ARIES-ACT-DCLL NWL Distribution and Revised Radial Build

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ARIES Project Meeting
Gaithersburg, MD
July 27 - 28, 2011

Neutron Wall Loading Distribution

ARIES-ACT-DCLL Parameters (aggressive physics)

Fusion Power	2767.5 MW
Major Radius	6 m
Minor Radius	1.5 m
Elongation	2.2

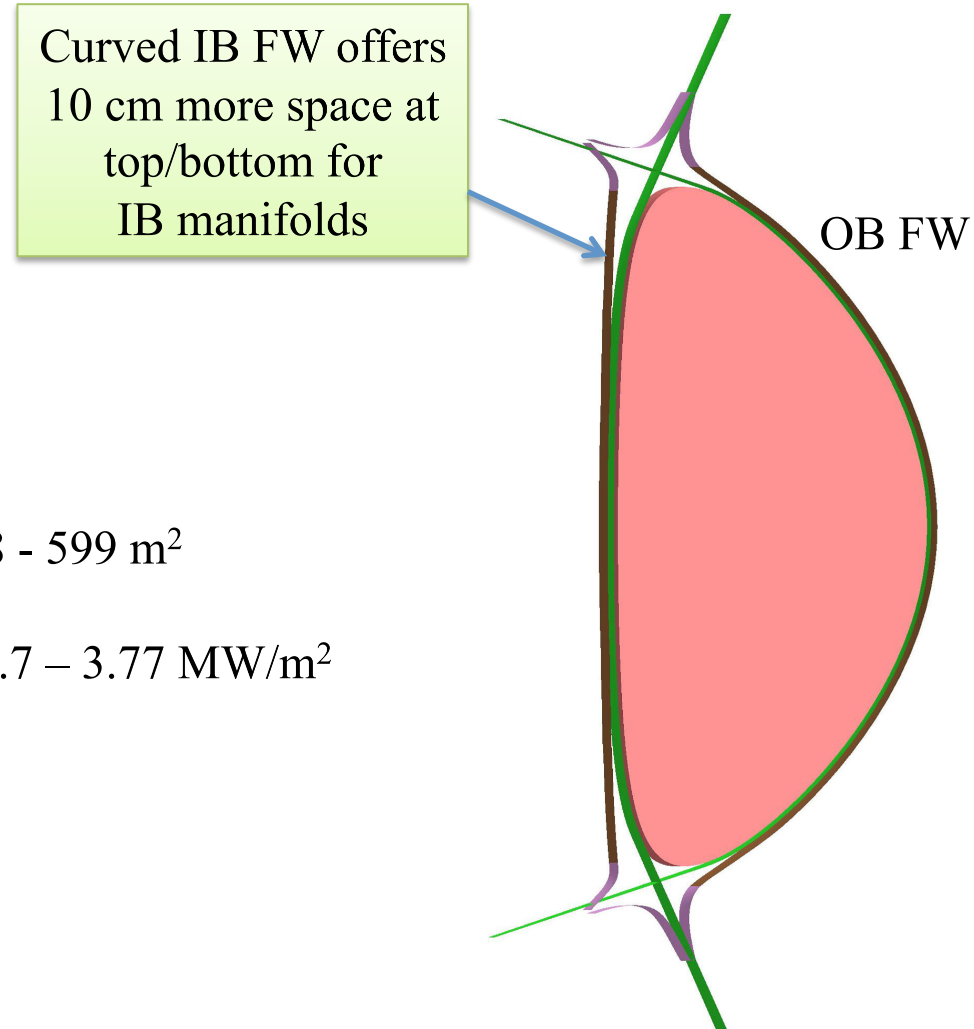
Plasma surface area = 565 m2

Surface area @ 10 cm from plasma = 588 - 599 m^2

