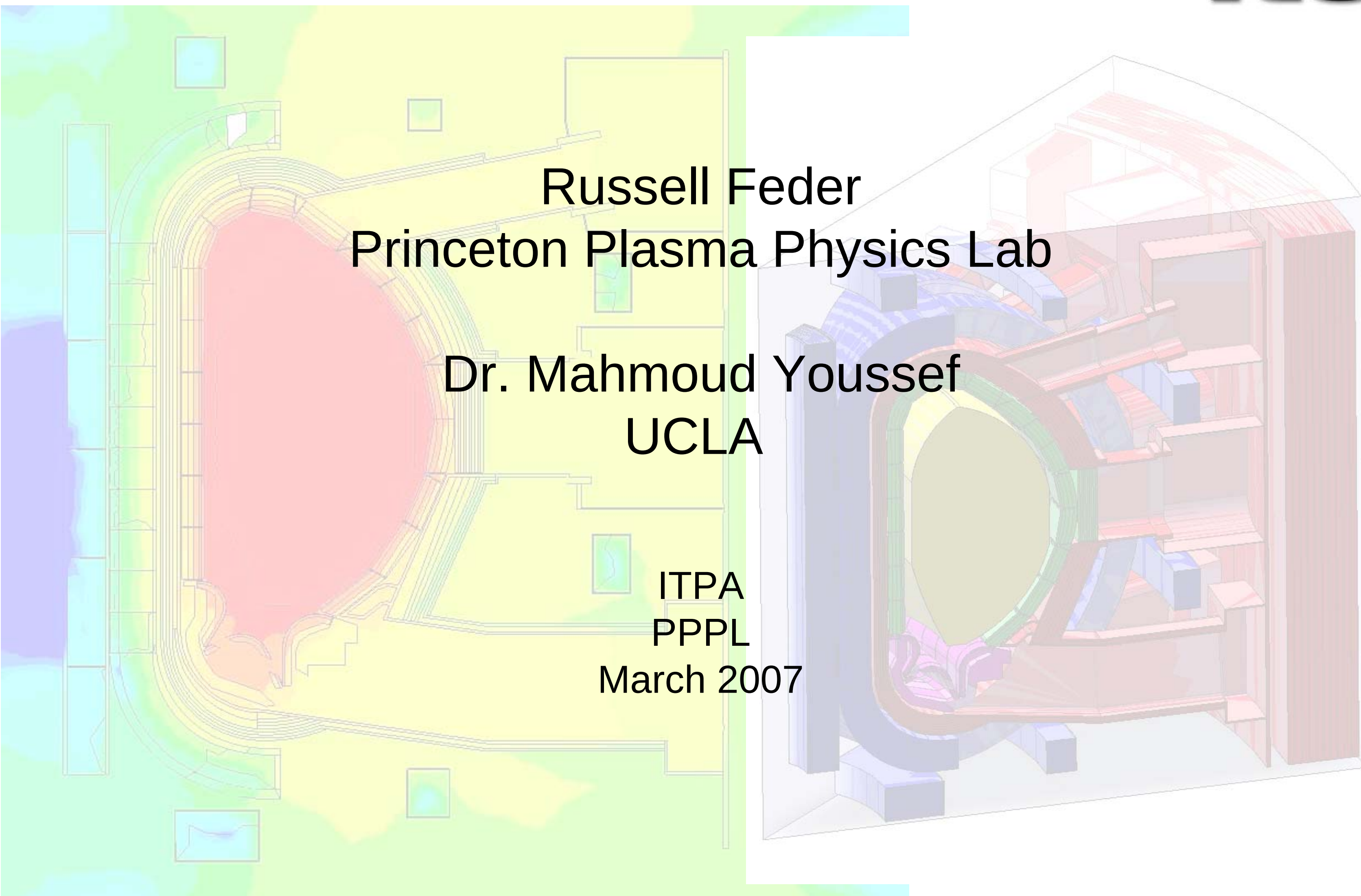
PPPL ITER NEUTRONICS ANALYSIS



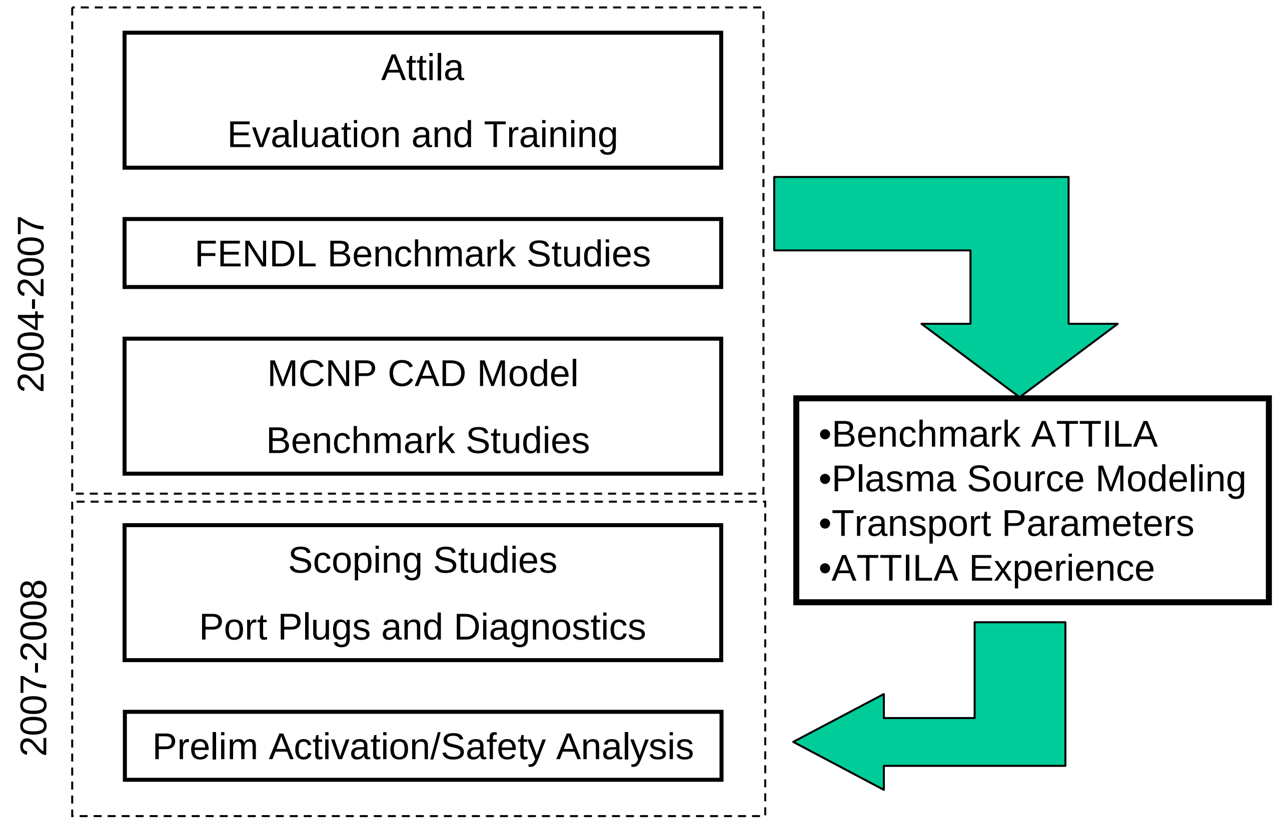
Russell Feder
Princeton Plasma Physics Lab

Dr. Mahmoud Youssef
UCLA

ITPA
PPPL
March 2007

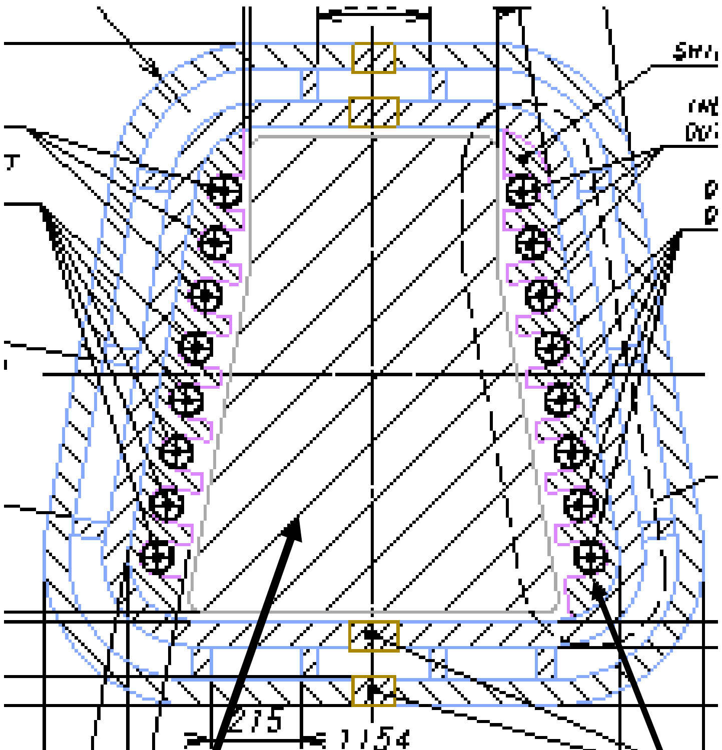
PPPL ITER NEUTRONICS ANALYSIS

Objective: Develop *neutronics analysis* capability at PPPL to support US ITER diagnostic and port plug design.



