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Breeding Blanket Modules Testing in ITER
An International Program on the Way to DEMO

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Outline of the Presentation

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4. *Main TBM Testing Parameters*
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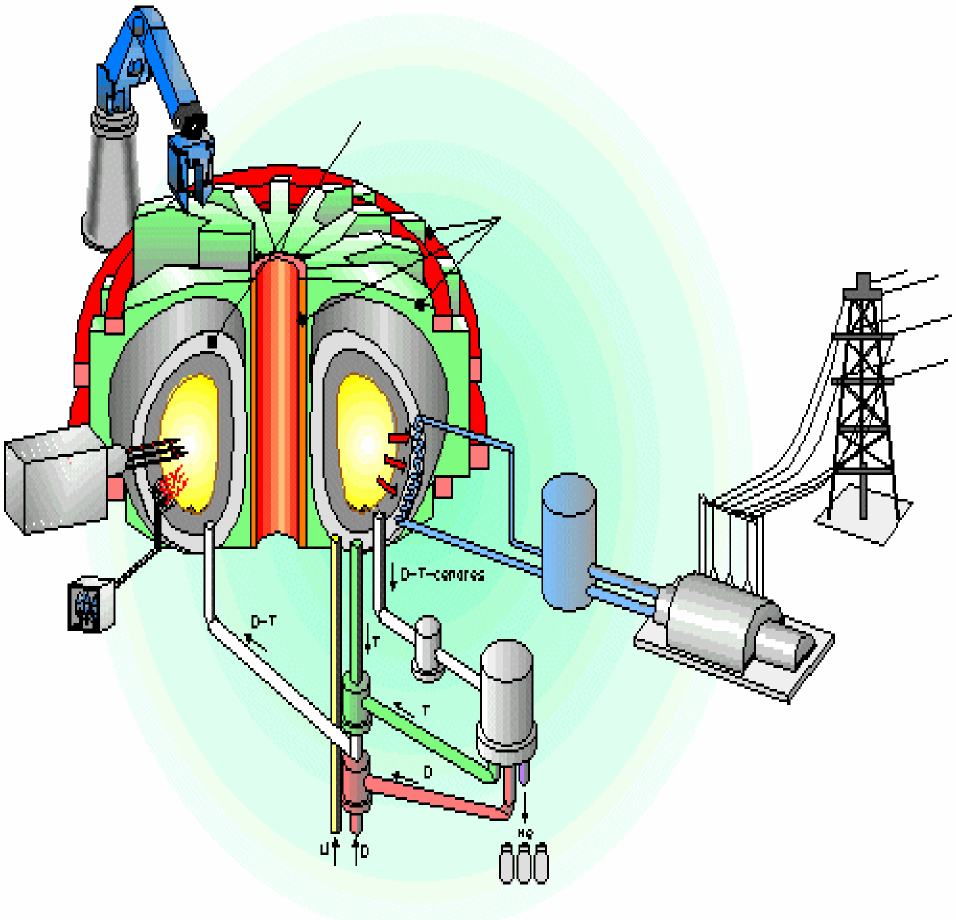
1. Introduction *(1/2)*

DEMO : the reactor immediately after ITER (DEMOnstration reactor)



Three crucial functions for a DEMO Breeding Blanket

- **Convert** the neutron energy (80% of the fusion energy) in heat and collect it by mean of an high grade coolant to reach high conversion efficiency (>30%)
  ➔ in-pile heat exchanger
- Produce and recover all **Tritium** required as fuel for D-T reactors
  ➔ Tritium breeding self-sufficiency
- Contribute to neutron and gamma **shield** for the superconductive coils
  ➔ resistance to neutron damages

1. Introduction *(2/2)*

Tritium Breeding Blankets : complex component submitted to very severe working conditions, needed in DEMO, not present in ITER

- ITER is an unique opportunity to tests mock-ups: Test Blanket Modules (TBMs)
- It is an ITER mission : *"ITER should test tritium breeding module concepts that would lead in a future reactor to tritium self-sufficiency, the extraction of high grade heat and electricity production."* (ITER SWG Report to the IC)

  ➔ TBMs have to be representative of a DEMO breeding blanket, capable of ensuring tritium-breeding self-sufficiency using high-grade coolants for electricity production

ITER Test Blanket Working Group : created to coordinate test blanket program and to verify the program integration in ITER

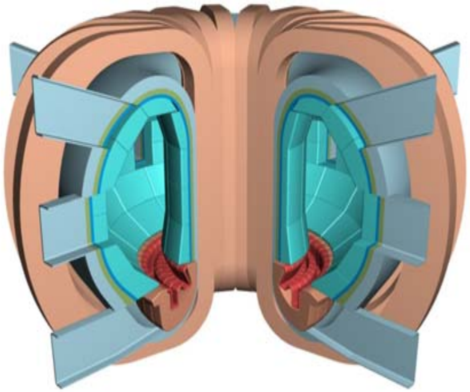
- is formed by members from all six ITER Parties and from ITER Team
- additionally, it promotes collaboration on R&D between two or more ITER Parties
- makes recommendation on TBM testing time schedule, feasibility, and usefulness

