Benchmarking the CAD-based ATTILA Discrete Ordinates Code with Experimental Data of Fusion Experiments and to MCNP Results in Simulated ITER

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P. Wilson, M. Sawan, et al. , UW, USA (MCNPX-CGM CAD-based Results)

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Topics

- **Deterministic versus Monte Carlo methods in nuclear analysis:** ***Pros and Cons***
- **ATTILA code:**
  - ***Features and Capabilities***
- **Results of Benchmarking ATTILA** **(ATTILA has gone through validation procedures in order to be accepted as one of the design tools for ITER according to ITER QA procedures)**
  - **3 Fusion Integral Experiments** ***(comparison to experimental Data and MCNP Results)***
  - **ITER CAD-Model** ***(Comparison to MCNPX CGM CAD-based Results***
- **Conclusions**

Advantages and Disadvantages

Deterministic codes

Advantages:

- **Fluxes and responses are calculated everywhere. No need to redo separate runs if additional responses are needed.**
- **Shorter time to run a case compared to Monte Carlo methods.**

Disadvantages:

- **Large disc space is required to store angular flux**
- **Ray effect due to angular discretization**
- **Cross section should be shielded particularly in resonance regions**

Monte Carlo codes

Advantages:

- **Complex geometry can be modeled accurately. However, extensive effort is needed to generate the appropriate "geometry cards". This is why CAD-based versions are in progress.**

Disadvantages:

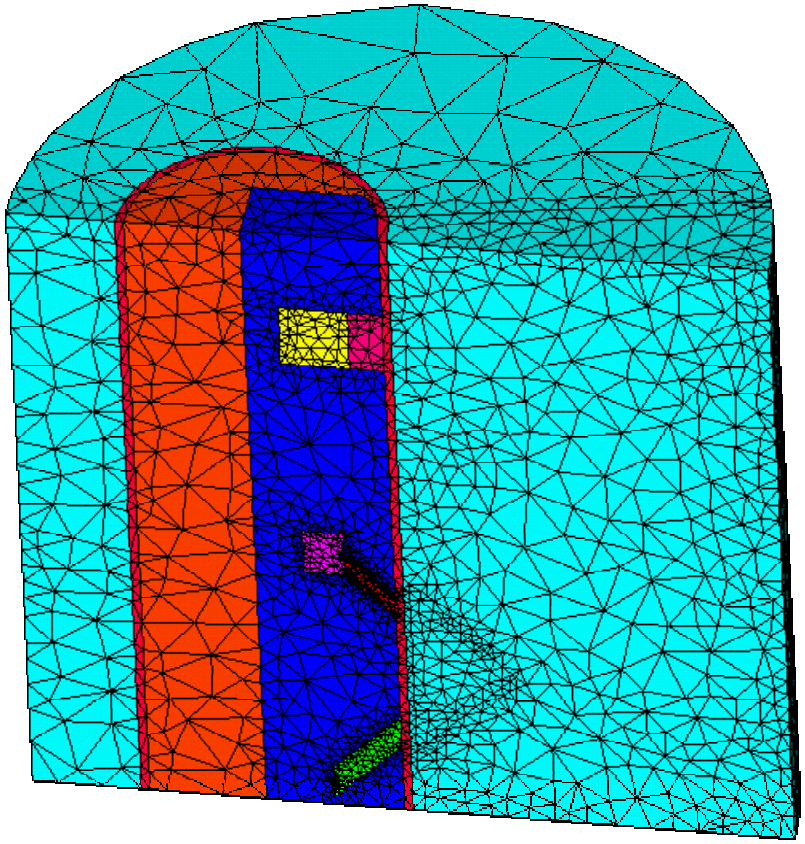
- **Fluxes and responses are calculated at pre-selected locations**

Visualization of the responses requires generating many tallies at various planes.

What is Attila?

- **A finite element discrete ordinates (Sn/Pn) neutron, gamma and charged particle transport code using 3D *unstructured grids (tetrahedral meshes)***
- **Geometry input from CAD (Solid Works, ProE)**
- **Complete visualization of the solution field *(e.g. Flux, current response function, etc.)***
- **Supplied by Transpire Inc.** , (Gig Harbor, WA, USA)

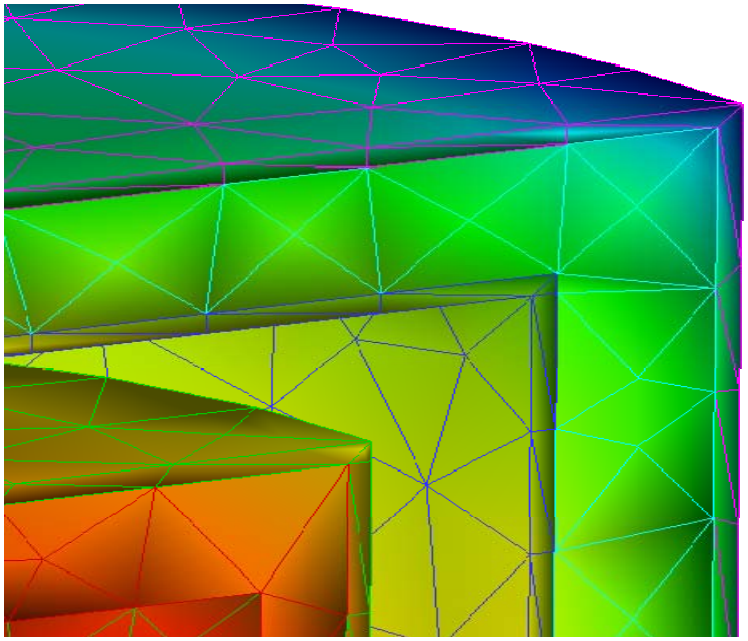
Spatial Discretization in ATTILA (Example)



Local element volumes can vary by more than 10^7 within a single model

High element anisotropy for directionally dependent resolution

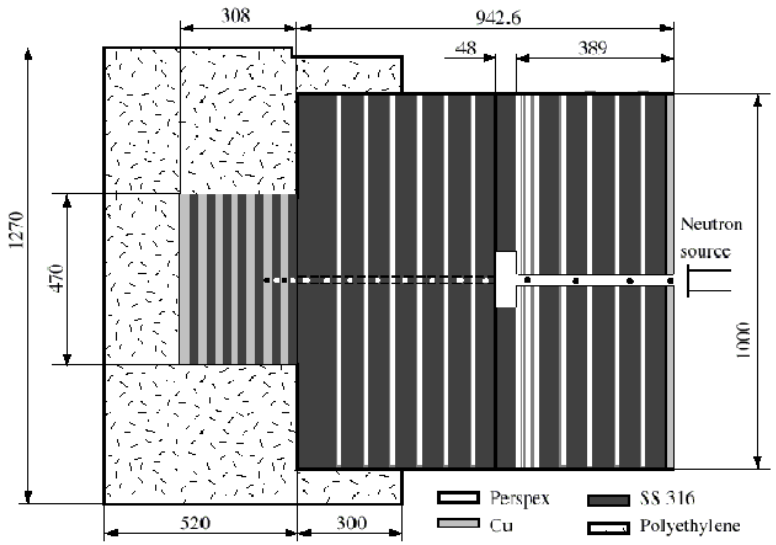
Use of layering techniques to control mesh size

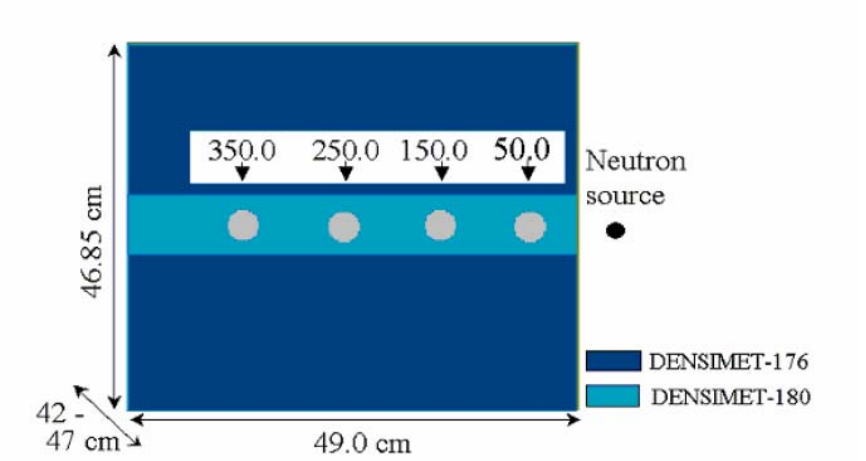


Some New Features (under testing)

