



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

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# Background Info and Concerns

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- **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).

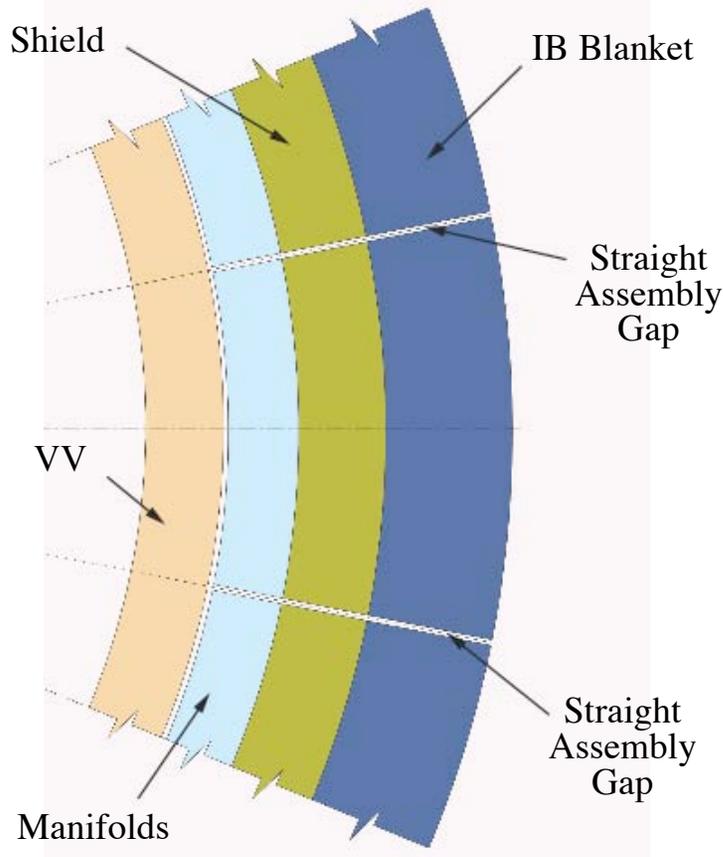
# Inboard

## Summary of Previous Results

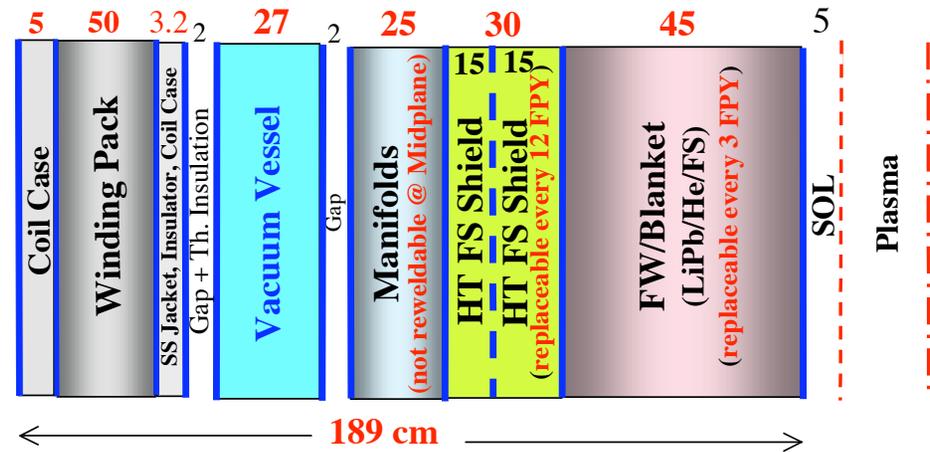
(4/2009 Presentation by Bohm/El-Guebaly)

# Inboard Model with Radial Manifolds

(recent radial build has no manifolds near IB midplane)

