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

L. El-Guebaly
Fusion Technology Institute
UW - Madison

Contributors:
J. Lyon (ORNL), X. Wang (UCSD), and L. Waganer (Boeing)

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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).

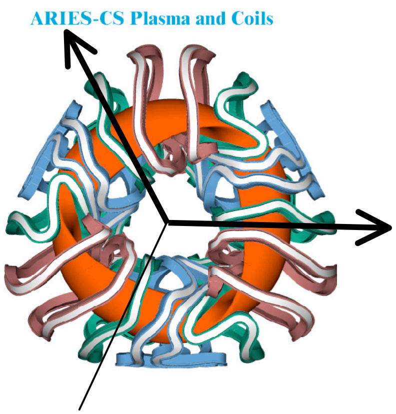
Blanket Concepts and Key Design Parameters

Breeder	Structure	FW/Blanket Coolant	Shield Coolant	VV Coolant
LiPb (reference)	**FS**	**He/LiPb**	**He**	**H_2O**
LiPb (back-up)	**SiC**	**LiPb**	**LiPb**	**H_2O**

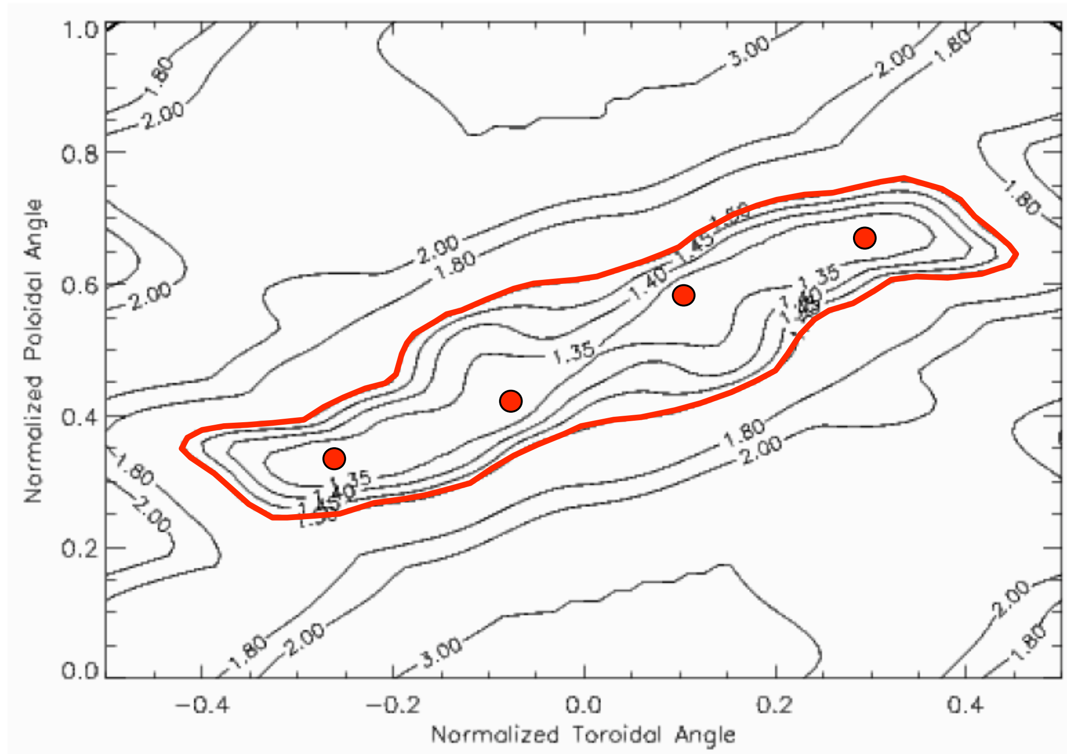
- 3 FP configuration
- Major Radius = 7.75 m
- Minor Radius = 1.7 m
- $\Box_{min}$ = 1.3 m (for both concepts ?)
- Peak $\Box \approx 4$ MW/m^2
- Average $\Box \approx 2.6$ MW/m^2
- 15% of FW for divertor system
- Internal VV (located inside magnets)
- Port maintenance approach.

