



Near-Final Radial Build and Nuclear Parameters

L. El-Guebaly

Fusion Technology Institute
UW - Madison

Contributors:

L-P. Ku (PPPL), J. Lyon (ORNL),
R. Raffray, S. Malang, X. Wang (UCSD)

ARIES-CS Project Meeting

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UW

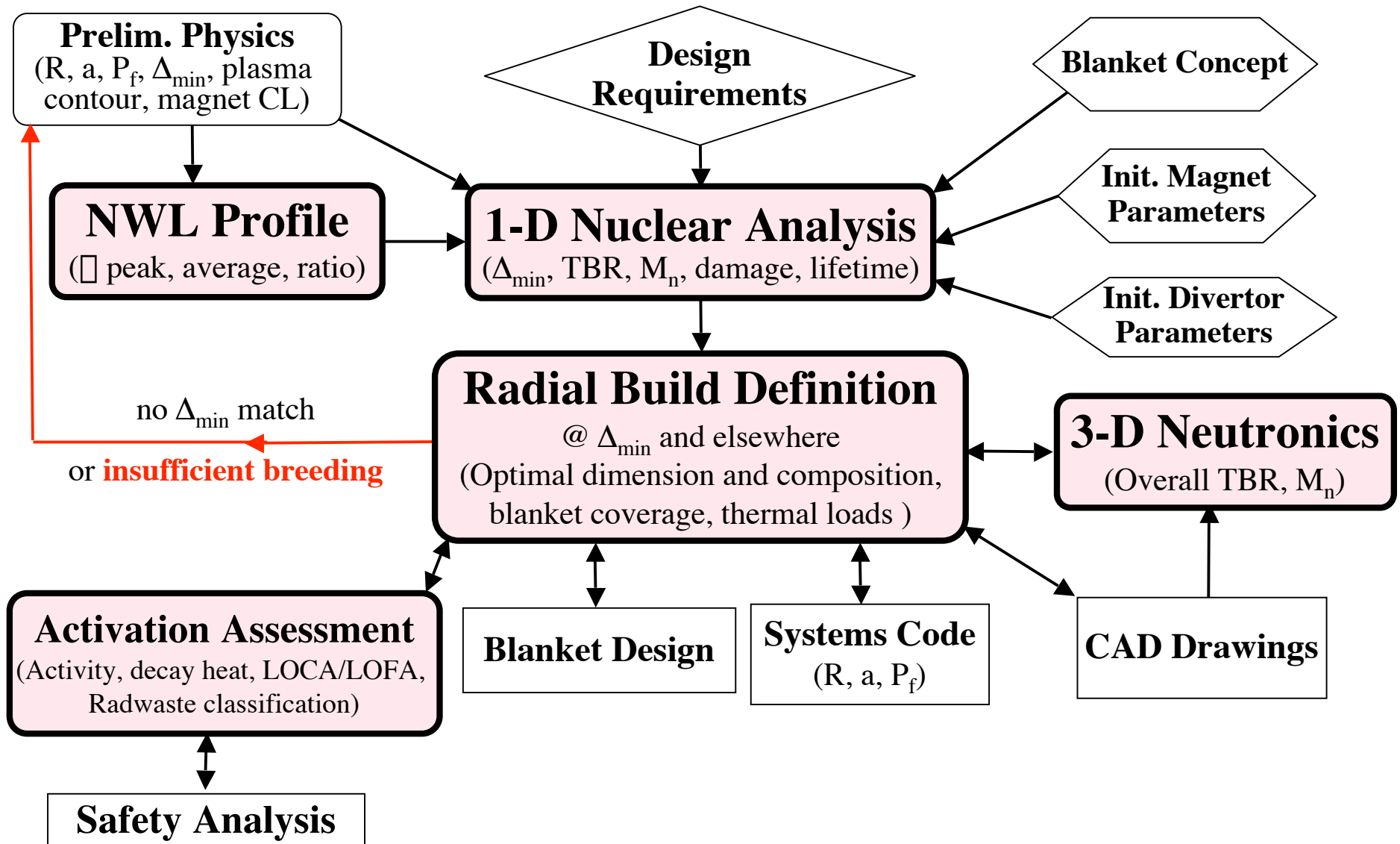
UW Action Items

- ✓ 1. Check blanket coverage and TBR for $R = 7.5$ and 8 m. Need plasma-midcoil separation contours from PPPL
- 2. Optimize local shield behind helium access tubes
- ✓ 3. Provide radial build at cross-section through He access tube near delta-min
- ✓ 4. Update shield vs. NWL scaling law
- ✓ 5. Update power fraction to blanket Pb-17Li coolant, blanket and shield He, shield-only zone He and divertor He
- ✓ 6. Update He:LiPb power split using 28 MWe pumping power for div He and 97 MWe for blanket He.
- ✓ 7. Check magnet activation for candidate structures (get composition from Leslie)
- ✓ 8. Provide heat load to 35-cm thick inter coil structure
- 9. Provide radial build for 2 field period configuration. Received plasma-midcoil separation contours from PPPL
- 10. Provide radial build for advanced LiPb/SiC system
- ✓ 11. Provide radial build for full blanket coverage
- ✓ 12. Redefine reference radial build and post it on UW website

Contents

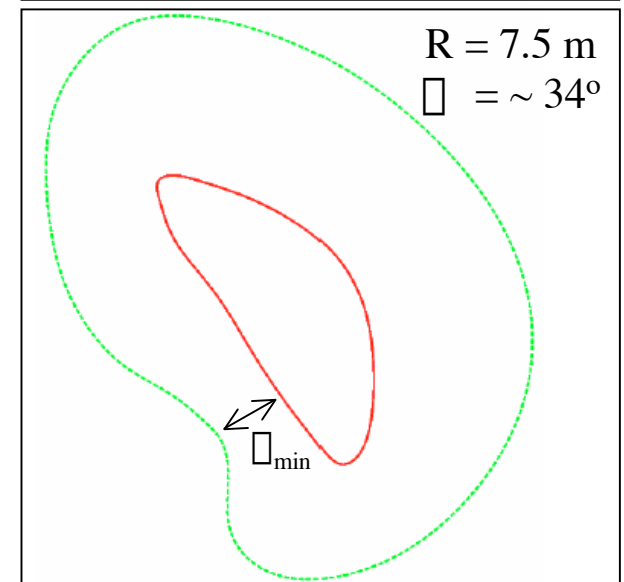
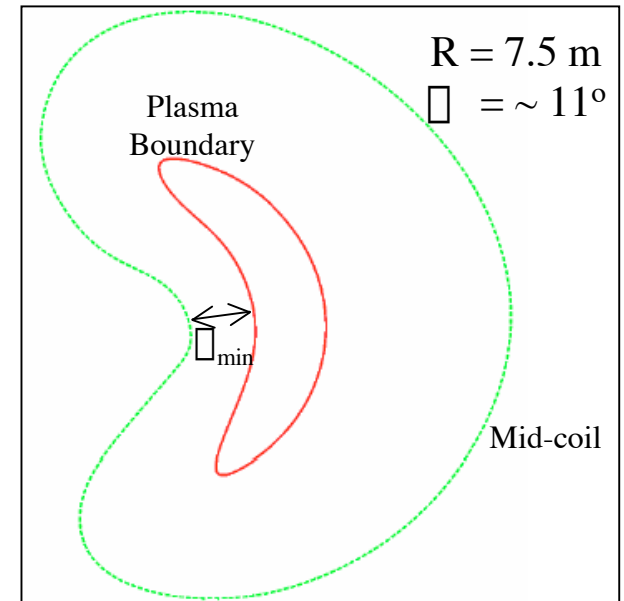
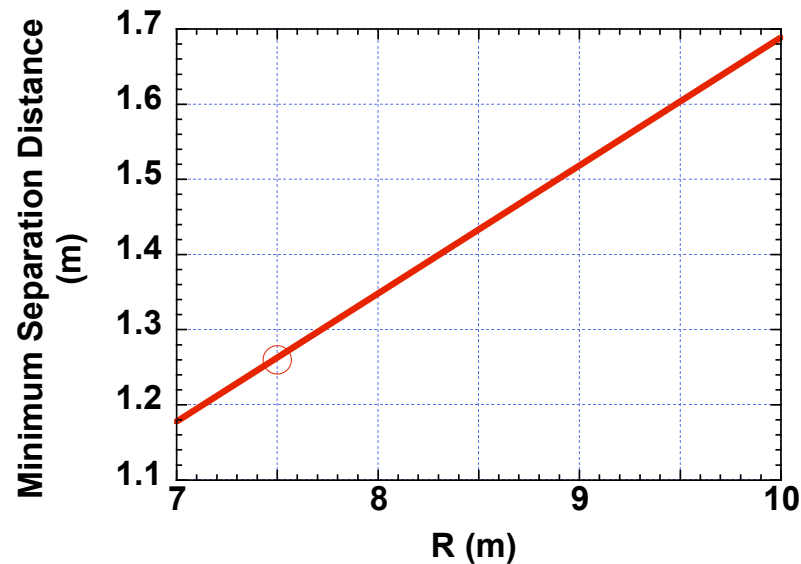
- Plasma - mid-coil separation **contours for $R = 7 - 8.5$ m machines.**
- Rationale for **$R = 7.5$ m** design.
- **Near-final** radial build **and** nuclear parameters.
- Orientation of **He access tubes** to mitigate streaming problem.
- **Streaming** concerns for divertor region.
- Updates:
 - **Heat load** to all components
 - **Power split** between He/LiPb coolants.
- Future plan and publications.

