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Innovations in 3-Dimensional Neutronics Analysis for Fusion Systems

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Overview

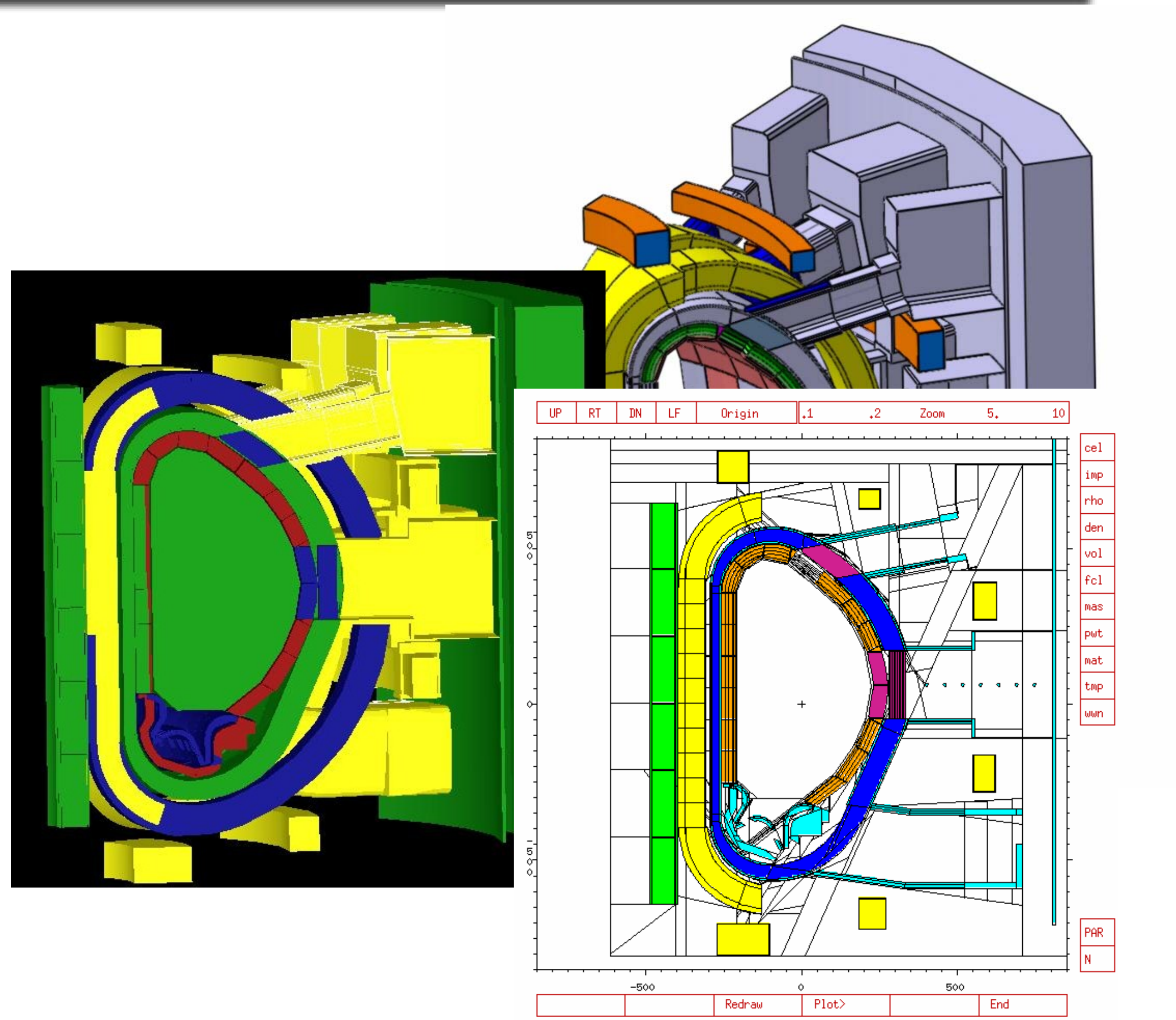
- Motivation & Background
- Tools
  - Monte Carlo
  - Deterministic
- Applications
- Current issues
  - Model development
  - QA & ITER Benchmark

Motivations

- Reduce impacts of manual conversion of 3-D model data
  - Time
  - Simplifications
  - Errors
- Extend richness of geometric representation

McCAD FZK (Germany)

- Translator approach
- Production experiences
  - IFMIF
  - ITER ECH Port

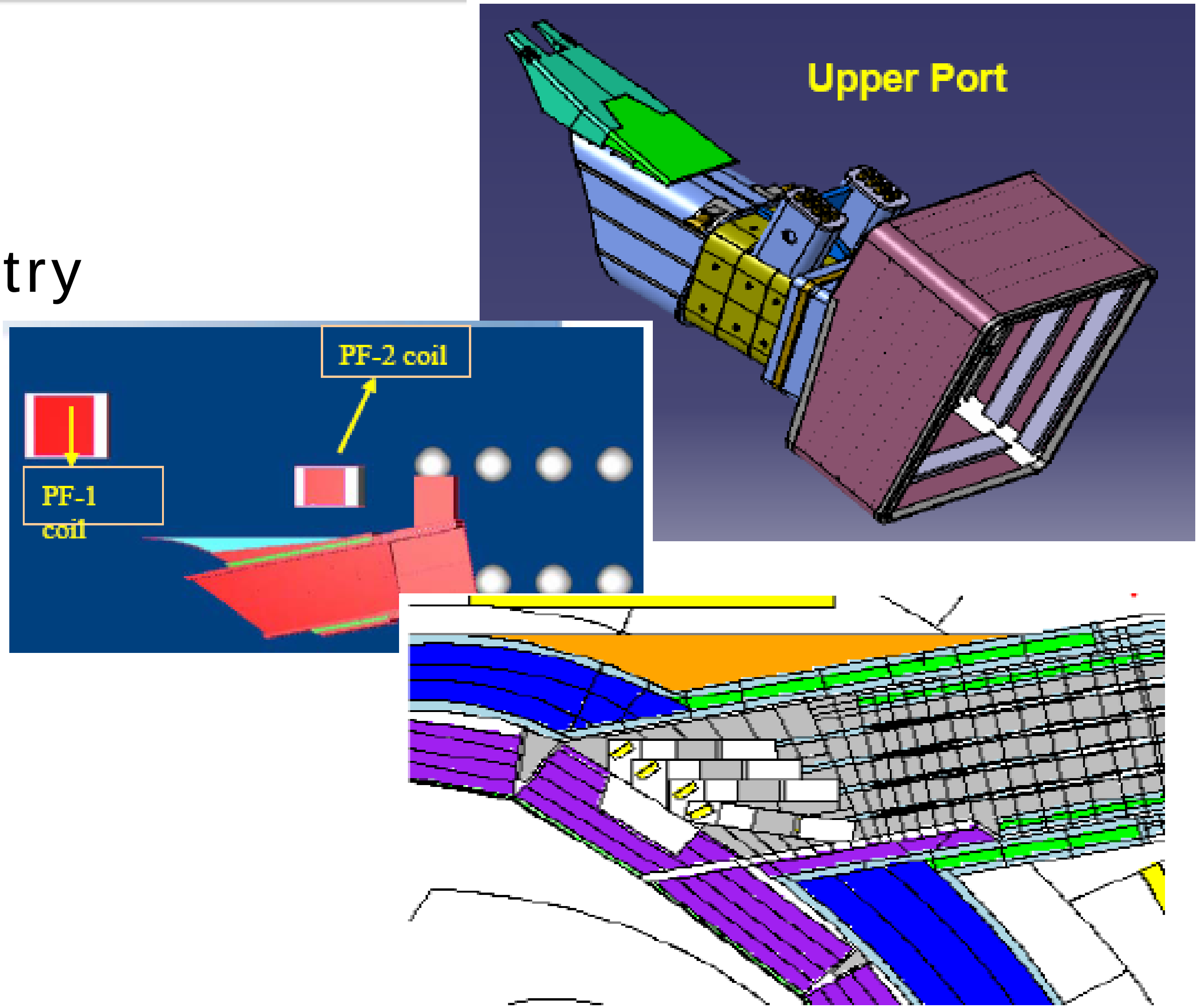


U. Fischer, et al

Monte Carlo Tools

MCAM ASIPP (China)

