



DCLL Blanket for ARIES-AT: Major Changes to Radial Build and Design Implications

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ARIES-Pathways Project Meeting

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Objectives

- Redesign ARIES-AT with DCLL system (a la ARIES-CS).
- Define new IB, OB, Div radial builds for ARIES-AT-DCLL.
- Assess implications of DCLL blanket on ARIES-AT engineering, physics, and economics.

ARIES-AT Reference Design

Fusion Power	1755 MW
Major Radius	5.2 m
Minor Radius	1.3 m
Peak Γ @ IB, OB, Div	3.1, 4.8, 2 MW/m ²

SiC/SiC Composite Structure

LiPb/SiC Blanket

Discrete LiPb Manifolds

HT S/C Magnet @ 70-80 K

No W on FW

Calculated Overall TBR	1.1
η_{th}	$\sim 60\%$
Availability	85%

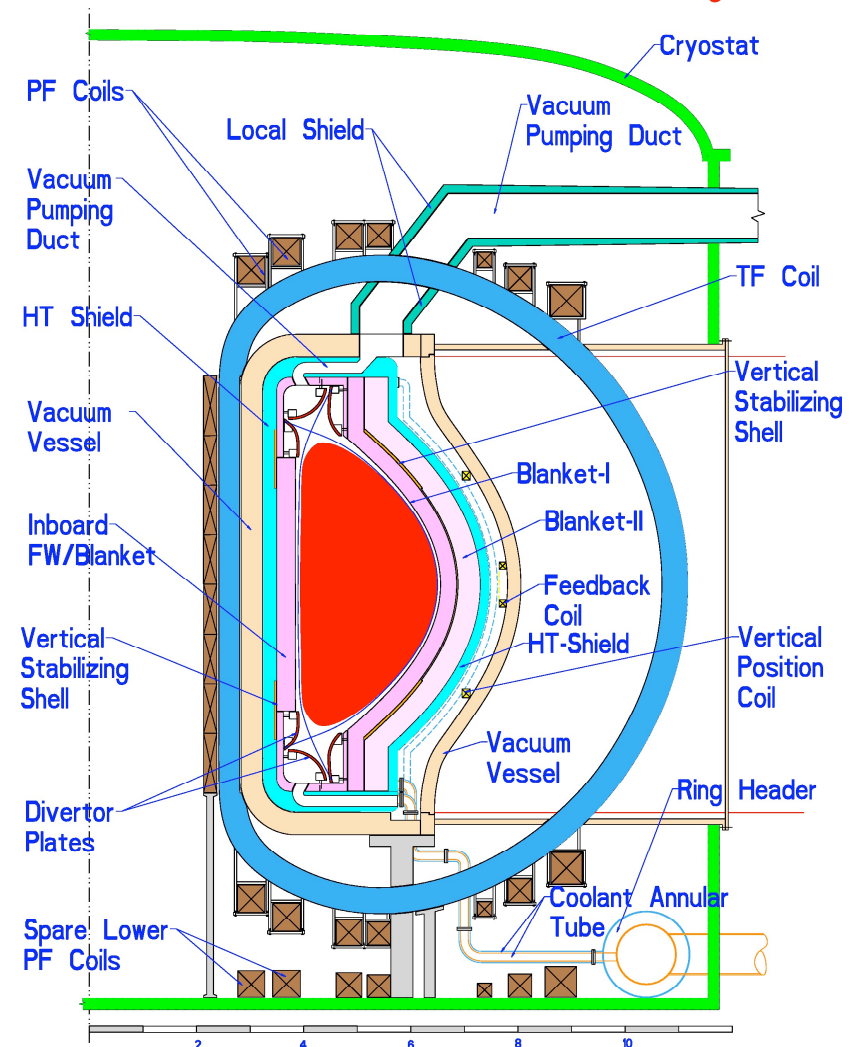
Plasma Control:

5 W Shells on IB and OB

2 Vertical Position Coils

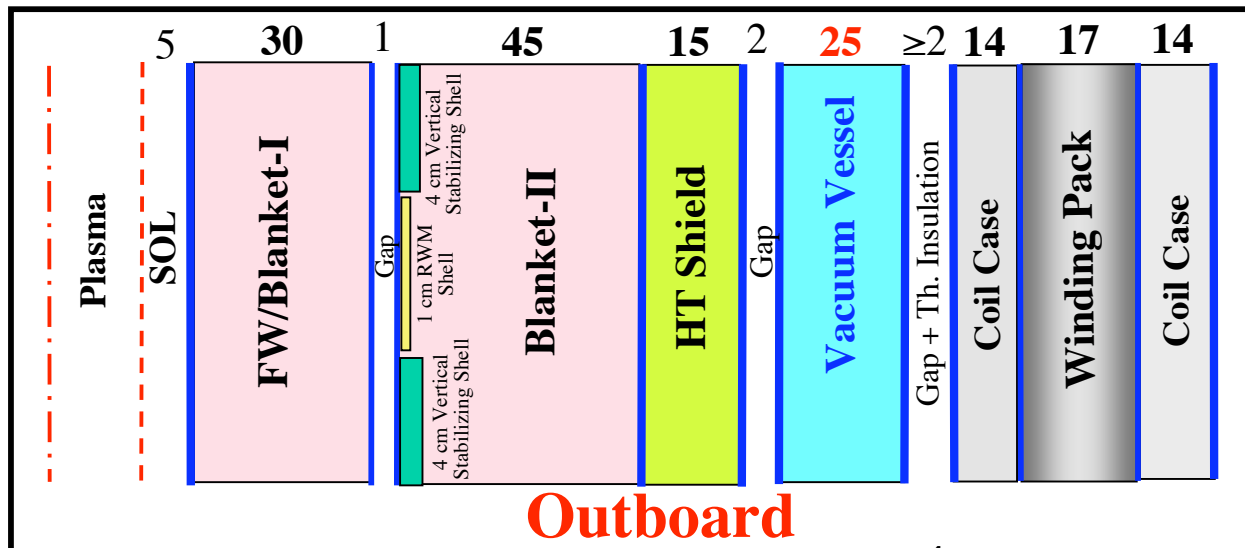
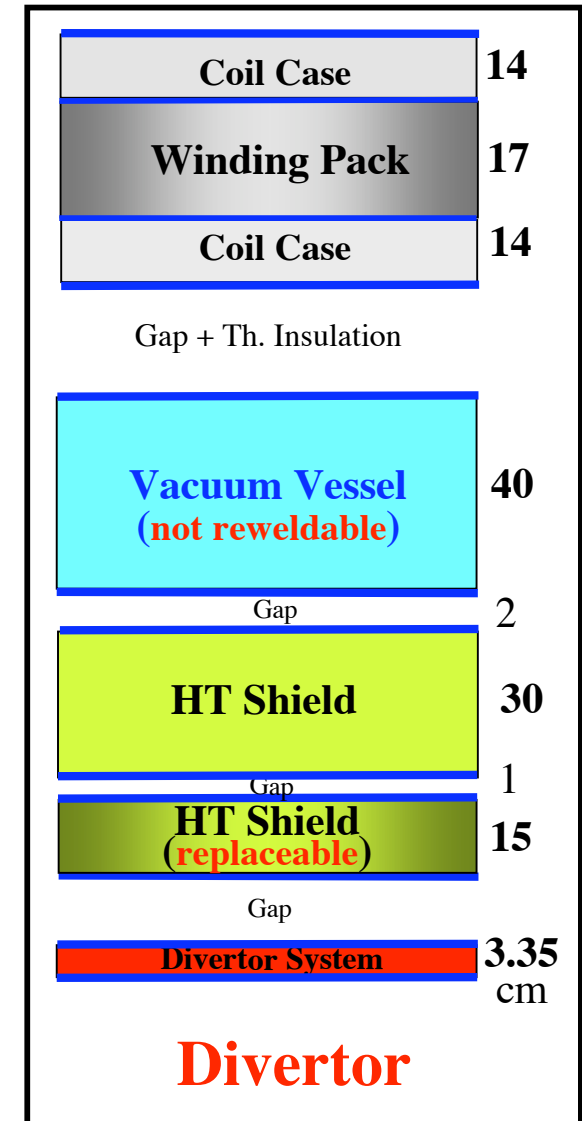
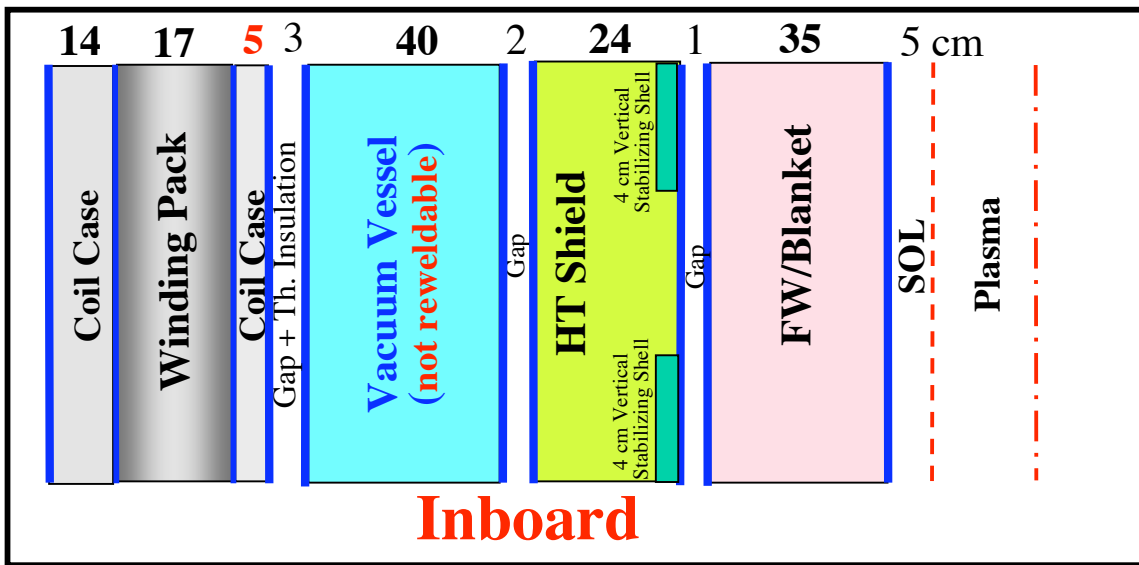
2 Feedback Coils

