



Final Radial Builds for LiPb/FS/He and LiPb/SiC Systems

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ARIES-CS Project Meeting

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UCSD



UW Action Items

- ✓ 1. Revise radial build for 7.75 m case and post it on UW website.
- ✓ 2. Define local shield behind helium access tubes.
- ✓ 3. Provide radial build for full blanket coverage and send to J. Lyon.
- ✓ 4. Define heat load to intercoil structure.
- ✓ 5. Define size of bioshield.
- ✓ 6. Provide radial build for advanced LiPb/SiC system.
- 7. Provide **NWL distribution** for R= 7.75 m design (received neutron source profile from J. Lyon and plasma surface and magnetic axis trajectory from L-P Ku).
- 8. Check **NWL at divertor** and **assess streaming** through divertor He access pipes (need divertor location from UCSD).
- 9. Perform **3-D nuclear analysis** for R= 7.75 m design (need CAD input data from UCSD for **all** components, including blanket variation, divertor system, SOL variation, and penetrations).
- 10. Provide **decay heat** for LOCA/LOFA and safety analyses.
- 11. Help define **replacement cost**.
- 12. Provide radial build for **2 FP** configuration (received plasma-midcoil separation contours from L-P Ku).



Blanket Concepts and Key Design Parameters

Breeder

Structure

FW/Blanket Coolant

Shield Coolant

VV Coolant

LiPb (reference)

FS

He/LiPb

He

H₂O

LiPb (back-up)

SiC

LiPb

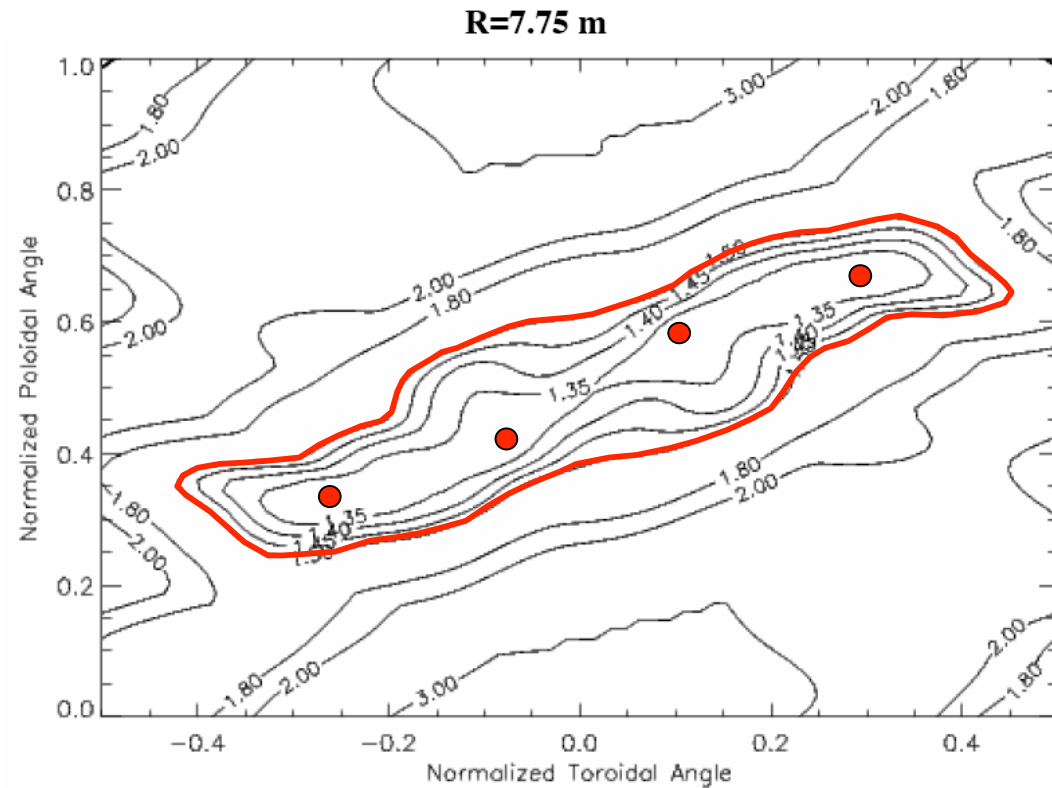
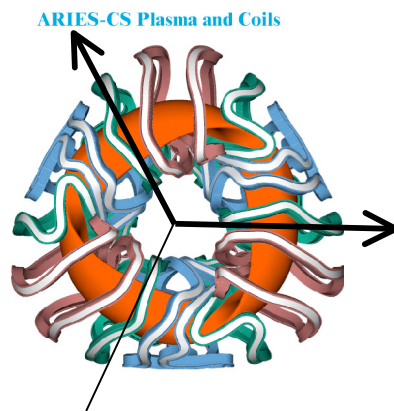
LiPb

H₂O

- 3 FP configuration
- Major Radius = 7.75 m
- Minor Radius = 1.7 m
- $\square_{\min} = 1.3$ m (for both concepts ?)
- Peak $\square \approx 4$ MW/m²
- Average $\square \approx 2.6$ MW/m²
- 15% of FW for divertor system
- Internal VV (located inside magnets)
- Port maintenance approach.

