Impact of Medium-Temperature Magnet and 2-FP Configuration on Radial Build

Laila El-Guebaly
Fusion Technology Institute
University of Wisconsin - Madison

With input from:
L. Bromberg (MIT), J. Lyon (ORNL), and L.P. Ku (PPPL)

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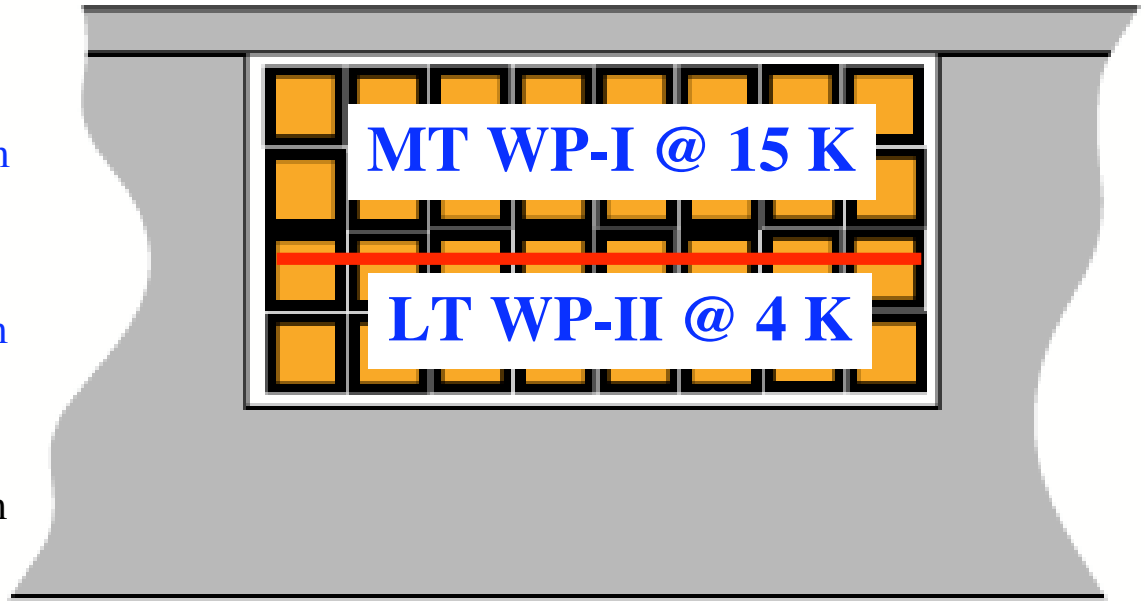
New Magnet Design (L. Bromberg)

Plasma/Blanket/Shield/VV

Coil Case - 2 cm
Insulator - 0.2 cm
Winding Pack-I - 17 cm
Winding Pack-II - 14 cm
Insulator - 0.2 cm
External Structure - 18 cm



Magnet Homogeneous Composition:
45% 316-SS (gray)
50% winding packs (orange/black)
5% GFF polyimide (white)

MT Winding Pack-I:
12.7% MgB_2
45.5% Cu
15.5% He @ 15 k
17.3% 316-SS
9.0% GFF poly.

LT Winding Pack-II:
9.6% NbTi
54.1% Cu
21.8% LHe @ 4 k
5.5% 316-SS
9.0% GFF poly.

Implications of New Magnet Design on Radial Build

	Old Magnet#	New Magnet
Inner Coil Case	2-10 cm	2 cm
Structure	Incalloy	SS-316
Conductor	Nb_3Sn @ 4K	MgB_2 @ 15 K NbTi @ 4 K
Winding Pack	20 cm	31 cm
Delta min	Δ_{min}	Δ_{min} + 5 cm
Fast n Fluence Limit	10^{19} n/cm^2	?
Local Heating Limit	2 mW/cm^3	?
Total Heating Limit	50 KW	?
Cryogenic Heat Load	< 15 MW*	?

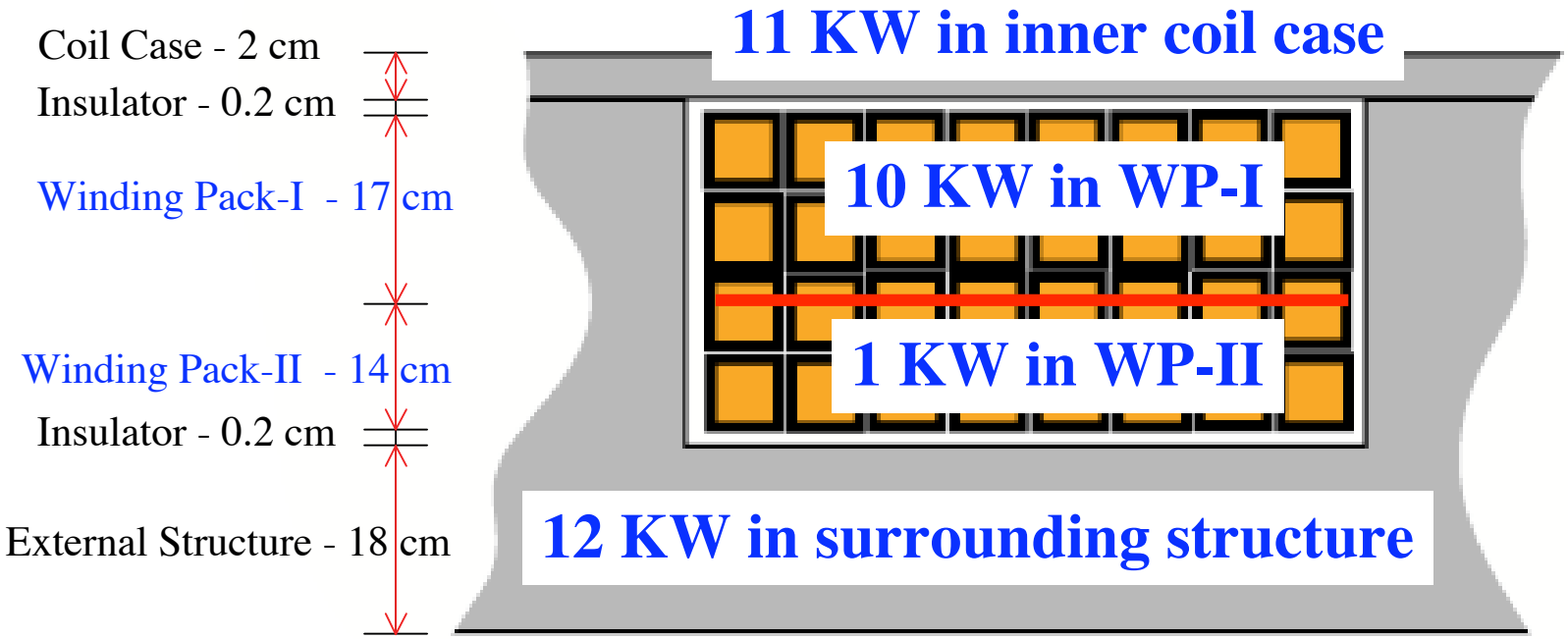
- New magnet results in ~10% higher fluence and ~25% higher local heating.
- To keep fluence below 10^{19} n/cm^2 (?), thicken shield by ~1 cm.
- Local heating is around 1 mW/cm^3. Is this acceptable?

