

# 3-D Assessment of Neutron Streaming through Inboard Assembly Gaps

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# Outline

- Introduction
- 3-D Model used
- Results
- Conclusions

# Introduction

- Assembly gaps between modules allow increased levels of radiation to reach components
- Radiation streaming through these gaps needs assessment to be sure components are well protected
- Previous Work:
  - T.D. Bohm, M.E. Sawan, P. Wilson, “Radiation Streaming in Gaps between ITER First Wall Shield Modules”, *Fusion Science and Technology*, in press 2009
  - L.A. El-Guebaly, M.E. Sawan, “Shielding Analysis for ITER with Impact of Assembly Gaps and Design Inhomogeneities”, Proc. 8<sup>th</sup> International Conference on Radiation Shielding, Arlington, Texas, 24-28 April 1994, p. 1047, 1994

# Introduction continued

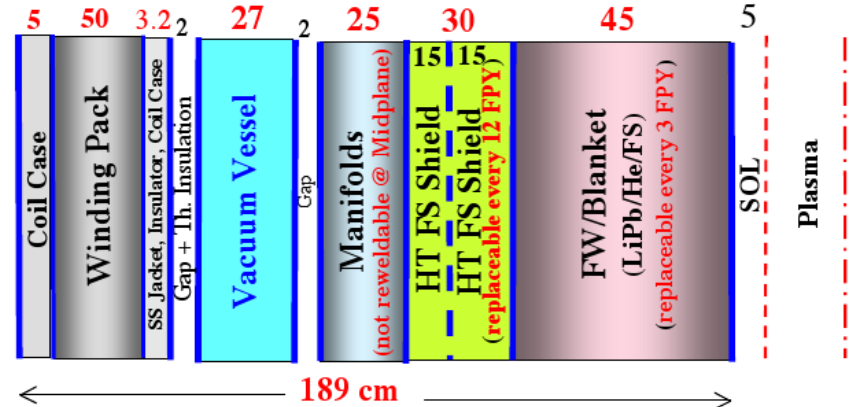
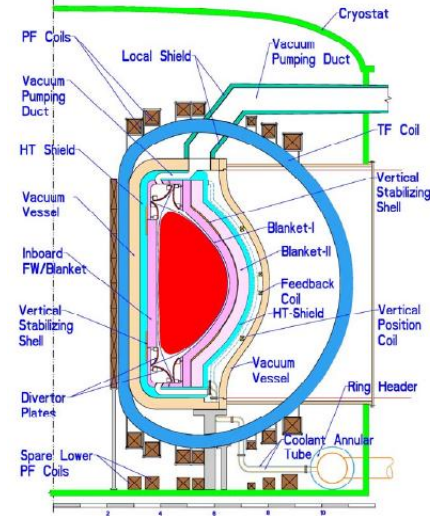
- During operation, gaps will close due to thermal expansion and neutron induced swelling
- Will examine range of gap sizes from no gap to some reasonable maximum gap size



# ARIES 3-D Inboard Model

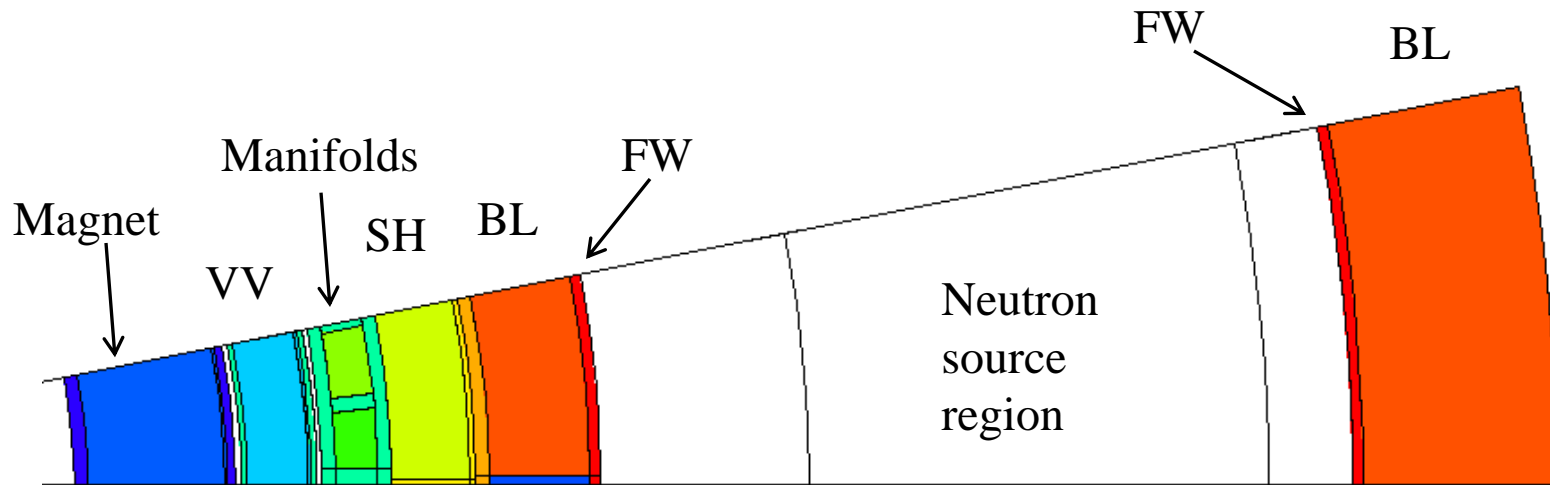
- Basis is ARIES-AT DCLL radial build by El-Guebaly (1/21/2009 presentation)
- MCNPX v27a 3-D Monte Carlo transport code
- FENDL v2.1 cross section library