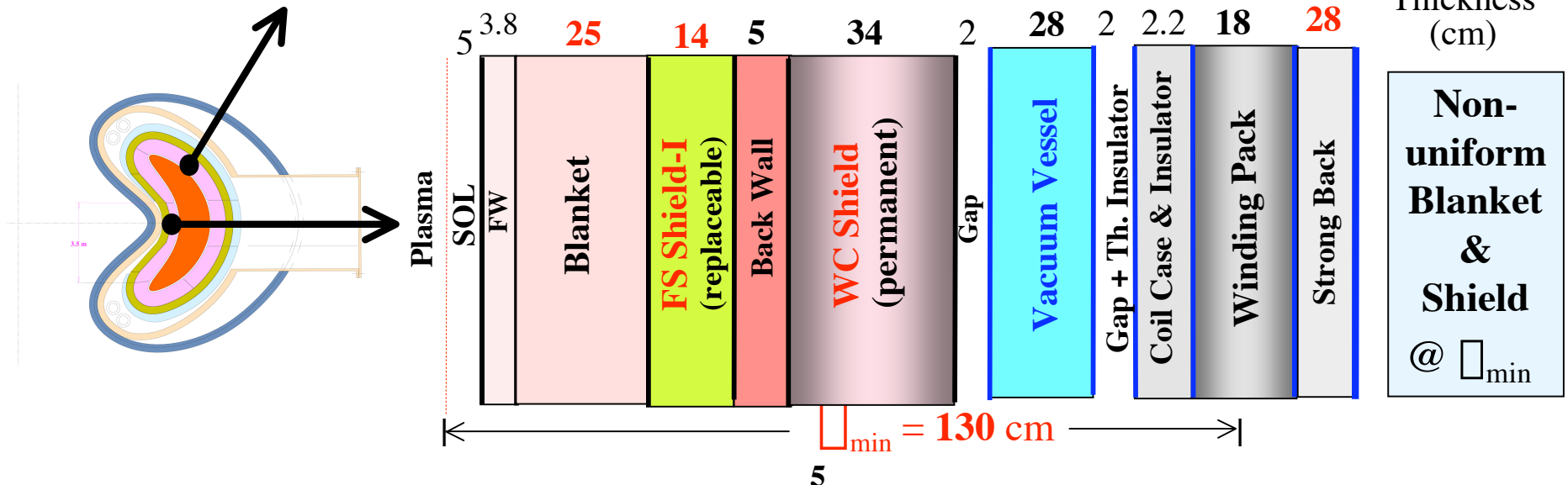
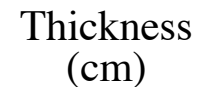
$$R = 7.75 \text{ m}$$

[4 $\square_{\min}$ per FP marked with red dots]