- **Integrated Activation Capability**
  - **Extension of current Integrated depletion module (similar to ORIGEN) to include decay source terms**
- **Group-wise Adaptive S_N Order**
  - **For ITER, can run 14 MeV source bin at a high Sn order to transport the primary flux**
- **Distributed Memory Parallel**
  - **Linear scaling achieved on test version up to 256 processors**
  - **A primary motivation is to distribute memory resources**

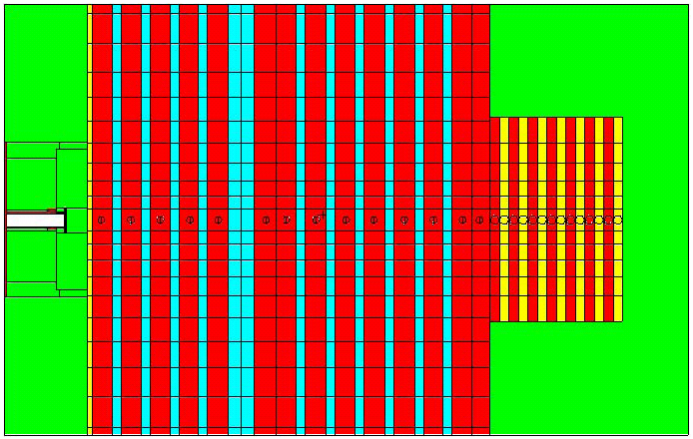
Benchmarks Experiments (FNG Facility)





Tungsten Experiment

Streaming Experiment



Bulk Shielding Experiment

Experiments performed at the FNG facility, ENEA, Frascati Italy

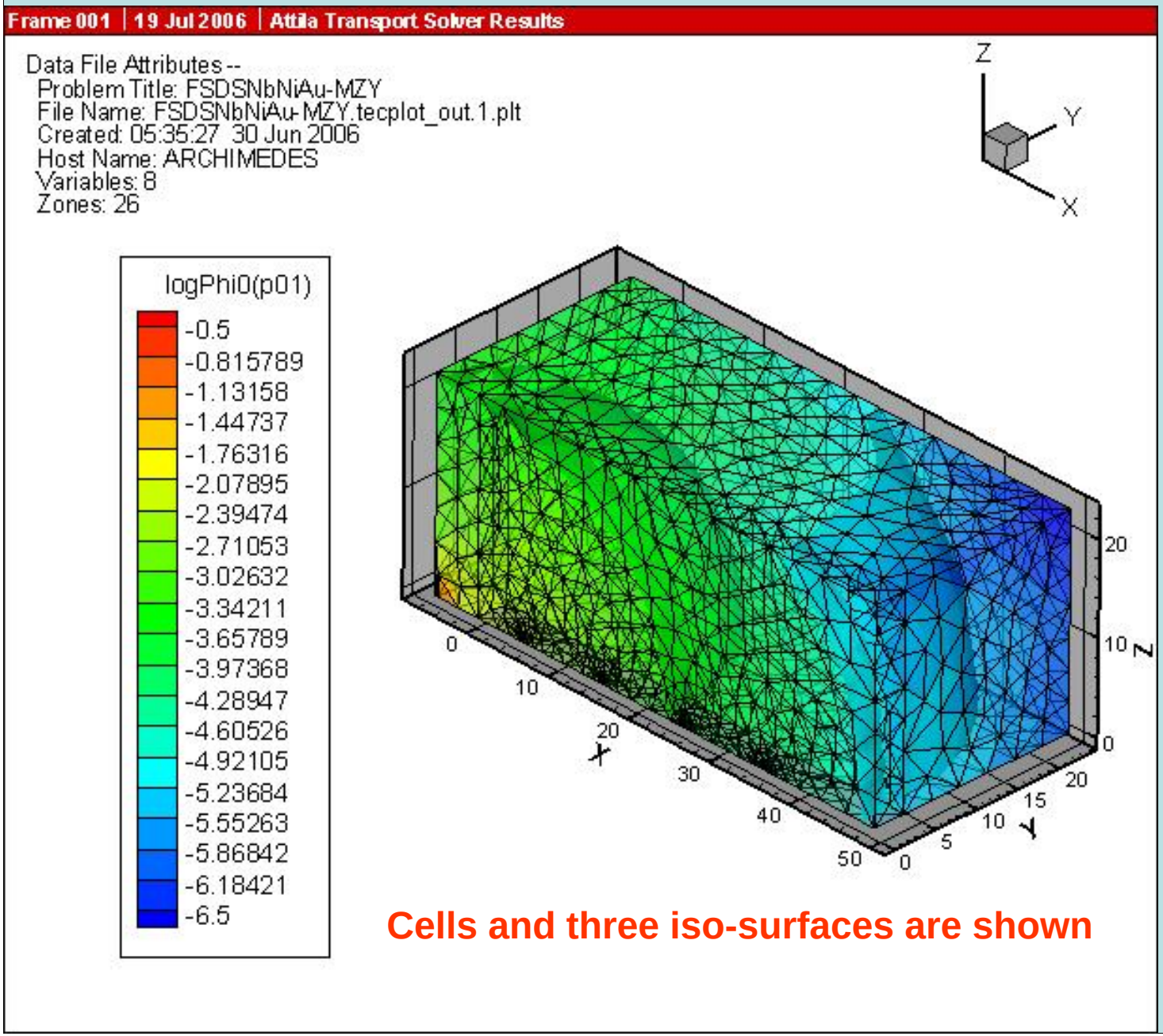
Measurements of many reactions rates

Measured Reactions

• Zr-90(n,2n)Zr-89,	Eth~12 MeV
• Ni-58(n,2n)Ni-57,	Eth~12 MeV
• Nb-93(n,2n)Nb-92,	Eth~ 9 MeV
• Al-27(n,a)Na-24,	Eth~ 5 MeV
• Fe-56(n,p)Mn-56,	Eth~ 3 MeV
• Ni-58(n,p)Co-58,	Eth~ 0.5 MeV
• In115(n,n'),	Eth~ 0.2 MeV
• Au197(n,g),	All energies

The accuracy in predicting these reactions is a good measure of how well the neutron spectrum and energy-dependent reactions rates are predicted.

Tungsten Experiment (Attila's Model and Calculation)



Cells and three iso-surfaces are shown

Calculations:

Quadrature:

S12

XS Scattering:

P3

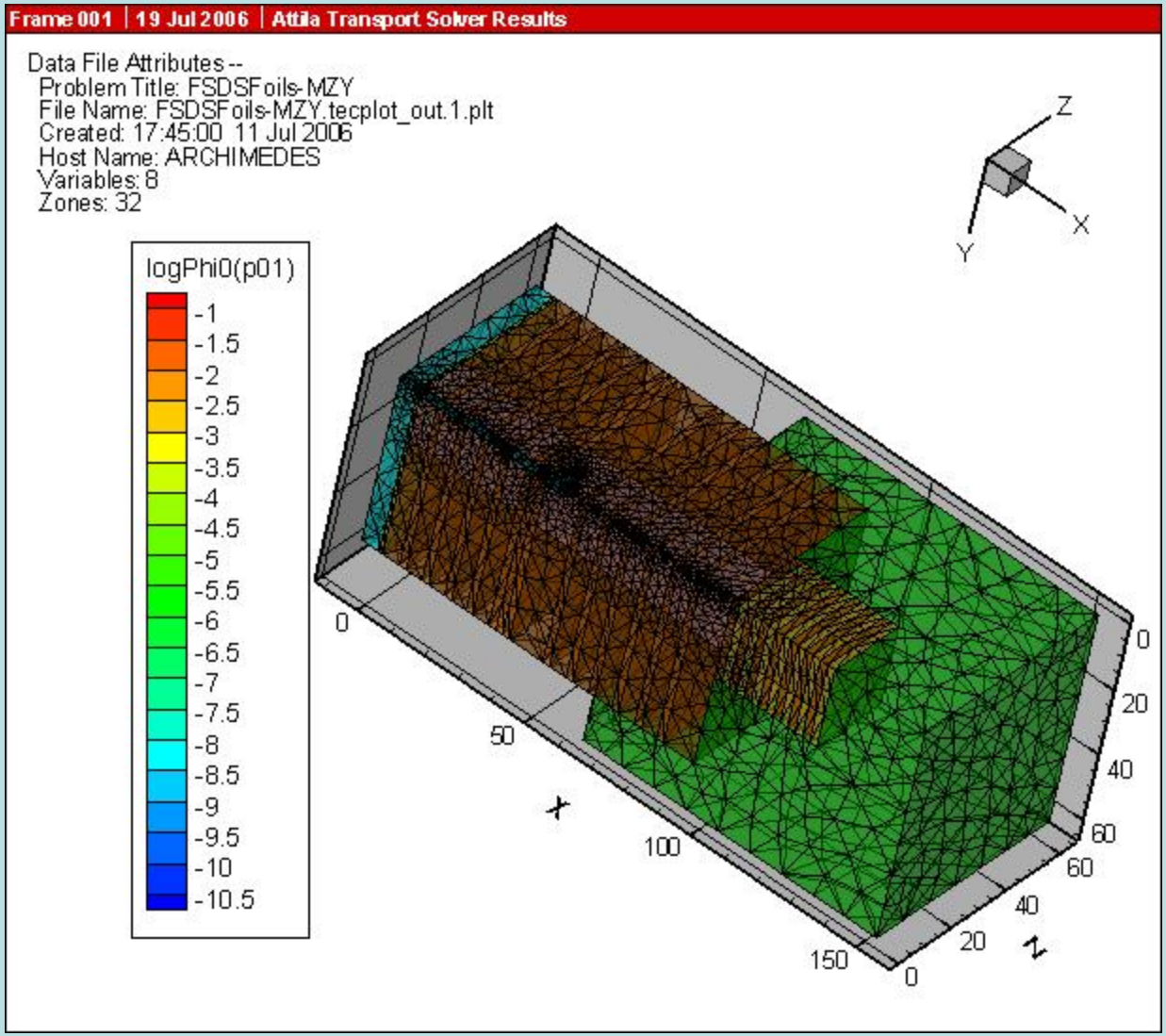
Number of Cells:

14681 cells for Nb, Ni, Au, Fe, In Foils

19398 cells

For Zr, Al, Mn foils

The Streaming Experiment (Attila's Model and Calculation)



Calculations:

Quadrature:

S16 (Gold),S18

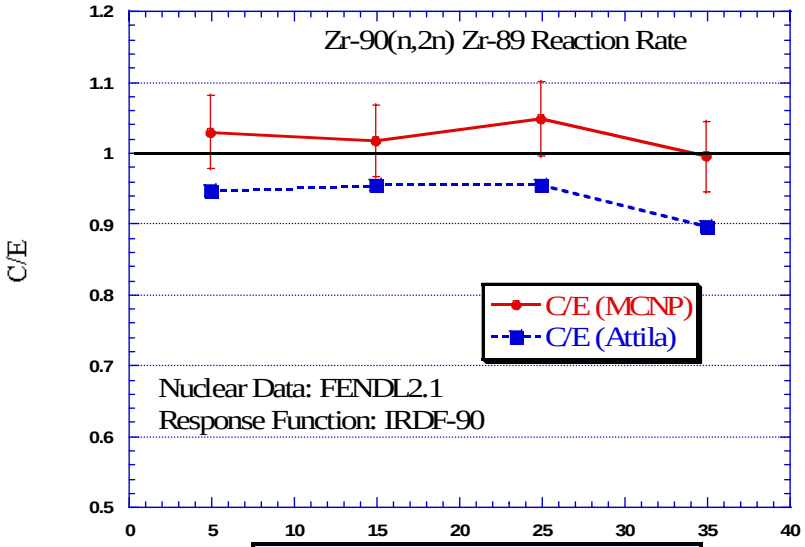
XS Scattering:

P4 (Gold), P5

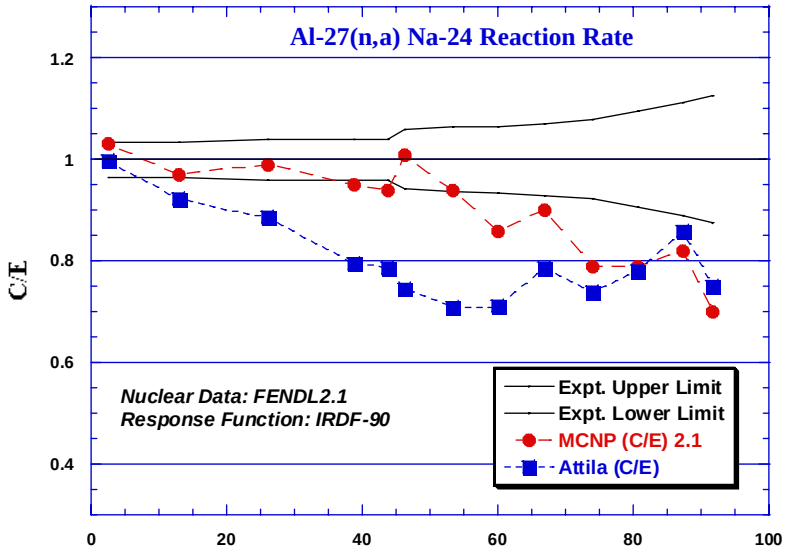
34,147 cells

for all foils except gold (32,217 cells)

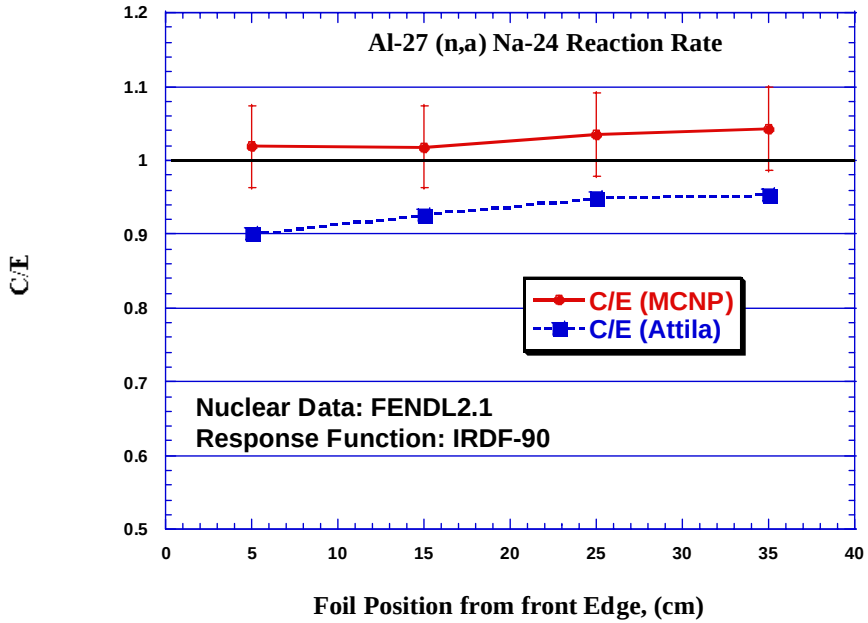
Examples of Calculated/Experimental (C/E) values

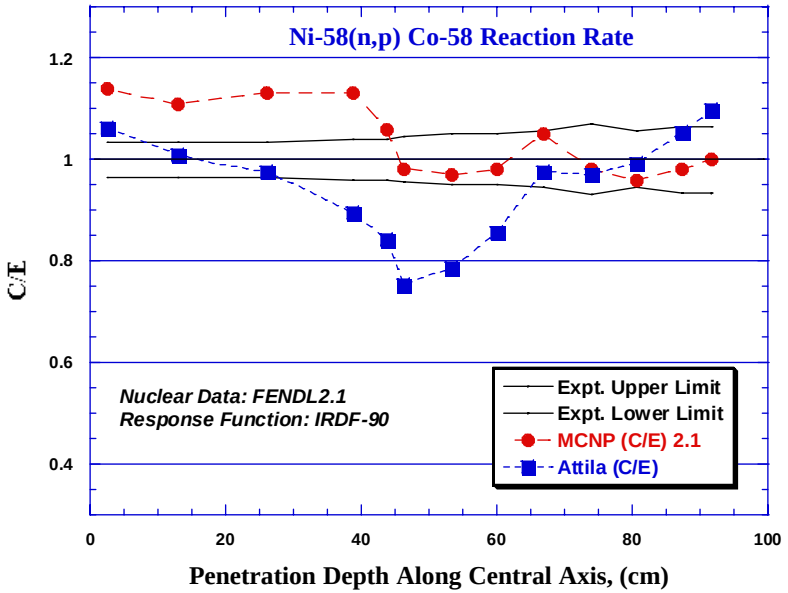


Tungsten Expt.



