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.

Nominal Blanket and Shield

(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	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.

Minimum Radial Distance Δ_{min}

(for Systems Code Analysis)

		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	–	–

Key Parameters for System Analysis (3 FP Configuration)

	Flibe/FS/Be	LiPb/SiC	LiPb/FS	SB/FS/Be	Li/FS
Δ_{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 (η_{th})	~45%	55-60%	~45%	~45%	~45%
FW Lifetime (FPY)	6.5	6	5	4.4	7
System Availability	~85%	~85%	~85%	~85%	~85%

Radial Builds have been Defined on Same Design Basis

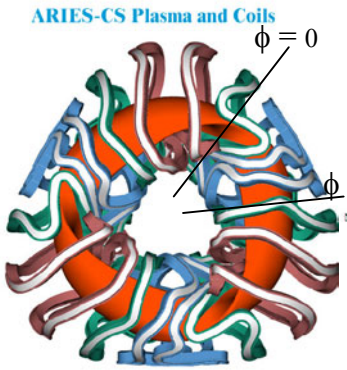
- **3 MW/m^2 peak** and **2 MW/m^2 average** neutron wall loadings for all designs, except for solid breeder concept (4.5 MW/m^2 peak Γ).
- **5 cm SOL** and **2 cm** minimum VV-magnet **gap**.
- **2 cm** thick inner **coil case**.
- **31 cm thick winding packs-I/II**.
- **1.1 overall TBR for 3 FP configuration** based on 92% uniform-blanket coverage fraction, 8% shield-only zones, 5 cm thick divertor plates/baffles (50/50 FS/He) covering 15% of FW area.
- **2 FP configuration** may require blanket everywhere (no shield-only zones).
- **≤ 1% nuclear heating in LT shield and/or VV**.
- Shield, VV, and magnet are permanent components.
- **Radiation limits to structural components**:
  - 3% burnup to SiC/SiC composites
  - 200 dpa to FS
  - 1 He appm @ VV.
- **Radiation limits for S/C magnet:**
  - 10^{19} n/cm^2 fast n fluence (E_n > 0.1 MeV)
  - 5 mW/cm^3 peak nuclear heating
  - 10^{11} rads dose to GFF polyimide
  - $6x10^{-3}$ dpa to Cu stabilizer
- Boundary between WC-shield and back wall will be adjusted to meet design requirements.

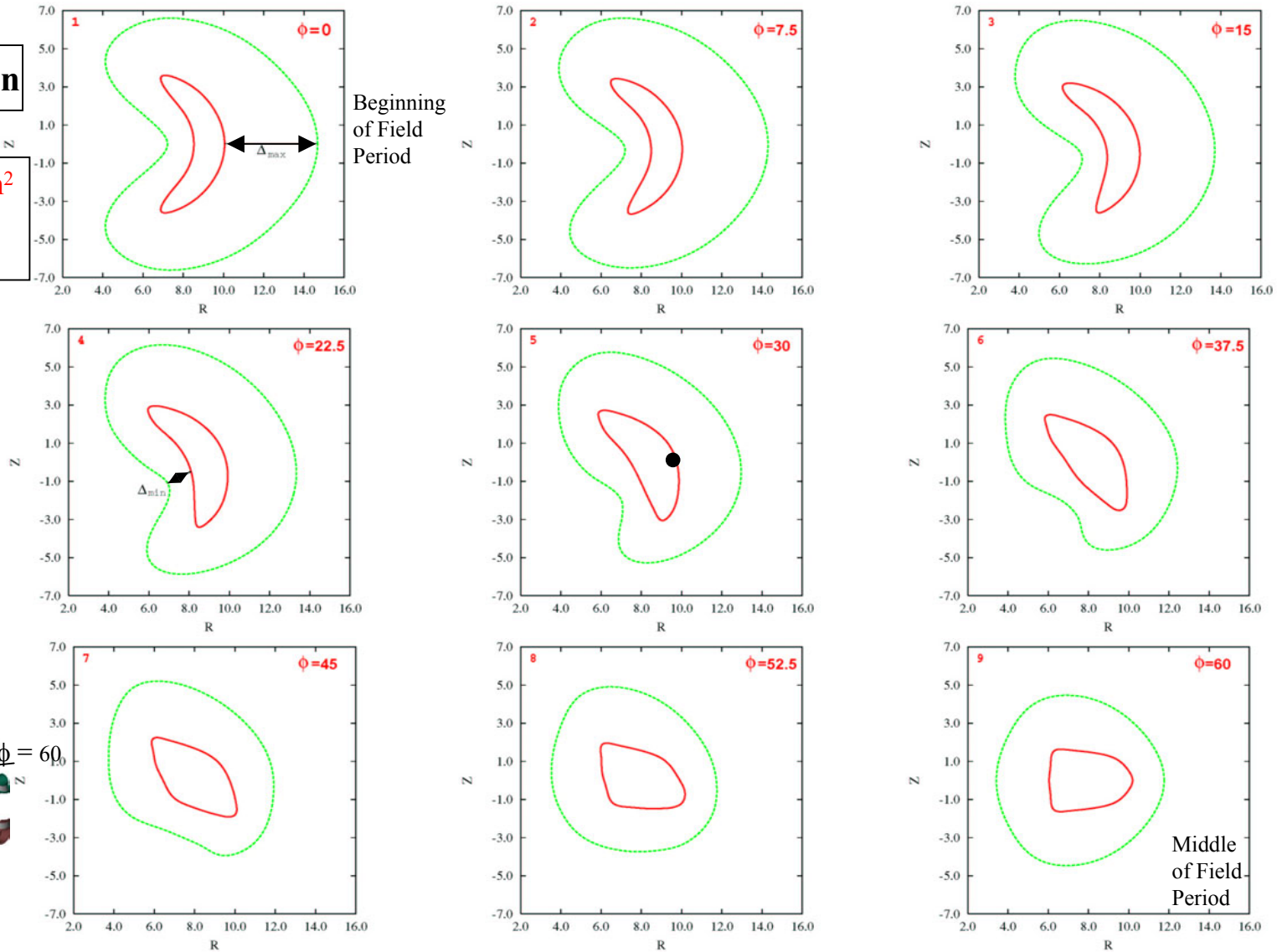
9 Xns of Plasma Boundary (red) and WP Center (green) Covering 1/2 Field Period (~9 m)

