Preliminary ACT-2 Power Core Design Definition

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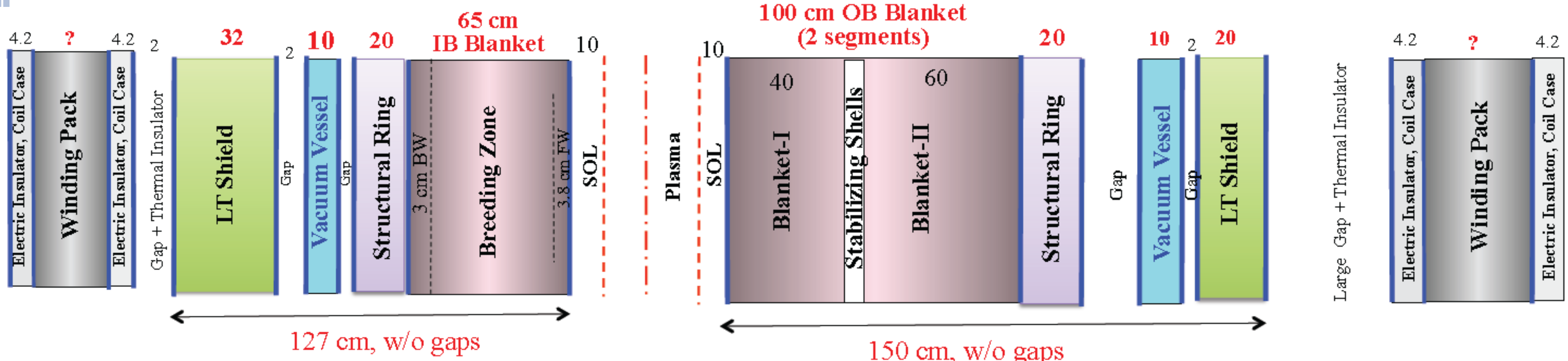
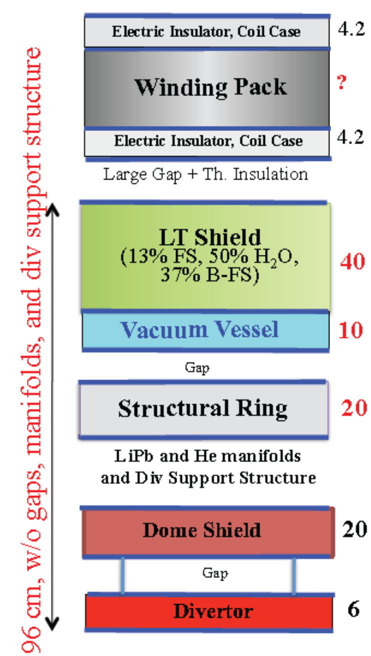
Germantown, DC
May 21-22, 2013

Overall Layout of the ACT-2 Will Be Similar to ACT-1



- Most design features of the ACT-1 will be adopted in ACT-2.
- Maintenance scheme of the DCLL power core will be the same.
- Integrated replacement units consist of structural ring and blankets and divertors, and they need to be replaced at the end of life-time.
- Low temperature shield is also arranged outside of the VV and will be cooled by water with room temperature.
- The inboard structural ring and VV are not re-weldable around mid-plane.



(Laila presented at ARIES Meeting ons Jan. 22-23, 2013)

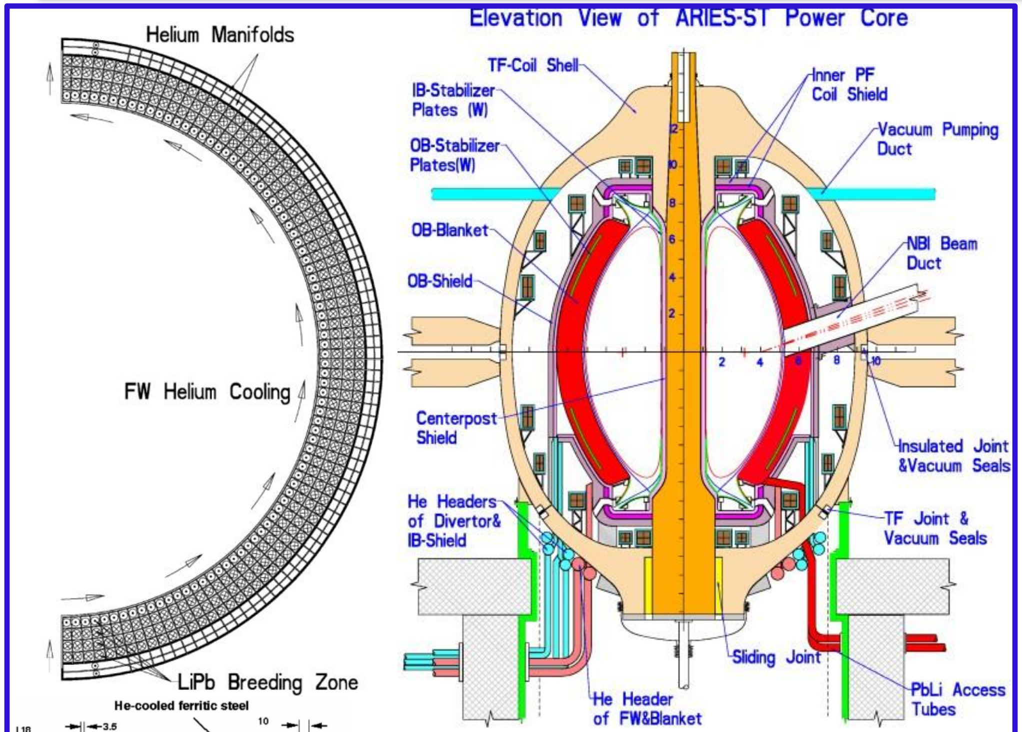
A Comparison of the ACT-1 and ACT-2 Power Core Components

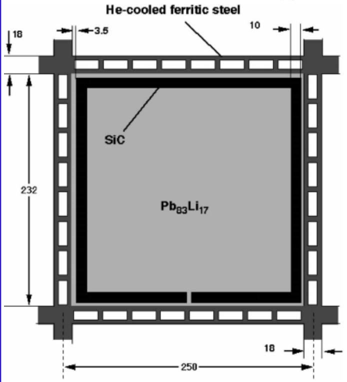
	ARIES-ACT-1	ARIES-ACT-2
Major Radius	6.25 m	>6.25 m
FW/Blankets	Li-17Pb cooled SiC/SiC structure Li-17Pb inlet pressure=1.95 MPa **600˚C<T(SiC/SiC)<1000˚C** T_{inlet}/T_{outlet}=740/1030 ˚C η_{th}=57.9%	Self-cooled RAFS (F82H) breeding zone He-cooled FW and blanket structure RAFS(F82H) Li-17Pb inlet pressure>~1.95 MPa **350˚C<T(F82H)<550˚C** Helium T_{inlet}/T_{outlet}=~350/450˚C **(TBD)** Pb-17Li T_{inlet}/T_{outlet}=~450/650˚C **(TBD)** η_{th}=? **(TBD)**
Structural Ring	Helium-cooled ODS steel structure T_{max}(ODS)<700˚C T_{inlet}/T_{outlet}=650/680˚C	Helium-cooled F82H steel structure **350˚C<T(F82H)<550˚C** T_{inlet}/T_{outlet}=350/450˚C **(TBD)**
Upper/Lower Divertor Sectors	Helium-cooled W-based divertor and ODS steel or Ta cartridge 800˚C<$T_{w\text{-}structure}$<1300˚C q_{peak}=~14 MW/m^2 T_{inlet}/T_{outlet}=700/800˚C	Helium-cooled W-based divertor and ODS steel or Ta cartridge 800˚C<$T_{w\text{-}structure}$<1300˚C q_{peak}=~14 MW/m^2 **(TBD)** T_{inlet}/T_{outlet}=700/800˚C
Vacuum Vessel	He-cooled ribbed bainitic FS (3Cr-3WV) structure, operating temperature at ~500˚C	He-cooled ribbed bainitic FS (3Cr-3WV) structure, operating temperature at ~500˚C
Water-Cooled LT Shield	Water-cooled bainitic FS (3Cr-3WV) and WC, operating at room temperature	Water-cooled bainitic FS (3Cr-3WV) and WC, operating at room temperature

Questions and Issues for Overall Layout of ACT-2 DCLL Power Core

1. Should we use the ATC-1 design approach to integrate the coolant manifold pipes to the blanket to be replaced together with the blanket modules ?
2. Should we integrate the coolant manifold pipes into the structural ring to make them to longer life-time components (proposed by Siegfried)?
3. How do we design the Helium cooling system to cool the first wall and all the blanket structure? How do we arrange the LM flow path?
4. How do we design the helium and LM coolant manifold pipes from the outside of the VV to the blanket segments? and how are the manifold pipes attached to the blanket segments?
5. Can we use **Ferritic/Martensitic steel** like F82H as structural material for ACT-2 blankets or do we have to use **ODS** or **advanced ODS-steel** (12YWT) in the front part of the FW with a higher tolerance for high temperature/stress and He concentration?
    - ✓ ARIES-ST, ODS steel FW box, 25 x 25 mm channels, 3 mm FW and second wall, designed for q”=0.95 MW/m^2, operation pressure P=12 MPa.
    - ✓ ARIES-CS, F82H steel FW box, 30 x 20 mm cooling channels, 3 mm advanced ODS-steel (12YWT) pressing in the front of 1 mm front wall, designed for q”=0.76 MW/m^2, operation pressure P=10 MPa.