R = 7.75 m

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



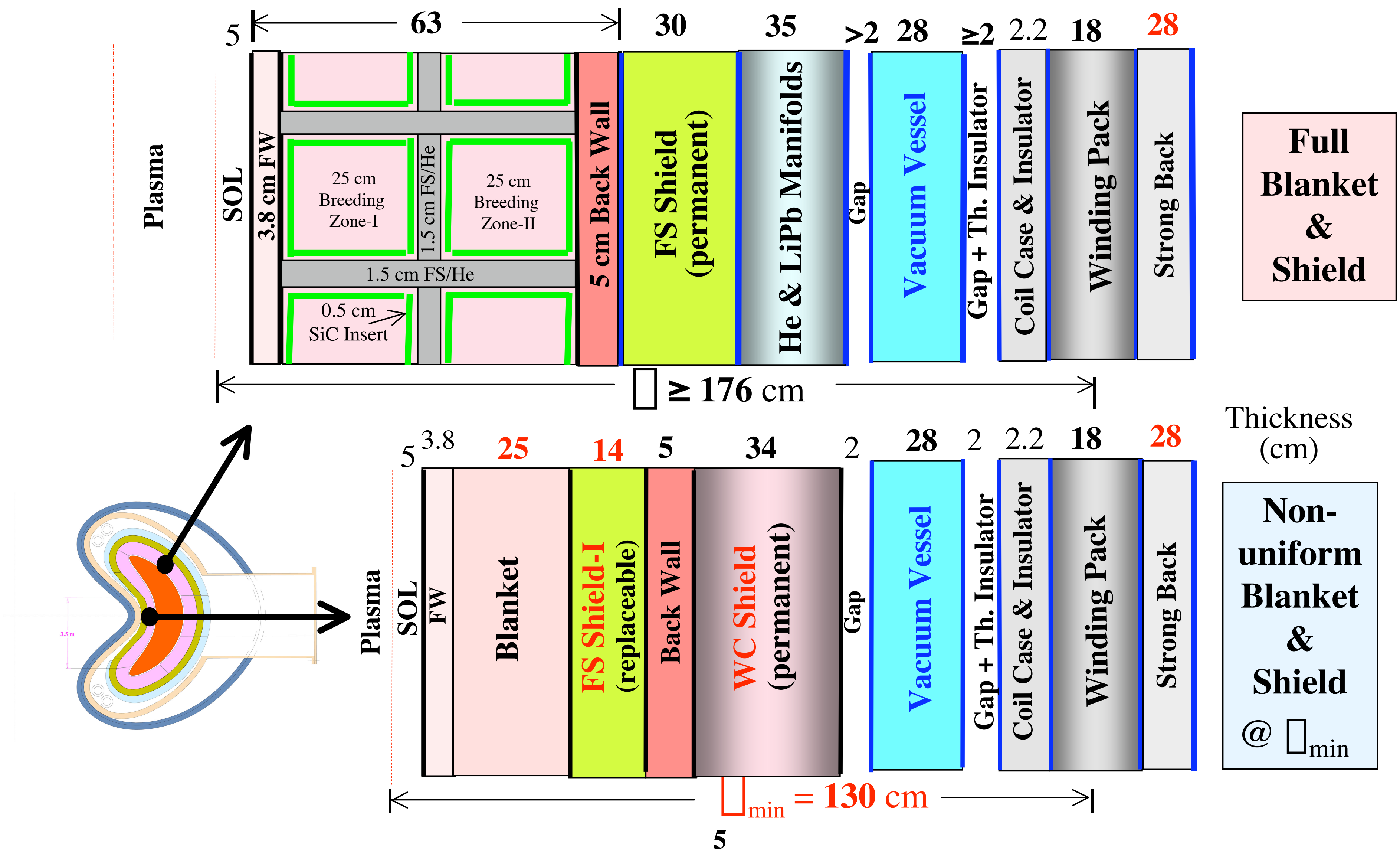
R=7.75 m



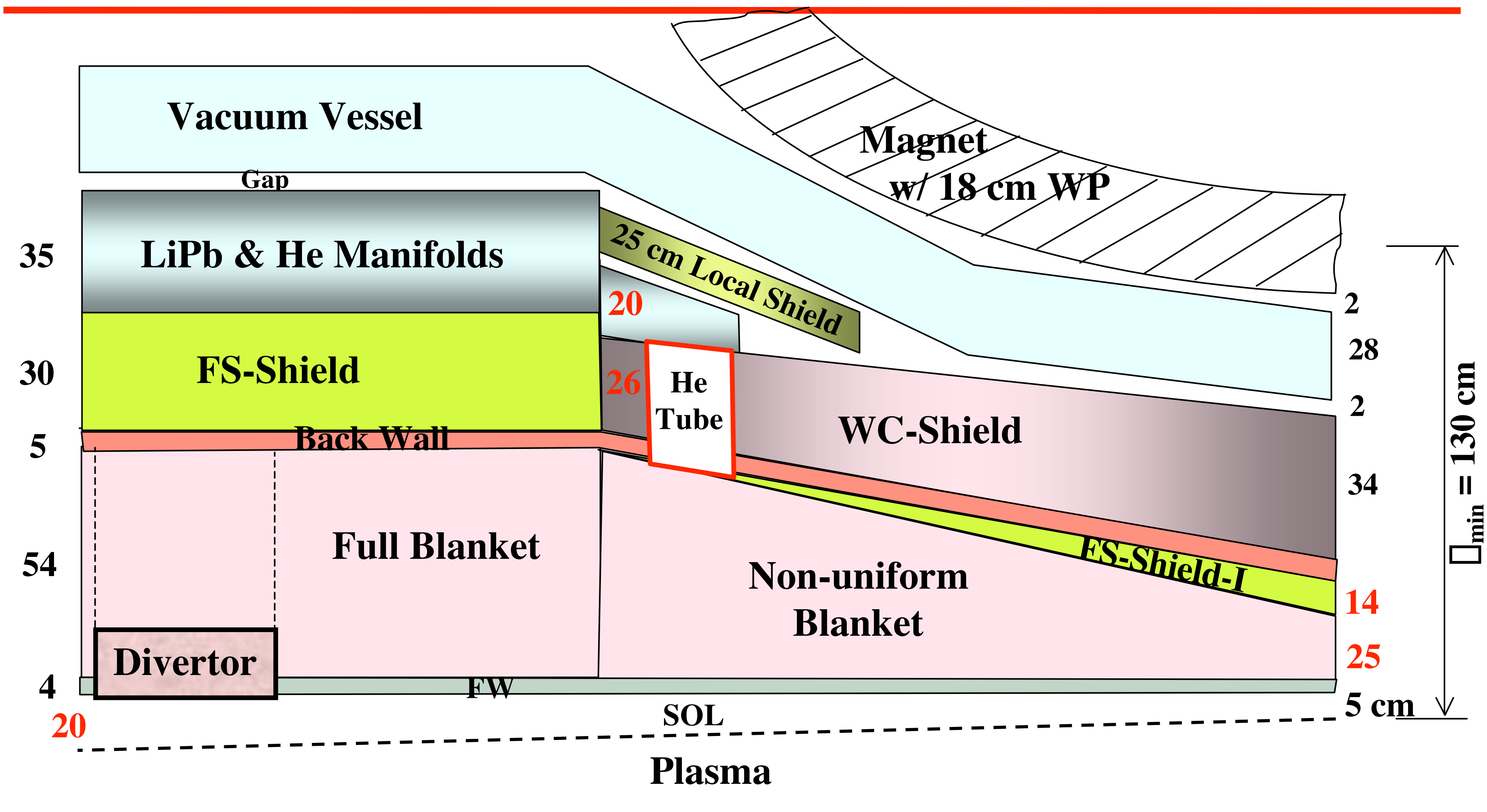
- **Non-uniform, tapered blanket inside red** contour covers ~**24%** of FW area.
- **Uniform blanket and divertor outside red** contour covers ~**76%** of FW area.

CAD should confirm UW coverage estimates

LiPb/FS/He Radial Build



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

Component	Thickness	Coverage Fraction		Composition
FW*	3.8 cm	85%	100%	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%	100%	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.)

Component	Thickness	Coverage Fraction	Composition
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_3Sn 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

(Inner Coil Case, Winding Pack, Strong Back and Intercoil Structure coverage fractions together: 100%)

* 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 η_{th} = 55 - 63%.**

Uniform LiPb/FS/He Blanket Everywhere

Main changes:

