Progress and Preliminary R&D Plans of China Solid Breeder TBM

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IV. Possible Collaboration with Other Parties

V. Summary
I. Introduction

- A description design and its performance analysis of CH HC-SB TBM have been carried out recently.

- A design description document (DDD) of the HC-SB TBM have been completed recently. The relevant R&D, test plans based on the TBM design were proposed.

- China hopes to widely collaborate with other ITER parties under TBWG framework, and expects to deliver a HC-SB TBM to ITER on day one. Possible collaboration field on TBM R&D with partiers have been given.
II. Design and Analyses of CH HC-SB TBM
Present design is based on the ¼ port size on Port C; However, It is easily extended to a half-port-space module.

Assumed Port Position for CH HC-SB TBM Module

630mm(d) X 660mm(w) X 890mm(h)
Modular Design on Structure

- **Be armor:** 2 mm
  - Max Temp.: 543°C
- **First wall:** thickness: 30 mm
  - Material: Eurofer
  - Max T: 530°C
  - Cooling tube: 18x14.5mm
- **Unit cells:** 3X3 sub-modules
- **He pressure:** 8 MPa

Integration view of structure design

Sub-modules:
- 0.190 m in toroidal
- 0.420 m in radial
- 0.260 m in poloidal
Main Characteristics

1. Modular structure design improve and strengthen the safety performance, reliability, maneuverability of test in ITER, and disassembly feasibility, more easy to replace the sub-module;
2. The BOT with ceramic pebble bed concept, Be as neutron multiplier are used in the design;
3. A U-shaped double-shell FW structure is used;
4. Each cell as a sub-module has relative independently cooling circuit (8 MPa He) and purge gas circuit (0.1 Mpa ). The cooling model in series connection from FW to sub-modules are used;
5. Each sub-module is a closed box by the top-lower plates with two side-plates.
Schematic view of CH HC-SB TBM

- **Outside of structure**
- **Cross-section of module**
- **Coolant manifold**
- **Configuration of Sub-modules**
- **Sub-module structure**
- **Cross-section of sub-module**
Exploded 3-D view of HC-SB TBM

Structure and components design in detail is on going.
Interface Description

HCS sub-system in TCWS

Test port general arrangement

TBM module assembly

Equatorial test port area with transporter

Transporter side wall pipe arrangement

Equatorial port and pipe area
# Design parameters for the HC-SB TBM

<table>
<thead>
<tr>
<th>Configuration</th>
<th>BOT (Breeder Out of Tube)</th>
<th>Modules: 3×3 Sub-modules</th>
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<tbody>
<tr>
<td>FW area Neutron wall loading Surface heat flux</td>
<td>0.564 m(W)×0.890 m(H)</td>
<td>0.591 m², 0.78 MW/m², 0.30 MW/m² (normal condition), 0.50 MW/m² (extreme condition)</td>
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<tr>
<td>Total heat deposition</td>
<td>NT-TBM, PI-TBM</td>
<td>0.76 MW</td>
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<td>Globe TBR</td>
<td>Lithium orthosilicate, Li₄SiO₄</td>
<td>1.15 (1-D), 80% Li-6</td>
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<tr>
<td>Tritium production rate</td>
<td>ITER operation condition</td>
<td>2.23×10⁻² g/d</td>
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<tr>
<td>Sub-module dimension</td>
<td>(P)×(T)×(R)</td>
<td>260 mm×190 mm×420 mm</td>
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<tr>
<td>Ceramic breeder (Li₄SiO₄)</td>
<td>Two size Thickness Max. Temperature</td>
<td>Diameter: 0.5-1 mm, pebble bed 90 mm (four zones) 737 °C</td>
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<tr>
<td>Neutron multiplier (Beryllium)</td>
<td>Two size Thickness Max. temperature</td>
<td>0.5-1 mm, Pebble bed 200 mm (five zones) + 2 mm (armor) 543 °C (Armor) 617 °C (Be Pebble bed)</td>
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<tr>
<td>Structure material</td>
<td>Ferritic steel Max. temperature</td>
<td>EUROFER 530 °C</td>
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<tr>
<td>Coolant helium (He)</td>
<td>Pressure Pressure drop Temp. range (inlet/outlet) Mass flow Diameter (OD/ID)</td>
<td>8 MPa 0.294 MPa 300/500 °C 0.73 kg/s 85/80 mm</td>
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<tr>
<td>Pipes size</td>
<td>Pressure Pressure drop</td>
<td>0.12 MPa 0.02 MPa</td>
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<td>He purge flow (He)</td>
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</table>
HC-SB TBM Auxiliary Sub-system

TBM

BC

HCS

CPS

VV

Port Cell

TWCS vault

Tritium Building

TMS

NMS

TES
Schematic views of Coolant flow

Toroidal cross-section

Coolant flow in FW

Coolant outlet to 9 sub-modules

Breeding zone Arrangement

Circuit 1 inlet

Circuit 2 inlet

Coolant Flow Direction

Coolant flow in the sub-module

Back-plate
HC-SB TBM Auxiliary Sub-system

Helium Cooling System (HCS)

Tritium Measurement System (NMS)

Tritium Extraction Subsystem (TES)

Coolant Purification System (CPS)

Neutron Measurement System (NMS)

Space Requirement:
The TES system must be installed in a glove box. The size of the Glove Box is: 5.5m x 1.2m x 5.5m (L x W x H).

