Final Radial/Vertical Builds for ARIES-ACT-SiC Power Core

L. El-Guebaly
Fusion Technology Institute
University of Wisconsin-Madison
http://fti.neep.wisc.edu/UWNeutronicsCenterOfExcellence

Contributors:
A. Jaber (UW),
X. Wang, M. Tillack, S. Malang, F. Najmabadi (UCSD),
C. Kessel (PPPL), A. Rowcliffe (ORNL)

ARIES Project Meeting
May 31- June 1, 2012
Gaithersburg, MD

Changes for ARIES-ACT Compared to ARIES-AT

- 20 cm thick He cooled Steel Ring (formerly HT shield)
  - LiPb replaced by 20% He, per M. Tillack (resulting in ~5 cm thicker build)
  - SiC replaced by 80% ODS-FS structure.
- **Thin** He-cooled VV, per F. Najmabadi (5-10 cm with 90% FS and 10% He; T < 550°C)
- Water-cooled LT shield (with WC or B-FS filler) placed outside VV (350 < T < 550°C).
- LT magnet (with **thin** coil cases) replacing HT magnet (with **thick** coil cases).
- Other changes:
  - Slight changes to LiPb/SiC blanket composition with 60% enriched LiPb
  - 3Cr-3WV FS for VV and LT shield, per A. Rowcliffe (no 316-SS as it produces HLW).

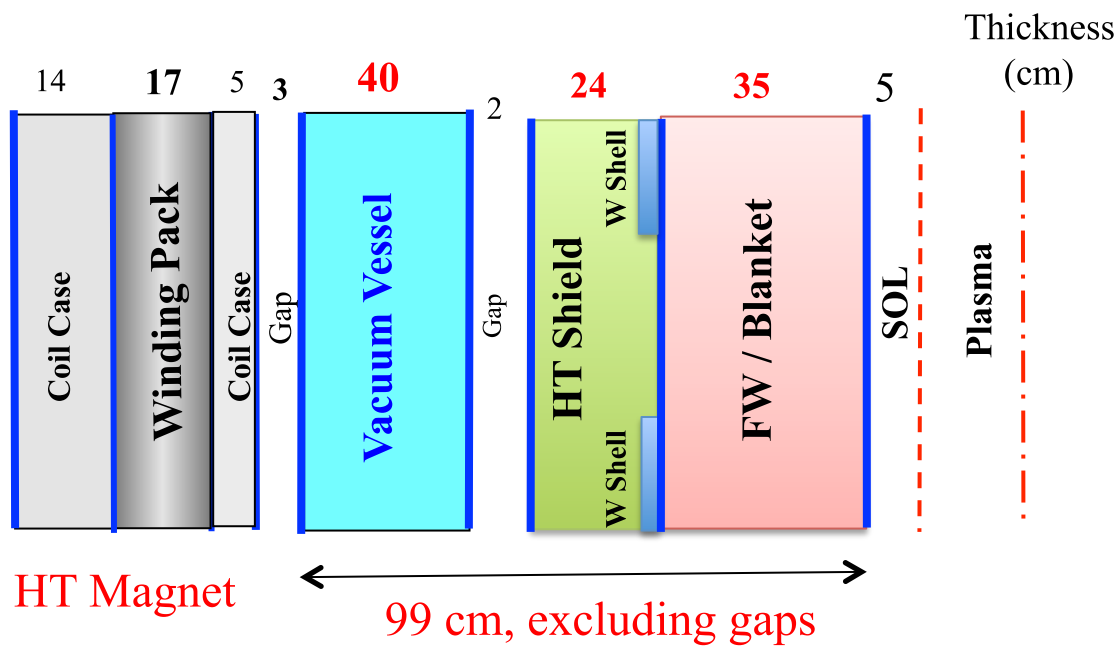
ARIES-ACT-SiC Radiation Limits

Calculated Overall TBR	1.05	
Net TBR (for T self-sufficiency)	~1.01	
Damage to Structure (for structural integrity)	3%	Burn-up for SiC/SiC composites
	200	dpa for advanced FS
	???	W structure of divertor
Helium Production @ Steel Ring & VV	---	(not reweldable during operation)
	1	He appm if reweldable
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

Inboard Radial Build

2006 ARIES-AT Inboard Radial Build

(Peak IB Γ = 3.2 MW/m^2)



VV:

