3-D Assessment of Neutron Streaming Through Assembly Gaps: Outboard Options

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Background Info and Concerns

- Straight assembly gaps allow 14 MeV neutrons to directly stream between modules, reaching components behind blanket/shield, raising damage to unacceptable level.
- Previous assessments indicated stepped gaps alleviate streaming problems.
- Multiple step, zigzag gap is more effective.
- During operation, gaps will partially close gradually due to thermal expansion and neutron-induced swelling.
- Preliminary estimate indicated **2 cm gap** is reasonable for ARIES operating conditions.
- We examined:
  - Inboard assembly gaps (4/2009 presentation)
  - Outboard assembly gaps (work in progress).
- **Goal**: redesign assembly gaps with shielding block to reduce damage to the no-gap level (or below radiation limits).

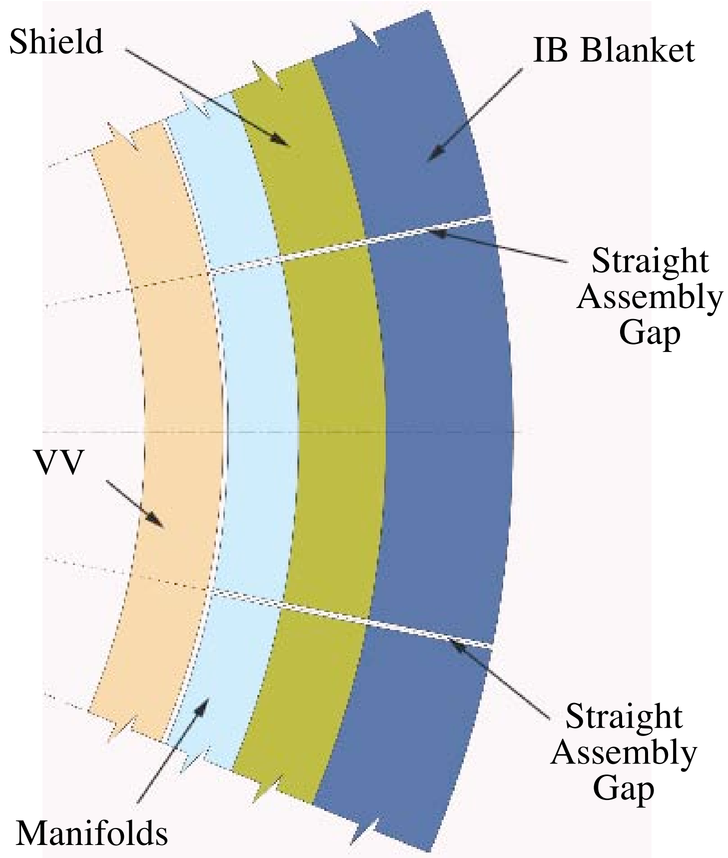
Inboard

Summary of Previous Results

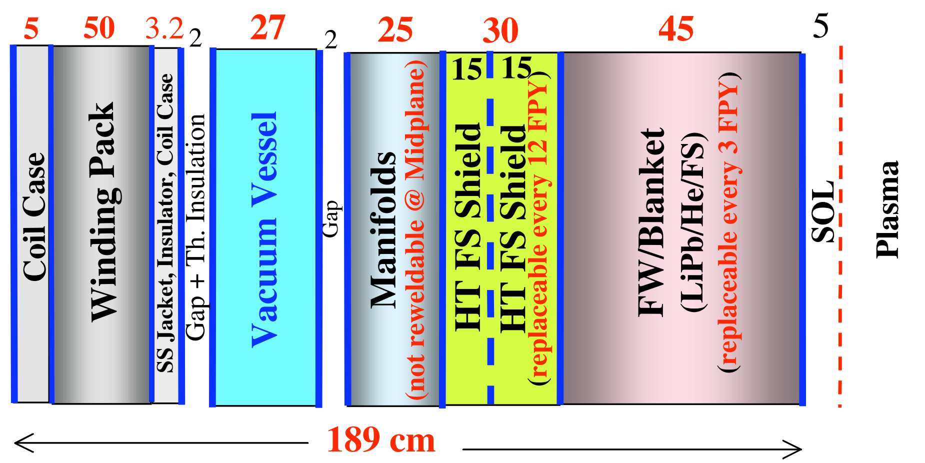
(4/2009 Presentation by Bohm/El-Guebaly)

