Radial Build Definition for Modified LiPb/FS/He System with SiC Inserts

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Breeding Blanket Concepts

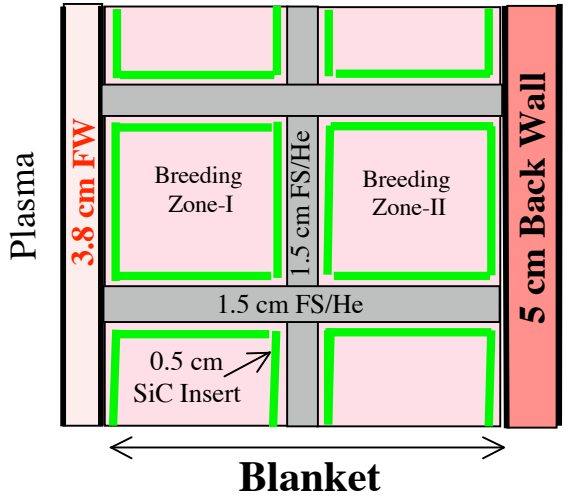
Breeder	Multiplier	Structure	FW/Blanket Coolant	Shield Coolant	VV Coolant
ARIES-CS:					
Internal VV:					
Flibe	Be	FS	Flibe	Flibe	H_2O
LiPb	**–**	**SiC**	**LiPb**	**LiPb**	**H_2O**
LiPb w/o SiC inserts	–	FS	He/LiPb	He	H_2O
new **LiPb w/ SiC inserts**	**–**	**FS**	**He/LiPb**	**He**	**H_2O**
Li_4SiO_4	Be	FS	He	He	H_2O
External VV:					
LiPb*	–	FS	He/LiPb	He or H_2O	He
Li	–	FS	He/Li	He	He
SPPS:					
External VV:					
Li	–	V	Li	Li	He

Selected for detailed analysis

Modified LiPb/FS/He Blanket Proposed by Malang/Raffray

Main features:

- 0.5 cm thick SiC inserts lining FS structure and serving as thermal and electric insulator
- Cooling channels between breeding zones
- Radial depth of breeding zone ≤ 30 cm
- 5 cm minimum thickness of back wall, not 9 cm
- 3.8 cm thick FW, not 4.8 cm
- More He and FS structure
- Less LiPb breeder.



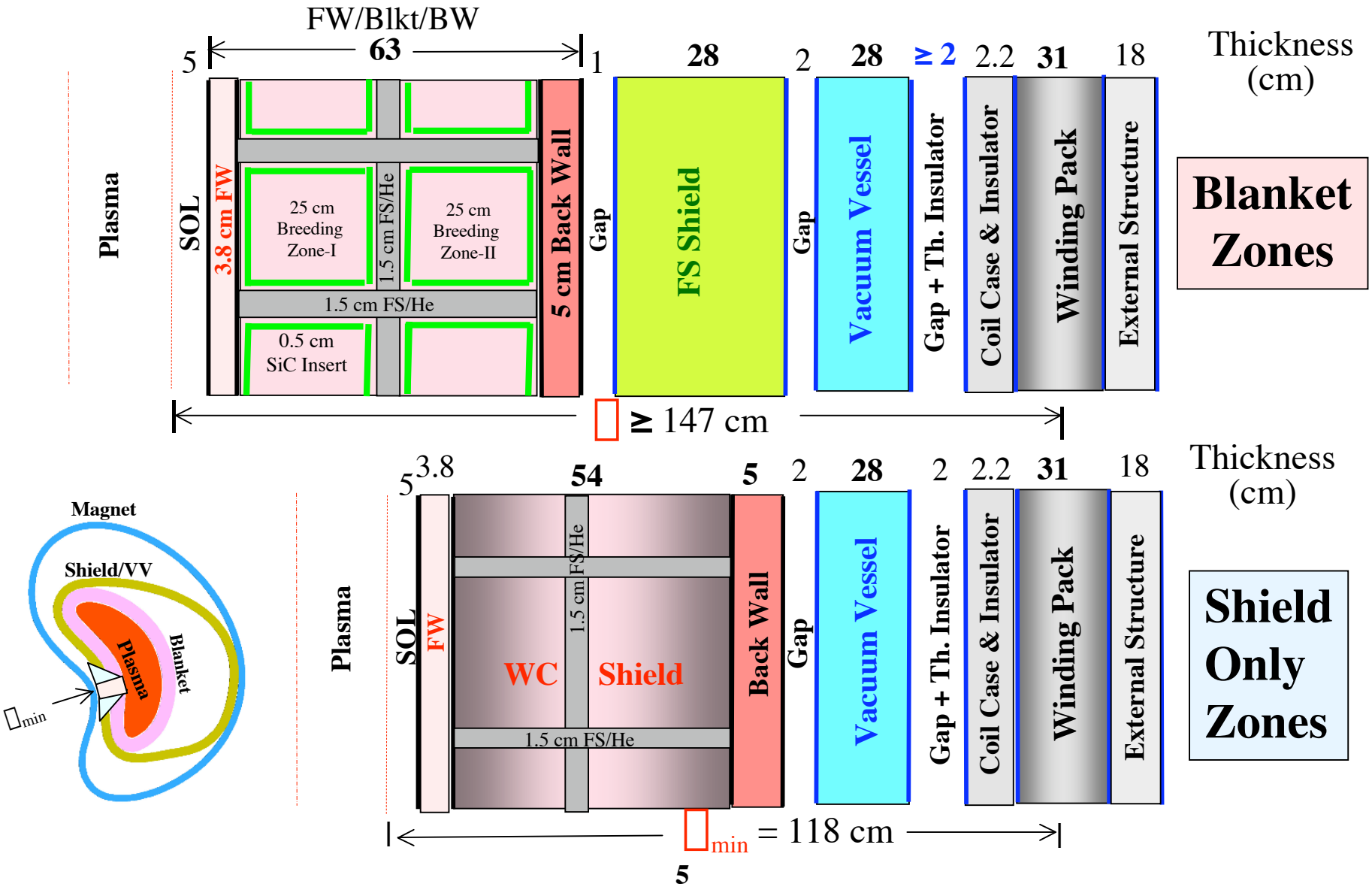
Blanket Composition:	**Old**	**New**
	90% LiPb	79% LiPb
	--- SiC Inserts	7% SiC Inserts
	3% FS Structure	6% FS Structure
	7% He Coolant	8% He Coolant