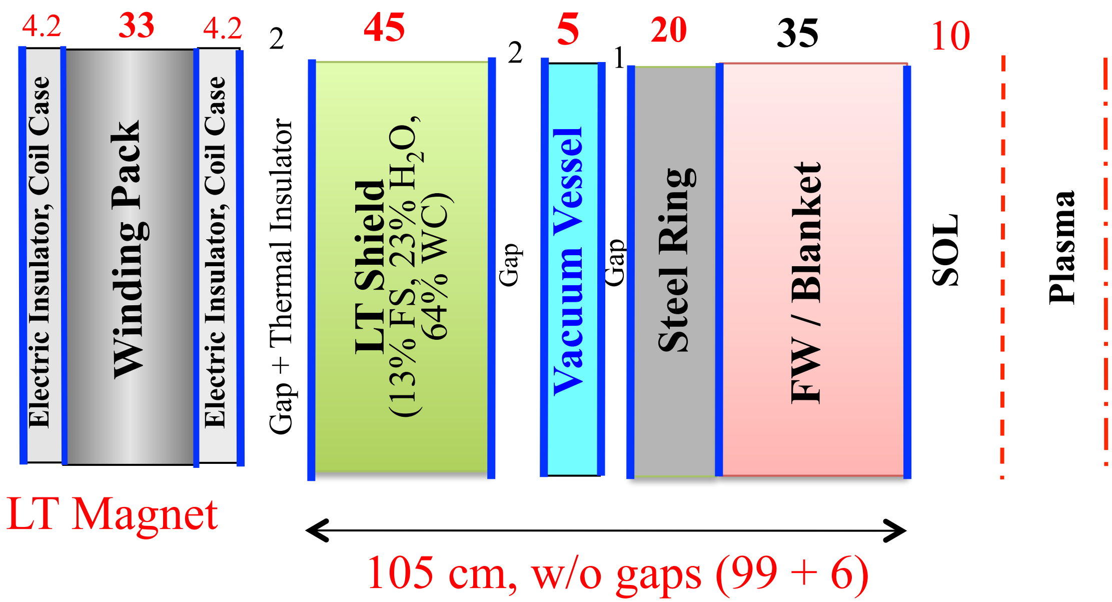
- 13% FS Structure
- 22% H_2O
- 65% WC

HT Shield:

- 15% SiC Structure
- 10% LiPb
- 70% B-FS filler
- 5% W Shell

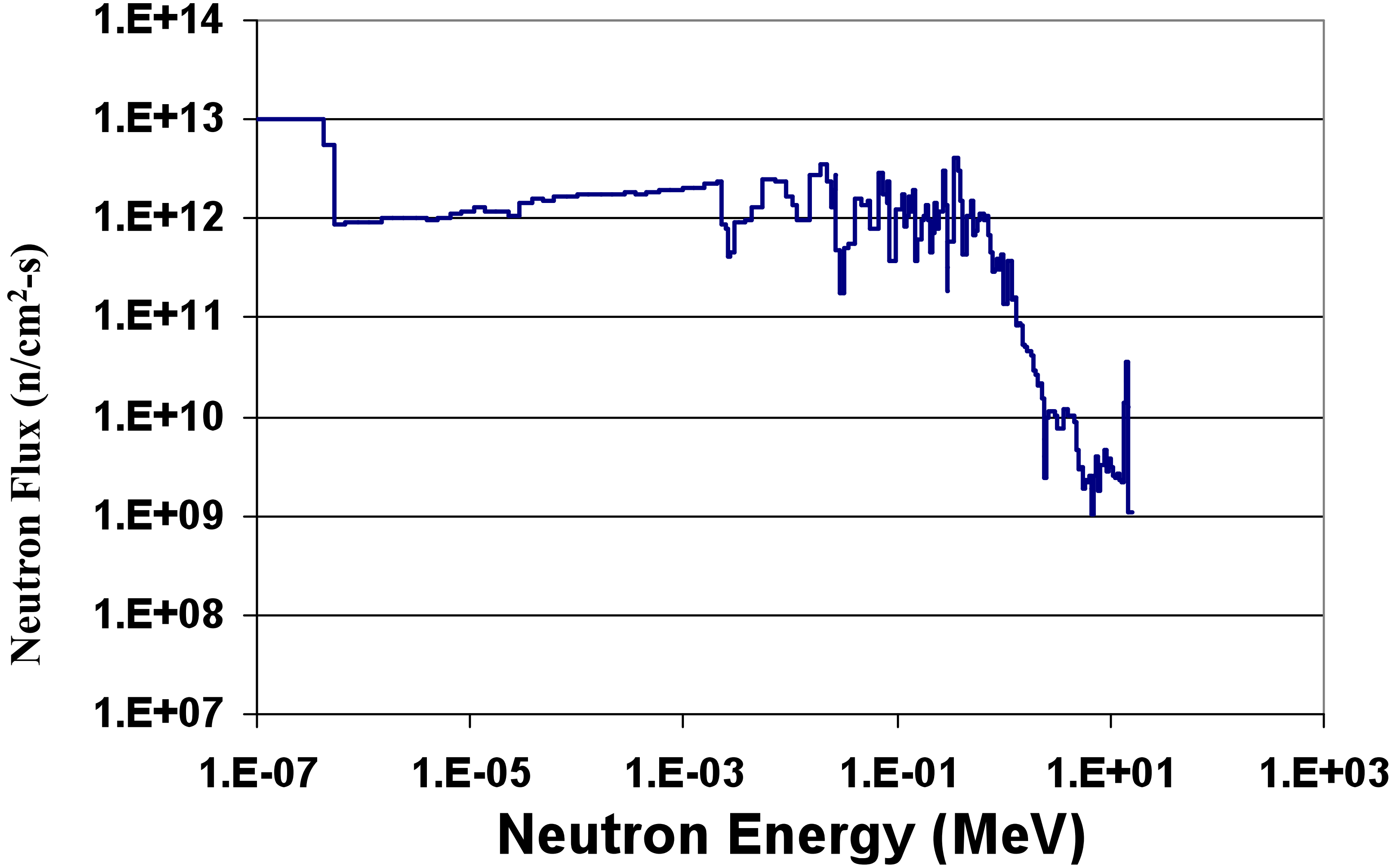
Most compact radial build with thick water-cooled VV

ARIES-ACT-SiC Inboard Radial Build at Midplane (Peak IB $\Gamma = 3.3$ MW/m^2)



- 6 cm thicker IB radial build compared to ARIES-AT
- LT shield thickness **and** composition optimized to protect magnet
- Steel Ring should be replaced every 10 FPY
- None of IB components is reweldable.
- VV, LT shield, and magnet are life-of-plant components
- Effect of neutron streaming through assembly gaps on damage and lifetimes of SR, VV, LT shield, and magnet are being assessed with 3-D analysis.