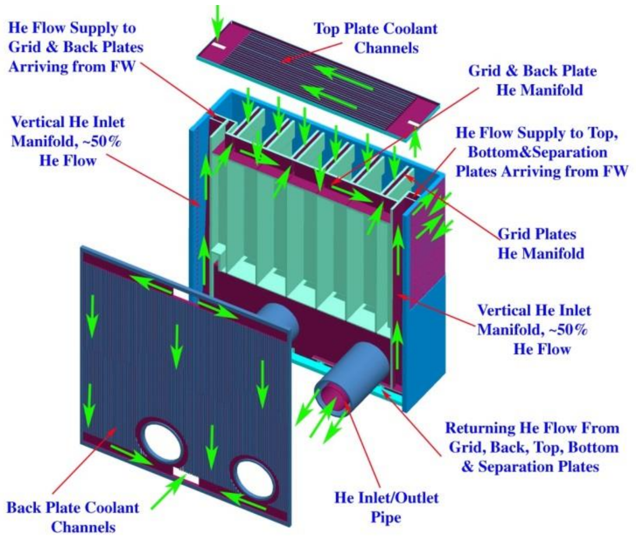
Lectures Learned from ARIES-ST and ARIES-CS DCLL Designs?

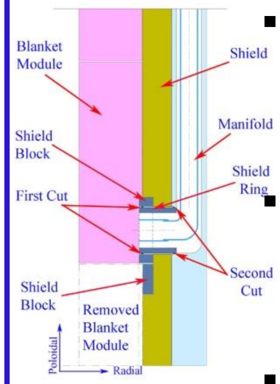




- Segmented entire power core into two sectors
- FW box 2.5 x 2.5 cm, breeding cell: 25x25 cm
- ODS steel FW to meet temp. and stress limits
- No detailed design of the Pb-Li manifolds and Helium flow paths

ARIES-ST DCLL design

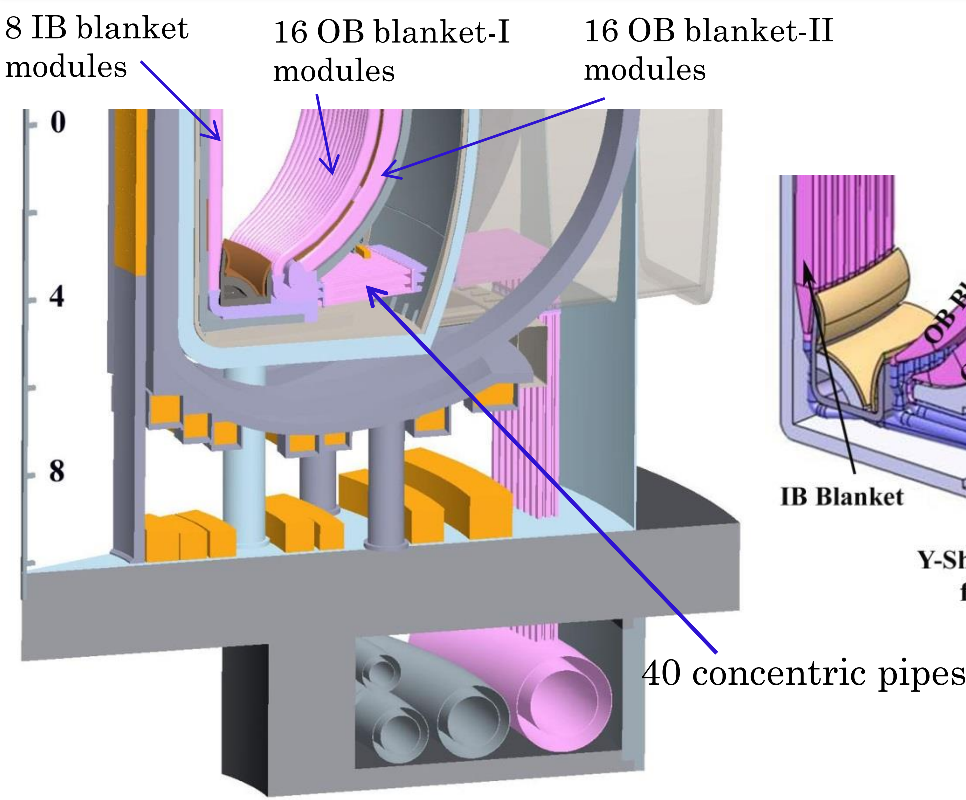




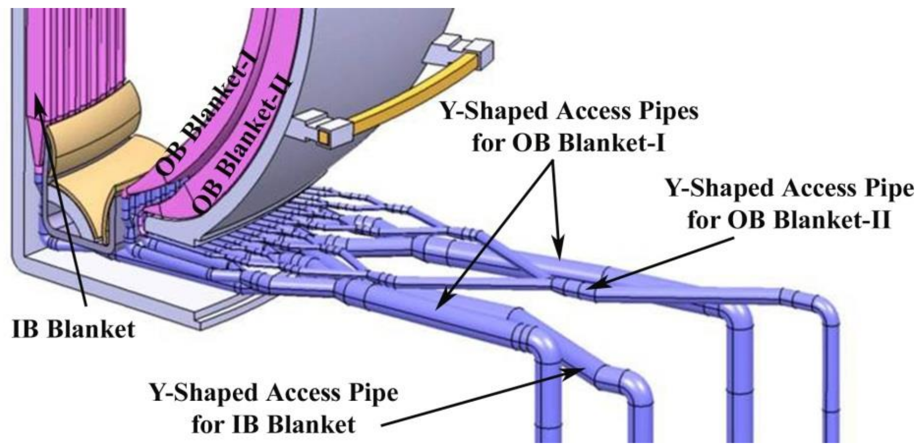
- Toroidal manifold pipe to distribute Pb-Li to the front breeding zone. 3D MHD issue?
- Radial access pipes connecting the blanket to manifolds behind the shield.
- Detailed design of He and Pb-Li flow paths.

ARIES-CS DCLL modular blanket design

Manifold Design of ACT-1 Can Be Applied to ACT-2 DCLL



Reference design of the ACT-1

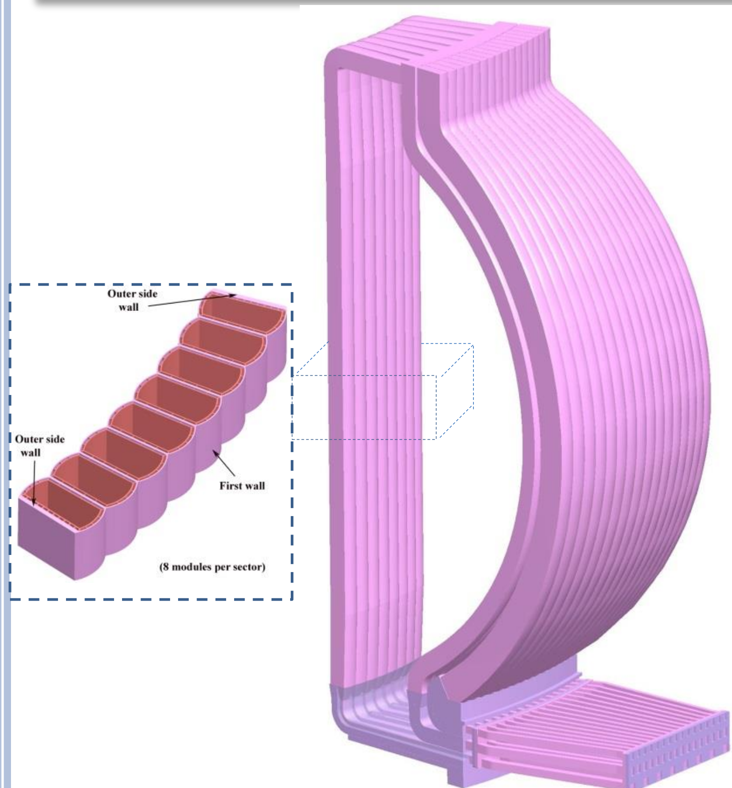


Alternative design of the ACT-1

- The manifold design for the ACT1 is to feed the single blanket module direct from the main Pb-17Li ring header without any merging of pipes. All blanket module pipes will be guided to the main Pb-17Li ring header pipes.

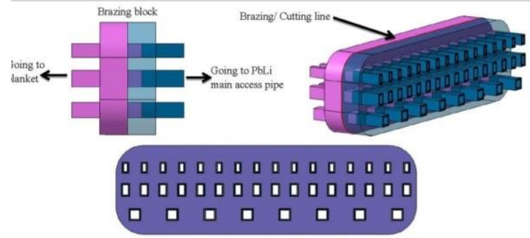
C. Koehly, M. Tillack, X.R. Wang and S. Malang, "Flow distribution systems for liquid metal cooled blanket" 25th SOFE, June 11, 2013.

