DCLL Blanket Analysis and Power Core Layout for ARIES-DB

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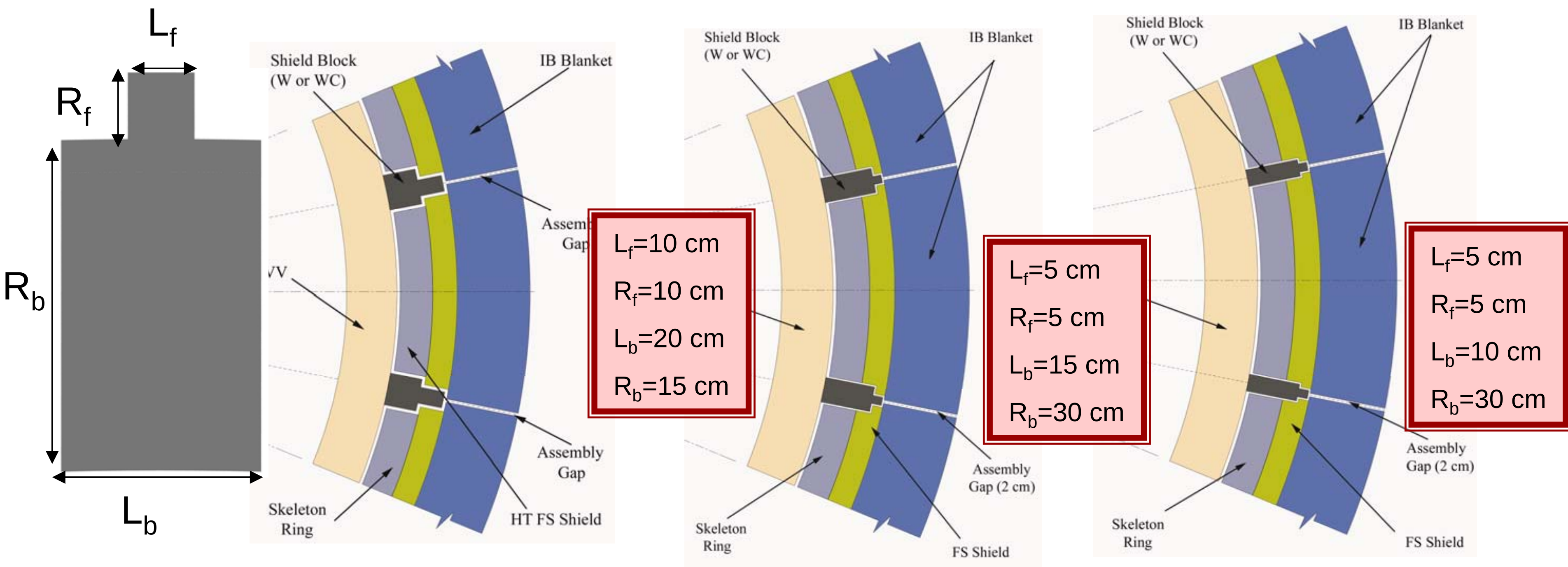
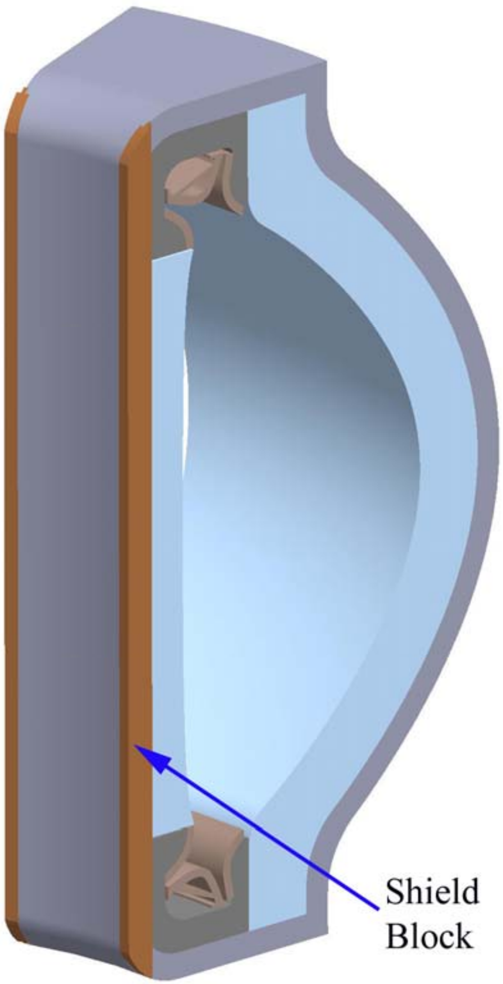
Shield Block Design Based on New Radial Builds for ARIES-DB DCLL



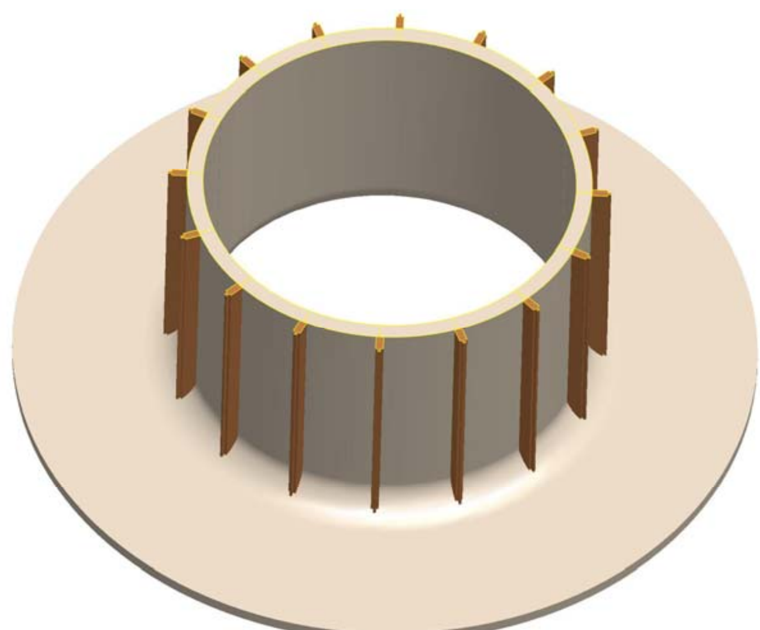
(Case A) **(Case B)** **(Case C)**

- Stepped shield blocks are needed to protect the inboard components, such as inboard VV, and inboard TF coil legs
- W or WC is assumed to be used for the shield blocks, and the shield blocks are cooled by radiation and conduction.
- The shield blocks are life-time components based on the DCLL design.