Cross Section of ARIES-AT Power Core Configuration



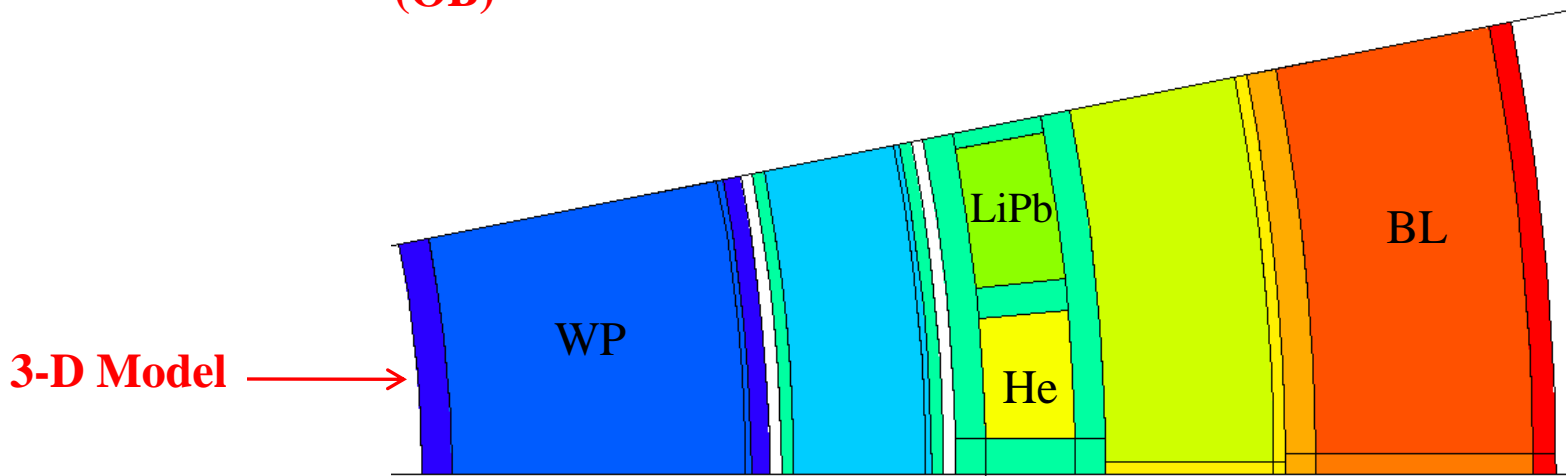
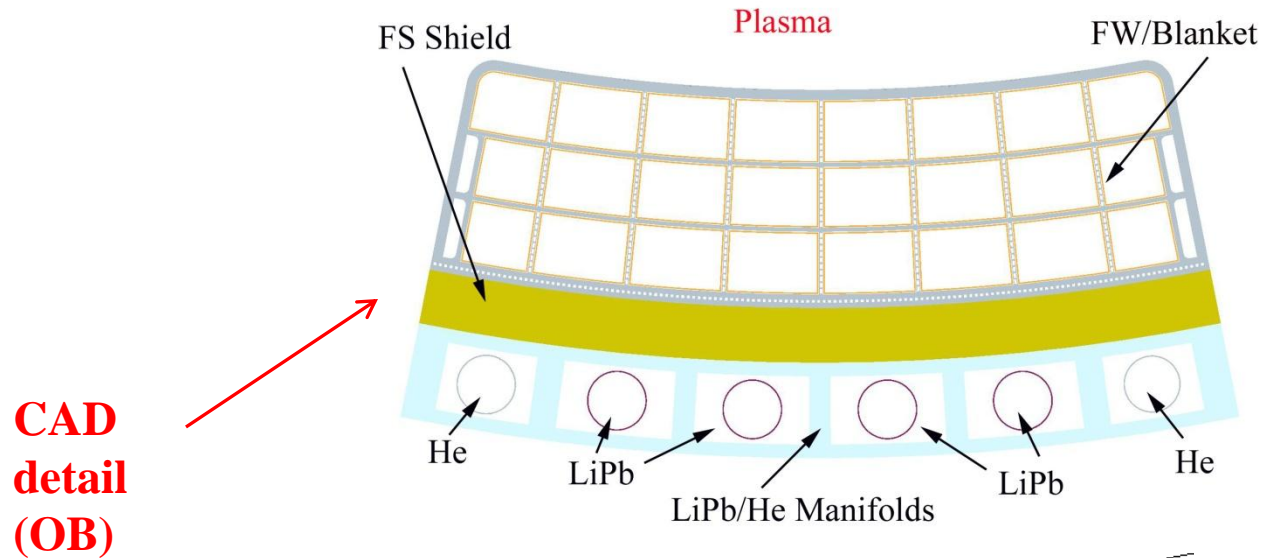
# 3-D Model

- 3-D partially homogenized model
- 11.25° sector (1/2 module) (w/ reflecting boundaries)
- Vertical extent 100 cm (w/ reflecting boundaries)
- Uniform volumetric source  $r=460-625$  cm
  - IB NWL = 3.4 MW/m<sup>2</sup>



