

# **US Plans and Strategy for ITER Blanket Testing**

**M. Abdou, D. Sze, C. Wong,  
M. Sawan, A. Ying, N. Morley**

**and**

**US ITER-TBM Team**

*Presented at the TOFE Meeting, September 14, 2004, Madison, WI*

# **US Plasma Chamber Systems/Blanket Effort has been redirected to support ITER**

- ❑ **With the US rejoining ITER, the Blanket/Chamber community concluded that it is very important for the US to participate in the ITER Test Blanket Module (TBM) Program (March 2003).**
- ❑ **Extensive deliberations have occurred in the US since March 2003 among the community, DOE and VLT.**
- ❑ **Reached consensus on a general framework for the direction of activities in the US Chamber/Blanket Program:**
  - **Provide fusion nuclear technology (FNT) support for the basic ITER device as needed**
  - **Participate in ITER TBM program and redirect good part of resources toward R&D for TBM**
  - **Encourage partners in international collaborations, such as IEA and JUPITER-II, to focus more on ITER TBM**
- ❑ **Important work has been carried out to implement the strategy.**
  - **A study of ITER TBM issues and US options was initiated**
  - **Some R&D was initiated**
  - **Rejoined TBWG, strong participation**
  - **The US interacted with all the other 5 parties to identify areas of collaboration**

# **What should the TWO US Blanket Options be for ITER TBM?**

- **This has been a central question for the US community since March 2003. A study was initiated to select the two blanket options for the US ITER TBM in light of new R&D results from the US and world programs over the past decade.**
- **Key conclusions reached early in the study:**
  - **Selection between solid and liquid breeders can not be made prior to fusion testing in ITER.**
  - **All Liquid Breeder Options have serious feasibility (“Go/No-Go”) issues. Need assessment.**
  - **Solid breeders are accepted by all parties.**
- **For the past year, the study has focused mostly on assessment of the critical feasibility issues for liquid breeder concepts. Examples of issues are MHD insulators, MHD effects on heat transfer, tritium permeation, corrosion, SiC insert viability, and compatibility.**
- **The study has been led by the Plasma Chamber community with strong participation of the Materials, Safety and PFC Programs. Many international “Experts” in key areas participated in several meetings and provided important input.**

# Liquid Breeder Blanket Options and Key Feasibility **Issues**

## 1. Self-Cooled Li / V

1.A. Li / V was the US choice for a long time. But negative results and lack of progress on serious feasibility issues are ALARMING.

- **MHD Effects**

Coating Development, Crack Tolerance

Engineering Design Solutions (that may not require coating)

- **Corrosion at High Temperature (coupled to coating development)**

- **Tritium Recovery and Control**

- **V Development**

## 2. Lead-Lithium

2.A. He-Cooled Pb-Li with FS

- **Tritium Permeation (Barrier Development), and Control**

- **Corrosion**

2.B. Dual Coolant with He-Cooled First Wall and Self-Cooled –Pb-Li breeding zone with **SiC INSERT** for electrical/thermal insulation (all structure FS)

- **SiC insert compatibility with Pb-Li (Corrosion temperature limit)**

- **SiC insert performance integrity (cracks in coating of the insert, etc.)**

- **Tritium Permeation and Control**

# Liquid Breeder Blanket Options (cont'd)

## 3. Molten Salt (Flibe/Flinabe)

3.A. Self-Cooled FLiBe with advanced FS structure

3.B.\* Self-Cooled FLiNaBe with FS structure

3.C.\* Dual Coolant: He-cooled FS structure and self-cooled FLiBe (with no need for insulation)

- Enhancing heat transfer and MHD effects on heat transfer
- Redox, tritium recovery and control

