Maintenance Studies for 3-Field Period and 2-Field Period Configurations

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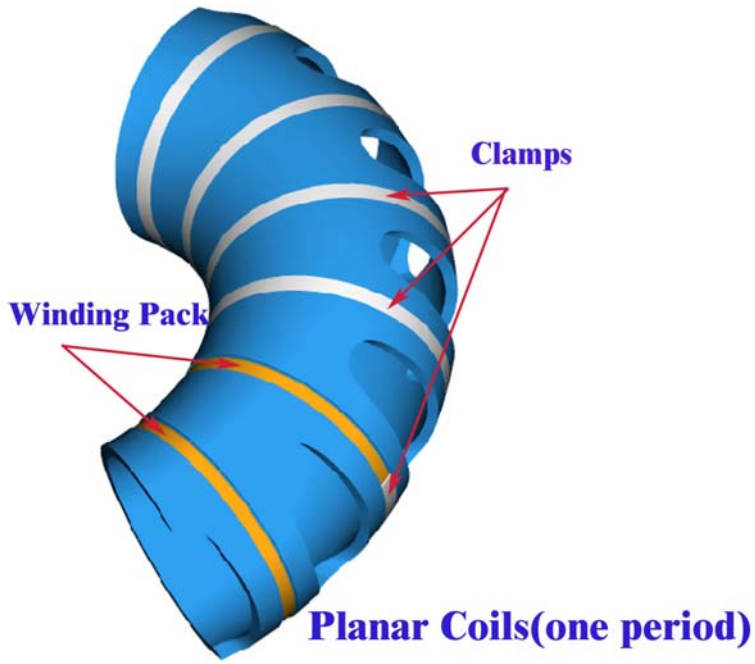
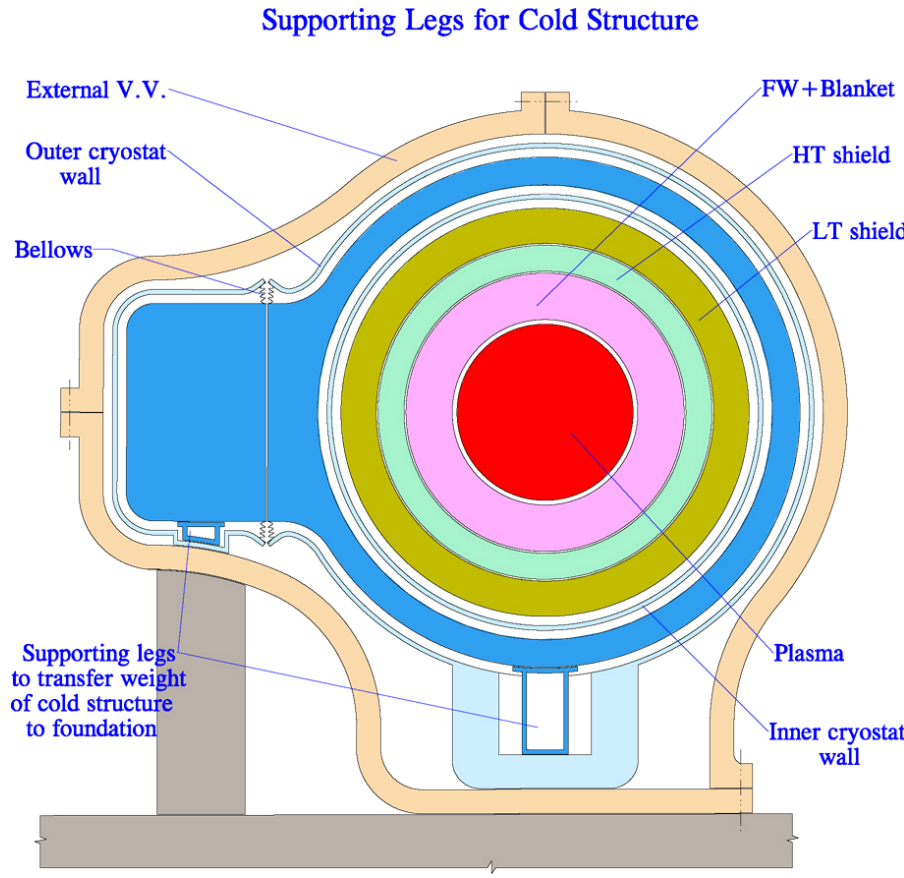
Outline

- **Refine/Verify Clearances for the Field-Period Maintenance Approach**
- **Layout of Power Core for Maintenance Scheme based on Module Replacement through Ports**
- **Another Possible Maintenance Scheme for 2-field Period Configuration?**
- **Available Port Dimensions for Several Cases**

Refine/Verify Clearances for the Field-Period Maintenance Approach

Field-Period Based maintenance Scheme Presented by S. Malang at Last ARIES Meeting





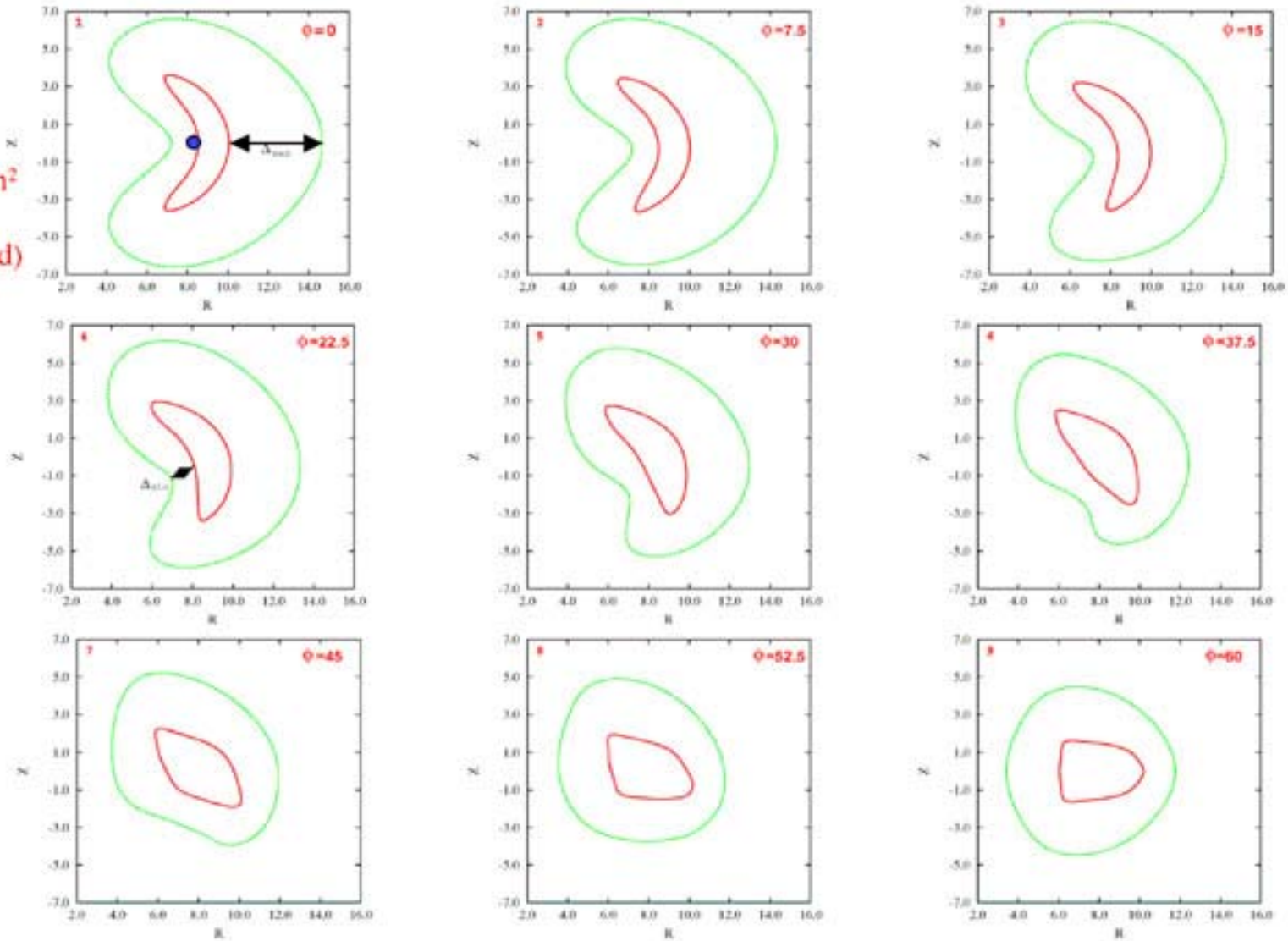
- **Simplified maintenance steps:**
  1. Open external vacuum vessel
  2. Pull out radially all in-vessel components
  3. Remove the two replaceable blanket units toroidally from each end