3 FP Configuration

Γ peaks @ ~3 MW/m^2 at OB midplane of Φ = 30^o Xn

Δ_{min} = 1.2 m





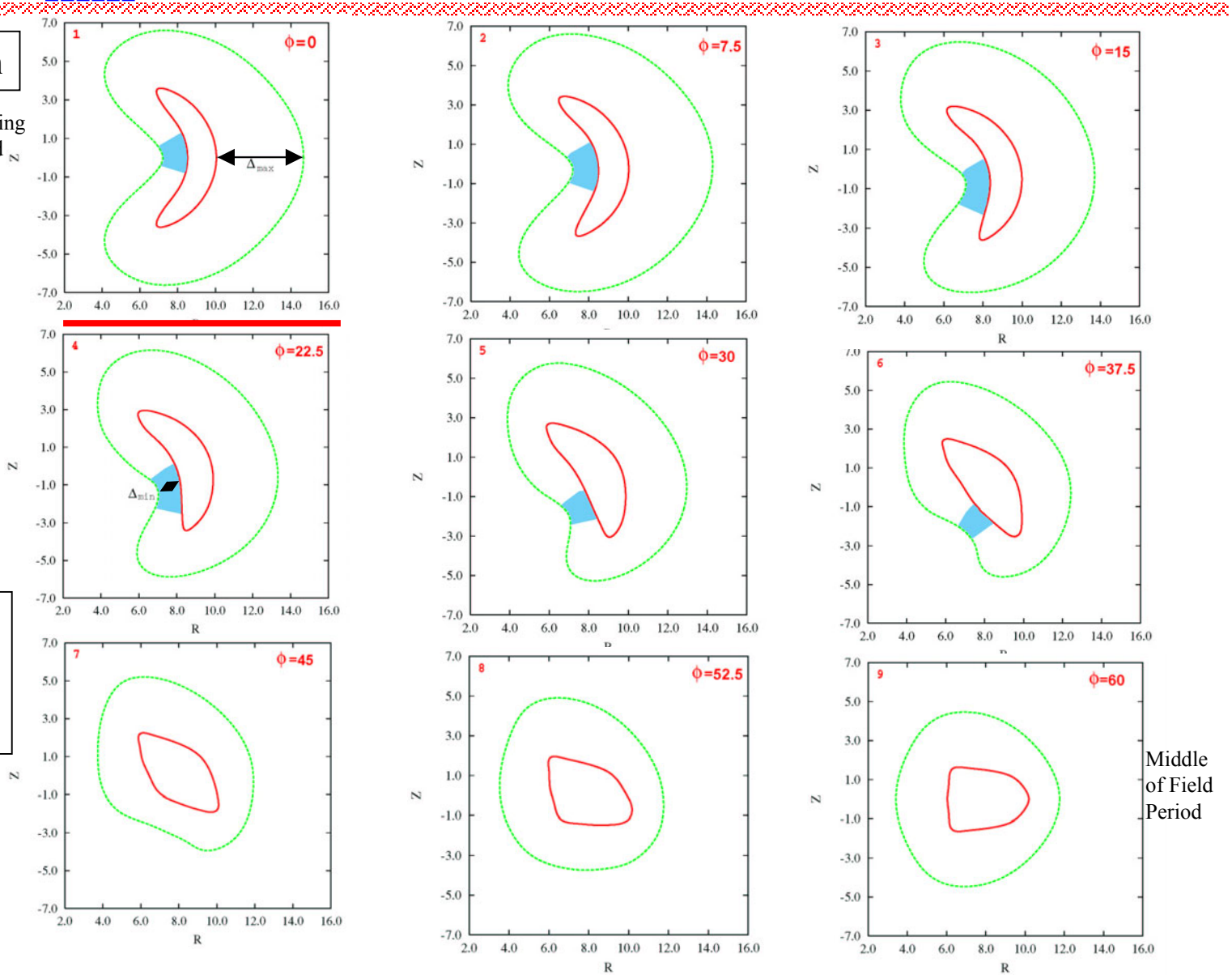
Beginning of Field Period

Middle of Field Period

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

3 FP Configuration

Beginning of Field Period

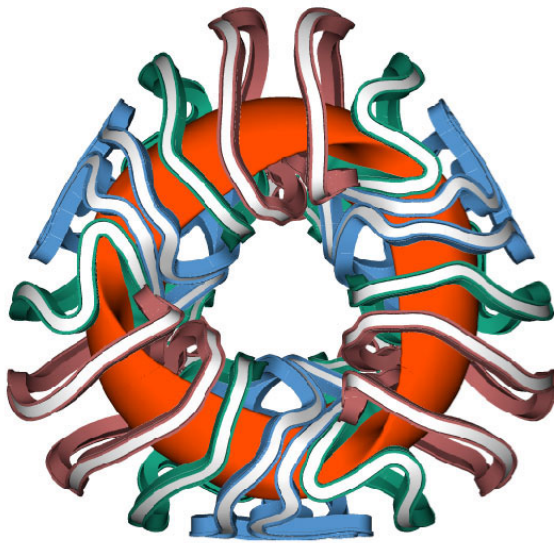


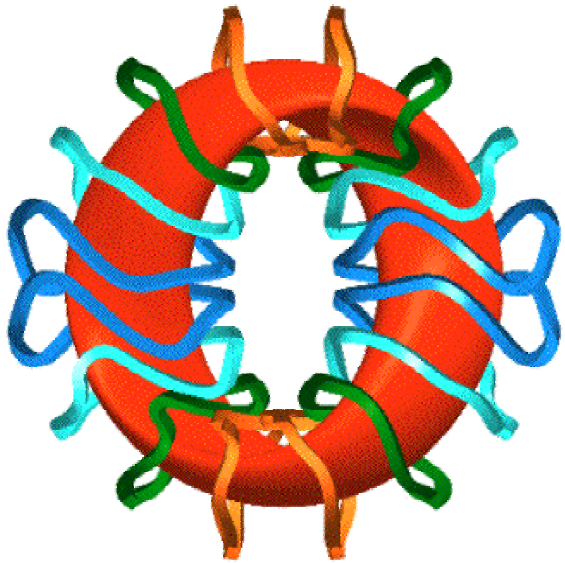
Middle of Field Period

Δ_{min} = 1.2 m

Blue areas:
~2 m Poloidal extent
~5.5 m Toroidal extent
~8% of FW area

ARIES-CS Plasma and Coils





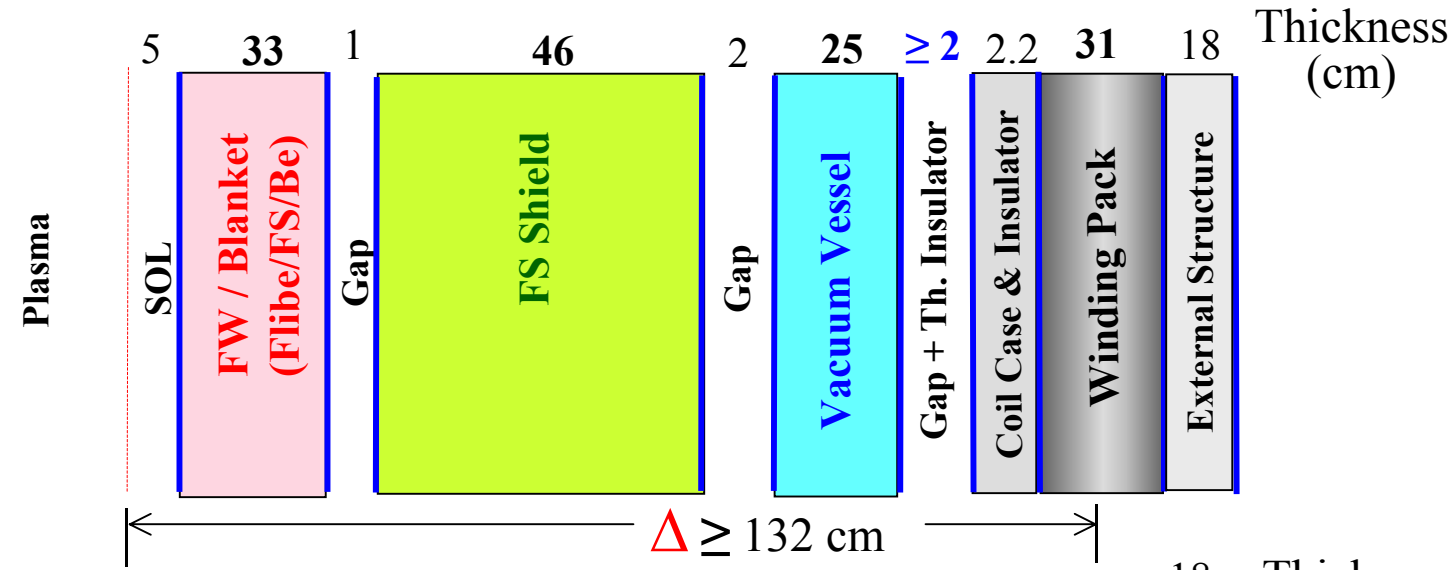
3 FP Configuration
R = 8.25 m
a = 1.85 m