  ➔ TBWG recommends TBMs testing to start the first day of ITER H-H operation

2. DEMO Breeding Blankets considered by ITER Parties

SOLID Breeders

- ► ***Helium-Cooled Ceramic Breeder (HCCB)*** concepts using Ferritic/Martensitic Steel (FMS) structures, Be-multiplier, and Li_2TiO_3 or Li_4SiO_4 or Li_2O ceramic breeder: *China, EU, Japan, RF, Korea, USA*
- ► ***Water-Cooled Ceramic Breeder (WCCB)*** concept using FMS structures, Be-multiplier, and Li_2TiO_3 or other ceramic breeder: *Japan*

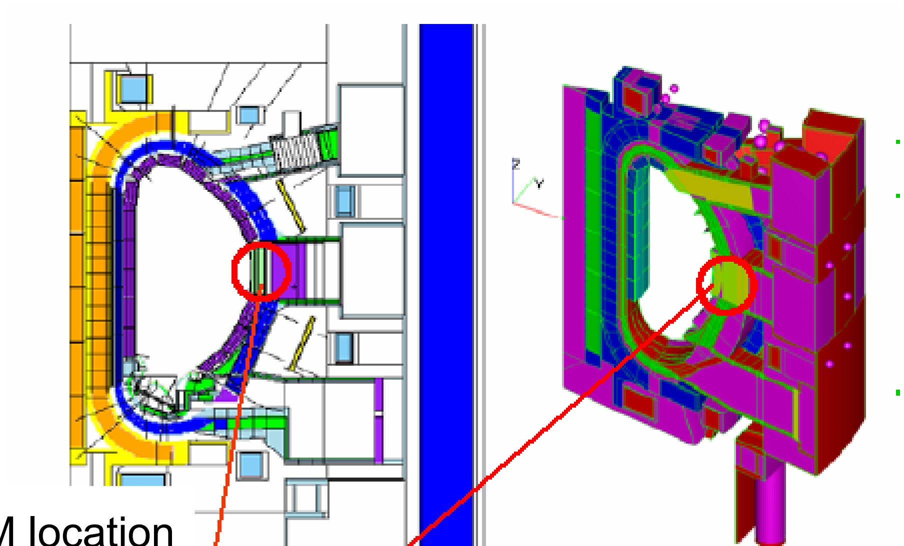


LIQUID Breeders

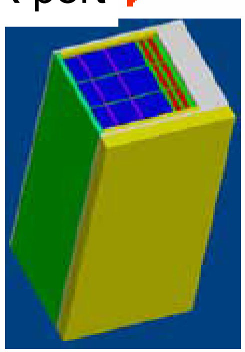
- ► ***Helium-Cooled Lithium-Lead (HCLL)*** concepts using liquid eutectic Pb-17Li, FMS structures: *EU, China*
- ► ***Dual Coolant "He/Pb17Li" (DCLL)*** concepts using liquid eutectic Pb-17Li, FMS structures: *US, China*
- ► ***Dual Coolant "He/Molten Salt" (DCMS)*** concepts using liquid FLiBe or FLiNaBe, FMS structures: *USA, Japan*
- ► ***Self-Cooled liquid Lithium (SCL)*** concept using Be-multiplier & Vanadium Alloy structures: *RF, Japan*
- ► ***Helium-Cooled liquid Lithium (HCLi)*** concept using FMS structures: *Korea*

3. Definition of Test Blanket Module System

Test Blanket Module (TBM) : mock-up of a DEMO blanket in ITER test port
TBM System : TBM + various associated systems in Tokamak & other buildings



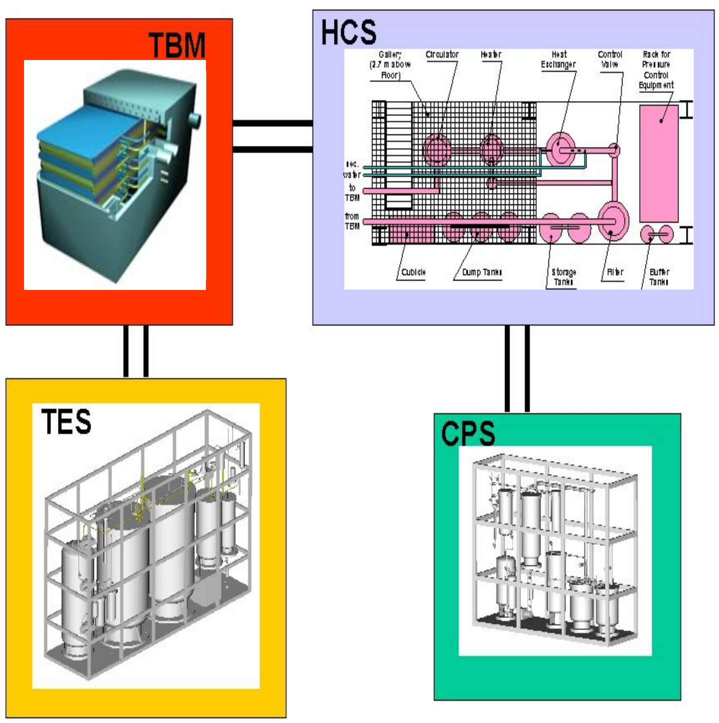
TBM location in a ITER port



HCS = (He) Coolant System, located in TWCS vault, connected with ITER heat rejection system

TES = Tritium Extraction System, located in Port Cell, connected Tritium building

