

Radial Build Definition for LiPb/SiC and Flibe/FS Systems

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

With Input from:

L.P. Ku (PPPL), R. Raffray, X. Wang (UCSD), S. Malang (FZK),
B. Merrill (INEEL), and L. Bromberg (MIT)

http://fti.neep.wisc.edu/FTI/ARIES/MAY2003/lae_radialbuild.pdf

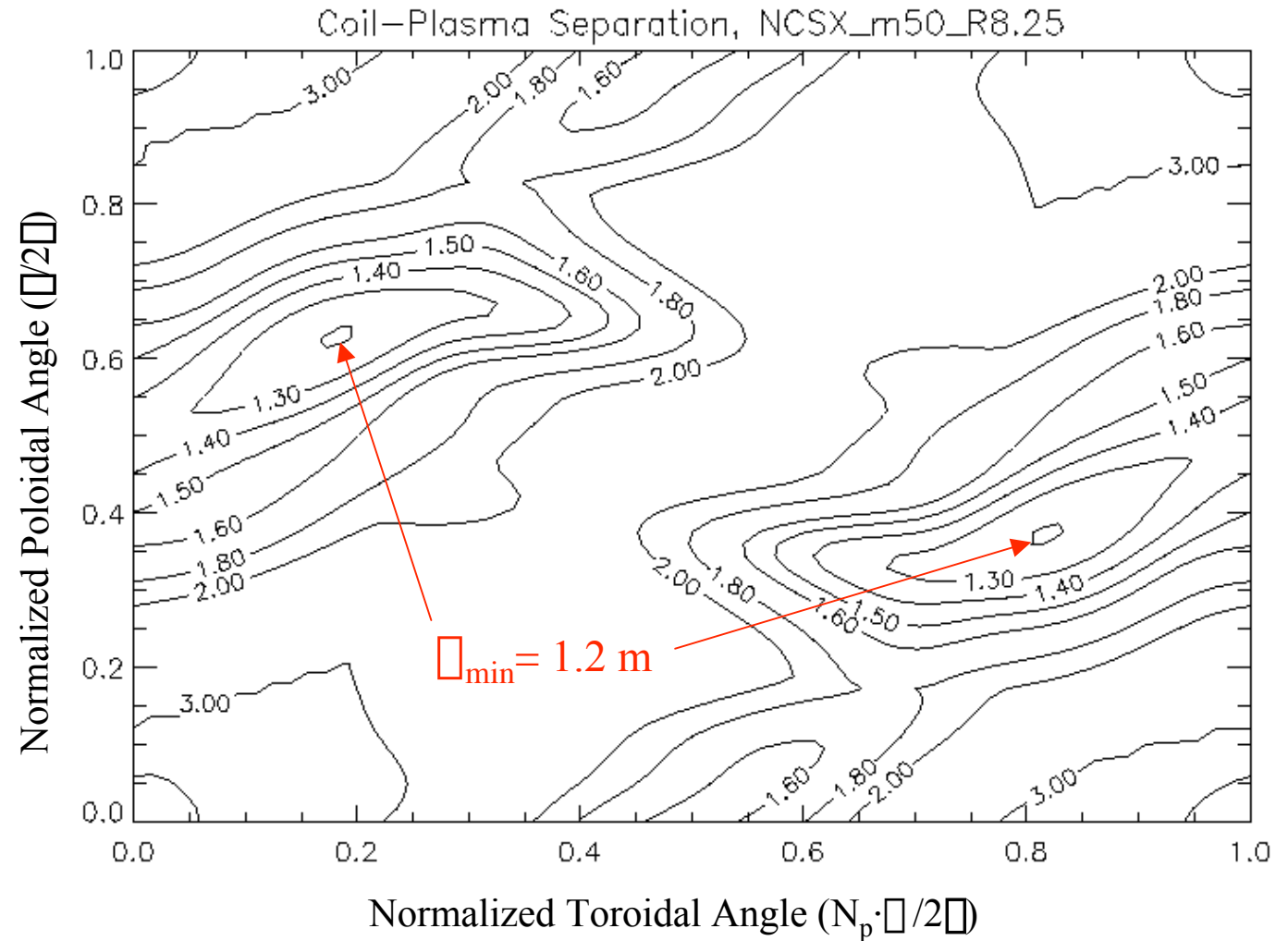
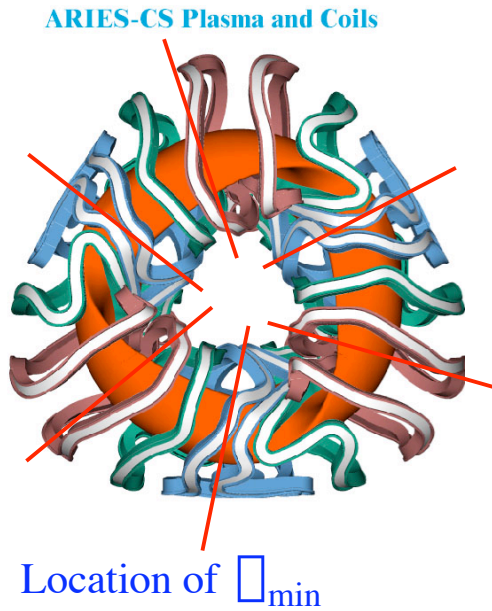
ARIES-CS Project Meeting
May 7, 2003
Livermore, CA

Initial Parameters

Net Electric Power	1000 MW _e
# of Field Periods	3
A	4.5
< R >	8.25 m
< a >	1.85 m
Average Neutron Wall Loading ($\bar{\phi}$)*	2 MW/m ²
FW Area	~ 800 m ²
Toroidal Length of Field Period	~ 9 m
Minimum Plasma-to-Coil Center Distance (ϕ_{\min})	1.2 m
# of ϕ_{\min} per Field Period	2
FW Coverage Fraction for Shield-only Zones	8%

* Corresponding peak ϕ is ~3 MW/m².

