ATR Experience with Attila™ - Update

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Acknowledgements

- **William Danchus – U of Idaho**
  Attila, SolidWorks & Relap5
  NASA FSP MODEL

- **Nathan Manwaring – BYU Provo**
  Attila, Star-CCM+, Relap5
  NASA FSP MODEL

Existing ATR Modeling and Simulation Methodology

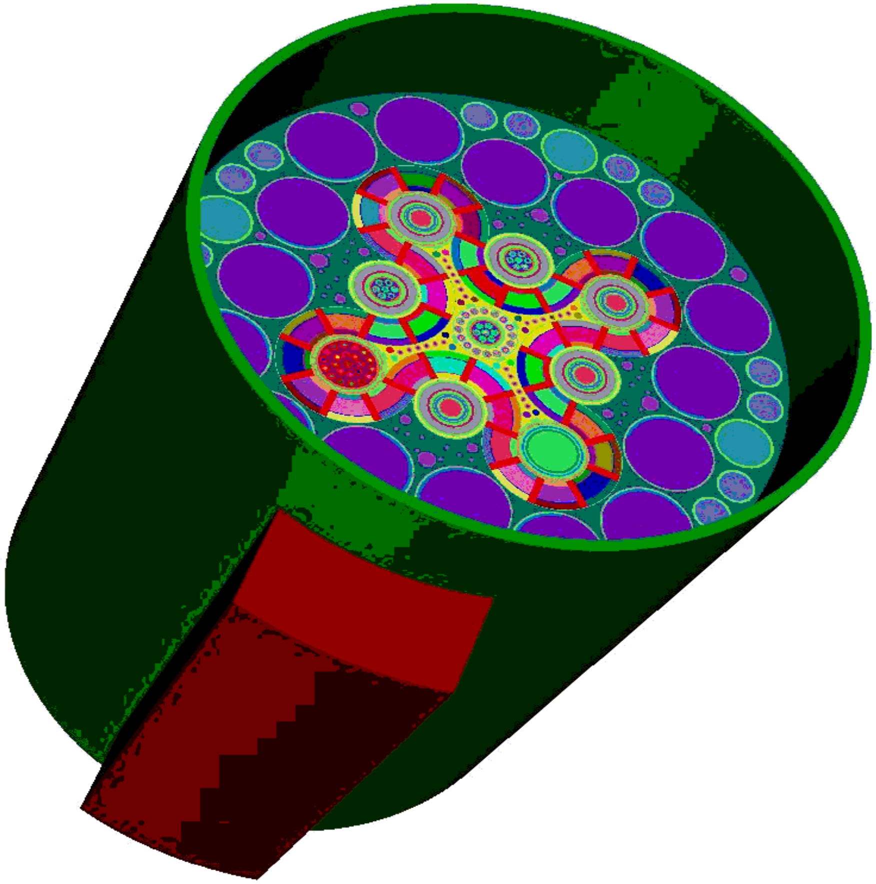
- ***Significant computational limitations (2D capability only, limited quantification of precision, cumbersome process, etc.). Unnecessary operational restrictions and conservatism***
- ***Hardware and software issues. Outdated and equipment and methods***
- ***Ancillary costs (ATRC runs, excess fuel purchases, environmental stewardship concerns, etc.).***
- ***Workforce retirement, acquisition, and retention considerations. Unavailability and loss of personnel and expertise to effectively use the legacy analysis methods. Standardized modern methods readily transferable to successive replacement personnel are needed***

Near-Term, Phase I Methodology Upgrades

- ***Modernize and standardize the ATR core analysis capability in the near term using industry standard current methods and verified software wherever possible.***
- ***Seven proposed subtasks will be focused around complementary multidimensional deterministic and stochastic (Monte Carlo) transport models of the reactor with integrated steady-state thermal feedback.***
- ***Integrate current RELAP-based core kinetics and safety analysis and CFD-based test loop safety analysis models.***
- ***Model verification and validation based on combination of historical data and new measurements, with standardized computational procedures and training***
- ***Estimated Phase I project duration is 48 Months***

HELIOS™ Model of ATR Core

Attila Model of the Advanced Test Reactor



Parallel Computing Test at Transpire

- **700,000 Tetrahedral Elements - 3D Model of Previous Slide**
- **16 Wall Clock Hours on 1 CPU at Transpire**
- **1 hour 23 minutes on 16 Distributed Memory CPUS at Transpire**
- **Peter Cebull HPC Optimization – 15 Minutes on IceStorm DMP (Distributed Memory Parallel)**
- **SCALE 27- 44 Group Libraries**
- **Collapsed to 5 Energy Groups in Attila – Keff =.99**

Present & Future Strategies

- Thin 3D Models for Meshing (Meshing is a Full Time Job)
- Extrude to 3D with New Transpire Tool
- Allows for placing Reflectors Top/Bottom
- Easier to Mesh in Thin 3D
- Tell Code # of Axial Layers
- Modify Core Materials for Reflectors
- Modify Names in SW
- Develop XS Sets from NEWT, Helios
- Compare to already existent SCALE XS Sets

HELIOS Model

Cross Section Data Generation

- Calculate resonance shielded microscopic cross sections

  Infinite homogeneous flux calculation with resonance absorbers over a few eV to 100 keV, includes resonance escape probabilities

  Reduces detailed full cross-section data to few group data

  Second calculation of neutron fluxes and reaction rates for geometry are calculated.

  Group fluxes and currents are energy integrated over groups.

  Spatial and angular discretizations.

  Current coupling and collision probabilities solution in 2-D.

  Tracks integrated particle transport probabilities from state to state

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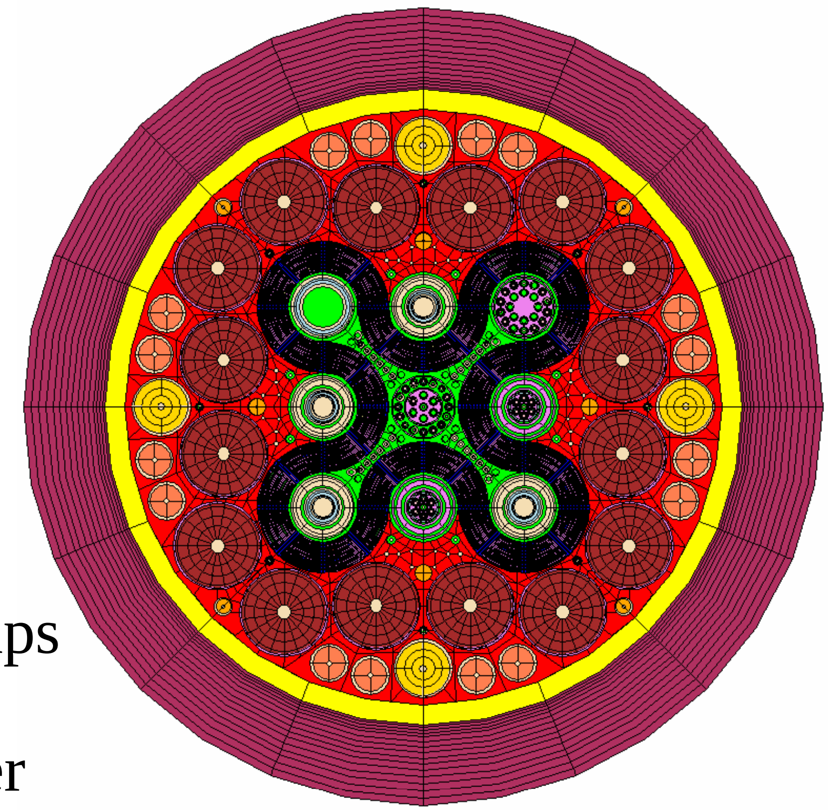
HELIOS Model

