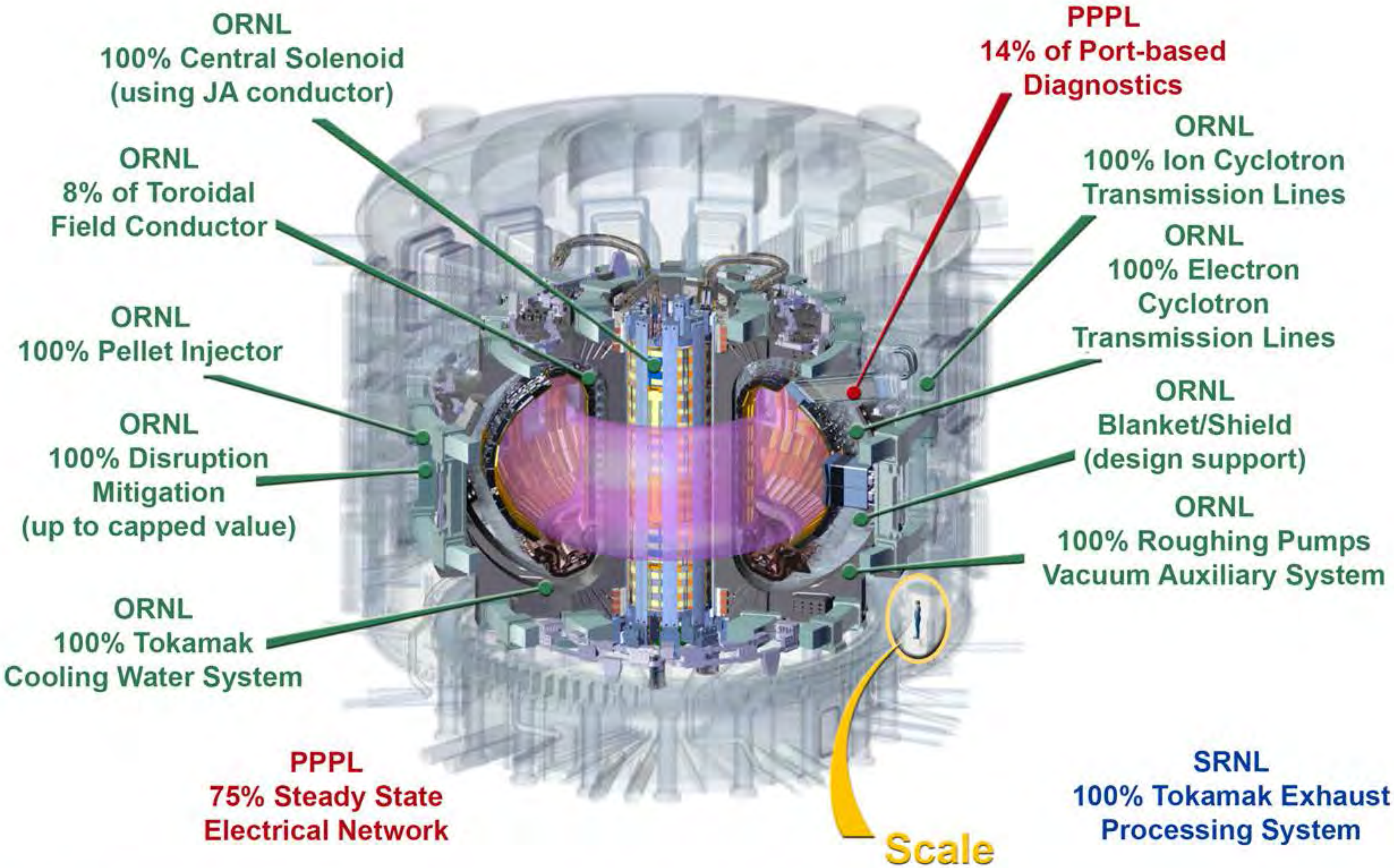
Burning Plasma Organization

January 23, 2015

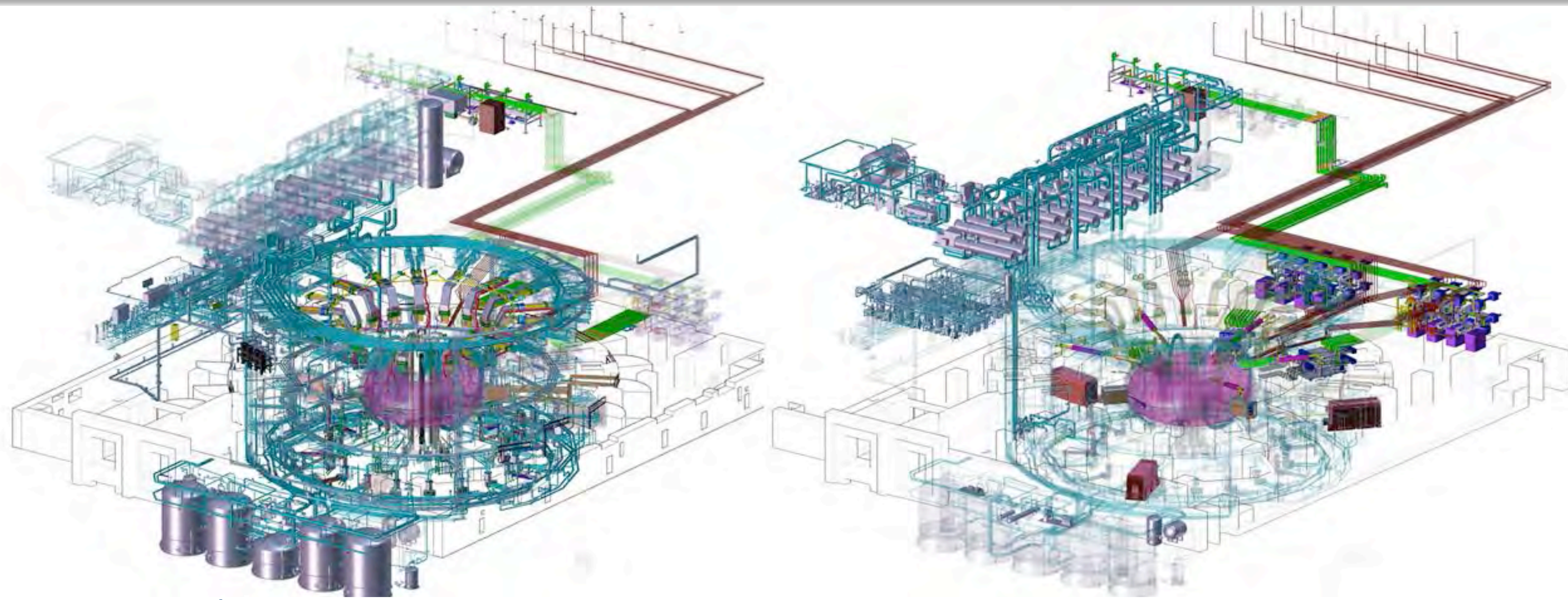


US Scope



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

Scope Delivered in 2 Phases



1st Plasma | **Post-1st Plasma**

Full Production

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

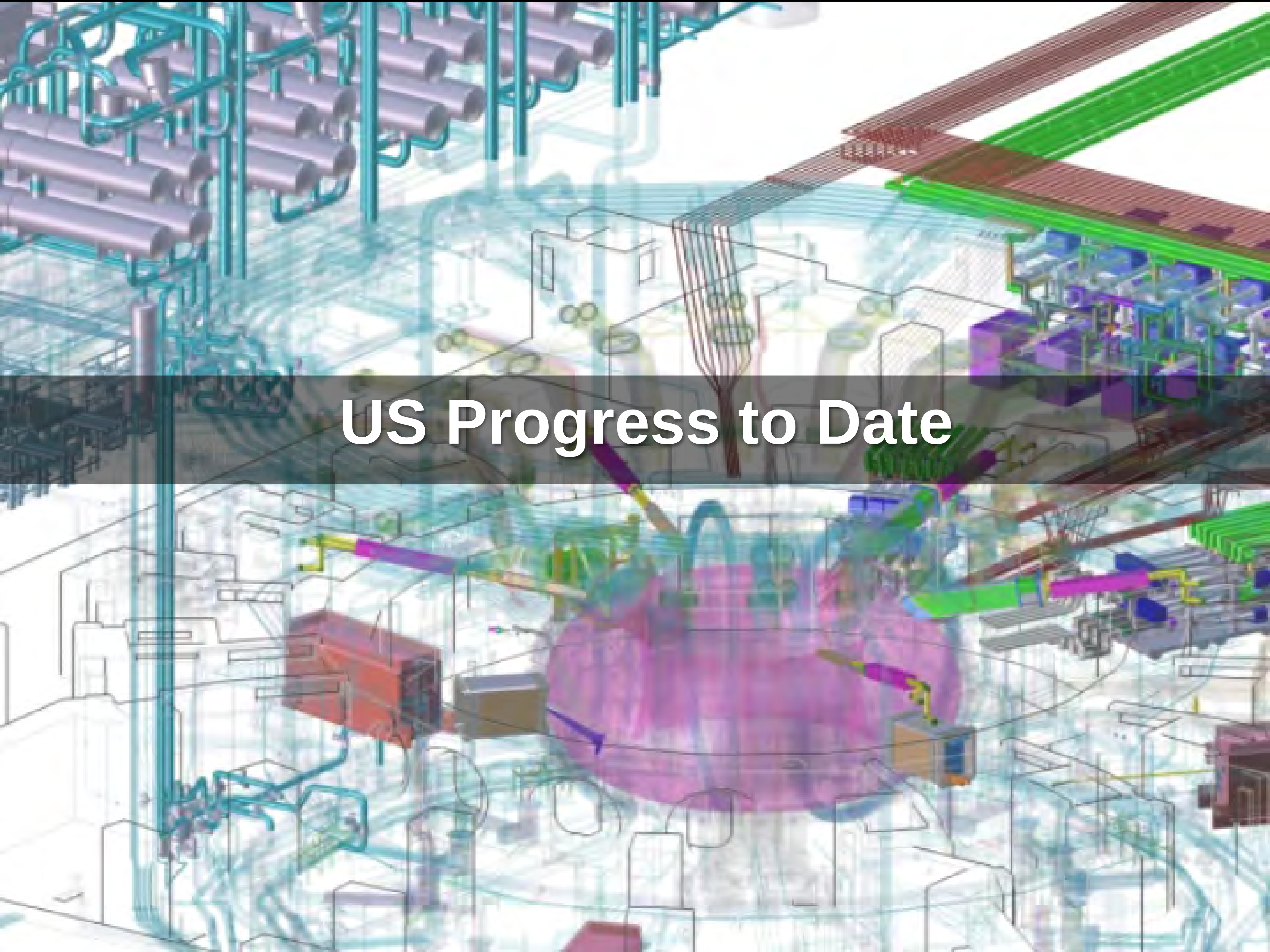
Partial Production | Completion of Production

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

Full Production

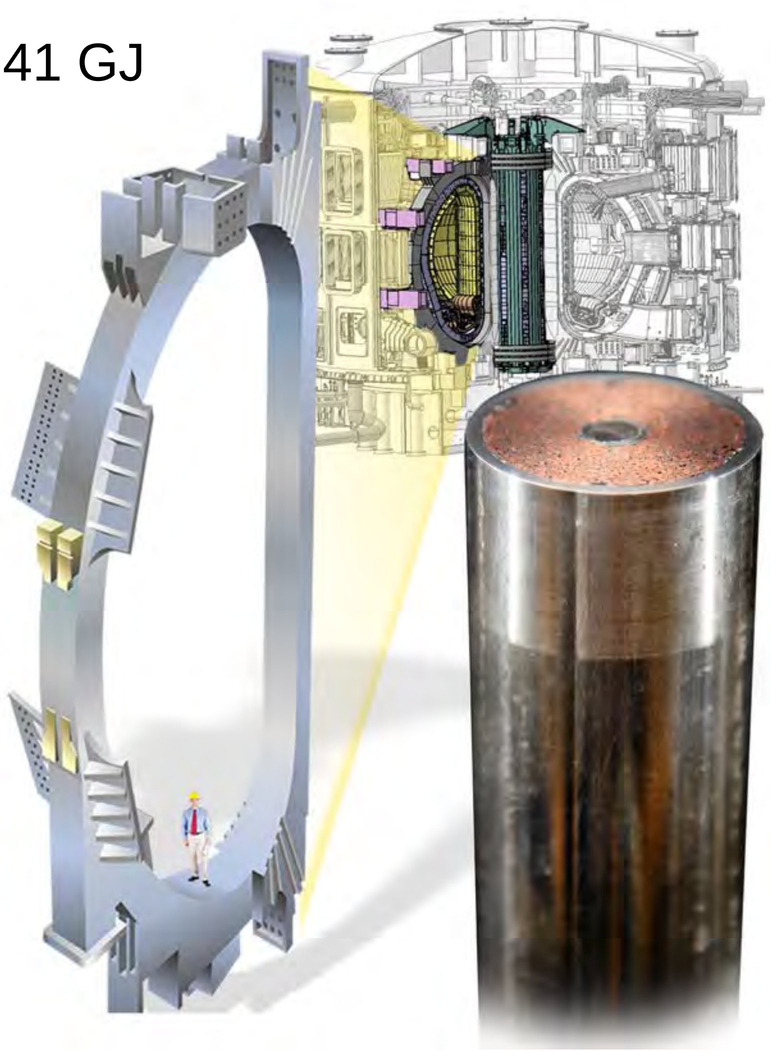
- Tokamak exhaust processing
- Disruption mitigation