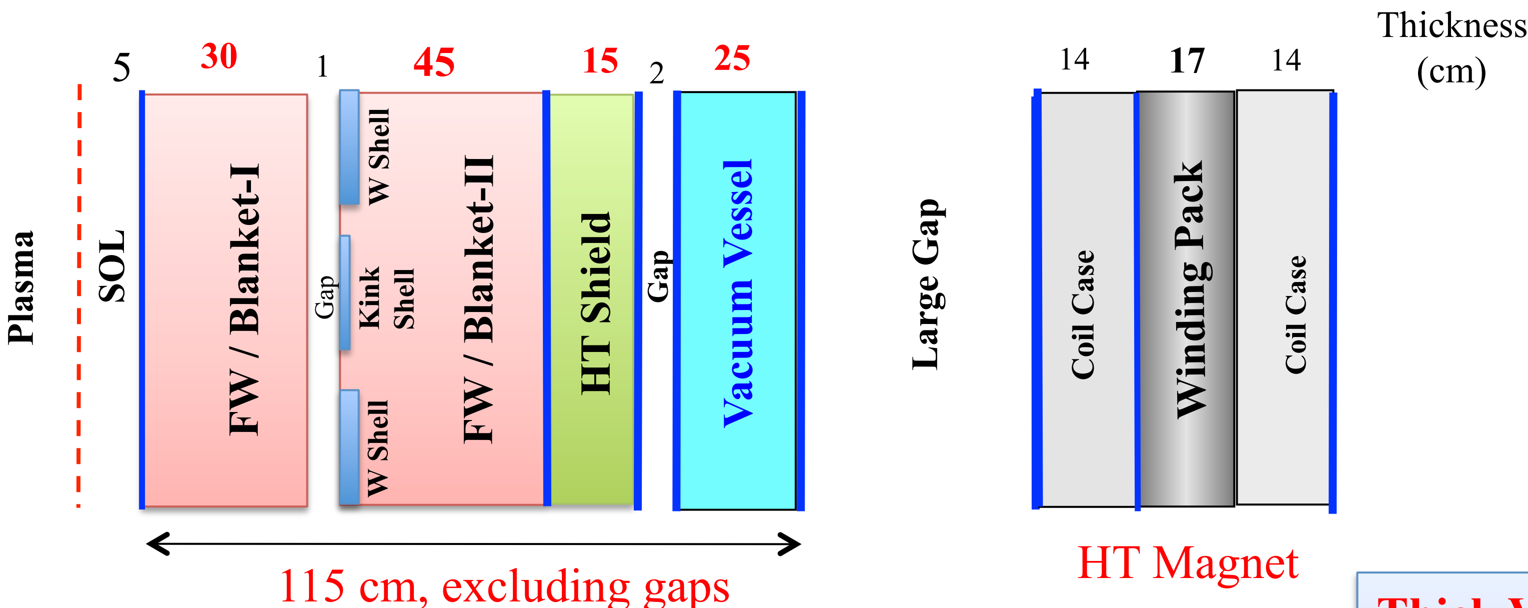
Neutron Spectrum at Surface of IB LT Shield
(3Cr-3VW FS)



Outboard Radial Build

2006 ARIES-AT Outboard Radial Build

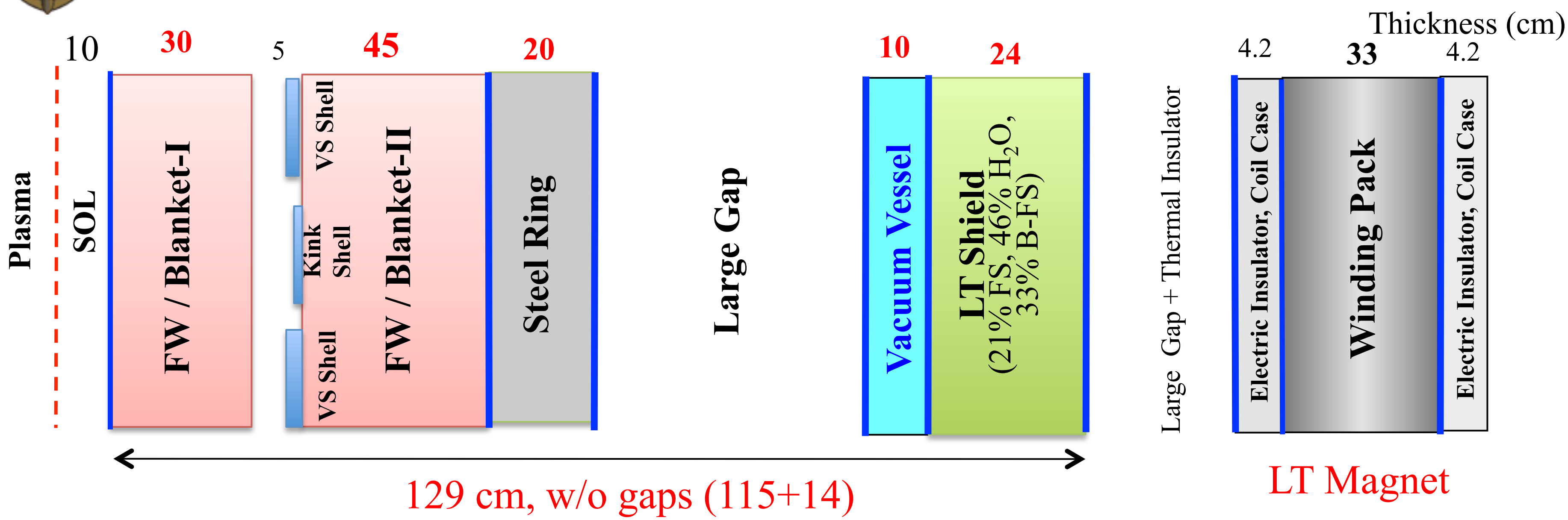
(Peak OB Γ = 4.8 MW/m²)



