Near-Final Radial Build and Nuclear Parameters

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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

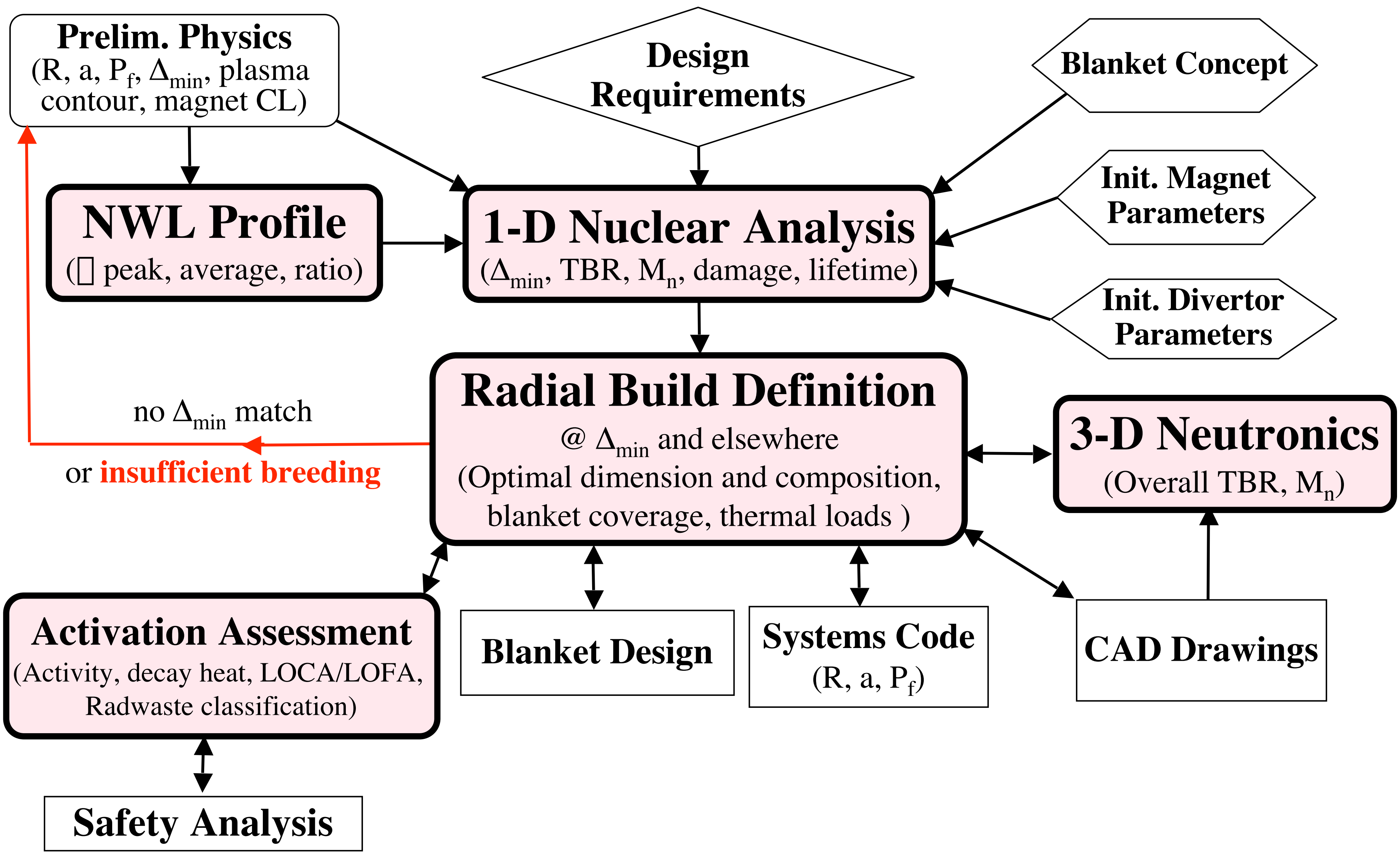
√ 11. Provide radial build for full blanket coverage

√ 12. Redefine reference radial build and post it on UW website

Contents

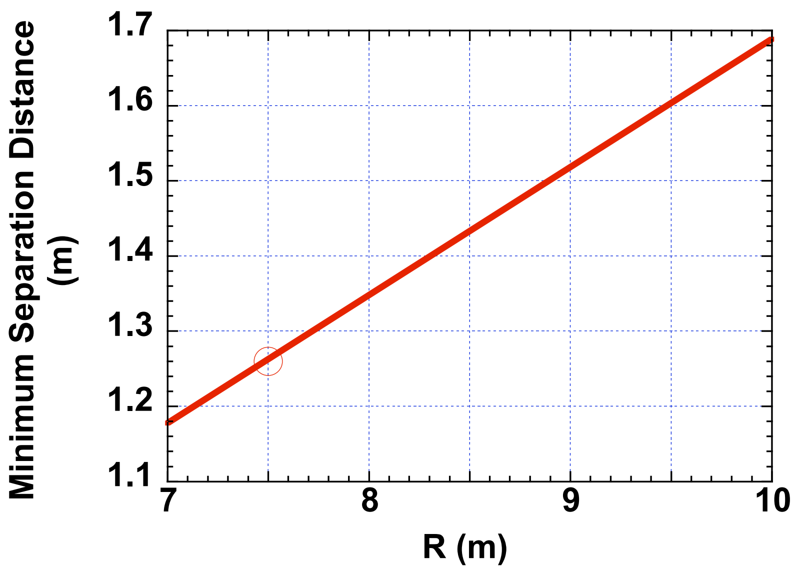
- Plasma - mid-coil separation contours for R = 7 - 8.5 m machines.
- Rationale for R = 7.5 m design.
- Near-final radial build **and** nuclear parameters.
- Orientation of He access tubes to mitigate streaming problem.
- Streaming concerns for divertor region.
- Updates:
  - Heat load to all components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

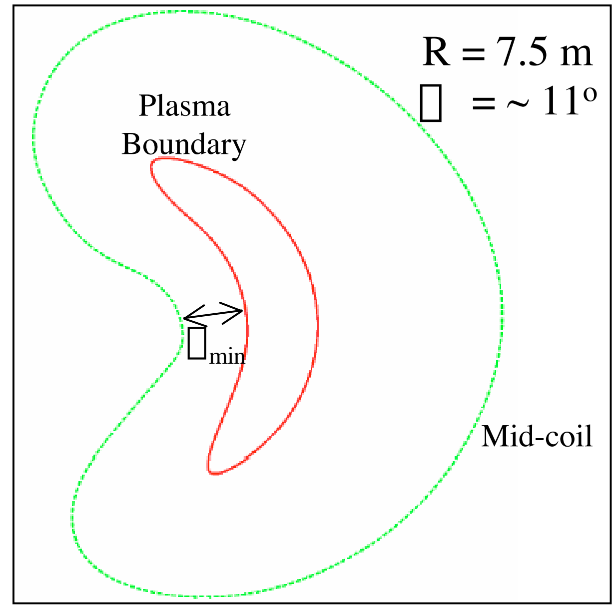
Insufficient Breeding for R= 7 m Machine Mandates Another Iteration