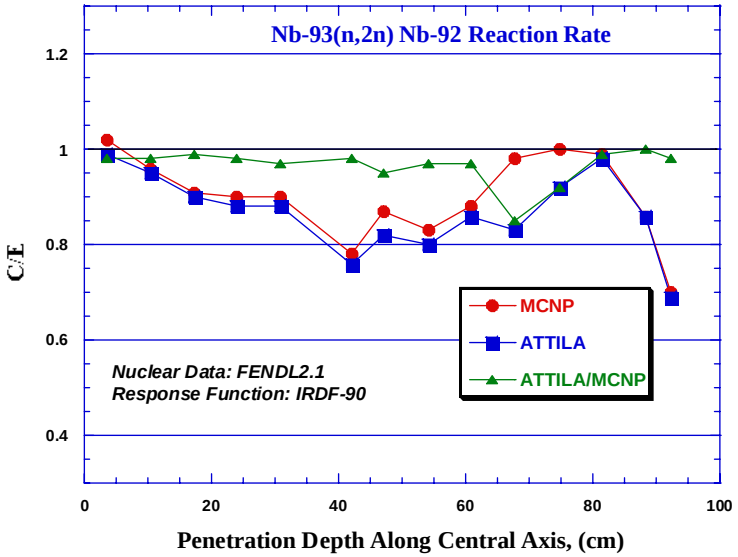
Streaming Expt.

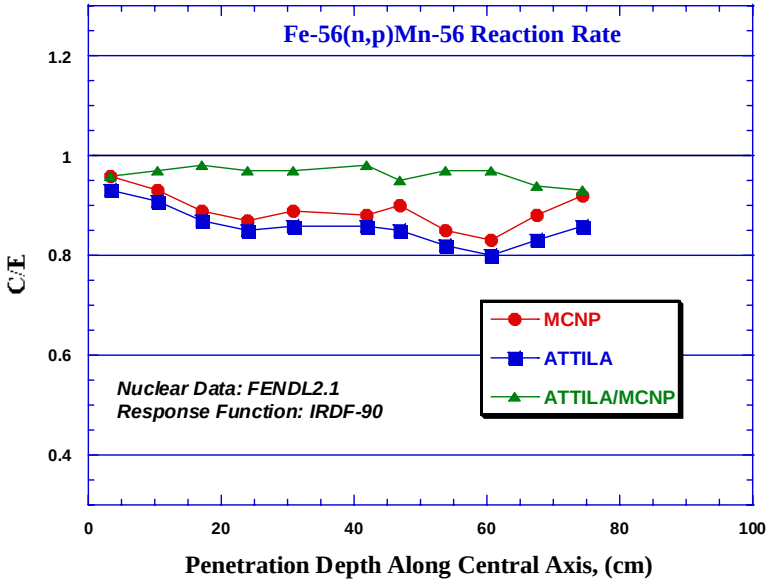


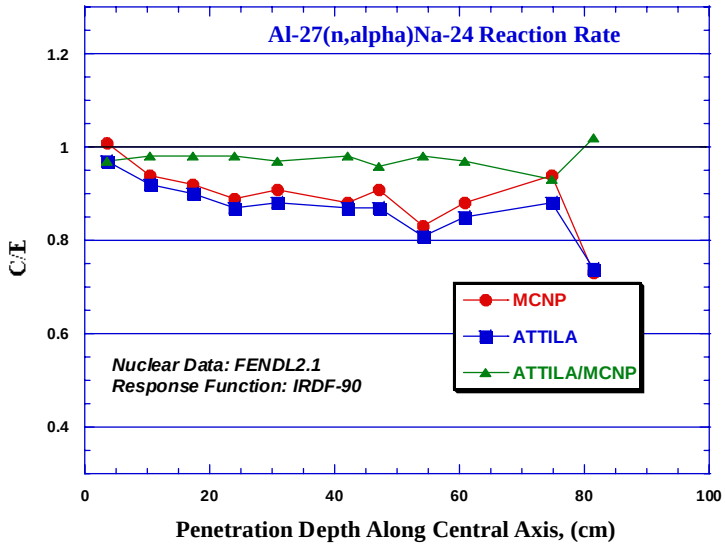


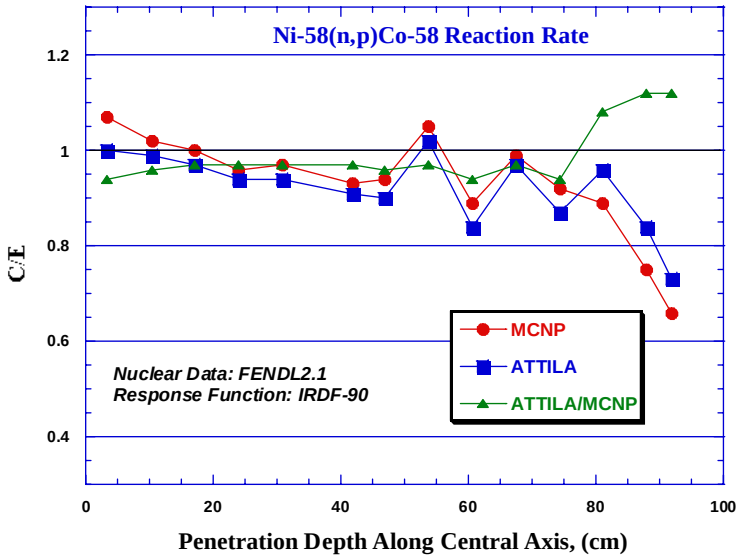
Examples of Calculated/Experimental (C/E) values

Bulk Shield Experiment









Average Estimates for the C/E Values and Deviation from Experiment

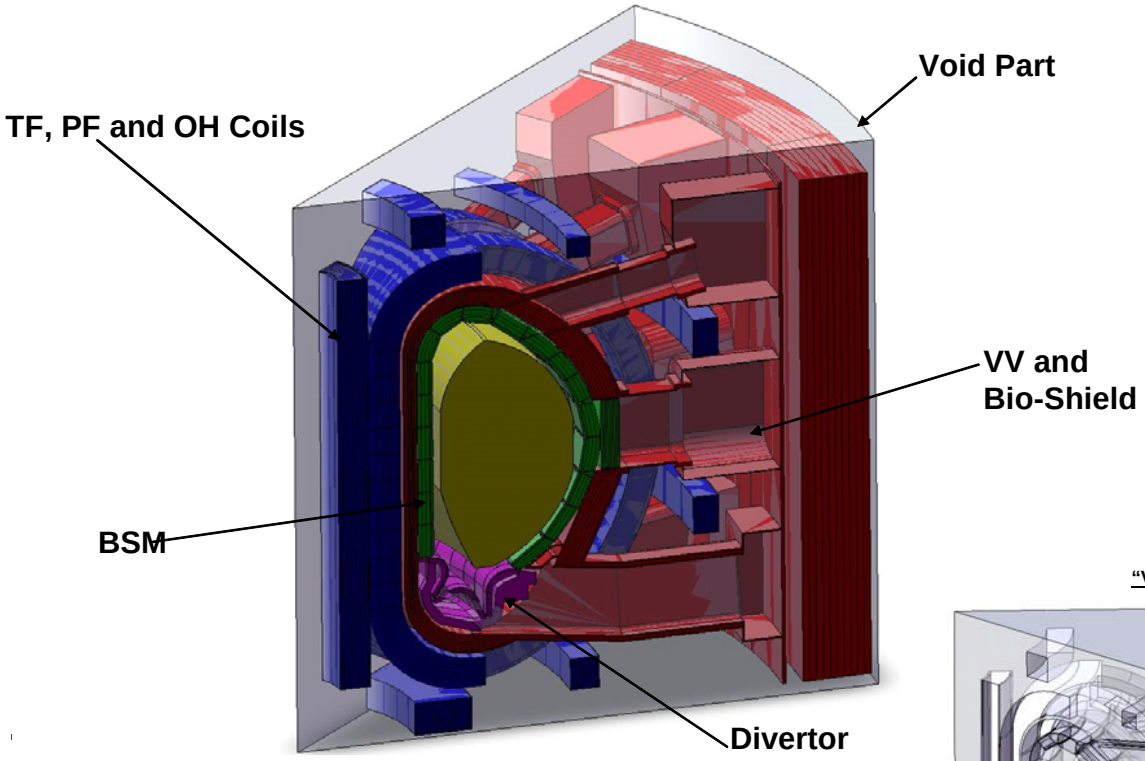
Reaction	Calculation Method	Experiment			
		Tungsten	Streaming		Bulk Shield
			Channel	Cavity	
Zr-90(n,2n)Zr-89	*MCNP*	*2%*			
	Attila	*-6%*			
Ni-58(n,2n)Ni-57	*MCNP*	*-1%*			
	Attila	*-6%*			
Nb-93(n,2n)Nb-92	*MCNP*	*1%*	*-4%*	*-6%*	*-10%*
	Attila	*-9%*	*-13%*	*-10%*	*-13%*
Al-27(n,a)Na-24	*MCNP*	*3%*	*-10%*	*-7%*	*-11%*
	Attila	*-7%*	*-20%*	*-11%*	*-13%*
Fe-56(n,p)Mn-56	*MCNP*	*-4%*			*-11%*
	Attila	*-14%*			*-14%*
Ni-58(n,p)Co-58	*MCNP*	*6%*	*4%*	*3%*	*-7%*
	Attila	*-4%*	*-6%*	*-3%*	*-8%*
In-115(n,n')In-115m	*MCNP*	*-6%*			*-23%*
	Attila	*-18%*			*-25%*
Au-197(n,g)Au-198	*MCNP*	*-1%*	*3%*	*7%*	
	Attila	*-10%*	*9%*	*10%*	

