



ARIES-AT Radial Build Definition: DCLL Blanket w/ Thin SiC Inserts

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Objectives

- **Redesign ARIES-AT with DCLL** system (a la ARIES-CS) and redefine radial builds with:
 - DCLL blanket and shield
 - < 90% Li enrichment
 - LiPb/He Manifolds (tentative composition/dimension/location)
 - **No** stabilizing shells (to be added later)
 - LT magnets (instead of HT magnets).
- **Assess impact of SiC inserts** on TBR:
 - **Reference:** 100% dense, 0.5 cm thick SiC insert
 - **Alternative:** 0.5-0.7 cm thick Ultramet SiC insert (0.3-0.5 cm 10% dense SiC foam sandwiched between 1 mm 100% dense impermeable CVD-SiC face sheets; 0.23-0.25 cm equivalent SiC thickness).
- **Compare** reference ARIES-AT with ARIES-AT-DCLL and highlight impact of DCLL system on overall design.

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%

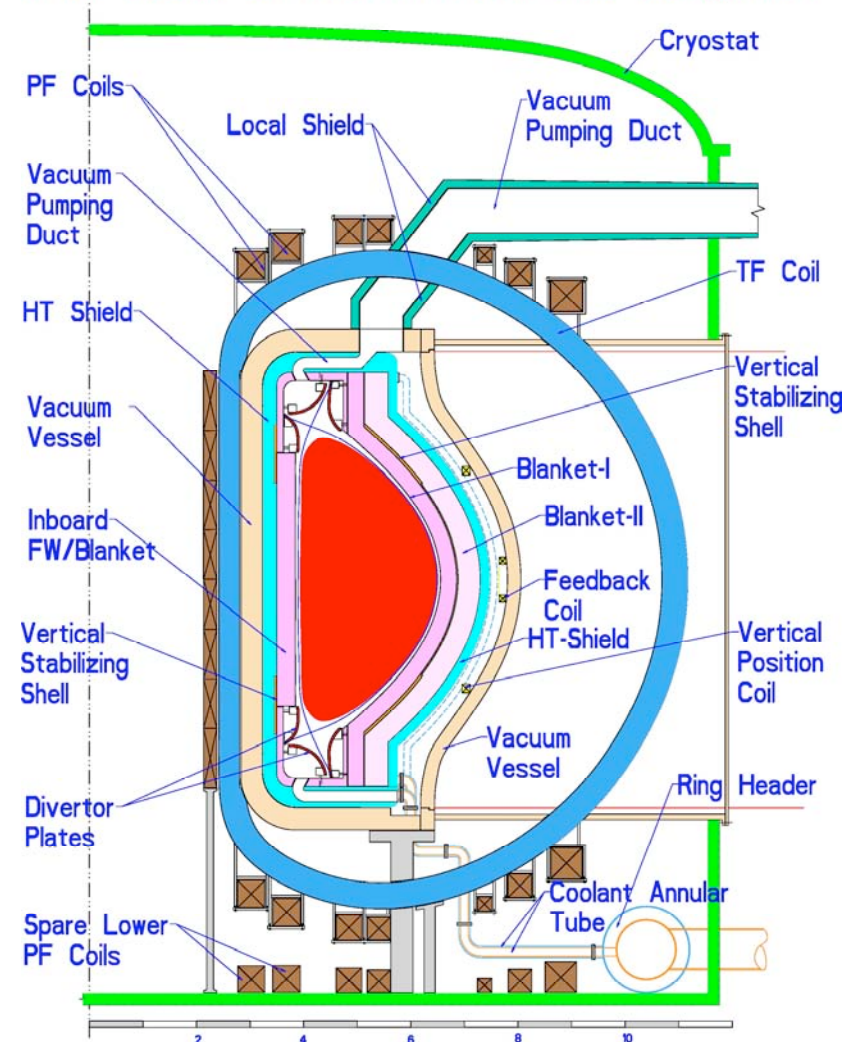
Plasma Control:

5 **Tungsten** Shells on IB and OB

2 Vertical Position Coils

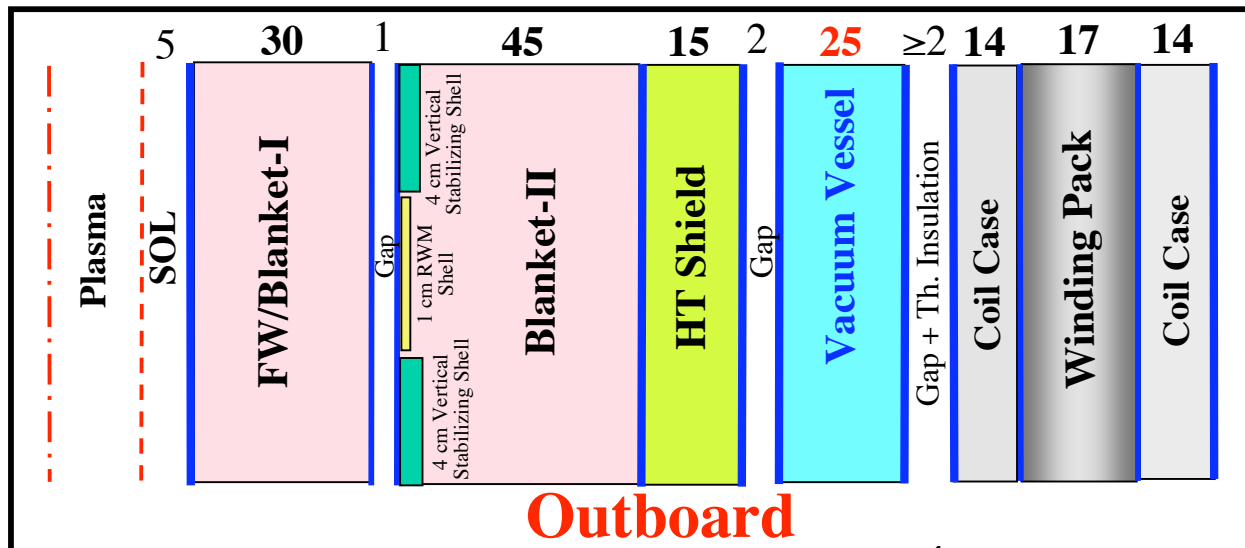
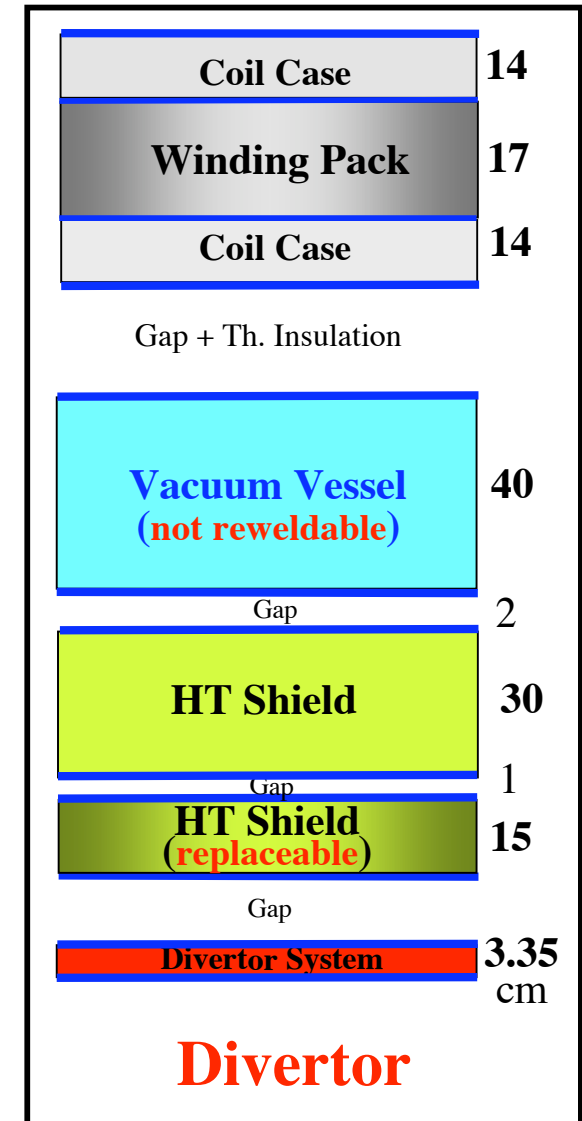
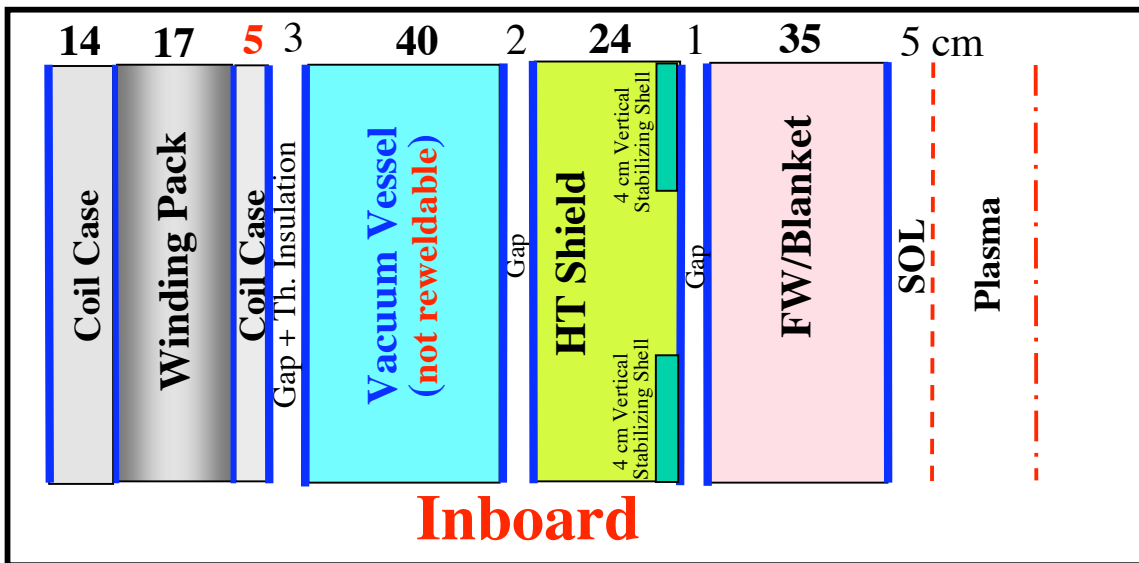
2 Feedback Coils