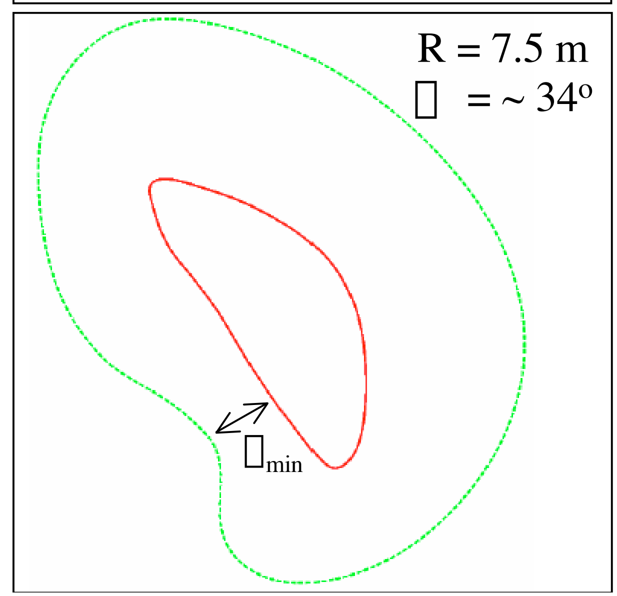


New Plasma – Mid-coil Separation Contours

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





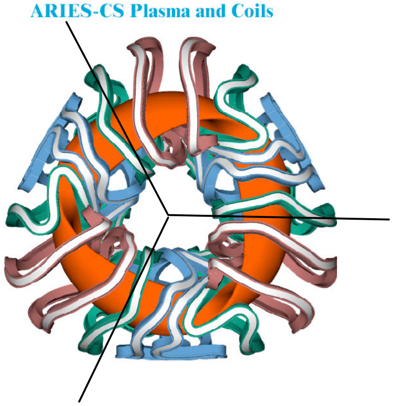


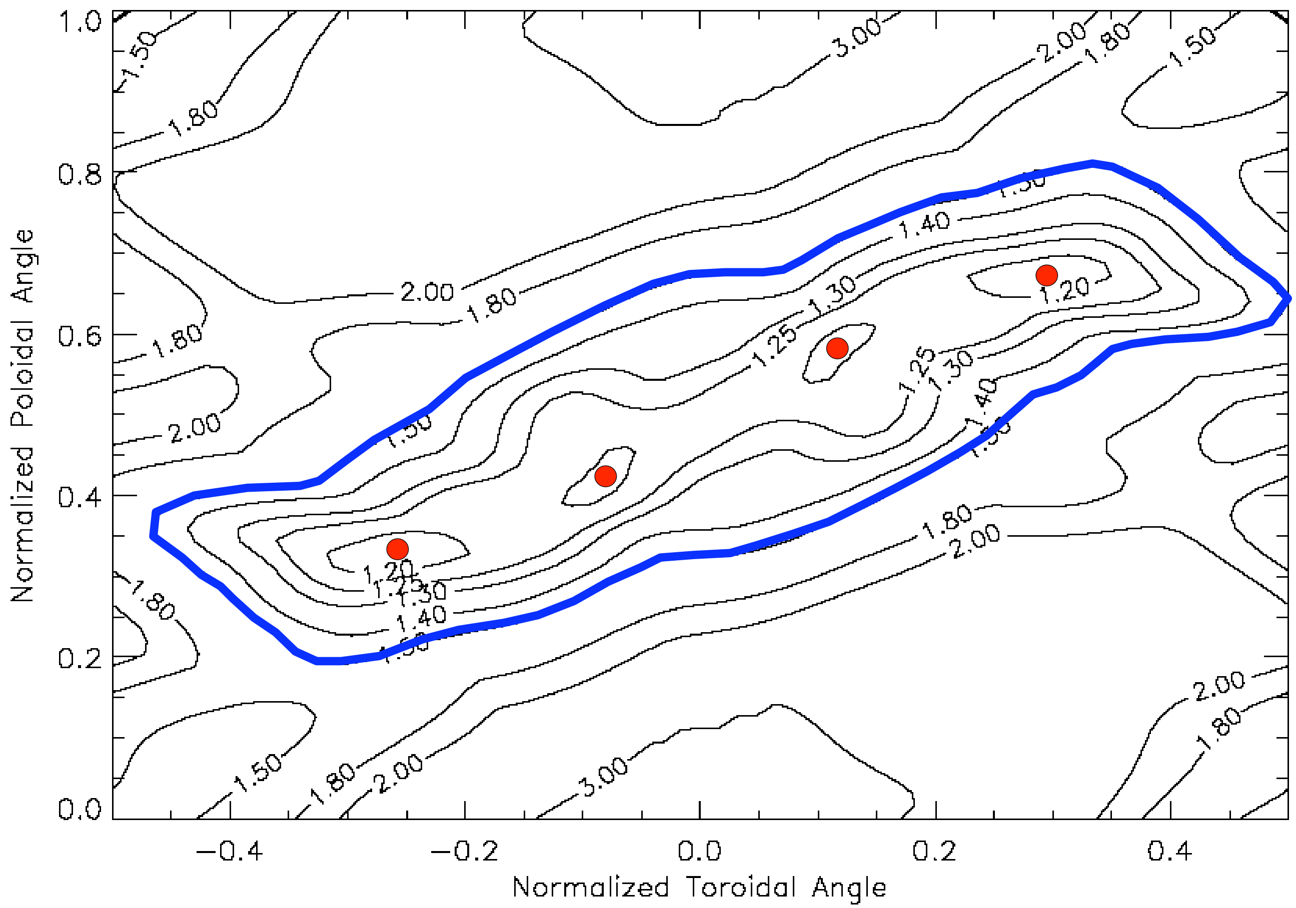
CAD Confirmed UW Estimate for Blanket Coverage Fractions

R= 7 m machine	UW Estimate	CAD
Non-uniform Blanket	35%	36%
Uniform Blanket	65%	64%