Insufficient Breeding for R= 7 m Machine Mandates Another Iteration



New Plasma – Mid-coil Separation Contours

- **From:** L-P Ku (PPPL)
- **Basis:** ARE physics
- **Configuration:** 3 FP
- 4 $\square_{\min}$ per FP
- $\square_{\min} \propto R$, starting at 1.18 m for $R = 7$ m





CAD Confirmed UW Estimate for Blanket Coverage Fractions

R= 7 m machine

**UW
Estimate**

CAD

Non-uniform Blanket

35%

36%

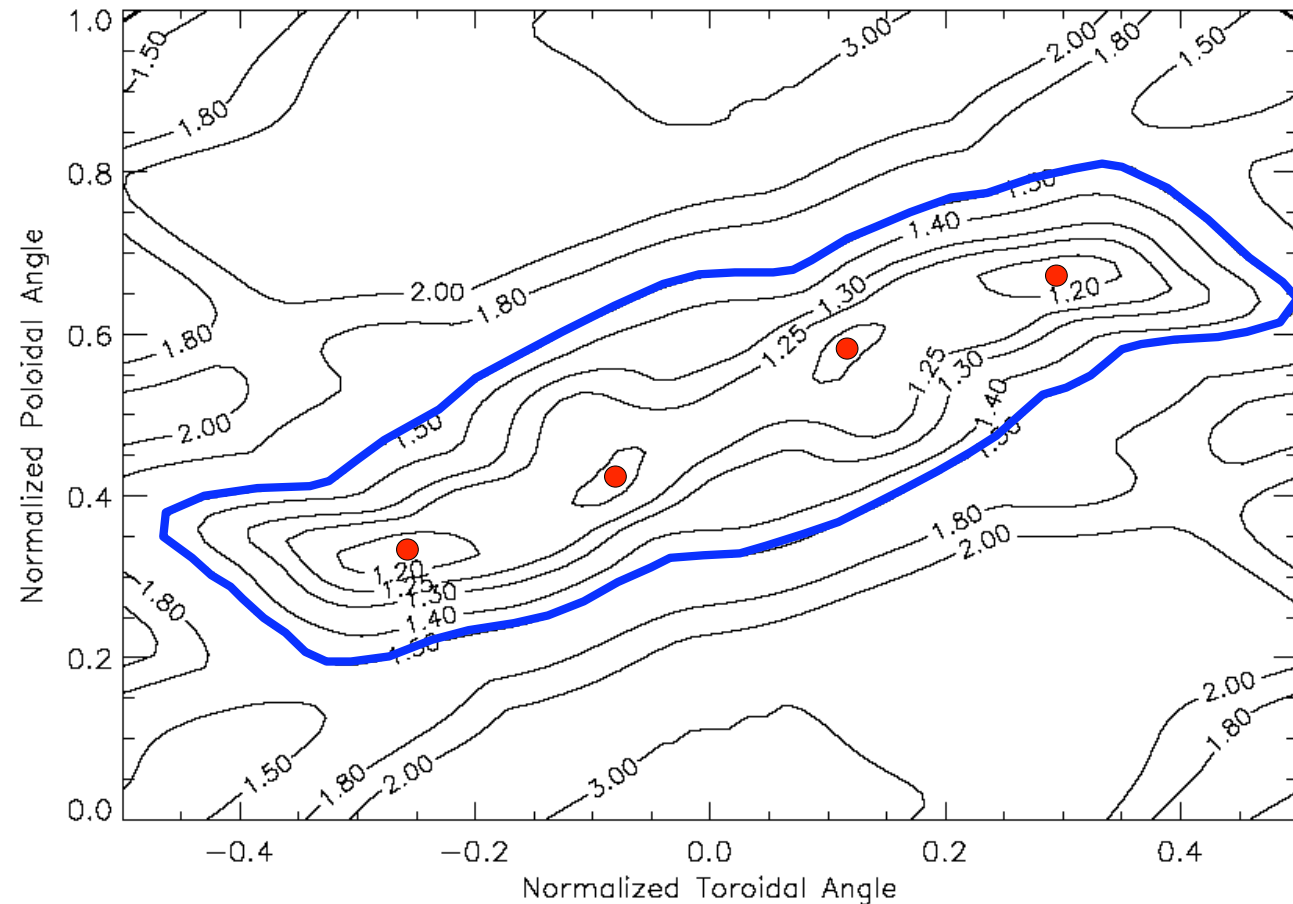
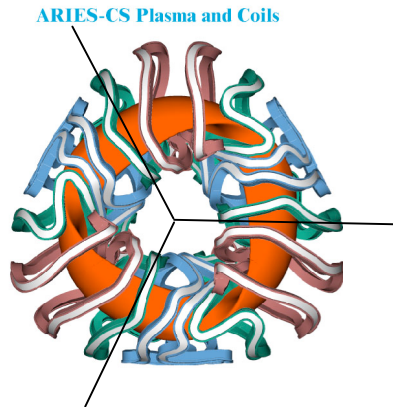
Uniform Blanket

65%

64%

$$R = 7 \text{ m}$$

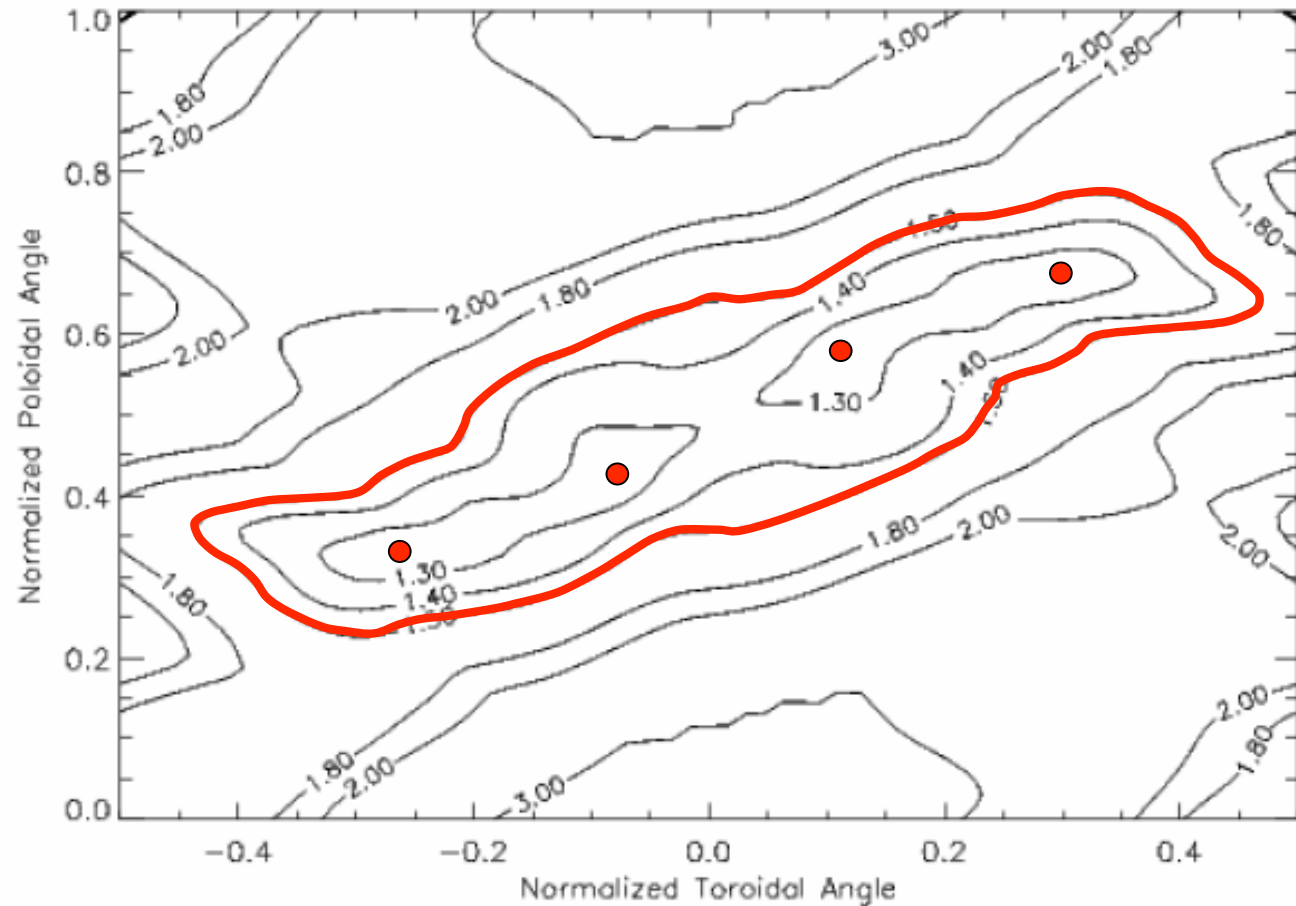
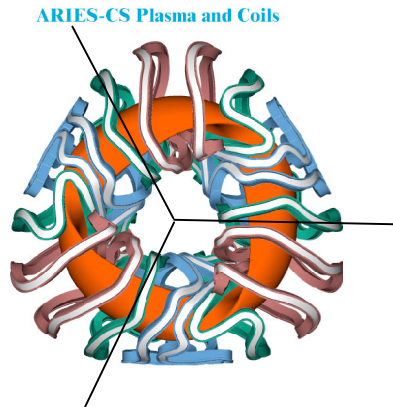
[$4 \square_{\min}$ (= 1.18 m) marked in red]