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

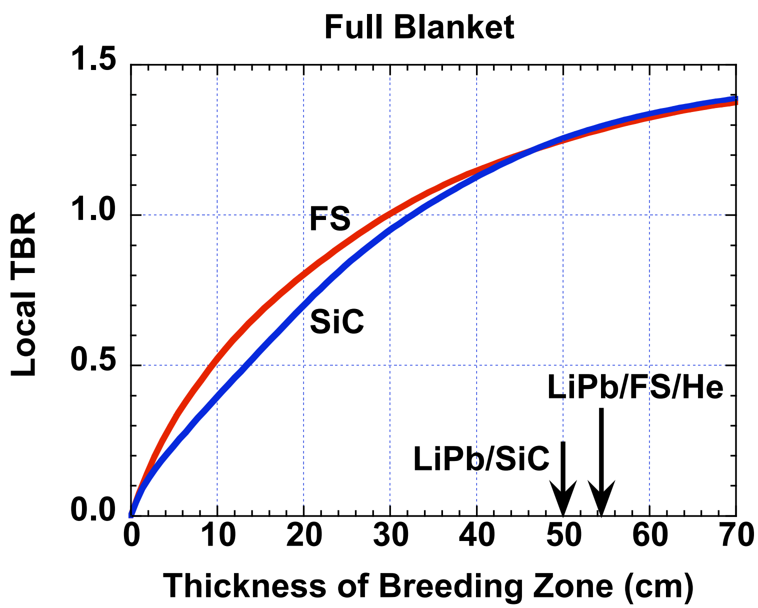
Full Blanket thickness = 50.3 cm (instead of 54.3 cm)

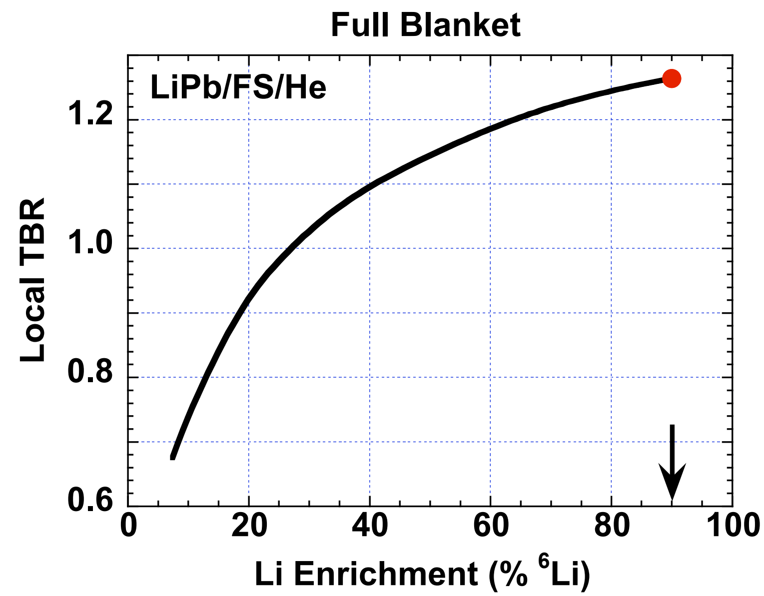
Blanket behind divertor = 31 cm (instead of 35 cm)

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

Uniform □ ≥ 175 cm
R = ?
COE = ?

