Status of US ITER

Kathy McCarthy
Project Director

Fusion Energy Sciences Advisory Committee

August 31, 2021
Outline

• ITER Background
• Overall ITER Project Progress
• US ITER Hardware Responsibilities
• US ITER Sub-Project 1 Baseline vs. Appropriations
• Overview of US ITER Hardware Design and Delivery
• ITER’s Role in the US Fusion Program
• Look-Ahead
ITER Mission: Demonstrate the scientific and technical feasibility of fusion energy

How does ITER contribute to the path to fusion energy?

ITER will:

• Achieve a deuterium-tritium plasma in which the reaction is self-sustained through internal heating ("Burning Plasma" facility)
• Produce 500 MW of fusion power for pulses of 400 seconds
• Demonstrate the integrated operation of technologies for a reactor-scale fusion power plant
• Test/demonstrate Tritium fuel breeding
• Demonstrate the safety characteristics of a fusion energy device

U.S. contributes ~9% for 100% of ITER science and intellectual discovery

During the construction phase the U.S will pay 9.09%; the U.S. will pay a 13% cost share during the operations phase.
ITER fusion “firsts”

• First fusion device categorized as a nuclear installation (France/ASN)
• Power-plant scale vacuum vessel
• Power-plant scale cryoplant
• >10,000 tons of superconducting magnets with a combined stored energy of 51 GJ
• Integrated operations of fusion systems
ITER Project is ~78% complete for First Plasma site construction and components
ITER celebrated the start of assembly in July 2020

French President Emmanuel Macron served as host for the international virtual event on July 28, 2020.
Tokamak assembly began in May 2020
Cryostat base installation
Cryostat base installation
Cryostat lower cylinder installed
First magnet was installed in tokamak pit
Next magnet awaiting installation
Testing of vacuum vessel sector assembly tooling
First vacuum vessel sector successfully docked
Tokamak pit is filling up
Sub-assembly of sectors is progressing

July 2021
Toroidal field coils installed for sector assembly

August 2021
US ITER Hardware Scope

US contributes 9% to construction
Hardware delivery in the US ITER Project is divided into two sub projects:
  – SP-1: design of all hardware and delivery of hardware for first plasma
  – SP-2: delivery of remaining hardware

SP-1 was baselined in 2017

Appropriations for hardware were lower than the baseline early on, but higher in recent years; total to date is a cumulative $97M deficient relative to baseline

Priority given to hardware needed for first plasma

With larger appropriations, we’ve been to restart activities that had to be put on hold
US ITER Hardware Scope
US contributes 9% to construction

Key:  Finished • Hardware in fabrication • Prototypes in fabrication • In design

Electron Cyclotron Heating Transmission Lines
Ion Cyclotron Heating Transmission Lines
Toroidal Field Coil Conductor (US Share 8%)
Steady State Electrical Network (US Share 75%)
Instrumentation and Controls

Central Solenoid

Tokamak Cooling Water System

Vacuum System Roughing Pumps

Tokamak Exhaust Processing System

Diagnostics (US Share 14%)

Pellet Injection Disruption Mitigation

Steady State Electrical Network (US Share 75%)
Most US ITER funding remains in the US

As of June 2021, ~$1.3 billion has been awarded to US industry and universities, and obligated to DOE national laboratories in 46 states plus the District of Columbia.

Awards to industry: ~$729M
Awards to universities: ~$26M
Obligations to National Laboratories: ~$506M

Total: ~$1.3B
Design, fabrication and deliveries continue across US scope

- Central Solenoid
- Tokamak Cooling Water System
- Electron Cyclotron
- Diagnostics
- Vacuum & Roughing Pumps
- Instrumentation & Controls
- Ion Cyclotron
- Pellet Injection
- Exhaust Processing
Central Solenoid Modules

Deliveries are underway!
CS Module 1 in Eloy, Arizona
Central Solenoid Modules

Module 1 is in France; will arrive at ITER site ~September 9

Module 2 is now at the Port of Houston

Transfer of Module 1 by barge from Fos (Port of Marseille)

Protection around Module 2 in Houston
Remaining modules are in fabrication

As of mid-August 2021

<table>
<thead>
<tr>
<th>Modules</th>
<th>Stations 1–2</th>
<th>Station 3</th>
<th>Station 4</th>
<th>Station 5</th>
<th>Station 6</th>
<th>Station 7</th>
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<th>Station 10</th>
<th>Shipping</th>
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<td>Receiving &amp; Winding</td>
<td>Joint &amp; Terminals</td>
<td>Stack &amp; Join</td>
<td>Heat Treatment</td>
<td>Turn Insulation</td>
<td>Ground Insulation</td>
<td>Vacuum Pressure Impregnation</td>
<td>Helium Piping</td>
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Multiple challenges had to be overcome

- Fabrication and qualification of 10 workstations
- Coax joint design and fabrication
- Test station power supply component failure
- Quench detection wire arc

Final coax joint configuration

Many lessons were learned and applied to next steps in fabrication

50 kA magnet charging power supply at GA. Photo: GA
Central Solenoid Assembly Tooling
final delivery planned for September

Lifting fixture passed factory acceptance testing in August 2021
Central solenoid structures fabrication and deliveries continue

Inner tie plate during cryogenic shock testing at PCC.