Inboard Model with Radial Manifolds

(recent radial build has no manifolds near IB midplane)

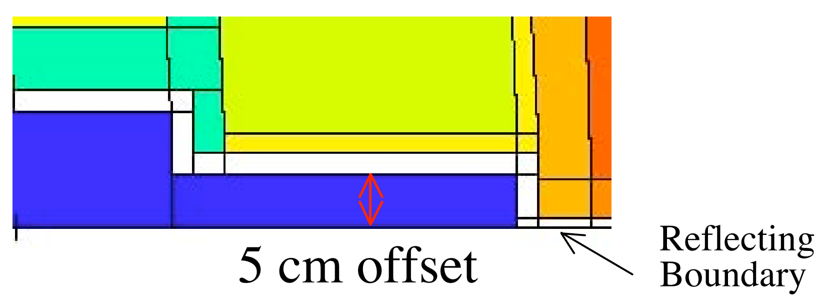


Midplane cross section of DCLL blanket system



We compared 3-D results for:

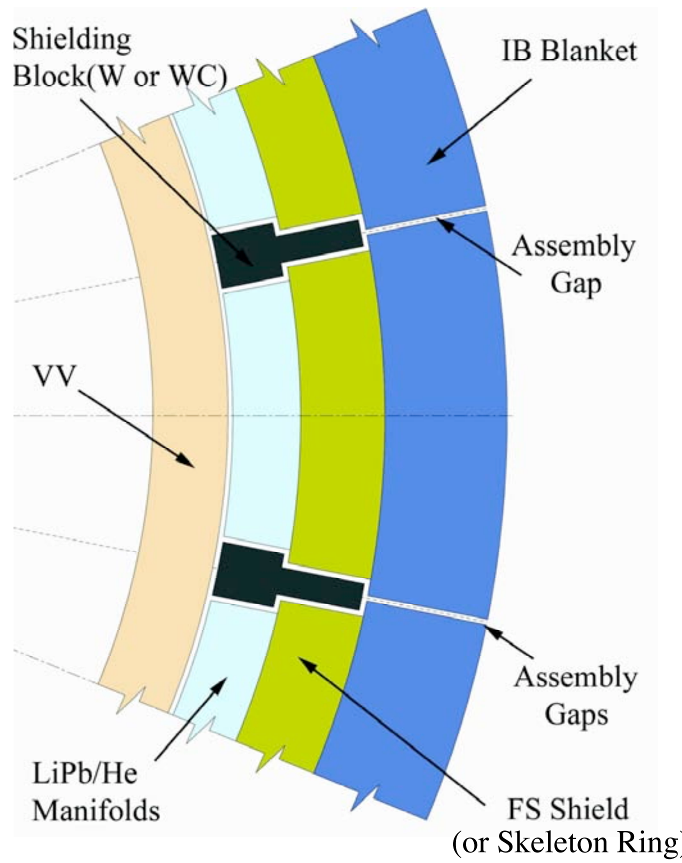
- **No** radial gaps
- 2 cm wide **straight** gaps
- 2 cm wide **double-step** gaps with **5 cm offset** - optimum based on ITER analysis*.



* T.D. Bohm, M.E. Sawan, P. Wilson, "Radiation Streaming in Gaps between ITER First Wall Shield Modules", *Fusion Science and Technology* 59 (2009) 731-735.

Novel Solution for IB Streaming Problem*

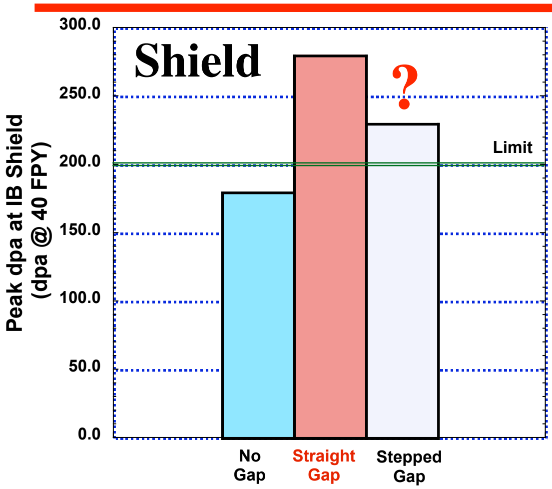
- Compatible solution with sector maintenance scheme.
- **Maintainable IB modules**:
  - Straight gap between blanket modules
  - Two-step gap from blanket to VV
  - WC shielding block within two-step gap to attenuate streaming neutrons.
- Per Malang, W-based shielding block can be:
  - Attached to VV
  - Radiatively cooled if average nuclear heating < 15 W/cm^3 and T > 1000^{o}C.
- For **average** IB NWL of 2.6 MW/m^2, calculated average nuclear heating ~2.5 W/cm^3 (<< 15 W/cm^3).
- Wang's thermo-mechanical analysis indicated T_{max} ~1220^{o}C (?) and acceptable thermal stresses (~170 MPa) for shielding block (8/2009 Presentation).

