



# 16<sup>th</sup> TOFE Updates

September 14 - 16, 2004

Madison, WI



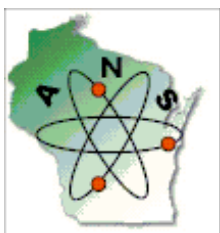
## Status of planning:

- ANS approved TOFE **proposal** in Nov 03.
- **Call for Papers** issued on Dec 1, 03.
- Identified members of **Technical Program Committee** and acceptances received.
- Potential **speakers** and session **chairs** have been identified and will be contacted in Jan 04.
- TOFE **website** available at <http://fti.neep.wisc.edu/tofe>
- Preliminary **meeting schedule** drafted for plenary, oral, and poster sessions and social activities.

## Key deadlines:

|                                       |                    |
|---------------------------------------|--------------------|
| One-page <b>abstracts</b>             | May 1, 2004        |
| Nominations for ANS-FED <b>awards</b> | May 31, 2004       |
| <b>Notification</b> to authors        | June 1, 2004       |
| Early <b>registration</b> deadline    | August 10, 2004    |
| <b>Hotel</b> reservation cutoff date  | August 10, 2004    |
| Full <b>papers</b> due at the meeting | September 14, 2004 |

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                       |
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|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | <p><b>Call for Papers</b><br/> <b>16<sup>th</sup> Topical Meeting on the<br/> Technology of Fusion Energy</b><br/> Monona Terrace Convention Center<br/> Madison, Wisconsin<br/> September 14 - 16, 2004</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |    |
| <p><b>Scope:</b> The TOFE meeting will provide a forum for sharing the exciting new progress that has been made in fusion research as well as presenting the future of national and worldwide fusion program.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                       |
| <p><b>Organizing Committee:</b><br/> <b>General Chair:</b><br/> Gerald Kulcinski (UW)<br/> <b>Vice Chair:</b><br/> Masahiro Seki (JAERI)<br/> <b>Technical Program Chair:</b><br/> Laila El-Guebaly (UW)<br/> <b>Assistant Technical Program Chairs:</b><br/> Ichiro Yamamoto (Nagoya U.)<br/> René Raffray (UCSD)<br/> <b>Finance Chair:</b><br/> James Blanchard (UW)<br/> <b>Publications Chair:</b><br/> Mohamed Sawan (UW)<br/> <b>Registration Chair:</b><br/> Mark Anderson (UW)<br/> <b>Student Awards:</b><br/> Paul Wilson (UW)<br/> <b>Special Events:</b><br/> John Santarius (UW)<br/> <b>Publicity and Webmaster:</b><br/> Dennis Bruggink (UW)</p> | <p><b>Sponsorship</b><br/> ANS Fusion Energy Division<br/> ANS Wisconsin Local Section<br/> Atomic Energy Society of Japan - FED<br/> US Department of Energy<br/> University of Wisconsin - Madison</p> <p><b>Technical Topics</b></p> <ul style="list-style-type: none"> <li>• Engineering of experimental devices • Power plant studies • High heat flux components • IFE target fabrication, injection, and tracking • In-vessel components (blanket, shield, vacuum vessel) • IFE chamber dynamics and clearing • Magnets</li> <li>• Nuclear analysis and experiments (neutronics, shielding, and activation) • Structural and breeding materials • Material and component test facilities • Blanket testing • Safety and environment • Radwaste management • Tritium handling and processing • Plasma engineering, heating, and control • Diagnostics • Fabrication, assembly, and maintenance • Power conversion and conditioning • Computational tools and validation experiments • Alternate, non-electric applications of fusion</li> <li>• Hydrogen production • Socioeconomics</li> </ul> |                                                                                       |
| <p><b>Deadlines:</b></p> <ul style="list-style-type: none"> <li>• Electronic submission of 400-word abstract - May 1, 2004</li> <li>• Author notification of acceptance - June 1, 2004</li> <li>• Final paper submission - September 14, 2004.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                         | <p>Please submit abstracts describing work that is new, significant, and relevant to both MFE and IFE fusion technologies. Electronic submittal system is available at the meeting web site: <a href="http://fti.neep.wisc.edu/tofe">http://fti.neep.wisc.edu/tofe</a></p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                       |
| <p><b>Accommodation:</b> Blocks of rooms have been reserved at two hotels for ANS-TOFE attendees. The Hilton (meeting hotel) is connected to the Monona Terrace by a skywalk and the Best Western is four blocks from the Convention Center. See the meeting web site for details.</p>                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                       |
| <p>For more information, please contact the Technical Program Chair: Laila El-Guebaly, 1500 Engineering Dr., Madison, WI 53706, Tel: (608) 263-1623, Fax: (608) 263-4499, E-mail: <a href="mailto:elguebaly@engr.wisc.edu">elguebaly@engr.wisc.edu</a></p>                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                       |
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# Tentative TOFE Schedule



|                | <u>Monday</u><br>9/13/04         | <u>Tuesday</u><br>9/14/04                                   | <u>Wednesday</u><br>9/15/04                                 | <u>Thursday</u><br>9/16/04                                     | <u>Friday</u><br>9/17/04            |
|----------------|----------------------------------|-------------------------------------------------------------|-------------------------------------------------------------|----------------------------------------------------------------|-------------------------------------|
| 8 - 10 AM      |                                  | Plenary<br>(4 invited papers)                               | Plenary<br>(4 invited papers)                               | Oral<br>(1, 2, or 3 // sessions,<br>6 papers per session)      | Project Meetings and Workshops<br>↓ |
| 10 - 10:30     |                                  | Coffee Break                                                | Coffee Break                                                | Coffee Break                                                   |                                     |
| 10:30 - 12     |                                  | Oral<br>(1, 2, or 3 // sessions,<br>5 papers per session)   | Oral<br>(1, 2, or 3 // sessions,<br>5 papers per session)   | Plenary<br>(2 invited papers<br>+ wrap-up talk)                |                                     |
| 12 - 1:30      |                                  | Lunch                                                       | Lunch                                                       | Lunch                                                          |                                     |
| 1:30 - 3:30 PM |                                  | Poster<br>(15 - 60 posters)<br>+ Refreshments               | Poster<br>(15 - 60 posters)<br>+ Refreshments               | Technical Tours<br>↓<br>Project Meetings<br>↓<br>and Workshops |                                     |
| 3:30 - 5:30    |                                  | Oral<br>(1, 2, or 3 // sessions,<br>6-7 papers per session) | Oral<br>(1, 2, or 3 // sessions,<br>6-7 papers per session) |                                                                |                                     |
| Evening        | Registration<br>& Mixer<br>6 - 9 | Reception<br>6 - 9                                          | Cash Bar: 6 - 7<br>Banquet / Awards<br>7 - 10               |                                                                |                                     |



# Neutronic Implications on Radial Build

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**With input from:**  
R. Raffray, X. Wang (UCSD), and S. Malang (FZK)

ARIES-CS Project Meeting  
December 3 - 4, 2003  
PPPL

# Candidate Blanket Concepts

| <u>Breeder</u>                                                                         | <u>Multiplier</u> | <u>Structure</u> | <u>FW/Blanket<br/>Coolant</u> | <u>Shield<br/>Coolant</u> | <u>VV<br/>Coolant</u> |
|----------------------------------------------------------------------------------------|-------------------|------------------|-------------------------------|---------------------------|-----------------------|
| <b><u>ARIES-CS:</u></b>                                                                |                   |                  |                               |                           |                       |
| <b>Internal VV:</b>                                                                    |                   |                  |                               |                           |                       |
| Flibe                                                                                  | Be                | FS               | Flibe                         | Flibe                     | H <sub>2</sub> O      |
| LiPb                                                                                   | —                 | SiC              | LiPb                          | LiPb                      | H <sub>2</sub> O      |
| LiPb                                                                                   | —                 | FS               | He/LiPb                       | He                        | H <sub>2</sub> O      |
| <b>External VV:</b>                                                                    |                   |                  |                               |                           |                       |
|  LiPb | —                 | FS               | He/LiPb                       | He/B-H <sub>2</sub> O     | He                    |
| LiPb                                                                                   | —                 | FS               | He/LiPb                       | He                        | He                    |
| Li                                                                                     | —                 | FS               | He/Li                         | He                        | He                    |
| <b><u>SPPS:</u></b>                                                                    |                   |                  |                               |                           |                       |
| <b>External VV:</b>                                                                    |                   |                  |                               |                           |                       |
| Li                                                                                     | —                 | V                | Li                            | Li                        | He                    |