Thick VV:
- 30% FS Structure
- 70% H_2O

HT Shield:
- 15% SiC Structure
- 10% LiPb
- 75% B-FS filler

ARIES-ACT-SiC Outboard Radial Build at Midplane (Peak OB Γ = 4.7 MW/m²)

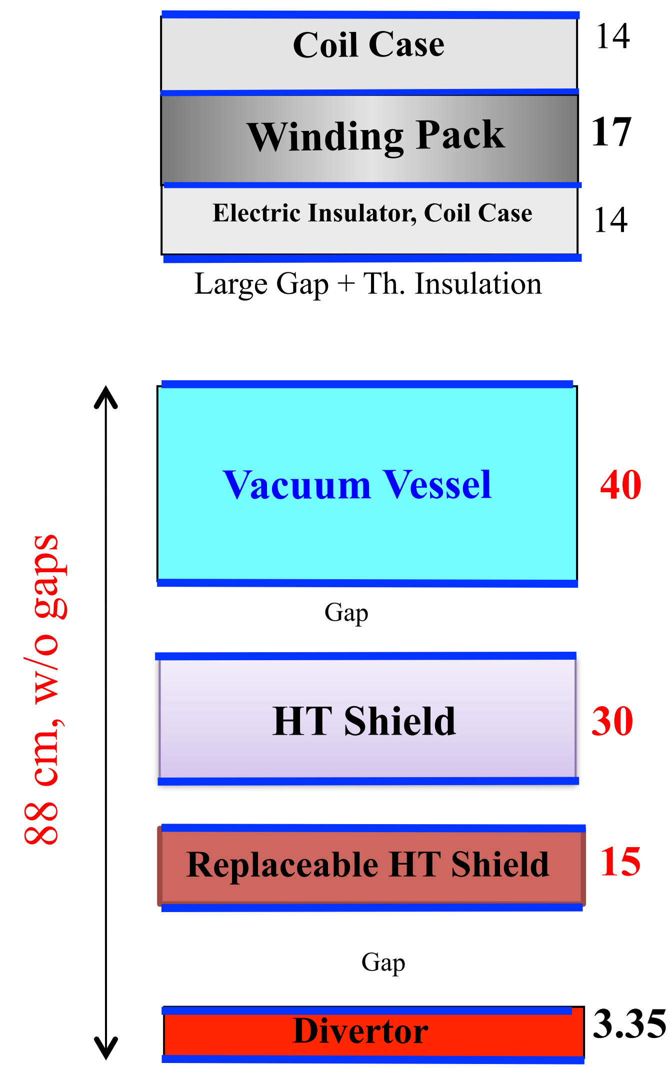


- 14 cm thicker OB radial build than ARIES-AT's due to:
  - Replacing LiPb in SR by He (~ 4 cm)
  - Thinner inner coil case for LT magnet (~ 10 cm)
- LT shield thickness **and** composition optimized to protect magnet
- Steel Ring and VV are not reweldable
- Without gaps, Steel Ring, VV, LT shield, and magnet are life-of-plant components
- Effect of neutron streaming through assembly gaps on damage and lifetimes of SR, VV, LT shield and magnet are being assessed with 3-D analysis.

Vertical Build

ARIES-AT Vertical Build

(Peak div $\Gamma = 2\ MW/m^2$)



VV (same as for IB):

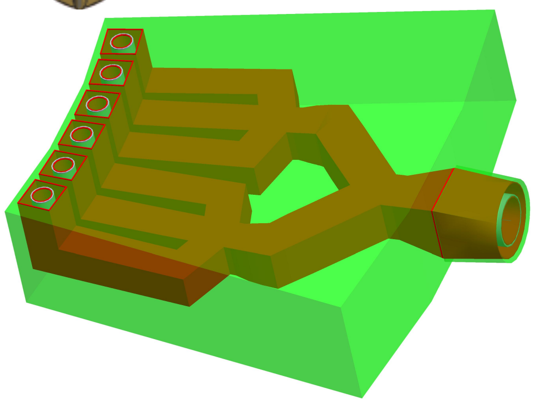
13% FS Structure
22% H_2O
65% WC

HT Shield:

15% SiC Structure
10% LiPb
75% B-FS filler

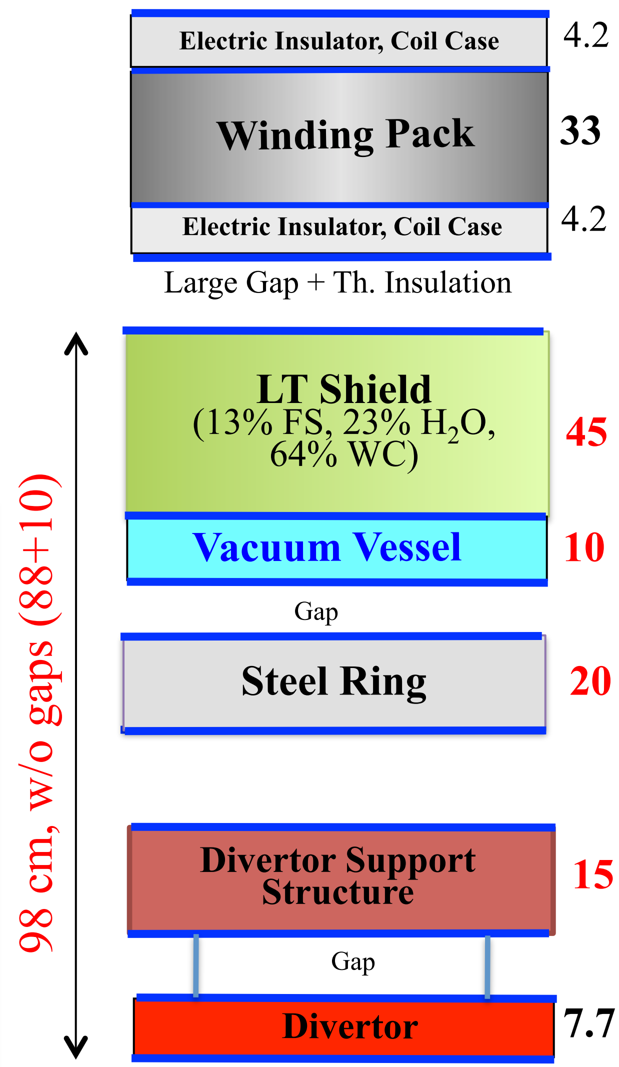
ARIES-ACT Vertical Build

(Peak div Γ = 2 MW/m²)



Manifolds embedded in shield:

- Manifolds supply LiPb to IB blanket
- Located between divertor and SR
- Contains vacuum pumping ducts.



- 10 cm thicker vertical build compared to ARIES-AT
- Same LT shield thickness **and** composition as for IB
- Lifetime of W-based divertor is unknown
- Steel Ring should be replaced every 20 FPY
- None of vertical components is reweldable
- Without gaps, VV, LT shield, and magnet are life-of-plant components
- Effect of neutron streaming through assembly gaps on damage and lifetimes of SR, VV, LT shield, and magnet should be assessed with 3-D analysis.

Blanket Composition

$Li_{15.7}Pb_{84.3}$ @ 700 ^{o}C; 8.8 g/cm^3 density; 60% enriched Li

	Thickness (cm)	Composition (volume %)
IB Blanket	35	18% SiC/SiC Composites 82% LiPb
OB Blanket-I	30	16% SiC/SiC Composites 84% LiPb
OB Blanket-II	45	19.3% SiC/SiC Composites 80.7% LiPb

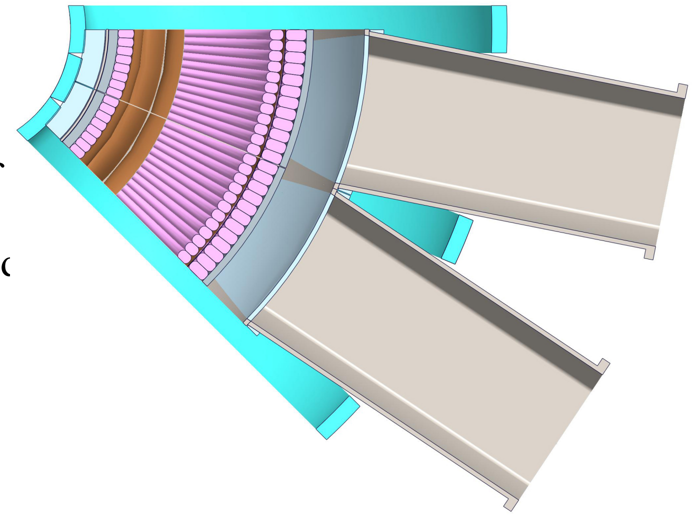
Neutron Streaming Assessment

(work in progress)

Concerns

Assembly gaps (2 cm wide):

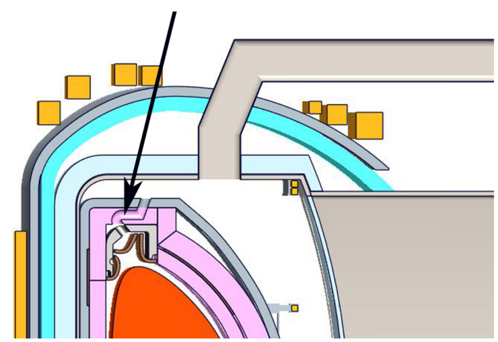
- 2 cm wide radial/poloidal assembly gaps reduce effectiveness of shield
- Damage behind straight gaps could increase by orders of magnitude
- During operation, thermal expansion and neutron-induced swelling will close the gap
- Zigzag all gaps to alleviate streaming problem.