LiPb /FS/He Radial Build has been Modified Using Same Design Basis

- **3 MW/m^2 peak** neutron wall loading.
- 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 zones, 5 cm thick divertor plates/baffles covering 15% of FW area.
- ≤ 1% nuclear heating in LT shield and/or VV.
- Shield, VV, and magnet are lifetime components
- **Radiation limits** to structural components:
  - 3% burnup to SiC/SiC composites
  - 200 dpa to FS
  - 1 He appm @ VV.
- Radiation limits to MT S/C magnet (same fluence as for LT S/C):
  - 10^{19} n/cm^2 fast n fluence
  - 5 mW/cm^3 local nuclear heating*
  - 10^{11} rads dose to GFF polyimide
  - $6x10^{-3}$ dpa to Cu stabilizer
  - 50 kW total nuclear heating.

* Dec 03 ARIES meeting, Bromberg's presentation, Page 20.

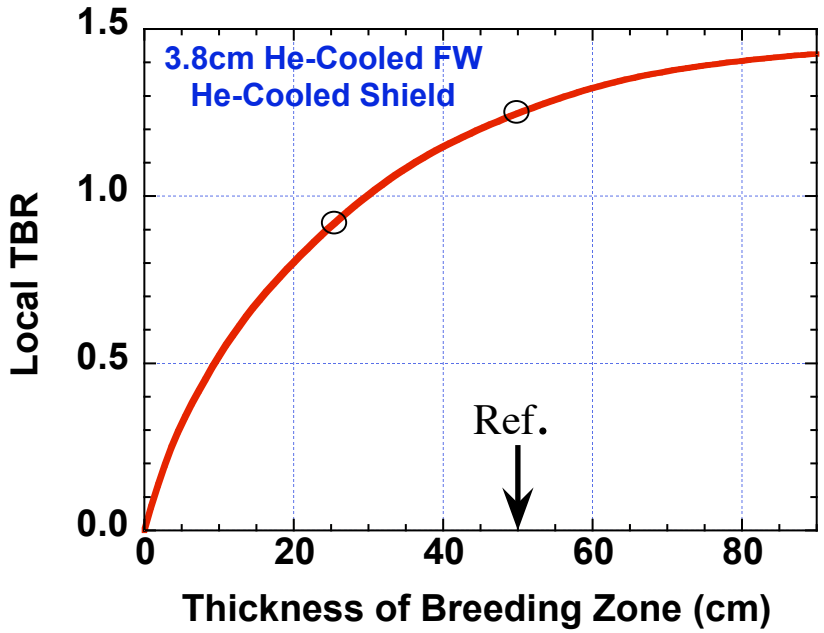
Modified LiPb/FS/He Radial Build
(Water-Cooled **Internal** VV)