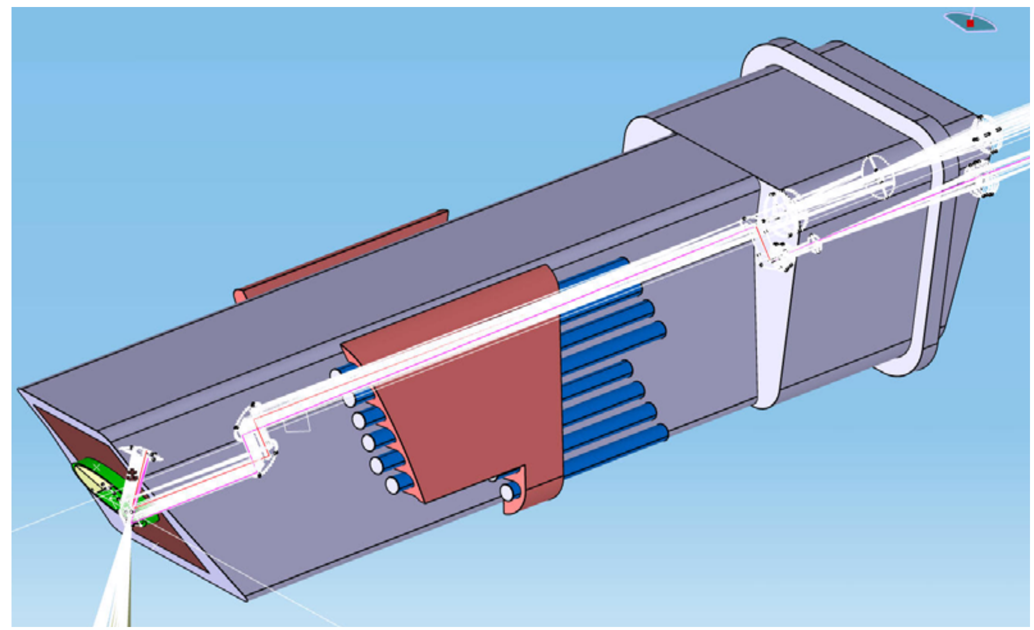
PPPL ITER NEUTRONICS ANALYSIS

A Neutronics Analysis Tool for Diagnostic Port Design Engineers



Upper Port Plug Cavity

BSM Water Supply Piping and Mount



Upper Port Plug VIS/IR Diagnostic

WHY USE ATTILA ?

A Neutronics Analysis Tool for Diagnostic Port Design Engineers

<u>Find a Way for PPPL Engineers to Evaluate Neutronics Implications of Diagnostic Designs</u>

•<u>Limited or No Neutronics Experience</u> → Collaborate with Neutronics Experts
•Strong Background In Finite Element Analysis (FEA) and Computer Aided Design (CAD) 3D Modeling
•Experience with LINUX Helps

<u>ATTILA Built for use by Non-Expert Design Engineers</u>

•Gamma and Neutron Flux Solution Everywhere in Model → MCNP Variance Reduction Techniques
•Easy to Visually Check Solution Accuracy
•TECPLOT Post Processing
•ATTILA Graphical User Interface (GUI) and Meshing → <u>Strong Technical Support from ATTILA</u>

