LA-UR-10-05816

MCNP6 V&V Of Some Unstructured Mesh Models:

Summer Student Slides

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ABSTRACT:

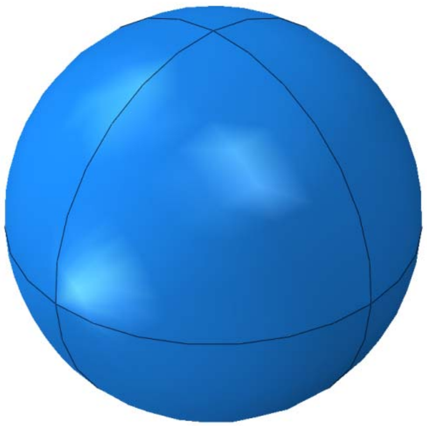
A new capability available in MCNP6 allows for the transport of neutrons and photons on unstructured mesh geometries created with Abaqus/CAE. Analysis of several benchmark-type problems will assist in the verification and validation process of this new capability. Three benchmark models were chosen to be studied: (1) the Osaka nickel sphere with a D-T neutron source, (2) a reactor pipe and shielding with an N-16 gamma source, and (3) the FNS vanadium cube assembly irradiated with a D-T neutron source. Solid models for each problem were constructed with Abaqus/CAE and the unstructured mesh representation of each was embedded as a mesh universe within a Constructive Solid Geometry (CSG) background. Parameter studies were performed for each model involving changes in type, order, and number of elements composing the mesh. The models were meshed with hexahedrons or tetrahedrons of either first or second order. The mesh seed size was also varied to increase or decrease the number of elements. Results from the unstructured mesh models were analyzed and compared to those obtained from the equivalent CSG models. Differences in computer run time and accuracy in volume calculations are important factors when considering the viability of this new option. It is known that computer run time increases proportionally with the number of elements in the mesh. Therefore, it is desirable to mesh models with the least number of elements as possible without compromising the accuracy of the volume calculations and consequently the results.

Objective: V&V

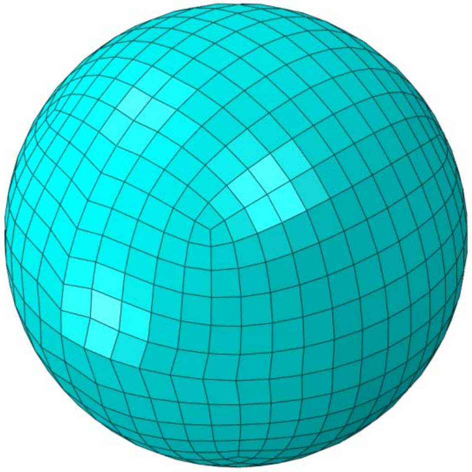
- **V&V of MCNP6's new capability of particle transport on unstructured mesh**
- **Build unstructured mesh geometries using Abaqus CAE**
- **Create MCNP input files with embedded mesh universe**
- **Run problems in MCNP6**
- **Analyze results**
  - **Volume accuracy**
  - **Computer runtime**
  - **Tallies**

Abaqus CAE

- **Computer Aided Engineering Software**
- **Use to build models**
  - **Easy to create complex geometries**
  - **Improves visualization**
    - 3D vs. 2D