Cross Section of ARIES-AT Power Core Configuration

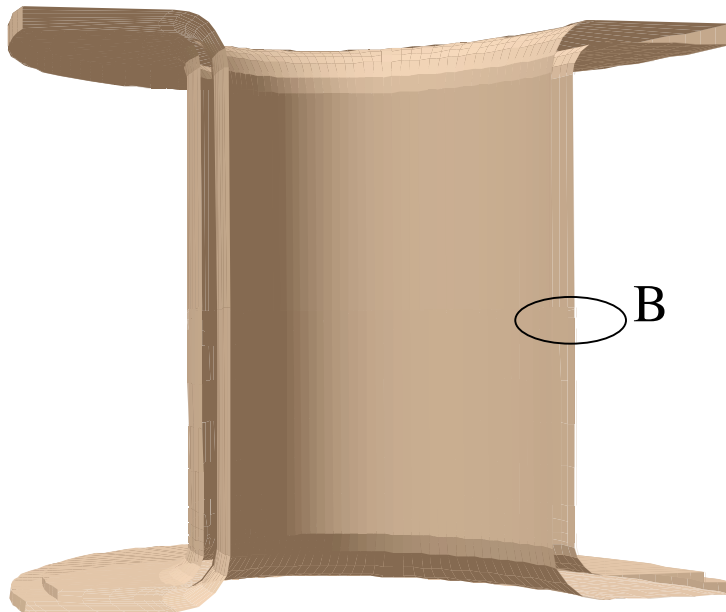


ARIES-AT Radial Builds: IB, OB, Div

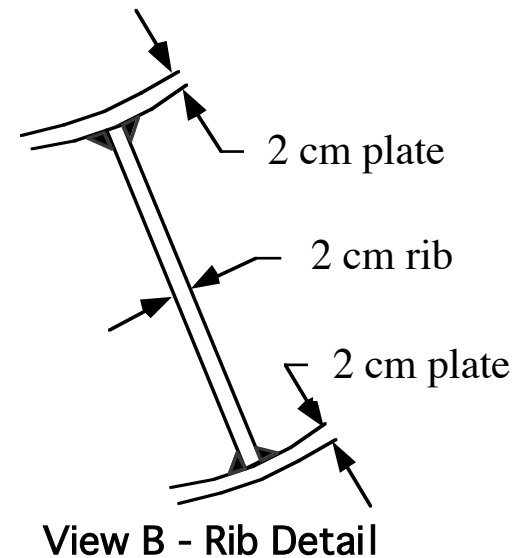
(SiC Structure)



ARIES-AT Vacuum Vessel (FS Structure)



IB and Top/Bottom VV
(not-reweldable)

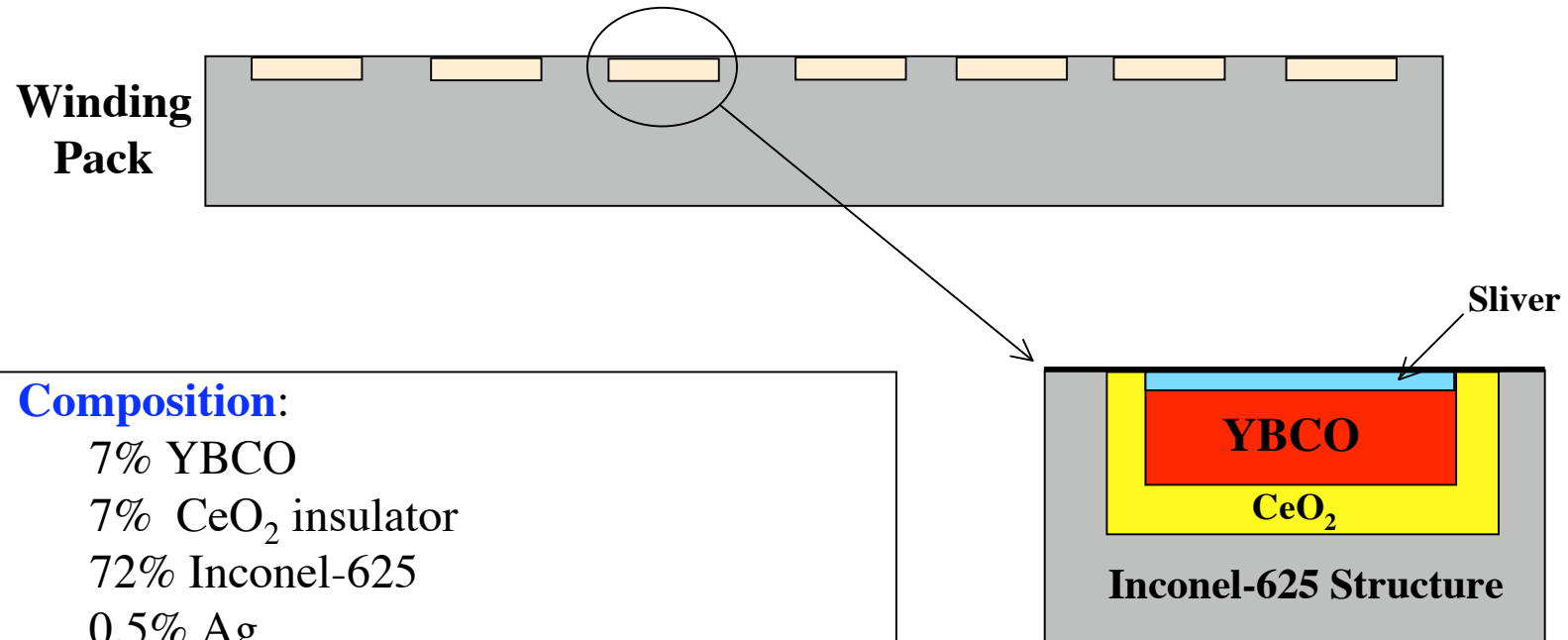


Dimension and Composition

40 cm IB VV: 13% FS, 22% H₂O, 65% **WC** Filler
40 cm T/B VV: 13% FS, 22% H₂O, 65% B-FS Filler
25 cm OB VV: 30% FS, 70% H₂O.

