

Dual-Cooled Blanket Modular Replacement Design Approach



UC San Diego



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Outline



- Introduction
- Modular Dual Coolant Blanket Design
 - Overall layout of the blanket module*
 - Lead-lithium flow scheme*
 - Helium flow scheme*
 - Initial thermal-hydraulic analysis results*
- Mechanical Attachment of the Blanket Replacement
- Layout of the Coolant Supply/Return Pipes and Manifolds
- Summary

Introduction



For Phase II, we decided to focus on:

➤ Maintenance Schemes:

(1) *Field-period based replacement including disassembly of modular coil system.*

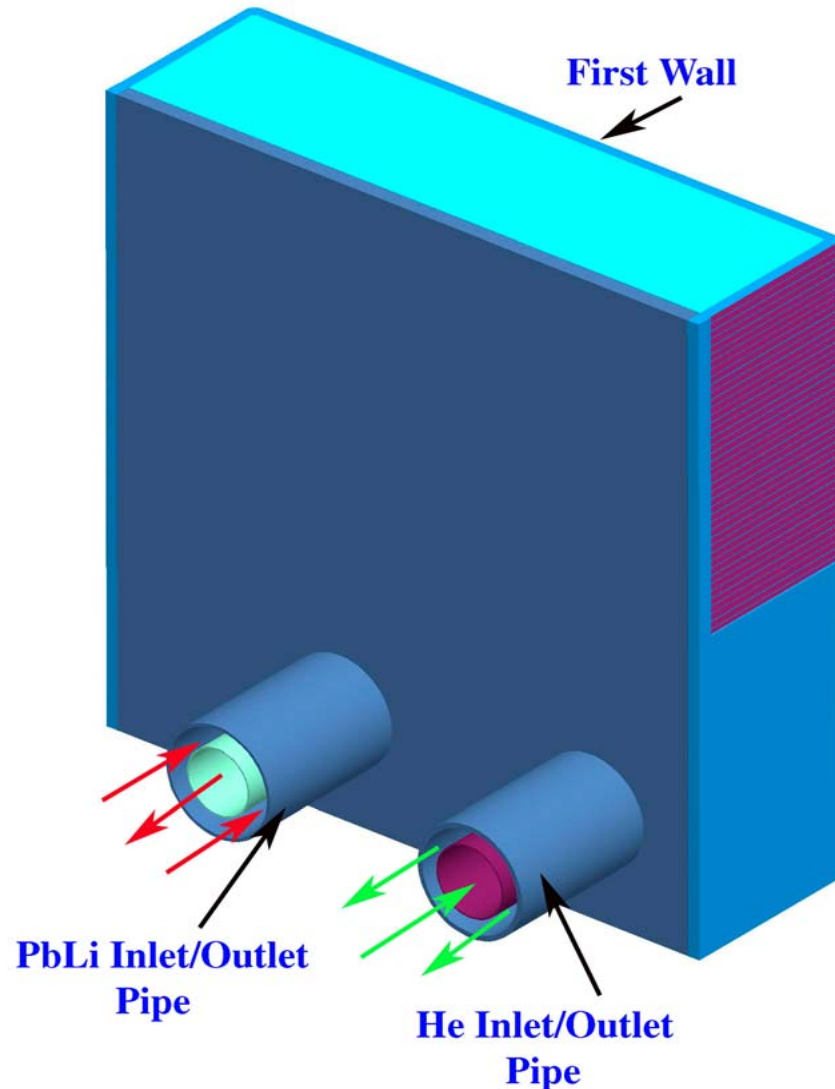
(2) *Replacement of a small blanket modules through a few ports(using articulated boom).*

➤ Blanket concepts:

(1) *-Dual coolant blanket with He cooled FW and blanket structure with RAFS(Reduced Activation Ferritic Steel) and self-cooled Pb-Li breeding zone.*

(2) *Pb-17Li+SiC/SiC blanket.*

Overall Layout of the DCLL Blanket Module



Major radius	8.25 m
Total FW area	824 m ²
Total number of blanket module	206
Maximum neutron wall load	4.7MW/m ²
Thermal power of the module	24.6 MW
Heat to be removed with Pb-17Li (~60% of total heat)	15 MW
Heat to be removed with He	10 MW
Helium system pressure	8 MPa

Example He inlet/outlet temperatures

350/450 °C

Examples Pb-17Li inlet/outlet temperatures

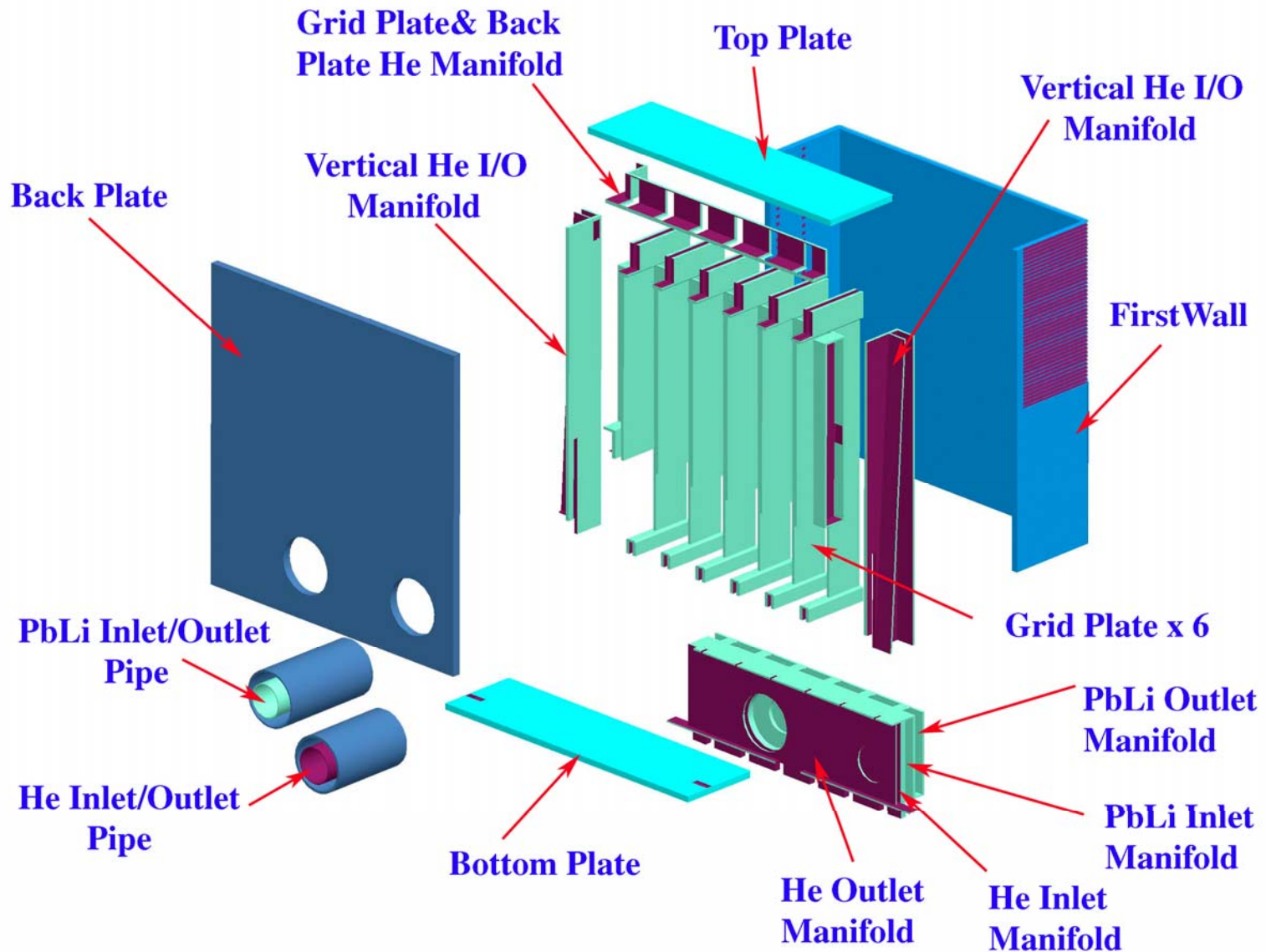
460/700 °C⁴

Radial Build of the Blanket Module

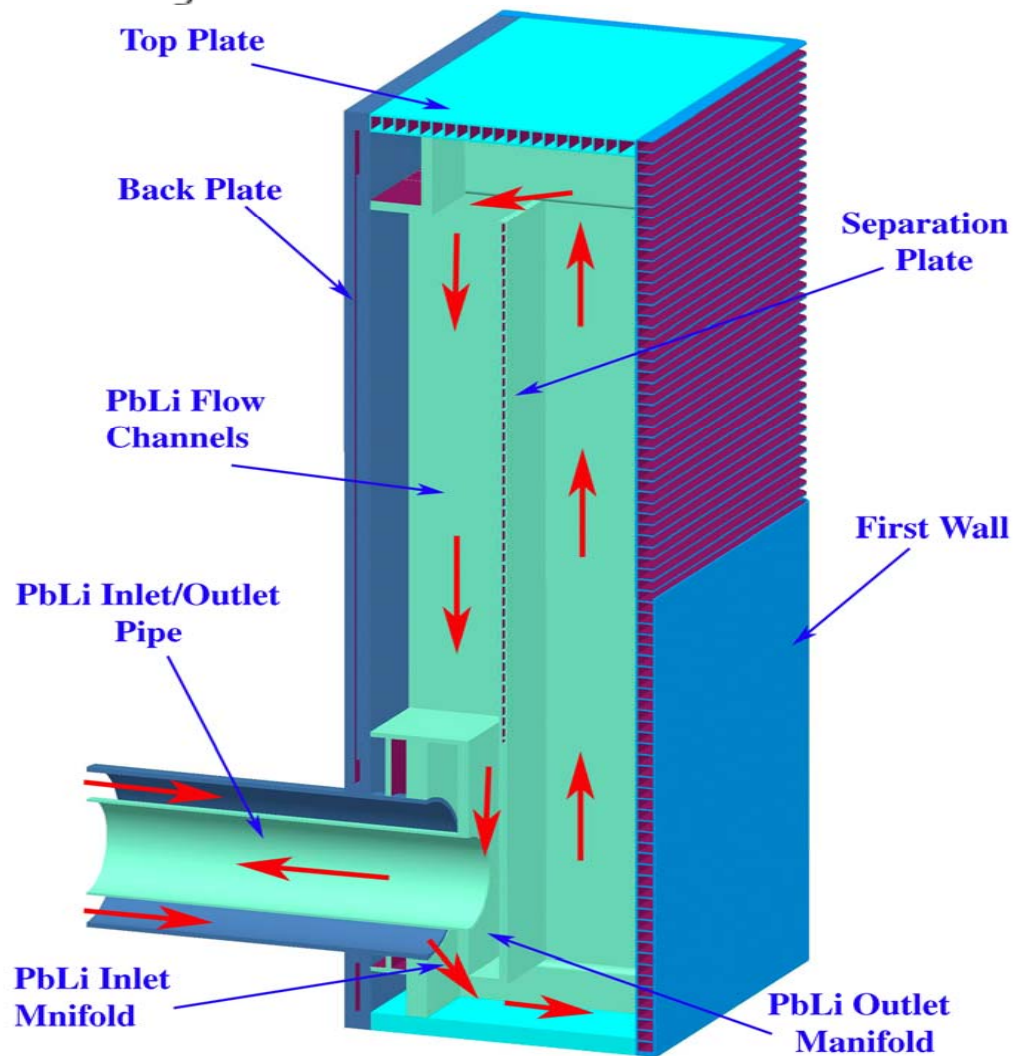


Zone	Description	Thickness (cm)
1	First wall	0.4
2	FW cooling channel	3.0
3	Second wall	0.4
4	SiC insert	0.5
5	Breeding channel 1	24
6	SiC insert	0.5
7	Separation plate	1.5
8	SiC insert	0.5
9	Breeding channel 2	24
10	SiC insert	0.5
11	Back plate	5.0
	Total	60.3