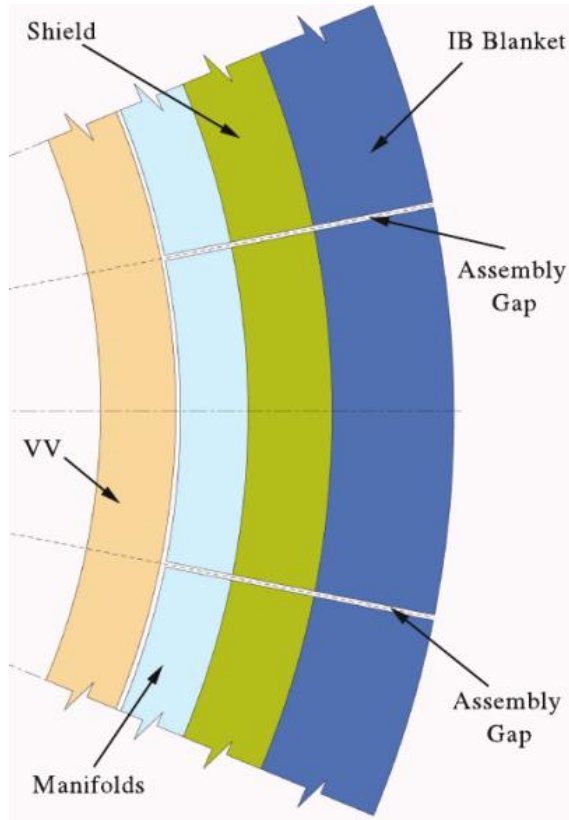
# No gap model

- Sidewalls included
- Manifolds included

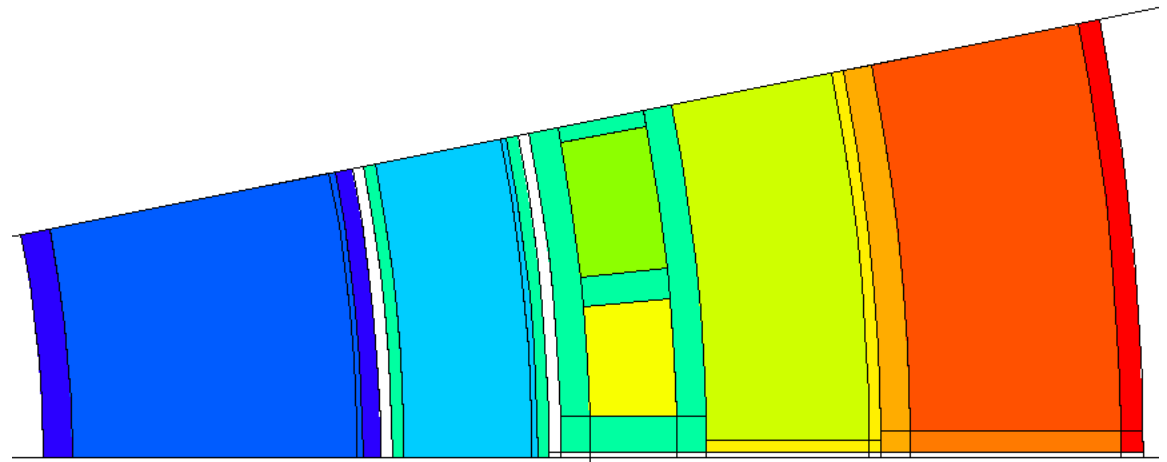


# Straight gap model

- 1, 2 cm gaps examined
- Gap reaches vacuum vessel

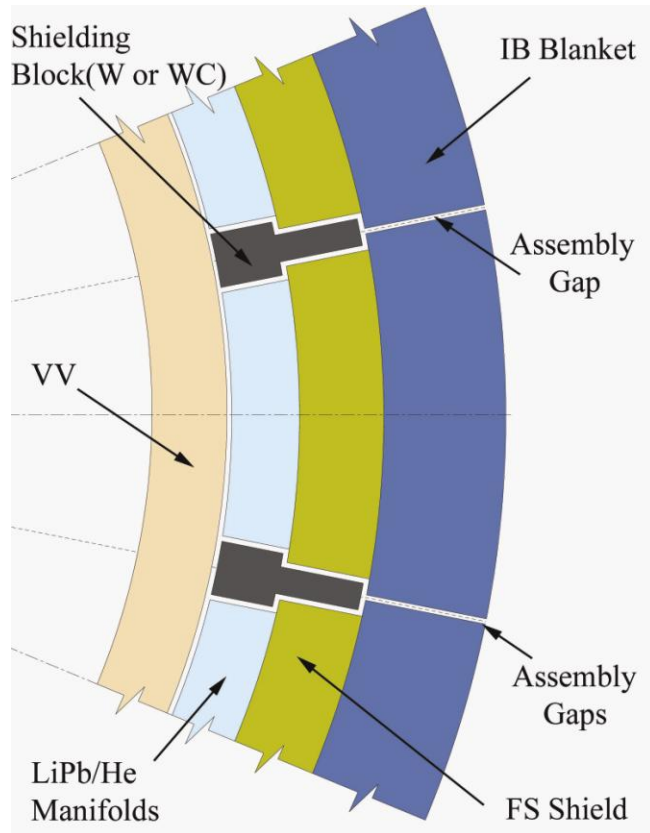


**3-D Model** →



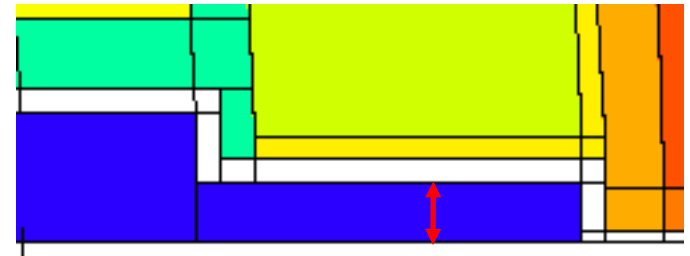


# Stepped gap model

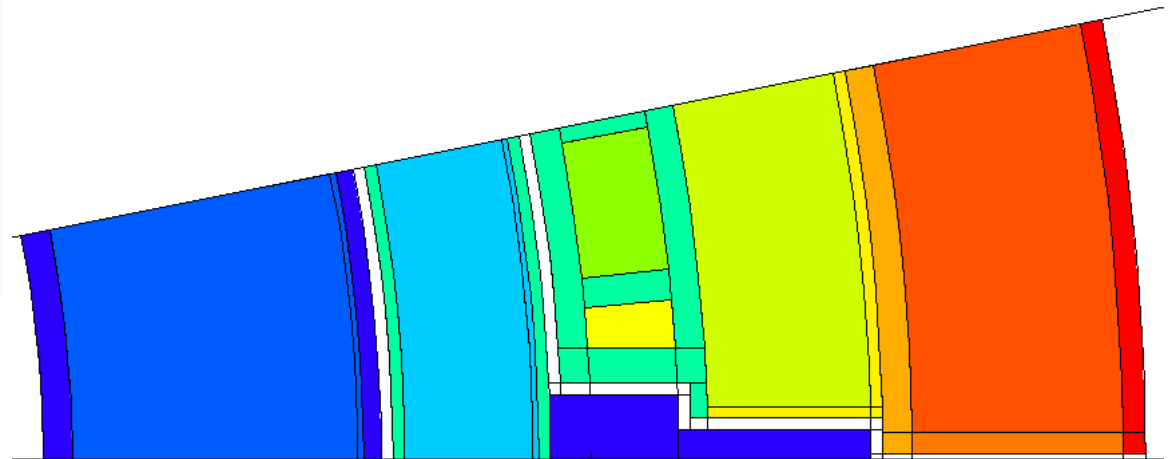


**3-D Model** →

- 1, 2 cm gaps
- Double step
- WC block
- Offset 5 cm

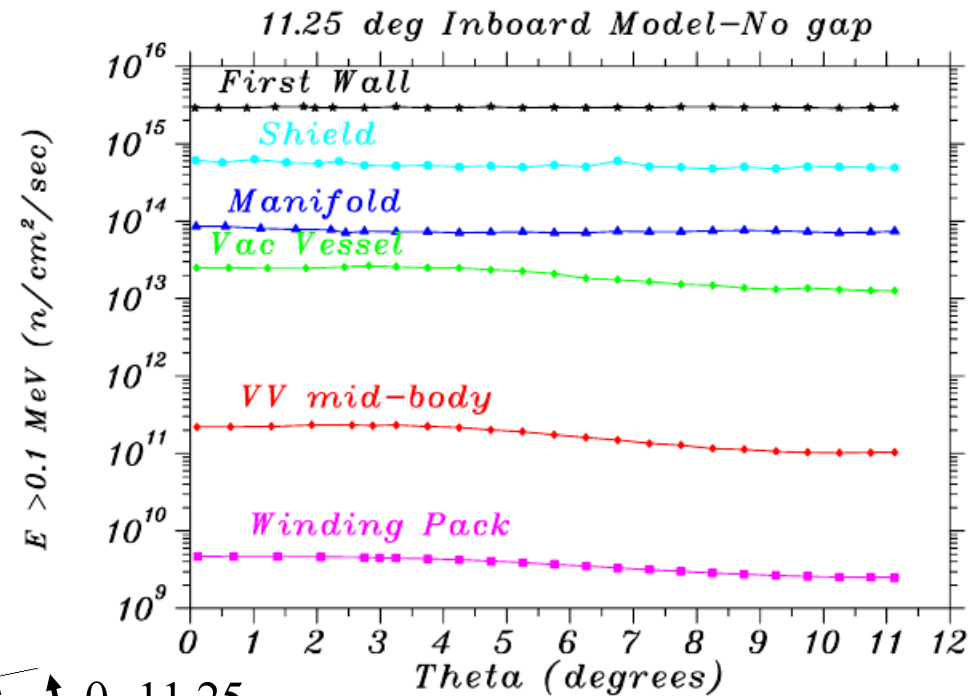
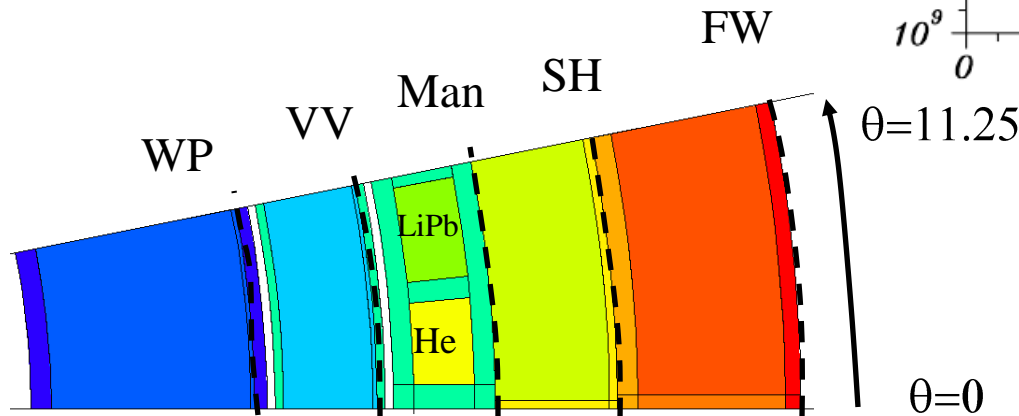