ARIES-AT TF/PF Magnet

(High-Temp S/C @ 70-80 K)



Composition:

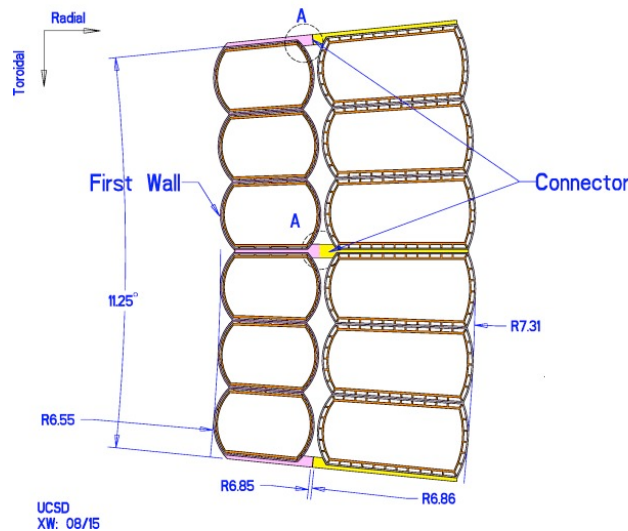
7% YBCO
7% CeO₂ insulator
72% Inconel-625
0.5% Ag
13.5% GFF Polyimide insulator.

Conduction cooling of WP from coil case.

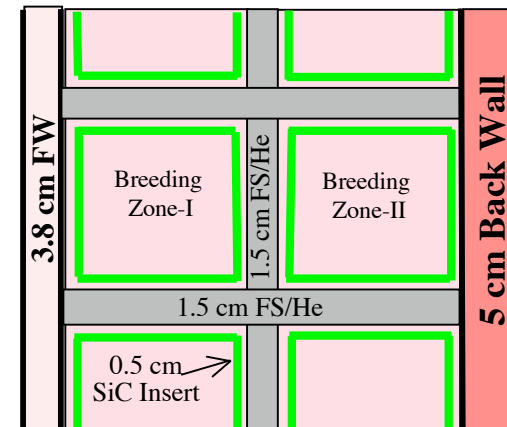
Coil case contains 5% LN cooling channels.

ARIES-AT Blanket Options

SiC Structure



FS Structure



Reference ARIES-AT OB Blanket

Breeder	LiPb
Coolant	LiPb
Structure	SiC

ARIES-AT-DCLL Blanket (a la ARIES-CS)

Breeder	LiPb
Coolant	He and LiPb
Structure	FS



ARIES-AT Compositions

	<u>ARIES-AT-LiPb/SiC</u> (Reference Design)	<u>ARIES-AT-DCLL</u>
Inboard:		
FW/Blanket	81% LiPb, 19%SiC	79% LiPb, 8% He, 6% FS, 7%SiC inserts
HT Shield	15%SiC, 10% LiPb, 70% B-FS Filler , 5% W shells	15%FS, 10% He, 75% B-FS Filler
Outboard:		
FW/Blanket-I	80% LiPb, 20%SiC	79% LiPb, 8% He, 6% FS, 7%SiC inserts
FW/Blanket-II	77% LiPb, 20%SiC, 3% W shells	79% LiPb, 8% He, 6% FS, 7%SiC inserts
HT Shield	15%SiC, 10% LiPb, 75% B-FS Filler	15%FS, 10% He, 75% B-FS Filler
Top/Bottom:		
Divertor System	40%SiC, 50% LiPb, 10% W	33% FS, 4% W, 63% He
Replaceable HT Shield	15%SiC, 10% LiPb, 75% FS Filler	15%FS, 10% He, 75% B-FS Filler
Permanent HT Shield	15%SiC, 10% LiPb, 75% B-FS Filler	15%FS, 10% He, 75% B-FS Filler



ARIES-AT Radiation Limits and Key Parameters

Calculated Overall TBR

1.1

Net TBR

~1.01

(for T self-sufficiency)

Damage to Structure

(for structural integrity)

3%

Burnup - SiC/SiC composites

200

dpa - advanced FS

Helium Production @ VV

(for reweldability of FS)

1

He appm

HT S/C TF & PF Magnets (@ 70-80 K):

Peak Fast n **fluence** to YBCO ($E_n > 0.1$ MeV)

10^{19}

n/cm²

Peak Nuclear **heating**

high

Peak **Dose** to GFF Polyimide insulator

$< 10^{11}$

rads

Plant Lifetime

40

FPY

Availability

85%

Operational Dose to Workers and Public

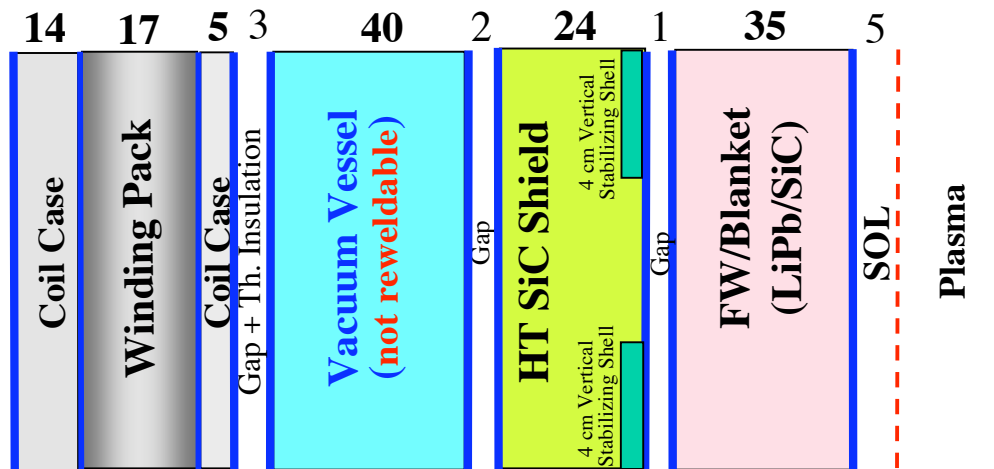
< 2.5 mrem/h

Changes and Updates

	<u>ARIES-AT-LiPb/SiC</u> (Reference Design)	<u>ARIES-AT-DCLL</u> *
Peak NWL @ IB, OB, Div	3.1, 4.8, 2 MW/m ²	3.1, 4.8, 2 MW/m ² (to be updated)
FS structure	ORNL FS	MF82H FS
LiPb:		
Li enrichment	90%	90%
Average temp	700 °C	580 °C
Density	8.8 g/cc	9 g/cc
OB blanket	Two segments	One segment
W shells:		
Two 4-cm-thick VS shells on IB: (toroidally continuous)	Between IB blanket & shield	Between IB blanket & shield?
Two 4-cm-thick VS shells on OB: (toroidally continuous)	Between OB blanket segments	Behind OB blanket?
1-cm-thick RWM shell on OB:	Between OB blanket segments	Behind OB blanket?
Shield coolant	LiPb	He
IB Blanket-shield gap	1 cm	---
VV model	Homogeneous	Heterogeneous with 2-cm-thick plates
Cross section data library	IAEA FENDL-2	IAEA FENDL-2.1