Shield Block Attachment



- The shield blocks are attached to the VV in order to keep them in place when the sectors are being replaced.
- A floating attachment of the shield block is used to allow some movements in toroidal and poloidal directions.
- The shield block could be segmented into a few pieces along poloidal direction to allow more thermal expansion and to reduce thermal stresses.



Cut through middle plane

Material Properties for Thermal and Thermo-mechanic Calculations

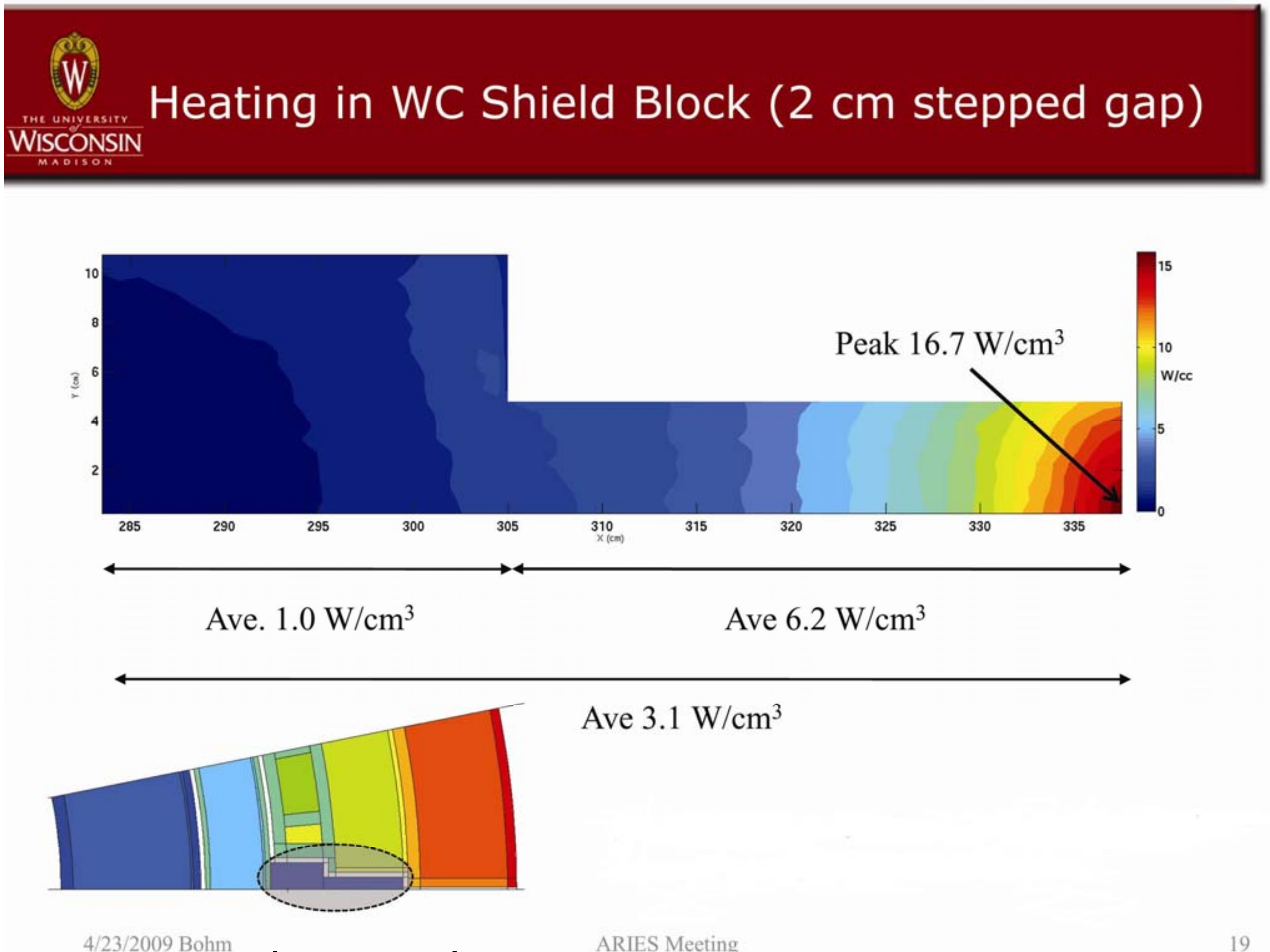
- Emissivity of W or WC blocks is assumed to be ~0.9

  For sufficient cooling by radiation, we depend on a high emissivity. In similar applications, a plasma-sprayed coating with mixture of Titanium and Alumina-oxide has been used, resulting in an emissivity >0.9 (any literature about this?)

- Data base of W for thermo-mechanics calculations

Temperature, ^oC	Thermal conductivity, W/m-K	Specific heat, J/Kg-K	Thermal expansion coefficient, 10^{-6} 1/K	Young's modulus, GPa	Poisson's ratio
600	127.4	146.8	4.83	386.7	0.29
800	117.6	152.4	4.90	378.7	0.29
1000	110.5	157.7	4.97	368.4	0.29
1200	105.5	162.8	5.04	356.0	0.29
1400	102.2	167.5	5.11	341.4	0.29