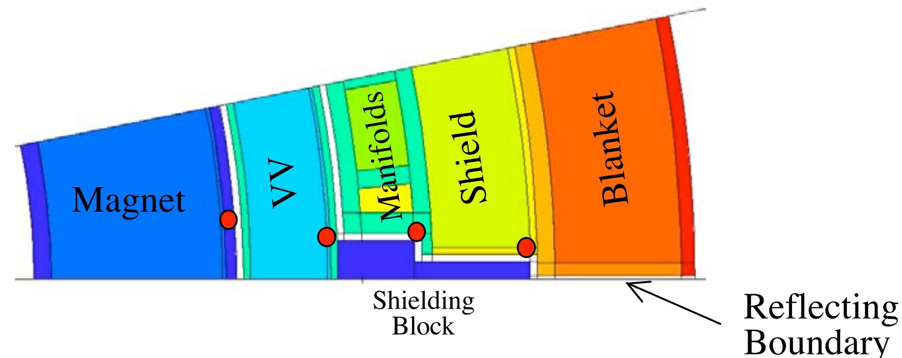


* T.D. Bohm, L.A. El-Guebaly, "3-D Assessment of Neutron Streaming through Inboard Assembly Gaps of ARIES Tokamak Power Plant," University of Wisconsin Fusion Technology Institute Report, UWFDM-1364 (June 2009). Available at: http://fti.neep.wisc.edu/pdf/fdm1364.pdf
To be presented at 19th TOFE.

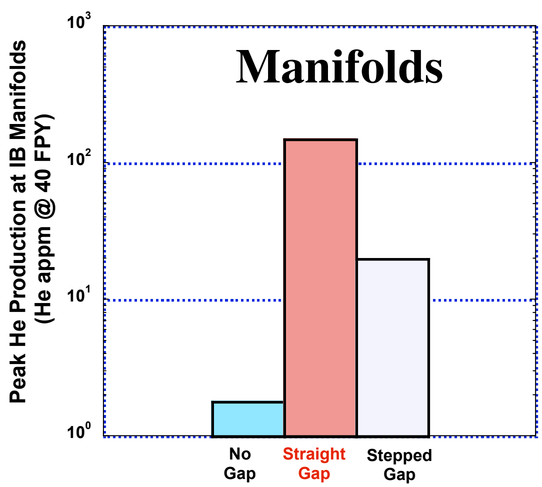
Summary of Inboard 3-D Results

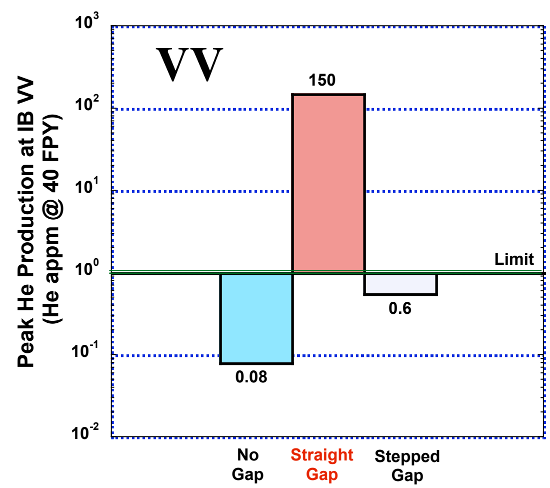
(2 cm Wide Gaps; Peak IB Γ = 3.4 MW/m^2)