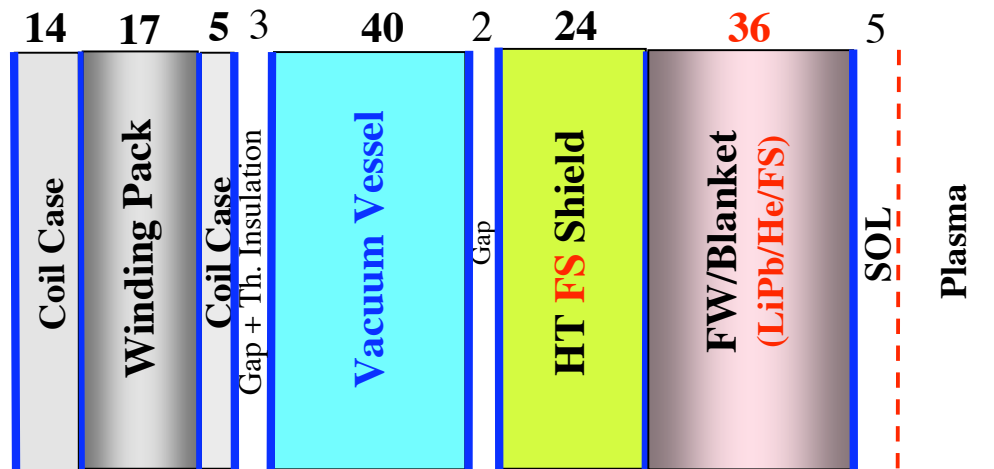
IB Radial Build

(3.1 MW/m² Peak NWL)



ARIES-AT
Reference IB-RB

← 141 cm →



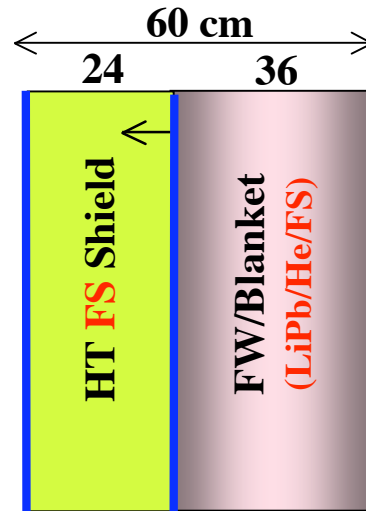
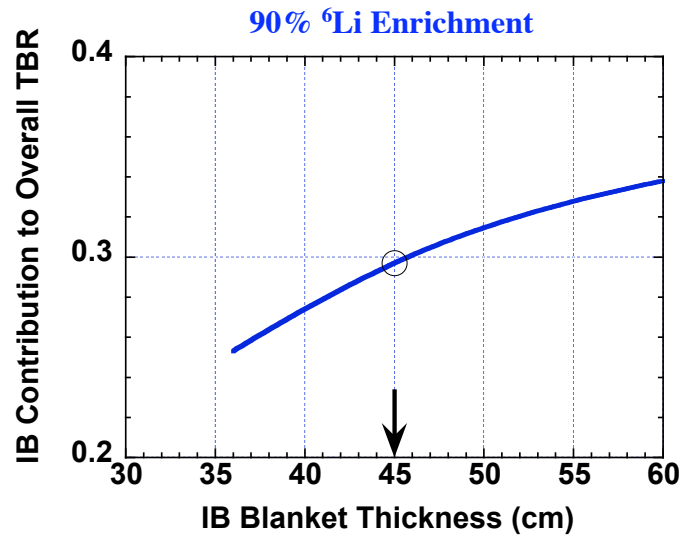
ARIES-AT-DCLL

IB-RB-I

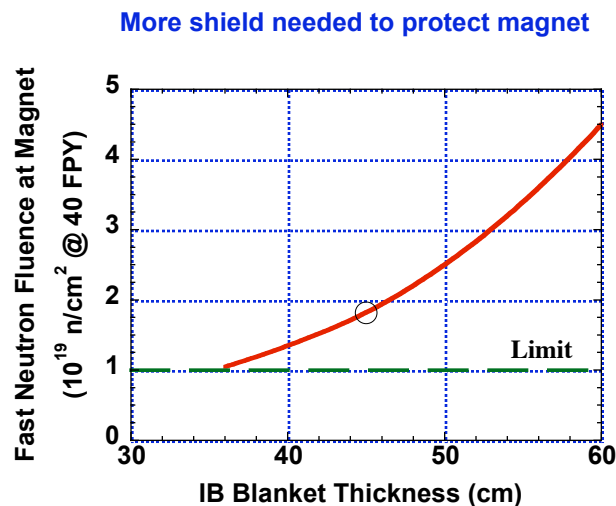
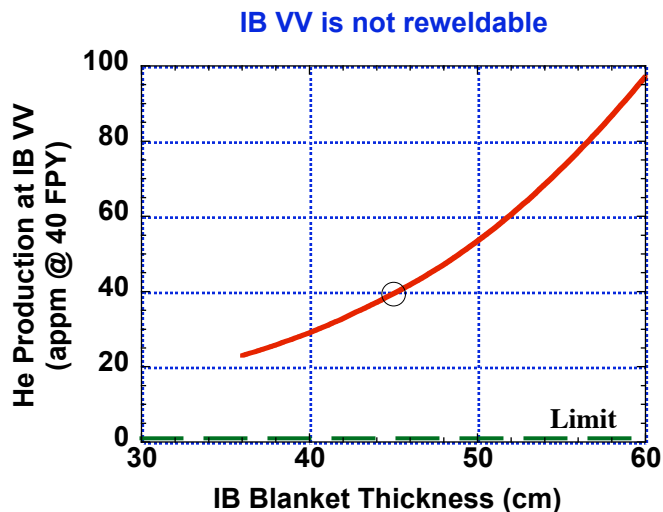
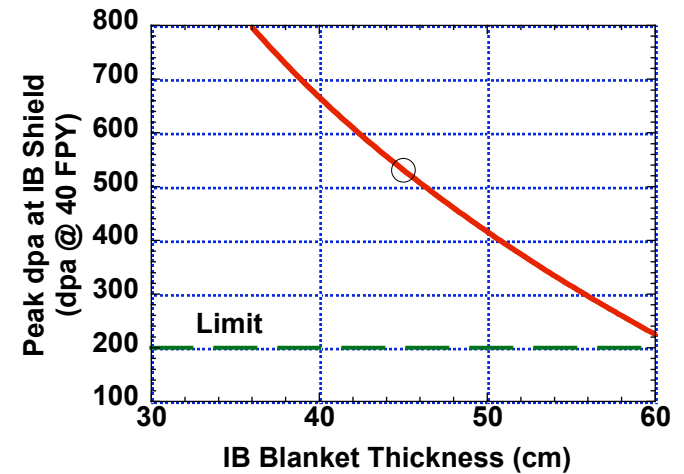
← B/S contain ~8 cm He →

IB Breeding & Radiation Damage

(Replacing IB Shield by Blanket)