R = 7 m

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

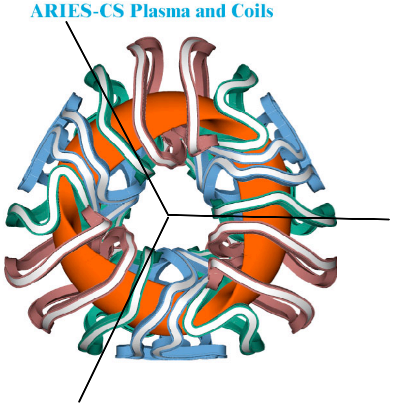


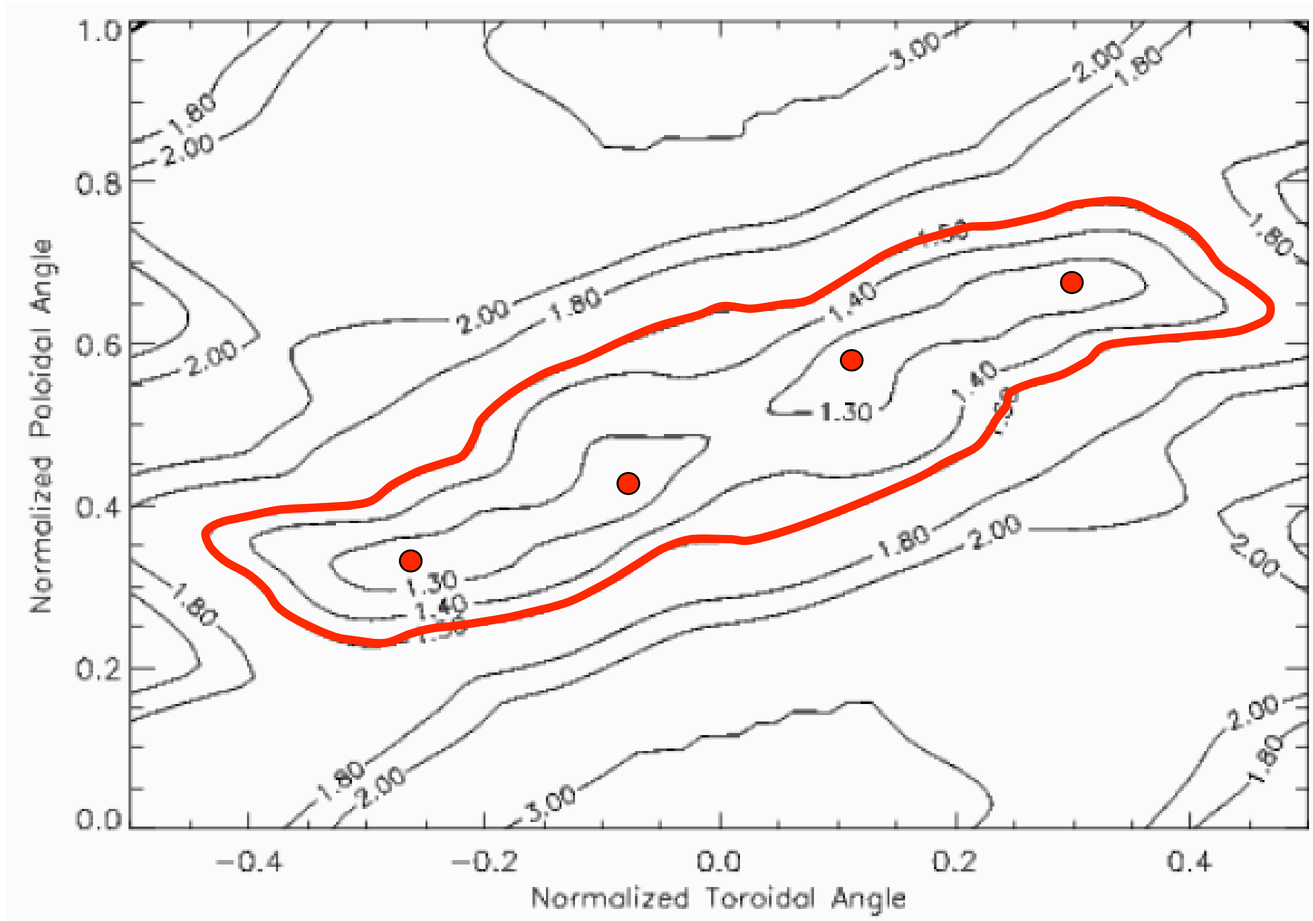


- **Uniform blanket and divertor** outside **blue** contour covers **~65%** of FW area.
- **Non-uniform, tapered blanket** inside **blue** contour covers **~35%** of FW area.

R = 7.5 m

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



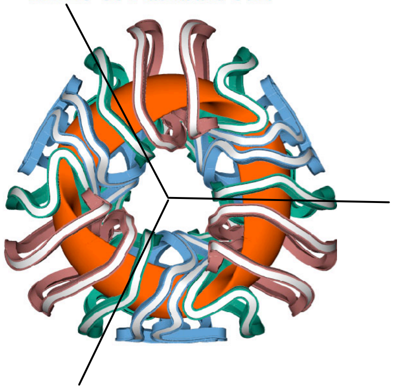


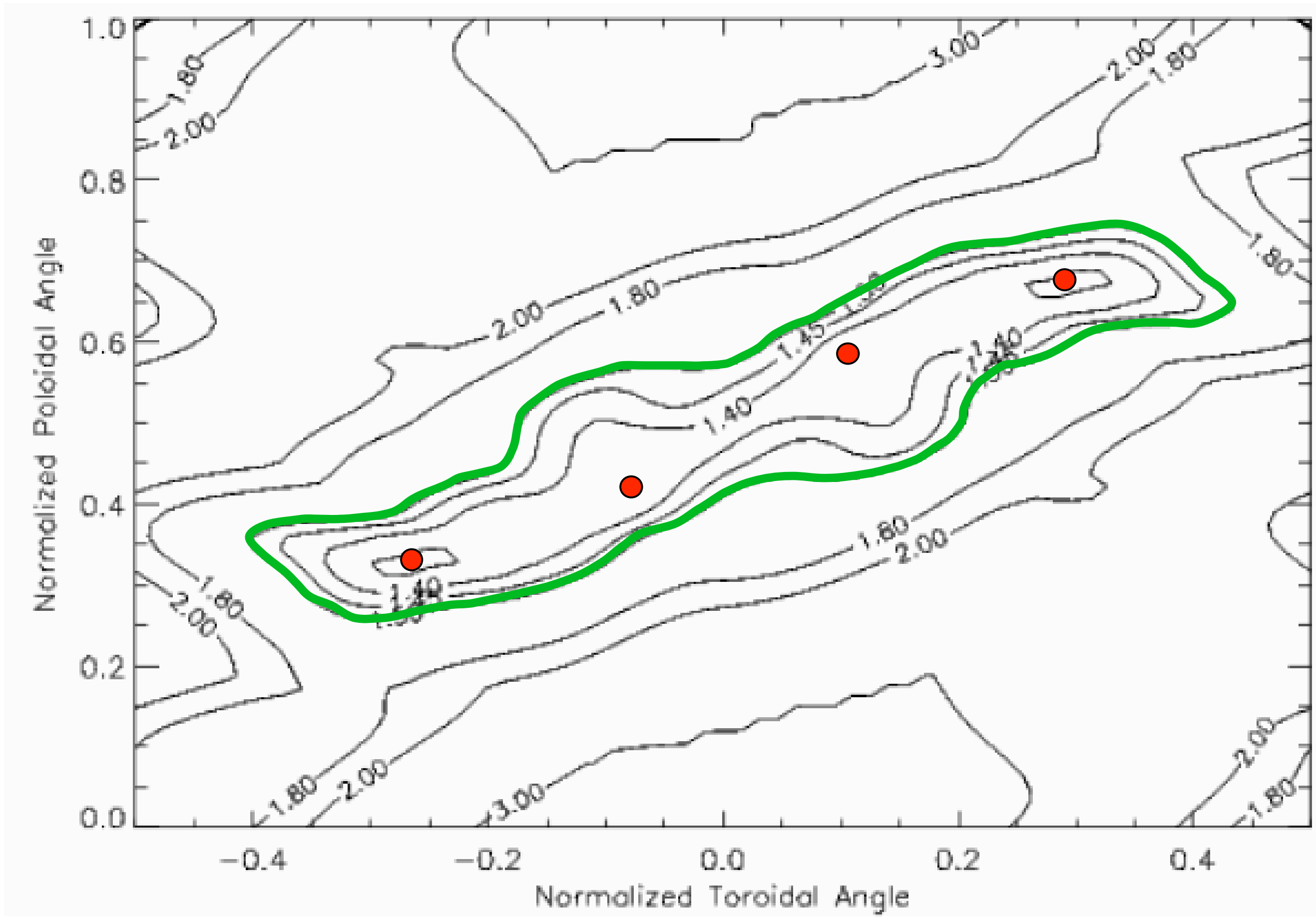
- **Uniform blanket and divertor** outside **red** contour covers **~72%** of FW area.
- **Non-uniform**, **tapered blanket** inside **red** contour covers **~28%** of FW area.