# General Remarks

- All blanket concepts can meet **breeding requirement** if:
  - Blanket covers most of FW area
  - Blanket installed behind divertor plates/baffles.
- **Non-uniform blanket** thickness is optimum for ARIES-CS.
- **Local WC shield** at  $\square_{\min}$  helps reduce machine size and enhance economics.
- $\square_{\min}$  varies slightly (within 10 cm) with blanket concepts.
- **Water** is superior, cheap shielding material that helps reduce shield size and cost.
- **For safety reasons:**
  - Exclude breeders incompatible with water (such as Li)
  - Do not use water to cool blanket containing LiPb and/or Be
  - Limit use of water to LT shield and VV.
- **LT shield/VV** contains low grade heat (  $\leq 1\%$  of total nuclear heating).



# Nominal Radial Distance Widely Varies with Blanket Concept

(Blanket/Shield Zone: 3 MW/m<sup>2</sup>)

□ (m)

## ARIES-CS:

### Internal VV:

Flibe/FS/Be

### Blanket/Shield/VV

1.06 (min)

### Plasma – Mid Coil

1.25\* (min)

LiPb/SiC

1.13

1.32\*

LiPb/FS/He

1.24

1.43\*

### External VV:



LiPb/FS/He/B-H<sub>2</sub>O

### Blanket/Shield

1.26

1.46##

LiPb/FS/He

1.51

1.78#

Li/FS/He

1.70 (max)

1.97# (max)

## SPPS:

### External VV:

Li/V

1.20

1.96@

\* Assuming 5 cm SOL, 10 cm half winding pack, 2 cm thick coil case, and 2 cm wide VV-magnet gap.

## Assuming 5 cm SOL, 10 cm half winding pack, 3 cm thick coil support tube, and 2 cm wide shield-magnet gap.

# Assuming 5 cm SOL, 10 cm half winding pack, 10 cm thick coil support tube, and 2 cm wide shield-magnet gap.

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



# Minimum Radial Distance Varies within 10 cm with Blanket Concept (Shield-only Zone : 3 MW/m<sup>2</sup>)

$\square_{\min}$  (m)

## ARIES-CS:

### Internal VV:

Flibe/FS/Be

### WC-Shield/VV

0.86

### Plasma – Mid Coil

1.05\*

LiPb/SiC

0.89

1.08\*

LiPb/FS/He

0.93

1.12\*

### External VV:



LiPb/FS/He/B-H<sub>2</sub>O

### WC-Shield

0.85

1.05##

LiPb/FS/He

0.88

1.15#

Li/FS/He

0.86

1.13#

## SPPS:

### External VV:

Li/V

—

—

\* Assuming 5 cm SOL, 10 cm half winding pack, 2 cm thick coil case, and 2 cm wide VV-magnet gap.

## Assuming 5 cm SOL, 10 cm half winding pack, 3 cm thick coil support tube, and 2 cm wide shield-magnet gap.

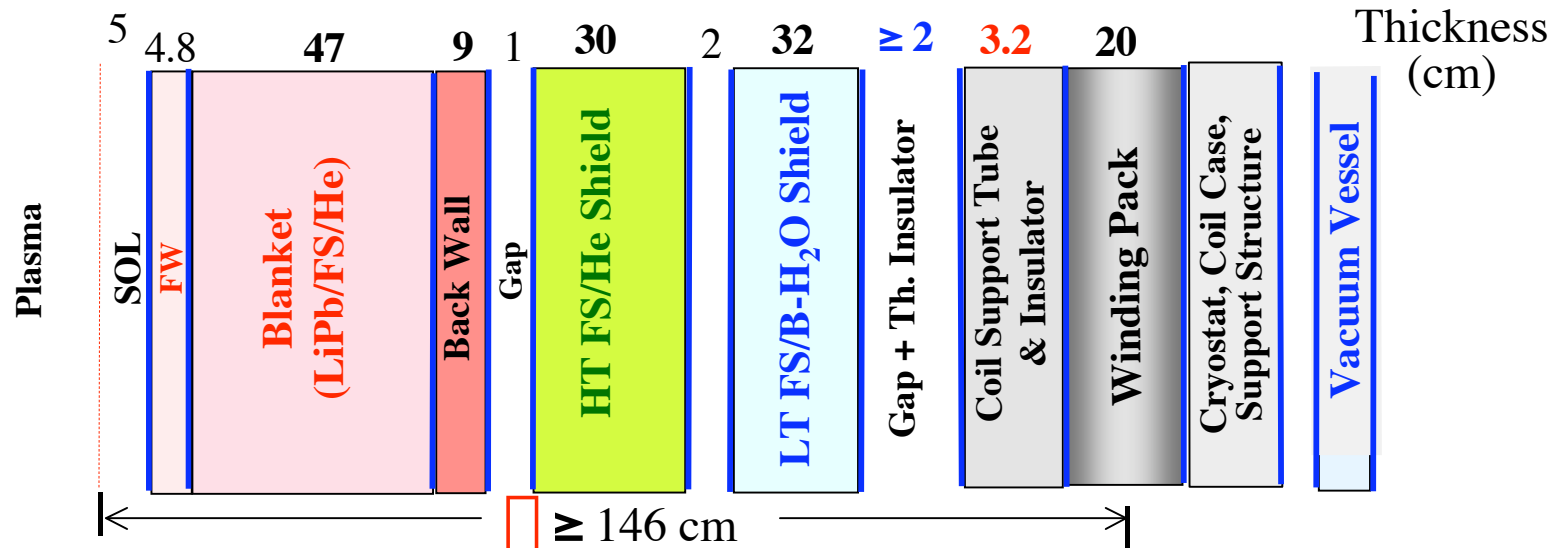
# Assuming 5 cm SOL, 10 cm half winding pack, 10 cm thick coil support tube, and 2 cm wide shield-magnet gap.

@ 15 cm SOL, 38 cm half winding pack, 15 cm thick cryostat, and 8 cm wide shield-magnet gap.

