Neutronics Assessment of the ITER First Wall/ Shield Modules

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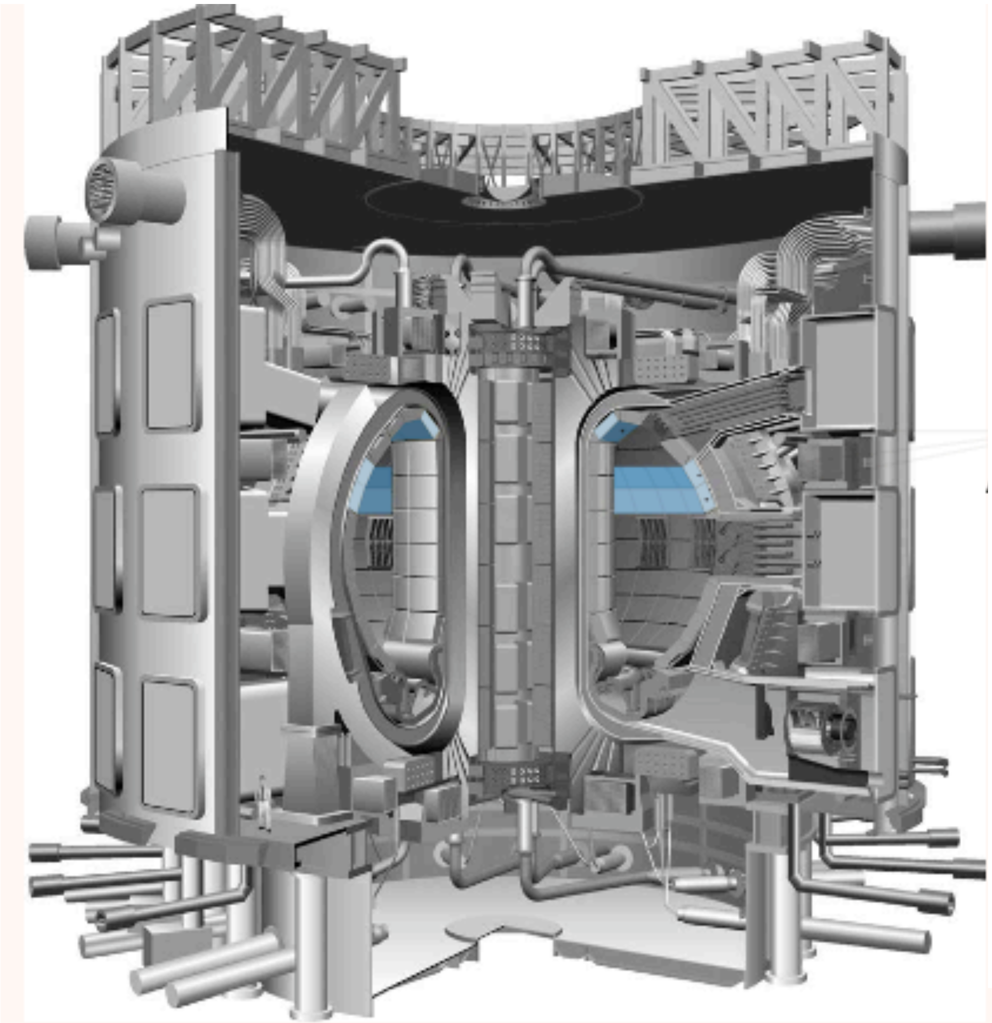
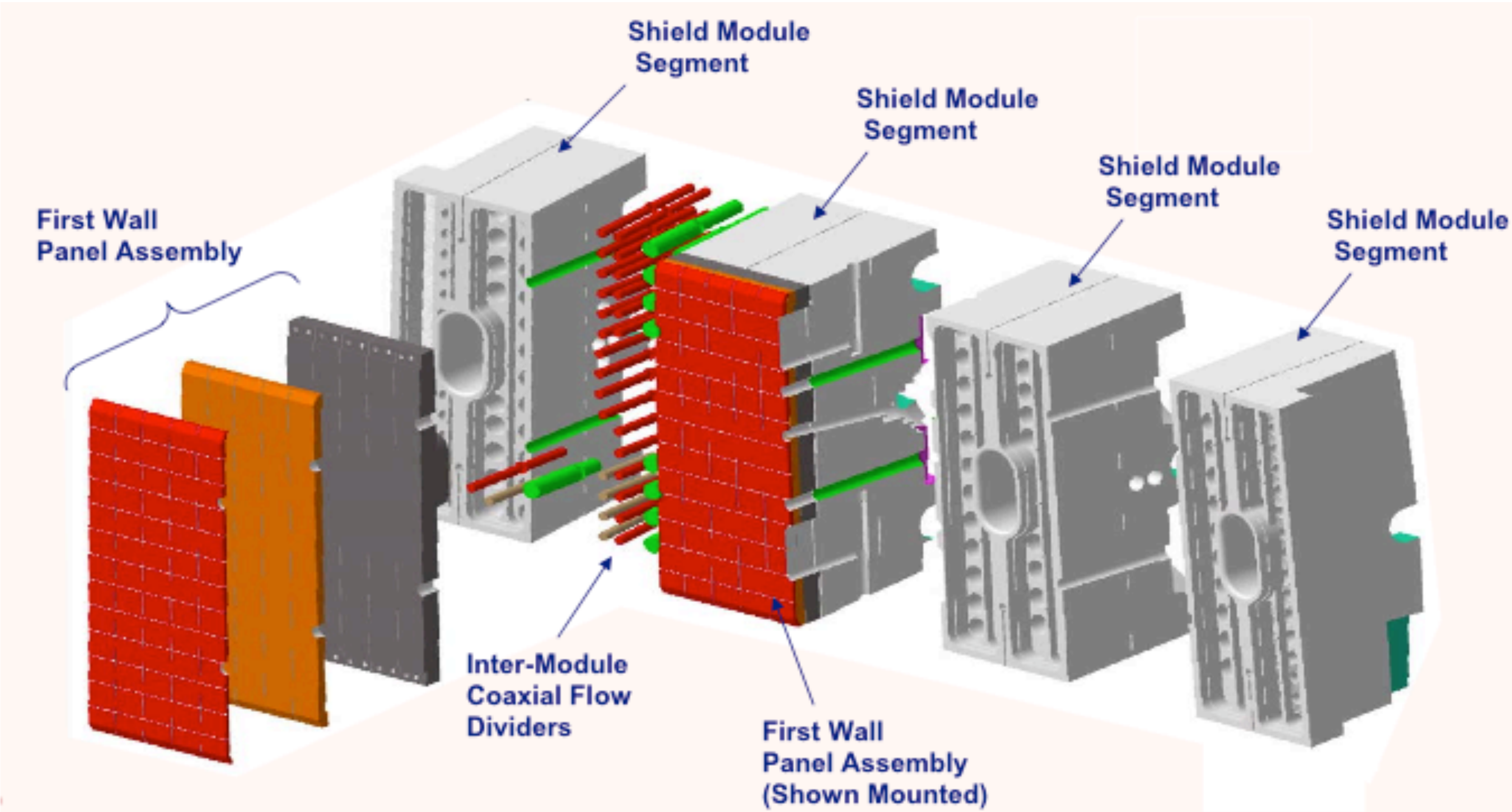
Detailed 3-D Neutronics Needed for FWS Module Design



- FWS modules 7, 12, and 13 are allocated to the US
- Modules are designed at SNL
- Design includes assessment of stresses and performing detailed CFD and EM analyses
- Detailed distribution of nuclear heating in the module is an essential input to design
- Mapping of SS radiation damage and He production in module and at front of VV is required to assess reweldability

FWS Module Elements



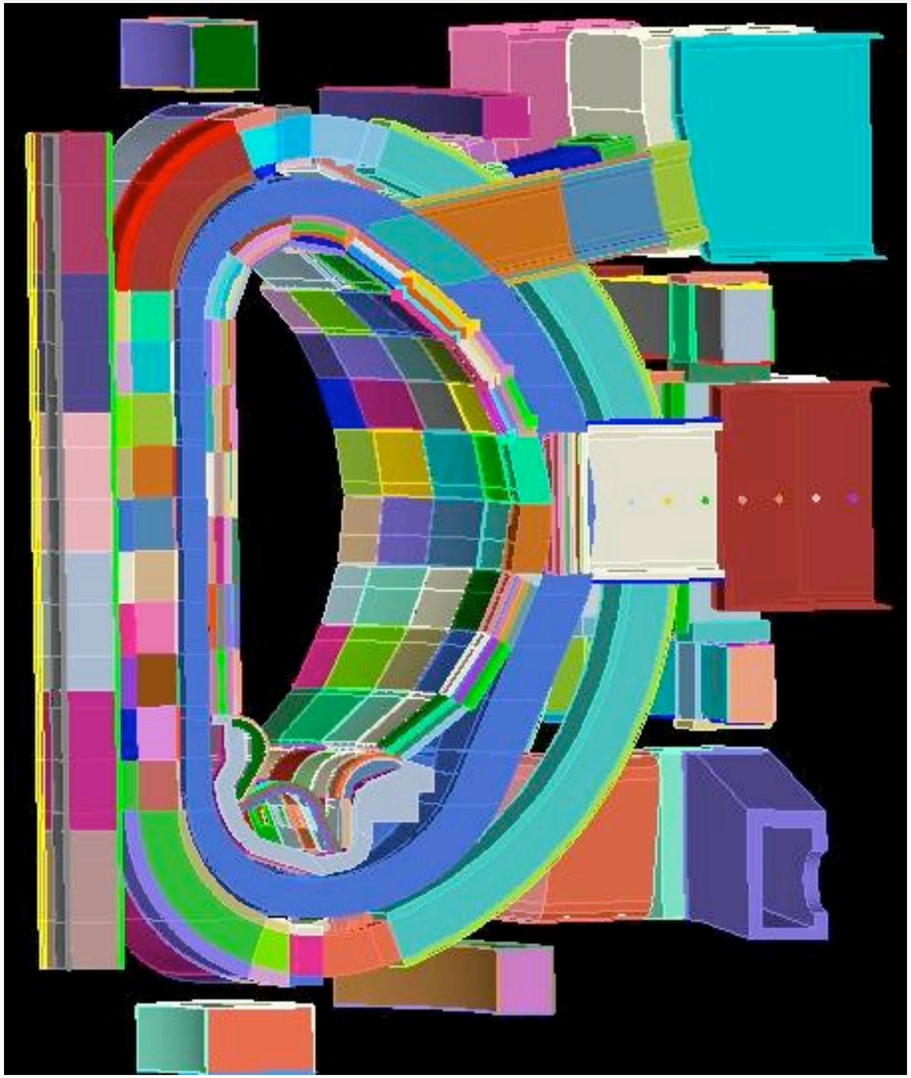
Neutronics Calculations Performed in Steps