Concerns with Clearance Available within Coil Configuration for Toroidal Removal of Blanket Unit was Investigated

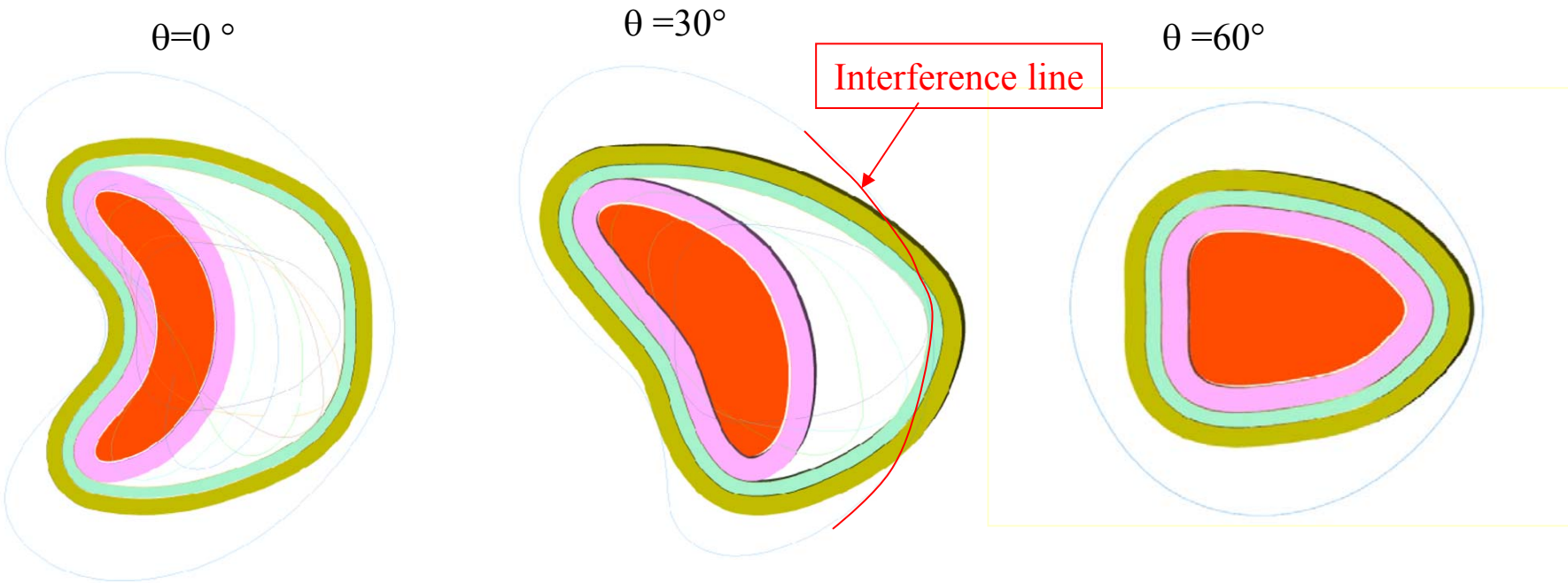
Δ_{max}~ 4.6 m

Γ peaks @ ~3 MW/m² at blue dot (middle of field period)

Δ_{min}= 1.2 m



Results from Previous CAD Analysis



- **More space is required at certain points to allow a replacement unit (in pink) be removed in the toroidal direction.**
  - **i.e. small changes either in plasma geometry, coil geometry, or thickness of blanket+shields (e.g. reduction to 82 cm).**

Can Local Shaving of Magnets or Shield/Blanket Provide Space for Removal of the Replacement Unit?

- **Example case with shielding only requirement used to highlight possible design solution (would need to be fully verified later for detailed blanket configuration and full accommodation of shielding and breeding requirements)**

- **Minimum distance between FW surface and inner surface of the coils is 100 cm to obtain sufficient shielding of the coil (100 cm estimated from 120 (minimum distance)- 5 (SOL) - 5(Coil case) -10 (half winding pack))**

- **Minimum thickness of replacement unit has to be (4.8+47+9) cm ~60 cm.**

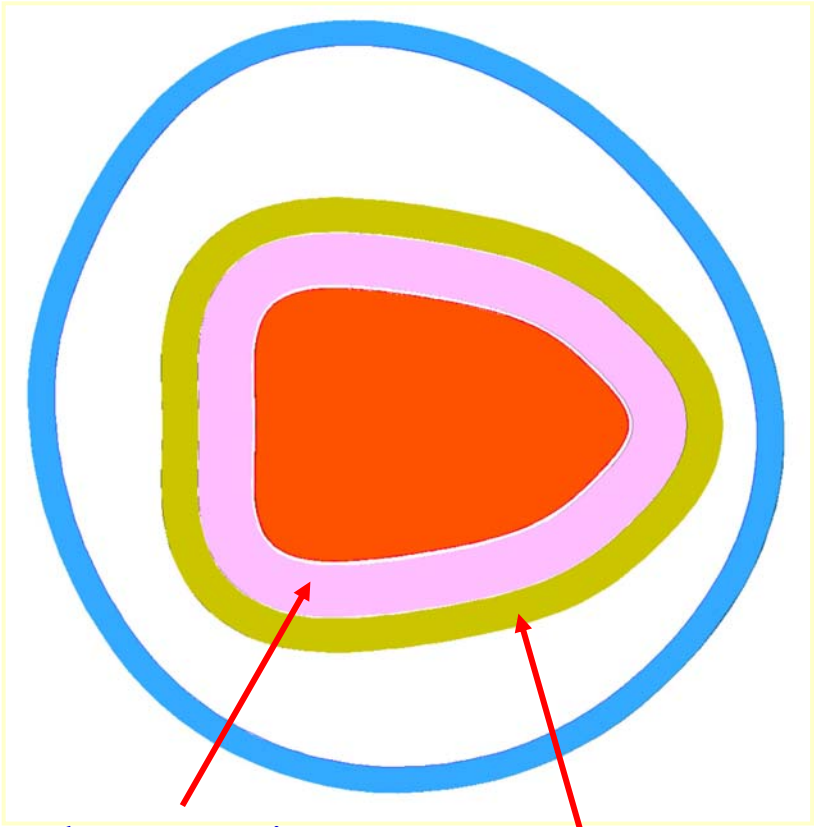
- **Thickness of the permanent shield (cold) is ~40 cm.**

- **The cross section of shield at θ=0° has to allow for the toroidal movement of the replacement unit at 60° and 50°, 40°, 30 °, 20° and 10° during removal**