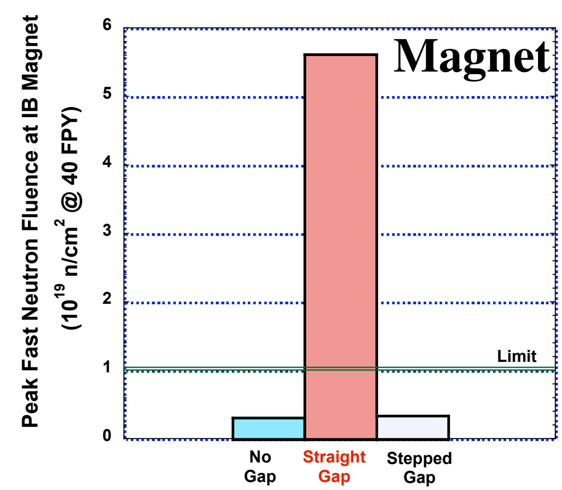




3-D model of half IB module





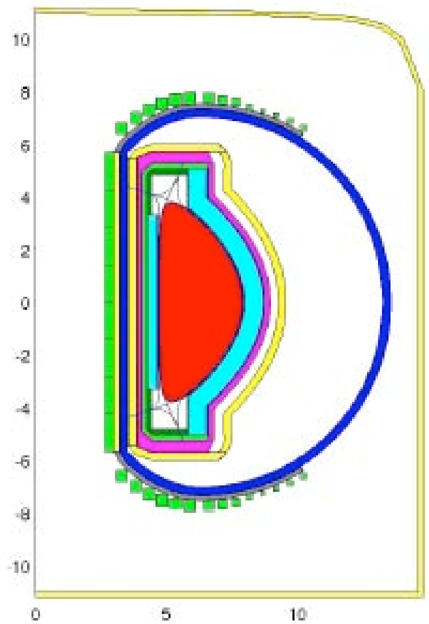


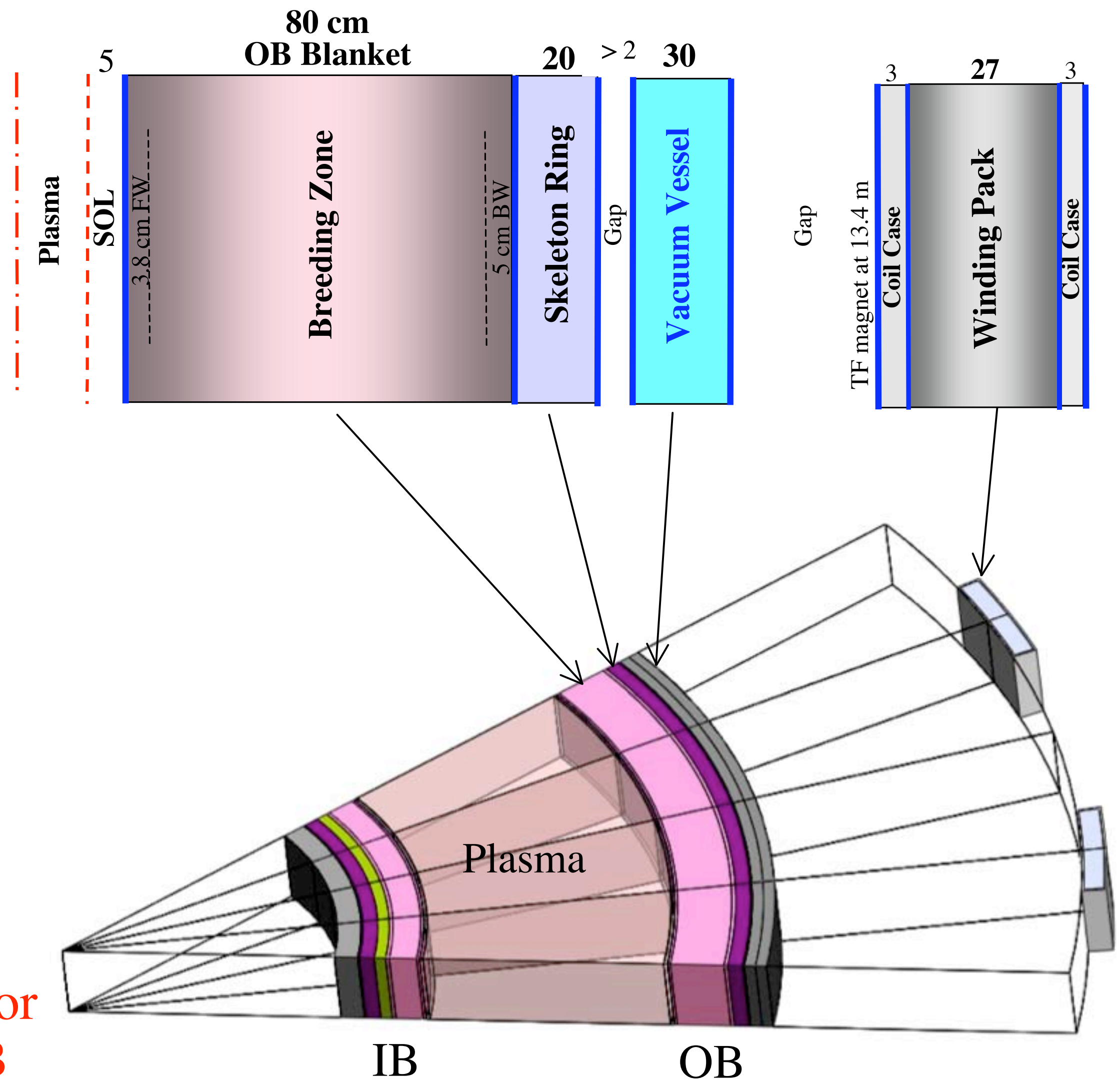
- Straight assembly gaps results in excessive damage and should be avoided.
- Stepped gaps with WC shielding blocks are effective in protecting IB components.
- Lower NWL and closure of gaps during operation help meet dpa limit at IB shield.