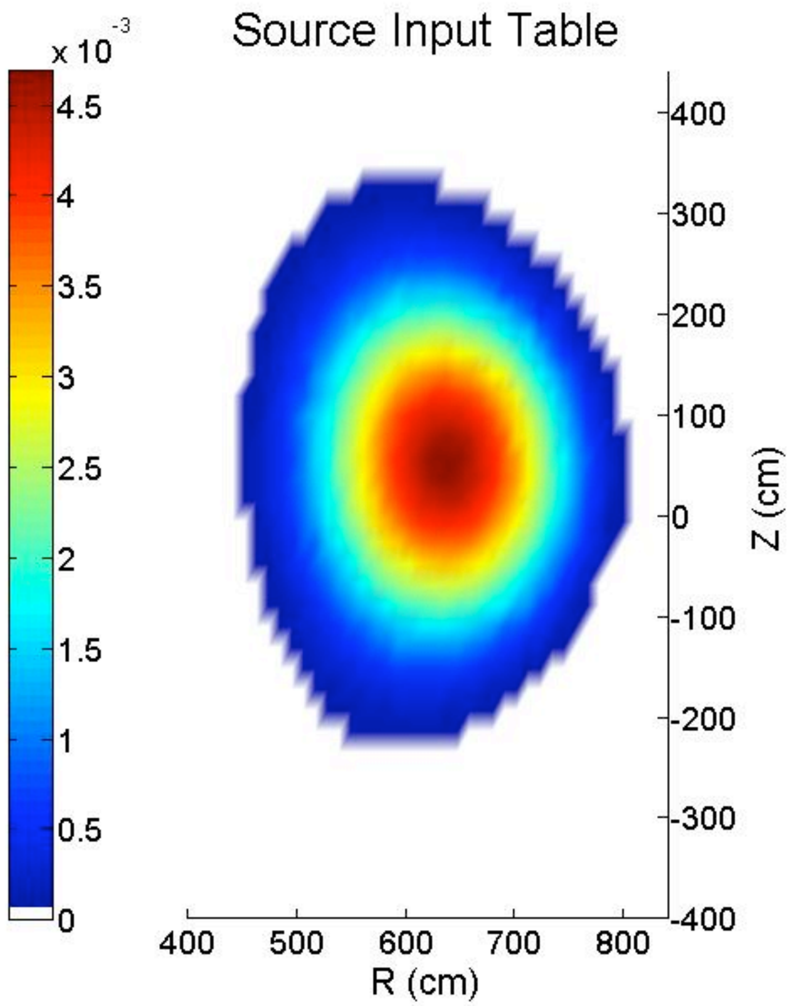
- Initial 1-D calculations
  - Use homogenized 8 radial layers
- Hybrid 1-D/3-D calculations
  - Place the detailed 3-D representation of Module 13 into a 1-D model to approximate coupling to full machine
- Calculation with FWS module integrated into full ITER model

1-D Analysis for FWS Modules

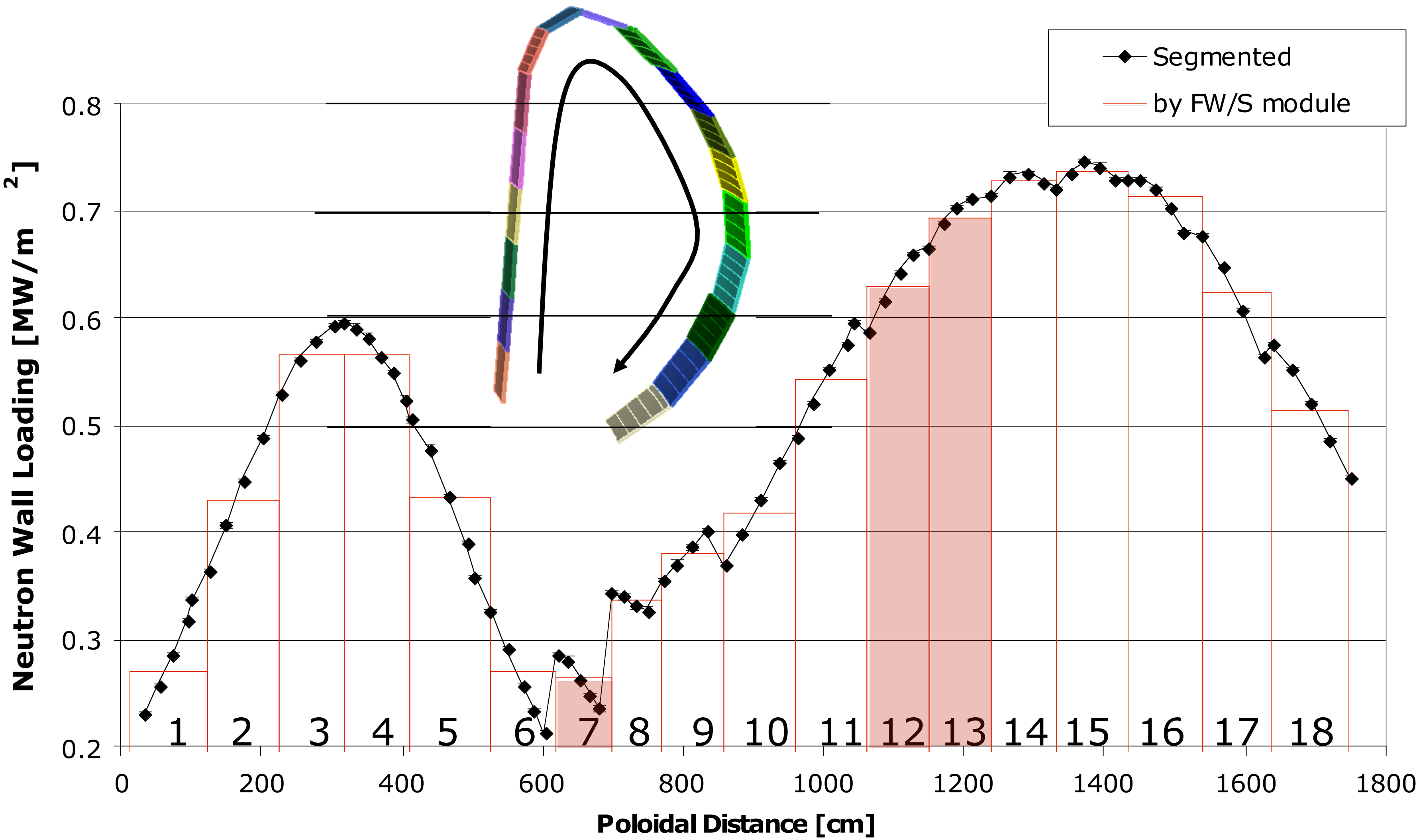
- Model basics
  - 1-D calculations on cylindrical geometry
  - Normalized to neutron wall loading on the front surface
    - Based on 3-D MCNPX-CGM calculations of the poloidal NWL distribution
  - Nuclear heating radial profiles calculated in each constituent material
  - Peak VV parameters calculated