R = 8 m

[4 □$_{min}$ (= 1.34 m) marked in red]

ARIES-CS Plasma and Coils

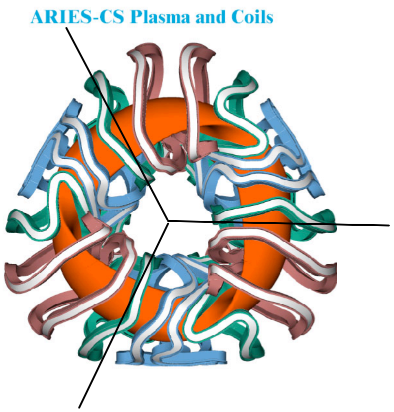


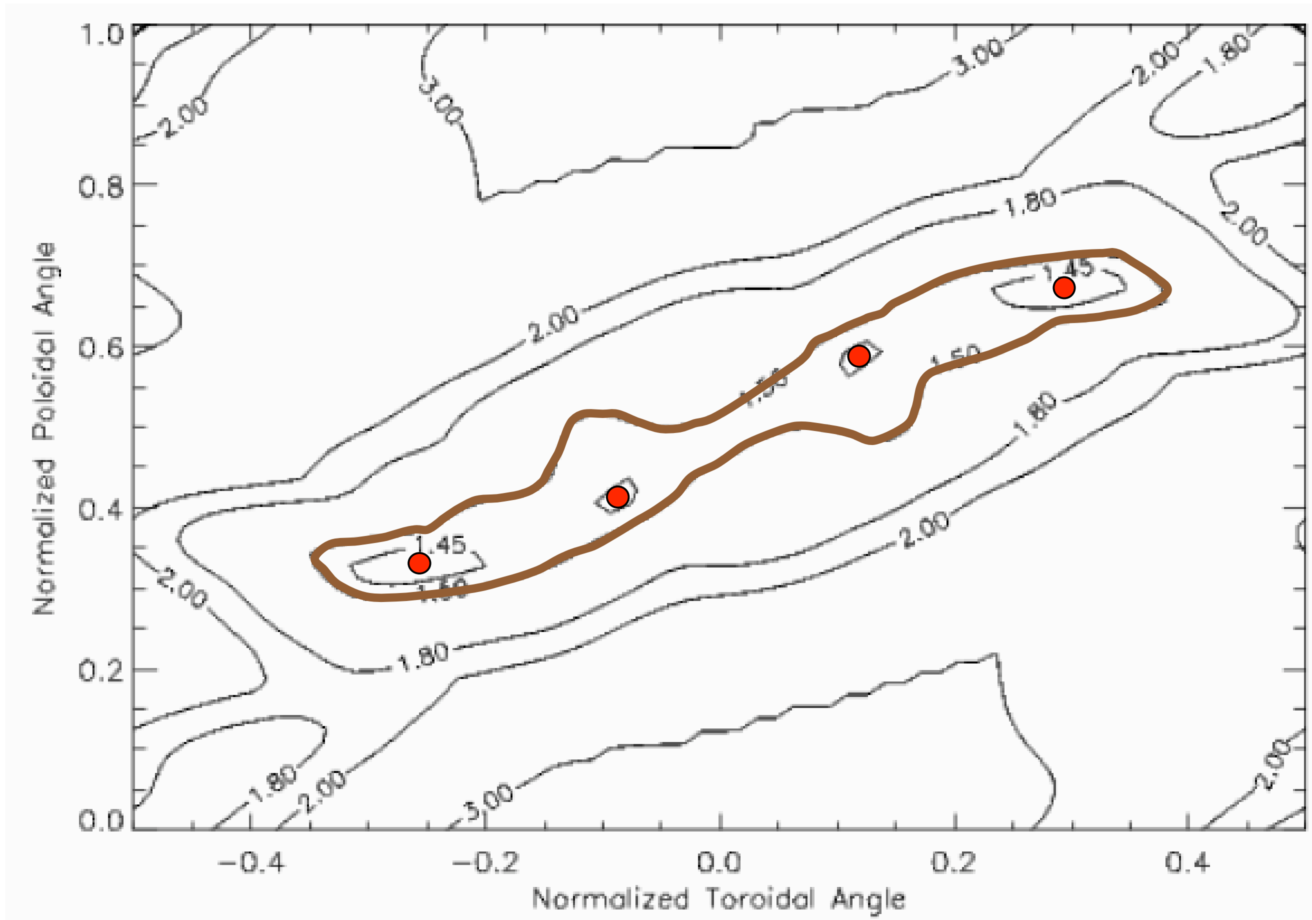


- **Uniform blanket and divertor** outside green contour covers ~**80%** of FW area.
- **Non-uniform, tapered blanket** inside green contour covers ~**20%** of FW area.

R = 8.5 m

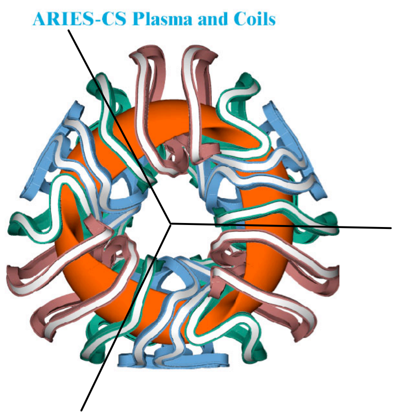
[4 □$_{min}$ (= 1.43 m) marked in red]