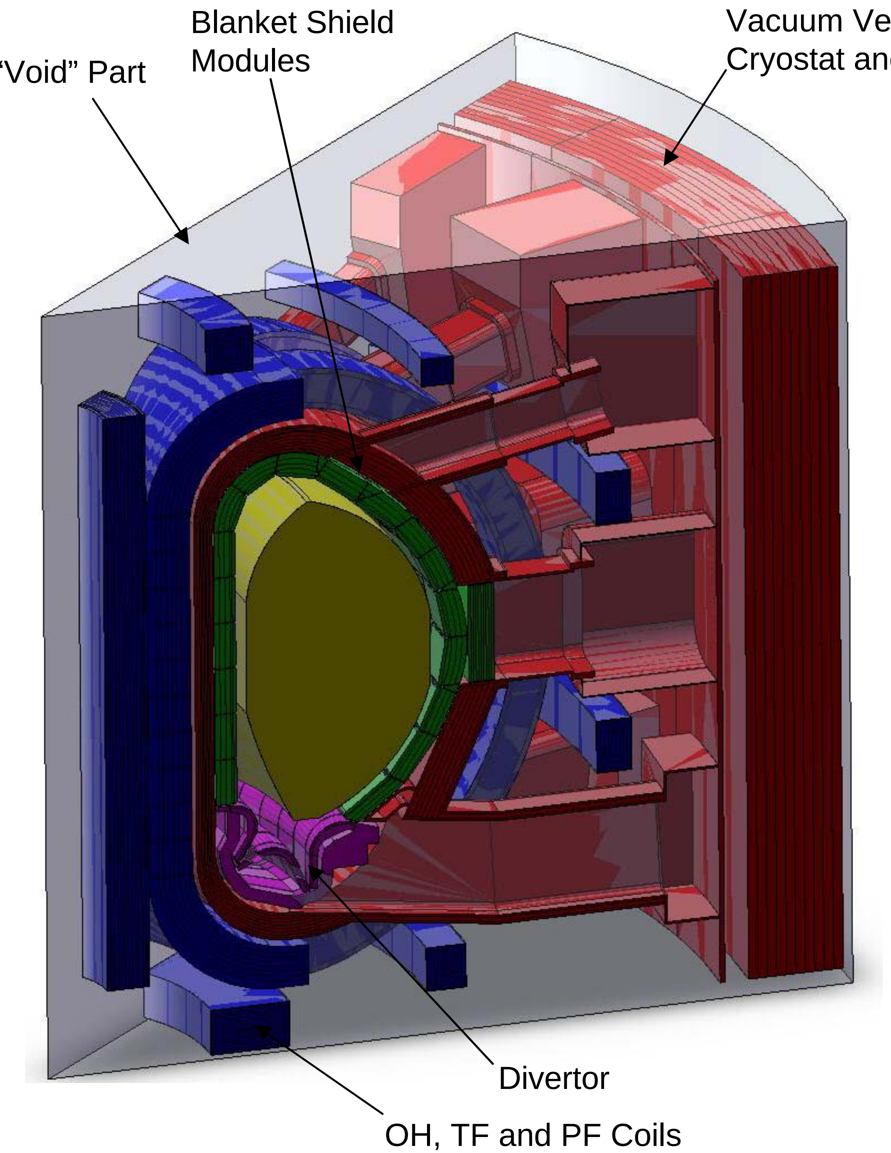
<u>Some Assembly Required!</u>

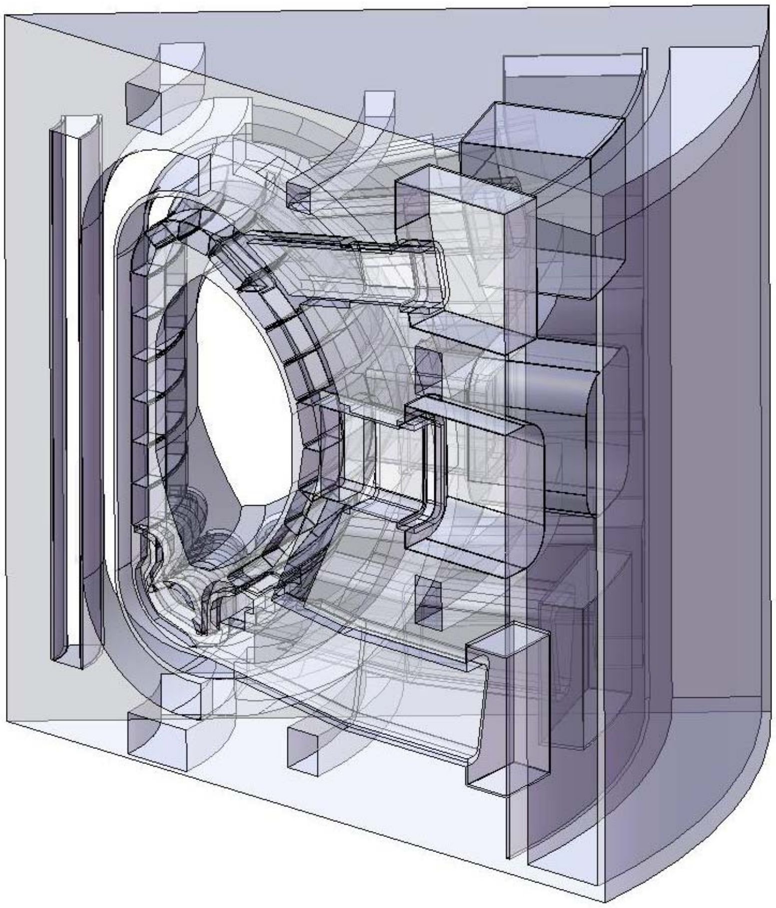
•Hardware → 64 Bit 4 Processor Opteron CPU with 16 GB of RAM
•Software → Solid Works Makes High Fidelity Parasolid Models for ATTILA

<u>Disadvantages of ATTILA</u>

MCNP Is the Only Licensed Neutronics Analysis Software → ATTILA Benchmarking
Special Techniques Required for Streaming Analysis