Need radiation limits for new magnet to update shield

 # With SPPS' composition.
*** Using 300 W/W.**

34 KW Nuclear Heating Deposited in Magnet

(LiPb/SiC System with Internal VV and 2 MW/m^2 av.)



Heat load differs with blanket/shield/VV concept

What is the limit for total nuclear heating?

Radial Builds Have Been Updated on Same Design Basis

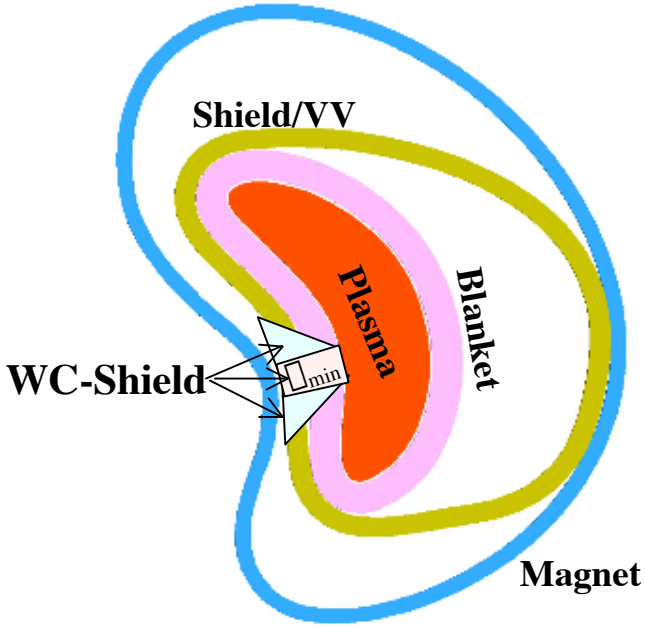
- **3 MW/m^2 peak** and **2 MW/m^2 average** neutron wall loadings.
- **5 cm SOL** and **2 cm** minimum VV-magnet **gap**.
- **2 cm** thick inner **coil case**.
- **31 cm thick winding packs-I/II**.
- **1.1 overall TBR for 3 FP configuration** based on 92% uniform-blanket coverage fraction, 8% shield-only zoned, 5 cm thick divertor plates/baffles covering 15% of FW area.
- **≤ 1% nuclear heating in LT shield and/or VV**.
- **Radiation limits to structural components**:
  - 3% burnup to SiC/SiC composites
  - 200 dpa to FS
  - 1 He appm @ VV.
- **Radiation limits to S/C magnet** (same as for LT S/C):
  - 10^{19} fast n fluence
  - 2 mW/cm^3 local nuclear heating
  - 10^{11} dose to GFF polyimide
  - $6x10^{-3}$ dpa to Cu stabilizer
  - 50 KW total nuclear heating.

Liquid Breeder Blanket Concepts

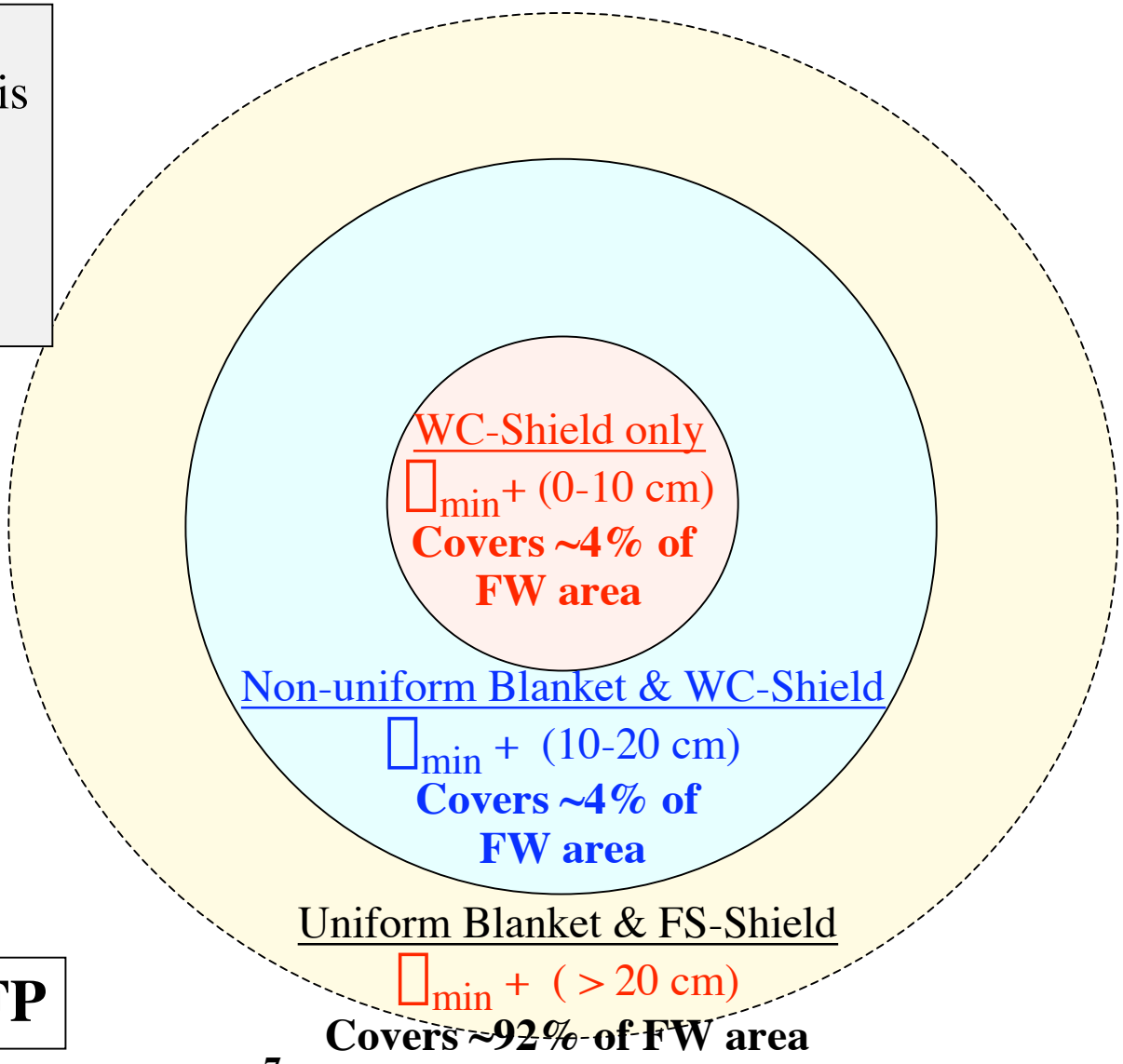
Breeder	Multiplier	Structure	FW/Blanket Coolant	Shield Coolant	VV Coolant
ARIES-CS:					
Internal VV:					
Flibe	Be	FS	Flibe	Flibe	H_2O
LiPb	–	SiC	LiPb	LiPb	H_2O
LiPb	–	FS	He/LiPb	He	H_2O
External VV:					
LiPb	–	FS	He/LiPb	He/B-H_2O	He
LiPb	–	FS	He/LiPb	He	He
Li	–	FS	He/Li	He	He
SPPS:					
External VV:					
Li	–	V	Li	Li	He