\square_{\min} Occurs Twice per Field Period

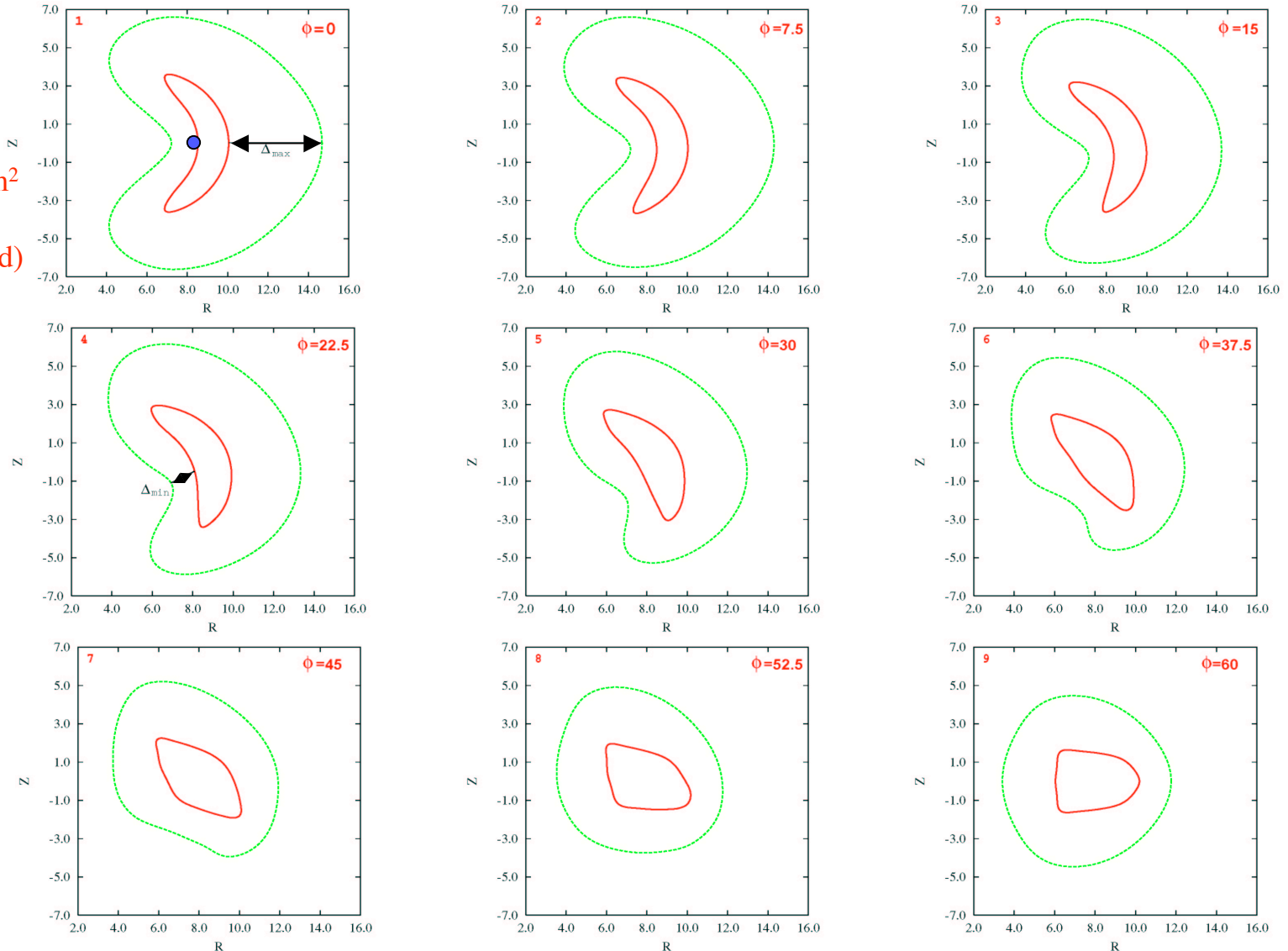


9 Xns of Plasma Boundary (red) and WP Center (green) Covering Half Field Period (~9 m)

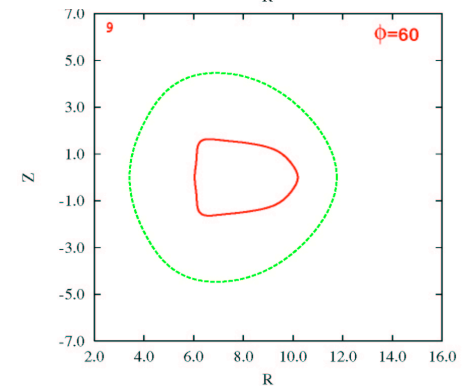
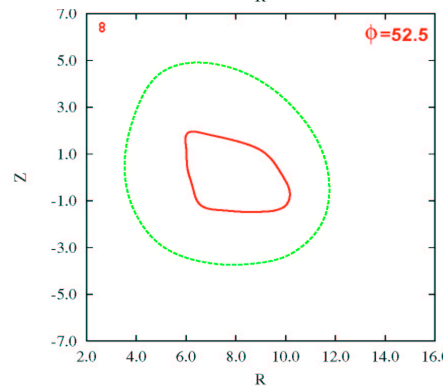
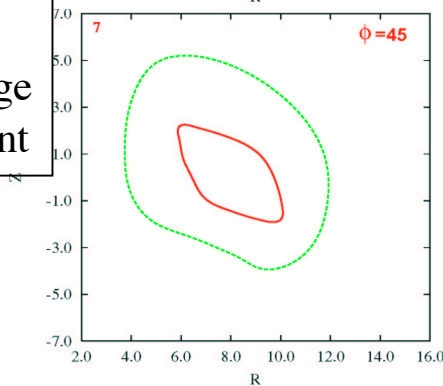
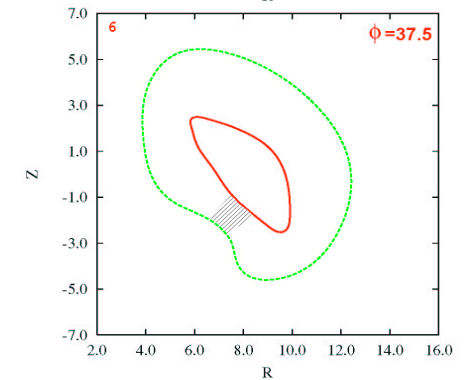
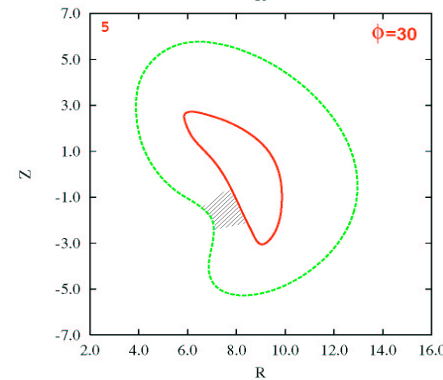
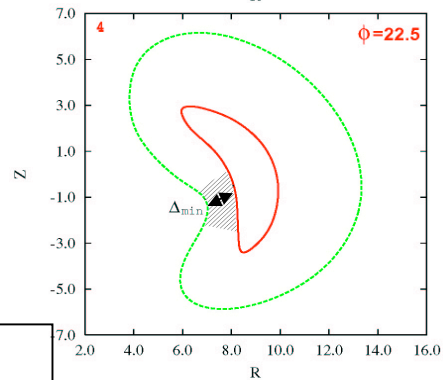
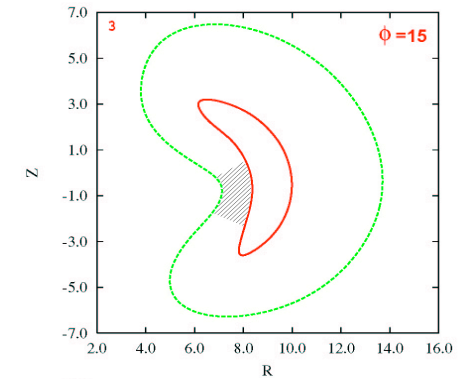