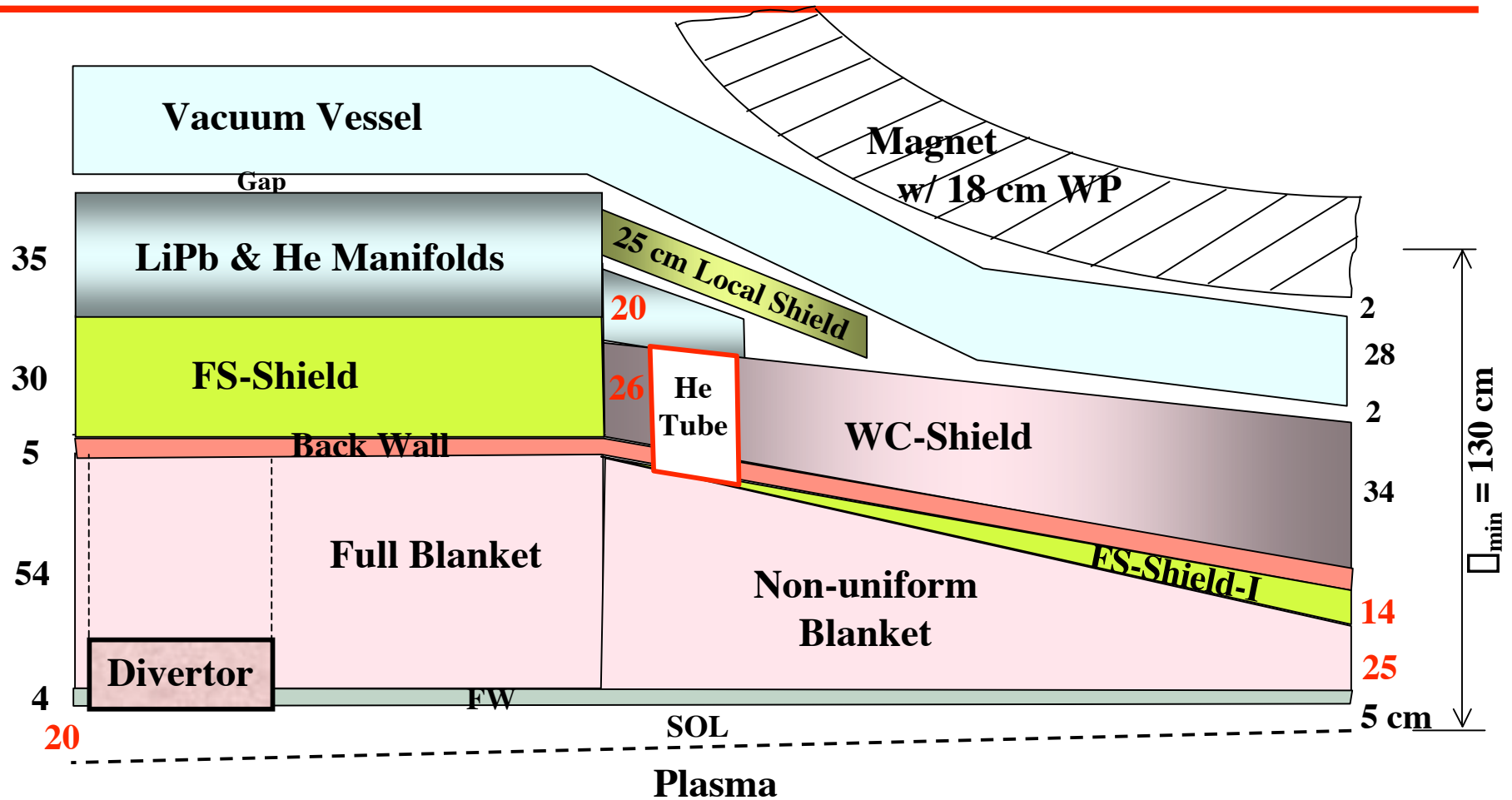


- Non-uniform, tapered blanket **inside red** contour covers $\sim 24\%$ of FW area.
- Uniform blanket and divertor **outside red** contour covers $\sim 76\%$ of FW area.

CAD should confirm UW coverage estimates



Radial / Toroidal Xn



Full Blanket/shield and Divertor
(61%+15%= 76% of FW area)

Non-uniform, Tapered Blanket/Shield
(24% of FW area)



LiPb/FS/He Compositions and Coverage Fractions

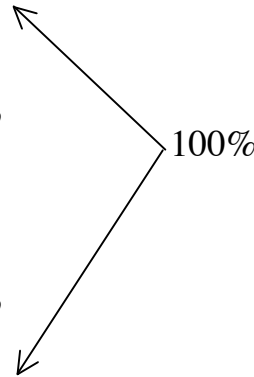
<u>Component</u>	<u>Thickness</u>	<u>Coverage Fraction</u>	<u>Composition</u>
FW*	3.8 cm	85%	34% FS Structure 66% He Coolant
Divertor System*	20 cm	15%	32.6% FS Structure 4.0% W 63.4% He Coolant
Blanket Behind Divertor*	35 cm	15%	75% LiPb (< 90% enriched Li) 9% SiC Inserts 8% FS Structure 8% He Coolant
Non-uniform Blanket*	25 - 54.3 cm	24%	76% LiPb (< 90% enriched Li) 8% SiC Inserts 8% FS Structure 8% He Coolant
Full Blanket*	54.3 cm	61%	79% LiPb (< 90% enriched Li) 7% SiC Inserts 6% FS Structure 8% He Coolant
Back Wall*	5 cm	100%	80% FS Structure 20% He Coolant
FS Shield	30 cm	76%	15% FS Structure 10% He Coolant 75% Borated Steel Filler
Manifolds	35 cm	80%	52.0% FS Structure 22.7% LiPb (< 90% enriched Li) 24.0% He Coolant 1.3% SiC Inserts

* Replaceable component.