US Progress to Date



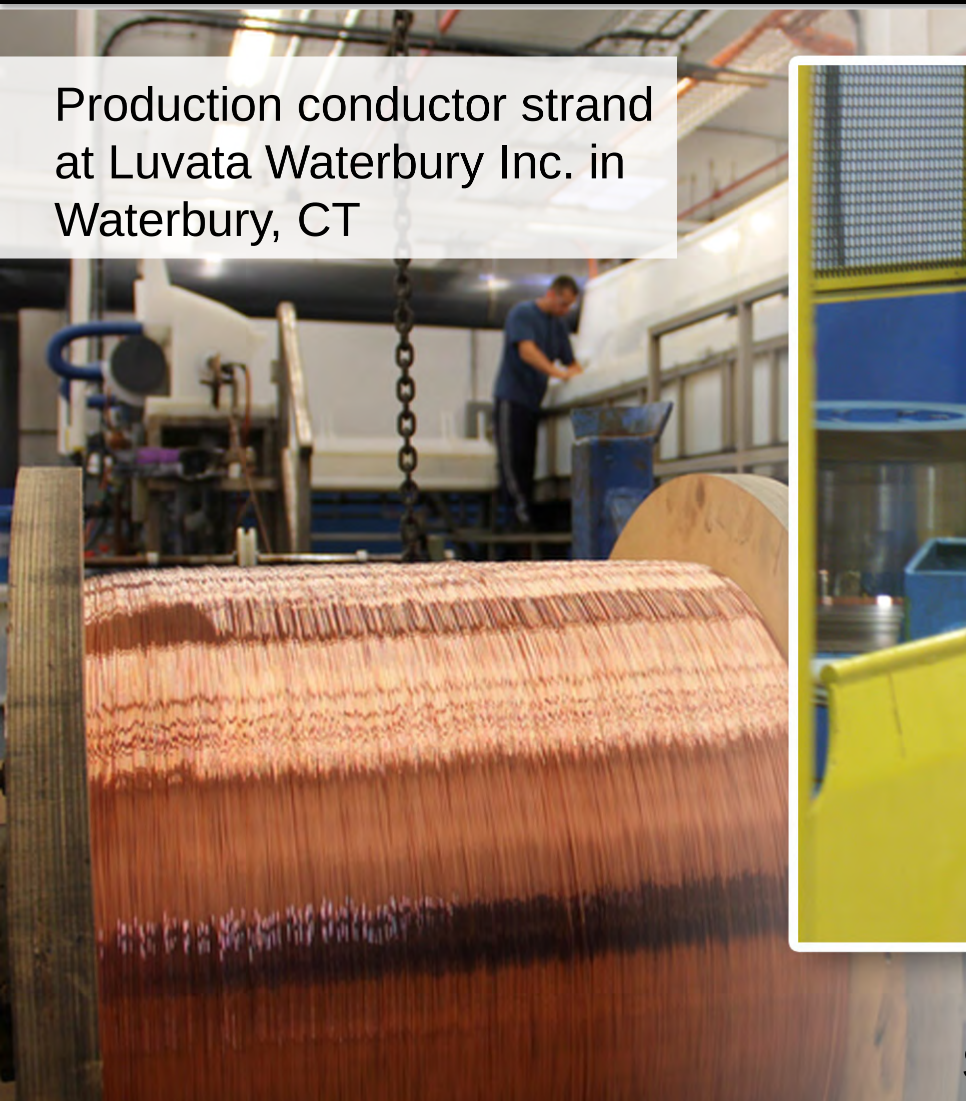
Toroidal Field Coil

- 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

All strand completed in FY13



Production conductor strand at Luvata Waterbury Inc. in Waterbury, CT

Production conductor strand at Oxford Superconducting Technology in Carteret, NJ

Toroidal Field Conductor

Cabling

Toroidal Field Conductor
Jacketing and Integration

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

Toroidal Field Conductor

Initial Shipments to EU Winding Facility

US TF 800 meter Dummy Conductor
US TF 100 meter Active Conductor (Oxford)

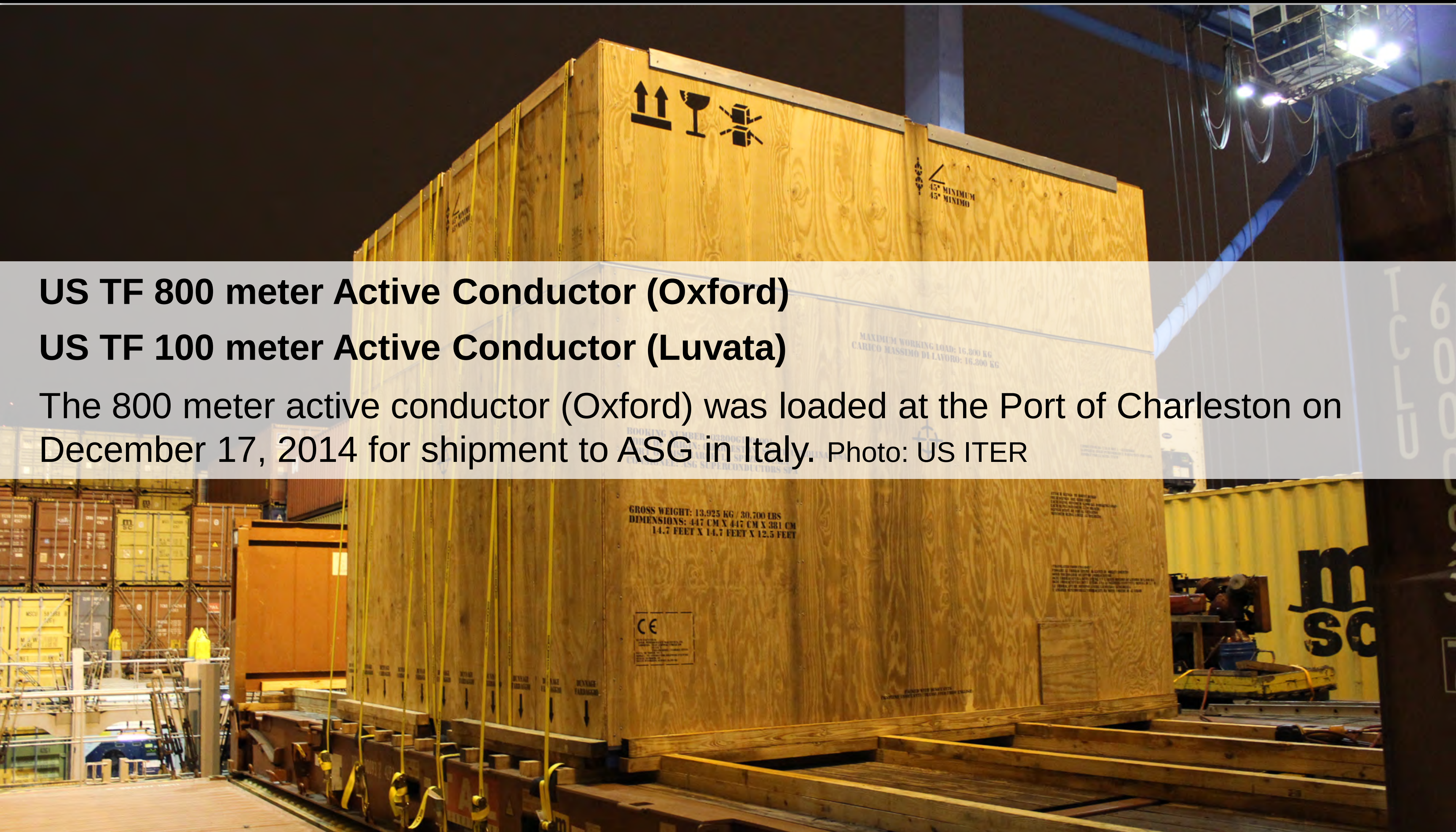
US 8% contribution includes over 4 miles of conductor, which is constructed from 40 tons (over 400 miles) of niobium-tin superconducting strand

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

US TF 800 meter dummy conductor – delivery at ASG in Italy

Toroidal Field Conductor

2015 TF Shipments to EU Winding Facility



US TF 800 meter Active Conductor (Oxford)

US TF 100 meter Active Conductor (Luvata)

The 800 meter active conductor (Oxford) was loaded at the Port of Charleston on December 17, 2014 for shipment to ASG in Italy. Photo: US ITER

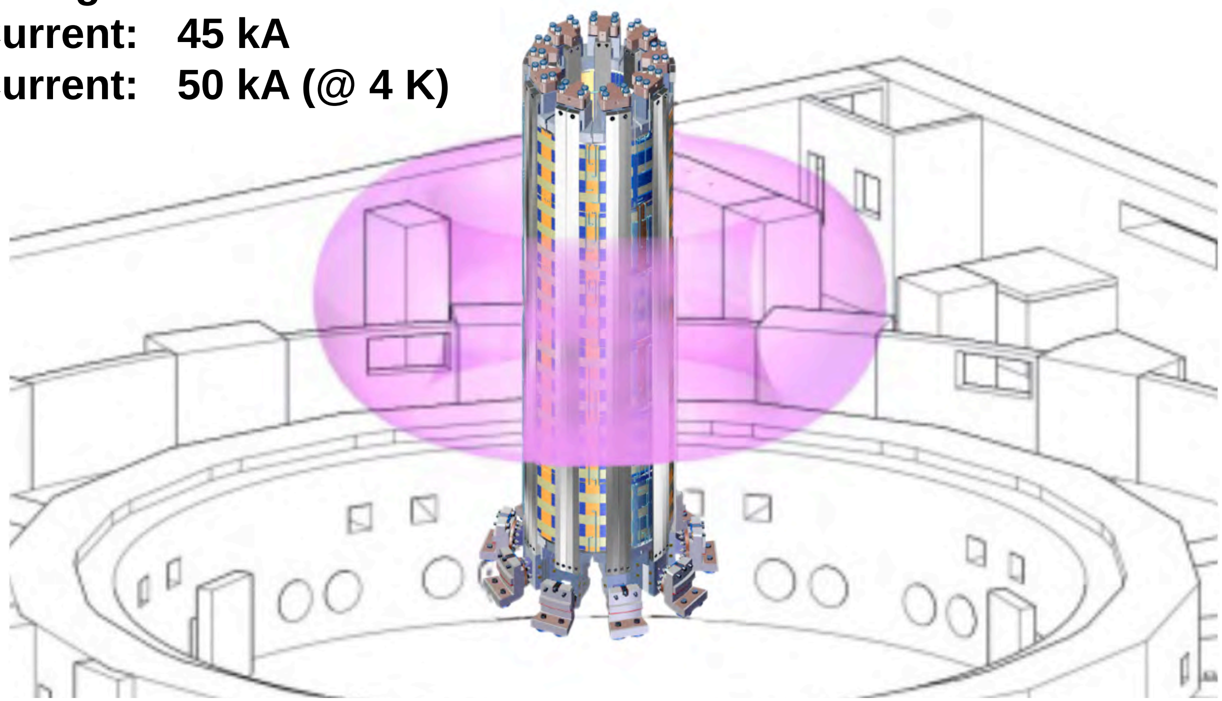
Toroidal Field Conductor
Technical Challenges

Resolved Challenges	Current Challenges
• Resolved scraping of trivalent Chromium plating during cabling by revised cabling configuration • Successful cabling of first production cable	• Twist-pitch length modification during jacketing • Successful demonstration of TF conductor performance (Tcs measurement on SULTAN Facility) • Recent strand breaks on OST cable run (use of alcohol as a lubricant/cooling agent is expected to resolve issue)

Central Solenoid
The Heartbeat of ITER

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



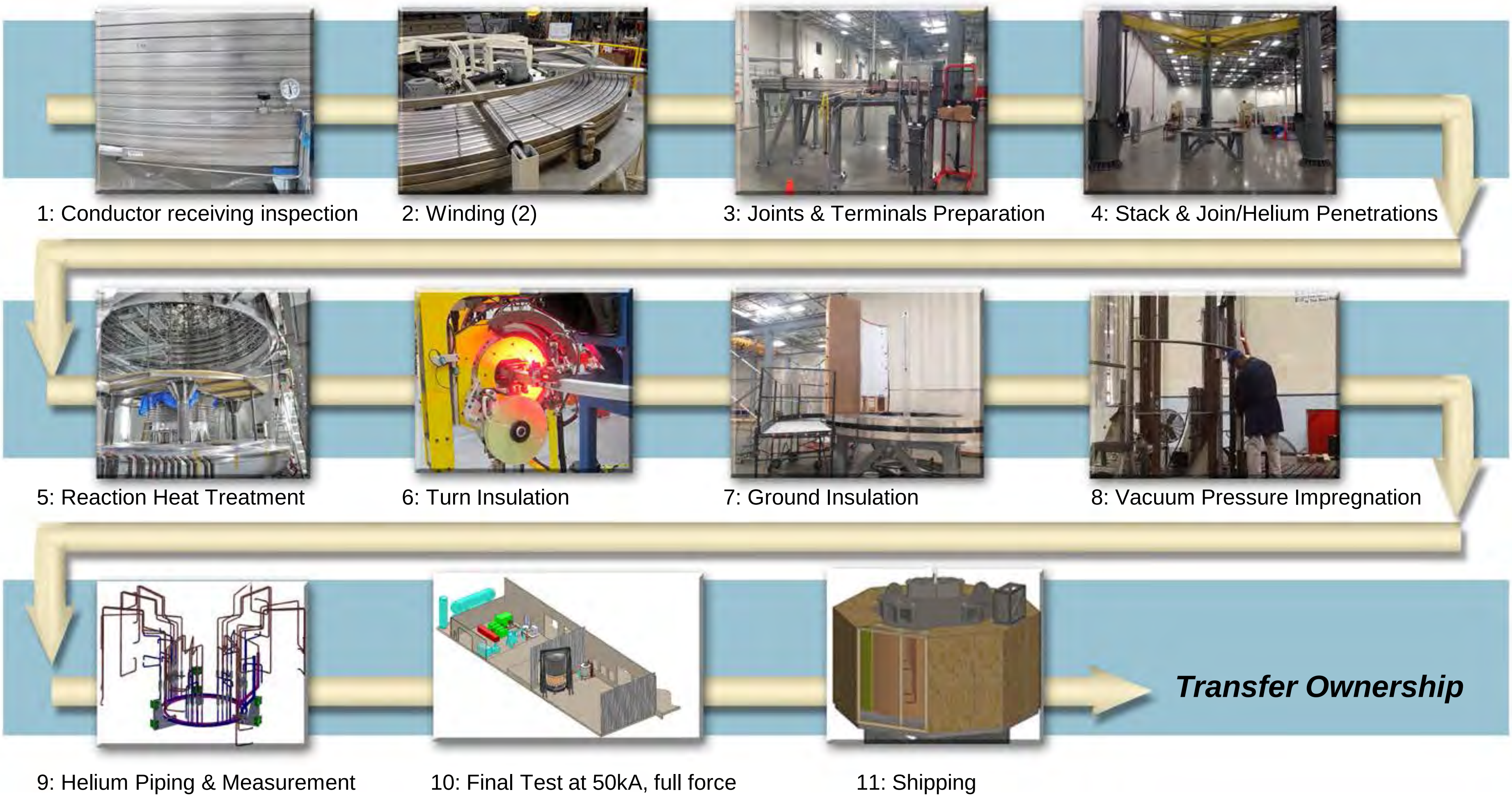
The most powerful pulsed superconducting electromagnet in history (5.5 Gigajoule stored energy capacity)

Central Solenoid Module
Fabrication Stations

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 winding underway

Module Tooling Stations are Being Installed at General Atomics



Central Solenoid
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.