Outboard

ARIES-DB OB Radial Build

(Radial Cross Section Through Magnet)



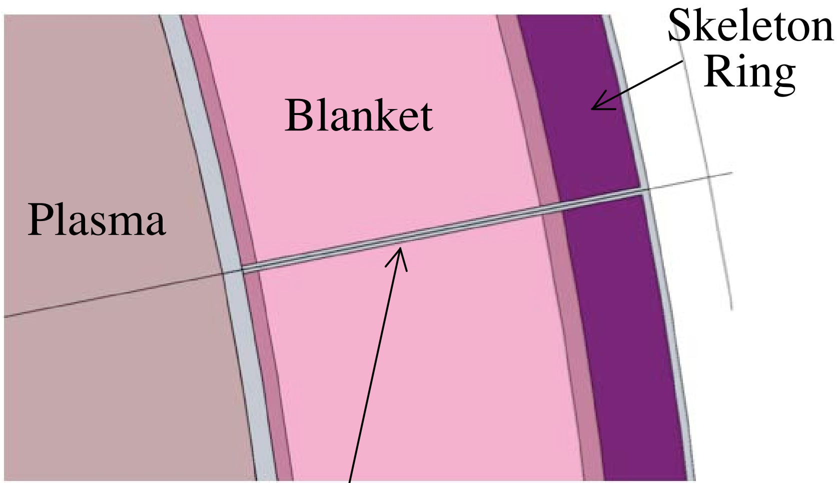


R = 6.4 m
a = 1.6 m
Peak OB NWL ~ 5 MW/m^2.
Per Wang:

- OB TF magnet @ 13.4 m to allow radial removal of Skeleton Ring
- Magnet toroidal width = 1.3 m.