ITER Geometry with Neutron Source Profile





NWL Distribution in ITER



Radial Build

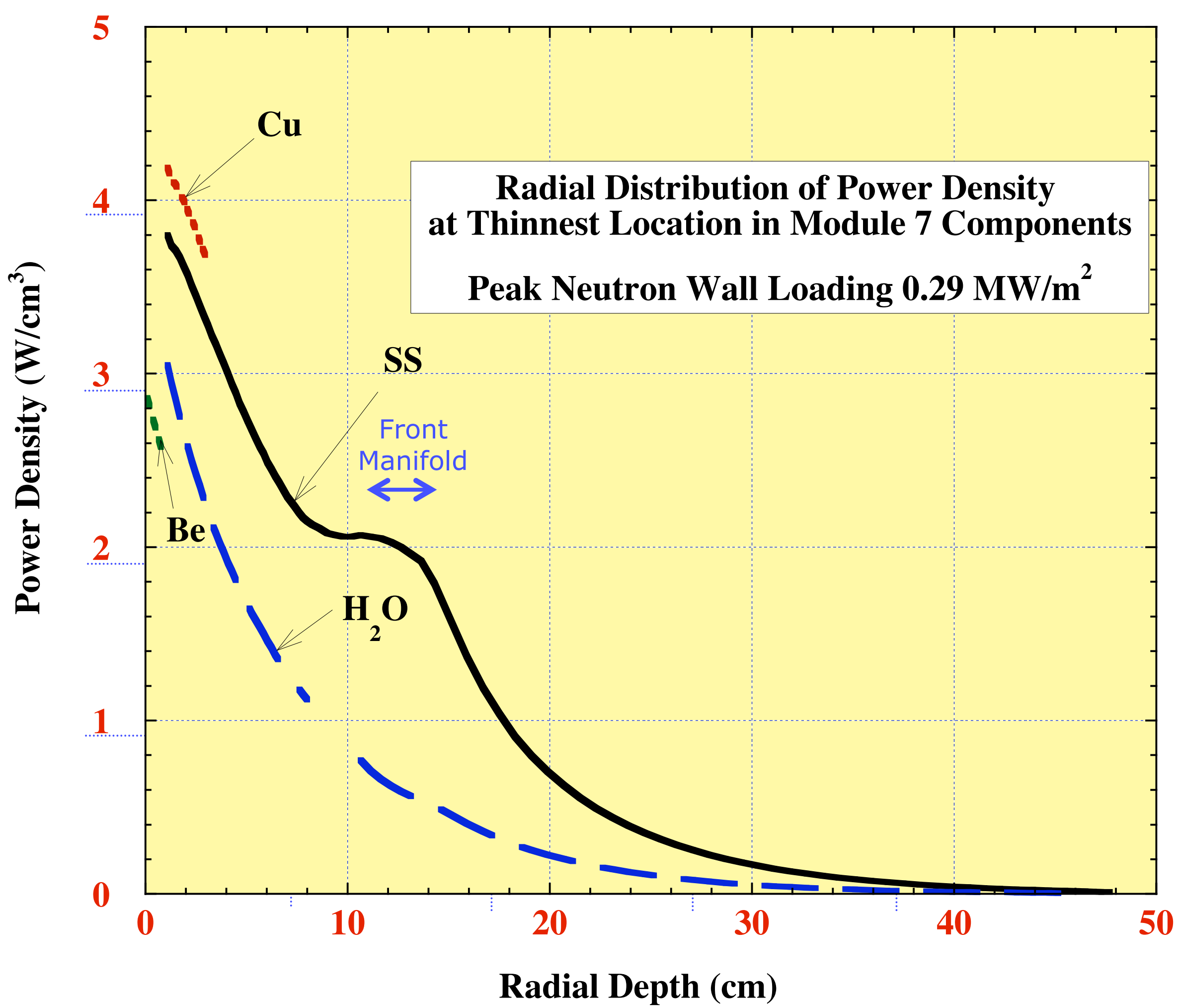
Module 7 (Thinnest poloidal location)

Zone	Description	Thickness (mm)	% Be	% CuCrZr	% SS316LN -IG	% H_2O
1	Be PFC	10	100	0	0	0
2	CuCr Zr heat sink	22	0	82.9	0	17.1
3	SS FW structure	49	0	0	84.6	15.4
4	Gap between FW and shield module	3	0	0	0	0
5	Fro nt shield SS plate	20	0	0	100	0
6	Front shield header	35	0	0	14	86
7	Bulk of shield module	320	0	0	70	30
8	Back shield SS plate	20	0	0	100	0
Total		**479**				

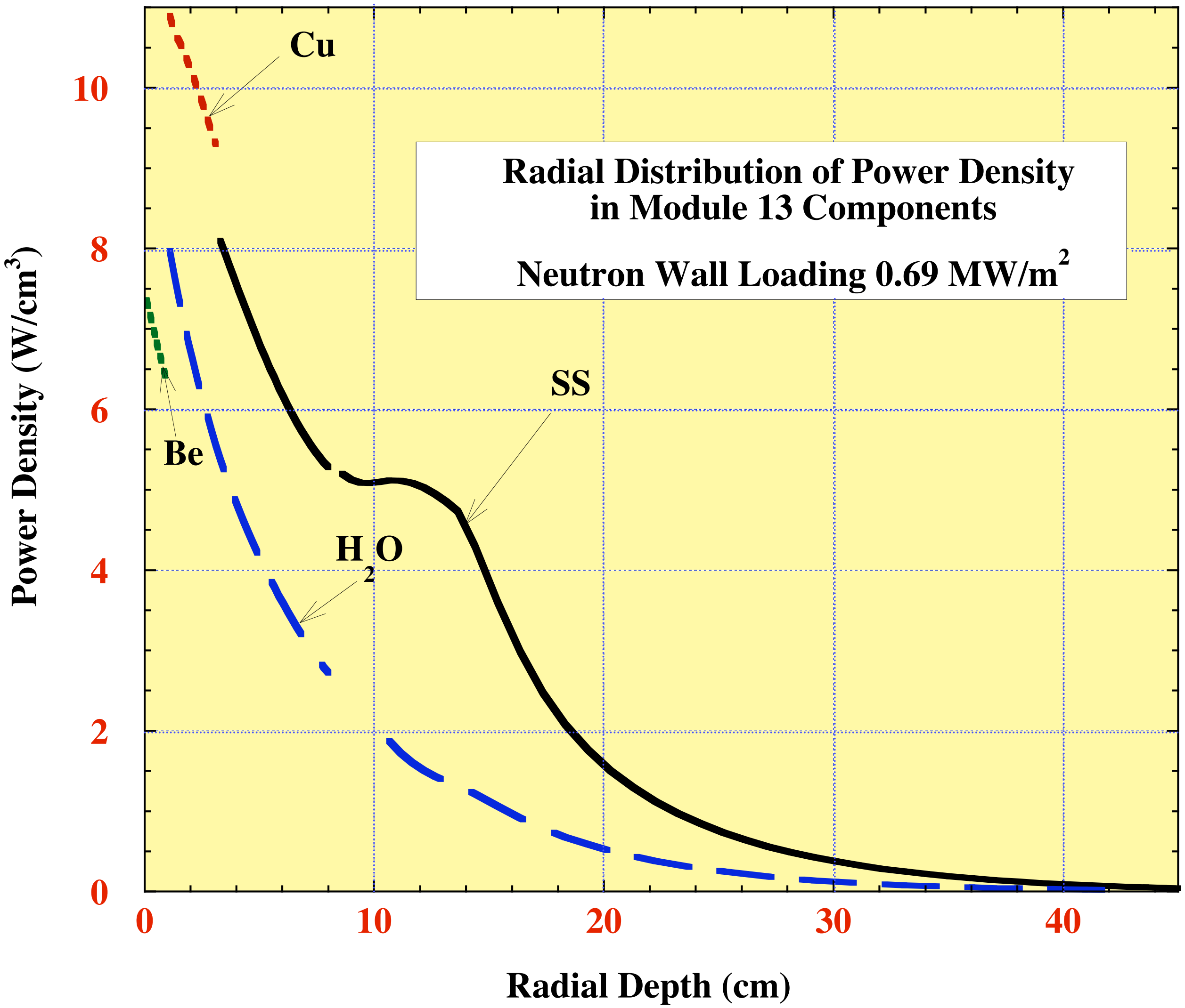
Modules 12 and 13

Zone	Description	Thickness (mm)	% Be	% CuCrZr	% SS316LN -IG	% H_2O
1	Be PFC	10	100	0	0	0
2	CuCr Zr heat sink	22	0	82.9	0	17.1
3	SS FW structure	49	0	0	84.6	15.4
4	Gap between FW and shield module	3	0	0	0	0
5	Front shield SS plate	20	0	0	100	0
6	Front shield header	35	0	0	14	86
7	Bulk of shield module	295	0	0	75	25
8	Back shield SS plate	20	0	0	100	0
Total		**454**				

Radial Variation of Power Density
Module 7 Components



Radial Variation of Power Density
Module 13 Components



Peak Parameters in SS316 Vacuum Vessel Behind FWS Modules

		Module 7	Module 12	Module 13
Thickness	[cm]	47.9	45.4	45.4
Neutron Wall Loading	[MW/m^2]	0.29	0.63	0.69
Power Density	[mW/cm^3]	11	34	37
He Production Rate	[appm/s]	1.1×10^{-9}	3.6×10^{-9}	3.9×10^{-9}
He Production @ 0.3 MWa/m^2 (*)	[appm]	0.019	0.061	0.066
dpa Rate	[dpa/s]	6.5×10^{-11}	2.0×10^{-10}	2.2×10^{-10}
dpa @ 0.3 MWa/m^2 (*)	[dpa]	0.0011	0.0034	0.0037

(*) For average ITER NWL of 0.57 MW/m^2, 0.3 MWa/m^2 fluence corresponds to 0.54 FPY

Impact of Water Coolant Manifold on Nuclear Parameters in VV

- 1-D calculations
  - radial build through water coolant manifold (provided by SNL)
  - poloidal locations corresponding to modules 7, 12, and 13
- Peak radiation parameters in VV calculated
  - Compare parameters behind manifold to parameters behind nominal FWS module
- Conservative estimate for peaking effect of manifolds