Central Solenoid Tooling Station:

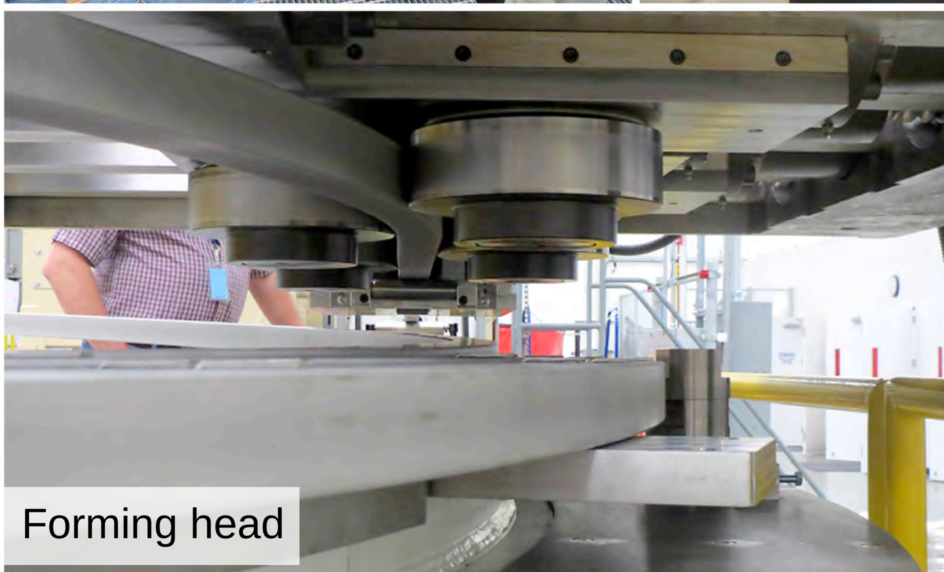
1st Winding Station Installed

MRR conducted in July 2014

De-spooler

Tractor drive and straighteners

Grit blast and cleaning



Forming head

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

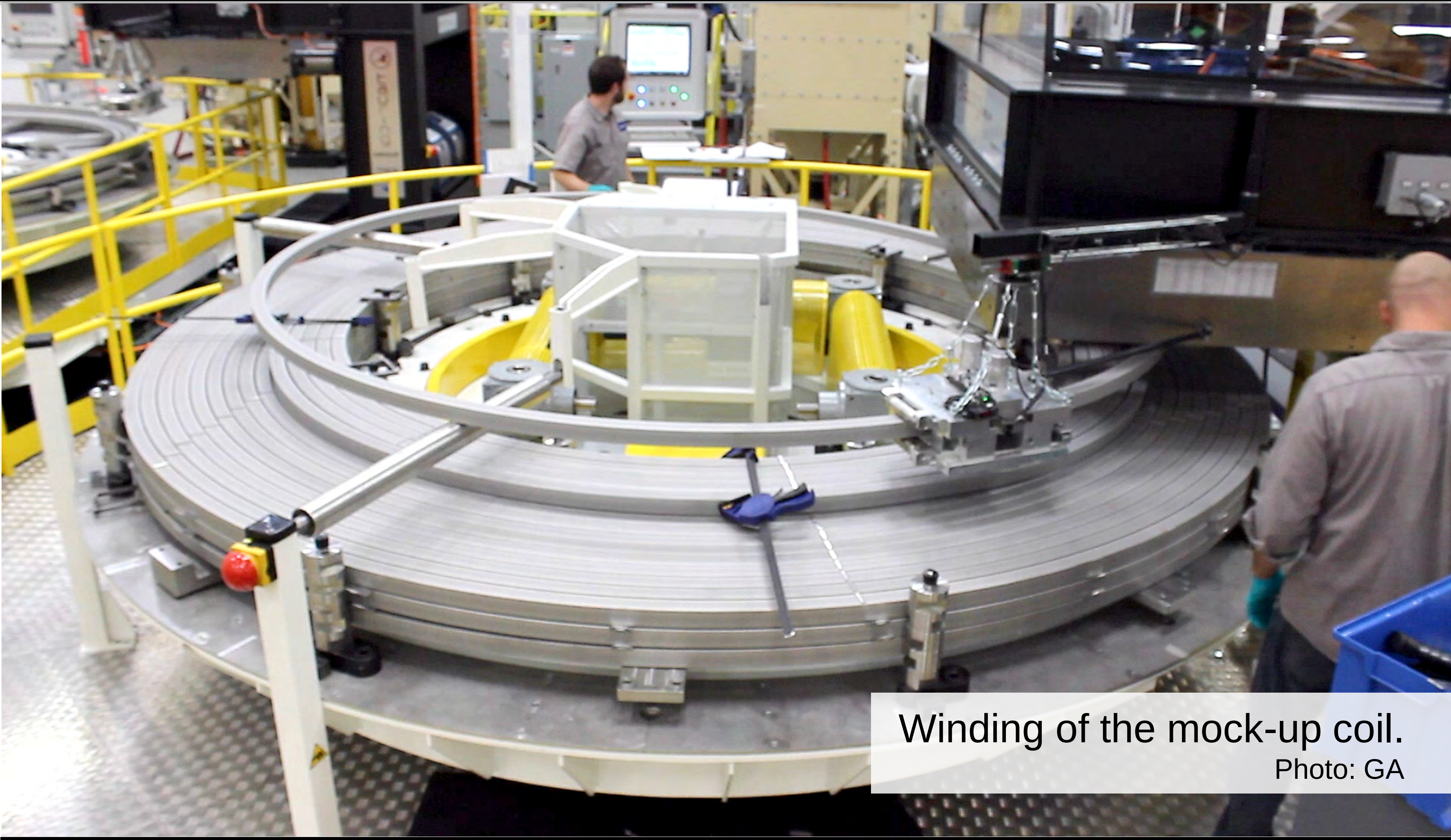
Central Solenoid
Winding Began in August

Conductor routed from the de-spooler of the winding.

Conductor routed through the straightener.

Photos: General Atomics

Central Solenoid Tooling Station:
Winding



Winding of the mock-up coil.
Photo: GA

Central Solenoid Tooling Station:
Heat Treatment Furnace

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 has been installed at General Atomics and is undergoing testing.

Central Solenoid Tooling Station:
Turn Insulation

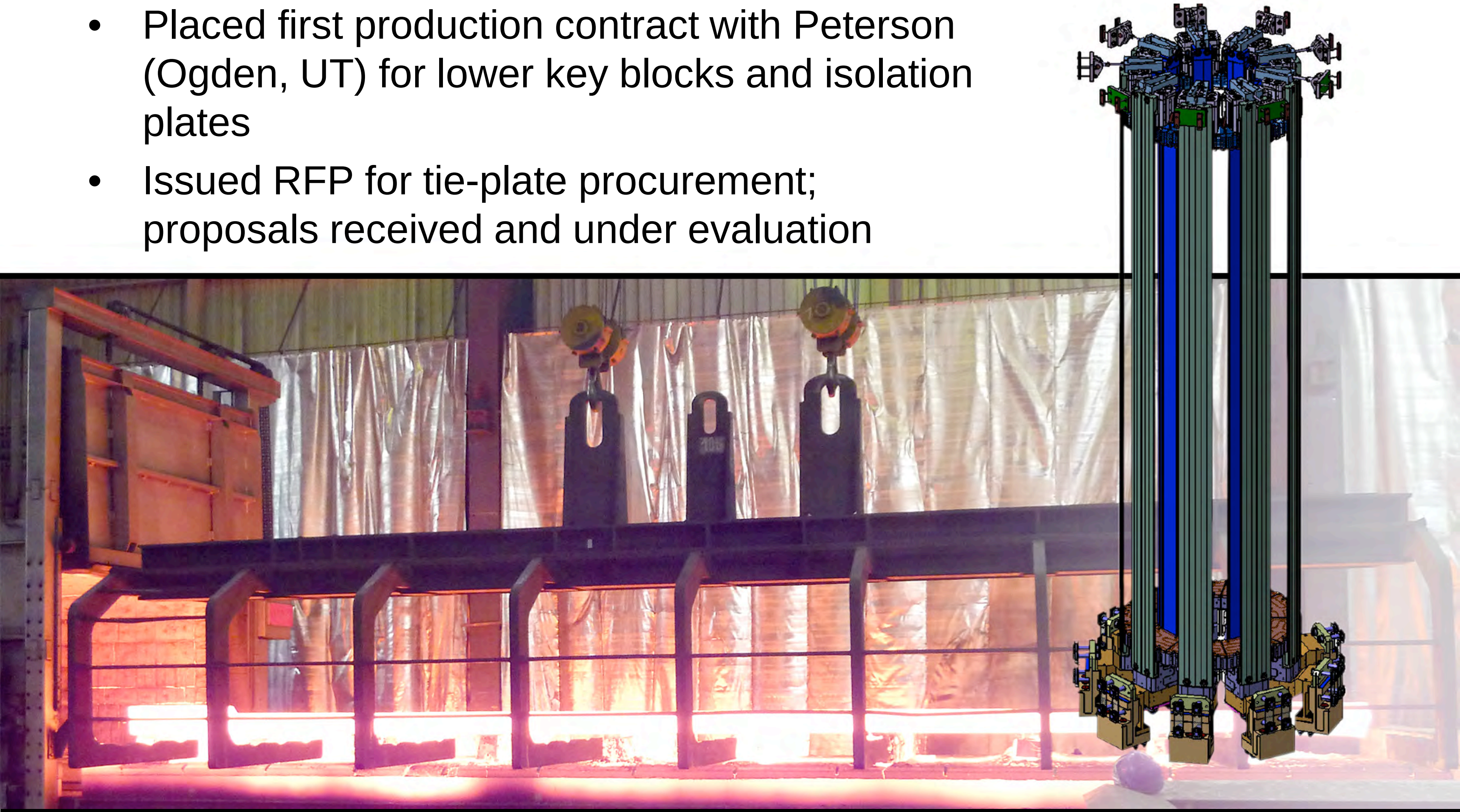
- Factory acceptance testing completed at vendors
- Units will be re-assembled and commissioned using mock hexapancake

Automated insulation taping heads

Construction activities at the turn insulation station

Central Solenoid Structures
Contracts

- Placed first production contract with Peterson (Ogden, UT) for lower key blocks and isolation plates
- Issued RFP for tie-plate procurement; proposals received and under evaluation



Central Solenoid
Technical Challenges

Resolved Challenges	Current Challenges
• Met winding station tolerances, successful factory acceptance test of winding station • Mock-up coil winding underway • Resolved path to avoid corrosion-cracking in JK2LB • Demonstrated fabrication of one-piece tie plates and tie plate procurement underway	• Non-Destructive Evaluation techniques to detect flaws in helium inlet, R&D work to resolve issue is near completion • Controlling grain size on one-piece tie plate (mitigated by further mechanical testing of forgings with relaxed grain size requirements) • Successful demonstration of friction lifting device

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

ITER Switchyard

Steady State Electrical Network

1st Plant Components Delivered to ITER Site

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

Steady State Electrical Network
1st Highly Exceptional Load

HV substation transformer unit at Hyundai Heavy Industries.
Photo: HHI

Steady State Electrical Network

1st Highly Exceptional Load Delivered to ITER Site

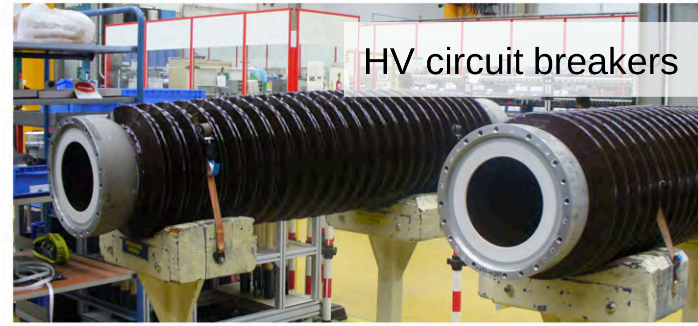
The main body of a HV substation transformer shown during unloading at Fos-sur-Mer. This was the first highly exceptional load delivered to the ITER Site. Photo: ITER Organization