Space Requirement:
A minimum net foot print area of 16 m² in the TCWS vault, and 0.5 m³ in transfer cask, will be needed for the assembly, maintenance and operation of the CPS.
Performance Analysis

a. Neutronics calculations
b. Activation analysis
c. Thermo-hydraulic Analysis
d. Thermo-Mechanical Analysis
e. Preliminary E-M analysis;
f. Preliminary LOCA, LOFA analysis, etc.,

Above performance analysis have been completed. The results in detail have been given in the CH HC-SB TBM DDD document.
Performance Analysis (Con’t)

Neutronics Calculation

Temperature distribution of the HC-SB test module

Stress distribution of the HC-SB test module

Neutronics

Thermo-hydraulic

Thermo-mechanical

Safety and Reliability Analysis

Coolant Flow Scheme

Safety and reliability

Flow scheme

E-M and Accident Analyses

E-M and accident analysis
III. Test and R&D plans
Relevant R&D plans

- **Continuously improve HC-SB TBM design**
  Interface of TBM, frame and auxiliary system design;
  Improve and develop relevant software and database;

- **Development of tritium measurement technology**;

- **Development of neutron diagnostic technology**;
Manufacturing of key components

Some necessary R&Ds are being performed for the ITER shielding blanket task in China. Relevant fabrication technology obtained will be useful for manufacturing of key components of TBM:

(1) HIP technology for joining different materials, such as Be/Cu;
(2) NDT inspection method;
(3) High heat flux (HFF) test facility and method, etc.
Development of RAFMs for TBM in China is being performed;

Development of the ODS (oxide dispersion strengthened) steels and vanadium alloy steel are on going in China;

Long-term is to develop SiC$_f$/SiC composites material for advanced fusion blanket concepts.
Ceramic Breeder and Neutron Multiplier

China has studied tritium-processing technology supported by national fusion program for many years. Knowledge accumulated in this field is useful for the TBM tritium technology.

Two kinds of ceramic breeder (Li₄SiO₄, Li₂TiO₃), are developing in China.
Equipments and Technique for Ceramic Breeder in CAEP

Melting-spraying unit for the production of Li$_4$SiO$_4$ pebbles

γ -LiAlO$_2$ pebbles

Separation System

Control System

Li$_2$ZrO$_3$ Pebbles
# Time schedule for ceramic breeder technologies

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<td>Designing of radiation capsule for material test, designing of tritium circuit</td>
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<td>Property test (mechanical, physical, chemical and thermal property)</td>
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<td>Structure and contents designing of tritium; breeder by computation simulation</td>
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<tr>
<td>Property test (radiation stability, tritium release behavior, tritium fabrication property)</td>
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<td>Tritium absorption and releasing behavior on tritium breeder</td>
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<tr>
<td>Tritium breeder fabrication as designed by computation simulation</td>
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Development of Neutron Multiplier

Main Chemical Composition of CH 2# and US S-65C**

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<th>Type No.</th>
<th>Elements (wt.%)</th>
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<tr>
<td></td>
<td>Be</td>
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<tr>
<td>Grade 2# (CH)</td>
<td>99</td>
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<td>S-65C VHP (US)</td>
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**Data from the Sixth Smelt Factory of Hunan Province.

- China has also large yielding capacity of Be and relevant experiences of neutron multiplier.
- China has built Be fabrication and manufactory in Ningxia Orient Non-ferrous Metal Group Co.
- A new project, to develop high quality Be in China, is being implemented for ITER.
Development of Tritium Technologies

- **Development of tritium extraction technology**
  - Instrumentation development;
  - Hydrogen isotope separation;
  - Tritium extraction;
  - He coolant purification simulation loop;
  - Tritium control technology;
  - Tritium release behaviour and required purge gas conditions.

- **Theoretical simulation and assessment**
  - Tritium cycle modelling (tritium permeation, tritium inventory).
Tritium Technologies (con’t)

- Develop tritium permeation barrier
  - amorphous TiN（TiC）films by IBAD;
  - Al₂O₃ film by ions coating-oxidation, CVD, explosive spray, etc.
    - TPRF >1000 is obtained in specimen experiments.
    - To be applied in practice in tritium permeation barrier.