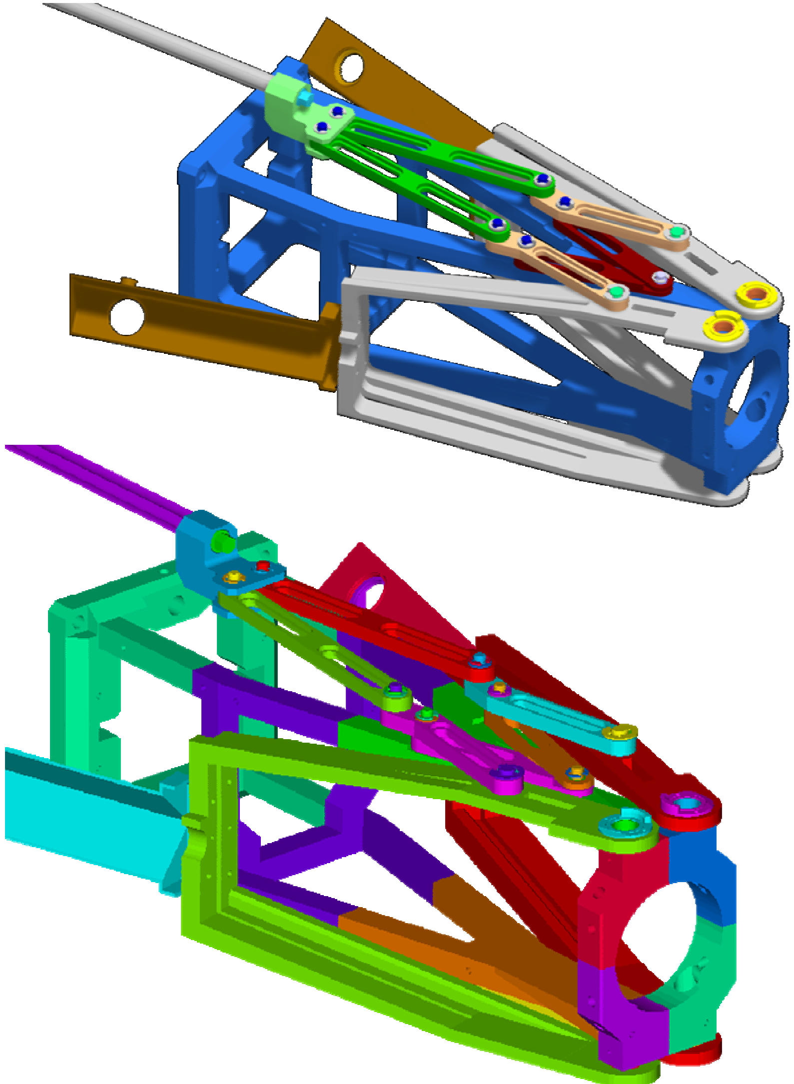
- Bi-directional translator
  - Large geometry manipulation feature set
- Production experience
  - TBM
  - Port limiter
  - etc…



Y. Wu, et al

TopAct Ratheon/LLNL

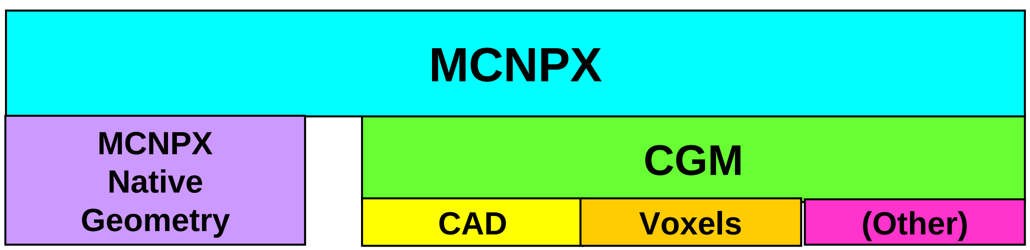
- Translator approach
- Production experience
  - NIF "Clamshell"
  - US ITER TBM



J. Latkowski, et al

MCNPX-CGM U.Wisc/SNL

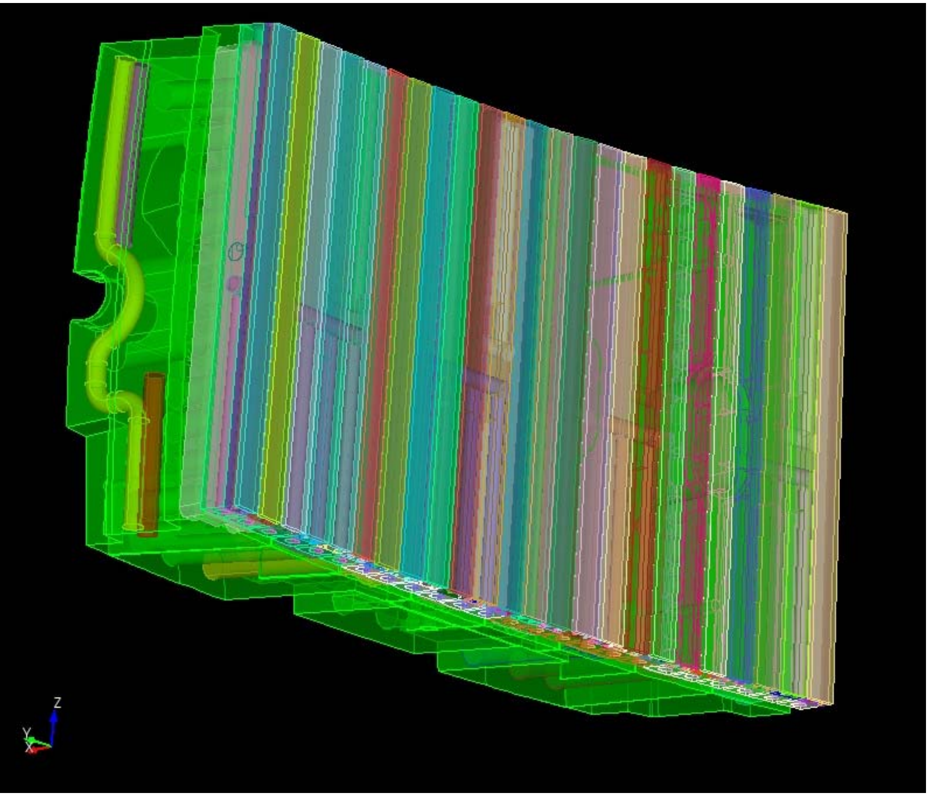
- Direct use of solid model geometry in MCNPX
  - Use Common Geometry Module (CGM) to interface MCNPX *directly* to CAD & other geometry data

