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

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

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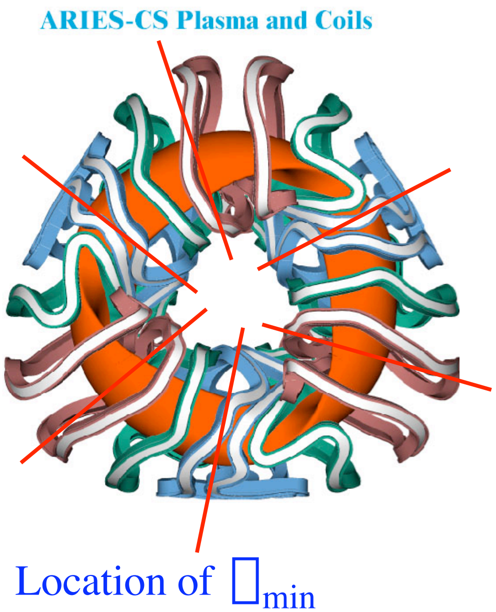
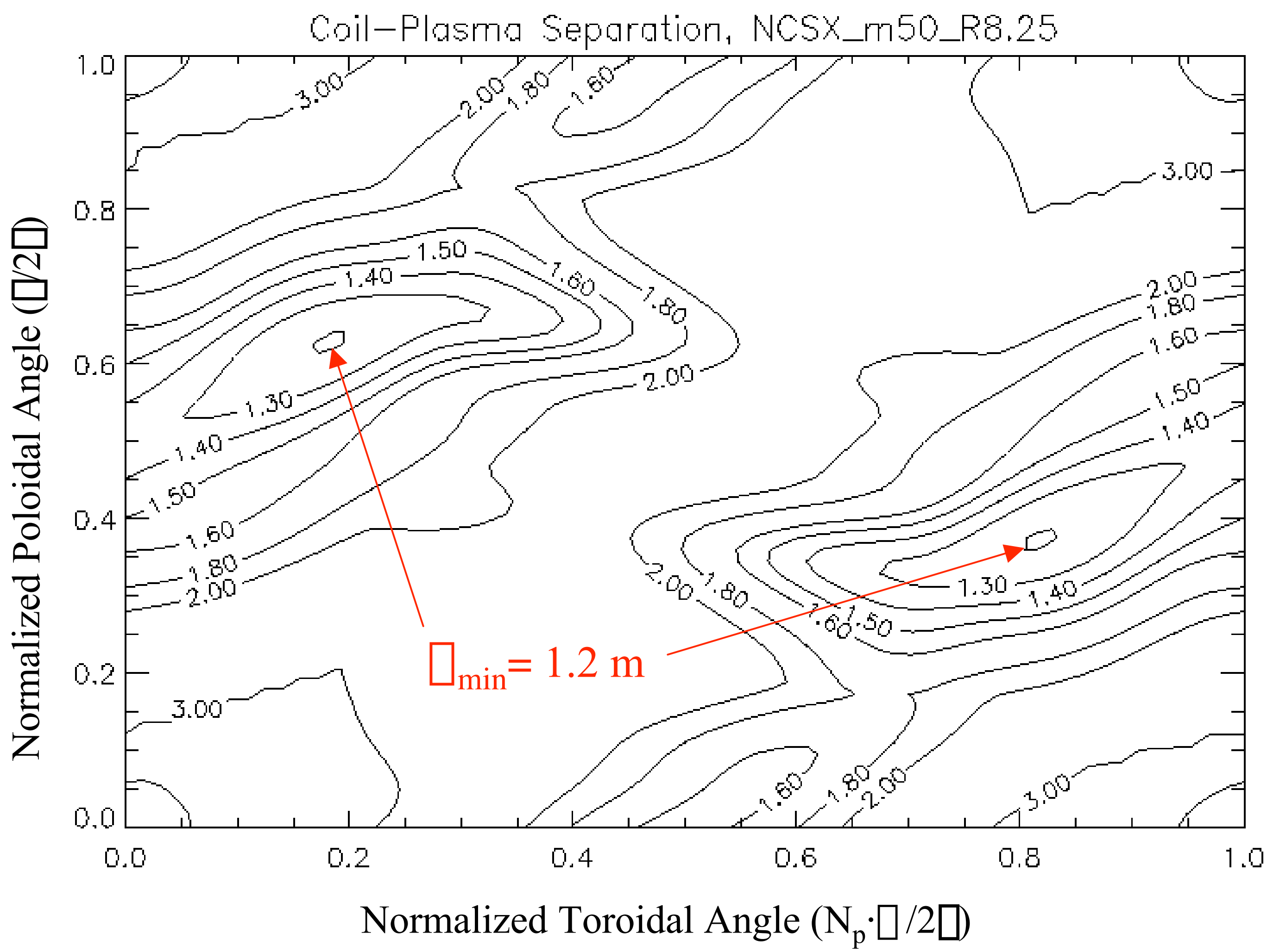
Initial Parameters