Average NWL @ 10 cm from plasma = 3.7 – 3.77 MW/m^2

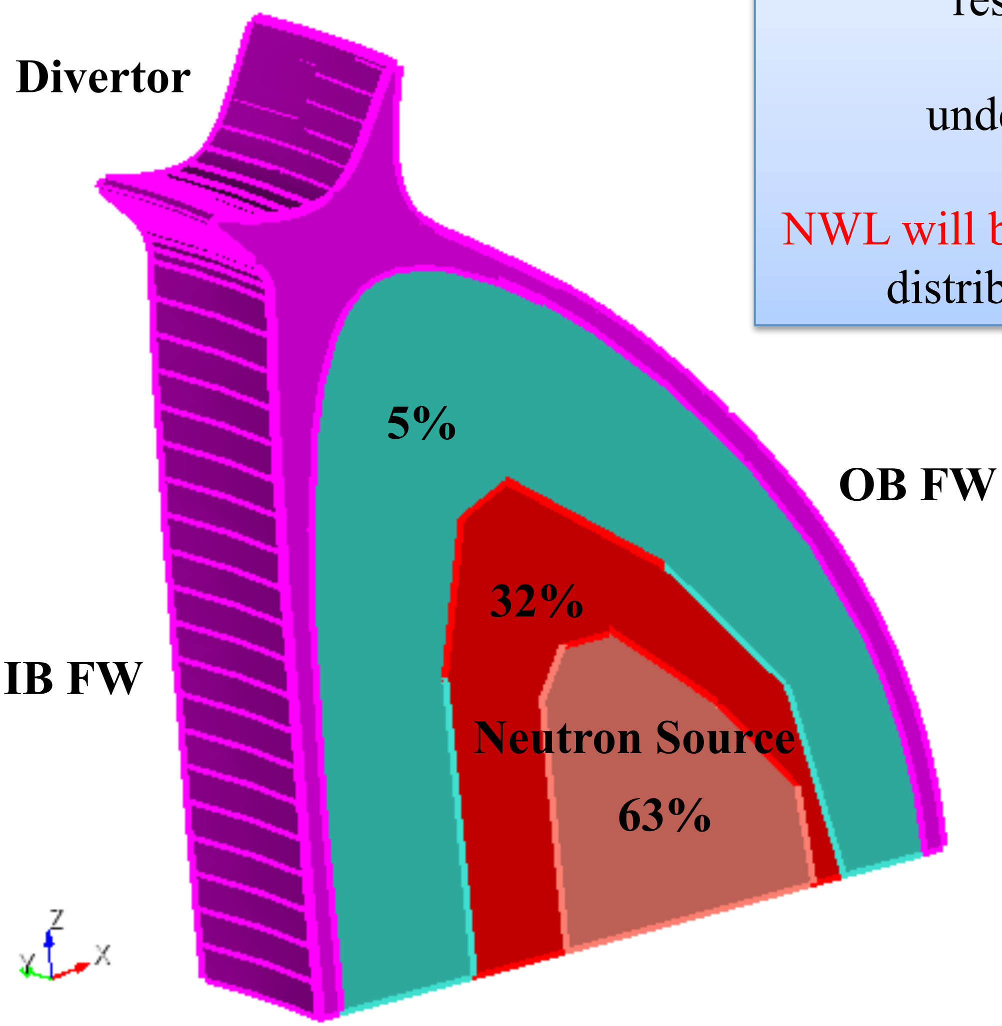
OB FW area = 350 m2

IB FW area = 180 m2



ARIES-ACT-DCLL FW and Div
(Courtesy of X. Wang (UCSD))

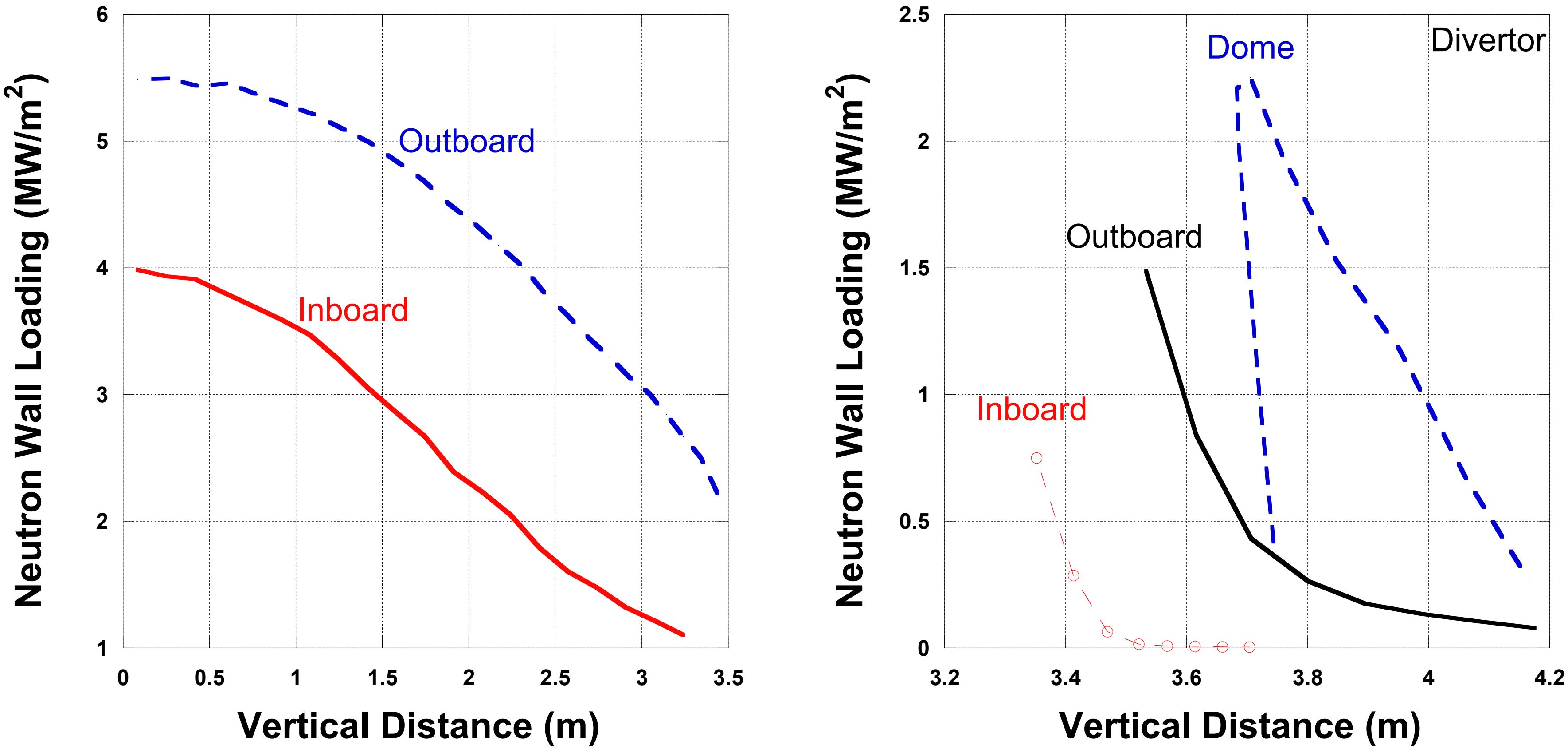
Neutron Wall Loading 3-D Model



<u>Approximate neutron source intensity</u>
results in exact OB and divertor
NWL distribution, but
underestimates peak IB Γ by 10%.