- Future R&D in the near future
  - Key technologies for components and subsystem
  - Tritium system loop test
Tritium Processing Equipments in CAEP

Electrolytic Cell

Hydrogen Purification Unit

Promising H, T and impurities on line analytical tools
Tritium Permeation Barrier Study in CIAE

Microstructure of the Fe-Al coating

The composition profile in the coating

Fe-Al intermetallic compounds in the coating layer

Process apparatus for the Fe-Al coating
# Time schedule for tritium technologies

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<td>On line analytic tools : MGC, QMS,…</td>
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<td>Tritium emergency-response system</td>
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<td>Tritium permeation barrier</td>
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<td>Demonstration system</td>
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<td>Integration and test of real system</td>
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Irradiation Test on High Flux Reactors

China has built a High Flux Engineering Test Reactor (HFETR) in the China Institute of Nuclear Power (CINP). HFETR is the largest one in Asia.

- **Neutron Flux:**
  - Thermal neutrons: $6.2 \times 10^{14}$ n/cm$^2$•sec; (E<0.625eV)
  - Fast neutrons: $1.7 \times 10^{15}$ n/cm$^2$•sec; (E>0.625eV)

- **Total power:**
  - 125 MW (th)

In addition, there are two sets experiment reactors with power of 20MW and 40MW are constructing in CIAE and CAEP of China.

- These facilities and their ability are useful for the irradiation experiment of the TBM structure materials, tritium breeders, neutron multiplier etc.
A High Temperature He Experiment Loop (HTHEL) with 700 °C and 8-10 Mpa, which is useful for HC-SB TBM design and R&D activities, is proposed to be built in China.

China has built a high temperature gas-cooled reactor (HTGR). The technologies and experiences gained in HTGR project are useful.

Temp.: 900 °C, Total Power: 10MW, Pressure: 3 MPa
## Design and R&D Schedule for HC-SB TBM

### Items | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | Day 1
---|---|---|---|---|---|---|---|---|---|---|---
### Design Phase
- Detail design
- Engineering design

### Materials Development
- Ceramic Breeder, $\text{Li}_4\text{SiO}_4$, $\text{Li}_2\text{TiO}_3$
- Structural material, (RAFS steel)
- Neutron multiplier, Be

### Performance Testing
- In-pile testing
- Out--pile testing

### Tritium Technology
- Tritium Extraction Technology
- Tritium permeation Barriers
- Coolant purification simulation loop
Out-of-pile Test

- Small-sized HC-SB TBM mock-up tests (scale 1:4 or larger)
- Ceramic pebble bed thermo-mechanical test
- First wall heat removal test and thermal cycle test
- Prototype TBM mock-up test
- Heat removal test and thermal cycle test
- TBM check-out with the auxiliary systems prior to ITER installation
In-of-pile Test

- Tritium release behavior and required sweep gas conditions;

- Thermo-mechanical behavior of ceramic breeder and Be pebbles under neutron irradiation conditions;

- Structure materials irradiation test;

- Mechanical properties test of irradiated ferritic steel samples;
## Time Schedule for CH HC-SB TBM Fabrication and Test

<table>
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<tr>
<th>Years</th>
<th>06</th>
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<tr>
<td>TBM Sub-components qualification.</td>
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<td>Small mock-ups fabrication</td>
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<td>TBM Functional tests</td>
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<td>Small and medium sizes mock-ups tests</td>
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<td>Full size mock-ups fabrication</td>
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<td>Full size mock-ups tests</td>
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<td>EM-TBM for installation</td>
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<td>CH EM-TBM fabrication</td>
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<td>CH EM-TBM acceptance tests</td>
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**Typical cost estimation:** about 0.1-0.2 Billion Chinese Yuan for one CH HC-SB TBM.
Domestic Cooperation Units on R&D for HCSB TBM

Ningxia Orient Non-ferrous Metal Group CO., LTD

Be pebbles

SWIP
Southwestern Institute of Physics
(TBMs)

TUNET
Tinghua Uni, Institute of Nucl. Energy Tech. (HCS)

CAEP
China Academy of Engineering Physics (CPS, TES, Breeder)

SICCAS
Shanghai Institute of Ceramics, Chinese Academy of Sciences (Ceramic Breeder)
V. Summary

- New progress and status of CH HC-SB TBM since last TBWG meeting are introduced briefly.

- Under the cooperation with domestic institutes, a preliminary design and analysis for CH HC-SB TBM module has been carried out. A design description document (DDD) have been completed recently.

- Preliminary R&D program, timescale and milestones, up to the installation in ITER (2015), as well as the collaboration expected with other Parties are presented.

- Relevant R&D on the key techniques will be preformed with the cooperation of domestic and international institutions and companies.
Thank you for your attention!