Computational Results



K=1.0306, no axial leakage

K_b=0.9967 critical, axial leakage

Run Time ~25 Minutes

100F, 2-D, Solid Be elevation, 44 groups

Relative Bundle Flux Zero Power

5		0.587666	0.666327					0.604825	0.526589	
4	0.819997			0.801563			0.761808			0.525144
3	0.677965				0.852362	0.83826				0.616123
2		0.830445			0.889823	0.884981			0.802243	
1			0.877166	0.925756			0.918281	0.875212		
-1			0.963218	0.960924			0.962283	0.964662		
-2		0.914203			1	0.993799			0.917601	
-3	0.775994				0.993799	0.993799				0.775569
-4	0.69402			0.948097			0.947757			0.694529
-5		0.697418	0.788566					0.789246	0.697163	
0	-5	-4	-3	-2	-1	1	2	3	4	5

Flux results agree well with MCNP

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NEWT Model

Cross Section Data Generation

- Calculate resonance shielded microscopic cross sections
  - Bondarenko treatment in the unresolved resonance energy range.
  - Boltzman Transport equation used to calculate the pointwise continuous energy flux.
  - Master library is corrected for resonance self shielding and other spectral/spatial effects.
- With no geometry specified for cross section processing, infinite homogenous medium is assumed (current model).
  - No Dancoff factor.
  - No spatial or angular variation in the flux for the boltzman Transport.
- Geometry can be added to the model for cross section processing.

NEWT Model

Computational Results

<u>44 group library (22 Thermal Groups)</u>

K_{eff}=1.0038

Run Time = ~55 hrs (Linux 2.66 GHz Xeon)

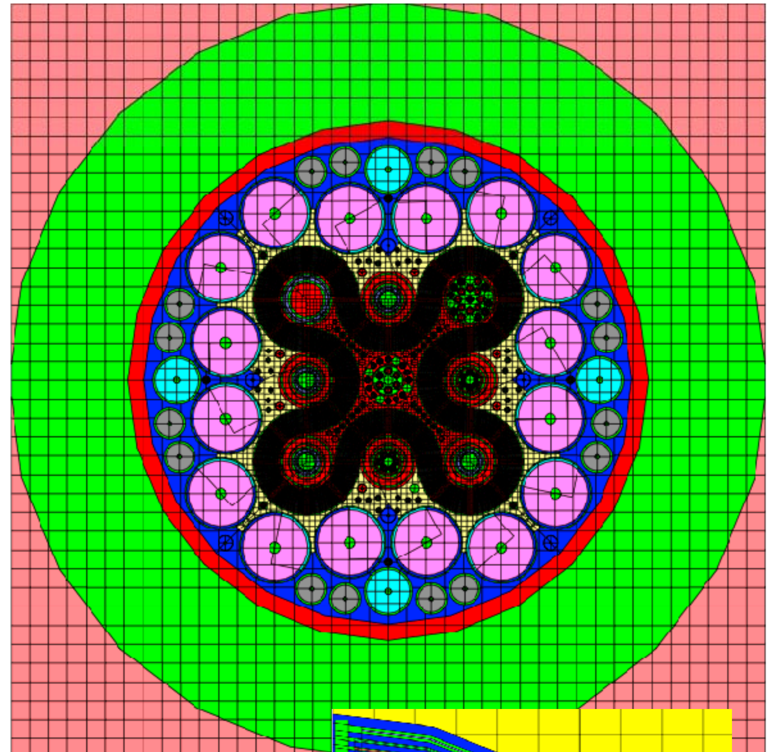
Run Time = ~24 hrs (OS X 3.2 GHz Xeon)

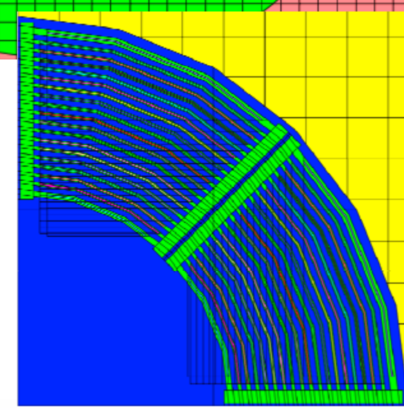
<u>238 group library (90 Thermal Groups)</u>

K_{eff}=0.9990

Run Time = ~166 hrs (Linux 2.66 GHz Xeon)

Run Time = ~83 hrs (OS X 3.2 GHz Xeon)

