Material Issues for the US ITER-TBM Program

Part I: US Strategy and Outline of Suggested Material Effort

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Outline

I. Background information

II. US Strategy for ITER TBM and brief description of selected concepts

III. Suggested “Materials” efforts for US TBM concepts

What is the ITER Test Blanket Module (TBM) Program?

- The ITER Test Program is managed by the ITER Test Blanket Working Group (TBWG) with participants from the ITER International Team and representatives of the Parties
- Breeding Blankets will be tested in ITER, starting on Day One, by inserting Test Blanket Modules (TBM) in specially designed ports
- Each TBM will have its own dedicated systems for tritium recovery and processing, heat extraction, etc. Each TBM will also need new diagnostics for the nuclear-electromagnetic environment
- Each ITER Party is allocated limited space for testing two TBMs. (No. of Ports reduced to 3. Number of Parties increased to 6)
- ITER's construction plan includes specifications for TBMs because of impacts on space, vacuum vessel, remote maintenance, ancillary equipment, safety, availability, etc.

Redirecting US Plasma Chamber Systems Effort 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)

- Reached consensus on a general framework for the direction of activities in the US Chamber/Blanket Program

- Key elements of the emerging framework are:

  - 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
  - Enhance international collaboration between all ITER Parties in carrying out the R&D and construction of the test facilities and modules
    - Examples include JUPITER-II program between US and Japanese Universities and new opportunities with Korea and China

Considerable progress on ITER-TBM has been made since the effort started in March 2003

Testing Blanket Modules in special ports has been a critical element in the ITER mission since its inception

Objectives of the ITER Test Blanket Module (ITER-TBM) Program:

1) First integrated experimental demonstration of the principles of tritium self-sufficiency

2) Develop the technology necessary to install breeding capabilities to supply ITER with tritium for its extended phase of operation

3) Provide experimental data vital to evaluating the feasibility, constraints, and potential of the D-T cycle for fusion systems.

- Blanket subsystems. Materials, and material interfaces, breeder/multiplier/structure/coolant/insulators/T barriers
- Neutronics, MHD effects, tritium release and transport, etc.
- Limitations on options for improving plasma physics performance, e.g., conducting shells, passive coils, thick armors/first wall

Adequate tritium supply is a central issue for the operation of ITER and the development of fusion energy.

TBMs will be inserted in ITER from Day 1 of its operation and will provide the first experimental data on the feasibility of the D-T cycle for fusion, and it is an important near-term milestone for the Chamber and Materials Program

TBWG work reaffirms the importance of TBM to blanket development programs in all parties, being a critical link between ITER and DEMO.

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Direction de l'énergie nucléaire
Cellule projets transverses

To :
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Thursday, July 22nd, 2004

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Object: *Framework for Test Blanket Activities*

Dear Sirs,

The ITER Test Blanket Working Group (TBWG) has made considerable progress in addressing the technical issues defined in its charge. We have provided you an interim report on the technical progress in June 2004.

Here, we would like to call your attention to the following important findings:

1. The ITER Test Blanket Module (TBM) Program is a central element in the plans of all Parties for the development of tritium breeding and power extraction technology. ITER provides the only available opportunity of critical tests of the blanket in the integrated fusion environment. Blanket testing has been one of the key missions of ITER. Our TBWG work reaffirms the importance of TBM to blanket development programs in all parties, being a critical link between ITER and DEMO.

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2. It has become abundantly clear that planning for and conducting the ITER TBM program requires a structured framework among the Parties either as a new arrangement under the ITER Joint Implementation Agreement or even as part of it. In any cases, the rights and responsibilities of the Parties and ITER organization should be clearly defined as far as TBWG activities are concerned.

We hope that some actions regarding these important issues for future ITER organization can be undertaken and to receive from you the corresponding guidelines.

Best Regards

Dr. Valeriy Chuyanov
TBWG Co-Chairman

Dr. Luciano GIANCARLI
TBWG Chairman

Copy:

- *TBWG Delegation Heads:*
  Prof. C. Pan (China), Dr. R. Laesser (EU), Dr. M. Akiba (J), Dr. B.G. Hong (Korea), Dr. Y. Strebkov (RF), Prof. M. Abdou (US)
- *TBWG Secretary, S. Hermsmeyer*

TBWG Effort, Port Allocation, and Preferences of the Parties

- TBWG was reactivated in October 2003. Several meetings were held to:
  1) discuss and agree on port allocation and concepts to be tested,
  2) plan for international collaboration, and
  3) provide ITER with details impacting the ITER device and plant (e.g. plasma exposure, off-normal events, ancillary equipment).