# Recommended LiPb/FS/He/B-H<sub>2</sub>O Radial Build (He-cooled External VV)

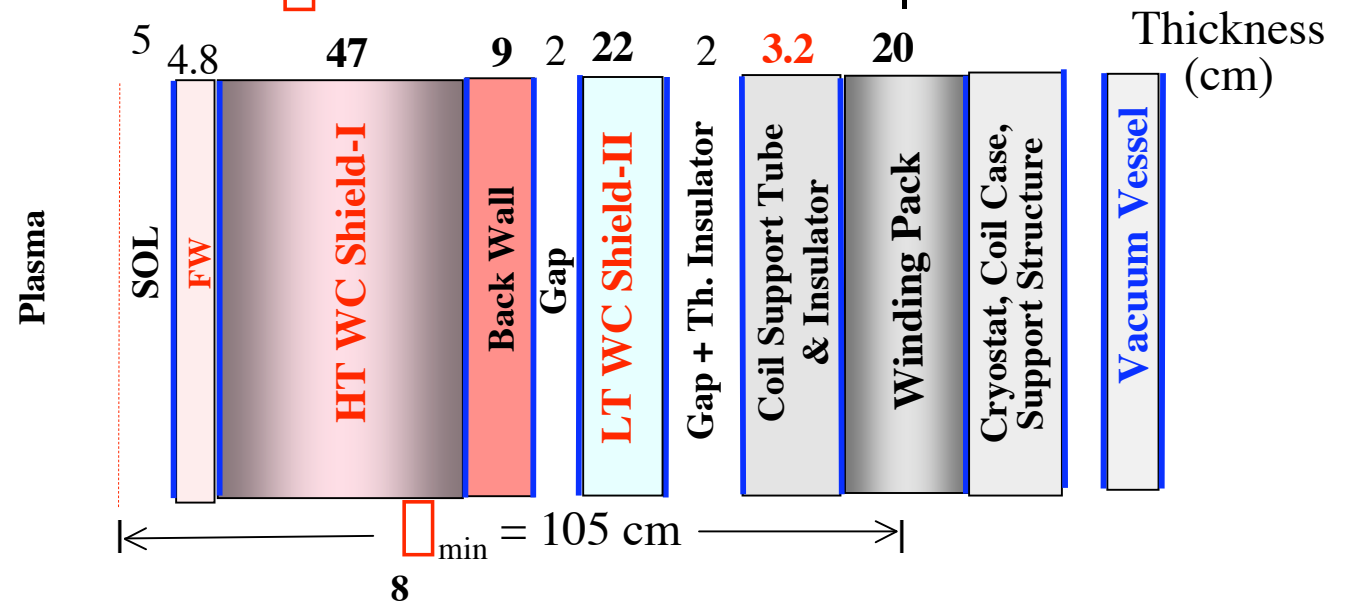


**Blanket  
Zones**



**Shield  
Only  
Zones**

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



# LiPb/FS/He/B-H<sub>2</sub>O System

## (He-cooled External VV)



### Components

**FW**

**Blanket**

**Back Wall**

**HT WC/He Shield-I\***

**LT WC/B-H<sub>2</sub>O Shield-II**

**HT FS/He Shield**

**LT FS/B-H<sub>2</sub>O Shield**

**Winding Pack**

(Composition not available. Used SPPS')

**VV**

### Composition

31% FS Structure

69% He Coolant

90% LiPb with 90% enriched Li

3% FS Structure

7% He Coolant

80% FS Structure

20% He Coolant

90% WC Filler

3% FS Structure

7% He Coolant

15% FS Structure

30% B-H<sub>2</sub>O Coolant

55% WC Filler

15% FS Structure

10% He Coolant

75% Borated Steel Filler

15% FS Structure

33% B-H<sub>2</sub>O Coolant

52% Borated Steel Filler

25% Incoloy Structure

20% Cu Stabilizer

15% Nb<sub>3</sub>Sn + Conduit

25% GFF Polyimide

15% LHe

30% FS Structure

70% He

\* Same constituents for blanket with WC replacing LiPb.

# Alternate LT Shield Options for LiPb/FS/He/B-H<sub>2</sub>O System

(He-cooled External VV)



| <u>Structure</u> | <u>Filler</u>                          | <u>Coolant</u>     | <u>LT Shield Thickness</u><br>(cm) | <u>Blanket &amp; Shield Thickness*</u><br>(cm) | <u>Plasma-Mid Coil Distance<sup>#</sup></u><br>(cm) |
|------------------|----------------------------------------|--------------------|------------------------------------|------------------------------------------------|-----------------------------------------------------|
| FS               | B-FS/B-H <sub>2</sub> O<br>(reference) | B-H <sub>2</sub> O | 32                                 | 126                                            | 146                                                 |
| FS               | ZrH <sub>1.7</sub>                     | He                 | 32**                               | 126                                            | 146                                                 |
| FS               | WC                                     | He                 | 37##                               | 131                                            | 151                                                 |
| FS               | B-FS                                   | He                 | 67                                 | 161                                            | 181                                                 |

\* Includes 5 cm FW, 47 cm blanket, 9 cm back wall, 30 cm HT shield (15% FS, 10% He, 75% B-FS), and 3 cm gaps.

# Includes 5 cm SOL, 2 cm gap, 3 cm coil support tube, and 10 cm half winding pack.

\*\* 15% FS, 10% He, 75% ZrH<sub>1.7</sub>.

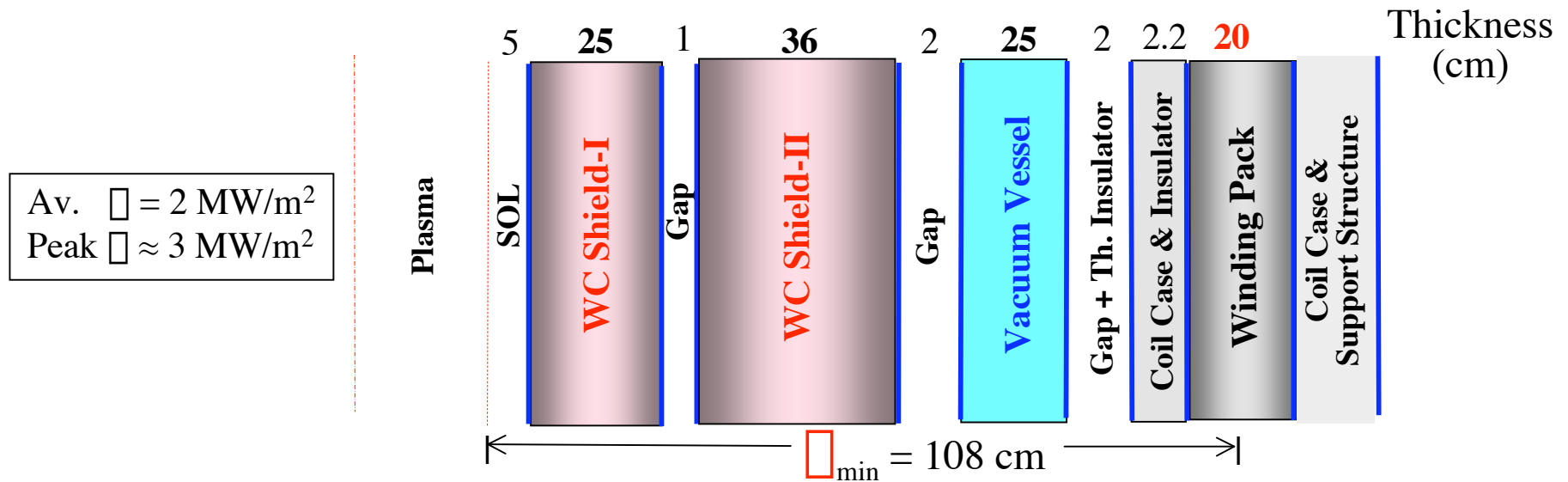
## 15% FS, 10% He, 75% WC.

@ 15% FS, 10% He, 75% B-FS.

# LiPb/SiC Blanket Concept Selected for Further Analysis

| <u>Breeder</u>                                                                         | <u>Multiplier</u> | <u>Structure</u> | <u>FW/Blanket<br/>Coolant</u> | <u>Shield<br/>Coolant</u> | <u>VV<br/>Coolant</u> |
|----------------------------------------------------------------------------------------|-------------------|------------------|-------------------------------|---------------------------|-----------------------|
| <b><u>ARIES-CS:</u></b>                                                                |                   |                  |                               |                           |                       |
| <b>Internal VV:</b>                                                                    |                   |                  |                               |                           |                       |
| Flibe                                                                                  | Be                | FS               | Flibe                         | Flibe                     | H <sub>2</sub> O      |
| <b>LiPb</b>                                                                            | —                 | <b>SiC</b>       | <b>LiPb</b>                   | <b>LiPb</b>               | <b>H<sub>2</sub>O</b> |
| LiPb                                                                                   | —                 | FS               | He/LiPb                       | He                        | H <sub>2</sub> O      |
| <b>External VV:</b>                                                                    |                   |                  |                               |                           |                       |
|  LiPb | —                 | FS               | He/LiPb                       | He/B-H <sub>2</sub> O     | He                    |
| LiPb                                                                                   | —                 | FS               | He/LiPb                       | He                        | He                    |
| Li                                                                                     | —                 | FS               | He/Li                         | He                        | He                    |
| <b><u>SPPS:</u></b>                                                                    |                   |                  |                               |                           |                       |
| <b>External VV:</b>                                                                    |                   |                  |                               |                           |                       |
| Li                                                                                     | —                 | V                | Li                            | Li                        | He                    |