Upper feeder brackets during forming at PCC.

Lower feeder brackets in final machining at PCC.
Tokamak Cooling Water System Fabrication and deliveries continue

Volume control tank delivered to the ITER site

Pump casing for the vacuum vessel primary heat transfer system primary pump
Fabrication underway for electron cyclotron heating transmission lines first articles

Waveguide prototypes at GA. Photo: GA
Diagnostics work is progressing

Low Field Side Reflectometer Test Antenna Block Assembly manufacturing development at General Atomics. Photos: GA

Test antenna block weldment

Test antenna weldment

Weld plugs antenna cap
Pellet expertise yields valuable R&D for disruption mitigation design

Recent experiments addressed

- Pellet formation (28.5 mm hydrogen and deuterium pellets)
- Pellet dispersion (28.5 mm deuterium pellets)
- Pellet fragmentation (28.5 mm deuterium pellets)
Tokamak exhaust processing is moving forward

System will require throughput of 240 Pa*m$^3$/sec (unprecedented by about 2 orders of magnitude)

Prototype contracts will be awarded soon (to manage risk).
ITER’s role in US fusion
Generating electricity from fusion energy requires resolution of three scientific/technological challenges.

- **Create and Sustain a Fusion Power Source**
- **Materials to Survive in the Fusion Environment**
- **Fuel Self-Sufficiency & Harnessing Fusion Power**

Approximate Technical Readiness Today:

1. **Imaginable**
2. **Plausible**
3. **Feasible**
4. **Practical**

**ITER will demonstrate and sustain this performance in fusion-power dominated regime (self-heated “burning plasma”)**

**Technical Readiness Level (TRL)**

<table>
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<tr>
<th>Imagineable</th>
<th>Plausible</th>
<th>Feasible</th>
<th>Practical</th>
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“Partnership in the international ITER fusion project is essential for US fusion energy development, as is supporting the continued growth of the private sector fusion energy industry… US partnership in ITER provides access to a high-gain reactor-scale burning fusion plasma and an accompanying US ITER research team and program to exploit this facility must be developed.”

“The Department of Energy should assure maximum possible access to ITER information for the members of the fusion pilot plant design teams.”
US ITER benefits US fusion activities...yielding new IP and experience

- Tools and strategies for plasma control and performance
- Superconducting magnet technologies
- Radiation transport analysis
- High-powered plasma heating
- D-T fuel cycle technologies
- Continuous plasma fueling
- Fusion materials
- Fusion power and particle handling
- Burning plasma science and diagnostics
MEMORANDUM FOR THE SECRETARY

THROUGH: KATHLEEN HOGAN
ACTING UNDER SECRETARY FOR SCIENCE
AND ENERGY

FROM: J. STEPHEN BINKLEY
ACTING DIRECTOR
OFFICE OF SCIENCE

SUBJECT: ACTION: Requesting Approval of and Signature on the U.S. Contributions to ITER Project Baselining Strategy Report to Congress

ISSUE: Whether to approve and sign the U.S. Contributions to ITER Project Baselining Strategy Report to Congress.

Thank You!
<table>
<thead>
<tr>
<th>100% R&amp;D and System Design</th>
<th>Full Fabrication</th>
<th>Partial Fabrication</th>
<th>Completion of Fabrication</th>
<th>Full Fabrication</th>
</tr>
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<tbody>
<tr>
<td>All Hardware R&amp;D (Complete)</td>
<td>• Central Solenoid (In fabrication; some items delivered)</td>
<td>[SP-1% / SP-2%]*</td>
<td>• Tokamak Cooling Water  [58% / 42%]</td>
<td>• Tokamak Exhaust Processing</td>
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<tr>
<td>All System Designs</td>
<td>• Toroidal Field Conductor (Complete)</td>
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<td>• Roughing Pumps        [56% / 44%]</td>
<td>• Diagnostics (five of seven)</td>
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<td>• Steady State Electrical Network (Complete)</td>
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<td>• Vacuum Auxiliary      [85% / 15%]</td>
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<td>• Pellet Injection       [ 9% / 91%]</td>
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<td>• Ion Cyclotron Heating [15% / 85%]</td>
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<td>• Electron Cyclotron Heating [55% / 45%]</td>
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<td>• Diagnostics (2 of 7)   [15% / 85%]</td>
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<td>• Diagnostic Ports       [10% / 90%]</td>
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<td>• Instrumentation &amp; Controls [44% / 55%]</td>
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*Percentage of work done in SP-1 and SP-2, respectively; does not represent work completed to date.
First Plasma
An ITER operational phase that includes: 1) integrated systems testing at low power, and 2) achievement of the specified first plasma and integrated systems testing of magnets at full field.

Post-First Plasma
A series of stages including fabrication, installation, and operations/research following the First Plasma phase, leading to achievement of full performance of engineering systems and operation with deuterium and tritium aimed at demonstrating a high-gain fusion “burning plasma.”