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

L. El-Guebaly
Fusion Technology Institute
UW - Madison

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THE UNIVERSITY of WISCONSIN MADISON

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

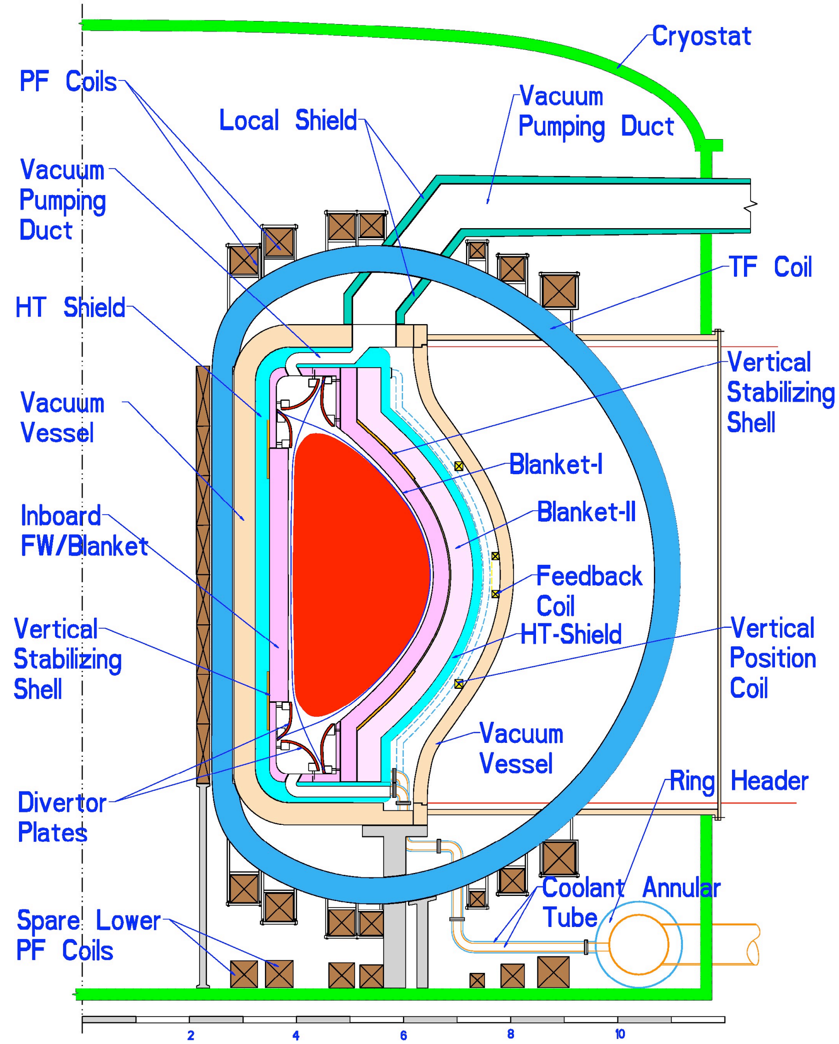
Fusion Power	1755 MW
Major Radius	5.2 m
Minor Radius	1.3 m
Peak Γ @ IB, OB, Div	3.1, 4.8, 2 MW/m^2

SiC/SiC Composite Structure
LiPb/SiC Blanket
Discrete LiPb Manifolds
HT S/C Magnet @ 70-80 K
No W on FW

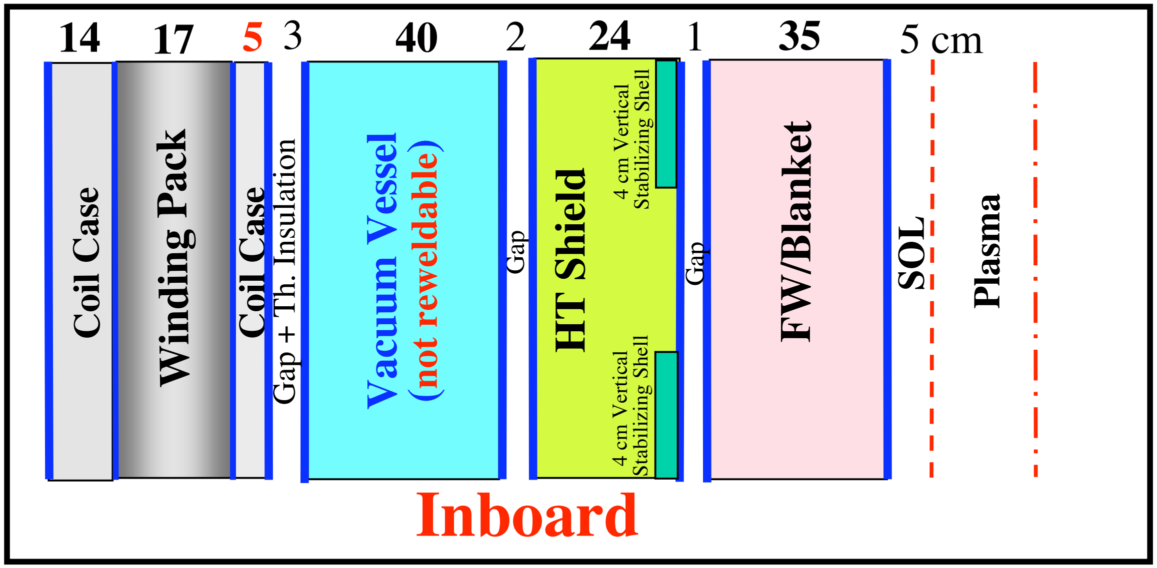
Calculated Overall TBR	1.1
η_{th}	~ 60%
Availability	85%

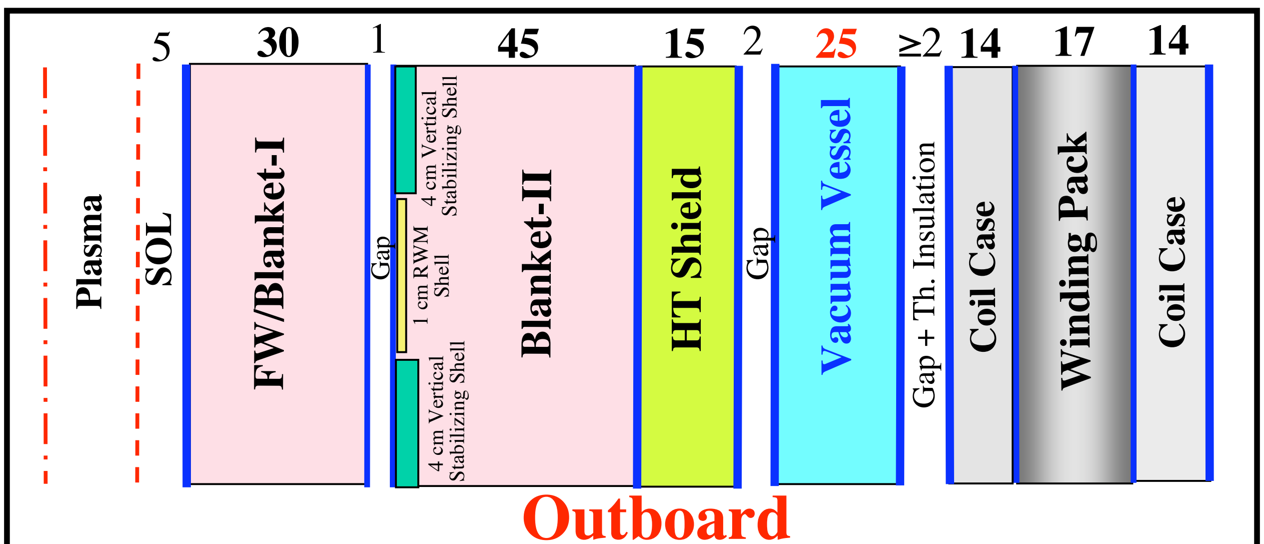
Plasma Control:
- 5 W Shells on IB and OB
- 2 Vertical Position Coils
- 2 Feedback Coils