- **Uniform blanket and divertor** outside **blue** contour covers ~**65%** of FW area.
- **Non-uniform, tapered blanket** inside **blue** contour covers ~**35%** of FW area.

$$R = 7.5 \text{ m}$$

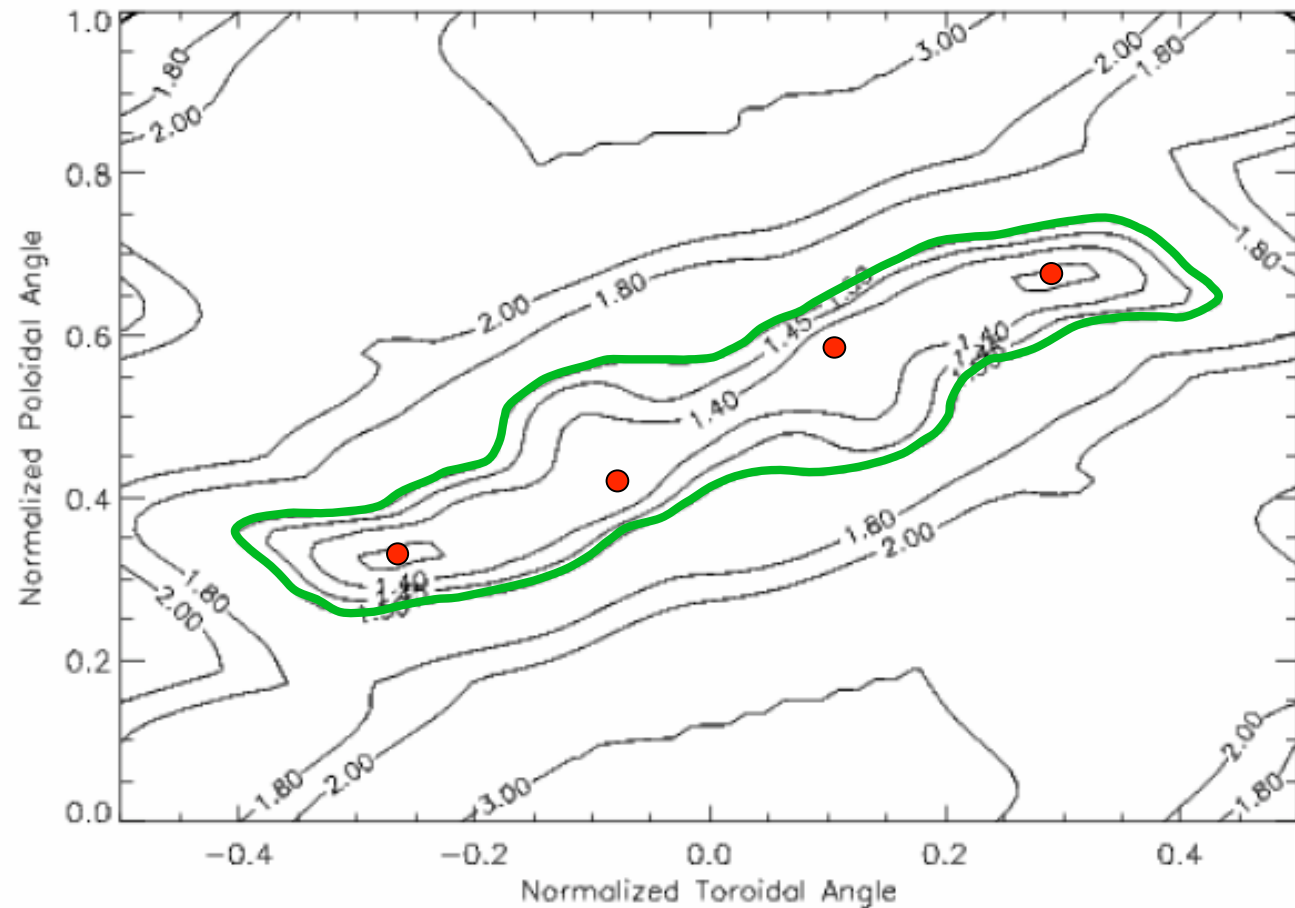
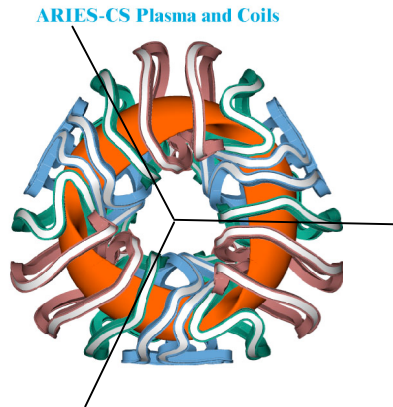
[$4 \square_{\min}$ (= 1.26 m) marked in red]



- **Uniform blanket and divertor** outside **red** contour covers **~72%** of FW area.
- **Non-uniform, tapered blanket** inside **red** contour covers **~28%** of FW area.

$$R = 8 \text{ m}$$

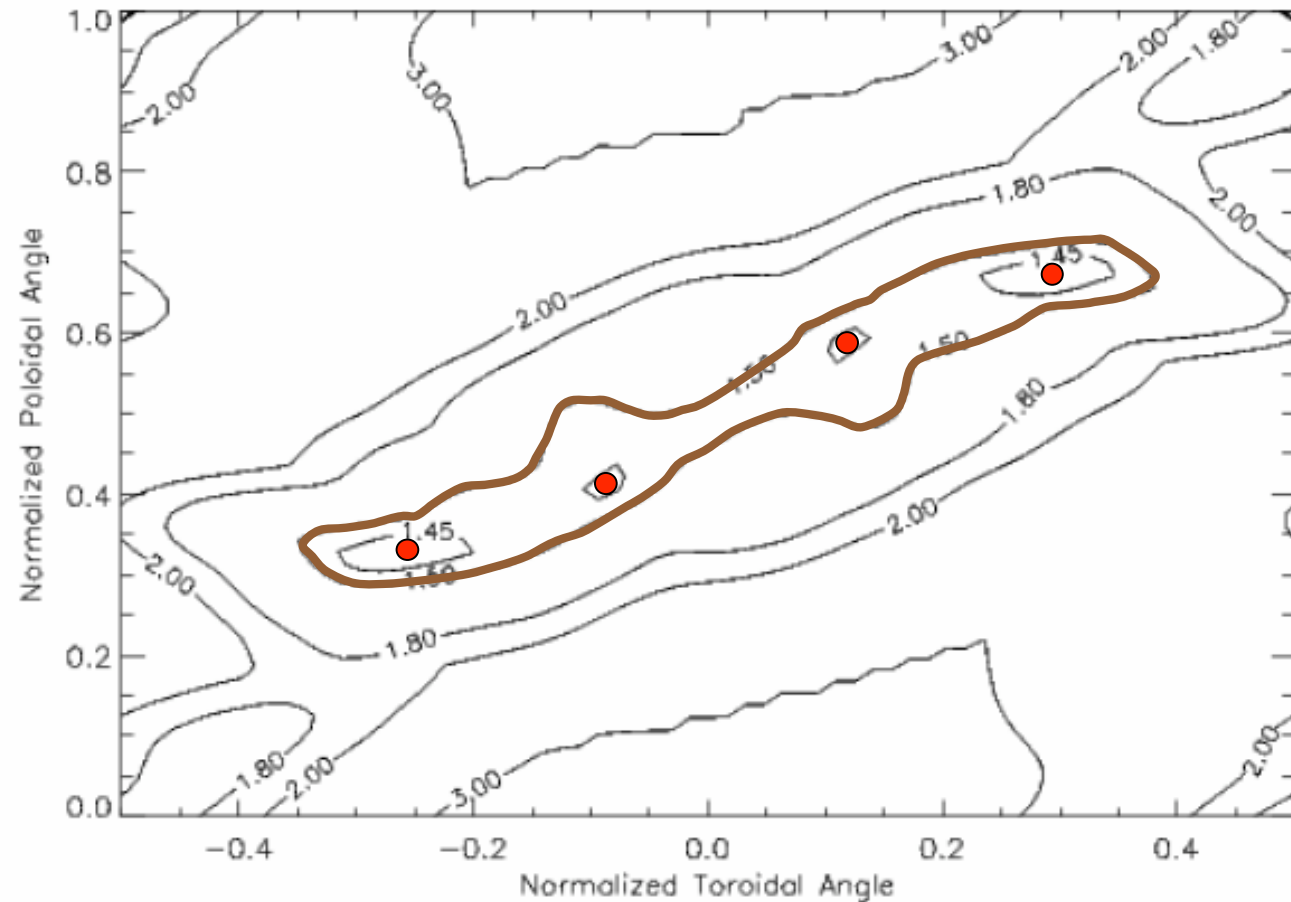
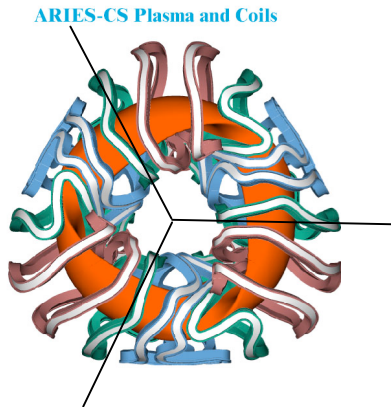
[$4 \square_{\min}$ (= 1.34 m) marked in red]