Offset 5 cm



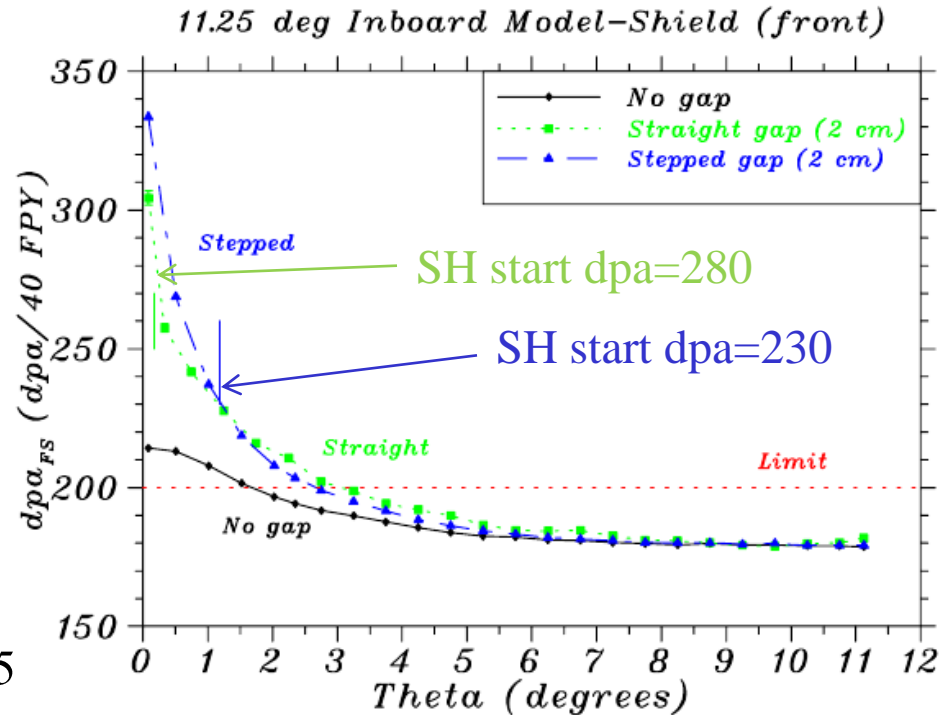
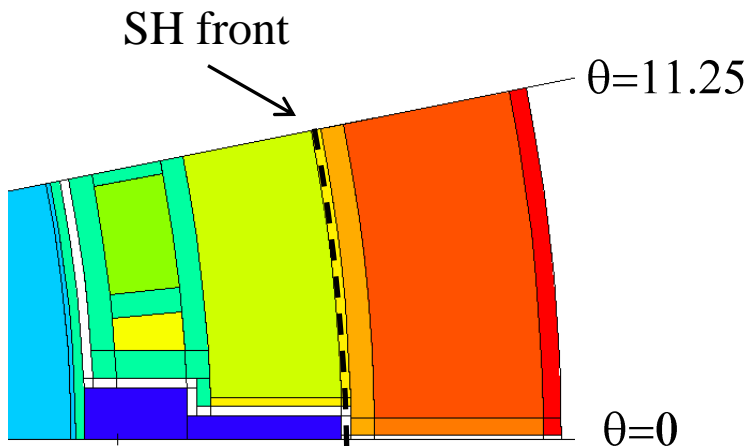
# No gap-Overall IB flux levels

- Almost 6 orders of magnitude attenuation
- Increased levels behind He manifolds (e.g. WP  $\sim 2x$ )



# dpa Shield Front (2 cm gaps)

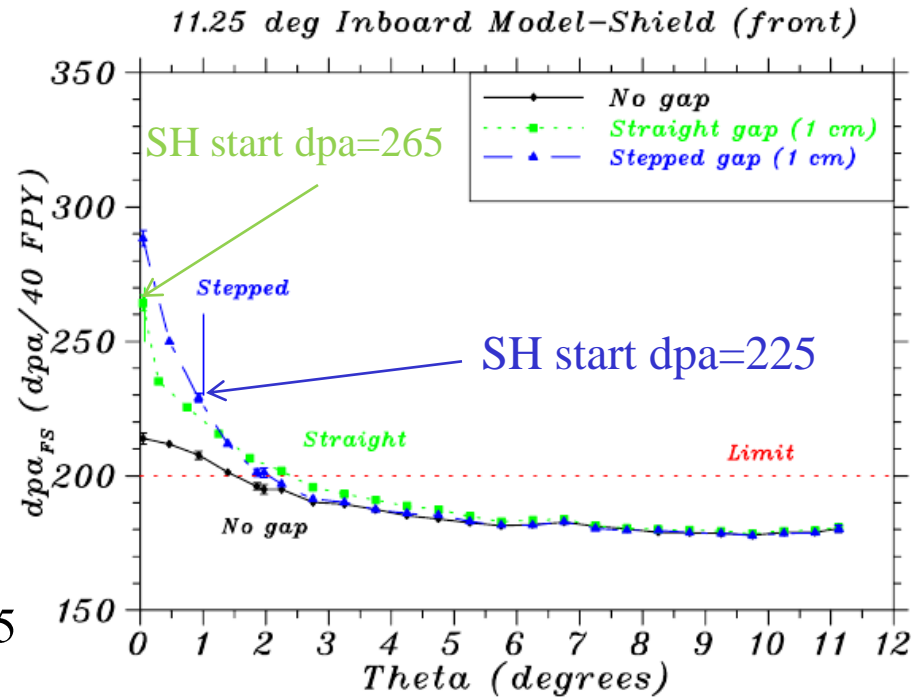
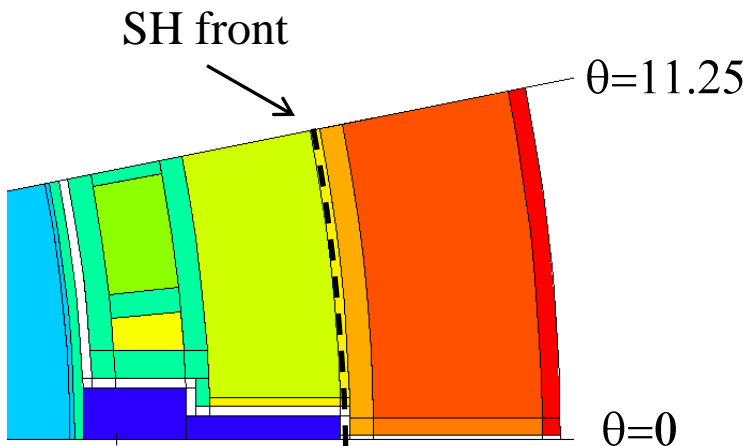
- Both gaps lead to strong peaking
  - Straight Gap  
(gap/nogap)<sub>max</sub> = 1.3
  - Stepped Gap  
(gap/nogap)<sub>max</sub> = 1.1



