The US ITER Role in Magnet Technology

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Representing Many…

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Introduction

- *Magnets are a large part of making ITER happen*
- *Most go forward scenarios have the US contributing some significant part of the magnet system*
- *With limited available resources is that a good use of dollars?*
- *This presentation will attempt to represent (in 10 minutes) a collective YES and define the organizational elements and deliverables for the US with respect to such a contribution*
- *It includes consideration of:*
  - *The US experience as a participant in the ITER EDA*
  - *Feedback from the present ITER central team*
  - *State of the ITER Magnet Systems design basis*
  - *Recommendations from members of the high field magnet infrastructure (suppliers in the US)*
  - *DOE (OFES/VLT) – What?; ITER Planning Activity (Sauthoff/PPPL)-How Much?; BPAC (Prager)- 7 Virtues?*
  - *MIT experience as a contributor to most all major US magnetic fusion initiatives and advance reactor studies- resulting data and tools*
  - *MIT present experience with advanced conductor and magnet designs for ICF, accelerators, detector magnets, interaction/final focus magnets, MRI, Medical applications, Launchers, Separators and Levitation and the respective infrastructure and developmental needs in these programs*

ITER Superconducting Magnet System

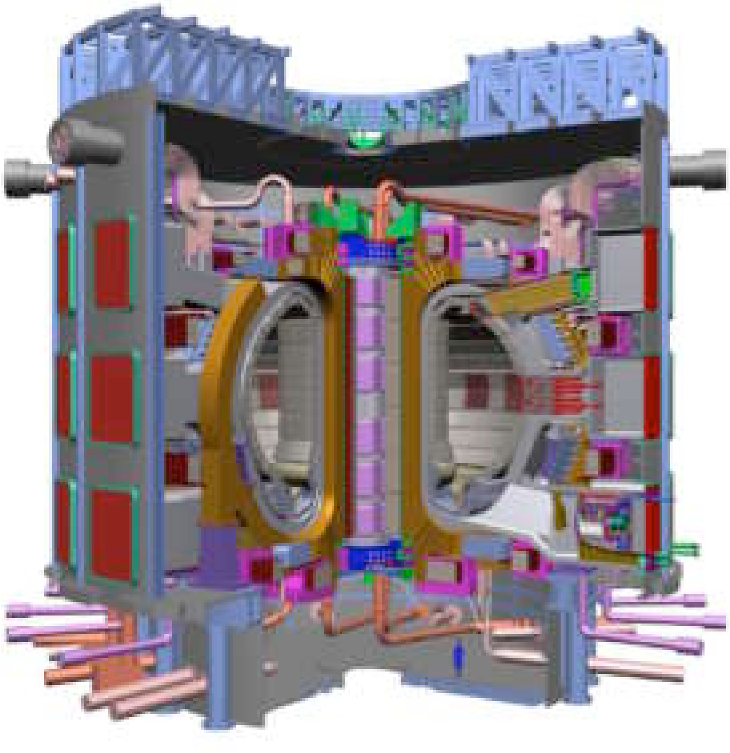
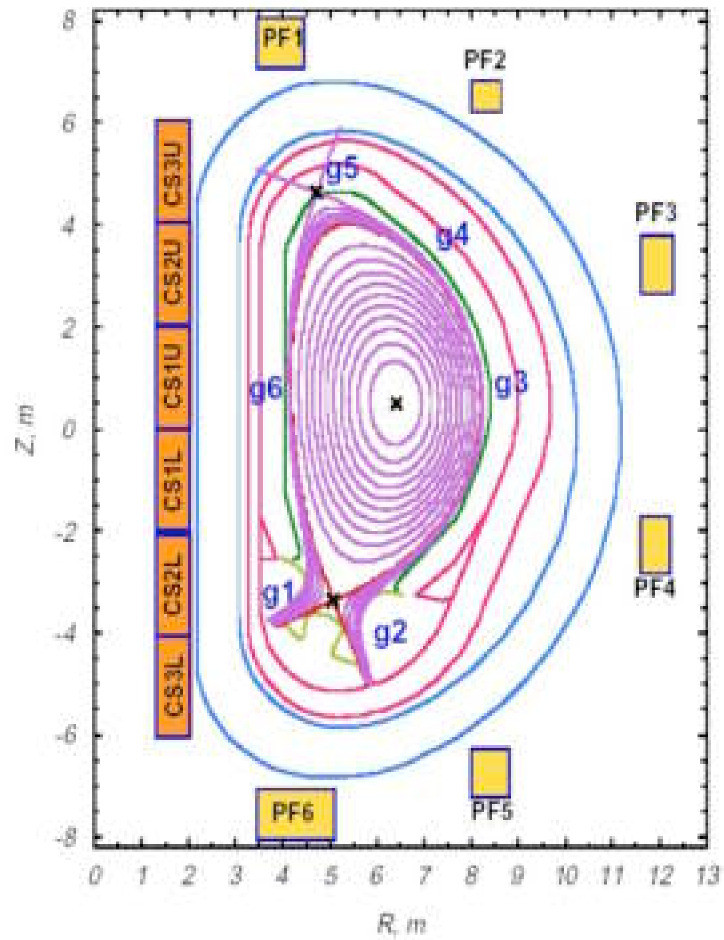