LiPb/FS/He Compositions and Coverage Fractions (Cont.)

<u>Component</u>	<u>Thickness</u>	<u>Coverage Fraction</u>	<u>Composition</u>
FS Shield-I*	0 -14 cm	24%	15% FS Structure 10% He Coolant 75% Borated Steel Filler
WC Shield	26 - 34 cm	24%	15% FS Structure 10% He Coolant 75% WC Filler
Vacuum Vessel	28 cm	100%	28% FS Structure 49% Water 23% Borated Steel Filler
Inner Coil Case (in front of WPs only)	2 cm	28%	95% JK2LB Structure 5% LHe Coolant
Winding Pack @ 4K	18 cm	28%	18.5% JK2LB Structure 48.2% Cu 12.8% Nb ₃ Sn 10.0% GFF Polyimide 10.5% LHe Coolant
Strong Back (behind WPs only)	28 cm	28%	95% JK2LB Structure 5% LHe Coolant
Intercoil Structure (between WPs)	20 cm [#]	72%	95% JK2LB Structure 5% LHe Coolant
Cryostat	5 cm	100%	100% 304-SS
Bioshield	200 cm	100% ?	85% Concrete 10% Mild Steel 5% He coolant



* Replaceable component.

~16 cm for outboard and ~28 cm for inboard, per Xueren.



Alternate Design Options

- Uniform **LiPb/FS/He** blanket everywhere.
- **LiPb/SiC** blanket with $\beta_{th} = 55 - 63\%$.



Uniform **LiPb/FS/He** Blanket Everywhere

Main changes:

Full blanket coverage fraction = 85%, assuming divertor covers 15% of FW area.

Full Blanket thickness = 50.3 cm (instead of 54.3 cm)

Blanket behind divertor = 31 cm (instead of 35 cm)

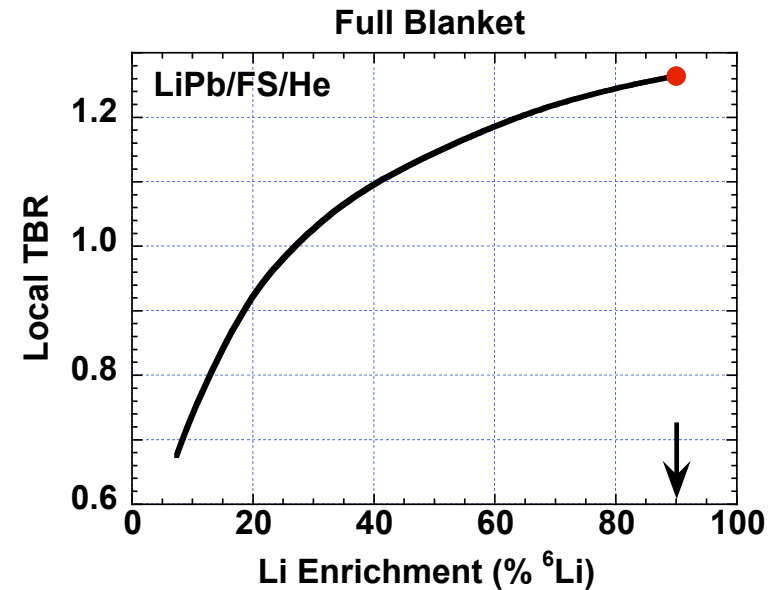
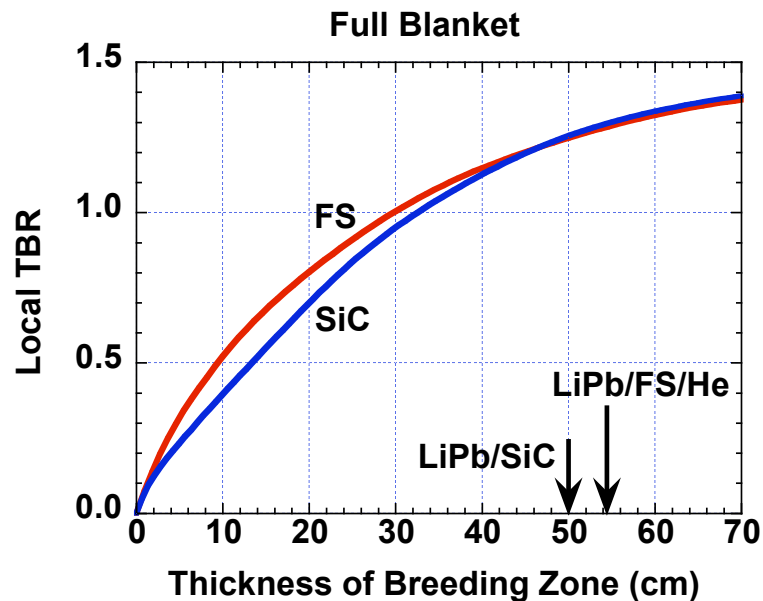
FS shield thickness = 33 cm (instead of 30 cm)

Uniform $\square \geq 175$ cm

R = ?