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



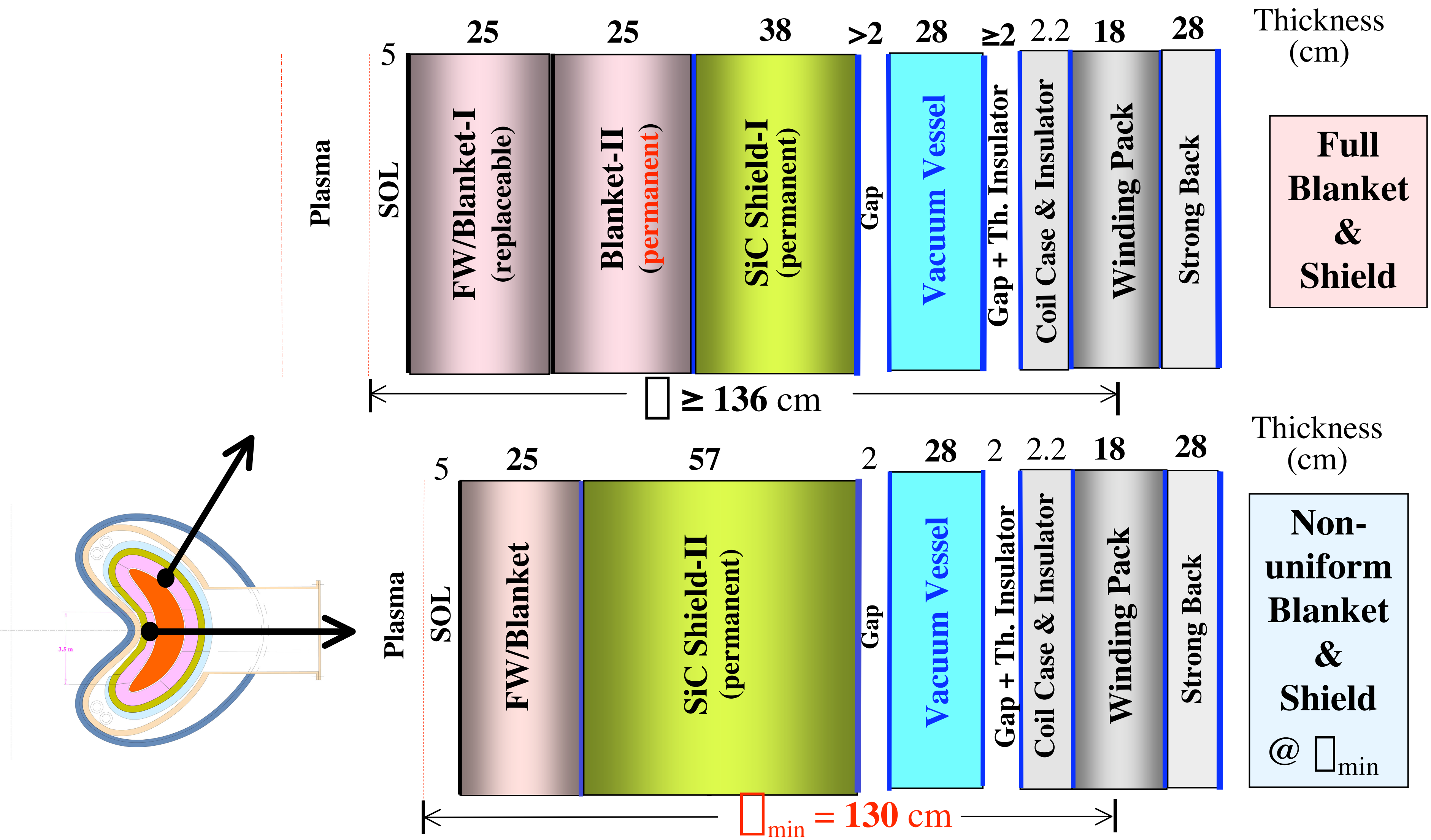


LiPb/SiC system:

- Expensive SiC/SiC structure (~ $500/kg).
- Absence of He coolant and He manifolds results in 40 cm thinner radial build.
- Discrete LiPb manifold □ no shielding function.
- No He access pipes □ no streaming problems.
- If $□_{min}$ = 1.3 m, use B-FS filler in SiC-shield-II
- $□_{min}$ ~ 1.23 m with WC filler in SiC-shield-II
- Higher $□_{th}$ □ smaller machine and lower COE.
- Light weight SiC structure □ 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

Component	Thickness	Coverage Fraction	Composition
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

100%

* Replaceable component.

25 cm replaceable and rest is permanent.

LiPb/SiC Compositions and Coverage Fractions (Cont.)

Component	Thickness	Coverage Fraction		Composition
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%	100%	18.5% JK2LB Structure 48.2% Cu 12.8% Nb_3Sn 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.

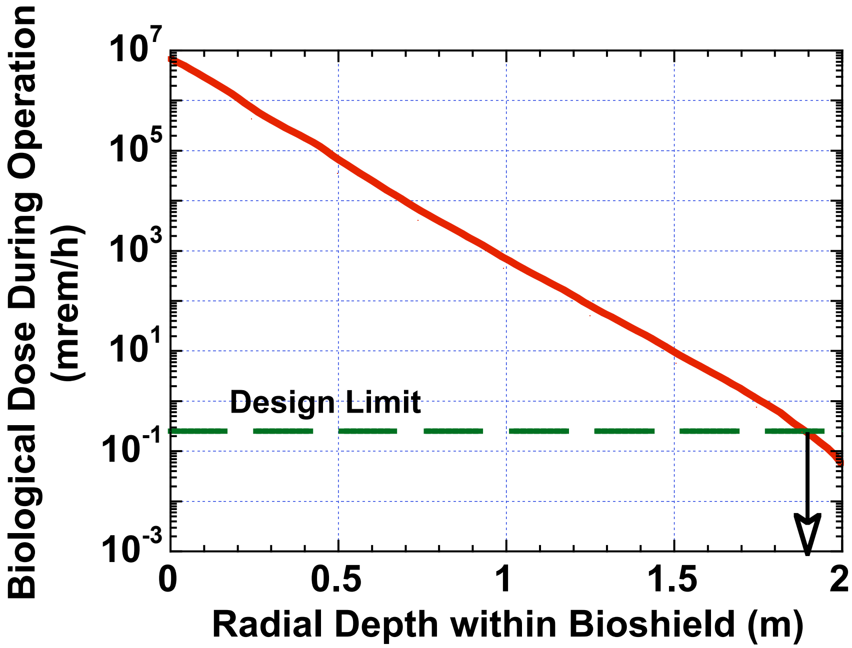
~16 cm for outboard and ~28 cm for inboard, per Xueren.