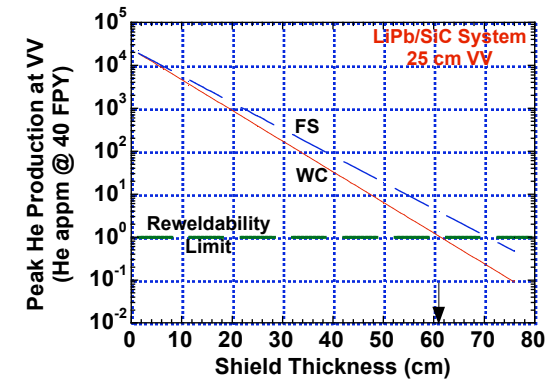
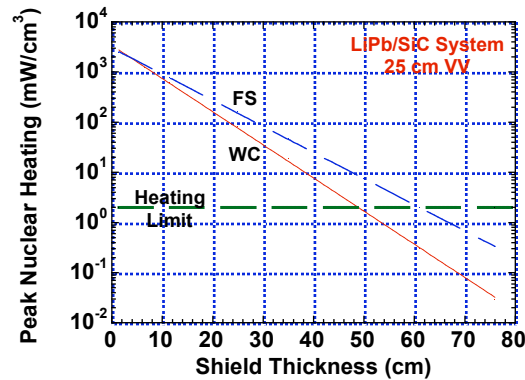
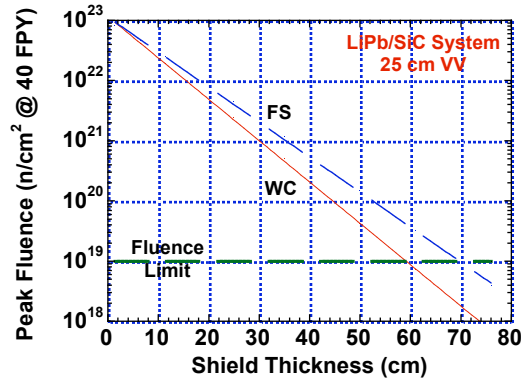
# Variation of Shield Thickness with $\phi$ (LiPb/SiC System; Internal VV)



$$\text{Change in WC Shield-II thickness (cm)} = 6.24 \ln (\text{av } \phi / 2)$$

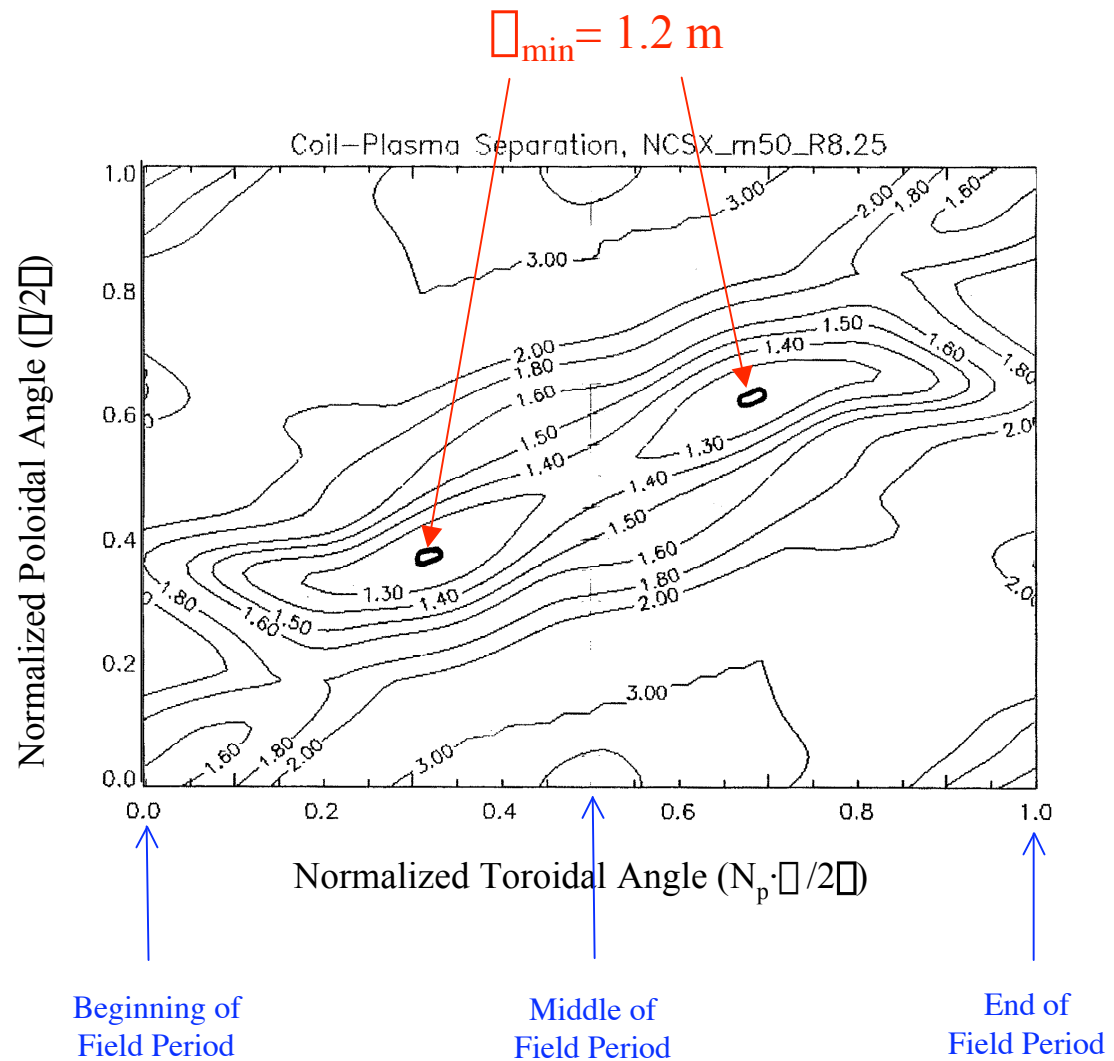
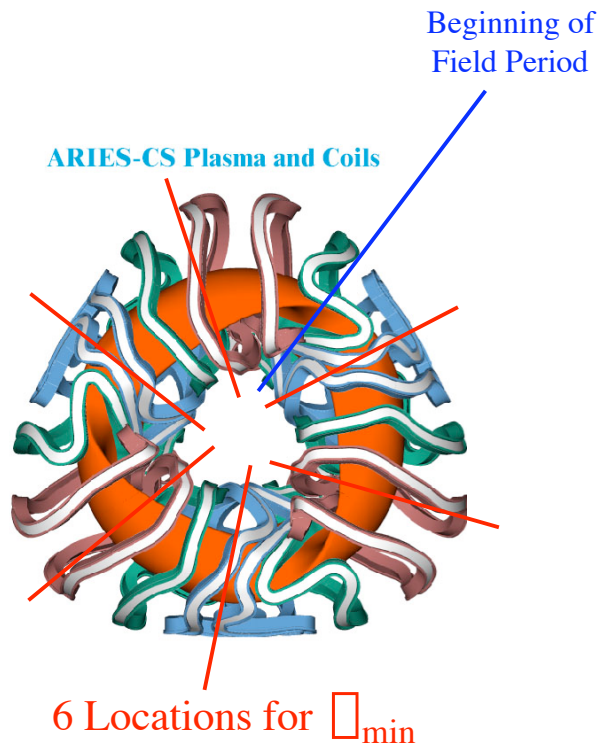
Example:  $\text{av } \phi = 4$  MW/m<sup>2</sup>, additional WC-shield thick. = 4.3 cm