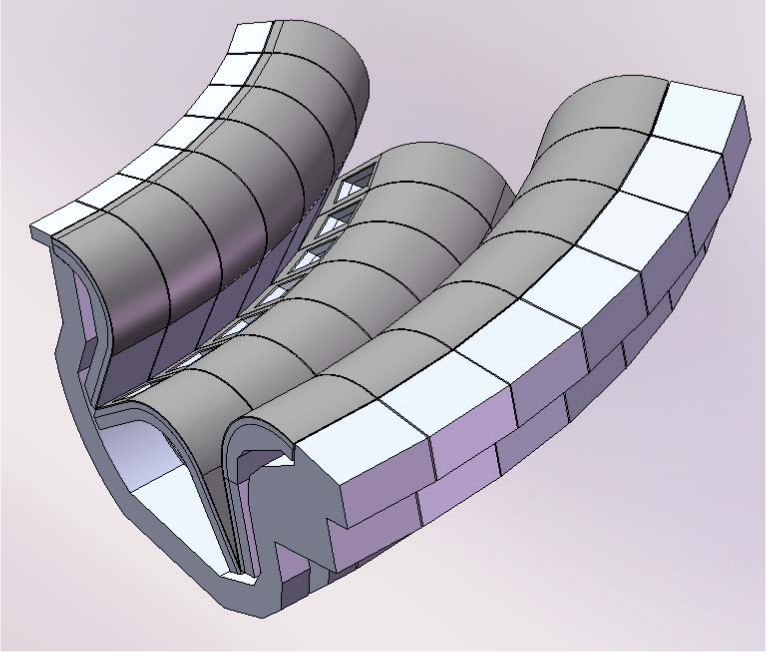
SolidWorks Benchmark CAD 40° Model



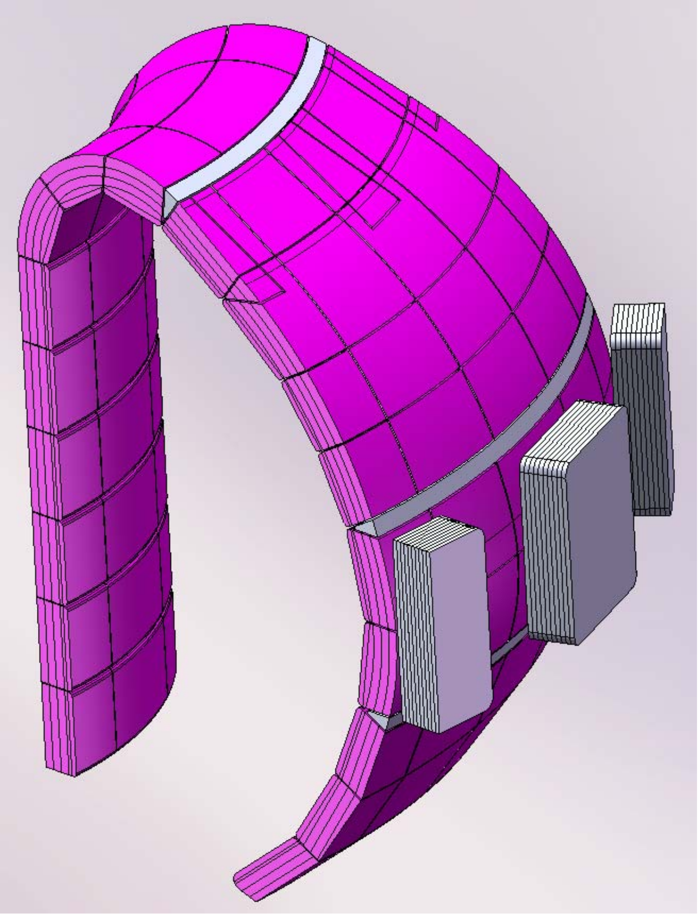


Void Part Solid Model

SolidWorks Benchmark CAD 40° Model



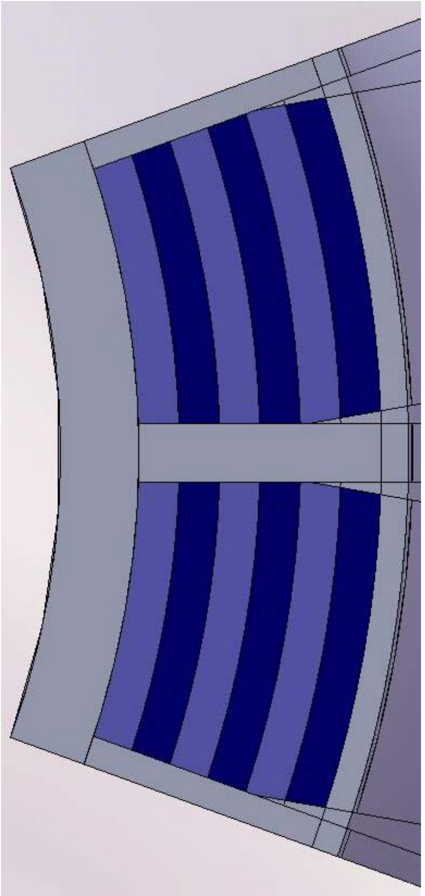
Benchmark Divertor Model



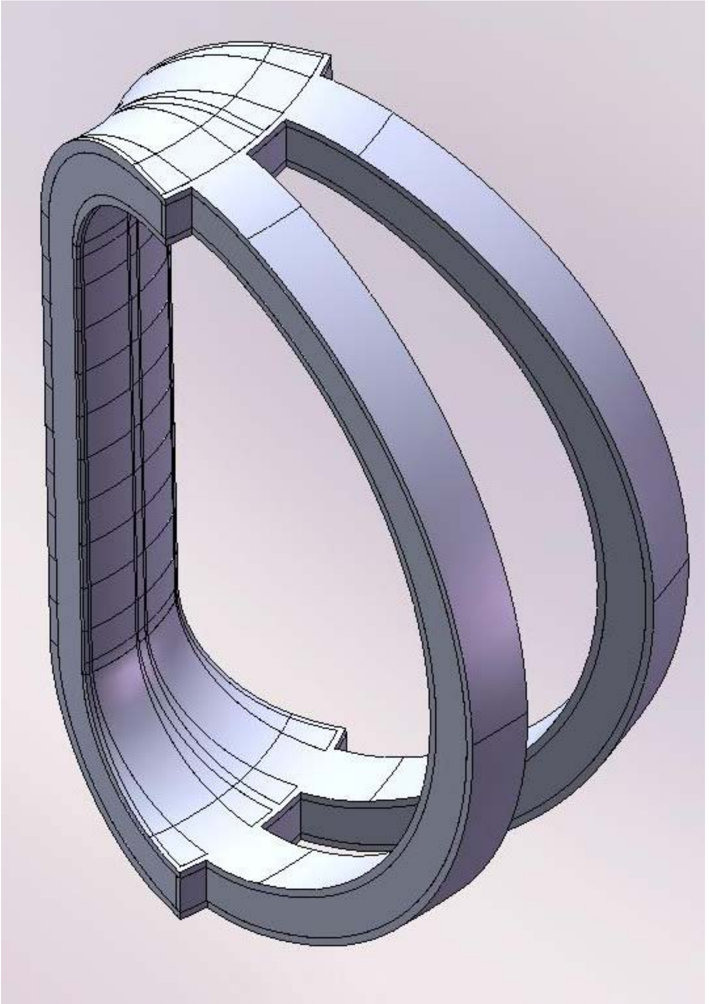
Benchmark BSM Model

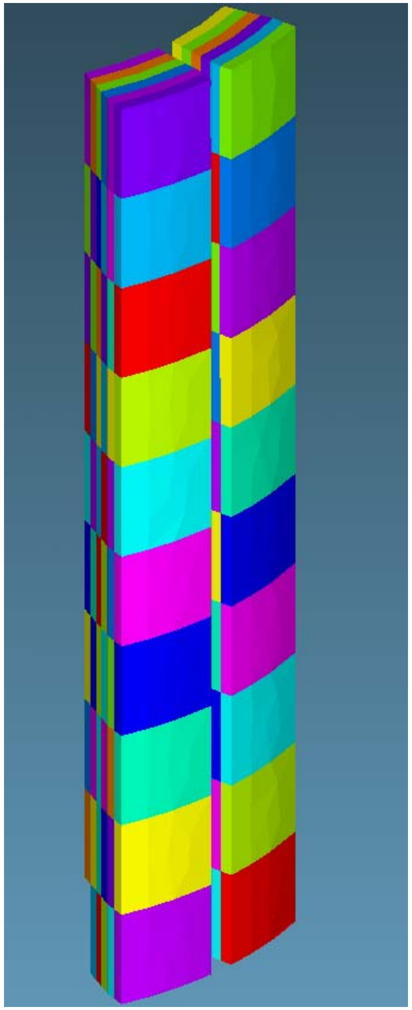
SolidWorks Benchmark CAD 40° Model

Revised TF Coil Model



Inboard Leg
Cross Section

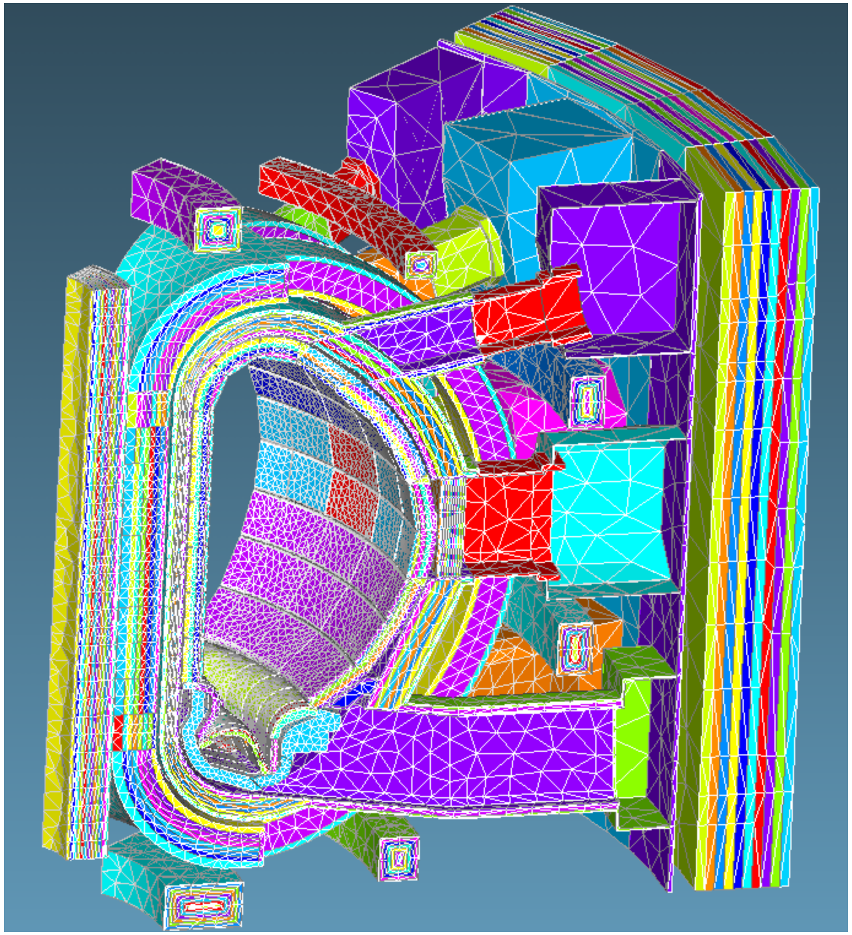




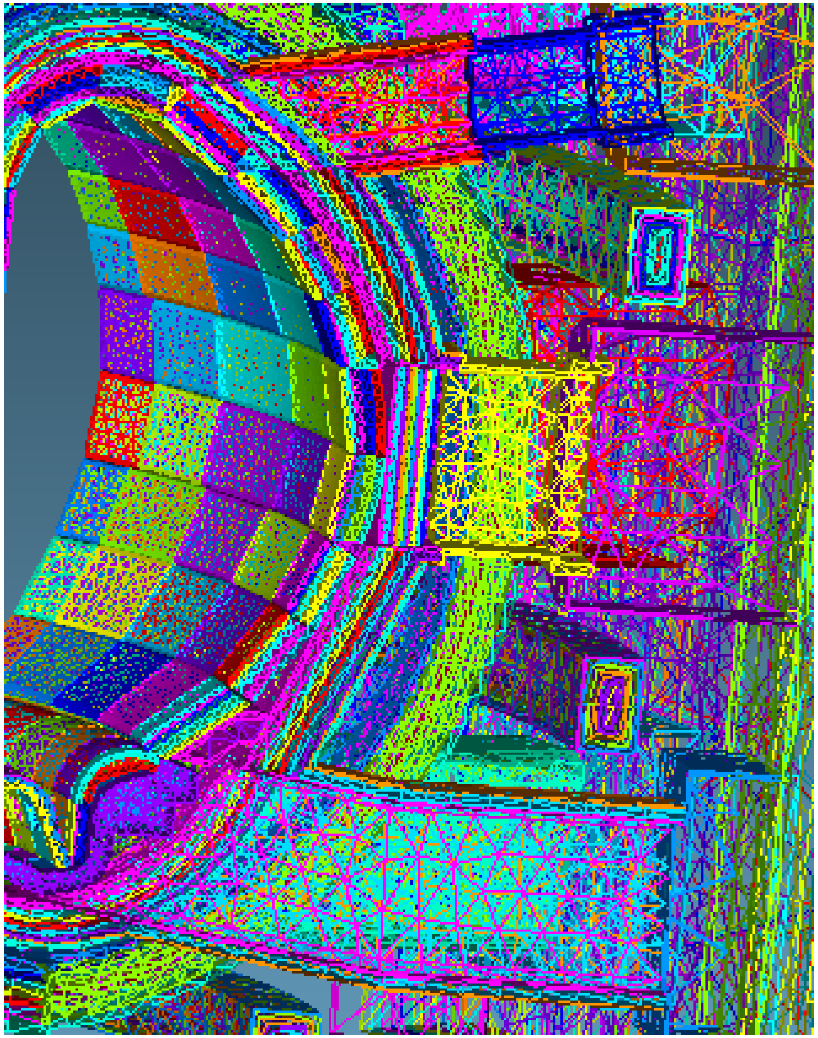
10 Left and Right
Inboard Winding Sections

