Status of Fusion Neutronics Predictive Capabilities

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VLT Research Highlight Presentation

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Nuclear Data Development for Fusion

- Represent US fusion neutronics community in the Cross Section Evaluation Working Group (CSEWG)
- Make sure that nuclear data needs for US fusion neutronics community are addressed satisfactorily
- Support development of updated FENDL-3 through participation in the IAEA sponsored Coordinated Research Project (CRP) and performing benchmark calculation for library validation and identification issues from the user's perspective

FENDL-2.1 Background

- Revision to FENDL-2.0 (1995/96)
- Compiled November 2003, INDC(NDS)-451
- 71 elements/isotopes
- Working libraries prepared by IAEA/NDS, INDC (NDS)-467 (2004)
- Reference data library for nuclear analysis of ITER and other fusion systems

Data Source for FENDL-2.1

No.	Library	NMAT	Materials
1	ENDF/B-VI.8 (E6)	40	^{2}H, ^{3}H, ^{4}He, ^{6}Li, ^{7}Li, ^{9}Be, ^{10}B, ^{11}B, ^{16}O, ^{19}F, $^{28-30}$Si, ^{31}P, S, ^{35,37}Cl, K, $^{50,52-54}$Cr, ^{54,57,58}Fe, ^{59}Co, ^{61,62,64}Ni, ^{63,65}Cu, ^{197}Au, $^{206-208}$Pb, ^{209}Bi, $^{182-184,186}$W
2	JENDL-3.3 (J33)	18	^{1}H, ^{3}He, ^{23}Na, $^{46-50}$Ti, , ^{55}Mn, $^{92,94-98,100}$Mo, ^{181}Ta,V
3	JENDL-3.2 (J32)	3	Mg, Ca, Ga
4	JENDL-FF (JFF)	4	^{12}C, ^{14}N, Zr, ^{93}Nb
5	JEFF-3 (EFF) JEFF3	4	^{27}Al, ^{56}Fe, ^{58}Ni, ^{60}Ni
6	BROND-2.1 (BR2)	2	^{15}N, Sn

- Majority (40) of materials in FENDL-2.1 taken from ENDF/B-VI.8
- Investigated effect of recently released ENDF/B-VII.0 (December 2006) on results for ITER calculational benchmark and four FNG ITER relevant integral experiments

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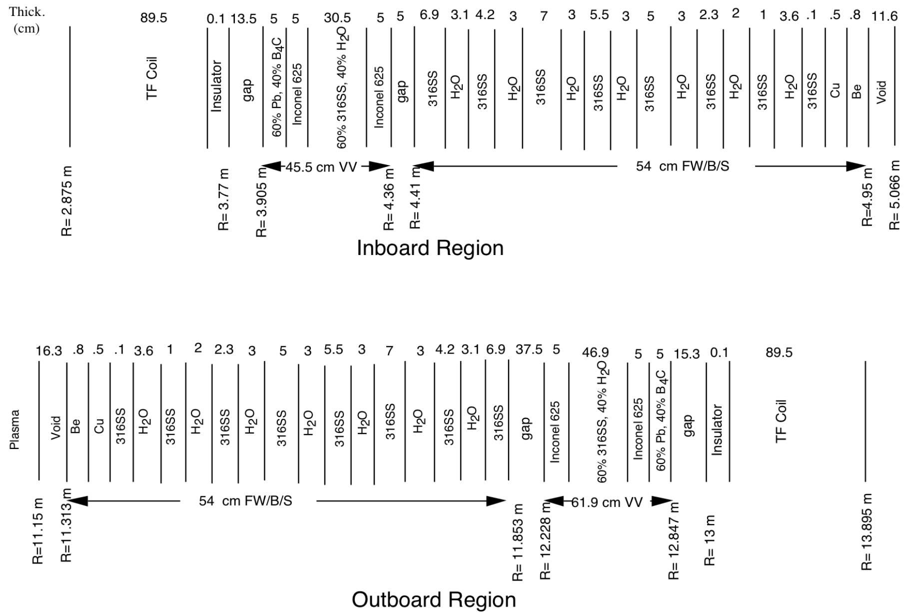
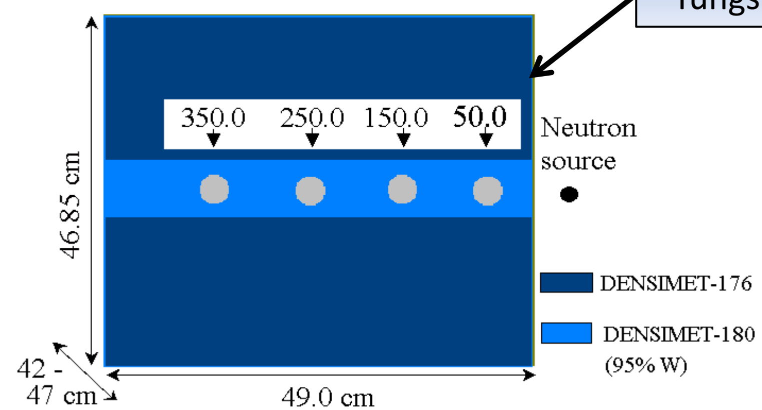
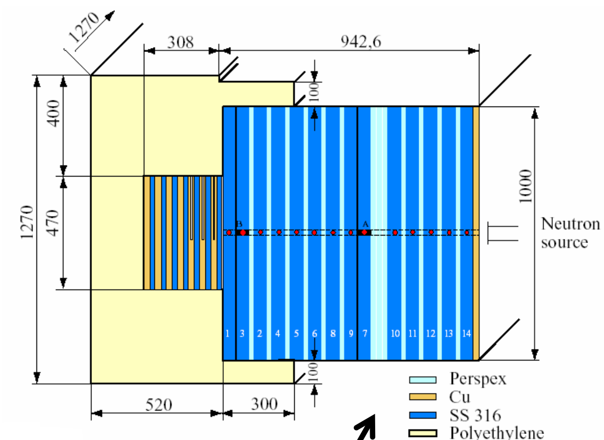
Calculational and Experimental Benchmarks



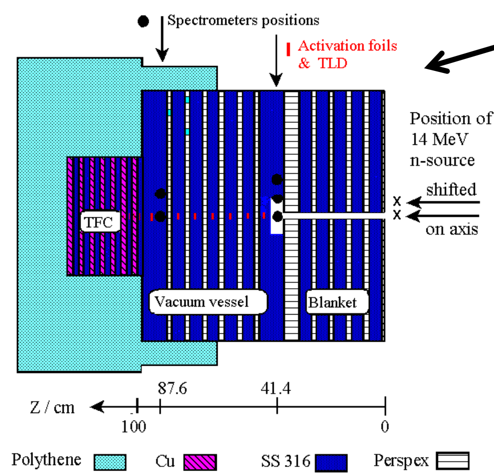
Tungsten

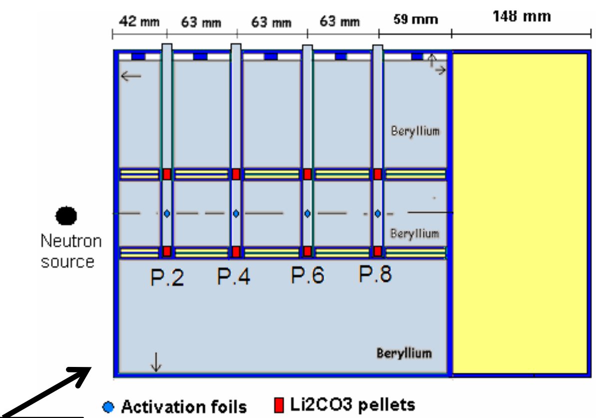




Bulk shielding

Streaming





HCPB breeder

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FENDL-3 Development

(http://www-nds.iaea.org/fendl3/)