# WC vs FS Shield (LiPb/SiC System; 3 MW/m<sup>2</sup>)



WC offers 10 cm thinner  $\square_{\min}$  compared to FS

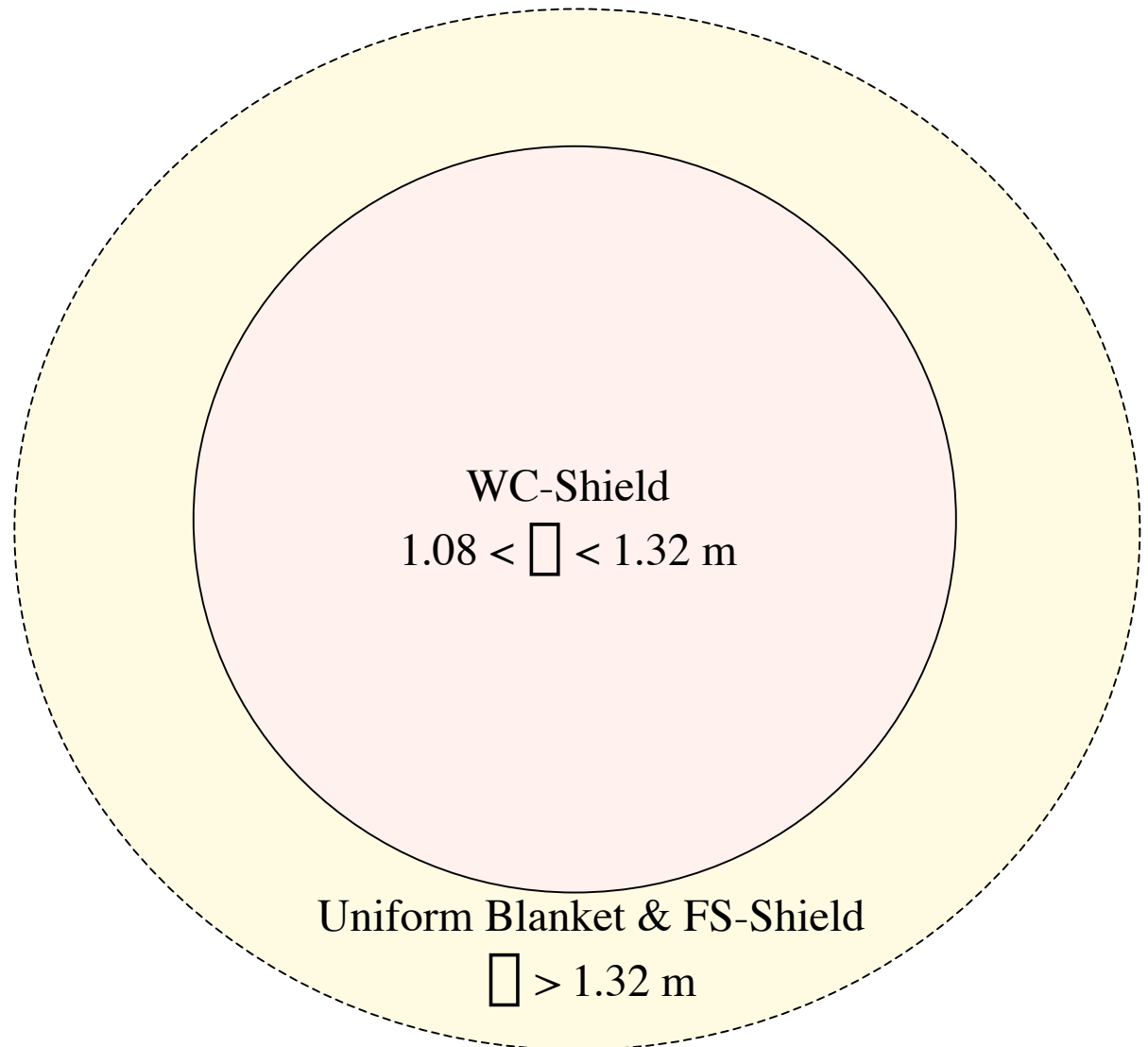
# $\square_{\min}$ Occurs Twice per Field Period



# Blanket and Shielding Zones (LiPb/SiC System)

## Option I:

- Largest WC volume
- Monitor WC decay heat
- $R_{\min} < 1.2 \text{ m}$   
     $R_{\text{av}} \leq 8.25 \text{ m}$



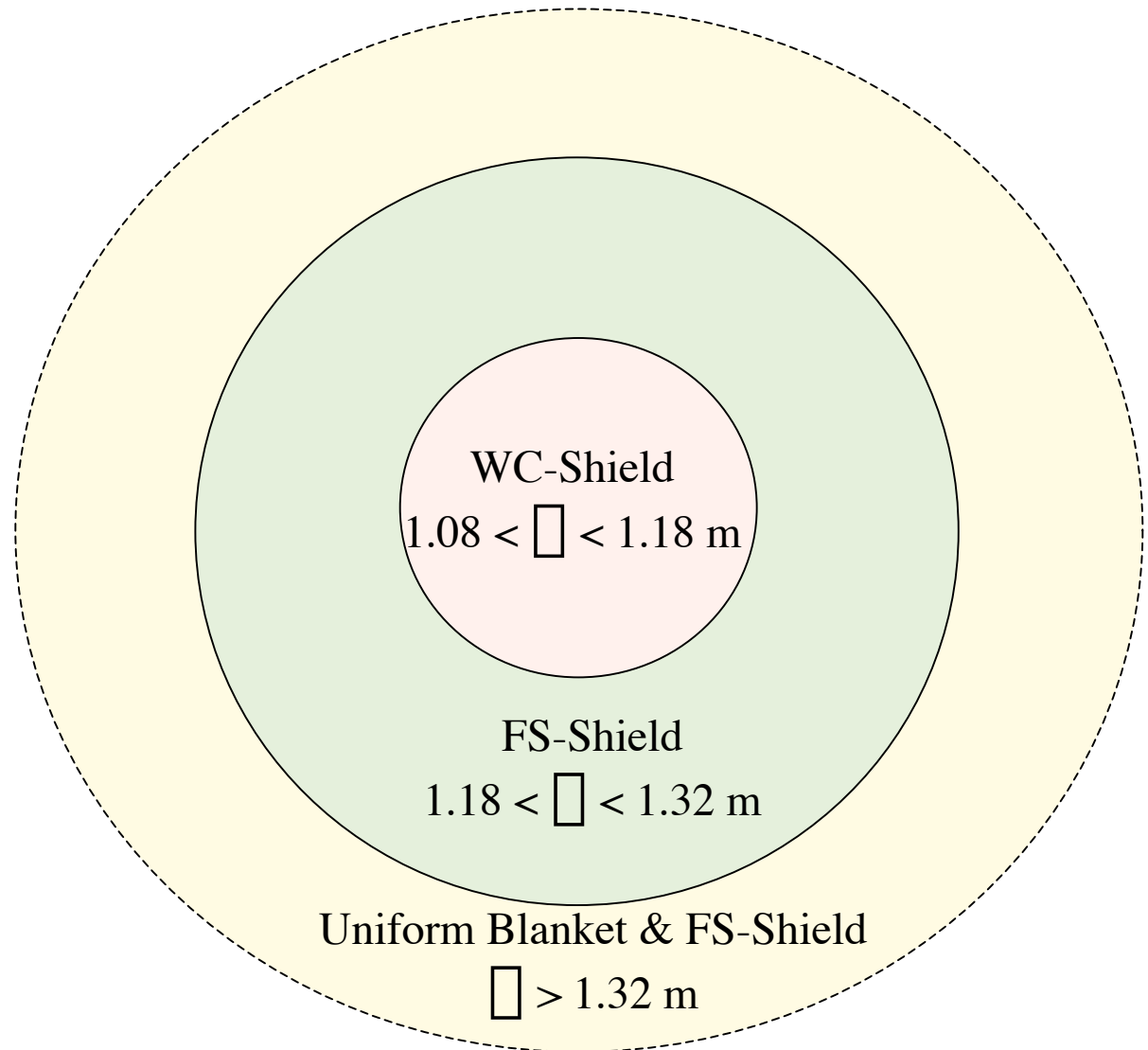
# Blanket and Shielding Zones (cont.) (LiPb/SiC System)