All cases exceed the dpa limit so the front part of shield must be replaceable

# dpa Shield Front (1 cm gaps)

- Reduced dpa levels and peaking compared to 2 cm gaps
- Still exceed the limit

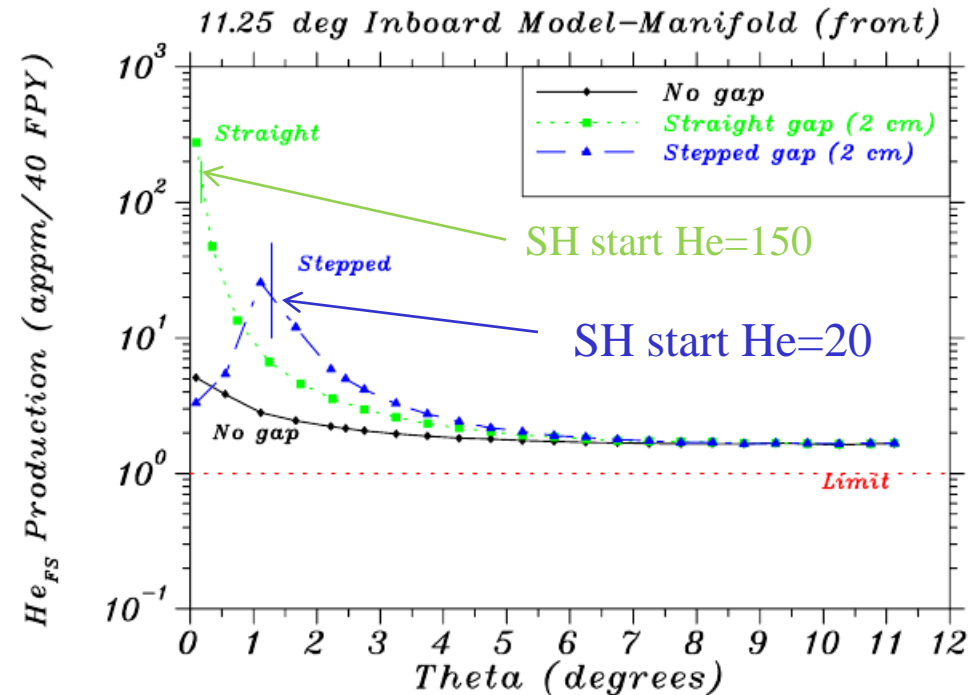
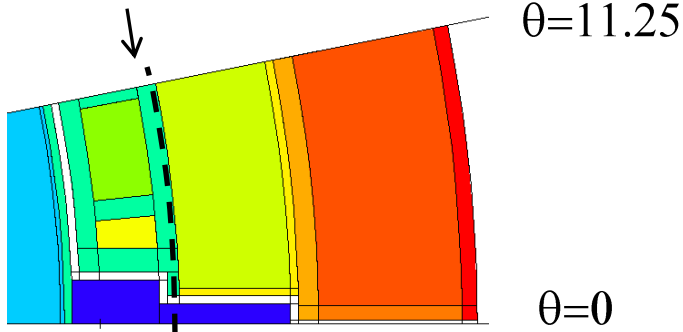


All cases exceed the dpa limit so the front part of the shield must be replaceable

# He production Manifold Front (2 cm gaps)

- Both gaps lead to very strong peaking
  - Straight Gap  
(gap/nogap)<sub>max</sub> = 30
  - Stepped Gap  
(gap/nogap)<sub>max</sub> = 8
- Stepped gap shifts peak

Manifold front

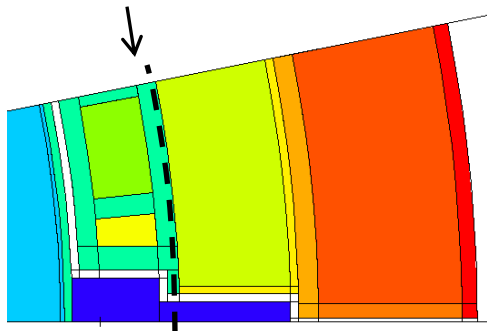


All cases exceed the He production limit so the front part of the manifold is not reweldable (note: new design requires no manifold on IB)

# He production Manifold Front (1 cm gaps)

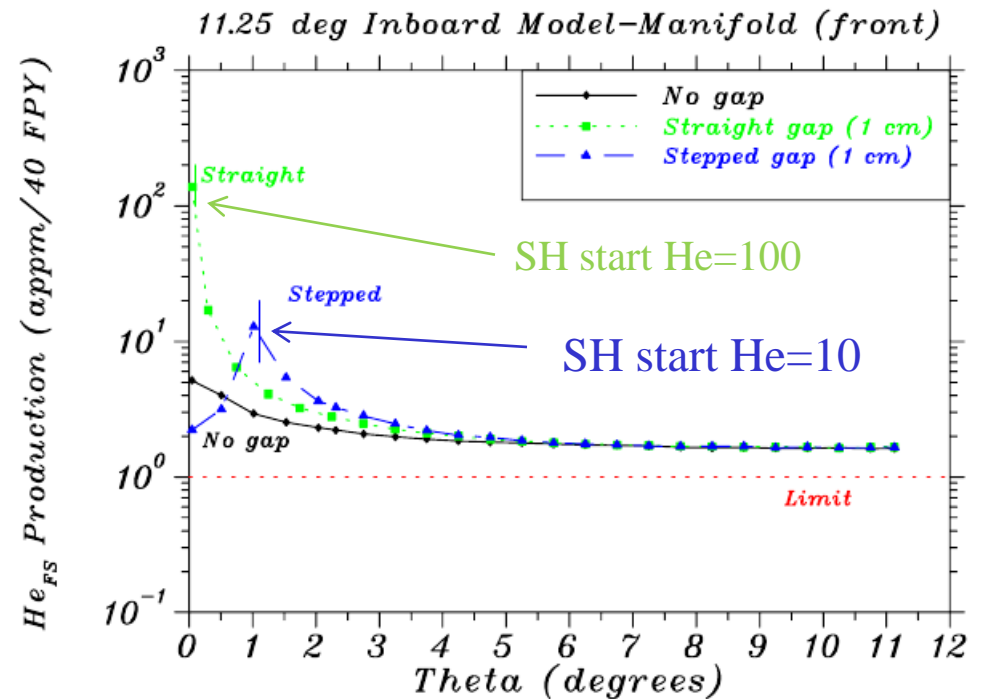
- Reduced He levels and peaking compared to 2 cm gaps