# US Selected Options for ITER TBM

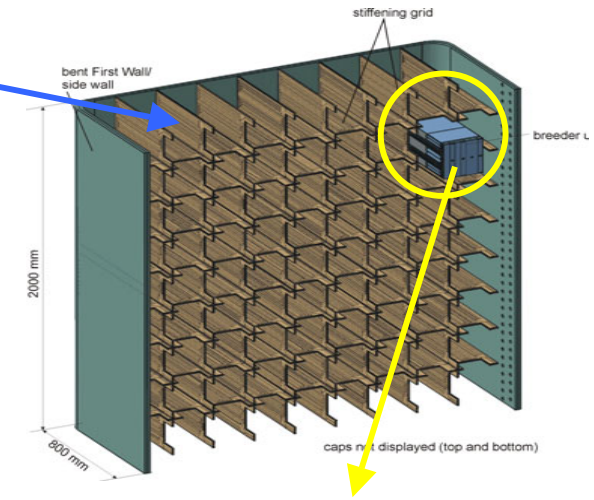
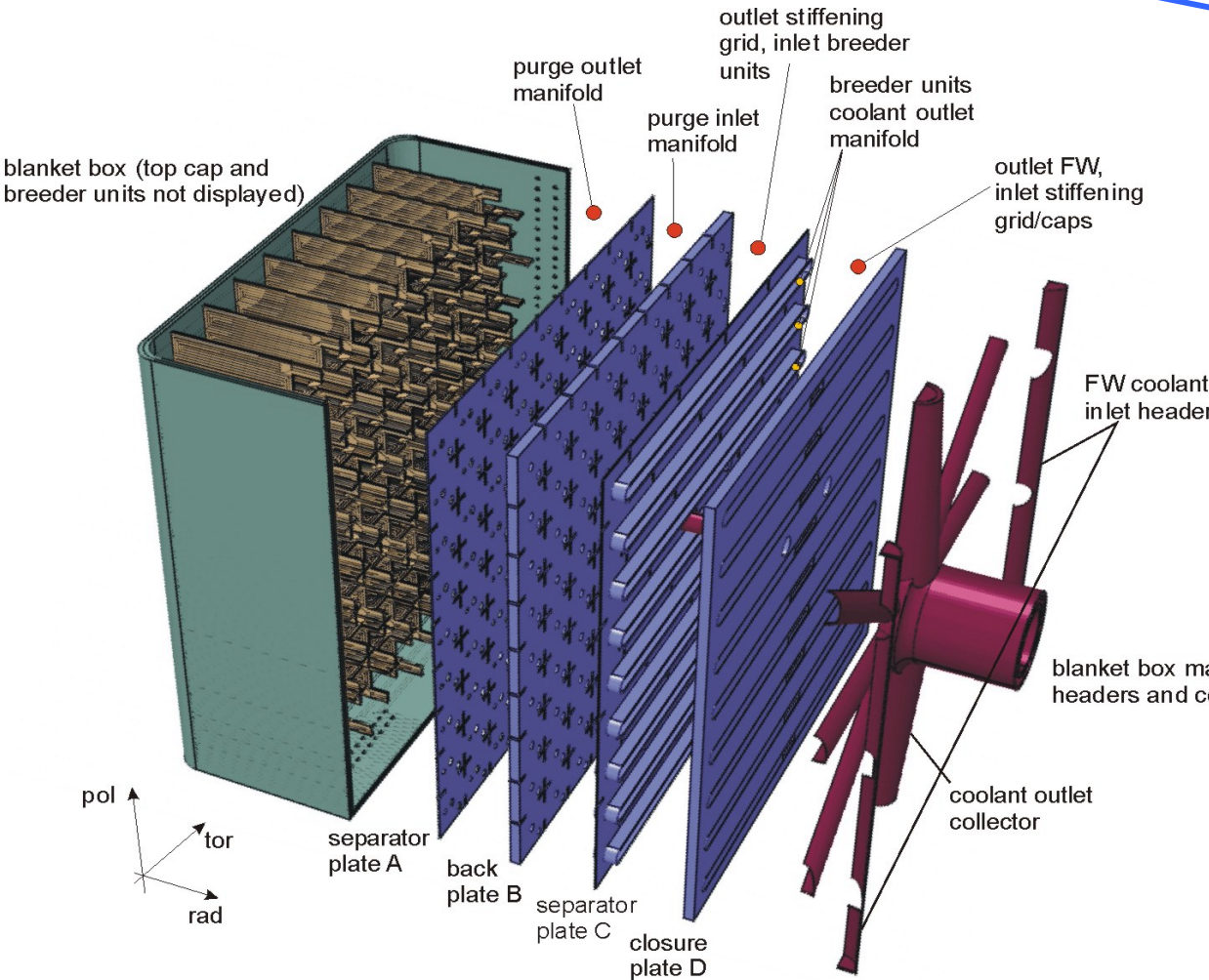
*The initial conclusion of the US community, based on the results of the technical assessment to date, is to select two blanket concepts for the US ITER-TBM with the following emphases:*