Maintenance ports:

- Shielding Doors needed at entrance of ports to attenuate neutrons
- Otherwise, damage at OB TF magnets will be excessive.

Div Pumping Duct



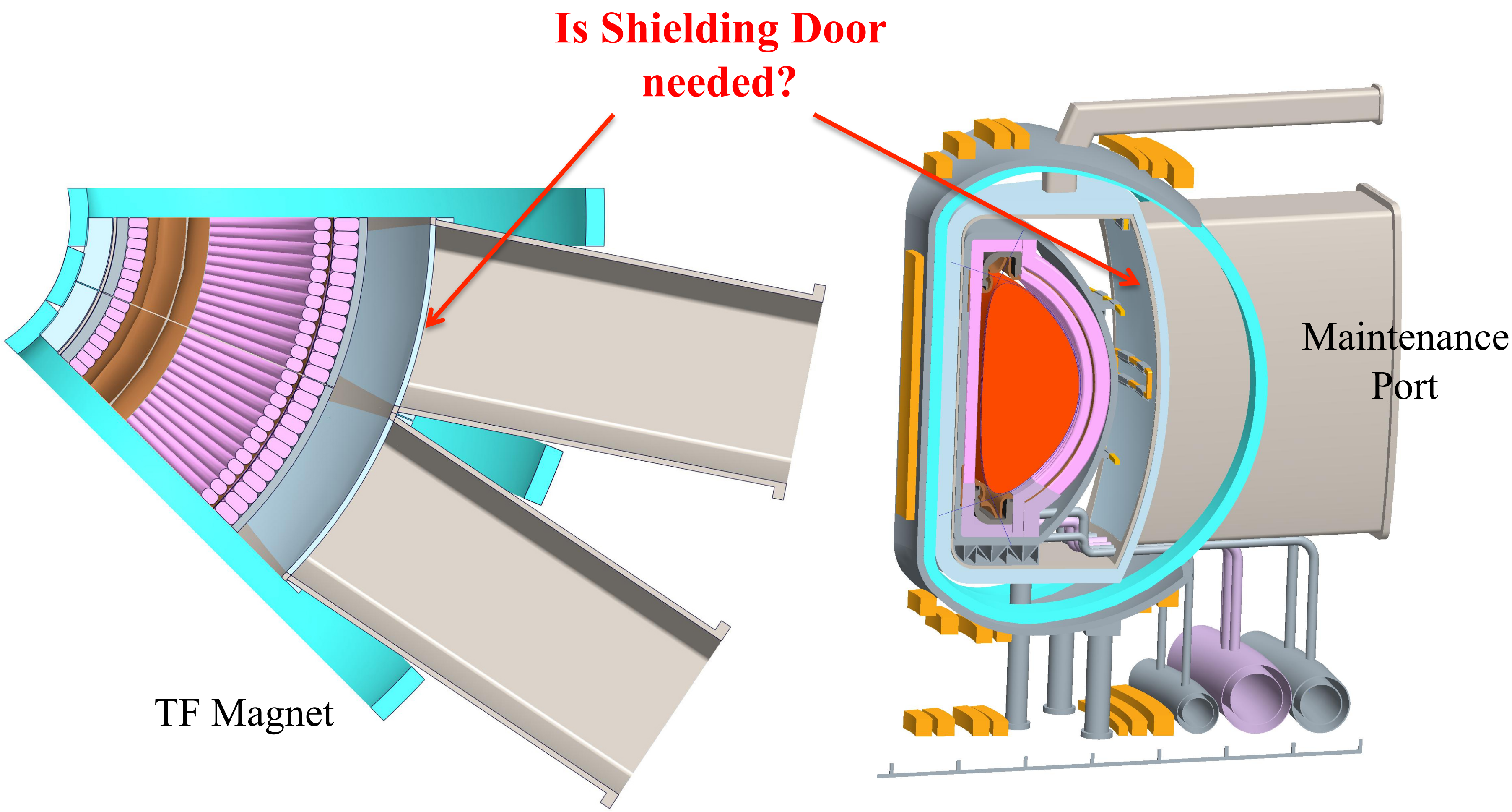
Penetrations for plasma heating/control (4 m^2 max):

- All penetrations should be surrounded with ~0.5 m thick shield to protect sides of TF magnets and externals.

Divertor pumping ducts (20 cm ID):

- Zigzagging the ducts alleviates streaming problem.