LiPb/FS/He Composition

Component	Composition
FW (3.8 cm)	34% FS Structure 66% He Coolant
Blanket (54.3 cm)	79% LiPb with 90% enriched Li 7% SiC Inserts 6% FS Structure 8% He Coolant
Back Wall (5 cm)	80% FS Structure 20% He Coolant
WC Shield	86% WC Filler 6% FS Structure 8% He Coolant
FS Shield	15% FS Structure 10% He Coolant 75% Borated Steel Filler
VV	28% FS Structure 49% **Water** 23% Borated Steel Filler

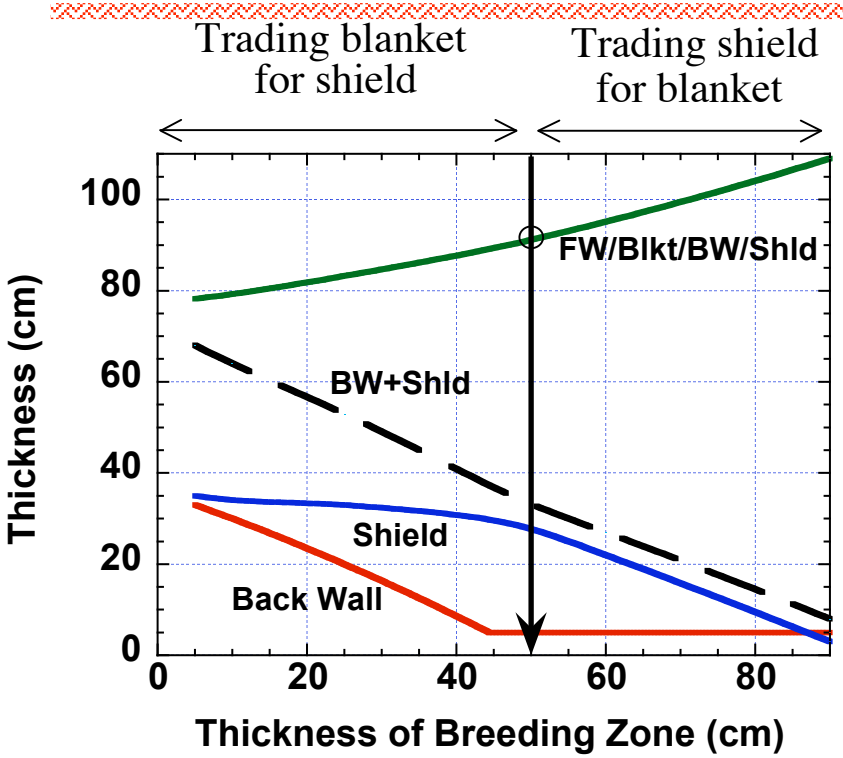
Tritium Breeding Capability

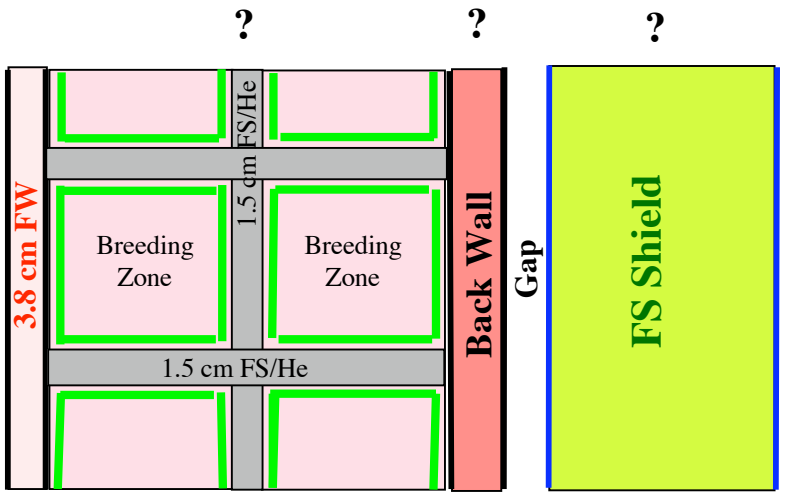


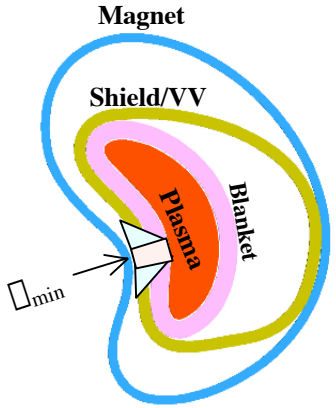
Breeding zone-I provides 70% of TBR

Blanket has 10% excess breeding margin

Blanket/Shield Tradeoff for Area Surrounding θ_{min}







- Shield offers better protection than blanket.
- Trading blanket for shield decreases radial build.
- Trading shield for blanket increases radial build.
- **Recommendations** for blanket zones surrounding θ_{min}:
  - Install Breeding Zone-I everywhere to enhance breeding
  - Vary Breeding Zone-II gradually from 0 to 25 cm.