- **Mesh**
  - **4, 5, and 6 sided elements**
  - **1^{st} and 2^{nd} order**

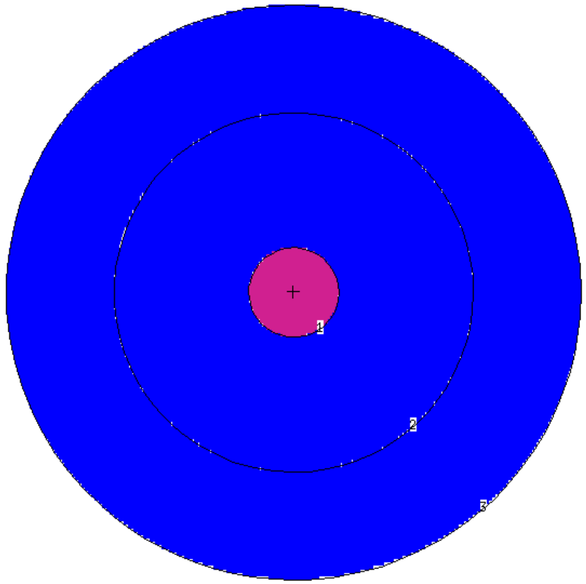


Benchmark-type Problems

- **Osaka nickel sphere**
- **Reactor pipe with shielding**
- **FNS vanadium cube assembly**
- **Reason for choosing:**
  - **Simple**
  - **Run quickly**
  - **Established benchmarks**
    - Published results

Osaka Nickel Sphere

- **Nickel sphere**
  - **Void in center**
- **Original model has 3 shells**
  - **Radii- 2.5, 10, 16 cm**
- **D-T neutron source at origin**



Osaka Mesh Models

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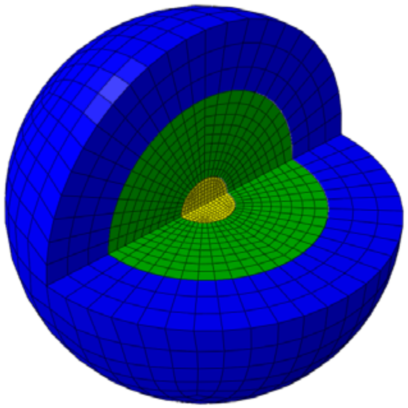
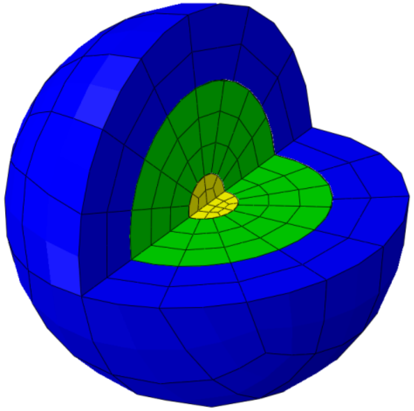
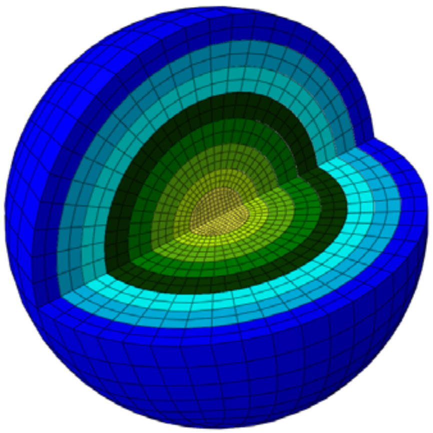
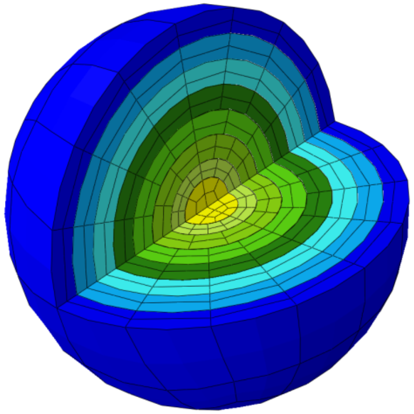
- **3 shell**
  - **1st order hex- 1%, 0.5%, 0.1% (within actual volume)**
  - **2nd order hex- 1%**