Exploded View of the DCLL Blanket Module

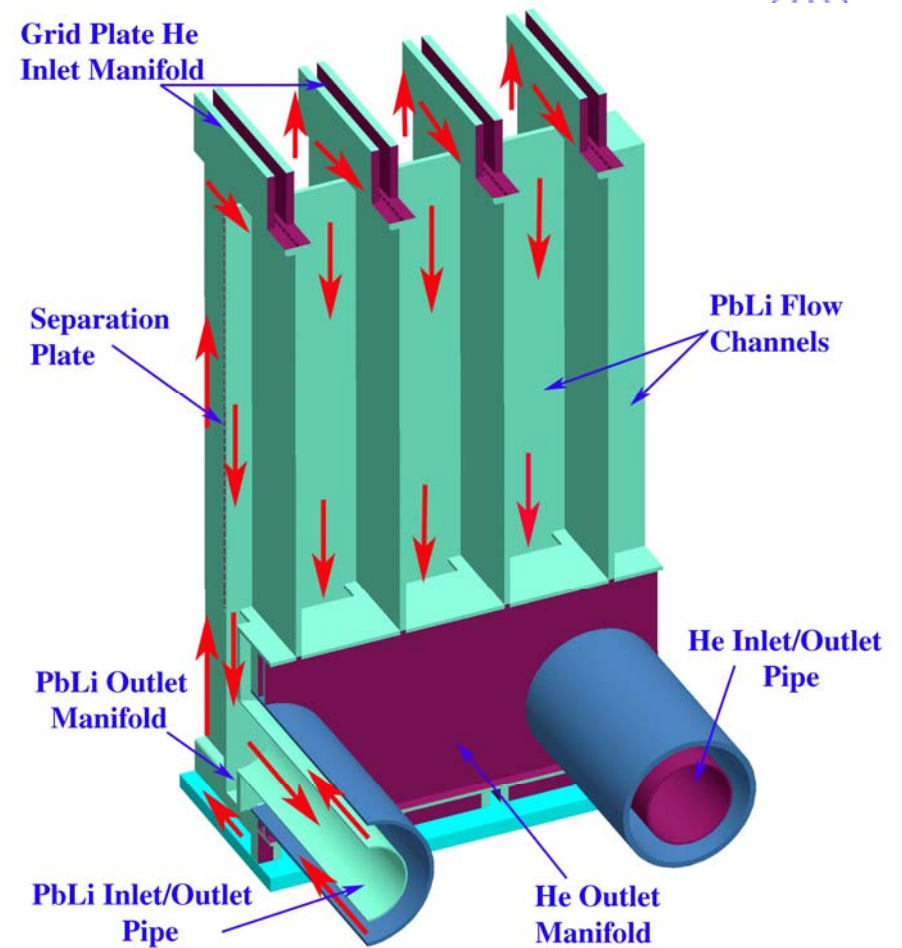
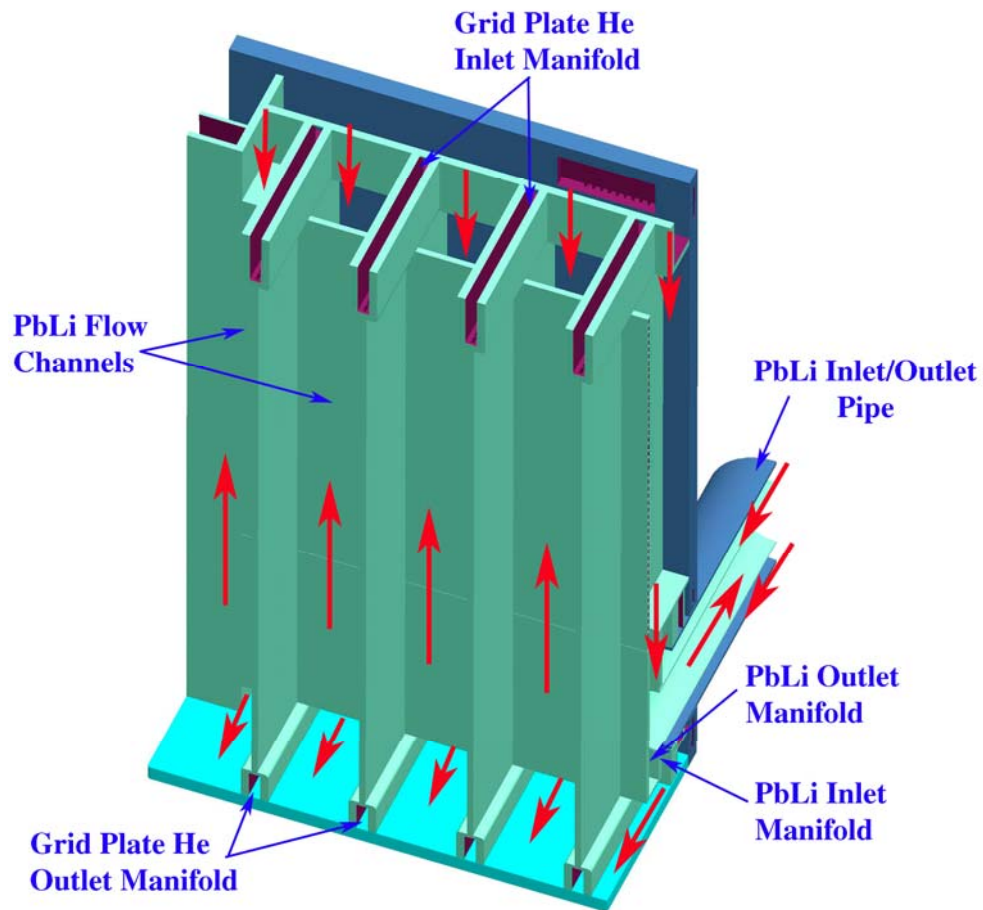


Layout of the Lead-Lithium Cooling System

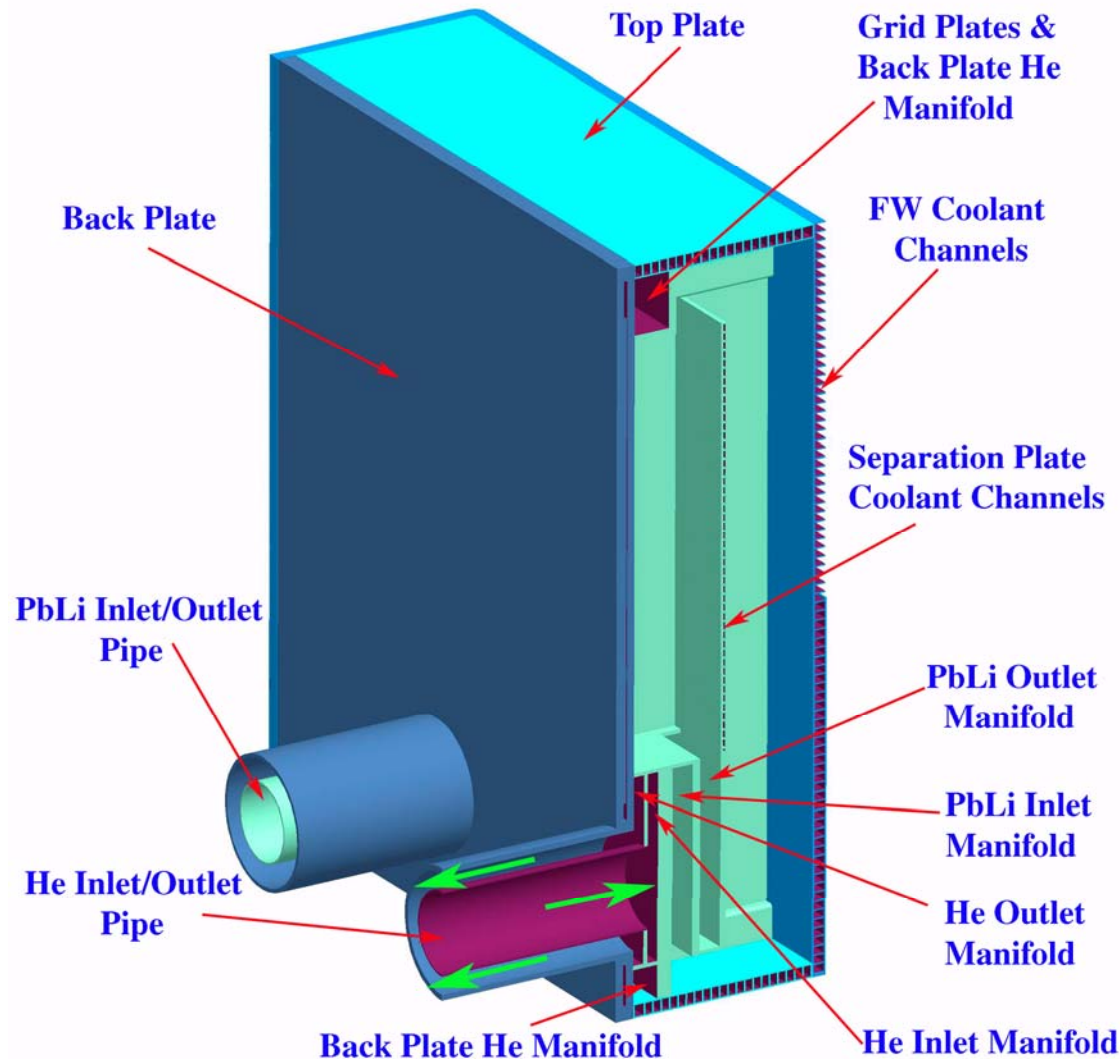


- ~60% of module power is assumed to be removed with Pb-17Li (up to ~15 MW).
- Example lead-lithium inlet/outlet temperatures ~ 460/700 °C.
- Thickness of FCI(flow channel insert, SiC-composite) is assumed about 5 mm, and the gap between the FCI and steel wall(filled with Pb-17Li) is about 1 mm.
- The FCI is not shown in the 3D CAD drawings.

Lead-Lithium Flow Scheme



Layout of the Helium Cooling System



➤ ~40% of module power is assumed to be removed with He (up to ~10 MW).

➤ Helium inlet pressure ~8 MPa.

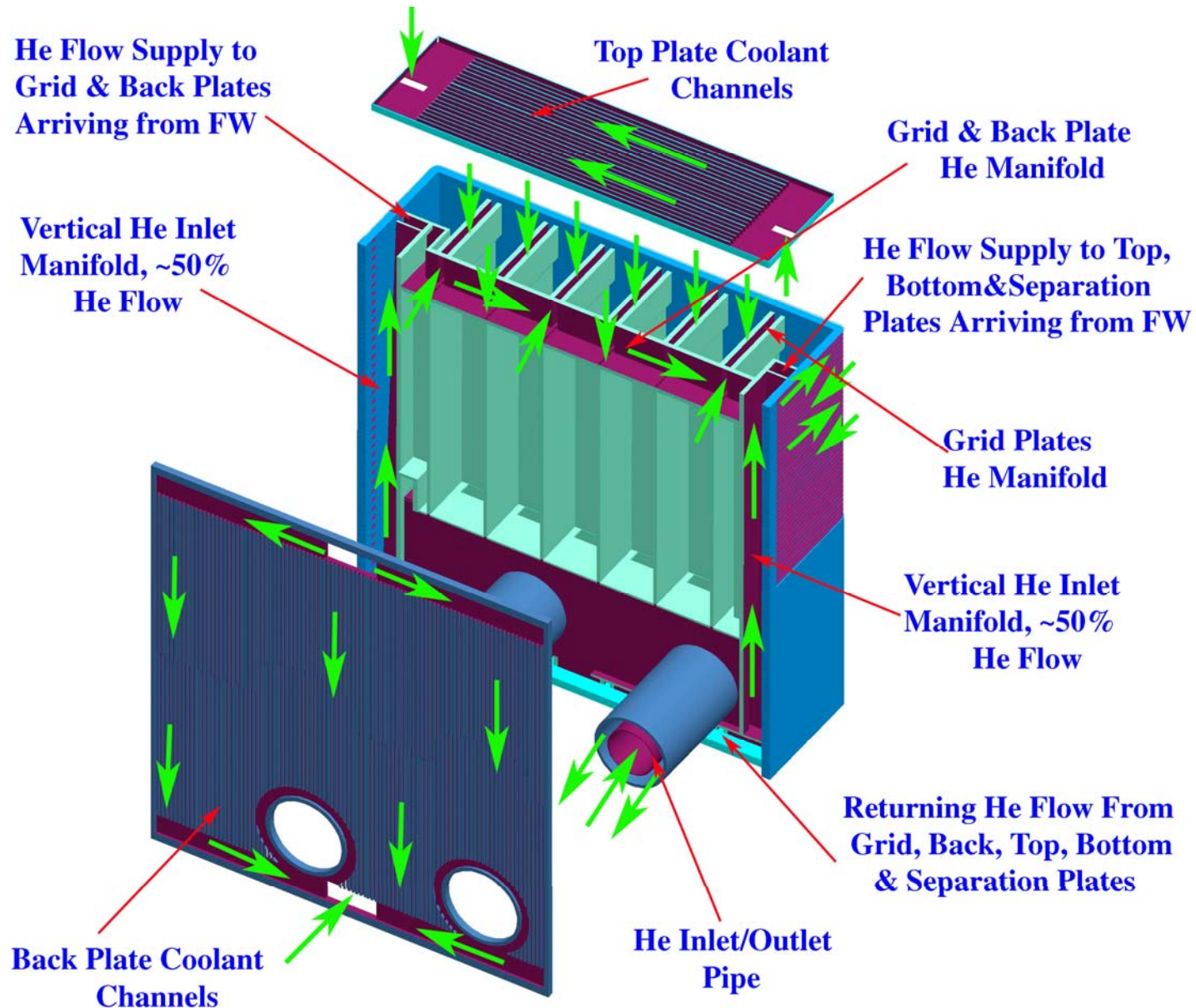
➤ Example Helium inlet/outlet temperatures ~ 350/450 °C.