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 (□)*	2 MW/m^2
FW Area	~ 800 m^2
Toroidal Length of Field Period	~ 9 m
Minimum Plasma-to-Coil Center Distance ($□_{min}$)	1.2 m
# of $□_{min}$ per Field Period	2
FW Coverage Fraction for Shield-only Zones	8%

* Corresponding peak □ is ~3 MW/m^2.

□$_{min}$ Occurs Twice per Field Period



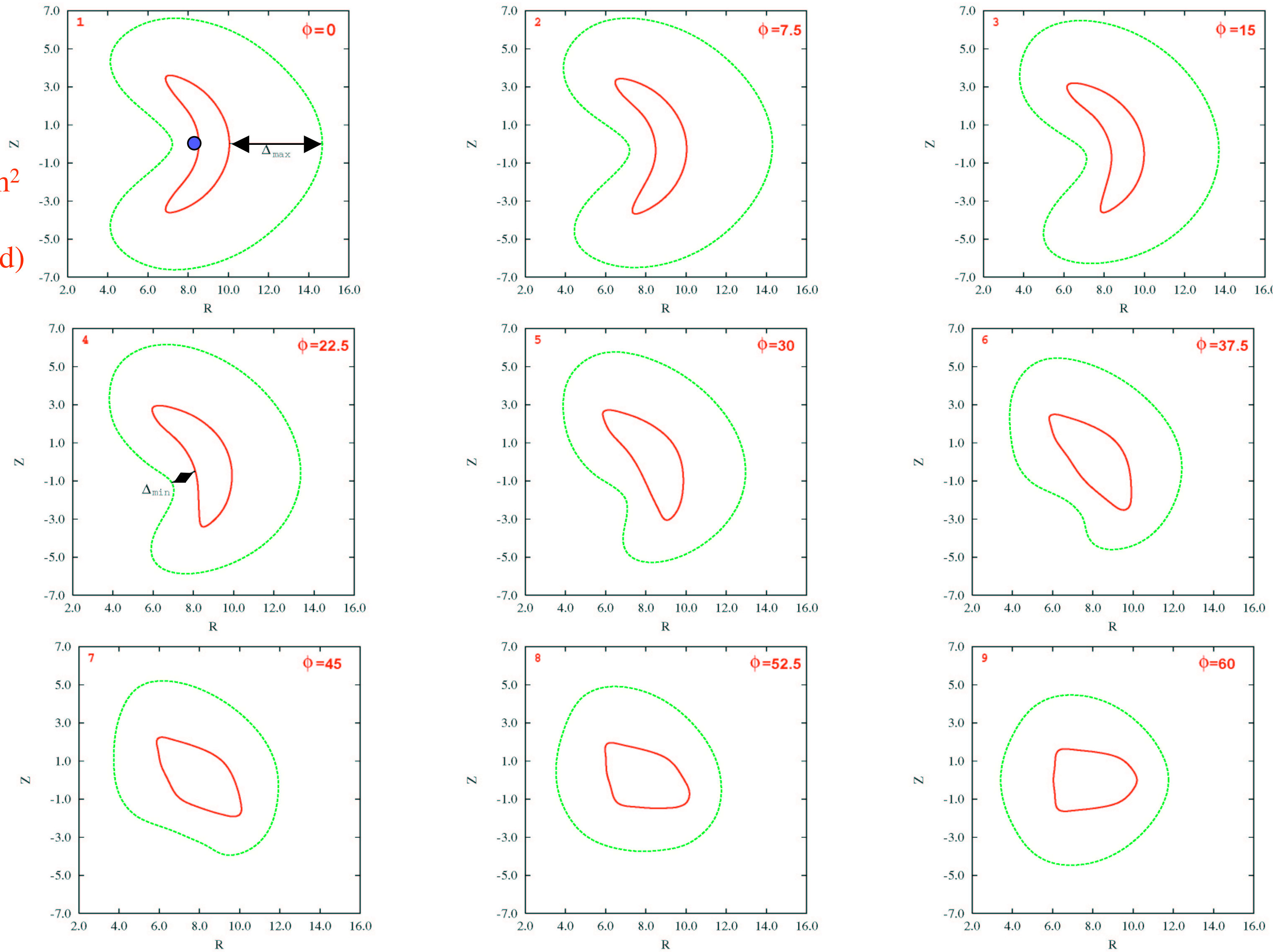


9 Xns of Plasma Boundary (red) and WP Center (green) Covering Half Field Period (~9 m)

Δ_{max}~ 4.6 m

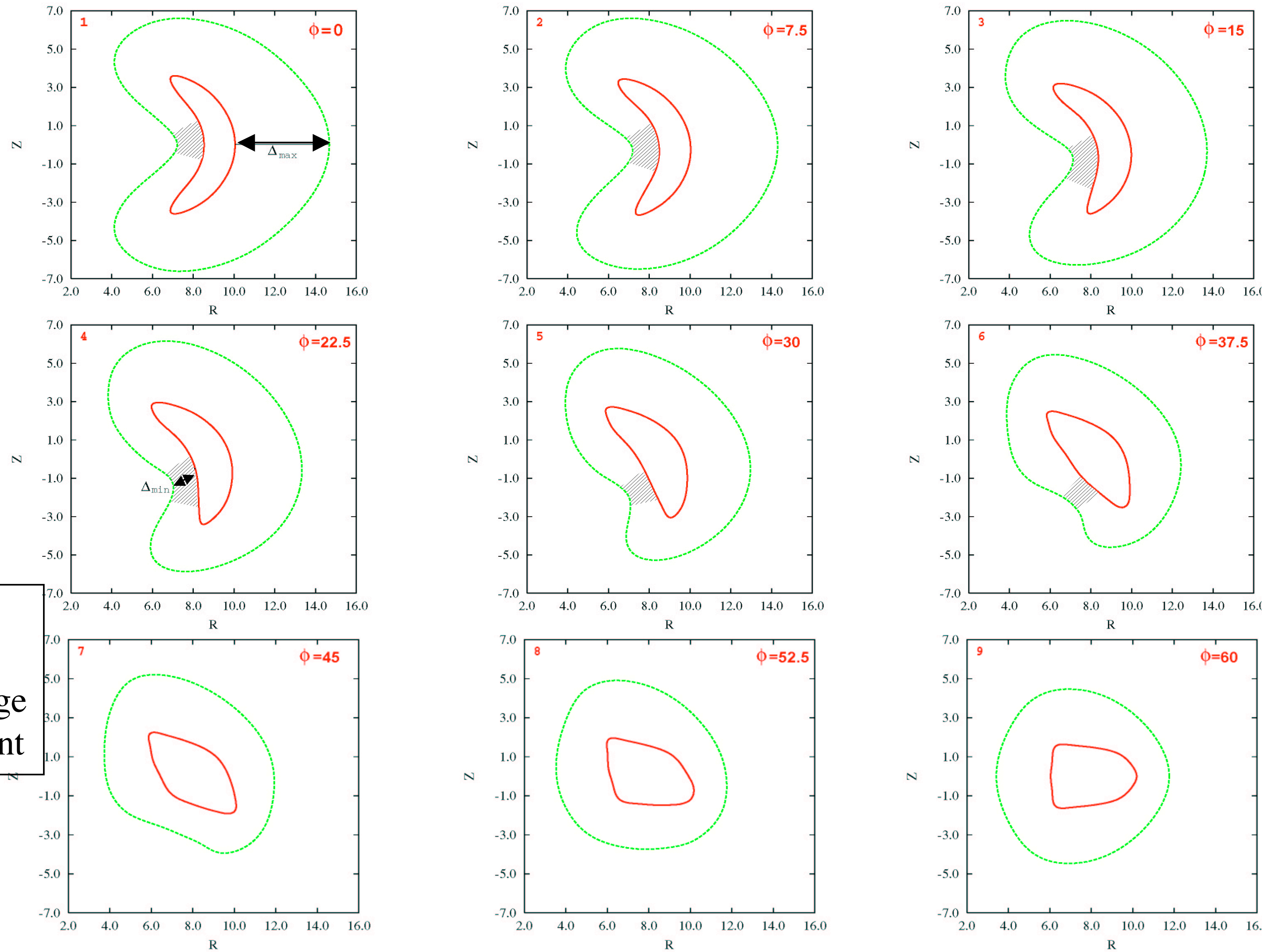
□ peaks @ ~3 MW/m^2
at blue dot
(middle of field period)