Distribution of Volumetric Heating Generation Used in Thermal Calculation



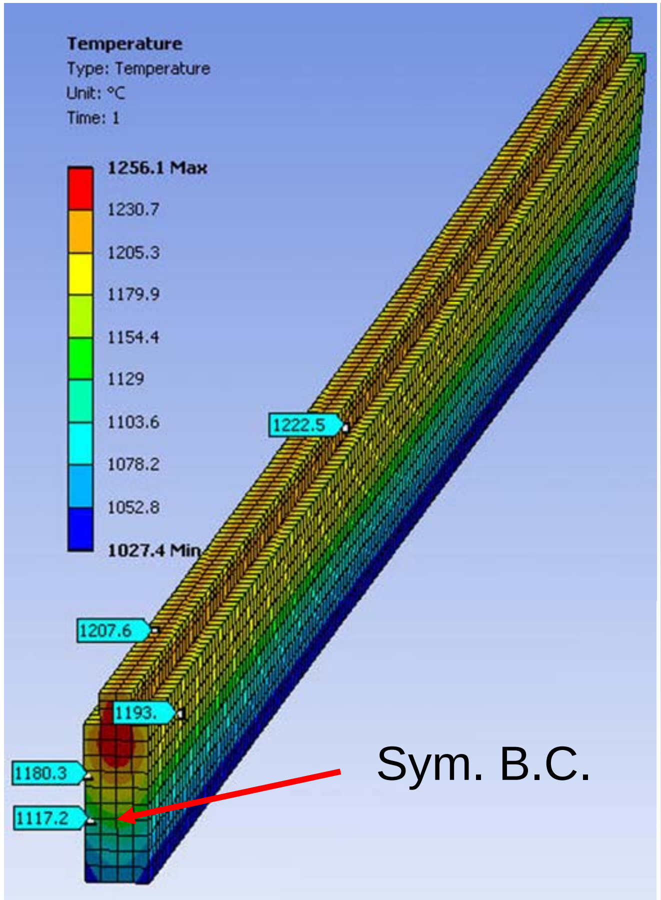
Tim D. Bohm

Total radial depth ~55 cm

- The nuclear heating rate calculated by Tim was based on ARIES-AT DCLL radial builds (presented by Laila on 1/21/2009).
- There is no nuclear heating rate available for all three cases (Case A, B, C).
- The same heating distributions are assumed in thermal calculation for a first approximation.

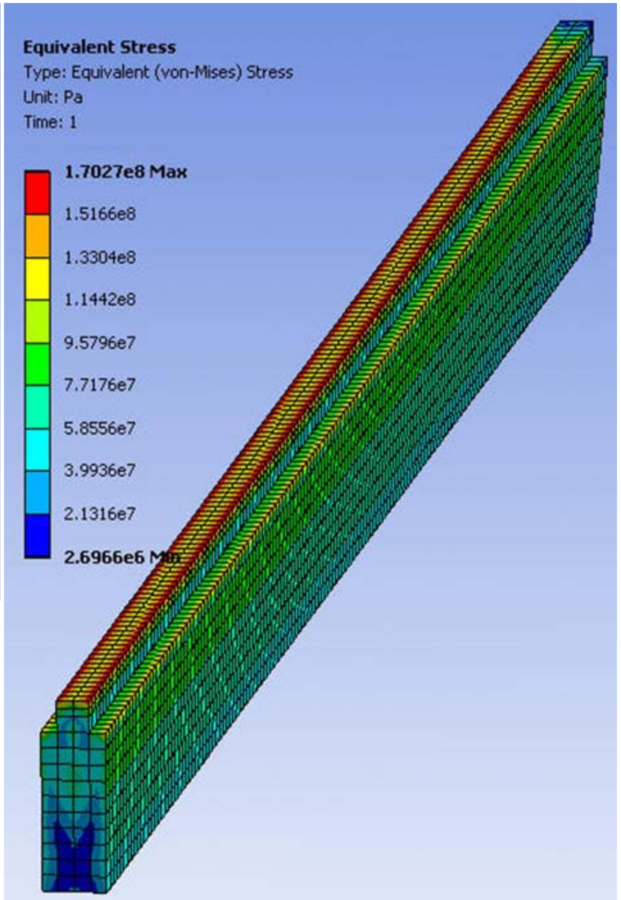
Example Thermo-Mechanic Analysis Results of the Blocks

- Boundary condition: heat radiating to all the surrounding surfaces, heat sink temperature for FS HT shield is ~800 K, and 573 K for VV.
- The surface temperature of both the Case A and B is too high (>1300 ºC).
- The maximum surface temperature for the Case C is ~1220 ºC, and the maximum thermal stresses are 170 MPa.
- **Only the Case C is acceptable by radiative cooling.**



Temperature distribution

(Case C)