Impact of Coolant Manifold on Peak Parameters in SS316 VV

Behind FWS Module 13

	Nominal	Manifold
Total Radial Build (cm)	45.4	48.9
Neutron Wall Loading (MW/m^2)	0.69	0.63
Power Density (mW/cm^3)	37	93
He Production Rate (appm/s)	3.9×10^{-9}	5.6×10^{-9}
He Production @ 0.3 MWa/m^2 (appm) (*)	0.066	0.095
dpa Rate (dpa/s)	2.2×10^{-10}	3.0×10^{-10}
dpa @ 0.3 MWa/m^2 (dpa) (*)	0.0037	0.0050

(*) For average ITER NWL of 0.57 MW/m^2, 0.3 MWa/m^2 fluence corresponds to 0.54 FPY

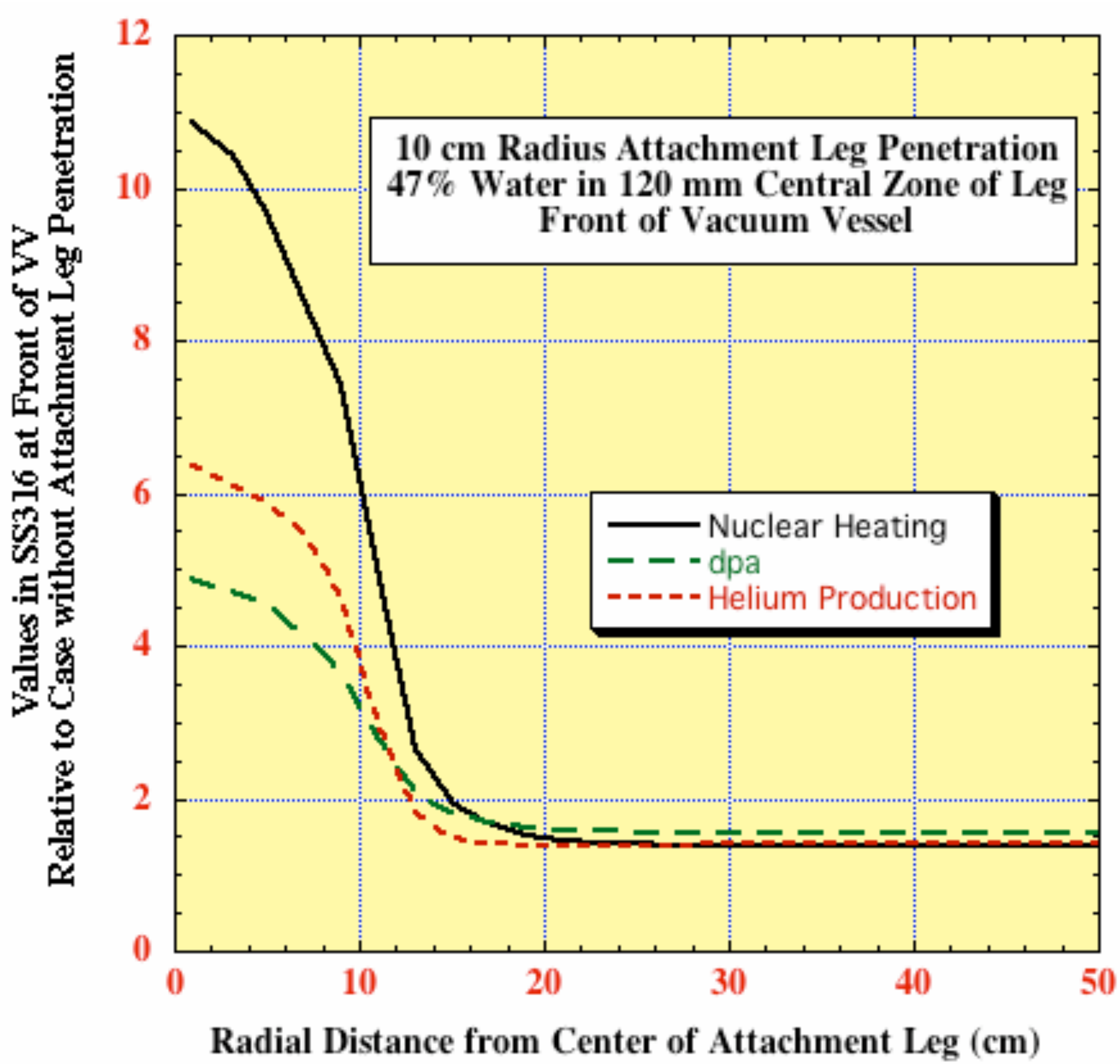
Peaking factor in VV nuclear parameters due to coolant manifold is **~1.4-2.5** with largest peaking in **power density**

Peaking in VV Behind FW Attachment Leg

- FW is attached with a leg:
  - Less thickness and
  - Less material than the shield module
- 2-D analysis performed to determine the effect of streaming through attachment leg
- Results calculated in VV as function of distance from attachment leg centerline
  - Nuclear heating
  - Radiation damage
  - Neutron flux
  - Gamma flux