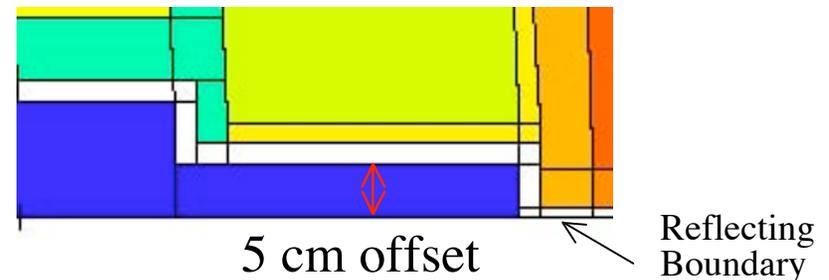


Midplane cross section of DCLL blanket system



We compared 3-D results for:

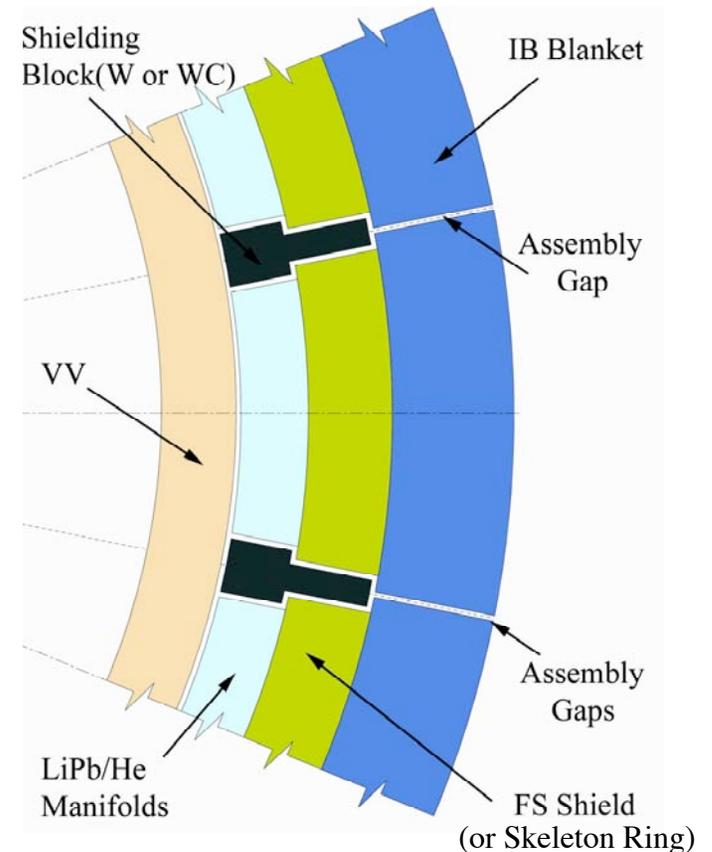
- No radial gaps
- 2 cm wide **straight** gaps
- 2 cm wide **double-step** gaps with **5 cm offset** - optimum based on ITER analysis\*.