Steady State Electrical Network

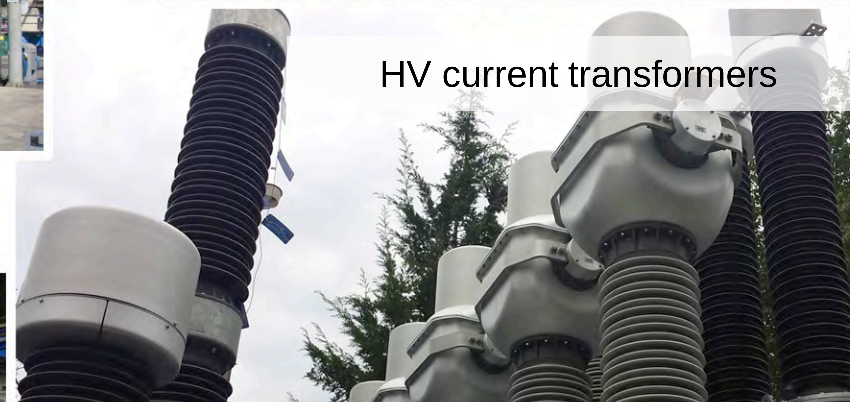
Completed FY14 and FY15 Deliveries

HV substation hardware

HV switches



HV circuit breakers



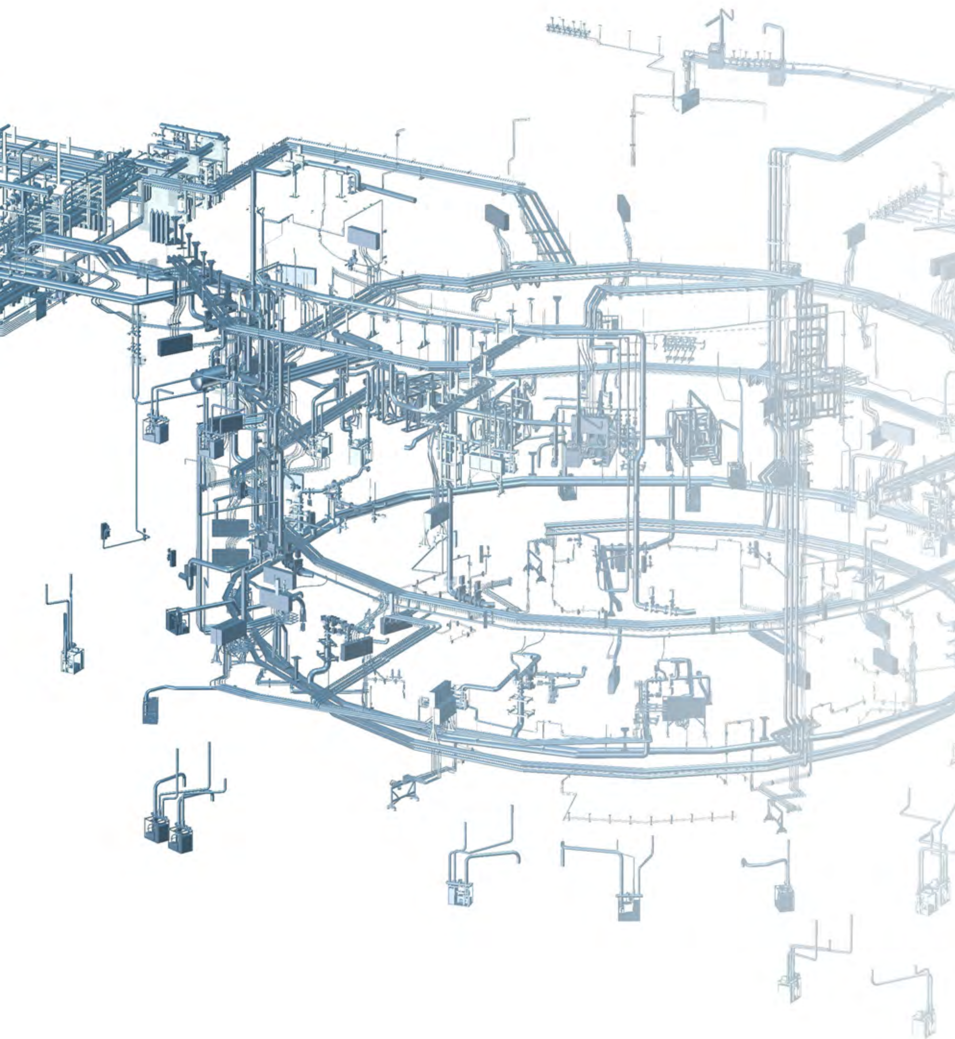
HV current transformers

UPS batteries

HV control and protection

Earthing resistors

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

Vacuum Auxiliary System and Roughing Pumps

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 (CTF) at the Oak Ridge National Laboratory

CVC assembly undergoing vacuum leak testing

Inner CVC core

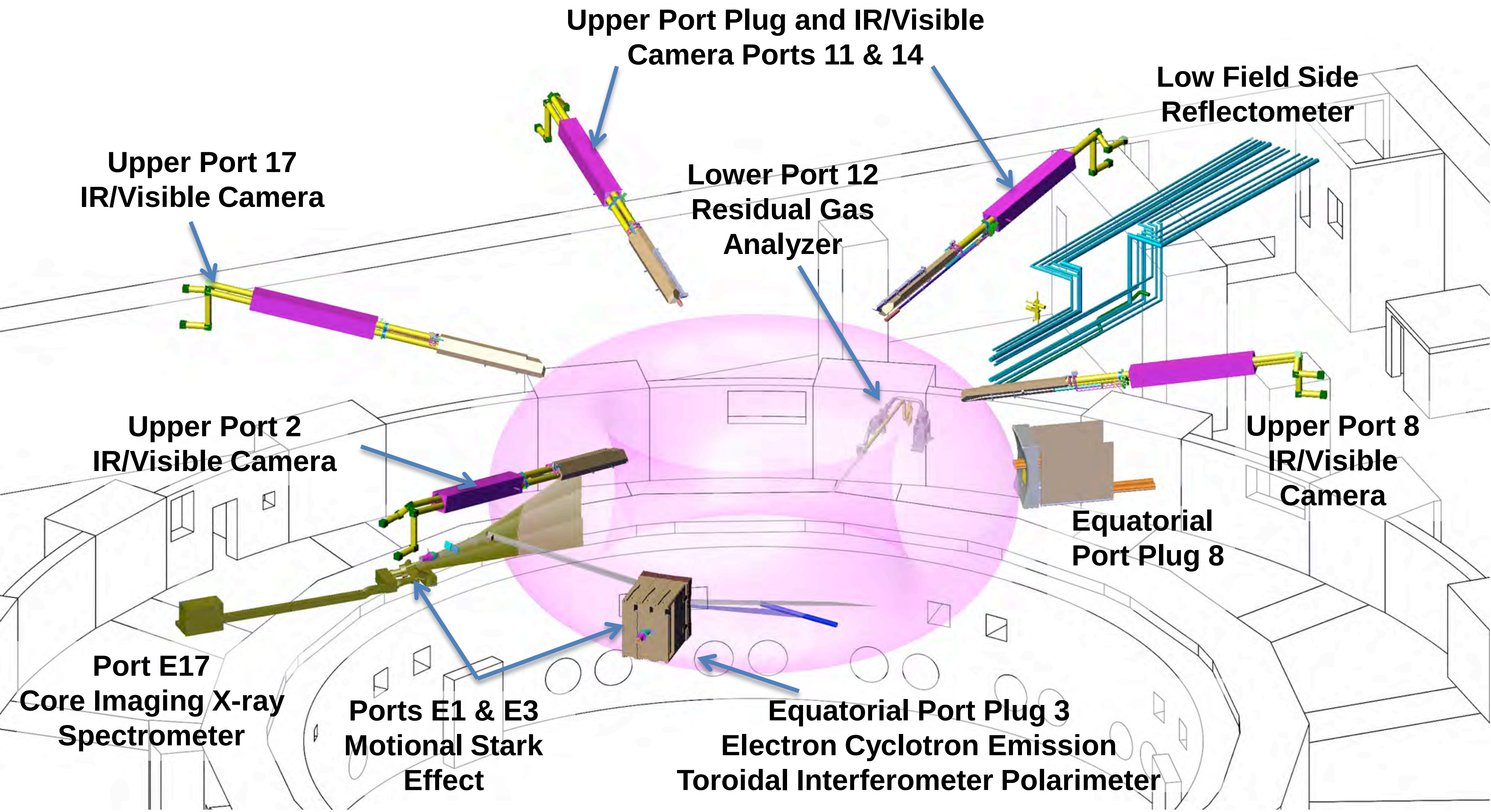
Cryogenic thermal shield to cool CVC core

Vacuum Auxiliary System and Roughing Pumps

Technical Challenges

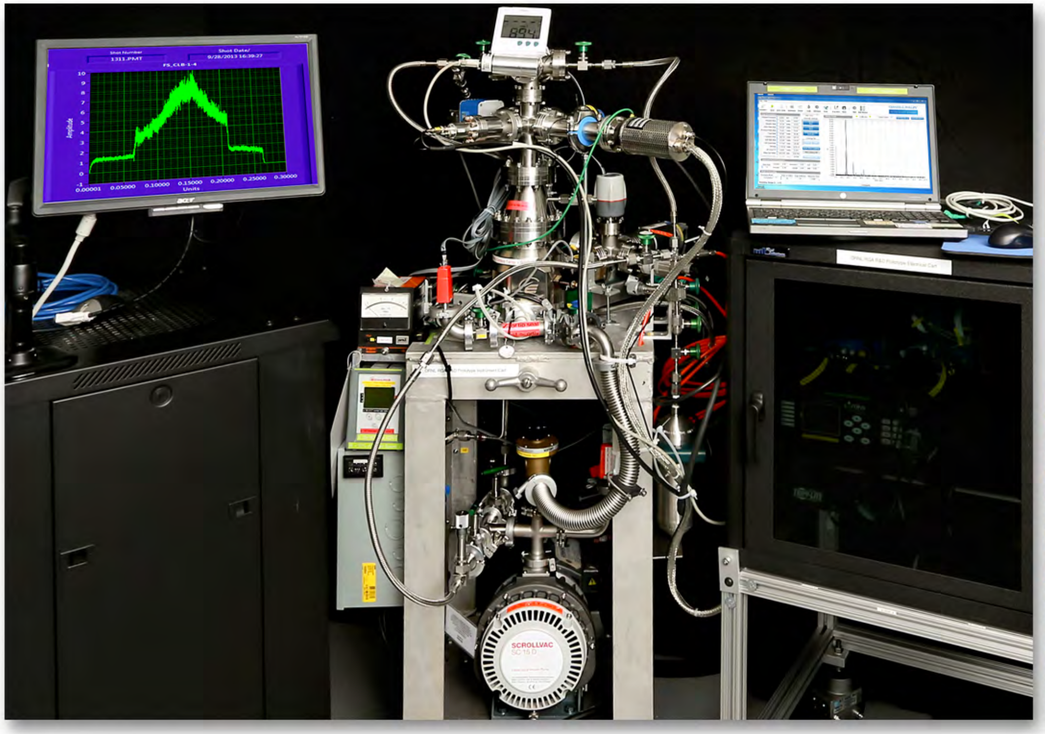
Resolved Challenges	Current Challenges
• Simplified US role in complex piping by IO arrangement (now signed)	• Performance of cryo-viscous compressor and screw pumps (testing is underway at ORNL)

