Minimum Radial Standoff: Problem Definition and Needed Info

L. El-Guebaly

Fusion Technology Institute
University of Wisconsin - Madison

With Input from:

S. Malang, R. Raffray (UCSD),
J. Lyon (ORNL),
and P. Heitzenroeder (PPPL)

ARIES Project Meeting
January 8-10, 2003
UCSD

THE UNIVERSITY of WISCONSIN MADISON

Outline

- Key elements and design options for compact radial build.
- Breeding assessment of example blanket design.
- Needed info for shielding analysis.
- Comparison between radial builds of SPPS, HSR, QA#2, and ARIES-CS !?.

THE UNIVERSITY of WISCONSIN MADISON

Initial Parameters
(Case QA#2*, per Lyon)

Net Electric Power	1000 MW_e
# of Field Periods	3
A	4.4
< R >	9.93 m
< a >	2.26 m
Average Neutron Wall Loading	1.37 MW/m^2
FW Area	~ 900 m^2
Minimum Plasma to Coil-Center Distance (Δ) (Scaled from ARIES-AT)	1.6 m

* J. Lyon's presentation, ARIES project meeting at PPPL, Oct 2-4, 2002.

Neutron Wall Loading Profile

- Toroidal/poloidal distribution will be determined with 3-D neutronics code MCNP.

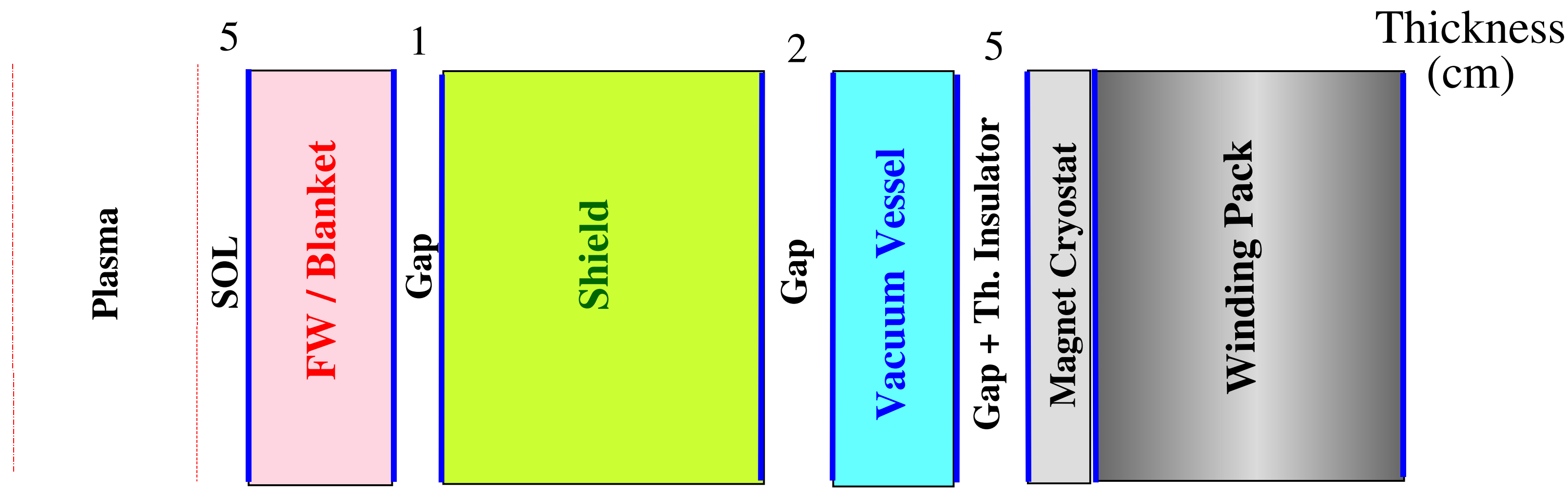
- Needed info:
  - Fusion power
  - Radial variation of neutron source
  - Magnetic shift.

- For now, **peak** NWL of 2 MW/m^2 will be used in preliminary shielding analysis.

- NWL may not peak at location of minimum plasma-coil distance.