\* 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\*

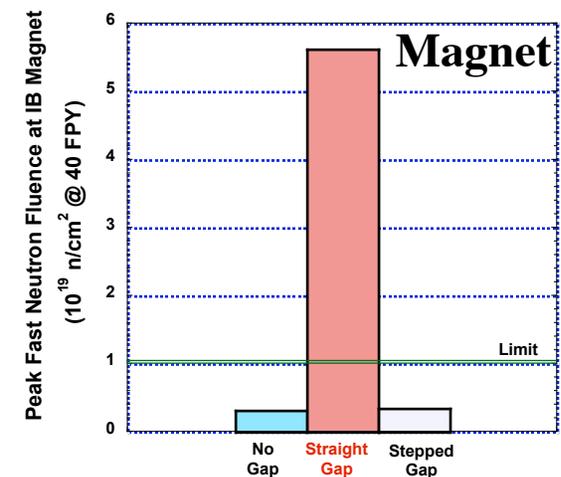
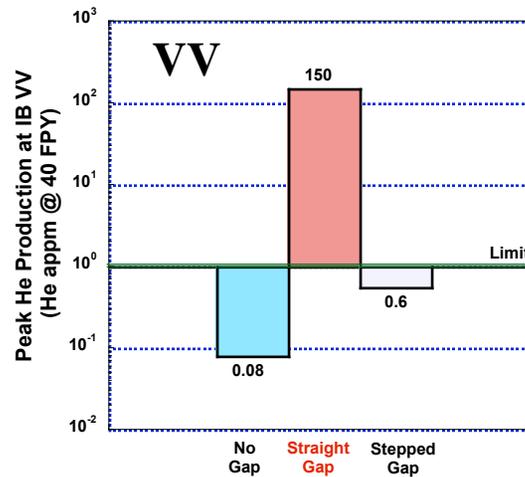
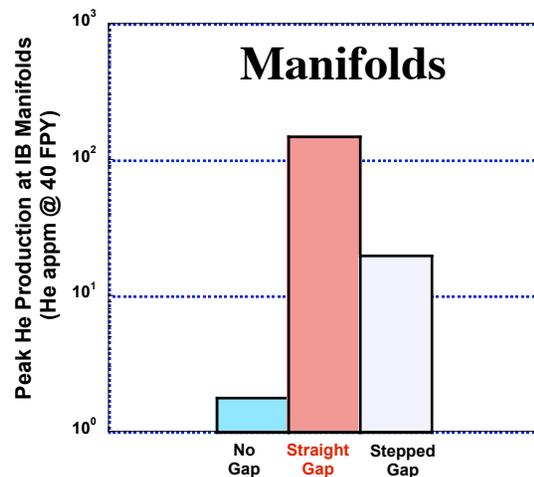
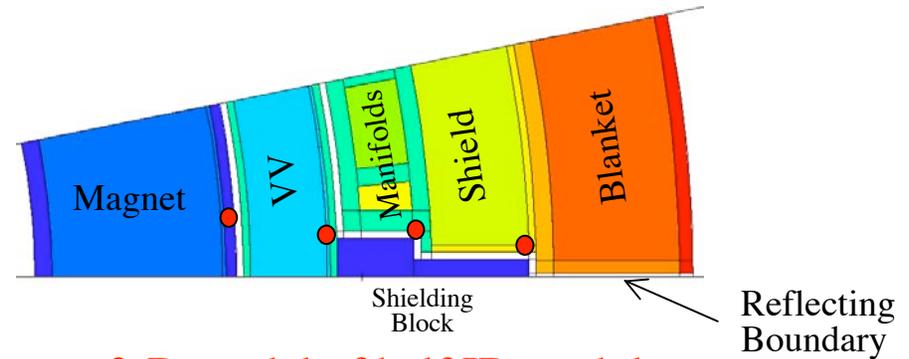
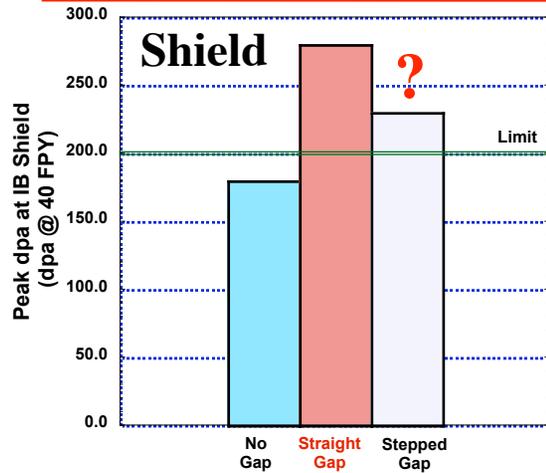
- **Compatible** solution with sector maintenance scheme.
- **Maintainable IB modules:**
  - Straight gap between blanket modules
  - Two-step gap from blanket to VV
  - WC shielding block within two-step gap to attenuate streaming neutrons.
- Per Malang, W-based **shielding block** can be:
  - Attached to VV
  - Radiatively cooled if average nuclear heating  $< 15 \text{ W/cm}^3$  and  $T > 1000^\circ\text{C}$ .
- For **average** IB NWL of  $2.6 \text{ MW/m}^2$ , **calculated average nuclear heating**  $\sim 2.5 \text{ W/cm}^3$  ( $\ll 15 \text{ W/cm}^3$ ).
- Wang's thermo-mechanical analysis indicated  $T_{\text{max}} \sim 1220^\circ\text{C}$  (?) and acceptable thermal **stresses** ( $\sim 170 \text{ MPa}$ ) 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, UWFDI-1364 (June 2009). Available at: <http://fti.neep.wisc.edu/pdf/fdm1364.pdf>  
To be presented at 19<sup>th</sup> TOFE.