Diagnostics

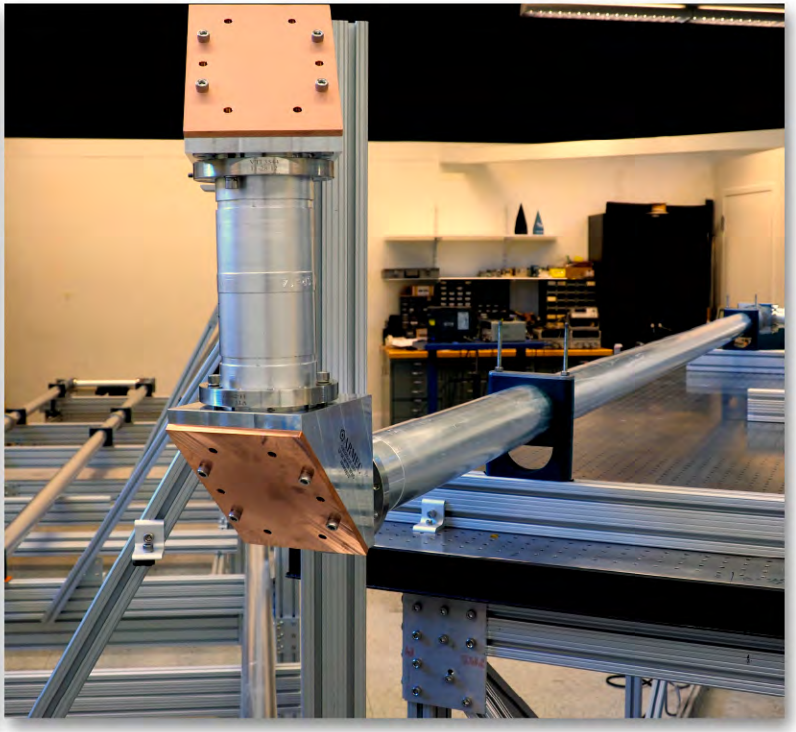


FY 2014 US Achievements:
Diagnostics

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



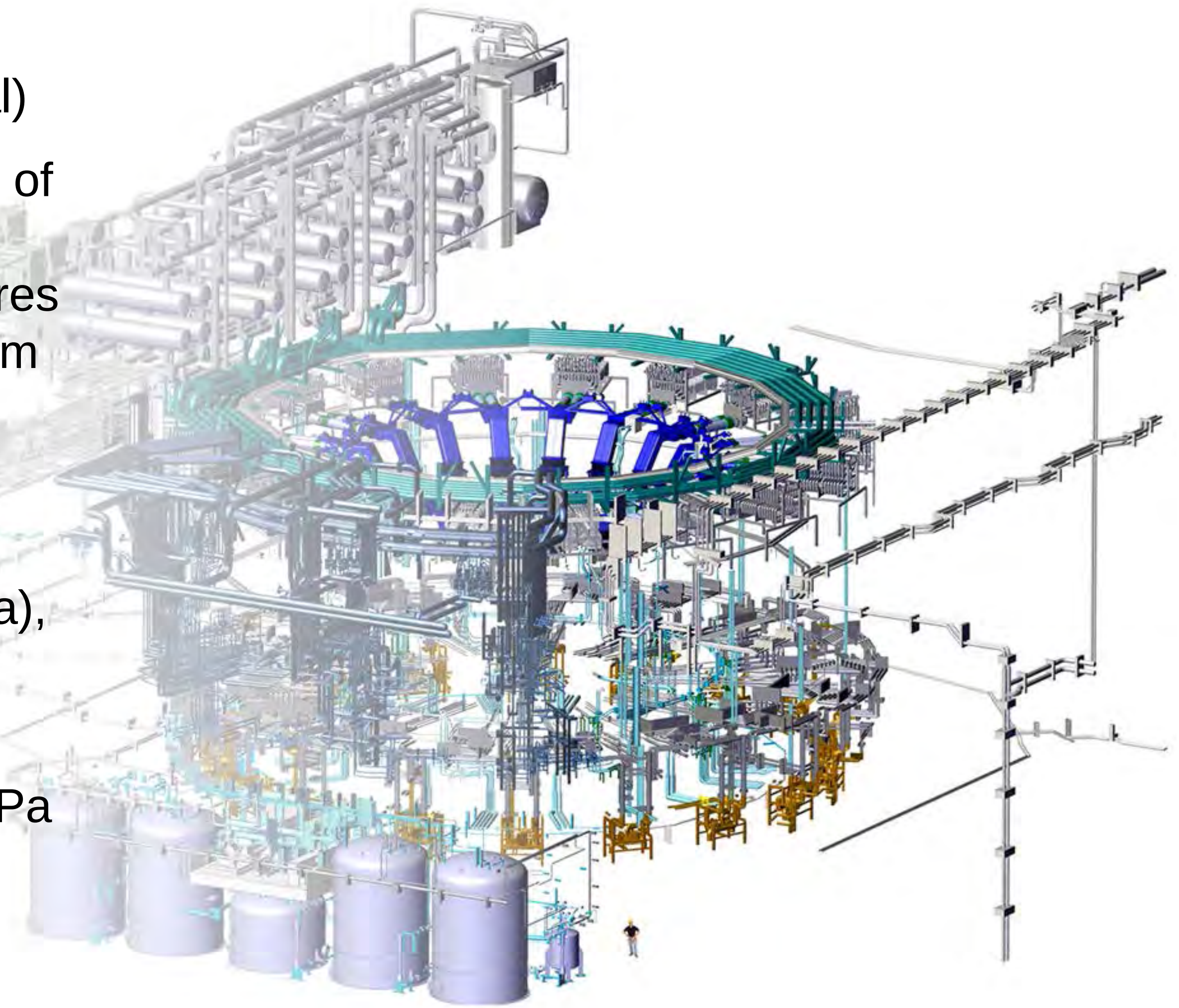
A test stand for the low-field-side reflectometer at UCLA mimics an ITER-like waveguide route.
Photo: US ITER/ORNL

Diagnostics
Technical Challenges

Resolved Challenges	Current Challenges
• Addressed overly complex interfaces between diagnostics from multiple DAs in each port plug by modularization and standardization	• Meeting radiation shielding requirements in the port plugs while simultaneously satisfying diagnostic measurement requirements and weight limits • Qualifying new technologies associated with in-situ calibration and mirror-cleaning capabilities

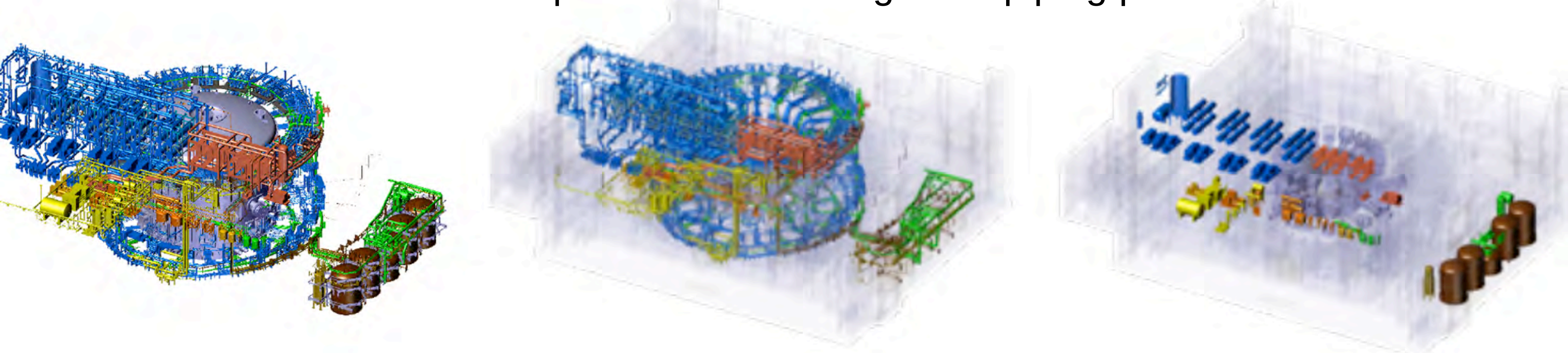
Tokamak Cooling Water System

- 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



TCWS Arrangements with IO Optimizes Roles and Responsibilities

- US scope defined in Procurement Agreement (PA) and unchanged (design, fabrication, and delivery)
- Subsequent Arrangements optimize the assignment of roles
  - US retains responsibility per the PA and provides major assemblies
  - IO as "subcontractor" performs final design and piping procurement



Full System = **Design & Piping** + **Equipment**

Full System
- Managed by USDA
- Design and procurement by USDA
- Installation by IO

Design & Piping
- Multiple (16) Contracts
- Managed by ITER IO
- Reviewed by USDA

Equipment
- Fabrication Contracts for 100+ assemblies managed by USDA

Tokamak Cooling Water System
Deliveries in FY15

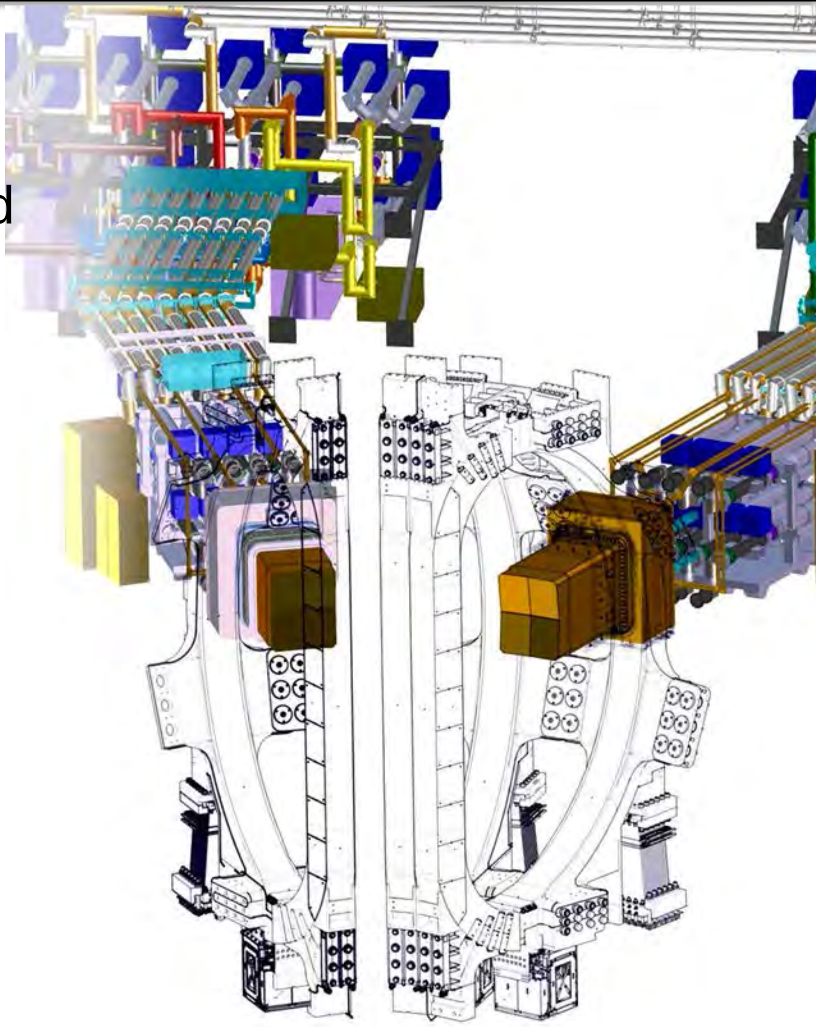
All drain tanks (four 61,000 gallon drain tanks and one ~30,000 gallon tank) will complete fabrication by February 2015. At left, a completed tank undergoes a lifting test. At right, tanks in earlier stages of fabrication.
Photo: US ITER

Tokamak Cooling Water Systems
Technical Challenges

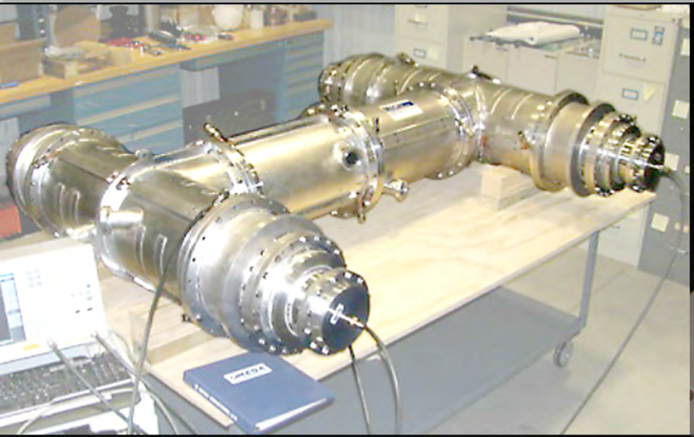
Resolved Challenges	Current Challenges
• Demonstrated successful processes for manufacture and ANB approval of nuclear-qualified components (specific EU requirements to vendor, involvement of ANB at factory) • Established IO-TCWS team to complete design/procure piping	• Redesign TCWS to reduce the consequences of ^{16}N gamma dose rate and ^{17}N fast neutrons to personnel and electronics • Finalize 1st Plasma scope and requirements • Oversight of IO as TCWS designer and piping manufacturer

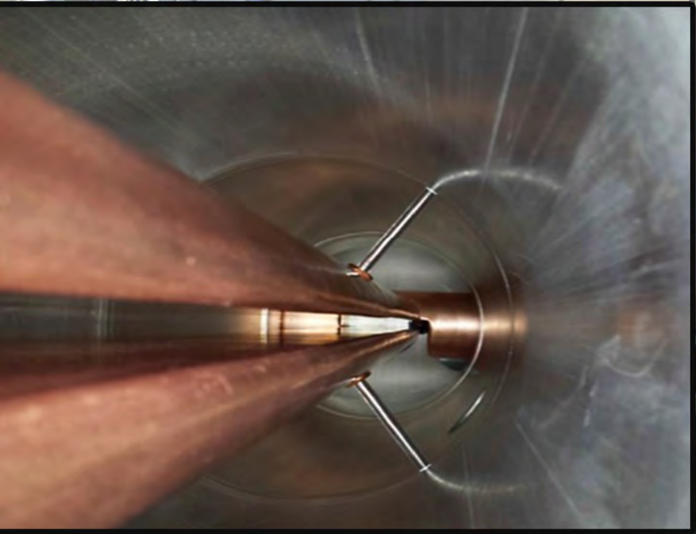
Ion Cyclotron Transmission Lines and Matching System

- 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



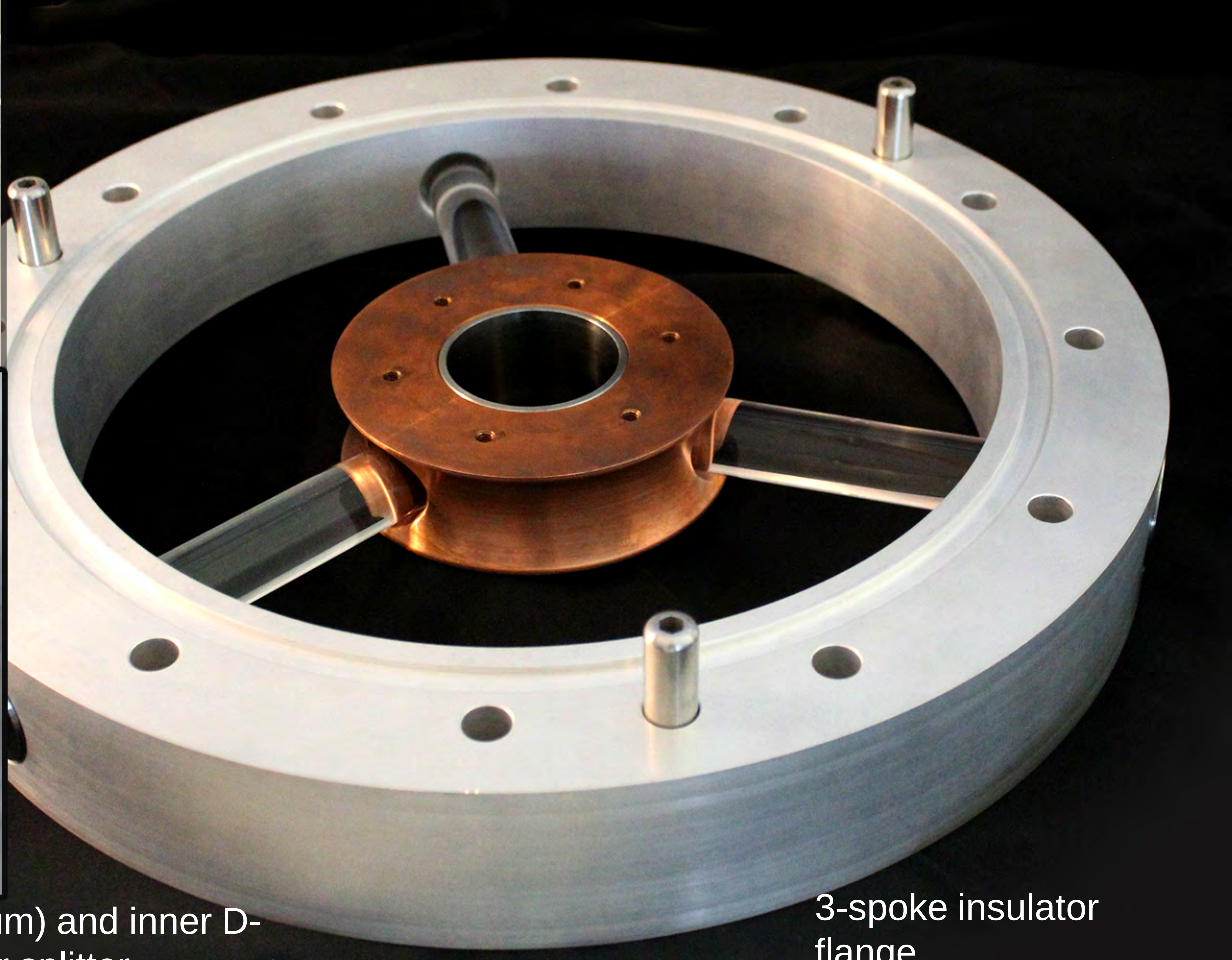
Ion Cyclotron Achievements





Internal view of outer conductor (aluminum) and inner D-shaped conductors (copper) of the power splitter.
Photo: Mega Industries, Gorham, ME