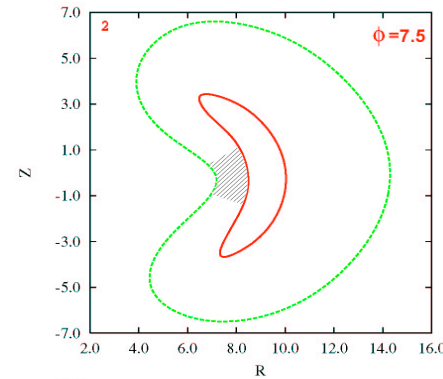
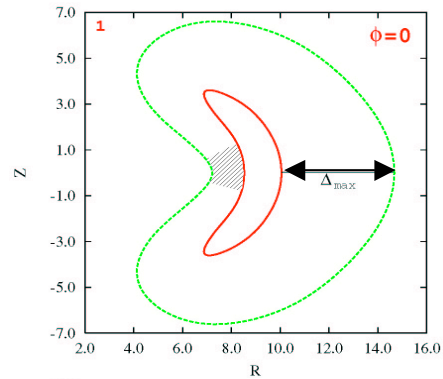
$\square_{\max} \sim 4.6 \text{ m}$

\square peaks @ $\sim 3 \text{ MW/m}^2$
at blue dot
(middle of field period)

$\square_{\min} = 1.2 \text{ m}$



Transition Region Between \square_{\min} and $\square_{\min} + 0.2 \text{ m}$ Covers $\sim 8\%$ of FW Area



$\square_{\min} = 1.2 \text{ m}$

Gray areas:

$\sim 2 \text{ m}$ Poloidal extent
17% Poloidal coverage
 $\sim 5.5 \text{ m}$ Toroidal extent