Cross Section of ARIES-AT Power Core Configuration



ARIES-AT Radial Builds: IB, OB, Div

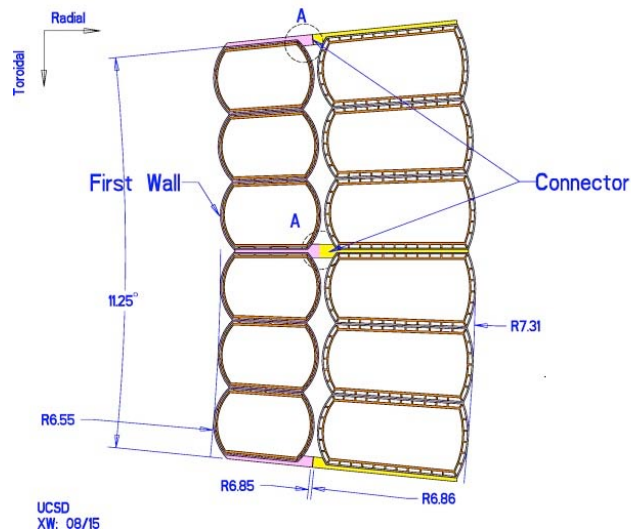
(SiC Structure; HT Magnets)



ARIES-AT Blanket Options

Reference ARIES-AT OB Blanket

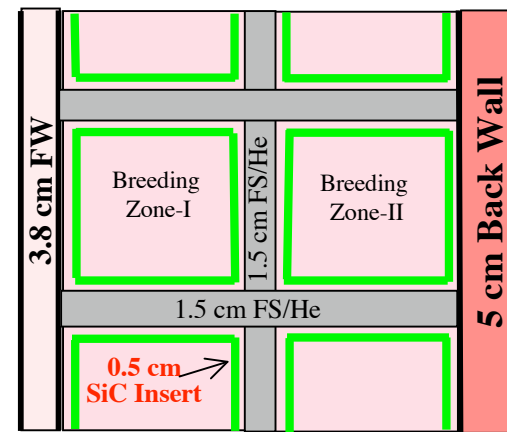
SiC Structure



Breeder	LiPb
Coolant	LiPb

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

FS Structure



Breeder	LiPb
Dual Coolants	LiPb and He



ARIES-AT Compositions

	<u>ARIES-AT-LiPb/SiC</u> (Reference Design)	<u>ARIES-AT-DCLL</u> 0.5 cm Ultramet, No Shells
Inboard:		
FW/Blanket	81% LiPb, 19%SiC	79% LiPb, 12% He/void, 6% FS, 3%SiC inserts
HT Shield	15%SiC, 10% LiPb, 70% B-FS Filler , 5% W shells	15%FS, 10% He, 75% B-FS Filler
VV	13% FS, 22% H ₂ O, 65% WC	17% FS, 34% H ₂ O, 49% WC
Outboard:		
FW/Blanket-I	80% LiPb, 20%SiC	79% LiPb, 12% He/void, 6% FS, 3%SiC inserts
FW/Blanket-II	77% LiPb, 20%SiC, 3% W shells	---
HT Shield	15%SiC, 10% LiPb, 75% B-FS Filler	15%FS, 10% He, 75% B-FS Filler
VV	30% FS, 70% H ₂ O	30% FS, 50% H ₂ O, 20% B-FS
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
VV	13% FS, 22% H ₂ O, 65% WC	22% FS, 48% H ₂ O, 30% B-FS



ARIES-AT-DCLL Radiation Limits and Key Parameters

Calculated Overall TBR	1.1	
Net TBR (for T self-sufficiency)	~1.01	
Damage to Structure (for structural integrity)	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 Nb ₃ Sn ($E_n > 0.1$ 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



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	3.4, 4.8, 2 MW/m ² (to be confirmed with 3-D)
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
SiC inserts	---	0.5 cm thick Ultramet
OB blanket	Two segments	One or two segments ?
Shells:		
Two VS shells on IB: (toroidally continuous)	4 cm W between IB blanket & shield	Cu shell between IB blanket & shield
Two VS shells on OB: (toroidally continuous)	4 cm W between OB blanket segments	Cu shell behind OB blanket or between OB blanket segments ?
RWM shell on OB:	1 cm W between OB blanket segments	0.5 cm Cu shell behind OB FW or between OB blanket segments ?
Breeder/coolant manifolds	Discrete	Toroidally continuous: 25 cm He/LiPb manifolds for IB blanket & shield 35 cm He/LiPb manifolds for OB blanket & shield 20 cm He manifolds for divertor shield (to be confirmed)
Shield coolant	LiPb	He
IB Blanket-shield gap	1 cm	---
VV model	Homogeneous	Heterogeneous with 2-cm-thick plates
Magnets	HT YBCO	LT Nb ₃ Sn (a la ARIES-RS)
Cross section data library	IAEA FENDL-2	IAEA FENDL-2.1

Ultramet SiC Inserts

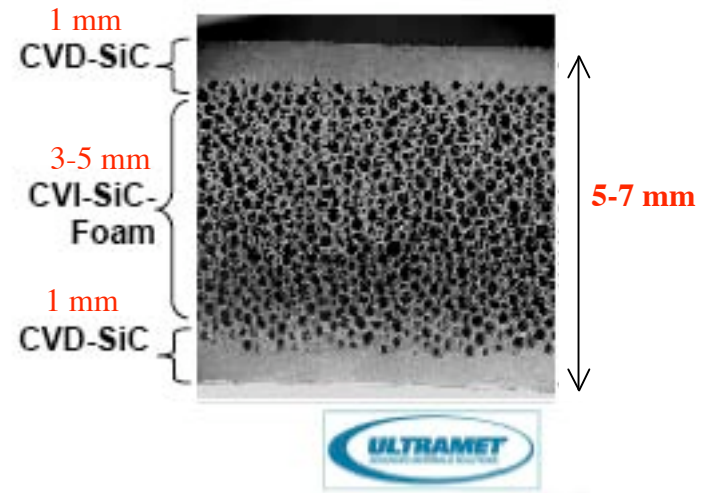
(Ref: S. Sharafat, Development Status of Flow Channel Inserts for the U.S.-ITER DCLL TBM; 18th TOFE, 2008)

Main features and advantages:

- 3-5 mm 10% dense foam
- Fully dense CVD SiC face sheets prevent LiPb ingress into foam
- Low SiC content (to alleviate impact on tritium breeding)
- Construction of long segments (> 75 cm) seems feasible
- Low-cost manufacturability
- Good strength, stiffness, and thermal stress resistance
- Low thermal and electrical conductivity.