COE = ?

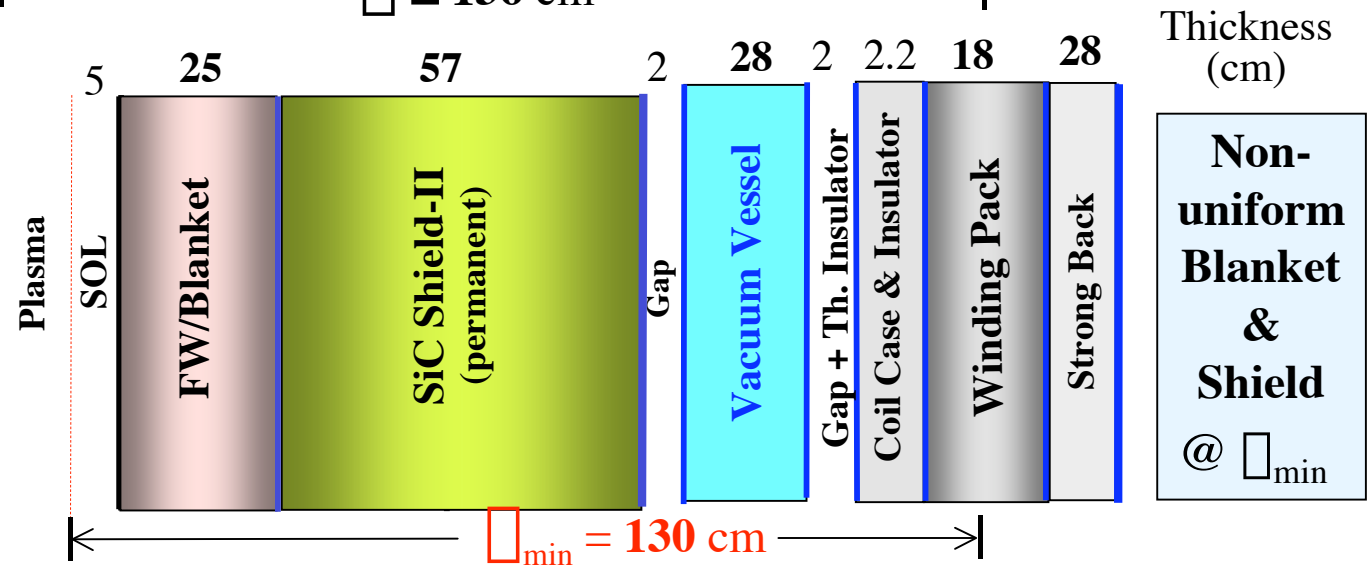
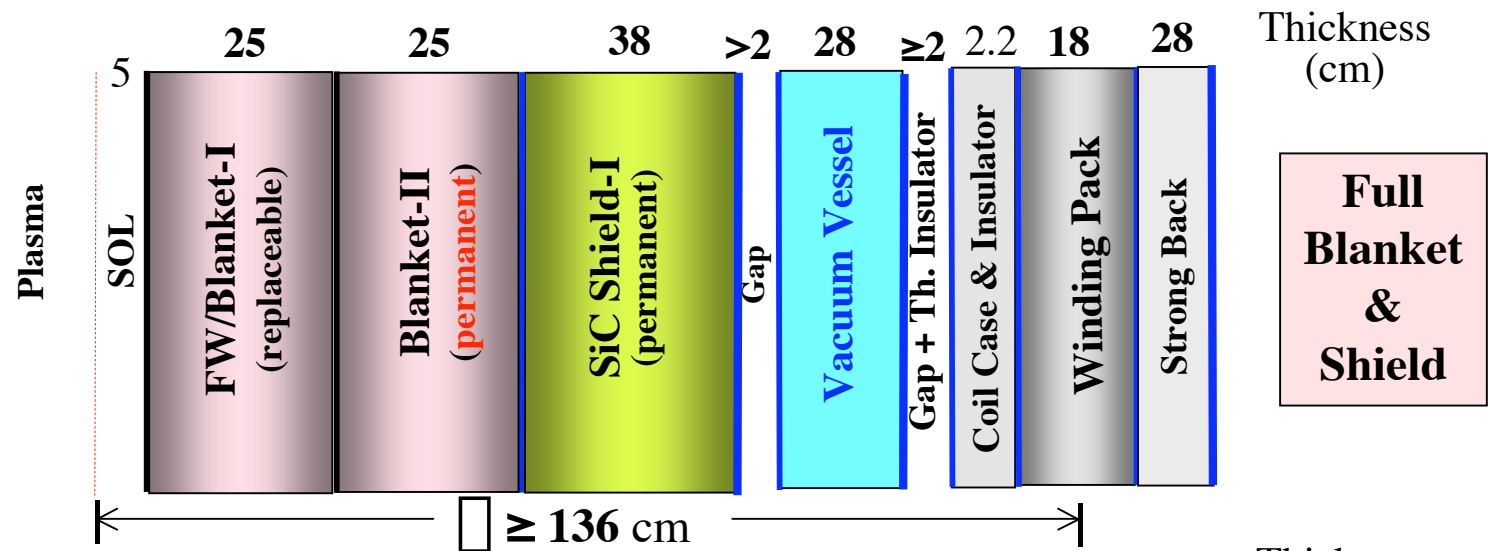
LiPb/FS/He and LiPb/SiC Blankets Offer Comparable TBR