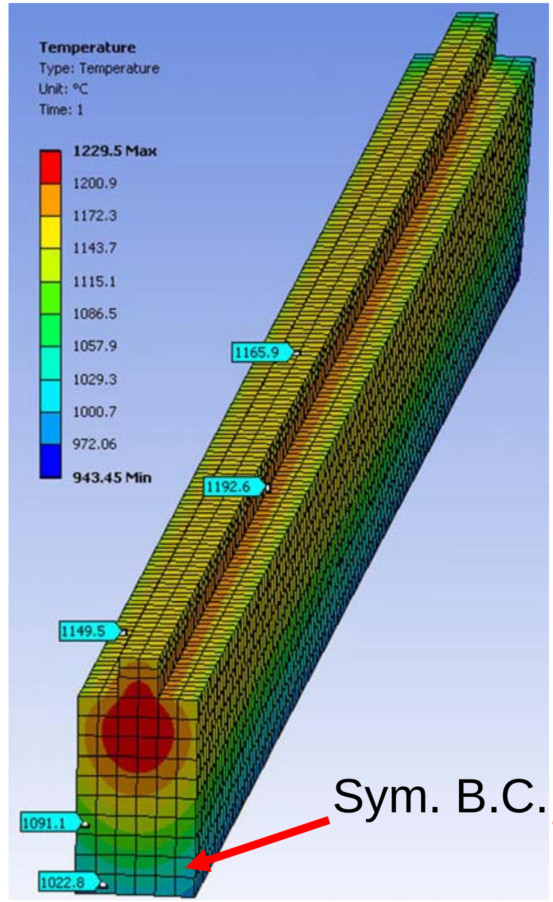


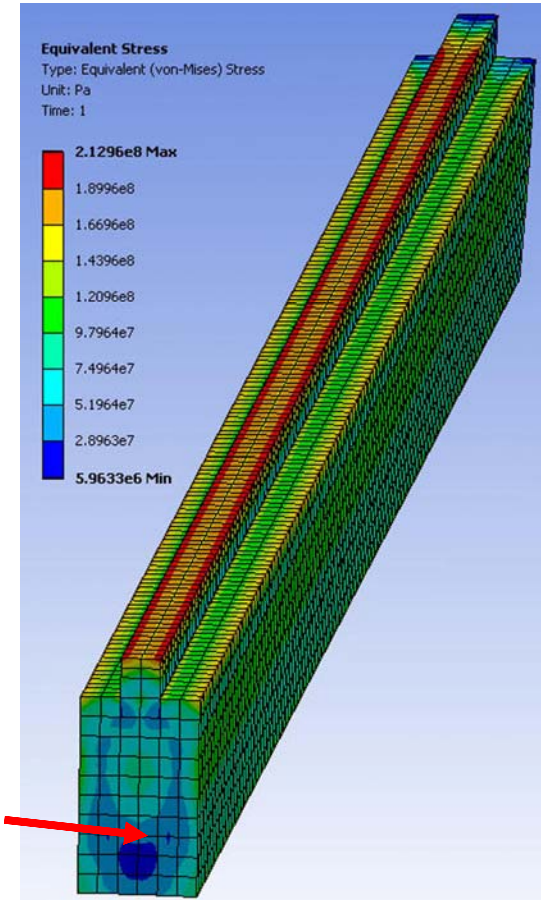
Thermal stresses

(Case C)

Both Case B and C Meet Maximum Surface Temperature Requirement If All Heating Values Multiplied By 0.75

- Considering the ratio of IB average to peak NWL, all heating values are multiplied by a factor of 0.75 (Suggested by Laila).
- Same boundary conditions are assumed.
- The maximum surface temperature for the Case B is ~1200 ºC and the maximum thermal stresses are 213 MPa.
- The maximum surface temperature for the Case C is ~1120 ºC, and the maximum thermal stresses are 154 MPa.
- **Both Case B and C are acceptable by radiative cooling.**





Temperature distribution

(Case B)

Thermal stresses

(Case B)

Layout of the Power Core for ARIES-DB DCLL

- ARIES-DB DCLL blanket layout are based on an example plasma shape from system code including updated radial build from neutronic analysis.

- Two cases were given to ARIES team by Zoran (July 24), and the first case was selected to be an example to develop the layout of power core:

  Plasma major radius: 6.4 m (6.6 m)

  Plasma aspect ratio: 4.0 (4.0)

  Plasma elongation: 2.2 (2.4)

  Fraction of radiated power to divertor: 95% (90%)

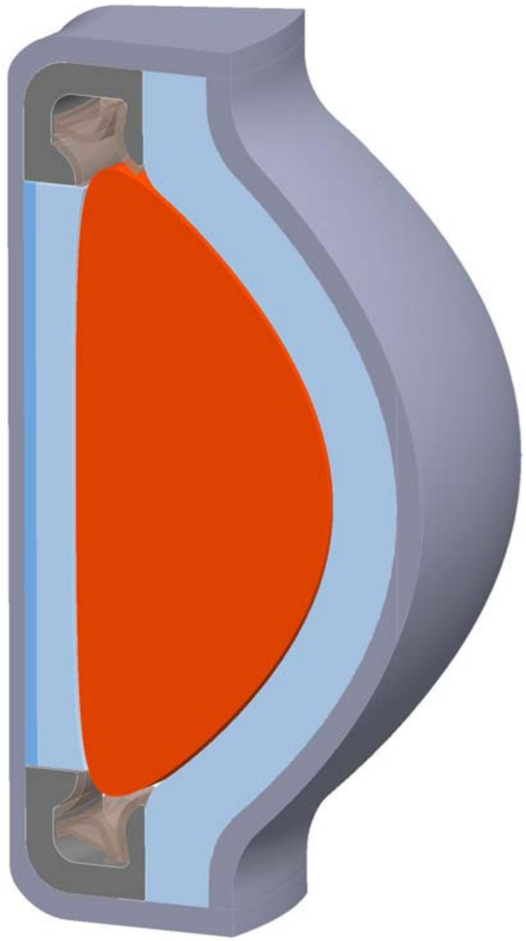
- Pro/E Results from an initial configuration