CPS = Coolant Purification System, TWCS vault



4. Main TBM Testing Parameters

Parameters	**H-H phase** Design Values (Typical Values)	**D-T phase** Design Values (Typical Values)	**DEMO** Typical Values
Surface heat flux on First Wall (MW/m^2)	0.3 (0.15)	0.5 (0.27)	0.5
Neutron wall load (MW/m^2)	-	0.78 (0.78)	2.5
Pulse length (sec)	Up to 400	400 /up to 3000	~continuous
Duty cycle	0.25	0.25	-
Nb of burn pulses			-
Average neutron fluence on First Wall (MWa/m^2)	-	0.1 (first 10 y)	7.5
Disruption heat load for recessed surface (MJ/m^2)	0.5 during 1 ms to 10ms		

5. ITER Testing Capabilities and Objectives (1/2)

ITER is the only opportunity for testing DEMO breeding blankets in a real fusion environment

► in H-H phase: relevant magnetic fields, surface heat fluxes, and disruption-induced loads

► in D-T phase: an additional relevant neutron flux, volumetric heat, and Tritium production with corresponding T-management capabilities.

► In late D-T, several back-to-back long pulses with defined heat loads have to be ensured.

Main TBM test objectives

- validation of structural integrity theoretical predictions under combined and relevant thermal, mechanical and electromagnetic loads
- validation of T-breeding predictions and of T-recovery process efficiency and inventories
- validation of thermal predictions for breeding blankets with volume heat sources
- demonstration of the integral performance of the blankets systems

Main test objectives in the H-H phase

► structural integrity of TBM structures and attachment during disruptions/VDE

► impact of Ferro-magnetic steel on magnetic fields deformation in static condition

► TBM system functions and remote handling equipment

► experimental support to TBM safety dossier

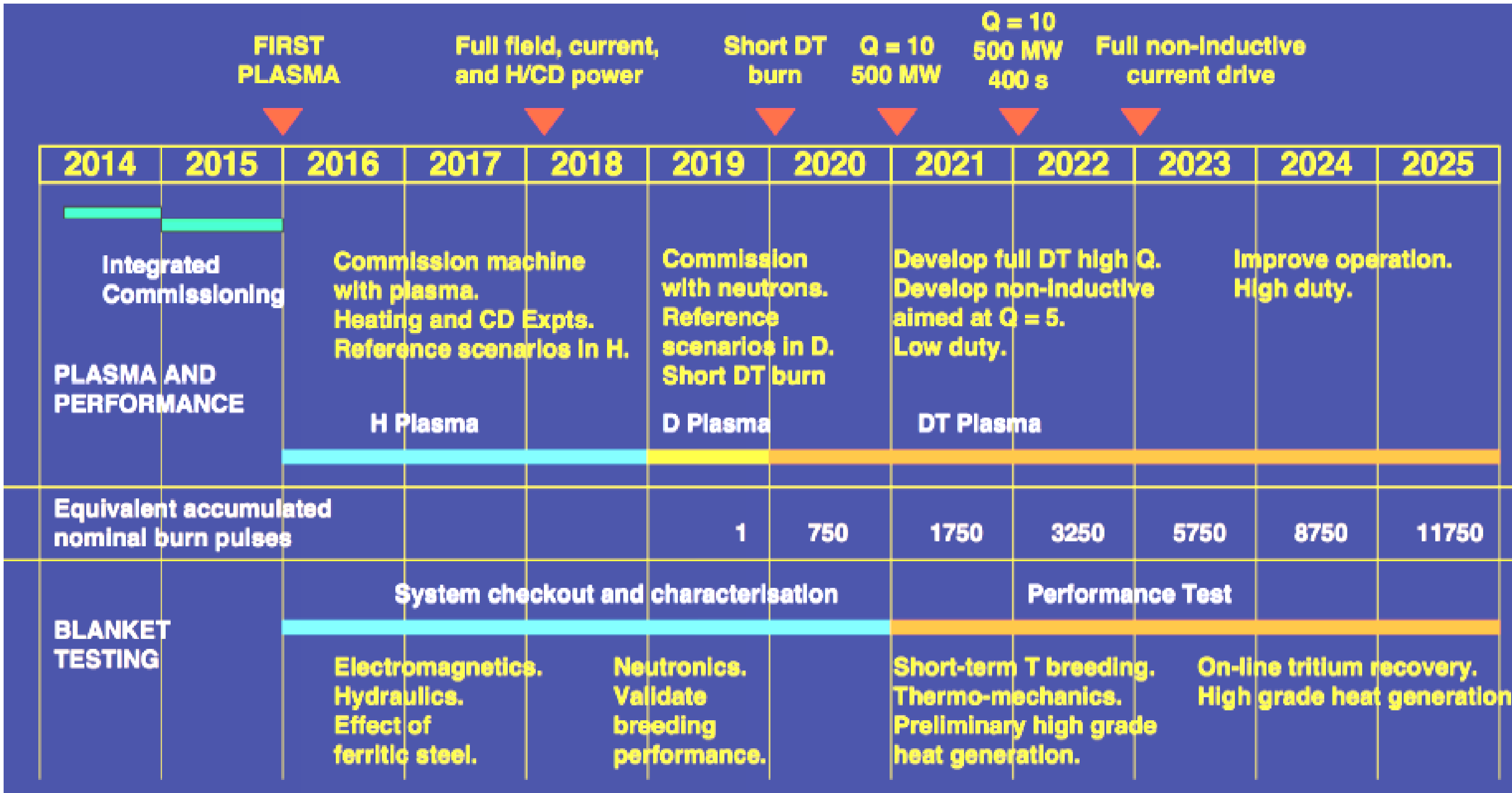
Strategy for the TBM testing

Compared to DEMO, ITER has a lower neutron flux, pulsed operations and very low neutron fluence