Blanket and Shield Arrangement
(3 FP Configuration)

- **Overall TBR** should be confirmed with 3-D analysis
- Monitor **WC decay heat**
- 1.11 m < □$_{min}$ < 1.18 m
- □$_{min}$ < 1.2 m
  □ av R ≤ 8.25 m



□$_{min}$ **occurs twice per FP**



Nominal Radial Distance Widely Varies with Blanket Concept

(Blanket/Shield Dimensions for CAD Drawings)

□ (m)

ARIES-CS:

	Blanket/Shield/VV	Plasma – Mid Coil
Internal VV:		
Flibe/FS/Be	**1.07** (min)	**1.32** (min)
LiPb/SiC	1.16	1.40
LiPb/FS/He	1.23	1.49
External VV:	**Blanket/Shield**	
LiPb/FS/He/B-H_2O	1.28	1.53
LiPb/FS/He	1.60	1.85
Li/FS/He	1.79 (max)	2.04 (max)

SPPS*:

External VV:		
Li/V	1.20	1.96

* 15 cm SOL, 36 cm half winding pack, 15 cm thick cryostat, and 8 cm wide shield-magnet gap.

Flibe/Be system offers thinnest blanket and wide breeding margin

Minimum Radial Distance Varies within 7 cm with Blanket Concept

(Δ_{min} for Systems Code Analysis)

Δ_{min} (m)

ARIES-CS:

	WC-Shield/VV		Plasma – Mid Coil	
Internal VV:				
Flibe/FS/Be	0.86	(min)	1.11	(min)
LiPb/SiC	0.89		1.14	
LiPb/FS/He	0.93	(max)	1.18	(max)
External VV:	**WC-Shield**			
LiPb/FS/He/B-H_2O	0.87		1.12	
LiPb/FS/He	0.93		1.18	
Li/FS/He	0.91		1.16	

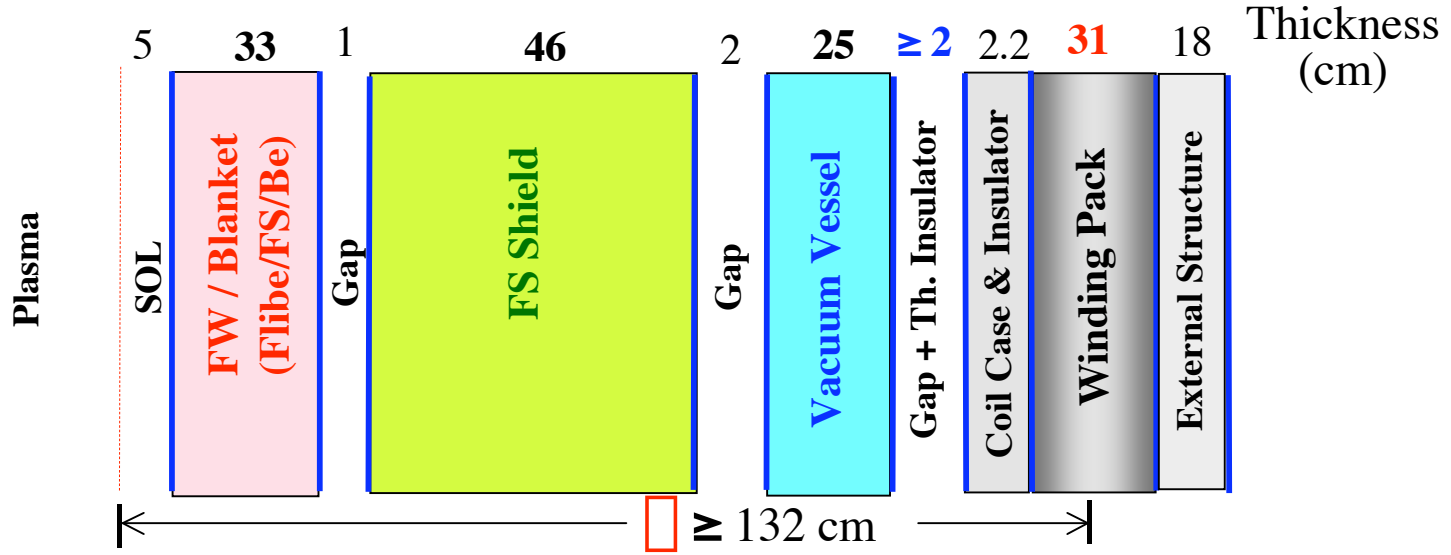
SPPS:

External VV:		
Li/V	–	–

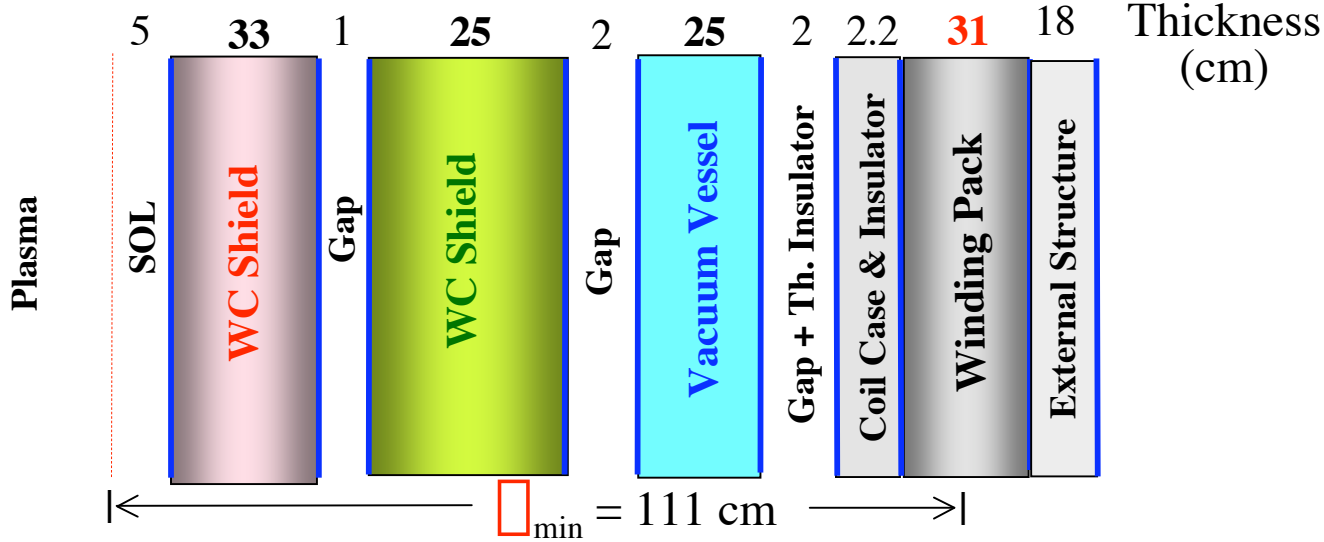
7 cm difference in Δ_{min} translates into 40-50 cm change in R