Connecting/Cutting "Brazing Blocks" and Locations for ACT-1 Maintenance

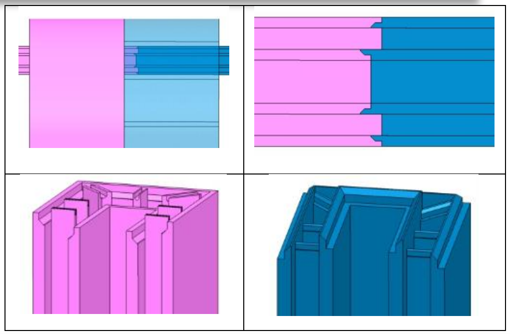


Manifold design of ACT-1

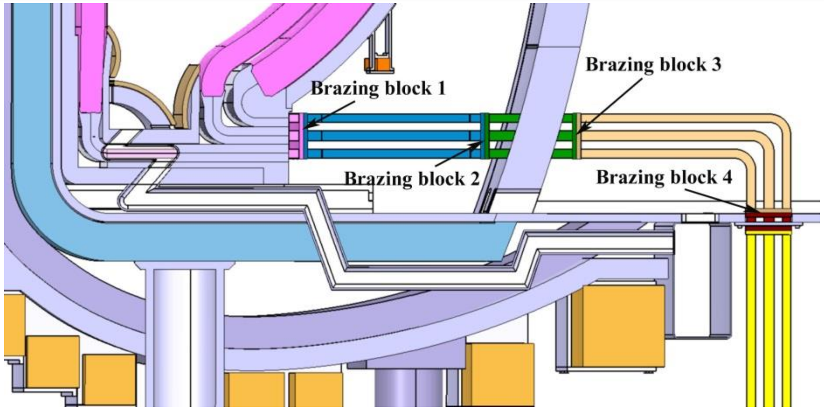
- There are 40 concentric access pipes connected to the blanket to the coolant ring header
    - ✓ 8 manifold pipes for IB blanket segment
    - ✓ 16 manifold pipes for OB blanket-I
    - ✓ 16 manifold pipes for OB blanket-II



Simplified sketch of brazing block



Details of brazing block/pipe connection: Top left: pair of two assembly brazing block halves with overlapping of one pipe on one side; Top right: pipe connection with different assembly levels and chamfers; Bottom left: Pipe 1; Bottom right: Pipe 2 (counter-piece of ending)

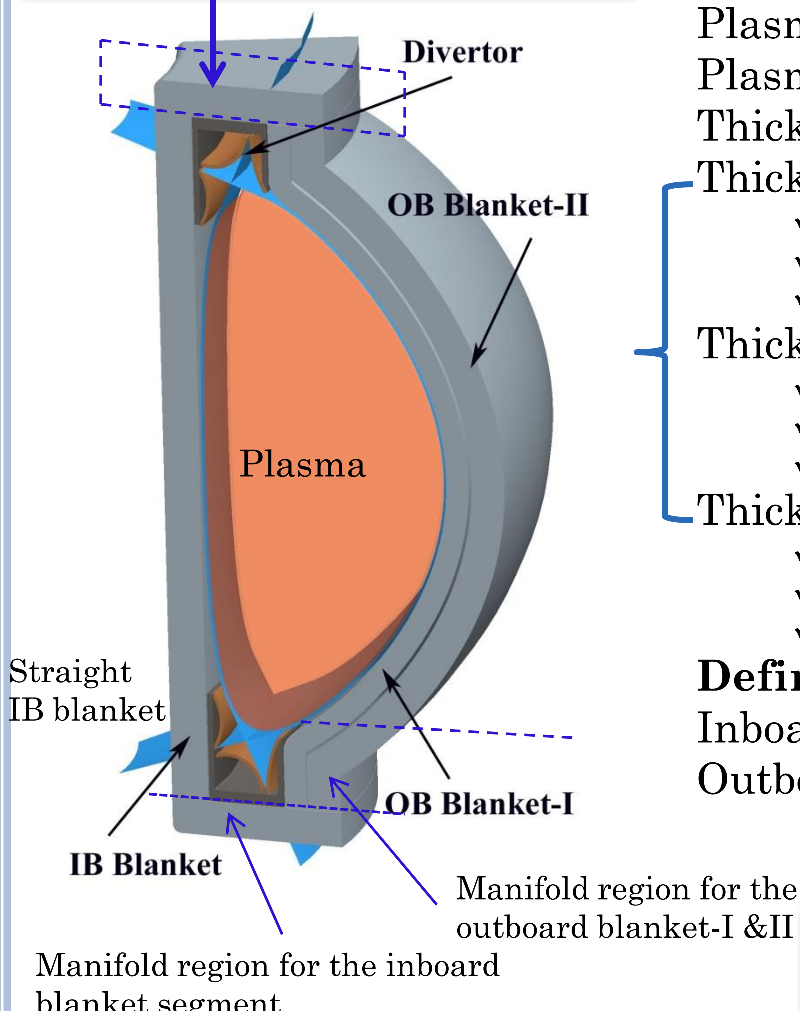


Cross-section of showing cutting locations of the blanket manifolding pipes

C. Koehly, M. Tillack, X.R. Wang and S. Malang, "Flow distribution systems for liquid metal cooled blanket" 25th SOFE, June 11, 2013.

INITIAL LAYOUT OF THE ARIES-ACT-2 DCLL POWER CORE

Do we need run the Pb-Li at the top of divertor region?



Assumptions for CAD modeling:

Plasma major radial, R=8.5 m
Plasma aspect ratio, A=4
Plasma minor radial, a= 2.125 m
Thickness of IB/OB SOL at mid-plane, 10 cm

Thickness of IB blanket, 0.65 m
- ✓ 3.8 cm first wall
- ✓ 58.2 cm breeding zone
- ✓ 3 cm back wall

Thickness of OB blanket-I, 0.4 m
- ✓ 3.8 cm first wall
- ✓ 33.2 cm breeding zone
- ✓ 3 cm back wall

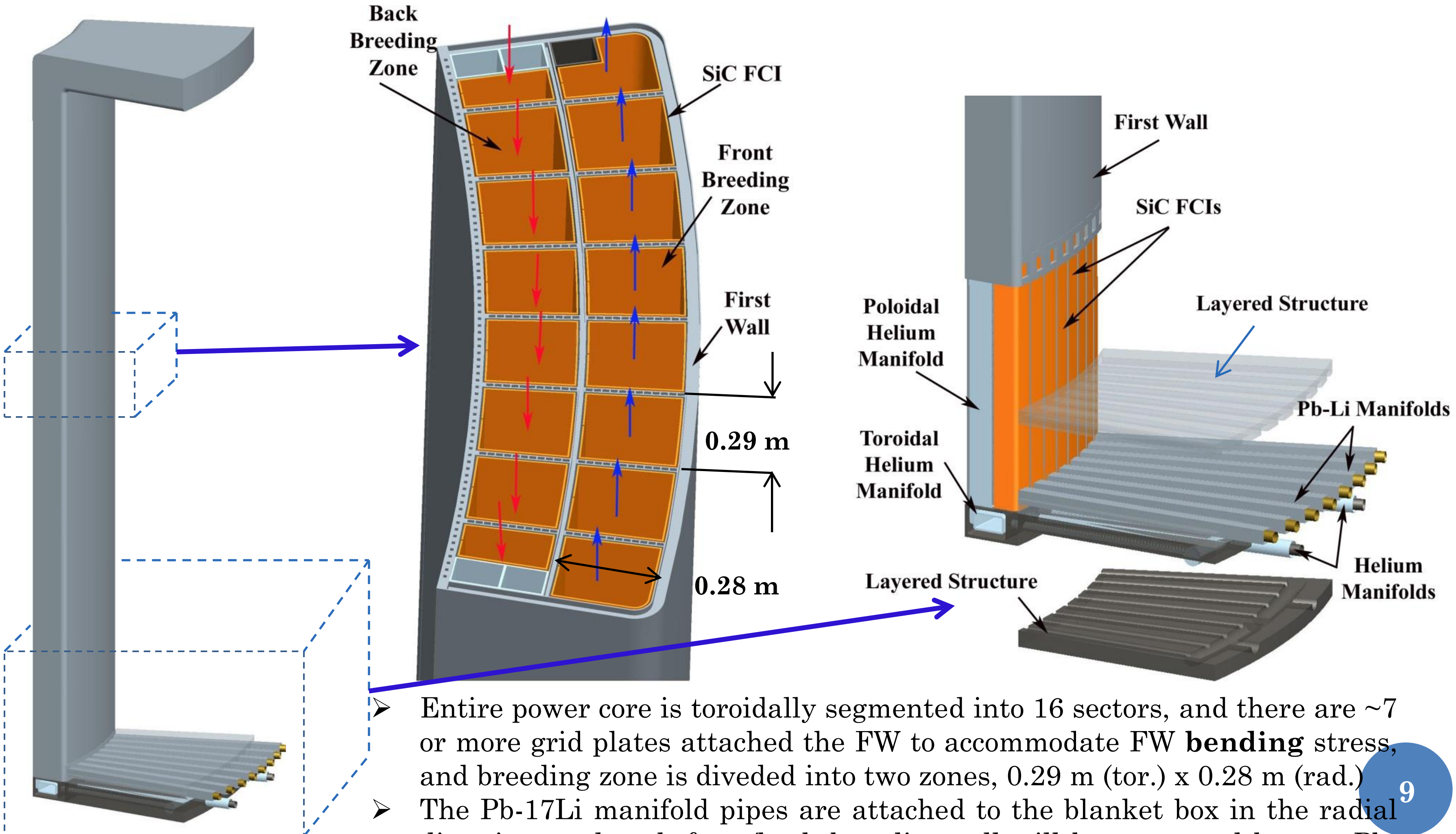
Thickness of OB blanket-II, 0.6 m
- ✓ 3 cm front wall
- ✓ 54 cm breeding zone
- ✓ 3 cm back wall

Definition of the divertor target plates and slots:

Inboard divertor target to the X-Point length>~0.48 m
Outboard divertor target to the X-Point length> ~0.76 m

Are there any new divertor design criteria to define the target plates and slots?