Testing is underway.

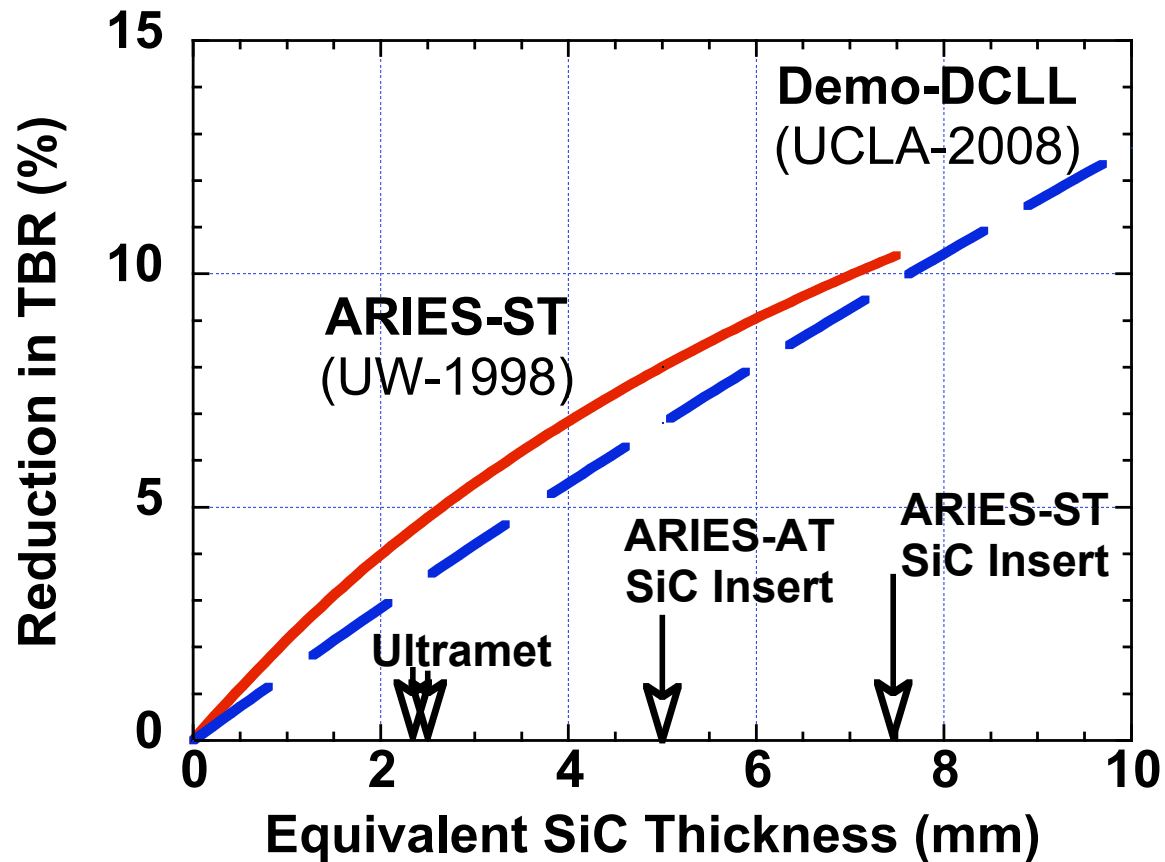
Results so far are promising.



For any type of SiC inserts:

Change of electric conductivity with neutron irradiation could be significant (0.4 at% Mg @ 3 FPY, per Sawan (UW)).

