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

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Objectives

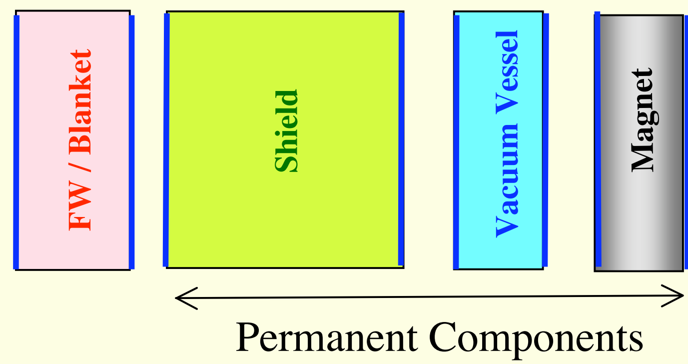
- Define radial builds for proposed blanket concepts.
- Propose innovative shielding approach that minimizes radial standoff.
- Assess implications of new approach on:
  - Radial build
  - Tritium breeding
  - Machine size
  - Complexity
  - Safety
  - Economics.

Background

- Minimum radial standoff controls COE, unique feature for stellarators.
- Compact radial build means smaller R and lower B_{max}

  $\Rightarrow$ smaller machine and lower cost.

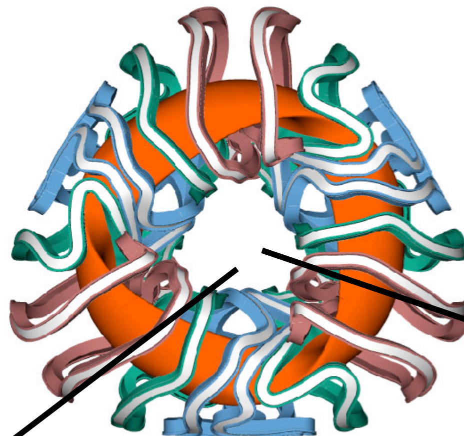
- All components provide shielding function:
  - Blanket protects shield
  - Blanket & shield protect VV
  - Blanket, shield & VV protect magnets

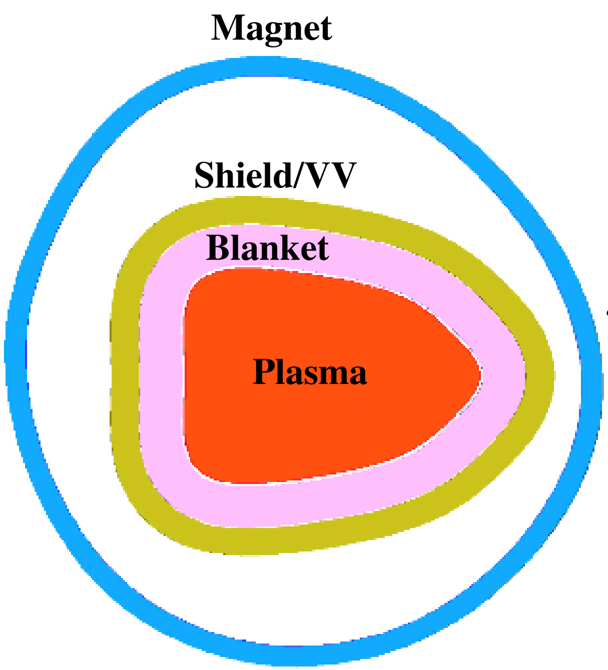


- Blanket offers less shielding performance than shield.
- Could design tolerate shield-only at Δ_{min} (no blanket)?
- What would be the impact on T breeding, overall size, and economics?

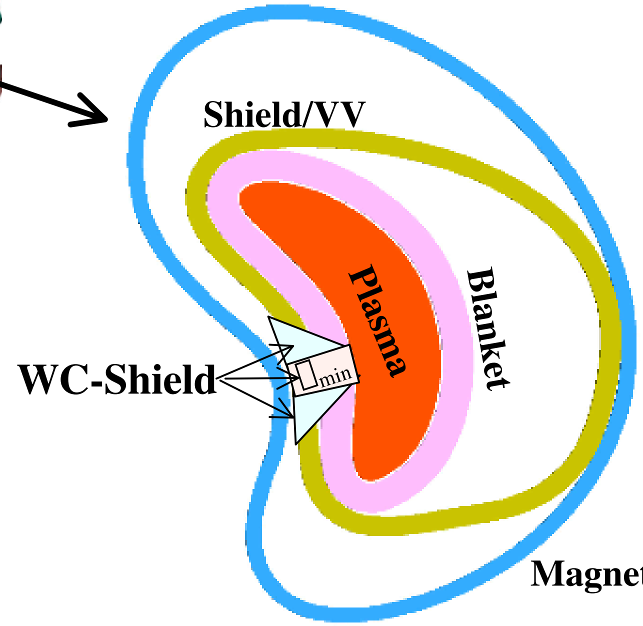
New Approach for Blanket & Shield Arrangement