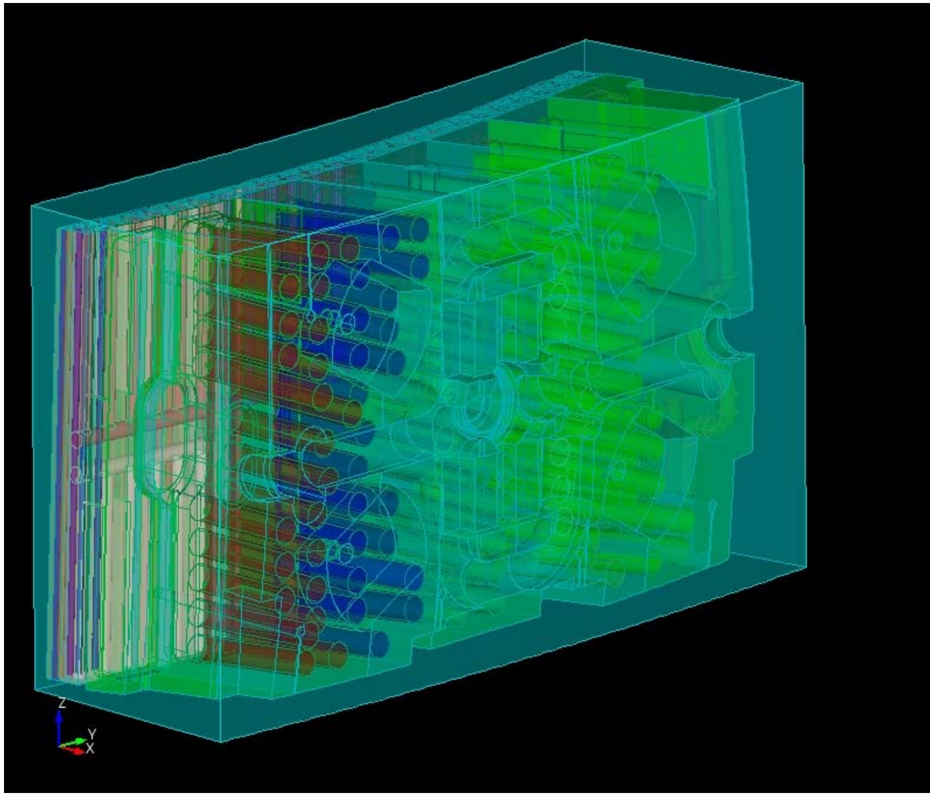


- Production experience
  - ITER FWS
  - ARIES-CS
  - HAPL

ITER FWS
Module 13 Mockup

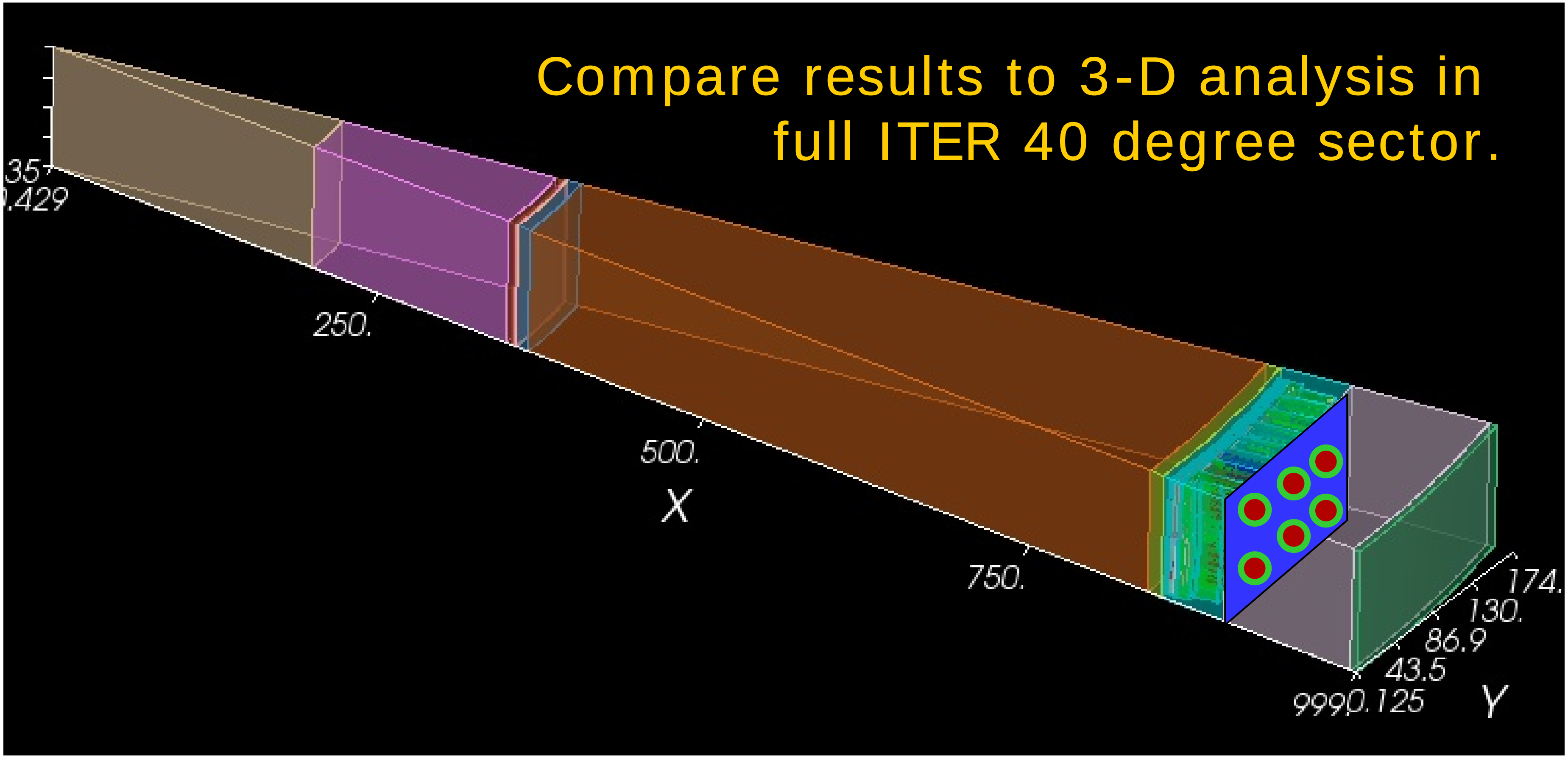
Model generated by designers using common tools facilitates analysis