- **8 shell**
  - **1st order hex- 1 %**
  - **2nd order hex- 1%**





Osaka Sphere Comparisons

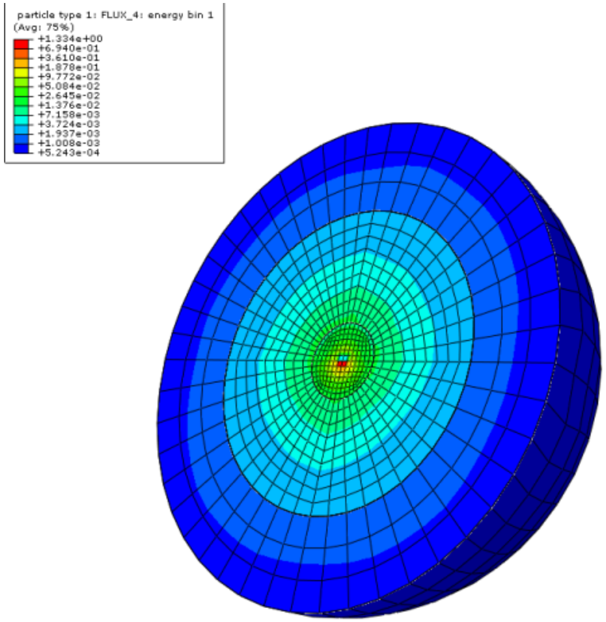
Model Name	Abaqus Mesh Volume (calc. by MCNP)	% Difference from Actual Volume	# Elements	Computer Runtime (minutes)
3shell CSG	N/A	N/A	N/A	11.7
3 shell 1 hex~ 0.1%	17,138.82	0.108	273,816	*17,280.4**
3 shell 1 hex~ 0.5%	17,077.71	0.466	29,000	1,807.9
3 shell 1 hex~ 1%	17,013.54	0.844	12,040	783.5
3 shell 2 hex~ 1%	17,122.34	0.204	488	N/A
8 shell CSG	N/A	N/A	N/A	15.7
8 shell 1 hex~ 1%	17,030.71	0.743	16,618	5,219.7
8 shell 2 hex~ 1%	17,134.44	0.133	1,256	N/A

*Actual Volume = 17,157.28

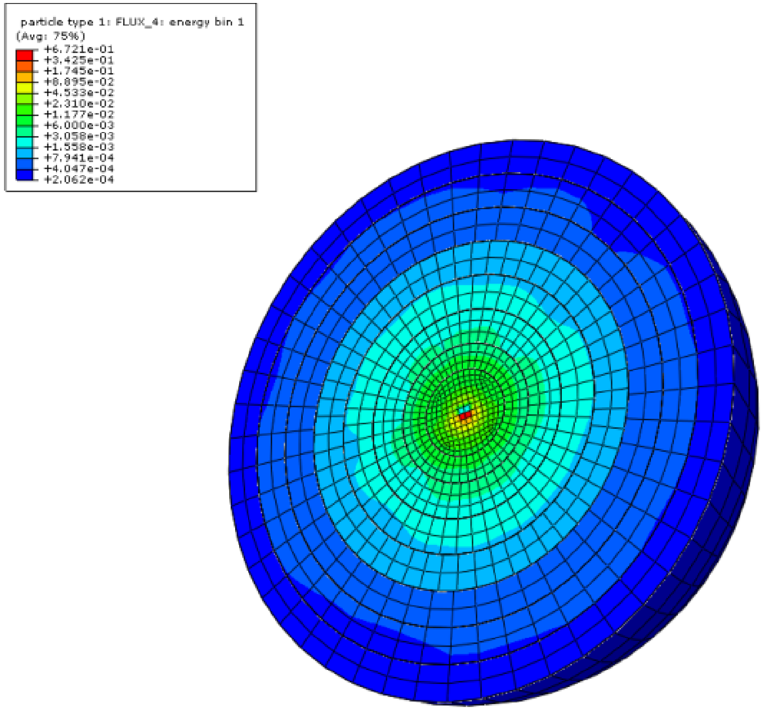
**Run on un-optimized code

Osaka Neutron Flux

3 Shell



8 Shell



Osaka Neutron Flux

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3 Shell Model - CSG vs. Mesh

Cell	Flux (neutrons/cm^2)	Statistical Error	%Difference from CSG
Void Center- CSG	4.42E-2	0.03%	N/A
Void Center- 1% mesh	4.35 E-2	0.02%	1.6%
Inner Ni shell- CSG	4.09E-3	0.06%	N/A
Inner Ni shell- 1% mesh	3.45 E-3	0.06%	15.6%
Outer Ni shell- CSG	9.68E-4	0.06%	N/A
Outer Ni shell- 1% mesh	9.57 E-4	0.06%	1.2%