- Select a helium-cooled **solid breeder** concept with ferritic steel structure and neutron multiplier, but without an independent TBM (i.e. support EU and Japan using their designs and their TBM structure and ancillary equipment). Contribute only unit cell and sub-module test articles that focus on particular technical issues of unique US expertise and of interest to all parties. (All ITER Parties have this concept as one of their favored options.)
- Focus on testing **Dual-Coolant liquid breeder** blanket concepts with potential for self-cooling. Develop and design TBM with flexibility to test one or both of these two options:
  - DC PbLi: a helium-cooled ferritic structure with self-cooled LiPb breeder zone that uses SiC insert as MHD and thermal insulator (insulator requirements in dual-coolant concepts are less demanding than those for self-cooled concepts);
  - a helium-cooled ferritic structure with low melting-point molten salt. Because of the low electrical and thermal conductivity of molten salts, no insulators are needed.

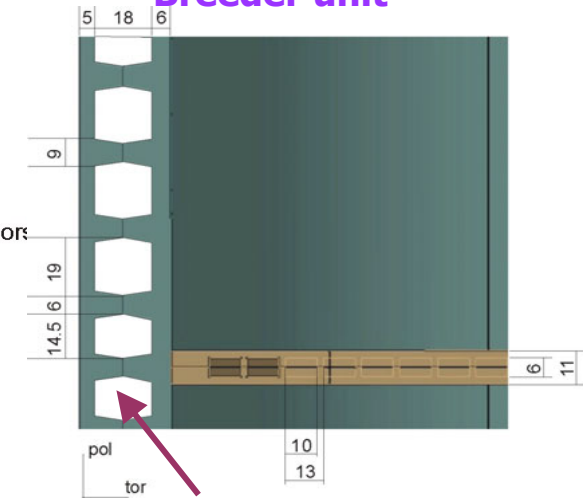
(The key issues for molten salt are being addressed under JUPITER-II and no additional work is planned under ITER-TBM.)

# Helium-Cooled Pebble Breeder Concept for EU

## Helium-cooled stiffening grid



## Breeder unit



## FW channel

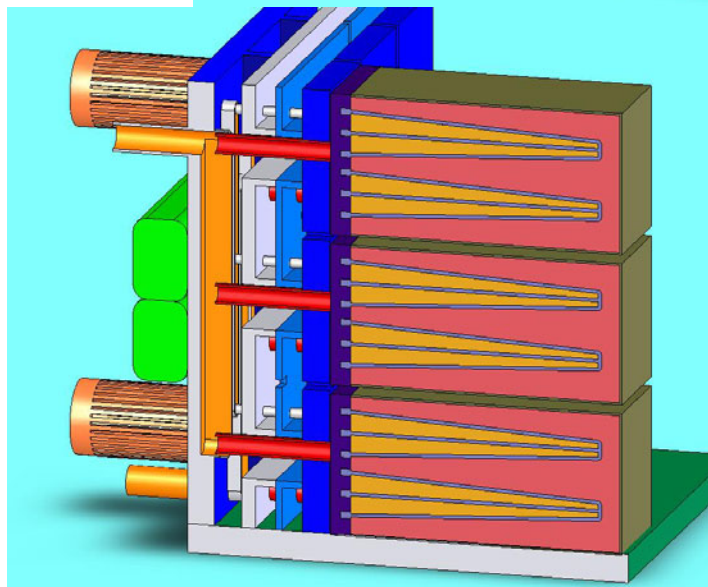
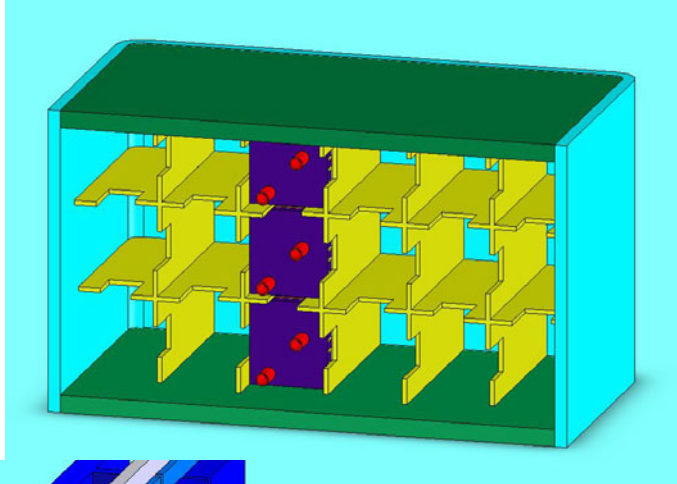
- The US can provide small breeder units “inside” the EU SB structure.
- US Issues: Tritium Release and Thermomechanical Interactions