2 FP Configuration
R = 7.5 m
a = 2 m

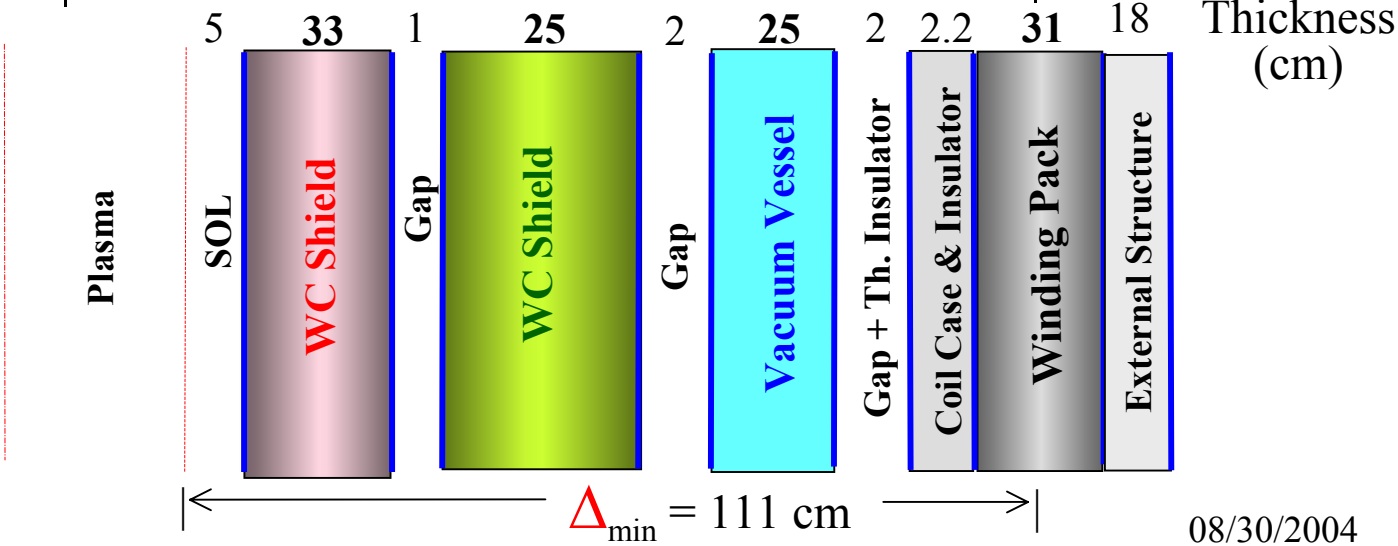
Internal VV

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

Blanket Zones



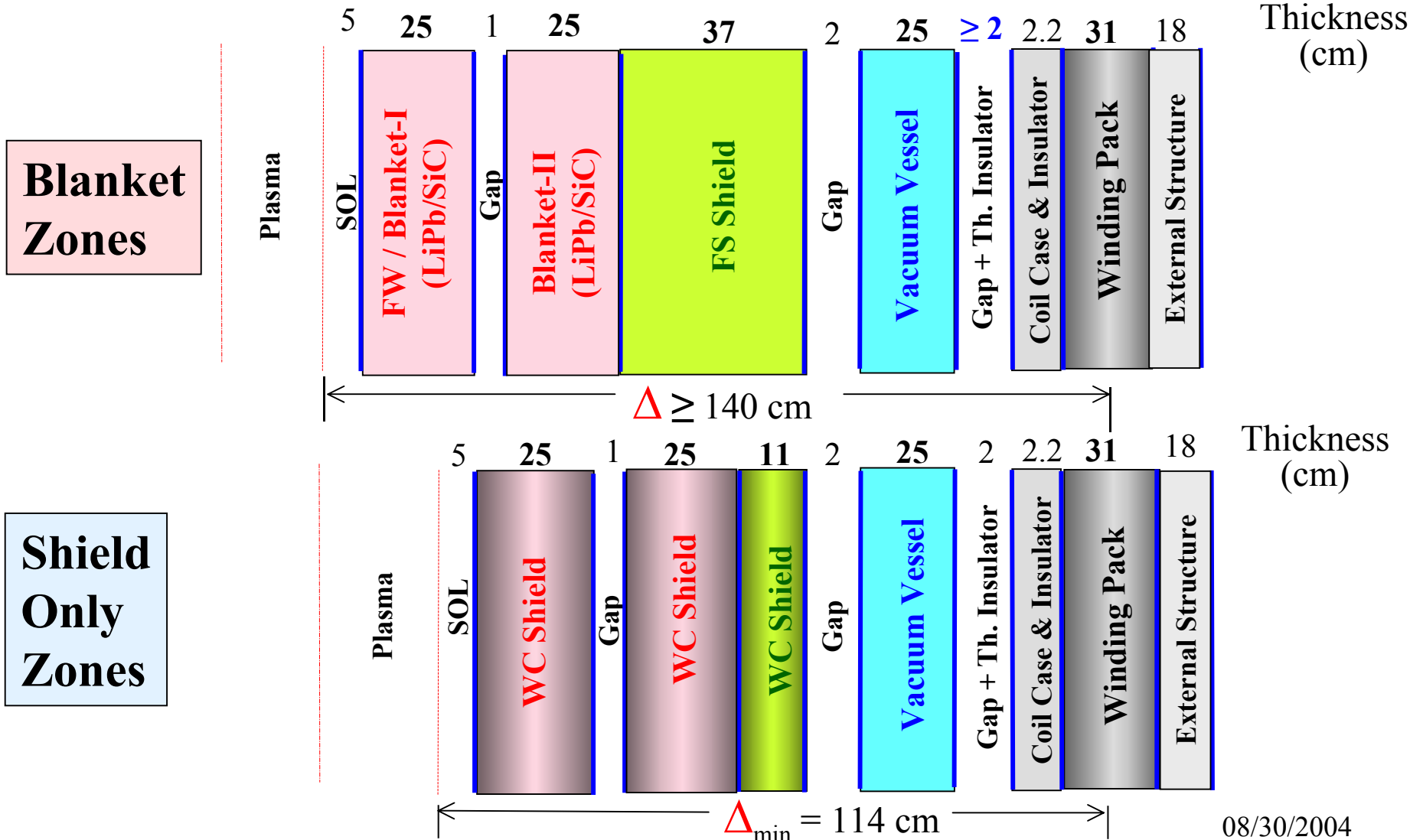