ARIES-CS Plasma and Coils





3 FP Configuration



Xn through nominal blanket & shield

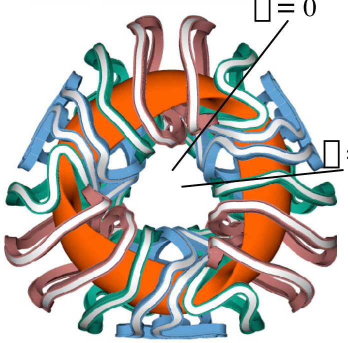
Xn at $\square_{min}$
(magnet moves closer to plasma)

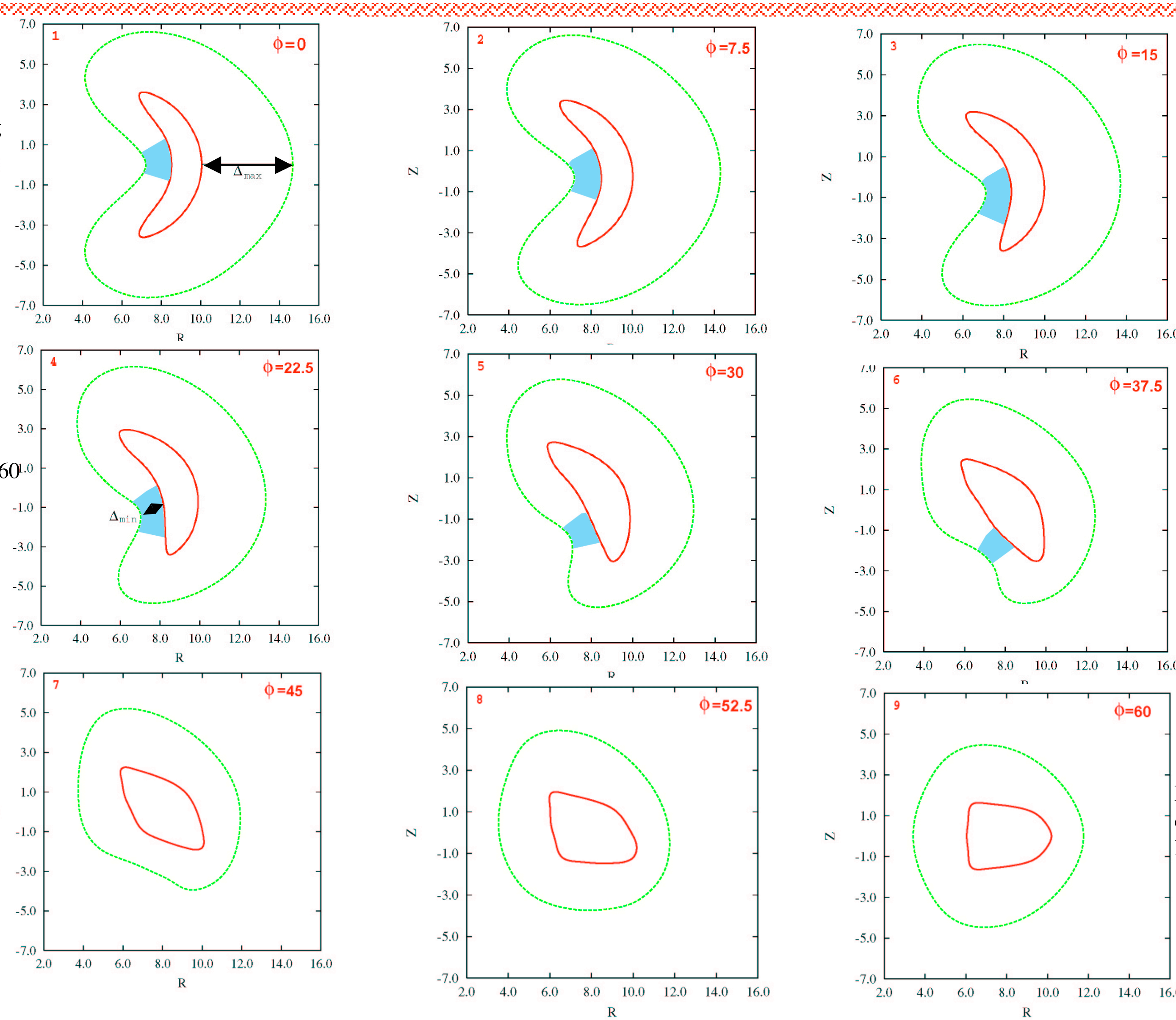
Shield-only Zone Covers ~8% of FW Area

3 FP Configuration

Beginning of Field Period

ARIES-CS Plasma and Coils





Middle of Field Period

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*	–	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

* With or without SiC inserts.

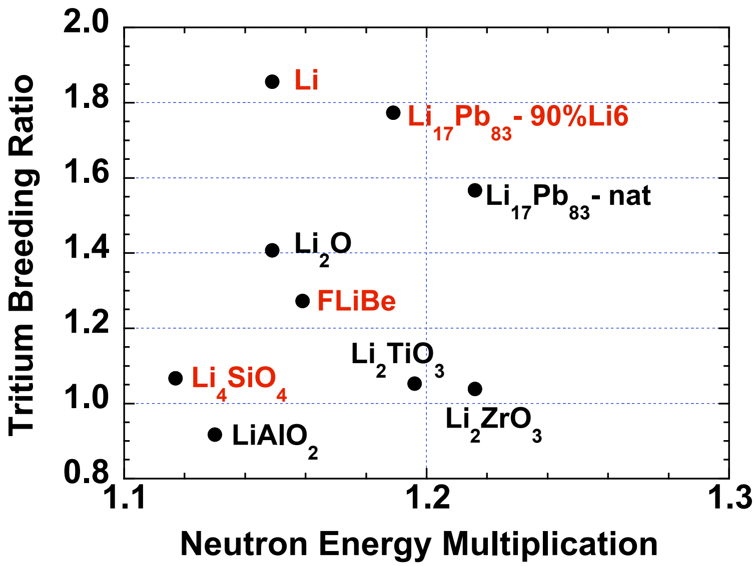