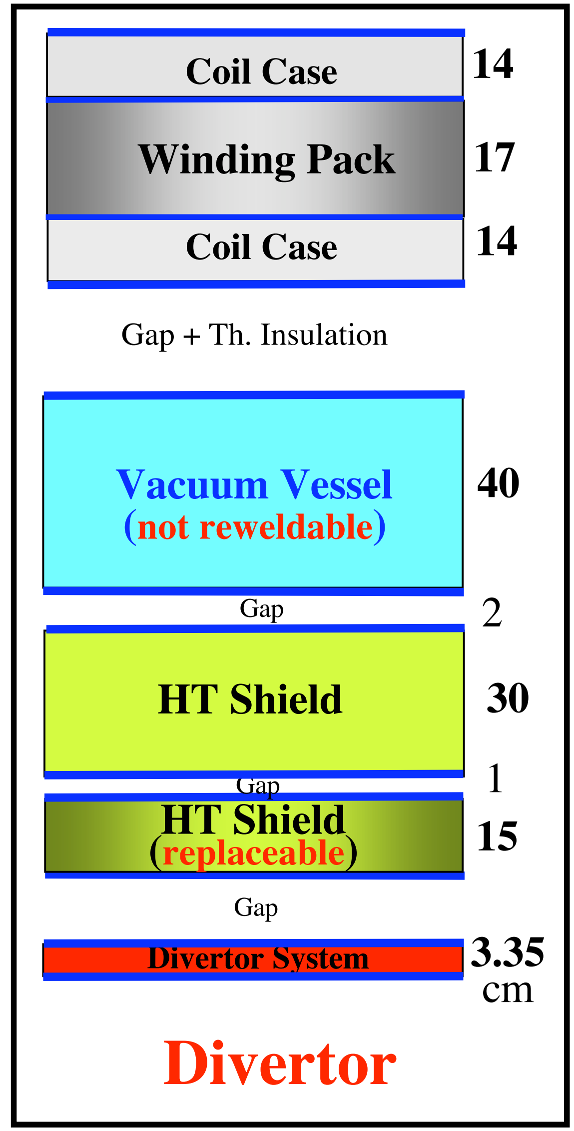
Cross Section of ARIES-AT Power Core Configuration



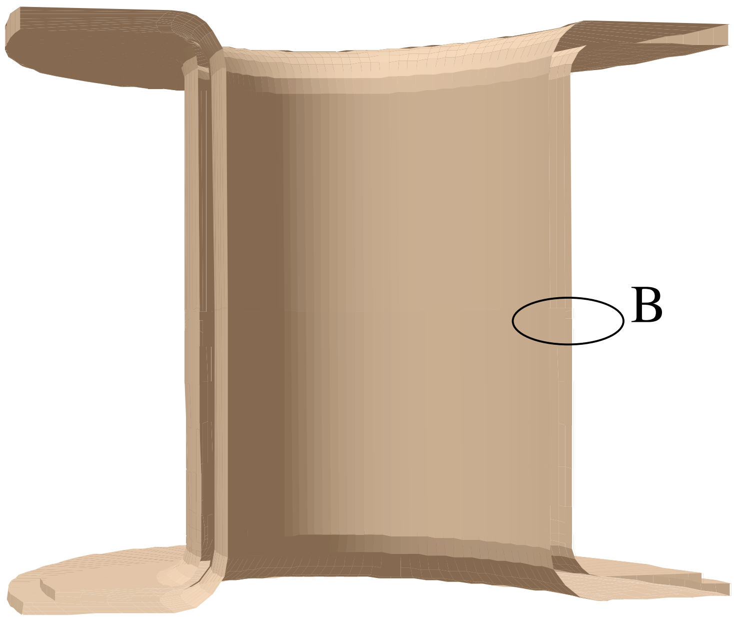
ARIES-AT Radial Builds: IB, OB, Div
(SiC Structure)



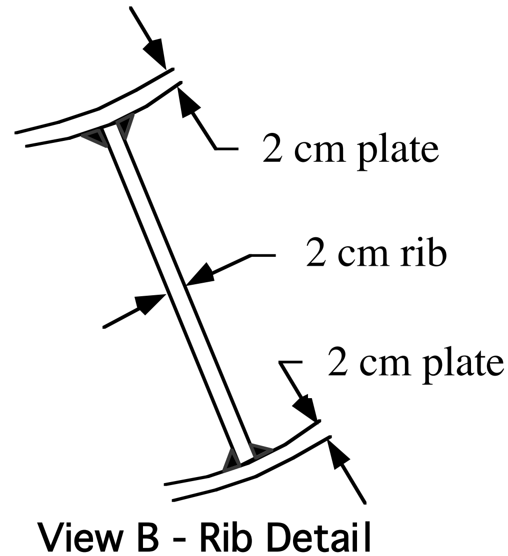




ARIES-AT Vacuum Vessel
(FS Structure)



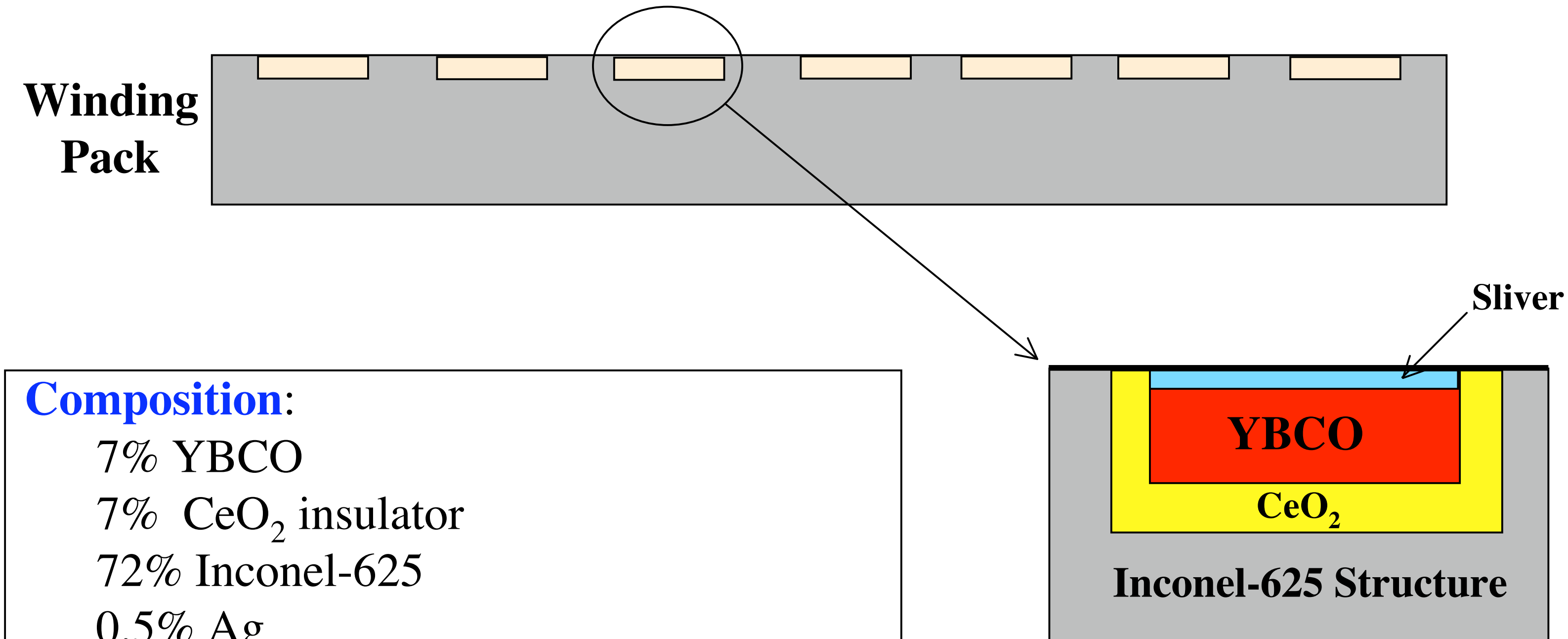
IB and Top/Bottom VV
(not-reweldable)