## Option II:

– Smallest WC volume

–  $\square_{\min} < 1.2 \text{ m}$

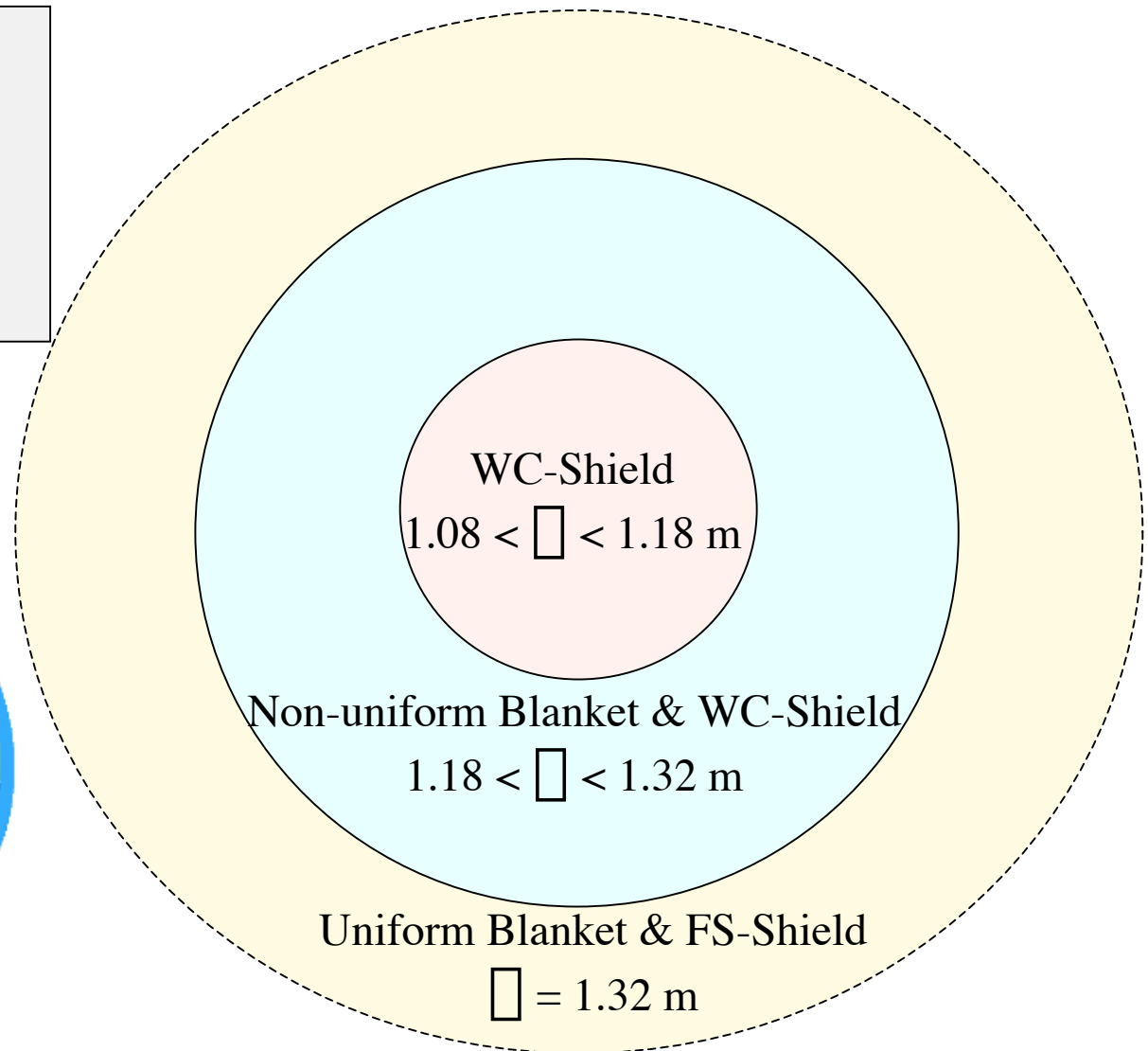
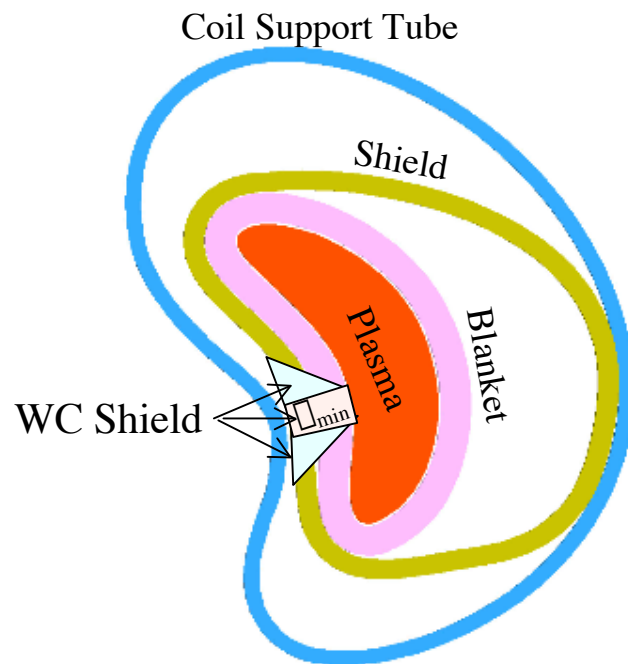
$\square_{\text{av}} R \leq 8.25 \text{ m}$



# Blanket and Shielding Zones (cont.) (LiPb/SiC System)

## **Option III (preferred):**

- Monitor WC decay heat
- **High breeding potential**
- $a_{\min} < 1.2 \text{ m}$
- $a_{\text{av}} R \leq 8.25 \text{ m}$