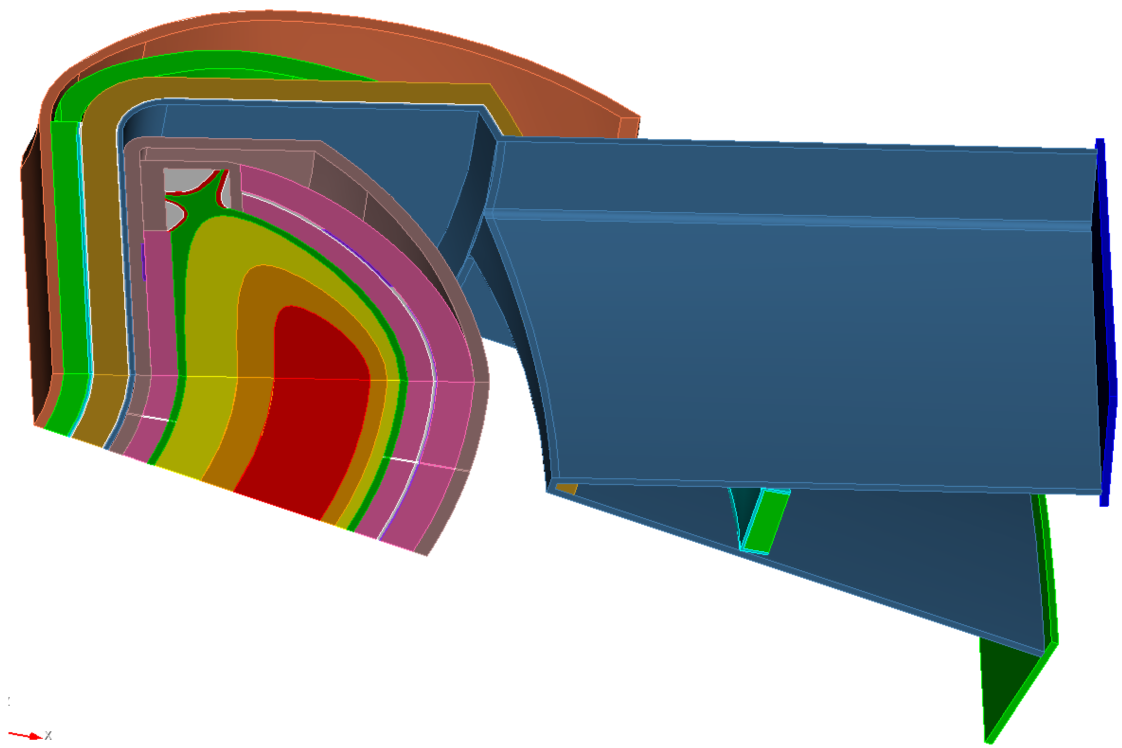
Maintenance Ports



How to accommodate OB penetrations (ICRF, EC, LH, etc.)?

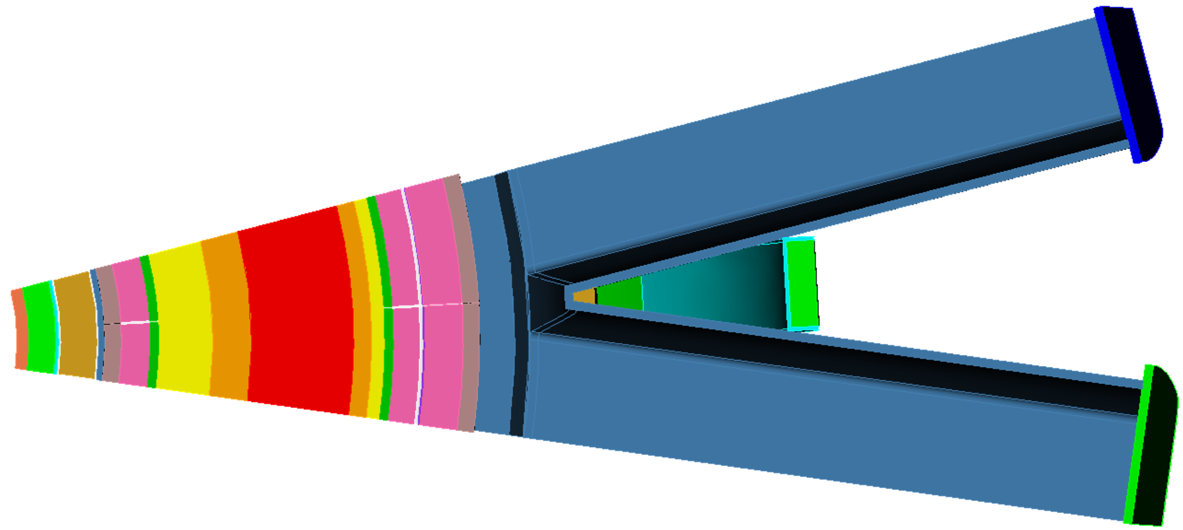
Maintenance Ports (Cont.)

- We modeled entire device for 3-D streaming analysis.