- An effort was initiated by the IAEA in 2008 to update the FENDL library with the objective of improving the status of nuclear databases for fusion devices including IFMIF
- The library (FENDL-3) represent a substantial extension of FENDL-2.1 library toward higher energies, with inclusion of incident charged particles and the evaluation of related uncertainties (covariance data)
- FENDL-3 will be released at the end of the 3 years of the Coordinated Research Project (CRP) activities

Expanded FENDL-3 General Purpose Neutron Library

- During the 2nd RCM held in March 2010, a decision was made to nearly double the number of materials in the library and the source of evaluation for each material was agreed on
- ***Materials added to the library*** were based on input obtained from the fusion neutronics community for ITER and IFMIF. These are 23 elements with their constituent isotopes:

  Re, Zn, Ag, Ba, Y, Cd, Ce, Ar, Er, Sb, Rh, Sc, Br, Ge, I, Lu, La, Cs, Pt, Hf, Gd, U, Th

- ***Only 3 actinide isotopes*** will be added as they are needed for neutron measurement by fission chambers (U-235, U-238) or exist in the ITER concrete (Th-232)
- Total number of isotopes in library increased to ***166***
- Evaluations to be utilized for these materials were selected

M.E. Sawan, "Summary Report from 2nd RCM on Nuclear Data Libraries for Advanced Systems – Fusion Devices (FENDL-3)," INDC (NDS)-567, IAEA (June 2010)

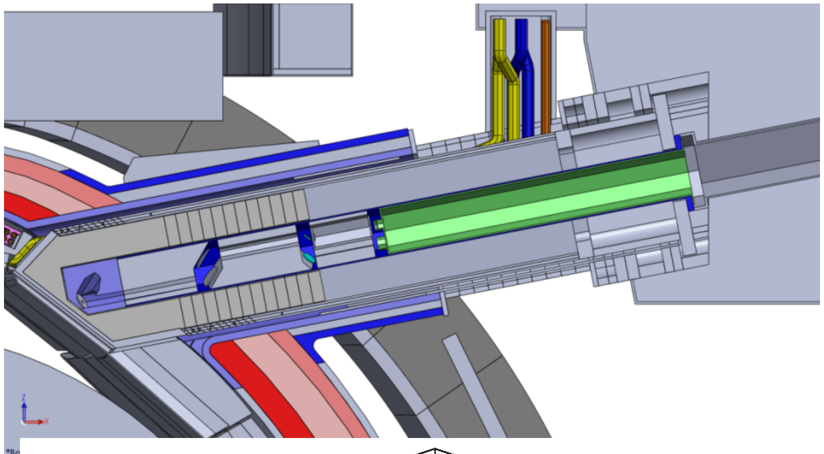
Neutronics Codes

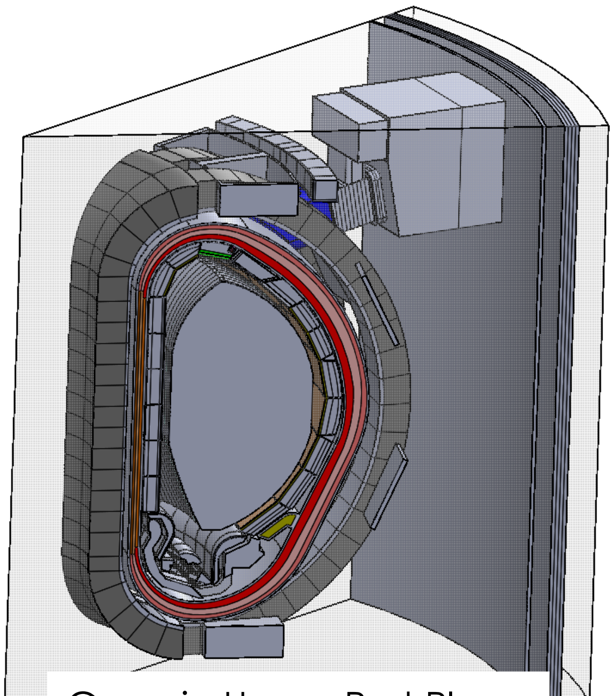
- Deterministic
  - PARTISN, DOORS, DENOVO, ATTILA
- Monte Carlo
  - MCNP, TRIPOLI
  - CAD-based
    - Translators: MCAM, McCAD
    - Direct coupling: DAGMC