Largest Deviation From Expt. Data

ATTILA: ~-25%, MCNP: ~-23%

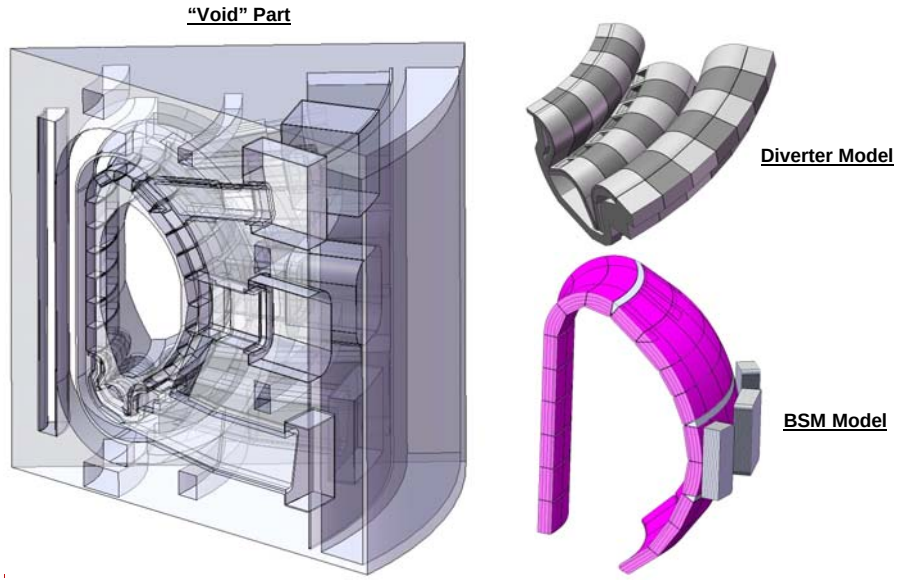
Largest Between ATTILA and MCNP ~ -12%

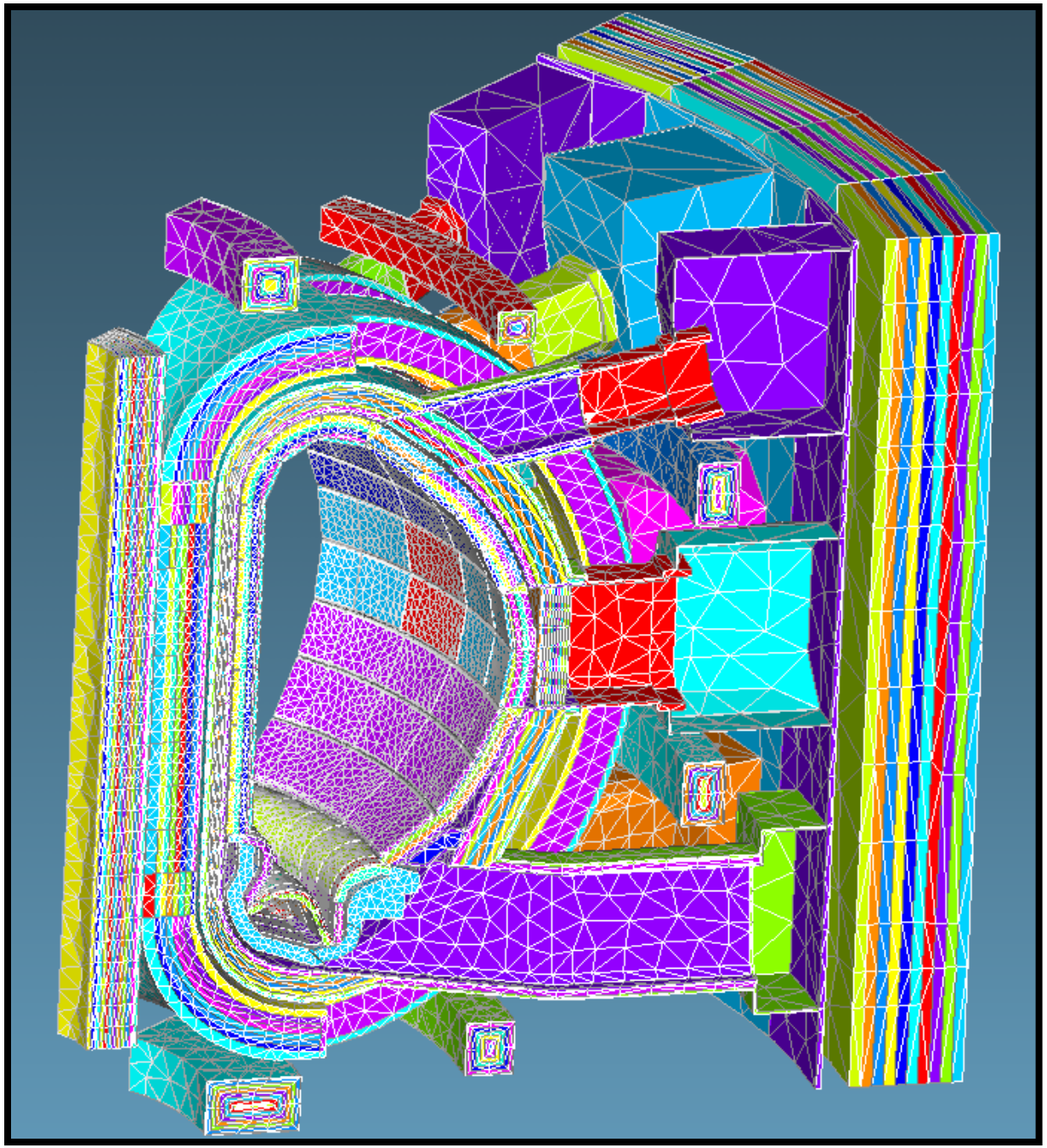
Benchmarking ATTILA with the ITER CAD-Model and Comparison to MCNP Results



The Blanket Shield Modules (BSM) and divertor CAD model integrated in the 40-degree CAD model