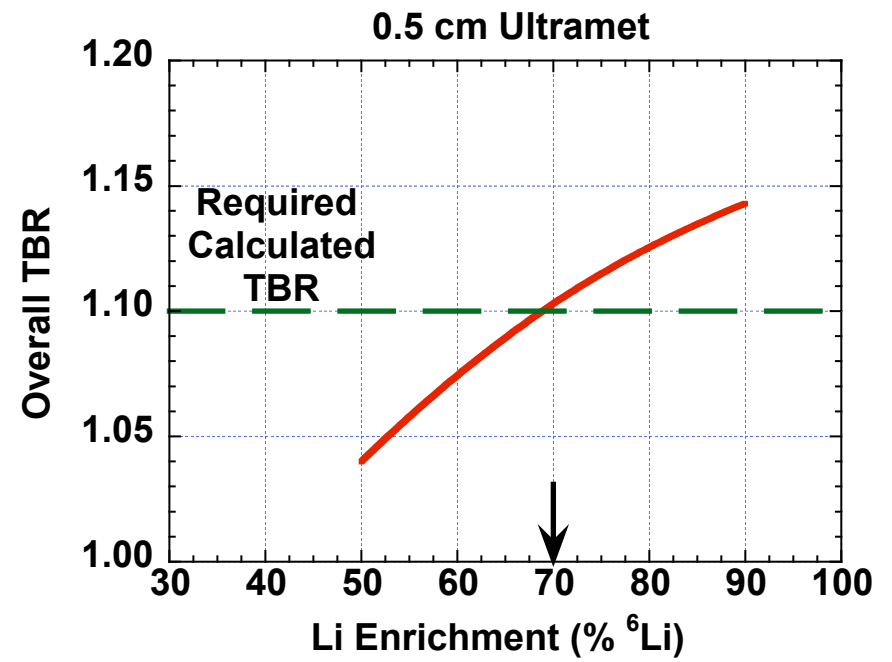
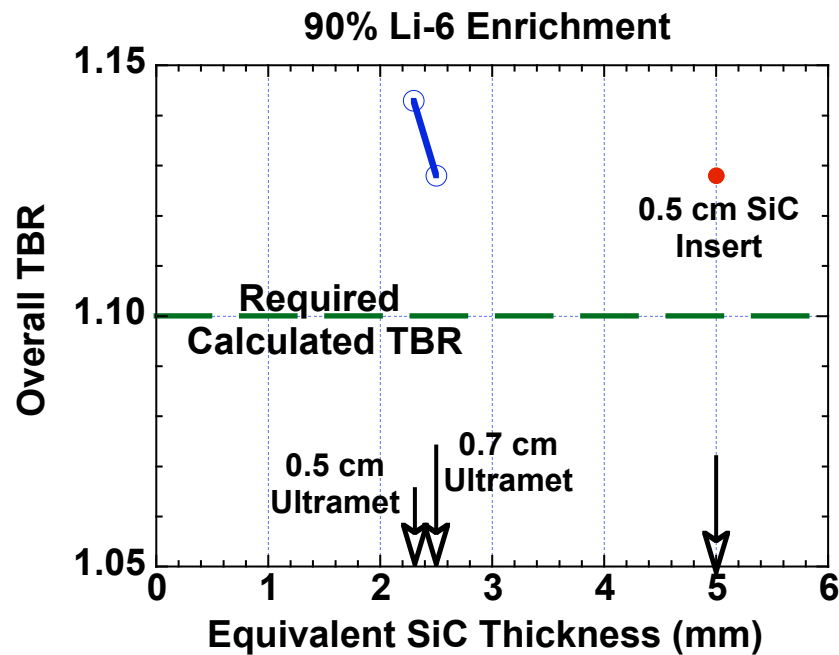
SiC Inserts Degrade Tritium Breeding



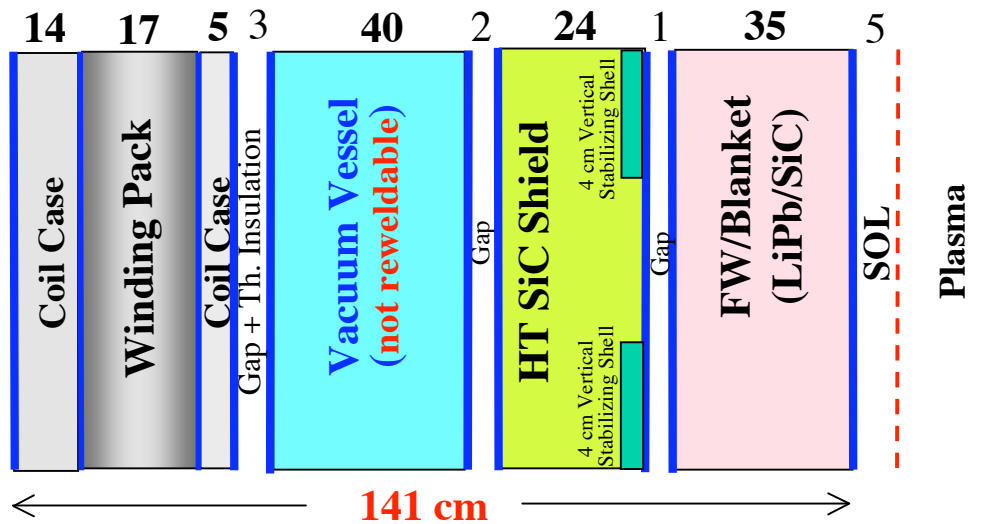
Ultramet alleviate impact of SiC on TBR,
allowing lower enrichment ($< 90\%$) and/or thinner blanket

ARIES-AT-DCLL TBR

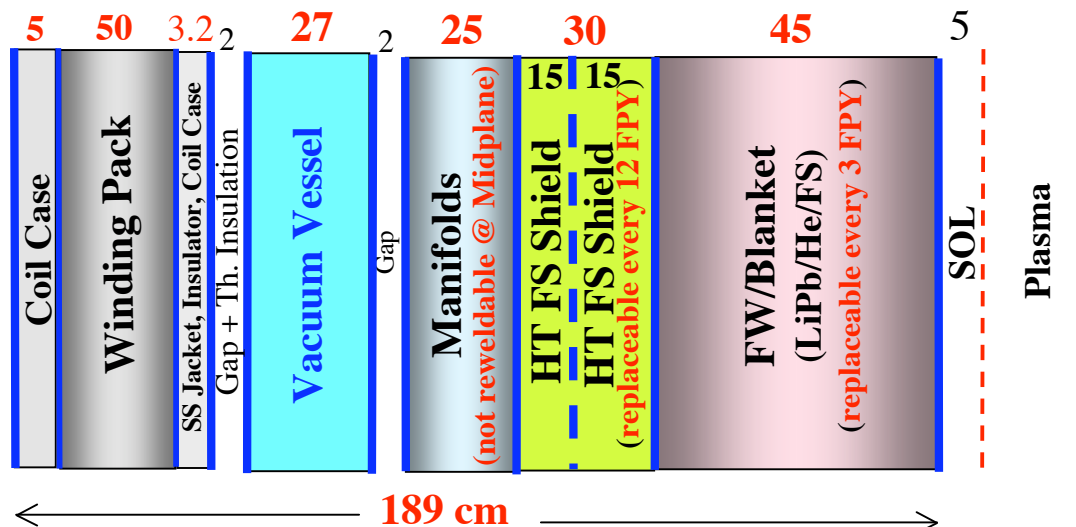
45 cm IB FW/Blanket/Back Wall
80 cm OB FW/Blanket/Back Wall
No Shells