# Blanket and Shielding Zones (cont.) (LiPb/SiC System)

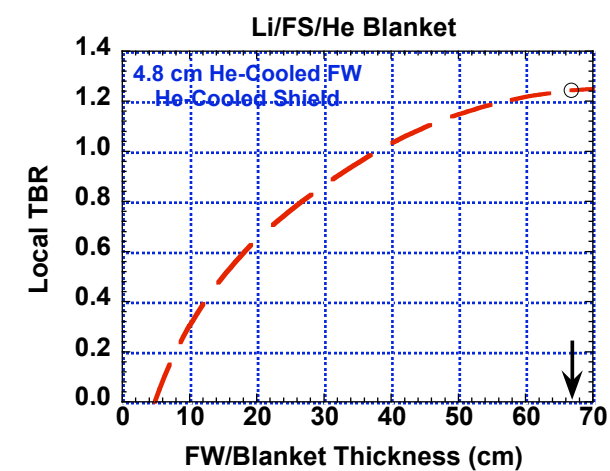
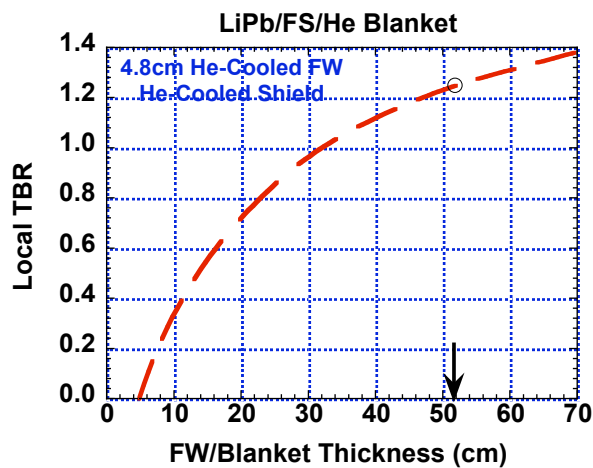
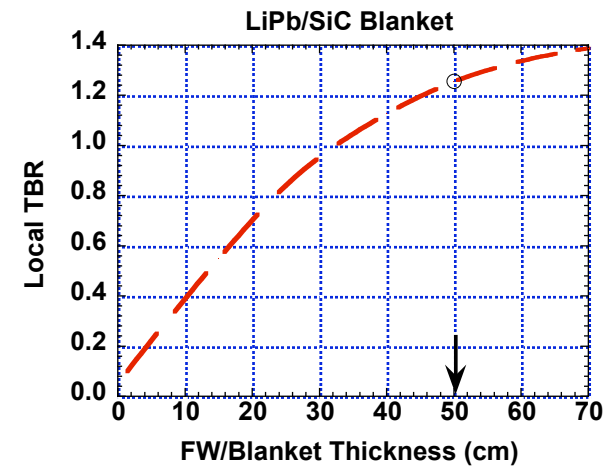
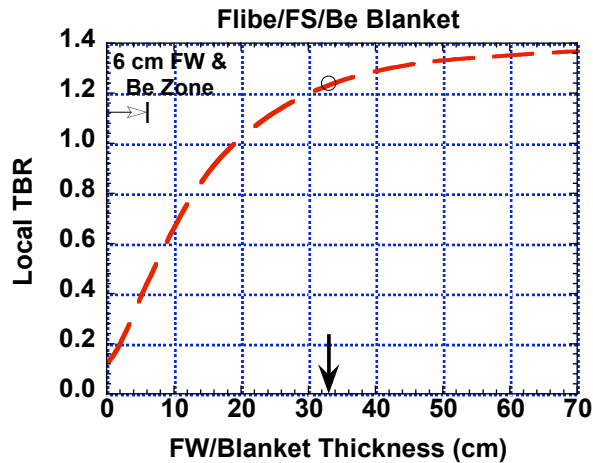
## Option IV(a la SPPS):

- No WC shield
- **Highest breeding potential**
- $\square_{\min} = \square_{\max} \approx 1.3 \text{ m}$   
 $\square \text{ R} > 8.25 \text{ m}$
- **Large volume of radwaste.**