Flibe/FS Radial Build
(Water-Cooled **Internal** VV)

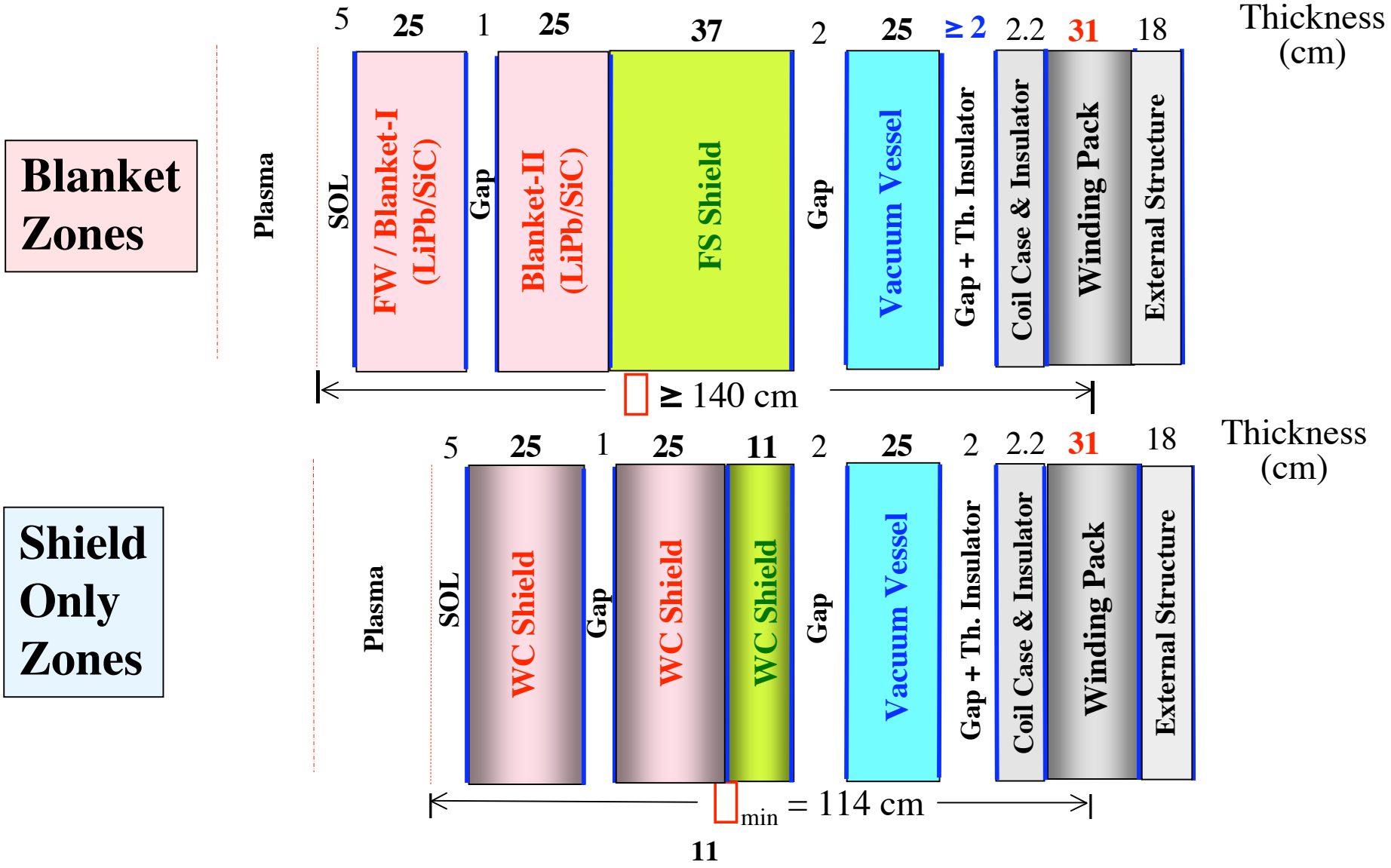
Blanket Zones



Shield Only Zones

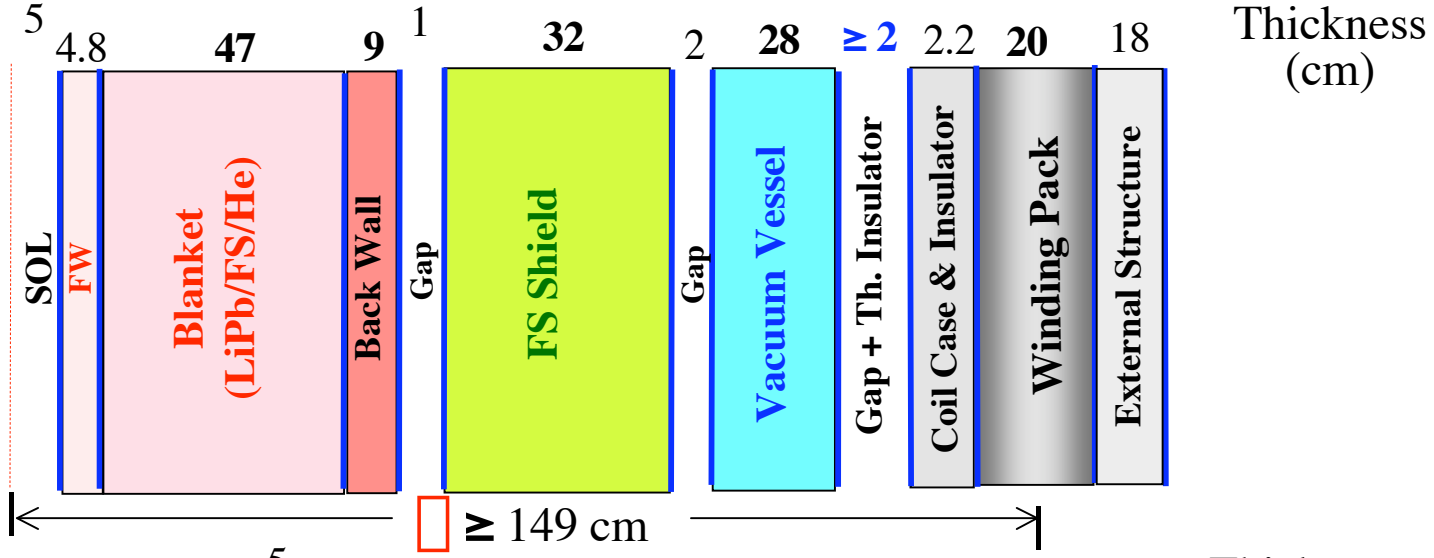


LiPb/SiC Radial Build
(Water-Cooled **Internal** VV)