THE UNIVERSITY of WISCONSIN MADISON

Key Elements Comprising Radial Build



- FW and Blanket recover 90% of n energy and breed T.
- All components are permanent, except FW/blanket and divertor.
- All components provide shielding function:
  - Blanket protects shield
  - Blanket and shield protect VV
  - All components protect magnets
  - All components and building protect workers and public.

THE UNIVERSITY of WISCONSIN MADISON

Design Requirements and Radiation Limits Influence Size and Constituents of Components

	Requirements / Limits	
Overall TBR (for T self-sufficiency)	1.1	
dpa @ FS-based shield (for structural integrity)	200 dpa	
Helium production @ VV (for reweldability)	1 appm	
Magnet damage:	**LT** (@ 4 k)	**HT** (@ > 60 k)
n **fluence** to Nb_3Sn or YBCO (n/cm^2, $E_n > 0.1$ MeV)	10^{19}	10^{19}
Dose to poly. insulator (rads)	10^{11}	10^{11}
Nuclear **heating** (mW/cm^3)	2	—
dpa to Cu stabilizer (dpa)	$6x10^{-3}$	—
Biological dose outside building (for workers and public protection)	2.5 mrem/h	

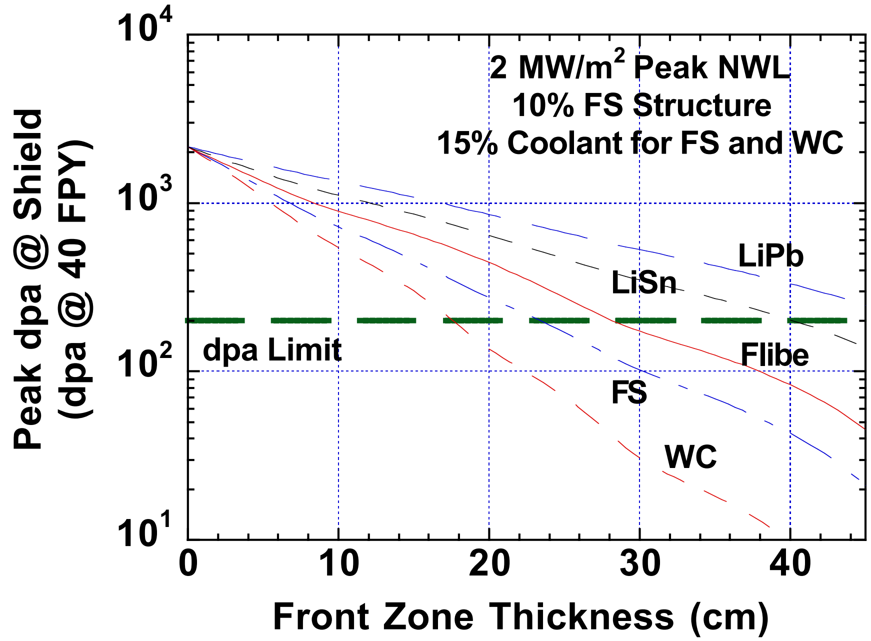
THE UNIVERSITY of WISCONSIN MADISON

Potential Breeders for Stellarator

Liquid breeders		**Solid breeders**
LiPb:	UWTOR-M, (UW, 1982)	Li_2O
	ASRA6C (KfK/UW, 1987)	Li_2ZrO_3
	HSR (Garching, 1999)	Li_4SiO_4
Li:	SPPS (UCSD, 1997)	Li_2TiO_3
Flibe:	FFHR (J, 1990-present)	$LiAlO_2$
Flinabe		
LiSn		

- Liquid breeders simplify stellarator blanket design.
- Flibe, Flinabe, LiSn, and all solid breeders require beryllium (or Pb) multiplier to meet breeding requirement.
- To control breeding level, adjust:
  - Blanket thickness
  - ^6Li enrichment (10 - 90%)
  - Amount of Be/Pb multiplier.
- Be may raise economic, safety, and resource concerns.