The 40-degree Solid Works CAD model of ITER

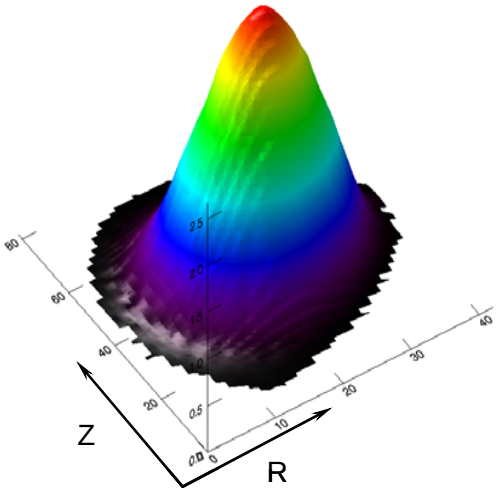




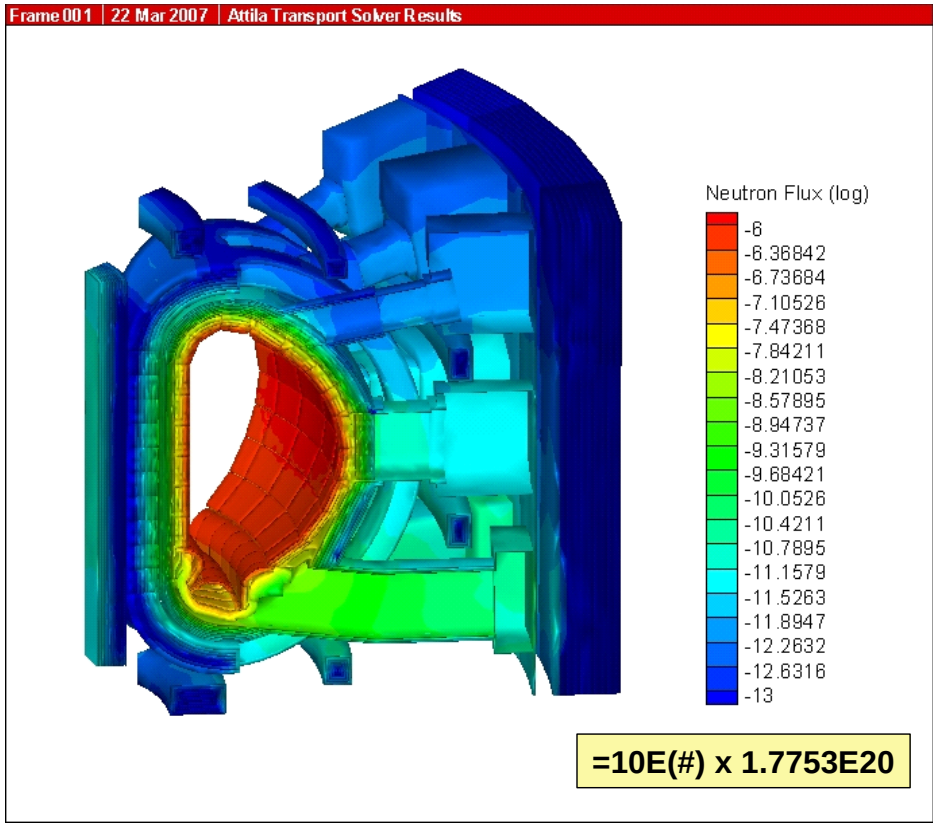
Mesh Scheme used in the calculation:

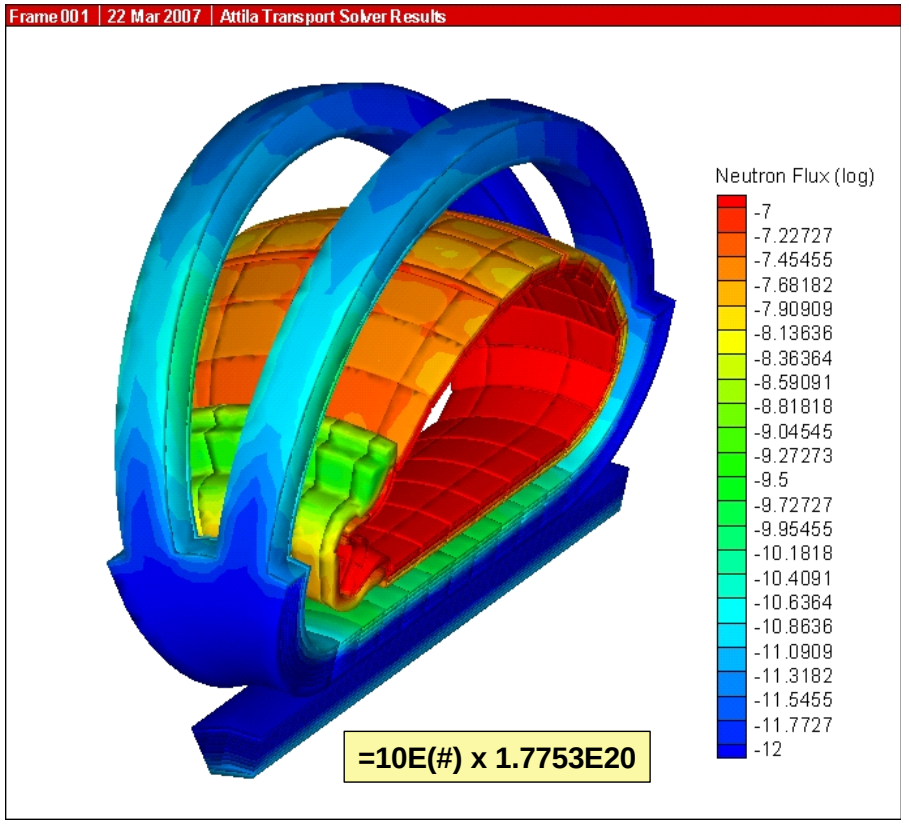
~500,000 mesh

Layering techniques is used to reduce mesh counts

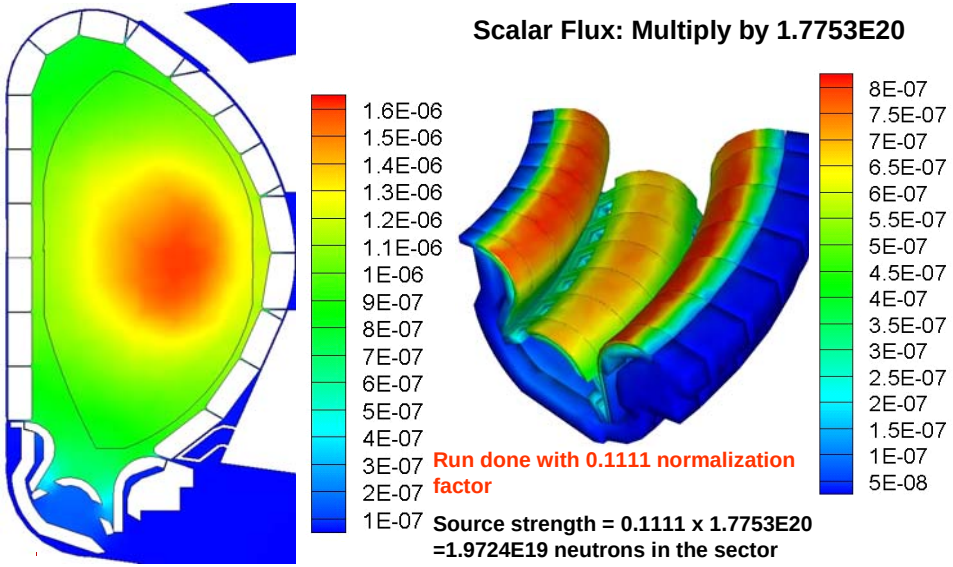


D-T plasma Source and its Strength





Scalar Flux: Multiply by 1.7753E20



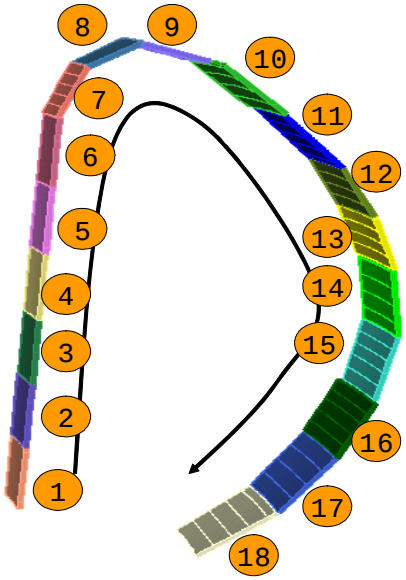
Run done with 0.1111 normalization factor