NWL will be updated using actual neutron source distribution on R-Z grid within plasma

NWL Distribution



Peak Γ @ IB	4 x 1.1 = 4.4 MW/m^2
Peak Γ @ OB	5.5 MW/m^2
Peak Γ @ Div	2.2 MW/m^2

Peak to av. NWL ≈ 1.5

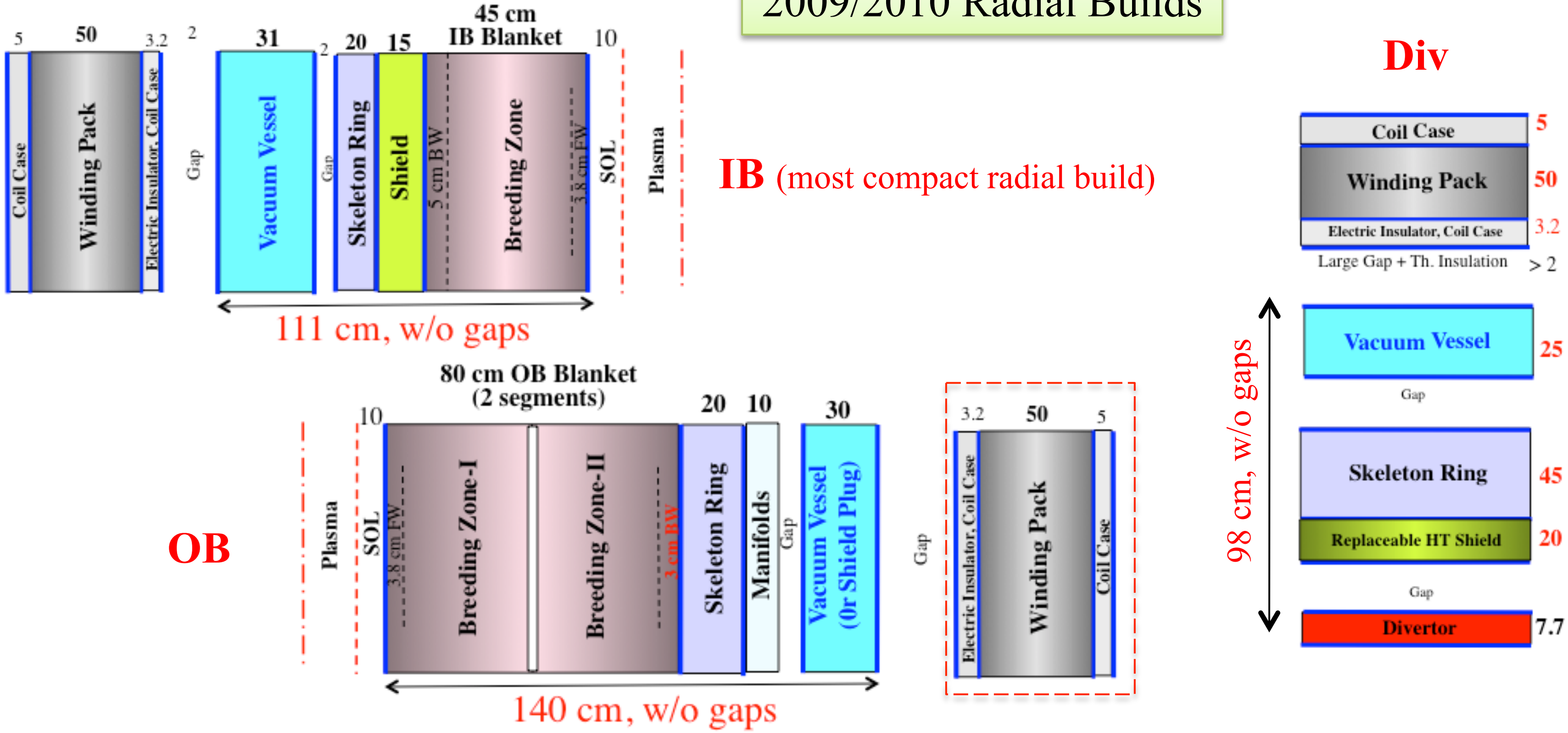
Too high for DCLL blanket, per S. Malang.

Revised Radial Builds:

- Inboard
- Outboard
- Divertor.

Initial Radial Builds

2009/2010 Radial Builds



Thicker blankets (0.65 m on IB and 1 m on OB) mandate redefining thicknesses and compositions of non-breeding components to satisfy design requirements and radiation limits.

Major Changes/Additions to Radial Builds

- Thicker IB Back Wall to protect Skeleton Ring for plant life:

  ⇒ no need for replaceable HT shield.

- Reweldable back of Skeleton Ring (at least 20 cm thick).
- Reweldable VV everywhere including IB. (None of previous ARIES design had reweldable IB VV at midplane).
- Exclude materials with high decay heat to control temperature during LOCA:

  ⇒ no WC filler in IB VV

  ⇒ no W (or WC) for Shielding Block behind IB assembly gaps.

- 2 cm thick He-cooled Thermal Shield between VV and magnets.