Shield Only Zones



Flibe/FS/Be Composition

Component	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

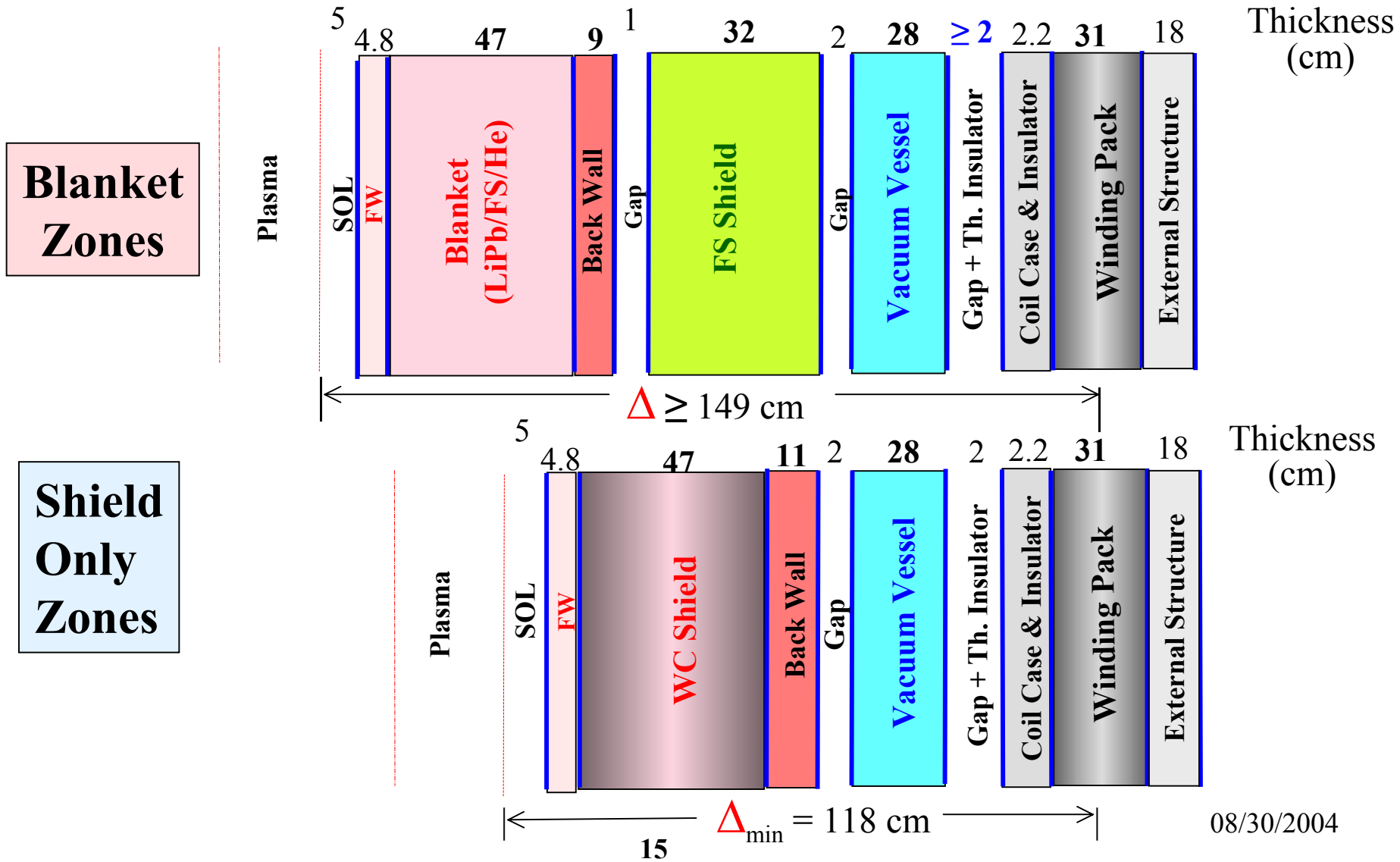
LiPb/SiC Radial Build
(Water-Cooled **Internal** VV)