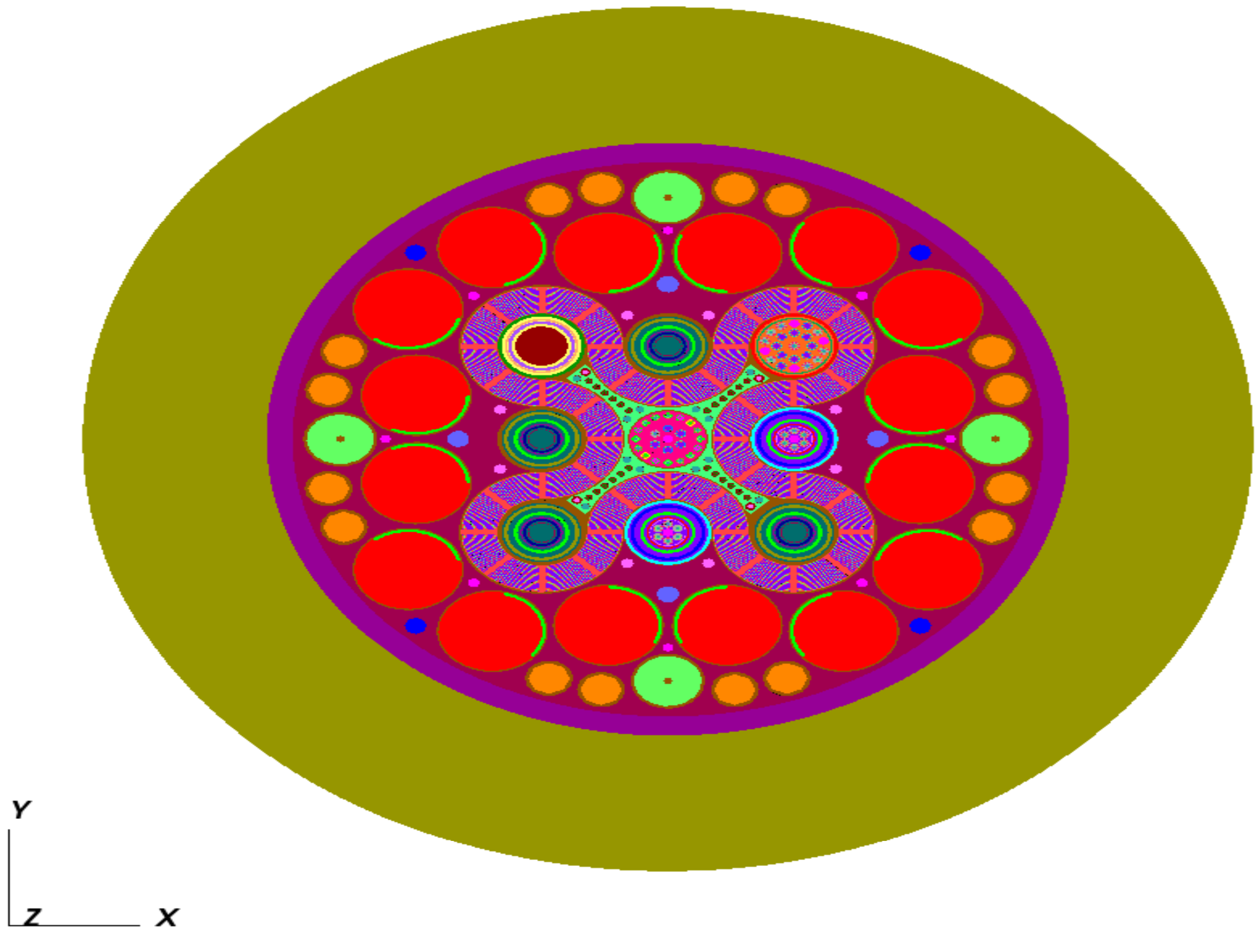




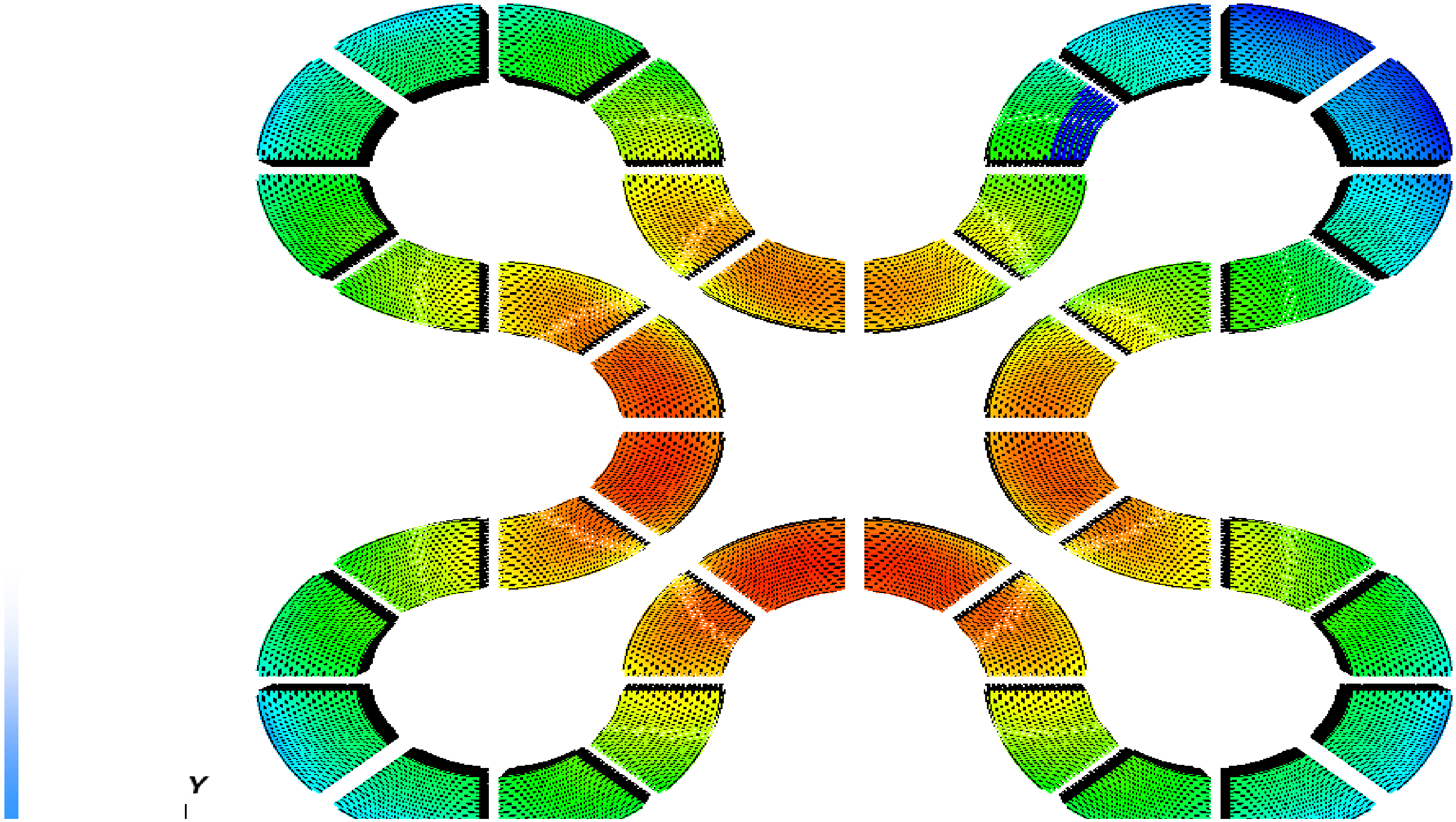
Approximate Relative Flux

	-5	-4	-3	-2	-1	1	2	3	4	5
5		0.494	0.595					0.490	0.441	
4	0.517			0.727			0.639			0.417
3	0.576				0.908	0.814				0.665
2		0.722			0.858	0.896			0.501	
1			0.949	0.882			0.841	0.931		
-1			0.920	0.971			0.930	0.972		
-2		0.795			0.952	0.947			0.788	
-3	0.665				1.000	0.995				0.636
-4	0.554			0.674			0.819			0.589
-5		0.585	0.816					0.678	0.557	