Dimension and Composition

40 cm IB VV: 13% FS, 22% H_2O, 65% WC Filler
40 cm T/B VV: 13% FS, 22% H_2O, 65% B-FS Filler
25 cm OB VV: 30% FS, 70% H_2O.

ARIES-AT TF/PF Magnet
(High-Temp S/C @ 70-80 K)



Composition:

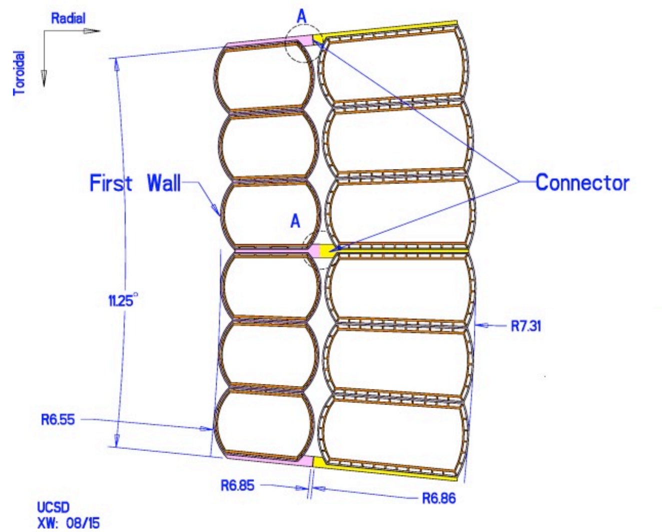
- 7% YBCO
- 7% CeO_2 insulator
- 72% Inconel-625
- 0.5% Ag
- 13.5% GFF Polyimide insulator.

Conduction cooling of WP from coil case.

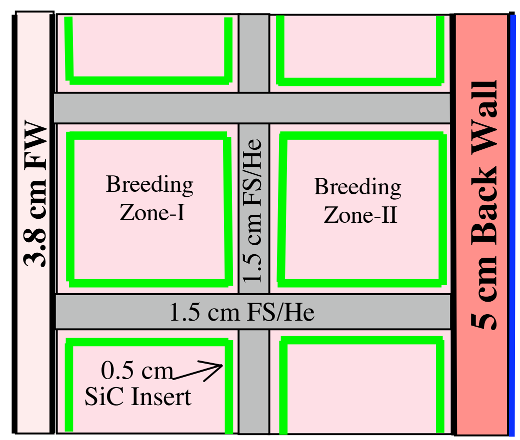
Coil case contains 5% LN cooling channels.

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

	ARIES-AT-LiPb/SiC (Reference Design)	ARIES-AT-DCLL
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

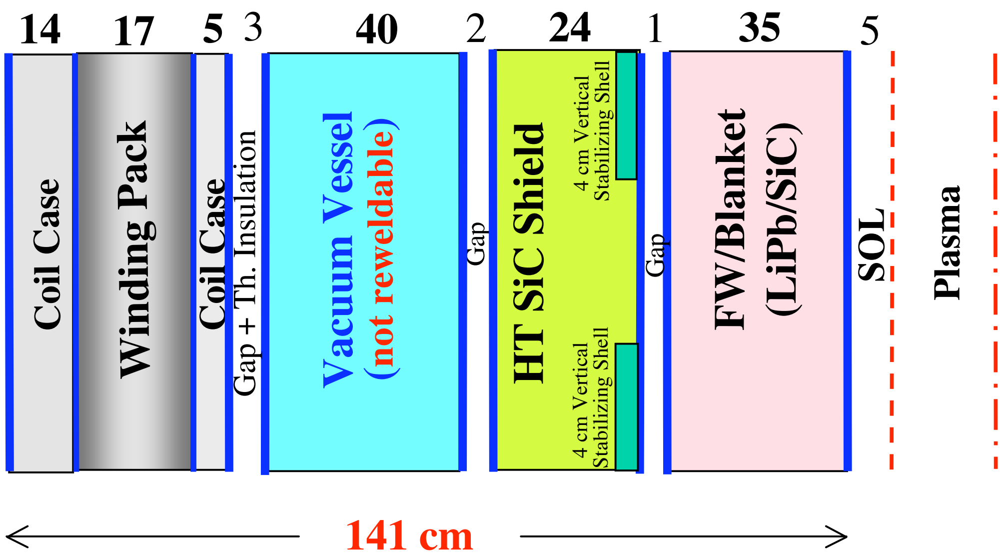
Calculated Overall TBR	1.1	
Net TBR (for T self-sufficiency)	~1.01	
Damage to Structure (for structural integrity)	3%	Burnup - SiC/SiC composites
	200	dpa - advanced FS
Helium Production @ VV (for reweldability of FS)	1	He appm
HT S/C TF & PF Magnets (@ 70-80 K):		
Peak Fast n **fluence** to YBCO ($E_n > 0.1$ MeV)	10^{19}	n/cm^2
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

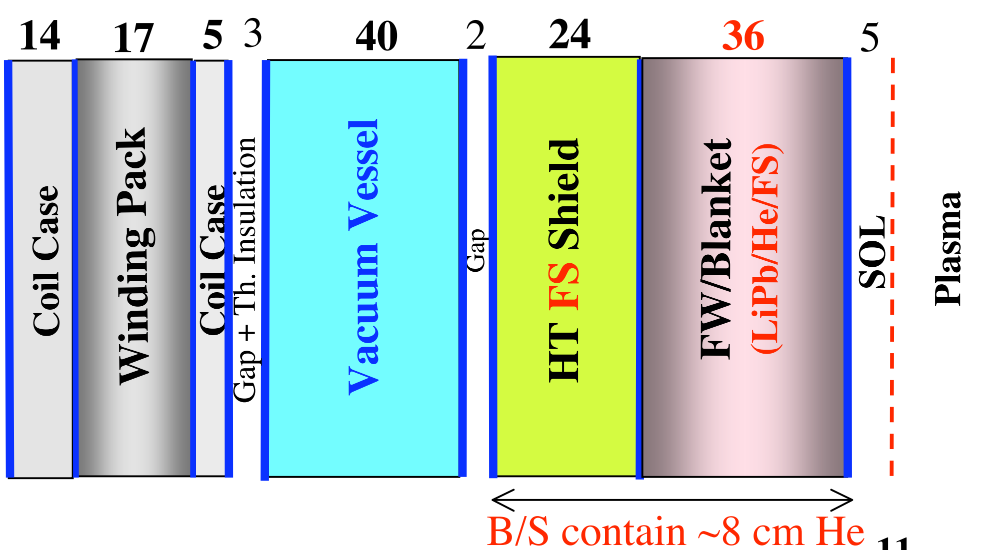
	ARIES-AT-LiPb/SiC (Reference Design)	ARIES-AT-DCLL*
Peak NWL @ IB, OB, Div	3.1, 4.8, 2 MW/m^2	3.1, 4.8, 2 MW/m^2 (to be updated)
FS structure	ORNL FS	MF82H FS
LiPb:		
Li enrichment	90%	90%
Average temp	700 ^oC	580 ^oC
Density	8.8 g/cc	9 g/cc
OB blanket	Two segments	One segment
W shells:		
Two 4-cm-thick 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