LiPb/SiC Composition

Component	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

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



LiPb/FS/He Composition

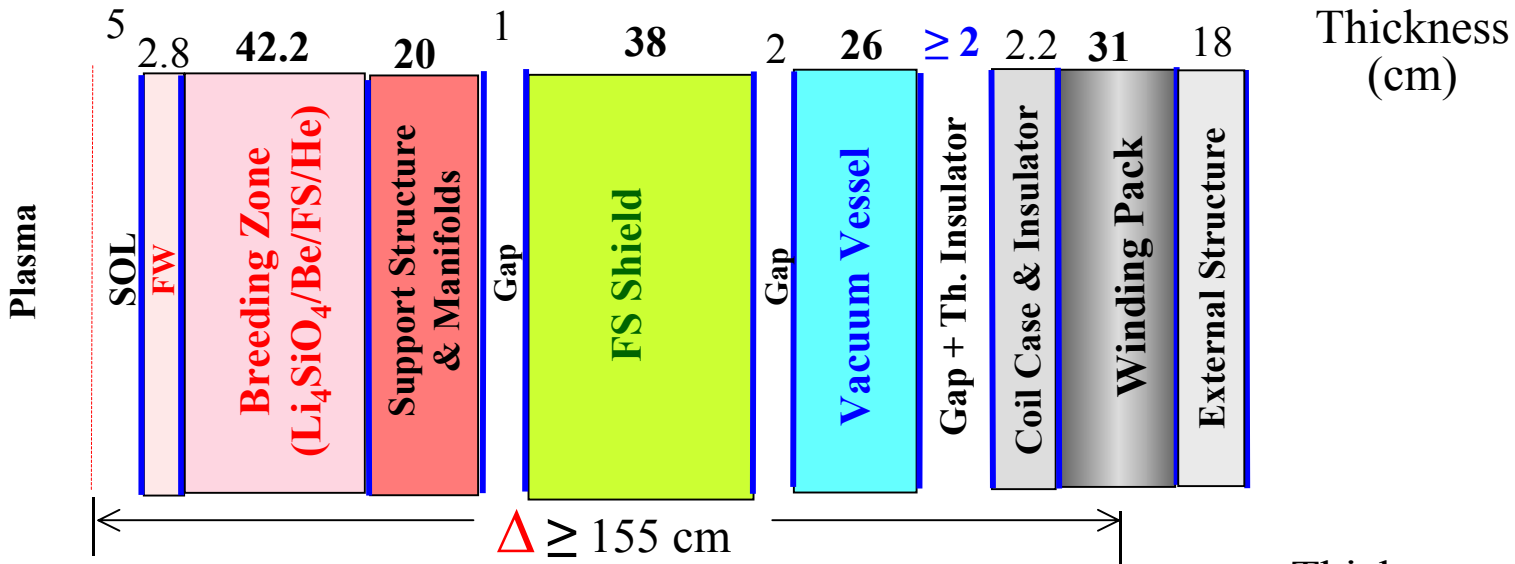
Component	Composition
FW	31% FS Structure 69% He Coolant
Blanket#	90% LiPb with 90% enriched Li 3% FS Structure 7% He Coolant
Back Wall	80% FS Structure 20% He Coolant
WC Shield*	90% WC Filler 3% FS Structure 7% He Coolant
FS Shield	15% FS Structure 10% He Coolant 75% Borated Steel Filler
VV	28% FS Structure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

Without SiC inserts.

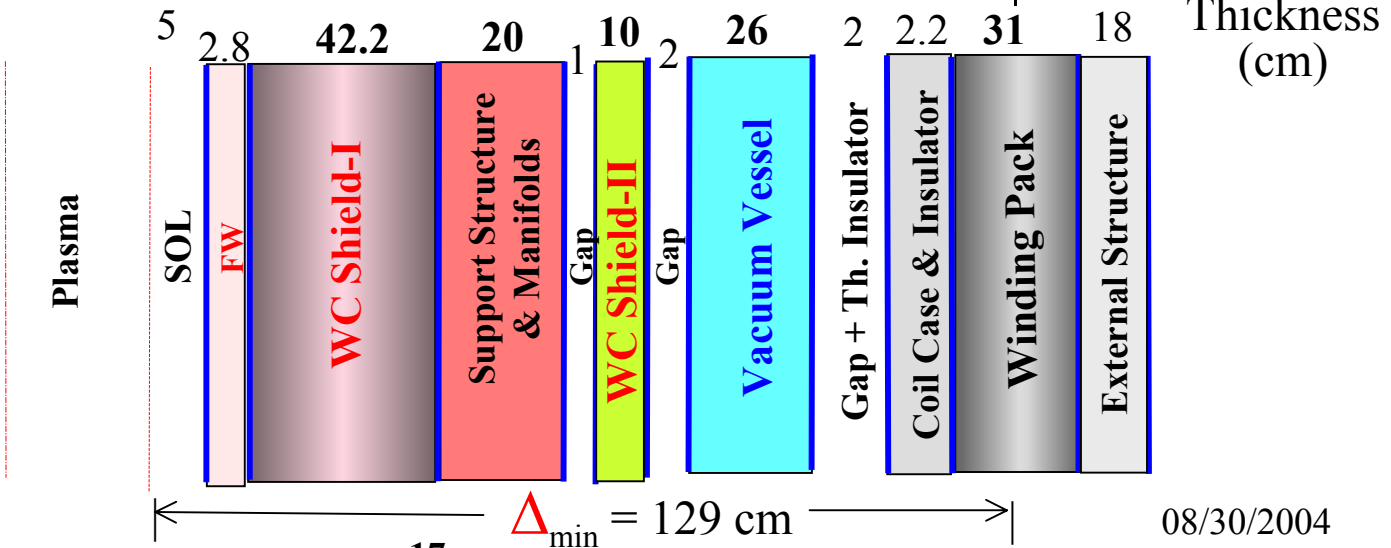
* FS and He contents will be adjusted later.

Li_4SiO_4/Be/FS/He Radial Build
(Water-Cooled **Internal** VV, 4.5 MW/m^2 peak)