Four-port 50/50 power splitter on the test bench



3-spoke insulator flange

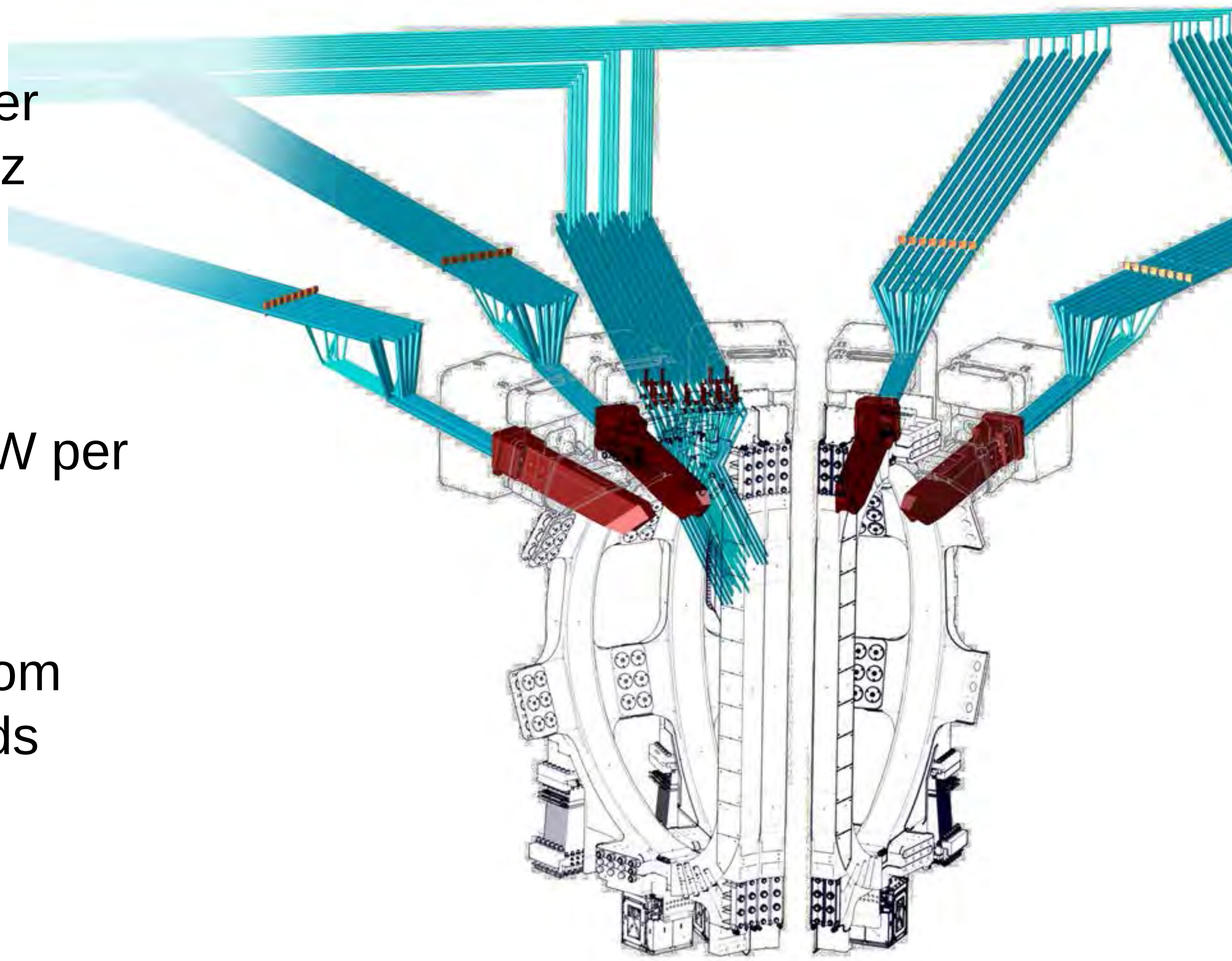
Ion Cyclotron Transmission Lines

Technical Challenges

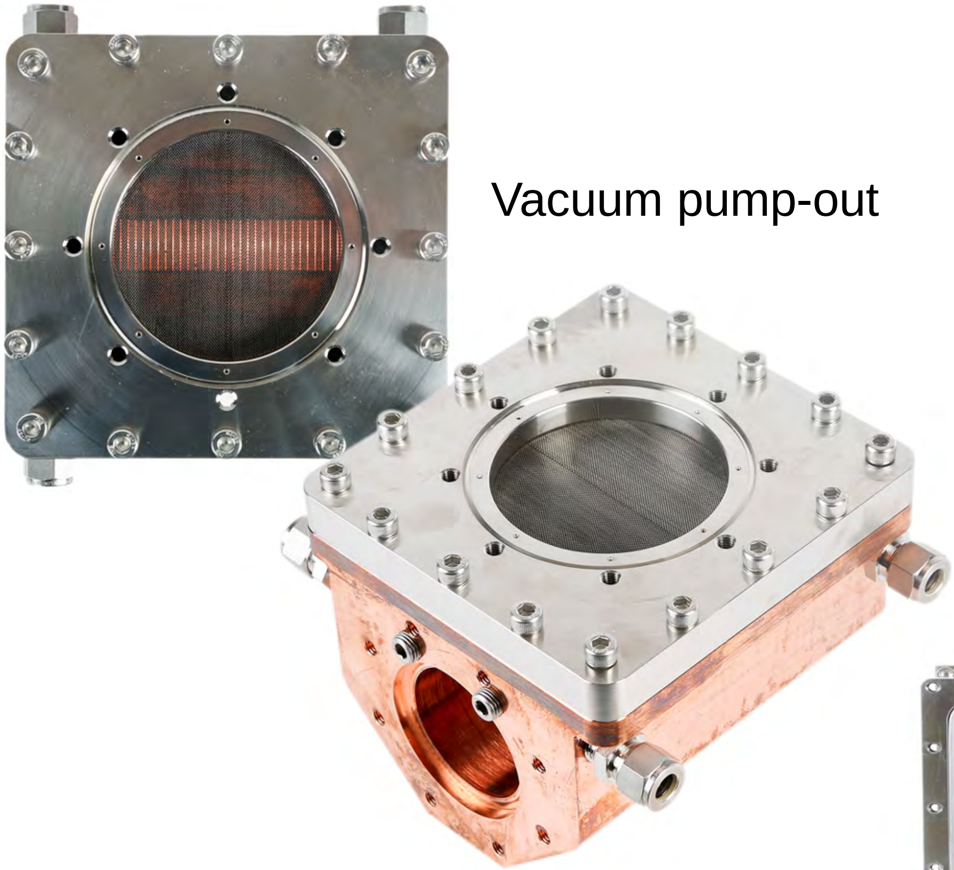
Resolved Challenges	Current Challenges
• Cooling of 50-Ohm components by pressurized air circulation • Successful testing of hybrid splitter to accommodate plasma load changes	• Building interfaces for penetrations through Tokamak Building wall and Port Cell wall for transmission line, services and cabling (especially meeting fire requirements) • Cooling of 20-Ohm components with water-cooling of inner conductor

Electron Cyclotron Transmission Lines

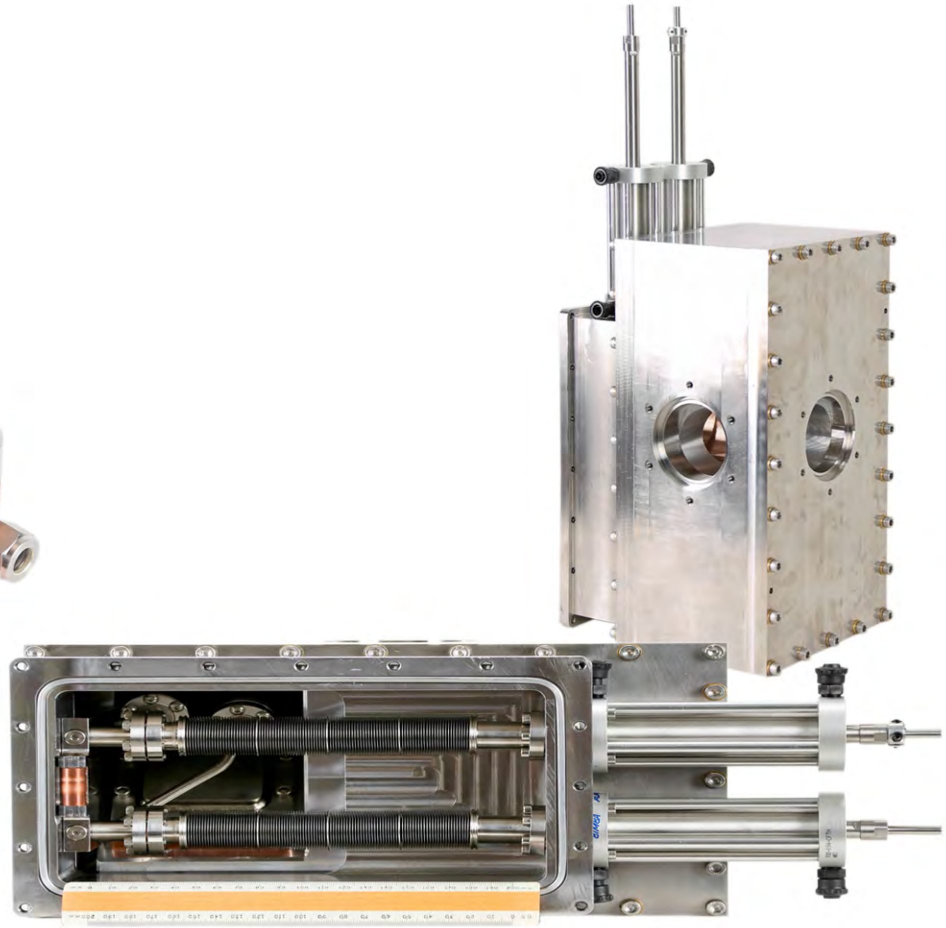
- Provide efficient power transfer from 170 GHz gyrotron sources to launchers
- Transmit up to 1.5 MW per line for 1 hour
- Transmission lines from 24 sources to 56 feeds