# Two types of "TBMs" have been proposed

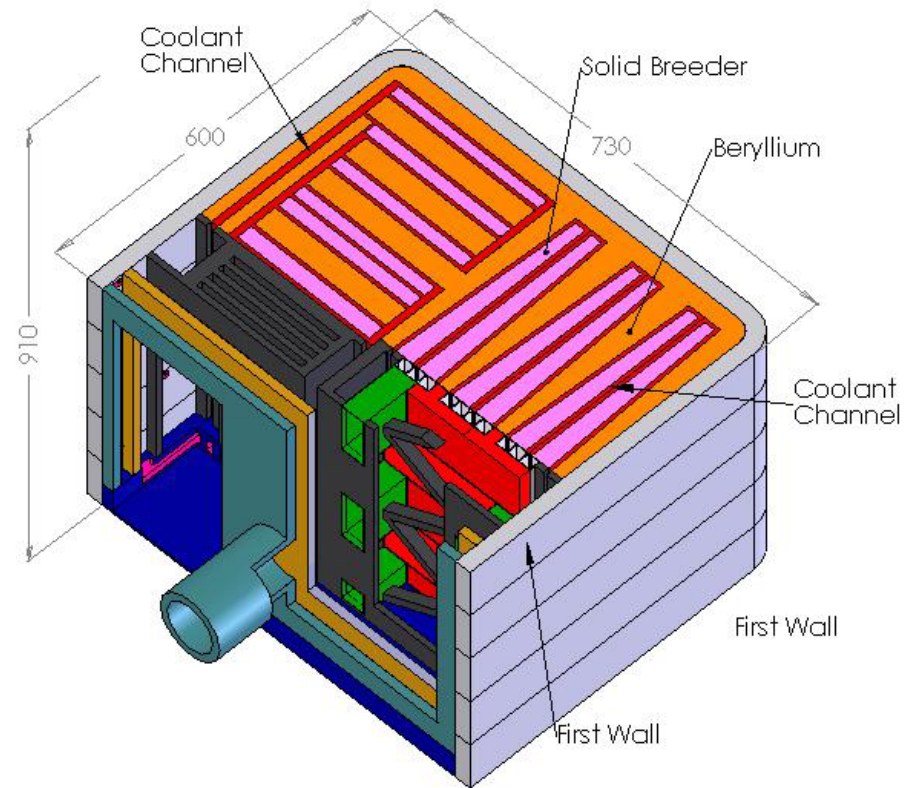
## 1. Unit cells (3)