Overall Helium Flow Scheme

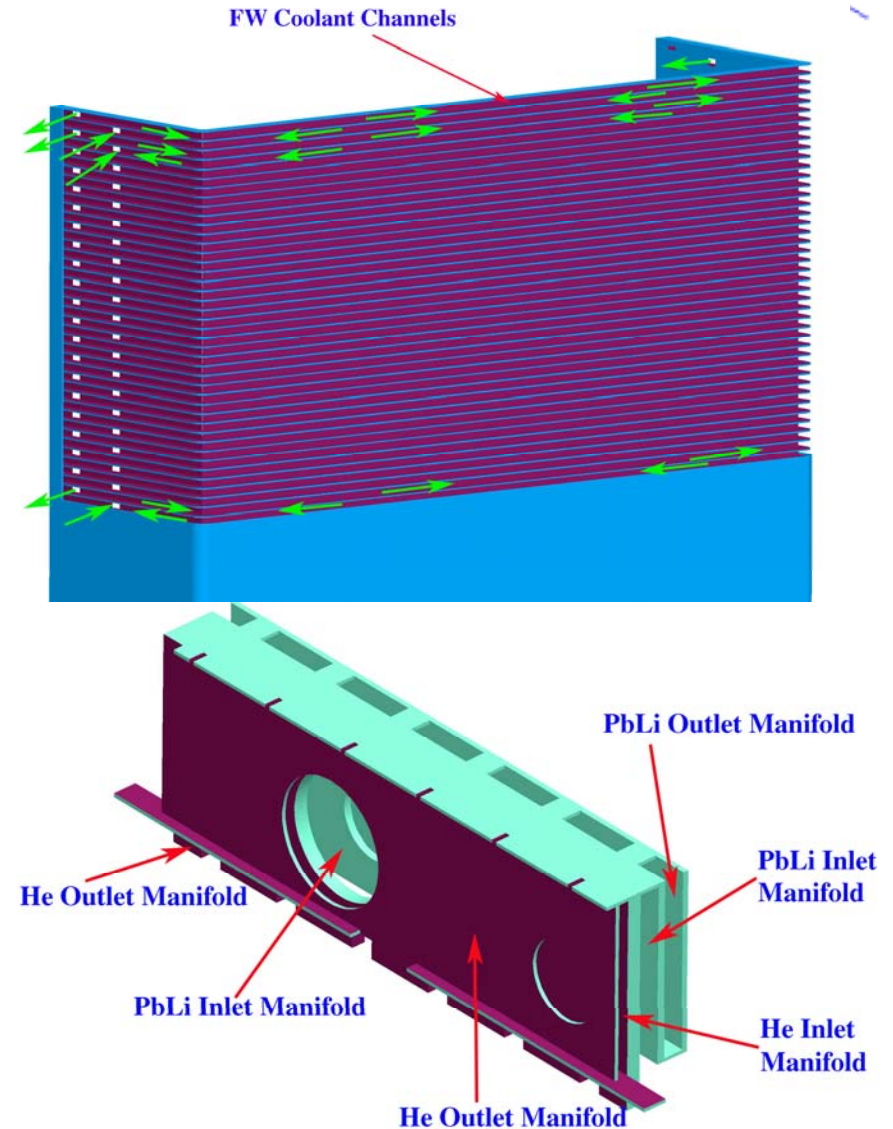
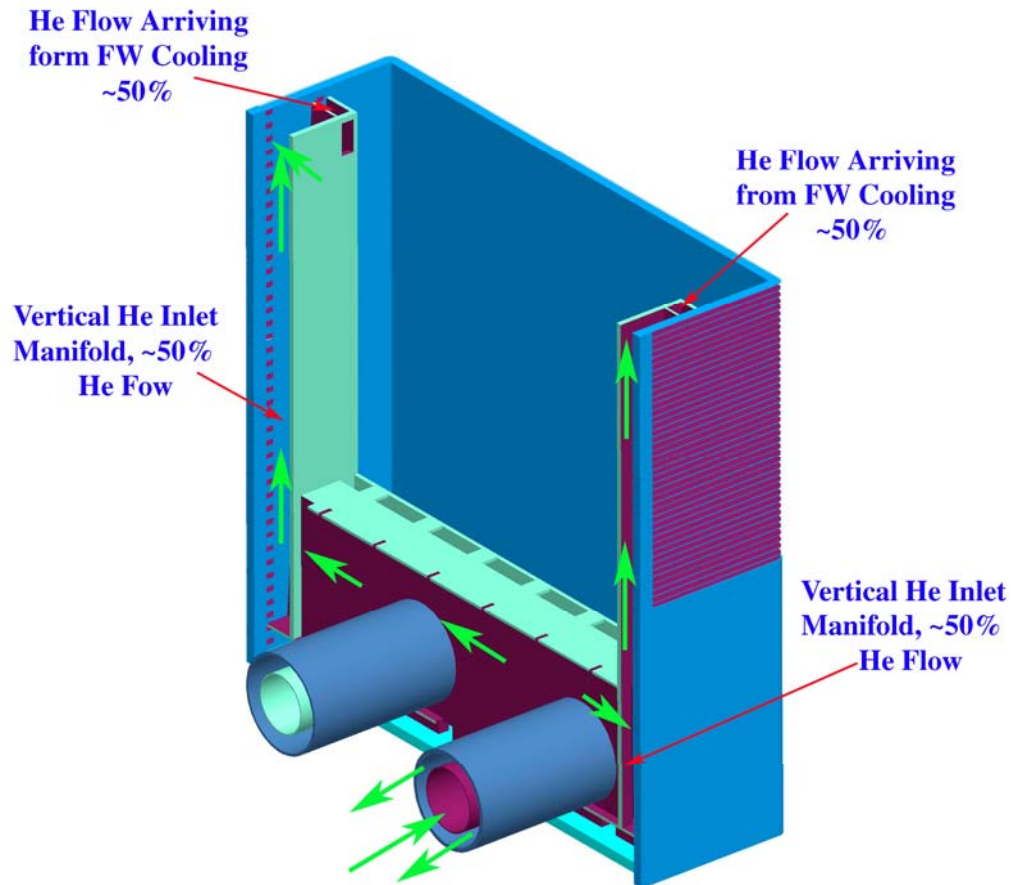


- The entire helium flow is entering the blanket box through the inner tube of a concentric pipe(purple), attached in radial direction to the back plates of the box.
- There is a toroidal manifold arranged at the corner between back and bottom plates, distributing the helium flow to the two poloidal inlet/outlet manifolds arranged at the corners between side wall and the back plate.
- Helium from these inlet manifolds is routed through side wall and first wall alternatively, and the flow is collected in the poloidal inlet/outlet manifolds. There is a tapered dividing wall arranged in the poloidal inlet/outlet manifolds, separating the inlet flow to the SW/FW from the outlet flow coming from SW&FW.
- There is a toroidal manifold arranged in the corner between top and back plates which is connected to one poloidal outlet manifold, and the helium flow(~50% of total flow rate) in this manifold is distributed to the poloidal cooling channels in the grid plates and back plate.
- The helium flow(~50% total flow rate) from another poloidal outlet manifold will be distributed to the toroidal cooling channels in the separation plate, top & bottom plates.

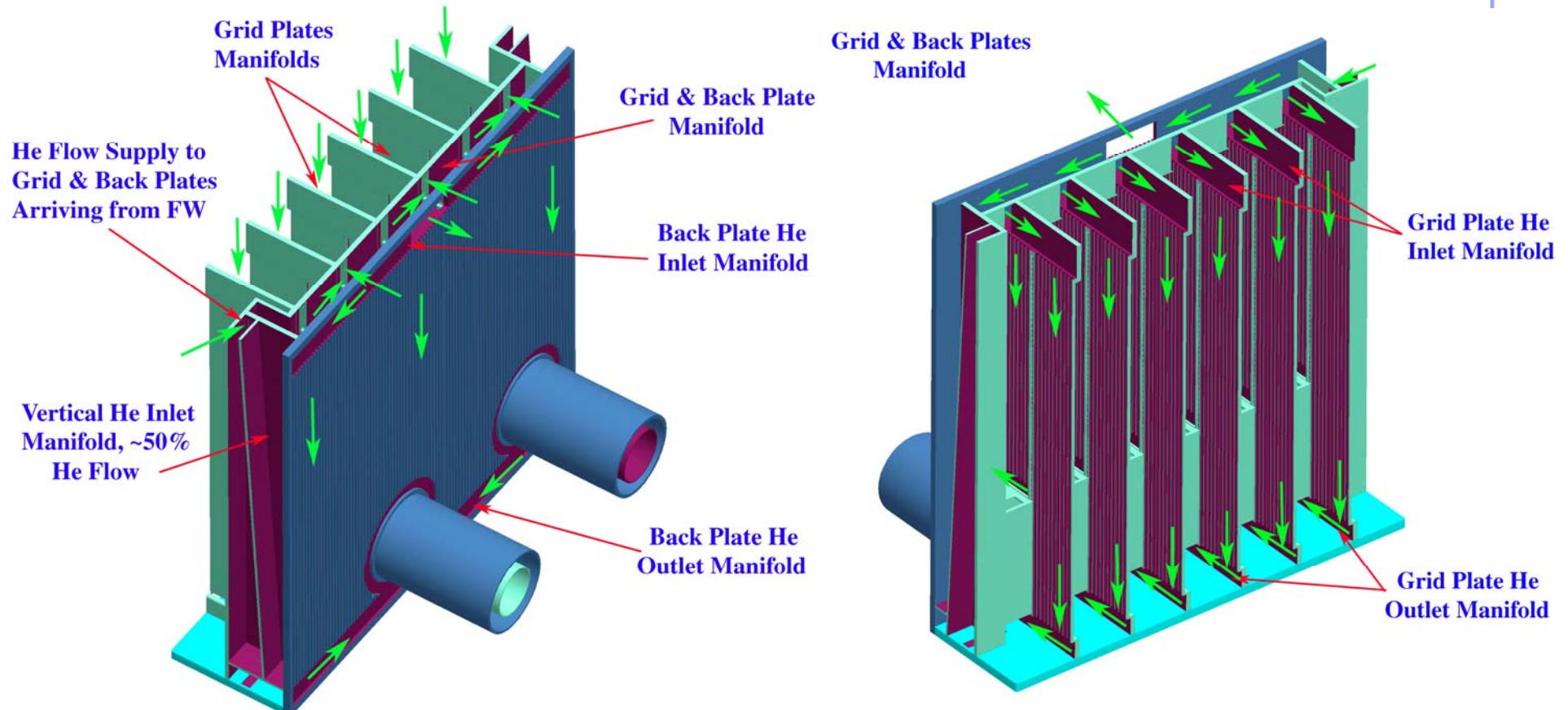
Overall Helium Flow Scheme(Cont.)