Generic Diagnostic Upper Port Plug Neutronics

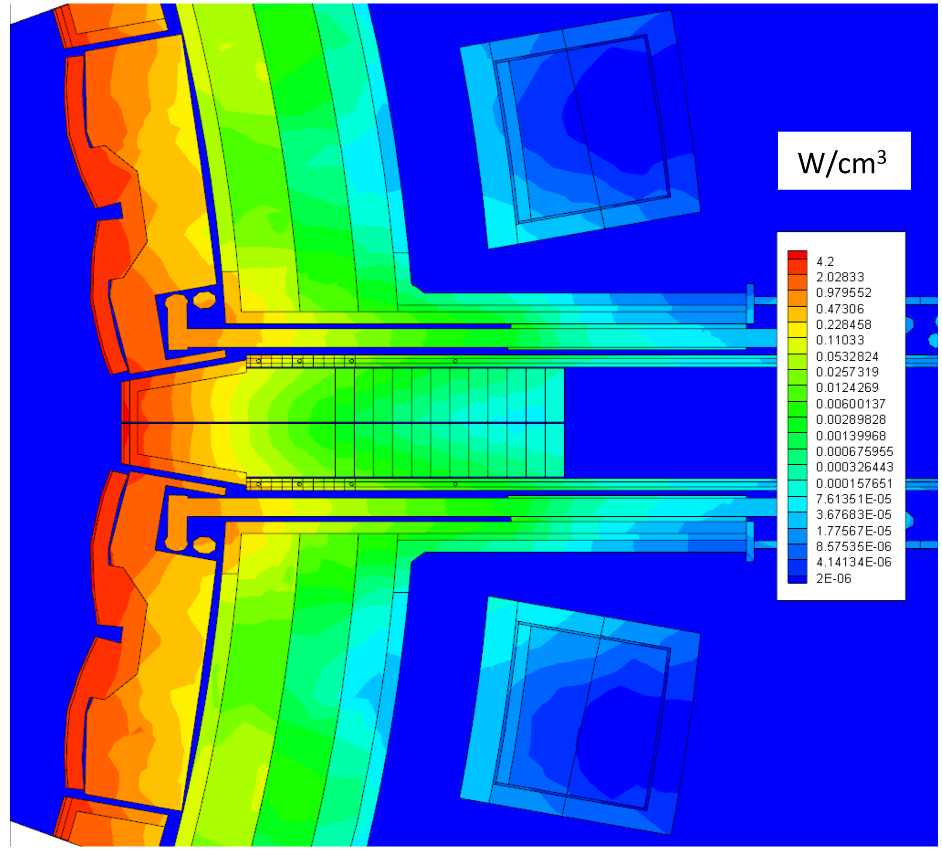
ATTILA

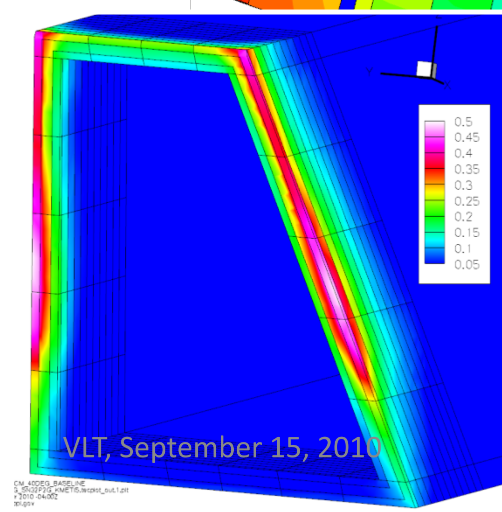
Section Through Upper Port
Showing the Visible/IR Camera Labyrinth





Generic Upper Port Plug
SolidWorks Analysis Model





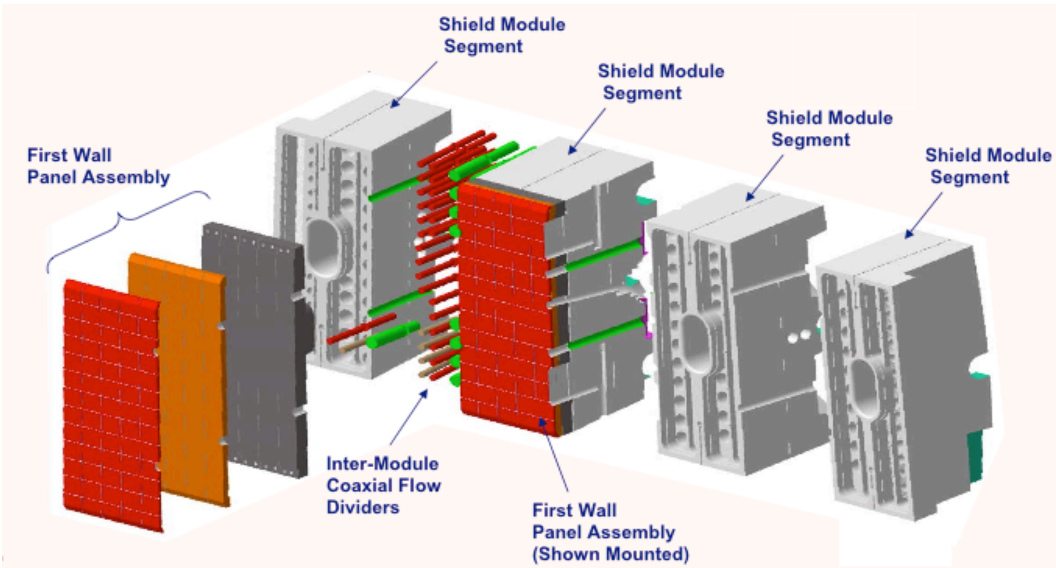
Generic Upper Port Nuclear Heating

Total: 316 kW
First Wall + Diagnostic Shield: 309 kW
GUPP Structure: 7 kW

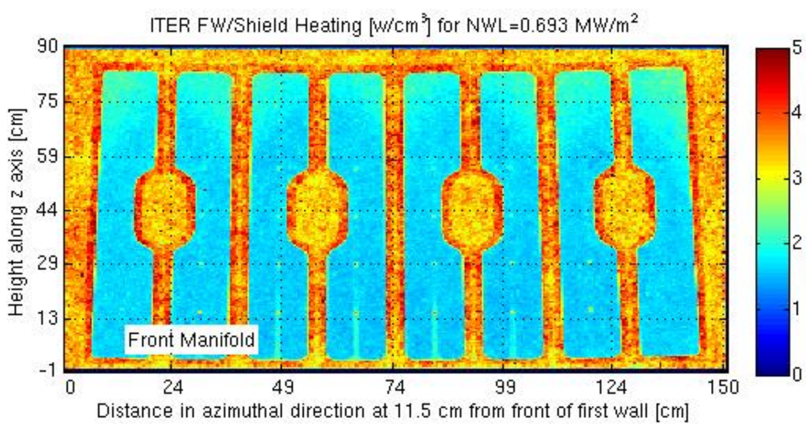
Direct Accelerated Geometry Monte Carlo (DAGMC)
Motivations

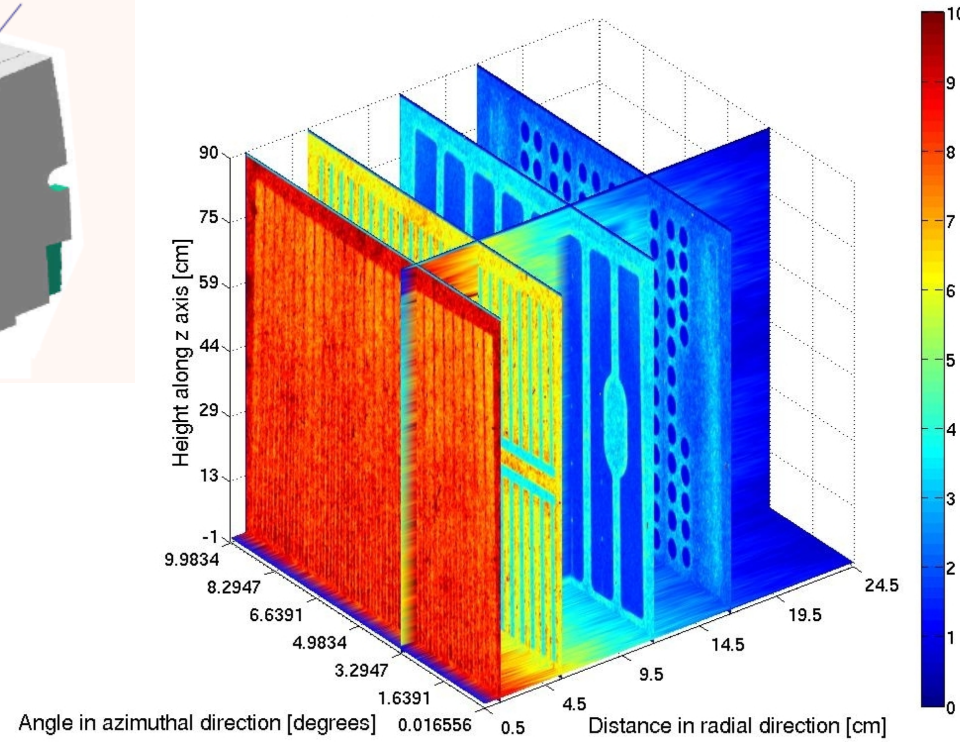
- **Cheaper**
  - Reduce human effort
- **Better**
  - Avoid human error in conversion
  - **Include higher-order surface descriptions in analysis**
- **Faster**
  - Reduce human effort – faster design iteration
  - **Provide common domain for coupling to other analyses**