➔ for each blanket design, several TBMs have to be developed making use of “engineering scaling” for addressing particular performances (“act-alike” TBMs)

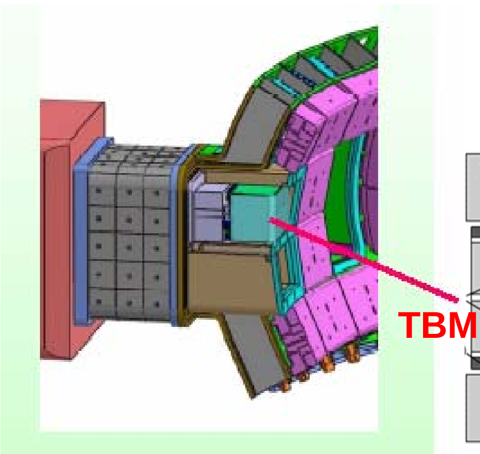
5. ITER Testing Capabilities and Objectives (2/2)

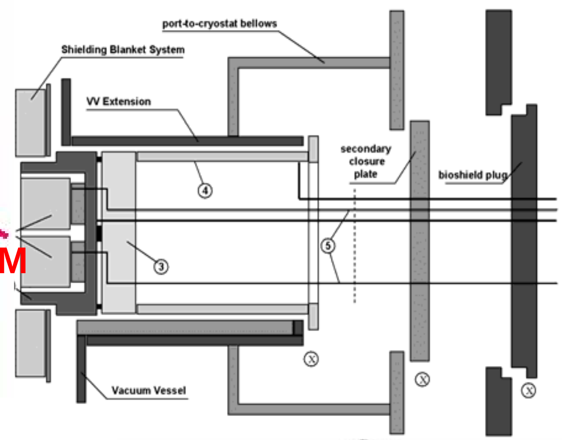
Typical TBMs testing time schedule in relation with ITER operation planning

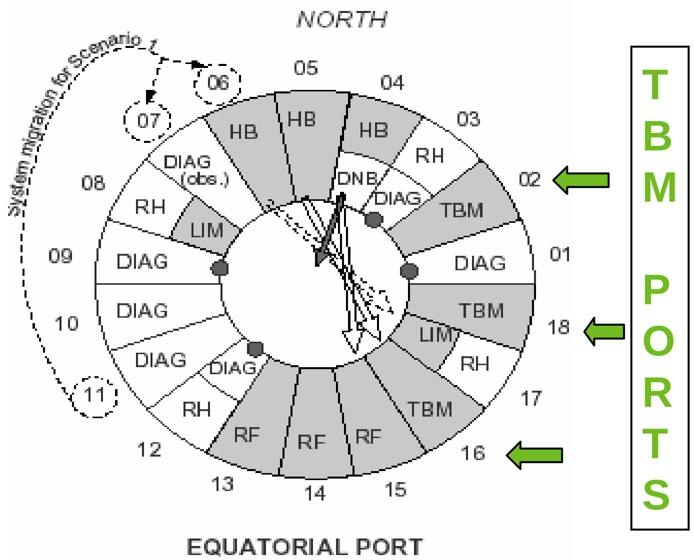


6. TBMs Arrangement in ITER and Interfaces

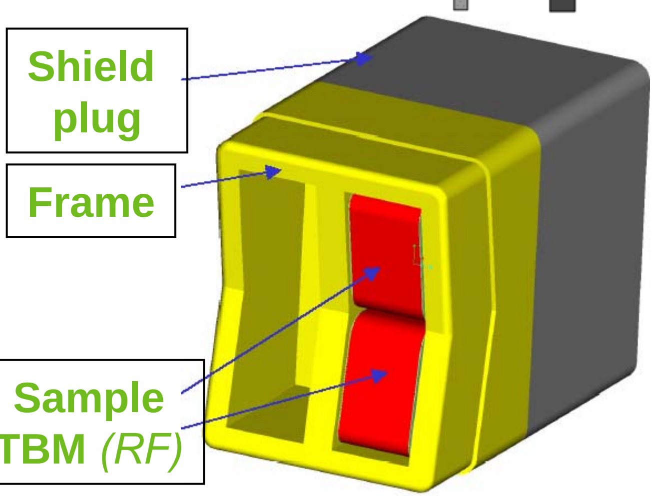
- 3 ITER equatorial ports (opening of 1.75 x 2.2 m^2) devoted to TBM testing
- TBMs installed within a water-cooled steel frame (thk. 10 to 20 cm), typically half-port size