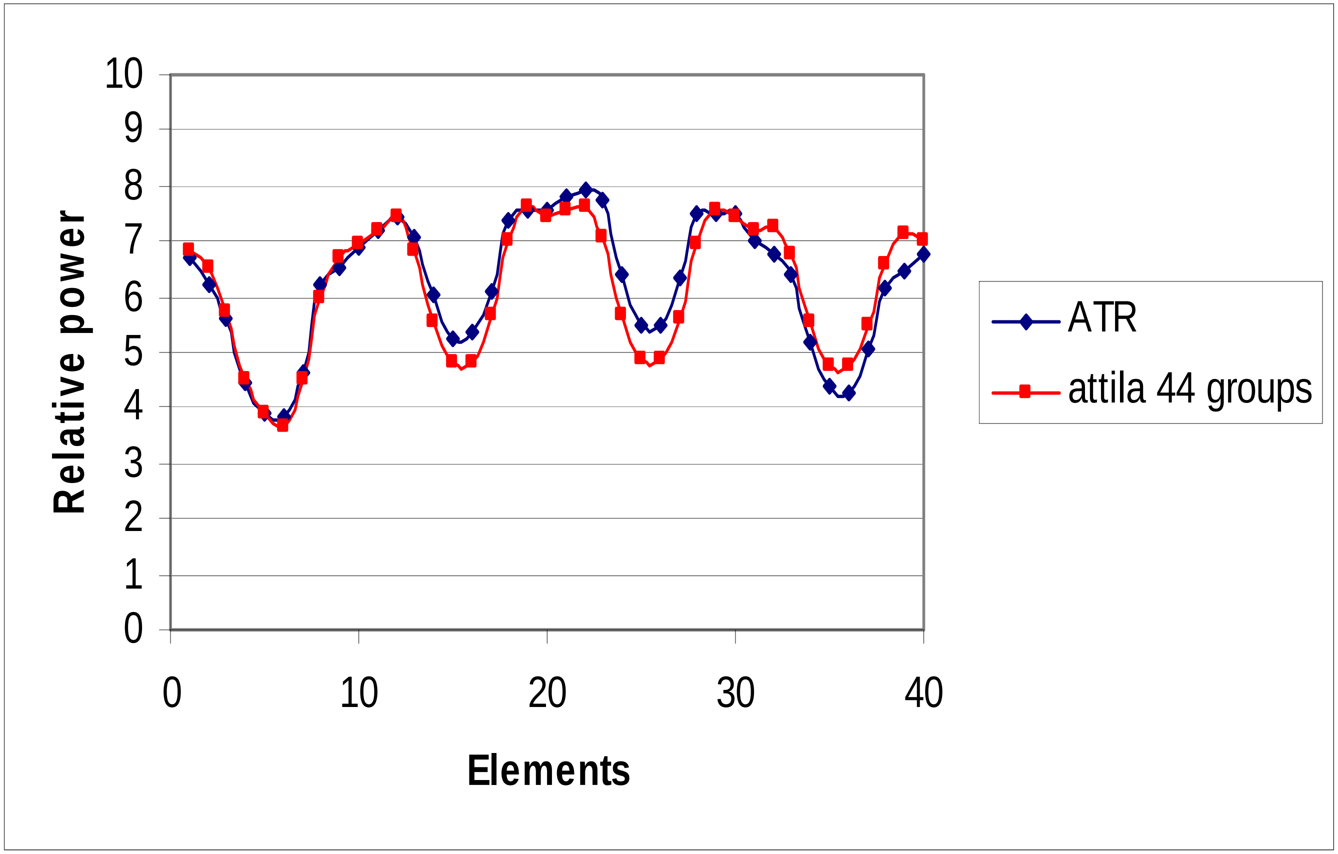
Attila 19 Plate Model



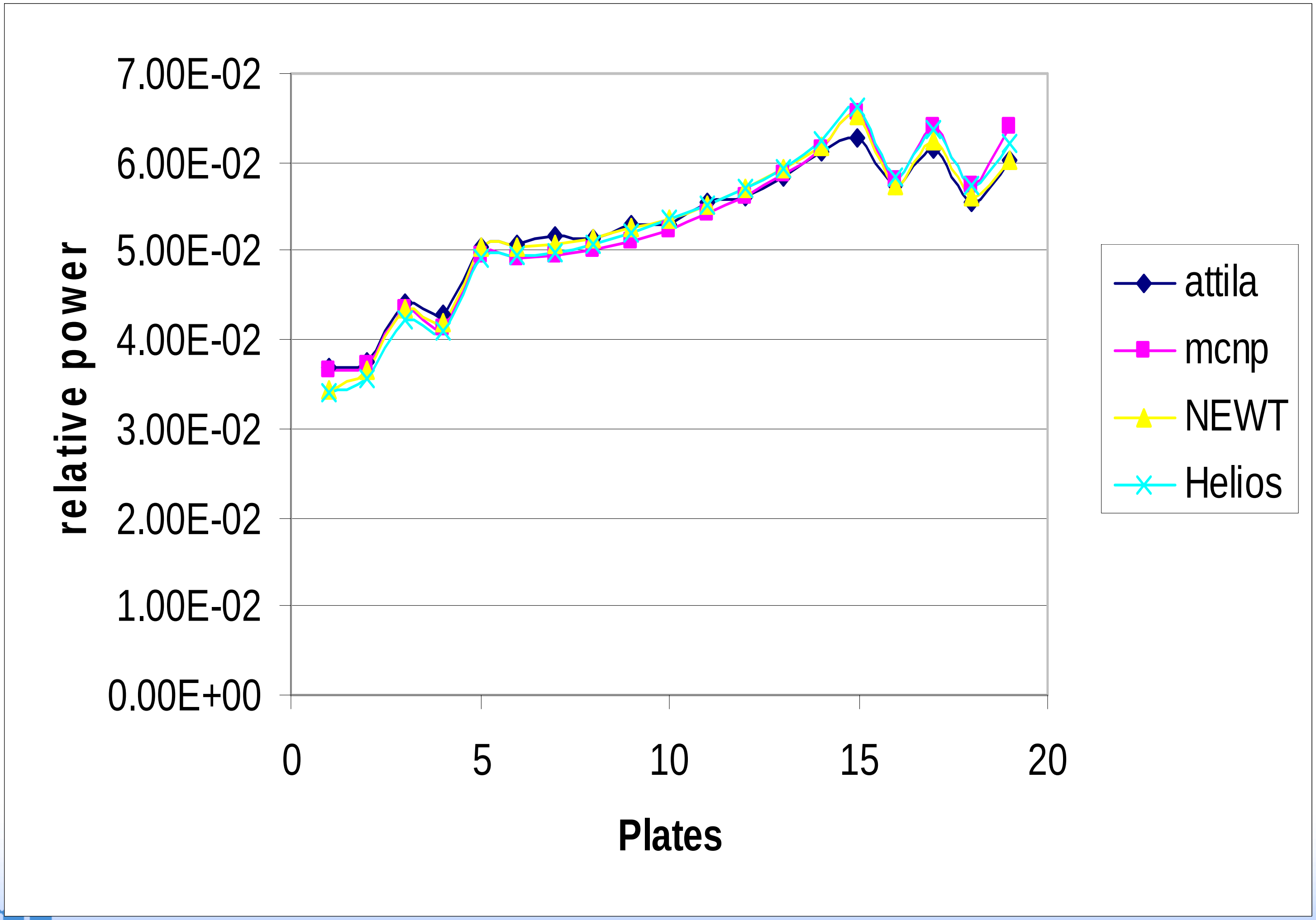
Attila Flux Distribution



Comparisons to CIC-94 Data



Radial Power Averaged over All Plates



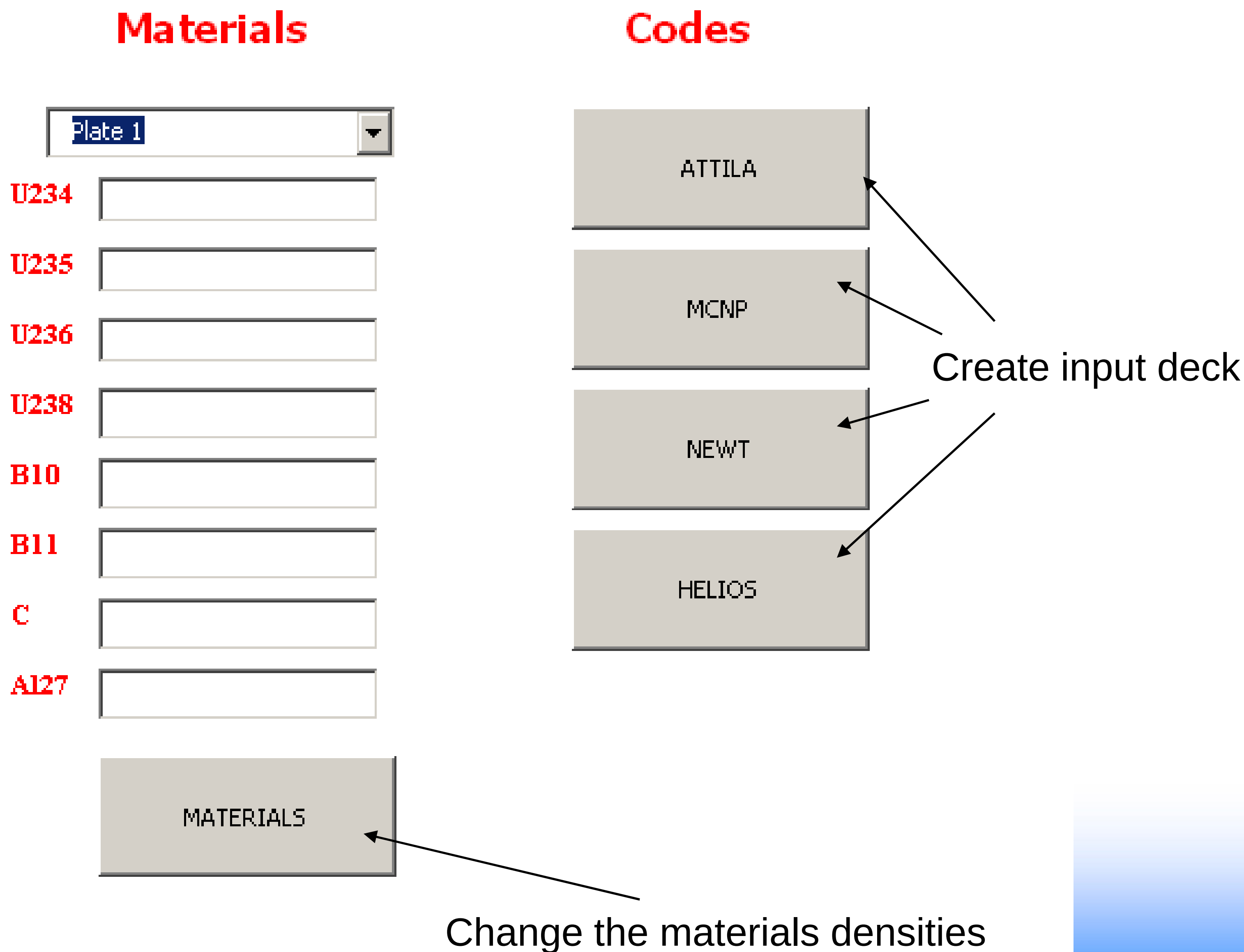
Run Times

- **32-64 CPU's on Icestorm**
- **1-2 Hours**
- **Mesh = 300 K Tets**

Attila Input

- **Attila GUI, Lots of Input**
- **Automated Edits using Excel by S. Frand**
- **Takes Input from SW Model, generates edit requests**
- **Makes XY Plots, PYTHON**
- **19 Plates X 40 Elements X 100 Edits = A Lot of Stuff you don't want to do by hand in the GUI**