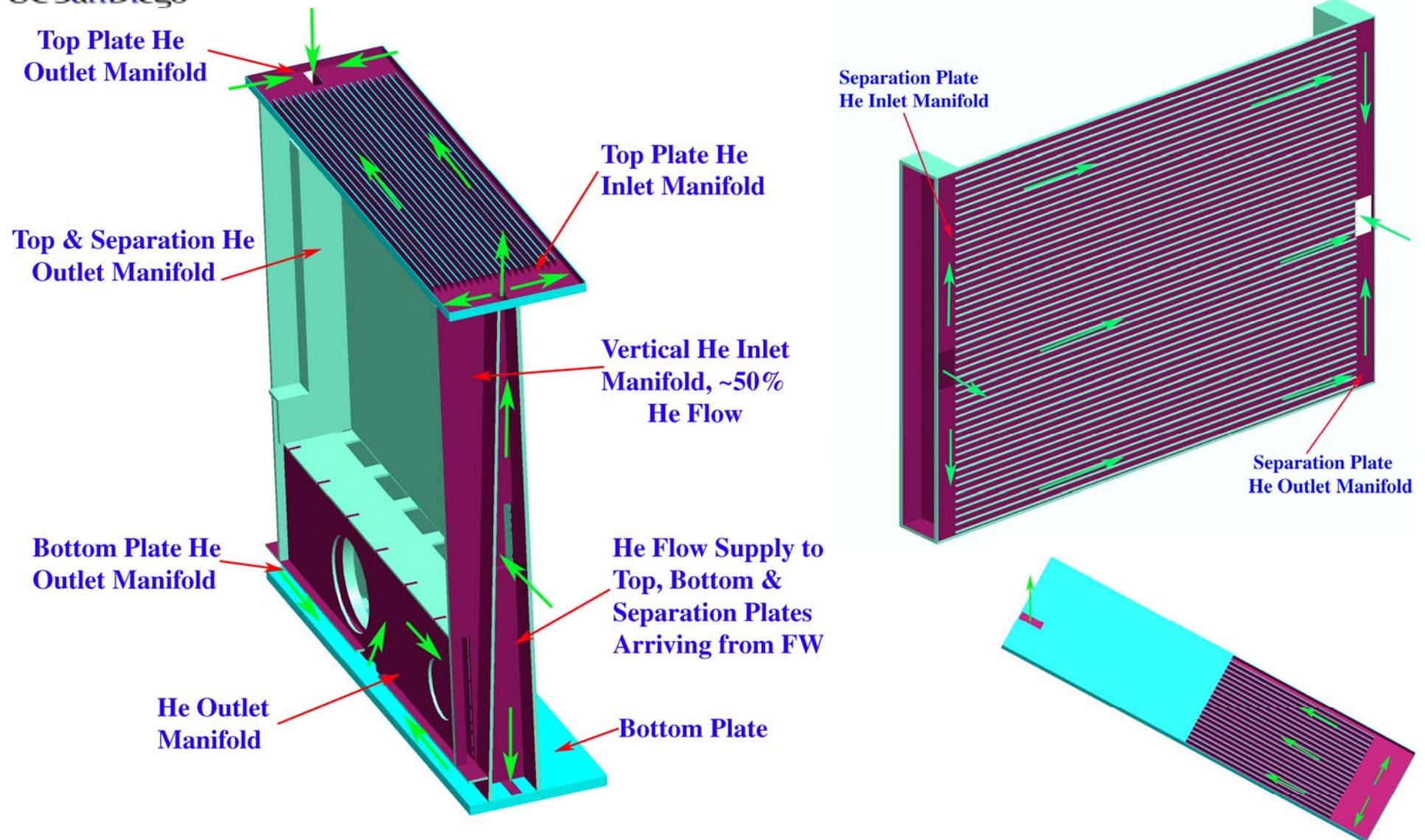
Helium Flow Scheme in FW and Side Wall



Helium Flow Scheme in Grid & Back Plates



Helium Flow Scheme in the Top, Bottom and Separation Plates

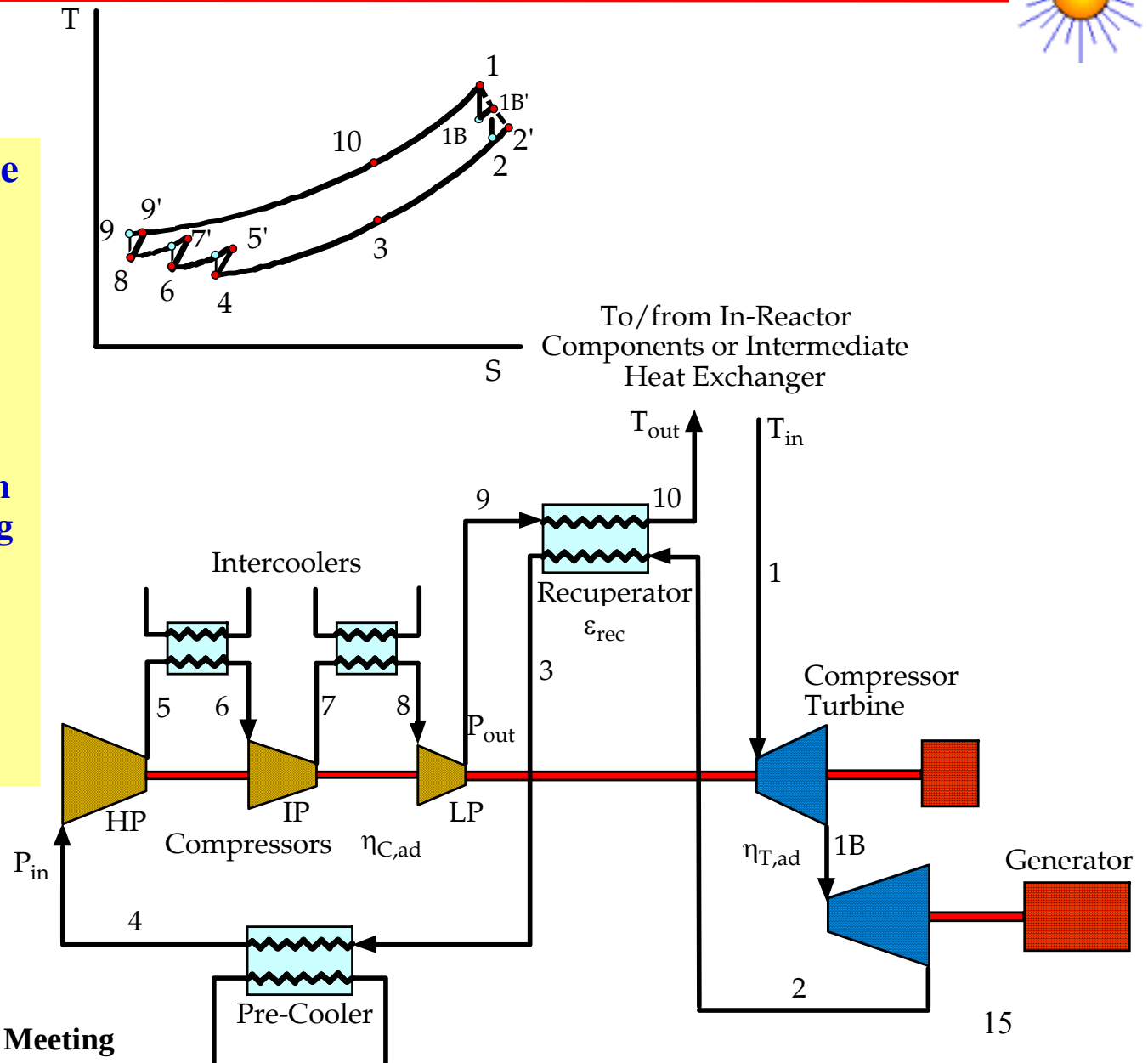


Example Brayton Cycle Considered



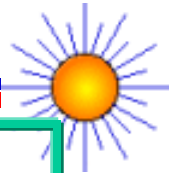
Set parameters for example calculations:

- Blanket He coolant used to drive power cycle
- Minimum He temperature in cycle (heat sink) = 35°C
- 3-stage compression
- Optimize cycle compression ratio (but < 3.5 ; not limiting for cases considered)
- Cycle fractional $\Delta P \sim 0.07$
- Turbine efficiency = 0.93
- Compressor eff. = 0.89
- Recuperator effectiveness = 0.95



*Presented by Rene at ARIES-CS Meeting
at UCSD, March 8, 2004

Initial Thermal Hydraulic for Helium Cooling System



Blanket module(toroidal x poloidal x radial), m ³	2 x 2 x 0.603
Maximum neutron wall loading, MW/m ²	4.7
Blanket energy multiplication factor	1.2
FW surface heat flux, MW/m ²	0.5
Total thermal power of one blanket module, MW	24.6
Thermal power to be removed with helium, MW	10
Coolant inlet pressure, MPa	8.0
Coolant inlet temperature, °C	350
Coolant outlet temperature, °C	450
Total flow rate of one blanket module, m ³ /s	2.86
<u>Assuming volumetric heating in the FW(Solider Breeding Blanket):</u>	
First wall steel, MW/m ³	46.5
First wall cooling channel, MW/m ³	7.58
Second wall steel, MW/m ³	42.3
Total FW heat to be removed, MW	4.33

Example Thermal Hydraulic Results



Helium inlet temperature, T_{in} , °C	364
Helium outlet temperature, °C	464
Pb-17Li Inlet temperature, °C	464
Pb-17Li outlet temperature, °C	663
Max. FW temperature, °C	554
Max. Interface FS/Pb-Li temperature, °C	500
Pressure drop in module, MPa	0.33
Pumping power in module, MW	1.23
Ratio of the Pumping Power to Thermal Power	5.0%
Brayton Cycle efficiency	~40.8%

Example Cycle Efficiency as a Function of Neutron Wall Loading Under Given Constraints

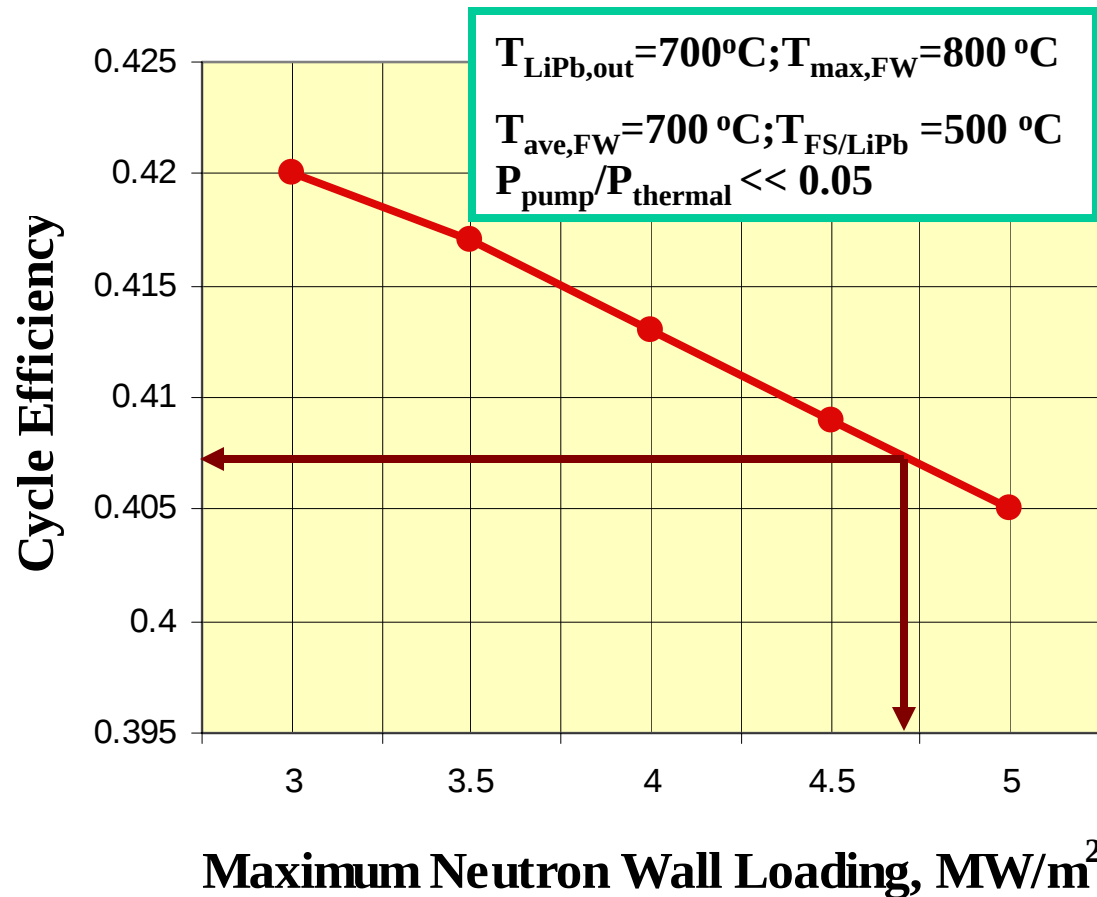


➤ For a fixed blanket thickness of 0.603 m (required for breeding), a maximum Γ of 5 MW/m² can be accommodated with:

$$T_{\max,FS} \ll 553^\circ\text{C}; \eta = 40.5\%$$

➤ The max. η correspond to Γ of 3 MW/m²:

$$T_{\max,FS} \ll 558^\circ\text{C}; \eta = 42\%$$



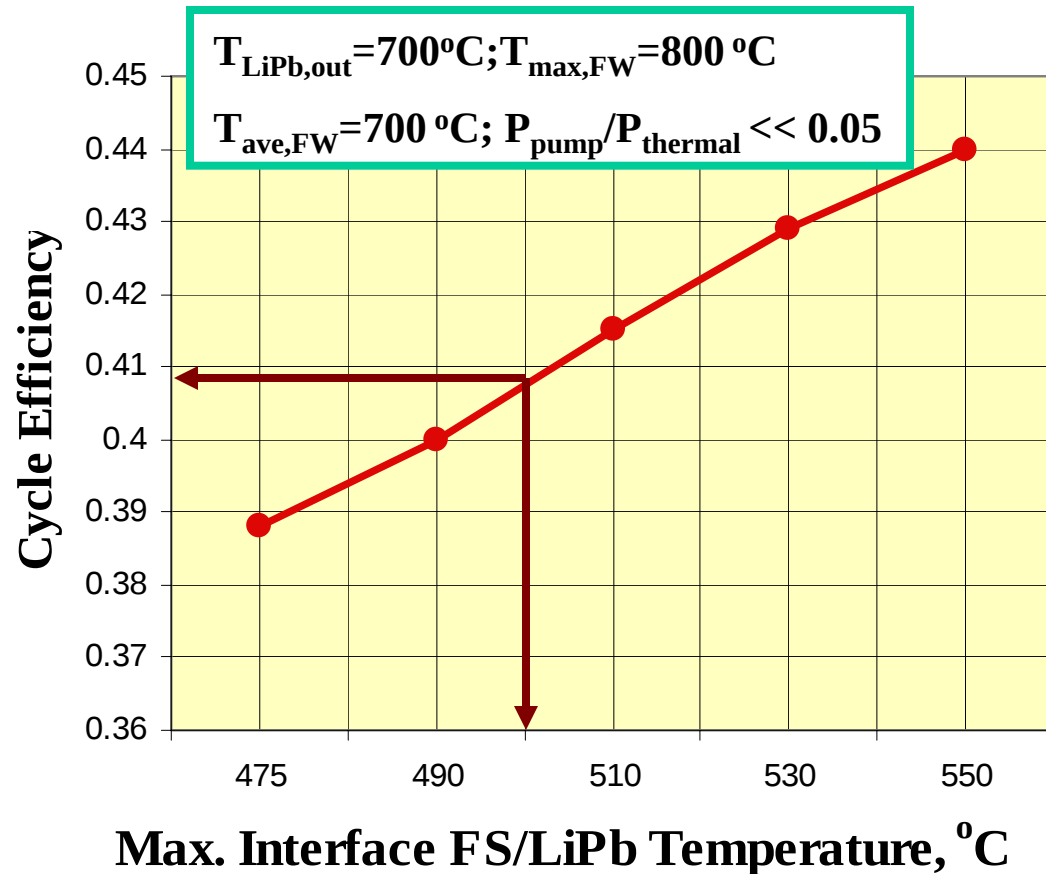
Example Cycle Efficiency as a Function of Interface FS/Pb-17Li Temperature



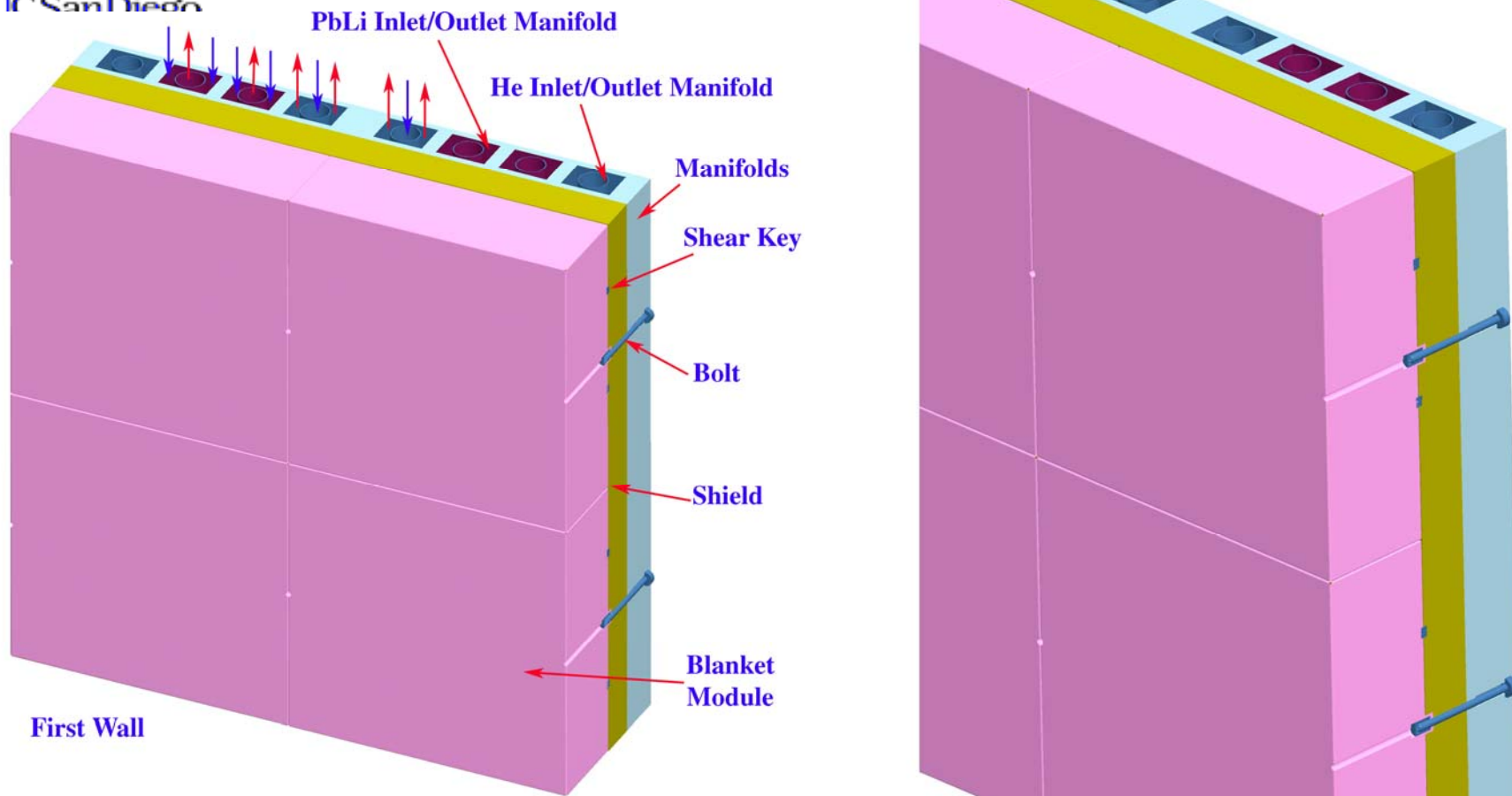
➤ For a fixed maximum neutron wall loading ~ 4.7 MW/m²,

-the max. $\eta \sim 38.8\%$,
 $T_{\max,FS} \ll 550^\circ\text{C}$ for an interface FS/LiPb temperature of 475°C ;

-the max. $\eta \sim 41.5\%$,
 $T_{\max,FS} \ll 563^\circ\text{C}$ for an interface FS/LiPb temperature of 510°C .

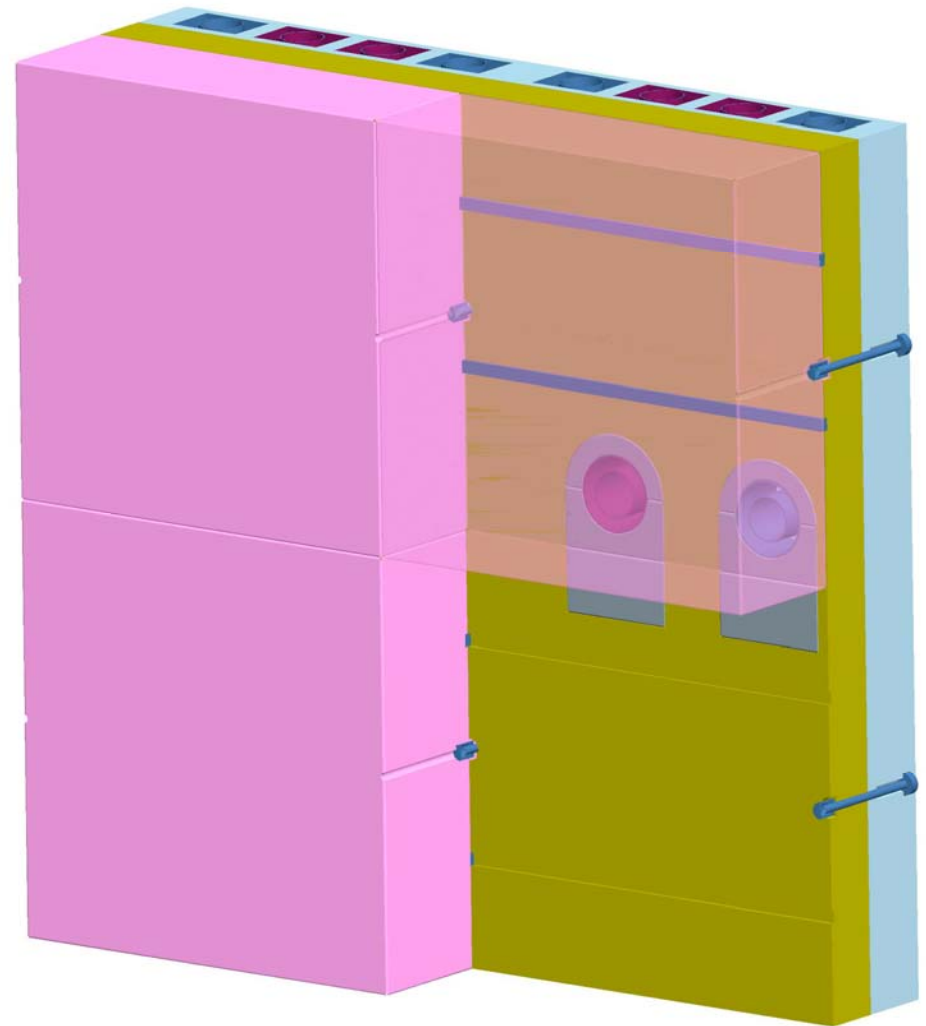
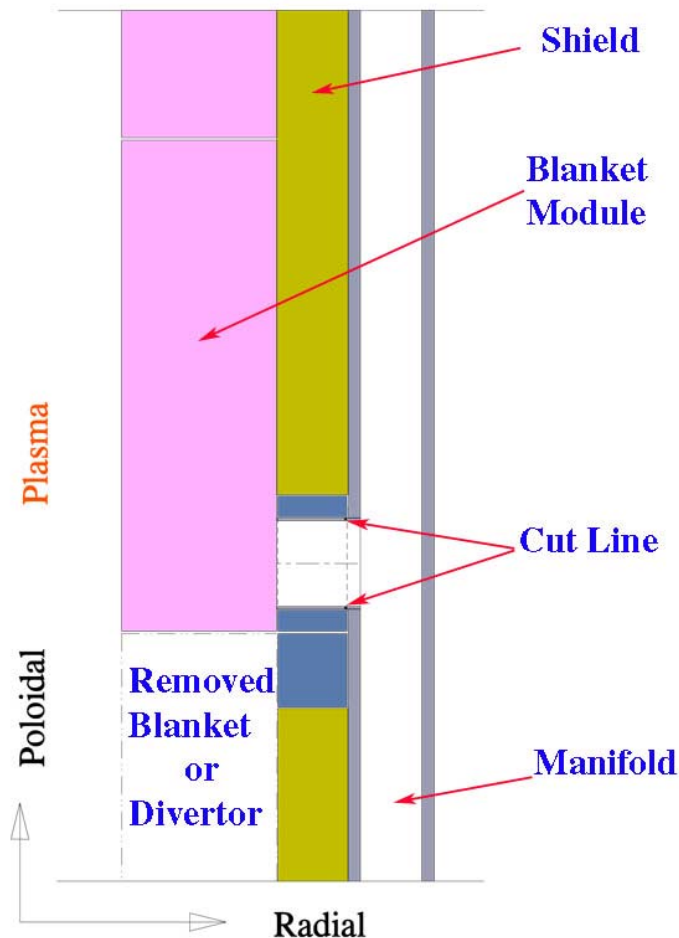


Mechanical Attachment of the Modular Blanket

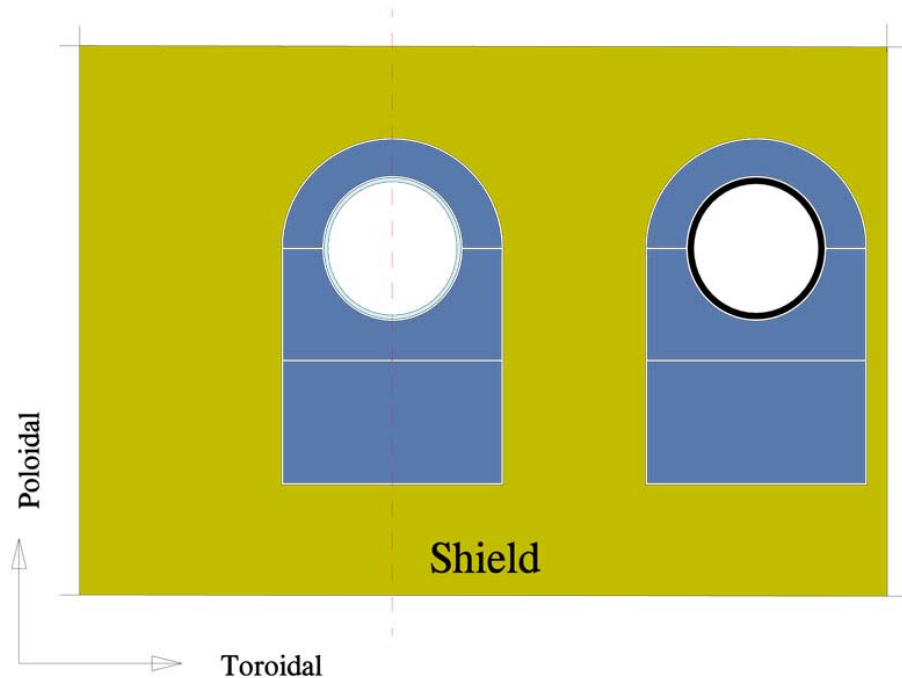


- There are one helium access tube and one Pb-17Li access tube per blanket module to connect to the manifold behind shield.
- Each module needs two manifolds to provide the helium and Pb-17Li flows, the manifold with dimension of 35 x 25 cm, and inside manifold with a 23 cm O.D. tube.