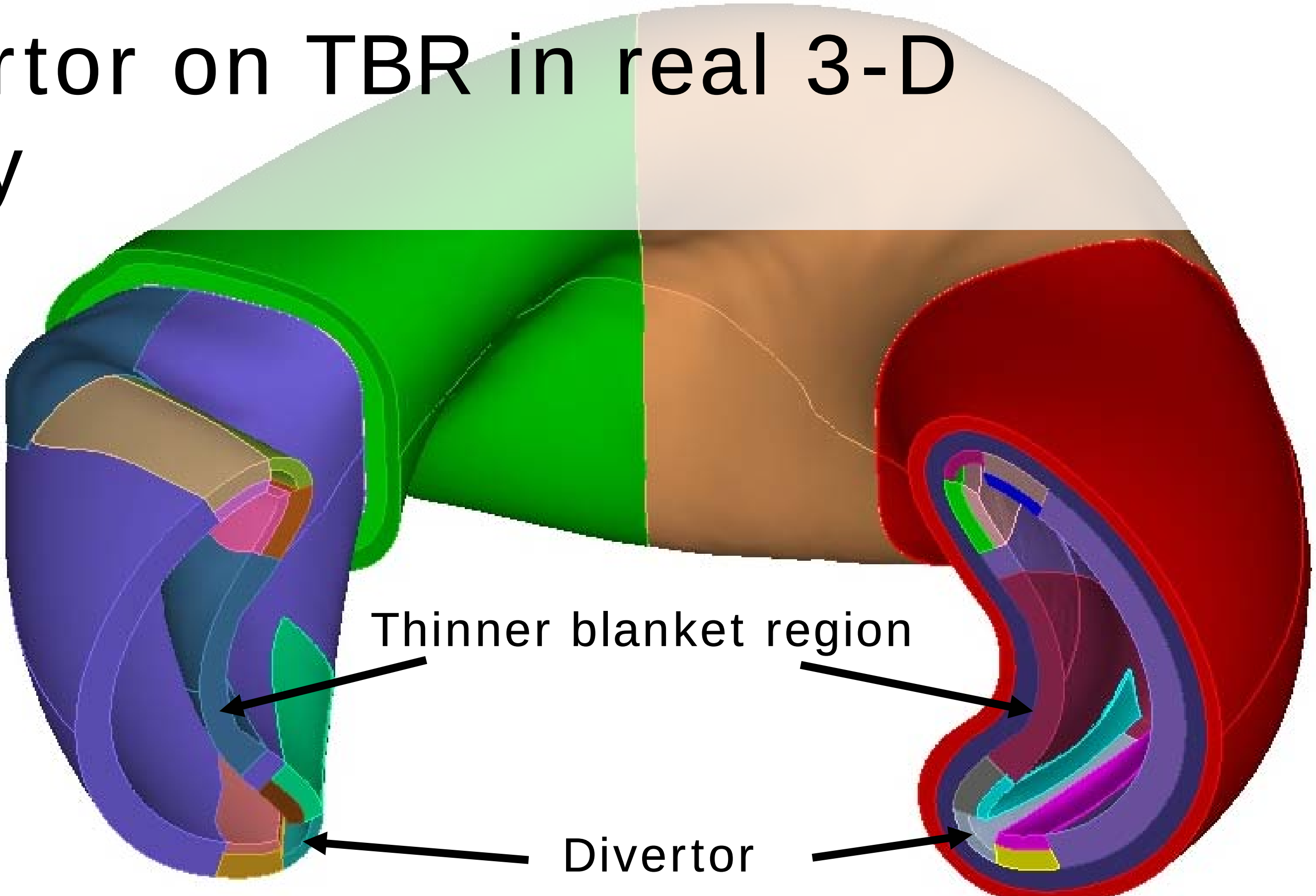
ITER FWS

Module 13 1-D/3-D hybrid analysis



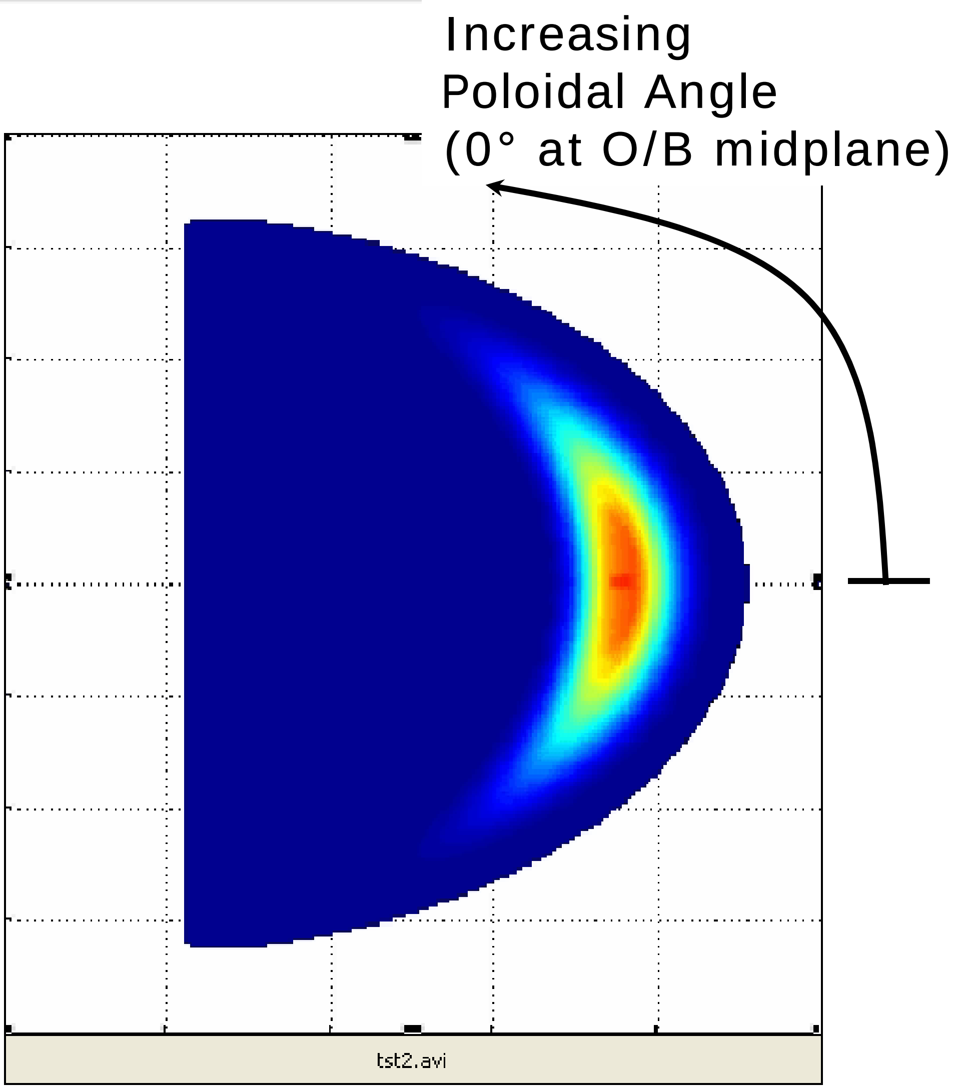
ARIES-CS Tritium Breeding Ratio

- Examine effect of non-uniform blanket and divertor on TBR in real 3-D geometry

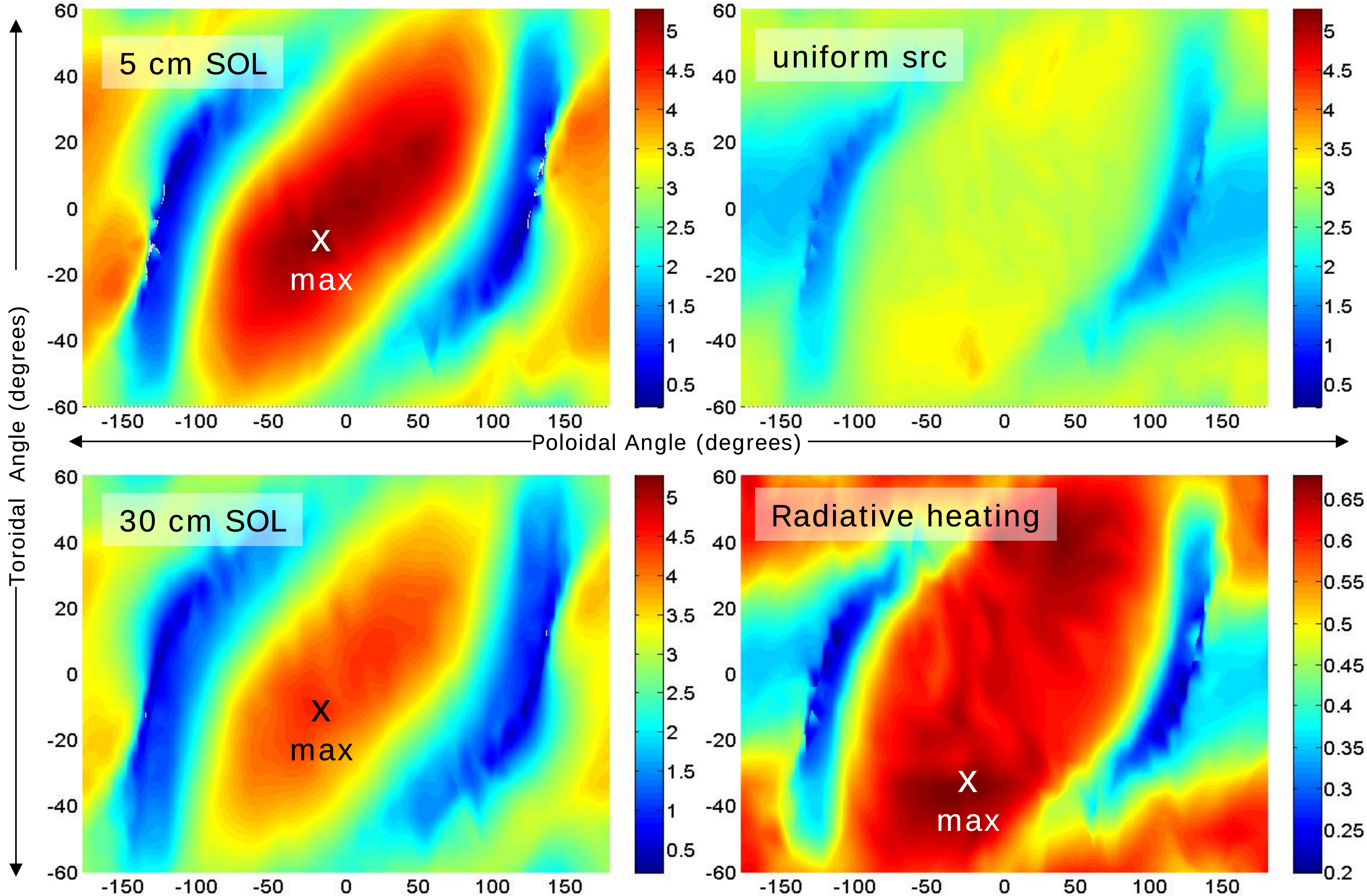


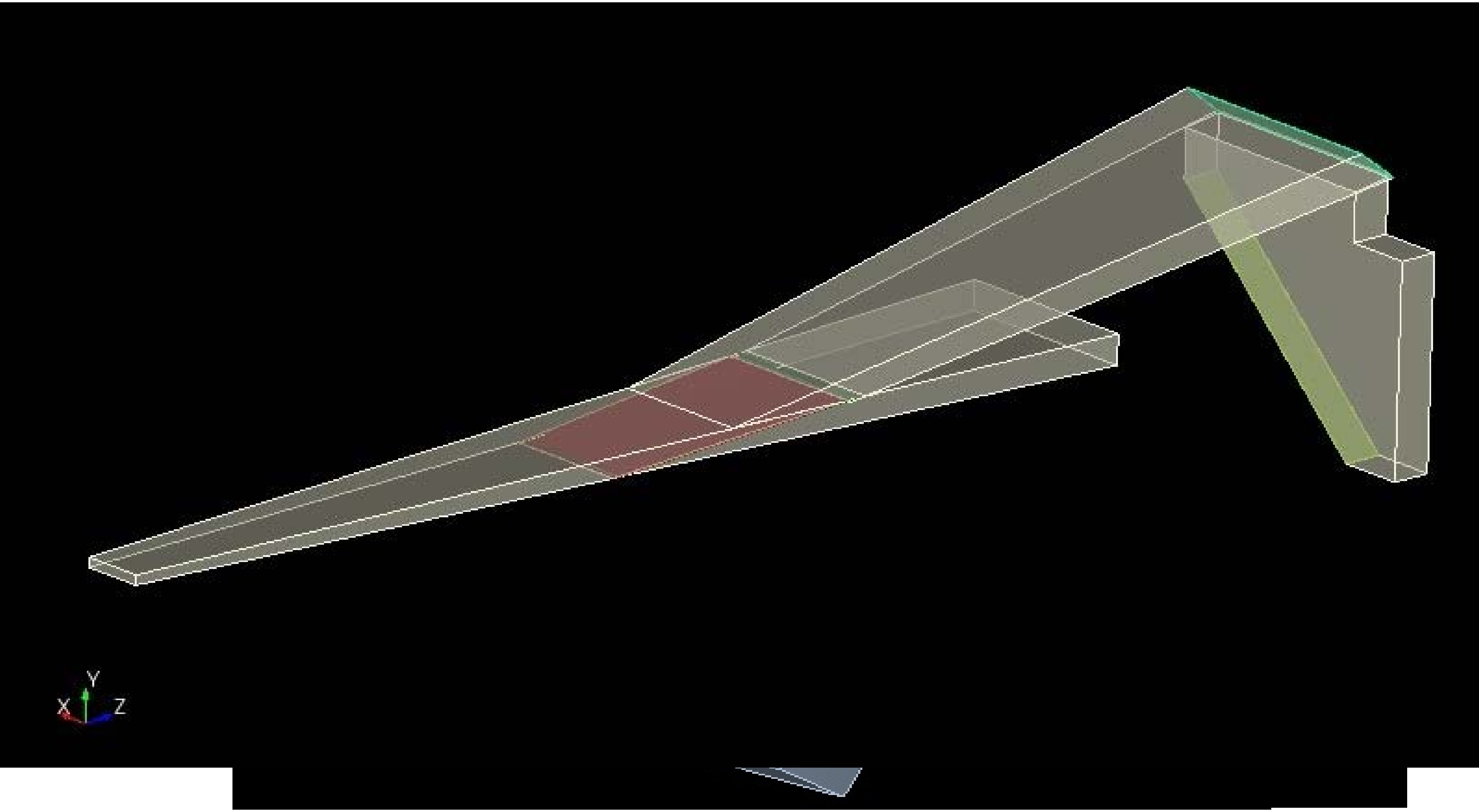
Neutron Source Methodology

- Generate hex mesh in real space from uniform mesh in flux coordinate space
- Generate cumulative distribution function for source density in hex mesh
- Sample hex mesh and mesh cells for source position



NWL Maps (colormaps in MW/m^2)