Radial Builds have been Defined Using Same Design Criteria

Peak n Wall Loading	3*	MW/m^2
Overall TBR (for T self-sufficiency)	1.1	
Damage Structure (for structural integrity)	200 3%	dpa - advanced FS burn up - SiC
Helium Production @ VV (for reweldability of FS)	1	appm
HT S/C Magnet (@ 15 K):		
Fast n **fluence** to Nb_3Sn (E_n > 0.1 MeV)	10^{19}	n/cm^2
Nuclear **heating**	5	mW/cm^3
Dose to polyimide insulator	10^{11}	rads
dpa to Cu stabilizer	$6x10^{-3}$	dpa
Machine Lifetime	40	FPY
Availability	85%	

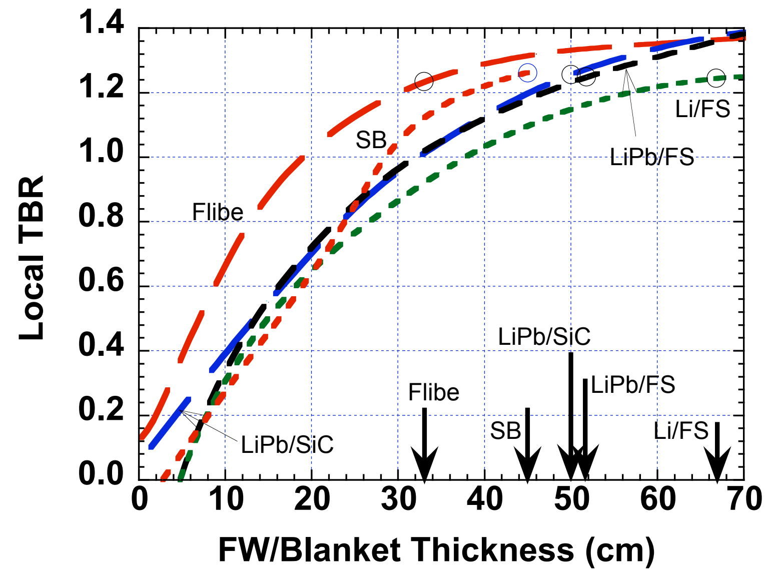
* 4.5 MW/m^2 for solid breeder concept.