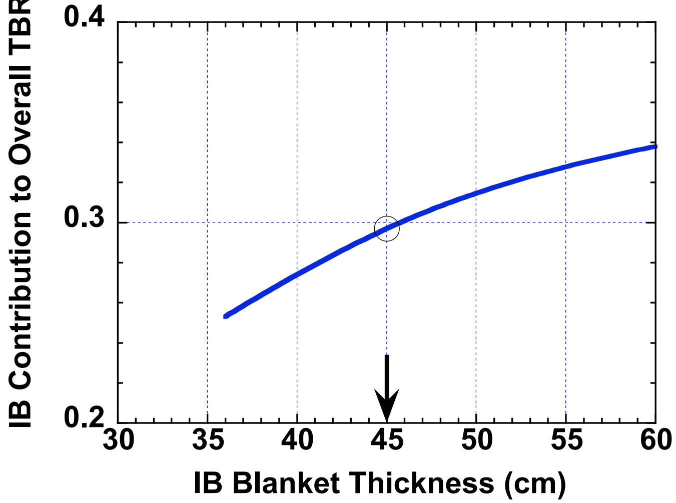


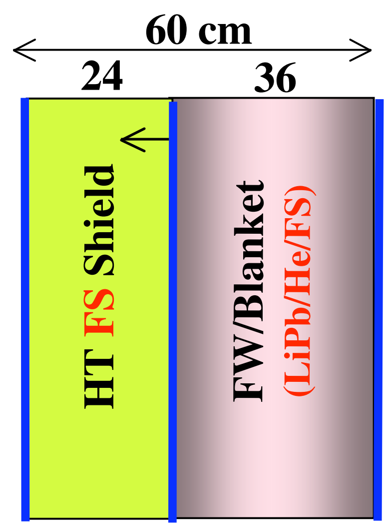
ARIES-AT-DCLL

IB-RB-I

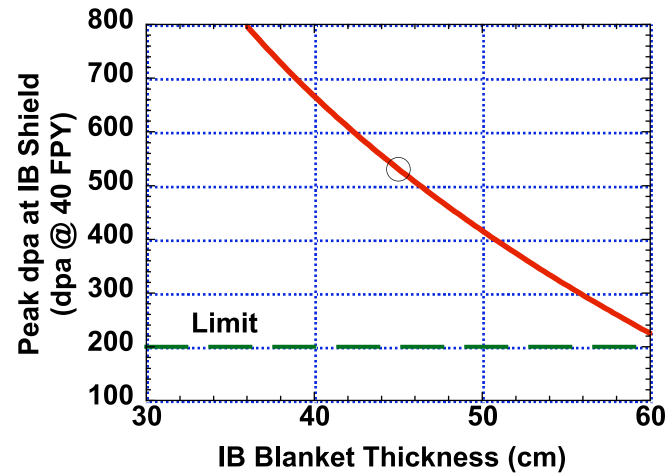
IB Breeding & Radiation Damage
(Replacing IB Shield by Blanket)

90% ^{6}Li Enrichment

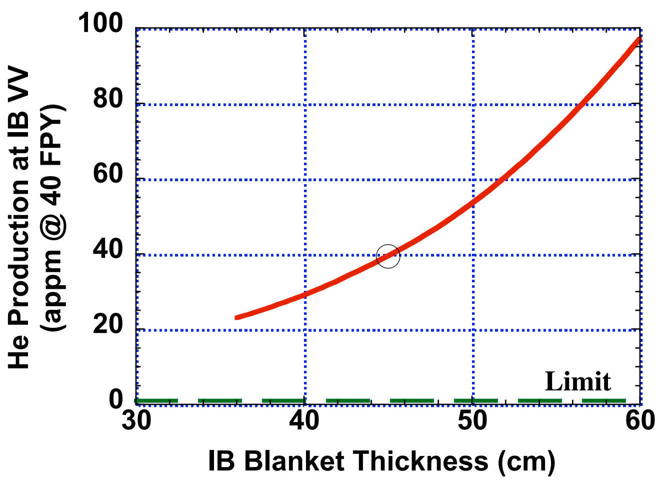




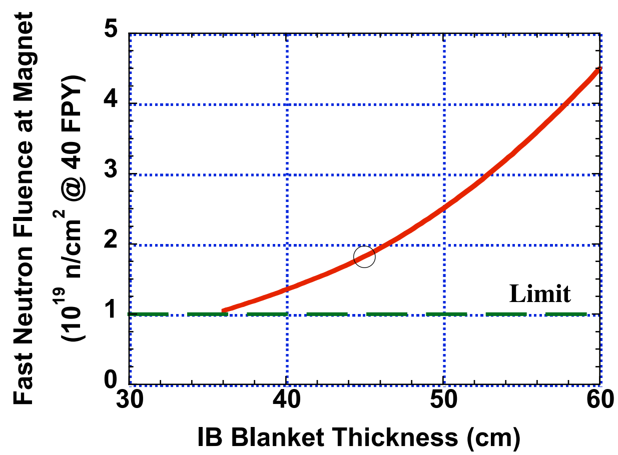
45 cm IB Blanket does not protect shield for 40 FPY