Design Requirements and Radiation Limits

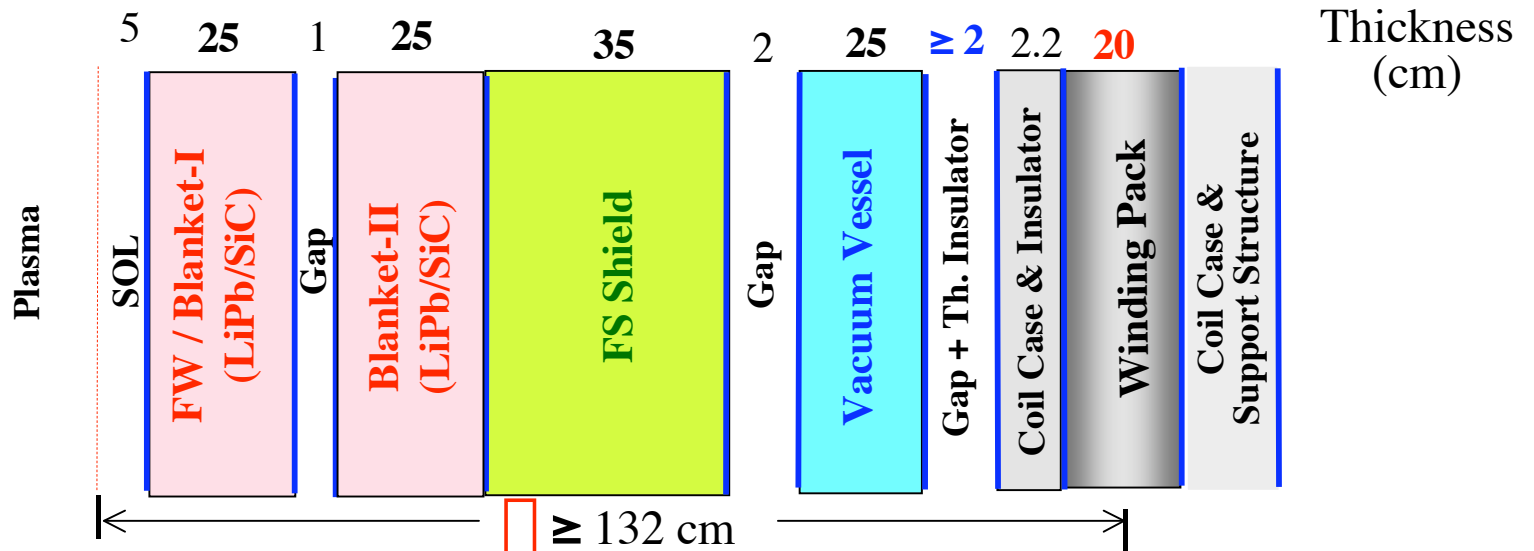
Overall TBR (for T self-sufficiency)	1.1
Burnup for SiC/SiC Composites (for structural integrity)	3%
dpa to FS Structure (for structural integrity)	200 dpa
Helium production @ VV (for reweldability of FS)	1 appm
LT S/C Magnet (@ 4K):	
n fluence to Nb ₃ Sn ($E_n > 0.1$ MeV)	10 ¹⁹ n/cm ²
Dose to polyimide insulator	10 ¹¹ rads
Nuclear heating	2 mW/cm ³
dpa to Cu stabilizer	6x10 ⁻³ dpa
Biological dose outside building (for workers and public protection)	2.5 mrem/h

Assumptions

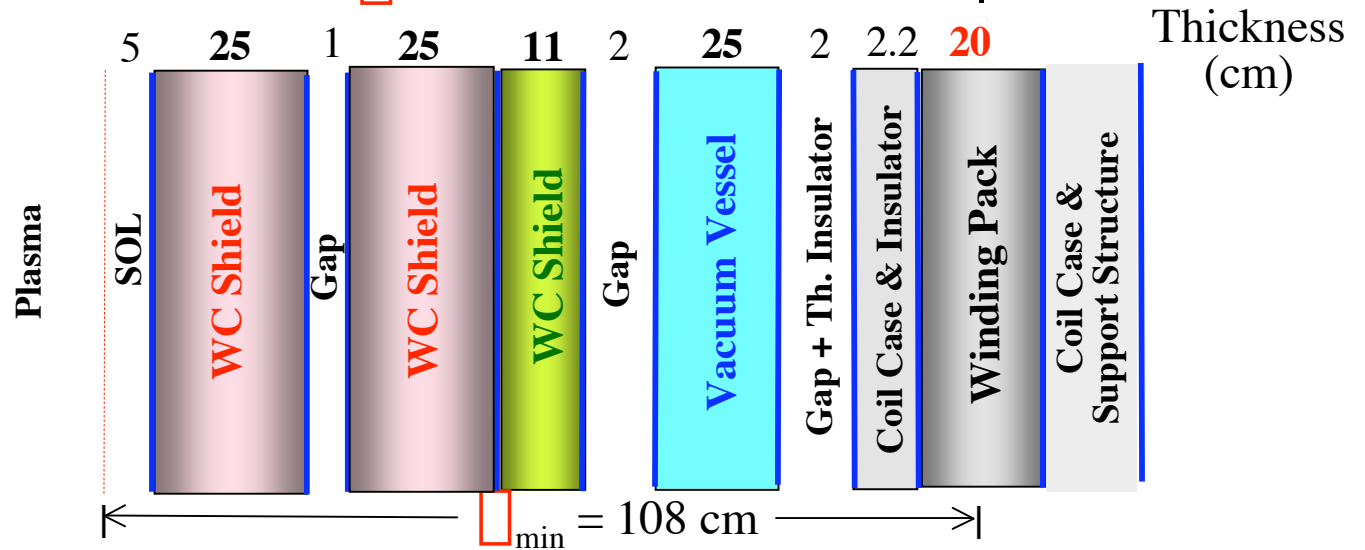
- Peak to average $\square = 1.5$
- **Penetrations** occupy 2% of FW area.
- **Divertor** plates/baffles:
 - 5 cm thick
 - 50% structure and 50% coolant
 - Cover 15% of FW area.
- ARIES-AT **FW/blanket composition** for LiPb/SiC concept.
- SPPS **magnet composition**.
- **1-D** poloidal neutronics **model** with av. $a = 1.85$ m.