Breeding Performance

Thick blanket; no structure; no multiplier



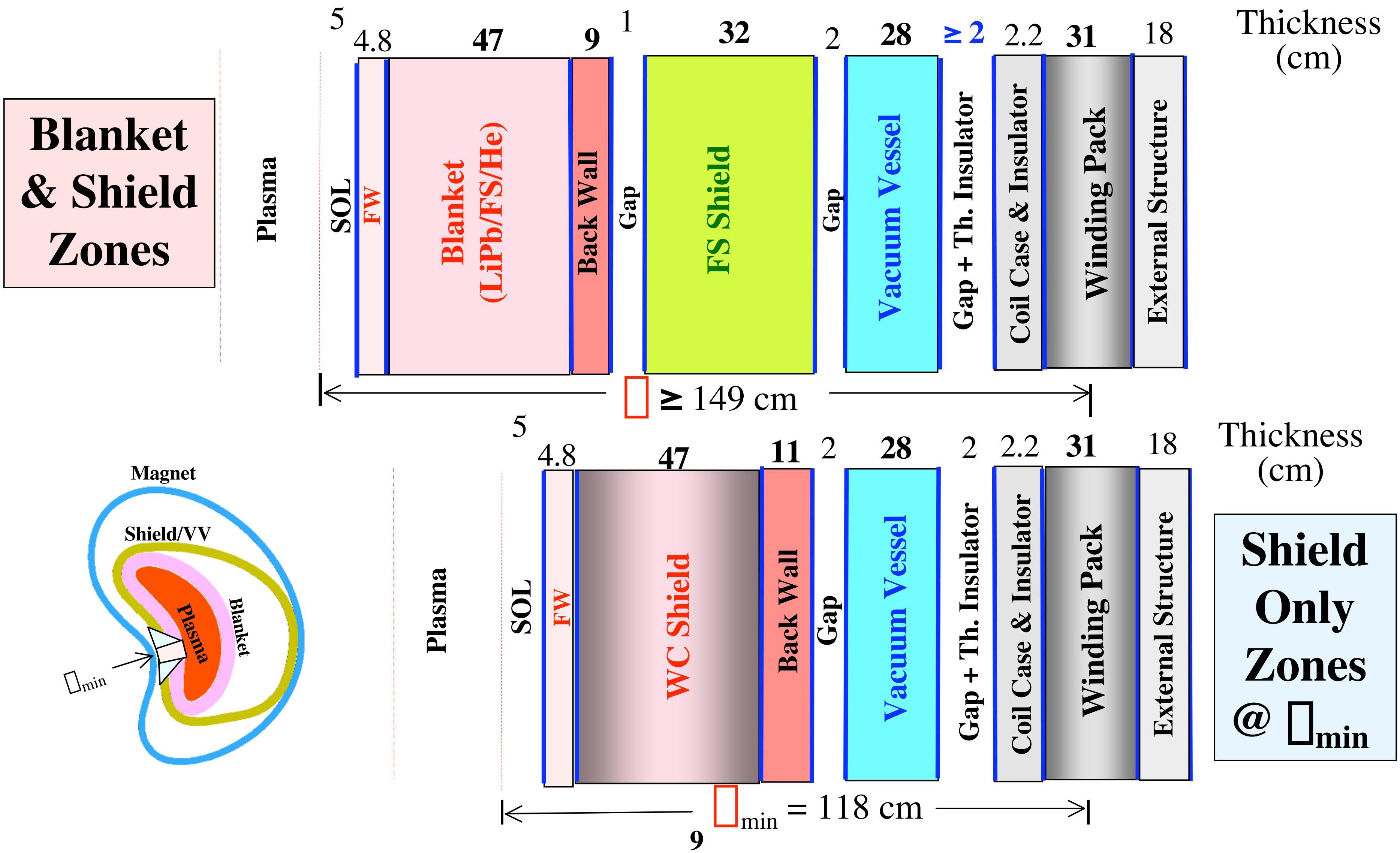
Actual Design



- Local TBR approaches 1.25.
- Blankets sized to provide 1.1 overall TBR based on 1-D analysis combined with blanket coverage fraction.
- 3-D analysis should confirm key parameters.