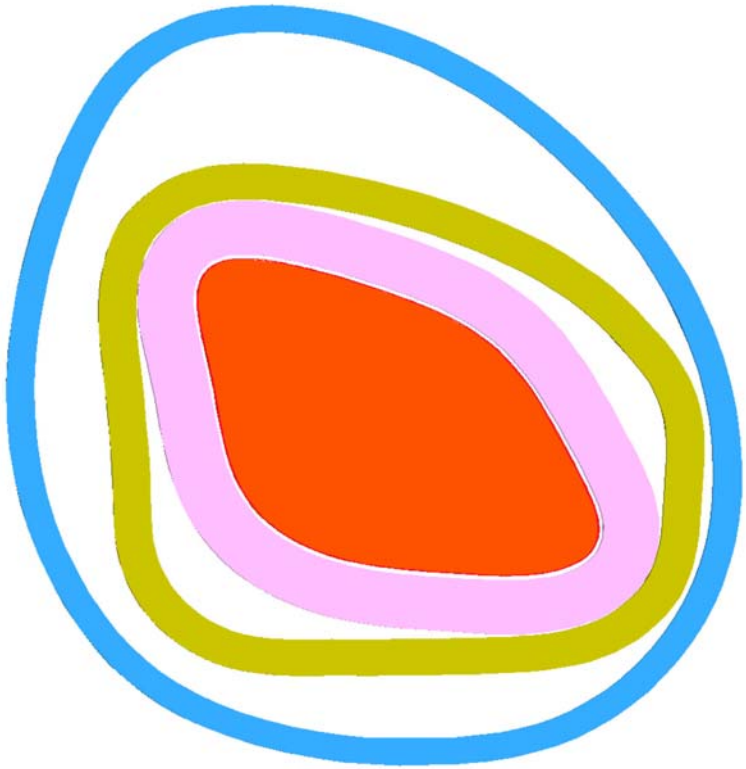
- **The cross section of shield at θ=10° has to allow for the movement of the replacement unit at 60° and 50°, 40°, 30 ° and 20° during removal, and so on…**