Osaka Neutron Flux

3 Shell vs. 8 Shell CSG

Cell	Flux (neutrons/cm^2)	Statistical Error
3 shell- 1	4.42 E-2	0.03%
8 shell- 10	4.42 E-2	0.03%
3 shell- 2	4.09 E-3	0.06%
8 shell- 20,21,22,23	4.07 E-3	0.07%
3 shell- 3	9.68 E-4	0.06%
8 shell- 30, 31,32	9.68 E-4	0.06%

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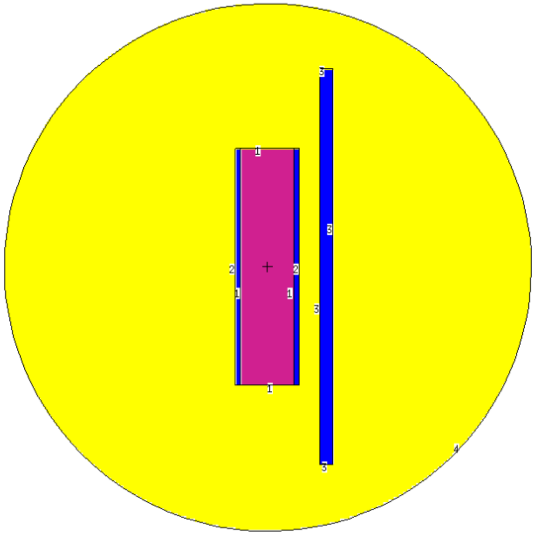
3 Shell vs. 8 Shell Mesh

Cell	Flux (neutrons/cm^2)	Statistical Error
3 shell- 1	4.35 E-2	0.02%
8 shell- 10	4.36 E-2	0.02%
3 shell- 2	3.45 E-3	0.06%
8 shell- 20,21,22,23	3.32E-3	0.05%
3 shell- 3	9.57 E-4	0.06%
8 shell- 30,31,32	7.78 E-4	0.06%

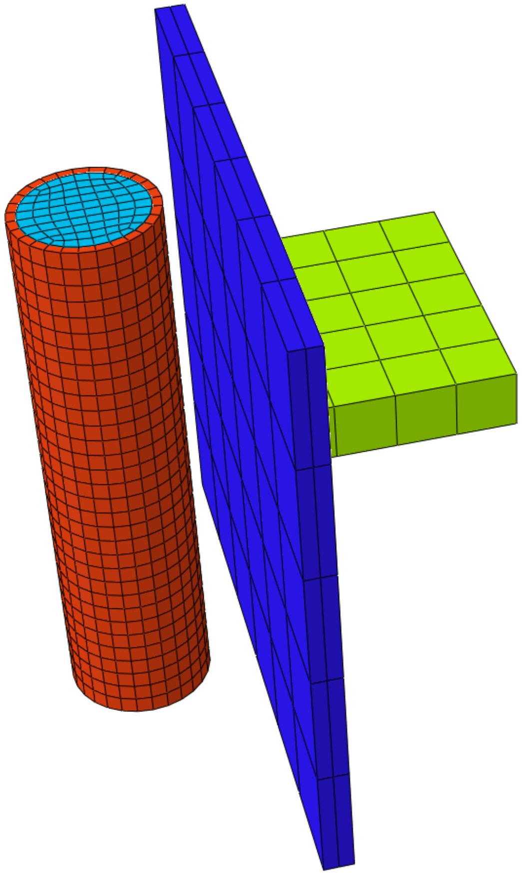
Reactor Pipe and Shielding

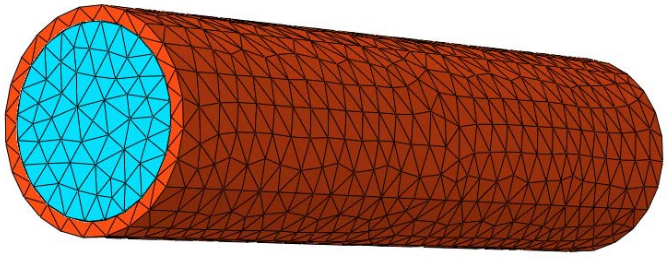
- **Steel Pipe w/ water**
  - **h= 91.4cm r=10.15 cm**
- **Steel Wall**
  - **Thickness= 5cm**
- **N-16 gamma source**
  - **Isotropic, volumetric**
- **Point Detectors**
  - **Inline**
  - **Offline – offset 40 cm from pipe center**