  Plasma volume= 628 m^3

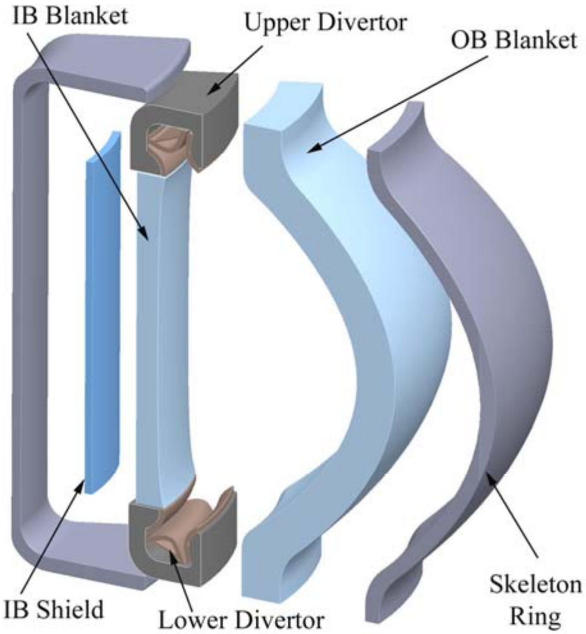
  Plasma surface area=636 m^2

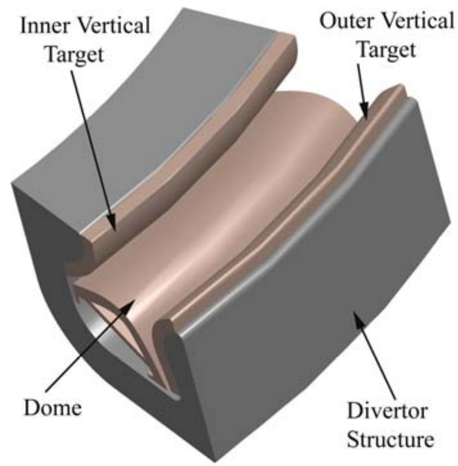
  First wall area=561 m^2

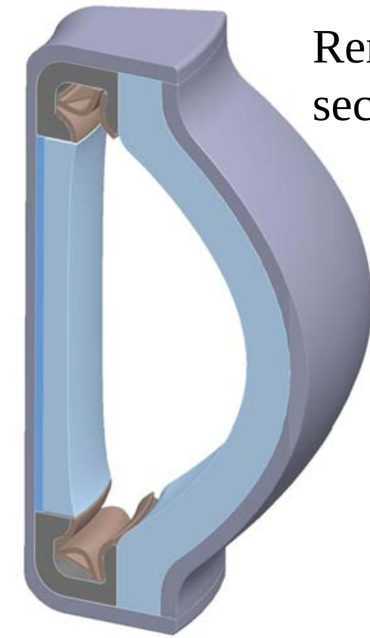
  Divertor area=166 m^2



Design of the Removable Power Core Sector







Removable sector

- ➢At the inboard region, the blanket and replaceable shield are combined to one component which extends over the entire height of the power core.
- ➢Upper and lower divertor targets as well as the “dome” are attached to a cassette-like strong structure which can be replaced in the hot cell without disassembling the blankets.
- ➢All the IB blanket, OB blanket, upper and lower divertor modules are integrated with the skeleton ring into one replacement unit and the unit is attached to the bottom structure of the VV.
- ➢The replacement unit is only fixed at bottom and it is allowed to expand freely relative to VV.

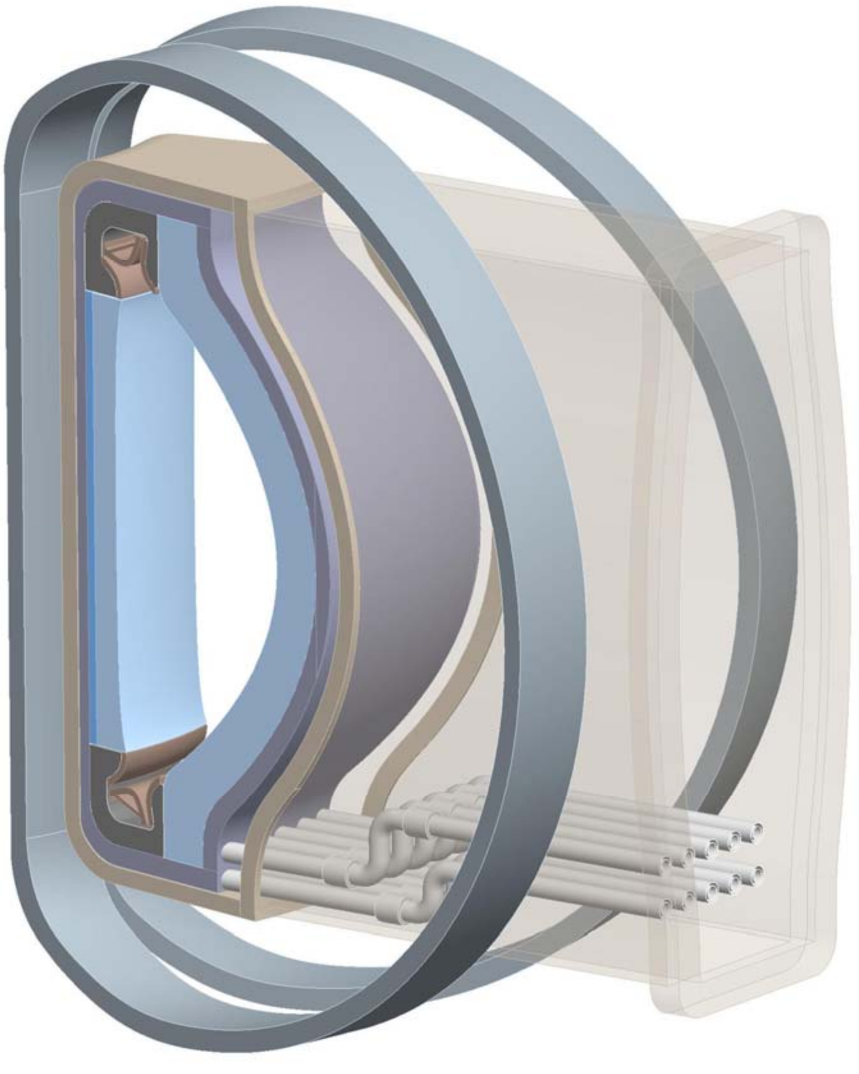
Connections of Coolant Access Tubes to Power Core

- All the connections between coolant access pipes and individual components are located at the outer side of the skeleton ring where the He-generation should be low enough to allow for re-welding.

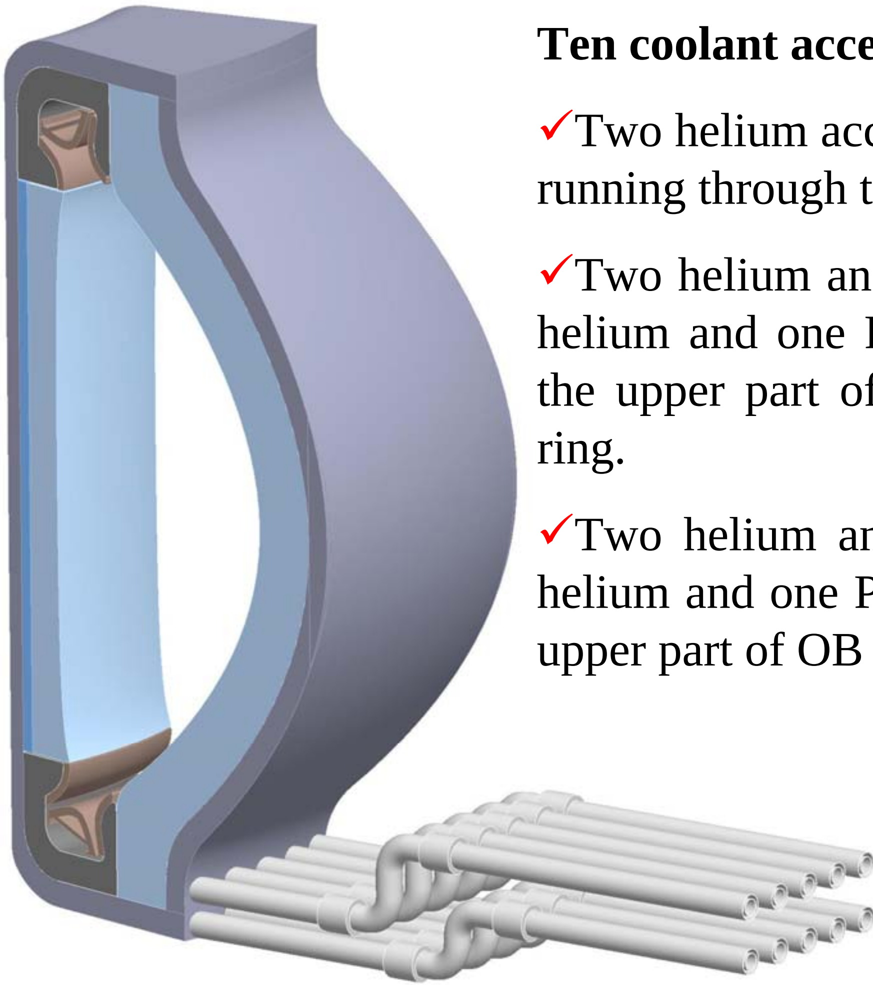
- It is desirable to attach all coolant access tubes to the sector close to the mechanical support point in order to avoid problems coming from differential thermal expansion.