ARIES-AT IB Radial Build



Reference

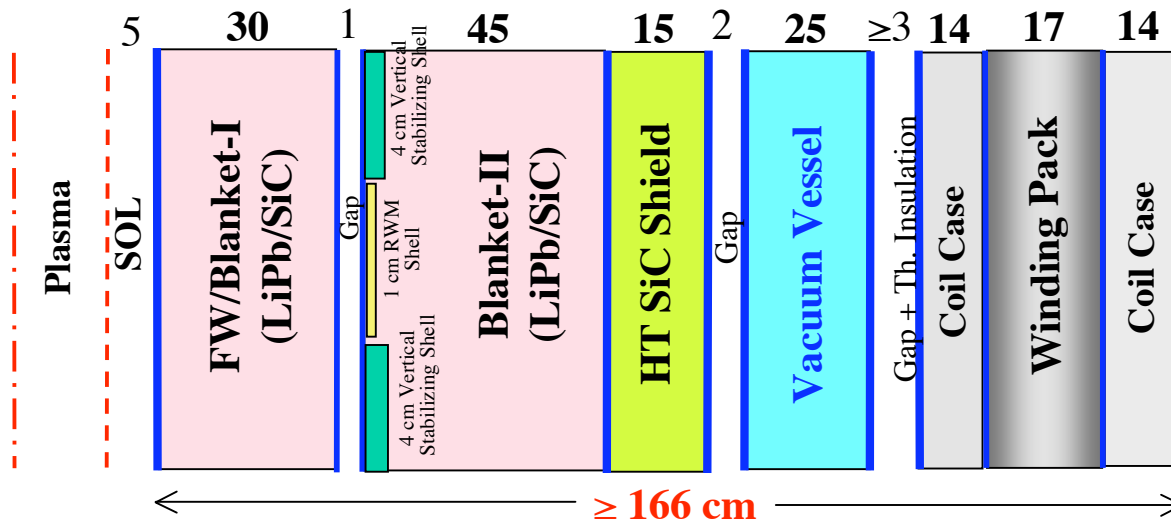


ARIES-AT-DCLL

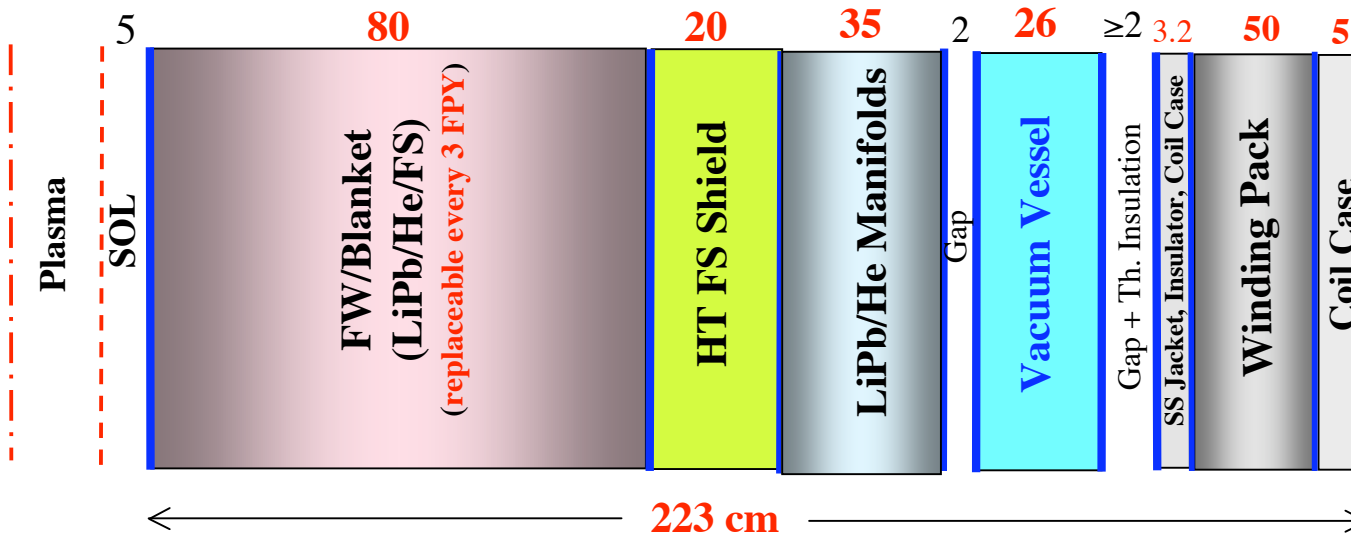
0.5 cm Ultramet
70% ⁶Li Enrichment
No Shells