Reactor Pipe Mesh Models

- **1st order hex**
  - **Small, medium, large**
- **Pipe and Water 1st order tet**
  - **Medium**
- **Block behind wall**
  - **Point detectors not currently working with mesh models**
  - **Area where point detectors will be**





Reactor Pipe Comparisons

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Model Name	Abaqus Mesh Volume (calc. by MCNP)	% Difference from Actual Volume	#Elements	Computer Runtime (minutes)
RP CSG	N/A	N/A	N/A	162.2
RP 1 hex - small	109,442.5	0.184	9,184	3,521.8
RP 1 hex - medium	109,311.6	0.304	3,864	1,601.1
RP 1 hex - large	107,856.8	1.65	524	547.1
RP 1 hex & tet-medium	109,197.3	0.408	17,699	N/A

*Actual Volume= 109,643.4

Flux in Reactor Pipe and Shielding

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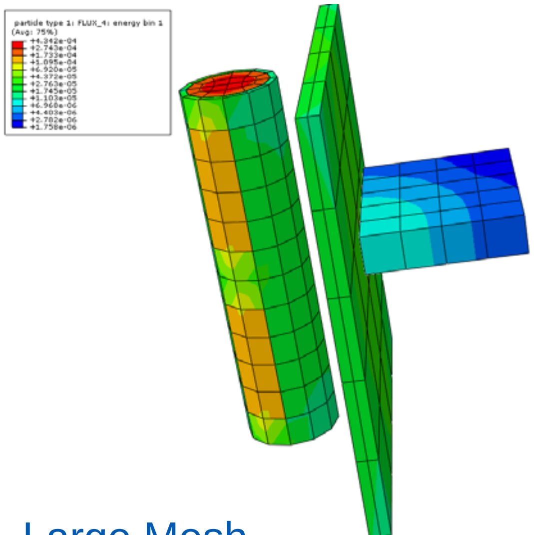
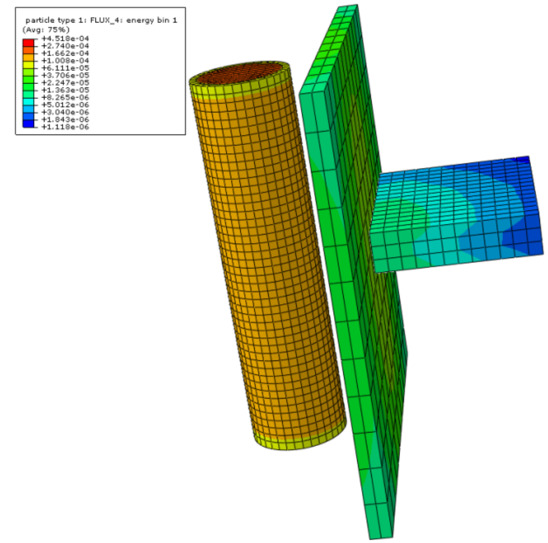
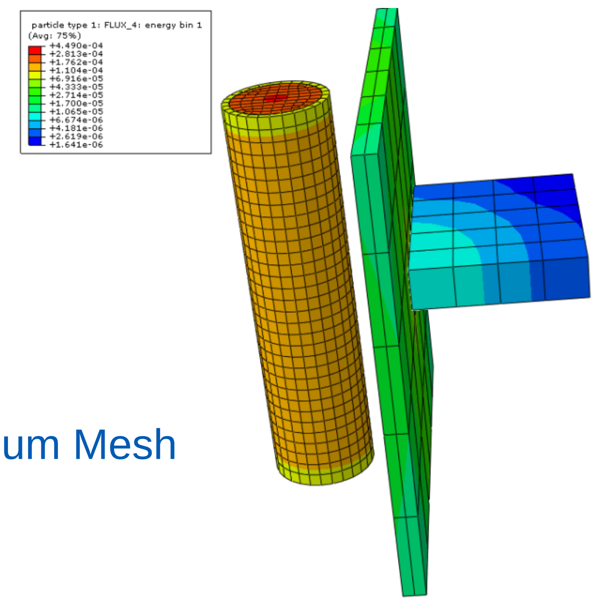