Representative Radial Build

(LiPb/FS/He System; Internal VV)



Nominal Radial Standoff Varies Widely with Blanket Concept

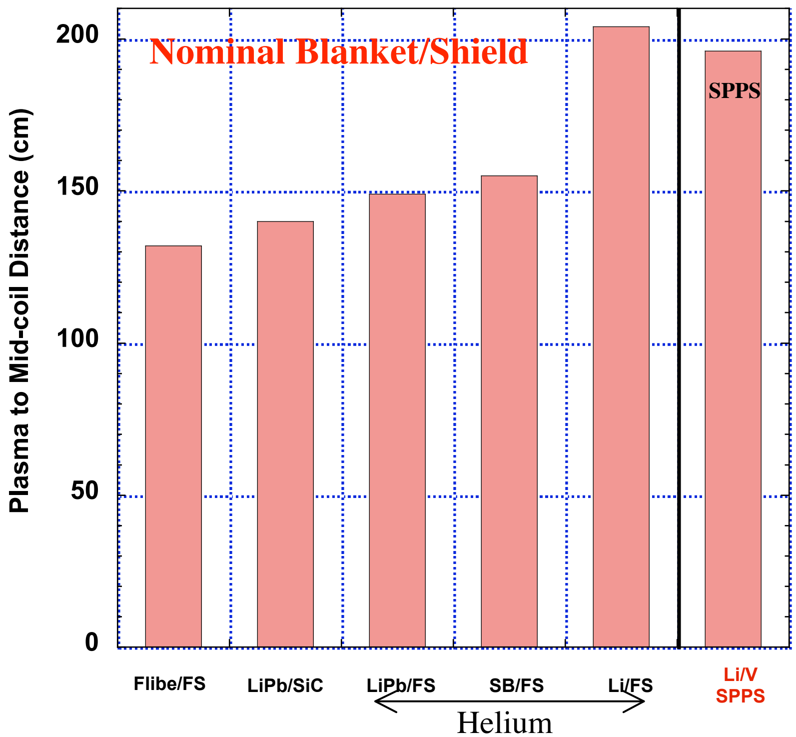
		Δ (m)
ARIES-CS:		
Internal VV:	**Blanket/Shield/VV/Gaps**	**Plasma – Mid Coil**
Flibe/FS/Be	**1.07** (min)	**1.32** (min)
LiPb/SiC	1.15	1.40
LiPb/FS/He	1.24	1.49
Li_4SiO_4/Be/FS/He	1.30 (max)	1.55 (max)
External VV:	**Blanket/Shield/Gaps**	
LiPb/FS/He/H_2O	1.22	1.47
LiPb/FS/He	1.60	1.85
Li/FS/He	1.79 (max)	2.04 (max)
SPPS*:		
External VV:		
Li/V	1.20	1.96

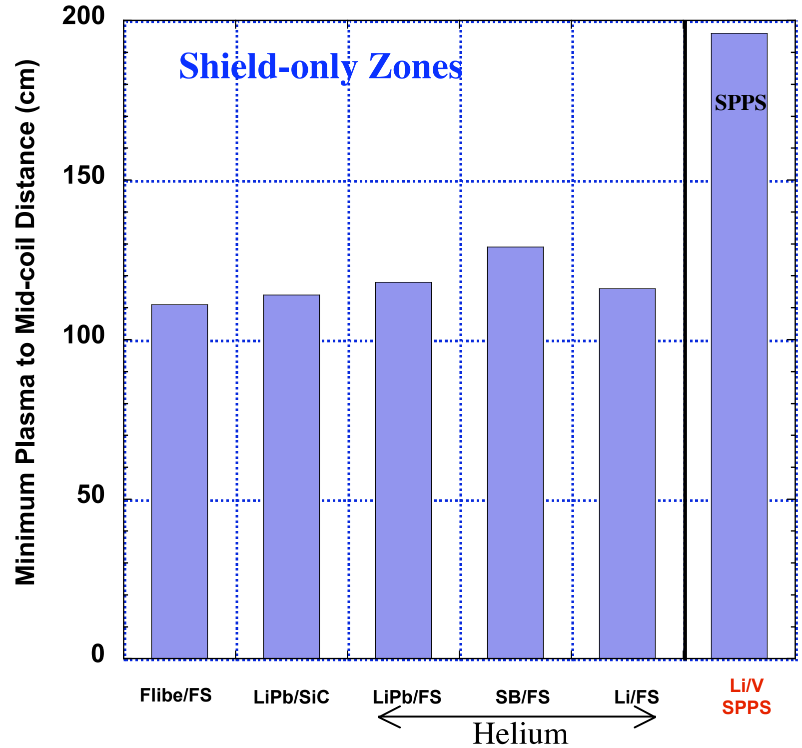
* 15 cm SOL, 36 cm half winding pack, 15 cm thick cryostat, and 8 cm wide shield-magnet gap.