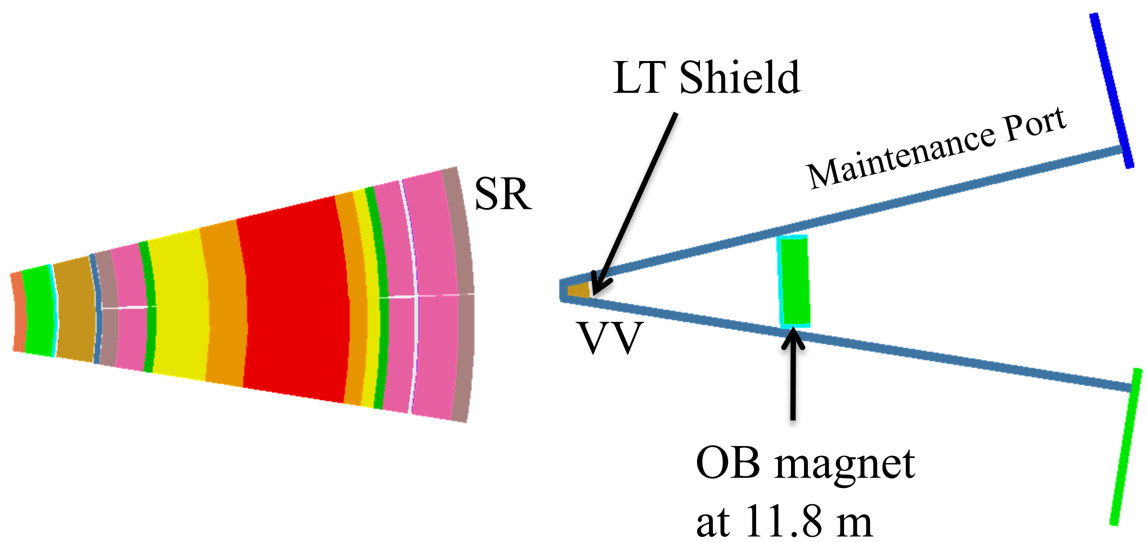


- <u>1st case considered</u>: **no** Shielding Door to:
  - Map neutron flux everywhere, specially within maintenance ports
  - Calculate nuclear heating in IB and OB legs of TF magnets.

3-D Neutronics Model



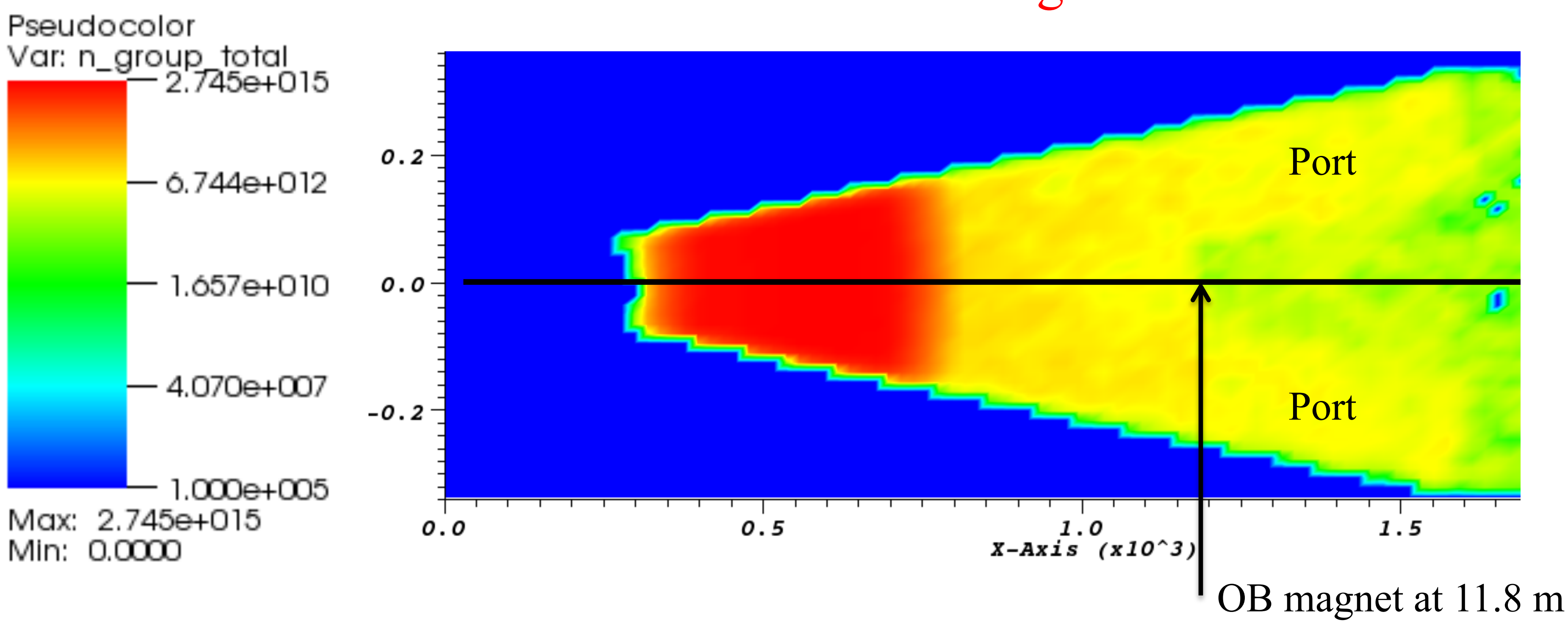
Isometric view



Cross Section at midplane

Map of Neutron Flux
Horizontal Cross Section at Midplane

No Shielding Doors



Higher flux within maintenance doors results in higher damage at OB TF magnet

TF Magnet Heating

	Inboard	Outboard
Total Nuclear Heating (MW)	1.6 KW	44 KW (too high!)
Cryogenic Heat Load* (MW)	**0.5 MW**	**13 MW**

Second largest load is conduction through magnet support, per L. Bromberg (MIT).

- Fast n fluence and peak heating at OB magnet expected to exceed limits.
- Shielding Door should be placed at entrance of maintenance ports to protect OB magnets.

* Using 300 W/W (i.e., 300 W needed to remove 1 W of nuclear heating).

TBD

By Dec 2012:

- Thickness and composition of Shielding Door (w/o water) or local shield surrounding port walls to protect sides of OB magnet and externals.
- Peak damage to IB and OB components with straight and zigzagged gaps.
- Scaling of shield with NWL for designs with conservative physics.

By June 2013:

- 3-D activation analysis (first ever for ARIES project) for designs with aggressive physics.

  (decay heat, WDR, recycling, and clearance with impact of gaps and penetrations)
- Temperature response during LOCA/LOFA.