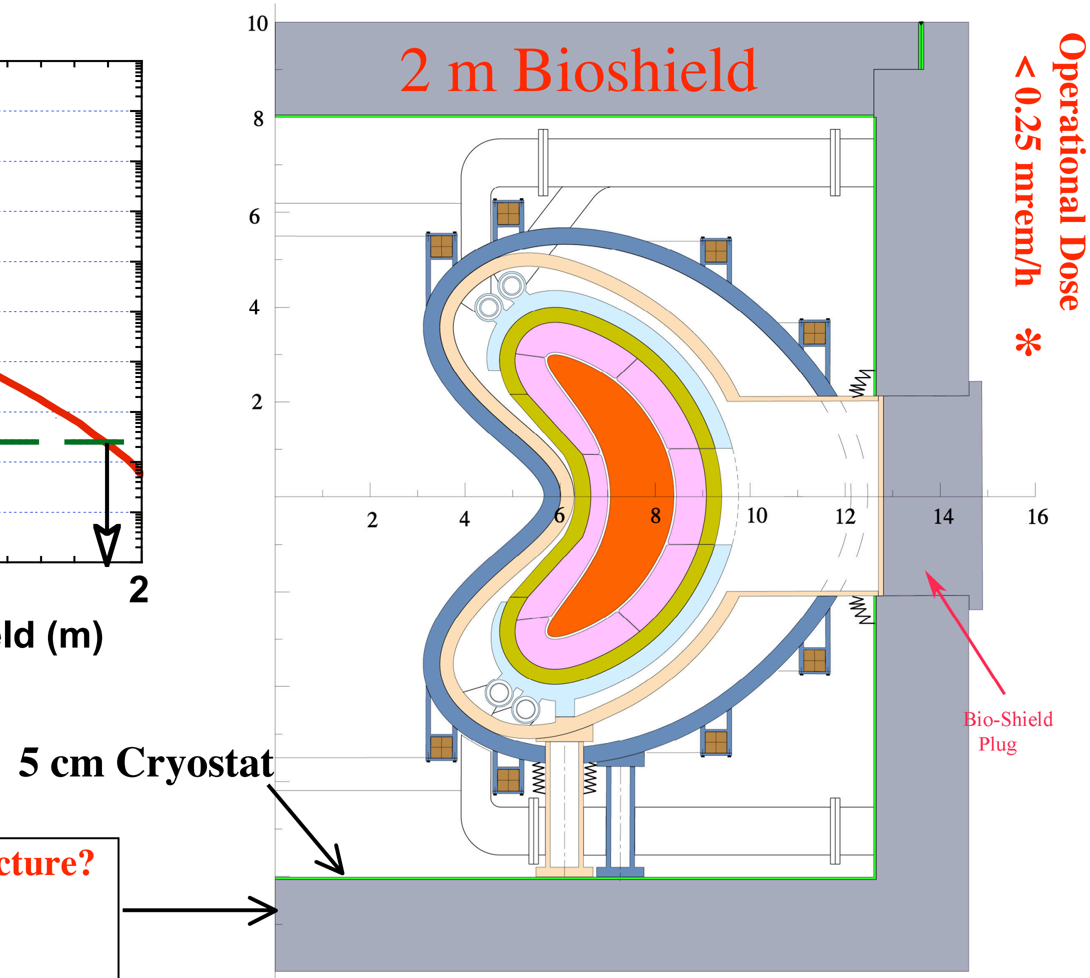
Design Requirements Satisfied Except at Divertor*

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 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 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





Where is the Primary Structure?

18% of FPC volume

- 383 m^3
- 70 cm thick steel

Key Parameters

	LiPb/FS/He	LiPb/SiC
□$_{min}$ (m)	1.3	≤ 1.3 ?
Overall TBR#	~ 1.1	
Li-6 Enrichment#	< 90%	
Overall Energy Multiplication#	~ 1.155	1.1
He : LiPb Power Ratio*	~ 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."

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* Abstract deadline extended to July 7, 2006.