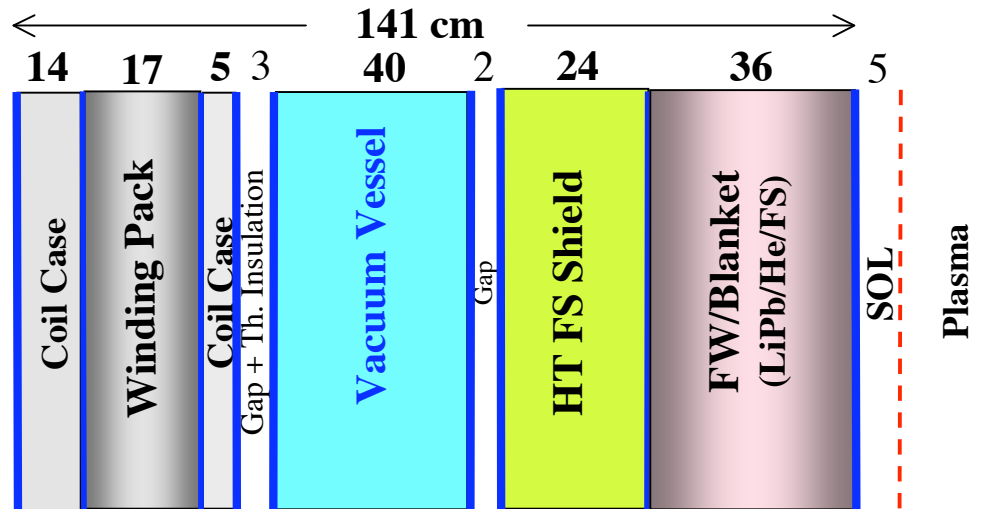


45 cm IB Blanket does not protect shield for 40 FPY



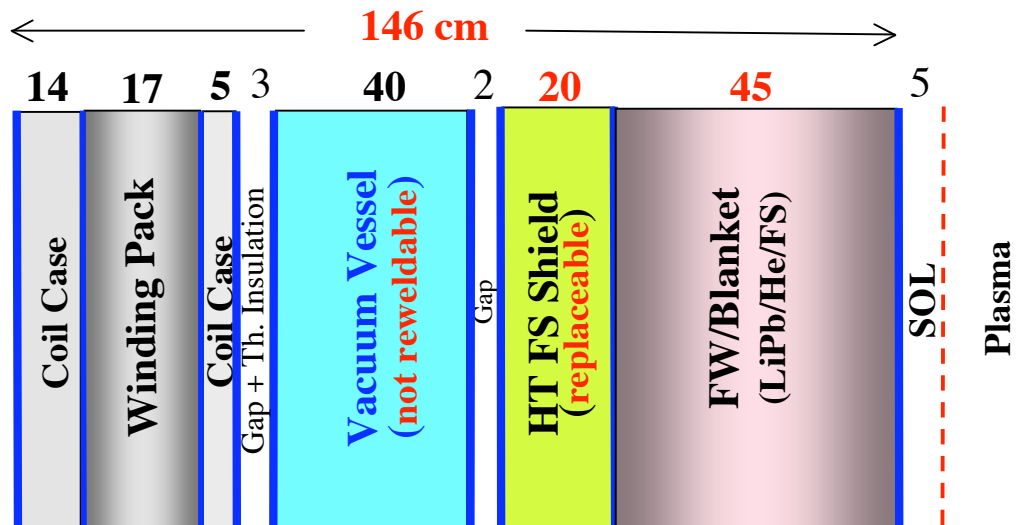
**45 cm blanket along
with 20 cm shield
(65 cm total)
protects magnet**

Recommended ARIES-AT-DCLL IB Radial Build (no LiPb/He Manifolds; no W Shells)



ARIES-AT-DCLL

IB-RB-I



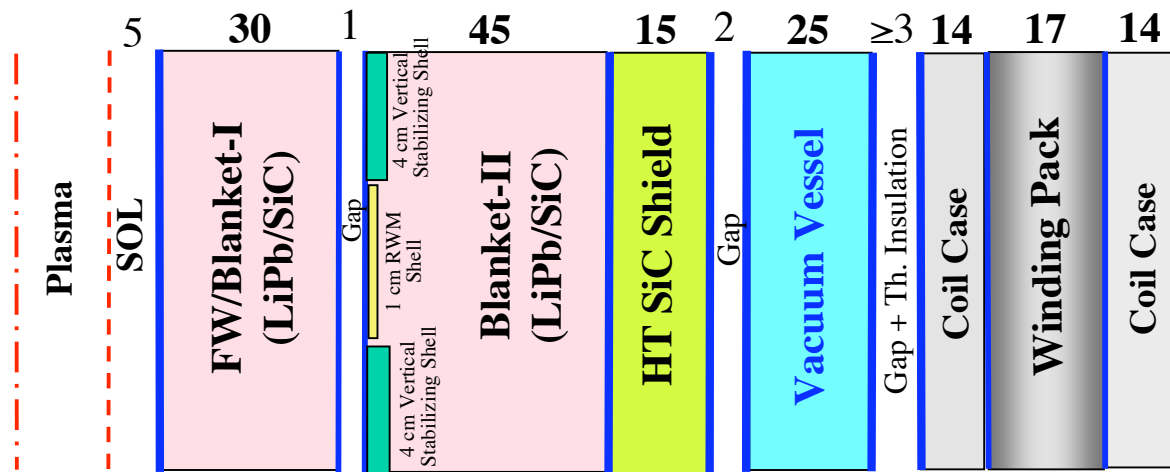
Recommended IB RB

ARIES-AT-DCLL

No LiPb/He Manifolds
No W Shells

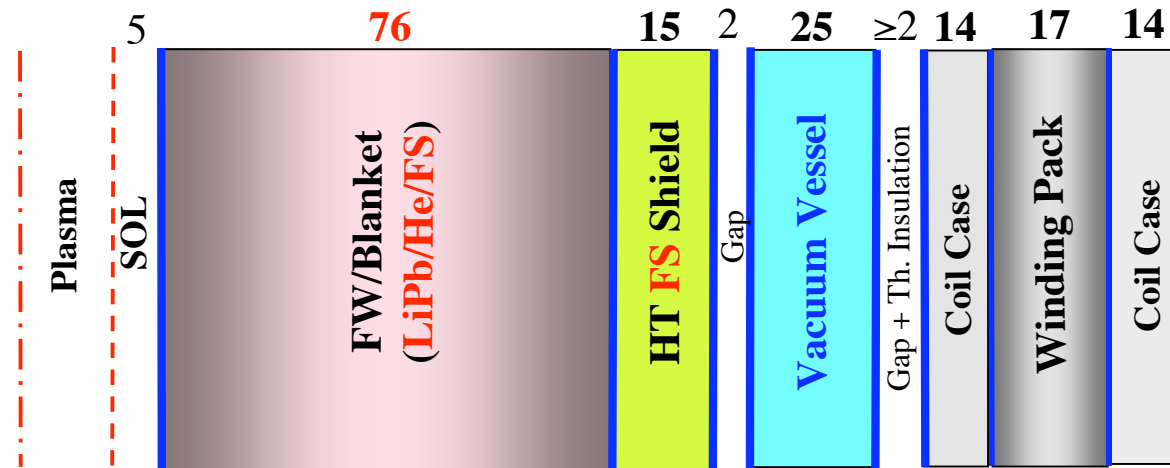
OB Radial Build

(4.8 MW/m² Peak NWL)