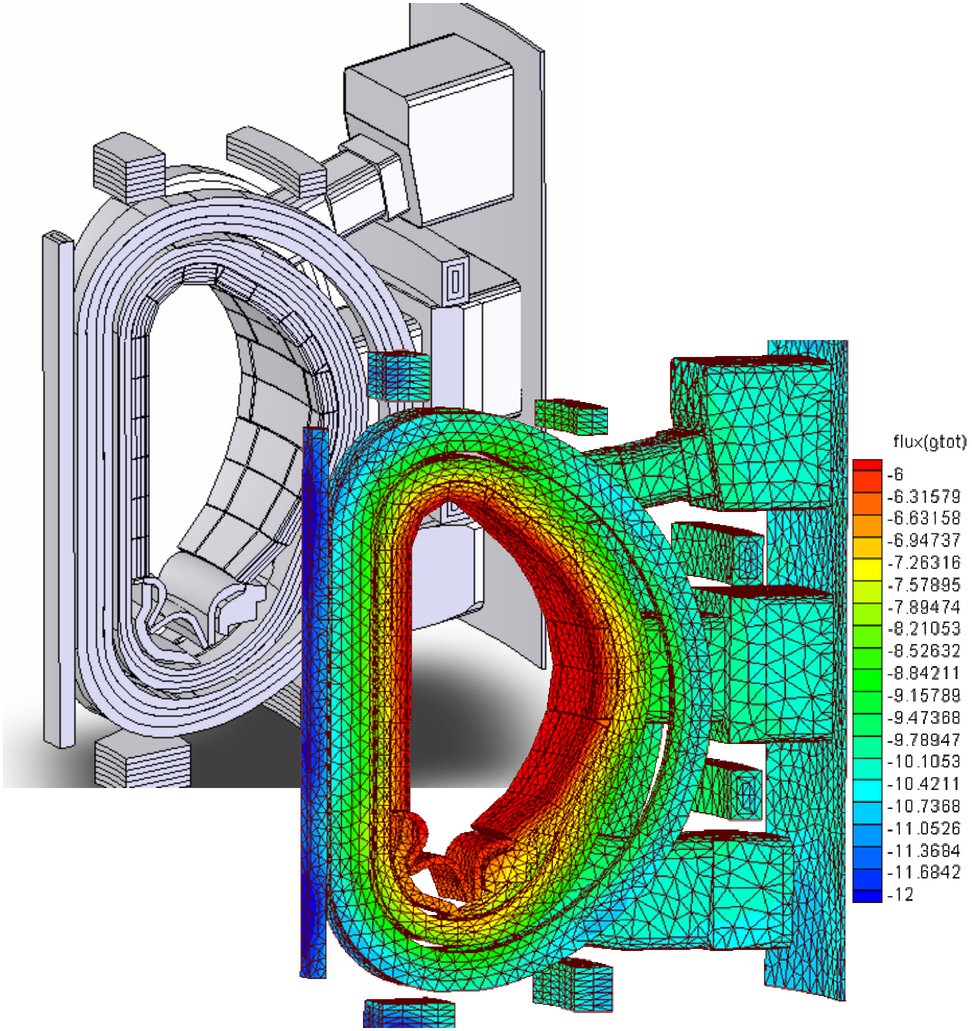



Y
X
Z

Deterministic

ATTILA Transpire

- Finite element discrete ordinates
  - Automated tetrahedral mesh generation
- Production experience
  - ATR
  - Medical phyics facility shielding



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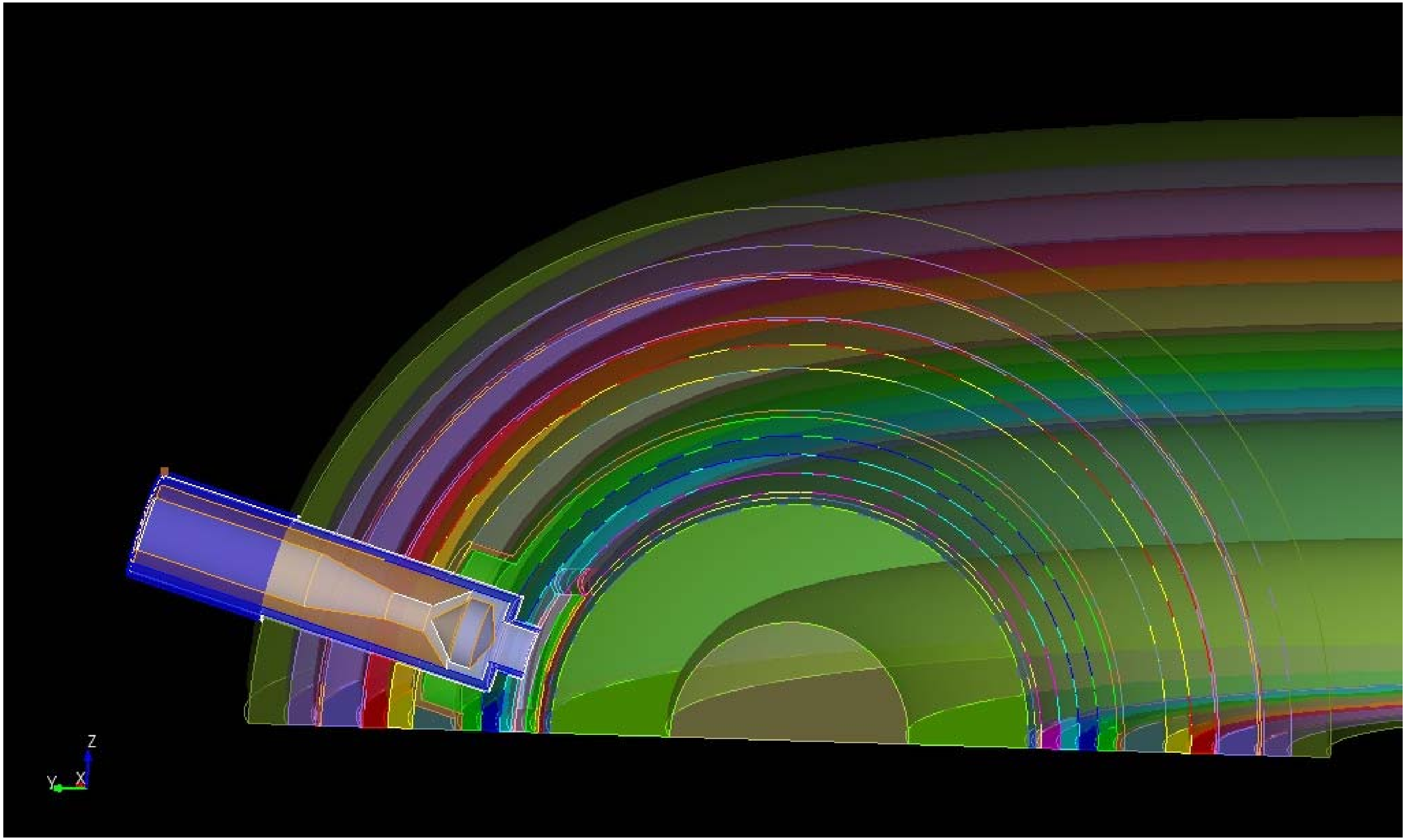
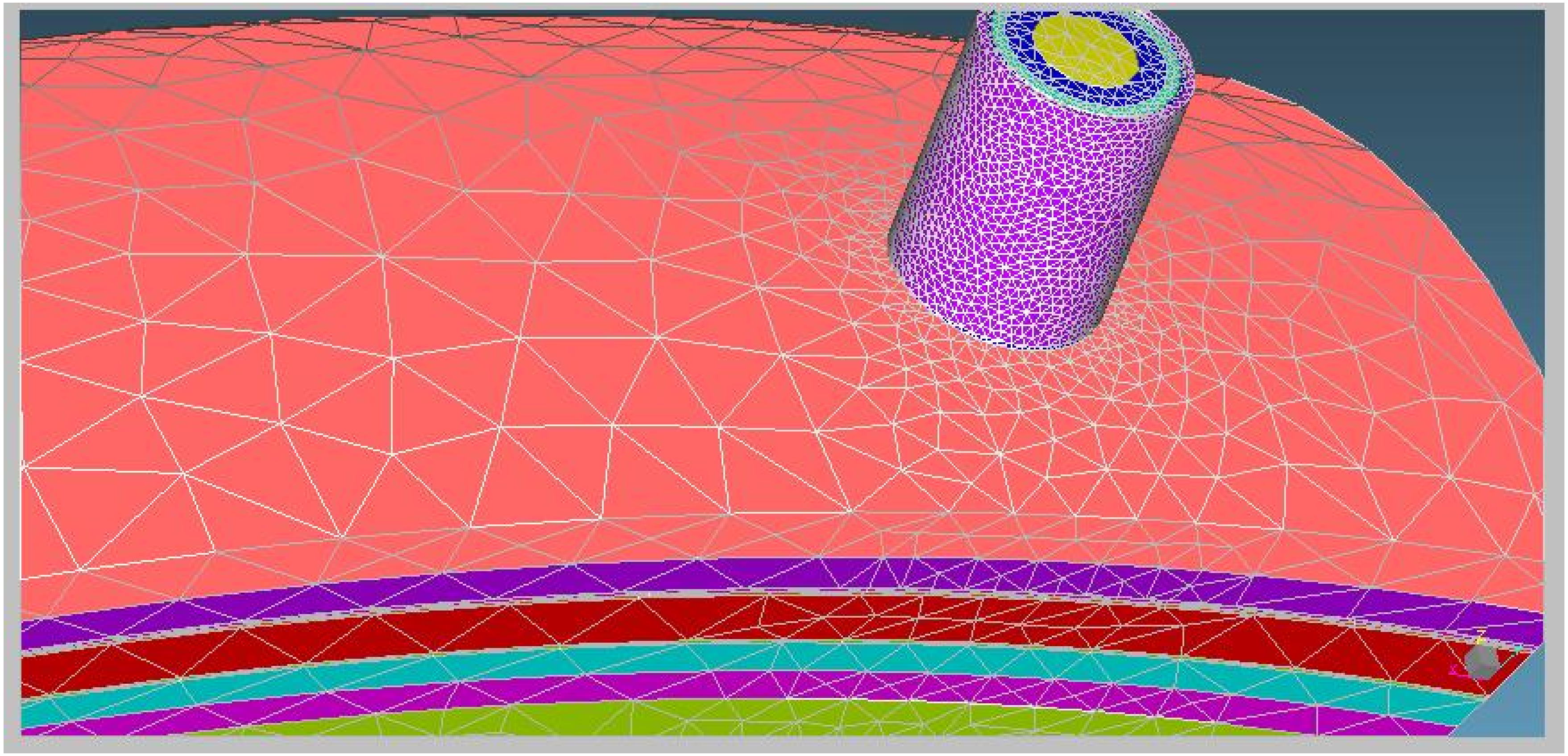
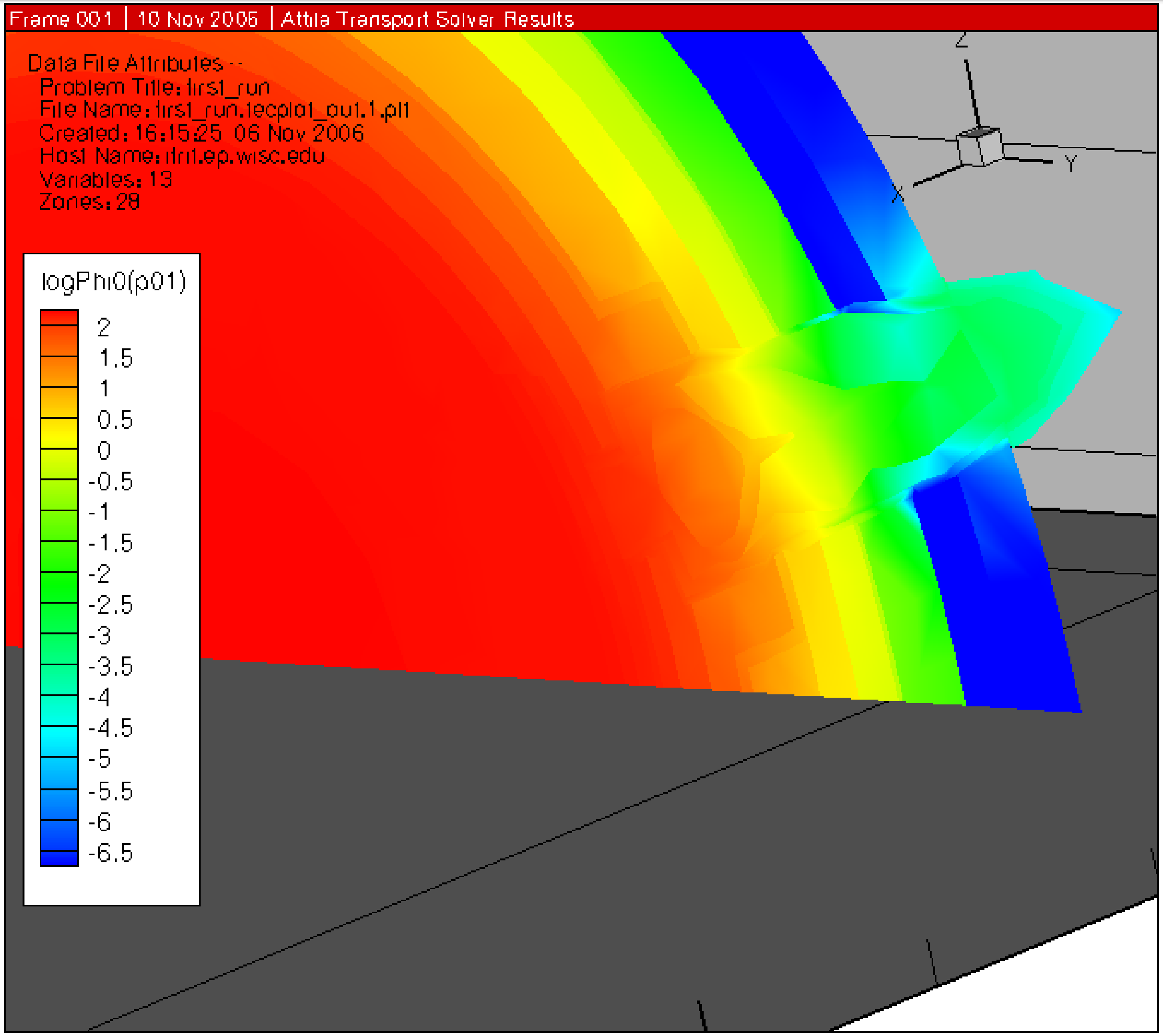
ARIES-CS Divertor Duct Shielding Mockup Solid Model