Δ_{min} Varies within 20 cm with blanket Concept

		Δ_{min} (m)
ARIES-CS:		
Internal VV:	**WC-Shield/VV**	**Plasma – Mid Coil**
Flibe/FS/Be	0.86 (min)	1.11 (min)
LiPb/SiC	0.89	1.14
LiPb/FS/He	0.93	1.18
Li_4SiO_4/Be/FS/He	1.04 (max)	1.29 (max)
External VV:	**WC-Shield**	
LiPb/FS/He/H_2O	0.95	1.20
LiPb/FS/He	0.93	1.18
Li/FS/He	0.91	1.16
SPPS:		
External VV:		
Li/V	–	–

Comparison Between Radial Builds





- **Flibe** system offers most compact radial build, but Be raises safety and economic concerns.
- **He coolant** occupies 10-30 cm of radial standoff.
- **Water** is effective shielding material for VV
  - avoid breeders incompatible with water (such as Li).

New Shielding Approach Introduces Design Issues

- **Benefits**:
  - Compact radial standoff
  - Small R and low B_{max}
  - Low COE.

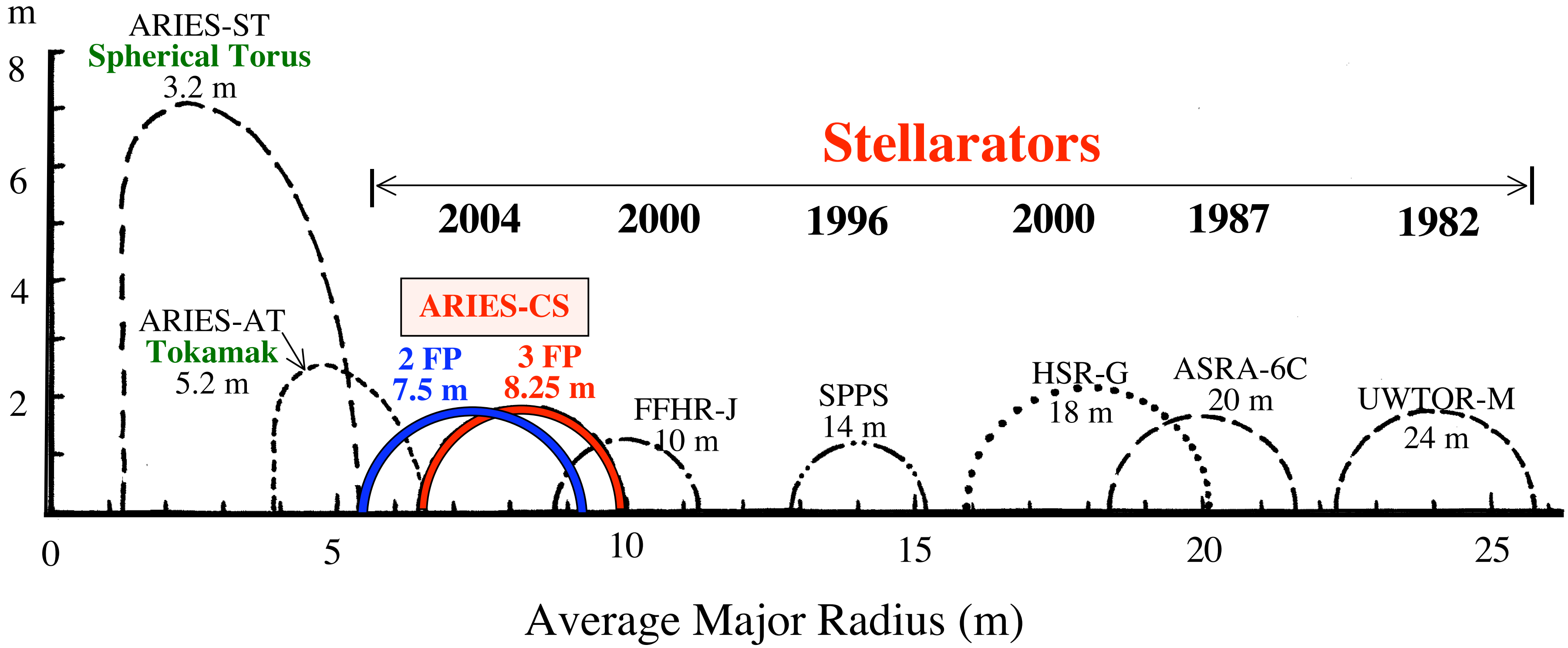
- **Challenges** (to be addressed in Phase II of study):
  - Integration of shield-only zones with surrounding blanket.
  - Incorporation of decay heat removal loop for WC-shield.
  - Handling of massive WC-shield during maintenance.