FW Attachment Leg Impact

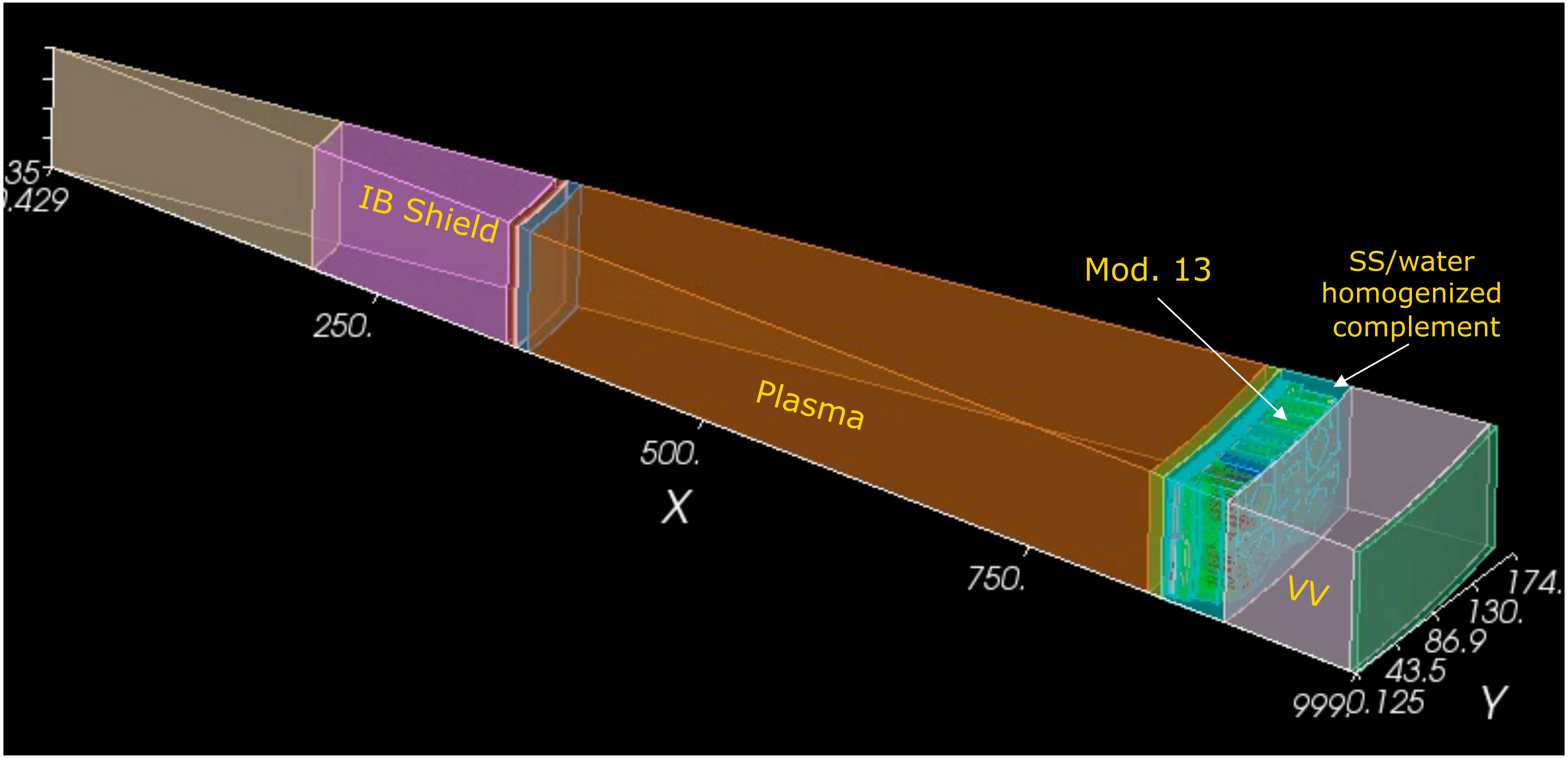
Significant Peaking in Power Density



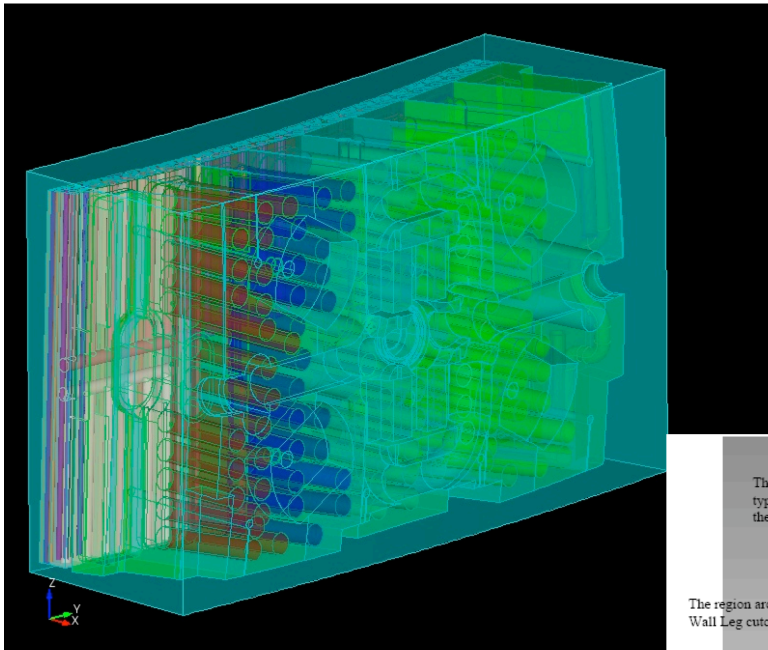
10 cm attachment leg radius

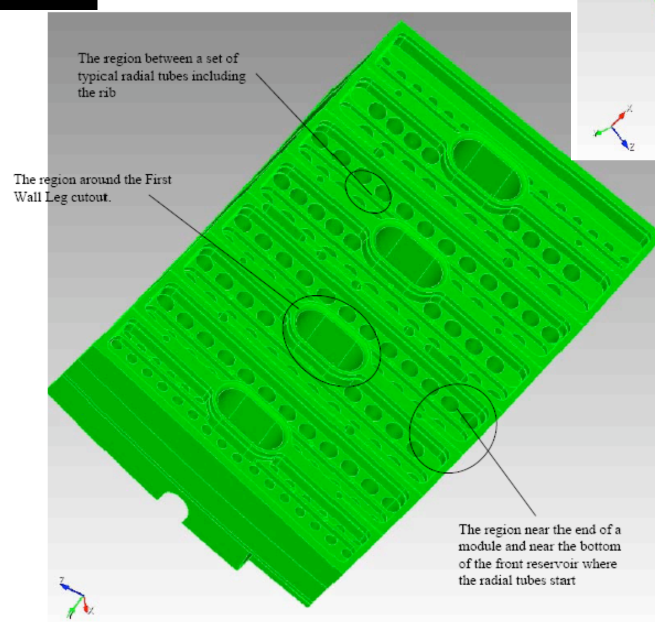
- Power density peaking **~11x higher**
- Relative peaking is smaller for *radiation damage* and *gas production*
- Higher peaking occurs in nuclear heating since it is dominated by gamma heating

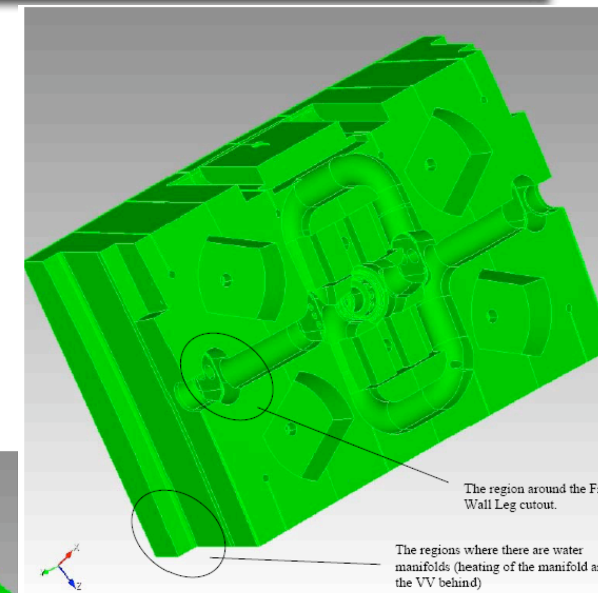
3-D Modeling
Module 13 1-D/3-D hybrid analysis



Module 13 detail



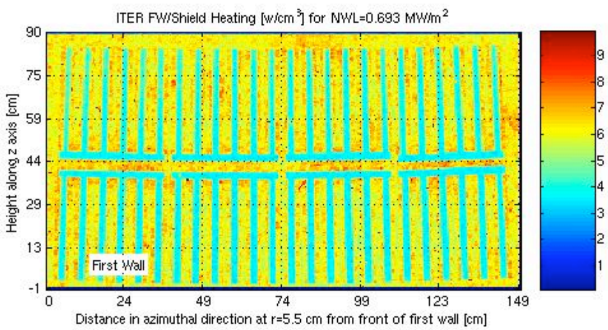


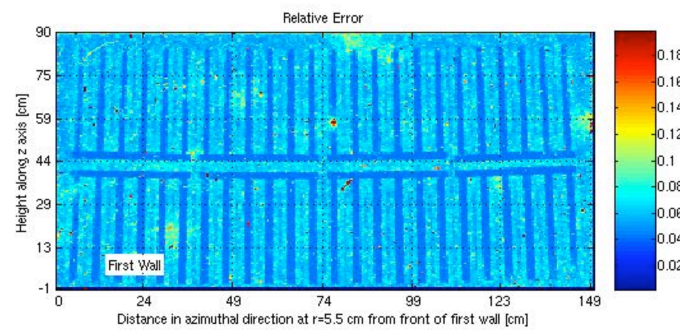


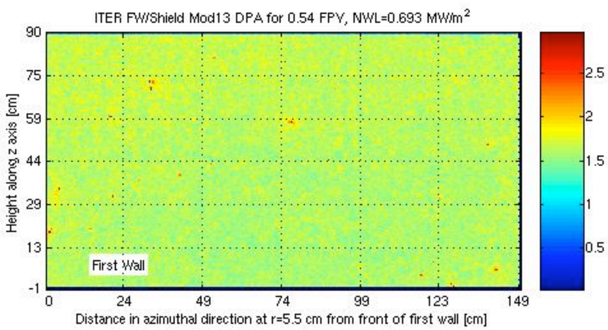
Module 13 1-D/3-D Hybrid Calculations with MCNPX-CGM

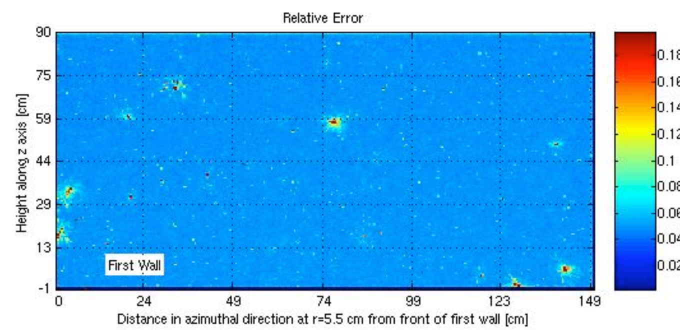
- Total of 17 million source particles sampled using 17 parallel processors
- Total CPU time is 111 Days (15.8 weeks) on 1.4/1.7 GHz Athlon
- Mesh-based weight windows used for variance reduction
- Utilized the mesh tally capability of MCNPX to determine detailed distribution of nuclear heating, dpa, and He production
- Cumulative end-of-life parameters determined for the ITER average FW fluence goal of 0.3 MWa/m^2
- Responses calculated on 0.5 cm x 0.5 cm x 1 cm meshes

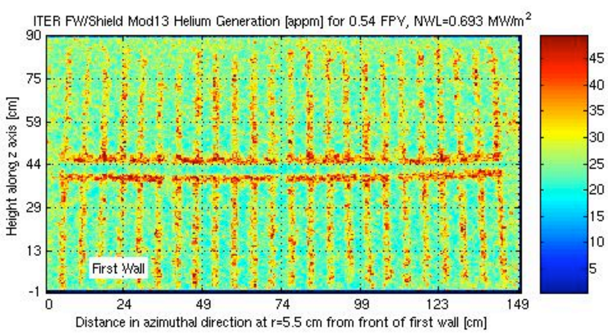
Nuclear responses at a distance of 5.5 cm from front of FW