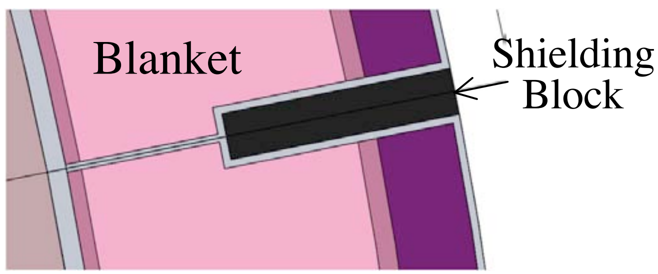
UW CAD Model for 1/8 of ARIES-DB

UW CAD Model for 3-D Streaming Analysis using CAD-MCNP Approach



2 cm **straight gap** from
FW to Skeleton Ring

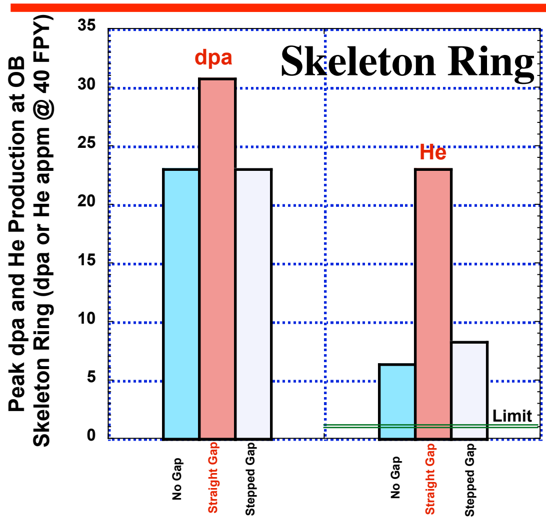
Single Step Gap

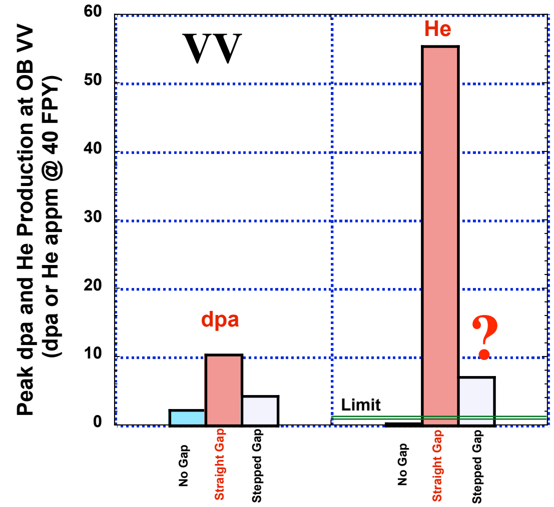


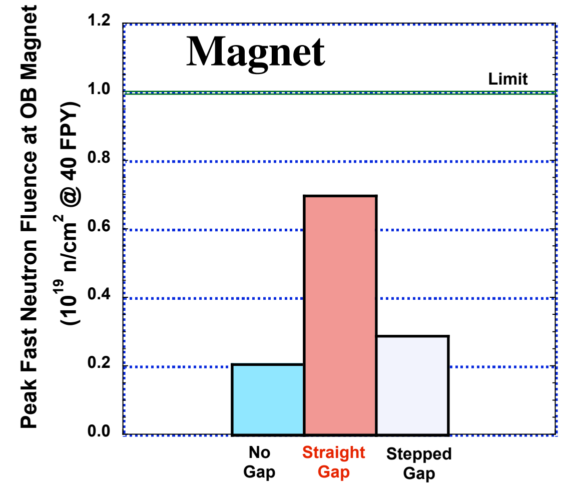
Good option to protect outer components, but
OB blanket cannot **not** be maintained with sector maintenance scheme

3-D Results for Straight and Single Step Gaps

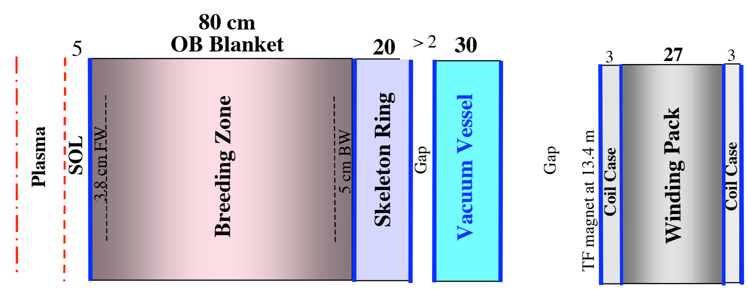
(2 cm Wide Gaps; Peak OB Γ = 5 MW/m^2)