Detailed High-Resolution, High-Fidelity Calculations with DAG-MCNP in CAD Model of ITER FWS Module 13



Interesting heterogeneity effects revealed





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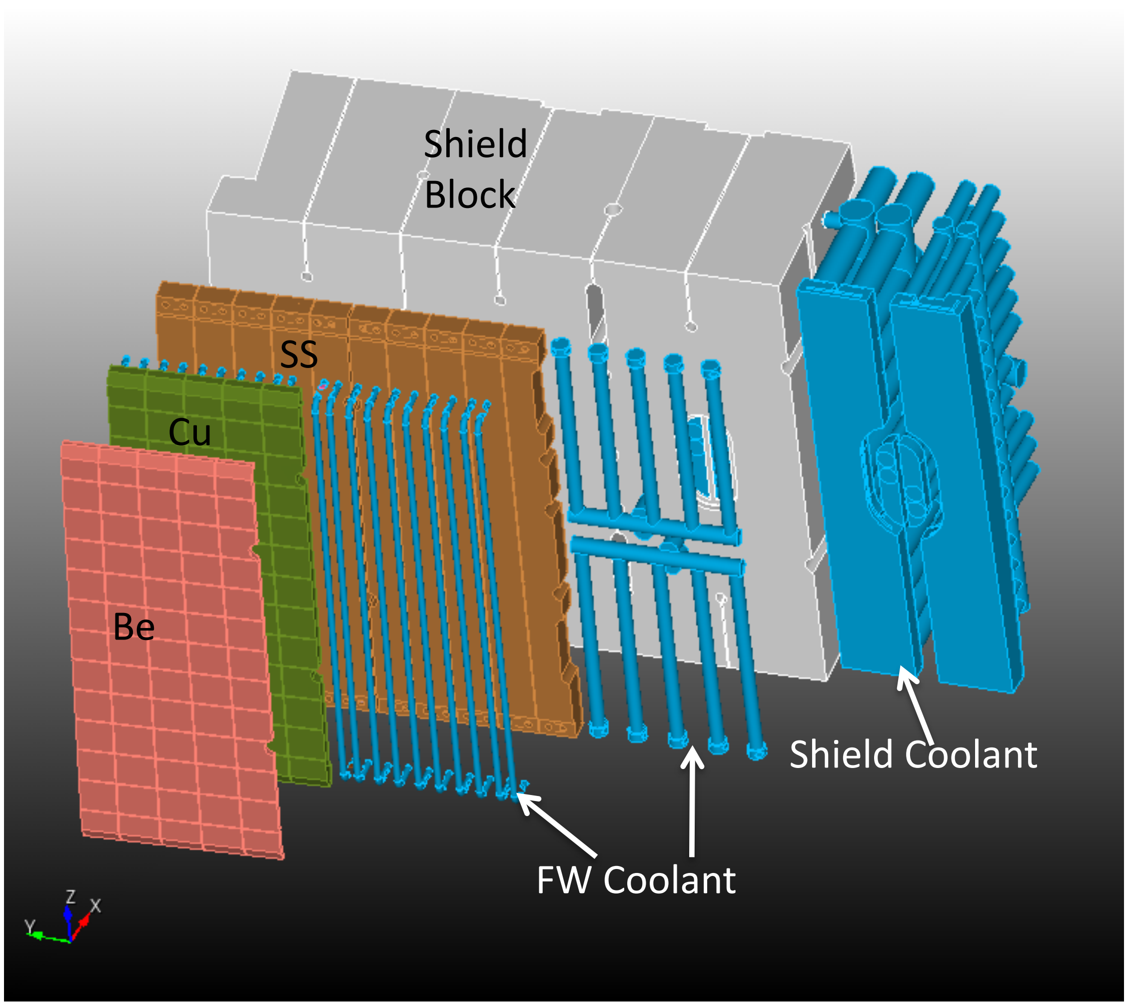
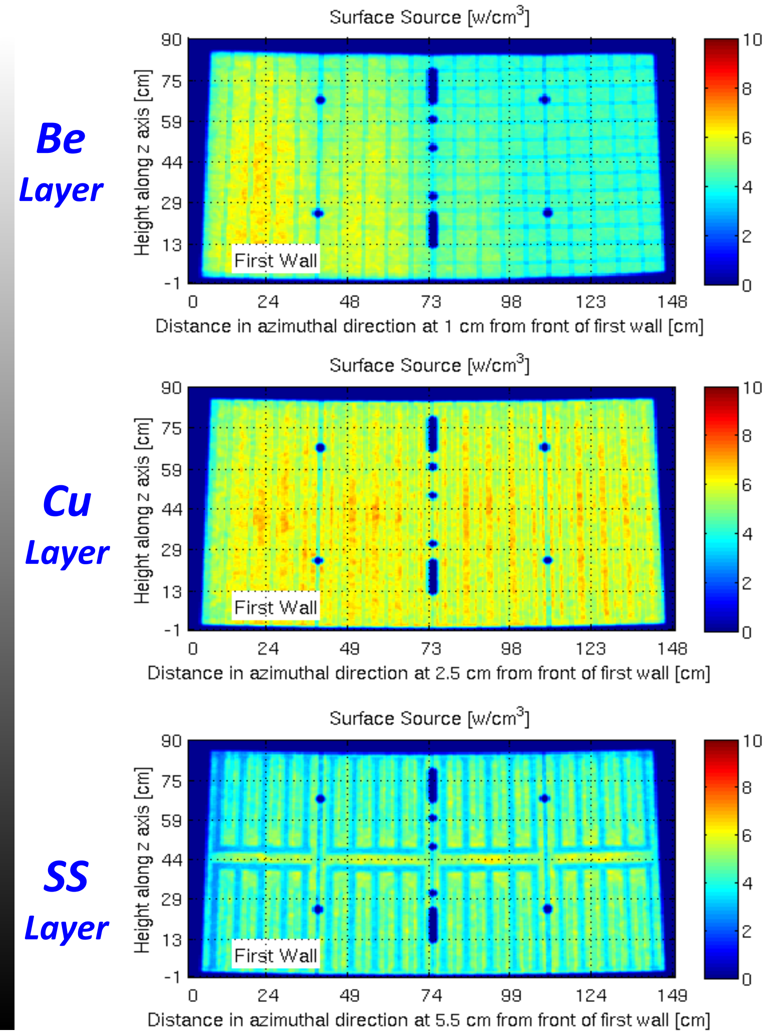
Detailed Calculations with DAG-MCNP for Revised FWS Module Design