Visual basic interface



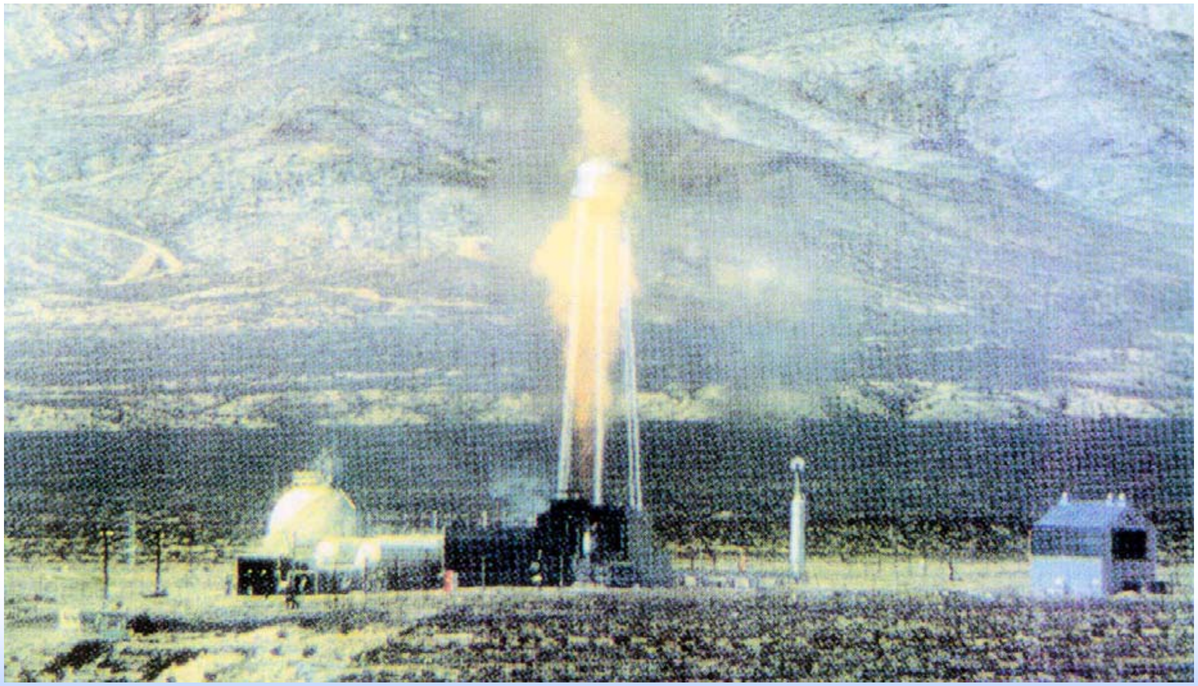
Attila

- Creating 2 files :
  - Attila.inp = parasolid + material card + cross section
  - Attila.input.inp = edits (reaction rate, flux…)

MCNP and NEWT

- Creating 1 file :
  - Atr = Geometry + cross section + material card
  - Newt = Geometry + cross section + material card

NTR



Pewee core

Thermal reactor (Fuel UC, 93% U235)

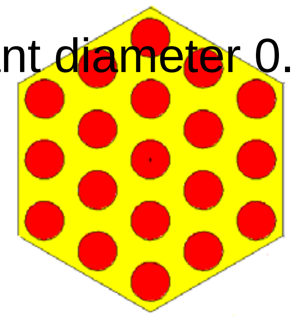
Core fueled radius 22.99 cm

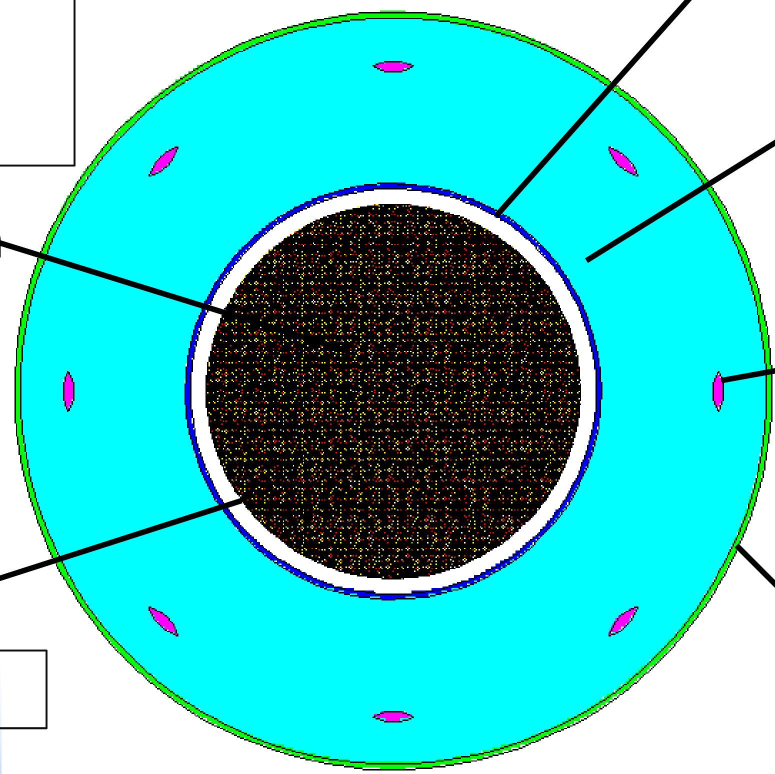
Fueled length 129.54 cm

Hexagonal fuel diameter 1.9 cm

19 coolant channels (hydrogen)

Coolant diameter 0.279 cm





Graphite 1cm

Beryllium 20 cm

Control drums (boron)

Pressure vessel Aluminum 2 cm

Thermal expansion gap 2.5 cm

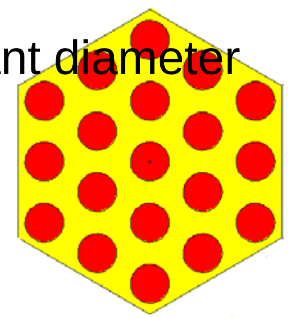
New core

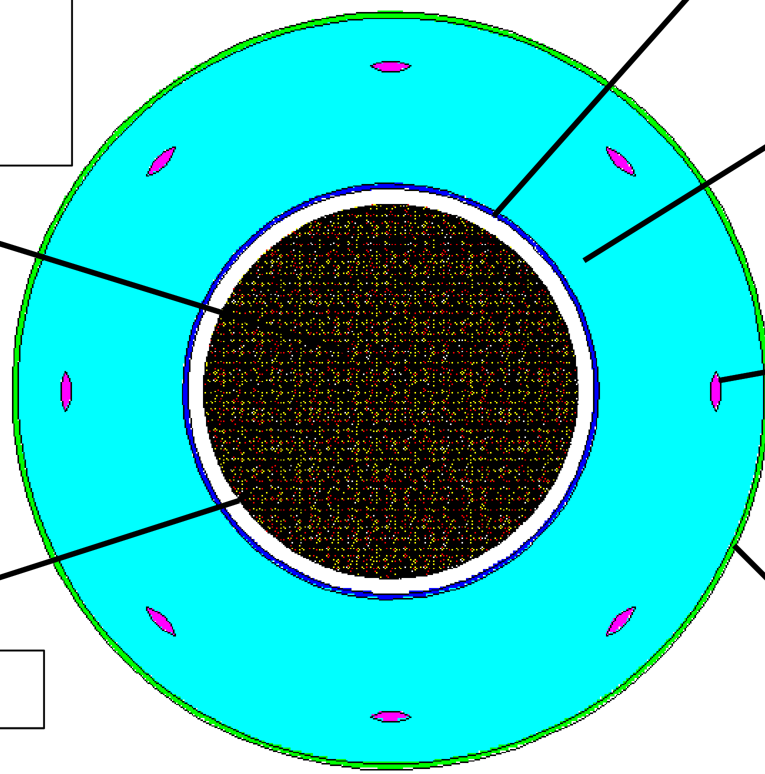
- **Fast reactor**
- **Fuel UN (93% U235)**
- **Tungsten-Rhenium matrix**

Hexagonal fuel diameter 1.9 cm

N coolant channels (hydrogen)