- There are 3 ports for testing
  - There is a Port Master for each port

- Five Working Subgroups were formed to examine technical issues and coordinate among the parties

Blanket Concepts for ITER-TBM Selected by the Various Parties

- Solid Breeders
  - He/SB/Be/FS: All parties are strongly interested
  - H_2O/SB/Be/FS: Only Japan (some interest from China)

- Liquid Breeders
  - He/LiPb/FS (Separately cooled): EU lead (one of two main concepts for EU, interest from other parties)
  - Dual Coolant (He/LiPb/FS with SiC): US lead, strong interest from EU and other parties
  - Li/V (Self-cooled): Russia is main advocate (but no significant resources on R&D!)
  - Molten Salts: US and Japanese Universities want the option to decide later whether to test

Port Allocations for ITER TBM

Port A	Port B	Port C
He-Cer (1)	H_2O-Cer	Li/V
He-Cer (2)	He-LiPb	Dual Coolant (LiPb or Molten Salt)
Port Master A: Boccaccini	Port Master B: Enoeda	Port Master C: Kirillov
Working Group* → Cer/He	2 Working Groups* → H_2O-Cer, He-LiPb (include DC)	2 Working Groups* → Li/V, Molten Salt

*Members nominated by each interested party (not necessarily members of TBWG).

II. US Strategy for ITER TBM and Brief Description of Selected Concepts

Highlights of US Strategy for ITER TBM

(Evolved over the past year by the community, DOE and VLT)

- The US will seek to maximize international collaboration. There is a need for all parties to collaborate, and to possibly consider a more integrated plan among the ITER parties for carrying out the R&D and construction of the test modules.

- ITER TBM should be viewed as a collaborative activity among the VLT program elements. While the Blanket/Chamber Program provides the lead role for ITER TBM, major contributions from other programs, e.g., Materials, Safety, PFC, are essential.

- The US community has now reached consensus on preferred options for ITER TBM (see separate slide), following assessment of new technical results obtained over the past few years

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.**
- **A key conclusion reached early in the study is:**

  - All Liquid Breeder Options have serious feasibility (“Go/No-Go”) issues.
- **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, corrossion, 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.**

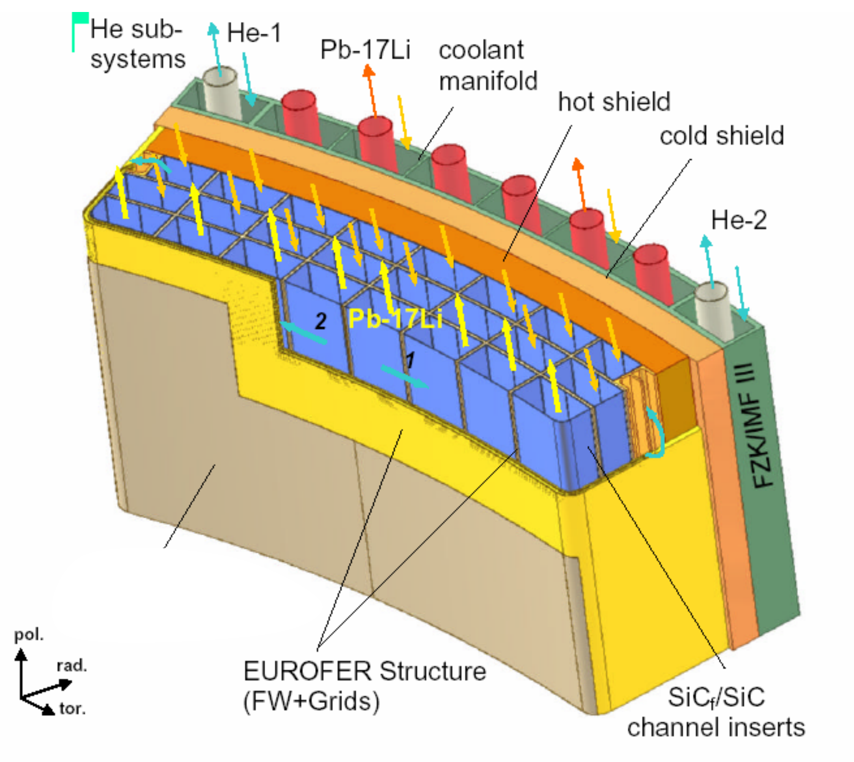
US Selected Options for ITER TBM

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:

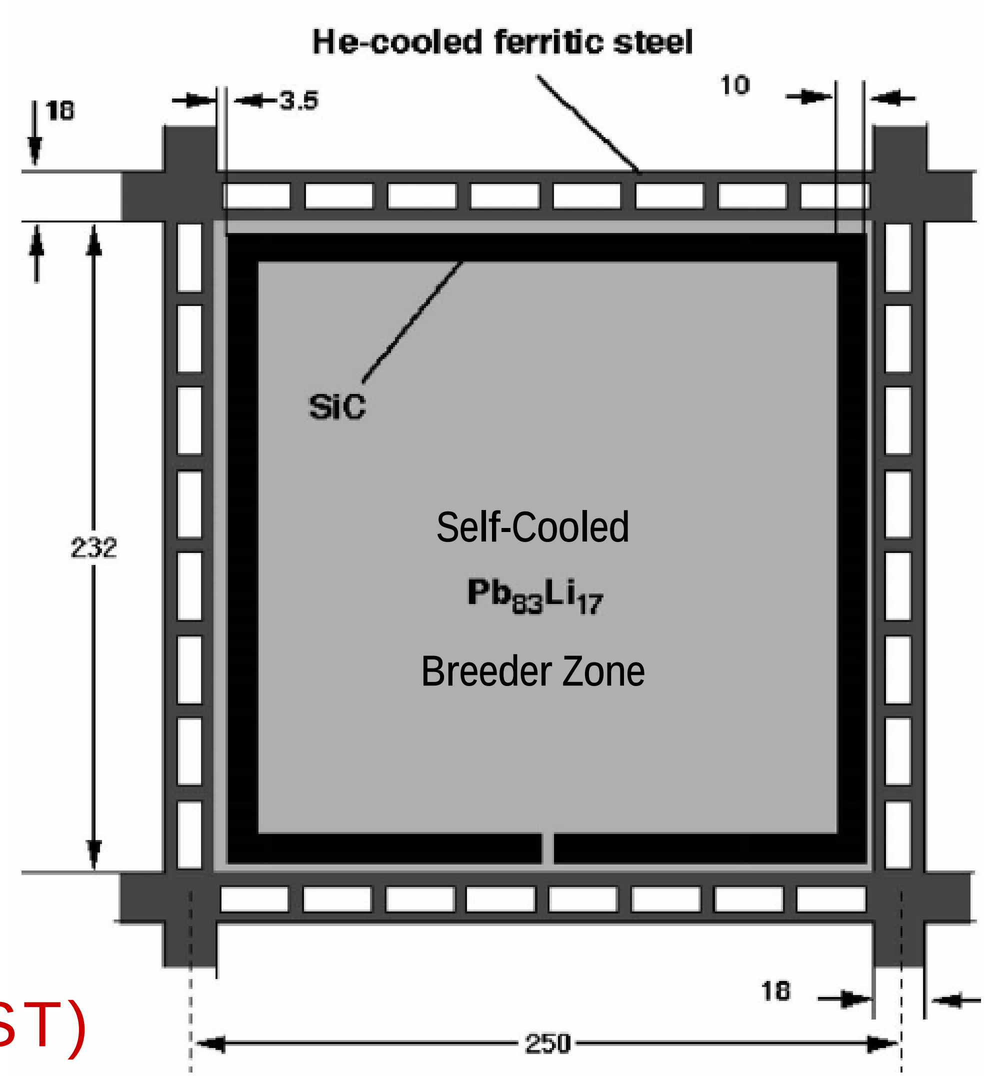
- Select a helium-cooled solid breeder concept with ferritic steel structure and neutron multiplier, but without a fully independent TBM. Rather, plan on unit cell and submodule test articles that focus on particular technical issues of interest to all parties. (All ITER Parties have this concept as one of their favored options.)
- Focus on testing Dual-Coolant liquid breeder blanket concepts with ultimate potential for self-cooling. Develop and design TBM with flexibility to test one or both of these two options (decision in 1-3 years):
  - 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. The choice of the specific lithium-containing molten salt will be made based on near-term R&D experiments and modeling. Because of the low thermal and electrical conductivity of molten salts, no insulators are needed.