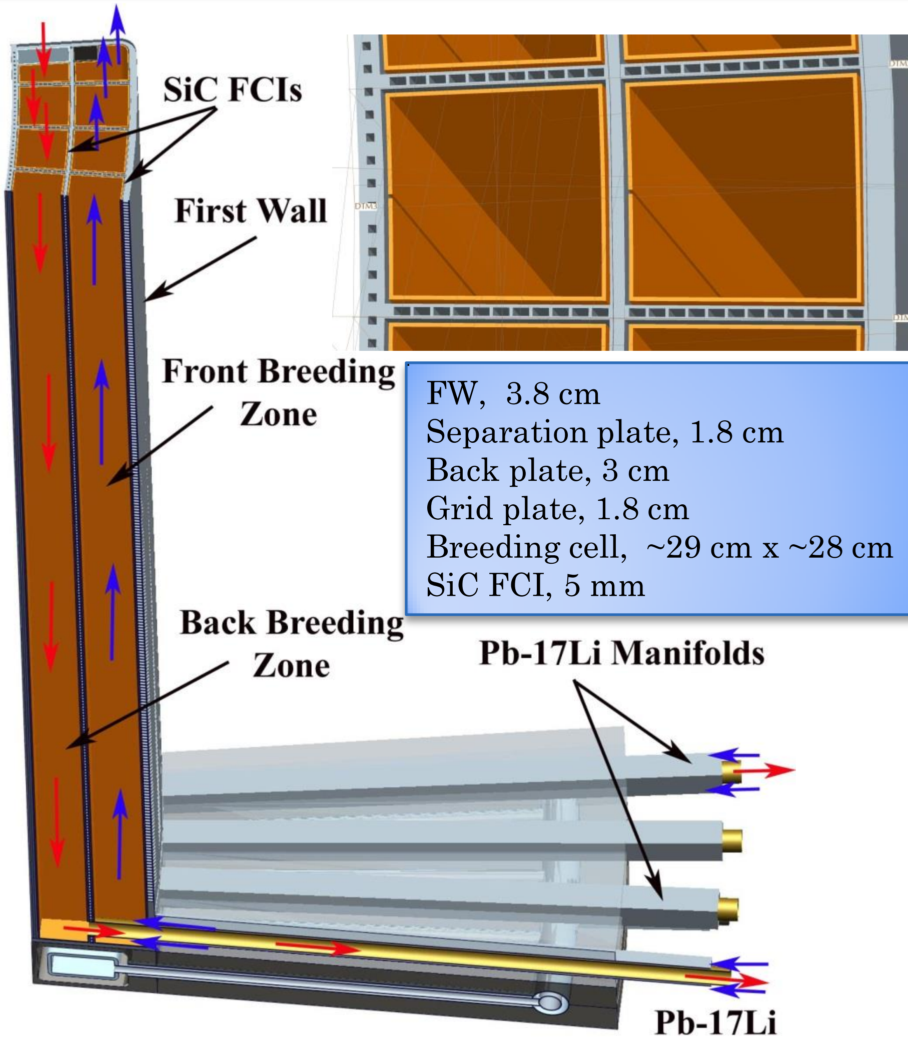
General Design of the ACT2 DCLL Blanket
Option 1: Large Blanket Box Concept



IB blanket sector

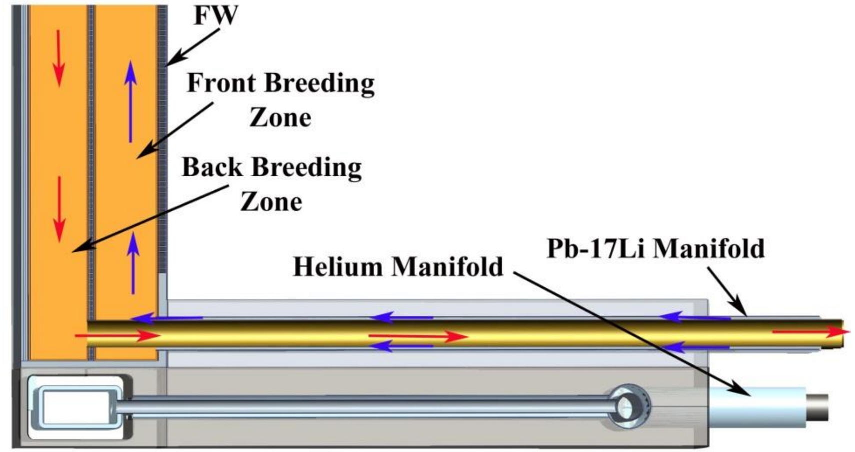
- Entire power core is toroidally segmented into 16 sectors, and there are ~7 or more grid plates attached the FW to accommodate FW **bending** stress, and breeding zone is diveded into two zones, 0.29 m (tor.) x 0.28 m (rad.)
- The Pb-17Li manifold pipes are attached to the blanket box in the radial direction, and each front/back breeding cell will be connected by one Pb-17Li concentric pipe to the ring header.
- Helium manifold pipes are attached to the bottom of the blanket box.

Layout of the Pb-17Li Cooling System for the ACT-2



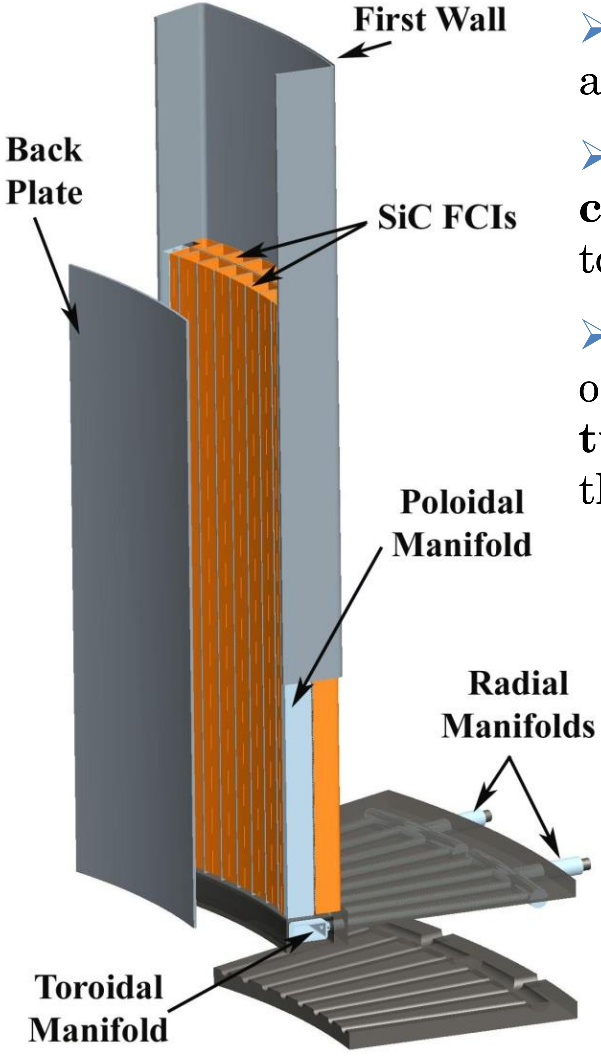
FW, 3.8 cm
Separation plate, 1.8 cm
Back plate, 3 cm
Grid plate, 1.8 cm
Breeding cell, ~29 cm x ~28 cm
SiC FCI, 5 mm

Cut-away view of the IB blanket



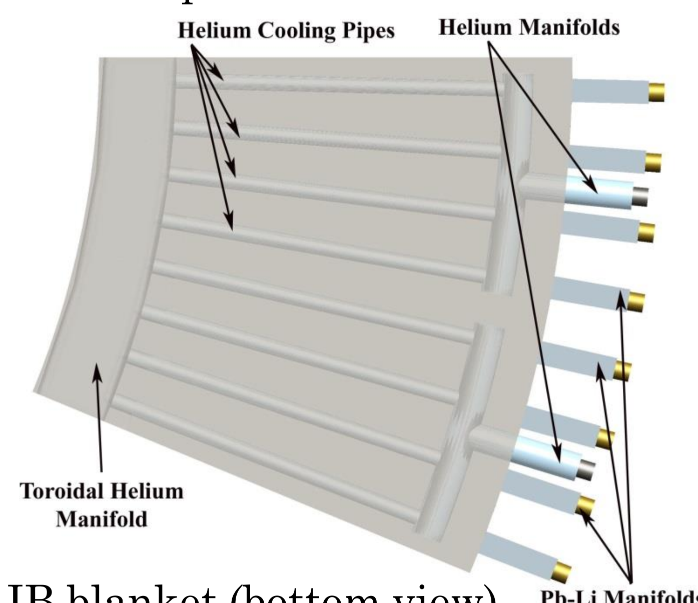
- Each front/back breeding cell is connected by one Pb-17Li concentric pipe with circular inner pipe and square outer pipe.
- Pb-17Li enters the blanket at the bottom, flows upwards to the top, makes a 180 degree bend, flows downwards to the bottom, and flows out from center duct of the manifold pipe.
- SiC FCIs (flow channel insert) have to be used in all breeding cells and access pipes for thermal and electric insulation.