Recommended LiPb/SiC Radial Build (Schematic; not to scale)

Blanket Zones



Shield Only Zones



LiPb/SiC System

Components

Replaceable Blanket-I

Permanent Blanket-II

FS Shield

WC Shield

VV

Winding Pack

(Composition not available. Used SPSS')

Composition

79% LiPb with 90% enriched Li
21% SiC/SiC Composite Structure

79% LiPb with 90% enriched Li
21% SiC/SiC Composite Structure

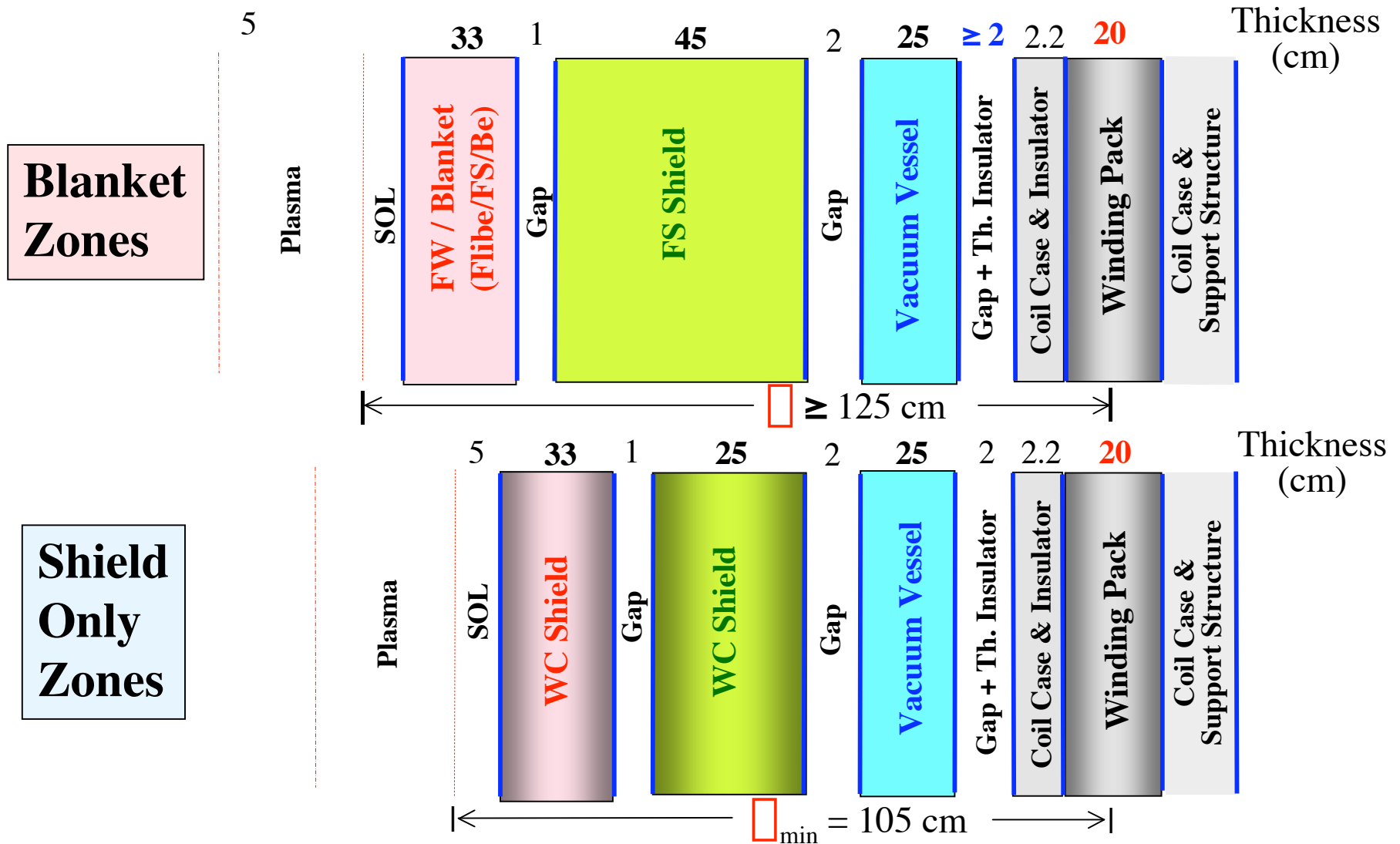
15% SiC/SiC Composite Structure
10% LiPb
75% Borated Steel Filler