Large Mesh



Small Mesh



Medium Mesh

Photon Flux in Block

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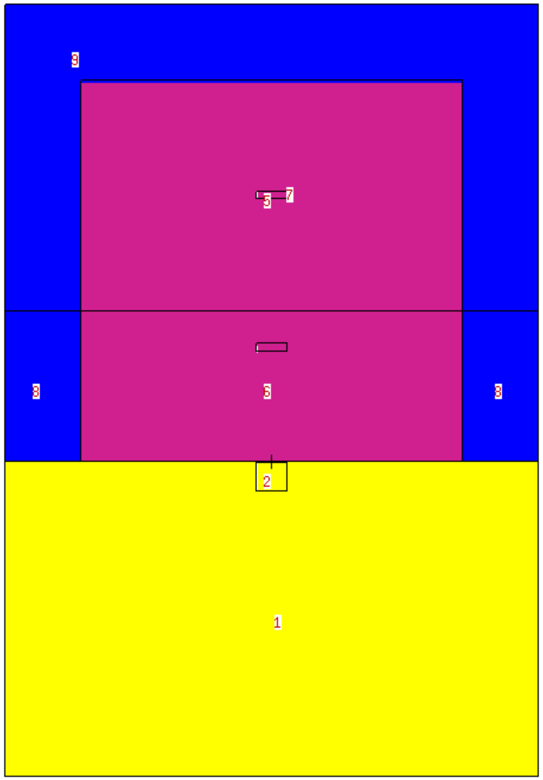
Model Name	Flux (photons/cm^2)	Statistical Error
RP- small mesh	4.47 E-6	0.22%
RP- medium mesh	4.46 E-6	0.22%
RP- large mesh	4.77	0.21%

FNS Vanadium Cube

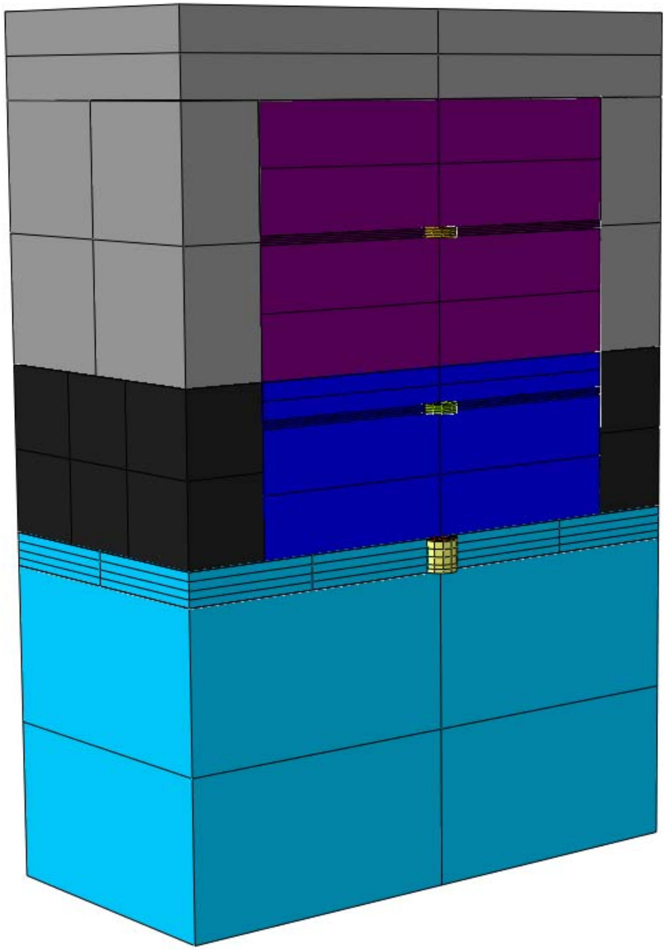
- **Vanadium cube assembly**
  - **25.4 cm x 25.4 cm**
- **Graphite reflector**
  - **Reduce neutron leakage**
- **D-T neutron source**