IB VV is not reweldable



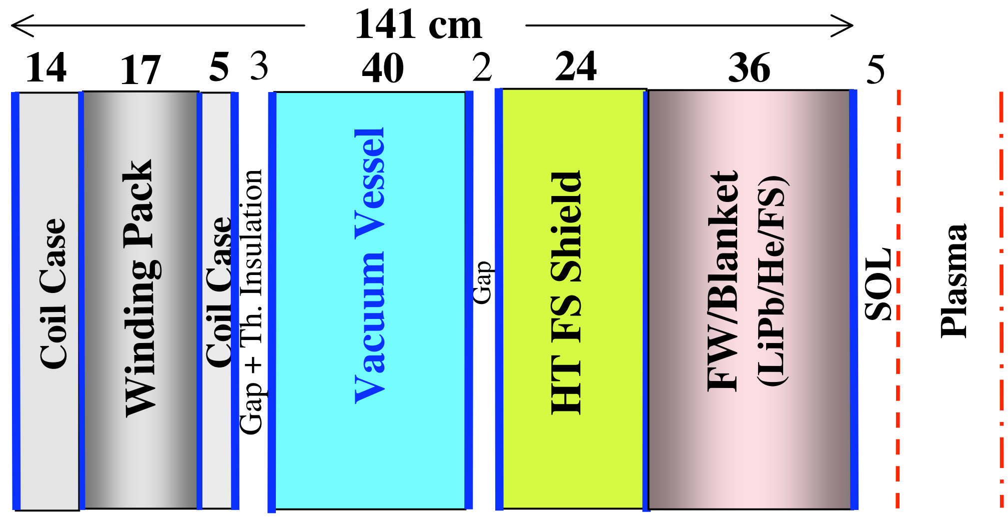
More shield needed to protect magnet



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

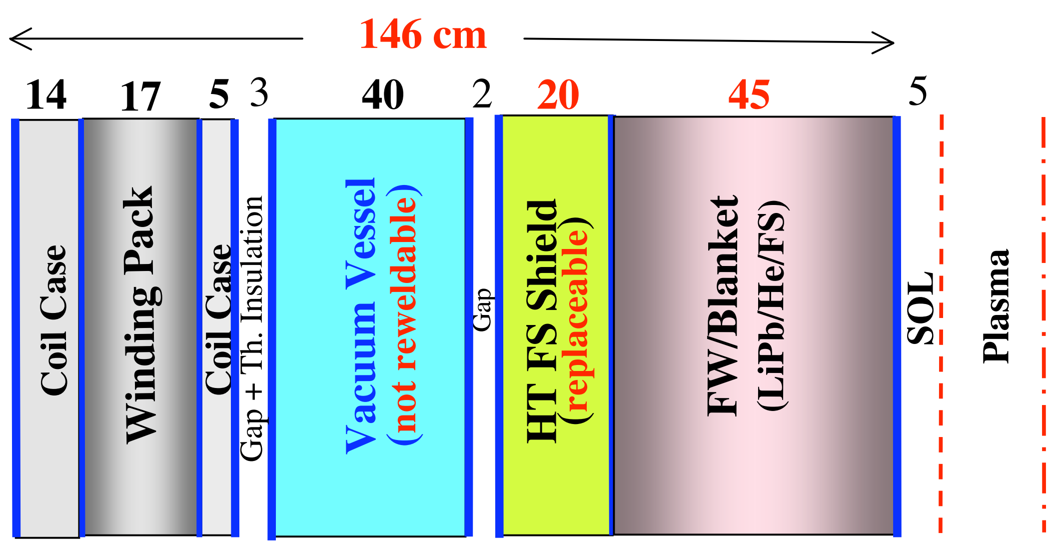
Recommended ARIES-AT-DCLL IB Radial Build

(no LiPb/He Manifolds; no W Shells)



ARIES-AT-DCLL

IB-RB-I



Recommended IB RB

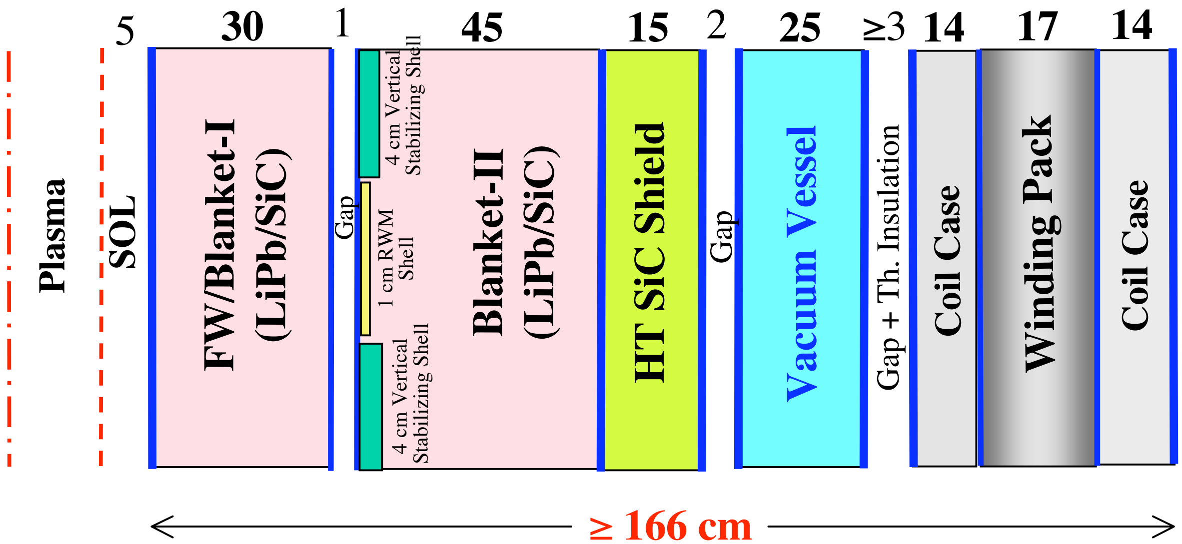
ARIES-AT-DCLL

No LiPb/He Manifolds

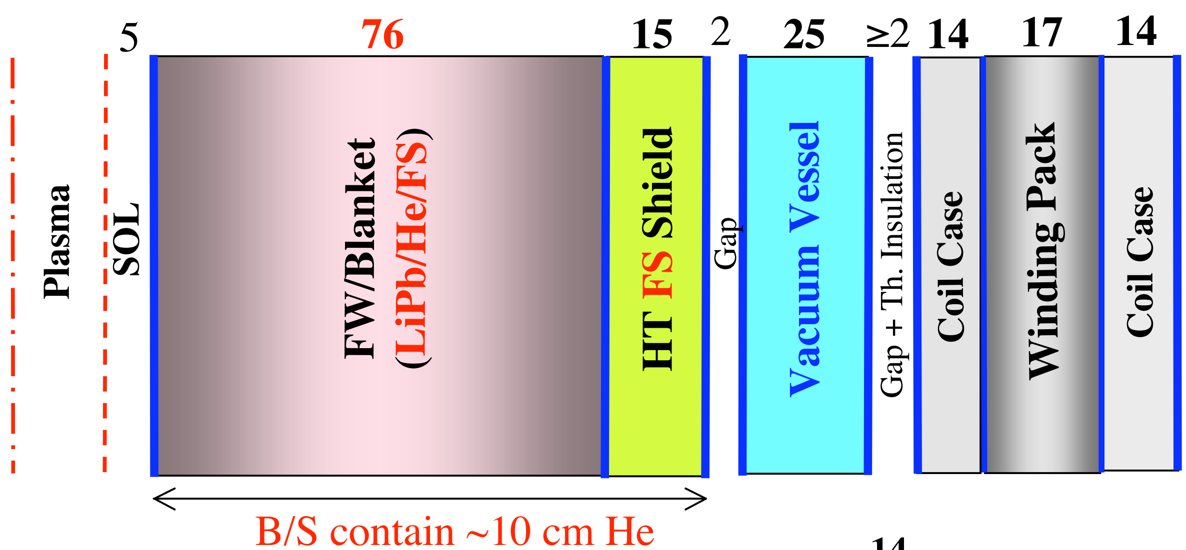
No W Shells

OB Radial Build

(4.8 MW/m² Peak NWL)