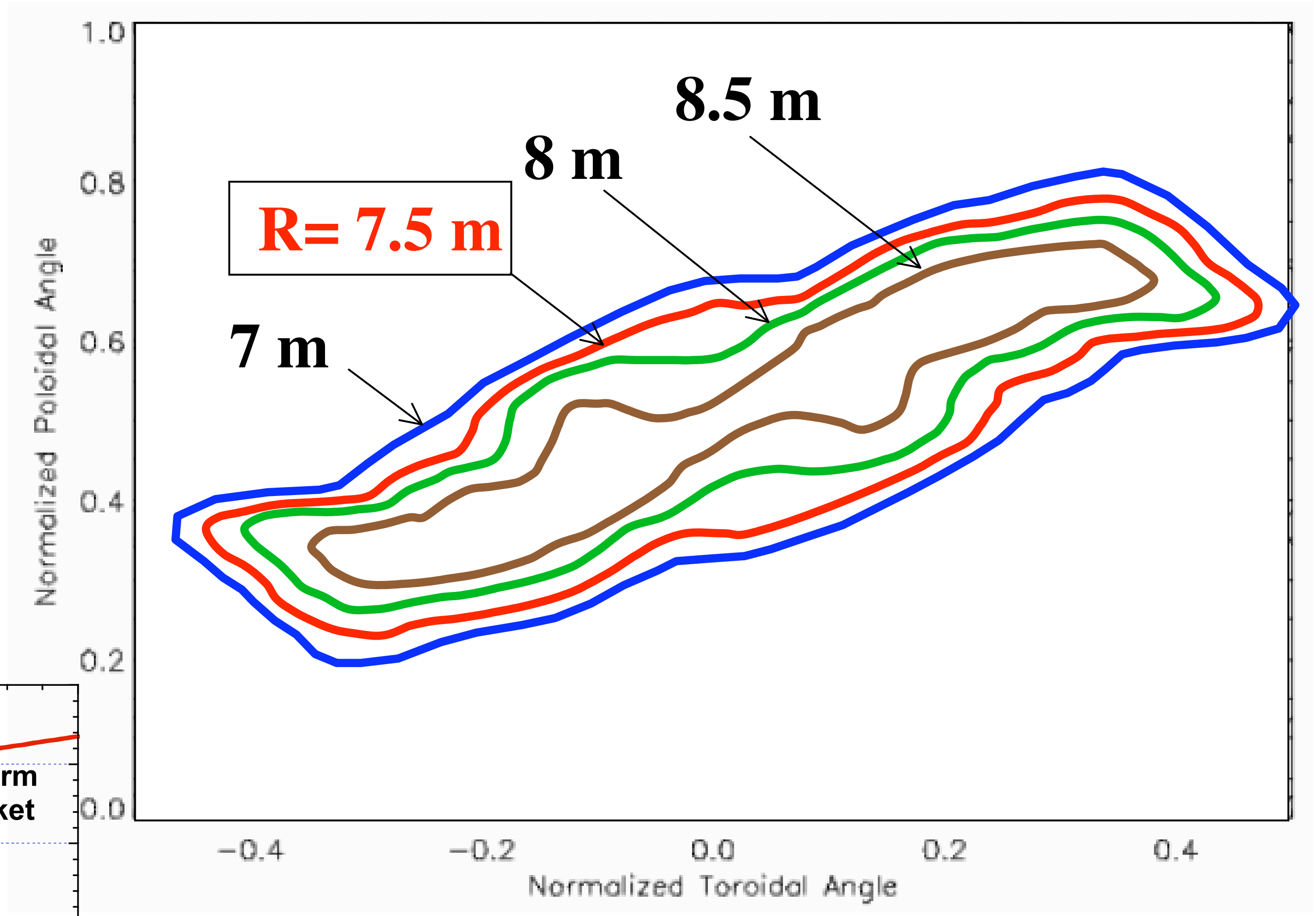


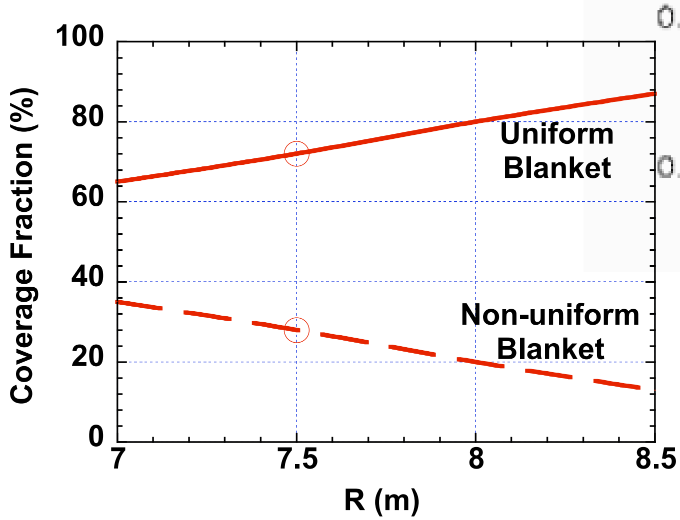


- **Uniform blanket and divertor** outside **brown** contour covers **~87%** of FW area.
- **Non-uniform, tapered blanket** inside **brown** contour covers **~13%** of FW area.