ARIES-AT
Reference OB-RB

≥ 166 cm

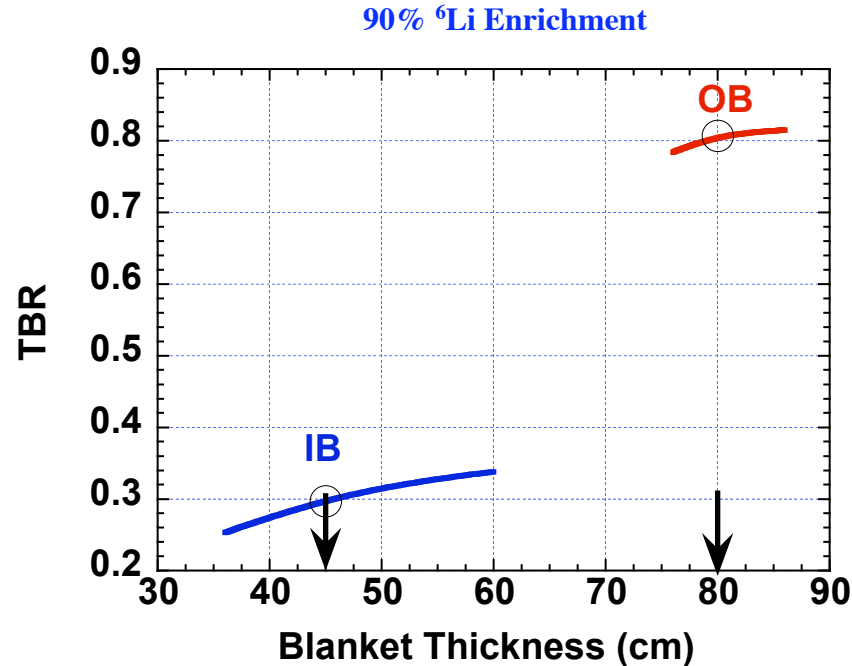


ARIES-AT-DCLL

OB-RB-I

B/S contain ~10 cm He

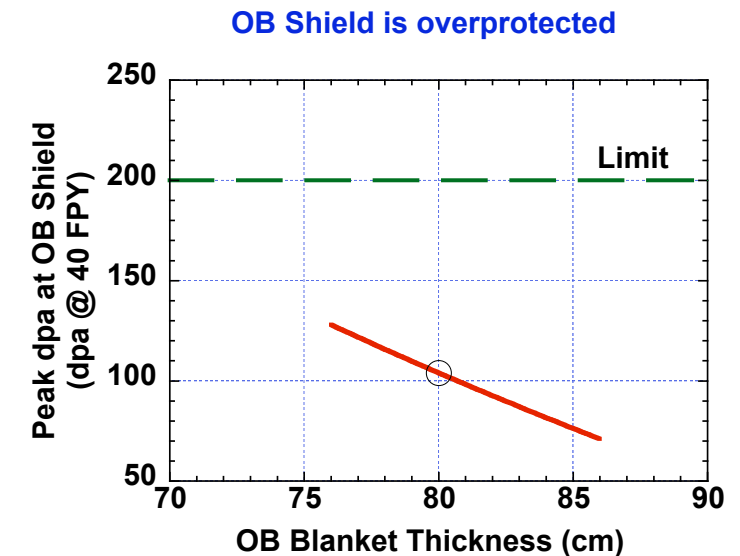
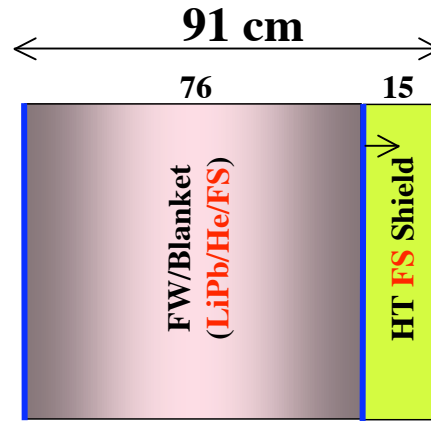
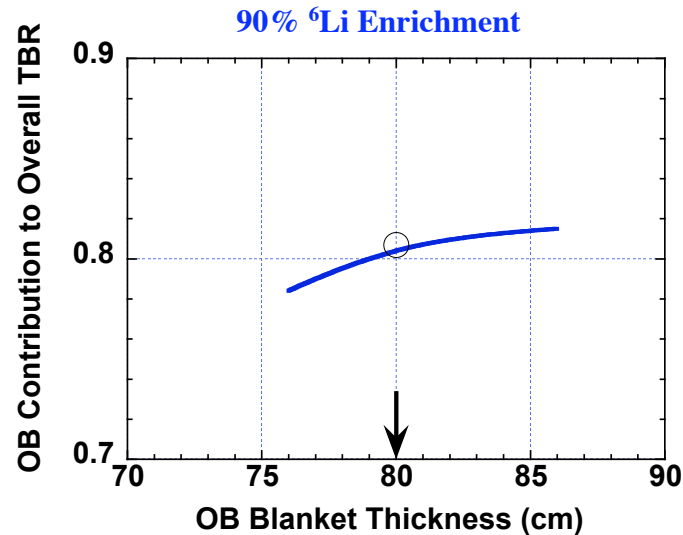
Calculated TBR Should be ≥ 1.1



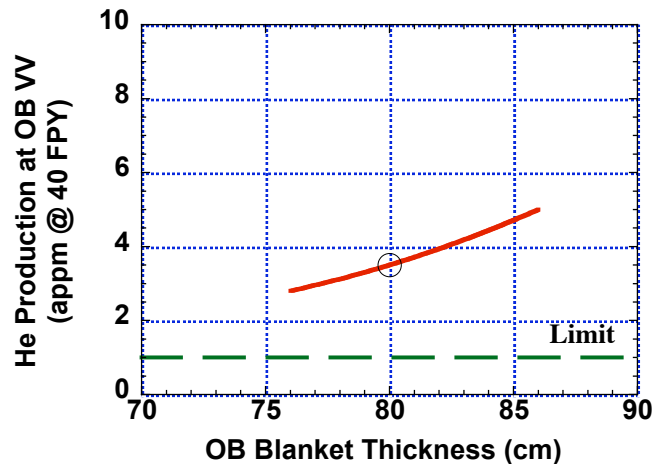
- **45 cm IB blanket** and **80 cm OB blanket** meet breeding requirement.
- Will **iterate with UCSD** to adjust FW/blanket composition, then readjust overall TBR and IB/OB radial builds.

OB Breeding & Radiation Damage

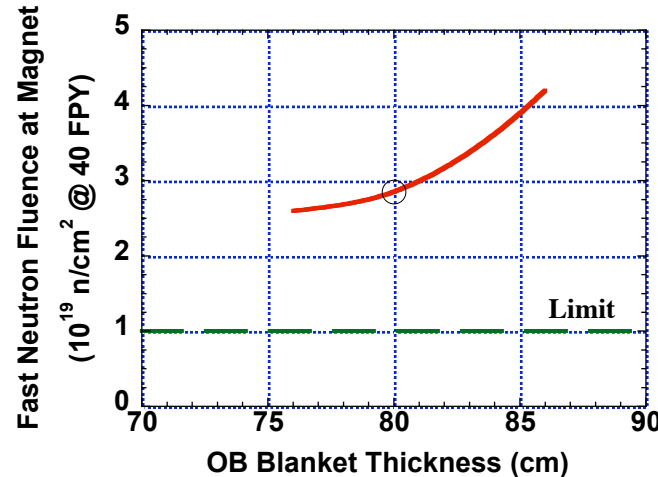
(Replacing OB Shield by Blanket)