- **Uniform blanket and divertor** outside **green** contour covers ~**80%** of FW area.
- **Non-uniform, tapered blanket** inside **green** contour covers ~**20%** of FW area.

$$R = 8.5 \text{ m}$$

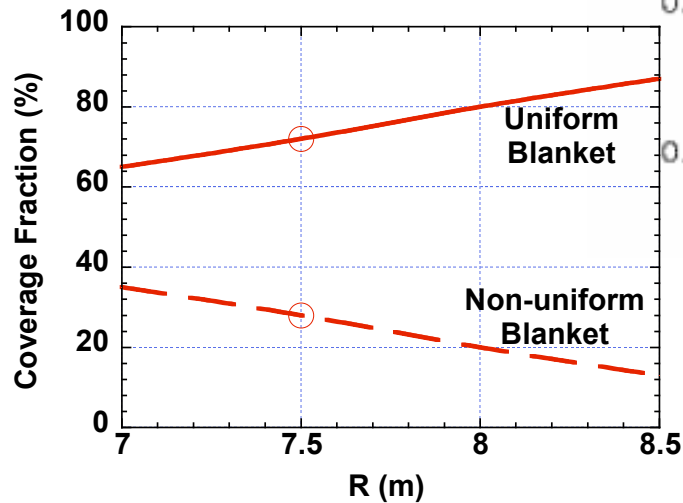
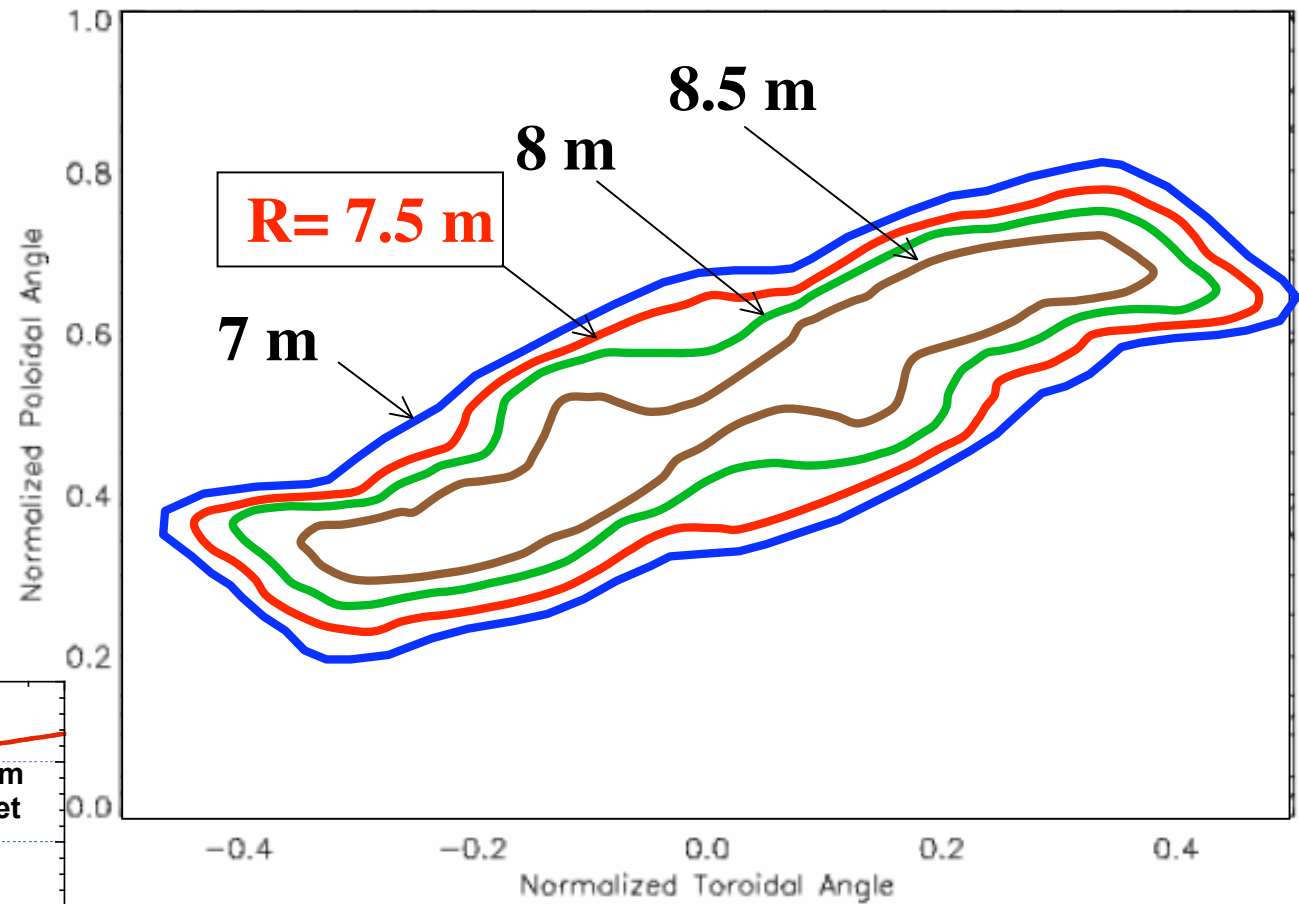
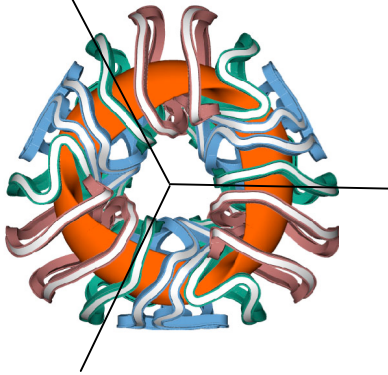
[4 $\square_{\min}$ (= 1.43 m) marked in red]



- **Uniform blanket and divertor** outside **brown** contour covers ~87% of FW area.
- **Non-uniform, tapered blanket** inside **brown** contour covers ~13% of FW area.