Non-uniform Blanket Coverage Decreases with R

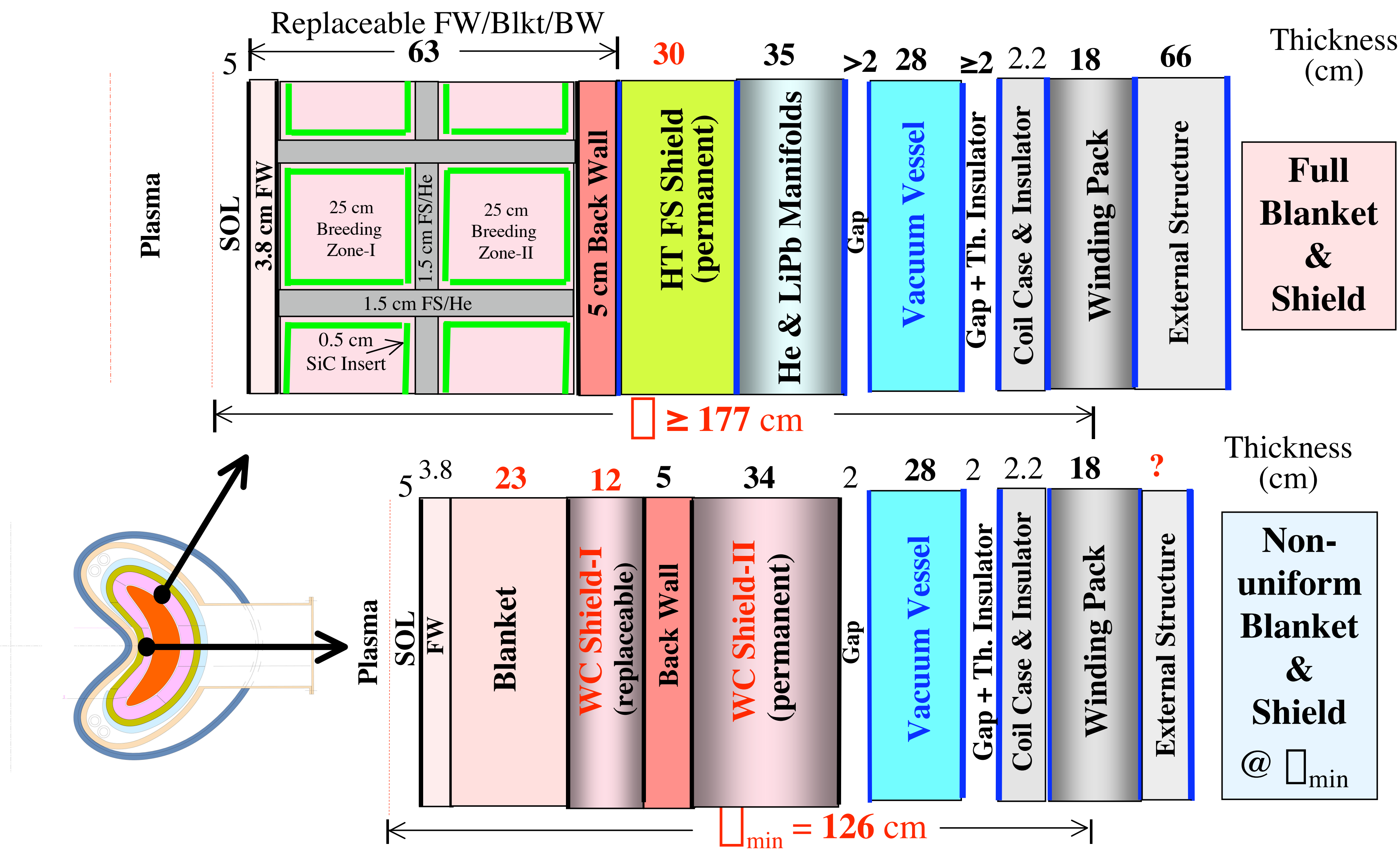






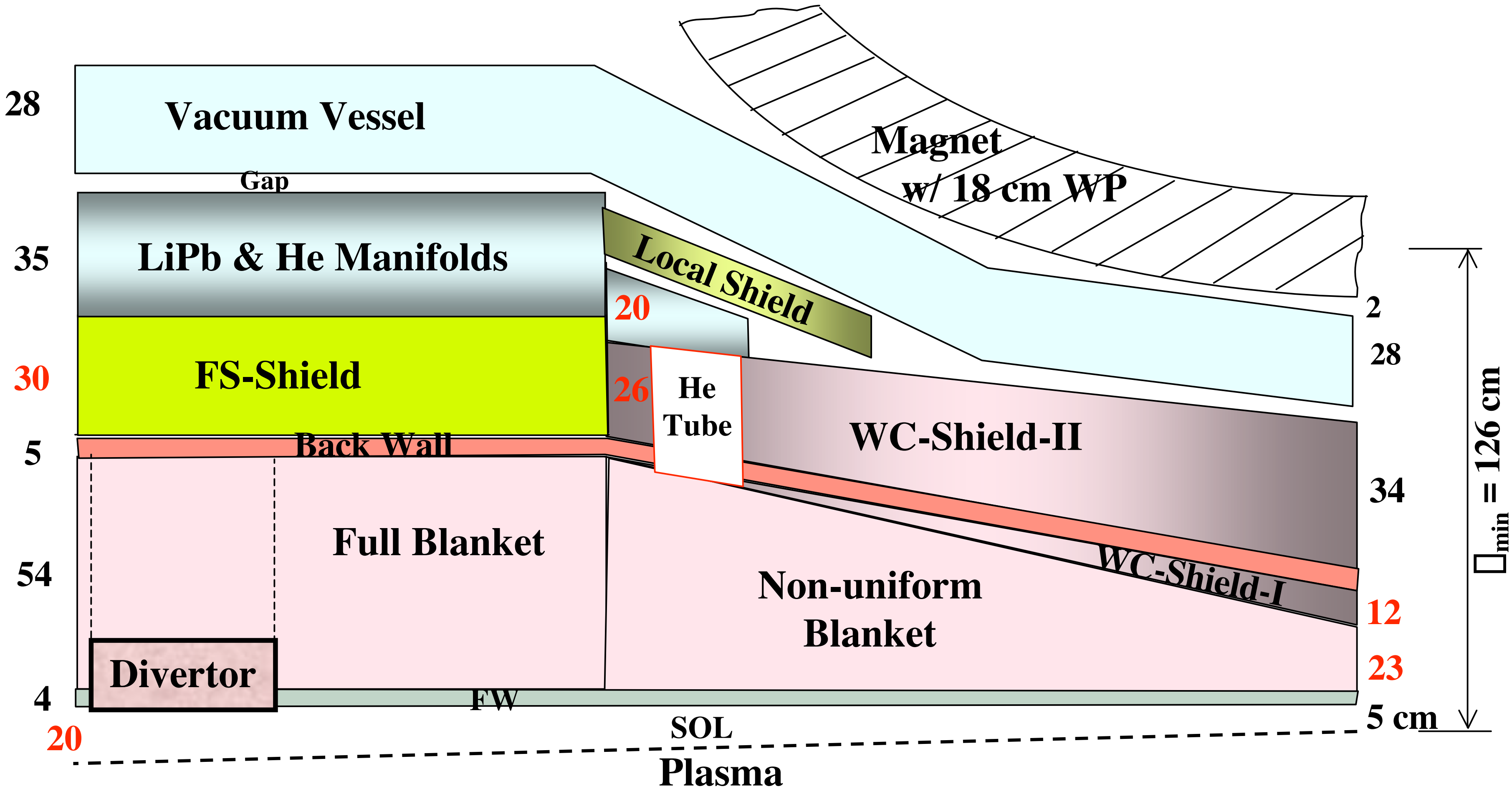
Near-Final Radial Build

(R= 7.5 m ; 4.5 MW/m^2 peak □)



Radial / Toroidal Xn

(R= 7.5 m ; 4.5 MW/m^2 peak □)

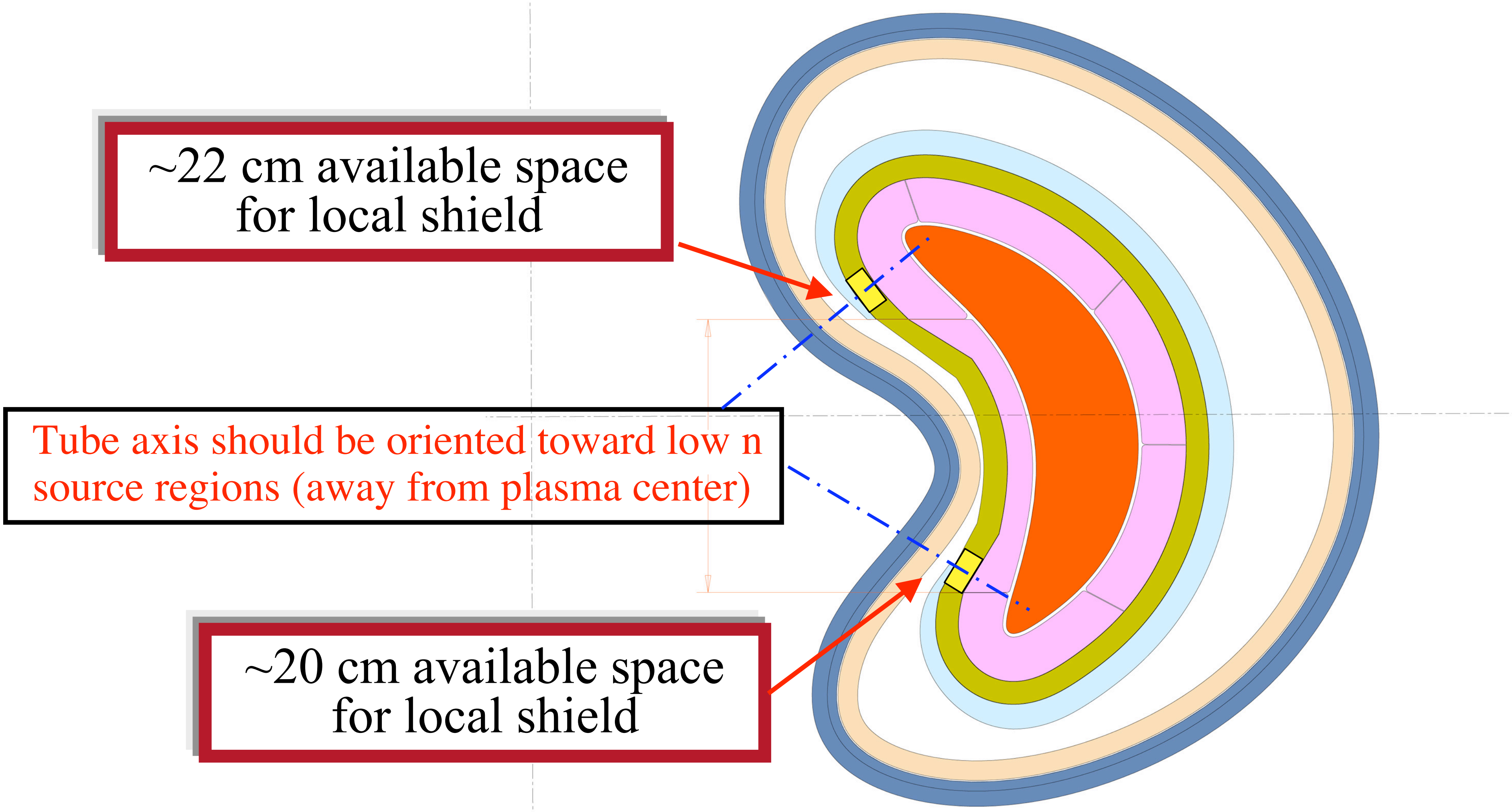


Full Blanket/shield **and** Divertor
(57%+15%= 72% of FW area)

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

Streaming Through Blanket He Access Tubes (Cont.)

(Non-uniform Blanket Region)