Manifold front



$\theta=11.25$

$\theta=0$

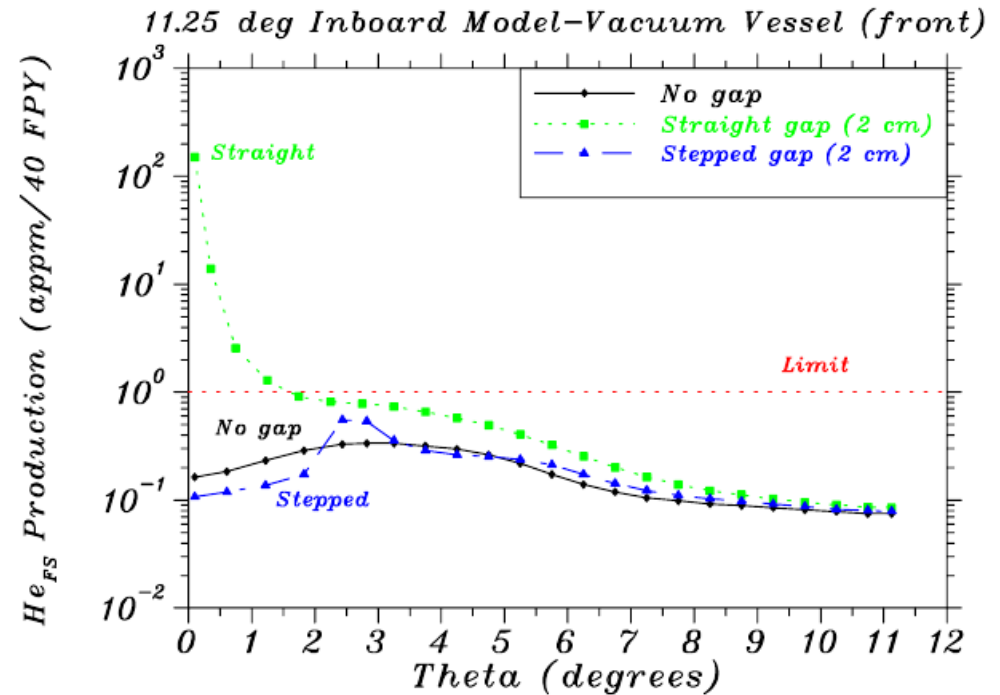
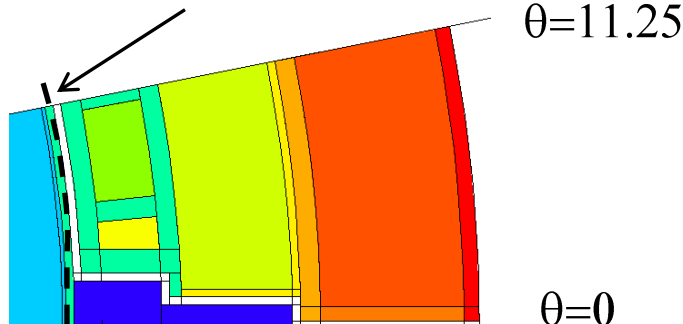


All cases exceed the He production limit so the front part of the manifold is not reweldable

# He production Vac Vessel Front (2 cm gaps)

- Straight gap leads to very strong peaking
  - $(\text{gap/nogap})_{\text{max}} = 900$
- Stepped gap not as strong
  - $(\text{gap/nogap})_{\text{max}} = 1.7$

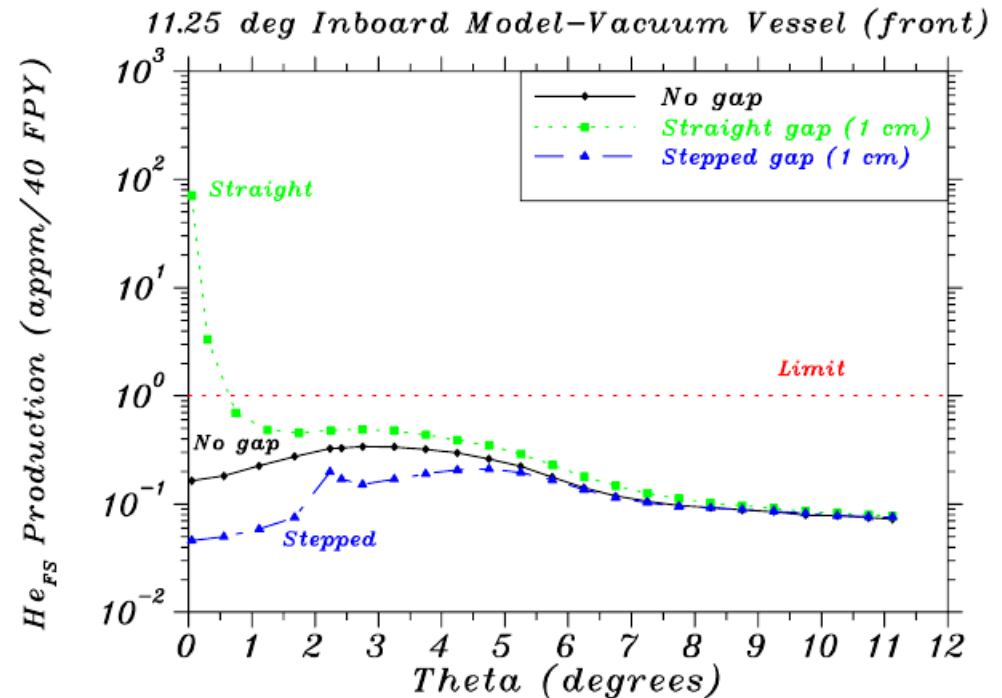
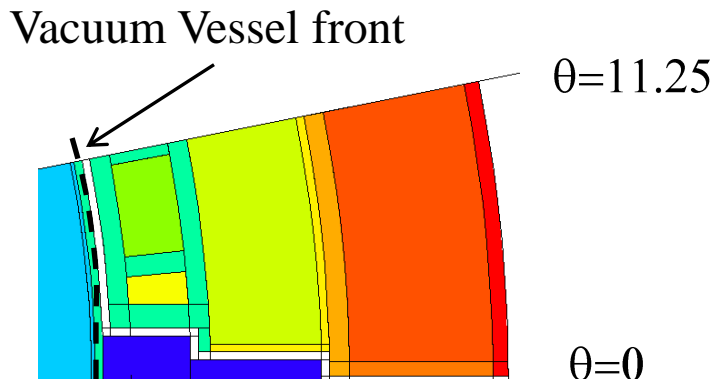
Vacuum Vessel front