LAYOUT OF THE HELIUM COOLING SYSTEMS



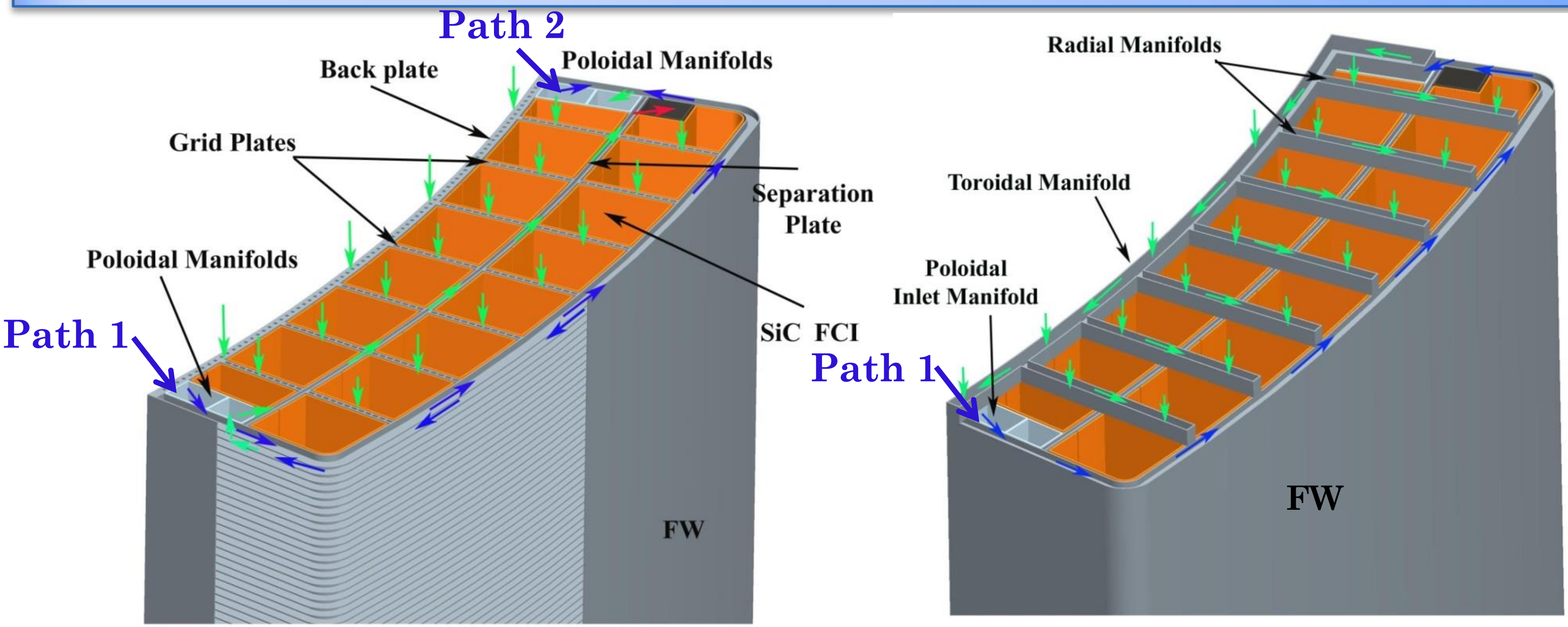
IB blanket (exploded view)

- Helium manifold pipes are embed into blanket structure and attached to the bottom of blanket box.
- The entire helium flow coming into one or two **radial concentric pipes** cools the structure and collects in the toroidal manifold pipes.
- There is **one toroidal manifold** arranged at the bottom of the blanket segment distributing the helium flow to the **two poloidal manifolds** arranged at the corners between the side wall and back plate.



IB blanket (bottom view)

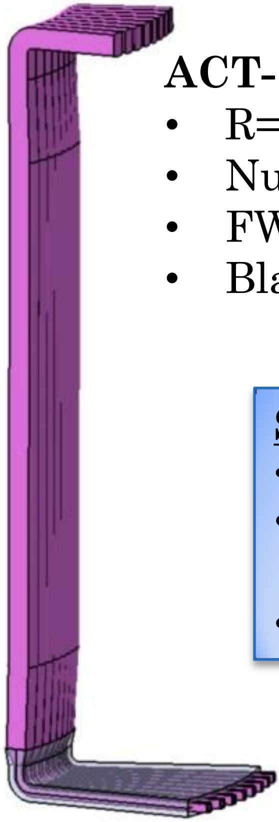
Layout of the Helium Cooling Systems (Cont.)



Middle section **Top section**

- **Path 1 (50%):** The He flow from the poloidal inlet manifold enters into side wall, cooling the FW and side wall, collecting in the poloidal outlet manifold, then, distributed to toroidal/radial manifolds at the top of blanket to cool the grid and back plates vertically. After cooling the grid and separation plates, the Helium is collected at the toroidal manifold and flows out.
- **Path 2 (50%):** The He flow from another vertical inlet manifold enters into side wall, cooling the FW and side wall, collecting in the poloidal outlet manifold, then distributed to toroidal channels of the separation plate, inlet manifolds of the top/bottom plates (top/bottom plates are not shown), then cool them toroidally.

General Design of the ACT2 DCLL Blanket Option 2: Small Modular Concept (By Christina)

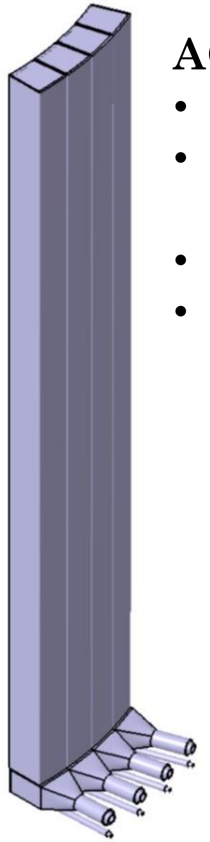


ACT-1 Inboard blanket sector

- R=6.25 m
- Number of blanket modules=8
- FW toroidal width=~0.17 m
- Blanket thickness=0.3 m

Similarities:

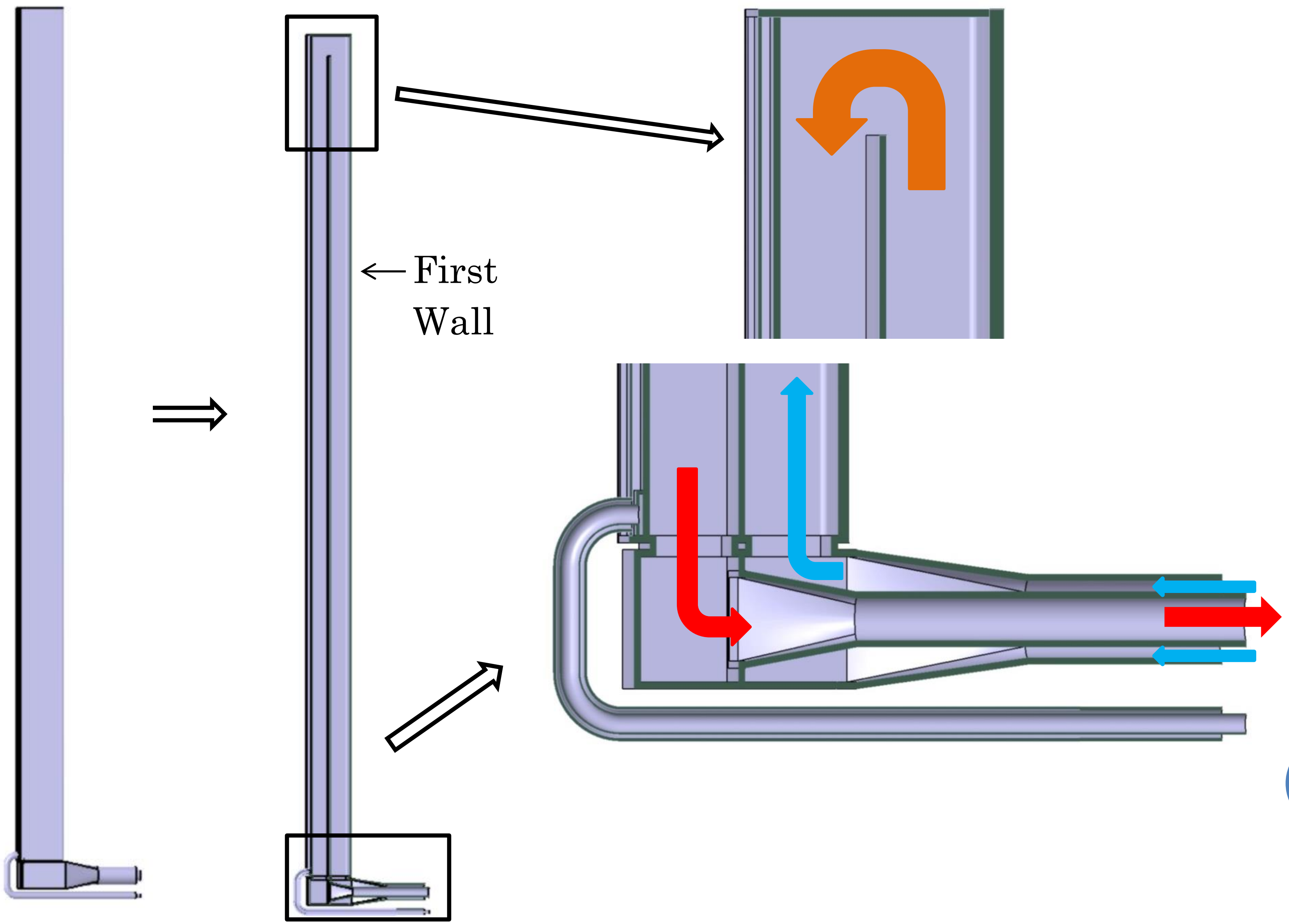
- **Multiple smaller modules**
- **Same Pb-Li flow scheme**
- **Feeded separately**