LiPb/SiC system:

- Expensive SiC/SiC structure (~ \$500/kg).
- Absence of He coolant and He manifolds results in 40 cm thinner radial build.
- Discrete LiPb manifold $\square$ no shielding function.
- No He access pipes $\square$ no streaming problems.
- If $\square_{\min} = 1.3$ m, use B-FS filler in SiC-shield-II
- $\square_{\min} \sim 1.23$ m with WC filler in SiC-shield-II
- Higher $\square_{\text{th}}$ $\square$ smaller machine and lower COE.
- Light weight SiC structure $\square$ Lower number of blanket modules
Shorter replacement time
Availability could exceed 85% ?
- Thin replaceable blanket suitable for FP maintenance approach.

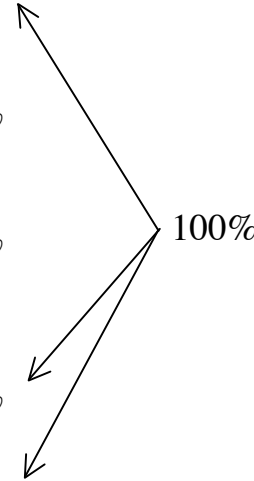
LiPb/SiC Radial Build (Near-Final)





LiPb/SiC Compositions and Coverage Fractions

<u>Component</u>	<u>Thickness</u>	<u>Coverage Fraction</u>	<u>Composition</u>
FW/Blanket-I*	25 cm	61%	21% SiC/SiC Structure 79% LiPb (< 90% enriched Li)
Blanket-II	25 cm	61%	21% SiC/SiC Structure 79% LiPb (< 90% enriched Li)
Divertor System*	20 ?	15%	33% SiC/SiC Structure ? 4% W 63% LiPb (< 90% enriched Li)
Blanket Behind Divertor*	25	15%	21% SiC/SiC Structure 79% LiPb (< 90% enriched Li)
Non-uniform Blanket[#]	25 - 50 cm	24%	21% SiC/SiC Structure 79% LiPb (< 90% enriched Li)
SiC Shield-I	38 cm	76%	15% SiC/SiC Structure 10% LiPb Coolant 75% Borated Steel Filler
SiC Shield-II	38 - 57 cm	24%	15% SiC/SiC Structure 10% LiPb Coolant 75% Borated Steel Filler



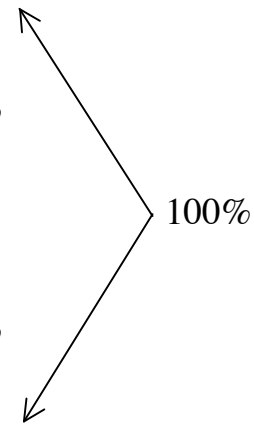
* Replaceable component.

[#] 25 cm replaceable and rest is permanent.



LiPb/SiC Compositions and Coverage Fractions (Cont.)

<u>Component</u>	<u>Thickness</u>	<u>Coverage Fraction</u>	<u>Composition</u>
Vacuum Vessel	28 cm	100%	28% FS Structure 49% Water 23% Borated Steel Filler
Inner Coil Case (in front of WPs only)	2 cm	28%	95% JK2LB Structure 5% LHe Coolant
Winding Pack @ 4K	18 cm	28%	18.5% JK2LB Structure 48.2% Cu 12.8% Nb ₃ Sn 10.0% GFF Polyimide 10.5% LHe Coolant
Strong Back (behind WPs only)	28 cm	28%	95% JK2LB Structure 5% LHe Coolant
Intercoil Structure (between WPs)	20 cm [#]	72%	95% JK2LB Structure 5% LHe Coolant
Cryostat	5 cm	100%	100% 304-SS
Bioshield	200 cm	100% ?	85% Concrete 10% Mild Steel 5% He coolant



* Replaceable component.