MCNP plot

Vanadium Cube Mesh Models

- 1^{st} order hex
  - Small, medium, large meshes



Vanadium Cube Volume Comparisons

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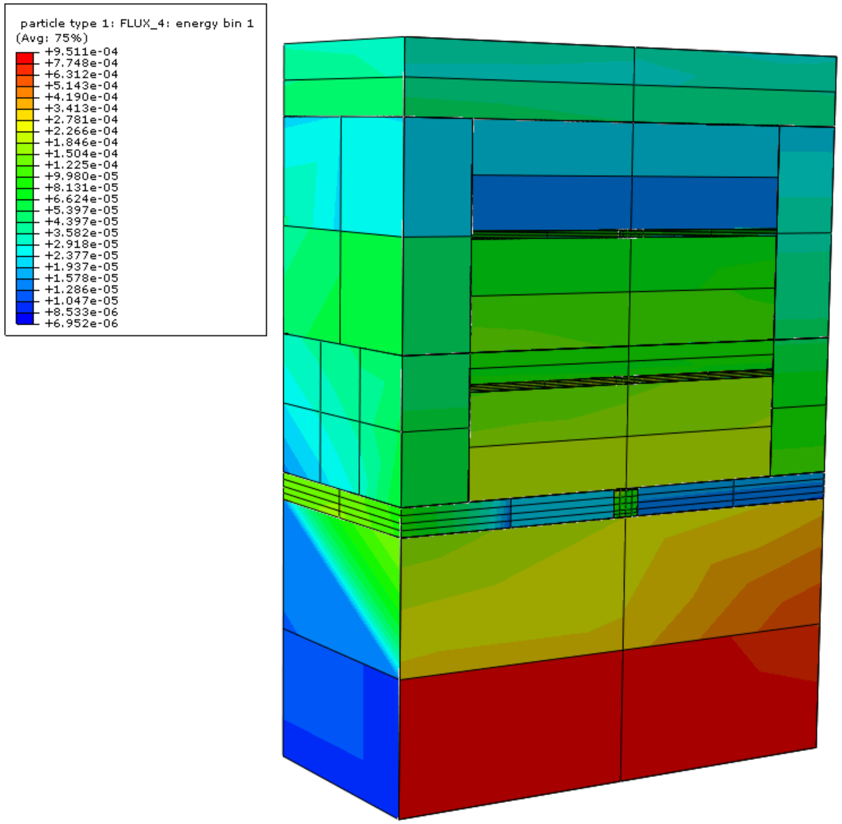
Model Name	Abaqus Mesh Volume (Calc. by MCNP)	% Difference from Actual Volume	#Elements	Runtime (minutes)
VC CSG	N/A	N/A	N/A	
VC 1 hex-small	65,098.12	0.00146	7,128	
VC 1 hex-medium	65,098.08	0.00141	2,736	
VC 1 hex- large	65,097.72	0.00085	700	2,710.8