RAFS/He/Pb-17Li Dual Coolant Blanket Concept

- ❑ The reason fusion needs high temperature materials is for high coolant temperature for efficient power conversion
- ❑ MHD effects in high velocity channel flows leads to very high primary stresses that materials must accommodate
- ❑ IDEA – the Dual Coolant Concept: use the poor thermal and electrical conductivity of SiC as an advantage
  - Cool structure with He so LM velocity can be low and LM bulk temperature can be higher than the wall temperature
  - Use a SiC insert to electrically and thermally insulate the LM from the wall
  - **Result: potential for high bulk temperature with lower MHD pressure drop using RAFS**



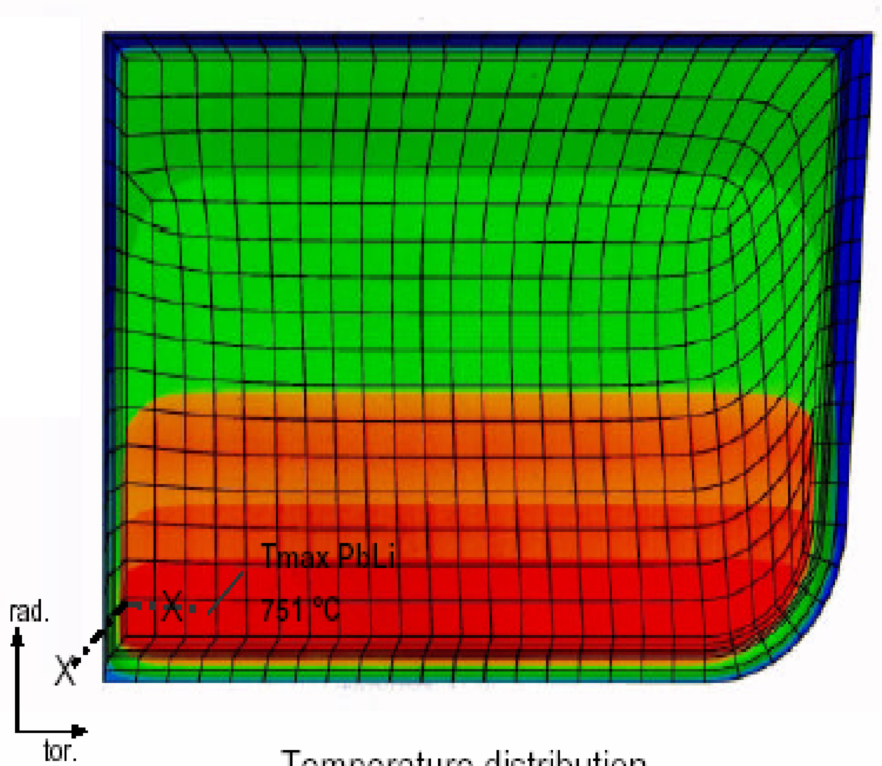
Closeup of a Pb-17Li Breeder Channel



(from ARIES-ST)