- All LM access tubes should be designed as concentric tubes with the “cold” inlet flow (~450^{o}C) in the annulus, cooling in this way the inner tube (~700^{o}C) to a temperature allowing the use of RFFM-steel.

- All He access tubes should also be designed as concentric tubes with the “hot” outlet He (~450^{o}C) in the annulus in order to make the structure temperature as uniform as possible.



Arrangement of the Access Tubes

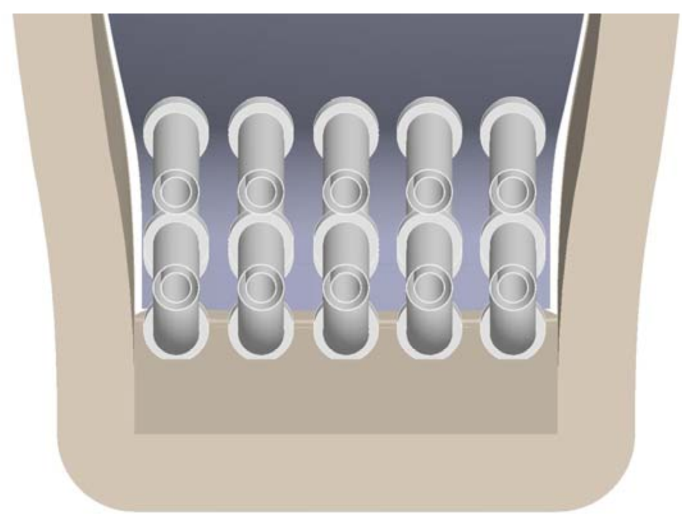


Ten coolant access tubes are needed for feeding each sector,

✓Two helium access tubes for divertor, one for the upper divertor running through the OB skeleton ring;

✓Two helium and two PbLi access tubes for the IB blanket, one helium and one PbLi running through OB skeleton ring to feed the upper part of IB blanket, other two through lower skeleton ring.

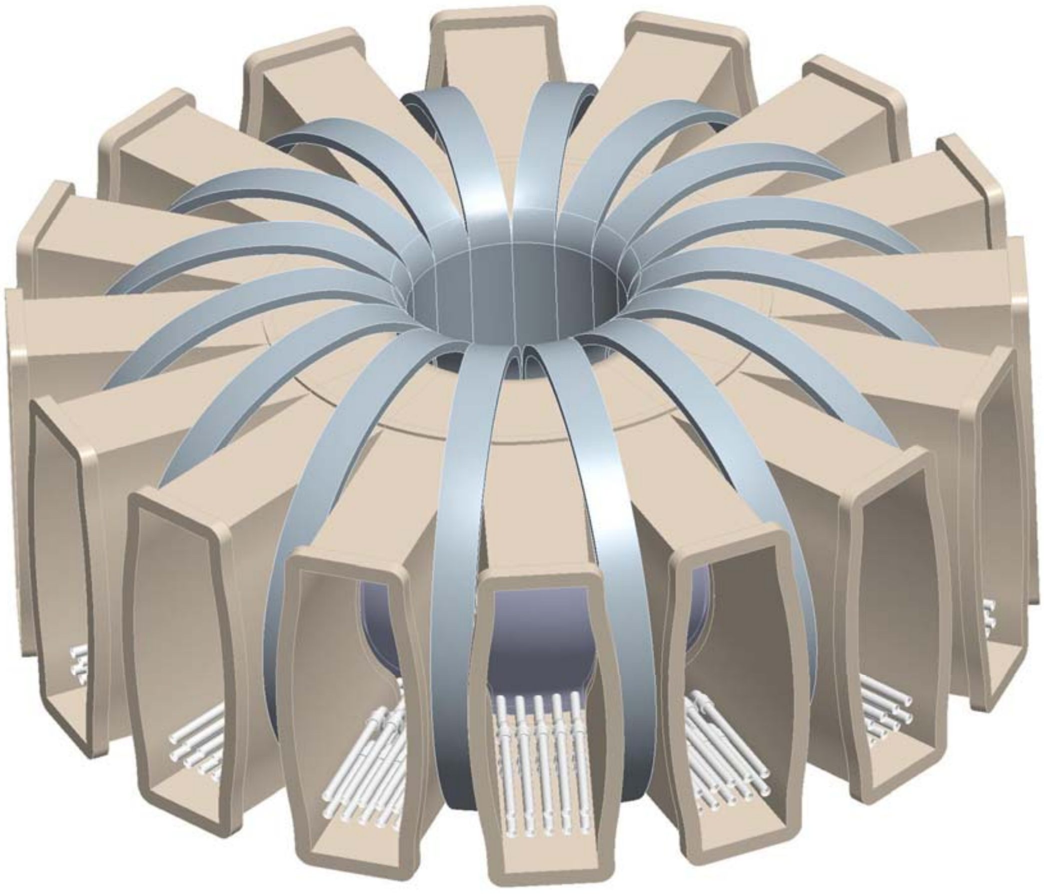
✓Two helium and two PbLi access tubes for OB blanket, one helium and one PbLi running though OB skeleton ring to fee the upper part of OB blanket, other two from bottom.