Cross Sections of Replacement Unit/Shield/Coil at 60° and 50°

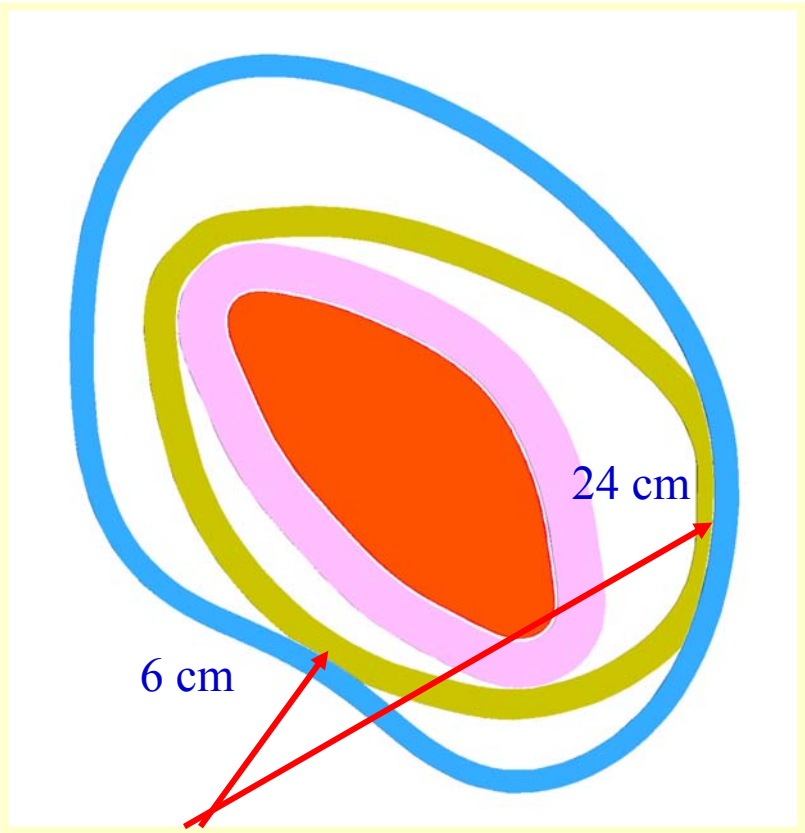
θ =60°



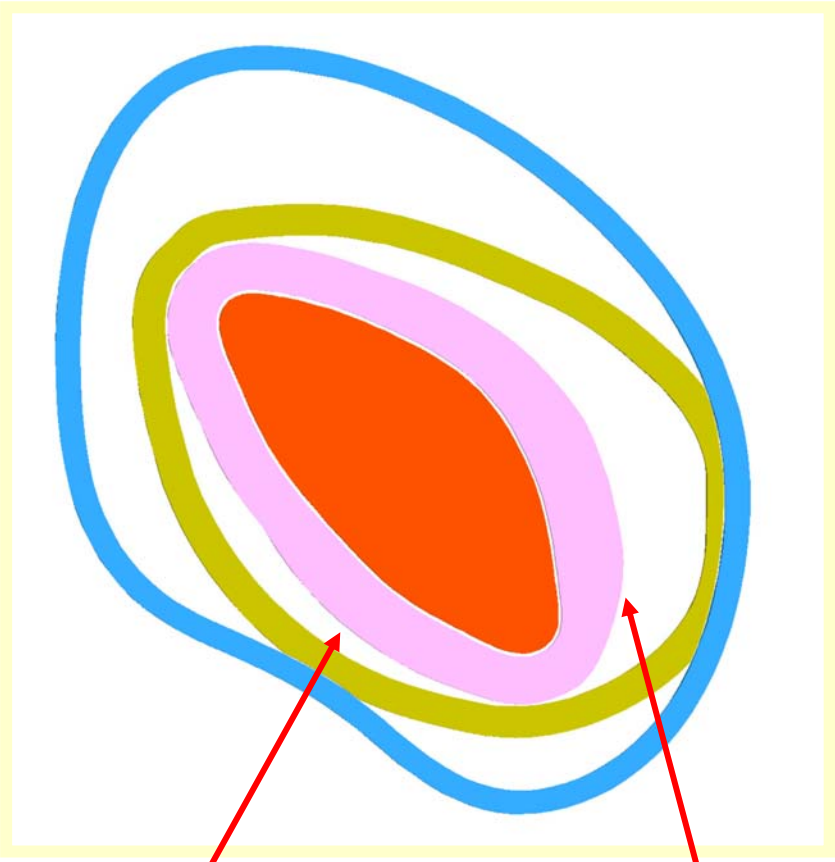
θ=50°



Cross Sections of Replacement Unit/Shield/Coil at 40°

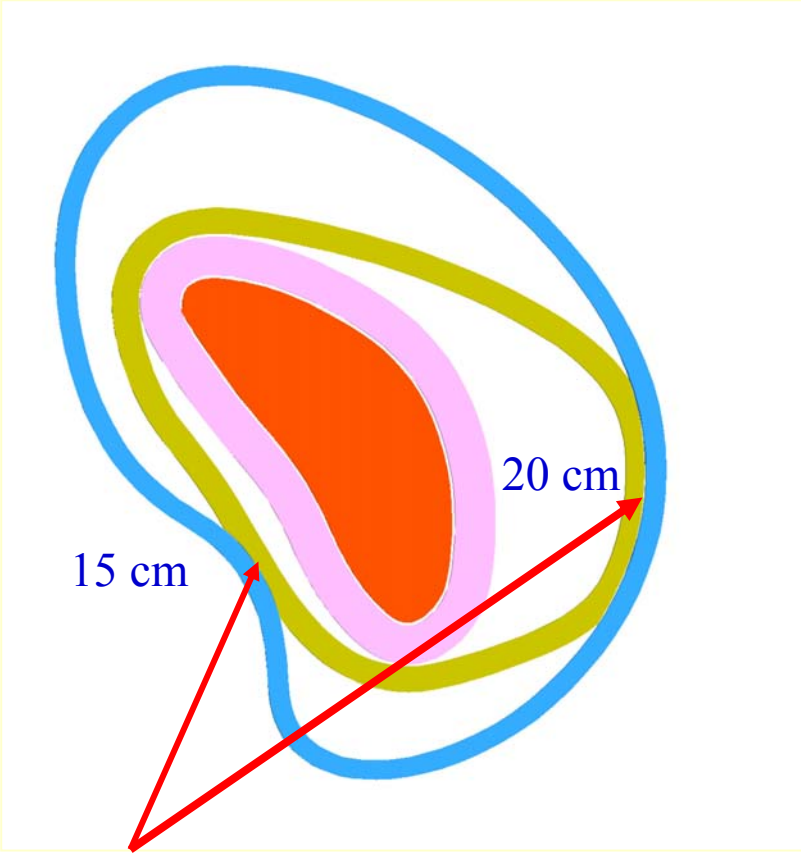


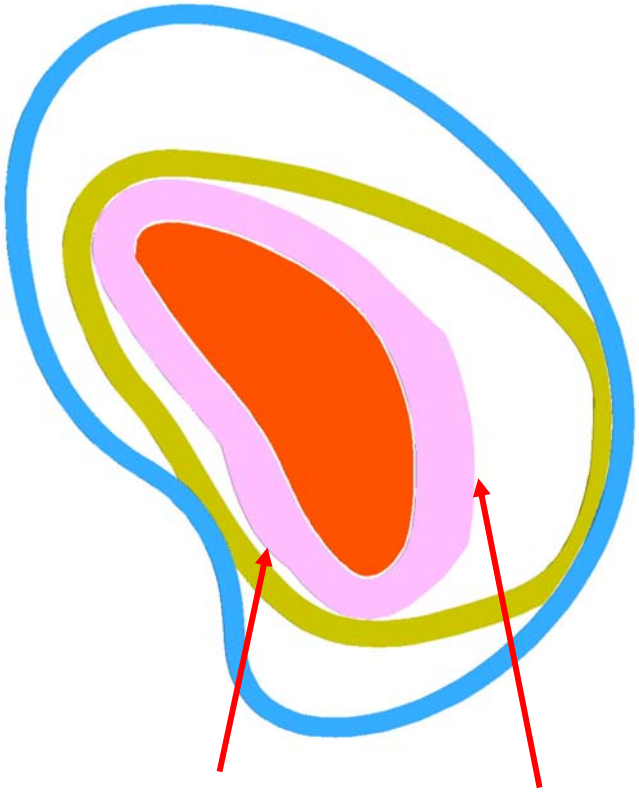
The shield has to be shaved locally to avoid interference



The same thickness of removed material is added to the replacement unit.

Cross Sections of Replacement Unit/Shield/Coil at 30° (similar problem)





The shield has to be shaved locally to avoid interference

The same thickness of removed material is added to the replacement unit.

Cross Sections of Replacement Unit/Shield/Coil at 20°, 10° and 0°

θ =20° θ =10° θ =0°

There are no interferences at the 30°, 20°, and 10° locations during the toridal removal operation of the replacement unit.

Summary

- **The field period replacement seems possible for a combined thickness (blanket+shield) of 100 cm (required for coil shielding) by shaving off the shield thickness and correspondingly adjusting the blanket thickness at a few locations to prevent interferences.**

- **This reflects well on the potential feasibility of this maintenance scheme .**

- **However, more detailed analysis would be required for confirmation of such a maintenance scheme based on given blanket and shield designs including local variation of shield and blanket configurations/thicknesses and verification of the accommodation of various requirements such as shielding and breeding.**

Layout of Power Core for Maintenance Scheme based on Module Replacement through Ports

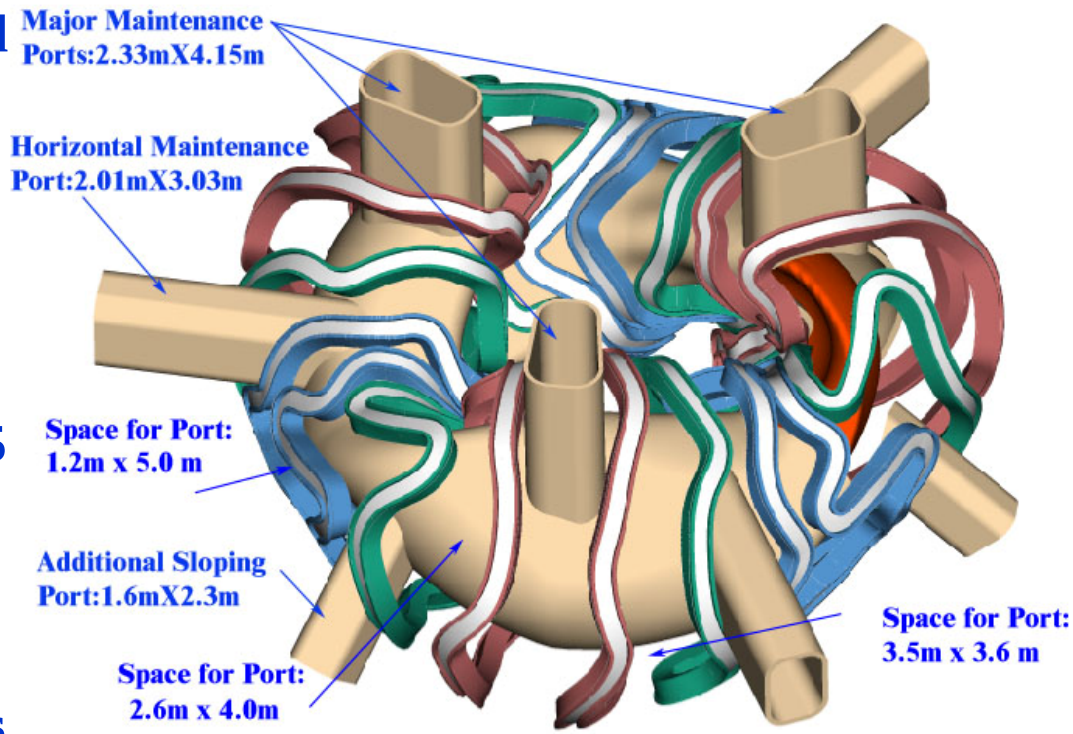
Modular Design Approach Using Selected Ports and Articulated Boom Previously Discussed for 3-Field Period Configuration

- Preliminary assessment of port sizes and possible number of ports was done for the 3-field period configuration initially considered

- Initial findings indicated the possibility of a modular maintenance scheme utilizing articulated booms for replacing module of sizes ~2 m x 2 m x 0.25 m and empty weight < 1 ton

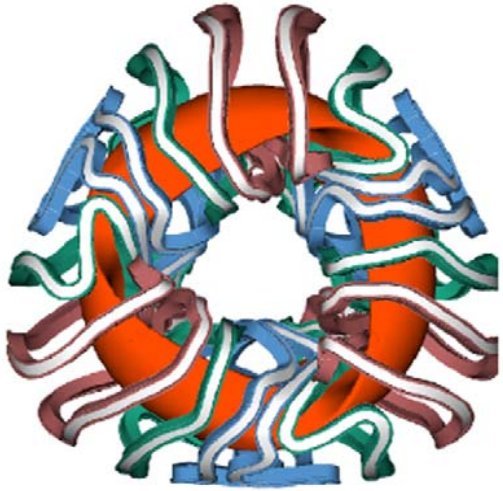
- However, no detailed system layout (including blanket, shields, vacuum vessel, coil structure and cryostat) was done at that time

Space Available for Ports for NCSX-Based 3-Field Period Configuration (R=8.25 m)