# Summary of Inboard 3-D Results

(2 cm Wide Gaps; Peak IB  $\Gamma = 3.4 \text{ MW/m}^2$ )

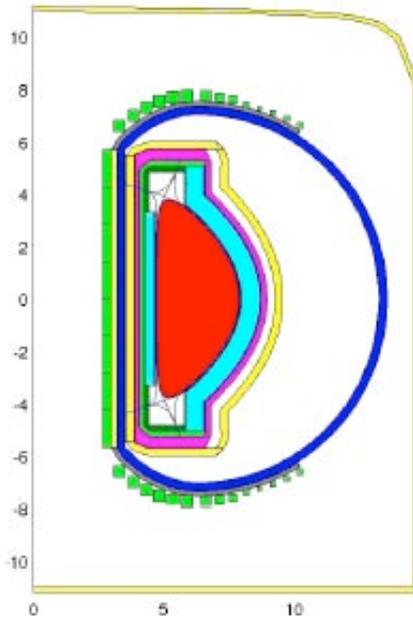


- **Straight** assembly gaps results in excessive damage and should be avoided.
- **Stepped** gaps with WC shielding blocks are effective in protecting IB components.
- **Lower NWL and closure of gaps** during operation help meet dpa limit at IB shield.

# Outboard

# ARIES-DB **OB** Radial Build

(Radial Cross Section Through Magnet)



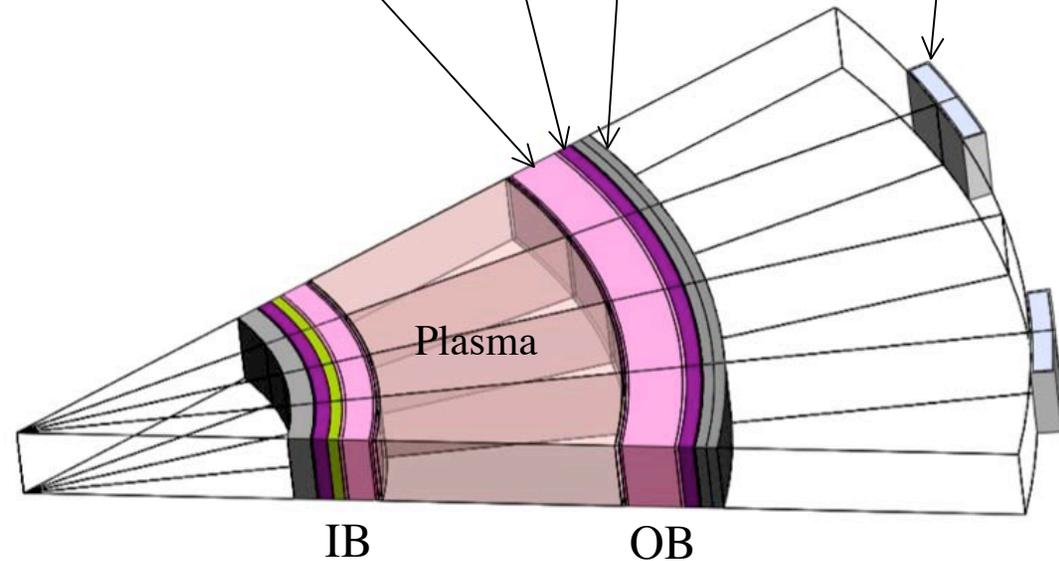
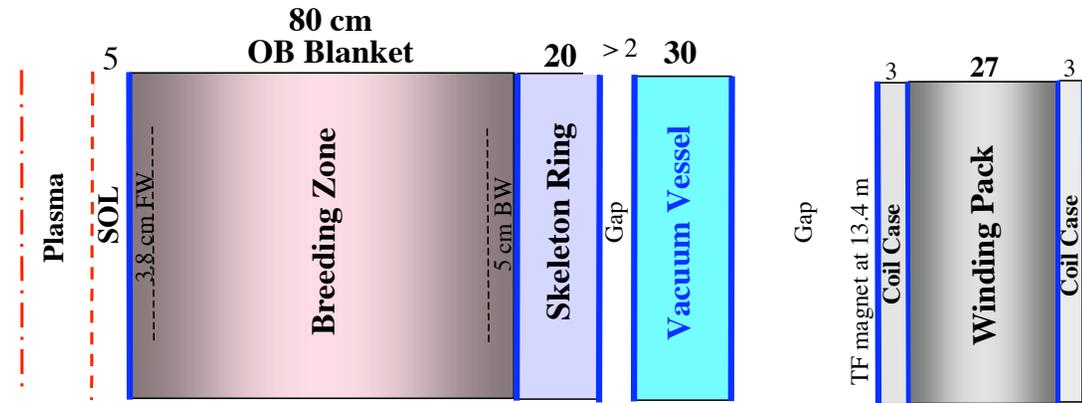
$R = 6.4 \text{ m}$