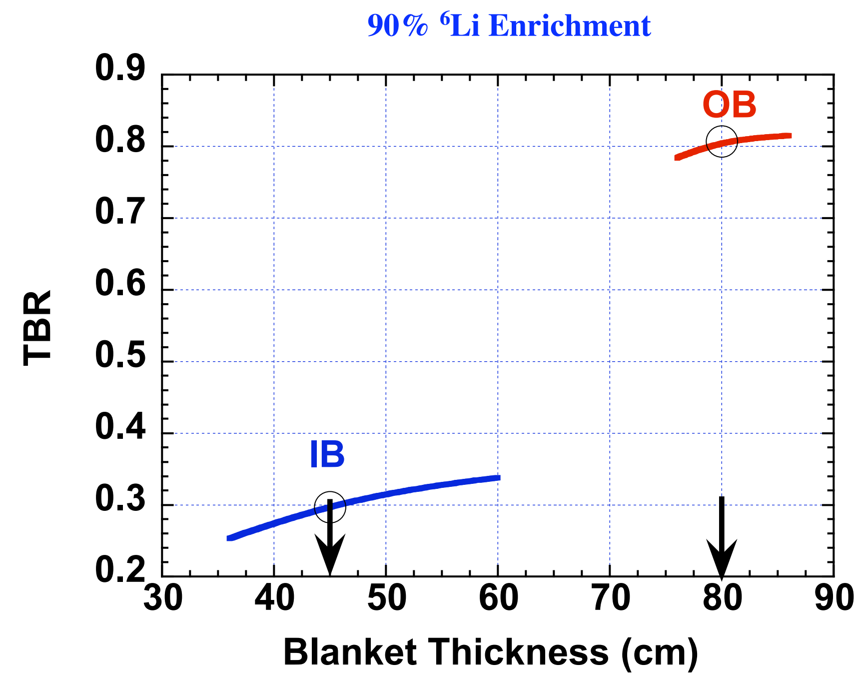
ARIES-AT
Reference OB-RB



ARIES-AT-DCLL

OB-RB-I

Calculated TBR Should be ≥ 1.1

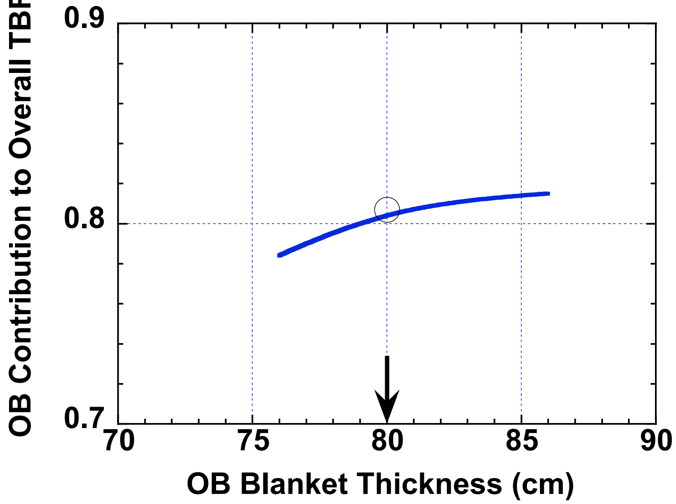


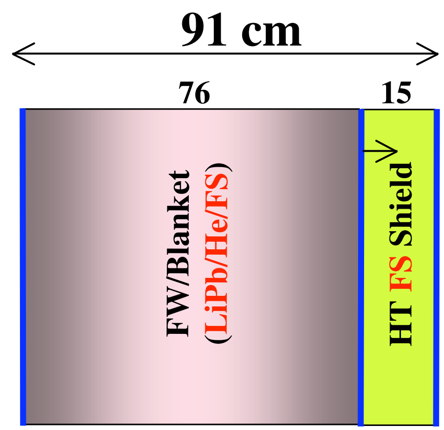
- **45 cm IB blanket** and **80 cm OB blanket** meet breeding requirement.
- Will iterate with UCSD to adjust FW/blanket composition, then readjust overall TBR and IB/OB radial builds.

OB Breeding & Radiation Damage

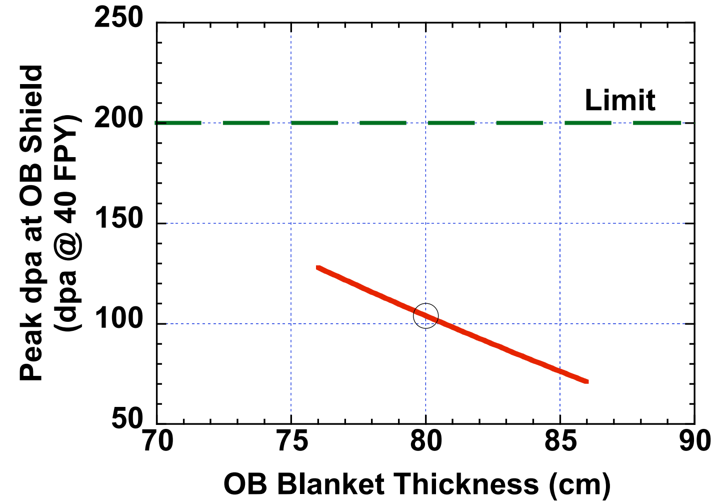
(Replacing OB Shield by Blanket)