192.5 mm x 211 mm x 650 mm



## 2. Quarter-port Submodules

730 mm x 910 mm x 600 mm



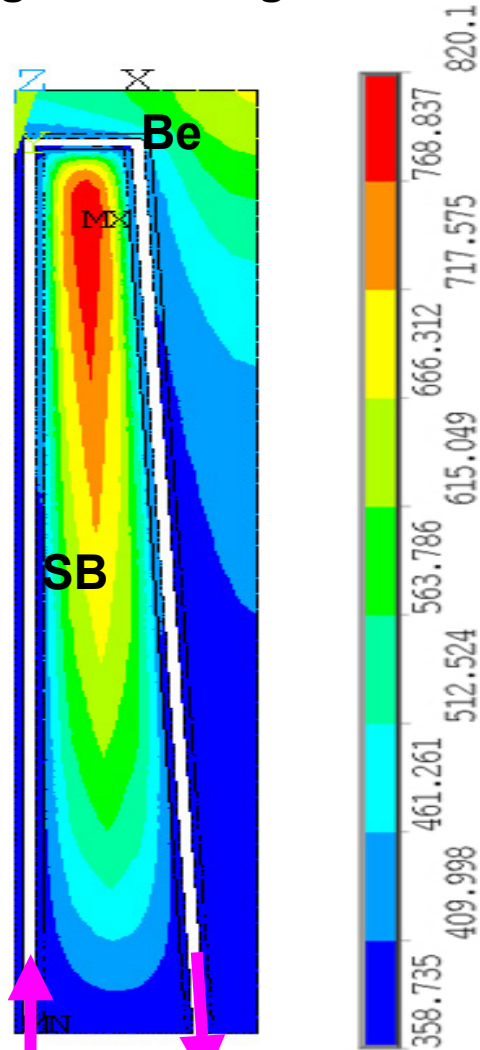
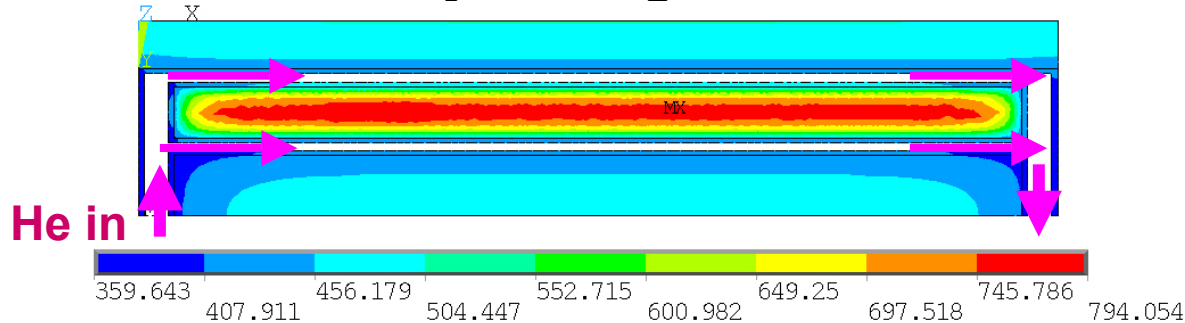
- The proposal calls to share the port space to test contemporaneously independent unit cells/submodules



# Analyses have been performed for TBM designs to preserve key prototype parameters (example: temperature profiles in breeding units)

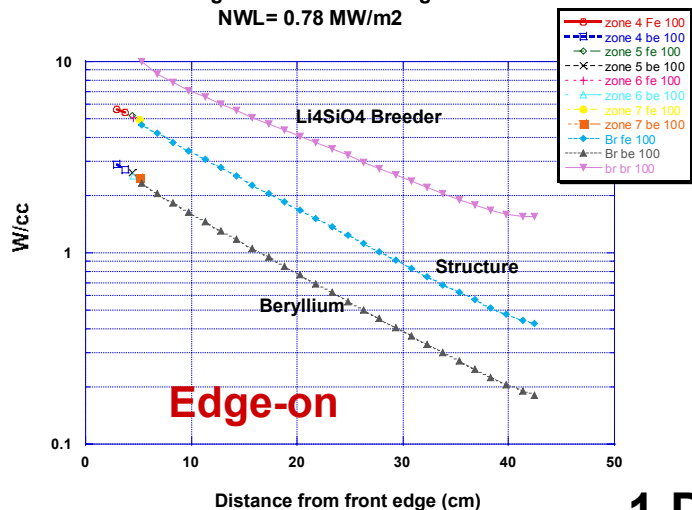
Layer configuration

Edge-on configuration

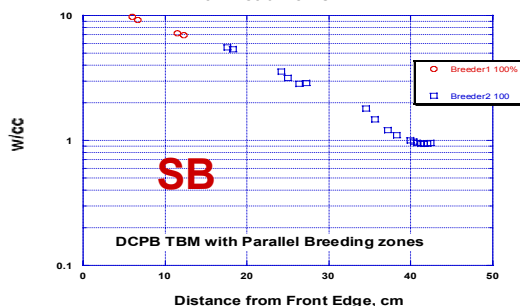


- Heat transfer coefficient  $1200 \text{ W/m}^2\text{k}$
- $K_{SB} = f(T)$ ;  $\sim 1 \text{ W/mk}$
- $k_{Be} = f(T, s)$   $6 \text{ W/mk}$  used
- $h_c = 4000 \text{ W/m}^2\text{k}$