Coolant diameter





Inconel

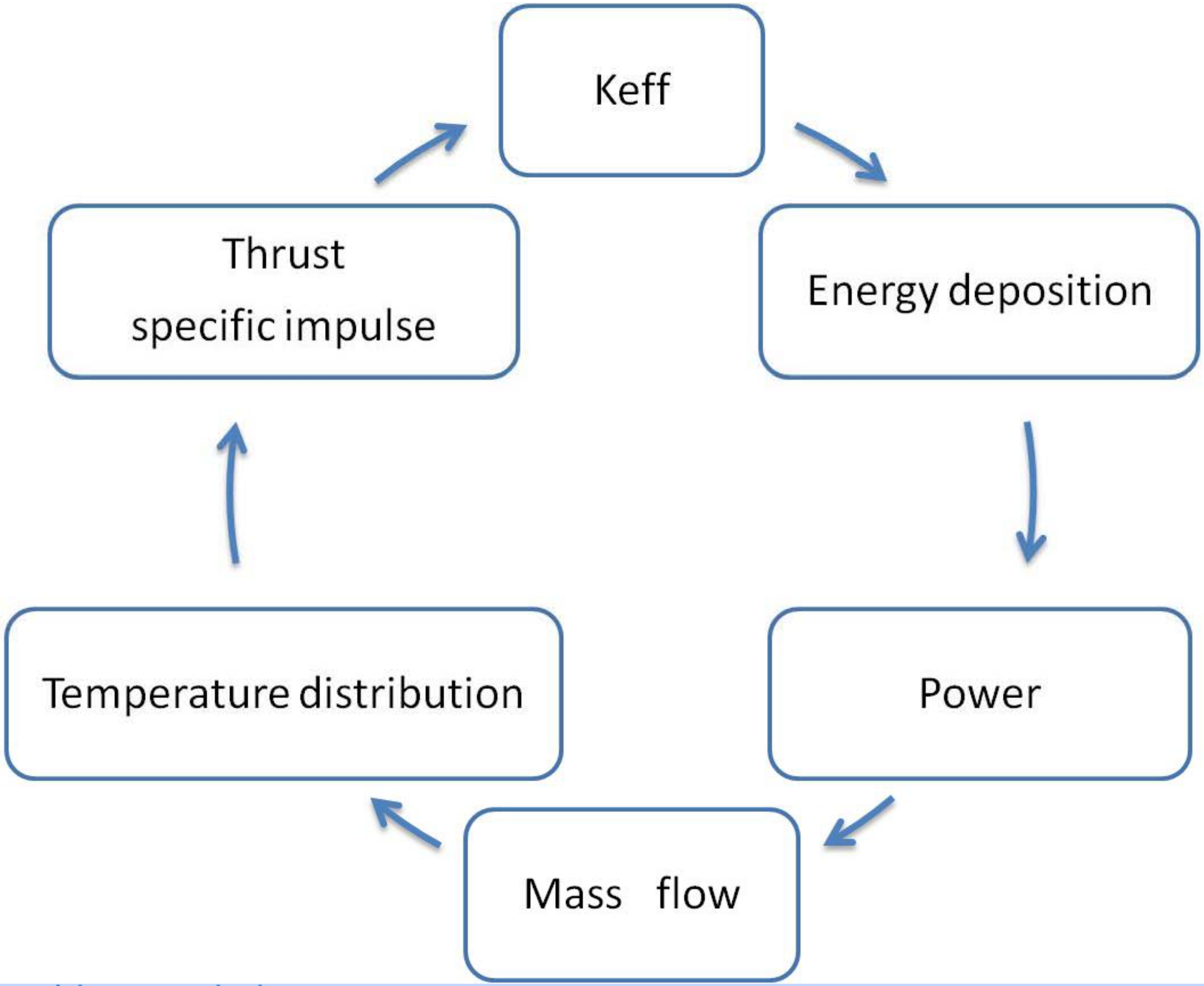
Beryllium

Control drums (boron)

Pressure vessel inconel

Thermal expansion gap

Objective


Keff
Energy deposition
Power
Mass flow
Temperature distribution
Thrust
specific impulse

Parameters

- Diameter of the coolant channels
- Number of coolant channels (19 , 37)
- Masse fuel (masse uranium)
- Ratio of the fuel inside the matrix
- Core radius
- Core length
- Reflector thickness
- Control drums

Optimization

$$V_{core} = V_{matrix} + V_{coolant}$$

Neutronic	Thermodynamic
$\frac{R_{core}}{L} = X$	$A_{coolant} = A_{pewee}$
$R_{core} = \left(\frac{V_{matrix} X}{\pi \left(1 - \frac{\pi R_{coolant}^2 N_{coolant/element}}{A_{element}} \right)} \right)^{1/3}$	$L = \frac{19 \cdot L_{Pewee} R_{coolant\_Pewee}}{N_{coolant/element} R_{coolant}}$ $R_{core} = \left(\frac{V_{matrix}}{\pi L \left(1 - \frac{\pi R_{coolant}^2 N_{coolant/element}}{A_{element}} \right)} \right)^{1/2}$

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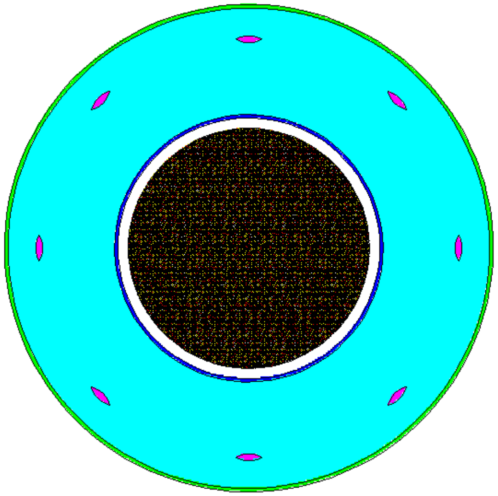
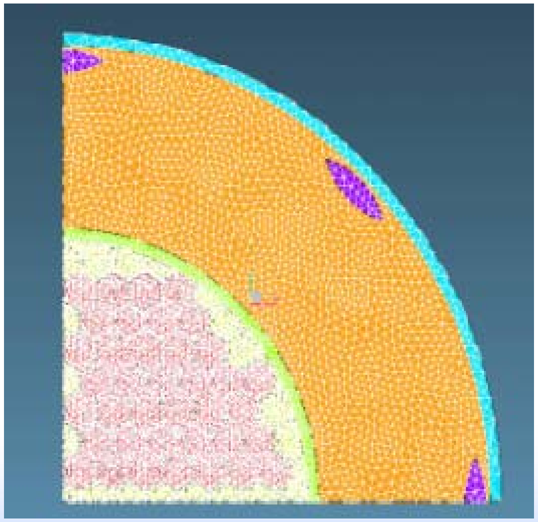
CODES

MCNP (stochastic)	
SolidWorks + ATTILA (deterministic)	