ATTILA Mesh for ARIES-CS Mockup



Duct Shielding Response



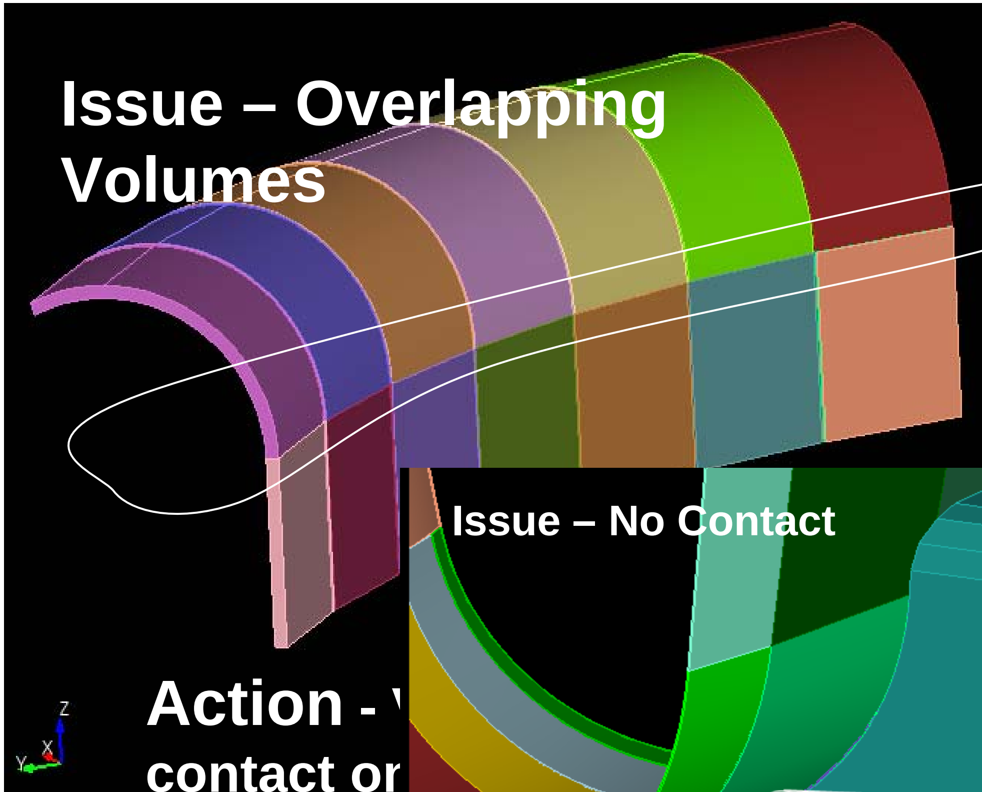
CAD Issues Requiring "Repair"

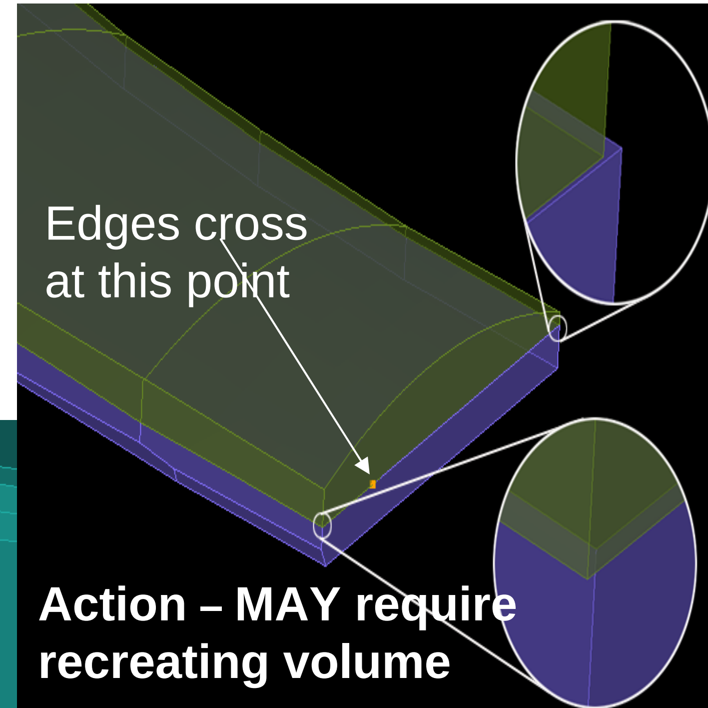
Human effort shifts from traditional MCNP model creation to CAD/Solid Model repair

- Overlapping Volumes (i.e.: clashes)
- Mating surfaces not contacting
- Slight "Misalignment"
  - Imprint generates ultra thin surfaces
  - Doesn't always require repair