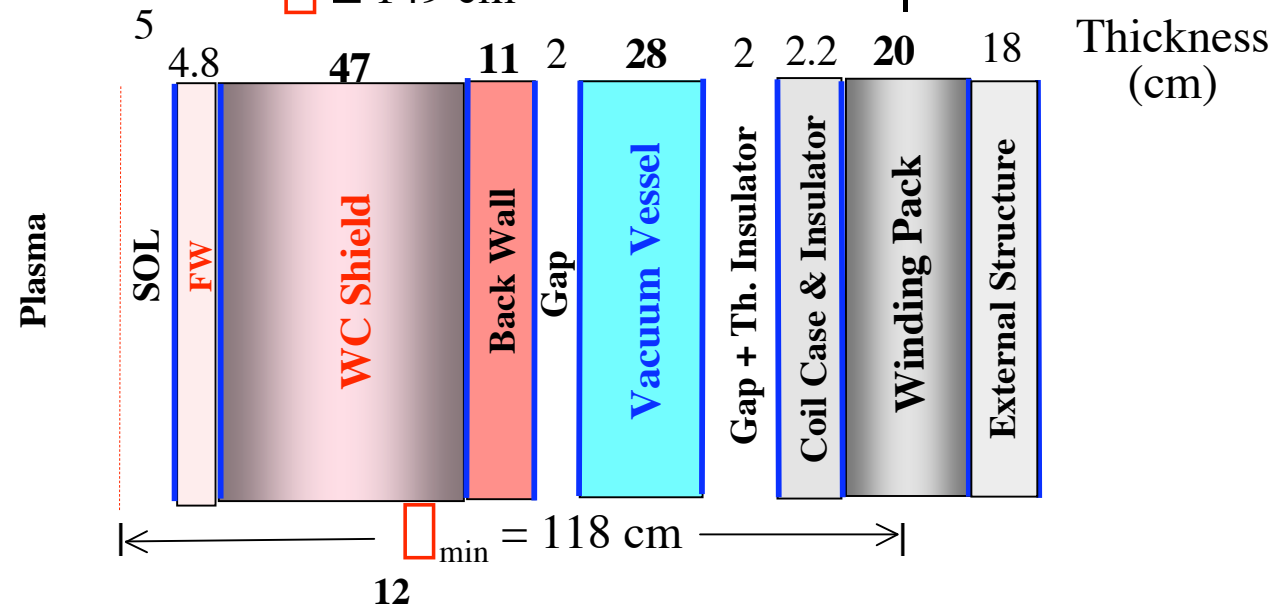


LiPb/FS/He Radial Build
(Water-Cooled **Internal** VV)