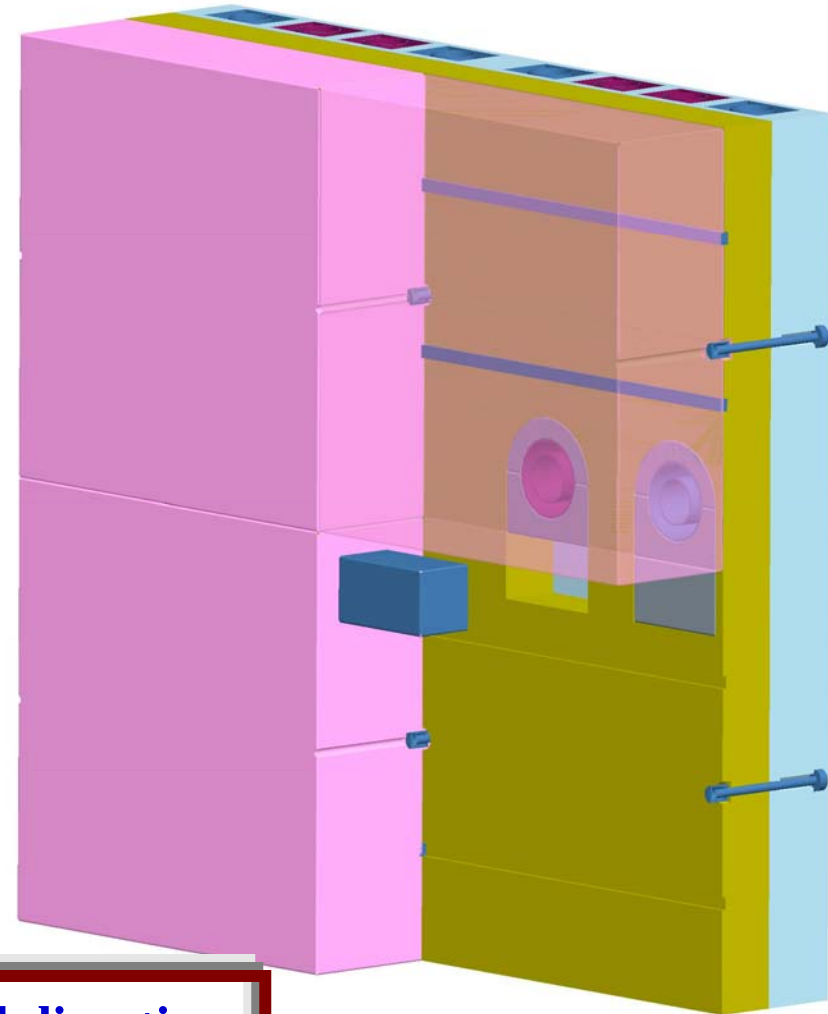
Blanket Module Replacement Is Based on Cutting/Rewelding of the Outer Tube of the Concentric Pipes from the Outside after Removing the Neighboring Blanket Module or the Divertor



Steps to Cut the Coolant Connections from the outside through the Open Window

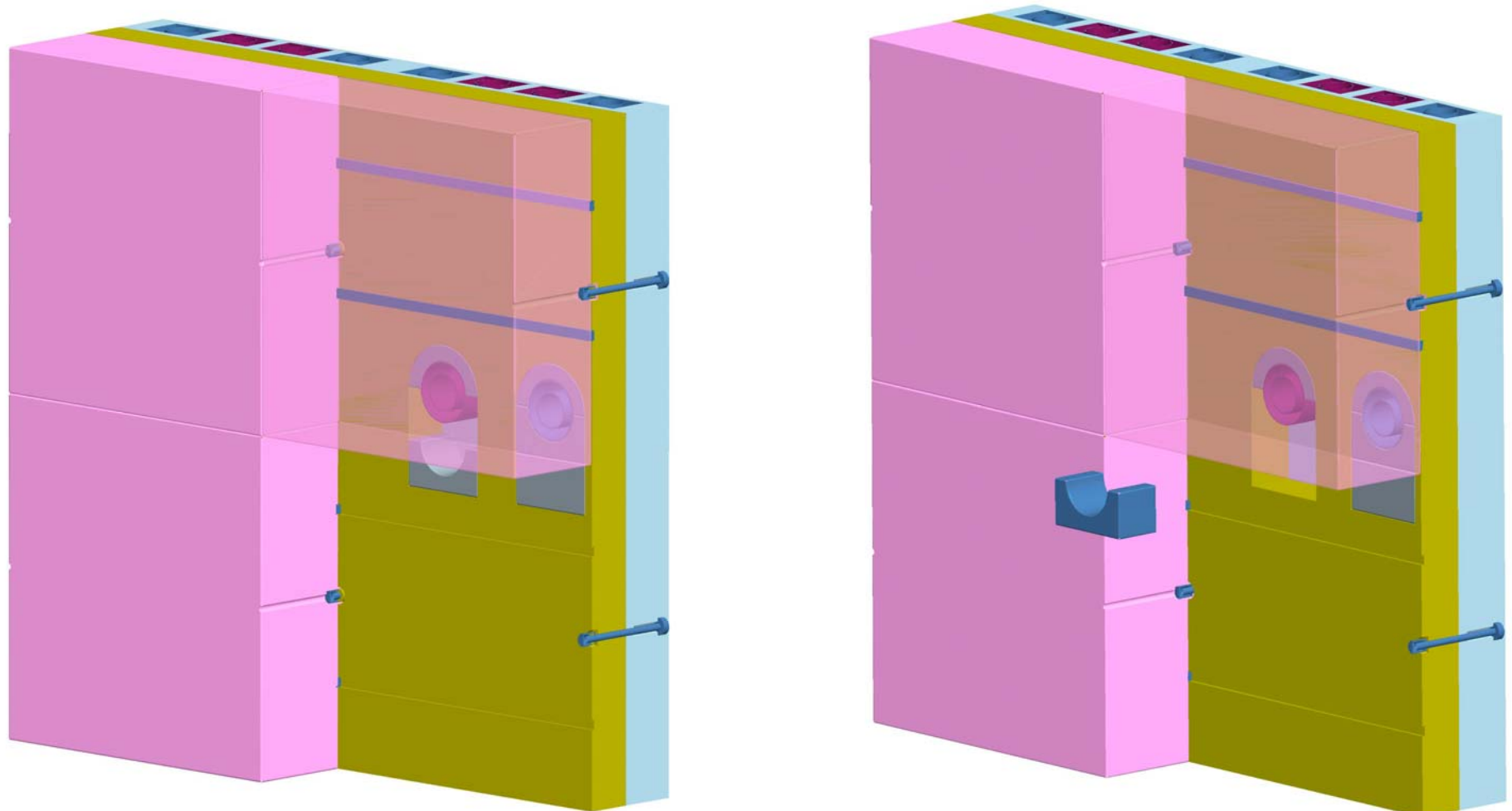


Back View (From the Shield)



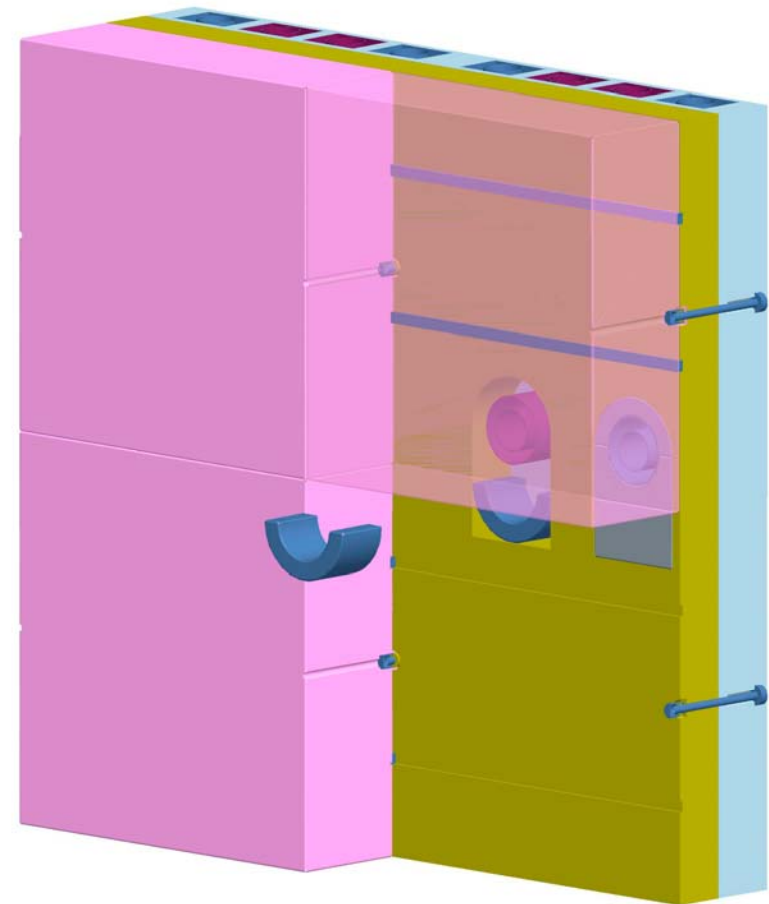
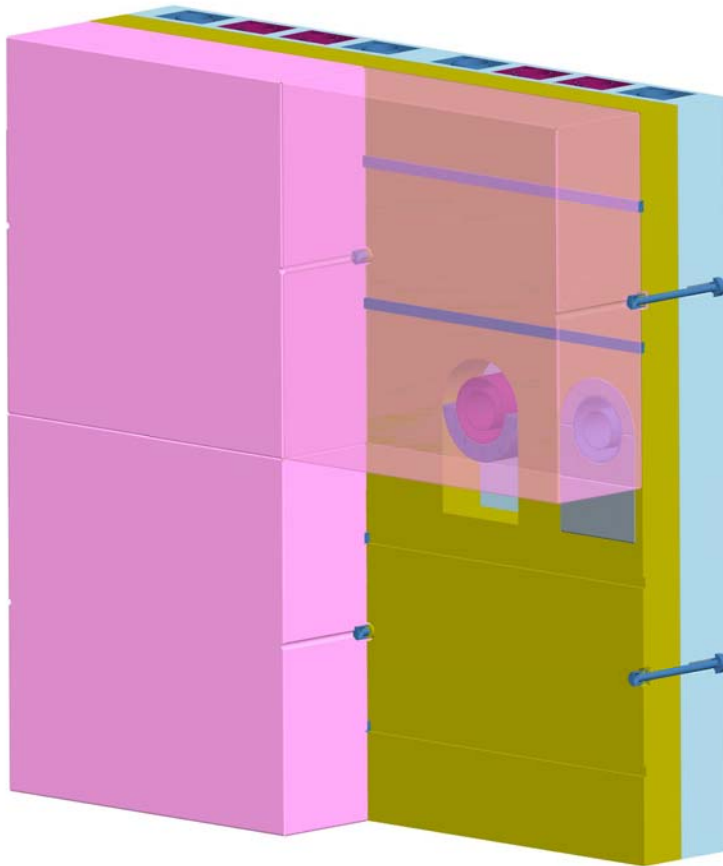
1. Remove the bottom piece in the radial direction.

Steps to Cut the Coolant Connections from the outside through the Open Window (cont.)