- Complex Surface Definition

Examples of Typical CAD Issues and Typical Repairs



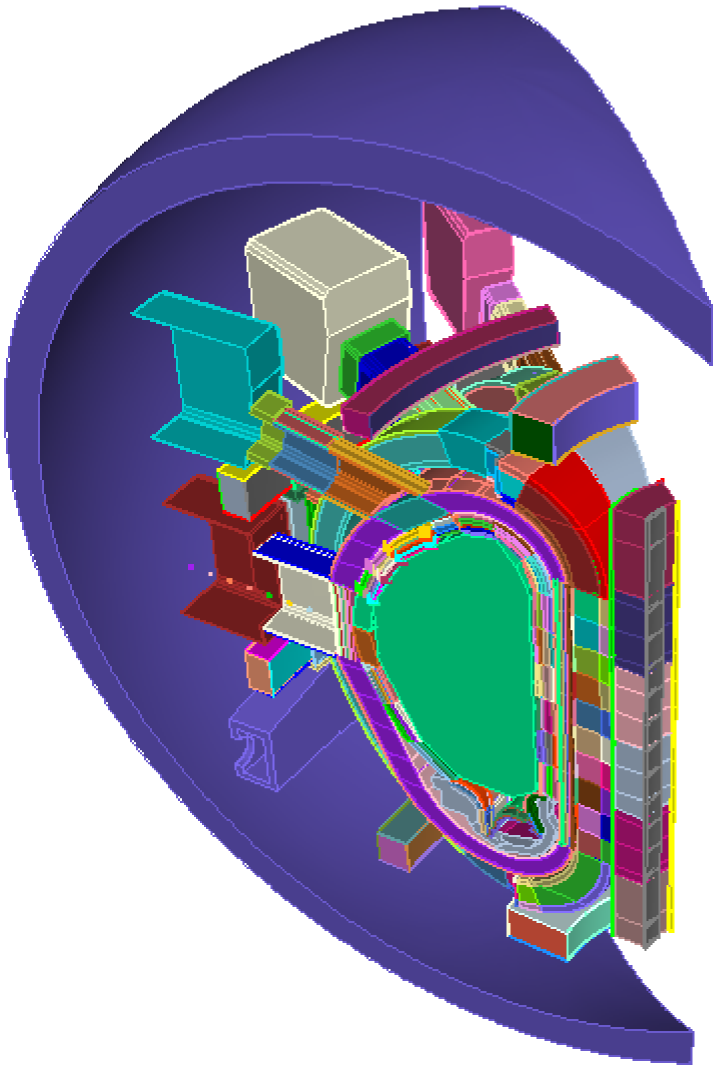


ITER QA & Neutronics

- Shift to licensing phase of large nuclear system
  - Need for 3-D analysis
  - Facilitate analysis with design modifications
  - Quality assurance of model development