More OB shield needed for reweldability of VV



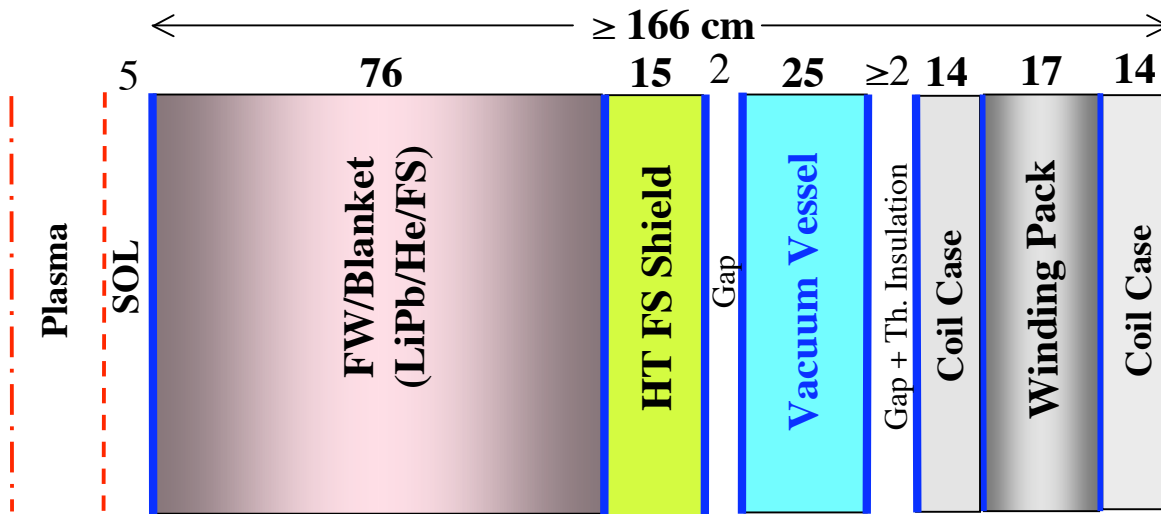
More shield needed to protect magnet



**80 cm blanket along
with 20 cm shield
(100 cm total)
protects VV and
magnet**

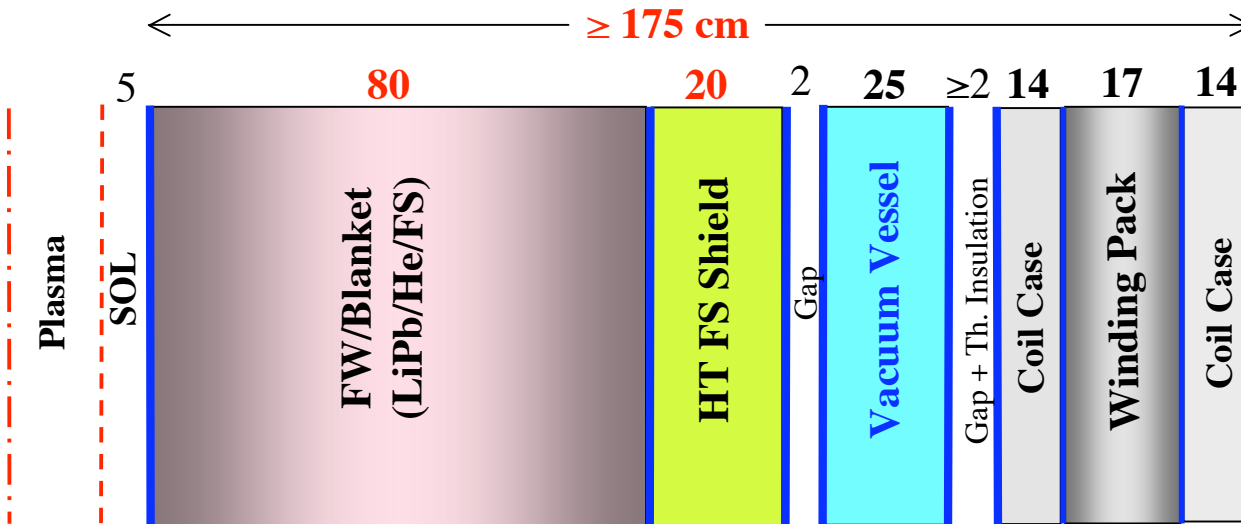
Recommended ARIES-AT-DCLL OB Radial Build

(no LiPb/He Manifolds; no W Shells)



ARIES-AT-DCLL

OB-RB-I



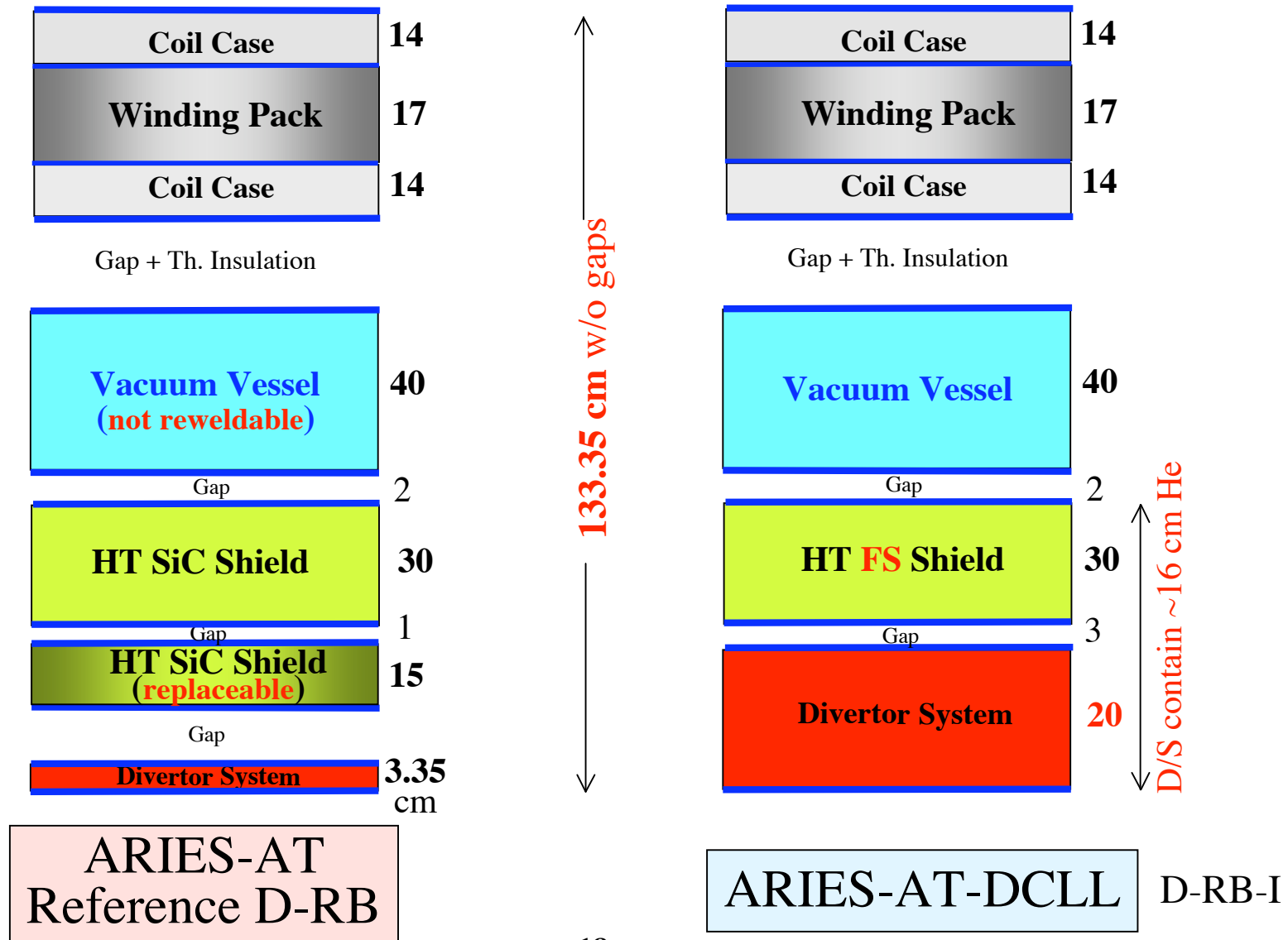
Recommended OB RB

ARIES-AT-DCLL

No LiPb/He Manifolds
No W Shells

Divertor Radial Build

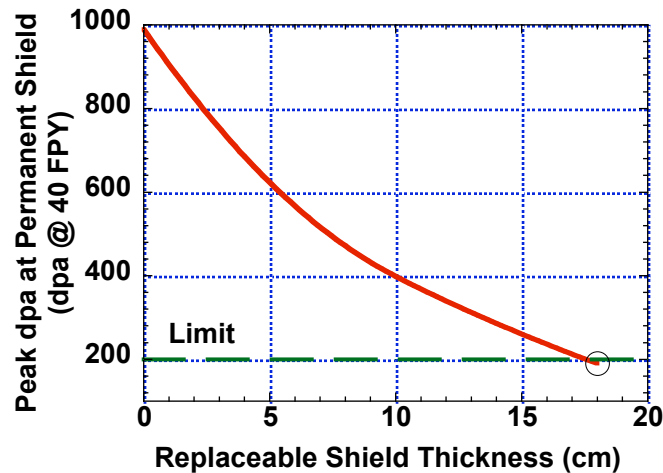
(2 MW/m² Peak NWL)



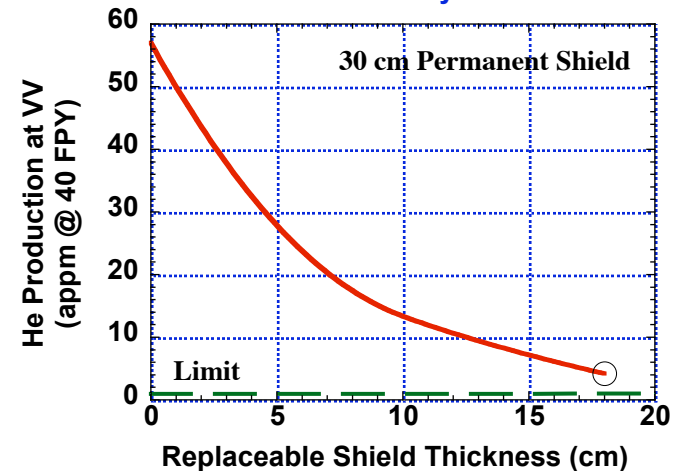
Divertor Radiation Damage

(Adding Replaceable Shield)