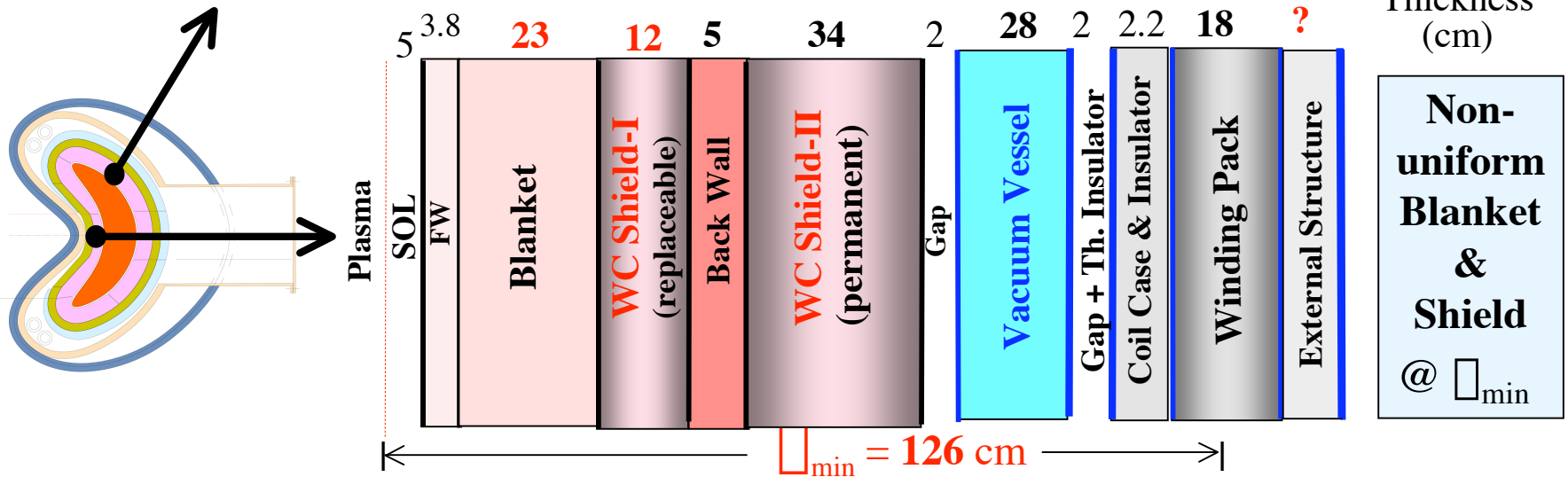
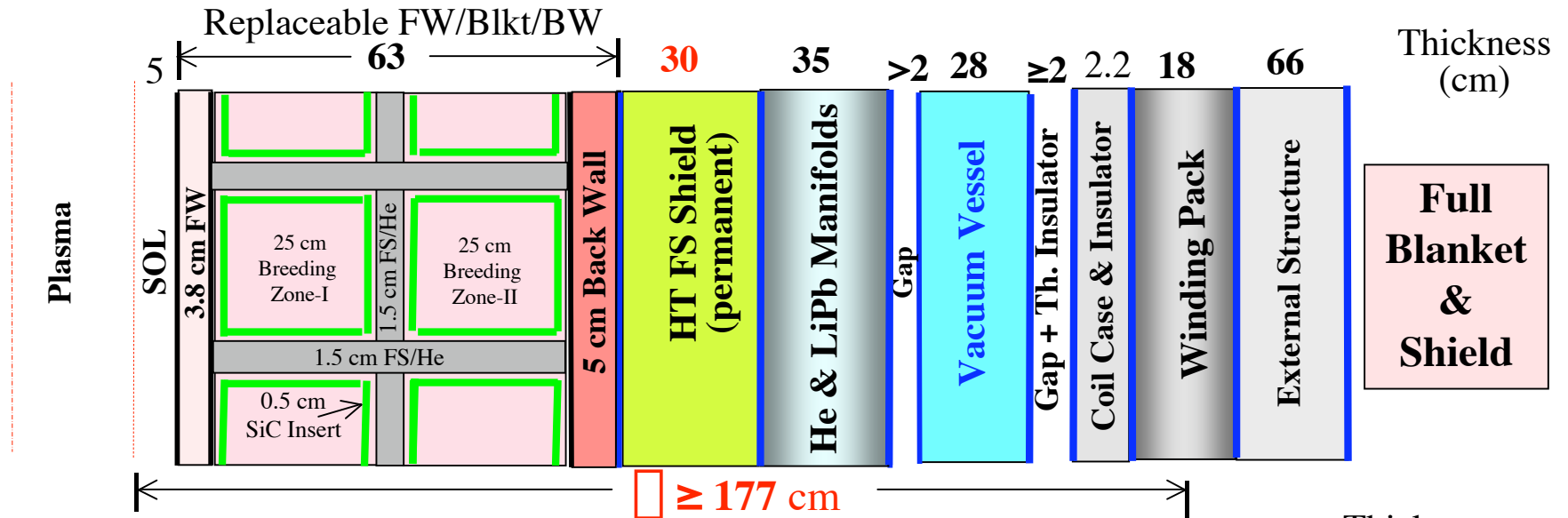
Non-uniform Blanket Coverage Decreases with R

ARIES-CS Plasma and Coils



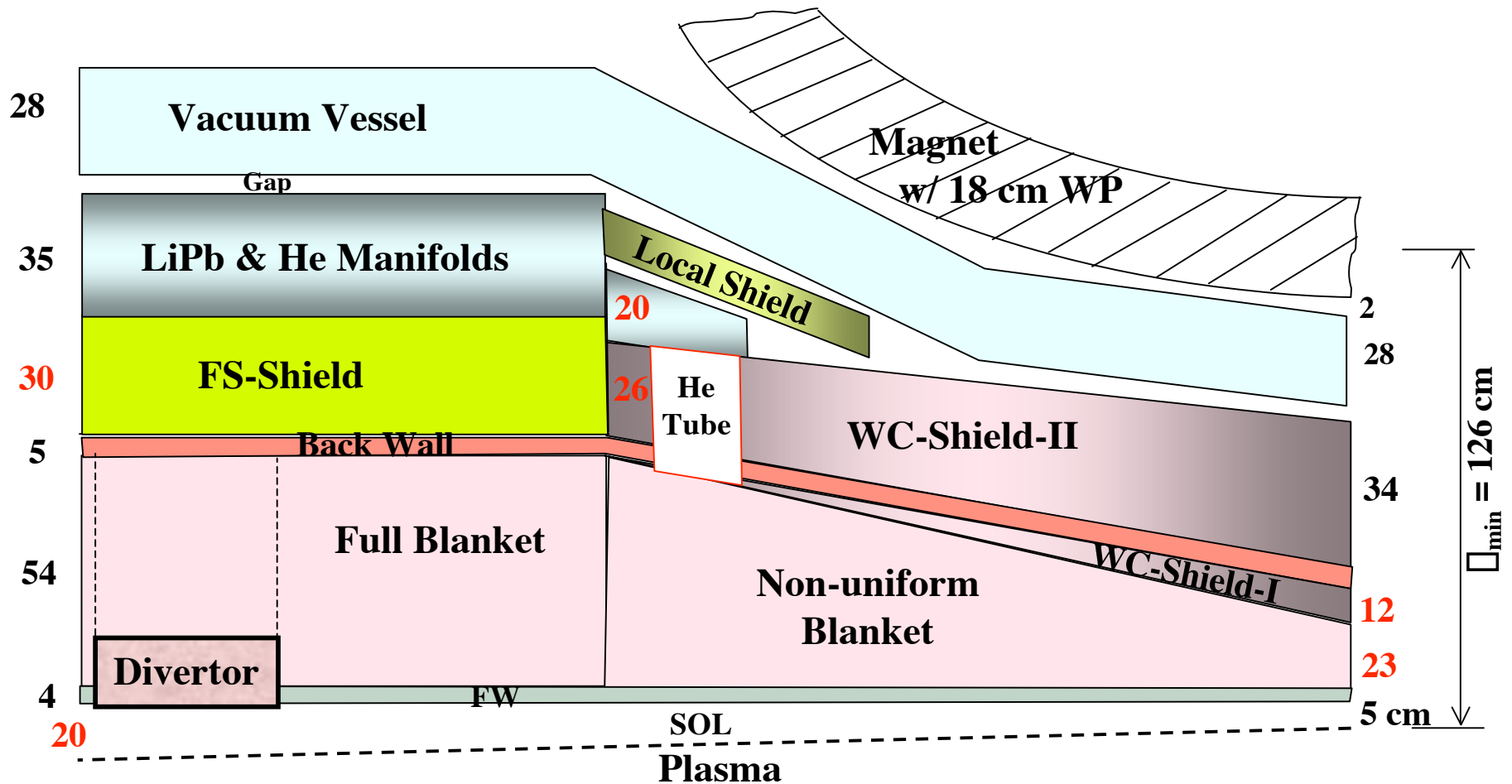
Near-Final Radial Build

($R = 7.5 \text{ m}$; 4.5 MW/m^2 peak $\dot{q}$)



Radial / Toroidal Xn

($R = 7.5 \text{ m}$; 4.5 MW/m^2 peak $\square$)



Full Blanket/shield and Divertor
($57\% + 15\% = 72\%$ of FW area)