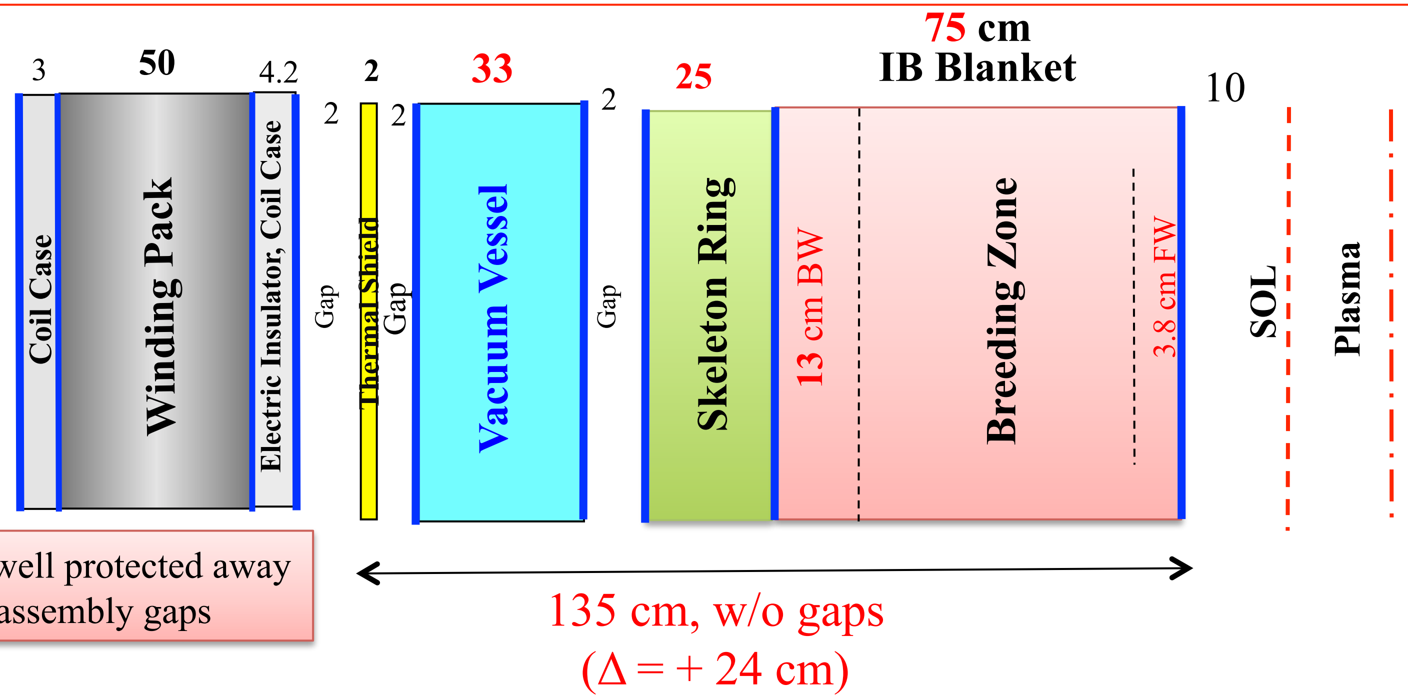
Changes lead to larger radial builds

ARIES-ACT-DCLL Radiation Limits

Calculated Overall TBR	1.1	
Net TBR (for T self-sufficiency)	~1.01	
Damage to Structure	200	dpa - advanced FS
(for structural integrity)	???	W structure
Helium Production @ Manifolds & VV	1	He appm
(for reweldability of FS structure)		
LT S/C Magnets (@ 4 K):		
Peak fast n fluence to Nb_3Sn (E_n > 0.1 MeV)	10^{19}	n/cm^2
Peak nuclear heating	2	mW/cm^3
Peak dpa to Cu stabilizer	$6x10^{-3}$	dpa
Peak dose to GFF polyimide insulator	$< 10^{11}$	rads
Plant Lifetime	40	FPY
Availability	85%	
Operational Dose to Workers and Public	< 2.5	mrem/h

ARIES-ACT-DCLL IB Radial Build

(Peak IB Γ = 4.4 MW/m^2)



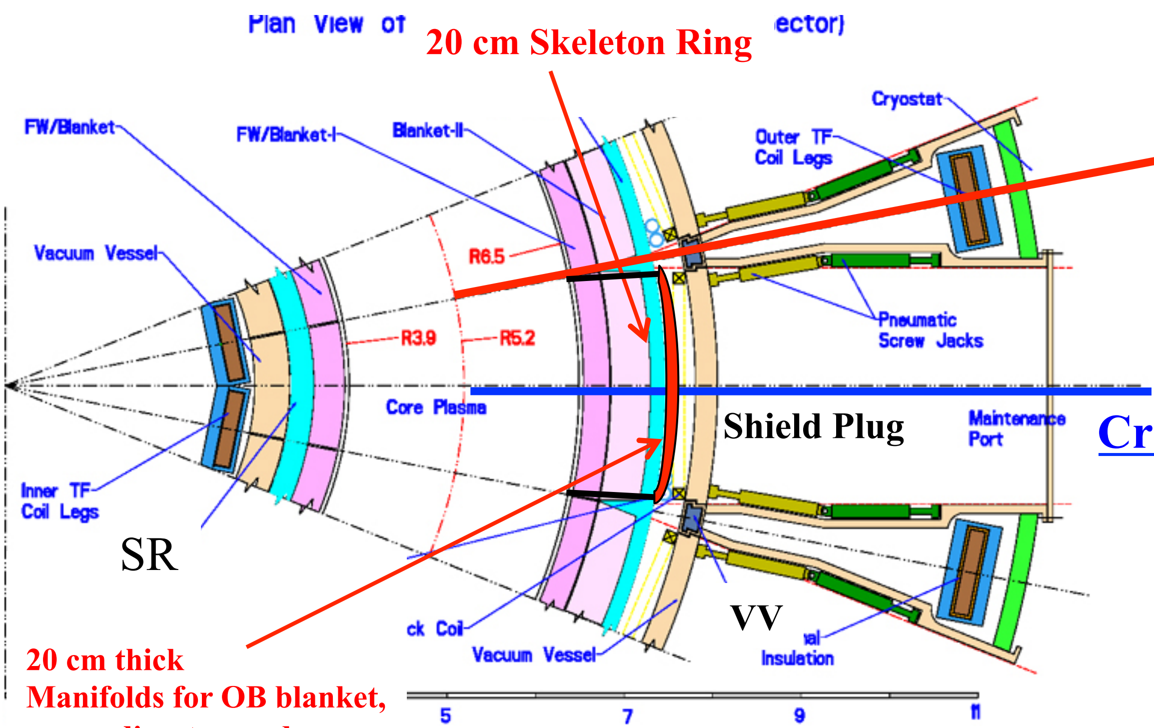
Magnet is well protected away from assembly gaps

Vacuum Vessel:
- 2 cm thick face sheets.
- Space in between filled with:
  - 15% steel structure, 25% B-steel, 60% water.
- Permanent component (16 dpa peak).
- Reweldable (1 He appm peak).
- Impact of n streaming through gaps TBD.