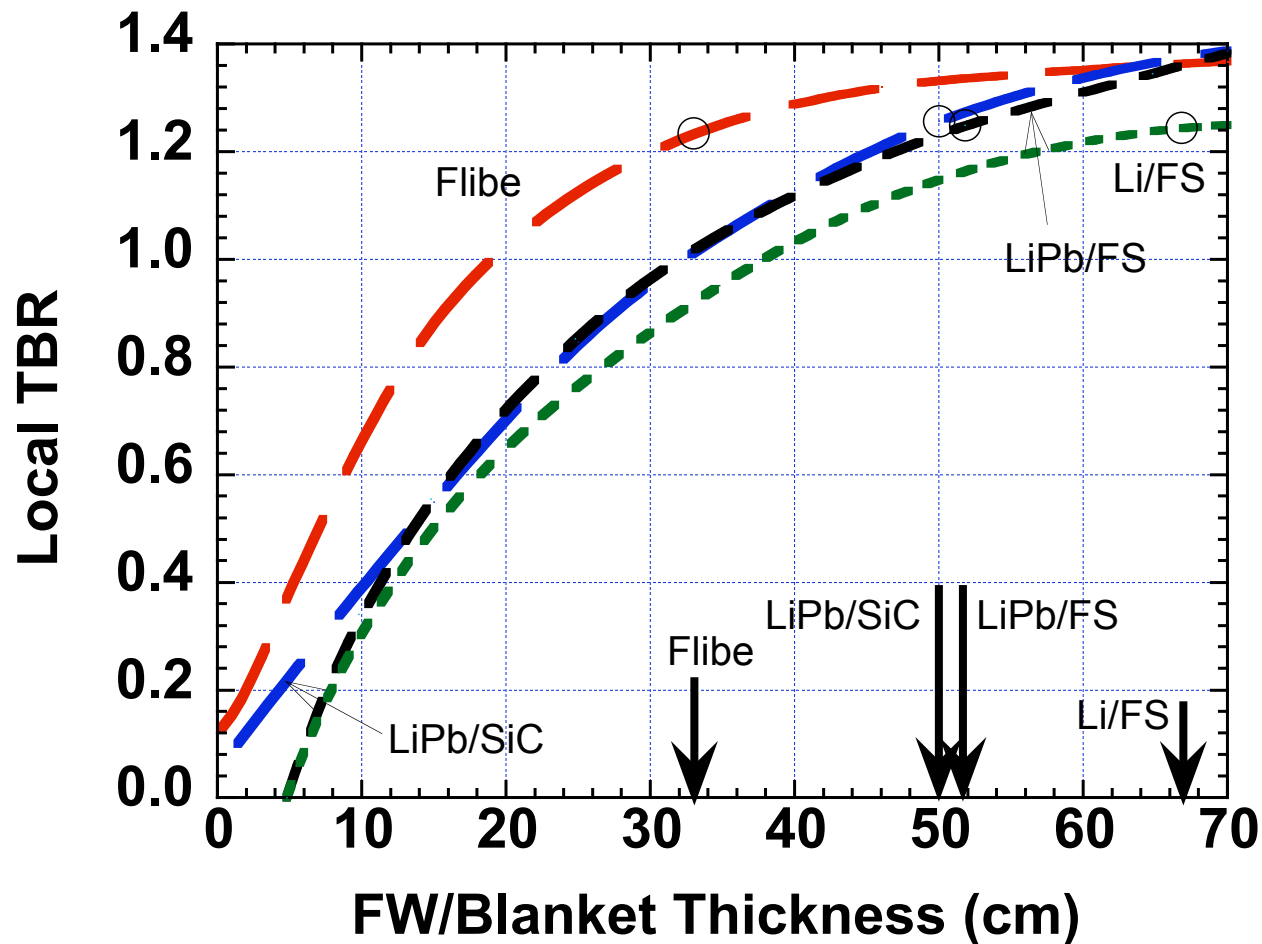
Uniform Blanket & FS-Shield

$\square \approx 1.3 \text{ m}$

# Front 10-20 cm of Blanket Provides ~50% of Local Breeding



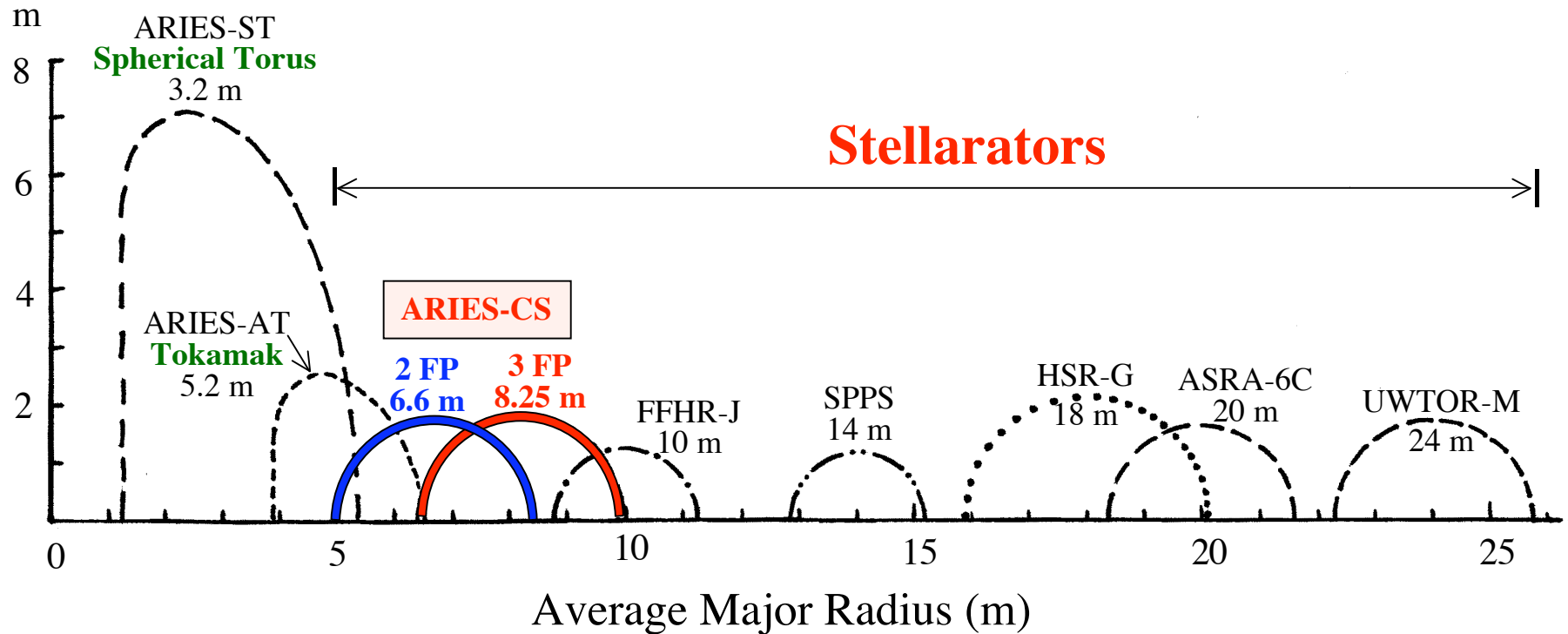
# Front 10-20 cm of Blanket Provides ~50% of Local Breeding (cont.)



# Stellarator Designs

| <u>Design</u> | <u>Organization</u> | <u>Year of Study</u> |
|---------------|---------------------|----------------------|
| UWTOR-M       | UW                  | 1982                 |
| ASRA-6C       | UW + German Labs    | 1987                 |
| SPPS          | UCSD                | 1994                 |
| HSR           | IPP - Germany       | 1994 (ongoing)       |
| FFHR          | NIFS - Japan        | 1995 (ongoing)       |
| ARIES-CS      | UCSD                | 2003 (ongoing)       |

# Comparison Between Major and Minor Radii



|                           |                           |                |                  |                   |                   |  |
|---------------------------|---------------------------|----------------|------------------|-------------------|-------------------|--|
| <b>Maintenance Scheme</b> | ARIES-CS-2FP<br>Modular ? | FFHR-J<br>?    | HSR-G<br>Modular |                   |                   |  |
|                           | ARIES-CS-3FP<br>Sector ?  | SPSS<br>Sector |                  | ASRA-6C<br>Sector | UWROR-M<br>Sector |  |

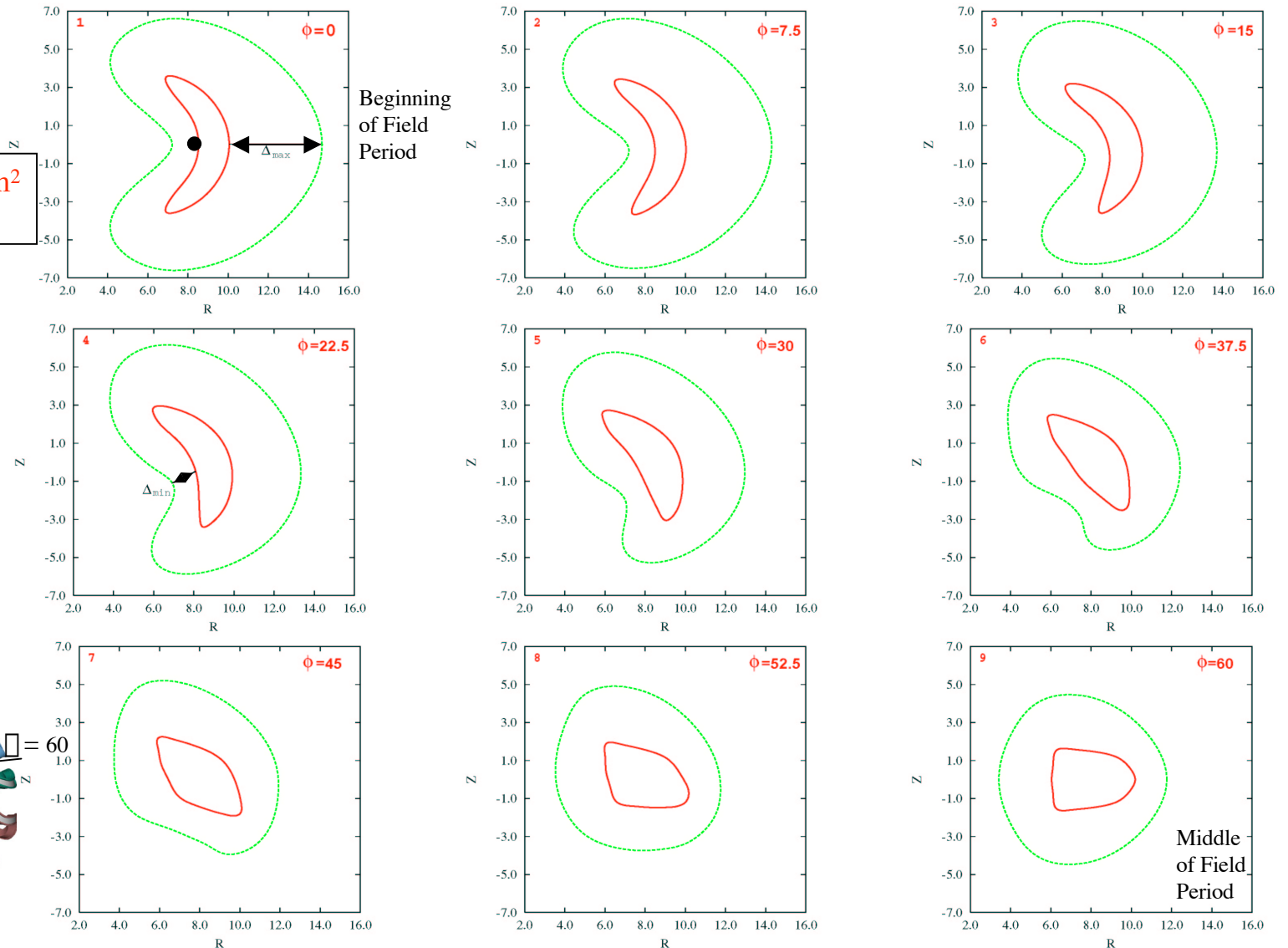
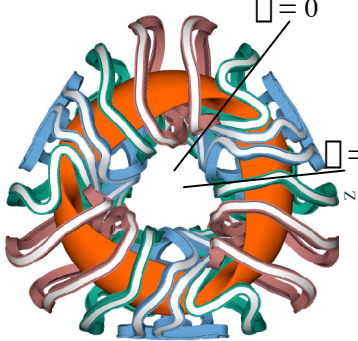
# 9 Xns of Plasma Boundary (red) and WP Center (green) Covering 1/2 Field Period (~9 m)

$\Delta_{\max} \sim 4.6 \text{ m}$

$\Delta$  peaks @  $\sim 3 \text{ MW/m}^2$   
at black dot

$\Delta_{\min} = 1.2 \text{ m}$

ARIES-CS Plasma and Coils



# Transition Region Between $\square_{\min}$ and $\square_{\min} + 0.2$ m Covers $\sim 8\%$ of FW Area