Monitor location/orientation of He access tubes as design develops

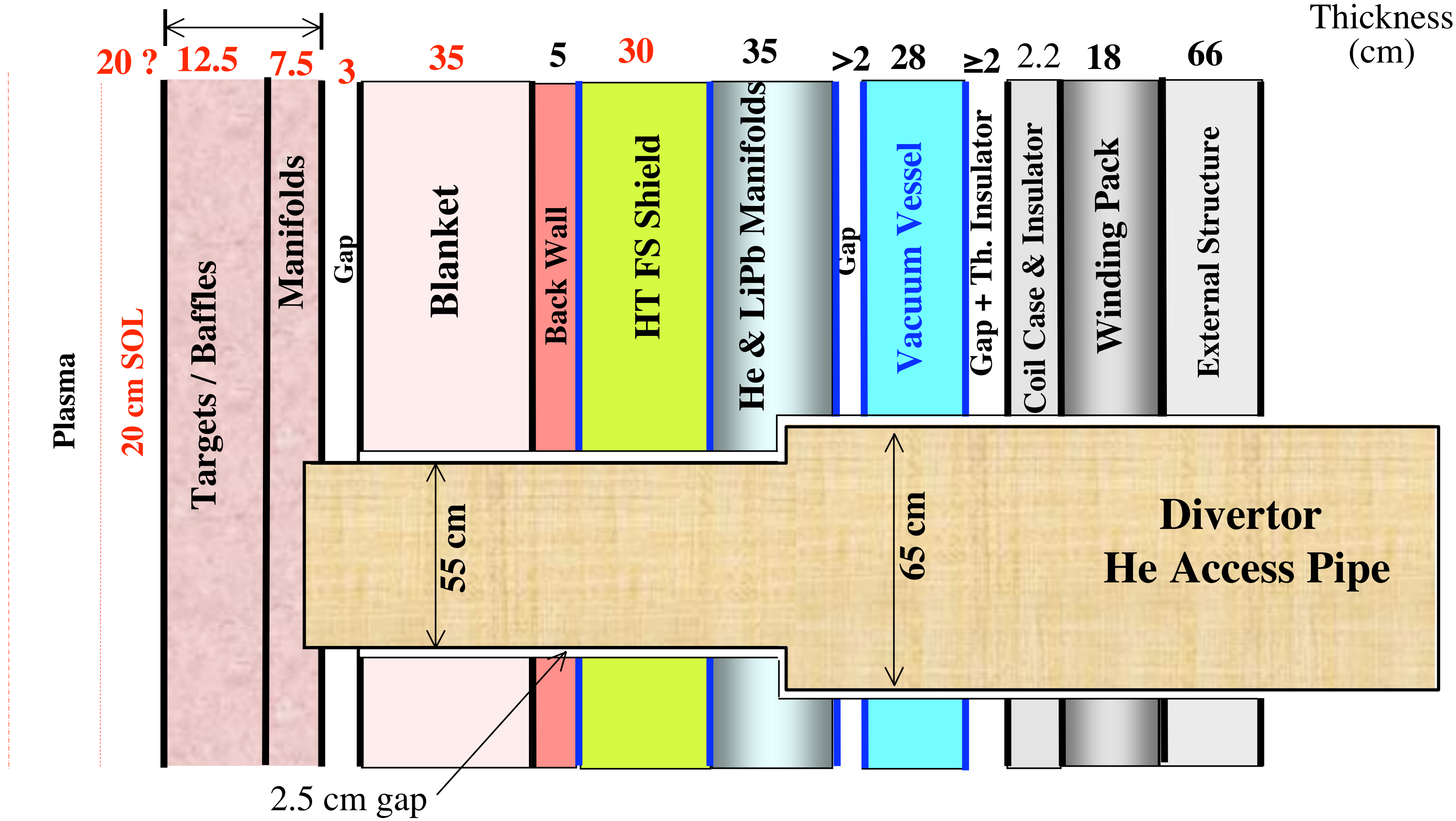
Streaming Through Blanket He Access Tubes
(Non-uniform Blanket Region)

- 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/m^2 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/m^2 peak □)

Component	Thickness	Coverage Fraction		Composition
FW*	3.8 cm	85%	100% (FW + Divertor System)	34% FS Structure 66% He Coolant
Divertor System*	20 cm	15%		32.6% FS Structure 4.0% W 63.4% He Coolant
Blanket behind Divertor*	35 cm	15%	100% (Blanket behind Divertor + Non-uniform Blanket + Full Blanket)	75% LiPb (90% enriched Li) 9% SiC Inserts 8% FS Structure 8% He Coolant
Non-uniform Blanket*	23 - 54.3 cm	28%		76% LiPb (90% enriched Li) 8% SiC Inserts 8% FS Structure 8% He Coolant
Full Blanket*	54.3 cm	57%		79% LiPb (90% enriched Li) 7% SiC Inserts 6% FS Structure 8% He Coolant
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.)

Component	Thickness	Coverage Fraction	Composition
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%	18.5% Incoloy-908 Structure 48.2% Cu 12.8% Nb_3Sn 10.0% GFF Polyimide 10.5% LHe Coolant
External Structure (behind WPs only)	56 +10 cm	33%	95% Incoloy-908 Structure 5% LHe Coolant
Inter Coil Structure (between WPs)	35 cm	67%	95% Incoloy-908 Structure 5% LHe Coolant

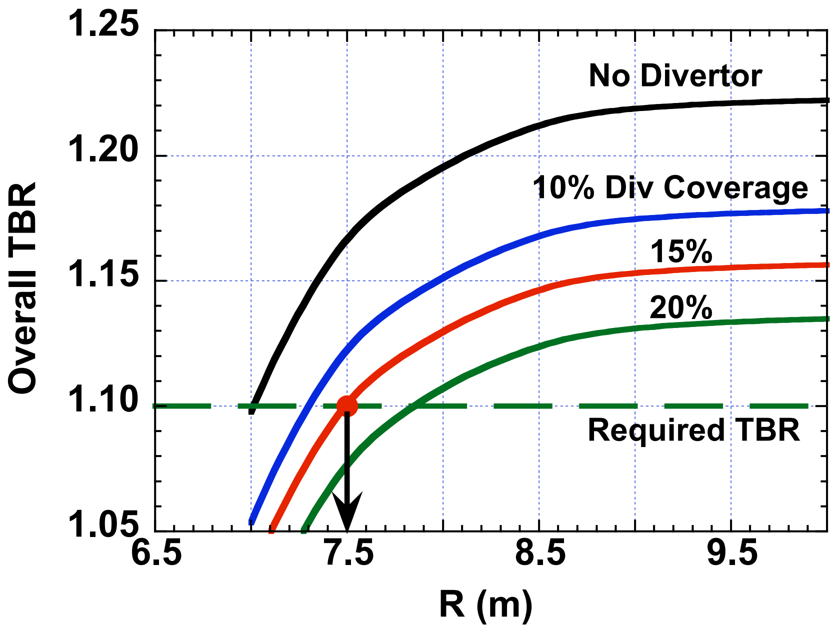
100%

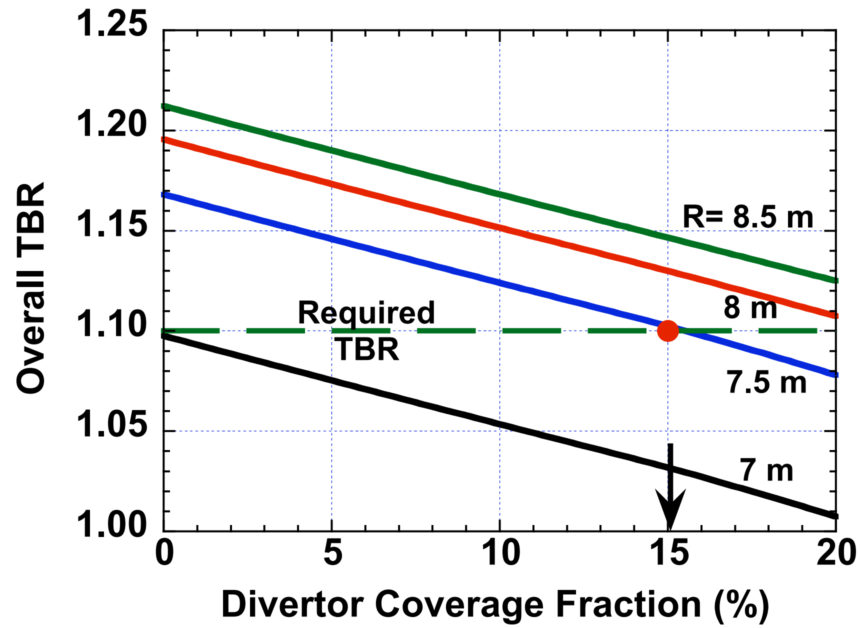
* Replaceable component.