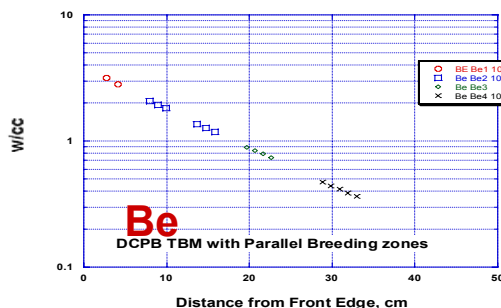
Heating Rate in the Breeding Unit  
NWL= 0.78 MW/m<sup>2</sup>



Nuclear Heating Rate in the Li<sub>4</sub>SiO<sub>4</sub> Breeder  
Wall Load= 0.78 MW/m<sup>2</sup>



Nuclear Heating Rate in the Beryllium Multiplier  
Wall Load= 0.78 MW/m<sup>2</sup>

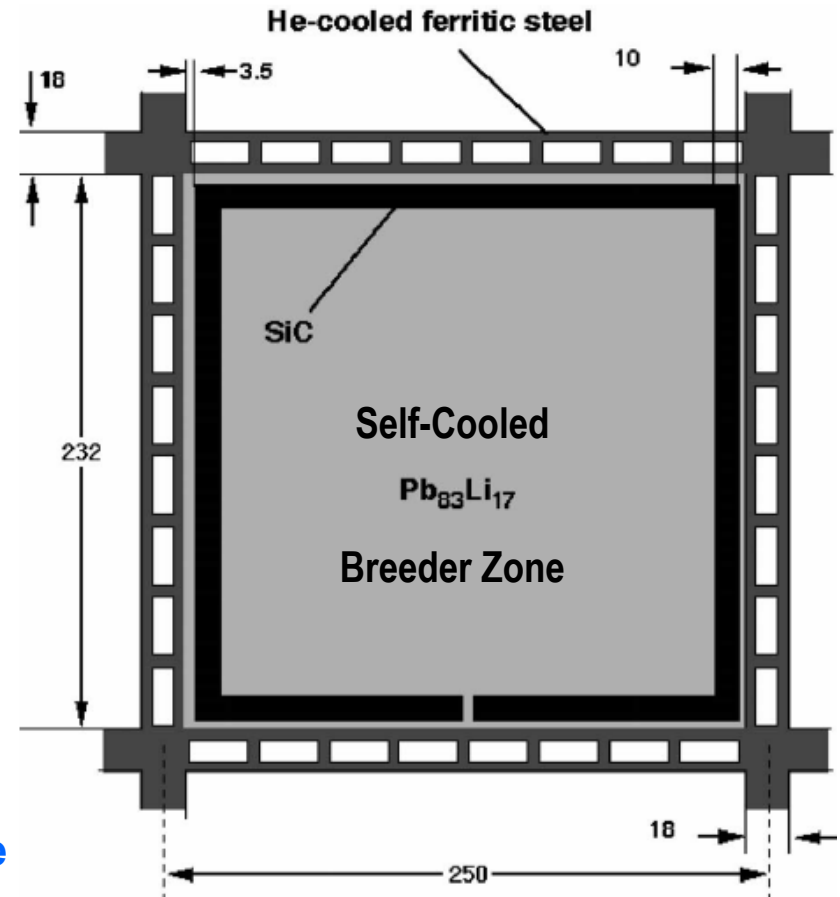


1-D nuclear heating rates

He in

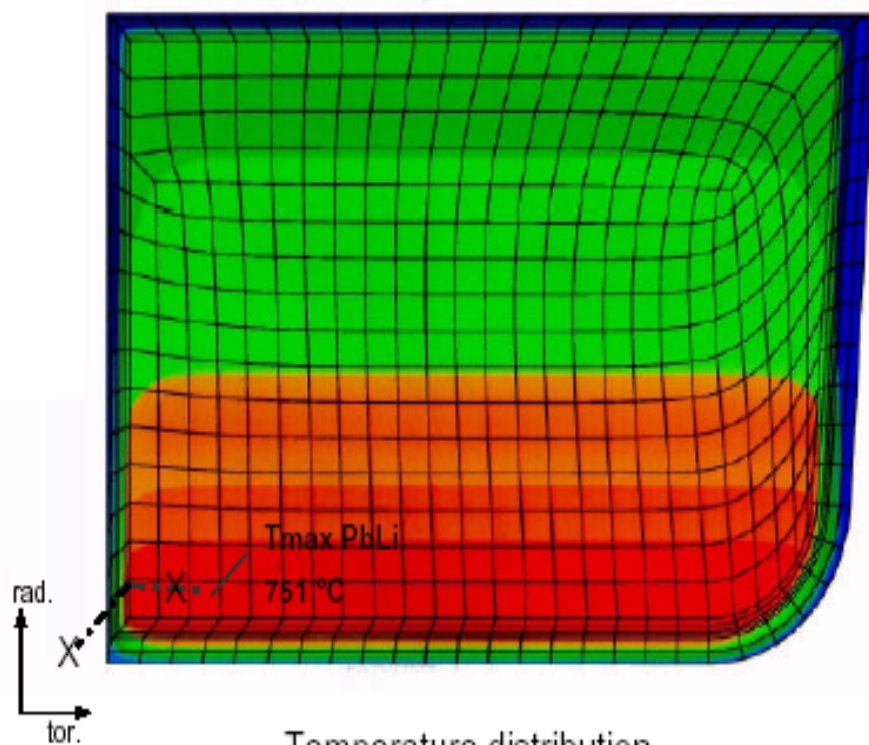
# FS/He/Pb-17Li Dual Coolant Blanket Concept