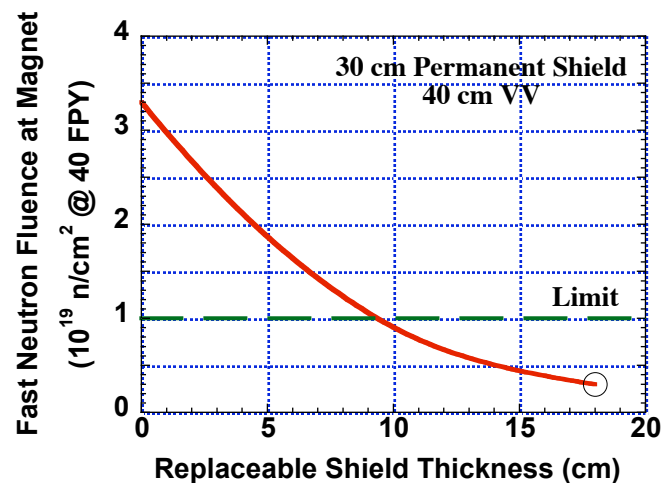
18 cm Replaceable shield protects permanent shield



40 cm Thick permanent shield needed for reweldability of VV

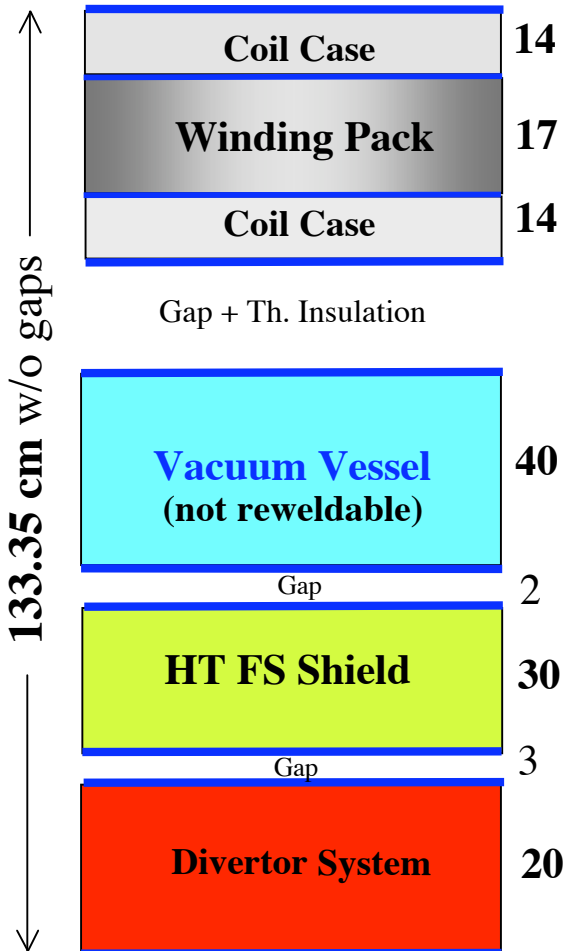


Magnet is over protected

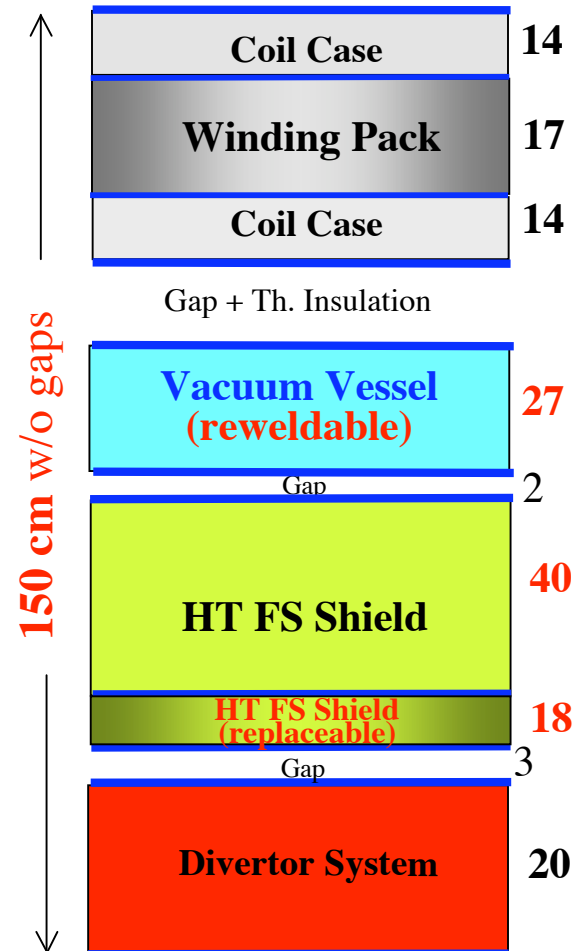


- **18 cm** replaceable shield and **40 cm** permanent shield protect VV.
- Shield and **27 cm** VV protect magnet.

Recommended ARIES-AT-DCLL Divertor Radial Build (no LiPb/He Manifolds)



ARIES-AT-DCLL D-RB-I



Recommended Div RB

ARIES-AT-DCLL

No LiPb/He Manifolds



Radiation Level

	IB	OB	Div.	Limit
Peak NWL (MW/m ²)	3.1	4.8	2	
dpa at shield (dpa @ 40 FPY):				200
Replaceable	540	---	1030	
Permanent	--- [#]	108	190	
He production at manifolds (He appm @ 40 FPY)	---	---	---	1
He production at VV (He appm @ 40 FPY)	19**	0.9	0.95	1
Magnet @ 70-80 K:				
Fast neutron fluence (10 ¹⁹ n/cm ² @ 40 FPY)	0.9	0.8	0.9	1
Nuclear heating (mW/cm ³)	0.2	4*	0.3	high

[#] May divide IB shield into replaceable and permanent components, ~10 cm each. Attach replaceable shield to Back Wall of blanket.

** Reweld at top/bottom, not around midplane.

* Will add boride in VV to lower magnet heating and activation.



Impact of DCLL System on ARIES-AT Economics

	<u>ARIES-AT-LiPb/SiC</u> (Reference Design)	<u>ARIES-AT-DCLL</u>	<u>Cost of</u> <u>ARIES-AT-DCLL</u>
Major radius	5.2 m	> 5.2 m	↑
Calculated overall TBR	1.1	1.1	
FW/blanket lifetime	4 FPY	2.8 FPY	↑
Overall energy multiplication	1.1	~1.15	↓
Structure unit cost (2004 \$)	510 \$/kg	103 \$/kg	↓
η_{th}	~ 60%	40-45%	↑
Cost of heat transfer/transport system (1992 \$)	\$126M	> \$300M	↑
He pumping power	---	> 100 MW _e	↑
Level of Safety Assurance (LSA) factor	1	2	↑
COE:			
in 1992 \$	48 mills/kWh	~ 60 mills/kWh	↑
in 2004 \$	60 mills/kWh	~ 80 mills/kWh	

Observations and Questions

Observations:

- DCLL **radial builds increased by 5-17 cm**, mainly due to He cooling $\Rightarrow$ Larger machine
- DCLL **Blanket segmentation** not allowed $\Rightarrow$ Large volume of radwaste
 - OB shells will be located outside blanket, far away from plasma $\Rightarrow$ No impact on breeding
 - Impact on physics and cost?
- Breeding with **< 90% enrichment** (for larger breeding margin) requires fairly thick IB and OB blankets
- **IB replaceable shield** could be divided into replaceable and permanent components to minimize radwaste stream
- **Boride material** will be added to OB VV to reduce magnet heating and activation
- **LiPb and He manifolds** will increase radial standoff and should **not** be placed at IB
- **Penetration shield** should surround pumping ducts to limit radiation damage at VV and magnet
- **NWL distribution** will be updated using actual neutron source profile within plasma, per Wilson (UW)
- **Future radial build** will include manifolds and W shells.

Questions :

- Discrete or continuous LiPb/He manifolds?
- Size, composition, and location of manifolds?
- Continue using HT YBCO TF/PF magnets? Switch to LT Nb₃Sn magnet?
- Impact of new shell location (outside sizable IB and OB blankets) on beta and other physics parameters?