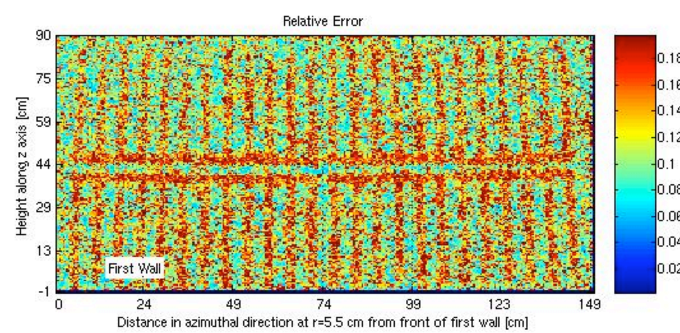




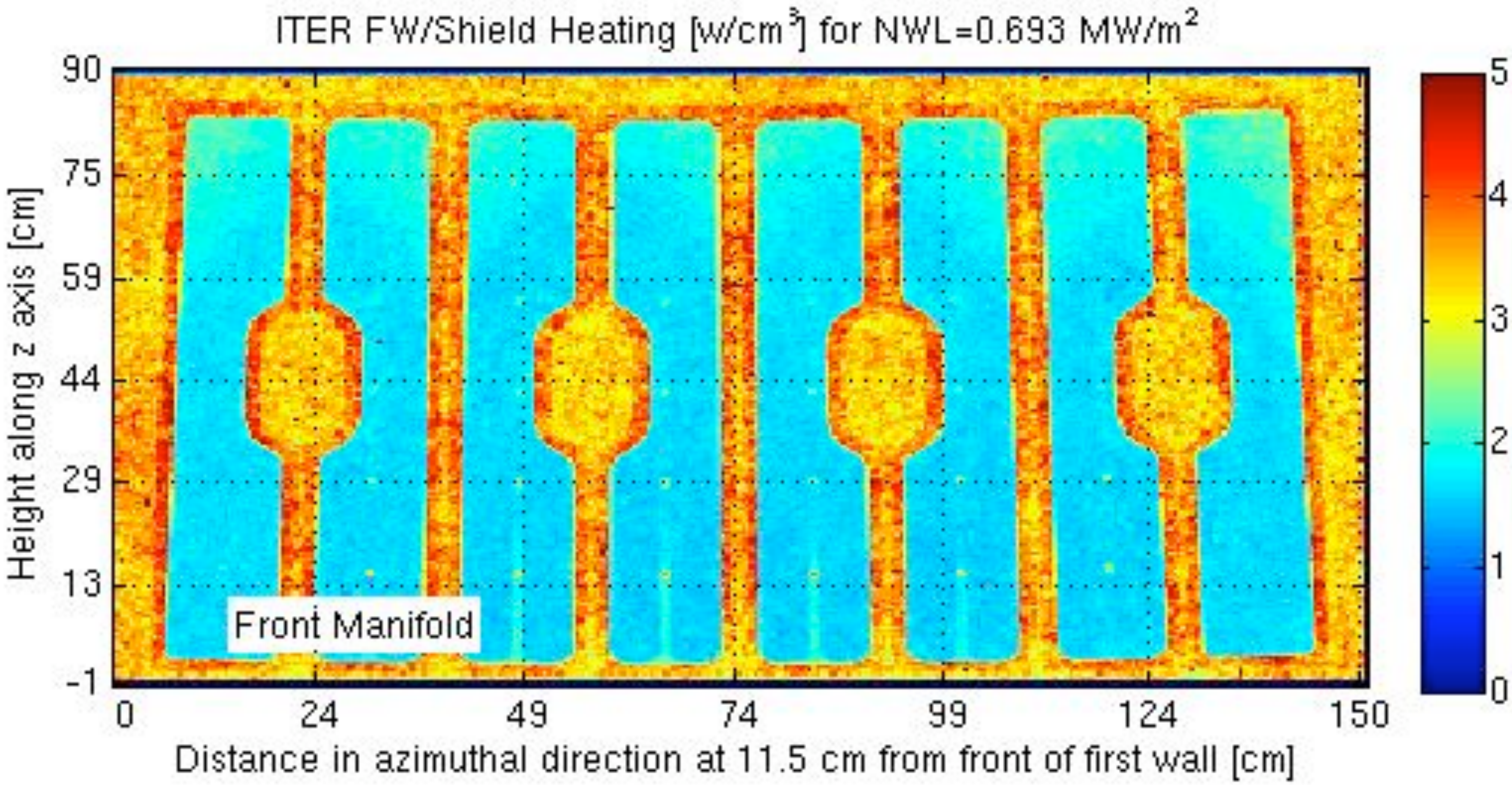




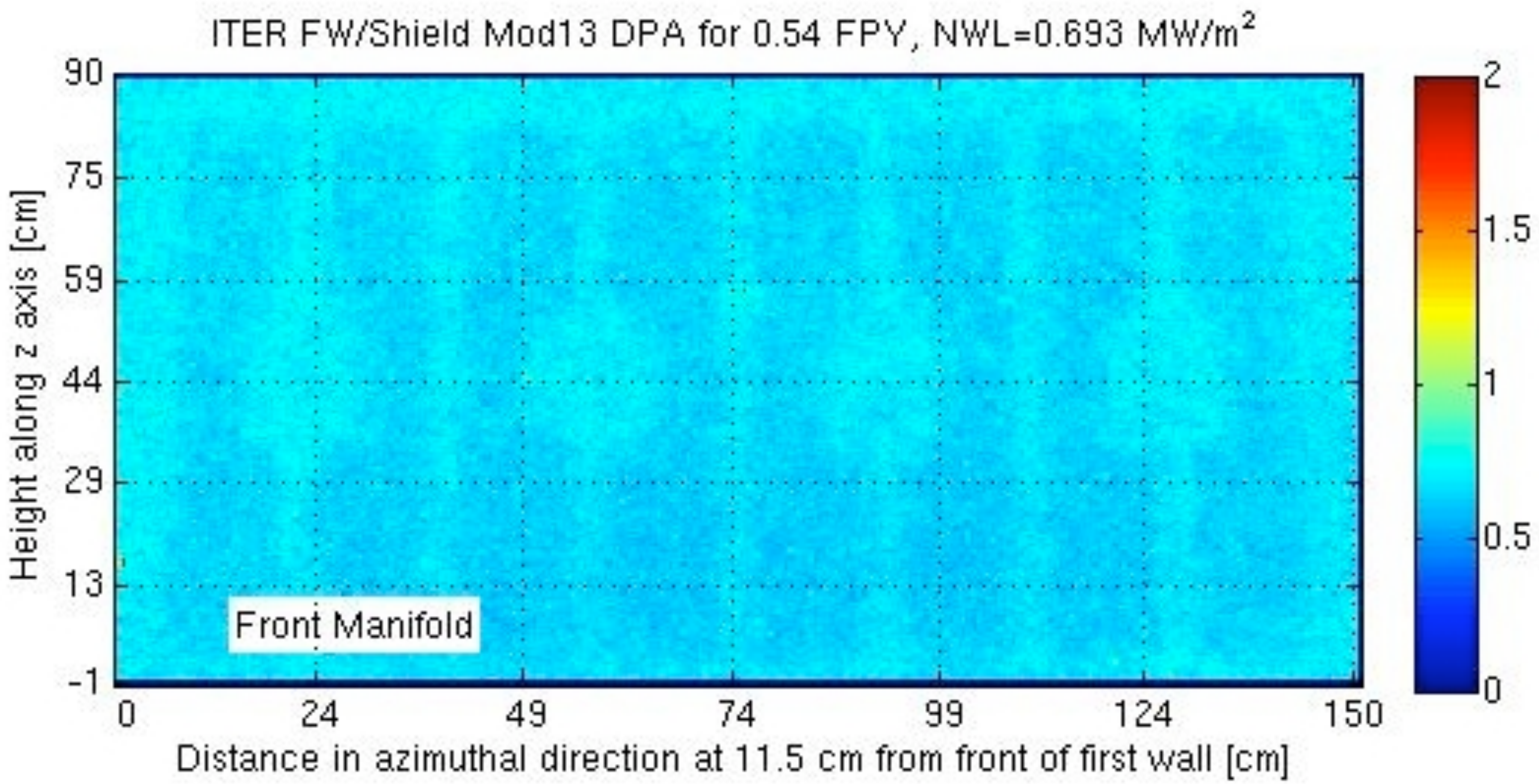




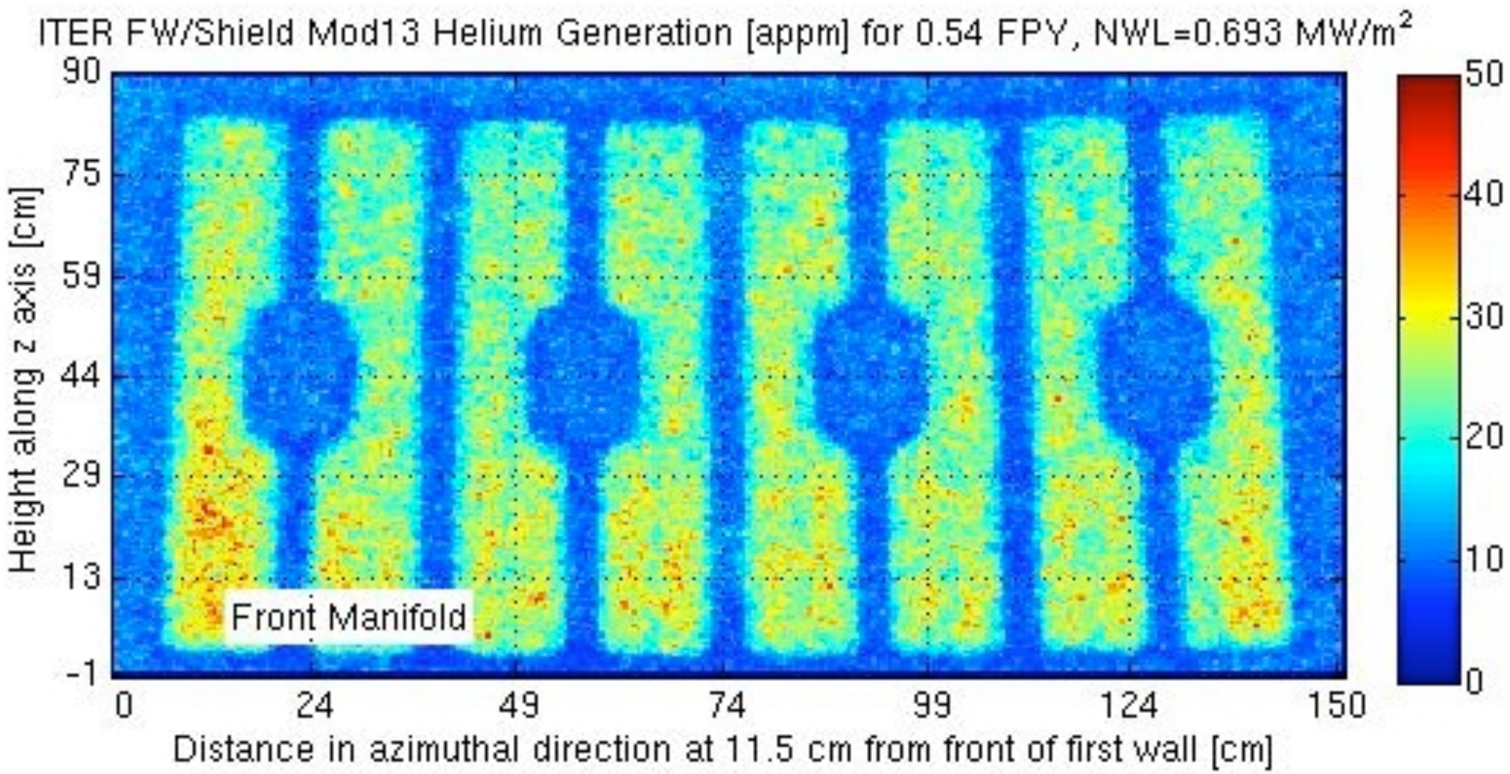
Nuclear Heating at a distance of 11.5 cm from front of FW