The stepped gap with WC shield block meets the He production limits so the VV is reweldable

# He production Vac Vessel Front (1 cm gaps)

- Reduced He levels and peaking compared to 2 cm gaps

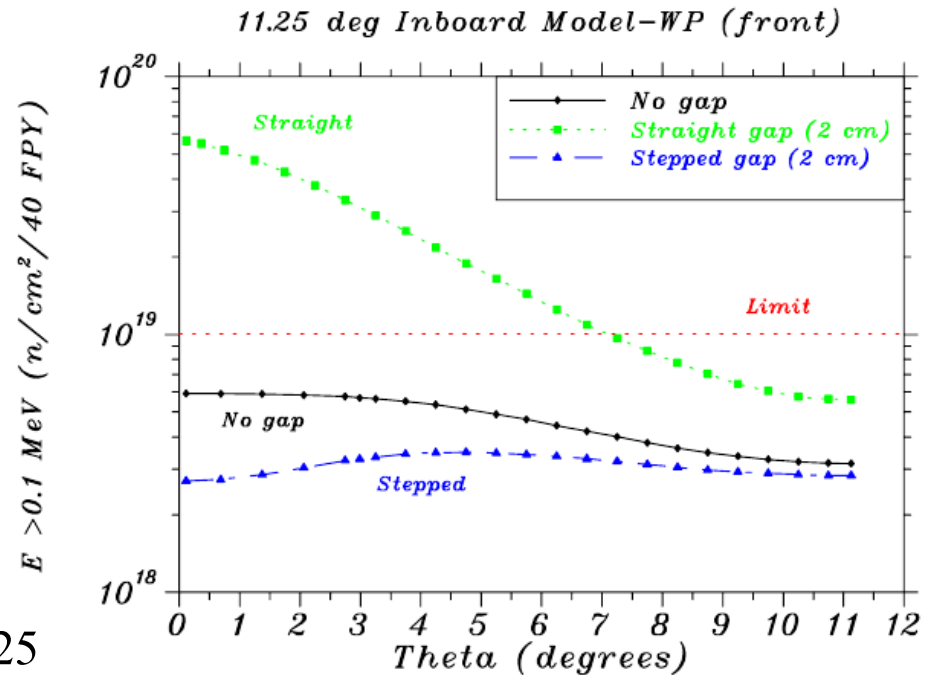
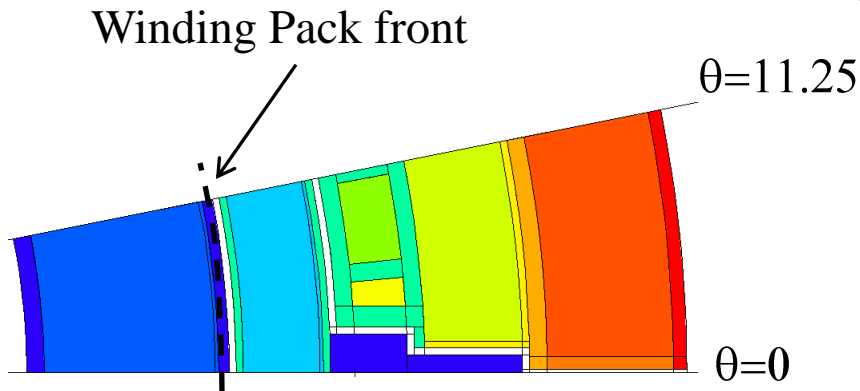


The stepped gap with WC shield block meets the He production limits so the VV is reweldable



# Fast Fluence Winding Pack Front (2 cm gaps)

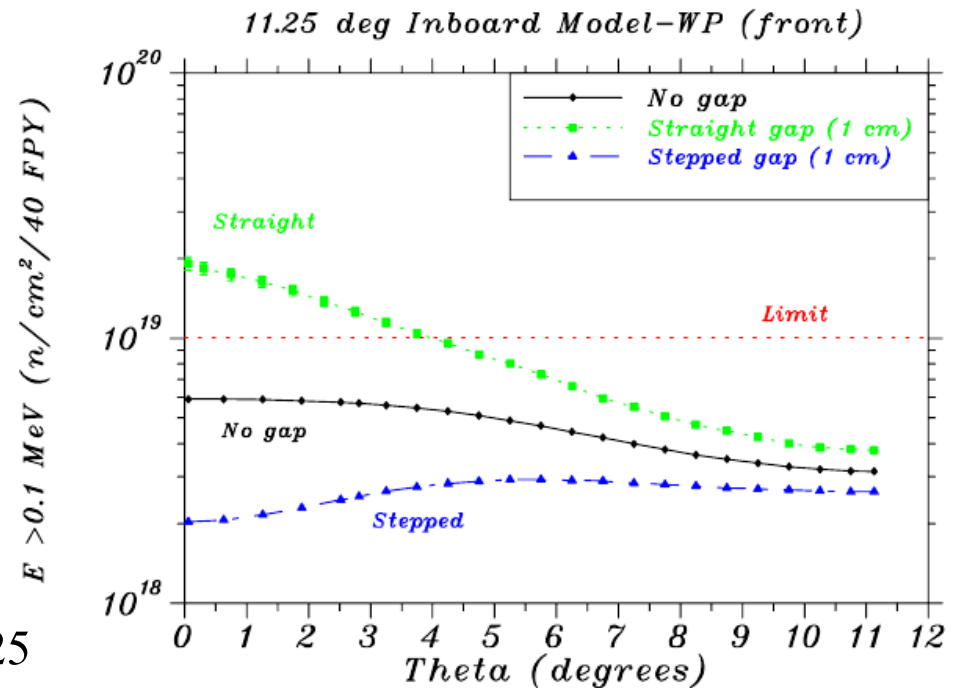
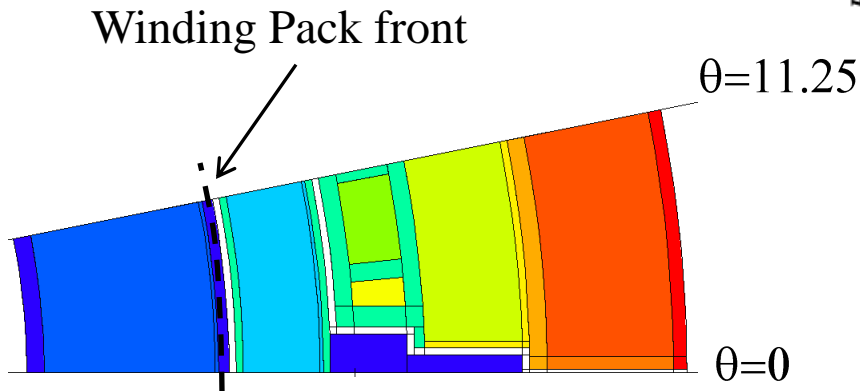
- Smoother peaks due to shielding effect of VV
- Straight gap has significant peaking
  - $(\text{gap/nogap})_{\text{max}} = 9.5$