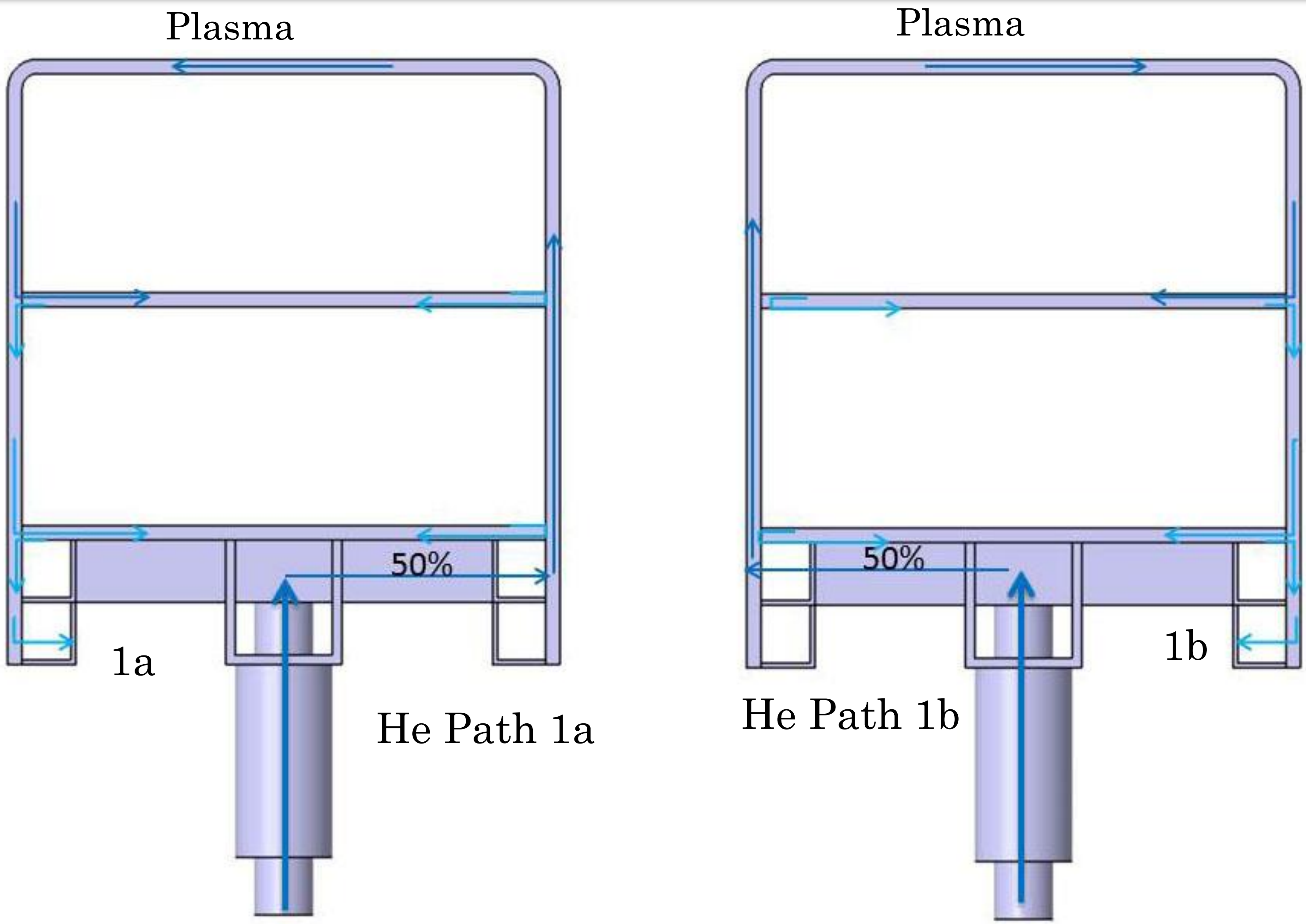
ACT-2 Inboard blanket sector

- R=~8.5 m
- Number of blanket modules=4 or more
- FW toroidal width=0.62 m
- 0.65 m thickness
  - Each PbLi module is feeded separately.
  - The Helium pipes of 4 module can be combined to one pipe after assembly to one sector.

ACT-2 DCLL IB Blanket – PbLi Flow Path (Small Modular Concept)

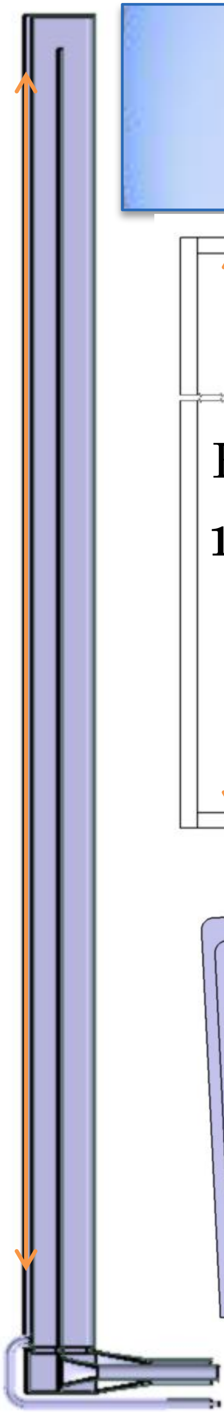


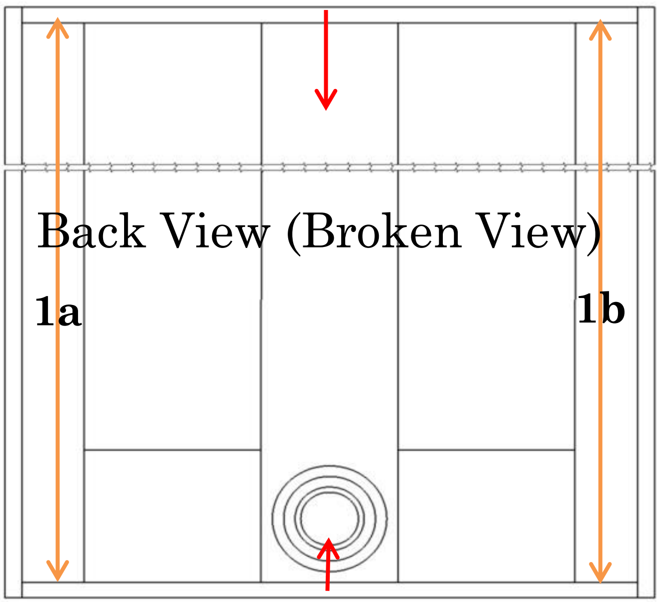
ACT-2 DCLL IB blanket – He Flow Path (Small Modular Concept)



- Cooling of first and side walls in counter flow

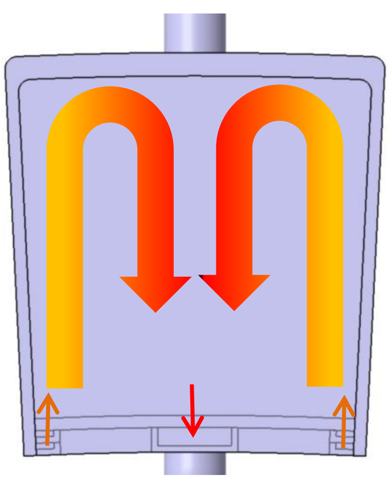
ACT-2 DCLL IB Blanket – He Flow Path 2 (Small Modular Concept)