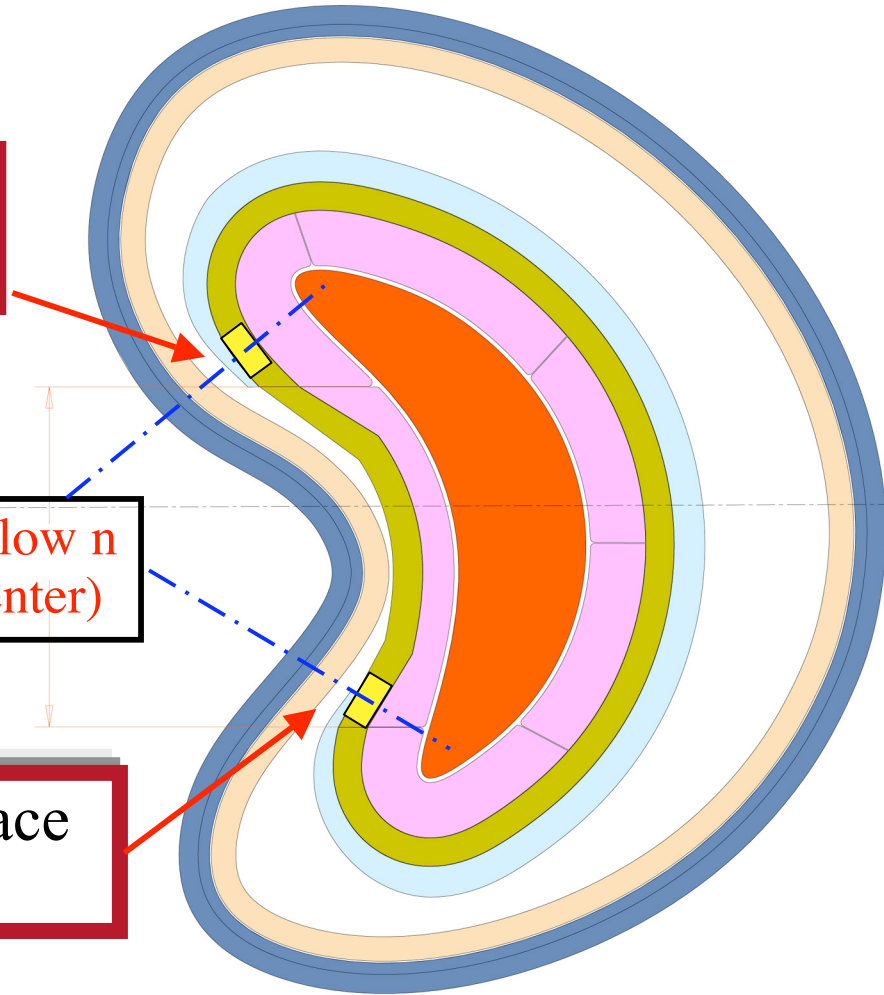
Non-uniform, Tapered Blanket/Shield
(28% of FW area)

Streaming Through Blanket He Access Tubes (Cont.) (Non-uniform Blanket Region)

~22 cm available space
for local shield

Tube axis should be oriented toward low n
source regions (away from plasma center)

~20 cm available space
for local shield



Monitor location/orientation of He access tubes as design develops



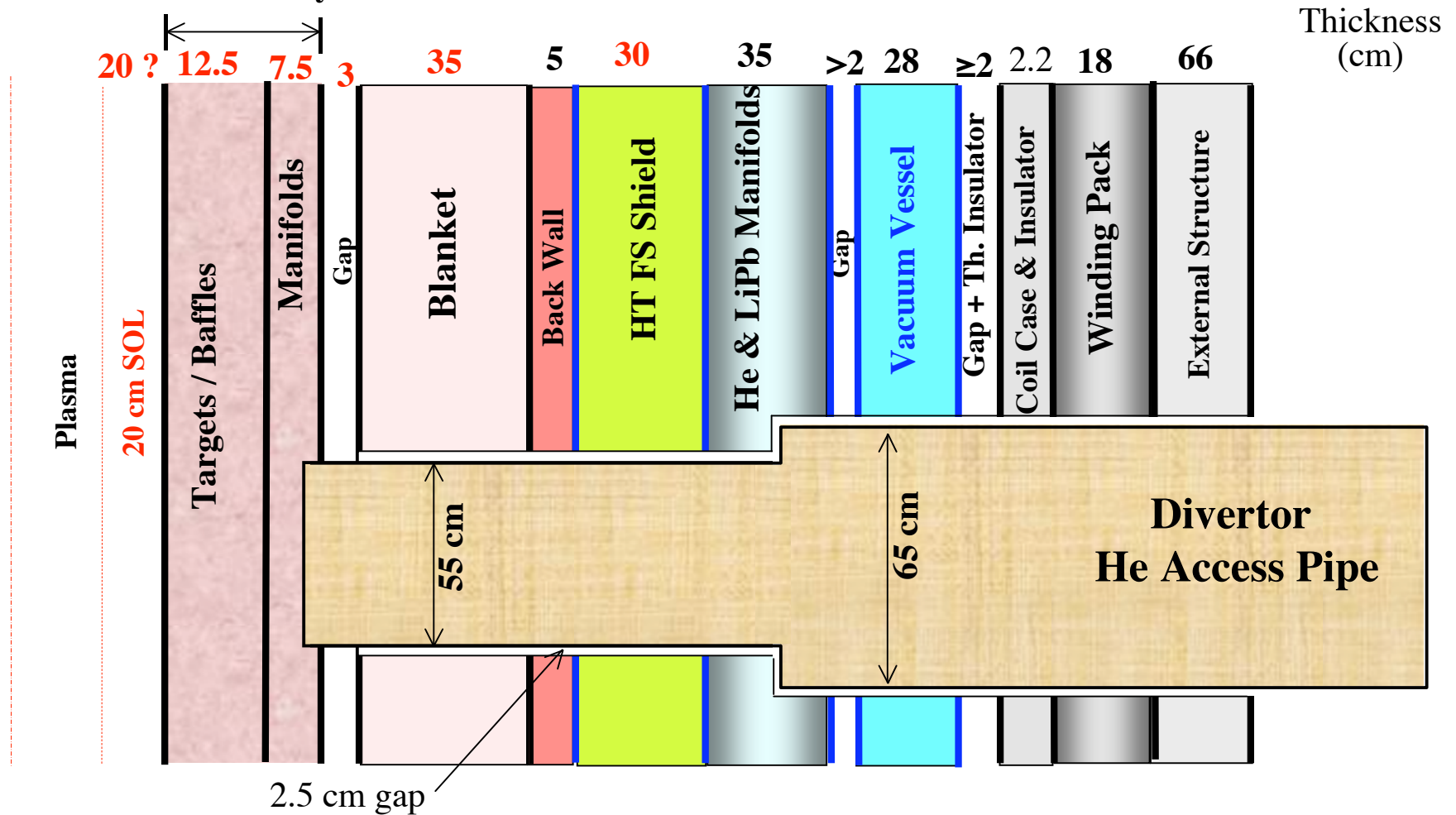
Streaming Through Blanket He Access Tubes (Non-uniform Blanket Region)

- Thermal analysis calls for 32 cm OD tubes to supply He from manifolds to blanket.
- Each tube replaces 32-40 cm of WC-shield and back wall.
- Neutrons streaming through He tube increase damage at VV and magnets.
- Careful choice of location and orientation of tubes alleviate streaming problem.
- ~20 cm thick local shield needed behind manifolds to protect VV and magnets.

Xn through Divertor System

(R= 7.5 m)

20 cm Divertor System



Xn through Divertor System (Cont.)

- **Damage** at shield and manifolds depends on NWL at divertor location.
- Xn through divertor and blanket (away from pipes) indicates **no problem** if peak NWL remains **below 2 MW/m²** at divertor surface.
- Neutron **streaming through He access pipes increases damage** to all components surrounding pipes.
- Malang suggested **shield inserts** to protect surrounding components. Shielding effectiveness of inserts will be assessed with 3-D analysis.

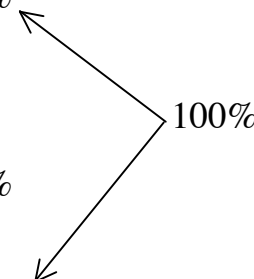
Compositions and Coverage Fractions

(R= 7.5 m ; 4.5 MW/m² peak $\square$)

<u>Component</u>	<u>Thickness</u>	<u>Coverage Fraction</u>	<u>Composition</u>
FW*	3.8 cm	85%	34% FS Structure 66% He Coolant
Divertor System*	20 cm	15%	
Blanket behind Divertor*	35 cm	15%	75% LiPb (90% enriched Li) 9% SiC Inserts 8% FS Structure 8% He Coolant
Non-uniform Blanket*	23 - 54.3 cm	28%	
Full Blanket*	54.3 cm	57%	
Back Wall*	5 cm	100%	80% FS Structure 20% He Coolant
FS Shield	30 cm	72%	15% FS Structure 10% He Coolant 75% Borated Steel Filler
Manifolds	35 cm	75%	52.0% FS Structure 22.7% LiPb (90% enriched Li) 24.0% He Coolant 1.3% SiC Inserts

* Replaceable component.

Compositions and Coverage Fractions (Cont.)