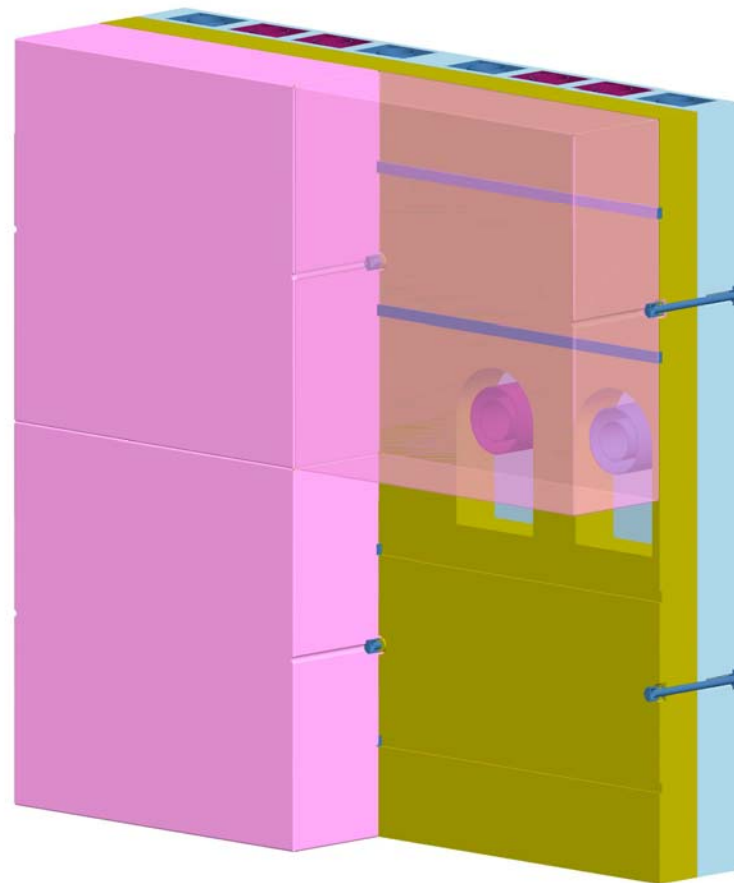
2. Lower the middle piece down vertically, then remove it in the radial direction.

Steps to Cut the Coolant Connections from the outside through the Open Window(cont.)



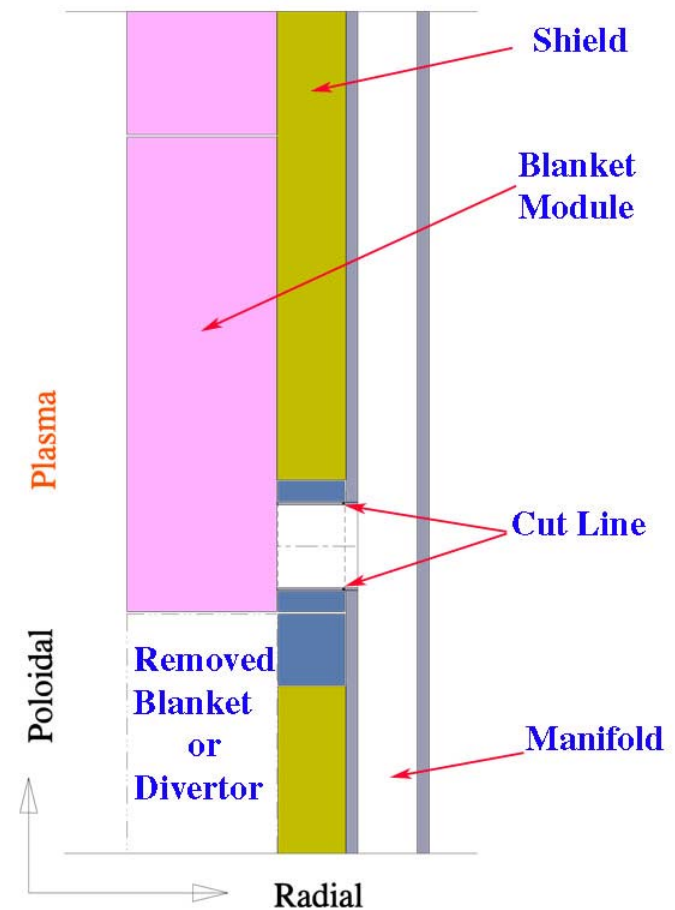
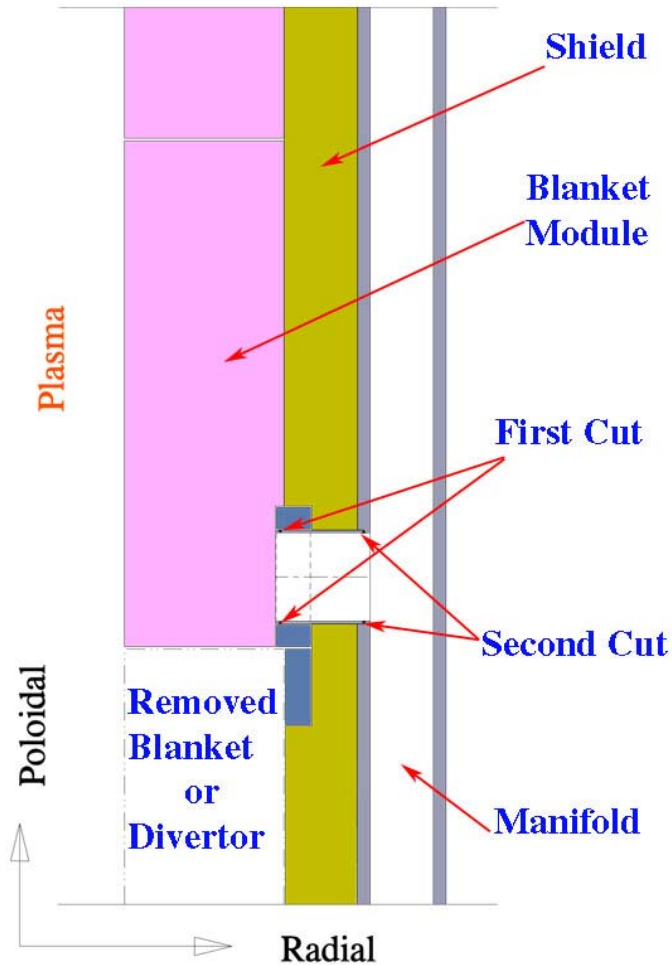
3. Turn the top piece 90 degree, and lower it down to position of the bottom piece, then remove it in the radial direction.

Steps to Cut the Coolant Connections from the outside through the Open Window(cont.)



4. Repeat the same procedures to remove the three pieces of shield around Pb-17Li connection tube, then use tools to cut the both helium and Pb-17Li connection tubes.

Alternative Way to Cut the Coolant Connection from the Open Window

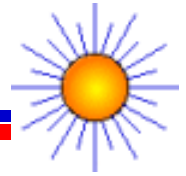


Alternative way(two cuts required for each tube)

Defining the Coolant Manifolds for the Modular Approach



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Maximum neutron wall load	4.5MW/m ²
Peak /Average ratio	1.62
Average neutron wall loading	2.78
Blanket energy multiply factor	1.10
Volumetric heating	2.52x10 ³ MW
Surface heat flux	0.5 MW/m ²
Total thermal power	2.93x10 ³
Number of supply and return pipes per field-period(2 for LM, 2 for He)	4
Number of penetration through VV per field-period	4
Number of access tubes per module	2
Total number of access tube	502

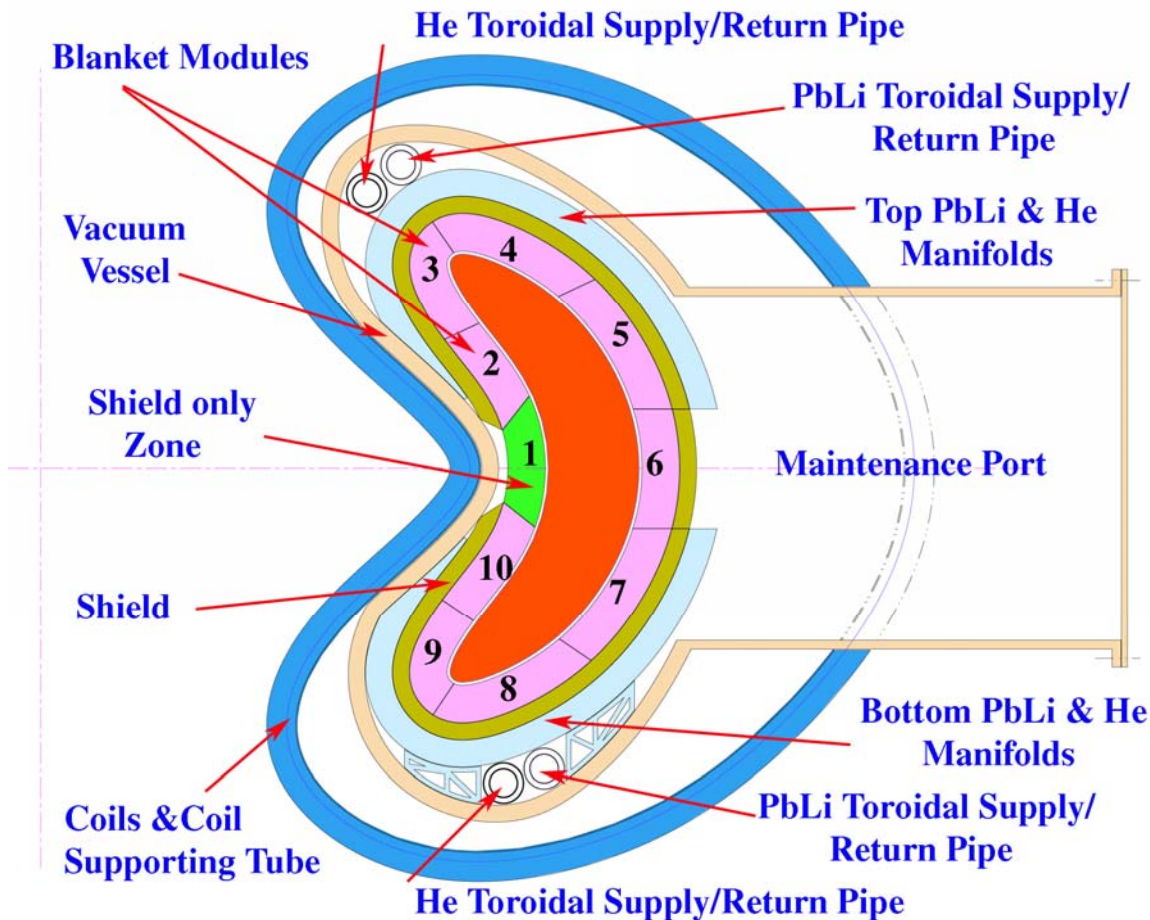
Toroidal Pb-17Li supply/return pipe

Thickness of the inner wall	0.5 cm
I.D of the inner tube	48 cm
Thickness of the outer tube	1.0 cm
O.D. of the outer tube	72 cm
Velocity	2.0 m/s

Toroidal Helium supply/return pipe

Thickness of the inner wall	0.5 cm
I.D. of the inner tube	46 cm
Thickness of the outer wall	1.5 cm
O.D. of the outer tube	68 cm
Velocity	100 m/s

Layout of the Coolant Manifold and Supply/Return Pipes(Cross Section at 0°)