ATTILA Tetrahedral Mesh

500,000 Elements → ~1 Week with 40 Energy Groups and Sn16 Quadrature



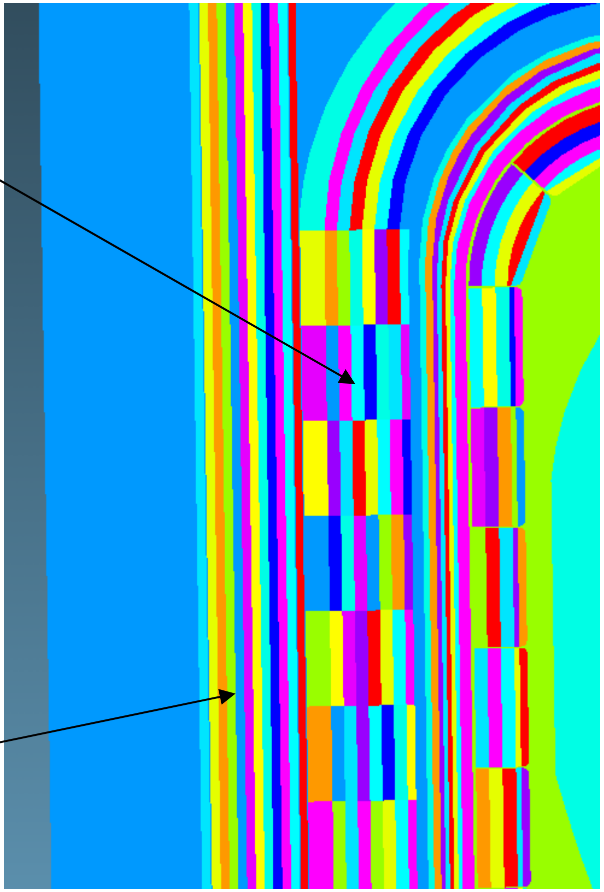
Layering and Variable Mesh Size



Benchmark Material Properties and Mixing

TF and OH Materials

TF Winding (M18):
%47.6 316LN-IG
%1.5 316L
%12.9 Liq. He
%6.3 Nb3Sn
%18 Epoxy
%13.7 Cu



OH Winding (M40):
%54.7 316LN-IG
%1.2 316L
%.6 Inconel
%11.2 Liq. He
%5.5 Nb3Sn
%15.8 Epoxy
%11 Cu

Isotope	A.D.	A. Fraction
Al27	7.520E-04	9.952E-03
B10	4.719E-07	6.246E-06
B11	1.728E-06	2.286E-05
Bi209	9.090E-08	1.203E-06
C12	3.467E-03	4.589E-02
Co59	2.015E-05	2.666E-04
Cr50	3.512E-04	4.647E-03
Cr52	6.512E-03	8.618E-02
Cr53	7.244E-04	9.587E-03
Cr54	1.770E-04	2.342E-03
Cu63	8.186E-03	1.083E-01
Cu65	3.648E-03	4.829E-02
Fe54	1.676E-03	2.218E-02
Fe56	2.536E-02	3.357E-01
Fe57	5.755E-04	7.616E-03
Fe58	7.526E-05	9.961E-04
H1	3.897E-03	5.157E-02
He4	2.369E-03	3.135E-02
K	3.036E-07	4.018E-06
Mg	2.144E-04	2.837E-03
Mn55	8.644E-04	1.144E-02
Mo100	5.722E-05	7.573E-04
Mo92	9.585E-05	1.269E-03
Mo94	5.847E-05	7.739E-04
Mo95	9.958E-05	1.318E-03
Mo96	1.032E-04	1.366E-03
Mo97	5.850E-05	7.742E-04
Mo98	1.463E-04	1.936E-03
N14	6.042E-04	7.996E-03
N15	2.182E-06	2.888E-05
Nb93	2.556E-06	3.382E-05
Nb93	2.573E-03	3.406E-02
Ni58	3.348E-03	4.431E-02
Ni60	1.247E-03	1.650E-02
Ni61	5.331E-05	7.055E-04
Ni62	1.672E-04	2.213E-03
Ni64	4.125E-05	5.460E-04
O16	4.866E-03	6.440E-02
P31	3.450E-05	4.566E-04
Pb206	2.223E-08	2.942E-07
Pb207	2.028E-08	2.684E-07
Pb208	4.786E-08	6.334E-07
S	1.141E-04	1.510E-03
Si28	1.916E-03	2.536E-02
Si29	9.641E-05	1.276E-03
Si30	6.289E-05	8.323E-04
Sn	4.000E-07	5.294E-06
Sn	8.577E-04	1.135E-02
Ta181	1.312E-06	1.736E-05
Ti46	6.394E-06	8.463E-05
Ti47	5.644E-06	7.469E-05
Ti48	5.474E-05	7.244E-04
Ti49	3.937E-06	5.210E-05
Ti50	3.694E-06	4.889E-05
V	1.864E-06	2.467E-05
W182	3.458E-08	4.576E-07
W183	1.858E-08	2.459E-07
W184	3.955E-08	5.235E-07
W186	3.630E-08	4.804E-07
Zr	5.205E-07	6.889E-06
Total A.D.	7.556E-02	

Cr52	6.512E-03	8.618E-02
Cr53	7.244E-04	9.587E-03
Cr54	1.770E-04	2.342E-03
Cu63	8.186E-03	1.083E-01
Cu65	3.648E-03	4.829E-02
Fe54	1.676E-03	2.218E-02
Fe56	2.536E-02	3.357E-01
Fe57	5.755E-04	7.616E-03
Fe58	7.526E-05	9.961E-04
H1	3.897E-03	5.157E-02
He4	2.369E-03	3.135E-02
K	3.036E-07	4.018E-06
Mg	2.144E-04	2.837E-03
Mn55	8.644E-04	1.144E-02

FENDL 2.1 ISOTOPES

ATOMIC DENSITY

ATOMIC FRACTION

ISOTOPIC ATOMIC FRACTIONS

TOTAL MIXTURE ATOMIC DENSITY

ATILLA INPUT

MCNP Plasma Source Definition

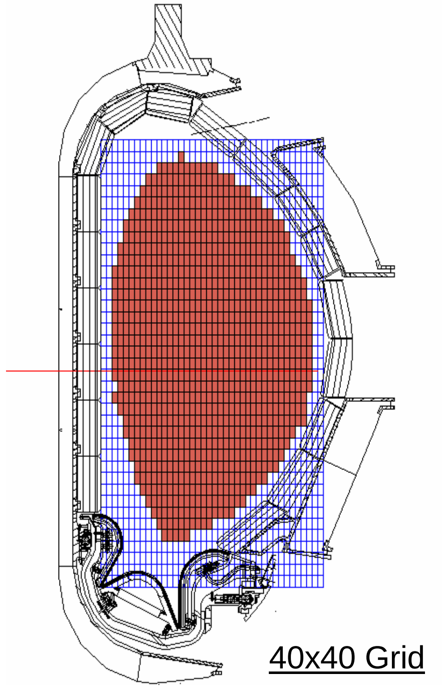
40x40 Probability Matrix → Each Cell Assigned a DT-neutron born probability

500 MW neutron power → 40° Normalization factor ~ 1.972E+19

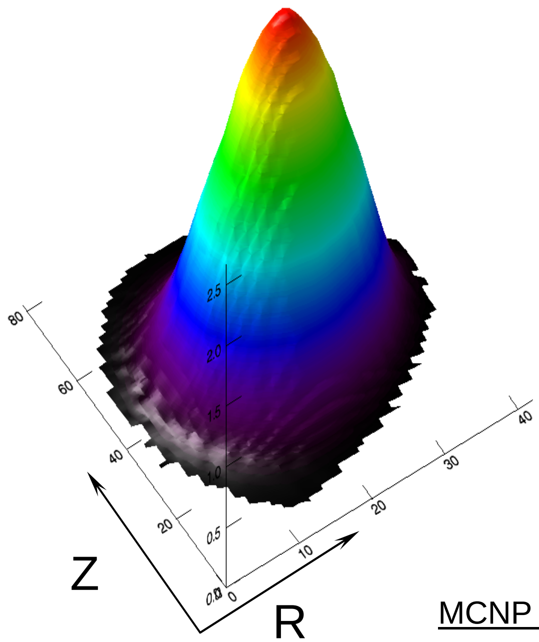
MCNP Matrix Mapped on to ATILLA Mesh With Specially Written Python Script

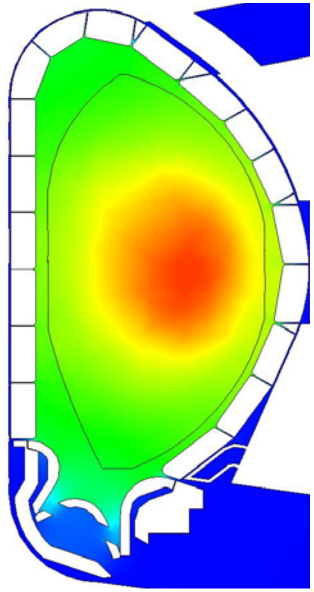
Reference Source Definition From ITER Nuclear Analysis Report (NAR) (G 73 DDD 2 W 0.2)

Use for Diagnostic Evaluations → Other Scenarios ??