~16 cm for outboard and ~28 cm for inboard, per Xueren.



Design Requirements Satisfied Except at Divertor*

Overall TBR

(for T self-sufficiency)

1.1

Damage to Structure

200 dpa - FS

3% Burnup - SiC

Helium Production @ Manifolds and VV

(for reweldability of FS)

1 appm

S/C Magnet (@ 4 K):

Peak fast n **fluence** to Nb₃Sn ($E_n > 0.1$ MeV)

10^{19} n/cm²

Peak nuclear **heating**

2 mW/cm³

Peak **dpa** to Cu stabilizer

6×10^{-3} dpa

Peak **dose** to electric insulator

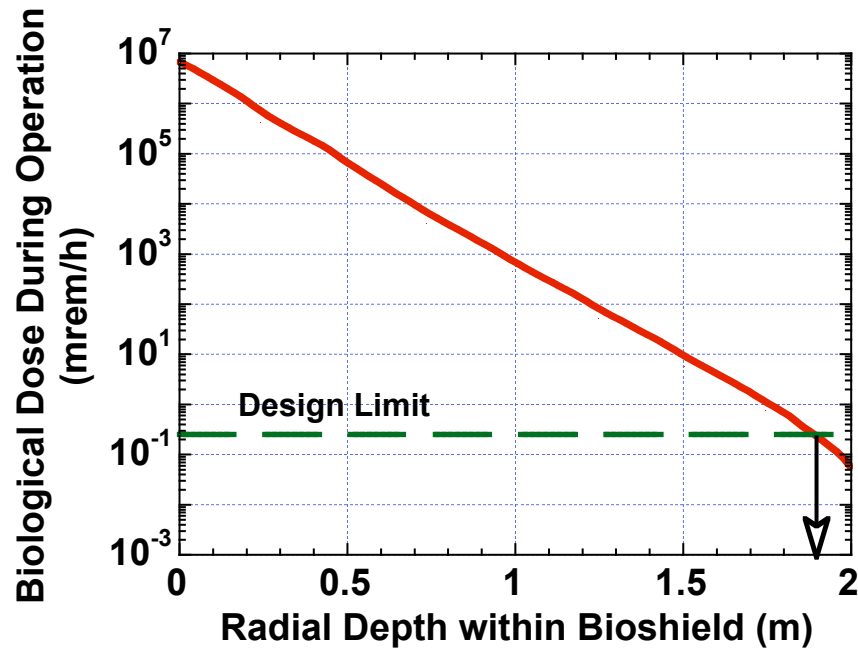
$> 10^{11}$ rads

Biological dose to workers/public during operation

< 0.25 mrem/h

* Due to undefined divertor location, unknown NWL, and streaming issues.