Blanket Zones



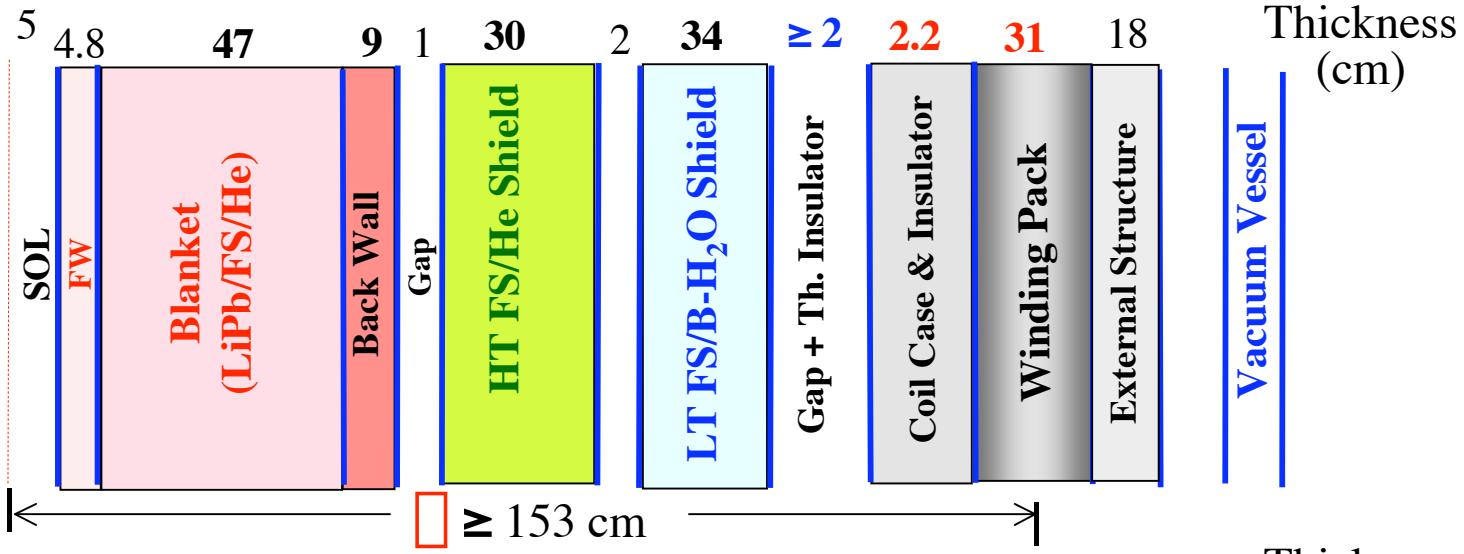
Shield Only Zones



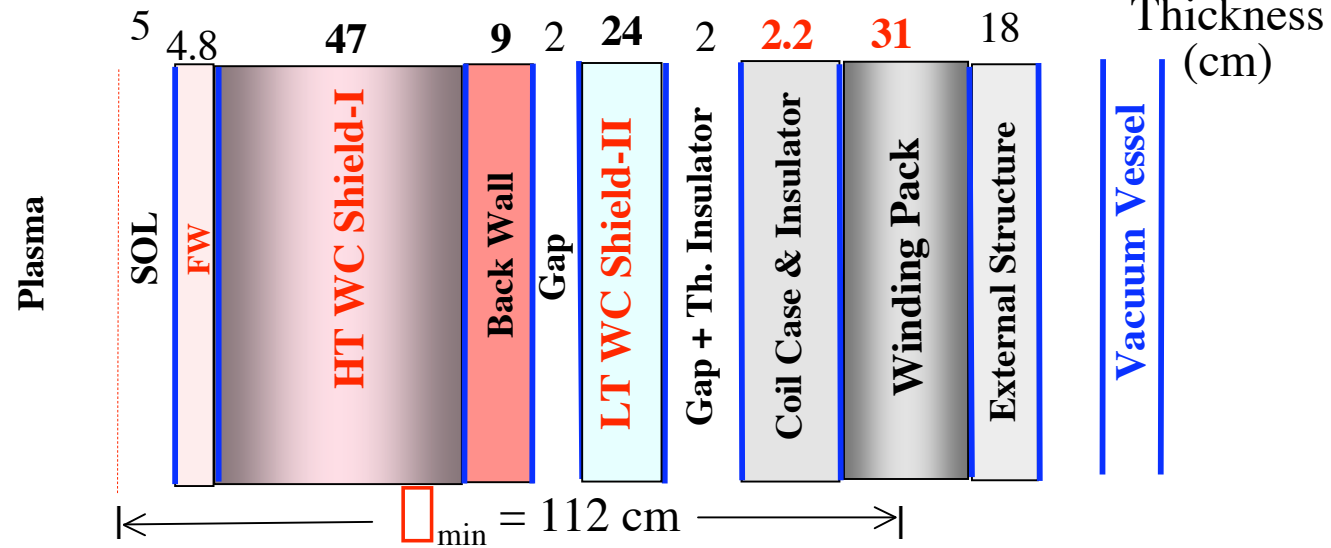
Boundary between WC-shield and back wall will be adjusted to meet design requirements

LiPb/FS/He/B-H_2O Radial Build
(He-cooled **External** VV)

Blanket Zones



Shield Only Zones



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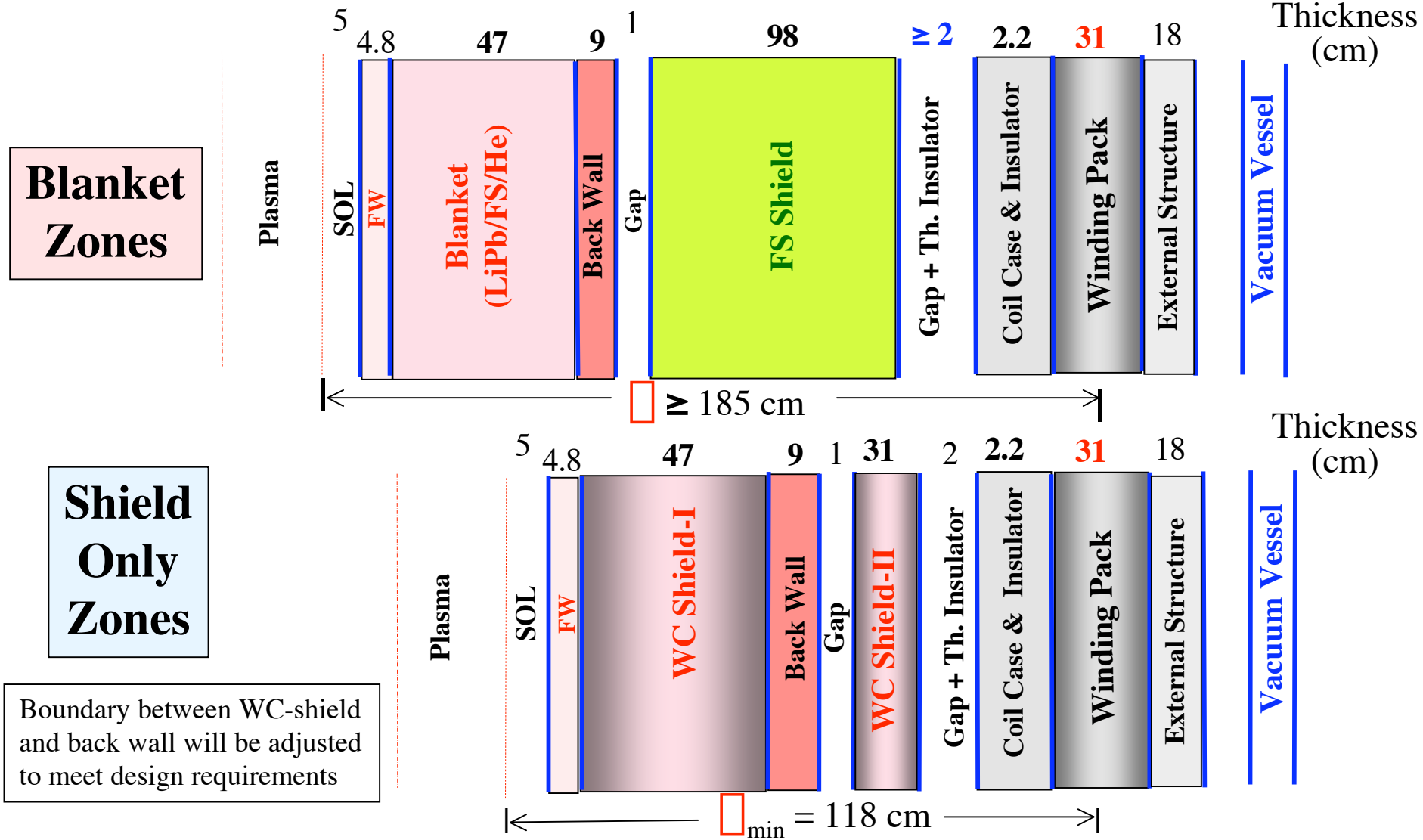
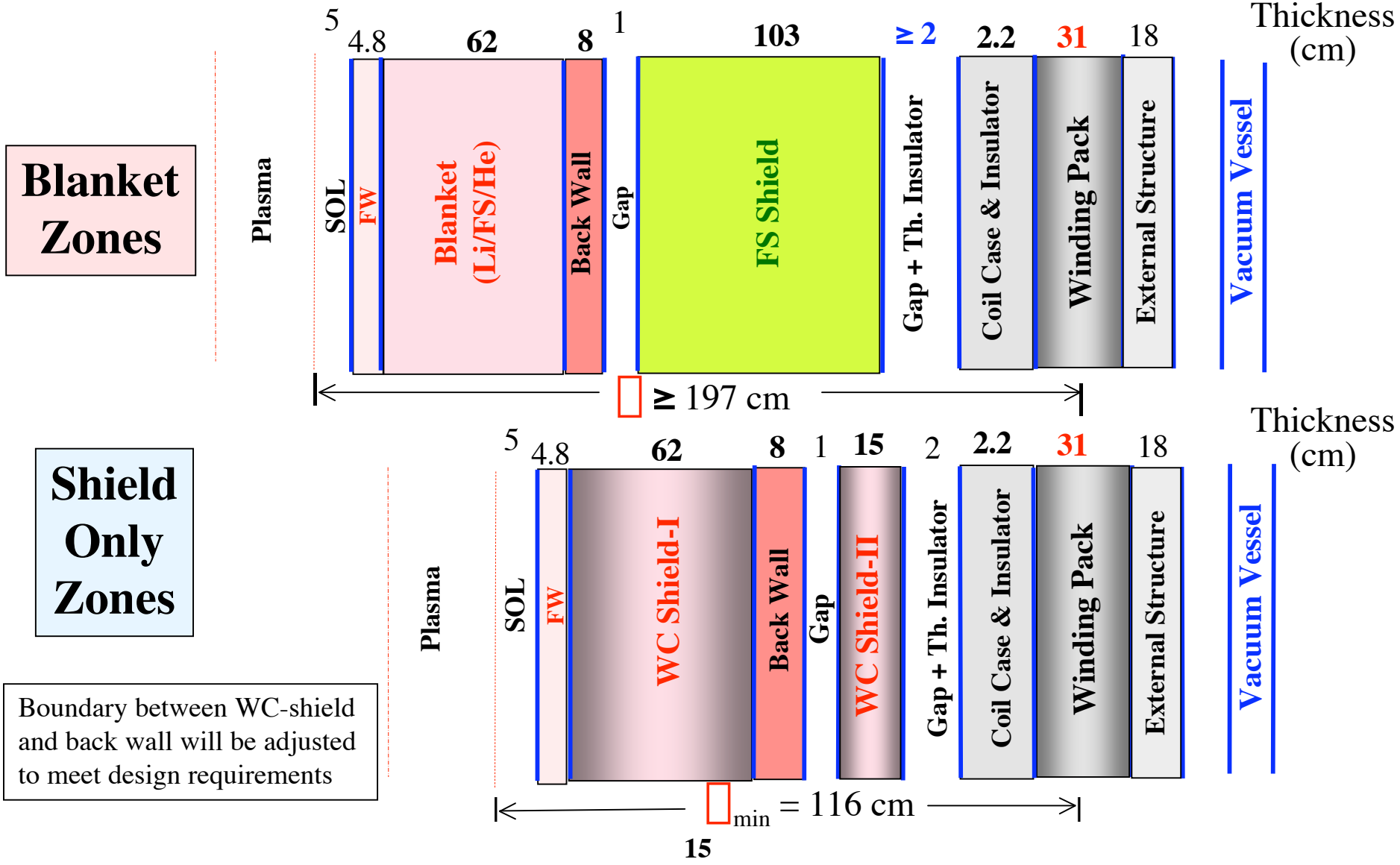
LiPb/FS/He Radial Build
(He-cooled **External** VV)