40x40 Grid

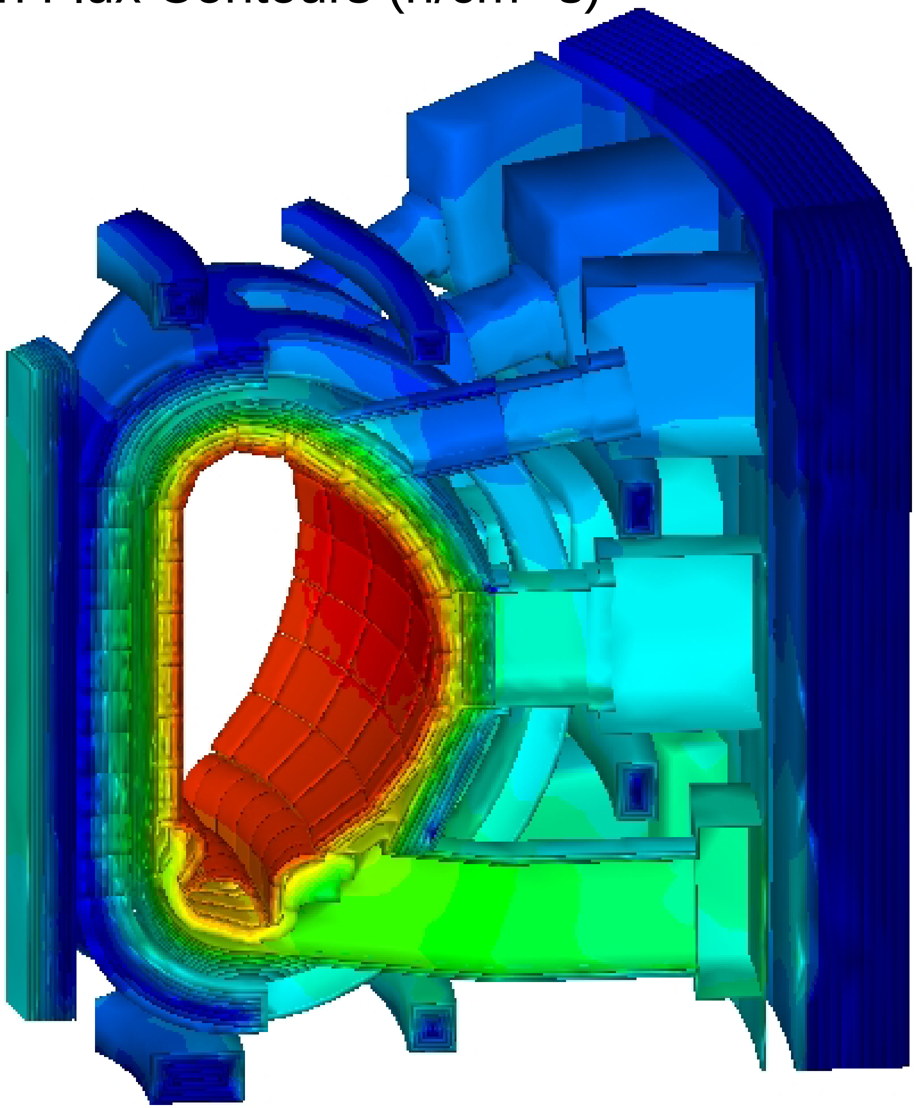




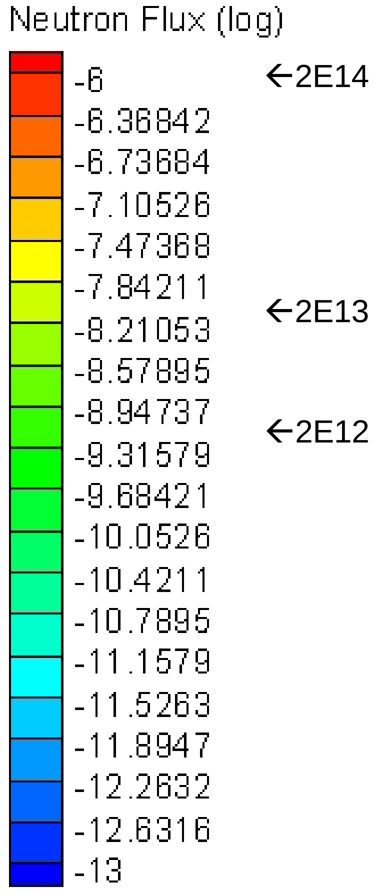
MCNP Source Distribution

ITER Benchmark Results

Neutron Flux Contours (n/cm^2-s)

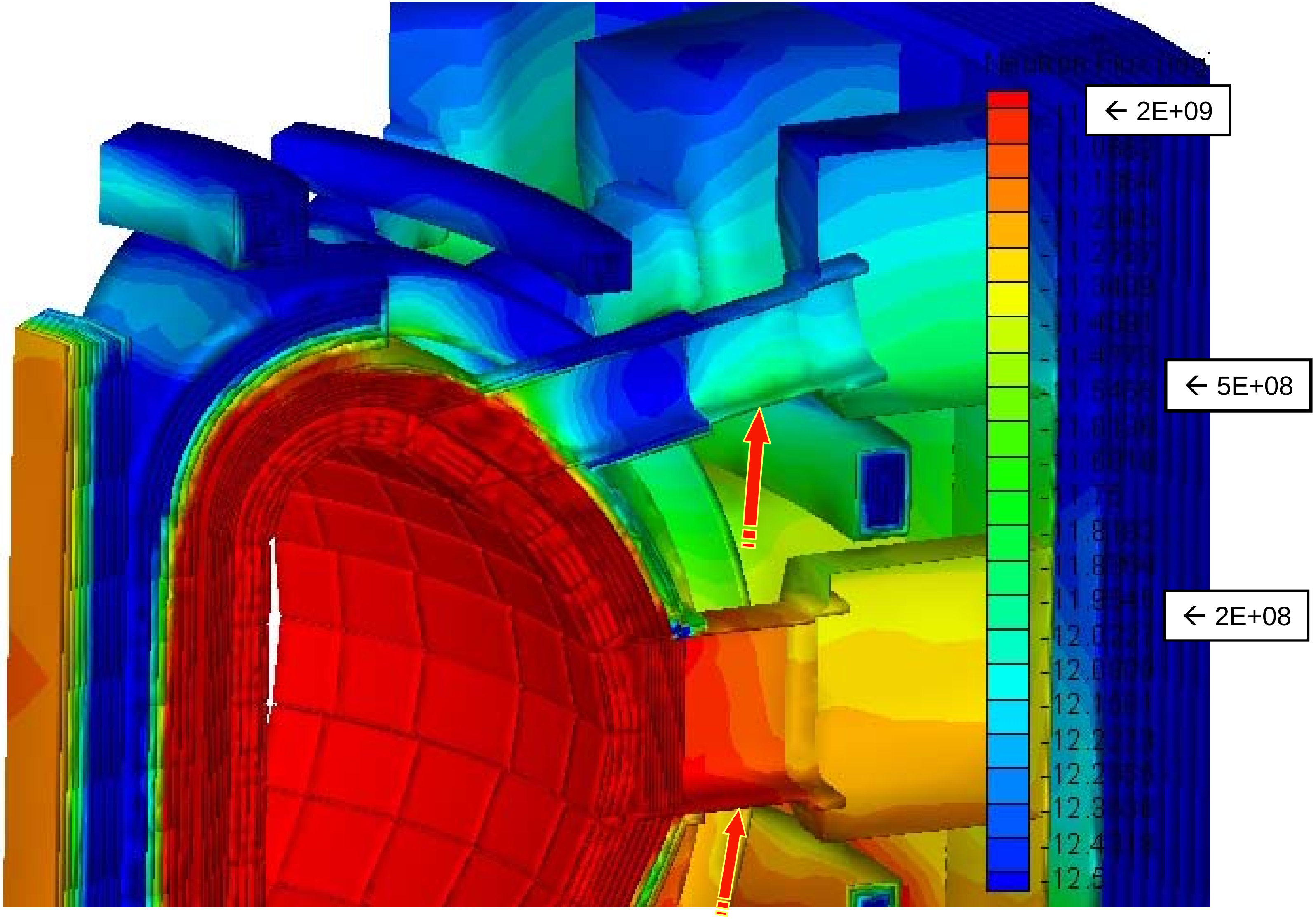


Scalar Flux (n/cm^2-s)
Flux = 1.7753E20*10^x



ITER Benchmark Results

Neutron Flux Contours (n/cm^2-s)