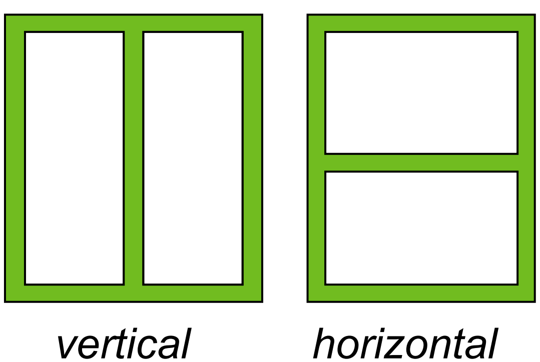






The TBMs first wall is recessed of 50 mm and protected with a Be layer





7. TBMs Proposals by ITER Parties for day_one *(1/3)*

- TBMs have to be DEMO-relevant ➔ TBMs proposal are derived from DEMO programs
- TBMs proposals divided in families corresponding to the different blanket types
- 5 Working Sub-Groups (WSG) corresponding to the 5 identified families settled by TBWG
- WSGs are charged to prepare test plans, to discuss technical issues, and to promote R&D collaboration between Parties

He-Cooled Ceramic Breeder concepts

☞ proposal to install a TBM since day_one from *China, EU, Japan, RF*

☞ proposal to contribute with a sub-module in other Parties TBM on day_one and future independent TBM in D-T phase from *Korea, USA*

Lithium-Lead concepts

Proposal to install a TBM since day_one of:

☞ Helium-Cooled design from *EU*

☞ Dual-Coolant (He+LiPb) design from *US*

☞Dual-Functional design which is initially a HCLL evolving later to DCLL from *China*

Water-Cooled Ceramic Breeder concept

☞ proposal to install a TBM since day_one from *Japan*

Lithium concepts

☞ proposal to install a TBM since day_one for a Self-Cooled design (SCLi) from *RF*

☞ proposal to install a TBM since day_one for a He-Cooled design (HCLi) from *Korea*

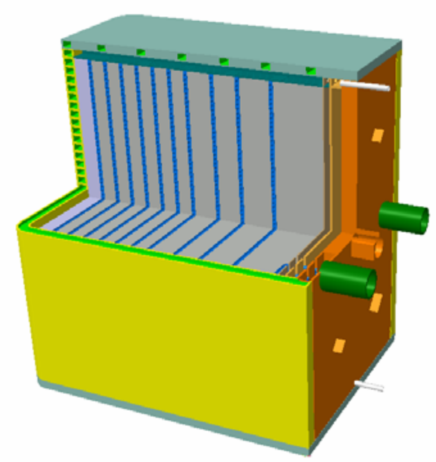
Molten Salt concepts

☞ No proposal of TBM at present

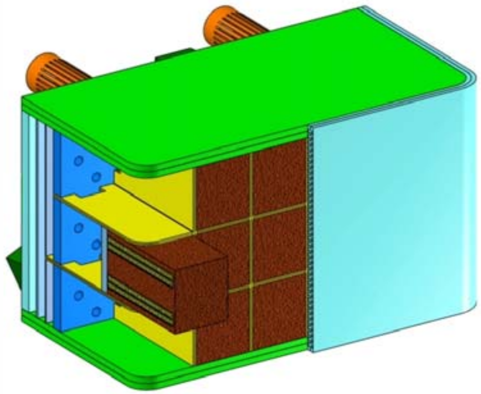
7. TBMs Proposals by ITER Parties for day_one *(2/3)*

Helium-Cooled Ceramic Breeder TBMs (HCCB)

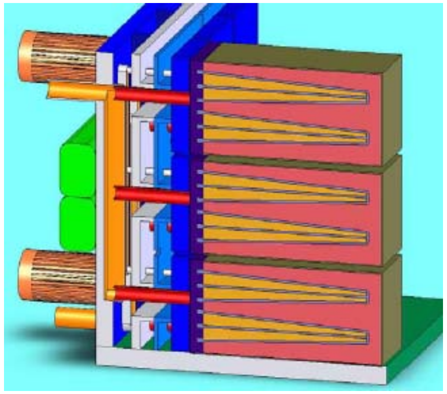
- *Structures:* F/M Steel
- *Multiplier:* Be pebble bed / porous blocks
- *Breeder:* Li_2TiO_3 or Li_4SiO_4 or Li_2O
- *Coolant:* He at 8 MPa, 300°C / 500°C