$a = 1.6 \text{ m}$

Peak OB NWL  $\sim 5 \text{ MW/m}^2$ .

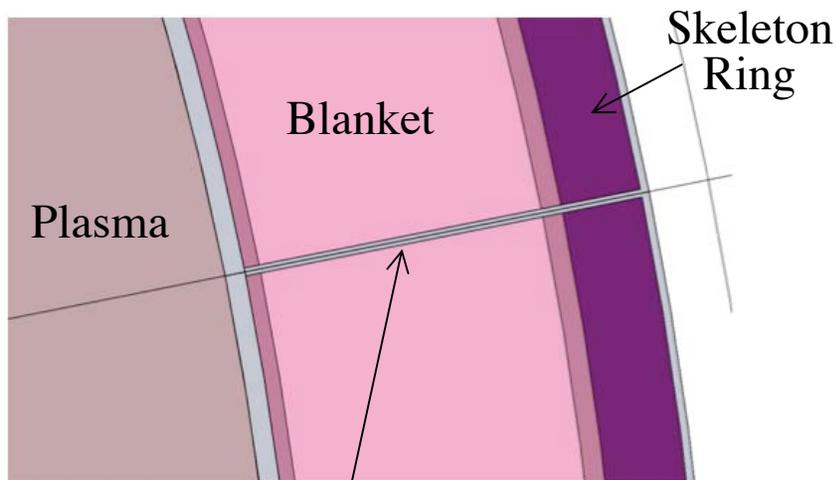
Per Wang:

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



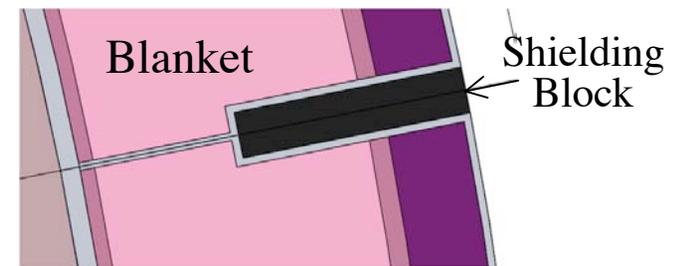
UW CAD Model for  
1/8 of ARIES-DB

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



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

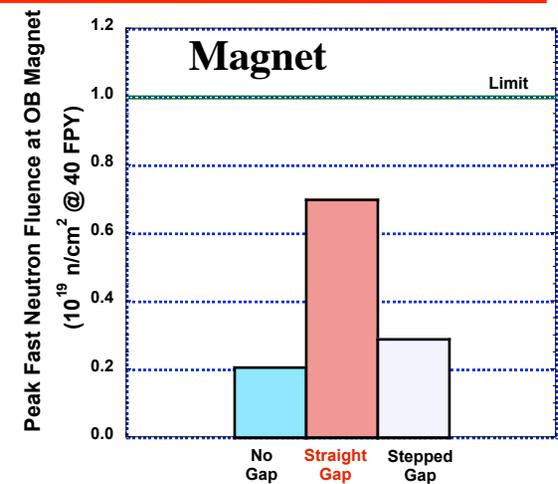
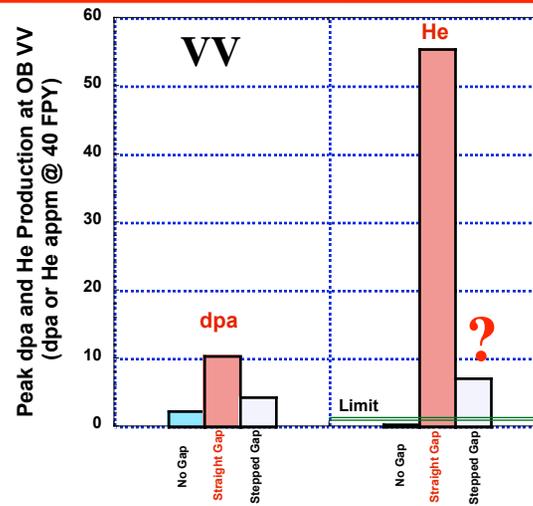
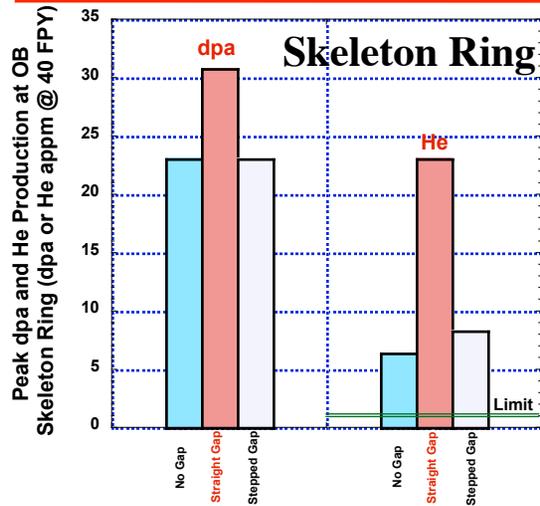
## Single Step Gap



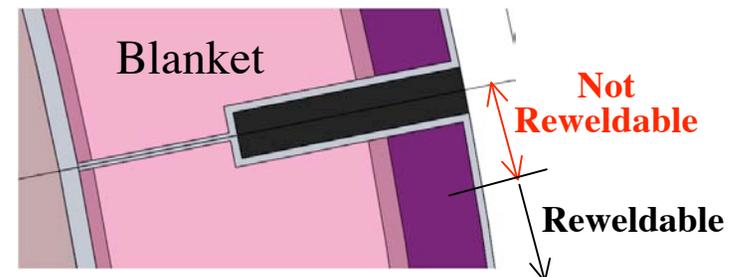
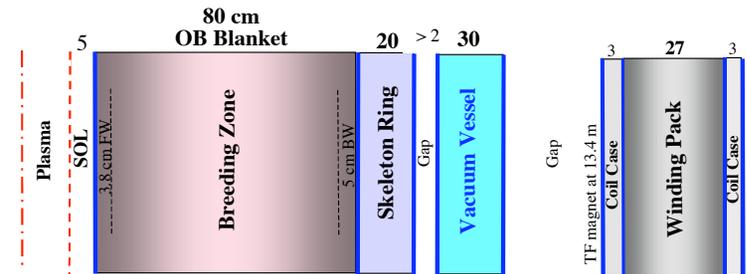
Good option to protect outer  
components, but  
**OB blanket cannot not be maintained**  
with sector maintenance scheme