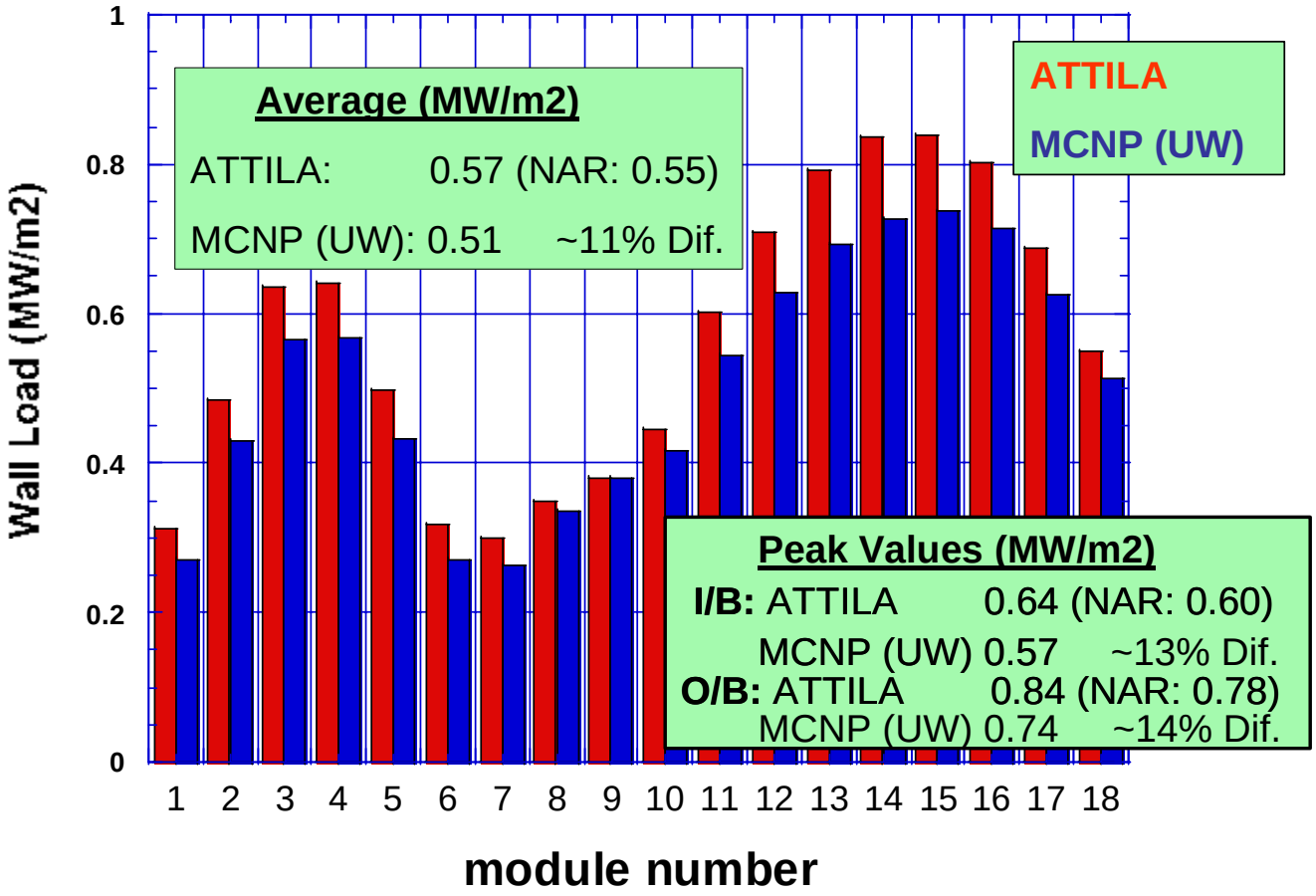
Source strength = 0.1111 x 1.7753E20 =1.9724E19 neutrons in the sector

- **Neutron Flux (solution) can be visualized at any location or at any plane**
- **Hot spots can be identified- Modification in the design can be altered to minimizes these spots**

Comparison to MCNPX-CGM CAD-Based Results (UW)

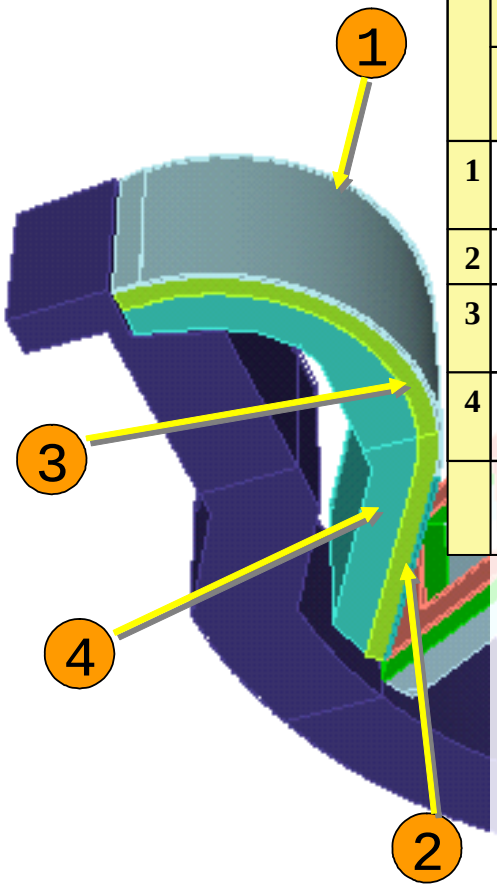
Neutron Wall Loading (NWL) at First Wall





Comparison to MCNPX-CGM CAD-Based Results (UW)

Neutron Flux and Total Heating in the Inboard Target Part of the Divertor Segment

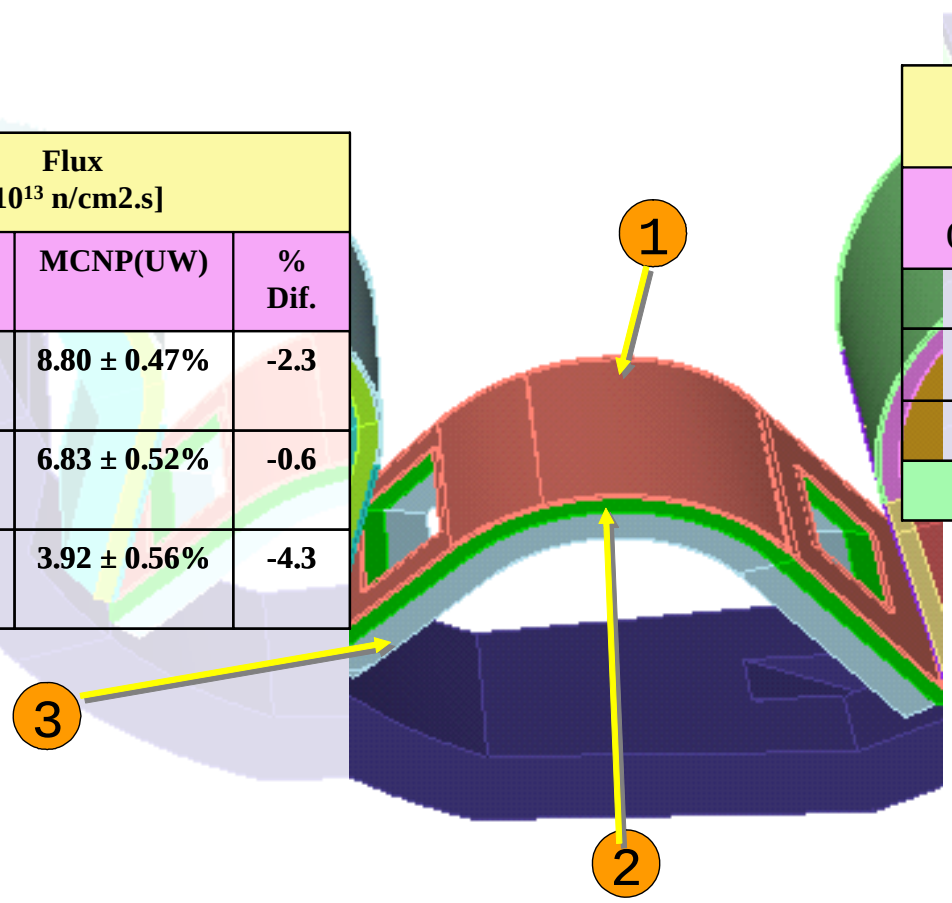


	Flux [10^{13} n/cm2.s]			Heating (n+g) [kW]		
	ATTILA (Sn40Sn16)	MCNP(UW)	% Dif.	ATTILA (Sn40Sn16)	MCNP(UW)	% Dif.
1	12.1	10.4 ± 0.56%	16.13	45.4	40.4 ± 0.3	12.4
2	6.06	5.88 ± 1.1%	3.1	1.94	1.6 ± 0.03	21.2
3	7.56	6.83 ± 0.58%	10.6	90.6	79.2 ± 0.6	14.4
4	3.61	3.17 ± 0.70%	14.0	101.4	85.3 ± 0.8	18.9
			TOT.	239.34	207±1.0	15.6

Comparison to MCNPX-CGM CAD-Based Results (UW)