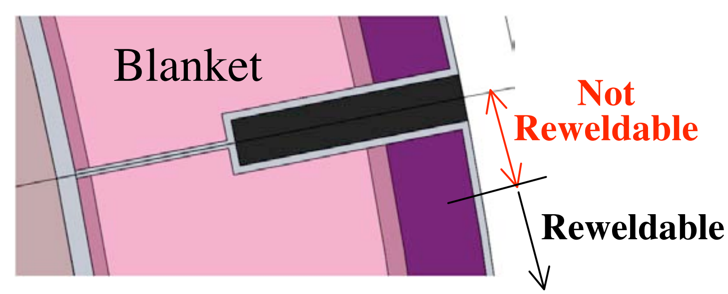




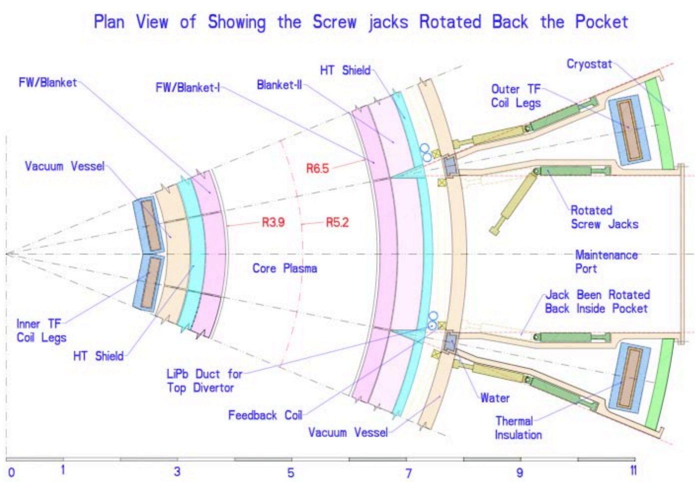


- Skeleton Ring, VV, and magnet are lifetime components even with straight gaps.
- However, straight gaps should be avoided to assure reweldability of VV
- Single step gaps with WC shielding blocks help reduce damage. VV and back of Skeleton Ring are reweldable at ~20 cm lateral distance from gap centerline
  - ⇒ Place **manifolds** at least 20 cm from gaps
  - ⇒ **Avoid** cutting/rewelding VV **behind** single step gaps.
- Redesign gaps to allow maintainable blanket.