# 3-D Results for Straight and Single Step Gaps

(2 cm Wide Gaps; Peak OB  $\Gamma = 5 \text{ MW/m}^2$ )

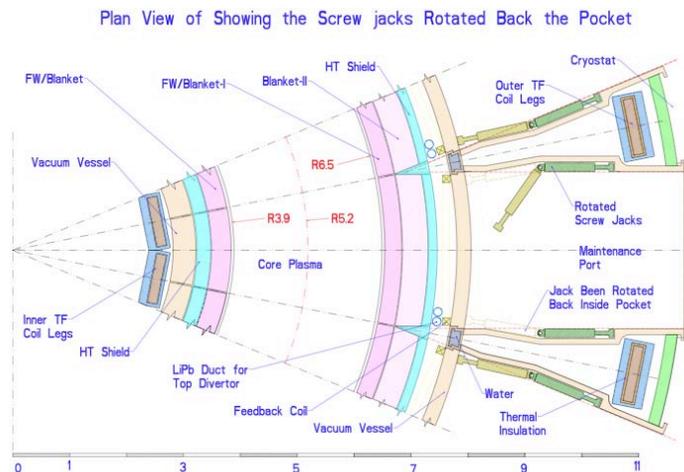


- Skeleton Ring, VV, and magnet are **lifetime components** even with straight gaps.
- However, **straight gaps should be avoided** to assure reweldability of VV
- **Single step gaps** with WC shielding blocks help reduce damage. VV and back of Skeleton Ring are **reweldable at ~20 cm lateral distance** 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.**