Skeleton Ring:
- 20% FS, 20% He, 60% B-FS.
- Permanent component (185 dpa peak).
- Reweldable at back.
- Impact of n streaming through gaps TBD.

Two OB Cross Sections

ARIES-ACT



20 cm thick Manifolds for OB blanket, upper divertor, and upper half of IB blanket

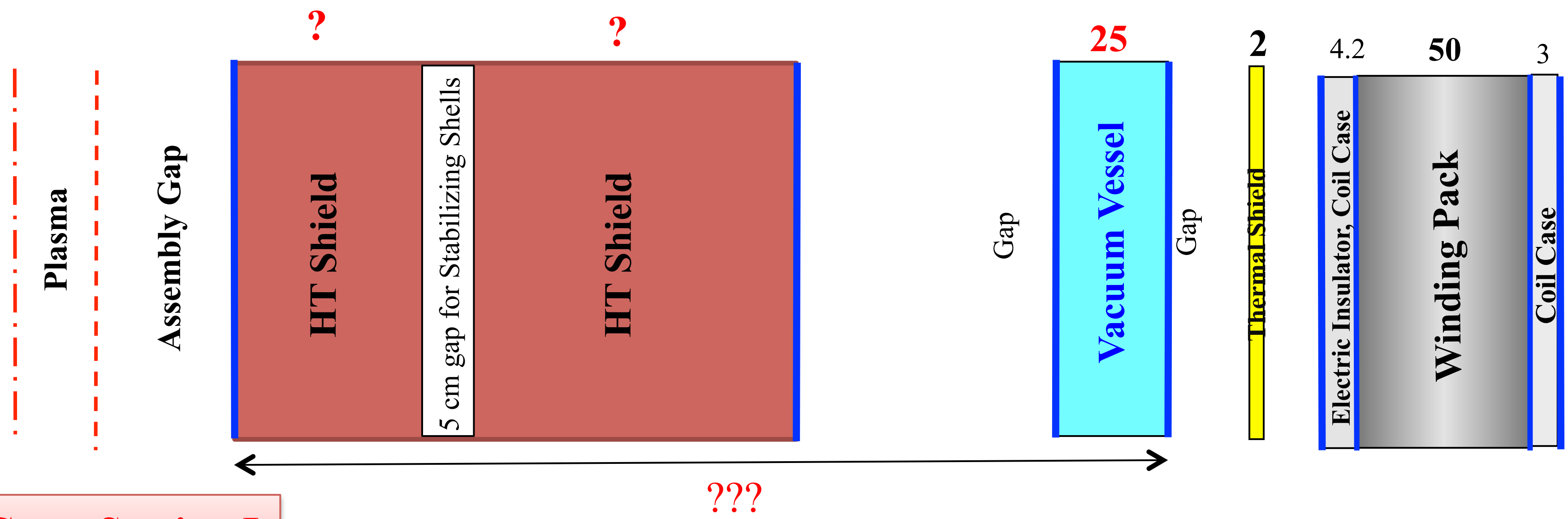
Cross Section I underneath magnet:

- Shield and VV only.
- No blanket.
- TBD with 3-D analysis.

Cross Section II between magnets:

- Blanket, SR, mnflds, and Shield Plug.
- These components along with port walls protect sides of magnets.
- This should be confirmed with 3-D analysis.

ARIES-ACT-DCLL OB Radial Build
Underneath Magnet (Peak IB Γ = 5.5 MW/m^2)



Cross Section I

HT Shield:

80% FS, 20% He, 60% B-FS
Replaceable and permanent components.
Thicknesses TBD with 3-D analysis to account for n streaming through assembly gaps.

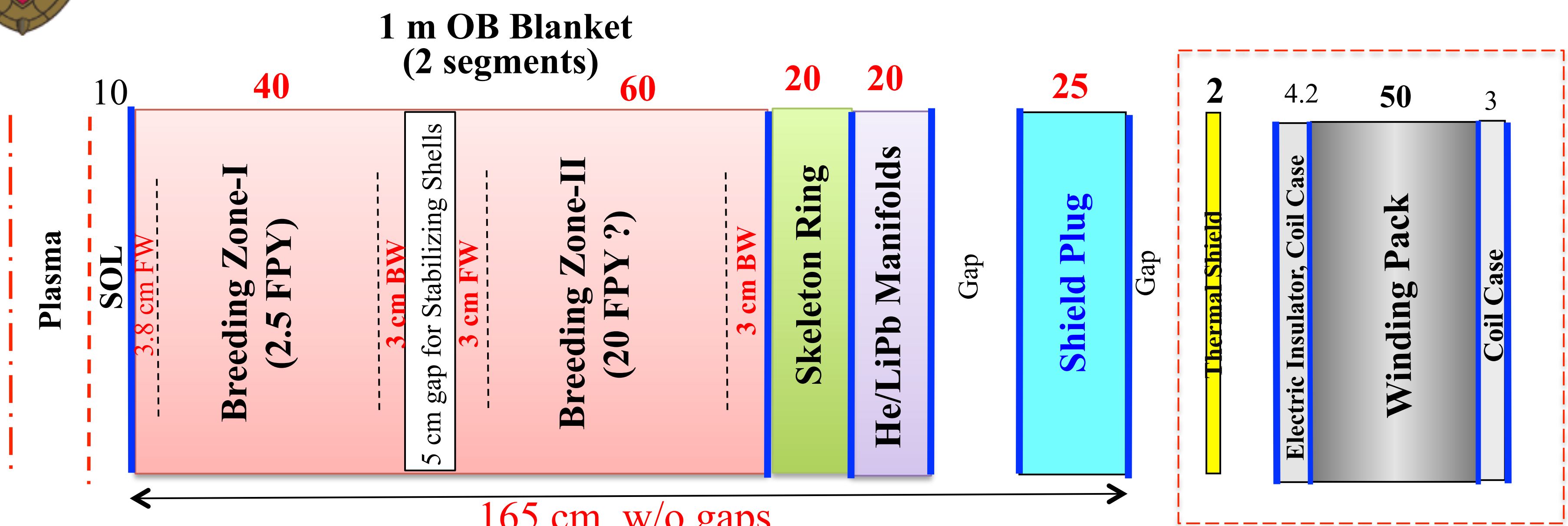
Vacuum Vessel:

2 cm thick face sheets.
Space in between filled with:

15% steel structure, 25% B-steel, 60% water.

Permanent component?
Reweldable?
Impact of n streaming through gaps TBD.

ARIES-ACT-DCLL OB Radial Build Between Magnets (Peak IB Γ = 5.5 MW/m²)



Cross Section II

Skeleton Ring/Manifolds:
- SR: 80% FS, 20% He.
- Permanent components (40 dpa peak).
- Reweldable manifolds (0.2 He appm peak).
- Impact of n streaming through gaps TBD.

Shield Plug:
- 2 cm thick face sheets (like VV).
- Space in between filled with:
  - 15% steel structure, 25% B-steel, 60% water
- Permanent component (4 dpa peak).
- Reweldable (0.08 He appm peak).
- Impact of n streaming through gaps TBD.

ARIES-ACT-DCLL Div Radial Build

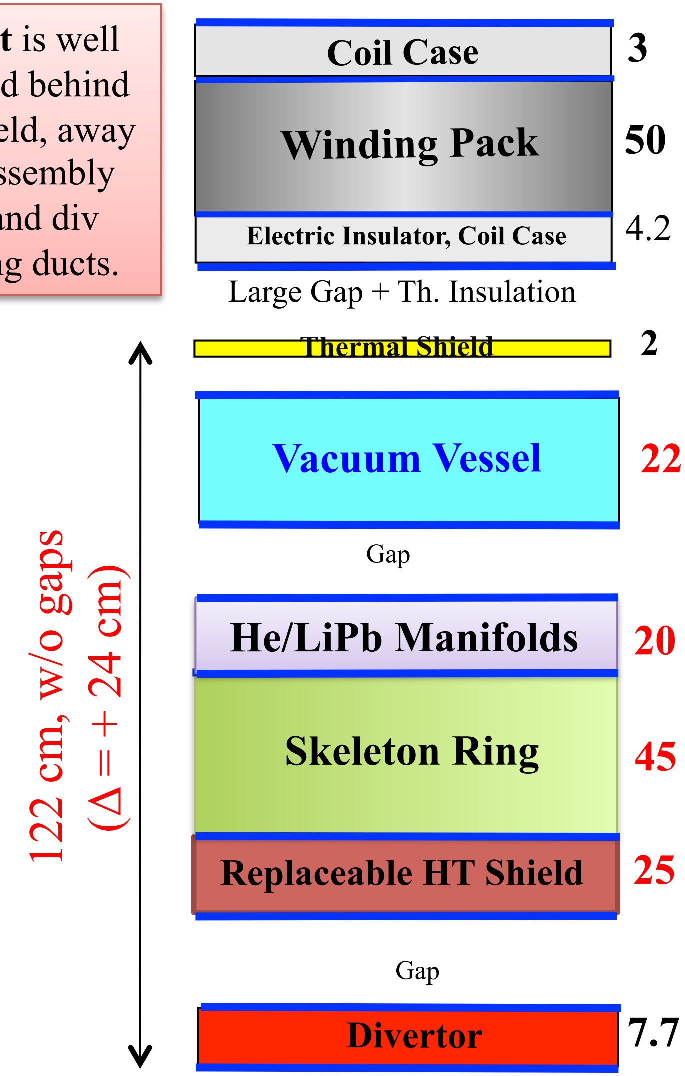
(Peak div Γ = 2.2 MW/m^2)

Vacuum Vessel:
- 2 cm thick face sheets.
- Space in between filled with:
  - 15% steel structure, 25% B-steel, 60% water.
- Permanent component (1.6 dpa peak)
- Reweldable (0.34 He appm peak).
- Impact of n streaming through gaps and pumping ducts TBD.

Skeleton Ring/Manifolds:
- SR: 80% FS, 20% He, 60% B-FS.
- Permanent SR (180 dpa peak).
- Reweldable manifolds (1 He appm peak).
- Impact of n streaming through gaps and pumping ducts TBD.

HT Shield:
- 80% FS, 20% He, 60% B-FS
- Replaceable every 5 FPY.
- Impact of n streaming on lifetime TBD.

Magnet is well protected behind bulk shield, away from assembly gaps and div pumping ducts.