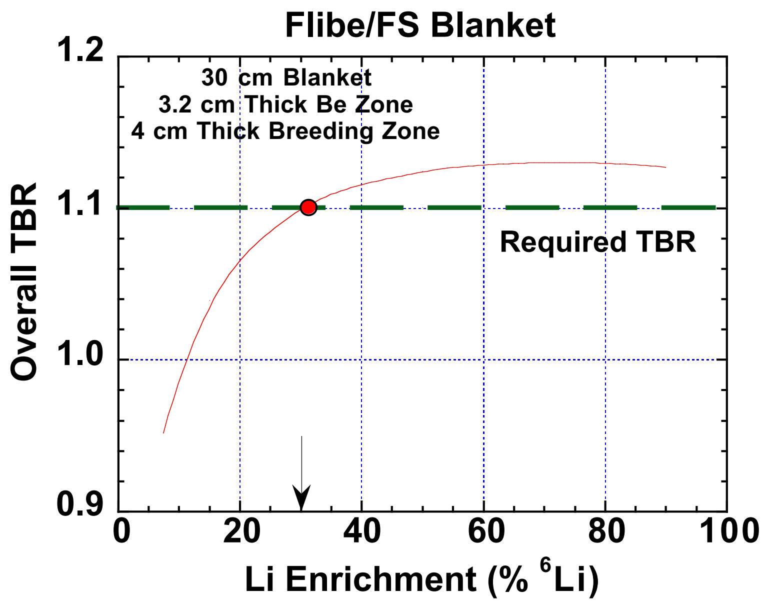
Blanket with High Shielding Performance Help Reduce Radial Build

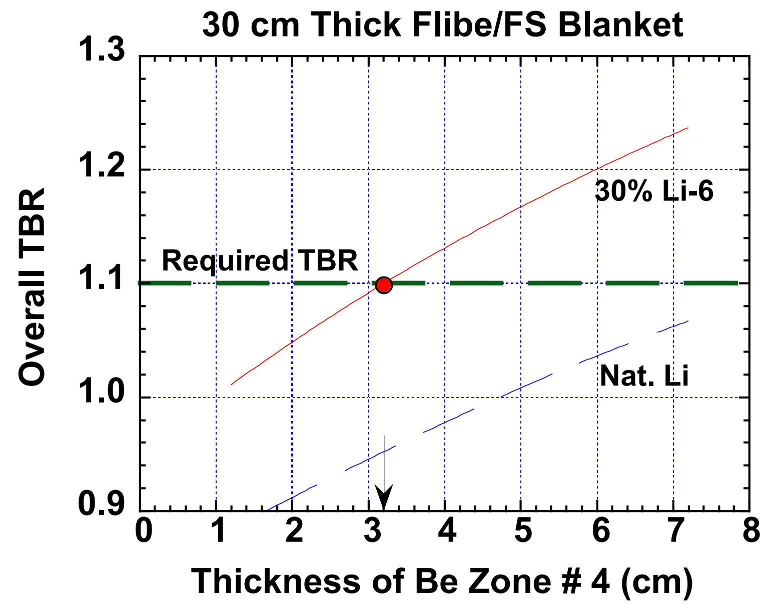


- Damage to shield is indicative of blanket shielding performance.
- Among liquid breeders, Flibe results in thinnest blanket (30 cm).
- For more compact design, replace blanket with WC-based shield in critical areas (at middle of each field period).

THE UNIVERSITY of WISCONSIN MADISON

Breeding Assessment of Flibe Blanket Option





- Details of example blanket design are covered in Malang's presentation.
- 30 cm thick blanket provides TBR of 1.1, assuming:
  - Penetrations occupy 2% of FW area
  - Divertor plates/baffles cover 15% of FW area and cooled with He
  - Shield-only zones occupy 2% of FW area (~ 2.5 m x 2.5 m each).
- Flibe blanket has ~15% excess breeding capacity (with more Be and higher enrichment).