Δ_{min}= 1.2 m



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

$\square_{min}$= 1.2 m



Gray areas:
~2 m Poloidal extent
17% Poloidal coverage
~5.5 m Toroidal extent

Design Requirements and Radiation Limits

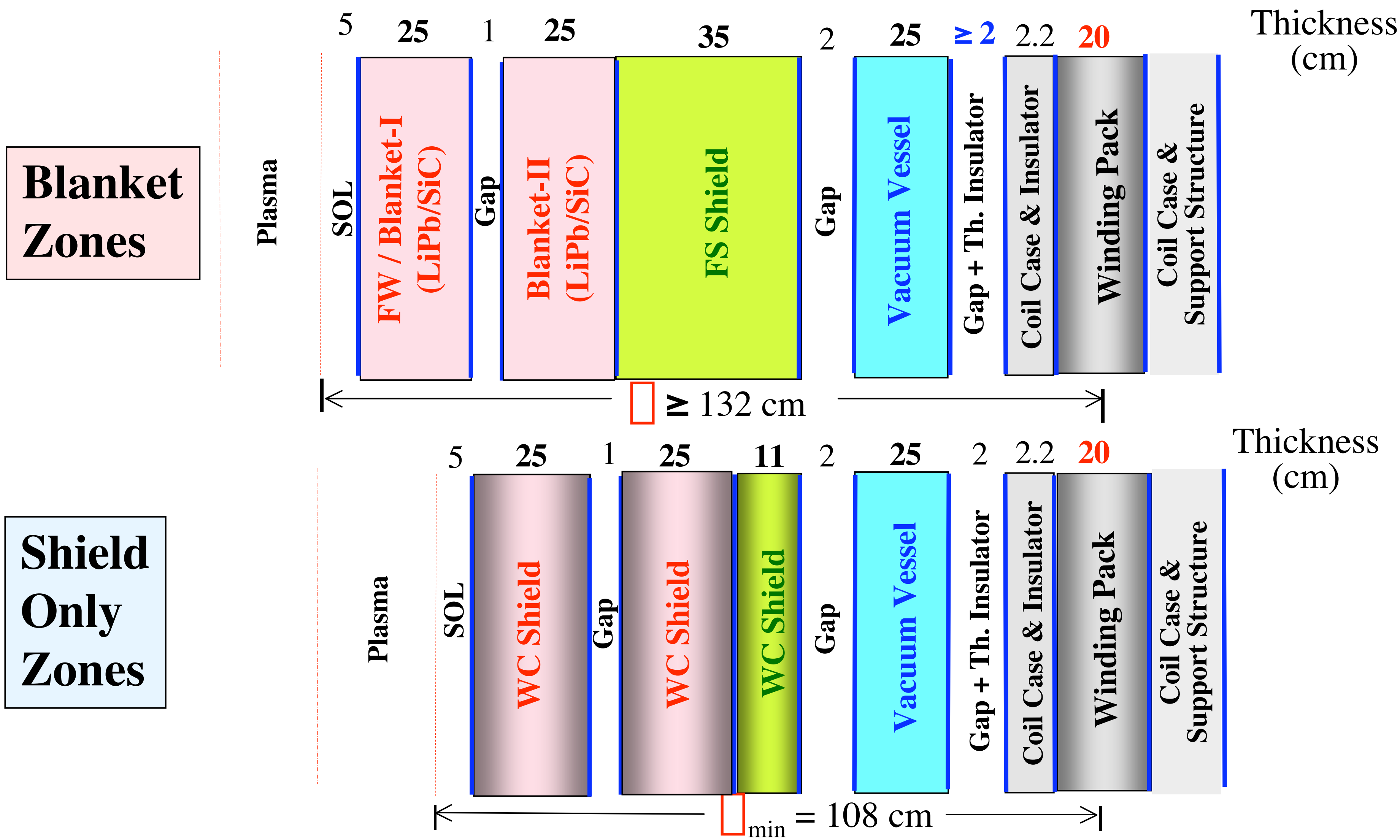
Overall TBR (for T self-sufficiency)	1.1	
Burnup for SiC/SiC Composites (for structural integrity)	3%	
dpa to FS Structure (for structural integrity)	200	dpa
Helium production @ VV (for reweldability of FS)	1	appm
LT S/C Magnet (@ 4K):		
n **fluence** to Nb_3Sn (E_n > 0.1 MeV)	10^{19}	n/cm^2
Dose to polyimide insulator	10^{11}	rads
Nuclear **heating**	2	mW/cm^3
dpa to Cu stabilizer	6×10^{-3}	dpa
Biological dose outside building (for workers and public protection)	2.5	mrem/h