China, TBM ¼ port

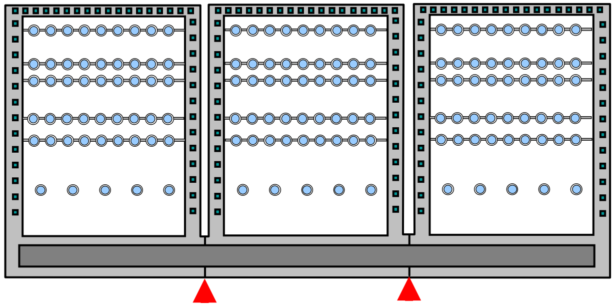


EU, TBM ½ port

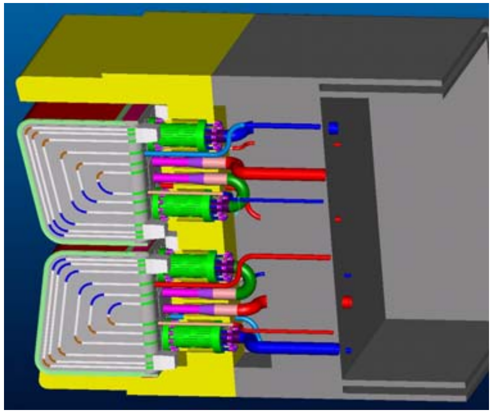


US, sub-module

Korea, sub-module *(under definition)*



Japan, TBM ½ port

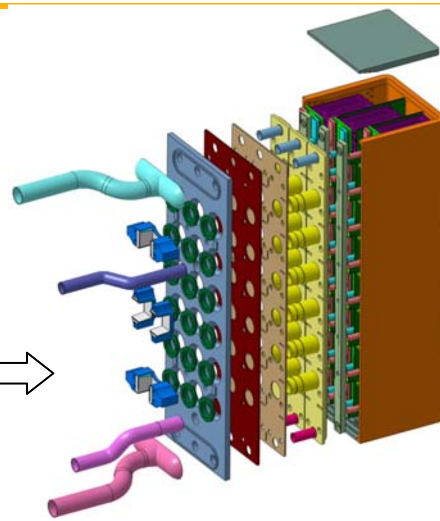


RF, TBM ½ port

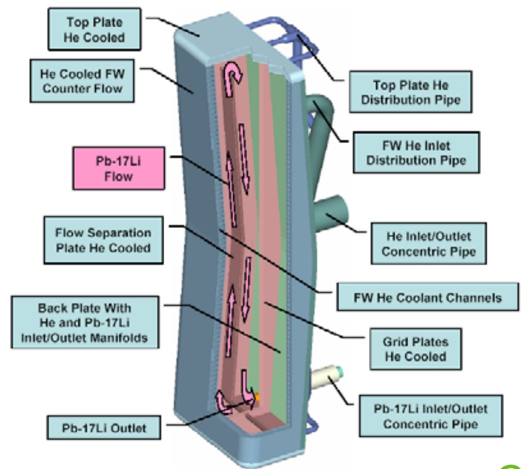
7. TBMs Proposals by ITER Parties for day_one *(3/3)*

Lithium-Lead (LL) TBMs

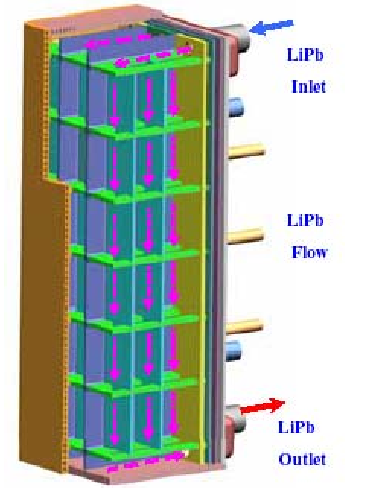
- *Structures:* F/M Steel
- *Multiplier/Breeder:* Eutectic Pb-16Li
- *Coolant:* He at 8 MPa, 300/500°C alone (HCLL) or with LiPb at 460/700°C (DCLL, DFLL)



EU, HC-TBM ½ port



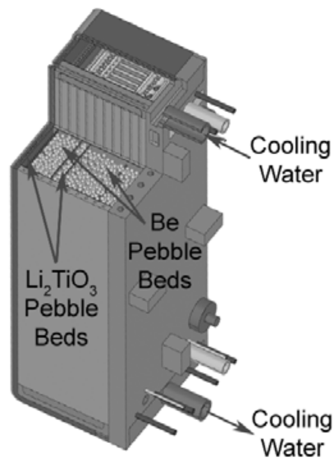
US, DC-TBM ½ port



China, DF-TBM ½ port

Water-Cooled Ceramic Breeder TBM

- *Structures:* FM Steel
- *Multiplier:* Be pebble
- *Breeder:* Li_2TiO_3
- *Coolant:* He at 8 MPa, 300/500°C

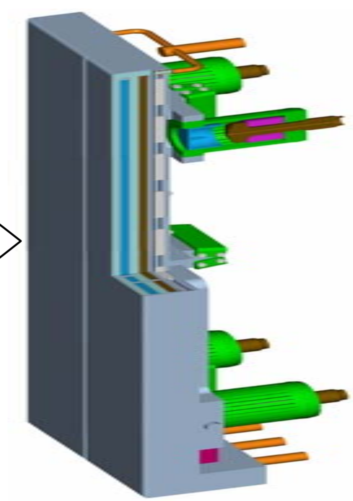


Japan, TBM ½ port

Liquid Lithium TBMs

- *Structures:* V-alloys
- *Breeder:* Lithium
- *Multiplier:* Be
- *Coolant:* Lithium at 250/530-550°C

(Korea He-coolant version is under definition)



RF, TBM ½ port

ITER TBWG

8. Test Port Allocation

Uncertainties on most TBMs test proposals

- ***technical*** **:** R&D is ongoing or even not yet started, future results could lead to other proposals
- ***financial*** **:** estimated funding effort (~80 M$ per TBM) may not be available on time
- ***time schedule*** **:** some TBMs may not meet the ITER day_one deadline

Required R&D on TBMs prior to installation in ITER

Main items: fabrication routes, irradiations effects, tests of TBM prototypical mock-ups (small, medium, full) for components performances and reliability, remote handling equipment, …