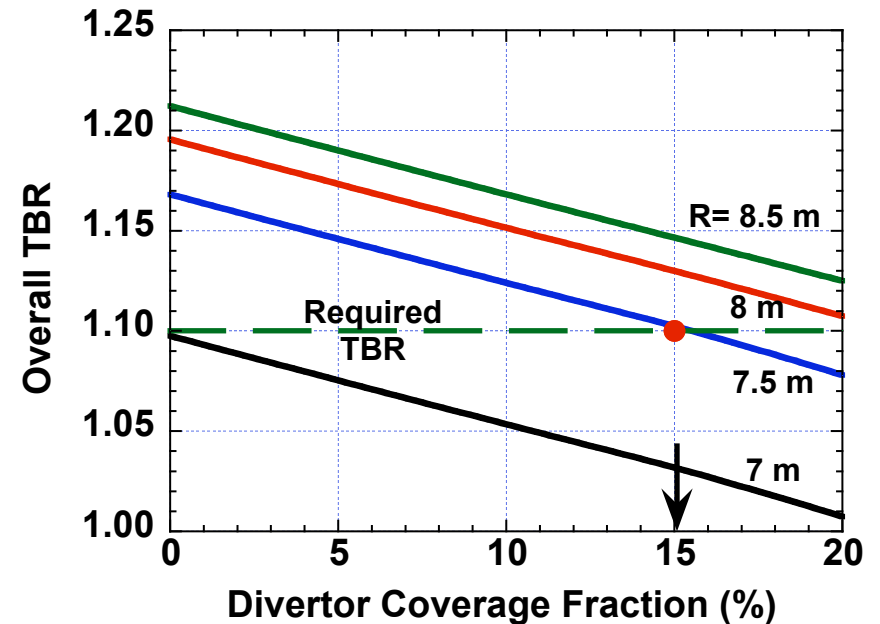
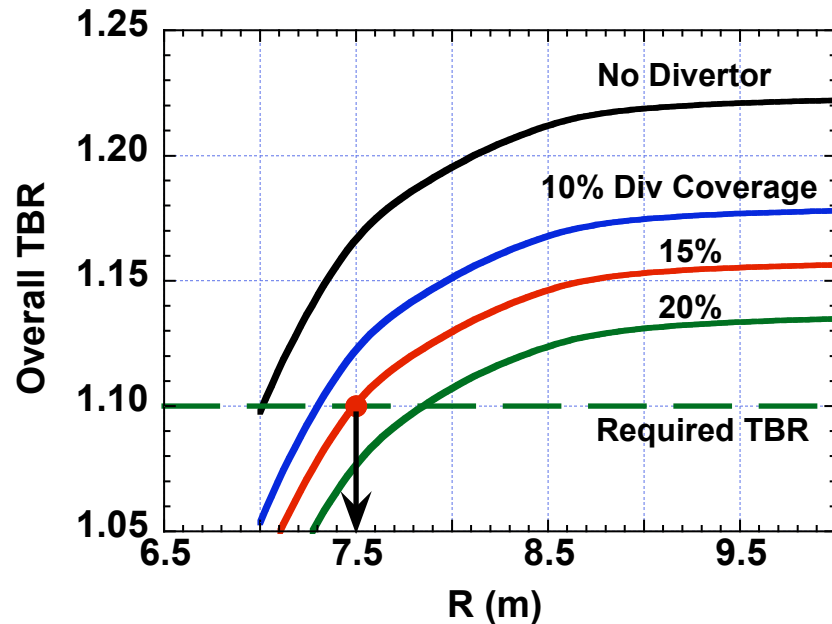
<u>Component</u>	<u>Thickness</u>	<u>Coverage Fraction</u>	<u>Composition</u>
WC Shield-I*	0 – 12 cm	28%	15% FS Structure 10% He Coolant 75% WC Filler
WC Shield-II	26 – 34 cm	28%	15% FS Structure 10% He Coolant 75% WC Filler
VV	28 cm	100%	28% FS Structure 49% Water 23% Borated Steel Filler
Inner Coil Case (in front of WPs only)	2 cm	33%	95% Incoloy-908 Structure 5% LHe Coolant
Winding Pack @ 4K	18 cm	33%	 100%
External Structure (behind WPs only)	56 +10 cm	33%	
Inter Coil Structure (between WPs)	35 cm	67%	
			18.5% Incoloy-908 Structure 48.2% Cu 12.8% Nb ₃ Sn 10.0% GFF Polyimide 10.5% LHe Coolant
			95% Incoloy-908 Structure 5% LHe Coolant
			95% Incoloy-908 Structure 5% LHe Coolant

* Replaceable component.

Overall TBR

- 1-D and 3-D TBR comparison indicated good agreement for **full** blanket coverage (no blanket variation, no divertor system, no penetrations) - refer to June 05 presentation.
- Overall TBR reported herein is based on 1-D results combined with blanket/divertor coverage.
- **Assumptions:**
 - **All regions** (divertor, full and tapered blankets) **have same importance for breeding**. Local breeding usually follows NWL distribution.
 - **Divertor system** covers 15% of FW area:
 - No variation of divertor coverage fraction with R
 - 12.5 cm thick divertor targets/baffles **and** alpha modules followed by 7.5 cm thick He manifolds
 - 55 cm OD He access pipe for each divertor plate (~ 2x 2 m each)
 - 3 cm wide gap between divertor and blanket.
 - **Thin blanket** (35 cm thick) behind divertor system.
 - **Penetrations** occupy 1% of FW area.

Overall TBR (Cont.)



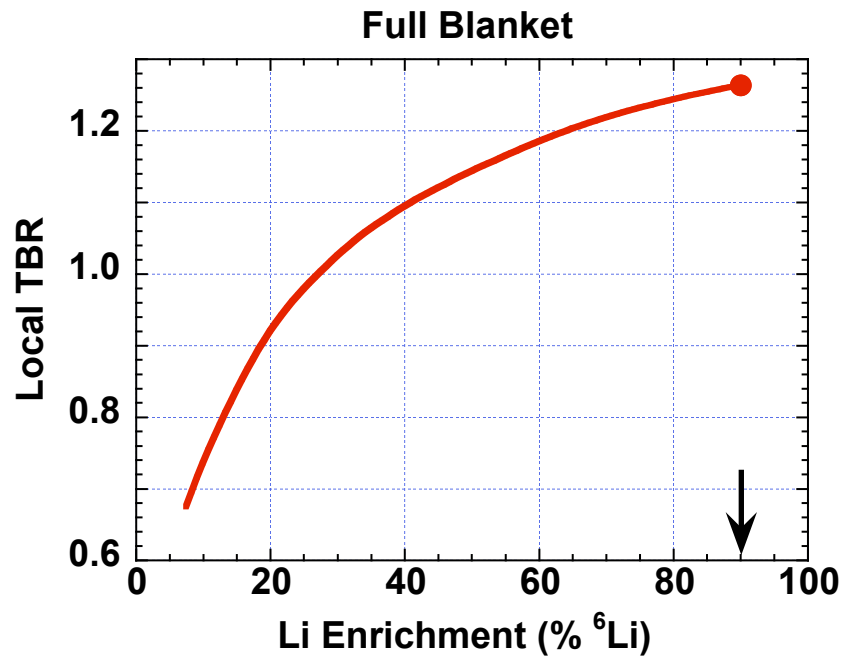
$R = 7.5 \text{ m}$
15% Divertor Coverage
Overall TBR ~ 1.1 based on 1-D estimate

Overall TBR (Cont.)

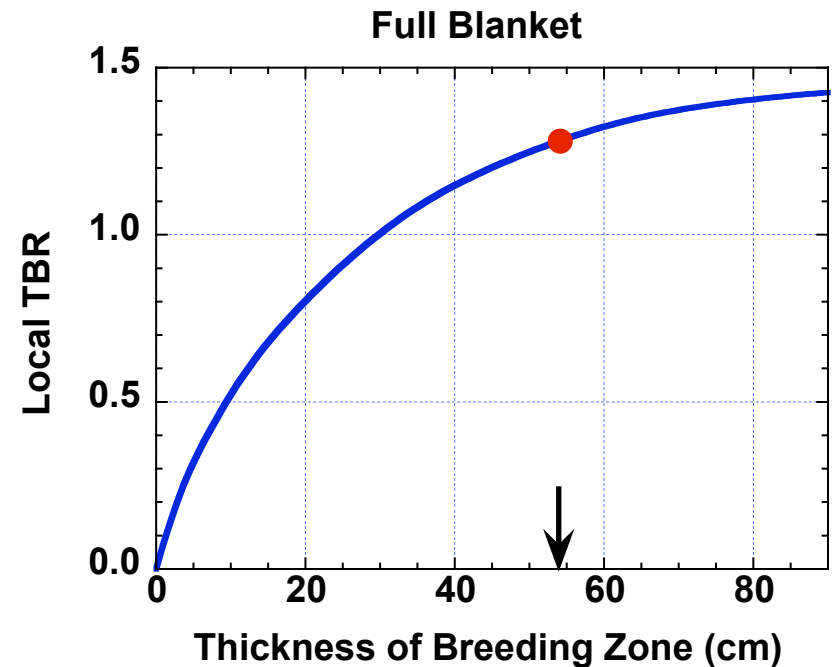
- 1-D TBR estimate **should be confirmed** with 3-D analysis.
- **Need CAD input file from UCSD** to couple it with MCNP 3-D neutronics code.
- **CAD data should include:**
 - Non-uniform SOL (5 - 20 cm)
 - Blanket variation
 - Divertor system
 - Penetrations.
- If 3-D results indicate:
 - **Over-breeding** (overall TBR > 1.1), lower Li enrichment below 90% (see next slide).
 - **Under-breeding** (overall TBR < 1.1):
 - Increase “full blanket” thickness by ~10 cm (see next slide), and/or
 - Increase major radius (□ R > 7.5 m).