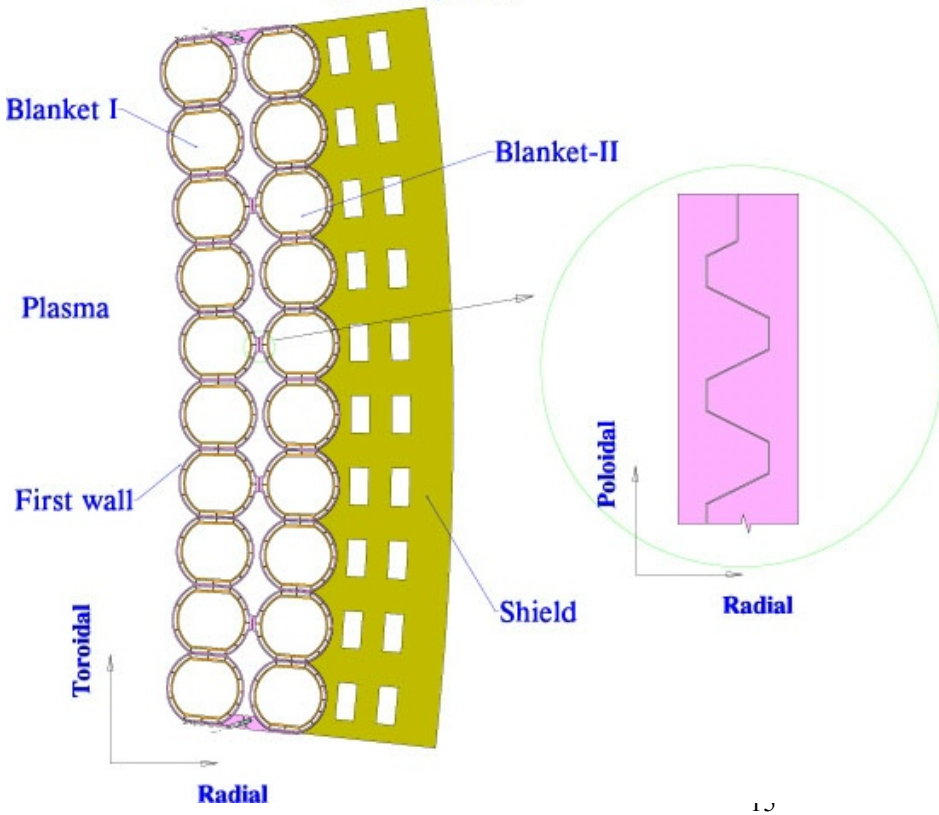
NCSX-like plasma and coils scaled to power plant size with 2 GW fusion power

Scoping Study of Different Modular Blanket Concepts was Done for Initial Example ARIES-CS Parameters, (e.g. Pb-17Li + SiC/SiC)



Major radius, R	8.3 m
Minor radius, <a>	1.85 m
Plasma aspect ratio	4.5
Plasma volume	550 m^3
Plasma boundary surface area	780 m^2
Minimum distance between plasma and center of coil winding, Δ_{min}	1.2 m
Magnetic field on axis, B	5.3 T
Volume average beta	4.1%
Plasma current, I_p	3.5 MA
Fusion power, P_f	2 GW
Ave. neutron wall loading, Γ_n	2.0 MW/m^2
Max. neutron wall loading (assumed)	3.0 MW/m^2

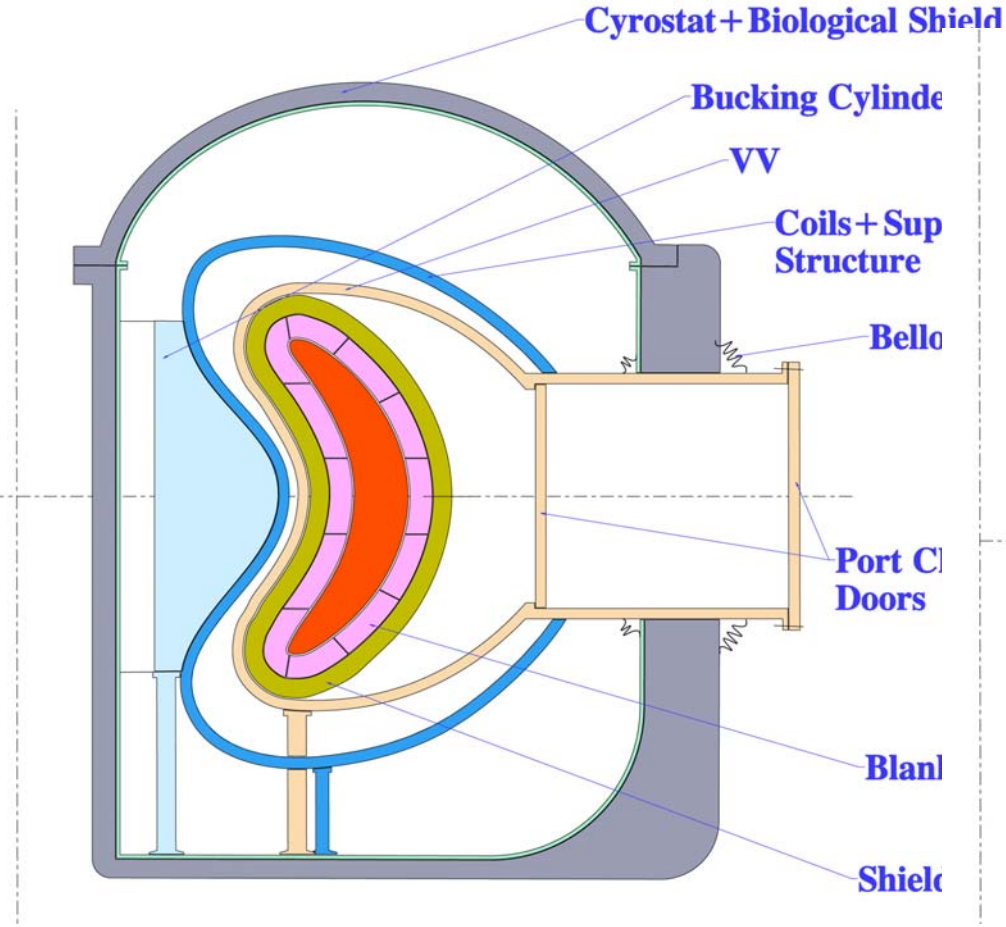
Cross Section of ARIES-CS Outboard Blanket/Shield (One Segment)



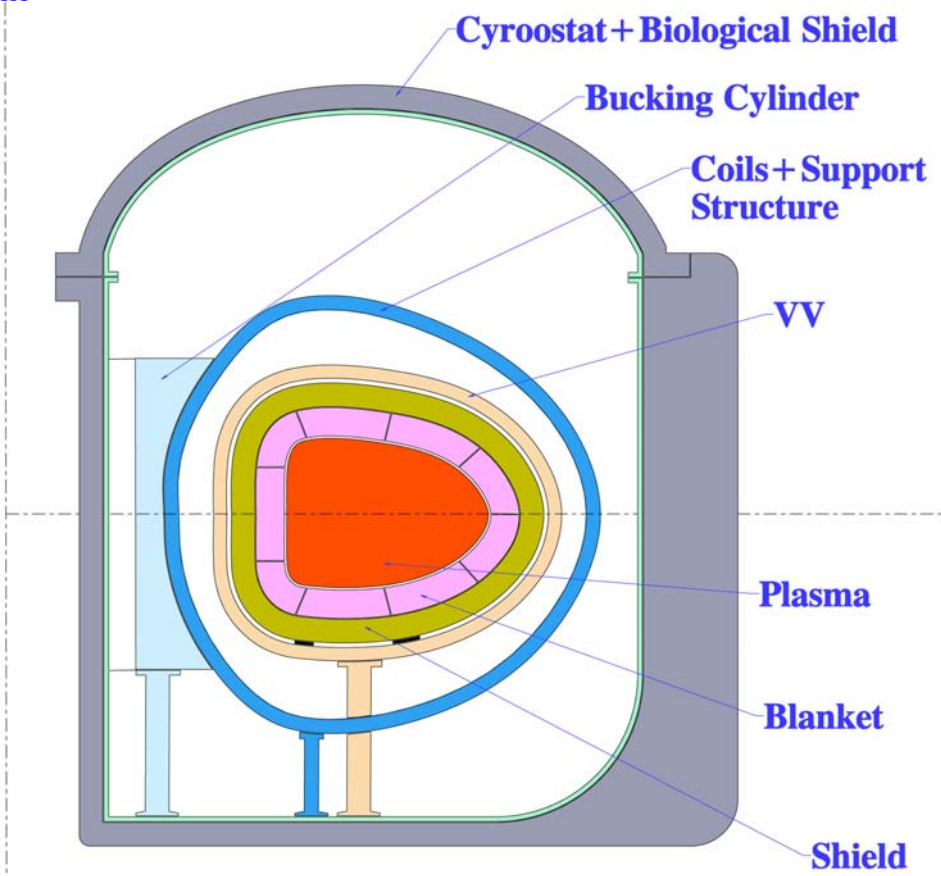
Vacuum Vessel Arranged Between Blankets and Coils