Key Parameters for System Analysis

	Flibe/FS/Be	LiPb/SiC	LiPb/FS	SB/FS/Be	Li/FS
$\square_{min}$	1.11	1.14	1.18	1.29	1.16
Overall TBR	1.1	1.1	1.1	1.1	1.1
Energy Multiplication (M_n)	1.2	1.1	1.15	1.3	1.13
Thermal Efficiency ($\square_{th}$)	~45%	55-60%	~45%	~45%	~45%
FW Lifetime (FPY)	6.5	6	5	4.4	7
System Availability	~85%	~85%	~85%	~85%	~85%

Integrated system analysis will assess impact of $\square_{min}$, M_n, and $\square_{th}$ on COE

Well Optimized Radial Build Contributed to Compactness of ARIES-CS



Major radius more than halved by advanced physics and technology, dropping from 24 m for UWTOR-M to 7-8 m for ARIES-CS and approaching R of advanced tokamaks.

Conclusions

- Innovative shielding approach has been developed for ARIES-CS.
- Combination of shield-only zones and non-uniform blanket represents best option for ARIES-CS.
- Solutions for challenges facing proposed shielding approach will be developed in Phase-II of study.
- Means of dimension control along with advances in physics and technology helped ARIES-CS achieve the compactness that other stellarators had not been able to achieve before.
- Positive trends in physics and engineering position compact stellarators for bright future.

Companion Presentations

Poster on Wednesday @ 1:30 - 3:30 PM:

Initial Activation Assessment for ARIES Compact Stellarator Power Plant

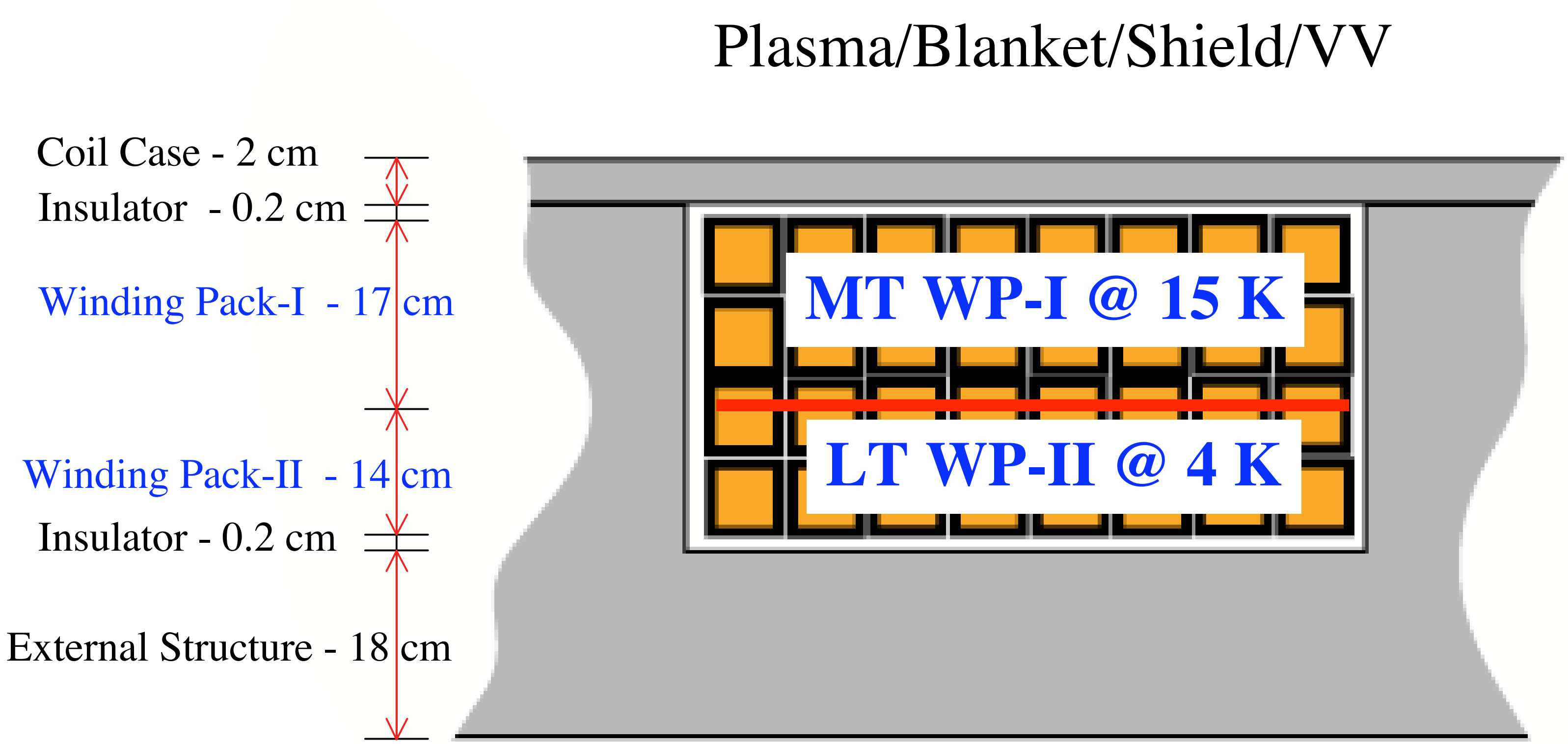
L. El-Guebaly, P. Wilson, D. Paige and the ARIES Team