Bioshield Should be ≥ 1.9 m Thick to Reduce Dose by 8 Orders of Magnitude



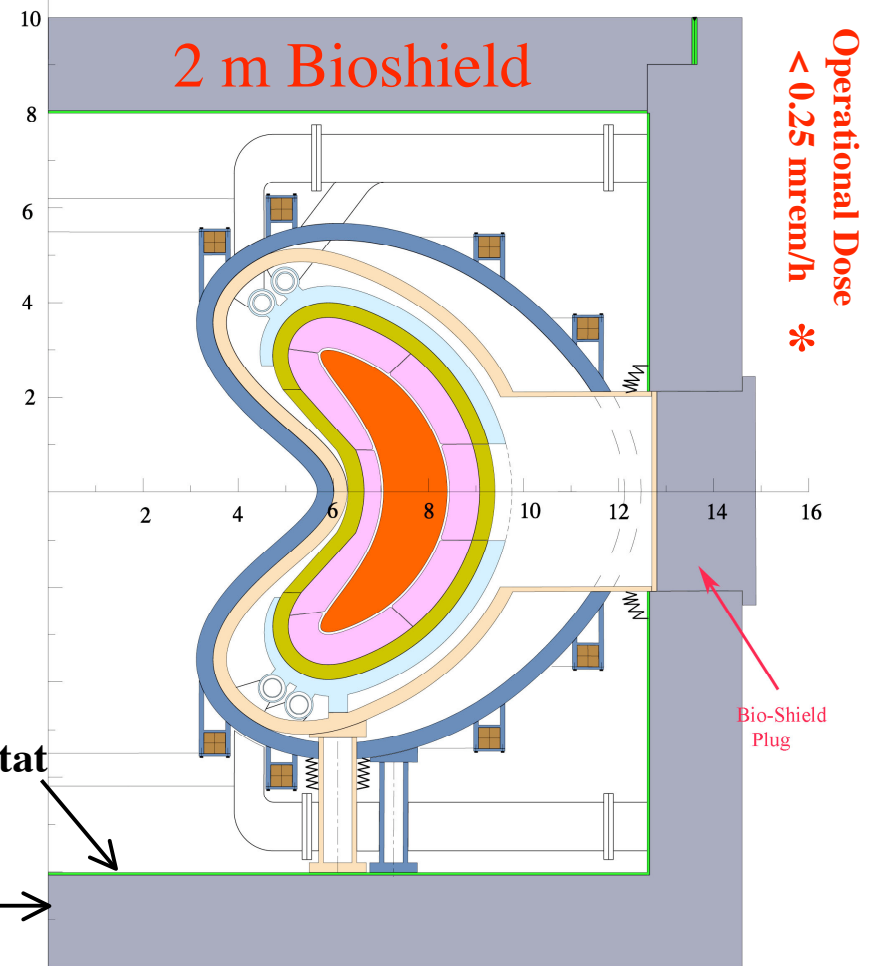
5 cm Cryostat

Where is the Primary Structure?

18% of FPC volume

□ 383 m³

□ 70 cm thick steel



Key Parameters

	<u>LiPb/FS/He</u>	<u>LiPb/SiC</u>
$\square_{\min}$ (m)	1.3	≤ 1.3 ?
Overall TBR [#]		~ 1.1
Li-6 Enrichment [#]		$< 90\%$
Overall Energy Multiplication [#]	~ 1.155	1.1
He : LiPb Power Ratio [*]	$\sim 48 : 52$	---
FW EOL Fluence (MWy/m ²)	15.7 - FS	18 - SiC
FW/Blanket/Divertor Lifetime (FPY)	3.9	4.5
# of Blanket Modules	~ 150	< 100 ?
System Availability	85%	$> 85\%$?
Plant Lifetime (FPY)		40

[#] TBD by 3-D analysis.

^{*} To be updated.

Future Plan

- Provide **NWL distribution** for $R = 7.75$ m design.
- Check **NWL at divertor** and **assess streaming** through divertor He access pipes (need divertor location from UCSD).
- Perform **3-D nuclear analysis** for $R = 7.75$ m design (need CAD input data from UCSD for **all** components, including blanket variation, divertor system, SOL variation, and penetrations).
- Provide **decay heat** for LOCA/LOFA and safety analyses.
- Update **heat load** to all components and He:LiPb **power ratio**.
- Help define **replacement cost**.
- Iterate with J. Lyon on **LiPb/SiC system**.
- Provide radial build for **2 FP** configuration.

ARIES-Related Publications

- **Two abstract submitted to 17th TOFE*** (Nov 13-15, 2006, Albuquerque, NM):
 - **L. El-Guebaly**, R. Raffray, S. Malang, J. Lyon, L.P. Ku, X. Wang, P. Wilson, D. Henderson, T. Tautges, M. Sawan, G. Sviatoslavsky, B. Kiedrowski, M. Wang, L. Bromberg, C. Martin, B. Merrill, L. Waganer, F. Najmabadi and the ARIES Team “[Overview of ARIES-CS In-vessel Components: Integration of Nuclear, Economic, and Safety Constraints in Compact Stellarator Design.](#)”
 - **P. Wilson**, B. Kiedrowski, T. Tautges, and **L. El-Guebaly**, “[Three-Dimensional Neutron Transport for ARIES-CS.](#)”
- **Three papers** will be submitted to **8th IAEA TM on Fusion Power Plant Safety** (July 10-13, 2006, Vienna, Austria):
 - **L. El-Guebaly**, “[Evaluation of Disposal, Recycling, and Clearance Scenarios for Managing ARIES Radwaste after Plant Decommissioning.](#)”
 - ✓ – **L. El-Guebaly**, R. Pampin (UK), and M. Zucchetti (Italy), “[Clearance Considerations for Slightly-Irradiated Components of Fusion Power Plants.](#)”
 - ✓ – **D. Petti** et al., “[Future Directions in U.S. Fusion Safety & Environmental Program.](#)”
- ✓ **UW-FDM** will be published soon: **L. El-Guebaly**, R. Pampin (UK), and M. Zucchetti (Italy), “[Insights from Clearance Assessments of Fusion Power Plants: ARIES and PPCS.](#)”

* Abstract deadline extended to July 7, 2006.