Blanket Zones

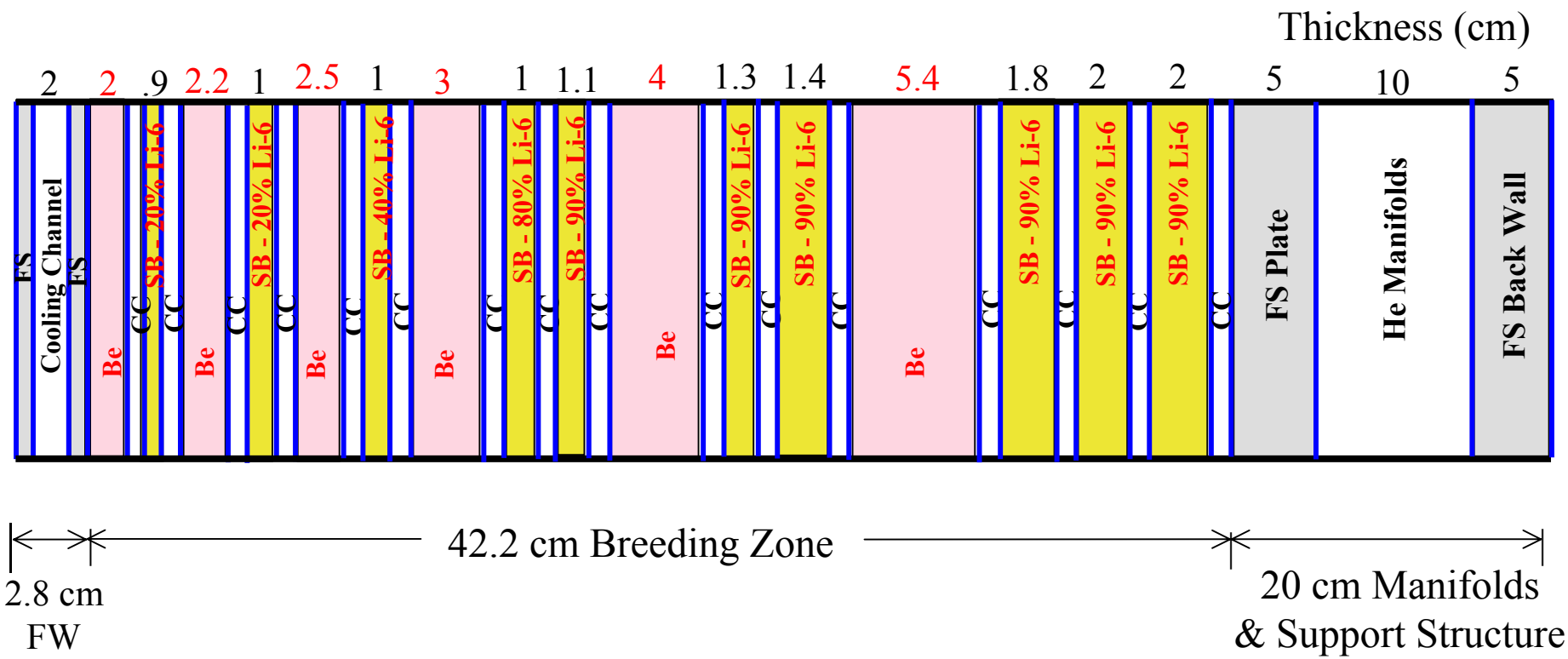


Shield Only Zones



Boundary between WC-shields will be adjusted to meet design requirements

Schematic of 65 cm Thick Blanket
(4.5 MW/m^2 peak)



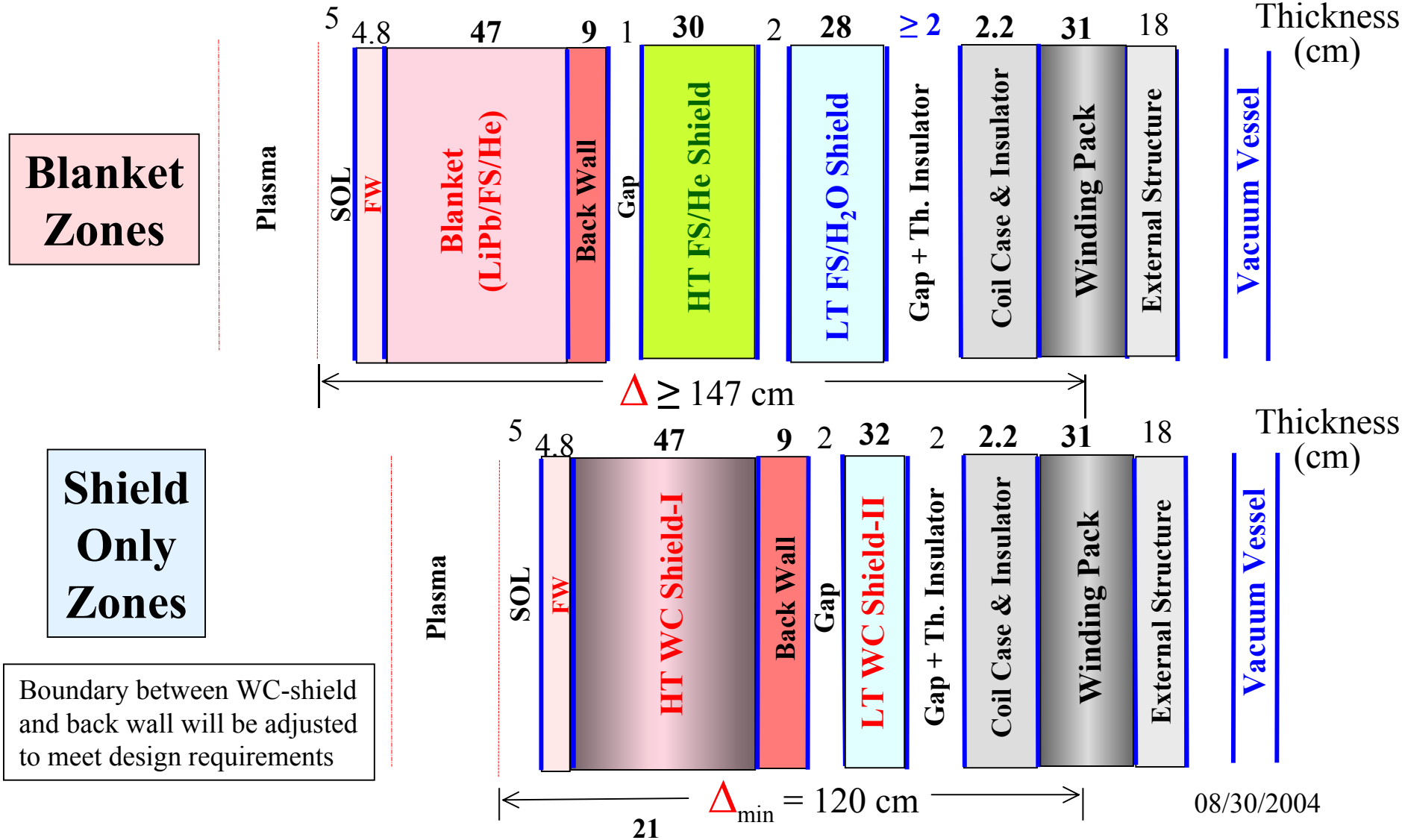
0.6 cm Thick Cooling Channel (CC)

Li_4SiO_4/Be/FS/He Composition

Component	Composition
Blanket	10% Li_4SiO_4 (20- 90% enriched Li) 17% Be 30% FS Structure 43% He Coolant
HT FS/He Shield	15% FS Structure 75% Borated Steel Filler 10% He Coolant
HT WC/He Shield-I & Manifolds	30% FS Structure 45% WC Filler 25% He Coolant
LT WC Shield-II	15% FS Structure 75% WC Filler 10% He Coolant
Vacuum Vessel	27% FS Structure 23% Borated Steel Filler 50% H_2O Coolant