- **In this case, the VV serves as an additional shield for the protection of the coils from neutron and gamma irradiation. No disassembling and re-welding of the VV is required for blanket maintenance. Provisions for cutting and re-welding of the VV have to be made only for the very unlikely case that coils have to be replaced or the VV itself fails.**
- **Considering the non-uniform shape and size of the modular coils, the VV for a CS with three field periods is assembled from six sectors. The assembly welds are arranged at the largest cross-section (at 0°) and the smallest cross-section(at 60°). This allows toroidally sliding the VV sectors into the coils of the field period.**
- **There is some flexibility in designing the shape of the VV within the following cross section constraints:**
  - **It must fit into the modular coils + supporting structure.**
  - **The space inside the VV must be sufficient for placing the breeding blanket and shielding modules.**
- **Breeding blankets and shielding modules have to be attached to the VV, and provisions for the arrangement of coolant access tubes and manifolds have to be made.**

Schematic Illustration of Vacuum Vessel Arrangement Between Blankets and Coils



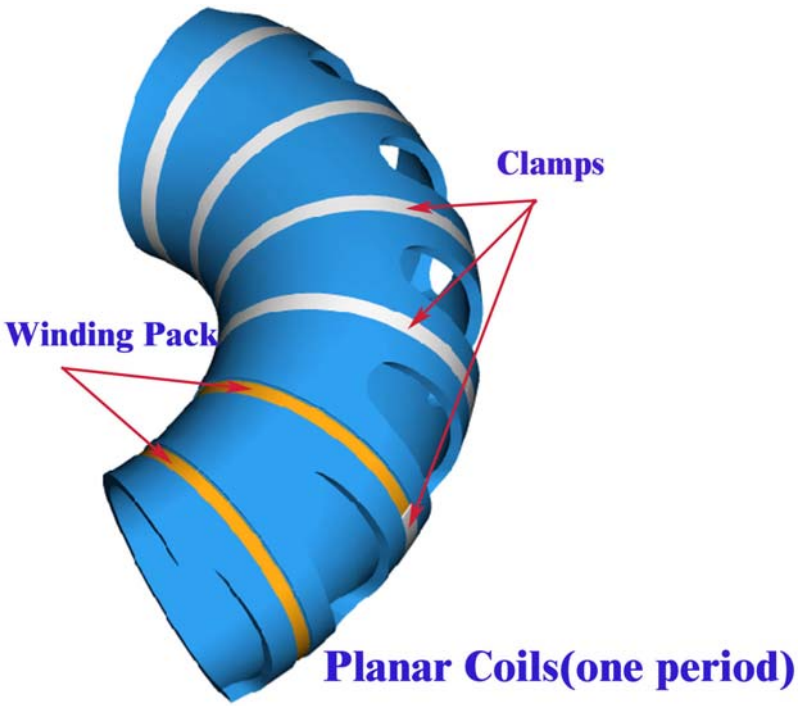
Cross section at 0°



Cross section at 60°

Coils of a Field Period Are Wound on a Common Supporting Structure

- **This design approach for the coil system has been previously described for the field-period based maintenance scheme.**



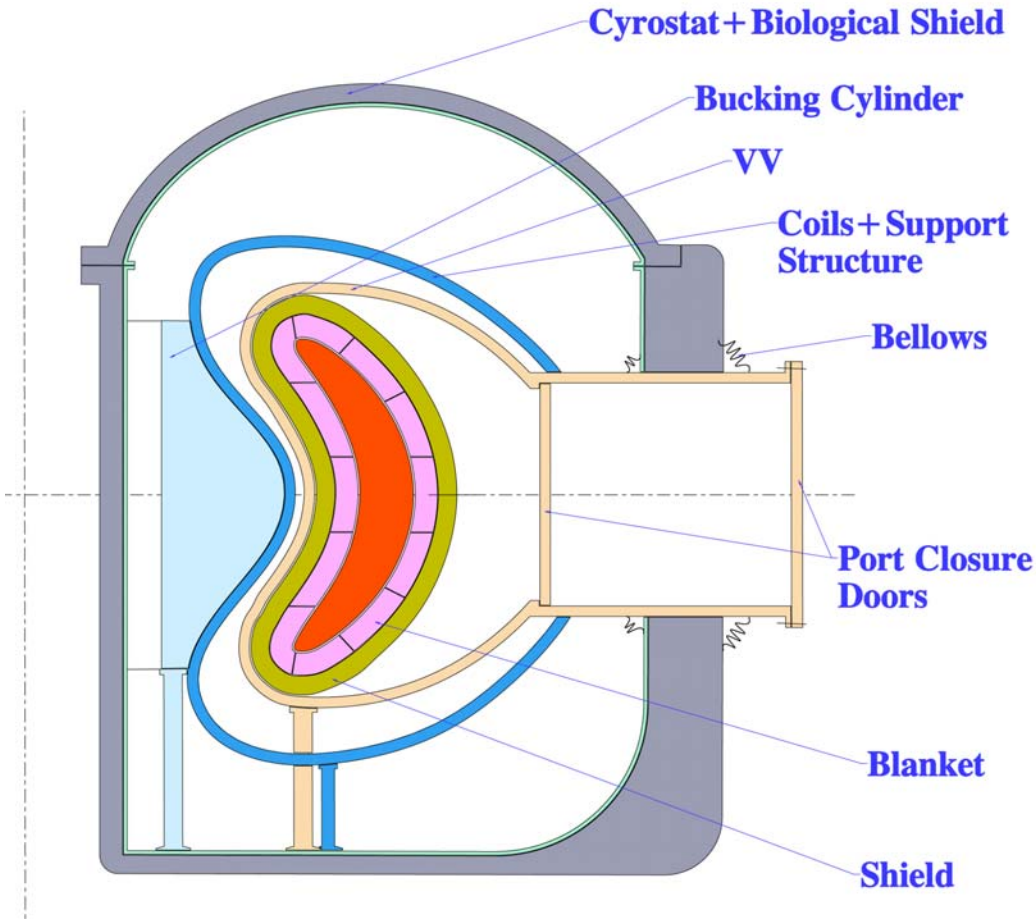
- **All out-of-plane forces are reacted inside the field period, and the centering forces are reacted by a strong bucking cylinder in the center of the torus.**

- **No separate cryostats for the different field period and the bucking cylinder are required since no disassembly is necessary for a blanket exchange.**

- **Thermal isolation between the cold coil+inter coil structure and the warm VV has to be provided.**

External Cryostat

- For thermal insulation, the entire coil system has to be enclosed in a common cryostat.
- This cryostat can serve at the same time as a second containment for the tritium in the VV.
- The most cost-effective design maybe to build this large cryostat as a concrete vessel with an internal steel liner (for sealing and serving also as a biological shield).