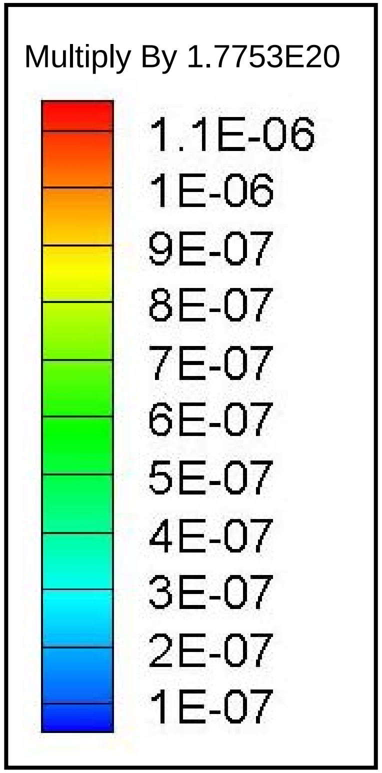
ITER Benchmark Results

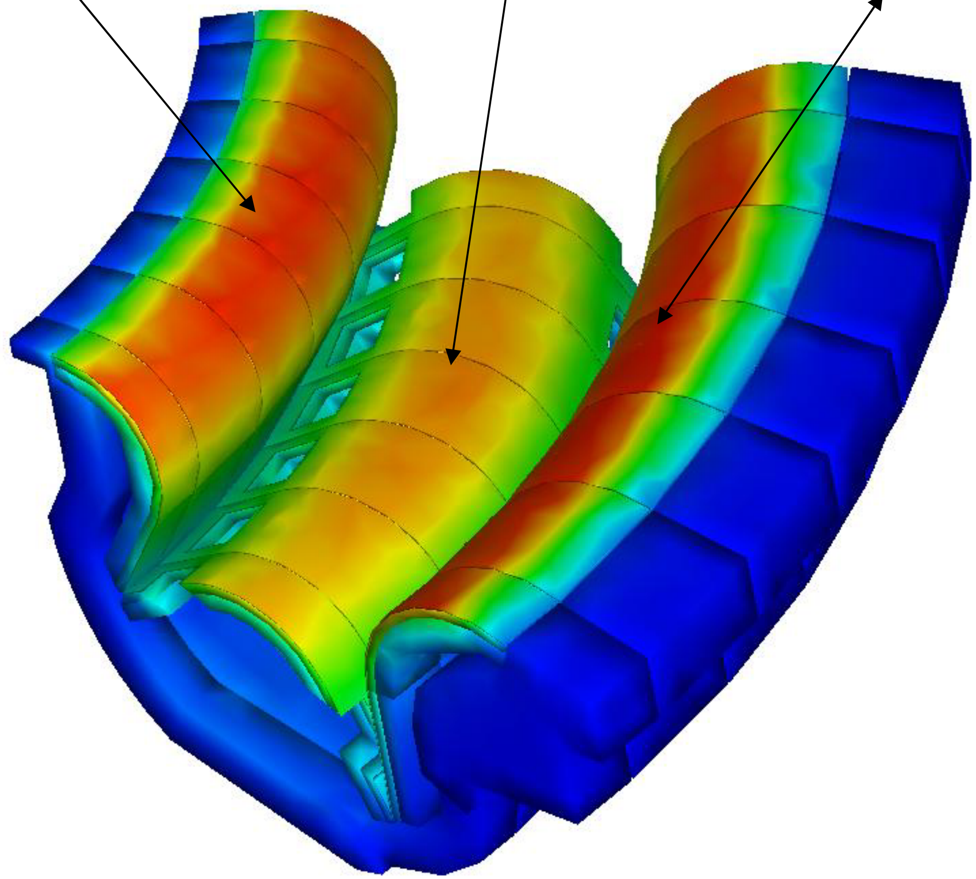
Divertor Neutron Flux (n/cm^2-s)

<u>Inboard Dome Surface Flux</u>
Attila: 12.8E+13
MCNP: 11.5E+13

<u>Center Dome Surface Flux</u>
Attila: 9.2E+13
MCNP: 9.50E+13

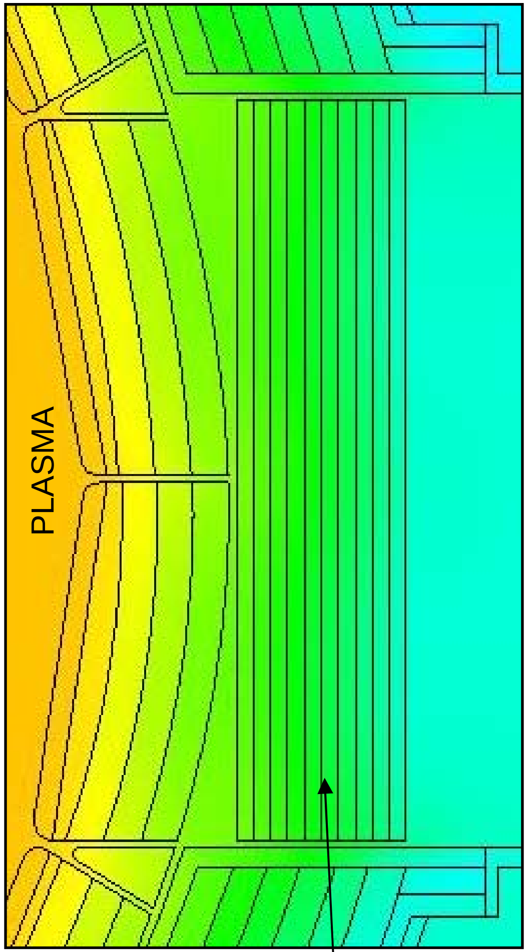
<u>Outboard Dome Surface Flux</u>
Attila: 11.2E+13
MCNP: 12.3E+13