Electron Cyclotron Achievements



Vacuum pump-out

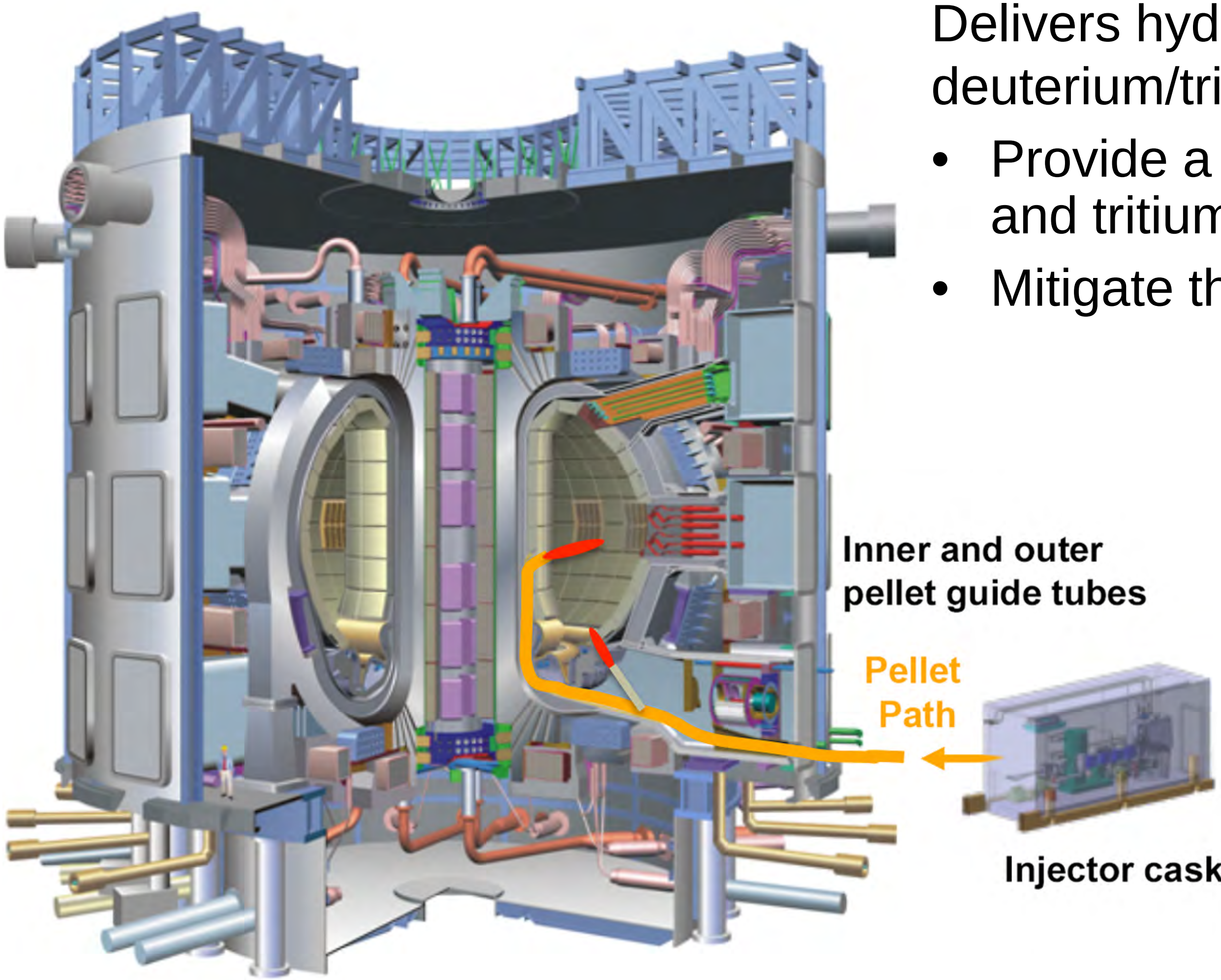


Microwave switch

Electron Cyclotron Transmission Lines
Technical Challenges

Resolved Challenges	Current Challenges
• Resolved necessary alignment/manufacturing tolerances to minimize power loss through mode conversion	• Building interfaces for penetrations through Tokamak Building wall and Port Cell wall for transmission line, services and cabling (especially meeting fire requirements) • Precise alignment needed to avoid excessive mode conversion power losses

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

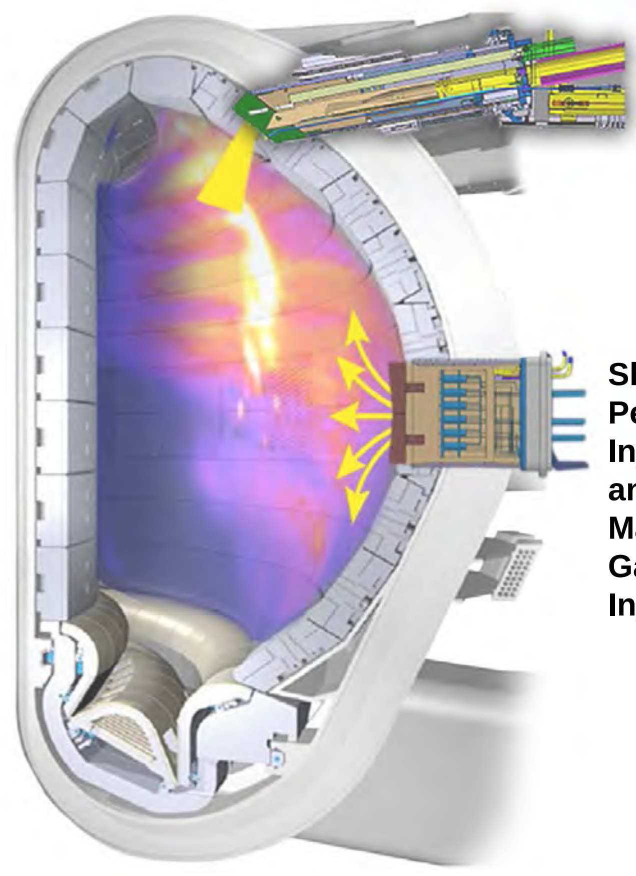
Disruption Mitigation System

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 ~20 ms or ~500 ms, respectively)

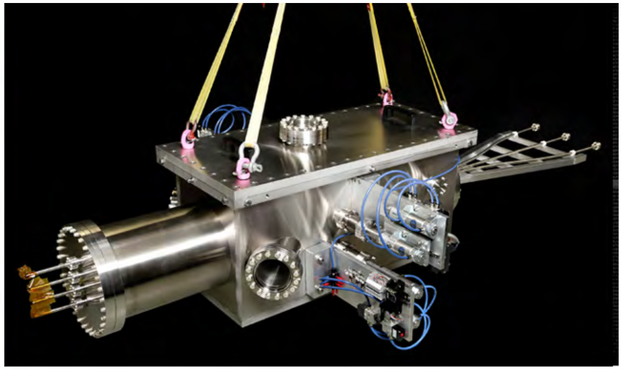
Configuration:

- Shattered pellet injectors (SPI) located outside three upper port cells with pellet shattered near plasma edge
- Multiple SPI located outside equatorial port cell with pellet shattered near plasma edge
- All SPI gas acceleration valve can be used for Massive gas injection (MGI) by not forming a pellet
- Guide and shatter tube are the only SPI/MGI components inside port plug

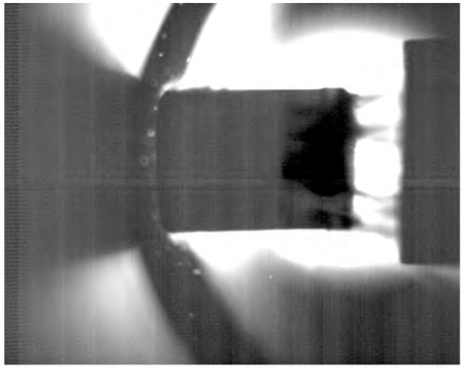


Pellet Injection and Disruption Mitigation Achievements

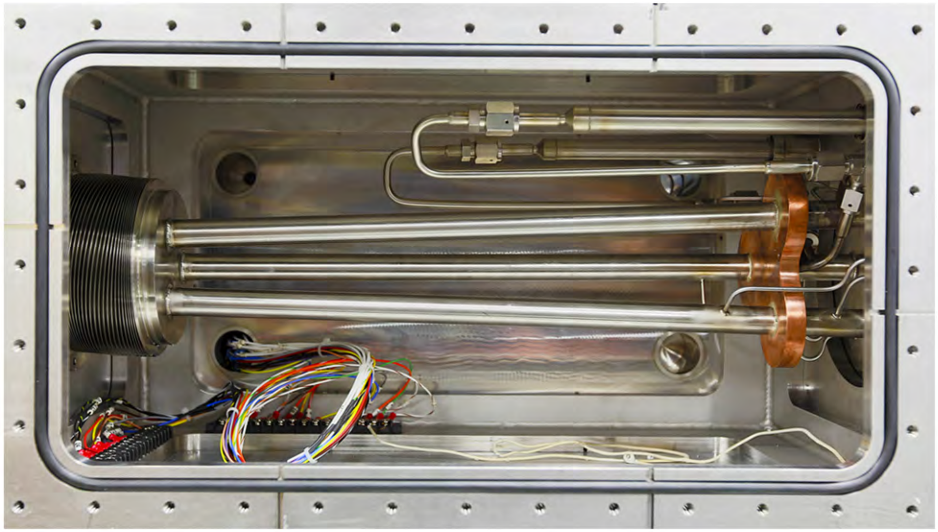
Twin-screw pellet extruder



Pellet guide tube selector test unit

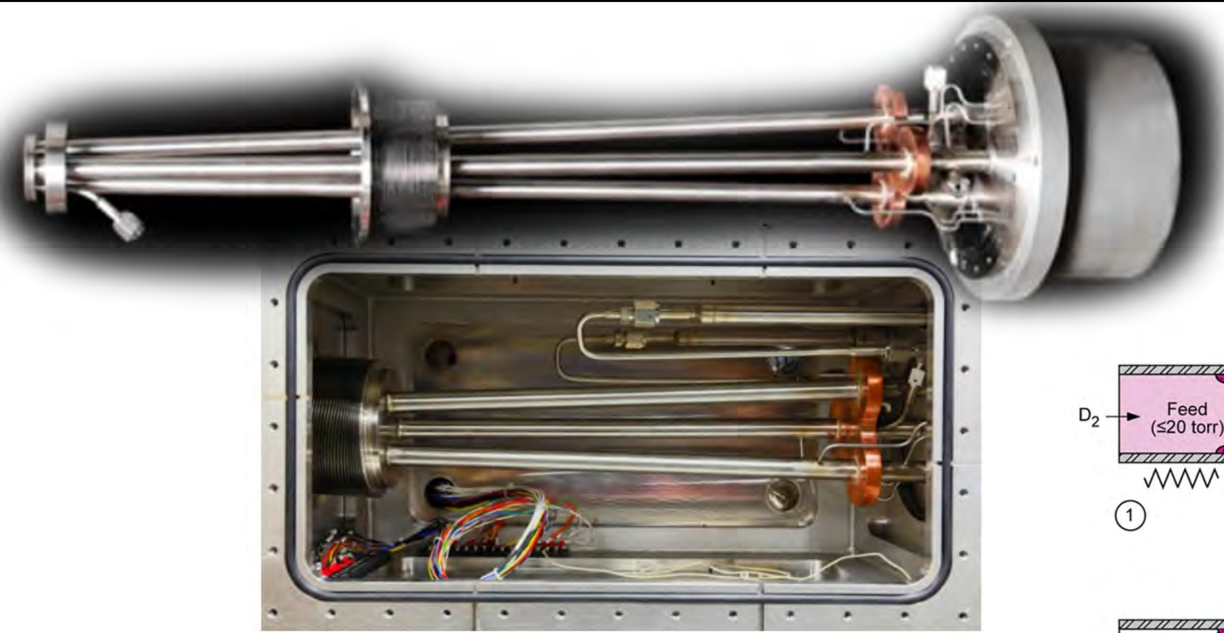


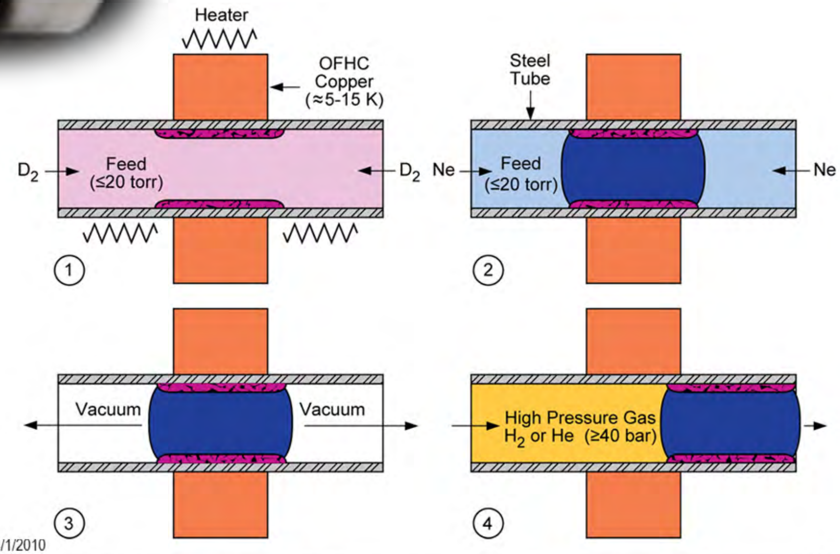
Deuterium-neon pellet formation testing

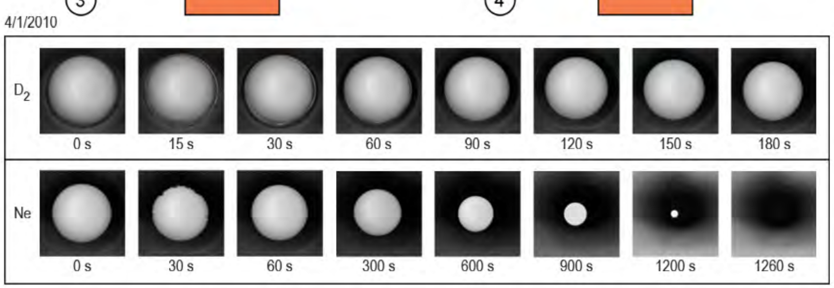


3-barrel unit prototype for disruption mitigation

Milestone Completed:
Shattered Pellet Injection 3-Barrel Testing







- Barrel diameter increased to 34 mm in order to study scaling of freezing/forming
- Larger size will reduce the number of barrels needed for Disruption Mitigation System

Pellet Injection
Technical Challenges

Resolved Challenges	Current Challenges
• Flexible barrel selector method to route the range of pellets for fueling or ELM pacing • Stimulated frequent ELMs to mitigate large ELMs on DIII-D	• Sustained high mass flow, long-pulse pellet forming extruder for long ITER pulse lengths