Assumptions

- Peak to average □ = 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)

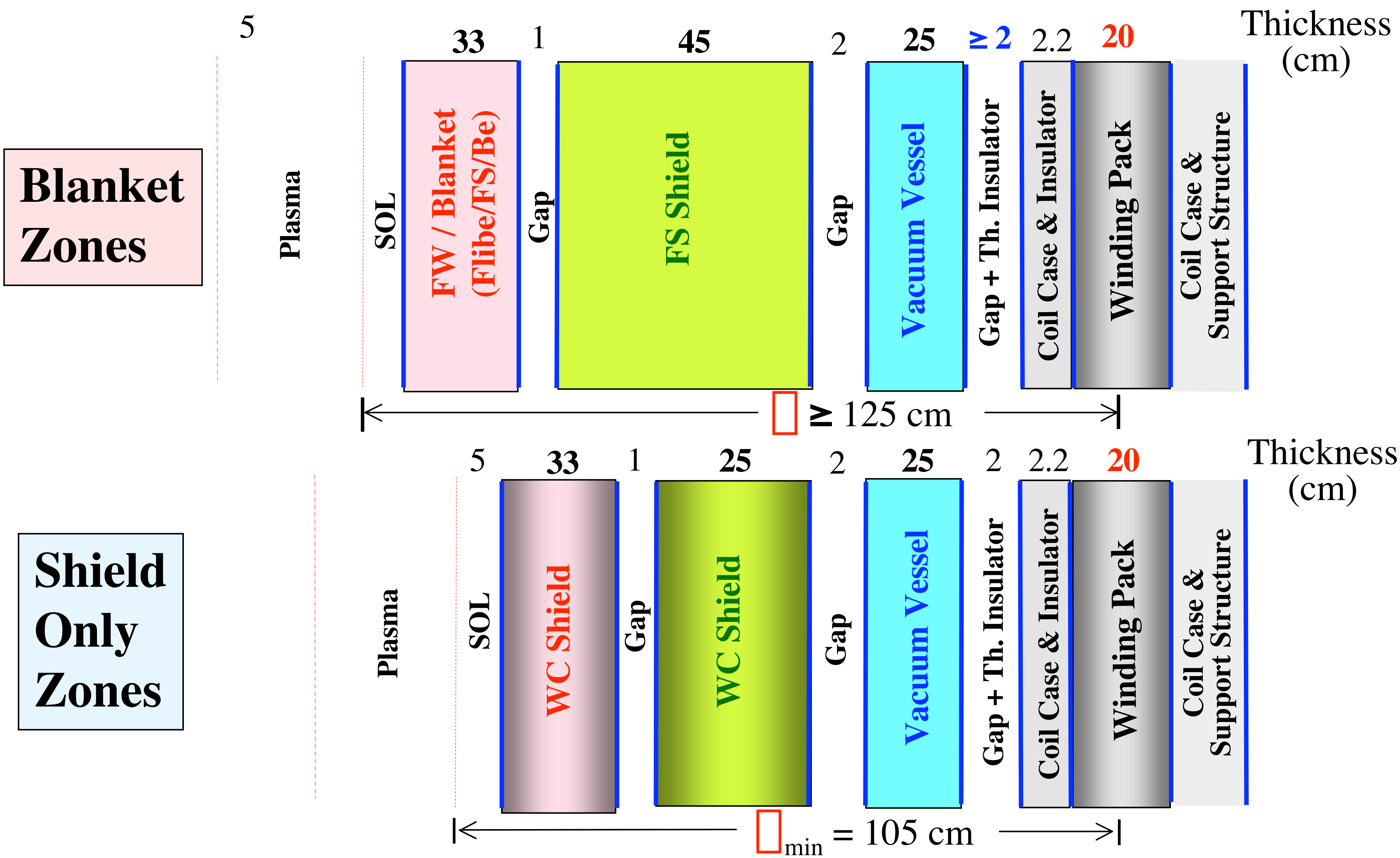


LiPb/SiC System

Components	Composition
Replaceable Blanket-I	79% LiPb with 90% enriched Li 21% SiC/SiC Composite Structure
Permanent Blanket-II	79% LiPb with 90% enriched Li 21% SiC/SiC Composite Structure
FS Shield	15% SiC/SiC Composite Structure 10% LiPb 75% Borated Steel Filler
WC Shield	20% SiC/SiC Composite Structure 10-15% LiPb 65-70% WC Filler
VV	28% FS Structure 49% Water 23% Borated Steel Filler
Winding Pack (Composition not available. Used SPPS')	25% Incoloy Structure 20% Cu Stabilizer 15% Nb_3Sn + Conduit 25% GFF Polyimide 15% LHe

Recommended Flibe/FS Radial Build

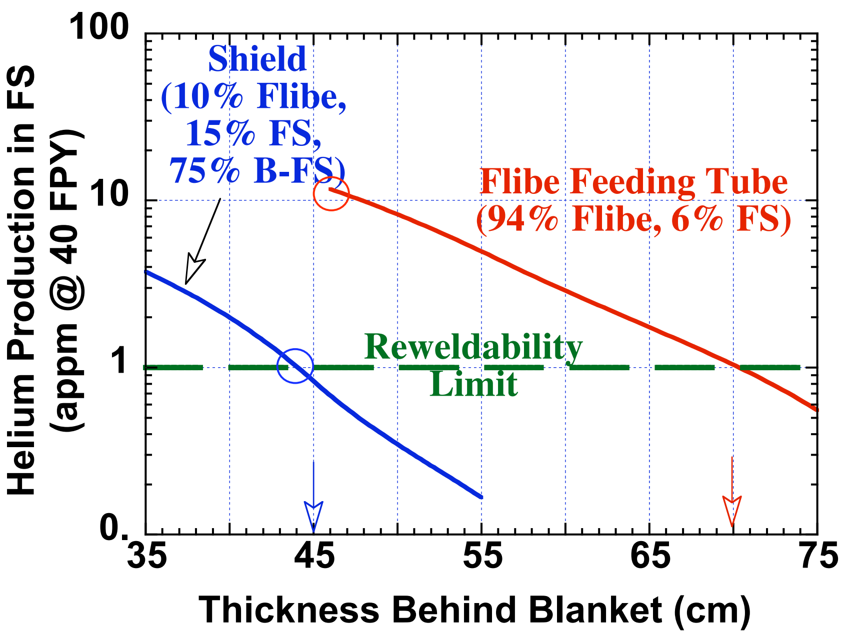
(Schematic; not to scale)