Overall TBR (Cont.)

Full Blanket/Shield Region



Solution for **over-breeding** blanket:
Reduce Li enrichment below 90%.



Solutions for **under-breeding** blanket:
Increase blanket thickness
(or increase major radius).



Heat Load to In-vessel Components

(R= 7.5 m, P_f= 2561 MW)

Thermal Power (MW _{th})	Full Blkt/Shld	Divertor Region	Non-uniform Blkt/Shld	Total	
FW	117	---	57	174	94%
Divertor	---	159	---	159	
Blanket	1141	171	516	1827	
WC-Shield-I	---	---	48	48	
Back Wall	9	3	10	22	6%
Shield	58	21	49	128	
Manifolds	6	2	---*	8	
Total	1330 (56%)	356 (15%)	680 (29%)	2366	

□ Overall M_n= 1.155

Low Grade Heat:
VV

13

0.5

0.6

14
(< 1%)

* Contribution included in full blanket/shield manifolds.

Power Split between He & LiPb Coolants

(R= 7.5 m, P_f = 2561 MW)

Thermal Power (MW _{th})	He	LiPb	Total
Surface Heat	512	---	512
90% of He Pumping Power	125	---	125
FW	174	---	174
Divertor	159	---	159
Blanket	168	1659	1827
WC-Shield-I	48	---	48
Back Wall	22	---	22
Shield	128	---	128
Manifolds	3	5	8
Leakage from LiPb to He	+100	-100	0
Total	1439	1564	3003

□ **He : LiPb power ratio = 48 : 52**



Design Requirements Satisfied Except at Divertor (Unknown Location and NWL)

Overall TBR

(for T self-sufficiency)

1.1

Damage to Structure

200 dpa

Helium Production @ Manifolds and VV

(for reweldability of FS)

1 appm

S/C Magnet (@ 4 K):

Peak fast n **fluence** to Nb₃Sn ($E_n > 0.1$ MeV)

10^{19} n/cm²

Peak nuclear **heating**

2 mW/cm³

Peak **dpa** to Cu stabilizer

6×10^{-3} dpa

Peak **dose** to electric insulator

$> 10^{11}$ rads

Machine Lifetime

40 FPY

Availability

~ 85% ?



Key Parameters for Economic Analysis

$\beta_{\min}$

1.26

Overall TBR

1.1

Overall Energy Multiplication

1.155

He : LiPb Power Ratio

48 : 52

FW EOL Fluence

15 MWy/m²

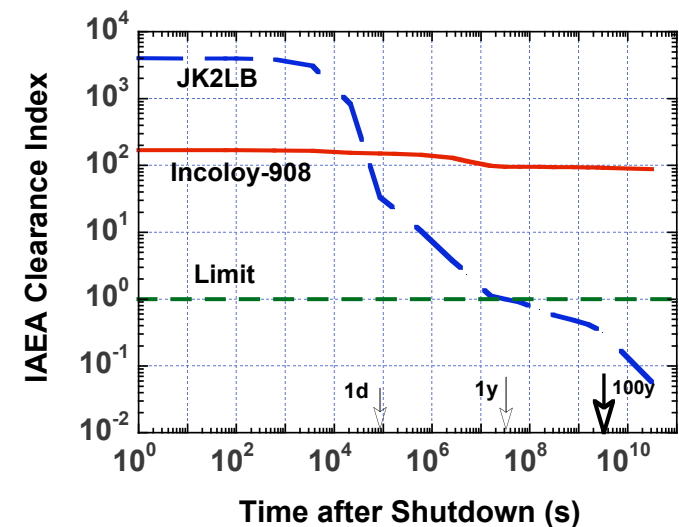
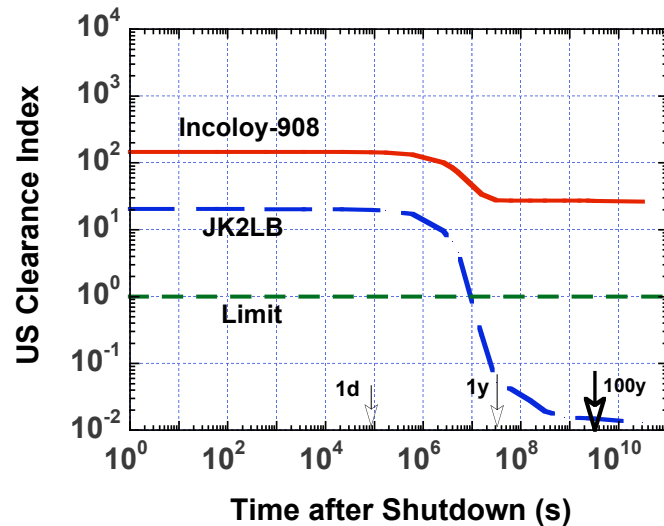
FW Lifetime

3.3 FPY (for 4.5 MW/m² peak β)

System Availability

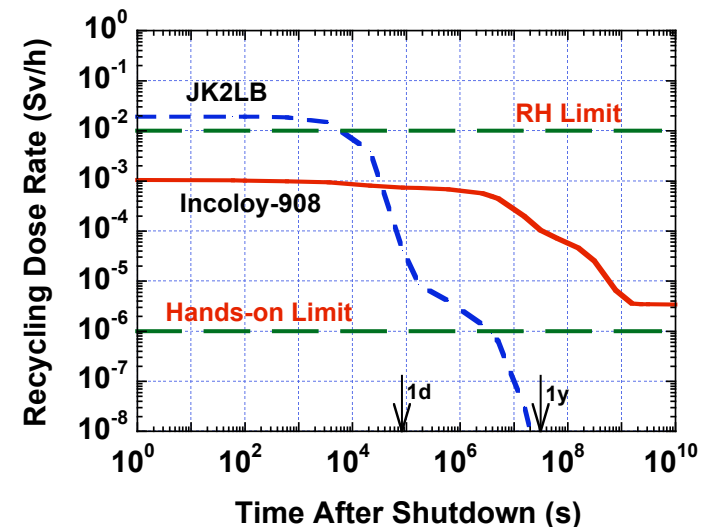
~ 85% ?

Magnet Structure: Incoloy-908 or JK2LB?



	Incoloy	JK2LB
Nb content	3 wt%	---
Class A WDR	0.1	0.0003
Clearable?	no	after 1 y
Recycle	remotely	hands-on

**^{94}Nb is main contributor to
CI and dose after 1 y**





Concluding Remarks and Future Plan

- **R= 7.5 m design offers adequate TBR. To be confirmed with 3-D analysis. Need CAD data from UCSD for all components, including divertor and penetrations.**
- Monitor location and orientation of **He access tubes**.
- Protection of components behind **divertor system** needs further assessment.
- **Future plan:**
 - Perform **3-D analysis** to confirm overall TBR and M_n for R= 7.5 m design.
 - Update **NWL distribution for R= 7.5 m design with non-uniform SOL** using latest parameters (neutron source profile, plasma surface, magnetic axis trajectory, and SOL variation).
 - **Check NWL at divertor** and assess **streaming** through divertor He access pipes
 - Document work.

ARIES-CS Publications

- **Two abstracts** submitted to **8th IAEA TM on Fusion Power Plant Safety**
(July 10-13, 2006, Vienna, Austria). Papers due at the meeting:
 - **L. El-Guebaly**, “Evaluation of Disposal, Recycling, and Clearance Scenarios for Managing ARIES Radwaste after Plant Decommissioning”
 - **L. El-Guebaly**, R. Pampin (UK), and M. Zucchetti (Italy), “Clearance Considerations for Slightly-Irradiated Components of Fusion Power Plants”.
- **Few abstracts will be submitted to 17th TOFE by June 9, 2006**
(Nov 13-15, 2006, Albuquerque, NM <http://tofe17.sandia.gov/home.html>)