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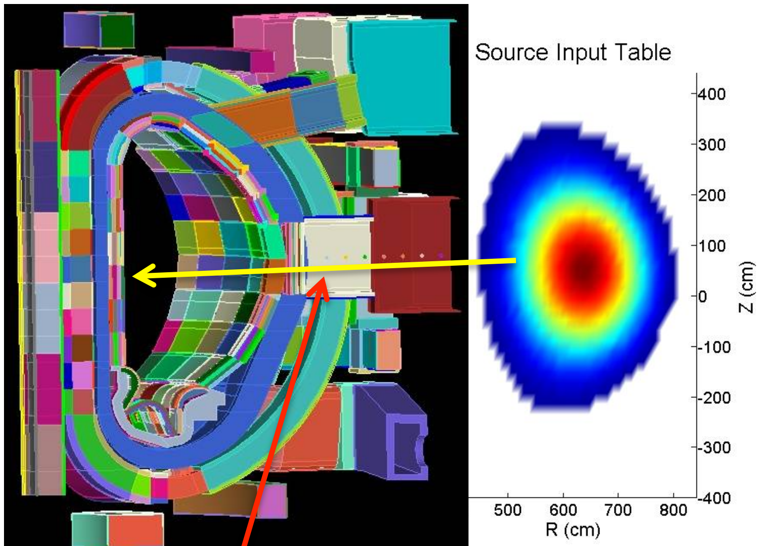
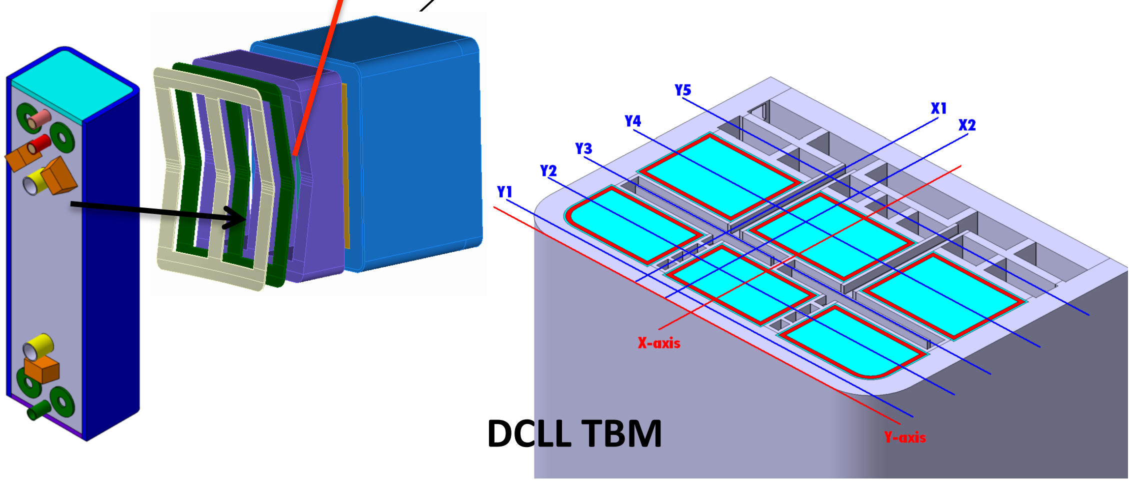
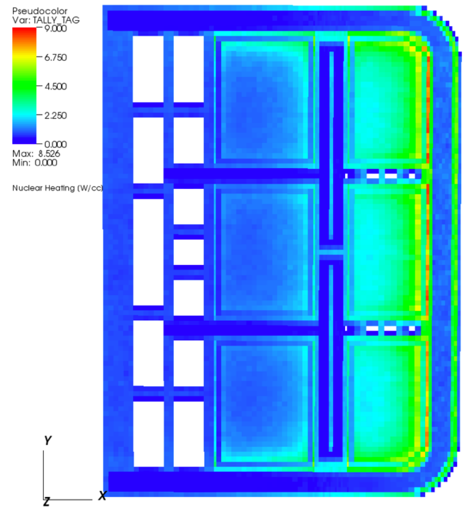
Detailed 3-D Neutronics for DCLL TBM