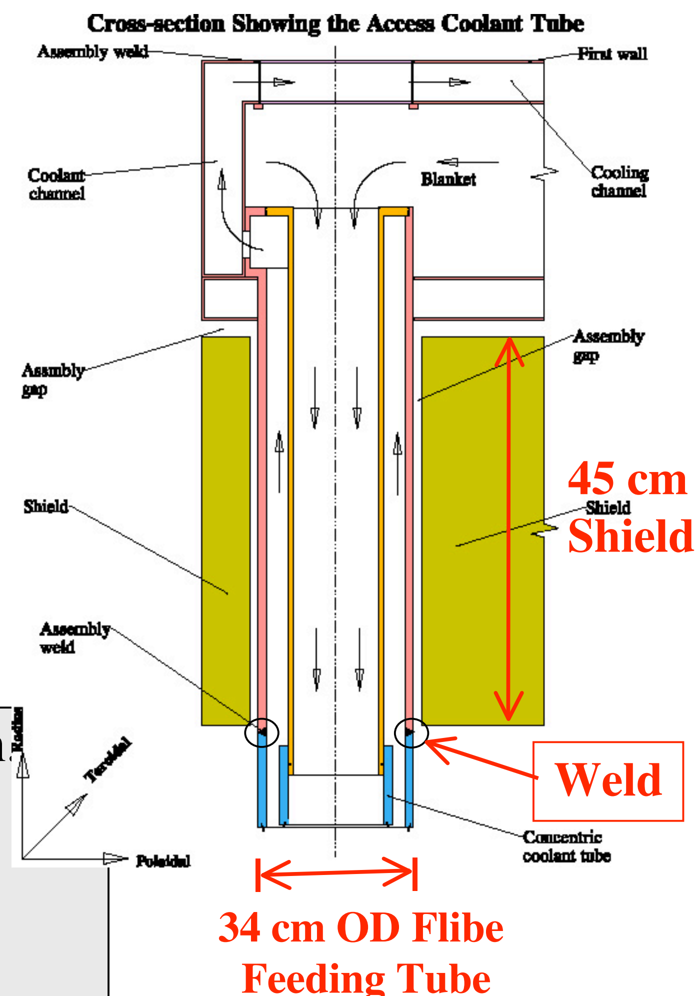


Flibe/FS System Updates

Components	Composition
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% Nb_3Sn + Conduit 25% GFF Polyimide 15% LHe