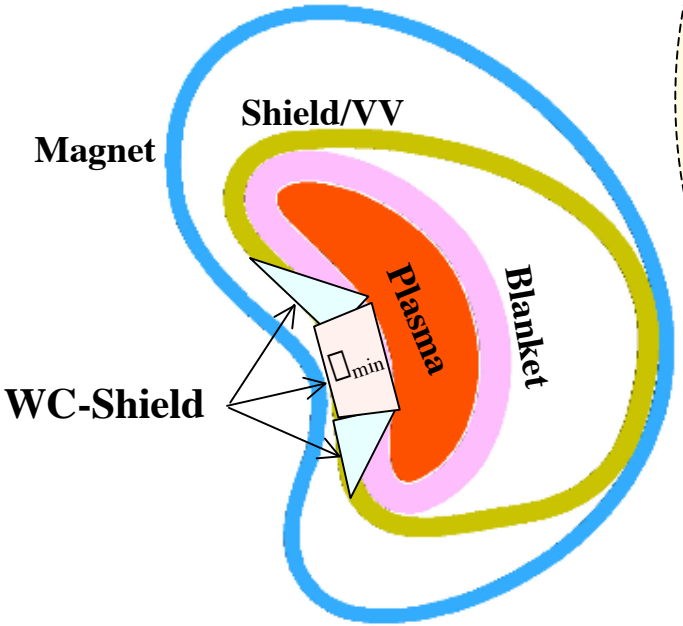
Boundary between WC-shield and back wall will be adjusted to meet design requirements

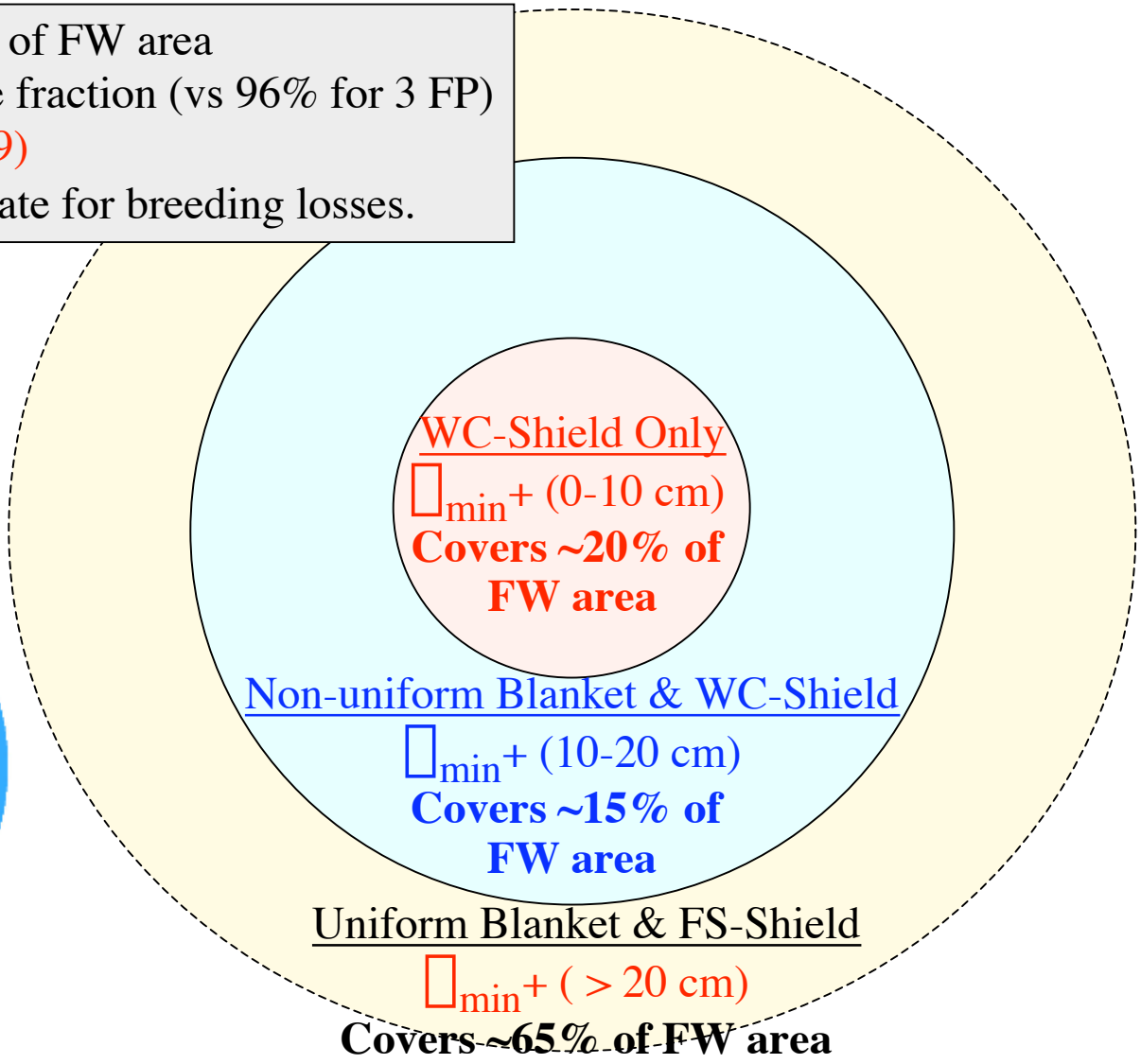
Li/FS/He Radial Build
(He-cooled **External** VV)