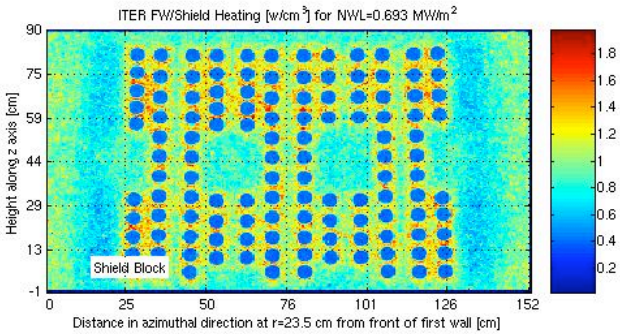
SS dpa at a distance of 11.5 cm from front of FW

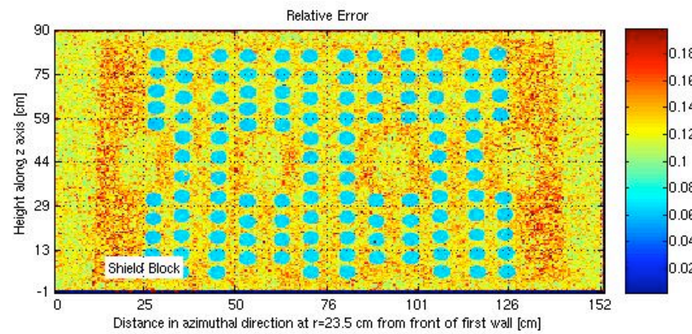


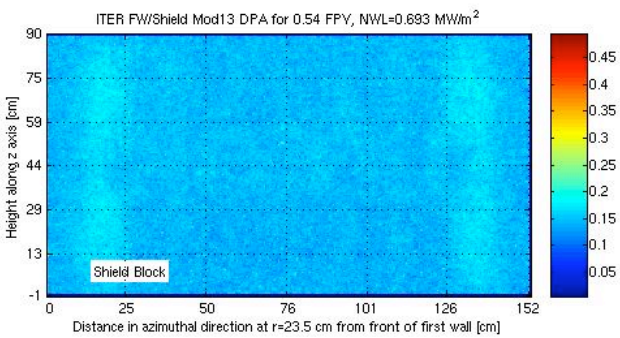
SS He Production at a distance of 11.5 cm from front of FW

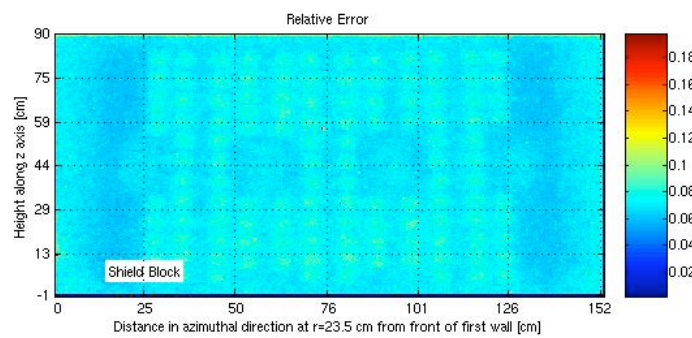


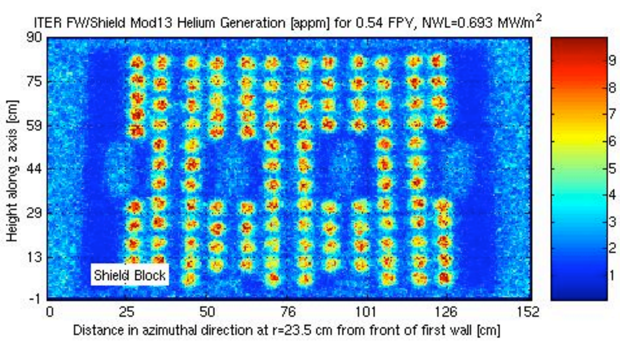
Nuclear responses at a distance of 23.5 cm from front of FW