IB Blanket Composition (75 cm thick)

	Thickness (cm)	Composition (volume %)
FW	3.8	8% ODS FS 27% MF82H FS, 65% He
Breeding Zone	58.2	77% LiPb (70% enriched Li) 7% MF82H FS, 3.7% SiC, 12.3% He/void (LiPb @ 580 ^{o}C; 9 g/cm^3 density; $Li_{15.7}Pb_{84.3}$)
Back Wall	13	80% MF82H FS, 20% He
Alternate FW design with W	3.8	8.2% W, 8.3% ODS-FS, 22.4% MF82H FS, 61.1% He

OB Blanket Composition (1 m thick)

	Thickness (cm)	Composition (volume %)
Blanket-I:		
FW	3.8	8% ODS FS 27% MF82H FS, 65% He
Breeding Zone-I	33.2	77.2% LiPb (70% enriched Li) 7% MF82H FS, 4.2% SiC, 11.6% He/void (LiPb @ 580 ^{o}C; 9 g/cm^3 density; $Li_{15.7}Pb_{84.3}$)
Back Wall	3	80% MF82H FS, 20% He
Alternate FW design with W	3.8	8.2% W, 8.3% ODS-FS, 22.4% MF82H FS, 61.1% He
Blanket-II:		
Front Wall	3	same as Back Wall
Breeding Zone-I	54	78.4% LiPb (70% enriched Li) 8.3% MF82H FS, 3.9% SiC, 9.4% He/void (LiPb @ 580 ^{o}C; 9 g/cm^3 density; $Li_{15.7}Pb_{84.3}$)
Back Wall	3	80% MF82H FS, 20% He

Magnet Composition

	Thickness (cm)	Composition (volume %)
He-cooled Thermal Shield	2	20% steel, 80% He (@ 80-100 k)
Coil Case	3	95% JK2LB steel, 5% LHe
Winding Pack (from C. Kessel)	50	70% JK2LB steel, 13% Cu, 2% Nb_3Sn, 10% LHe, 2.5% GFF Polyimide

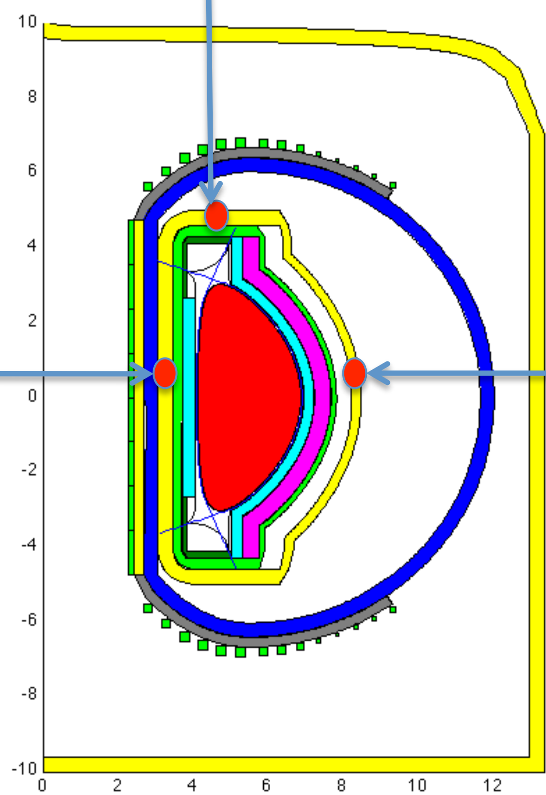
Magnet dimension and composition disagree with ASC ?!

VV Radiation Damage @ 40 FPY

(behind bulk blanket and shield, away from assembly gaps and penetrations)

@ Top/Bottom:
0.34 He appm
1.6 dpa
(not behind pumping ducts)
He/dpa = 0.2

@ IB midplane:
1 He appm
16 dpa
(not behind assembly gaps)
He/dpa = 0.06



@ OB midplane:
? He appm @ VV
? dpa @ VV

He/dpa = ? for VV

@ Shield Plug:
0.08 He appm
4 dpa

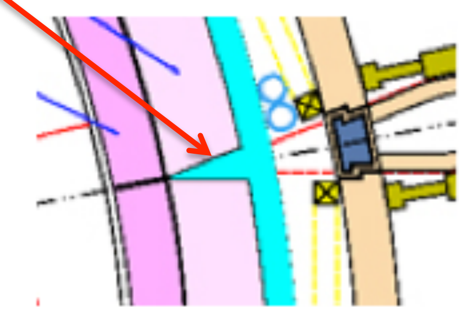
He/dpa = 0.02

This vertical cross section is misleading!
Only shield for Xn through VV and magnet.
NO VV and magnet behind OB blanket.

Streaming Concerns

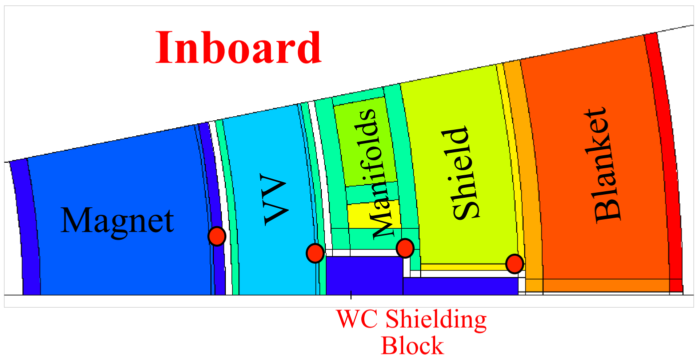
- With 3-D analysis, effect of neutron streaming on damage level should be assessed for:
  - Shield
  - Skeleton ring
  - Vacuum vessel
  - Stabilizing shell.