* Actual Volume= 65,097.17

Flux in Vanadium Cube



Vanadium Cube- Energy vs. Flux

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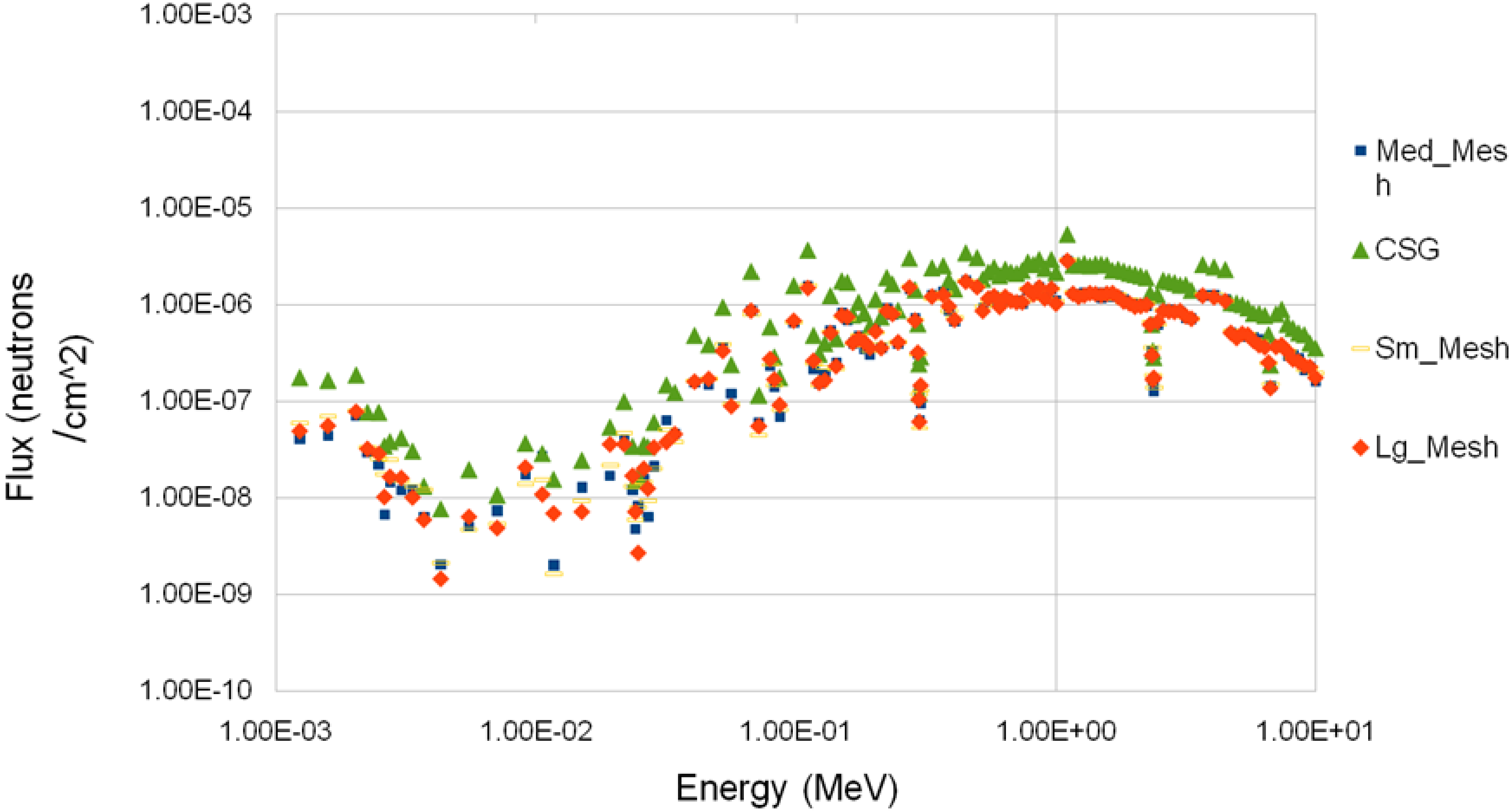

Conclusions

- **Most accurate volume comparisons- finest mesh**
  - **More important for curved surfaces**
- **Finer mesh -> more elements**
- **More elements -> longer runtime**
- **Hex vs. Tet**
  - **Less elements when using hexes**
  - **Choose the right shape for your model**

What I learned…

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- **How to use new software package- Abaqus CAE**
- **MCNP is the 'best' transport code available**
- **My project:**
  - **Interesting**
  - **Good amount of work**
  - **Helpful mentors ☺**
- **Great Experience!!**
- **Outside of work…**
  - **LA is a strange town**
  - **Green chili comes on everything**
  - **FAQ- Are you glowing yet??**
  - **How to dance from this guy**

Questions?