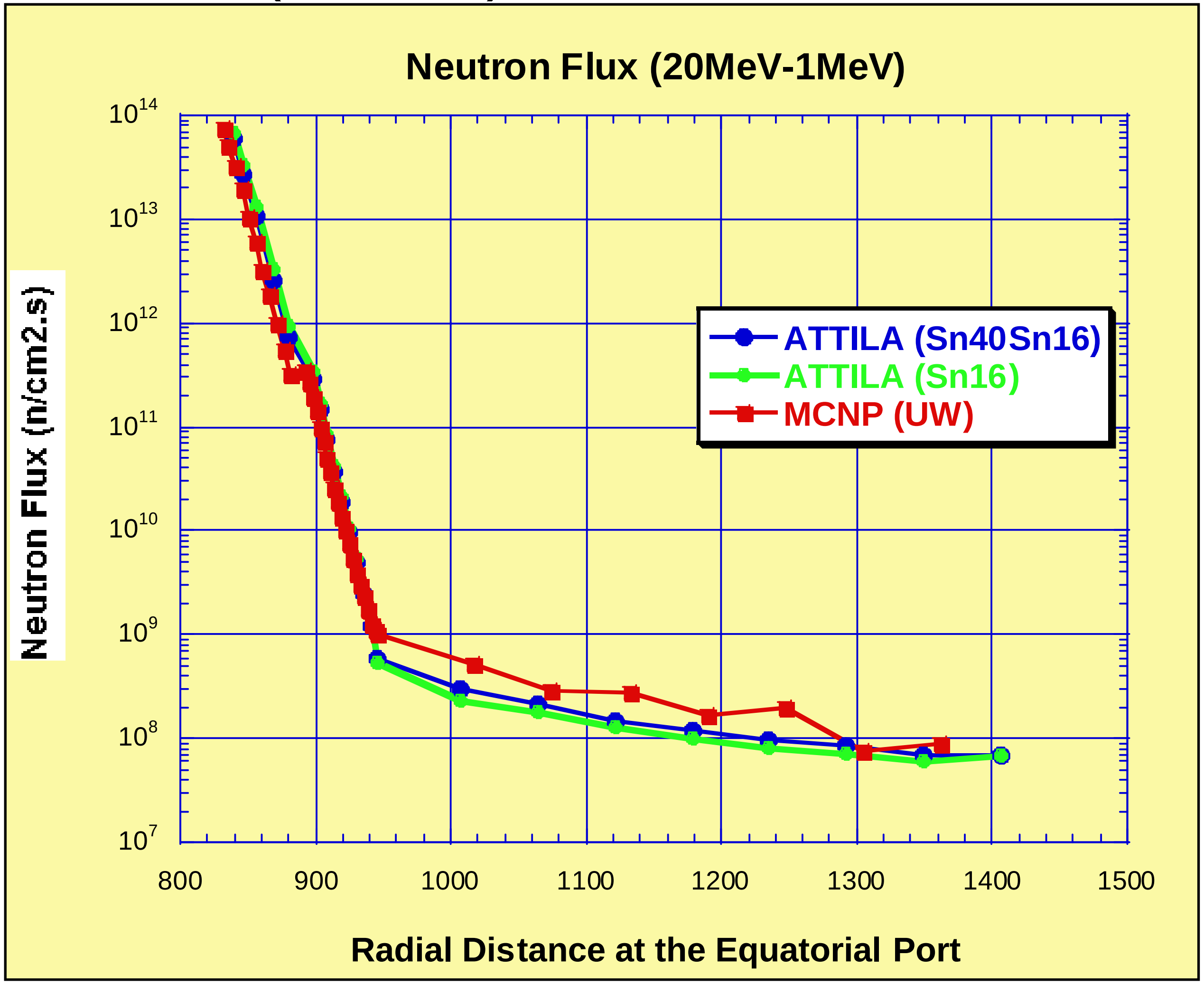


ITER Benchmark Results

Equatorial Port Neutron Flux (n/cm^2-s)

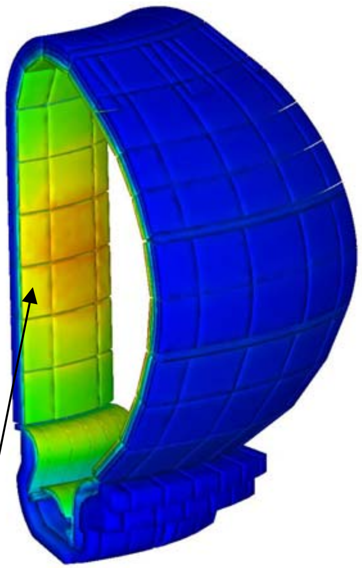


Equatorial Port
“Dummy” Plug Shielding

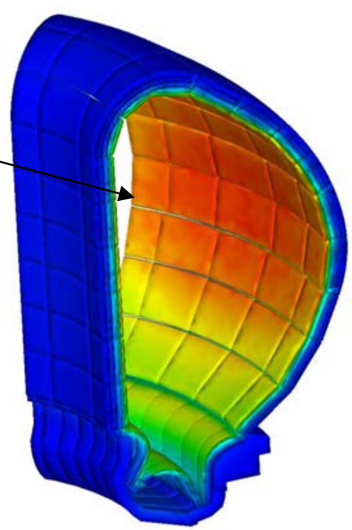


ITER Benchmark Results

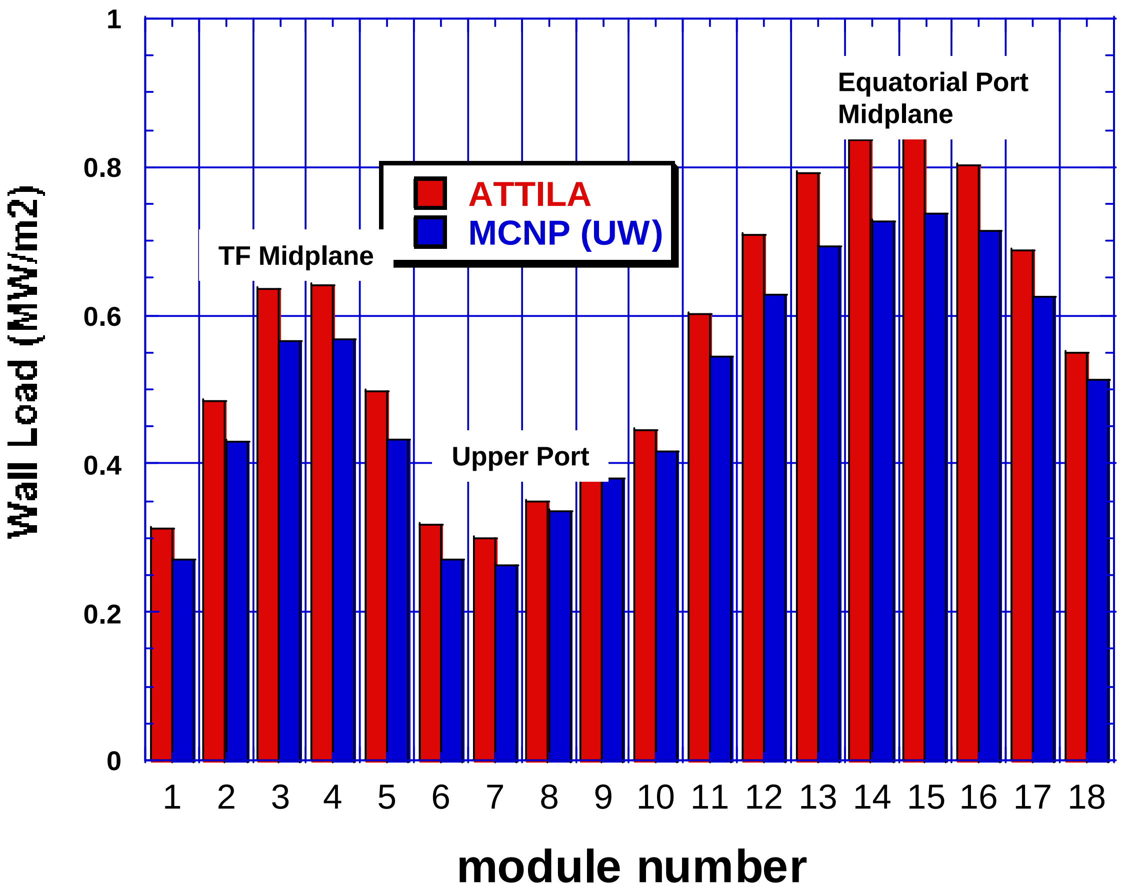
Boundary Condition Implementation Problems



Flux Not Uniform
In Toroidal Direction



Neutron Wall Loading (MW/m²)
Un-collided 14 MeV Neutrons



What's Next

ATTILA Capability Upgrades

Distributed Memory Parallel Processing

- Intended for production use in ITER applications
- Near linear scaling expected on up to 16-32 processors
- Parallel version will support periodic boundary conditions for arbitrary azimuthal segmentation
  - → Will be exact for 40 degree ITER

Activation Analysis

- A built-in activation capability is being added to Attila
- Activation module computes the activated source in every computational element
- Multiple pulse/decay cycle simulations can be performed

Boundary Source

- Global Model → Detailed Port Plug Models
- Economize Element Count and CPU Time
- Not Currently Under Development Because of DMP Upgrade

What's Next

Diagnostic Integration and Port Design Studies

1. Parametric Structures Study

    - Optimize Element Count for Port Plug Detail
    - What ITER Features Can We Not Model ?
      → Omit OH, TF and PF ?
      → Divertor Effect Equatorial or Upper Port Flux ?

- Baseline Port Plug Flux Model

    - How Far Behind Are We ?
    - Effect of Installation Gaps and Upper Port Water Supply Lines
    - ATTILA Activation Capability Evaluation

1. Upper Port Central Tube Analysis → Upper IR/VIS Diagnostic

2. Equatorial Port Studies

    → Integration Design Not Ready for Analysis