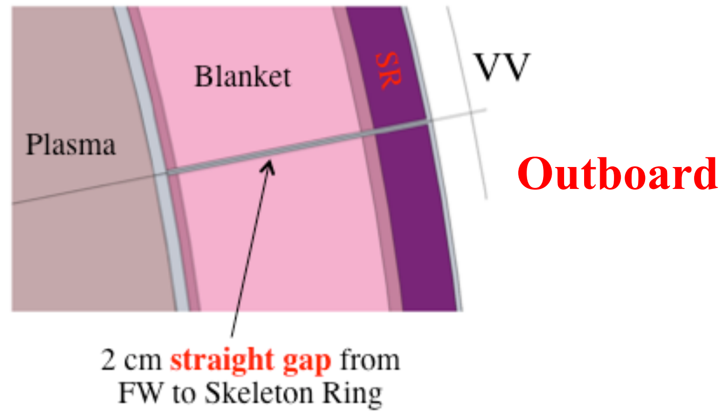
- ARIES-ACT-DCLL has several streaming problems due to:
  - Assembly gaps:
    - Horizontal/radial gap at IB midplane
    - Radial/poloidal assembly gaps between IB modules
    - Radial/poloidal assembly gaps between OB modules (blue wedged shape shield in ARIES-AT is **inefficient** and will be redesigned)
    - Radial/poloidal assembly gaps between divertor plates.
  - Large penetrations:
    - Plasma control
    - Fueling
    - Diagnostics
    - Divertor pumping ducts.

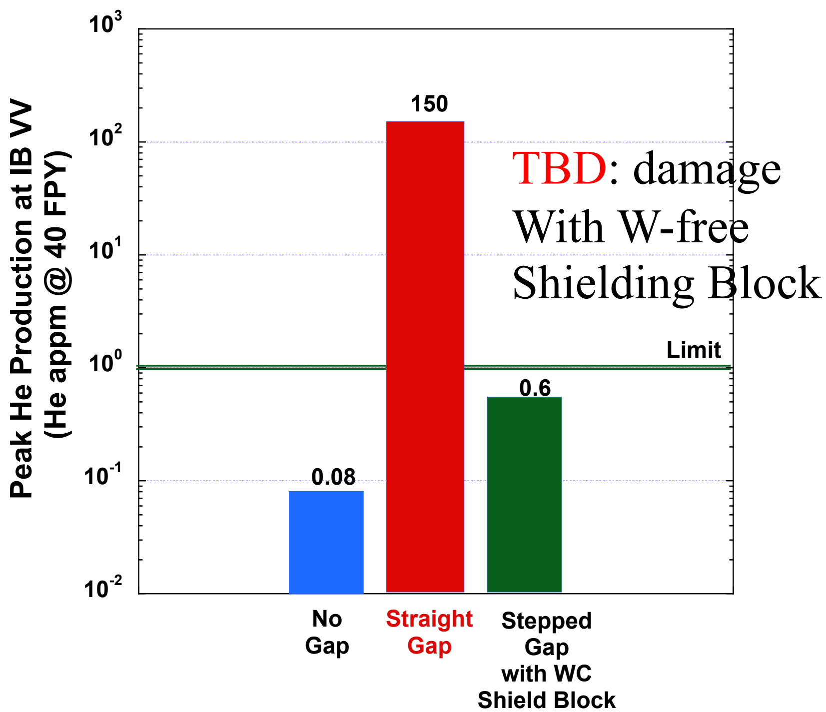


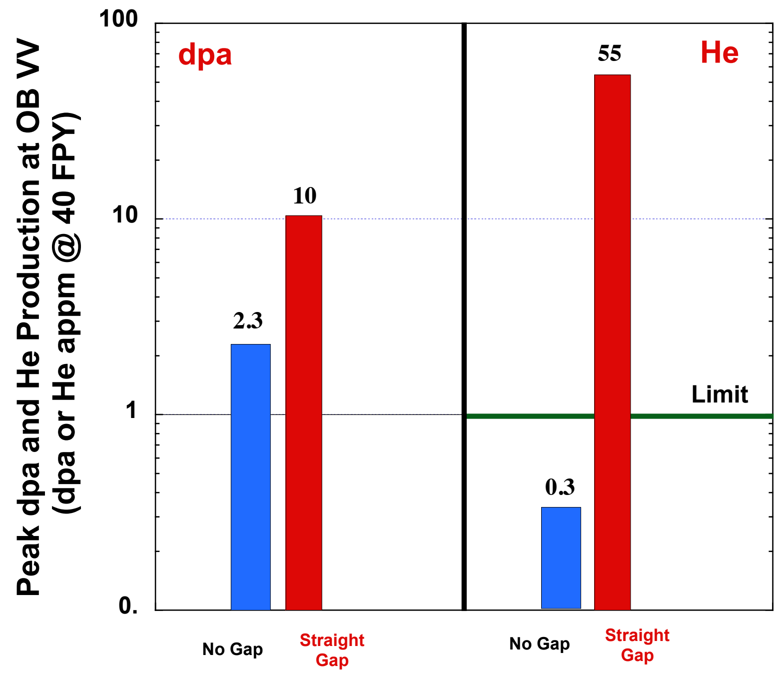
Examples of Neutron Streaming Effect

2 cm Wide Assembly Gaps increase He by > 1000 and dpa by > 4









Ongoing study

Final Remarks

- 3-D shielding/streaming analysis will be performed to:
  - Develop OB cross-section underneath magnet
  - Map radiation damage poloidally and toroidally, taking into consideration effect of neutron streaming through assembly gaps and large penetrations.

- FS-based designs should avoid using materials with relatively high decay heat (such as W and Mn-based steels) in order to control thermal response during transients (such as LOCA).

- Designing W-free Shielding Block behind assembly gaps is challenging!

- Seeking novel ideas to conduct/radiate decay heat to surroundings particularly for IB components.

- **Q**: type of steel for ARIES VV and Thermal Shield?