- ❑ The reason fusion pursued high temperature structural materials is for high coolant temperature.
- ❑ MHD effects in high-velocity channel flows leads to very high primary stresses.
- ❑ **IDEA** – the Dual Coolant Concept:∗
  - Cool structure with He so that FS can be used. “Decouple” surface from bulk heating.
  - Flow PbLi for self-cooling at low velocity
  - Use a SiC insert to electrically and thermally insulate the LM from the wall, so LM bulk temperature can be higher than the wall temperature (use the poor thermal and electrical conductivity of SiC as an advantage).
  - **Result: potential for high bulk temperature with lower MHD pressure drop using Ferritic Steel.**



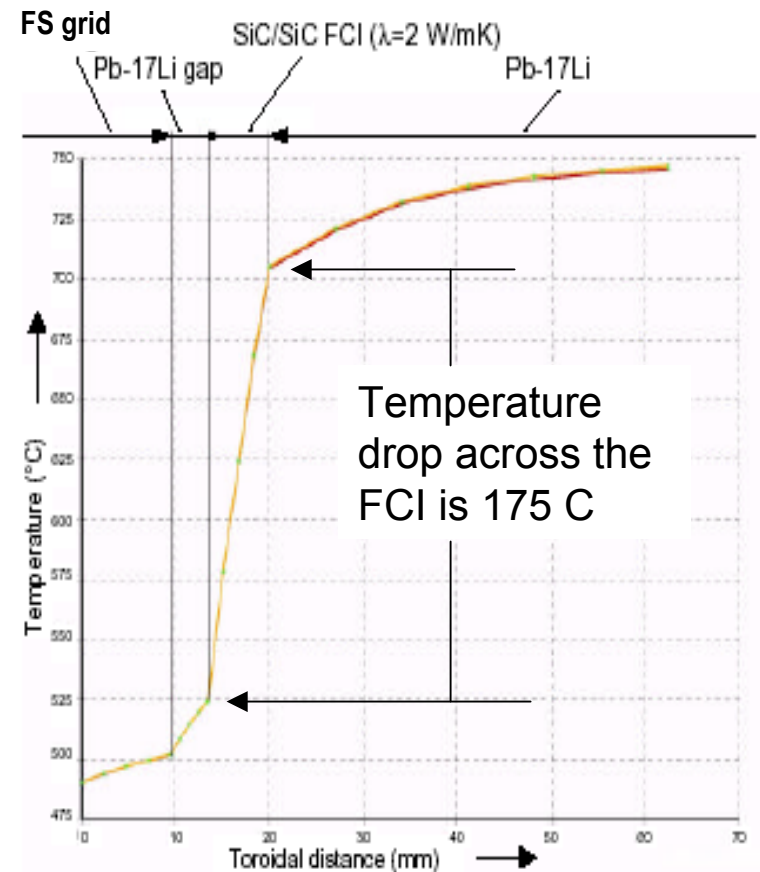
\* Dual Coolant concepts proposed by ARIES and EU