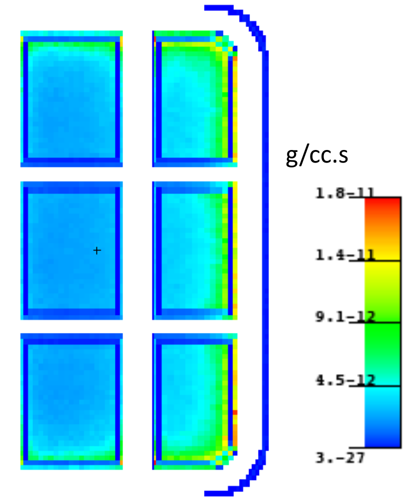




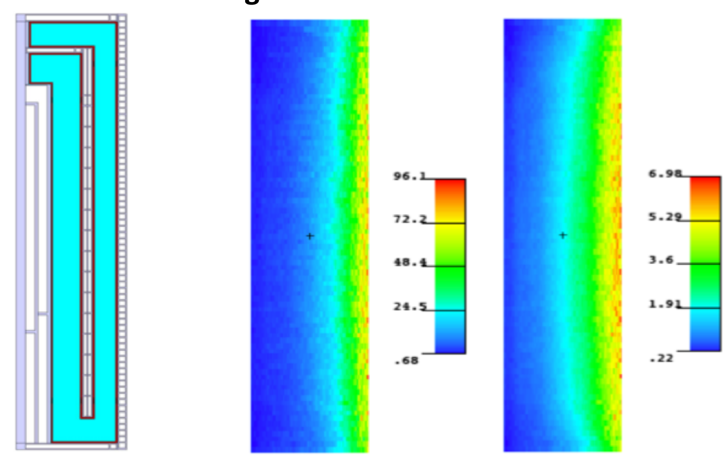
Mid-plane nuclear heating



Mid-plane T production

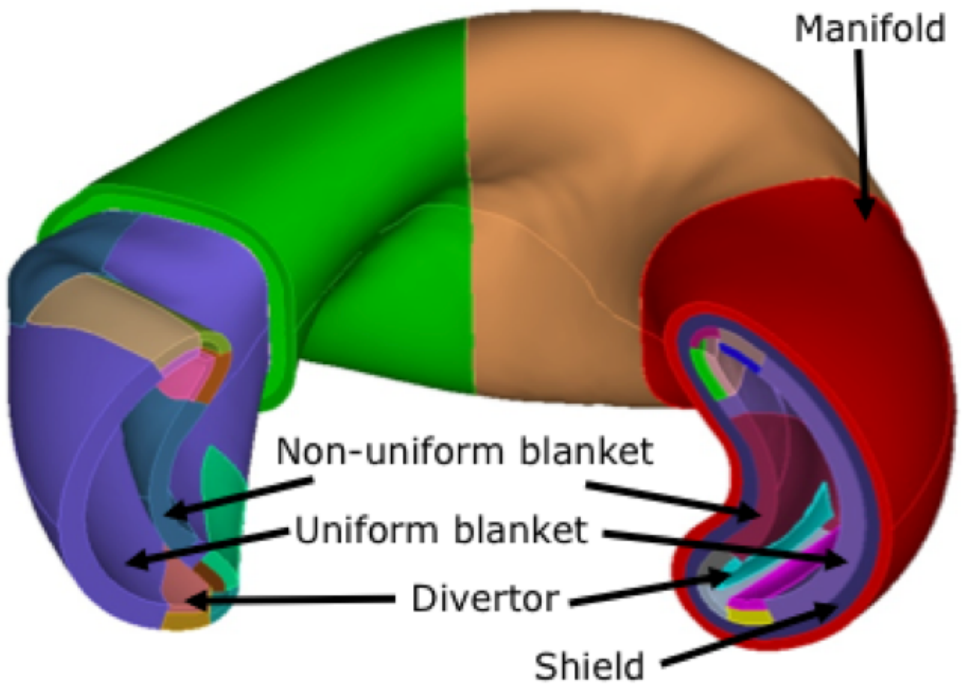


Steel damage at section X2

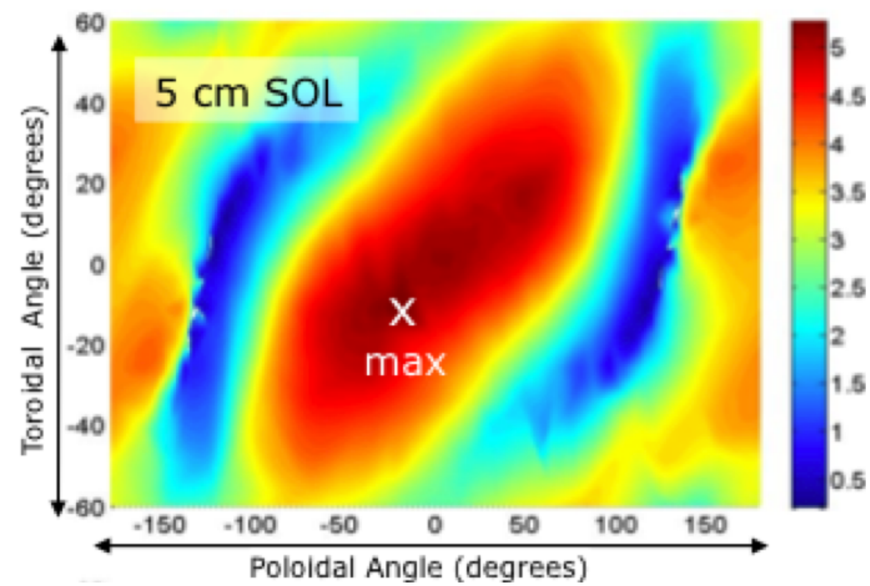


Cross section He appm/FPY dpa/FPY

Application to ARIES-CS Compact Stellarator

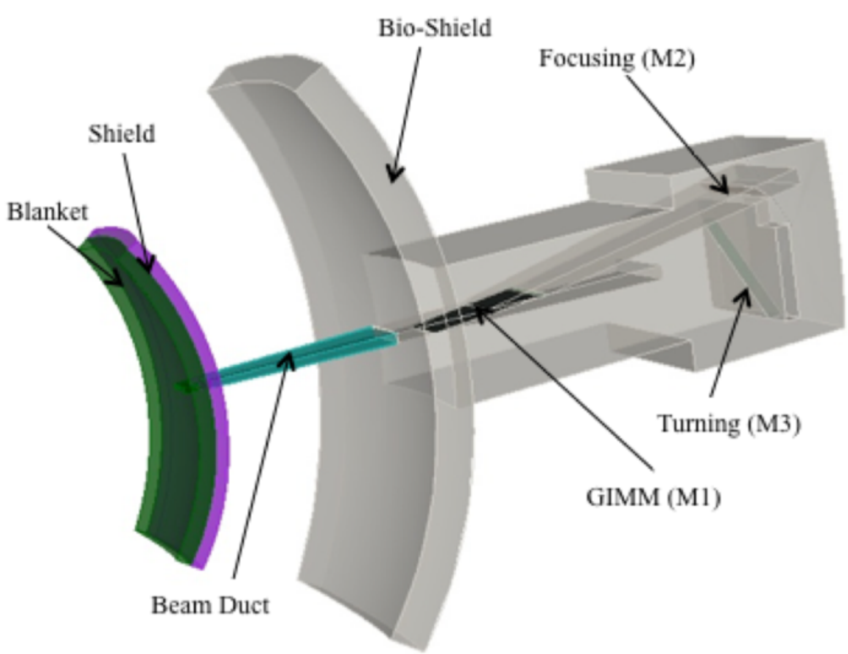


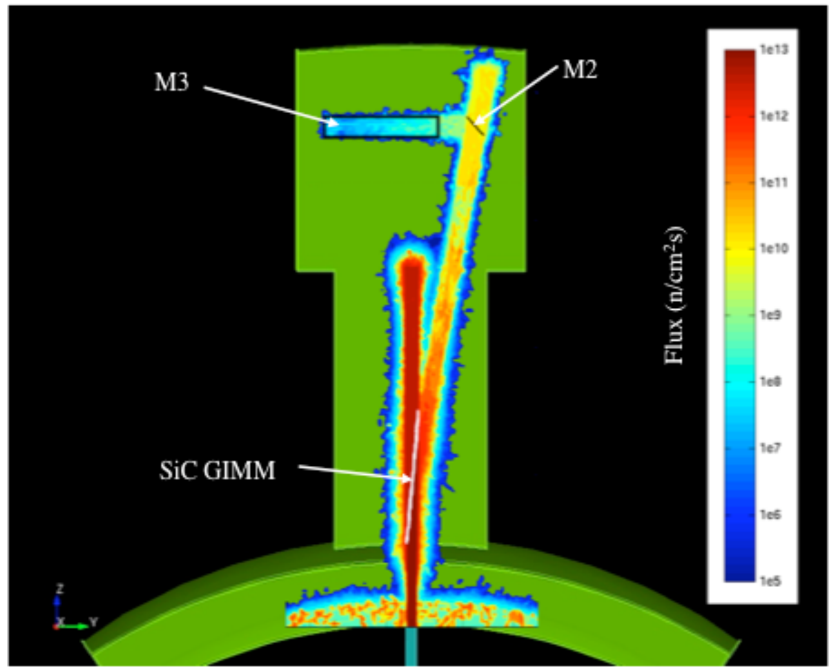
- Geometry and source complex
- Cannot be modeled by standard MCNP



Examined effect of helical geometry and non-uniform blanket and divertor on NWL Distribution,TBR and nuclear heating

HAPL Final Laser Optics





- Fast neutron flux at dielectric optics depends on material choice for the GIMM and total GIMM areal density
- AlBeMet GIMM results in highest flux level (factor of ~1.6 higher than with lightweight SiC GIMM)
- Significant drop in nuclear environment occurs as one moves from the GIMM to dielectric focusing and turning mirrors