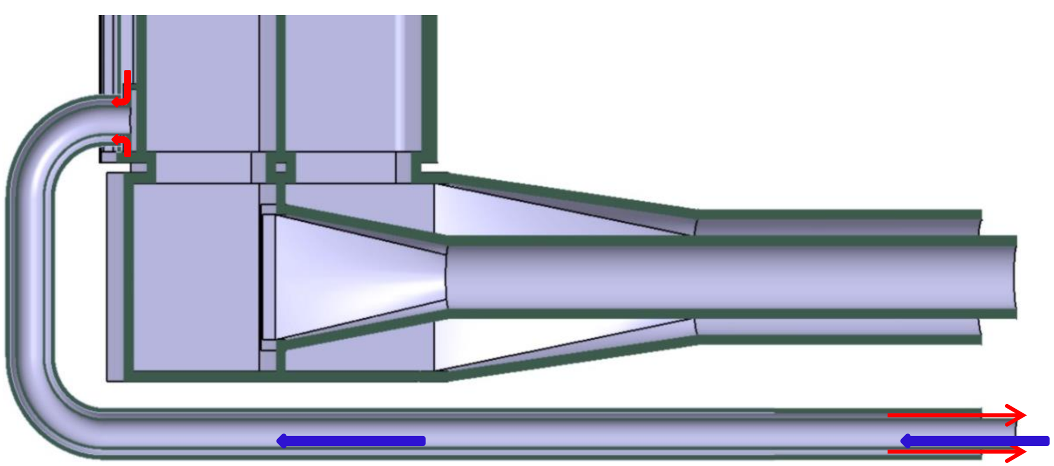




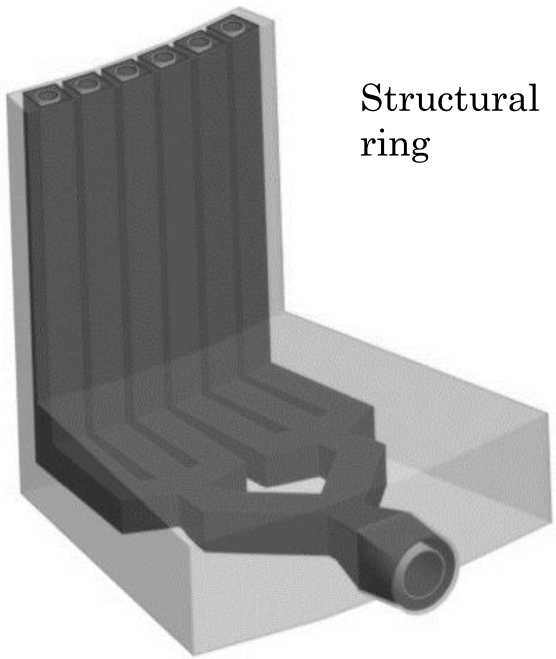
Cooling of top and bottom plates:

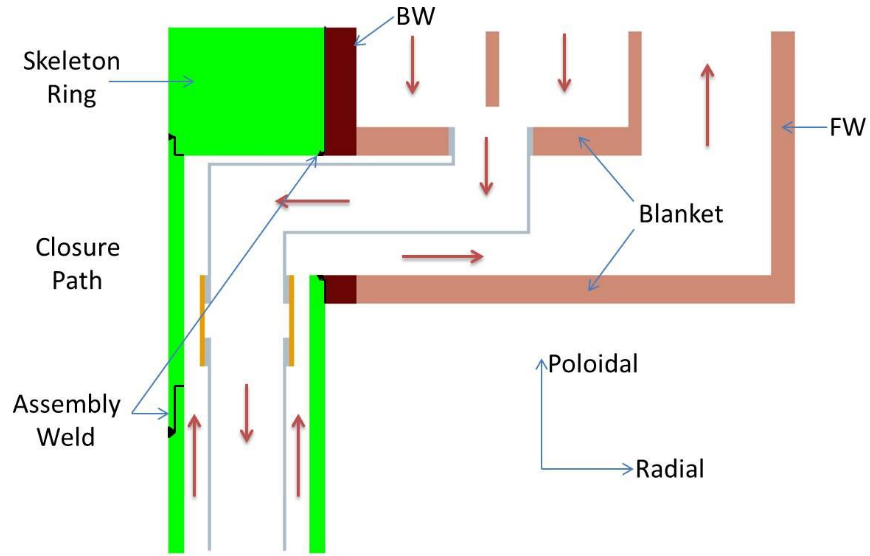
- Helium flows from the poloidal manifolds **1a and 1b** enter into the inlet manifolds of top and bottom plates at the back ends of inner sides.
- After cooling the top and bottom plates the Helium flow into the outlet manifolds of the top and bottom plate, then enters into a poloidal manifold behind the back plate and flow out at the bottom of the blanket.





Alternative Option for Attaching the Manifold Pipes (Siegfried)

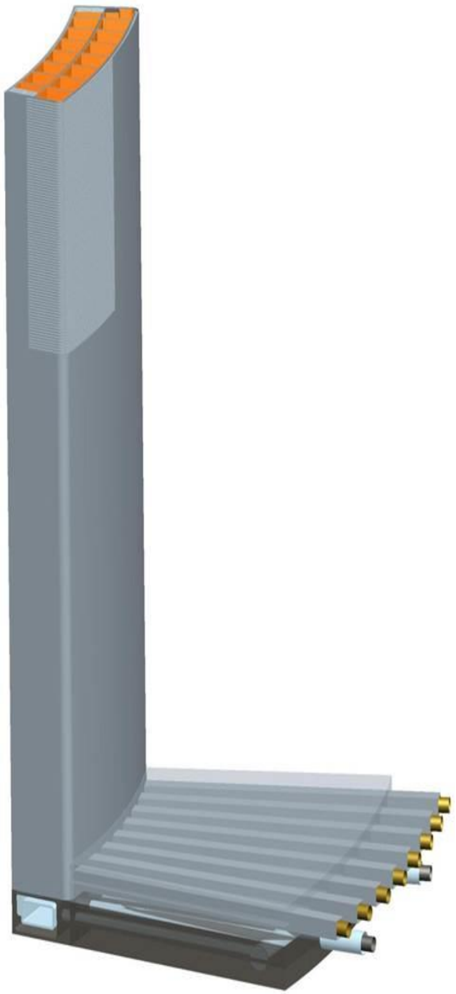




- Assumed the structural ring to be–reweldable in the outer zone (near the inner door of the VV).
- Embed Pb-Li manifold pipes into the structural ring.
- Cut the coolant access pipes to a sector outside the inner door of the vacuum vessel.
- Separate the IB blanket from the skeleton ring by opening the closure plate, cutting the assembly weld between skeleton ring and blanket back wall, and by opening the mechanical connection between these two components.
- Replace the old blanket by a new blanket.

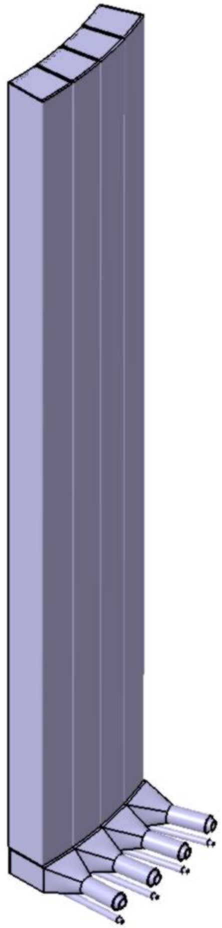
Siegfried Malang presented at ARIES Meeting on Jan. 23-24, 2012.

Summary of the ACT-2 DCLL Blanket Design Options



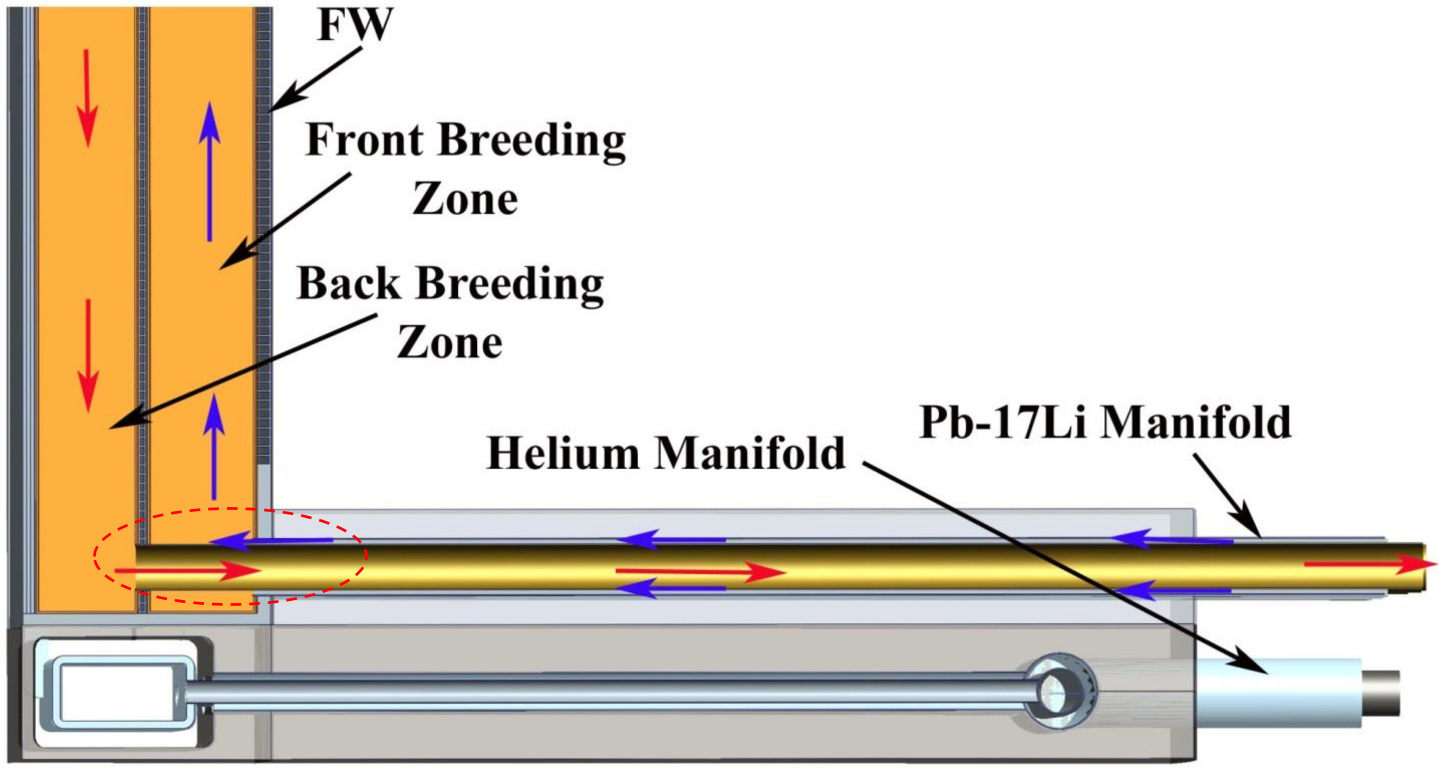
Large sector box

- A combination of several smaller blanket modules as ACT1 to one sector for ACT2 concept would remain the advantages of a simple manufacturing.
- However, it may result in more steel material (both side walls of two neighbored modules have to contain cooling channels) than a fabrication of just one big sector.
- A larger number of helium manifold pipes per sector will be required for small blanket modular design (depending how many blanket modules per blanket sector).
- Support analyses for both options are underway
  - ✓ to determine the **numbers** of the blanket module per sector (max. possible toroidal distance to resist He and Pb-Li pressure loads)
  - ✓ to determine the **dimensions** of the breeding cells and the **numbers** of breeding cell for the sector design option.