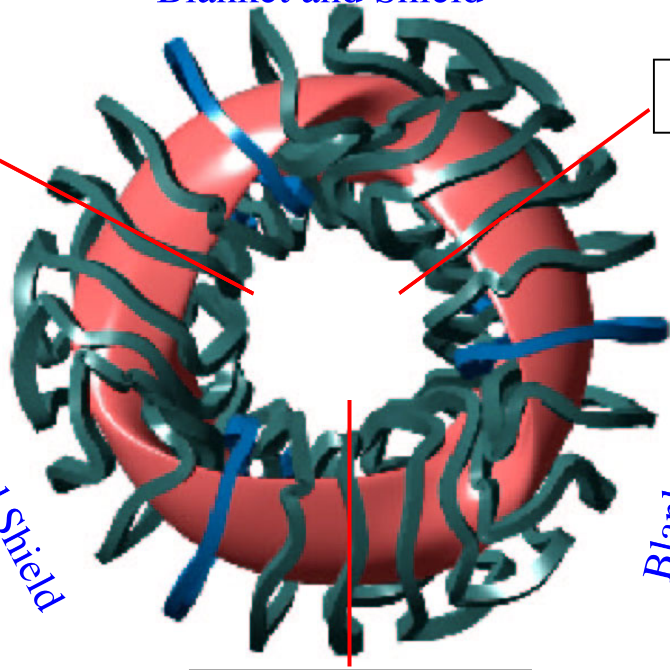
THE UNIVERSITY of WISCONSIN MADISON

Shielding and VV Components

- Low-cost steel-based shield could be 45 cm thick to ensure reweldability of VV at any time during operation (40 FPY).
- Steel-based shield consists of: 15% FS structure
10% coolant (Flibe)
75% **Borated-steel filler**.
- Replacing Borated-steel filler with **WC filler** reduces shield thickness by ~5 cm.
- VV will be cooled with water (good shielding material).
- Need info on magnet to develop VV design:
  - HT or LT magnet?
  - Any changes to radiation limits?
  - Winding pack composition and dimension
  - Cryostat thickness and composition (coil case, insulator, etc.)

THE UNIVERSITY of WISCONSIN MADISON

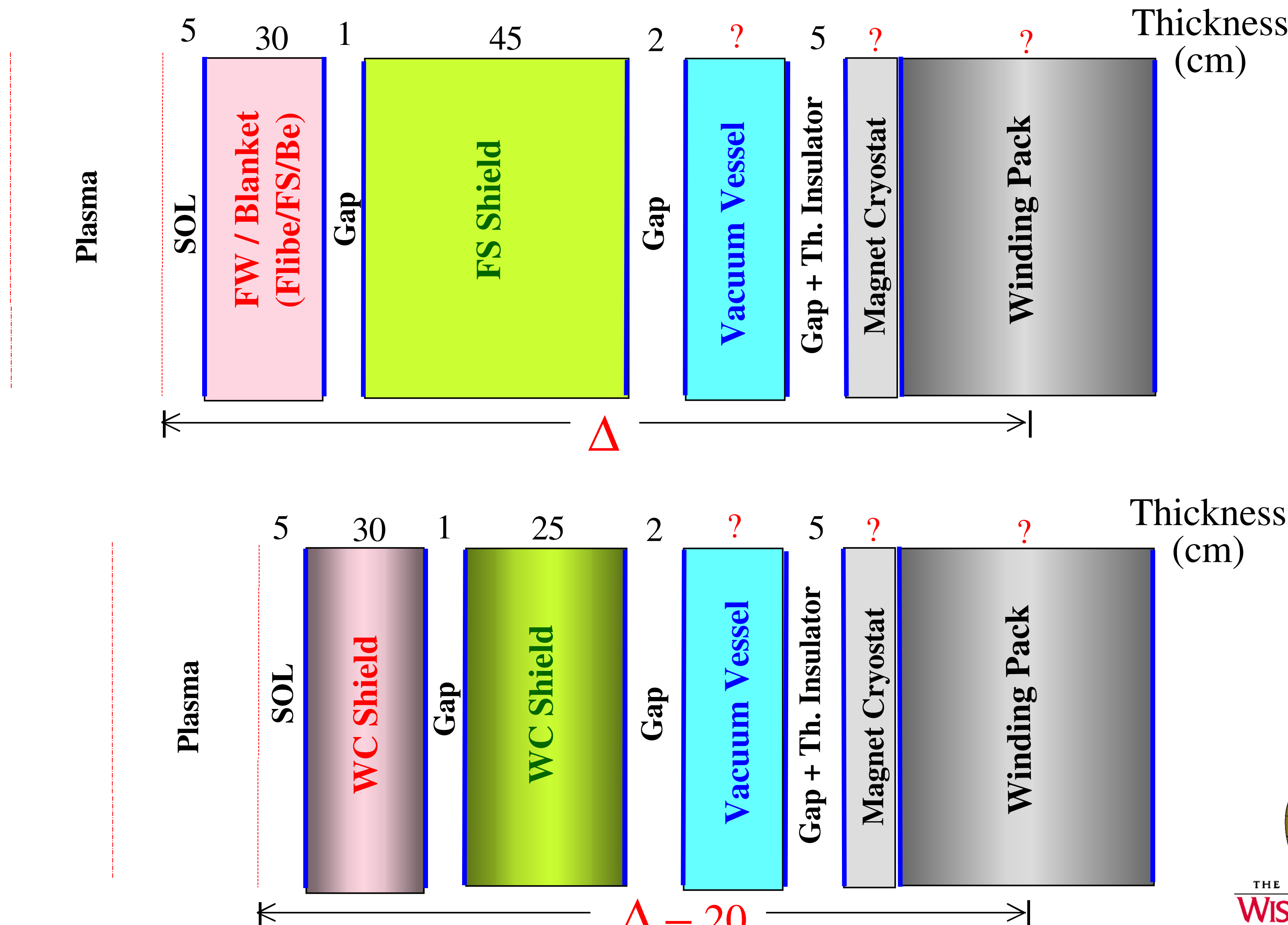
Shield-only Zones Offer up to 20 cm Reduction in Radial Build