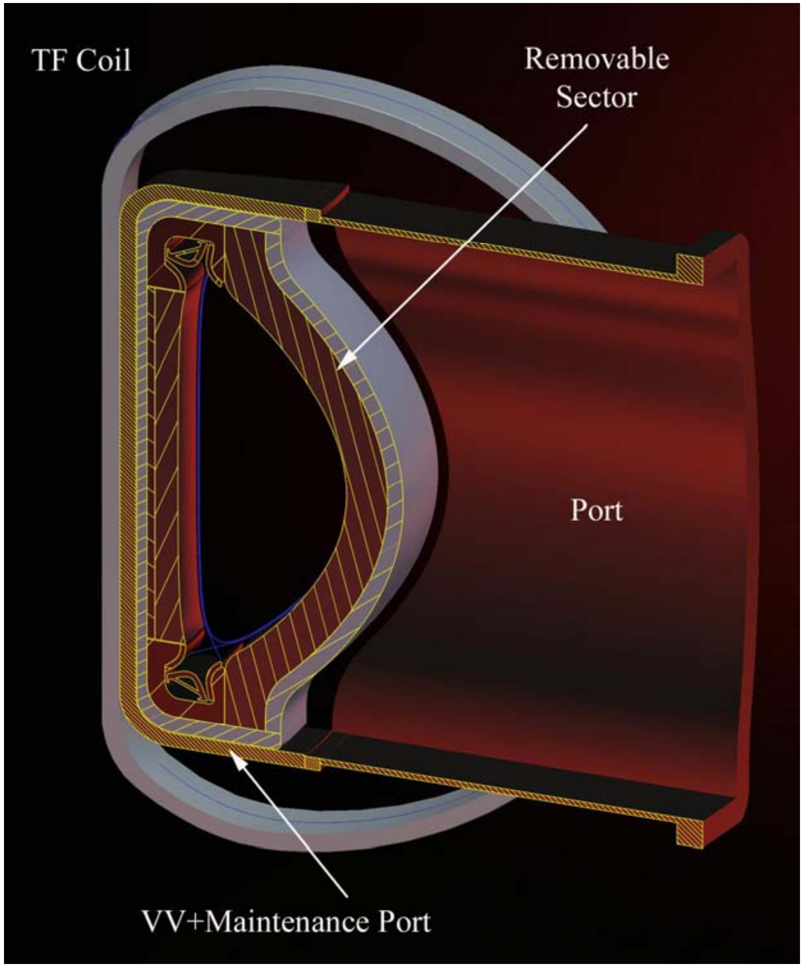
Cross section areas of inner and annular TBD.

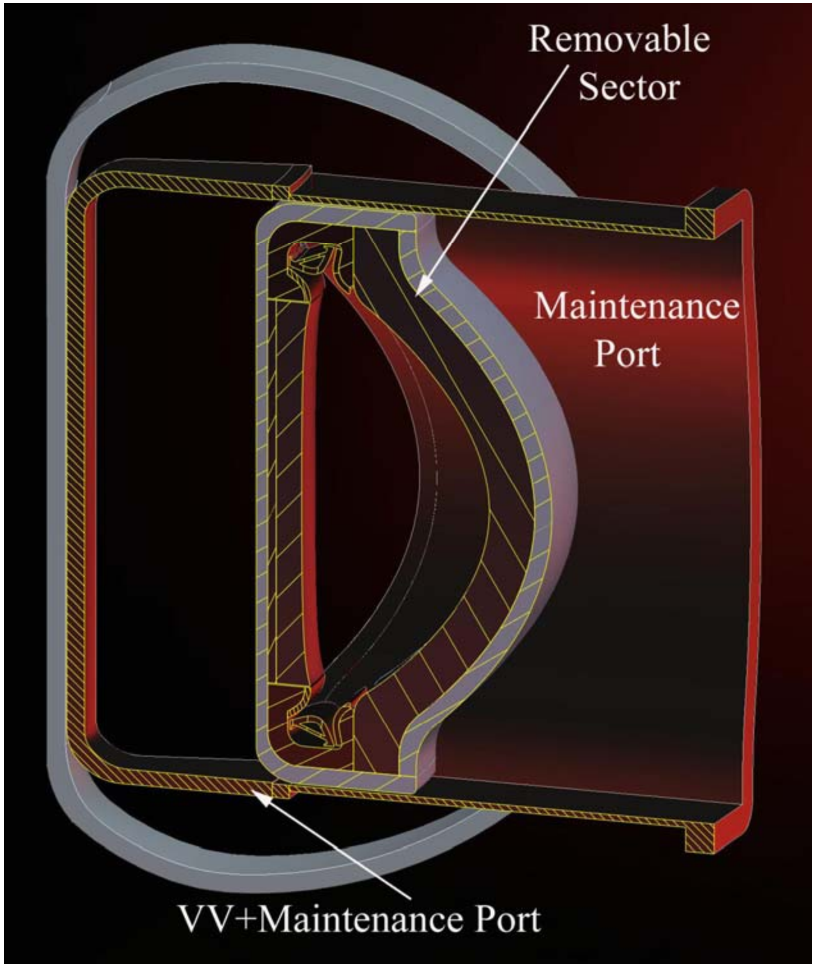
Sector Maintenance and Maintenance Ports

- Like ARIES-RS and ARIES-AT power core maintenance, the blankets, divertor and skeleton ring are toroidally segmented into 16 sectors, and there are 16 maintenance ports arranged between TF coils for the sector maintenance.
- For quick replacement of the power core components, the sectors are inserted and withdrawn horizontally through the ports.
- Cutting and disconnecting the access tubes attached to the sector components could be done through the maintenance ports.