$\Delta = 48$ cm

ARIES-AT OB Radial Build



Reference

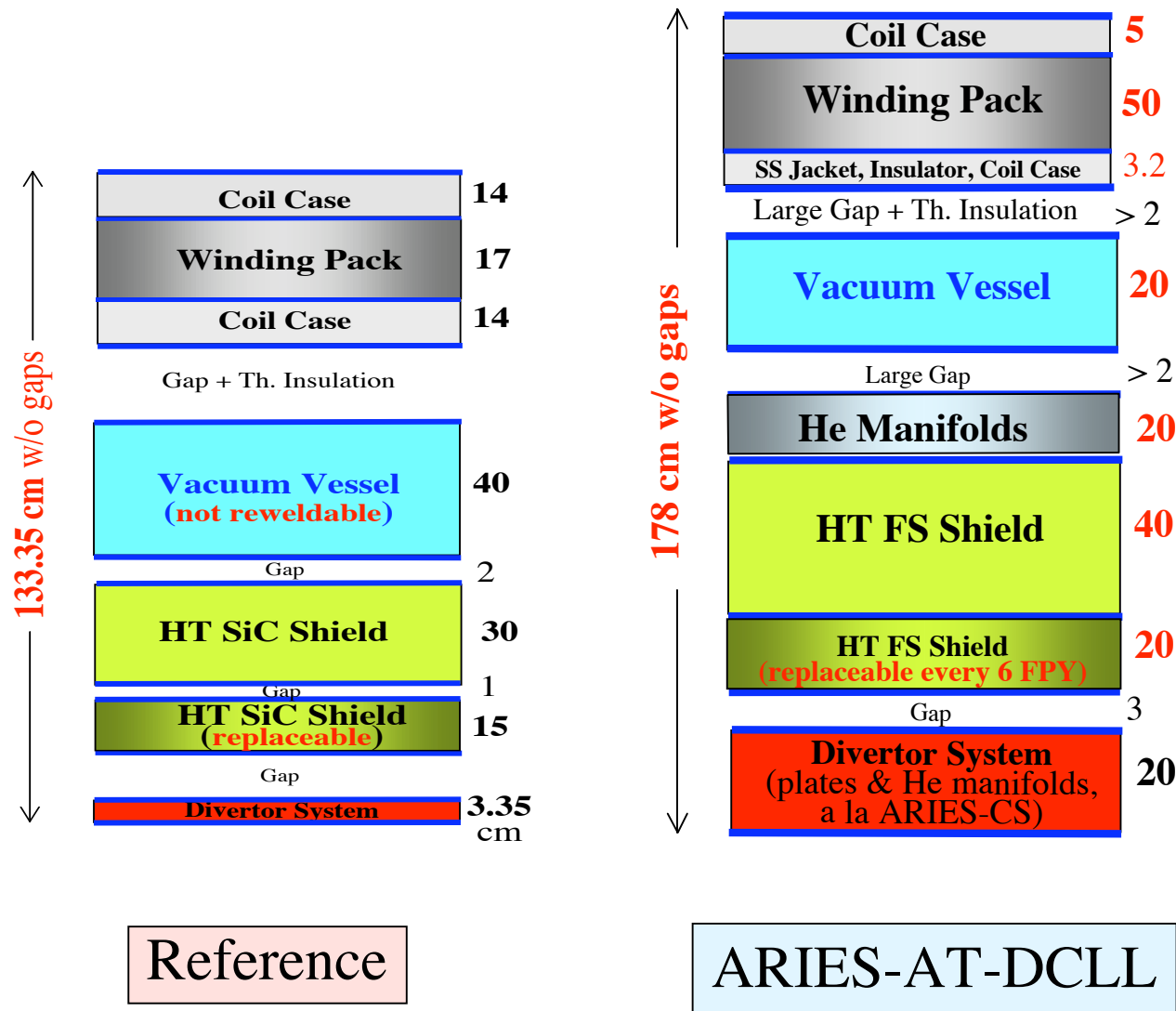


ARIES-AT-DCLL

0.5 cm Ultramet
70% ⁶Li Enrichment
No Shells

$\Delta = 57$ cm

ARIES-AT Divertor Radial Build



$$\Delta = 45 \text{ cm}$$

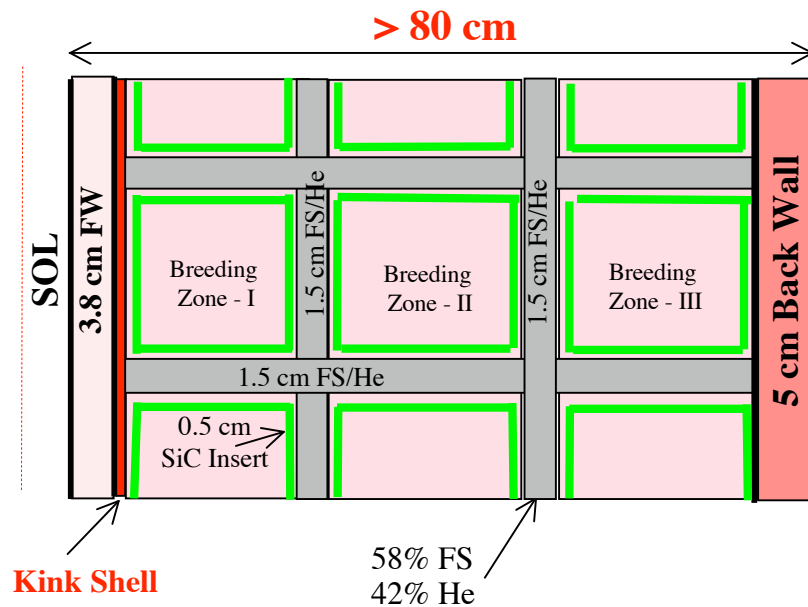
Radiation Level

	IB	OB	Div.	Limit
Peak NWL (MW/m ²)	3.4	4.8	2	
dpa at shield (dpa @ 40 FPY):				200
Replaceable	640	---	1080	
Permanent	160	109	160	
He production at manifolds (He appm @ 40 FPY)	5*	1	0.8	1
He production at VV (He appm @ 40 FPY)	1	0.2	0.1	1
HT Magnet @ 4 K: Fast neutron fluence (10 ¹⁹ n/cm ² @ 40 FPY)	1	0.5	0.7	1
Nuclear heating (mW/cm ³)	0.6	2	1	2