- In shield-only zones:
  - Replace blanket with WC-shield
    (10% FS, 15% coolant (Flibe), 75% WC filler)
  - Replace 45 cm thick FS-shield with 25 cm thick WC-shield
    (15% FS, 10% coolant (Flibe), 75% WC filler).
- Shield-only zones may introduce engineering problems that need innovative design solutions.

THE UNIVERSITY of WISCONSIN MADISON

Radial Build
(Flibe/FS Blanket Option)



Comparison Between Radial Builds

Thickness (cm):	SPPS	HSR[#,*,@]	QA#2[*]	ARIES-CS Blanket and Shield	ARIES-CS Shield only
SOL	15	30	5	5	5
FW/Blanket	36 (Li/V)	43 (LiPb/H_2O/FS)	30 (LiPb/SiC)	30 (Flibe/Fs/Be)	30 (Shield)
Gap	2	5	1	1	1
HT Shield	45	30 ?	49	45	25
Gap	2	–	2	2	2
VV or LT Shield	35	20 ?	20	?	?
Gap + Thermal Insulator	≥ 8	≥ 10	≥ 2	≥ 2	≥ 2
Cryostat + 1/2 Coil	15+38	15+30	51	?	?
Δ	196	183 ?	160	85 +?	65 +?

\# CD Beidler et.al., "Recent Developments in Helias Reactor Studies", March 2002, http://www.ipp.mpg.de/eng/for/bereiche/e3/for_ber_e3_proj_sss.html

* J. Lyon's presentation, ARIES project meeting at PPPL, Oct 2-4, 2002.

@ HSR numbers need to be confirmed. LiPb blanket/shield may not protect VV for life.

THE UNIVERSITY of WISCONSIN MADISON

Conclusions

- 30-cm-thick Flibe/FS blanket with Be multiplier offers good breeding margin and protects shield for life (40 FPY).
- 45-cm-thick FS shield assures reweldability of VV during operation.
- Up to 20 cm reduction in Δ is achievable with shield-only zones.
- To assess impact on R, B, and β, generate two cases with Δ and Δ-20 cm, using M_n= 1.2, η_{th} = 45%, FW lifetime = 10 FPY, and availability = 80%.
- Needed info to estimate Δ:
  - Magnet and cryostat (HT or LT, thickness, composition, radiation limits, etc.)
  - Divertor plates/baffles composition and coverage fraction
  - Penetrations coverage fraction
  - Plasma parameters (P_f, magnetic shift,etc.)
  - ϑ - Φ map for plasma-coil distance
  - Plasma shapes at various toroidal locations.

THE UNIVERSITY of WISCONSIN MADISON