External VV

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



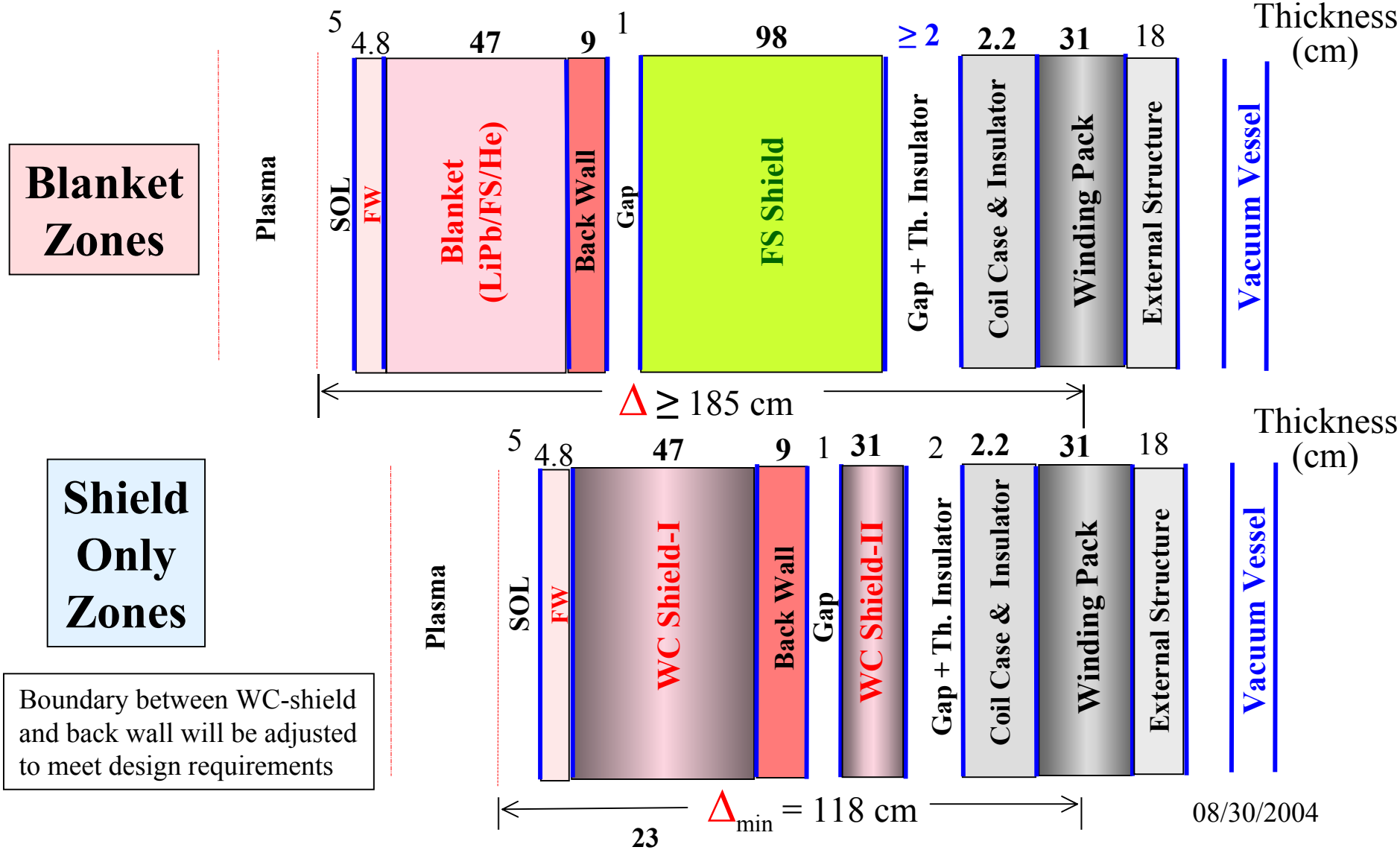
Boundary between WC-shield and back wall will be adjusted to meet design requirements

08/30/2004

LiPb/FS/He/H_2O 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
HT WC/He Shield-I	65% WC Filler 15% FS Structure 20% He Coolant
LT WC/H_2O Shield-II	15% FS Structure 40% H_2O Coolant 45% WC Filler
HT FS/He Shield	15% FS Structure 10% He Coolant 75% Borated Steel Filler
LT FS/H_2O Shield	15% FS Structure 60% H_2O Coolant 25% Borated Steel Filler
VV	30% FS Structure 70% He