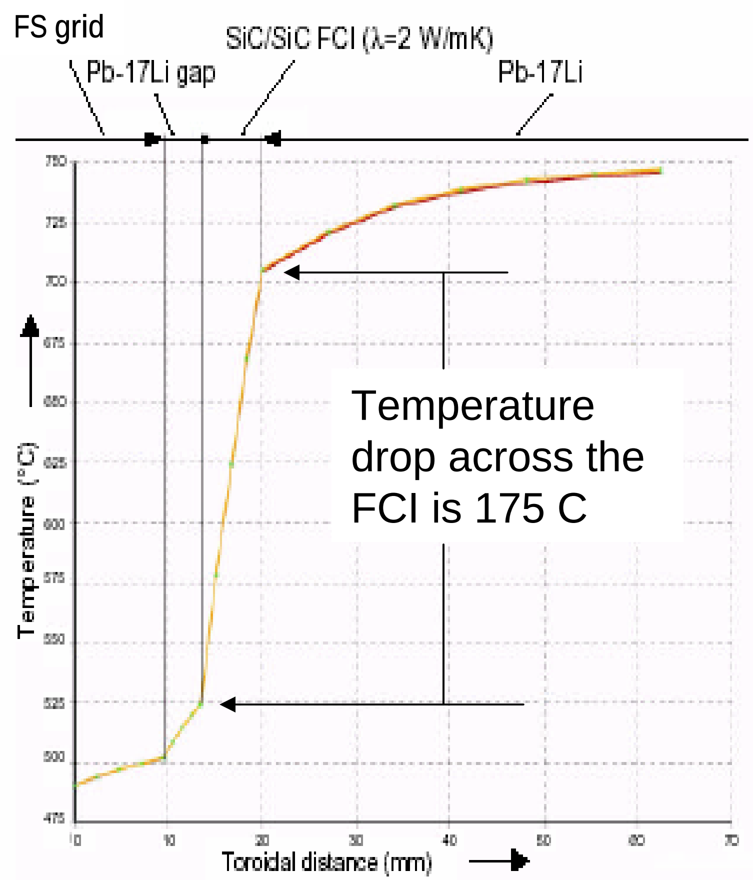
Dimensions in mm

Structure, Insert, and Breeder Temperatures



Temperature distribution

Pb-17Li: T_{max} / T_{avg} = 751 °C / 633 °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

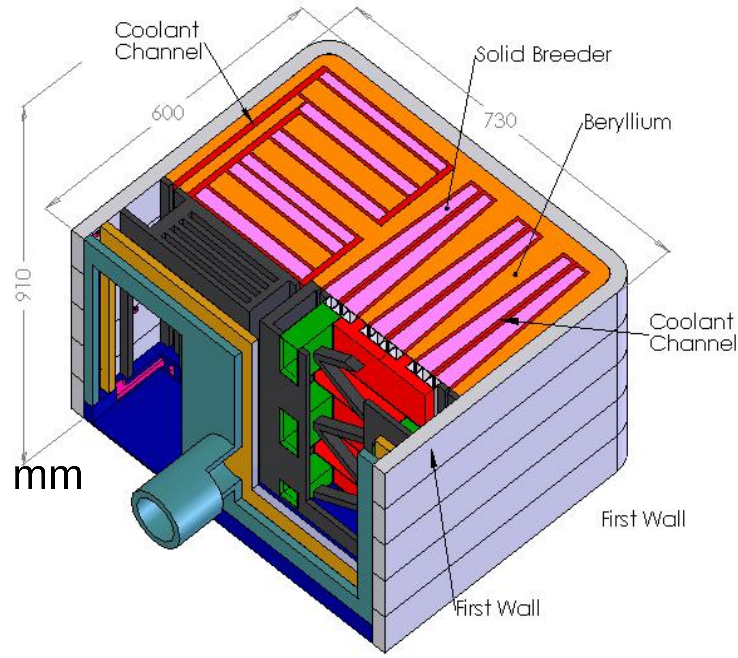
E) The insert shapes must be fabricable and affordable

Strategy for Testing Solid Breeder (He/SB/Be/FS) Concepts

Notes:

- The US plans on unit cells and submodule tests to address specific technical issues such as temperature window and temperature control (not a fully independent TBM, uses other Parties ancillary equipment)
- The world program (particularly EU and Japan) in this area is strong
- There are very good reasons why the US materials program should contribute to this area
    1. the only universally accepted concept,
    2. exciting issues with a lot of science,
    3. need to support US ITER-TBM.