The stepped gap with WC shield block meets the winding pack fast fluence limit

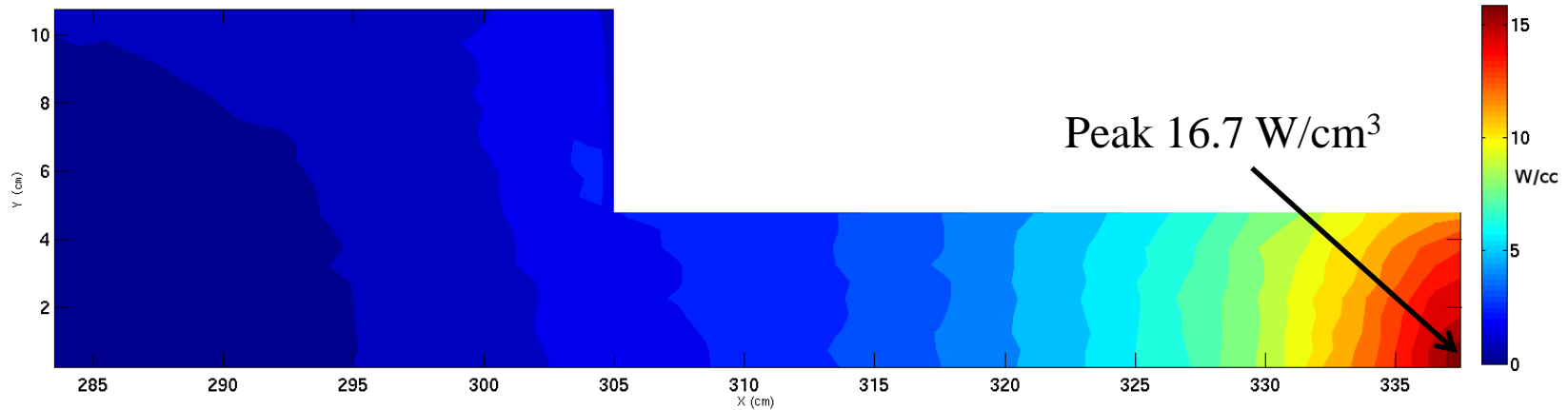
# Fast Fluence Winding Pack Front (1 cm gaps)

- Reduced fluence levels and peaking compared with 2 cm gap



The stepped gap with WC shield block meets the winding pack fast fluence limit

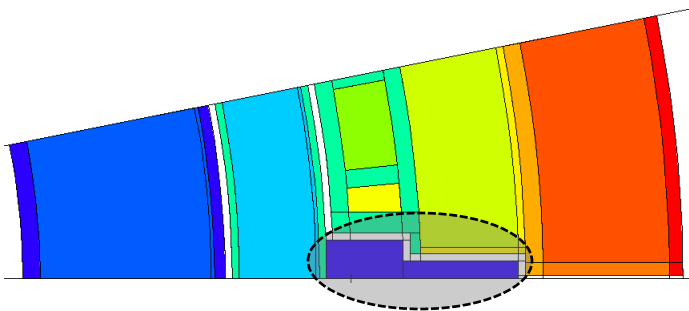
# Heating in WC Shield Block (2 cm stepped gap)



Ave.  $1.0 \text{ W/cm}^3$

Ave  $6.2 \text{ W/cm}^3$

Ave  $3.1 \text{ W/cm}^3$



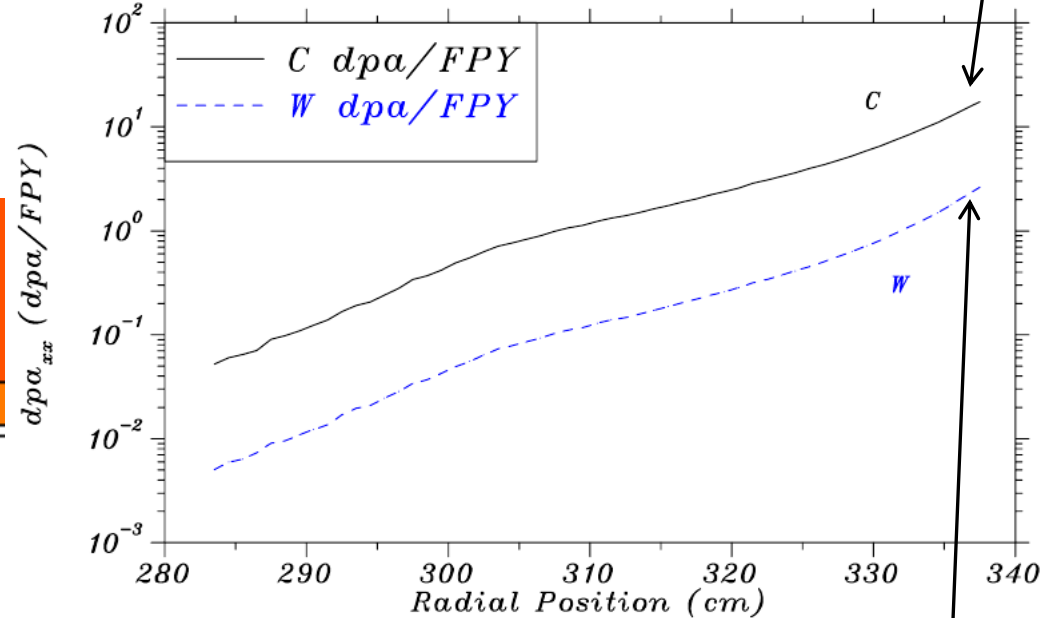
Per S. Malang, radiative cooling is feasible if average heating is below  $15 \text{ W/cm}^3$



# dpa in WC Shield Block (2 cm gap)

17 dpa/FPY

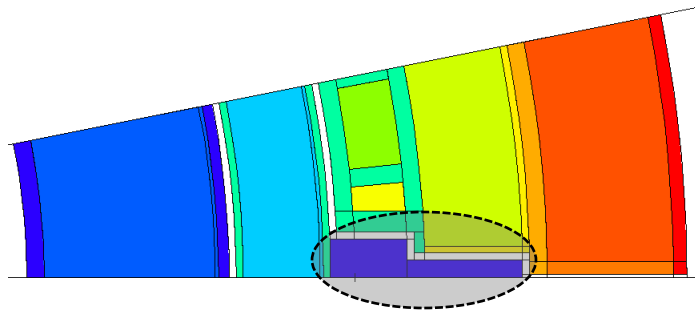
11.25 deg Inboard Model-2cm gap



2.6 dpa/FPY

Graph profiles

Materials experts need to decide if WC or W can be used as a structural component



# Conclusions

- Straight gaps allow too much radiation to reach components on the IB side for the ARIES-AT DCLL design
- Stepped gaps with WC shield blocks are needed to protect the IB components
- Will need to account for uncertainty in nuclear data
- Safety factor used with 1-D models should be adjusted accordingly