Nominal Radial Distance Varies within 7 cm

(Blanket/Shield Dimensions for CAD Drawings)

Δ (m)

ARIES-CS:

Internal VV:	**Blanket/Shield/VV/Gaps**	**Plasma – Mid Coil**
Flibe/FS/Be	1.07 (min)	1.32 (min)
LiPb/SiC	**1.15**	**1.40**
LiPb/FS/He w/o SiC inserts	1.24	1.49
new **LiPb/FS/He w/ SiC inserts**	**1.22**	**1.47**
Li_4SiO_4/Be/FS/He	**1.30** (max)	**1.55** (max)

External VV:	**Blanket/Shield/Gaps**	
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.

Minimum Radial Distance Varies within 4 cm

(ρ_{min} for Systems Code Analysis)

		ρ_{min} (m)		
ARIES-CS:				
Internal VV:		**WC-Shield/VV/Gaps**		**Plasma – Mid Coil**
	Flibe/FS/Be	0.86	(min)	1.11 (min)
	LiPb/SiC	**0.89**		**1.14**
	LiPb/FS/He w/o SiC inserts	0.93		1.18
new	**LiPb/FS/He w/ SiC inserts**	**0.93**		**1.18**
	Li_4SiO_4/Be/FS/He	1.04	(max)	1.29 (max)
External VV:		**WC-Shield/Gaps**		
	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	–		–

4 cm difference in ρ_{min} translates into ~25 cm change in R

Key Parameters for System Analysis (3 FP Configuration)

	Flibe/FS/Be	LiPb/SiC	SB/FS/Be*	LiPb/FS (w/o SiC inserts)	LiPb/FS (w/ SiC inserts)	Li/FS
η_{min}	1.11	1.14	1.29	1.18	1.18	1.16
TBR	1.1	1.1	1.1	1.1	1.1	1.1
Energy Multiplication (M_n)	1.2	1.1	1.3	1.15	1.14	1.13
Thermal Efficiency (η_{th})	45%	55-60%	45%	~ 45%	~ 45%	~ 45%
FW Lifetime (FPY)	6.5	6	4.4	5	5	7
FW EOL Fluence (MWy/m^2)	20	18	20	15	15	21
# of Blanket Replacements	6	6	9	7	7	5
System Availability	~ 85%	~ 85%	~ 85%	~ 85%	~ 85%	~ 85%

* Evaluated at 4.5 MW/m^2 peak n wall loading.

System analysis will assess impact of η_{min}, M_n and η_{th} on COE

Reference
Radial Builds and Compositions

Modified LiPb/FS/He system will be added to Reference Radial Build Document posted @

http://fti.neep.wisc.edu/aries/builds.pdf

It's updated frequently
to reflect latest changes to nuclear parameters
and dimensions/compositions of
ARIES-CS components
(FW, blanket, shield, VV, and magnet)

Conclusions

- Modified LiPb/FS/He system with SiC inserts results in:
  - No change to $\square_{min}$
  - 2 cm reduction in $\square_{nominal}$
  - Slight change to blanket/shield composition
- Two breeding zones (25 cm each) provide adequate breeding for 3 FP configuration.
- For 2 FP configuration, uniform blanket must be installed everywhere to meet breeding requirement (no shield-only zones). Blanket dimension will be determined.

Future Plan

- Redo blanket/shield tradeoff study for WC shield surrounding $\square_{min}$.
- Provide nuclear heating for detailed thermal analysis.
- Provide split between LiPb and He heat loads.
- Update new magnet model for shielding analysis.
- Generate decay heat for WC-shield only zones.
- Develop radial build for 2 FP configuration.
- Incorporate reviewers' comments and submit TOFE papers for publication in FS&T:

  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- **Initial Activation Assessment for ARIES Compact Stellarator Power Plant**

  L. El-Guebaly, P. Wilson, D. Paige and the ARIES Team

  3- **Views on Neutronics and Activation Issues Facing Thick Liquid-Protected IFE Chambers**

  L. El-Guebaly and the ARIES Team.

- Modify manuscript and submit **full paper** to FS&T:

  Evolution of Clearance Standards and Implications for Radwaste Management of Fusion Power Plants

  L. El-Guebaly, P. Wilson, D. Paige and the ARIES Team.