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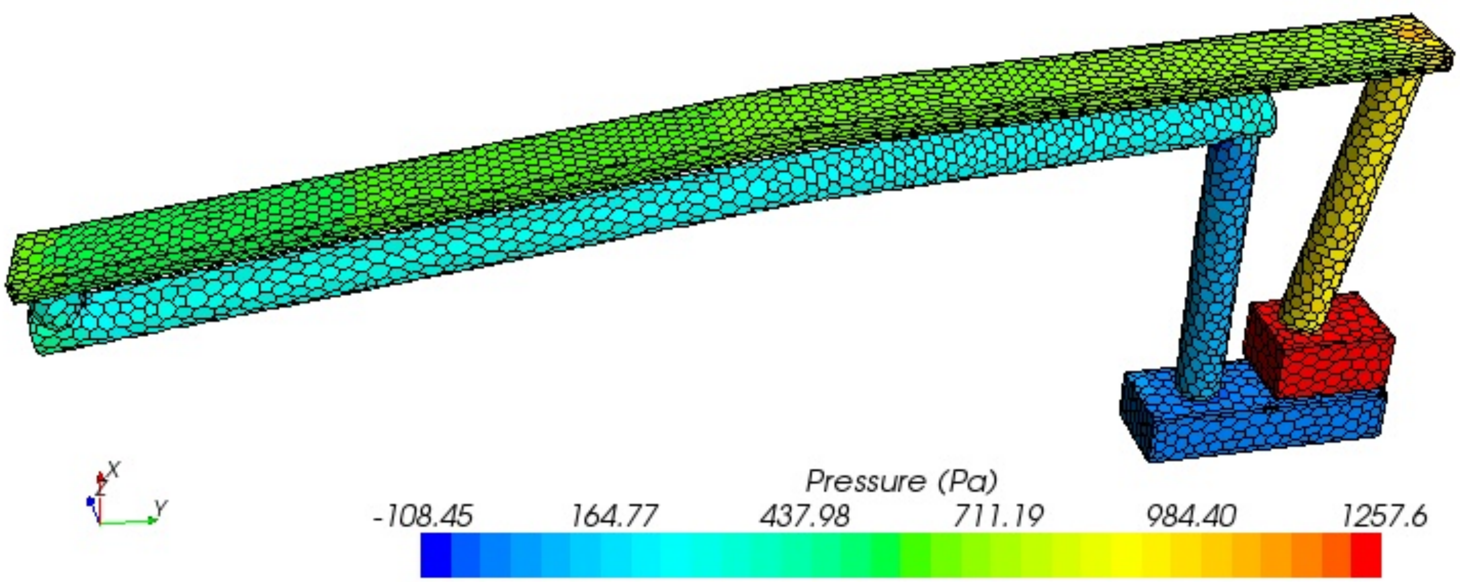
Multi-Physics: Coupling to CFD

- Fine mesh DAG-MCNP5 results
  - 1-3 mm Cartesian mesh overlay
  - Total nuclear heating
- Arbitrary mesh on CAD geometry
  - Tetrahedral
  - Polyhedral (Star-CCM+)
- Automated interpolation using MOAB

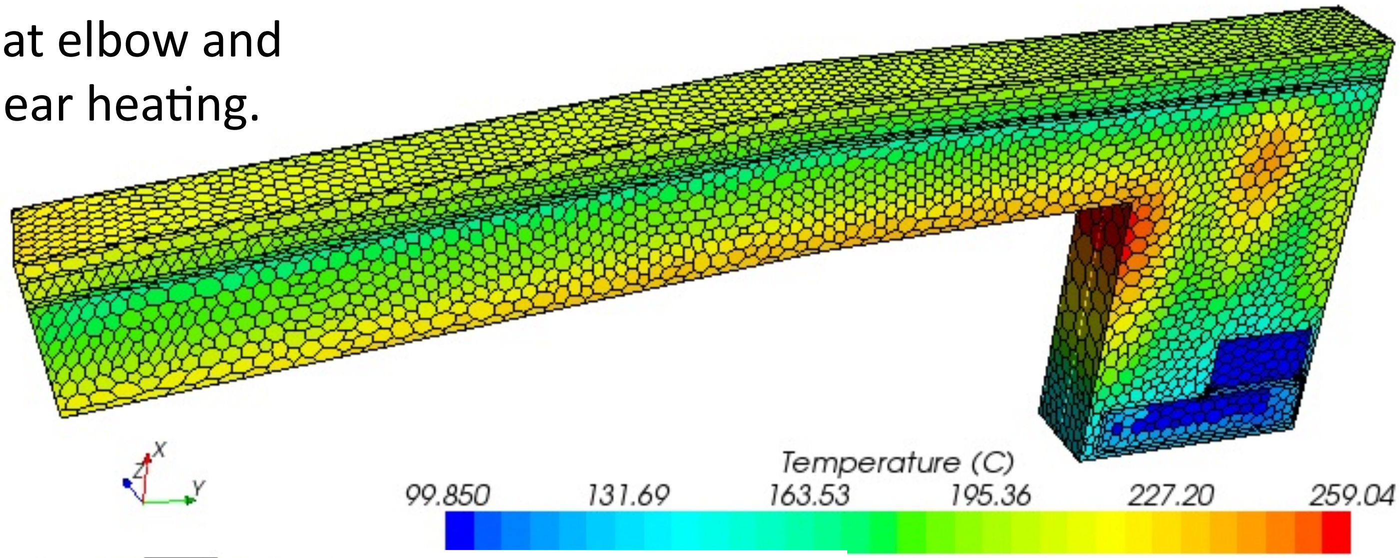
Multi-Physics: Coupling to CFD

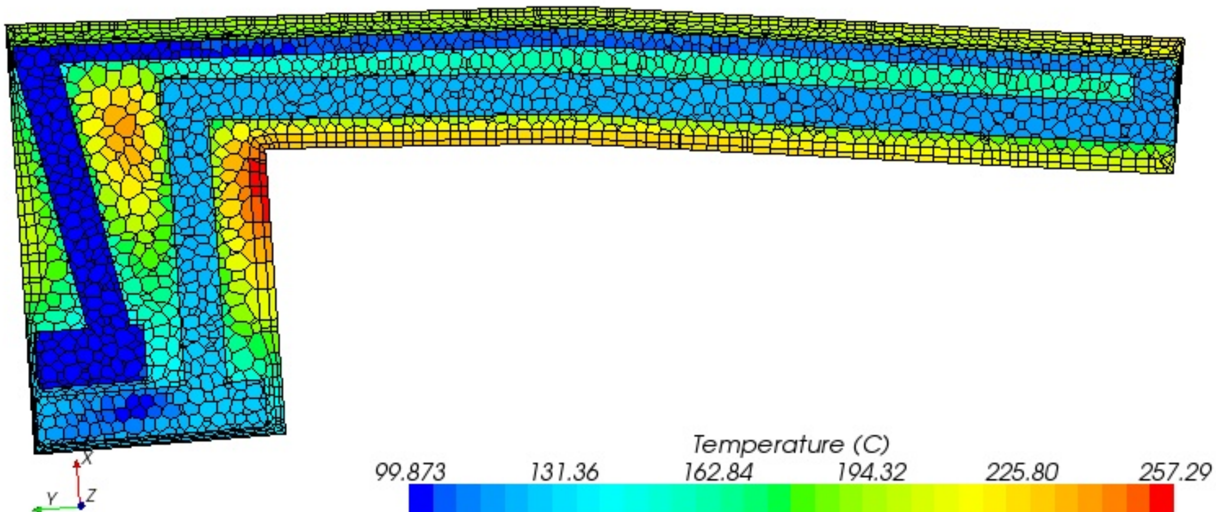
- 1 of 40 fingers in ITER First Wall concept
- Beryllium plasma facing component
- CuCrZr heat sink into pressurized water
- Steel backing for structural support
- 0.2 MW/m^2 heat flux onto Beryllium
- Inlet: 0.2 kg/s water, 373 K, 3 Mpa



Neutronics+CFD Coupling

Notice "hot spot" at elbow and center due to nuclear heating.