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



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

08/30/2004

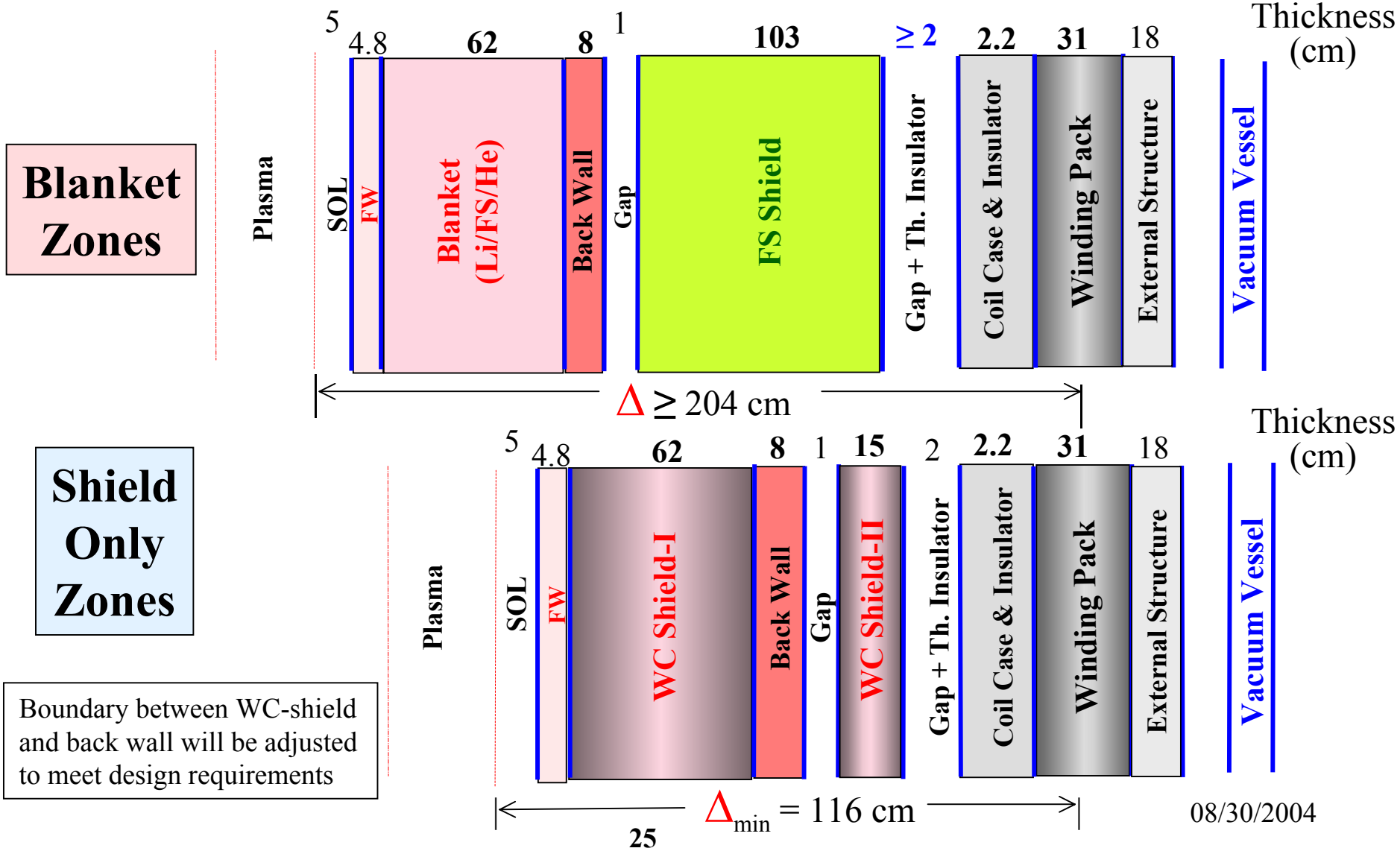
LiPb/FS/He Composition

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-I*	90% WC Filler 3% FS Structure 7% He Coolant
WC Shield-II#	15% FS Structure 10% He Coolant 75% WC Filler
FS Shield	15% FS Structure 10% He Coolant 75% Borated Steel Filler
VV	30% FS Structure 70% He

* FS and He contents will be adjusted later.

Same constituents for FS-shield with WC replacing B-FS filler. $ZrH_{1.7}$ filler could save 2-3 cm in radial build.

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



Li/FS/He Composition

Component	Composition
FW	31% FS Structure 69% He Coolant
Blanket	90% Li (natural) 3% FS Structure 7% He Coolant
Back Wall	80% FS Structure 20% He Coolant
WC Shield-I*	90% WC Filler 3% FS Structure 7% He Coolant
WC Shield-II#	15% FS Structure 10% He Coolant 75% WC Filler
FS Shield	15% FS Structure 10% He Coolant 75% Borated Steel Filler
VV	30% FS Structure 70% He

* FS and He contents will be adjusted later.

Same constituents for FS-shield with WC replacing B-FS filler. $ZrH_{1.7}$ filler could save 2-3 cm in radial build.

Magnet Design
(L. Bromberg - 2/04)

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.

ORNL FS Composition

Composition: 9Cr-2WVTa
Reference: R. Klueh, M.L. Grossbeck, and E.E. Bloom, Impurity content of reduced-activation ferritic steels and vanadium alloy, Fusion Materials Semiannual Progress Report for Period Ending December 31, 1996, U.S. Department of Energy Office of Fusion Energy Sciences, DOE/ER-0313/21 (April 1997).
Density: 7.78 g/cm^3

ORNL-FS	**wt %**		**wt%**
c	0.1	cd	0.05e-4
si	0.25	ta	0.07e-4
v	0.025	w	2.0
cr	9.0	os	0.02e-4
mn	0.5	ir	0.05e-4
fe	88.055	bi	0.05e-4
co	34e-4	eu	0.05e-4
ni	402e-4	dy	0.05e-4
nb	4e-4	ho	0.05e-4
mo	70e-4	er	0.05e-4
pd	0.18e-4	u	0.6e-4
ag	0.16e-4		

ODS FS Composition

ODS IEA Modified F82H Ferritic Steel
Composition: 9Cr-2WVTa
Reference: M. Billone (ANL) - 9/20/02
Density: ~7.78 g/cm^3

ODS-MF82H	**wt %**		**wt %**
b	3e-4	cd	0.4e-4
c	0.04	sn	10e-4
n	50e-4	sb	5e-4
o	0.13	ta	0.08
al	0.01	w	2.0
si	0.24	os	0.05e-4
p	50e-4	ir	0.05e-4
s	20e-4	bi	0.2e-4
ti	0.09	eu	0.05e-4
v	0.29	tb	0.02e-4
nb	3.3e-4	dy	0.05e-4
mo	21e-4	ho	0.05e-4
pd	0.05e-4	er	0.05e-4
ag	0.1e-4	u	0.05e-4

SiC/SiC Composition

Based on: SUPERSiC (r)
References: S. Sharafat, IPFR/UCLA, ARIES Study: Materials, Sept. 1993, pg 3.
Density: 3.217 g/cm^3 (64th CRC Handbook of Chemistry and Physics B-135).

SiC/SiC Composites	**wt %**		**wt %**
c	29.95	ag	0.002e-4
na	0.050e-4	cd	0.004e-4
si	70.05	in	0.001e-4
k	0.180e-4	sn	0.076e-4
sc	0.013e-4	sb	0.001e-4
cr	0.017e-4	cs	0.001e-4
fe	0.440e-4	ba	0.047e-4
co	0.013e-4	la	0.018e-4
ni	0.074e-4	eu	0.001e-4
cu	0.048e-4	tb	0.001e-4
zn	0.043e-4	yb	0.001e-4
ga	0.005e-4	hf	0.001e-4
as	0.003e-4	ta	0.001e-4
se	0.001e-4	w	0.032e-4
br	0.001e-4	ir	0.001e-4
rb	0.001e-4	pt	0.542e-4
sr	0.012e-4	hg	0.001e-4
zr	0.236e-4	th	0.001e-4
mo	0.041e-4	u	0.001e-4

LiPb Composition

Reference: S. Malang & K. Schleisiek, "Dual Coolant Blanket Concept", KFK5424, Karlsruhe, Nov 1994.

Density (@ 700 ^{o}C): 8.8 g/cm^{3}

LiPb	**wt %**
pb	99.29
li	0.7
zn	10e-4
fe	10e-4
bi	43e-4
cd	5e-4
ag	5e-4
sn	5e-4
ni	2e-4

Flibe Composition

Reference: # Liquid F_4Li_2Be

Impurities from H. Khater

Density (@ 460 °C): 2 g/cm^3

Flibe (BeF_2, $[LiF]_2$)	**wt %**
f	76.86
li	14.04
be	9.114
c	91e-4
o	0.0987
mg	5.5e-4
al	77e-4
si	27e-4
ti	19e-4
cr	9e-4
mn	11e-4
fe	0.0139
ni	13e-4
cu	7e-4

Comparison Between Major and Minor Radii