Maintenance Ports Arranged Between Modular Coils

- **The optimum locations for these ports are the 0° cross-sections. This enables the maximum height of the ports and the articulated boom for module handling. In this case, the VV sections can be already fabricated with parts of the maintenance ports attached to it.**

- **The ports have to bridge the space between VV and external cryostat. Bellows at the connections between port and cryostat allow for differential thermal expansion. In order to maintain the double containment of tritium, there should be two doors of the port, one at the VV and one at the outside of the cryostat. Many details of this system are very similar to the solutions proposed in ARIES-RS.**

Summary

- **A CS layout for breeding blanket module replacement with an articulated boom is proposed with the following features:**

  - **Common support structure of all coils in an entire field period.**

  - **Internal vacuum vessel and entire coil system (composed of modular coils, inter-coil structure and bucking cylinder operating at liquid He temperature) enclosed in a common cryostat.**

  - **For the 3-field period configuration considered (with 6 coils per field period), it is proposed to have a maintenance port per field period at the 0° degree cross section bridging the gap between VV and cryostat.**

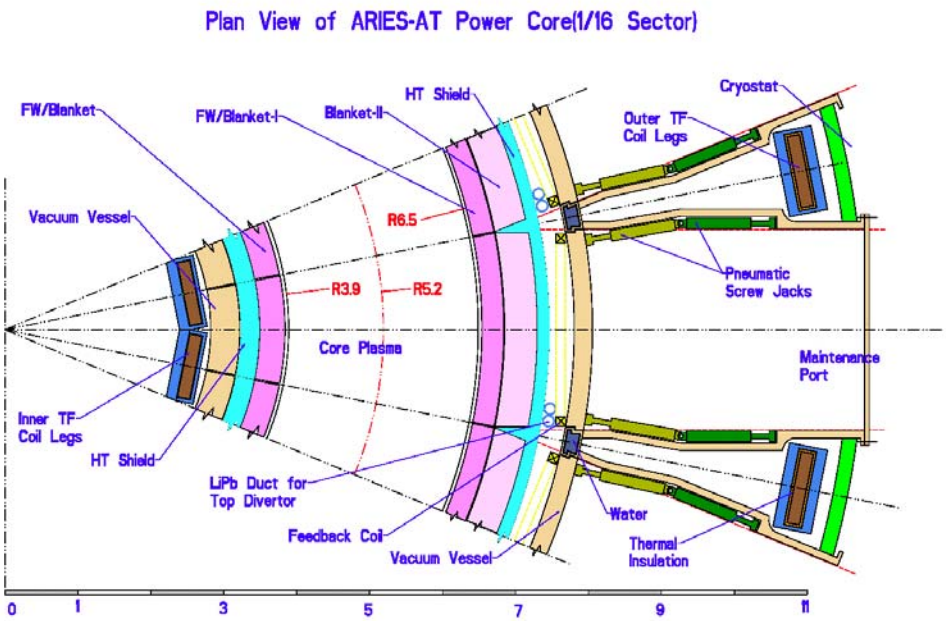
  - **VV and cryostat build a double containment system for tritium in the plasma chamber, which is maintained in the port area by two closure doors.**

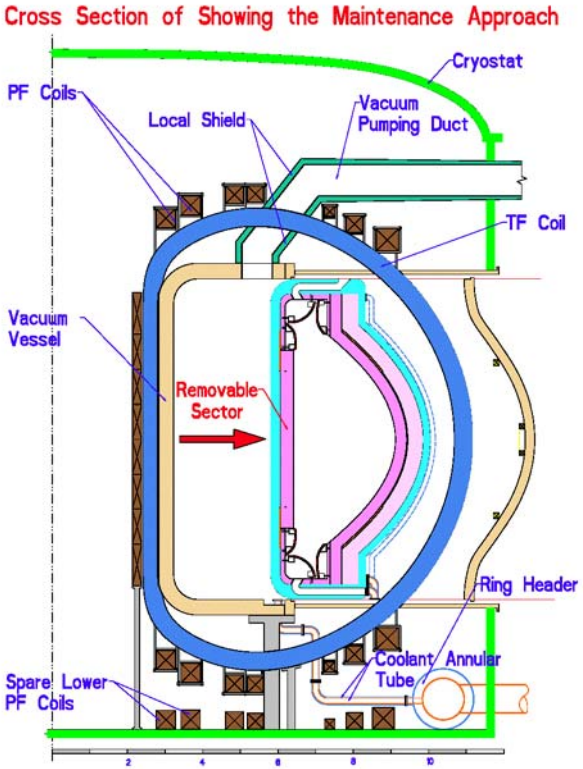
  - **The optimum shape of the VV and the possibility to fabricate the cryostat as a concrete vessel should be further evaluated.**

  - **The suggested layout can be extended to the maintenance method with blanket module replacement through maintenance ports arranged between each pair of adjacent modular coils.**

Another Possible Maintenance Scheme for 2-field Period Configuration?

Is a Sector-Based Maintenance Approach on a Per-Coil Basis (as for ARIES-AT) Possible for a CS Configuration





- **Midway between a modular maintenance approach and a field-period based maintenance approach**
  - Reasonably-sized component to be removed as compared to field period based approach
  - Disassembly of replacement unit done out side reactor and does not require articulated boom as for modular approach
- **Is it at all possible for a CS configuration?**
  - Is there enough space between each pair of adjacent coils to remove a sector unit?

2-Field Period Configuration (example case from J. Lyon based on P. Garabedian's Configuration)

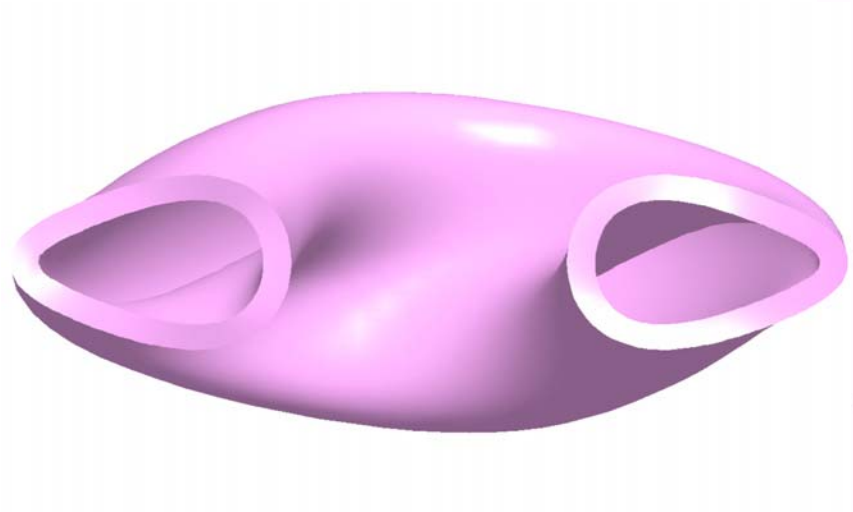
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

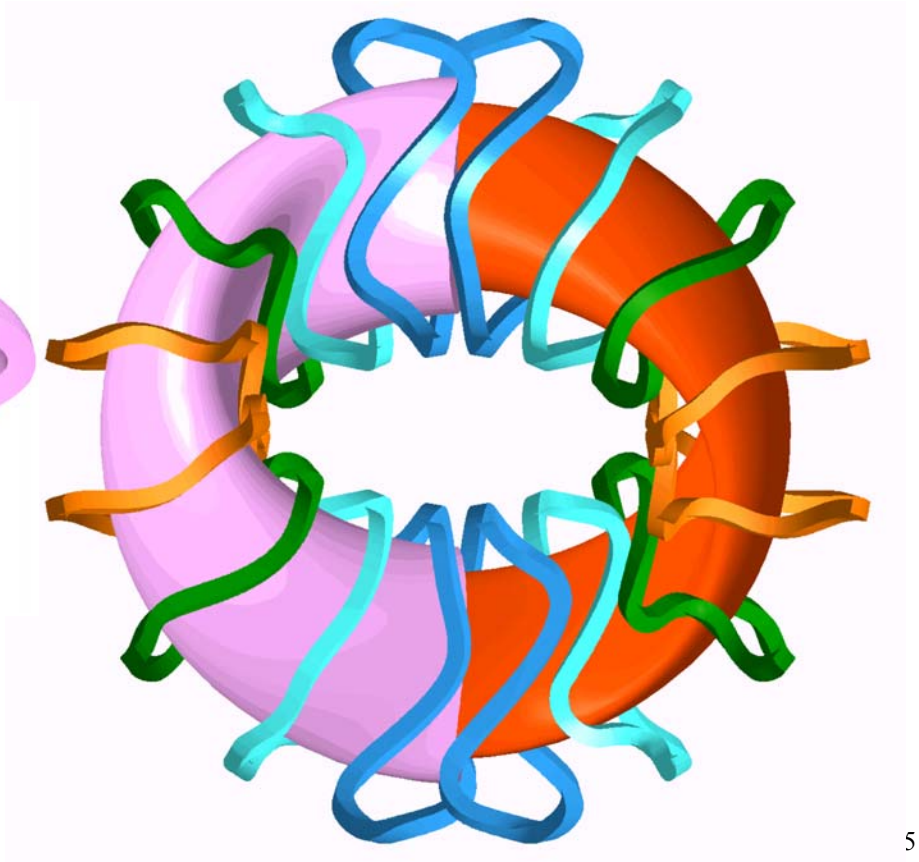
R = 6.62 m
B (axis) = 6.55 T
<β> = 4.47%
16 coils (8 per period)
Coil pack dimension = 40 cm x 40 cm
Fusion power = 2 GW
Plasma aspect ratio = 3.75