20% SiC/SiC Composite Structure
10-15% LiPb
65-70% WC Filler

28% FS Structure
49% Water
23% Borated Steel Filler

25% Incoloy Structure
20% Cu Stabilizer
15% Nb₃Sn + Conduit
25% GFF Polyimide
15% LHe

Recommended Flibe/FS Radial Build (Schematic; not to scale)



Flibe/FS System Updates

Components

Blanket

82% Flibe with 30% enriched Li
10% FS Structure
8% Be

FS Shield

15% FS Structure
10% Flibe
75% Borated Steel Filler

WC Shield

10-15% FS Structure
10-15% Flibe
75% WC Filler

VV

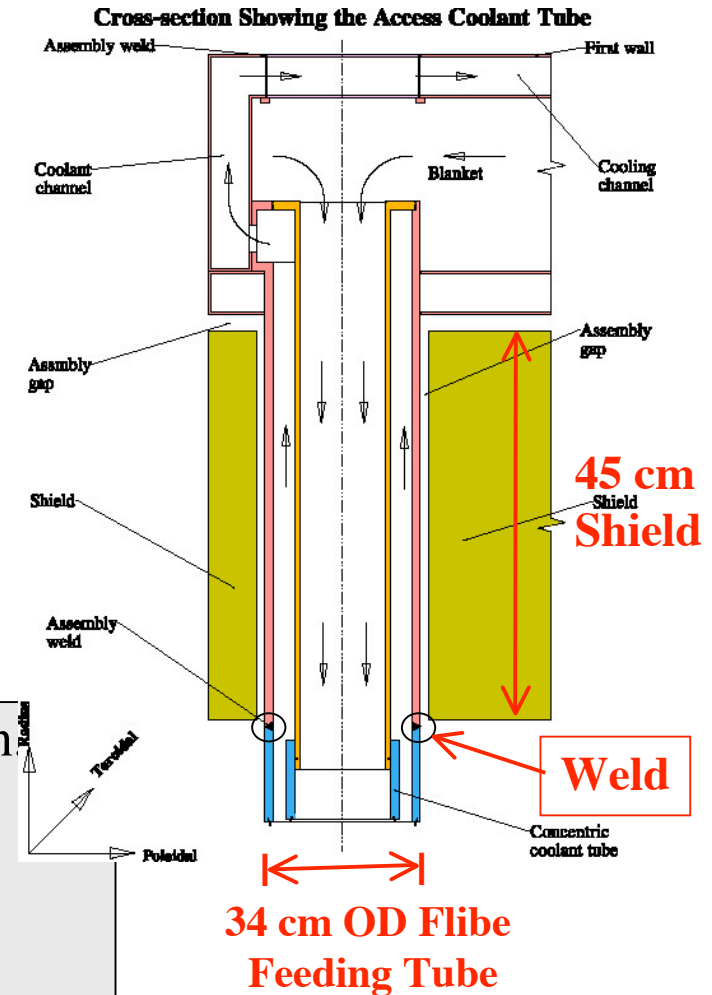
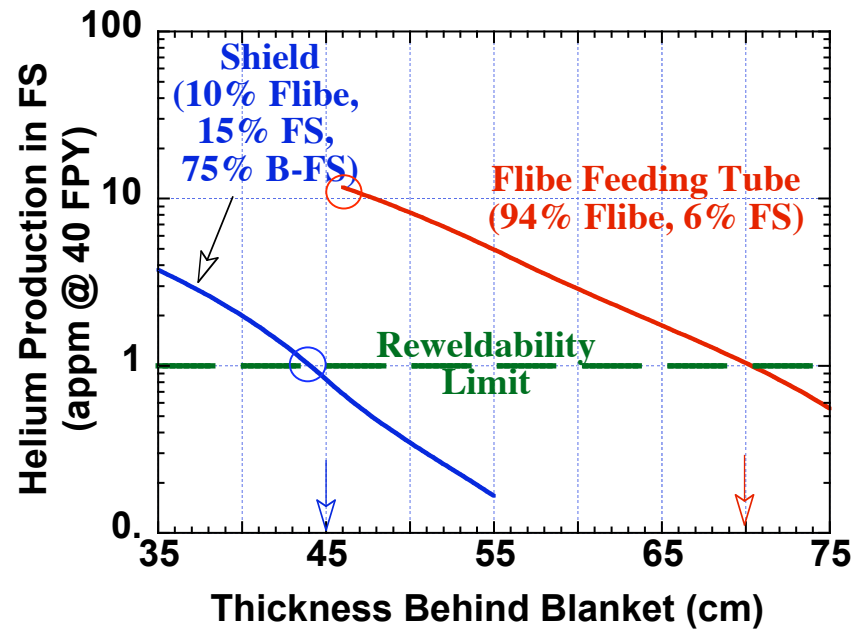
28% FS Structure
72% Borated Water

Winding Pack

(Composition not available. Used SPPS')