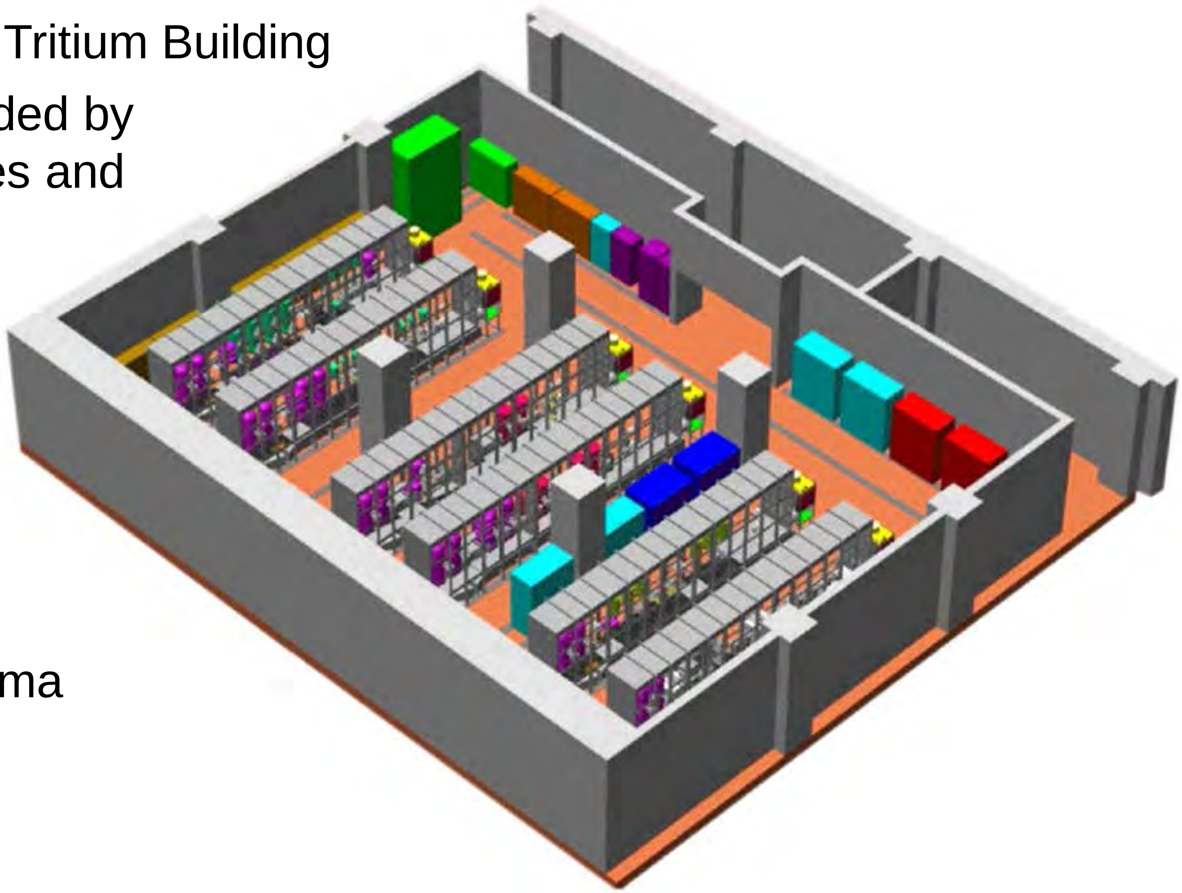
Disruption Mitigation
Technical Challenges

Resolved Challenges	Current Challenges
• Successful testing of shattered pellet technology in DIII-D • Successful forming and acceleration of large Deuterium/Neon pellets	• Achievable system response time of gas and pellets at high reliability • Reliable sealing of massive gas injection valve

Tokamak Exhaust Processing System

Configuration:

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



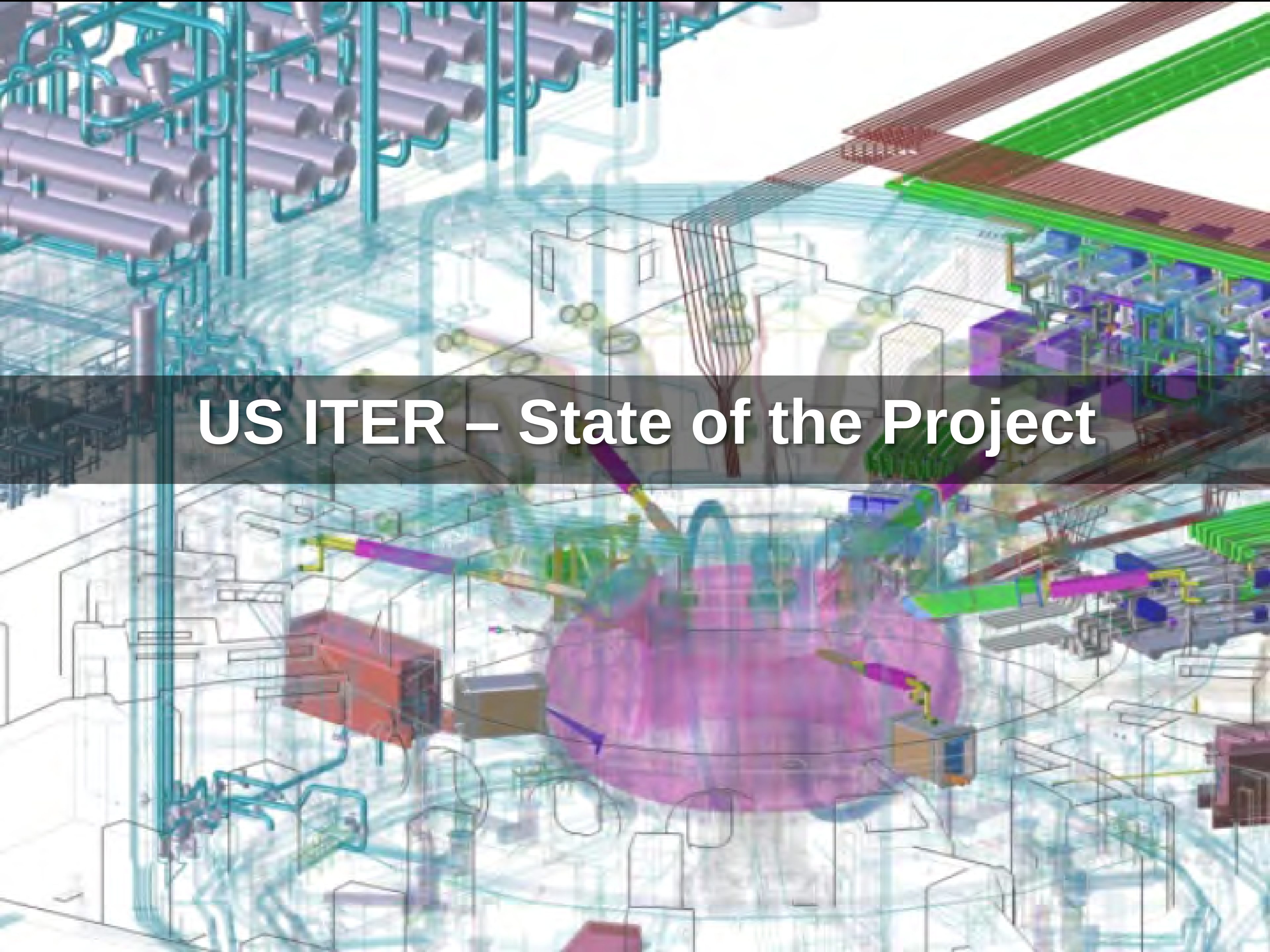
Status:

- In preliminary design
- TEP required for DT Plasma

Tokamak Exhaust Processing
Technical Challenges

Resolved Challenges	Current Challenges
• Availability of manufacturer for specialty equipment (Permeator and Palladium Membrane Reactor) for 10x flow rate with unique ITER concentrations and requirements	• Tritium inventory limit related to fire zones

US ITER – State of the Project



Near-Term (FY 2014-16) Status Summary

FY14

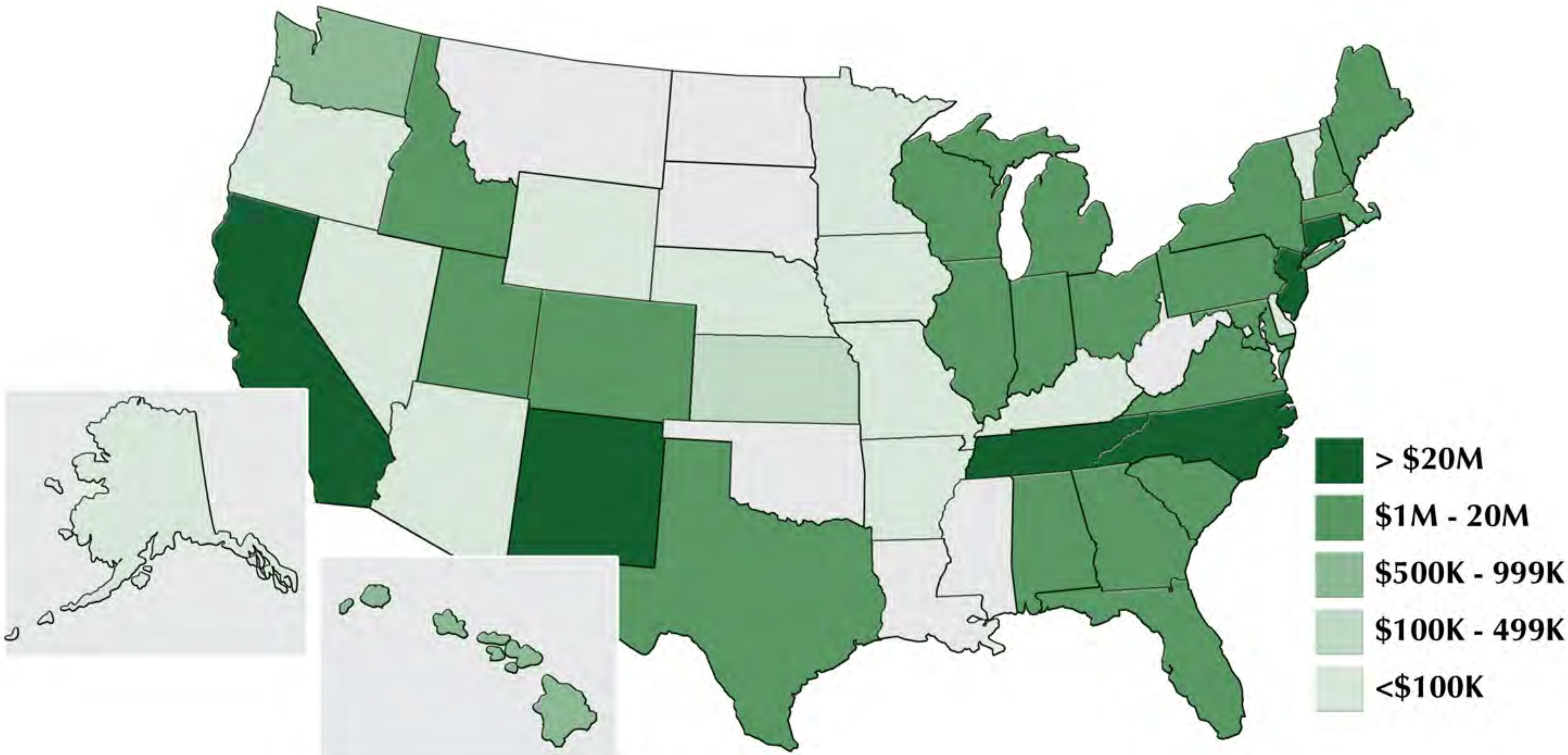
- Fabrication underway for critical-pacing items
  - ~2/3 (by value) of US hardware systems in final design or beyond
- ~1/2 (by value and number) of planned contracts have been awarded
- Key hardware deliveries on-going

FY15-16

- At the end of FY16,
  - Only one procurement arrangement remaining to be signed
  - 28% of US hardware deliveries needed for 1st Plasma will be complete
  - One US hardware contribution will be complete in FY16 (toroidal field coil conductor)

Over $682M in Awards and Obligations

US Industry and University Awards, and DOE Lab Funding: ~$682M

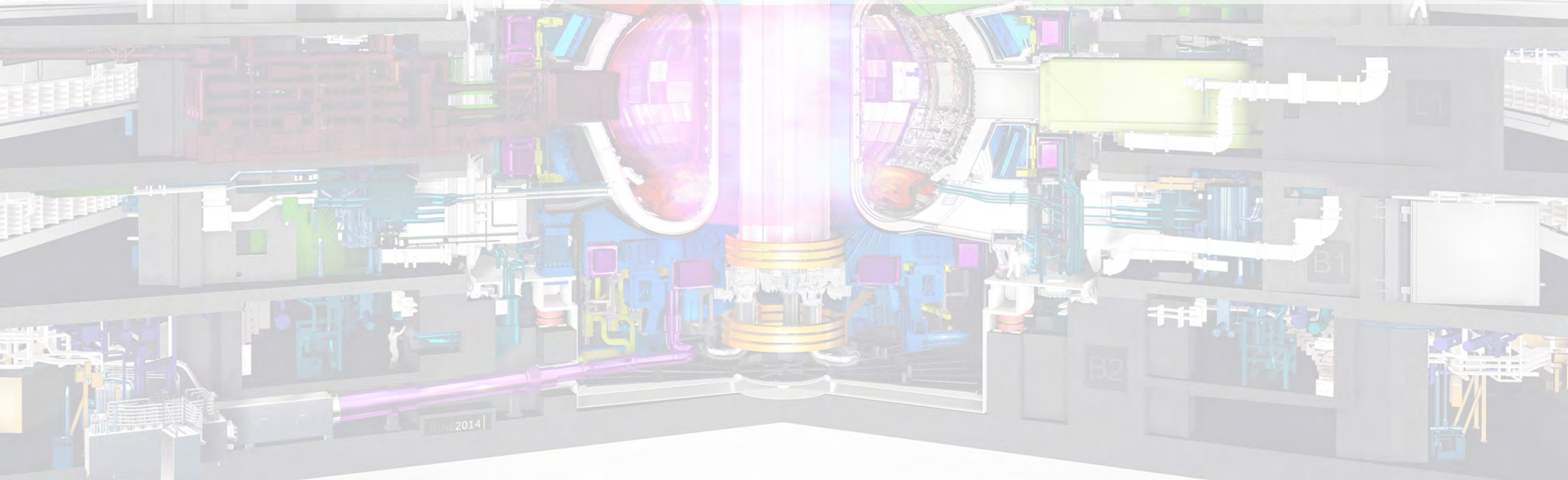


Data as of September 30, 2014

Note: Data above does not reflect contracts awarded to US Industry by the EU (>$55M)

International Status

- New ITER Organization Director-General nominated
- Schedule update anticipated by the end of CY2015
- Major site construction progress is underway



ITER Site

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