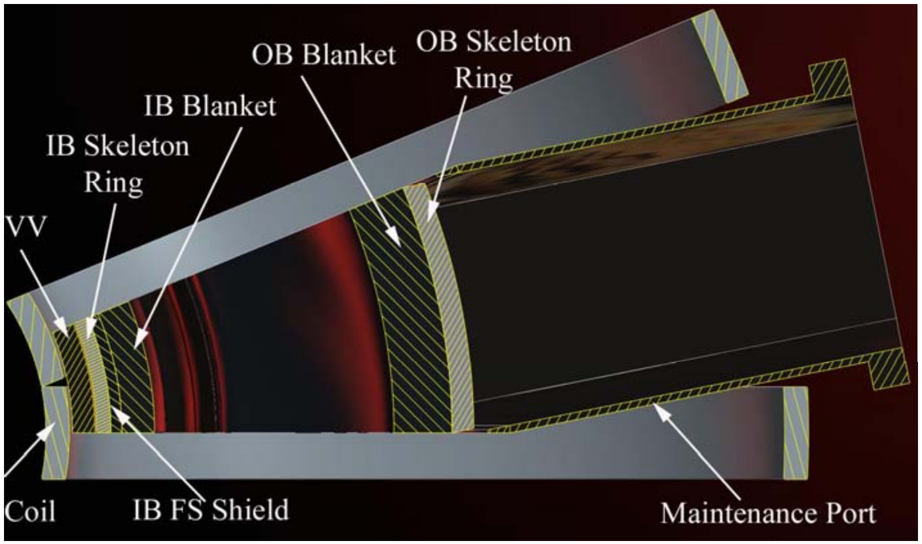


Example of the Sector Withdrawn Horizontally



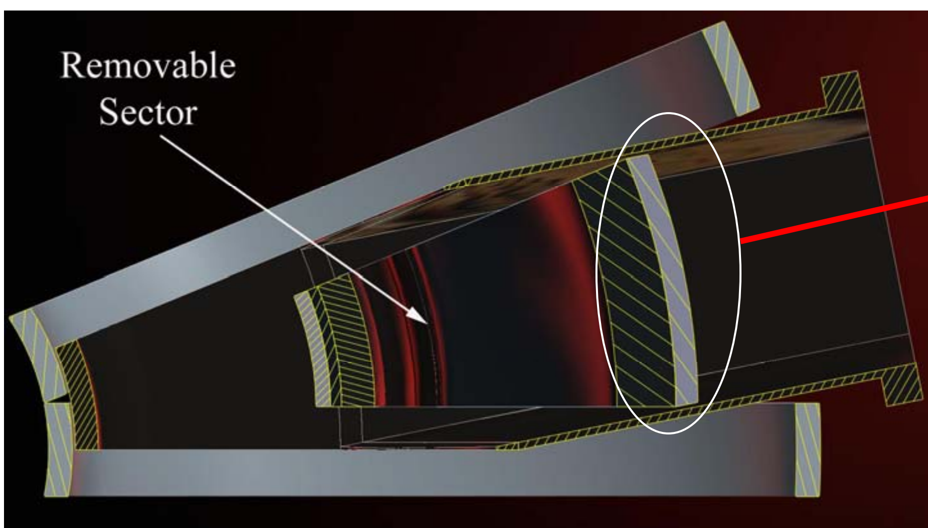


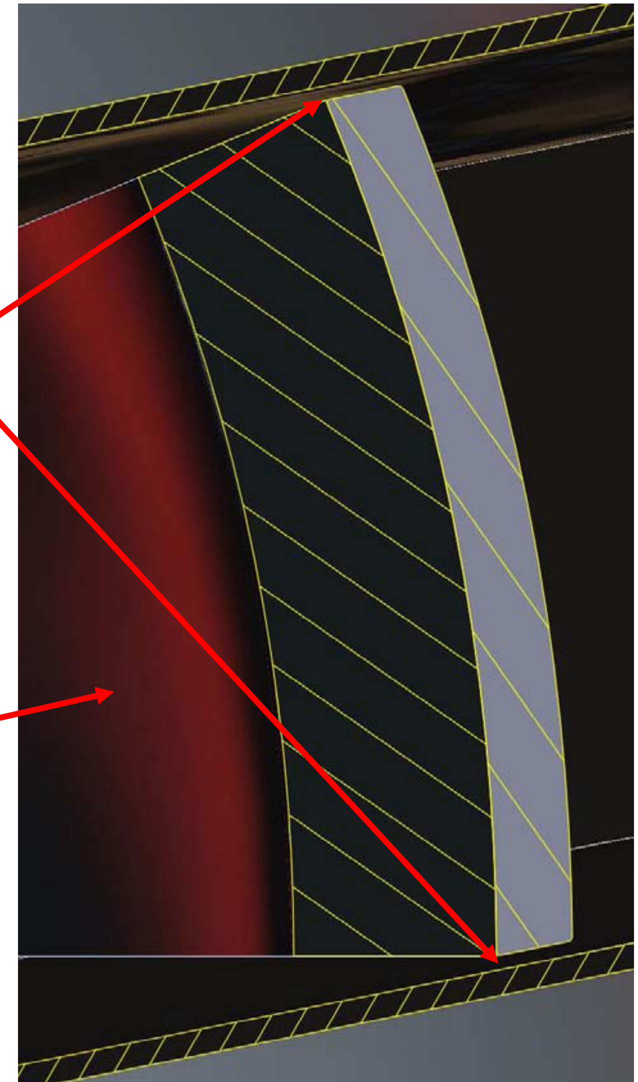
Example of the Removable Sector Withdrawn Horizontally



5 cm

Clearance





Summary

- Three cases of the shield blocks were analyzed, and the Case C with smaller toroidal width shows lower surface temperature and thermal stresses.
- However, the geometry of the shield block (Case C) needs neutronic calculations to look into the block dpa and radiation damage in the VV and TF coils.
- The DCLL blanket layout was developed based on sector maintenance and an example plasma shape from system code including updated radial build from neutronics analysis.
- *Tasks for near future include:*
    - ✓ *Developing details of blanket configuration and coolant routing*
    - ✓ *Thermal-fluid and thermo-mechanical supporting analysis*
    - ✓ *Integration of He-cooled divertor design in overall ARIES-DB*