An Overview of the US DCLL ITER TBM Program

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For the U.S. FNST Program

The US is functioning with limited funding as the interface coordinator on the DCLL concept with support from Korea. Results presented to IO are as consistent as possible and in most cases conservative.

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US DCLL TBM Team

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Korea:
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The US-Selected Dual Coolant Lead Lithium (DCLL) TBM concept provides a pathway to high coolant outlet temperature using current generation of structural materials:

- Use of RAF/M steel with Helium cooling and SiC for flow channel insert (FCI) for thermal and electrical insulation between PbLi and RAFM steel structure
- Breeder PbLi moves at a slow velocity of < 10 cm/s, allowing PbLi Tout @ 700° C leading to combined gross ηth > 40% with the use of CCGT for DEMO

**DCLL Evolution:**
- Developed in ARIES-ST US-the EU-PPS
- APEX and in Adopted for ARIES-CS
- Similar concept considered in US-IFE-HAPL program
DCLL He loop & AEU
Design evolution
FCI development
TBM experiments in DIII-D
He-loop Development-V1 and V2

V1. 2005 DDD report

V2. With addition of pressure control, cleanup and tritium recovery loops

DCLL TCWS area
He-loop Development-V3

V3. Addition of separate regeneration and cryogenic loops
He-loop Development-V4

V4. Simplified design with tritium getter and removable desiccant module
3-D view of the DCLL Helium Loop
3D-DCLL- AEU Equipment in port cell area
DCLL- AEU Equipment Side View
Layout Plan in AEU - Top View & Side View
(Will Need to Work Closely with the WCCB TBM Team)

Top view

Side view

Vertical shaft

Space for WCCB pipes

Space for WCCB components

W2620

L8500

H3680
DCLL He loop & AEU
Design evolution
FCI development
TBM experiments in DIII-D
DCLL TBM Design Highlights

1. PbLi flow direction adjusted to account for effects from natural convection, as determined by MHD and H/T analysis to optimize DEMO power performance
   a. PbLi inlet in back channel from the top with downward flow
   b. PbLi outlet flow in front channel upward flow
   c. PbLi with two individual inlet and outlet pipes

2. He flow cooling all RAFM steel elements
   a. FW has 2 circuits, 7 passes per circuit from bottom to top
   b. He flows in modularized grid plate and in radial direction
   c. Uses multi-layered back plate distribution design configuration
Proposed DCLL TBM Re-design Continuing

Improvements focused on He flow distributions:

- Initial flow at the bottom
- Bottom and top plates
- Side and FW wall plenum
- Toroidal and radial grid plates

Hot spot elimination

Coupled T/H, neutronics and structural analysis
Outline

DCLL He loop & AEU
Design evolution
FCI development
TBM experiments in DIII-D
Concept of Nested FCI

- New engineering solution to mitigate thermal stress
- Internal layer serves mostly as electrical insulator
- Thermal insulation is shared between the two layers
- No stringent requirements on \( \sigma \). Irradiation does not affect the FCI performance

- SiC-fiber/SiC-matrix composites are promising candidates.
- Other forms of SiC (porous SiC), such as SiC-Foam are alternatives.
SiC-Foam Based FCI Approach

Objective, using silicon carbide, open-cell-foam-core develop FCI prototype that:
- Provides **thermal insulation** between high temperature liquid Pb-17Li tritium breeder and structural material
- Provides **electrical insulation** between Pb-17Li and structural material to mitigate MHD effects

Results:
- Comprehensive thermomechanical modeling was performed and correlated with experimentally derived performance.
- At 700 °C the composite structure exhibited low thermal (~ 3 to 6 W/m-K) and electrical conductivity (< 0.1 S/m).
- Immersion testing of development specimens in PbLi for 100 hours at 0.7 MPa and 600°C resulted in no metal ingress.
- FCI prototype segments up to 100 x 100 x 300 mm long were successfully fabricated along with a segment joint coupling
- FCI prototype thermal testing showed a high thermal gradient across the wall at steady-state with 600°C ID and 453°C OD.
- Immersion testing of a FCI prototype in PbLi at 560°C, at ambient pressure, for 6 hours resulted in no metal ingress.
Outline

DCLL He loop & AEU
Design evolution
FCI development
TBM experiments in DIII-D
Impacts of TBM ferromagnetic effects on ITER performance

Physics experiments were performed in DIII-D in Nov. 2009. Details have been organized with community inputs and review.
GOAL: Measure Effects of Test Blanket Module (TBM) Ferromagnetism on Plasma for ITER

Ferromagnetic TBM module pair makes a local “speed bump” field error

- ~1% mid-to-peak in ITER
- Comparable toroidal field coil ripples in JET & JT60U significantly reduced H-mode confinement
- It is not yet known how to predict consequences of one or a few magnetic “speed bumps”

Calculated by S Putvinski, at plasma surface
Mock-up Approximates Magnetization of Two ITER TBMs in One ITER Equatorial Port

Mock-up Has 2 Racetrack Coils in One DIII-D Equatorial Port

- Racetrack coils $\Leftrightarrow M_{TOR}$
- Vertical solenoid $\Leftrightarrow M_{POL}$
  - Separate power supplies for $M_{TOR}$ and $M_{POL}$ to match $q$

- Moveable, $\Delta R \approx 1.0$ ‘ITER-meter’
- Matches ITER TBM far field
- Capable of $\sim 3x$ ITER $\Delta B/B_0$
  - Matches surface-average amplitude of the 6 ITER TBMs
  - Does not match their spectrum

TBM mock-up coil assembly fits into custom port cavity
DIII-D TBM Mock-up is about as tall as a scaled-down ITER TBM.

DIII-D port is considerably narrower than a scaled ITER TBM port.

Mock-up secured in its channel with cooling water attached.

Mock-up rolled into equatorial port cavity.

Schaffer, VLT Conference Call, 2010 July 21
DIII-D Mock up Experiment, Key Results

- TBM mock-up experiments provided essential data to the ITER Organization
  - TBM consequences on plasmas appear to be smaller than feared
  - Theory to extrapolate confinement to ITER is not yet mature
    > Mock-up data will help benchmark theory
  - Results should be applicable to other small (with respect to plasma) ferromagnetic error fields

- Future experiments are needed to determine if n=1 error compensation alone:
  - Will safeguard tolerance to locking in H-mode
  - Will affect plasma braking
US DCLL TBM Development Summary

- We continue to assess the DCLL TBM design in all relevant areas with the goal for DEMO and with support by R&D efforts.

- We are performing the function as the DCLL TBM interface coordinator with support from Korea and responding to near term action items from IO.