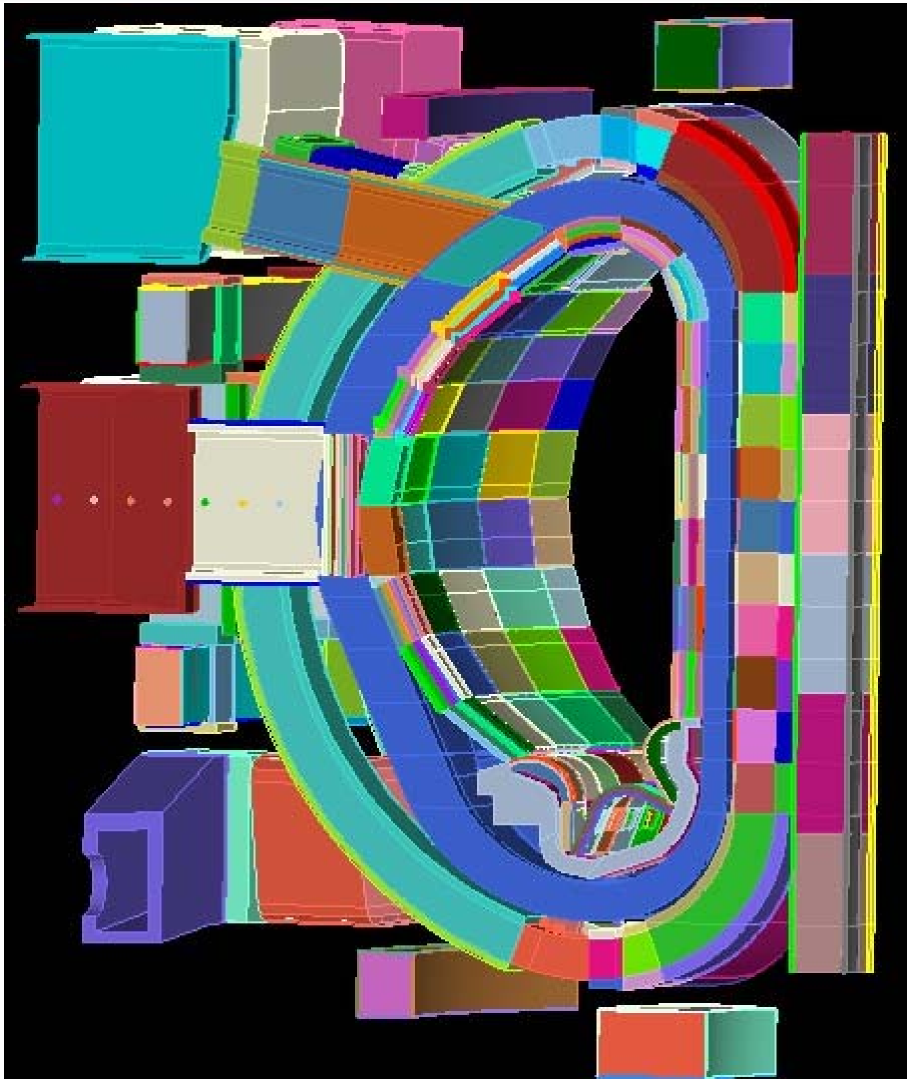
ITER Benchmark

- 802 cells
  - 23 in complement
- 9834 surfaces
  - 397 on reflecting boundary

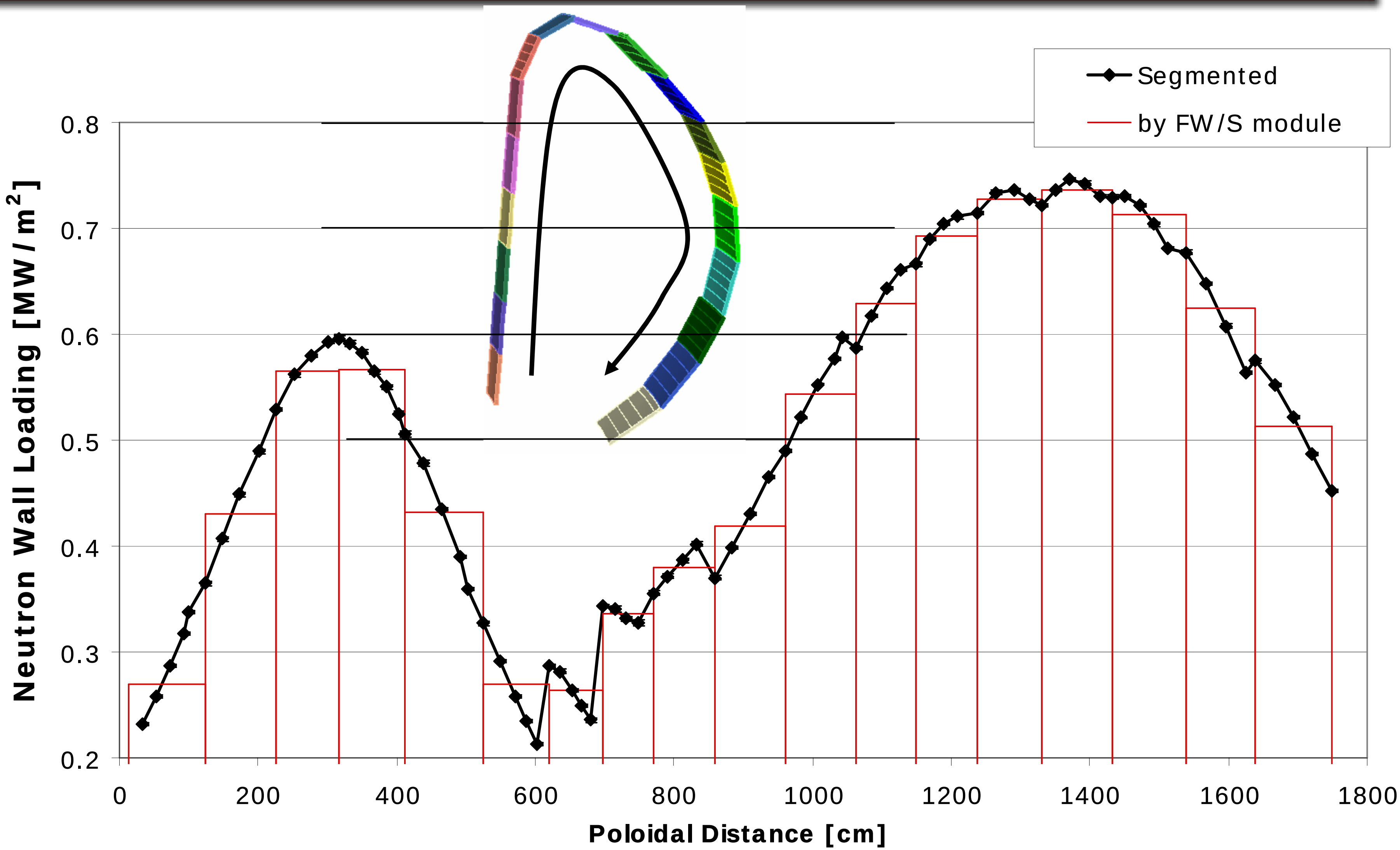


ITER Benchmark

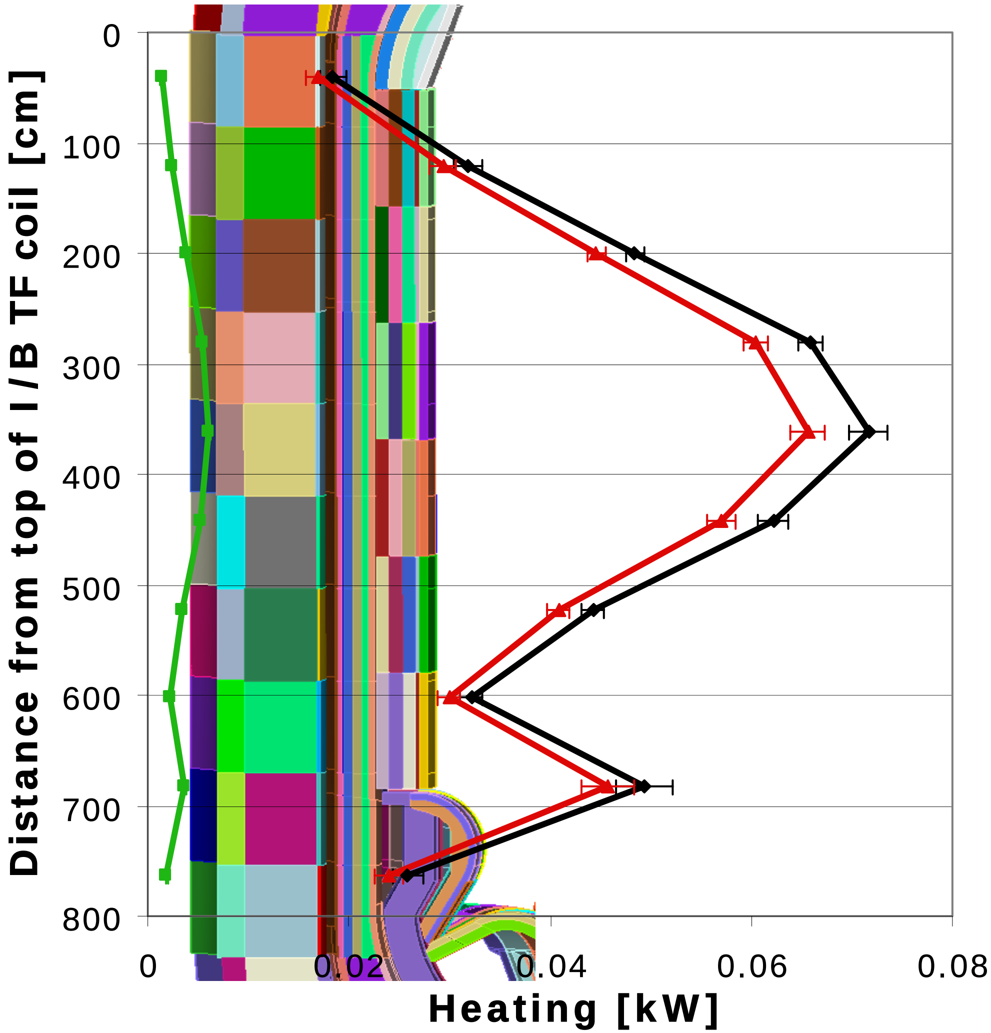
- Comparing 4 results
  - Neutron wall loading
  - Divertor fluxes and heating
  - Magnet heating
  - Midplane port shielding/streaming
- Participants
  - UW, FZK, ASIPP, JAEA + ATTILA



Neutron Wall Loading : results



TF Coils : results

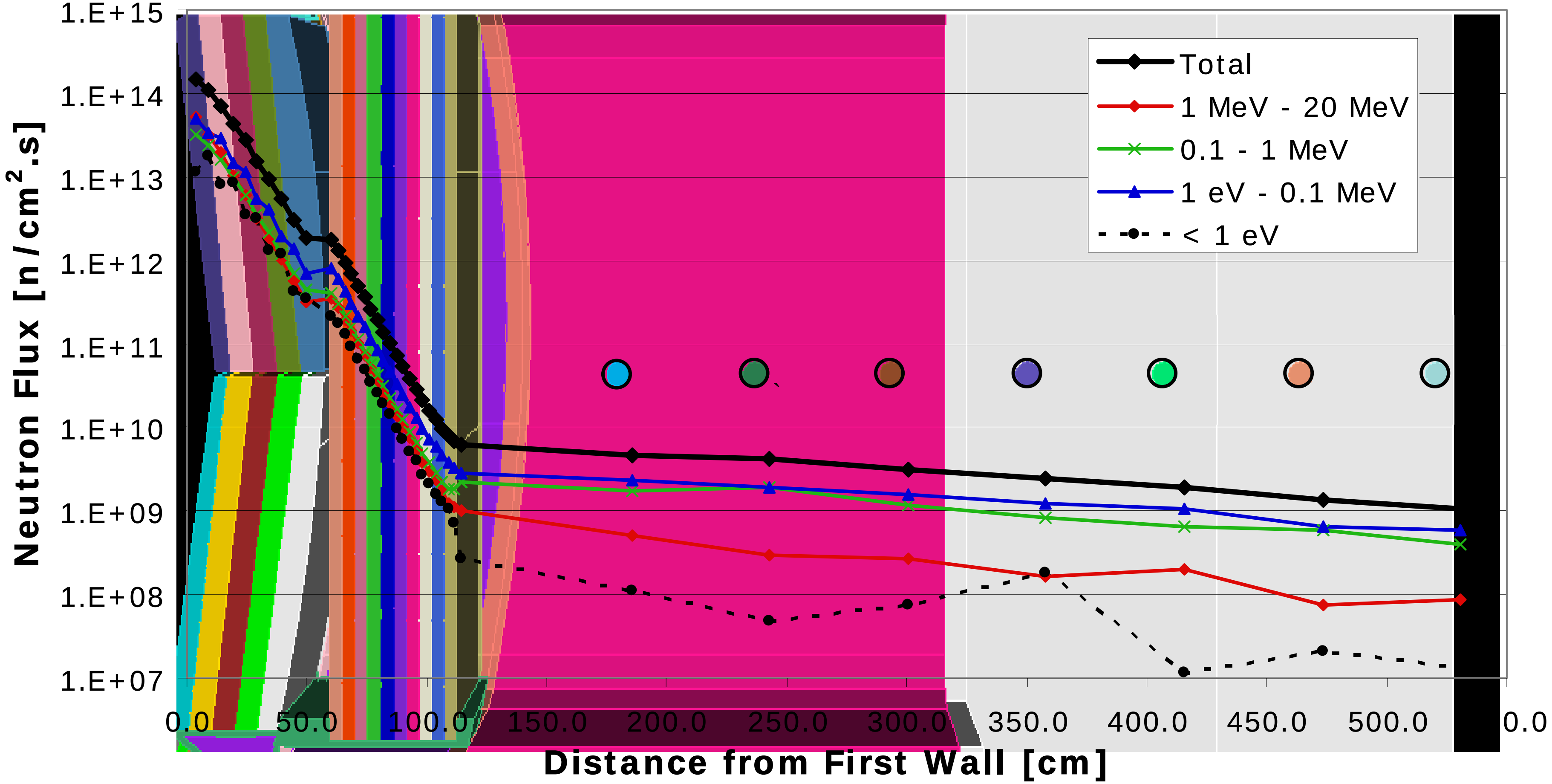


Nuclear Heating (W)

Neutron	Photon	Total
1.39 ± 0.05	17.0 ± 0.6	18.4 ± 0.6
2.47 ± 0.06	29.4 ± 0.6	31.8 ± 0.7
3.82 ± 0.04	44.6 ± 0.4	48.4 ± 0.5
5.41 ± 0.05	60.4 ± 0.6	65.8 ± 0.6
6.03 ± 0.12	65.6 ± 0.9	71.6 ± 1.0
5.16 ± 0.08	57.0 ± 0.7	62.2 ± 0.8
3.38 ± 0.04	40.9 ± 0.5	44.3 ± 0.6
2.27 ± 0.04	29.9 ± 0.5	32.2 ± 0.6
3.66 ± 0.08	45.7 ± 1.3	49.4 ± 1.4
1.88 ± 0.05	24.0 ± 0.7	25.9 ± 0.7
35.5 ± 0.2	**415 ± 2.3**	**450 ± 2.5**

8.1 kW in all TF I/B legs

Mid-plane Port : results



Future Developments

- Advanced tetrahedral mesh tallies
- Coupled deterministic/Monte Carlo
- Coupled activation/photon transport

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Questions?

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