90% ^{6}Li Enrichment

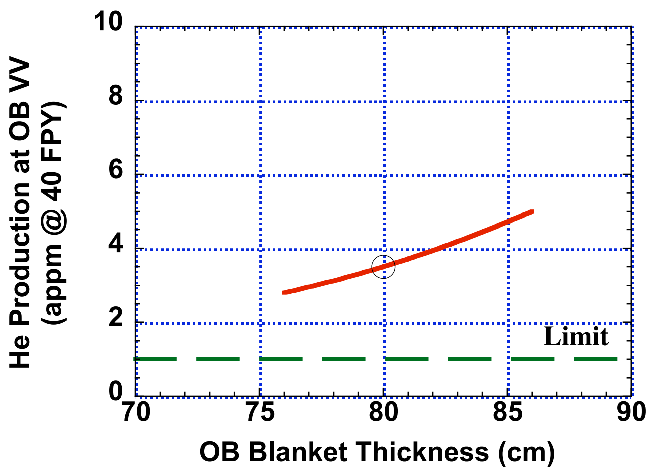




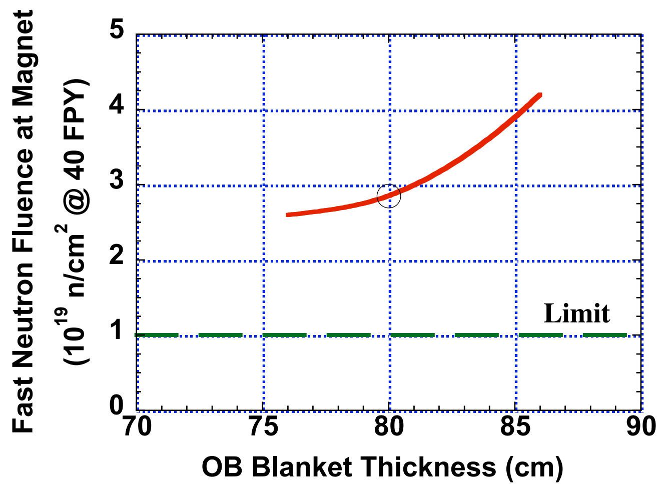
OB Shield is overprotected



More OB shield needed for reweldability of VV

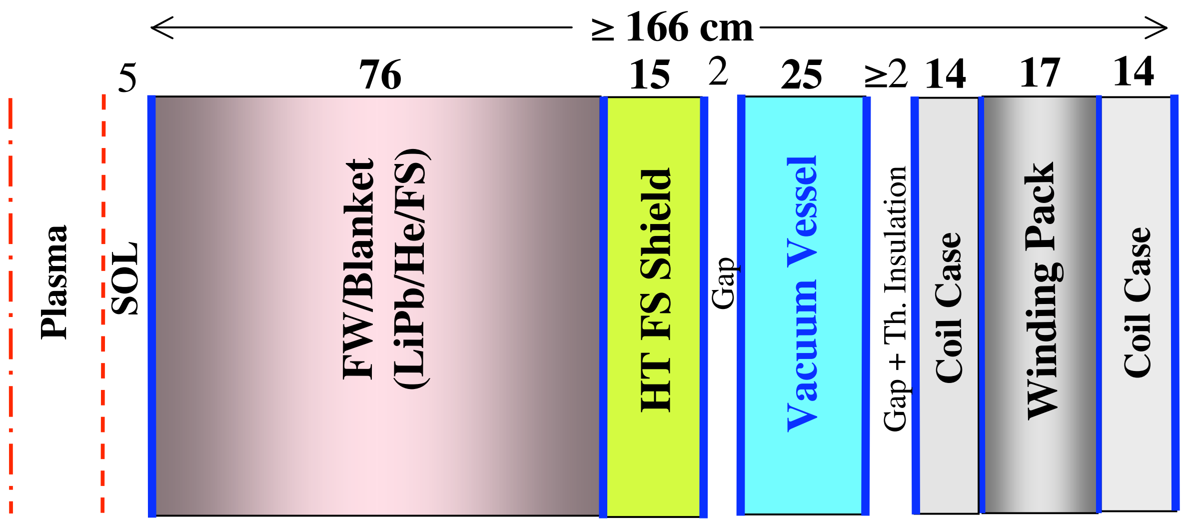


More shield needed to protect magnet



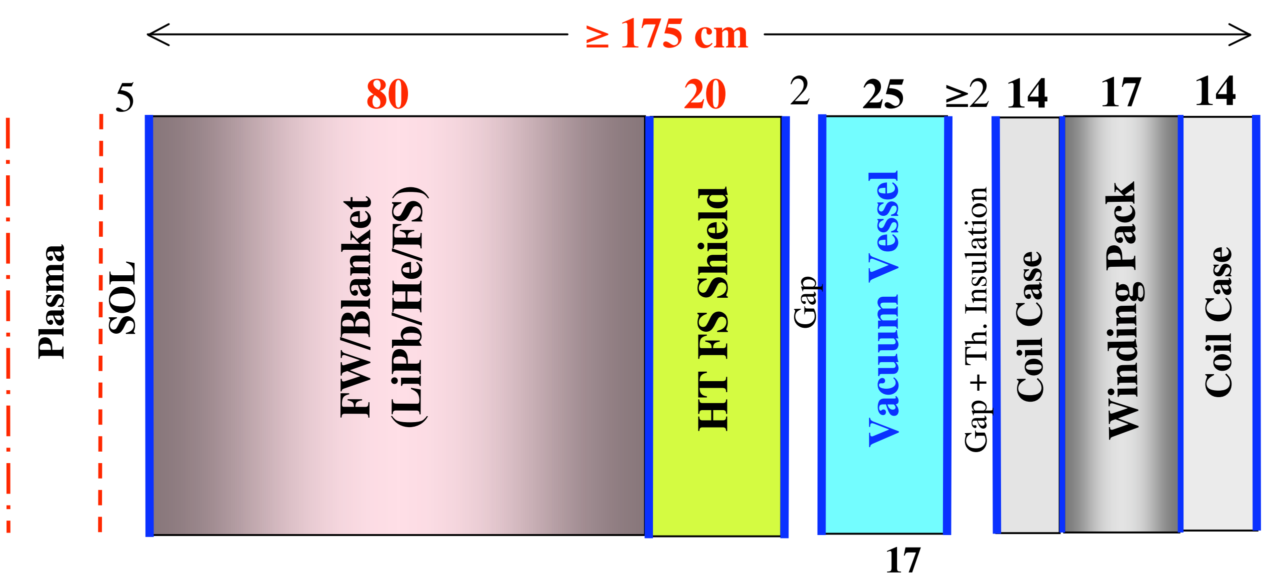
80 cm blanket along with **20 cm** shield (100 cm total) protects VV and magnet