Oral on Tuesday @ 10:30 - 12 AM:

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

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

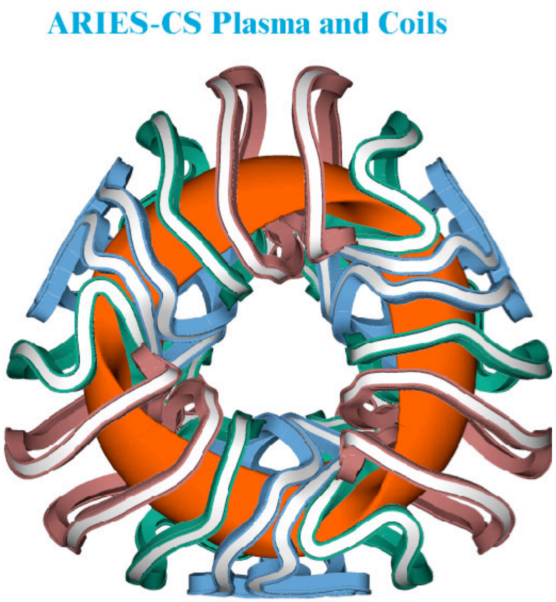
Magnet Design

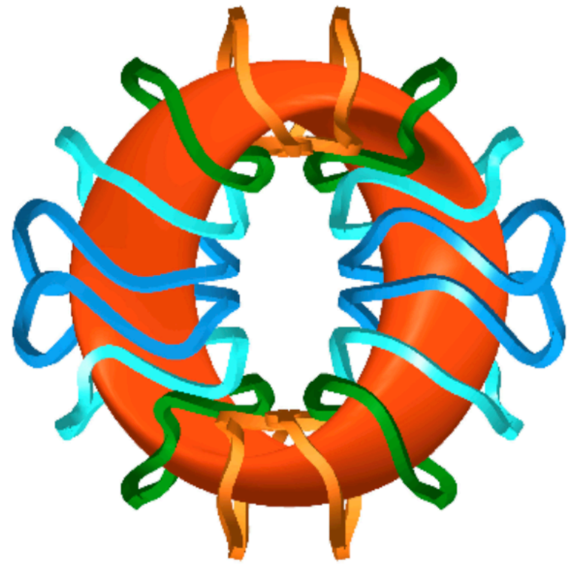


Magnet Homogeneous Composition:
- 45% 316-SS (gray)
- 50% winding packs (orange/black)
- 5% GFF polyimide (white)

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.





3 FP Configuration
R = 8.25 m
a = 1.85 m

2 FP Configuration
R = 7.5 m
a = 2 m

LiPb/FS/He Composition

Component	Composition
FW	31% FS Structure 69% He Coolant
Blanket#	90% LiPb with 90% enriched Li 3% FS Structure 7% He Coolant
Back Wall	80% FS Structure 20% He Coolant
WC Shield*	90% WC Filler 3% FS Structure 7% He Coolant
FS Shield	15% FS Structure 10% He Coolant 75% Borated Steel Filler
VV	28% FS Structure 49% **Water** 23% Borated Steel Filler

Without SiC inserts.

* FS and He contents will be adjusted later.