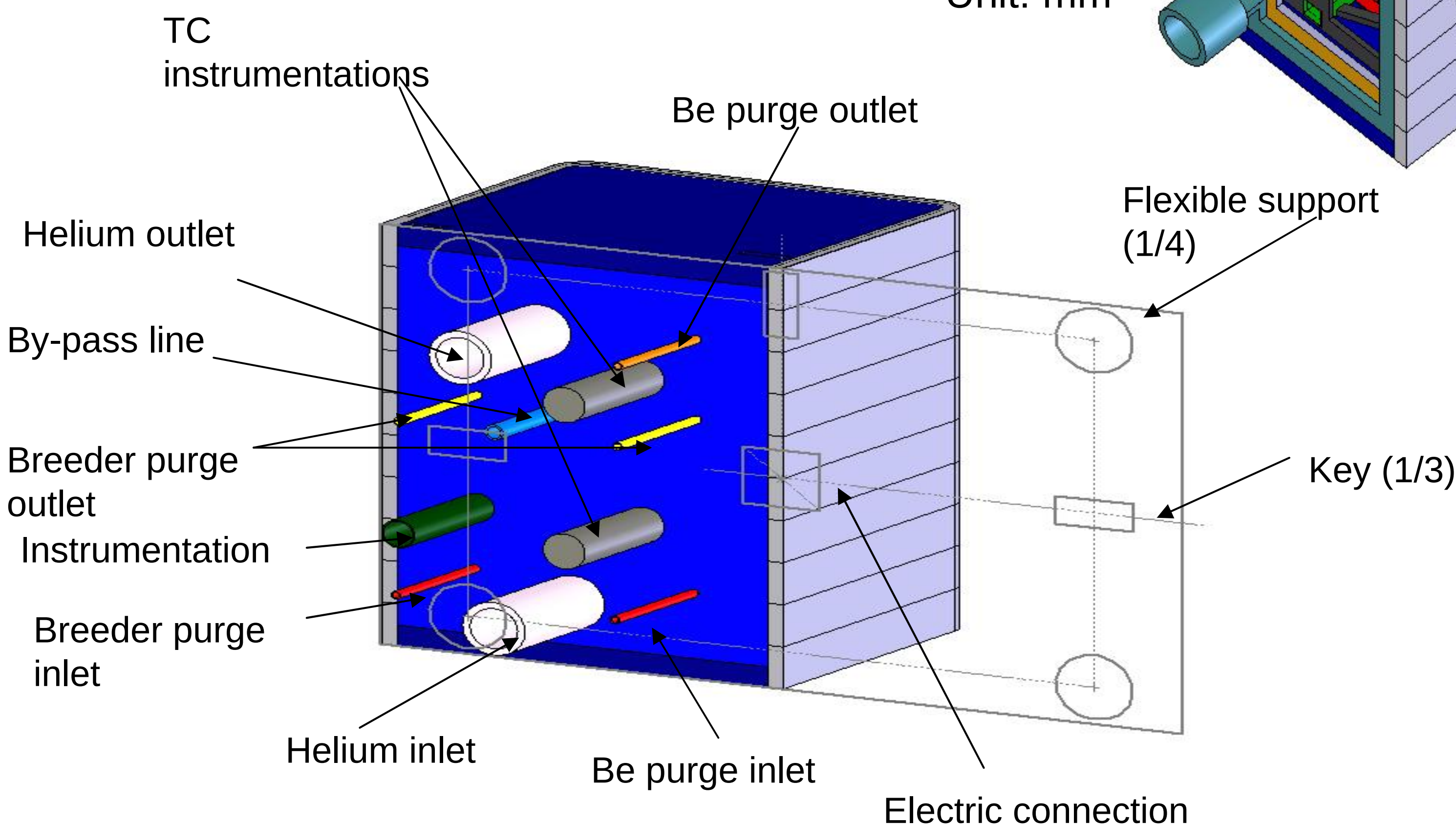
Example Helium-Cooled/RAFS Solid Breeder Submodule



Unit: mm

Issues:

- **Tritium Release**
- **Thermo-mechanical Interactions**
- **Configuration Exploration**



III. Suggested "Materials" Effort for US TBM Concepts

Ferritic Steel

Notes:

- Reduced Activation Ferritic Steel is the structural material in the US ITER TBM Concepts (also in ALL the Parties' ITER TBM Concepts, with the exception of the Russian Li/V)
- EU and Japan have substantial effort on RAFS structure for their ITER TBMs (including fabrication, joining, qualification, etc.)