Figure 1.2.1-2 ITER Tokamak Cutaway



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ITER Magnetic System- some details

- Conductor
  - Nb3Sn- CS and TF
  - NbTi- PF and correction coils
  - 355 kIUA direct cost (x1.439 → $US2002)
- Central Solenoid
  - Six identical modules, 700 tons total mass
  - Modules composed of 4 layer and 6 layer CICC pancakes
  - 41 kIUA
  - conductor (from above category) 80-100 kIUA
- Toroidal Field Magnets
  - 18 coils assembled as 9 cased doublets
  - Winding laid in channeled plates to take the shear
  - TF structure carries the net magnetic load and many interfaces
  - 117 IUA
- Poloidal Field Magnets and Correction Coils
  - PF coils will have to be built on site
  - Correction coils also NbTi, similar scale large radius
  - 49.7 kIUA
- Structures, Feeders add another 209 kIUA for a total of 762 kIUA

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Why Should USA Participation Include Magnets?

- ITER wants us to include magnets and conductor in the US scope- leverage on management structure is possible
- The bulk of the required R&D dollars have already been spent (because magnets are on the critical path)
- Conductor improvements (HEP, KSTAR …) have further increased margins
- Magnets (obviously) are central to a tokamak
  - US a historical key contributor to the ITER EDA (CSMC)
  - Baseline winding pack technology (CICC) originated in the US (strongest design basis, codes, tools here)
  - Confinement and stability depends intimately on field errors (we have a tradition in the US of coupling fabrication tolerances to field error mitigation)
  - Operational Characteristic [off normal events] also modeled here- Transient loads and disruptions vs. coil forces /stability
- We have the intellectual and plant capability to participate successfully
  - On going participation in ITER continues
  - We see a well defined U/Lab/Industrial *go forward* model as appropriate
- The magnet subsystem of most interest to us (CS) has the lowest risk, a sound design basis, and clear technological benefits to the US advanced magnet infrastructure (development programs and industry)

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ITER Central Solenoid Model Coil

Test Program Objectives:

- Perform model coil demonstration tests under ITER operating conditions
  - DC operation to 13T, 46 kA and 640 MJ (inner + outer)
  - Pulsed operation to simulate the ITER scenario for the CS
  - 0.6 T/s to 13T
- Characterization of the performance of the conductors and joints
  - AC losses, current sharing temperature, quench properties
- Characterization of the Mechanical, Thermal and hydraulic behaviors
  - no instabilities observed
- Limited lifetime testing with more than 10,000 cycles for the inserts
  - 1.2 T/s to 13T for the Nb3Sn insert
- Test of insert coils using all likely conductor types

All of these objectives were completed successfully

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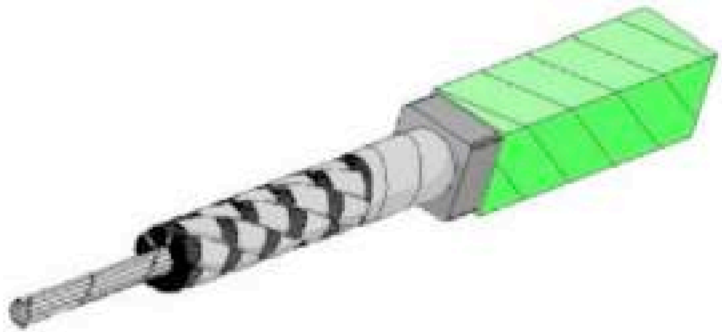
US Participation in the CSMC (1992-2003)

Inner Module
(US)

- Conductor- IGC, Teledyne Wah Chang
- Cabling- BIW
- Conduit Material- Inco Alloys
- Inner Module Fab- Lockheed Martin, MIT
  - Winding, heat treatment (Wall Colmonoy), insulation, impregnation, assembly
- SC Buses and Structures- Lockheed Martin
- Testing Program Support- MIT, LLNL

(LM core group now at General Atomics)