# Structure, Insert, and Breeder Temperatures



Temperature distribution

Pb-17Li:  $T_{\max} / T_{\text{avg}} = 751^\circ\text{C} / 633^\circ\text{C}$



Temperature gradient along X-X

# **Dominant Issues for Dual Coolant Blankets: FCI Properties and Failures**

- A) Electrical and thermal conductivity of the SiC/SiC perpendicular to the wall should be as low as possible to avoid velocity profiles with side-layer jets and excess heat transfer to the He-cooled structure.**
- B) The inserts have to be compatible with Pb-17Li at temperatures up to 700-800°C.**
- C) Liquid metal must not “soak” into pores of the composite in order to avoid increased electrical conductivity and high tritium retention. In general “sealing layers” are required on all surfaces of the inserts.**
  - Even if the change in conductivity results in modest increase in pressure drop, it could seriously affect flow balance.**
- D) There are minimum primary stresses in the inserts. However, secondary stresses caused by temperature gradients must not endanger the integrity under high neutron fluence.**
- E) The insert shapes must be fabricable and affordable.**

# Technical Details from the US ITER-TBM efforts are presented at this conference

- **Morley**, “Thermofluid Magnetohydrodynamic Issues for Liquid Breeders”, Session: ITER Test Blanket Modules, Tue 4:50-5:10
- **Ying**, “Engineering Scaling Requirements for Solid Breeder Blanket Testing”, Session: ITER Test Blanket Modules, Tue 5:10-5:30
- **Smolentsev**, “MHD Effects on Heat Transfer in a Molten Salt Blanket”, Poster Session: Thermal & MHD Analyses, Wed 3:30-5:30
- **Youssef**, “Activation Analysis for Two Molten Salt Dual-Coolant Blanket Concepts for the US Demo Reactor”, Poster Session: Nuclear Analysis & Experiments, Tue 1:30-3:30
- **Wong**, “Assessment of Liquid Breeder First Wall and Blanket Options for the Demo Design”, Session: Breeding Blanket Development, Wed 4:10-4:30
- **Sawan**, “Neutronics Assessment of Molten Salt Breeding Blanket Design Options”, Wed 4:30-4:50



# **Why is ITER TBM Critical?**

**Why is it necessary for the US to participate in ITER TBM?**



# ITER Blanket Testing is Essential to:

- Achieve a key element of the “ITER Mission”
- Establish the conditions governing the scientific feasibility of the D-T cycle, i.e., determine the **“phase-space”** of plasma, nuclear, material, and technological conditions in which tritium self-sufficiency can be attained
  - The D-T cycle is the basis of the current world plasma physics and technology program. There is only a “window” of physics and technology parameters in which the D-T cycle is feasible. We need to determine this “window.” (If the D-T cycle is not feasible the plasma physics and technology research would be very different.)
  - Examples of questions to be answered:
    - Can we allow low plasma-edge recycling?
    - Is high plasma-edge recycling necessary for T self sufficiency?
    - Are advanced physics modes acceptable?
    - Is the “temperature window” for tritium release from solid breeders sufficient for adequate TBR?
    - Is there a blanket/material system that can exist in this phase-space?

# **ITER Blanket Testing is Essential to (cont'd):**

- **Achieve the most critical milestone in blanket and material research: testing in the integrated fusion environment**

(ITER construction and operation is for the next 30 years. Without such fusion testing, material and blanket research loses “focus”, relevance: Why are we doing any research in these areas then?)

- **Develop the technology necessary to install breeding capabilities to supply ITER with tritium for its extended phase of operation**
- **Resolve the critical “tritium supply” issue for fusion development**
  - and at a fraction of the cost to buy tritium for large D-T burning plasma

# Tritium Consumption and Production

## Tritium Consumption in Fusion is HUGE!

**55.8 kg per 1000MW fusion power per year**

## Production & Cost

- **CANDU Reactors: 27 kg from over 40 years, \$30M/kg (current)**
  - **Fission reactors: 2-3 kg per year. It takes tens of fission reactors to supply one fusion reactor.**
- \$84M-\$130M per kg, per DOE Inspector General\***

## Conclusions

- **The cost of blanket development and ITER TBM is a fraction of the cost to “purchase” tritium for a burning plasma facility such as ITER.**
- **“Availability” of external tritium supply for continued fusion development is an issue.**
- **Large power DT facilities must breed their own tritium. (This is why ITER’s extended phase was planned to install a tritium breeding blanket.)**

# World Tritium Supply Would be Exhausted by 2025 if ITER Were to Run at 1000MW at 10% Availability (OR at 500 MW at 20% availability)