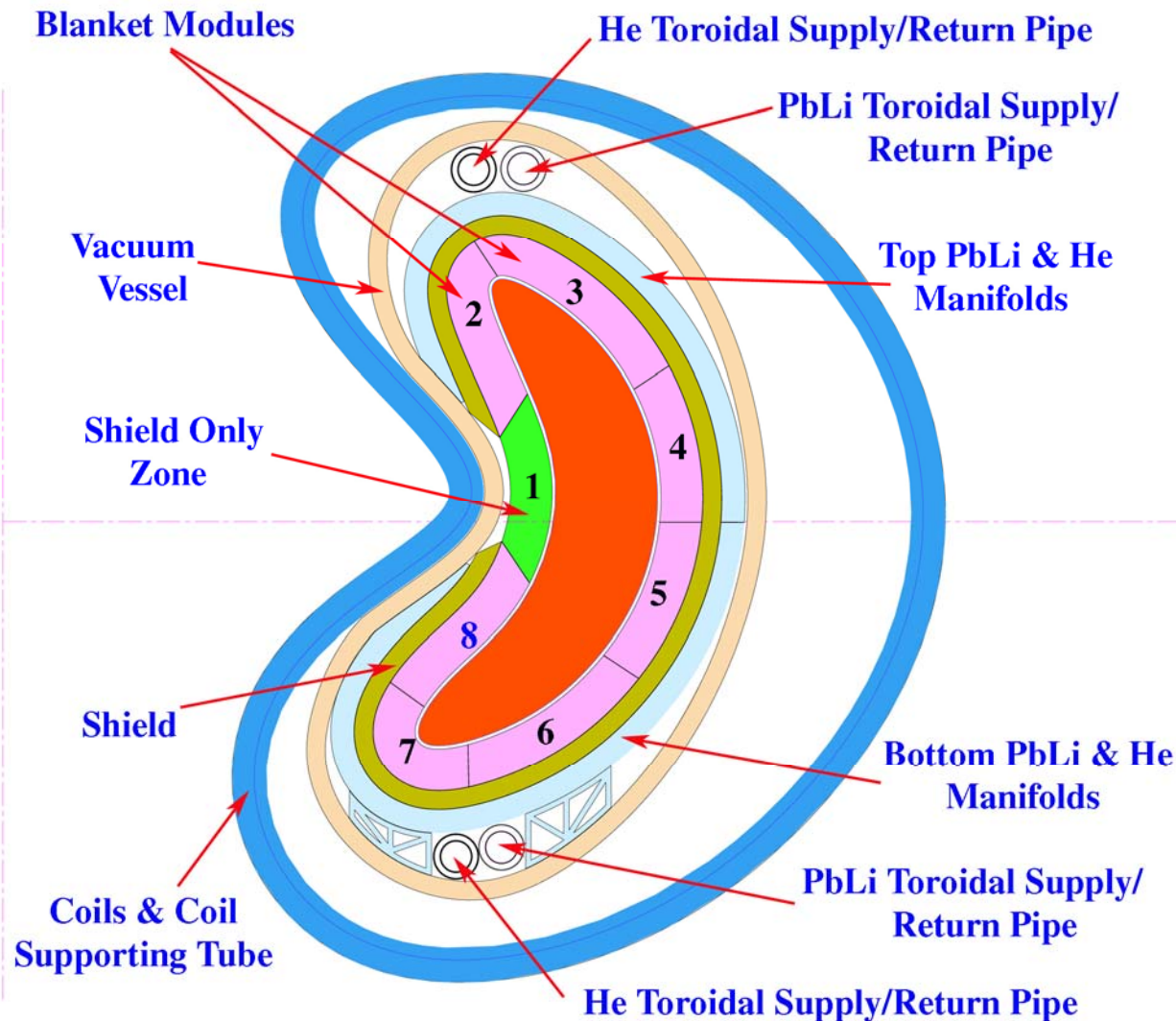
- There are 10 blanket modules .
- Supply/return pipes are placed inside of VV to reduce the penetrations of coolant access tubes through the VV.
- The Top PbLi & He Manifolds provide PbLi flow and He flow to blanket module #1 to module #5. Radial thickness of the manifold is assumed to be 45 cm.
- The Bottom PbLi & He Manifolds provide PbLi and He flows to blanket module # 6 to module #10. The Radial thickness of the manifolds are the same as the top manifolds.

Cross-section at 0°

Layout of the Coolant Manifolds and Supply/Return Pipes (Cross Section at 10°)



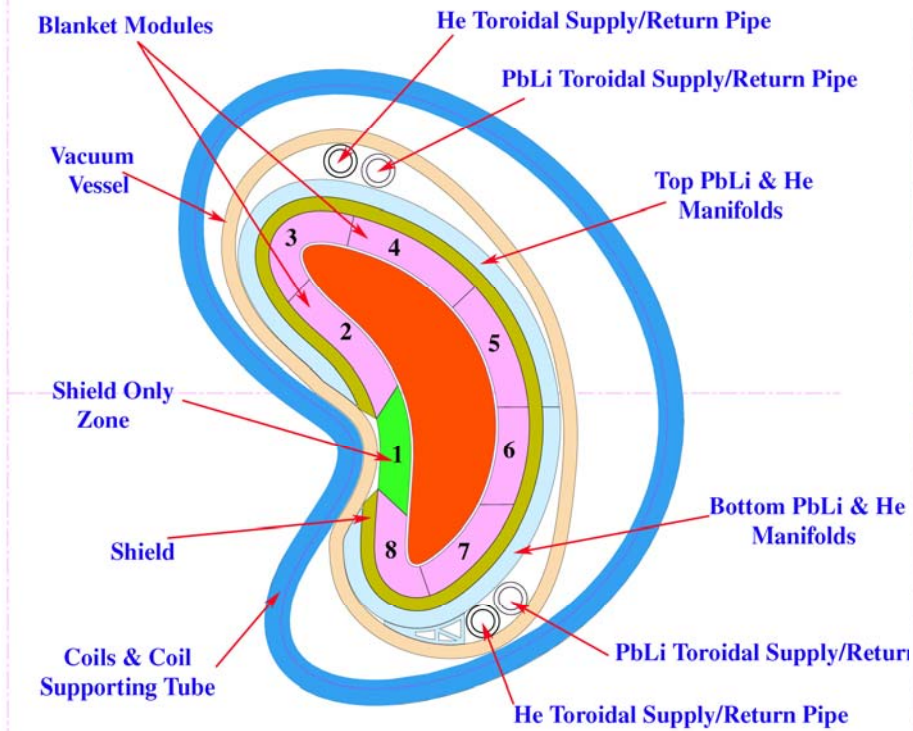
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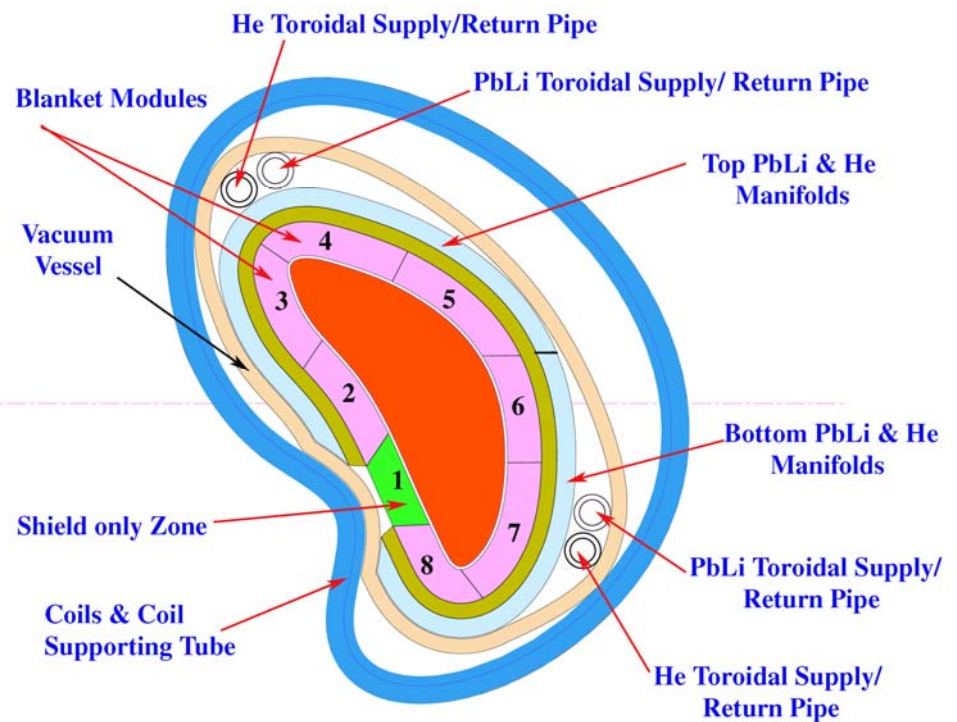
➤ The Top PbLi & He Manifolds supply PbLi flow and He flow to blanket module #1 to module #. Radial thickness of the manifold is assumed to be 35 cm.

➤ The Bottom PbLi & He Manifolds supply PbLi and He flows to blanket module # 5 to module #8. The Radial thickness of the manifolds are the same as the top manifolds.

Layout of the Coolant Manifolds and Supply/Return Pipes(Cross Sections at 20° and 30°)



20°

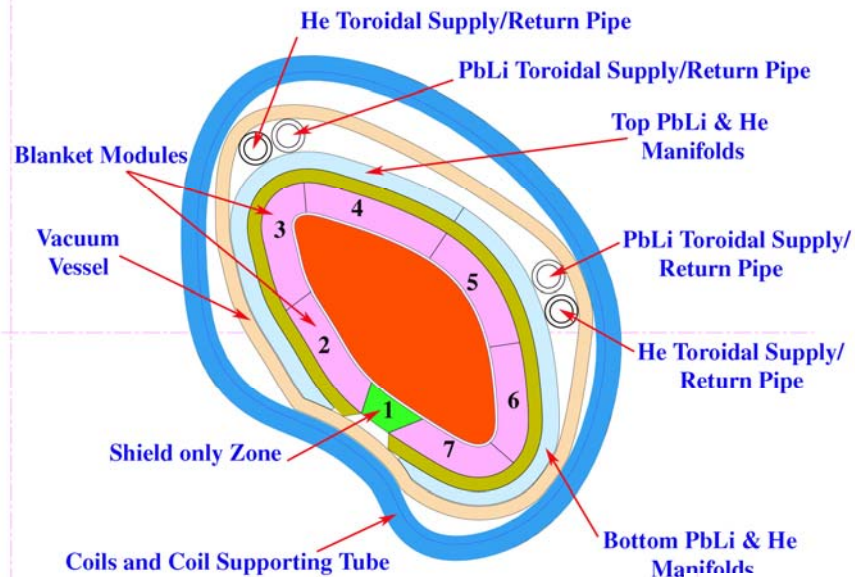


30°

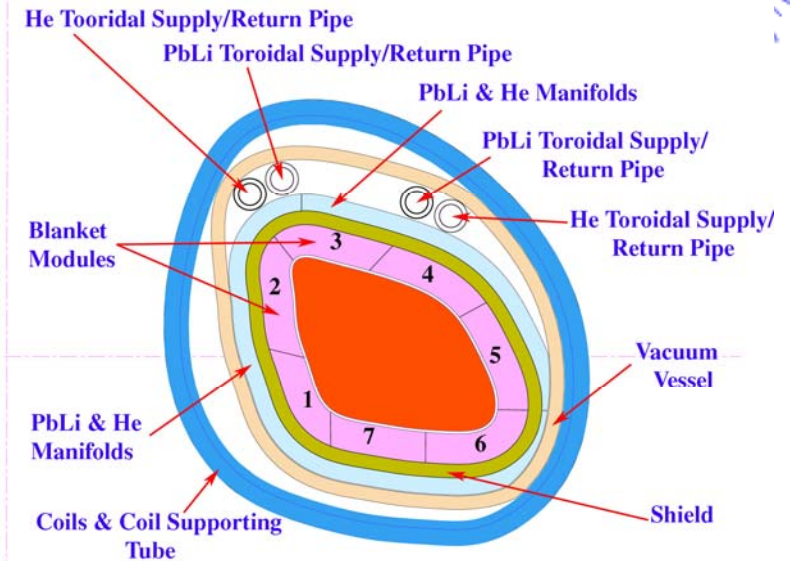
Layout of the Coolant Manifolds and Supply/Return Pipes (Cross Section at 40°, 50° and 60°)



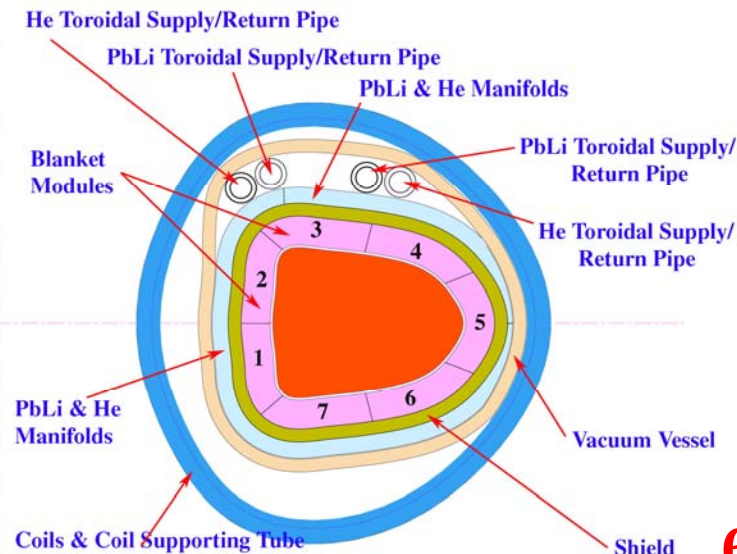
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40°



50°



60°

Summary



➤ Dual-cooled blanket module design for the modular maintenance schemes is proposed.

➤ For an example max. Γ of 4.7 MW/m² and a limit of interface FS/LiPb temperature of 500 °C:

$$\eta \sim 40.7\%, T_{\max, \text{FS}} \ll 554^\circ\text{C}, P_{\text{pump}}/P_{\text{thermal}} \ll 0.05$$

➤ Blanket module replacement is based on cutting/re-welding of the outer tube of the concentric pipes from the outside after removing the neighboring blanket module or the divertor.

➤ Both helium and lead-lithium supply/return pipes are arranged inside of VV in order to reduce numbers of penetration through the VV.