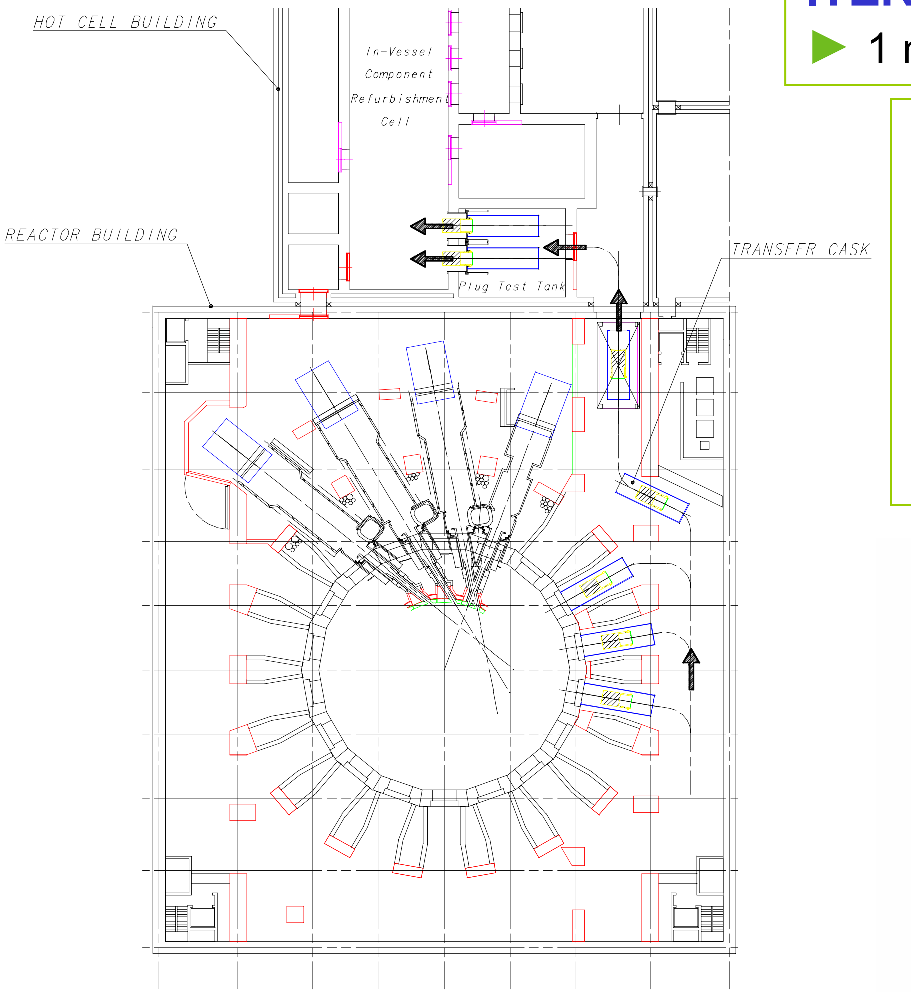
TBWG proposal: Flexibility

- each Party develops the appropriate TBMs systems proposals, assuming testing space is available
- priorities and selection will be made by an "Ad Hoc" group after uncertainties will disappear (few years before TBM commissiong)

Minimum requirement : coolant connections at each test port

System type	Test Port nb. 16	Test Port nb. 18	Test Port nb. 2
He-coolant	***2 lines***	***2 lines***	***3 lines***
H_2O-coolant	**-**	***1 line***	**-**
ITER heat rejection system	available	available	available
He purge gas	4 lines	4 lines	4 lines
ITER component cooling system	1 line	1 line	1 line

9. TBMs Maintenance Operations and Replacement



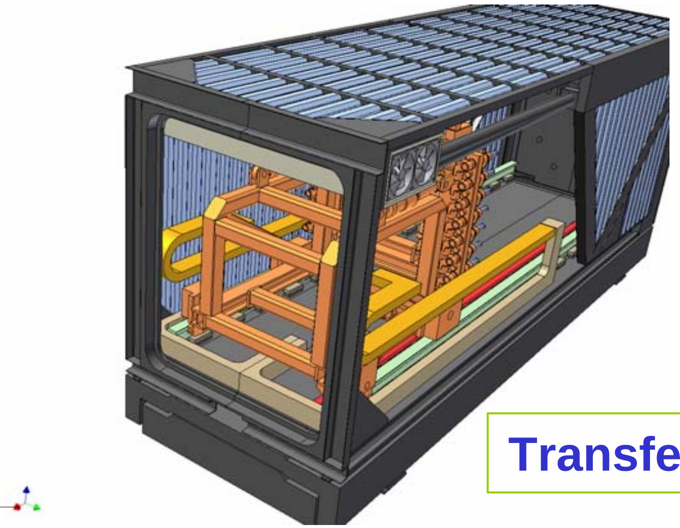
TBM Transfer Cask to Hot Cell

ITER Scheduled Maintenance

- 1 month each year, 4 months before D-T phase

TBM Replacement

- Required synchronization with ITER scheduled maintenance
- Port plug removal using a transfer cask and TBMs replacement in the hot cell
- All 3 test port plugs may need simultaneous replacement