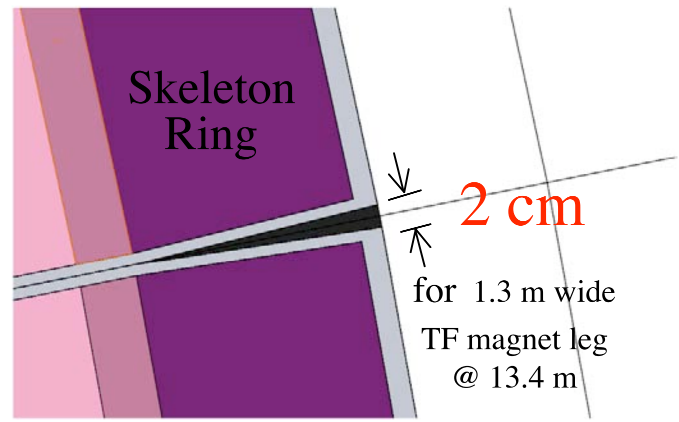
Alternate Option-I for OB Gaps



ARIES-AT

Wedge Shielding Block

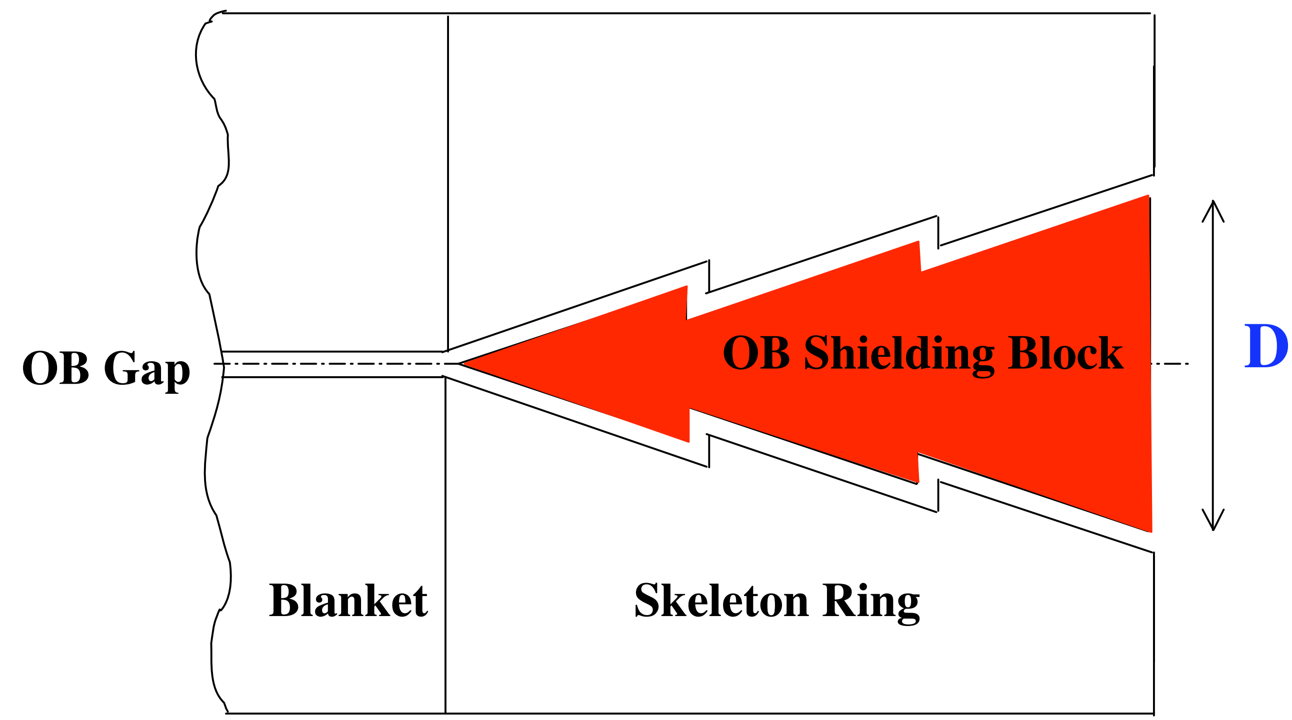
(ala ARIES-AT)



OB blanket is maintainable, but skinny wedge seems inadequate for attenuating streaming neutrons.

Alternate Option-II for OB Gaps

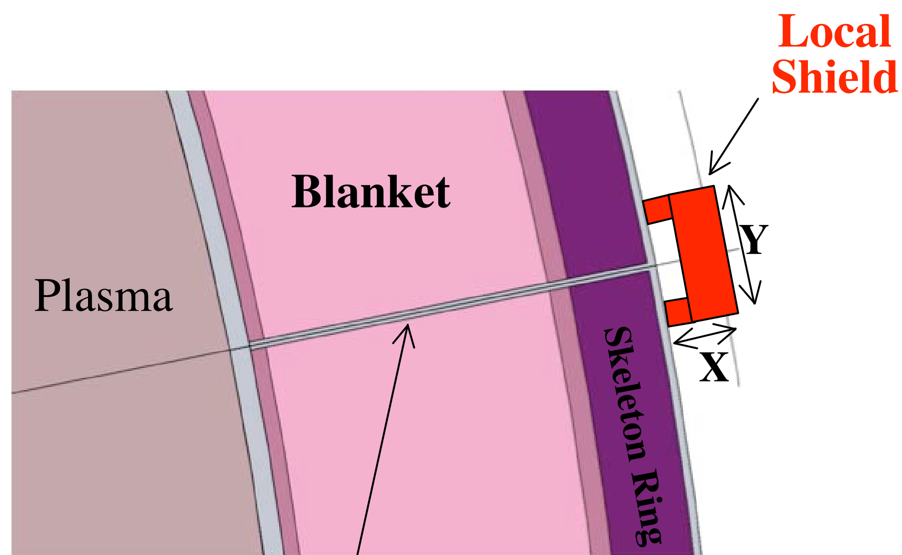
Two-step gaps



- Wedge dimension "D" can be optimized with 3-D streaming analysis.
- Larger "D" means:
  - Better attenuation for streaming neutrons
  - Outer legs of TF magnets can be moved inward, close to plasma (ripples?).
- Clearance?
- Attach to VV?
- Lifetime?

Alternate Option-III for OB Gaps

Local shield behind gaps



2 cm **straight gap** from FW to Skeleton Ring

- Local shield dimensions (X and Y) can be optimized with 3-D streaming analysis to determine lateral distance from gap where VV and back of Skeleton Ring are reweldable.
- Local shield should be removed before replacing blanket.
- Attach to Skeleton Ring?
- Lifetime?

Conclusions

- IB streaming problem is solvable with two-step gaps and WC shielding blocks.

- OB streaming problem seems solvable. Effectiveness of proposed options should be examined with 3-D streaming analysis and CAD modeling.