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



ARIES-AT-DCLL

OB-RB-I



Recommended OB RB

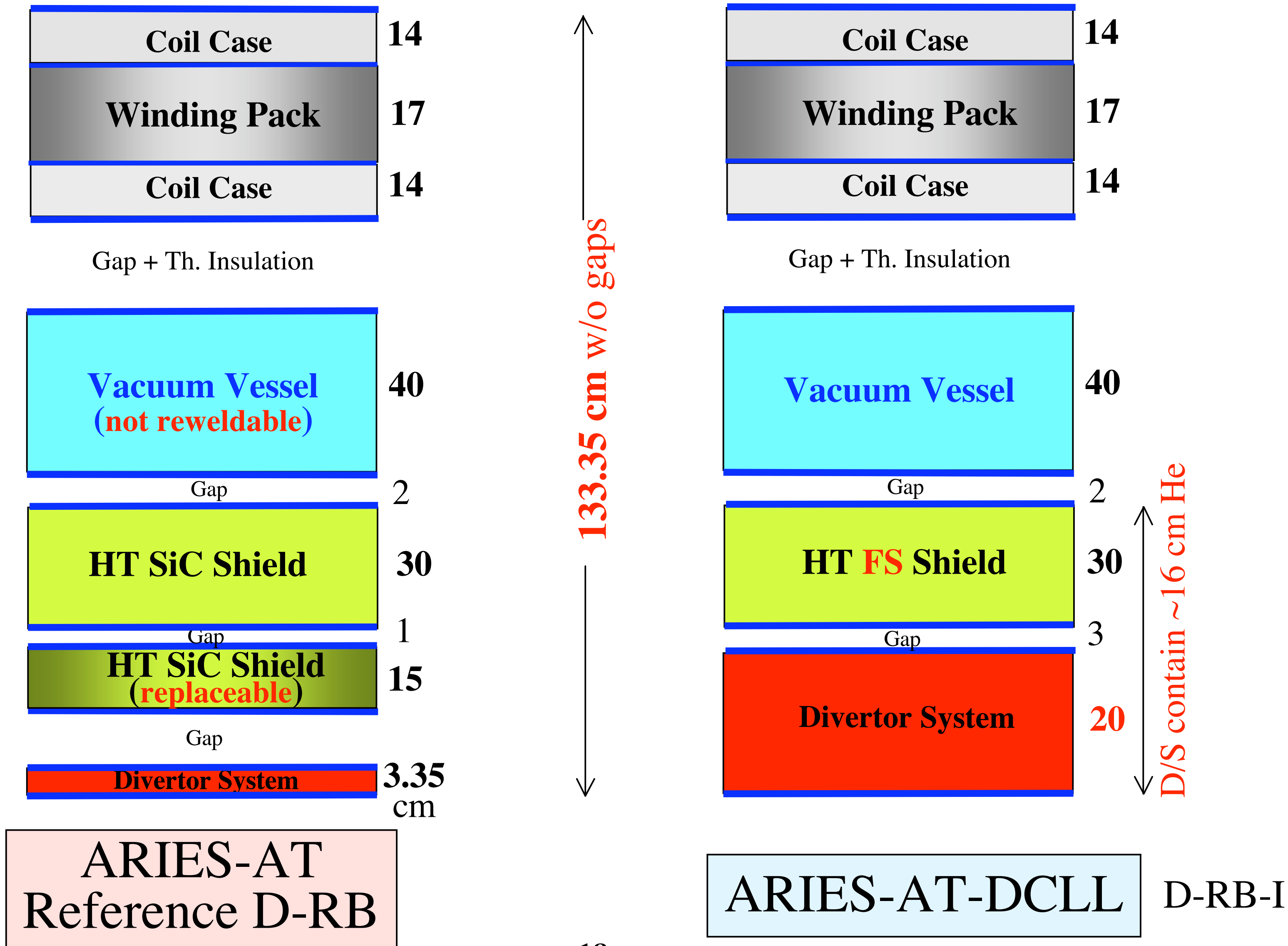
ARIES-AT-DCLL

No LiPb/He Manifolds

No W Shells

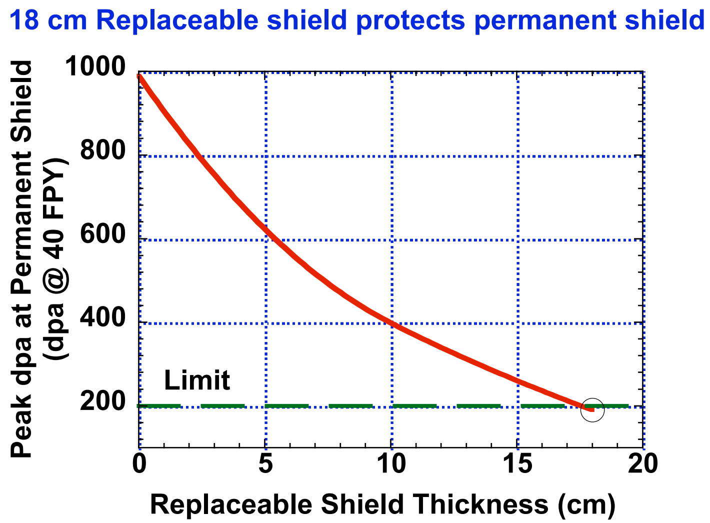
Divertor Radial Build

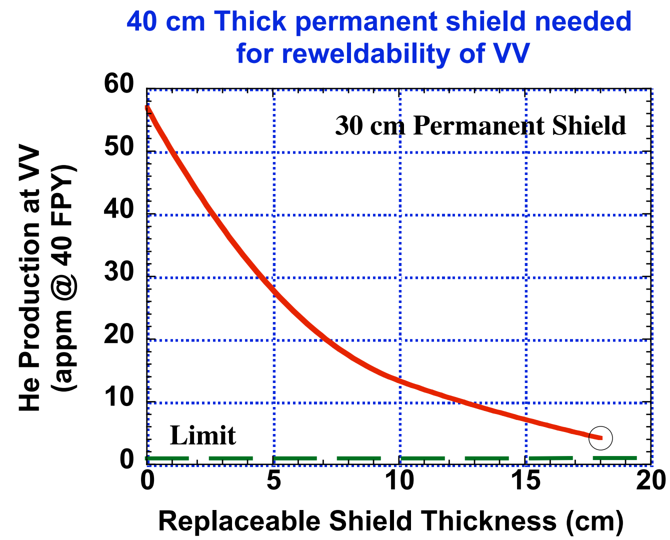
(2 MW/m^2 Peak NWL)

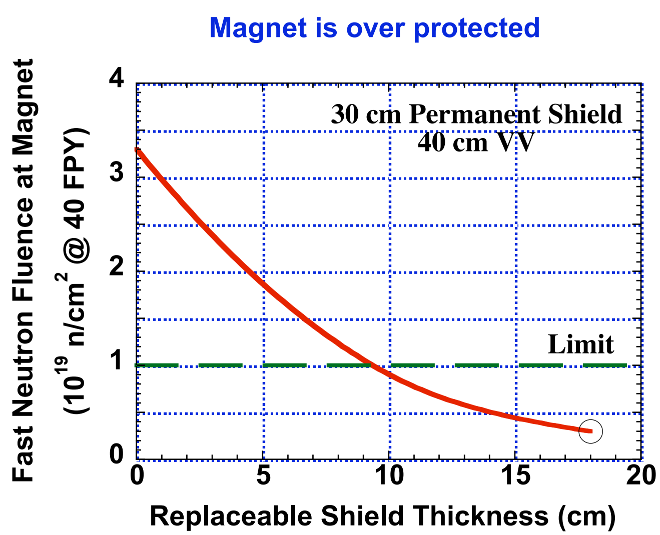


Divertor Radiation Damage

(Adding Replaceable Shield)

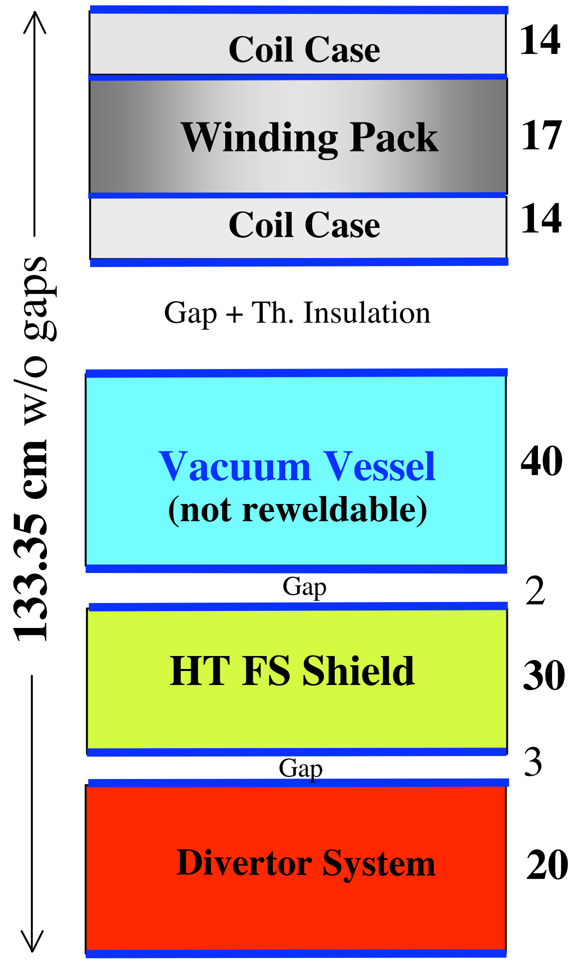




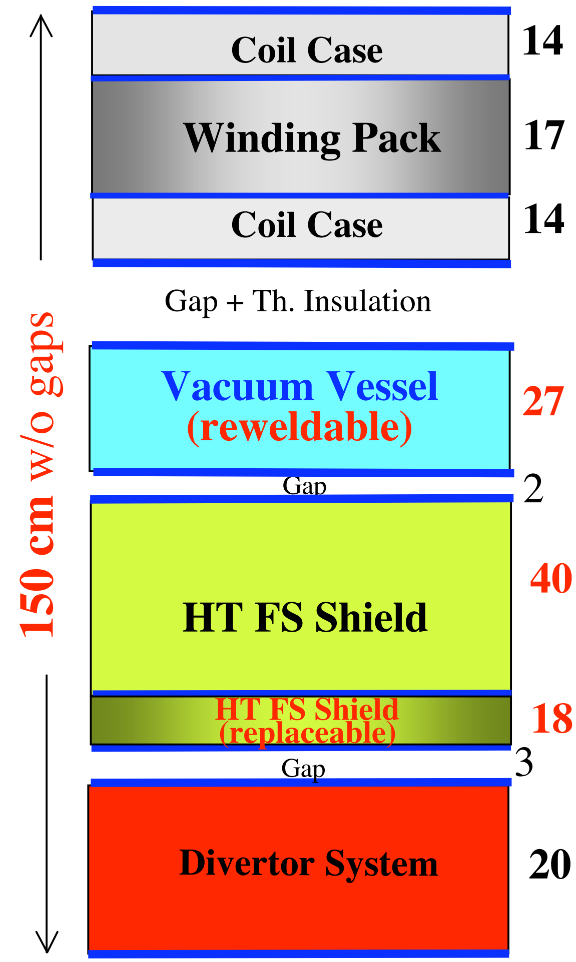


- **18 cm** replaceable shield and **40 cm** permanent shield protect VV.
- Shield and **27 cm** VV protect magnet.

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

	ARIES-AT-LiPb/SiC (Reference Design)	ARIES-AT-DCLL	Cost of ARIES-AT-DCLL
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 ⇒ Larger machine
- DCLL Blanket segmentation not allowed ⇒ Large volume of radwaste
  OB shells will be located outside blanket, far away from plasma ⇒ 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 Nb_3Sn magnet?
- Impact of new shell location (outside sizable IB and OB blankets) on beta and other physics parameters?