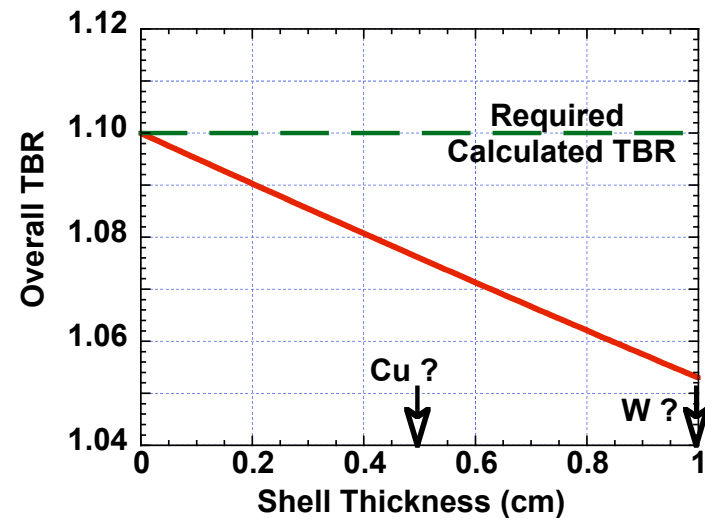
* Rewelding allowed at top/bottom, not around midplane.

Kink Shell Behind OB FW ?

- Could Cu (or W) kink shell be placed behind OB FW?
- Integration of kink shell with blanket?
- Impact on breeding?



ARIES-AT-DCLL OB Blanket
with kink shell behind FW

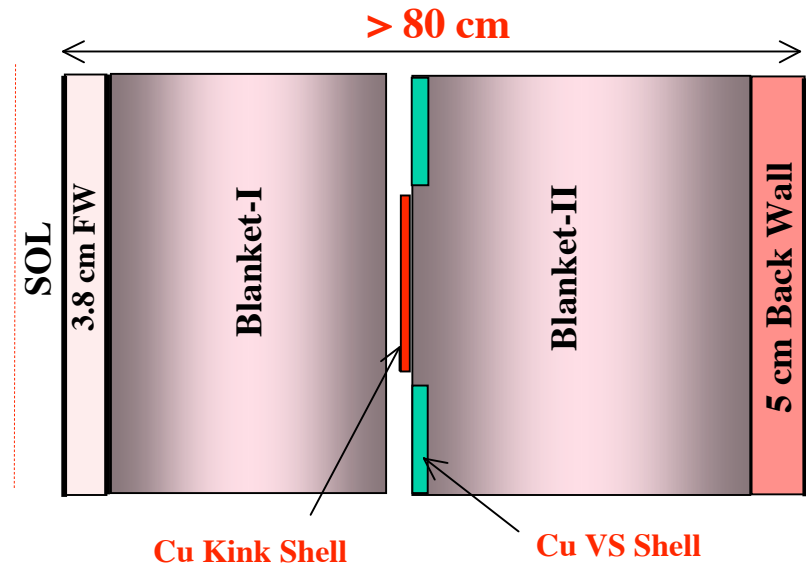


IB and/or OB Blanket
should be thickened to compensate
for losses in breeding

Shells Between OB Blanket Segments ?

- Could OB blanket be segmented into two segments?
- **Advantages:**
 - Less integration problems
 - Less impact of shells on breeding
 - Lifetime of back segment > 3 FPY (~15 FPY)
 - Notable reduction in lifecycle radwaste volume.

ARIES-AT-DCLL OB Blanket
with Cu kink and VS shells
between OB blanket segments
(blanket temp < 700 °C)





Impact of DCLL System on ARIES-AT Economics

	<u>ARIES-AT-LiPb/SiC</u> (Reference)	<u>ARIES-AT-DCLL</u>	<u>Cost of</u> <u>ARIES-AT-DCLL</u>
IB, OB, Div radial standoff*	135, 160, 133	185, 219, 178	↑
Major radius	5.2 m	> 5.2 m	↑
Calculated overall TBR	1.1	1.1 w/o shells	
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	

* Excluding gaps.

Observations and Needed Info

Observations:

- **DCLL system** increases radial standoff $\Rightarrow$ Larger and costly machine
- 0.5 cm **Ultramet** has less impact on breeding compared to 0.5 cm SiC inserts
- **IB manifolds** are not reweldable near midplane.
- Adding **stabilizing shells** will degrade breeding, requiring thicker IB/OB blankets
- **Segmenting OB blanket** offers design advantages.

Needed info:

- **Locations** of kink shells, vertical stabilizing shells, and feedback coils
- One or two **OB blanket segments**?
- Confirm **manifolds** size, composition, and location.

To be considered:

- Change of **SiC electric conductivity** with neutron irradiation
- Change of **electric conductivity of stabilizing shells** with neutron irradiation