Excessive Helium Generation at Welds of Flibe Feeding Tube

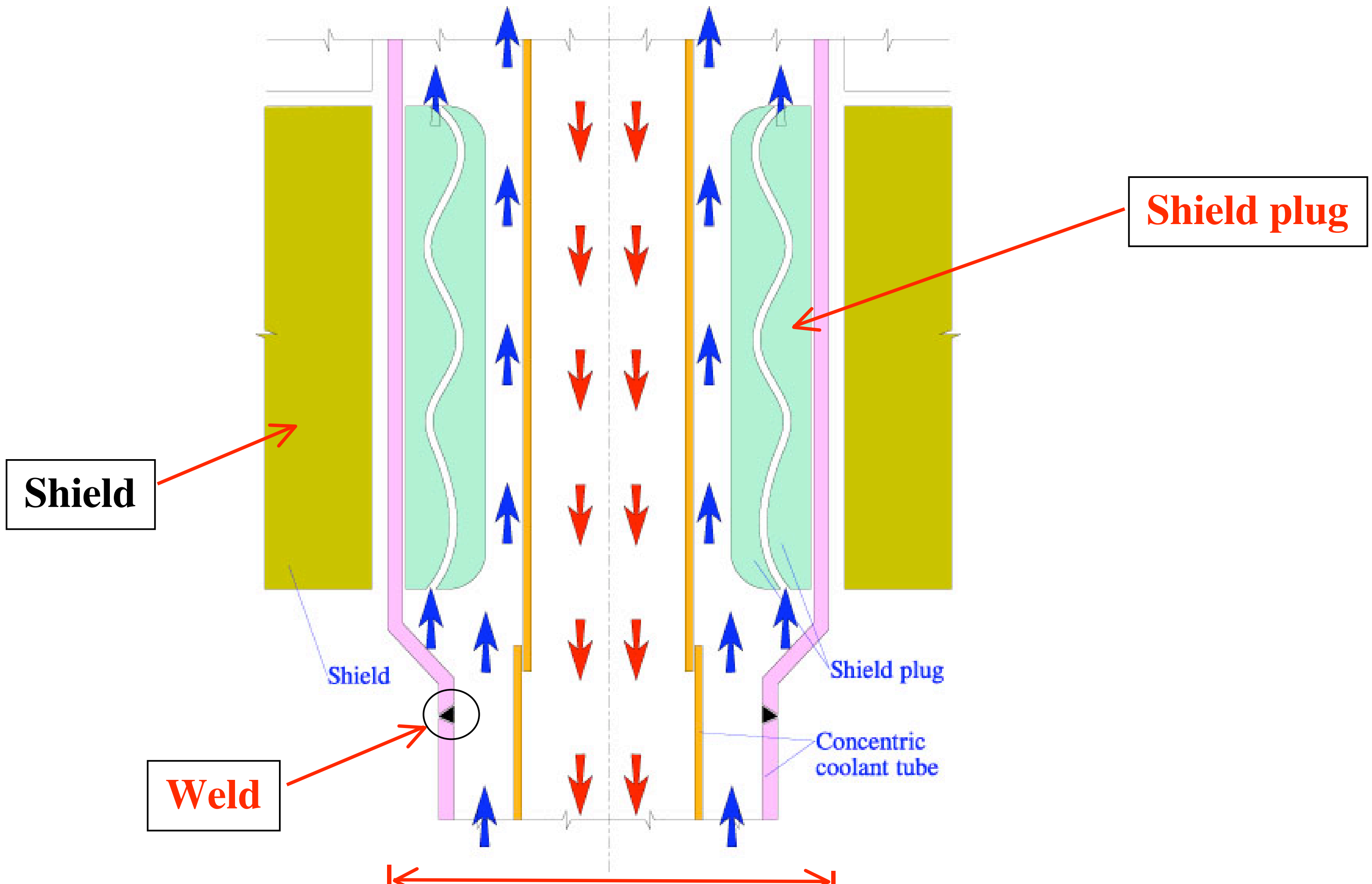




- FS Shield is superior to Flibe in neutron attenuation
- 45 cm Flibe does not allow rewelding of tubes
  - Move welds 25 cm away from back of shield, if design allows

    Or, insert shield plug to protect welds, per Malang.

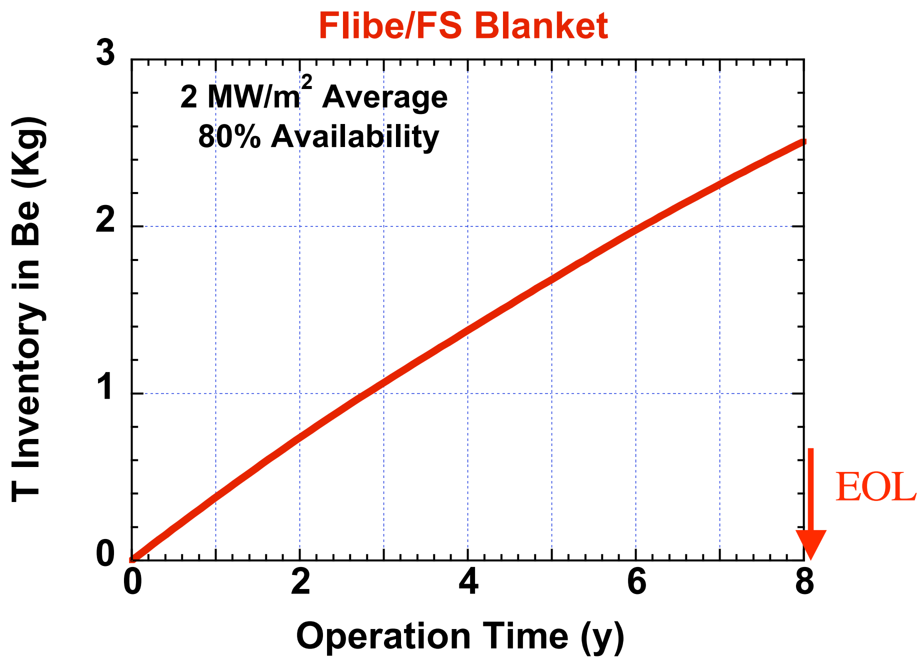
Shield Plug Protects Welds of Feeding Tubes
(Wang's Drawing)



40 cm OD Flibe Feeding Tube

Tritium Bred in Beryllium Raises Safety Concern, Unless Released

<u>Assuming no T release</u>,
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 □

	SPPS	ARIES-CS			
	Li/V	Flibe/FS		LiPb/SiC	
		Blanket and Shield	Shield only	Blanket and Shield	Shield only
Peak □ (MW/m^2)	**2**	**3**	**3**	**3**	**3**
Thickness (cm):					
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			
	Li/V	Flibe/FS		LiPb/SiC	
		Blanket and Shield	Shield only	Blanket and Shield	Shield only
Thickness (cm):					
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
□	**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 !?

# of Modules*	Blanket only	Blanket + WC-Shield
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

	Flibe/FS/Be	LiPb/SiC
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 □ 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 $\square_{min}$ 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, $\square_{min}$ etc)
  - Determine boundary between replaceable and permanent components.
- Reported <u>preliminary</u> nuclear parameters may change as design develops and/or as more rigorous 3-D analyses are performed.

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* Under development at UW.