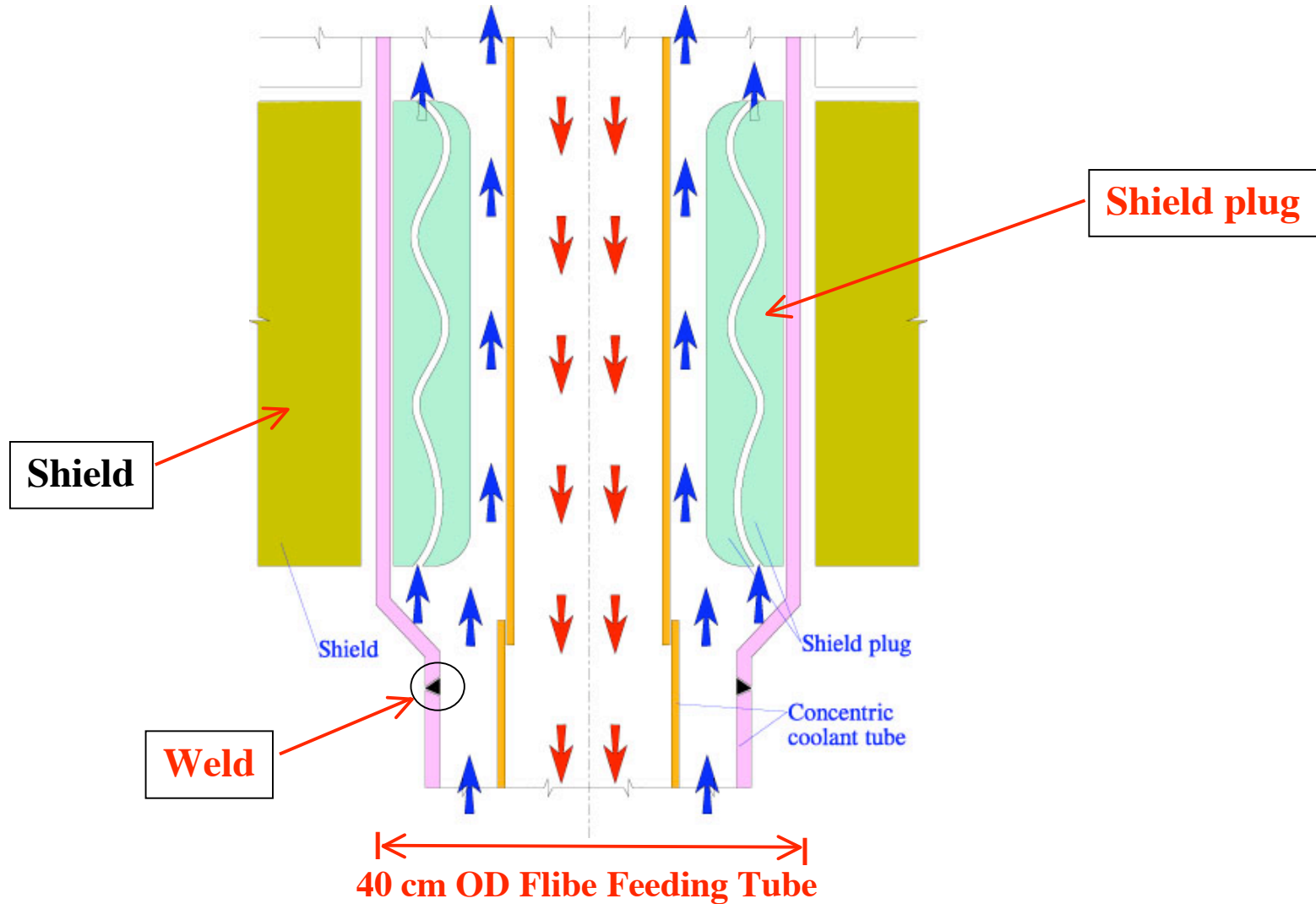
25% Incoloy Structure
20% Cu Stabilizer
15% Nb₂Sn + Conduit
25% GFF Polyimide
15% LHe

Excessive Helium Generation at Welds of Flibe Feeding Tube



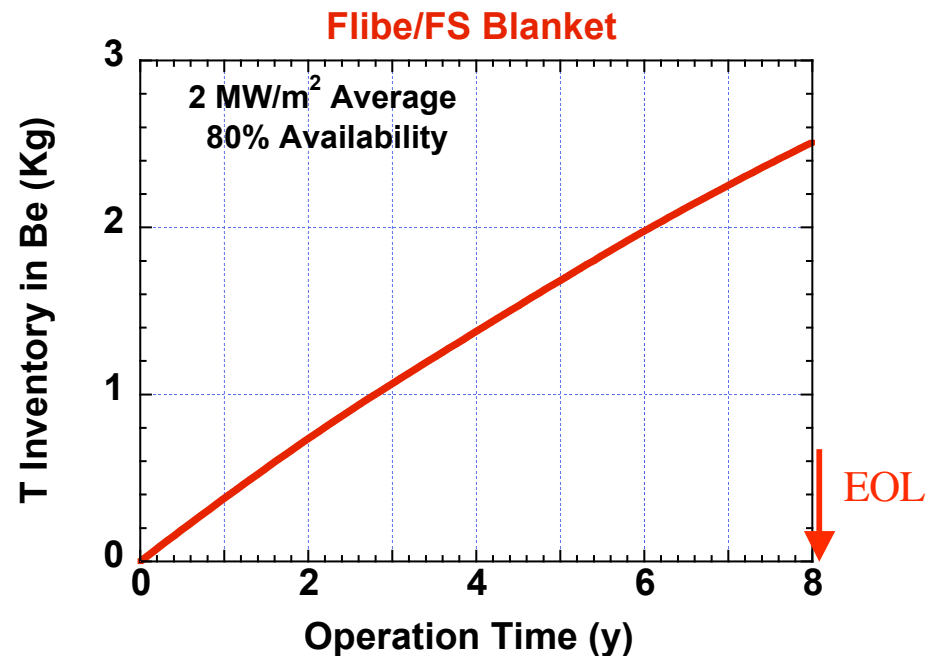
- FS Shield is superior to Flibe in neutron attenuation
- 45 cm Flibe does not allow rewelding of tubes
 - Move welds 25 cm away from back of shield, if design allows
 - Or, insert shield plug to protect welds, per Malang.**