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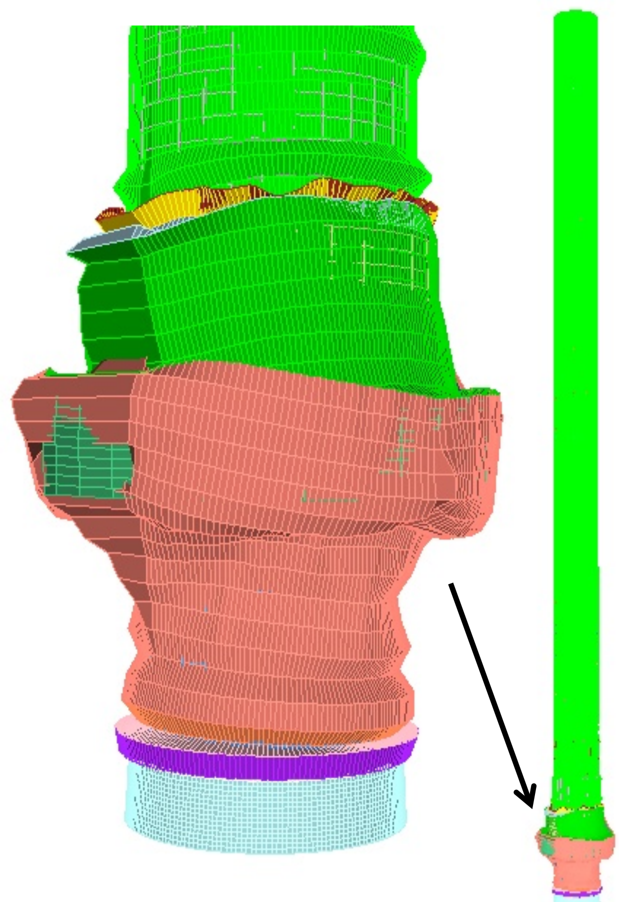
Research Directions

Analysis of Deformed Systems

- Thermal response can lead to structural/geometric changes
- Nuclear analysis on deformed system will help understanding the feedback on performance parameters
- Not applied yet for fusion but used for deformed fission reactors



Research Directions

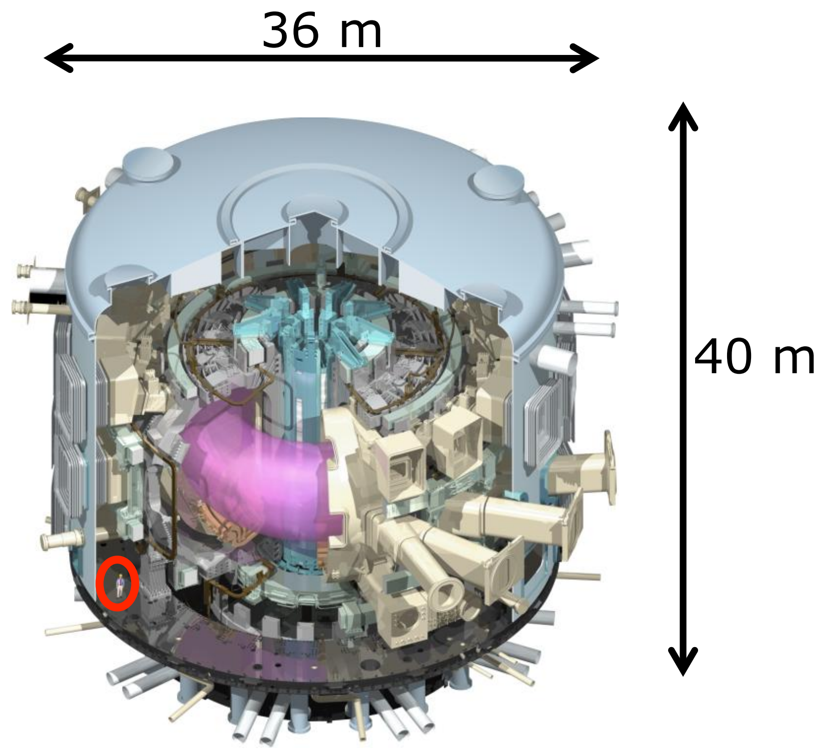
Advanced Mesh Tallies

- Perform tallies on arbitrary polyhedral mesh
  - Prototype exists for tetrahedral mesh
- Get detailed isotopic compositions after activation/transmutation
- Solve separate activation problem in millions of mesh elements
- Use previous source sampling capability to represent distributed photon source

Research Directions

Hybrid Methods

- Monte Carlo not well-suited to deep penetration problems
- Deterministic methods not well suited to gap streaming problems
- Use deterministic methods to develop importance maps for Monte Carlo problems

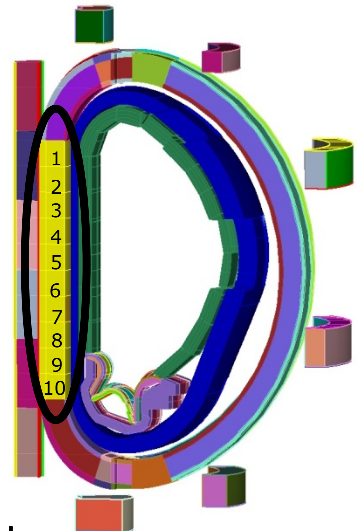


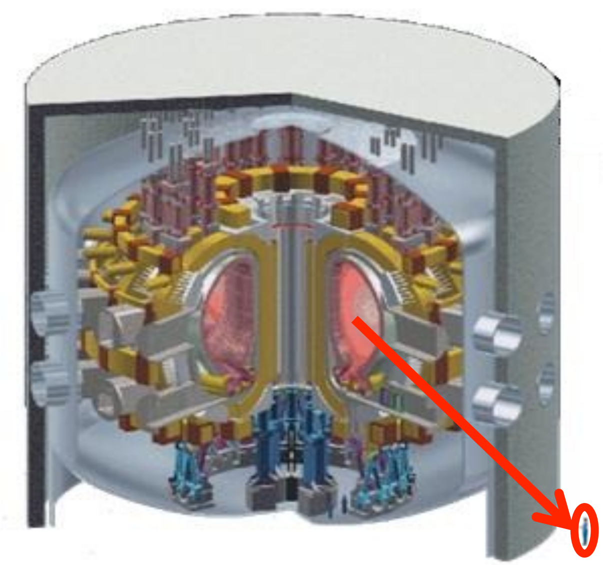
- Large size
- Complex geometry
- Massive shielding

ORNL hybrid methods (CADIS, FW-CADIS) suitable for fusion applications

ITER magnet heating

	Time (day)	Max. uncertainty	Normalized FOM
Analog	121.3	5.9%	1
WWG	11.0	3.6%	30
FW-CADIS	0.8	4.5%	275





ITER prompt dose

	Dose (mrem/hr)	Relative uncertainty	Time (day)	Normalized FOM
MC (No CADIS)	0.48	76.7%	610.0	1
MC (CADIS)	0.27	3.8%	8.6	10,566
Denovo	0.18	280 million cell 1 hr, 14 400 cores = 610 processors days		

Summary

- An updated comprehensive (ns to 150 MeV, activation, p, d, covariance) fusion evaluated nuclear data library FENDL-3 that is suitable for all fusion systems will be developed, validated, and released by the end of 2011
- Progress made on improving fusion neutronics predictive capabilities for accurate and fast analysis of the large geometrically complex fusion systems
- Many challenging issues remain to allow efficient automated integration with other multi-physics analyses

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