Transfer cask

10. Safety Considerations

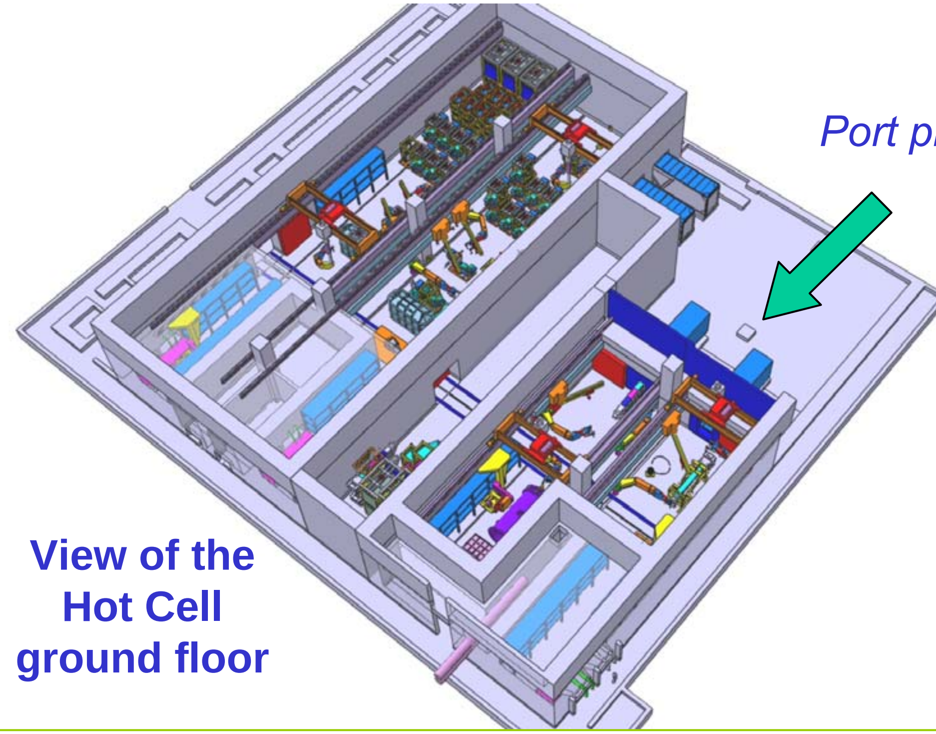
- Need to ensure that TBMs do not adversely affect the safety of ITER (coordinated ITER and Parties efforts).
- Safety requirements deal with confinement functions of the TBM systems.
- Three classes of off-normal situations have been analyzed:
  - ✓in-vessel loss-of-coolant from the TBM;
  - ✓loss-of-coolant within the TBM;
  - ✓ex-vessel loss-of-coolant.
- The assessment has addressed a number of concerns or issues that are directly caused by TBM system failure, that is:
  - ✓(a) vacuum vessel pressurization,
  - ✓(b) vault pressure build-up,
  - ✓c) purge gas system pressurization,
  - ✓(d) temperature evolution in the TBM,
  - ✓(e) decay heat removal capability,
  - ✓(f) tritium and activation products release from the TBM system, and
  - ✓(g) hydrogen and heat production from chemical reactions.

➔ ***No major concerns have been identified provided some counter-measures are taken (e.g., limited volume for liquid metals)***

11. Hot Cells and Post Irradiation Examination

Hot Cell operations for Test Port Plugs

- No significant difference with operations for other Port Plugs
- Transfer cask locked to Hot Cell port plug, then TBMs are replaced from inside
- TBM mounting /dismounting operations are possible, including:
  -cut/welding/inspection of hydraulic pipes,
  -connections/disconnection of joints and cables,
  -small repairs



View of the Hot Cell ground floor

Post Irradiation Examinations

- Only few TBMs can be stored in Hot Cell. Present assumption is that they will be considered as rad-waste if not claimed
- TBWG considers essential to perform PIE for fully exploiting the TBM test program
- PIE on large pieces may need PIE facilities on ITER site
- Small samples PIE may be best performed on existing facilities in Parties Laboratories but cutting facilities should be available in Hot Cell. Other equipments are also required.

12. Main Conclusions and Recommendations *(1/2)*

- The tests of DEMO-relevant TBMs in ITER will give essential information for the breeding blanket development for DEMO
- Space available in Test Ports, Port Cells, TWCS vault & in Hot Cell is limited and cannot satisfy all the present Test Blanket program proposed by Parties.
  The TBWG decided to leave a maximum flexibility on the definition of port allocation until more technical (and financial) information will be available.
  Coolant connection types at each port have therefore been fixed.
  Cooperation between Parties on TBMs activities could be the key of a successful blanket test program.
- For all TBMs significant R&D is still required and therefore, from the technical point of view, it is technically premature to select now the best performing candidates.
  It will be necessary to select them at least 5 y before the TBM installation in ITER.
  The TBWG therefore recommends to focus the blanket R&D programs on TBMs R&D and out-of-pile testing and to focus the design effort on the TBM engineering designs and on TBM integration in ITER.
- TBM testing in the initial H-H phase is essential to verify TBM compatibility with ITER operation (including disruption), to support the safety dossier for D-T phase operations and to validate remote operations on the on the TBM systems.

12. Main Conclusions and Recommendations *(2/2)*

- After successful ITER operations, breeding blankets development will remain one of the most challenging issues to be addressed for designing and constructing a DEMO reactor.
  In particular, high-fluence irradiation effects have to be verified in another facility (e.g., neutron source).

- To allow comprehension and interpretation of the results of TBM testing in ITER, it is essential to develop corresponding DEMO blanket designs and to use DEMO-relevant technologies.
  TBM performance are meaningful only if extrapolated to DEMO blankets. Therefore, DEMO blankets have to be defined in details prior TBMs design final selection.

- General long term comment: the difficulty of the task suggests to optimize the design of the DEMO reactor plant with respect to the need of the breeding blankets performances.

Information: Details of the Parties Test Blanket program proposals are given in the talks following this one.