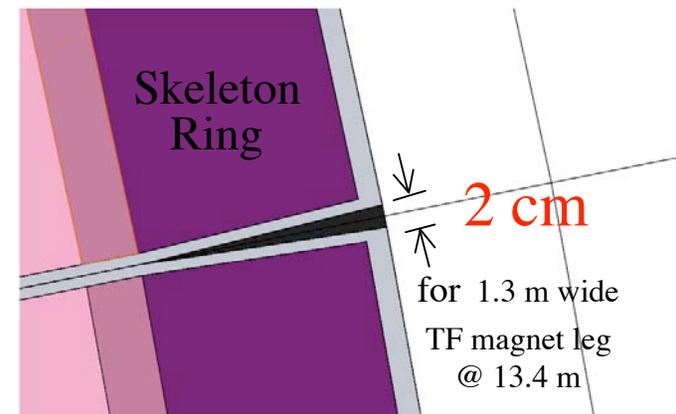


# Alternate **Option-I** for OB Gaps

## Wedge Shielding Block (ala ARIES-AT)



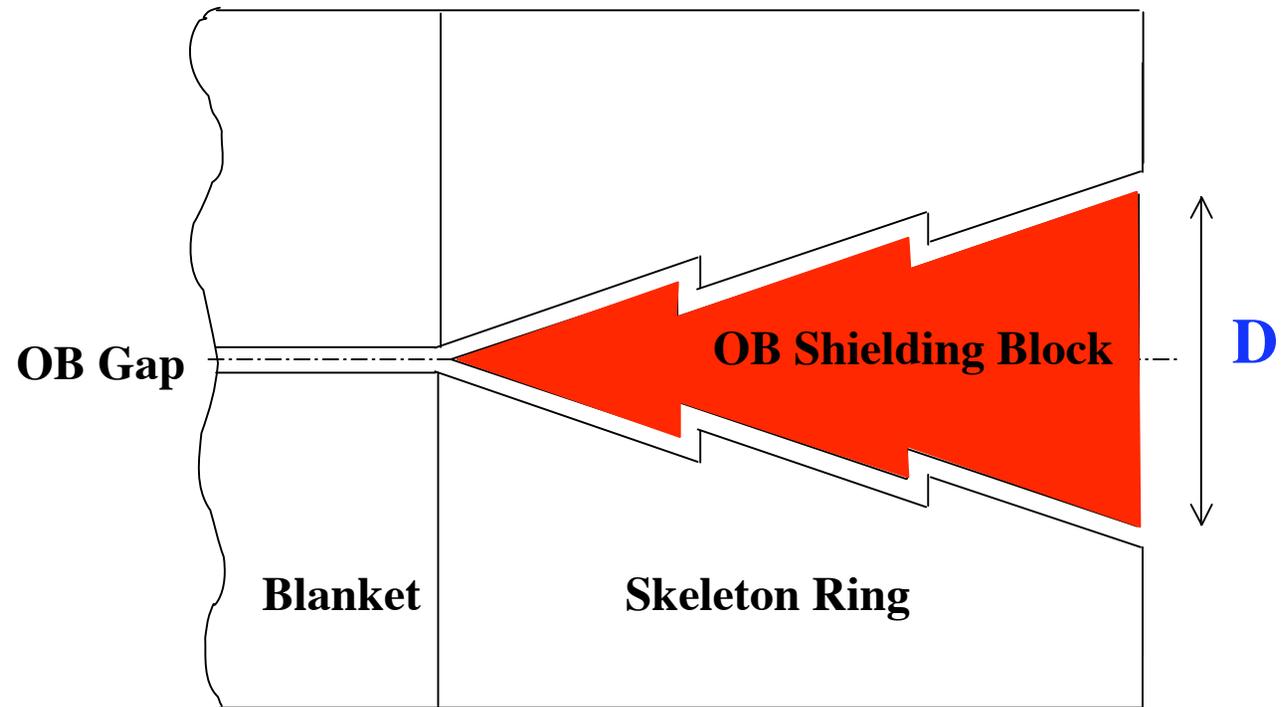
## ARIES-AT



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

# Alternate **Option-II** for OB Gaps

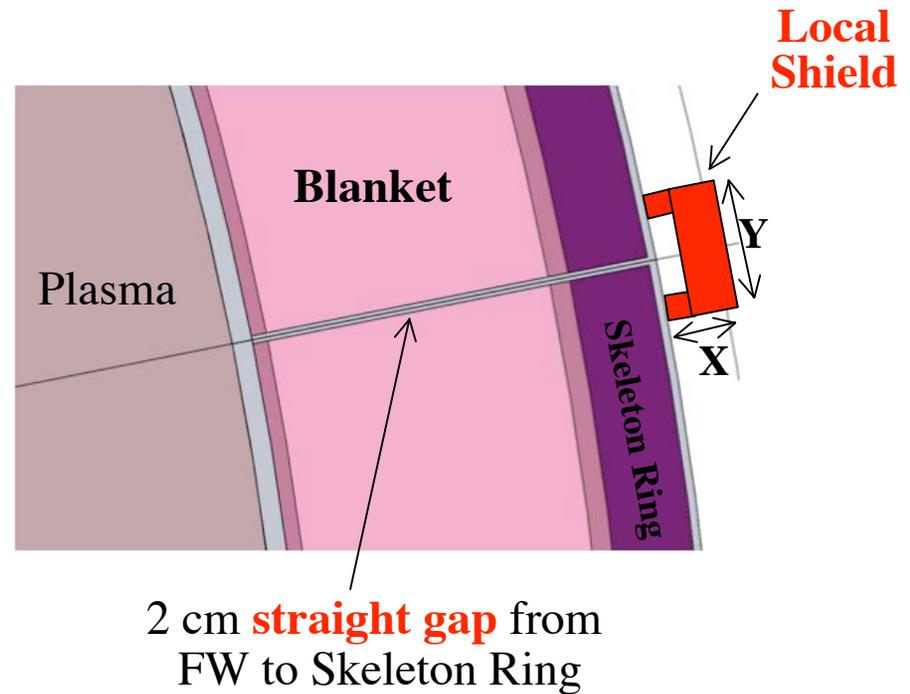
## Two-step gaps



- **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



- **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

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- **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.