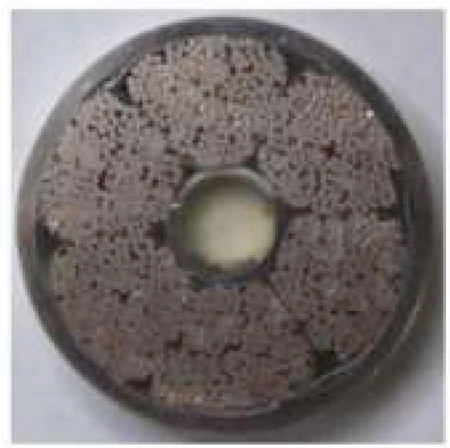
CSMC Conductors



Nominal Operating Condition	
Current	46 kA
Magnetic Field	13 T

5 cm

CS Model Coil, CS Insert
(Incoloy 908)



TF Insert
(Titanium)

NbAl Insert
(Stainless Steel)

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Importance of CSMC to ITER

- ITER CS performance requirements exceeded, analyses tested, structure confirmed
- Multiple conductor vendors involved-US, Japan, EU and RF
- Demonstration of the wind, react, insulate and transfer process on a useful large scale
  - Process specification demonstrated successful control of SAGBO
- Demonstration of two types of tooling capability, terminations, heat treatment and insulation (US and Japan processes)
- Structures and components for assembly
  - Providing for axial preloading and mechanical integrity of the assemblies
- Demonstration of interface control among 4 parties including QA and licensing (all meeting Japan pressure vessel code requirements)

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Importance of CSMC to the US

- Collaboration model was successful- University/National Lab/Industrial Team Model:
  - U/Lab manages the technical baseline: R&D programs; Analysis: E&M, Structural, Stability, Thermal, Thermal-Hydraulic, Field Errors; Qualification Testing; Interfaces
  - Lead Industrial team builds the production facility- conductor integration, winding, heat treatment, insulation, assembly
  - Integrated Subsystem Vendors: strand, cabling, conduit, extrusion, structure, instrumentation
  - Build-to-Print quotations for components
- Natural Productivities of each group are exploited
- We think that this is still the right model for the US to consider for ITER Construction

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Present USA ITER Magnet Related Effort

- Same basic CSMC team is making an assessment of the ITER CS baseline in support of the US negotiation position
  - Bottoms up cost estimate* to a complete programmatic WBS
  - Break out ITER Package Costing (conductor, CS, magnet feeders)
  - Preliminary manufacturing feasibility assessment
- Last Model Coil Test Meeting (Workshop on Magnet Technology) was held at MIT in August 2002
  - 4 days, 57 presentations
  - included most key US, Japan, EU and RF Lab and ITER Team members
  - Most ITER magnet technical issues discussed
  - Also included contributions from non-ITER advanced magnet programs
- Garching Magnet Meeting (this week)- 7 US contributions
  - Martovetsky (LLNL)- ITER Model Coils- test results & assessment
  - Feng (MIT) – Analysis of CS Performance and Conductor Design
  - Minervini (MIT)- (1)ITER Magnet R&D Priorities; (2) US Strand Capabilities, (3) Incoloy 908 Status
  - Schultz (MIT)- (1)Modeling Strain; (2)Global Strand Production & Scheduling
- SOFE- Titus (MIT) ITER CS Inner Transition Stress Analysis
- Some interest in PTF joint testing for EU Team
- Loan CSMC layer winder for development work for EU team

*(CSMC EDA activity did not have such a baseline at the start; to manage the effort we think this is the most important first step)

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Proposed US Scope

CS, CS conductor, CS Structure (vertical integration best)

- Sole source ~$200M (US2002)
- Share with Japan (50/50)~$100M (US2002)
- Supporting (Management, Procurement, Liaison and Technology) Program $32M ($3.5M/yr over 9 year program)

(Conductor and winding pack components important for US industry)

- Role in the ITER Central Team
  - Supporting analysis and testing
  - Magnet review boards
  - Magnet instrumentation development- flow, temp, quench
  - Requirements Docs; Design Desc Docs; Critical Item Specifications and procurement packages [at least for systems we build]
  - Field quality and error analysis
  - Interfaces

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US ITER CS Programmatic Goals

- Contribute to ITER and add value
- Support US Fusion Science Goals
- Strengthen US magnet infrastructure
- Add more students to magnet technology program
- Link technology developments (design, analysis, components, winding packs and structures) to other fields and programs
  - We see 10 Tesla proton radiation therapy systems
  - We see 15 Tesla focusing magnets for colliders and secondary beam production
  - We see novel A15 conductor configurations in levitation/propulsion systems
  - We see A15 conductor performance / enhancements assisting basic and applied science to move forward
  - We see ramp rate limitations, radiation resistance and force density limits as key technology issues for a number of applications

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