- **Jim has analyzed several cases both for the 3-field period and 2-field period configurations**
- **We need to choose a few cases to be used for the more detailed engineering analysis**
- **Port size estimates for several cases are shown later**

Maintenance Approach on a Per-Coil Basis for a CS Configuration: Setting the Problem

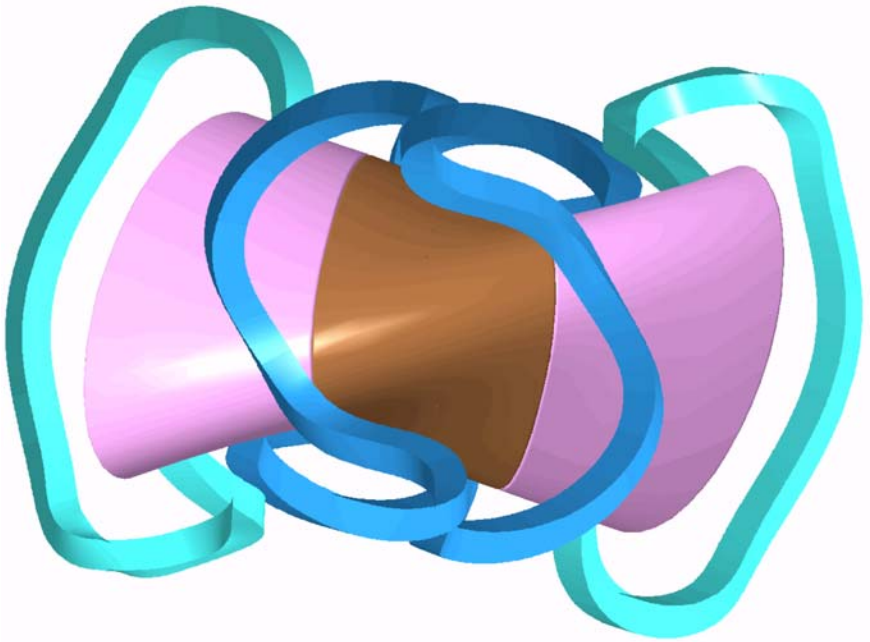
- **Assessment done for 2-field period configuration which provides the largest space between coils**
- R=6.62 m
- Schematic shown for limiting case with 60 cm blanket+FW and with shape following the plasma contour
- Actual case would require additional thickness for other components to be removed (hot shield)

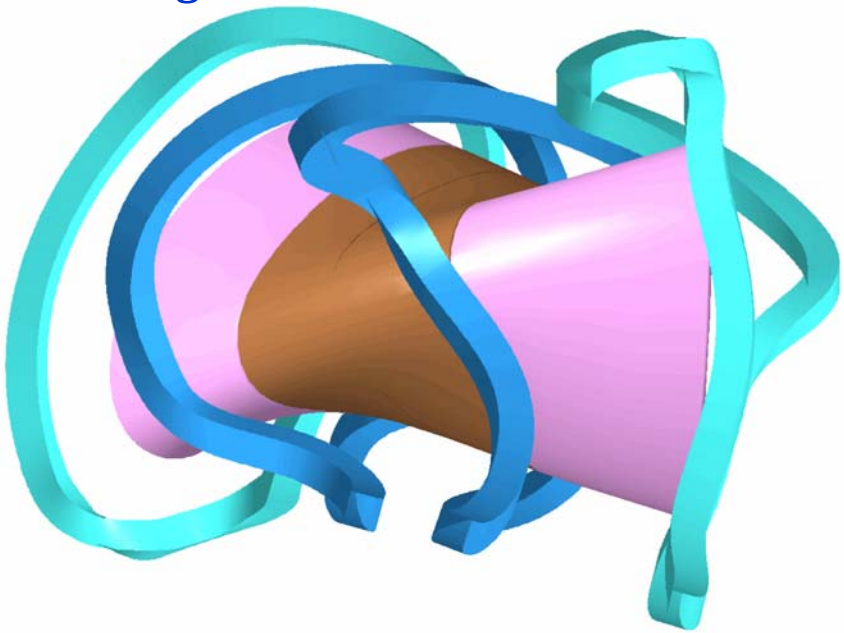




Clearance Between Coils is a Major Challenge for Sector Based Maintenance

8 sectors for 2-field period configuration





- **Clearly even for this limiting case, there is a major clearance problem for this maintenance scheme for R=6.62m (or in this range)**
- **Considering the need to add ~0.4 m (or more) for shield, such a scheme would only work for a very large reactor**
  - **More amenable if sector further divided (e.g. in three toroidal subsectors)**
  - **At present low priority effort on estimating minimum size reactor for application of such as scheme**
  - **Effort could be expanded if system study results point to larger reactor (>10 m)**

Available Port Dimensions for Several Cases

Comparison of Horizontal Port Access Area Between Adjacent Coils for Different Configurations

Horizontal space available between coils,
toroidal dimension x poloidal dimension (m x m)

Port / Configuration	Port #1	Port #2	Port #3	Port #4	Port #5	Port #6	Port #7	Port #8
NCSX-like 3-field period R=8.25 m	2.3 x 11.0	1.5 x 10.2	1.2 x 5.0	2.0 x 3.0	3.5 x 3.6	2.2x10.5		
R=9.68 m	2.8 x 12.8	1.8 x 11.9	1.4 x 5.9	2.4 x 3.6	4.1 x 4.2	2.6x12.3		
R=6.1 m	1.8x8.3	1.1x7.7	0.9x3.8	1.5x2.3	2.6x2.7	1.7x7.9		
2-field period R=8 m*	3.9 x 10	4.1 x 8.9	4.3 x 5.4	3.8 x 4.6	4.7 x 5.0	3.9 x 7.9	3.9 x 10.0	4.7 x 10.9
R=6.62 m	3.2 x 8.2	3.4 x 7.4	3.5 x 4.5	2.5 x 3.8	3.9 x 4.1	3.3 x 6.5	3.3 x 8.3	3.9 x 9.0
R=6.34 m	3.0 x 7.9	3.2 x 7.0	3.4 x 4.2	2.4 x 3.6	3.7 x 3.9	3.1 x 6.2	3.1 x 7.9	3.7 x 8.6

* Assuming a coil cross-section of 0.57 m x 1.15 m

Future Work Includes:

- **More detailed system layout for module replacement scheme (to a level on par with what was done for field period-based maintenance replacement)**
  1. through restricted number of ports
  2. through ports between every pair of adjacent coils

- **Evolve ceramic breeder blanket design**
  - Start with module configuration
  - Build on design work already done (e.g. EU He-cooled pebble bed blanket for DEMO)

- **Getting ready to converge on one maintenance scheme and example design for given reactor configuration for more detailed study this year**
  - e.g. Modular design (with ceramic breeder blanket?) for 2-field period configuration based on modular maintenance scheme
  - e.g. Larger blanket replacement unit (with dual-cooled or self cooled liquid breeder?) for field-period based maintenance approach for 3-field period configuration
  - More detailed and focused study of layout scheme could then be performed, such as designing the local variation in blanket and shield thickness (and materials) for field period-based maintenance approach
  - Try to achieve this by the next ARIES meeting or so
  - Must include close interaction between engineering, system and coil design (physics)
  - Need information on divertor location and heat loads to evolve design compatible with choice of blanket and coolant