Suggested Effort:

- **The US Material Program should undertake the responsibility for "delivering" the RAFS structure for the US ITER TBM**

  This includes:

  - Definition and execution of any required R&D
  - Interactions with EU, Japan, and other parties, maintaining access to their results/experience, and making collaborative agreements
  - Exploring and enhancing capabilities of US industry to deliver the TBM structure (also how the entire TBM will be assembled, contracted, etc.)

Materials Issues for DC PbLi Concept

(Among the highest priorities for liquid breeders. Results within the next 1-3 years will be critical in guiding the US ITER TBM decisions)

1. Initial Assessment and Experiments

- Assessment and characterization of the most suitable currently available SiC/SiC composite material for use in flow channel insert (FCI). This includes measurement of electrical/thermal conductivity (especially perpendicular to the plane).

- Assessment of suitable sealing layers on the composite to avoid soaking in of Pb-17Li, including capsule tests to determine the integrity of the layer and the solubility in PbLi. [Couple closely to MHD experiments and crack tolerance assessment research under Plasma Chamber Program] [Also encourage SBIR activity]

Materials Issues for DC PbLi Concept (cont'd)

<u>2. Substantial Effort (that follows success in 1)</u>

- Initiation of irradiation experiments for SiC/SiC composites up to 1-3 dpa to determine the impact on the mechanical properties as a function of temperature, and the effect of radiation on thermal and electrical conductivities.
- Establishment of the compatibility temperature limits of the selected SiC-composite with Pb-17Li. This requires experiments in a thermal convection loop at temperatures up to 1000°C and a temperature gradient in flow direction. The loop should allow the investigation of material transport between the SiC composite at the high temperature, and ferritic steel tubes or coupons at lower temperatures. (Some experts believe this is the number 1 issue)
- Development of the special SiC-composite material needed for the conditions in FCI's (low electrical and thermal conductivity perpendicular to the plane, no high strength required since there are no primary stresses to the FCI). Also develop fabrication technology.
- LiPb/FS compatibility: We need to keep connected with EU activities possibly via IEA collaboration.

Materials Issues for DC Molten Salt Concept

- **The key material issue for molten salts are currently being addressed under the JUPITER-II program:**
  - Develop REDOX control in MS. REDOX control experiment is ongoing at INEEL, under JUPITER-II collaboration. The INEEL experiment uses a chemical process to simulate a nuclear process. The INEEL experiment is a necessary condition, but not a sufficient condition to develop REDOX control. Further experiments on REDOX control will be required.

- **Other Material Tasks for Molten Salts (LOWER Priority relative to DC PbLi):**
  - Establish the MS database, particularly the physical properties of LiBeF3 and FLiNaBe.
  - Establish MS compatibility limits with FS. Corrosion tests need to be done.
  - Tritium control. Permeation barriers and efficient tritium extraction and recovery process need to be developed. [Possible IEA activity]

Suggested Materials Program Effort for Solid Breeder (He/SB/Be/FS) Concepts

- Specific issues related to solid breeder and beryllium pebbles
  - Further study of microstructure (grain size, open porosity) and fabrication process and their impact on performance
  - Acquisition of ceramic breeder and beryllium pebbles for the TBM program.
- Other areas where the Materials Program can contribute and participate (possibly through IEA and next phase JUPITER Collaboration)
  - In-pile experiments to study radiation induced sintering on solid breeder materials as a function of temperature and fluence
  - Characterization of radiation swelling and tritium inventory in beryllium at high temperatures
  - In-pile performance evaluation of unit cell or submodule assemblies
- Materials development for advanced concept explorations
  - Advanced material forms of solid breeder materials (e.g. foams, high conductivity ceramics)
  - Beryllium intermetallic compounds for high temperature operations

Tritium Permeation

- Tritium Permeation is emerging as a persistently serious issue for most (some believe for ALL) concepts
- Developing acceptable solutions requires integrated efforts among many programs: Materials, PFC, Safety, Plasma Chamber
- Dai-Kai Sze will address this more in his presentation

Concluding Remarks

1. The ITER Test Blanket Module (TBM) Program is a critical element in ITER's mission. For all parties, it is a critical link between ITER and DEMO

2. The US ITER TBM must be a collaborative activity among the VLT program elements. Major contributions from all programs including Plasma Chamber, Materials, PFC, Safety, and Tritium are essential.

3. Specific suggestions for substantial Material Program Tasks for ITER TBM were highlighted.