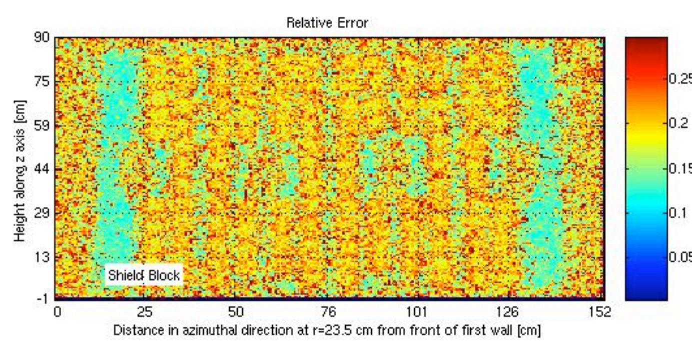




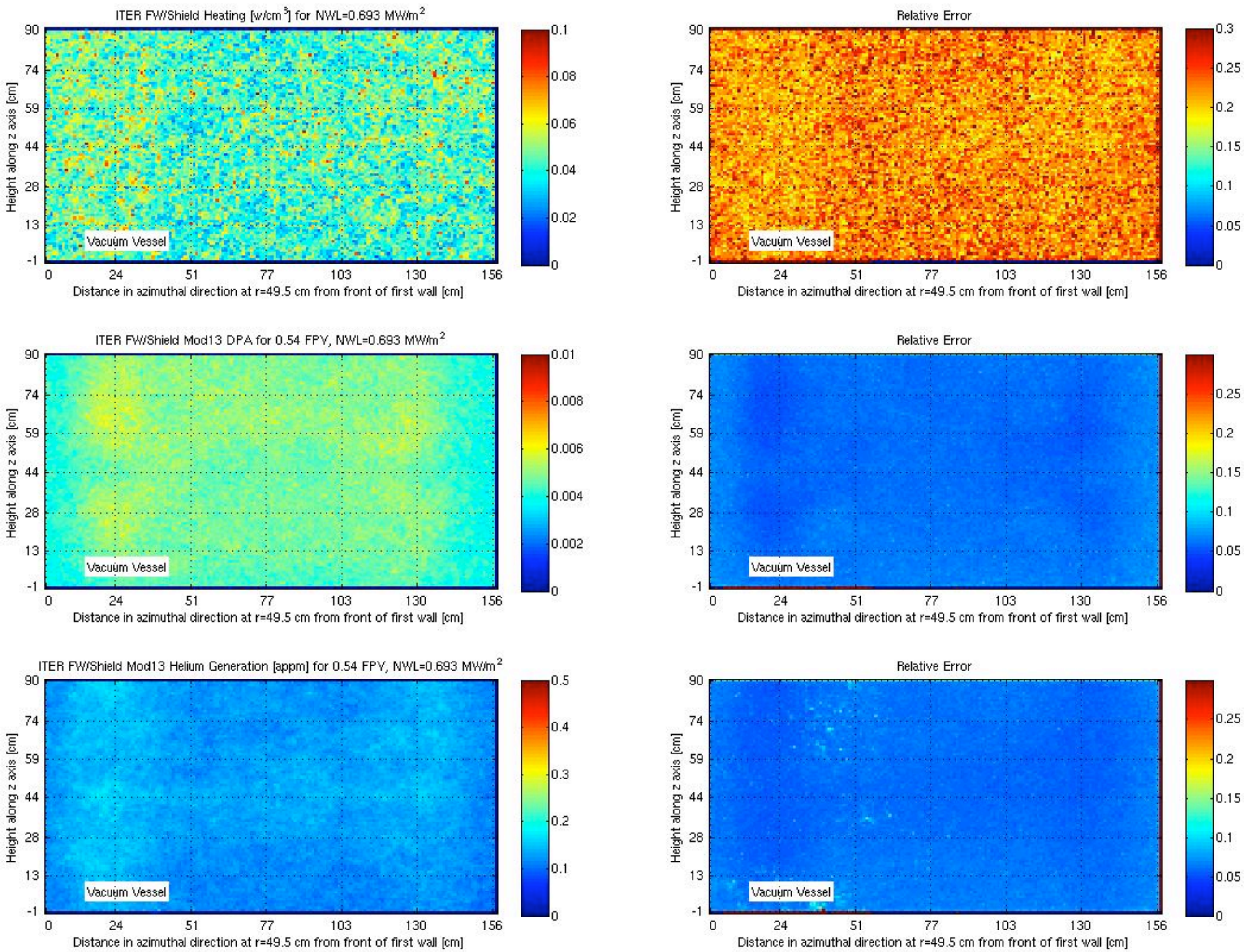




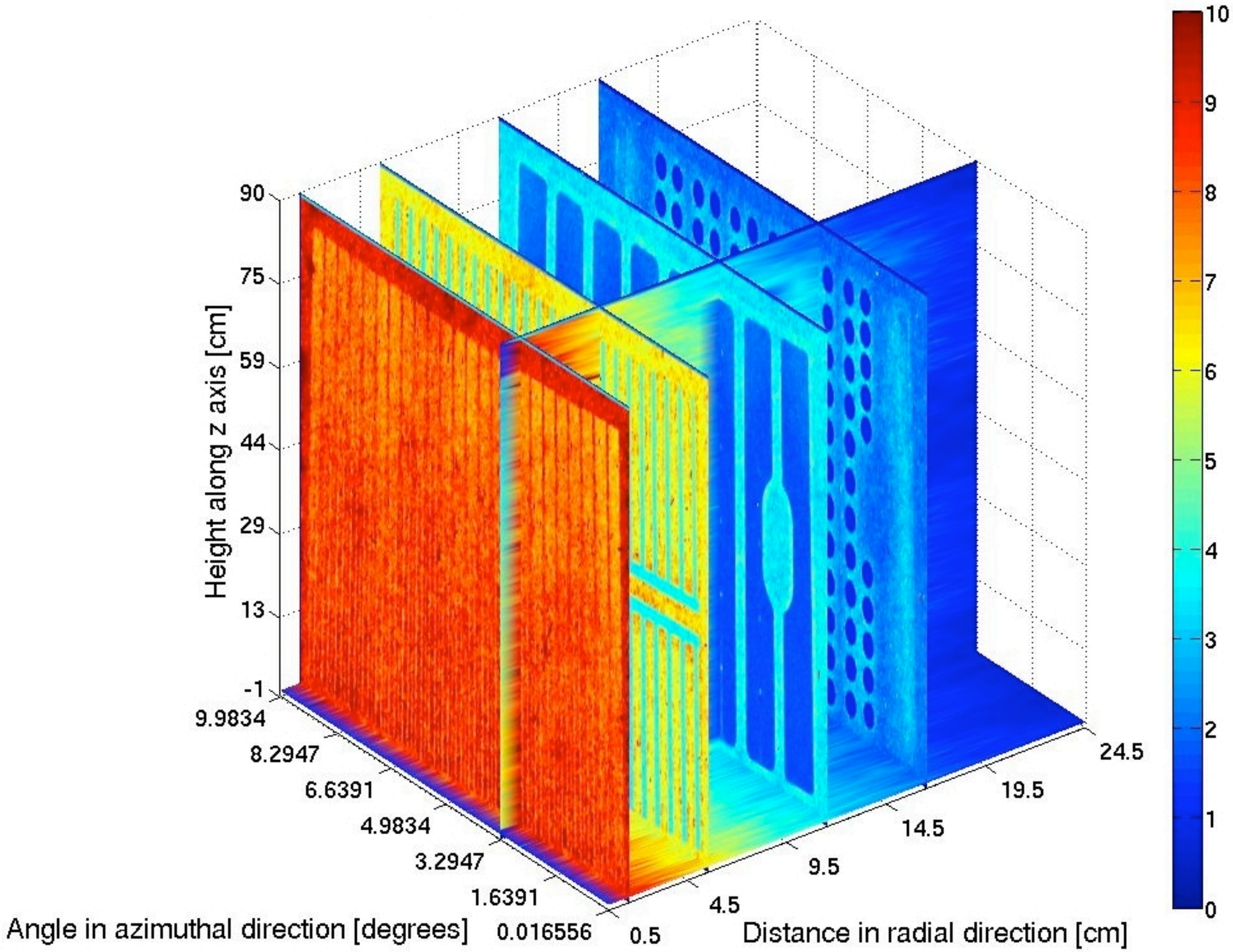




Nuclear responses at VV (49.5 cm from front of FW)



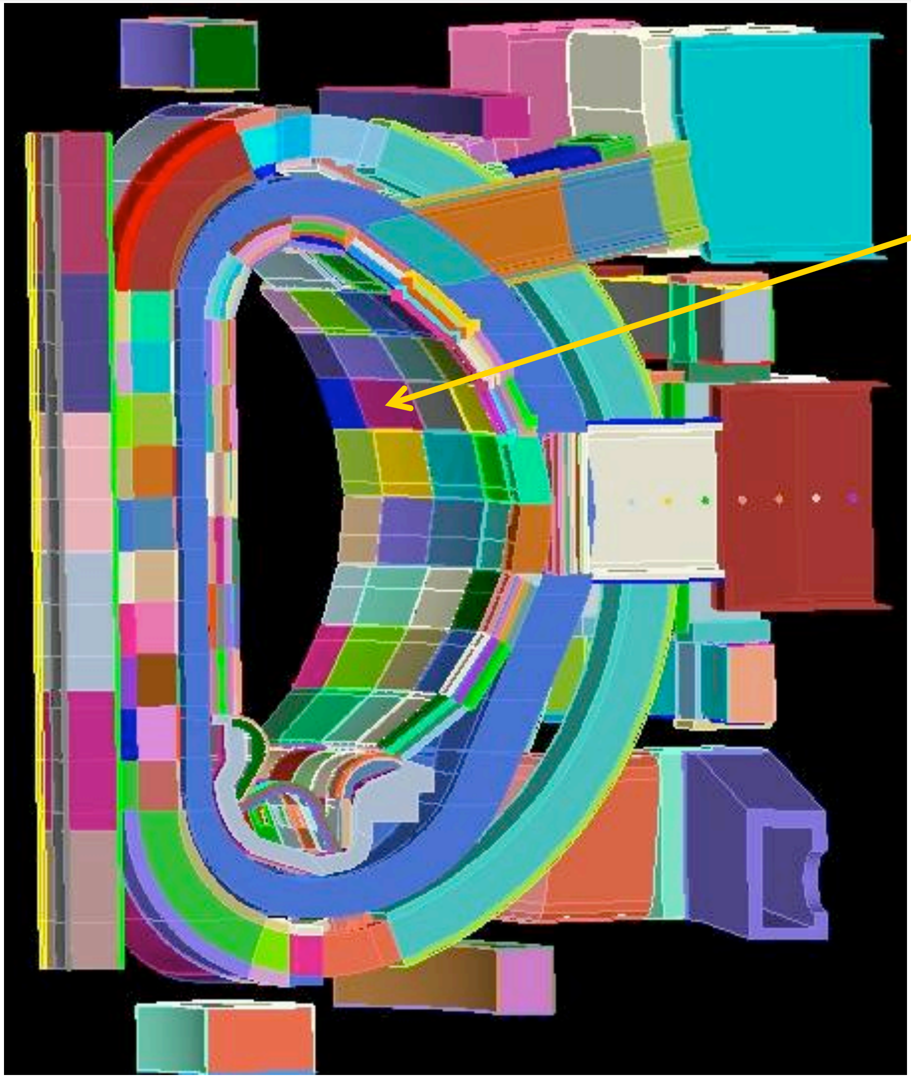
3-D Visualization of Nuclear Heating in FWS Module 13

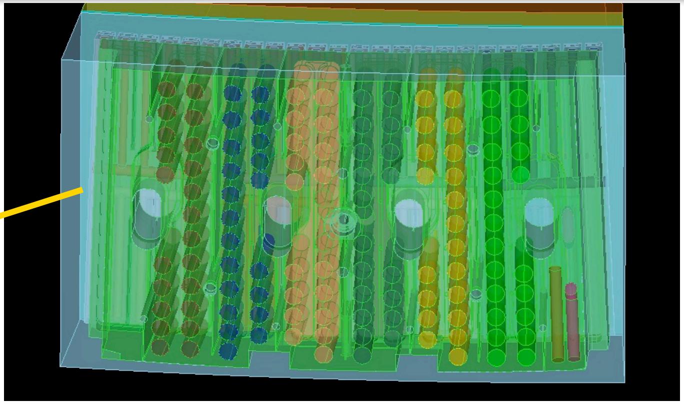


Important effects observed from high-fidelity 3-D results

- Significant variations in heating and He production occur at each radial location as a result of heterogeneity while much less variation is observed in dpa
- While nuclear heating is higher in steel than in water regions, the steel nearest the water sees the highest nuclear heating because of gamma generation in the water itself and softer neutron spectrum in SS resulting in more gamma generation
- He production in the steel immediately adjacent to the water is larger than the average He production in the steel due to softer neutron spectrum resulting in increased He production primarily in the B-10 in SS316LN-IG (has 10 wppm B) and Ni

Plans for Full 3-D Analysis





- CAD model for Mod. 13 is being inserted in a simplified full ITER model with accurate source profile in plasma
- Water coolant manifold adjacent to FWS module will be included
- Detailed heating, dpa, and He production profiles will be generated using the integrated 3-D model
- Analysis will be repeated for modules 7, 12