Breeding Concerns for 2 FP Configuration

- Shield-only zones cover 20% of FW area
  - ~80% blanket coverage fraction (vs 96% for 3 FP)
  - Overall TBR < 1 (~ 0.9)
- Redesign blanket to compensate for breeding losses.



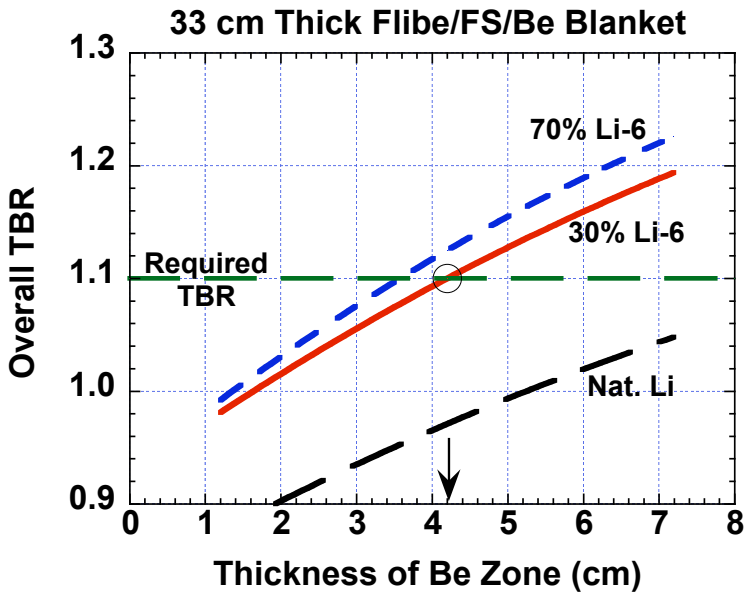


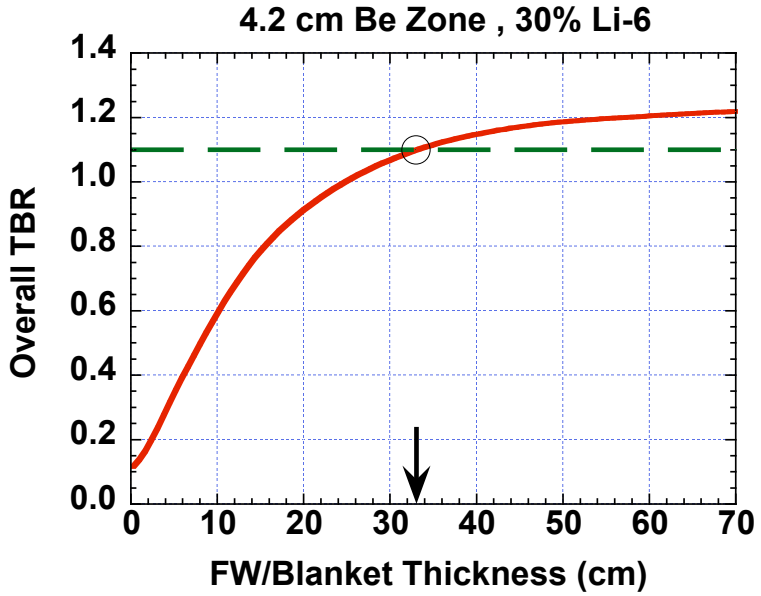
Breeding Concerns for 2 FP Configuration (cont.)

- LiPb and Li blankets may not provide enough breeding.

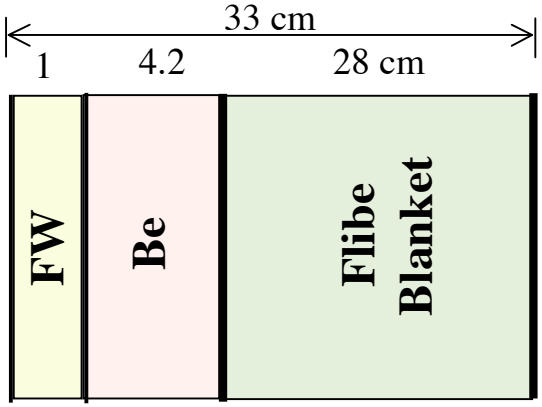
- **Flibe/FS/Be** blanket offers relatively large breeding margin. Potential solutions that could satisfy breeding requirement include:
  - Adding more beryllium (> 4.2 cm thick Be zone)
  - Thickening blanket > 33 cm
  - Enriching Li > 30%.

Flibe/FS/Be Blanket Offers Relatively Large Breeding Margin





- Combination of more Be and thicker blanket could increase TBR by 15-20%.
- Higher enrichment than 30% is less effective.



Conclusions

- Combination of shield-only zones and non-uniform blanket is an optimum configuration for ARIES-CS.
- Radial builds should be updated as MgB_2 radiation limits become available.
- Overall TBR of 1.1 should be confirmed with 3-D analysis. CAD-MCNP interface will simplify 3-D modeling.
- Breeding of 2 FP configuration is marginal. Candidate blankets with Be multiplier could meet breeding requirement.

Future Plan

- Develop radial build for solid breeder blanket concept.
- Develop CAD-MCNP interface for 3-D modeling.
- Submit 1-2 abstracts to 16th TOFE :

  1- **Benefits of Radial Build Minimization and Requirements Imposed on ARIES Compact Stellarator Design**

  L. El-Guebaly, R. Raffray, S. Malang, J. Lyon, L.P. Ku and the ARIES Team

  ? 2- **Three -Dimensional Modeling of Complex Fusion Devices Using CAD-MCNP Interface**

  M. Wang, T. Tautges, D. Henderson, L. El-Guebaly, M. Sawan, P. Wilson, X. Wang and the ARIES Team.