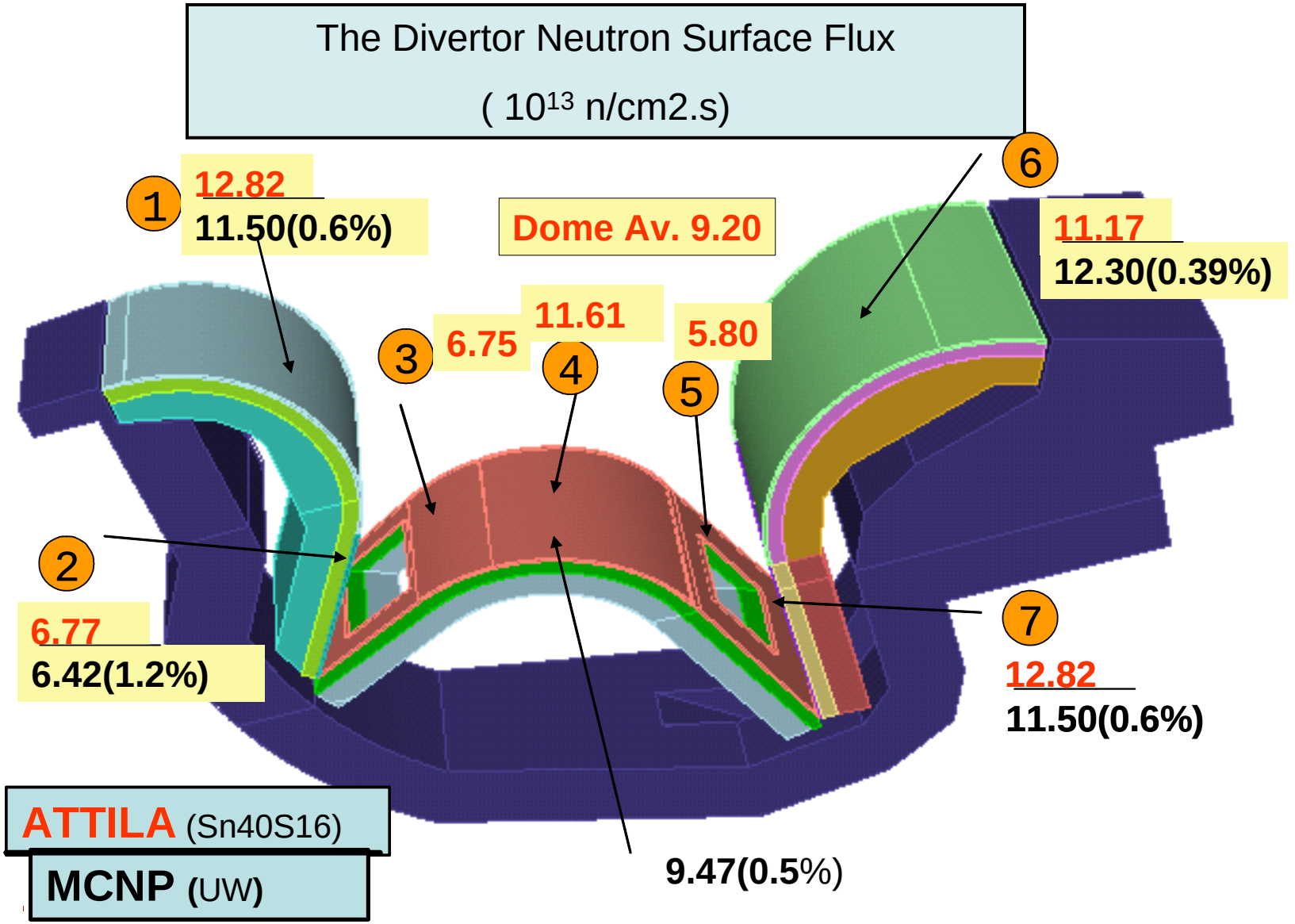
Neutron Flux and Total Heating in the Central Dome Part of the Divertor Segment

	Flux [10^{13} n/cm2.s]		
	ATTILA (Sn40Sn16)	MCNP(UW)	% Dif.
1	8.60	8.80 ± 0.47%	-2.3
2	6.79	6.83 ± 0.52%	-0.6
3	3.75	3.92 ± 0.56%	-4.3



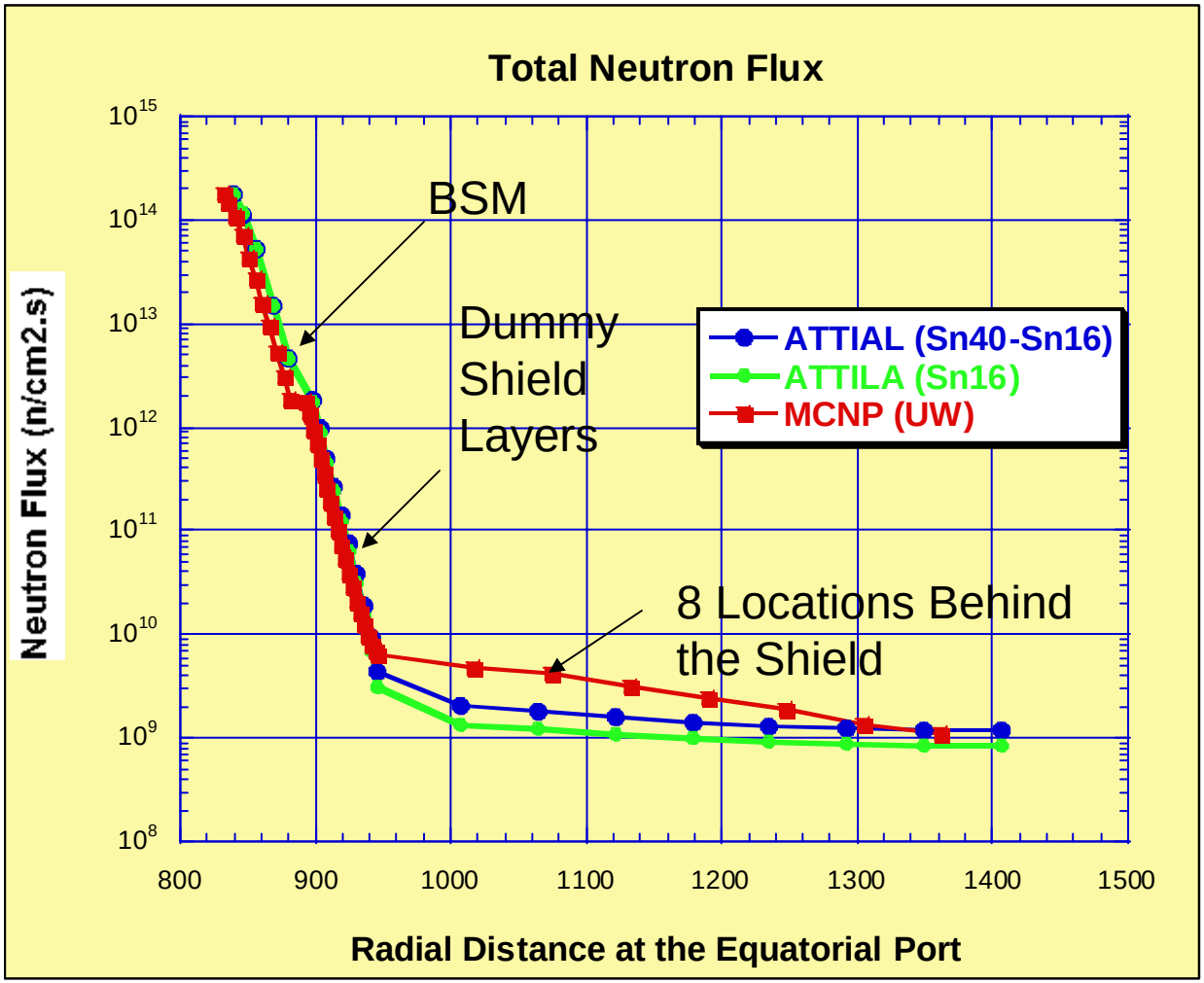
Heating (n+g) [kW]		
ATTILA (Sn40Sn16)	MCNP(UW)	% Dif.
52	58.1 ± 0.4	-9.8
102	100 ± 0.7	2.1
114	110 ± 0.8	4.0
268	268 ± 1.1	~0

Comparison to MCNPX-CGM CAD-Based Results (UW)



Comparison to MCNPX-CGM CAD-Based Results (UW)

Total Neutron Flux in the Dummy Blanket Shield Modules (BSM) and the Dummy Shield Layers Placed at the Equatorial Port)



Conclusions of Benchmarking

Integral Experiments:

Maximum Deviation from Experimental Values: ATTILA: ~-25%, MCNP: ~-23%. Max. Difference between ATTILA and MCNP ~ -12%

ITER CAD Model (Difference between ATTILA and MCNP):

- Neuron Wall Load: Max. ~15%
- Divertor neutron flux: Max. ~14%, Total Nuclear Heating: ~ 15%
- BSM and Shield at Equatorial port: ~ 5%
- Large difference at deep locations behind shield(~30%)

Based on these marginal differences ATTILA has been accepted as a supportive 3-D design tool for ITER

In Progress

- **Using ATTILA for Designing the Diagnostics Ports in ITER**
- **Benchmarking ATTILA for Activation and Dose Calculations**