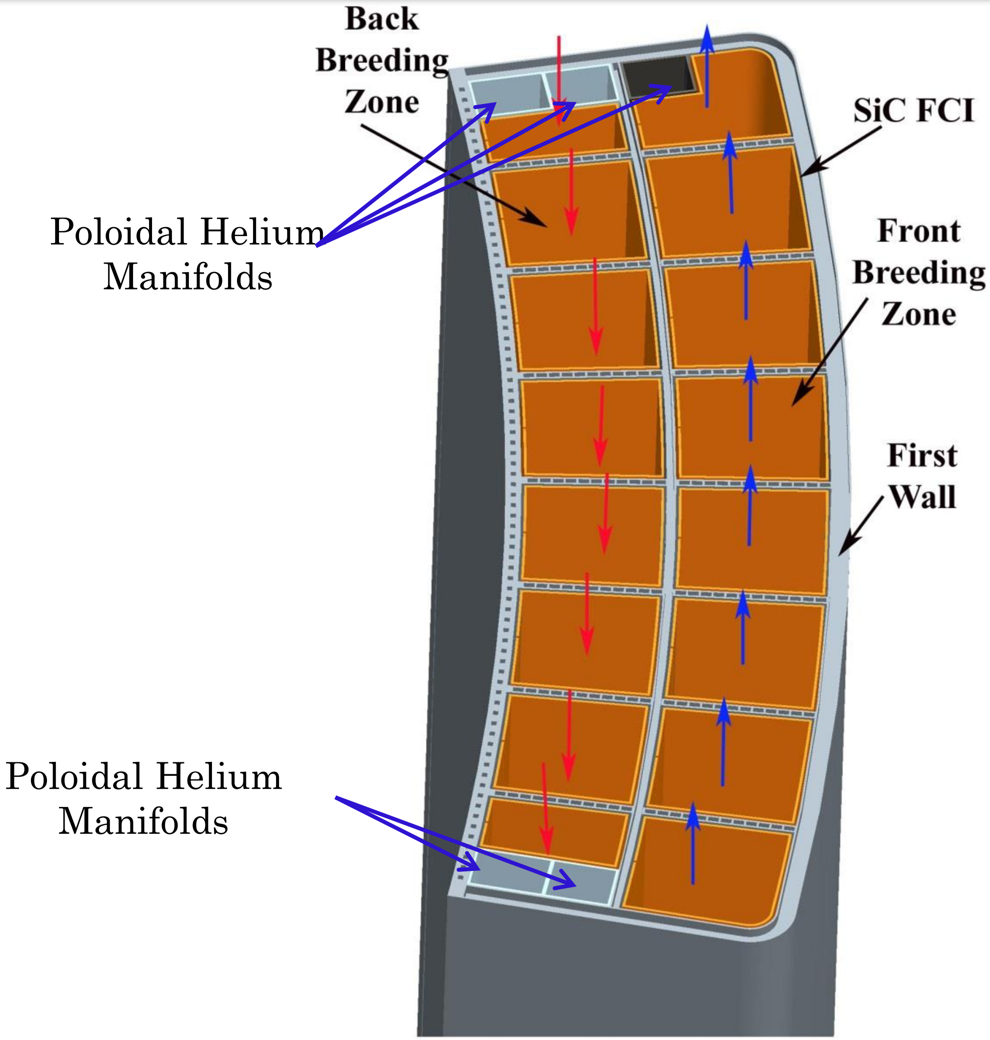
Small modular

Need More Details at Transition Region from Pb-Li Manifold to Front/Back Breeding Cell



- Need more details at the transition region which the Pb-17Li enters in the blanket front breeding zone and flows into the outlet manifold.
- SiC inserts are shown in the front and back breeding zones, but not shown in the manifold pipes.
- Manifold developed in Christina's model can probably be used, but has to be checked in detail.

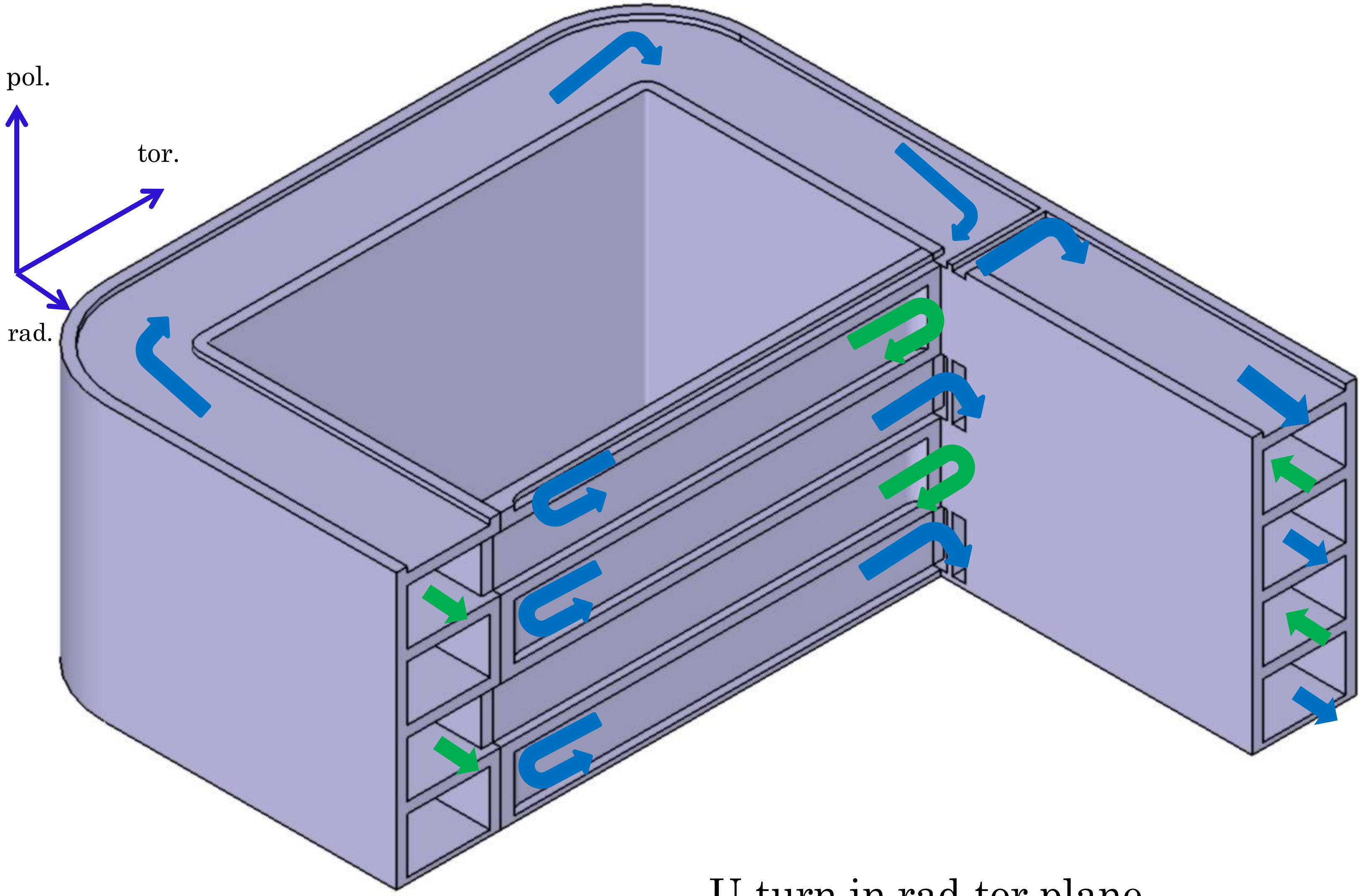
Can We Arrange the Poloidal Helium Manifolds Behind Back Plate of the Blanket?



To arranged helium manifolds behind the back plate.

- ✓ increasing Pb-Li composition ratio which is good for TBR
- ✓ simplifying the geometry at the breeding zones.
- ✓ resulting in increasing the thickness of IB blanket from 65 to 70 cm.

Extra Slide: Helium Flow Path For Small Blanket Module Concept



U-turn in rad-tor plane