Shield Plug Protects Welds of Feeding Tubes (Wang's Drawing)



Tritium Bred in Beryllium Raises Safety Concern, Unless Released

Assuming no T release,
T inventory in Be reaches
2.5 kg at EOL (6.5 FPY, 8.1 y)



Per B. Merrill:

- T release is temperature and fluence dependent (800 °C @ BOL and 600 °C @ EOL).
- Bakeout helps release some of T. Remaining inventory is unknown.
- T inventory exceeding 1 kg raises safety concern in accidents driving Be above 800 °C.



ARIES-CS Offers 6-28% Reduction in B/S/VV Thickness Relative to SPPS, Despite Higher β

	SPPS		ARIES-CS			
	<u>Li/V</u>	<u>Flibe/FS</u>		<u>LiPb/SiC</u>		
		Blanket and Shield	Shield only	Blanket and Shield	Shield only	
Peak β (MW/m ²)	2	3	3	3	3	
<u>Thickness (cm):</u>						
FW/Blanket-I	36	33	33	25	25	
Gap	–	–	–	1	1	
FW/Blanket-II	–	–	–	25	25	
Gap	2	1	1	–	–	
HT Shield	45	45	25	35	11	
Gap	2	2	2	2	2	
VV or LT Shield	35	25	25	25	25	
Total B/S/VV	120	106	86	113	89	
Net Saving	–	14	34	7	31	

More Reduction (33-46%) in \square_{\min} due to Thinner SOL and Magnet

	SPPS	ARIES-CS			
	<u>Li/V</u>	<u>Flibe/FS</u>		<u>LiPb/SiC</u>	
<u>Thickness (cm):</u>		<u>Blanket and Shield</u>	<u>Shield only</u>	<u>Blanket and Shield</u>	<u>Shield only</u>
SOL	15	5	5	5	5
B/S/VV	120	106	86	113	89
Gap + Th. Insl.	≥ 8	≥ 2	≥ 2	≥ 2	≥ 2
Cryostat#	15	2.2	2.2	2.2	2.2
1/2 Winding Pack	38	10	10	10	10
\square	196	125	105	132	108
Net Saving	-	71	91	64	88

Coil case and electric insulator.

Reduction in \square_{\min} translates into smaller R and lower B_{\max}
relative to SPPS

WC-Shield-Only Zones Introduce Engineering Problems

- **Benefits:**

- 15-20% thinner radial build
- 15-20% smaller R
- Lower COE !?

- **Potential engineering problems:**

- Integration of WC-shield with blanket system
- Accommodation of WC decay heat removal loop
- Any WC high level waste?
- Heavy WC zones Smaller, **many** modules (≤ 3 tonnes each)
- Longer replacement time
- Lower availability !?

<u># of Modules*</u>	<u>Blanket only</u>	<u>Blanket + WC-Shield</u>
Flibe System	~ 66	60 + 70 = 130
LiPb System	~ 35	32 + 45 = 77

* 3 tonnes each module; WC shield covers 8% of FW area.



Key Parameters for ARIES-CS System Analysis

	<u>Flibe/FS/Be</u>	<u>LiPb/SiC</u>
TBR	1.1	1.1
Energy Multiplication	1.2	1.1
Thermal Efficiency	45%	~60%
FW Lifetime (FPY)	6.5	6
Replaceable Blanket:		
Thickness (cm)	33	25
Mass (tonnes)	197	105 (□ Fewer modules)
Cost* (M\$)	27	42
System Availability	80%	> 80%

* FS @ \$70/kg, Be @ \$610/kg, SiC/SiC @ \$400/kg

Integrated system analysis could assess impact on COE

Conclusions

- Initial β estimates of 125 cm and 133 cm seem adequate for Flibe/FS and LiPb/SiC systems, respectively, based on 1-D analysis and several assumptions
- 20-24 cm reduction in radial build is achievable with shield-only zones at β_{\min} locations, pending significant saving in COE and innovative solutions to WC shielding problems.
- As design progresses, 3-D nuclear analysis is needed to:
 - Generate neutron wall loading profile using CAD-MCNP interface*
 - Confirm key nuclear parameters (TBR, M_n , lifetime, β_{\min} etc)
 - Determine boundary between replaceable and permanent components.
- Reported preliminary nuclear parameters may change as design develops and/or as more rigorous 3-D analyses are performed.

* Under development at UW.