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 m

15% Divertor Coverage

Overall TBR ~ 1.1 based on 1-D estimate

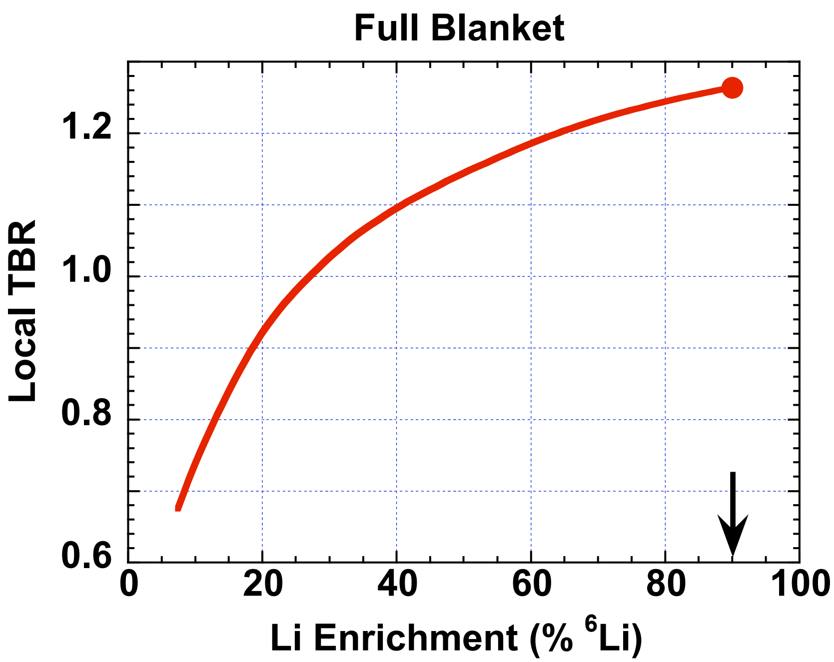
Overall TBR (Cont.)

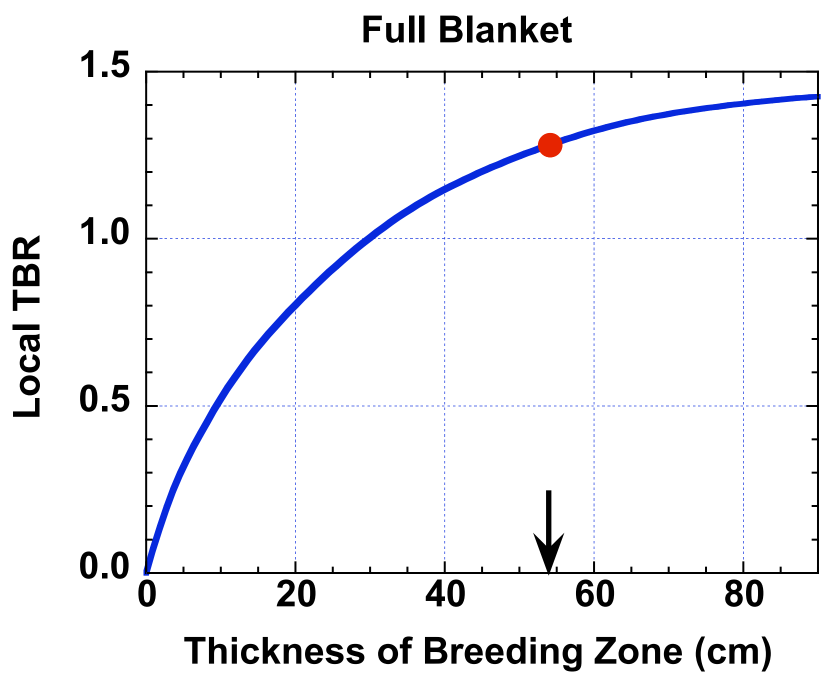
- 1-D TBR estimate should be confirmed with 3-D analysis.
- **Need** CAD input file from UCSD to couple it with MCNP 3-D neutronics code.
- CAD data should include:
  - Non-uniform SOL (5 - 20 cm)
  - Blanket variation
  - Divertor system
  - Penetrations.

- 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**	
Shield	58	21	49	**128**	6%
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

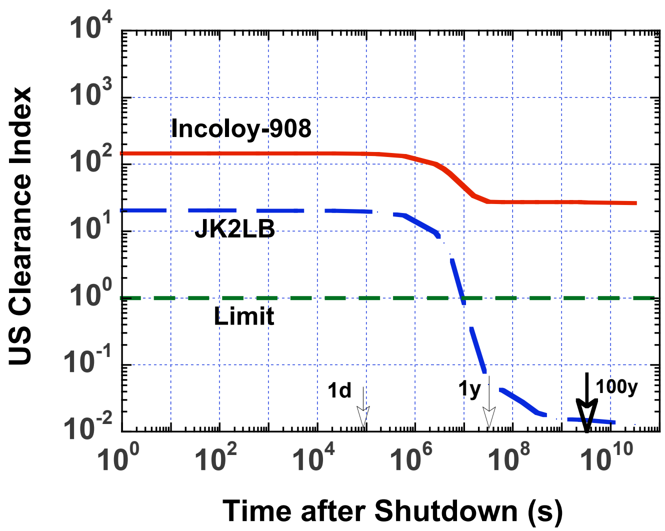
Design Requirements Satisfied Except at Divertor (Unknown Location and NWL)

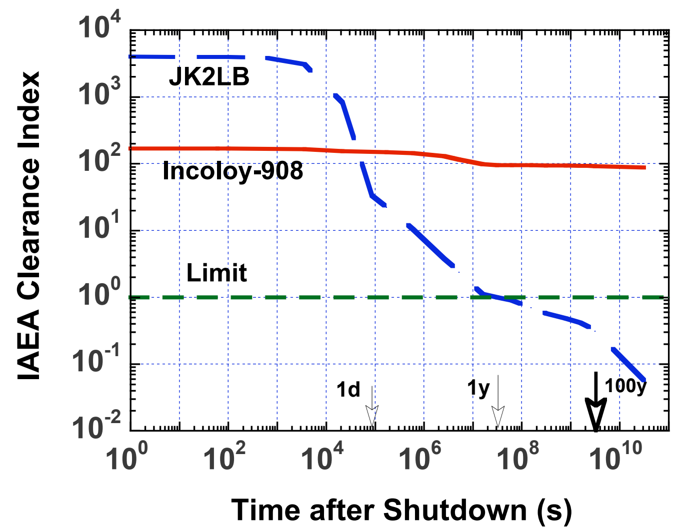
Overall TBR (for T self-sufficiency)	1.1	
Damage to Structure	200	dpa
Helium Production @ Manifolds and VV (for reweldability of FS)	1	appm
S/C Magnet (@ 4 K):		
Peak fast n **fluence** to Nb_3Sn (E_n > 0.1 MeV)	10^{19}	n/cm^2
Peak nuclear **heating**	2	mW/cm^3
Peak **dpa** to Cu stabilizer	$6x10^{-3}$	dpa
Peak **dose** to electric insulator	> 10^{11}	rads
Machine Lifetime	40	FPY
Availability	~ 85%	?

Key Parameters for Economic Analysis

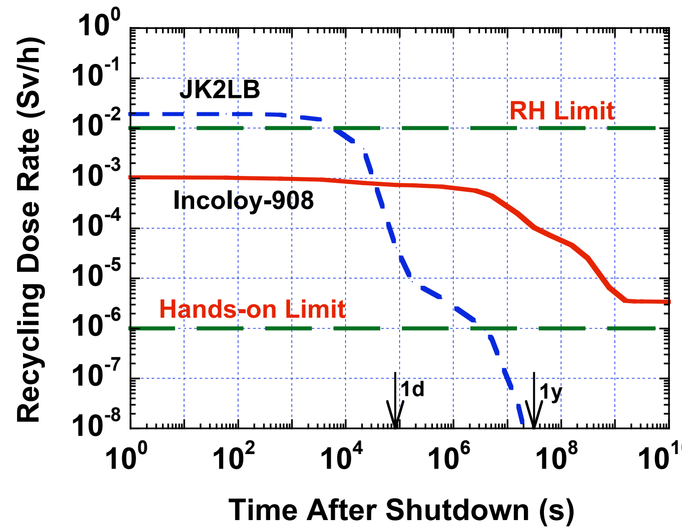
$□_{min}$	**1.26**
Overall TBR	**1.1**
Overall Energy Multiplication	**1.155**
He : LiPb Power Ratio	**48 : 52**
FW EOL Fluence	**15 MWy/m^2**
FW Lifetime	**3.3 FPY** (for 4.5 MW/m^2 peak □)
System Availability	**~ 85%** ?

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)