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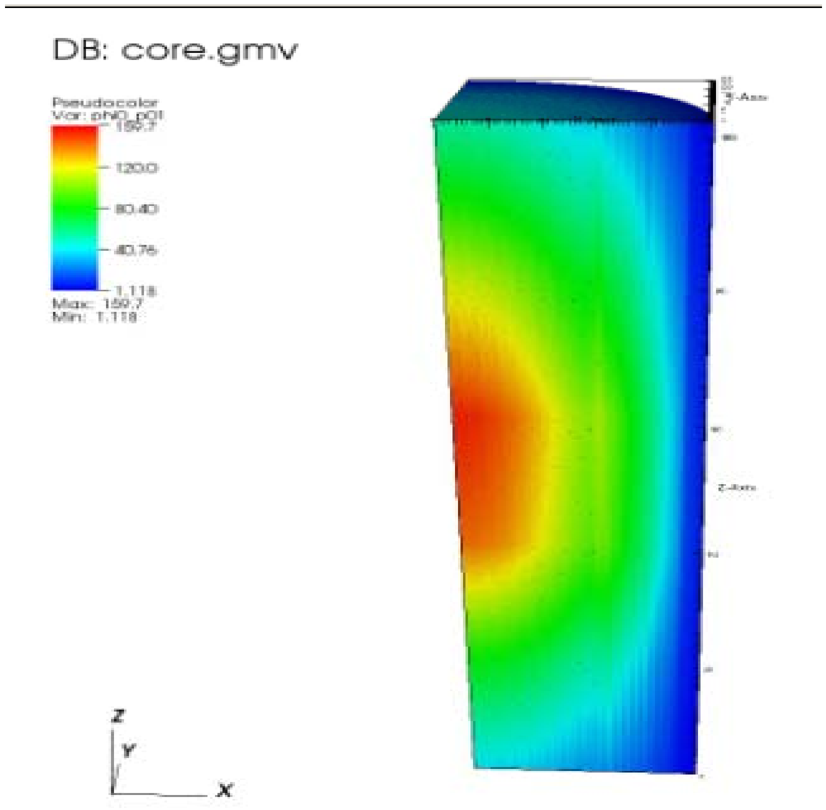
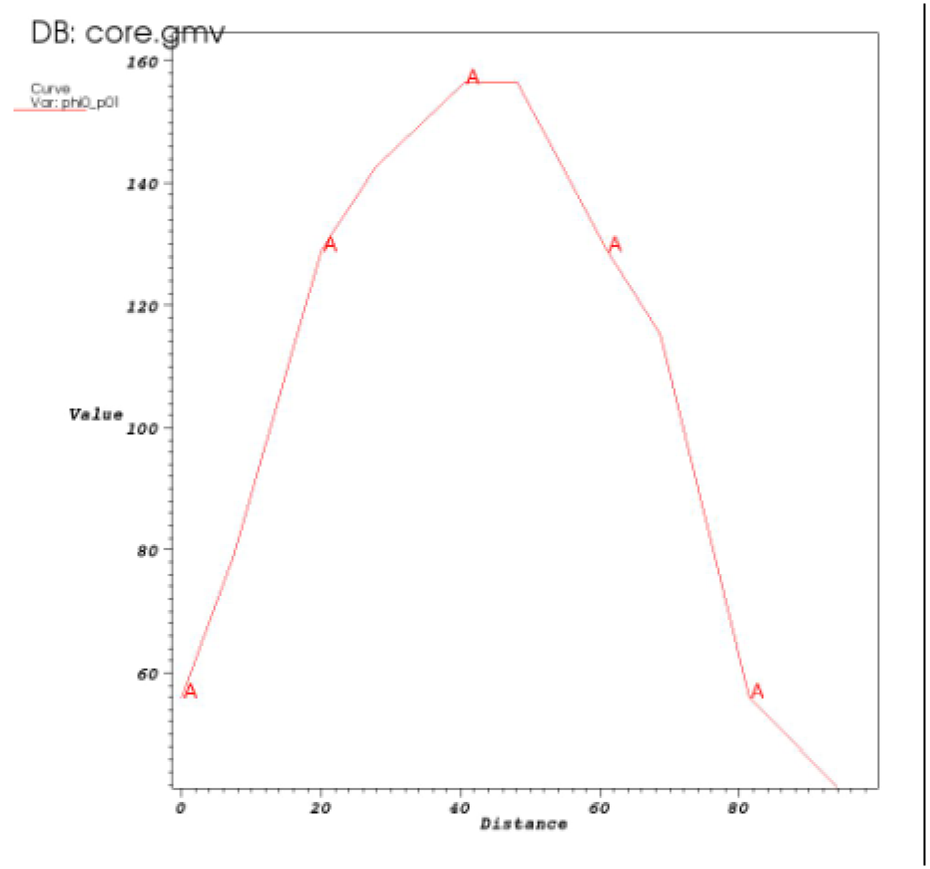
ATTILA



DB: core.gmv
Pseudocolor
Var: phi0_p01
159.7
120.0
80.40
40.76
1.118
Max: 159.7
Min: 1.118
Z
Y
X

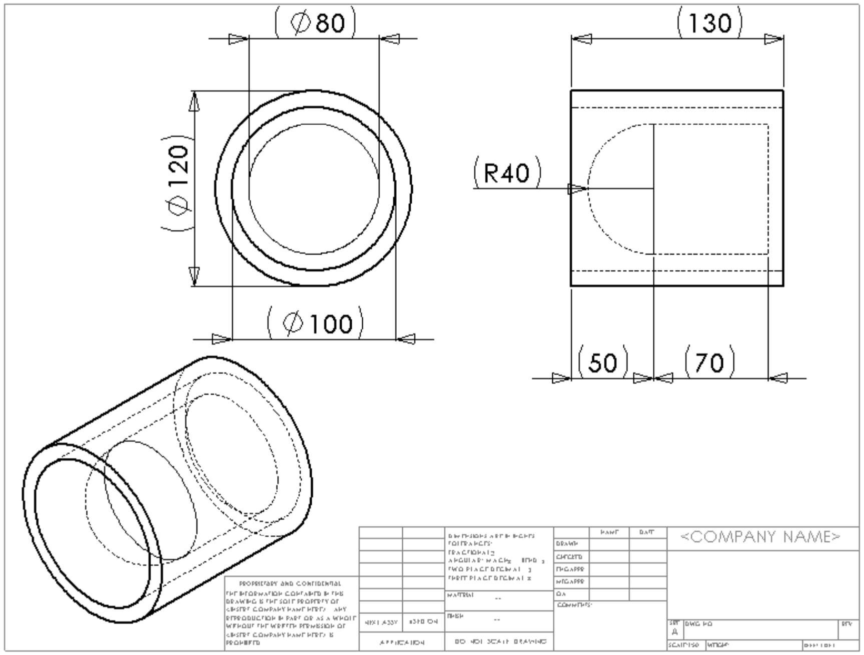


DB: core.gmv
Curve
Var: phi0_p01
Value
Distance
160
140
120
100
80
60
0
20
40
60
80

Light Bulb Rx

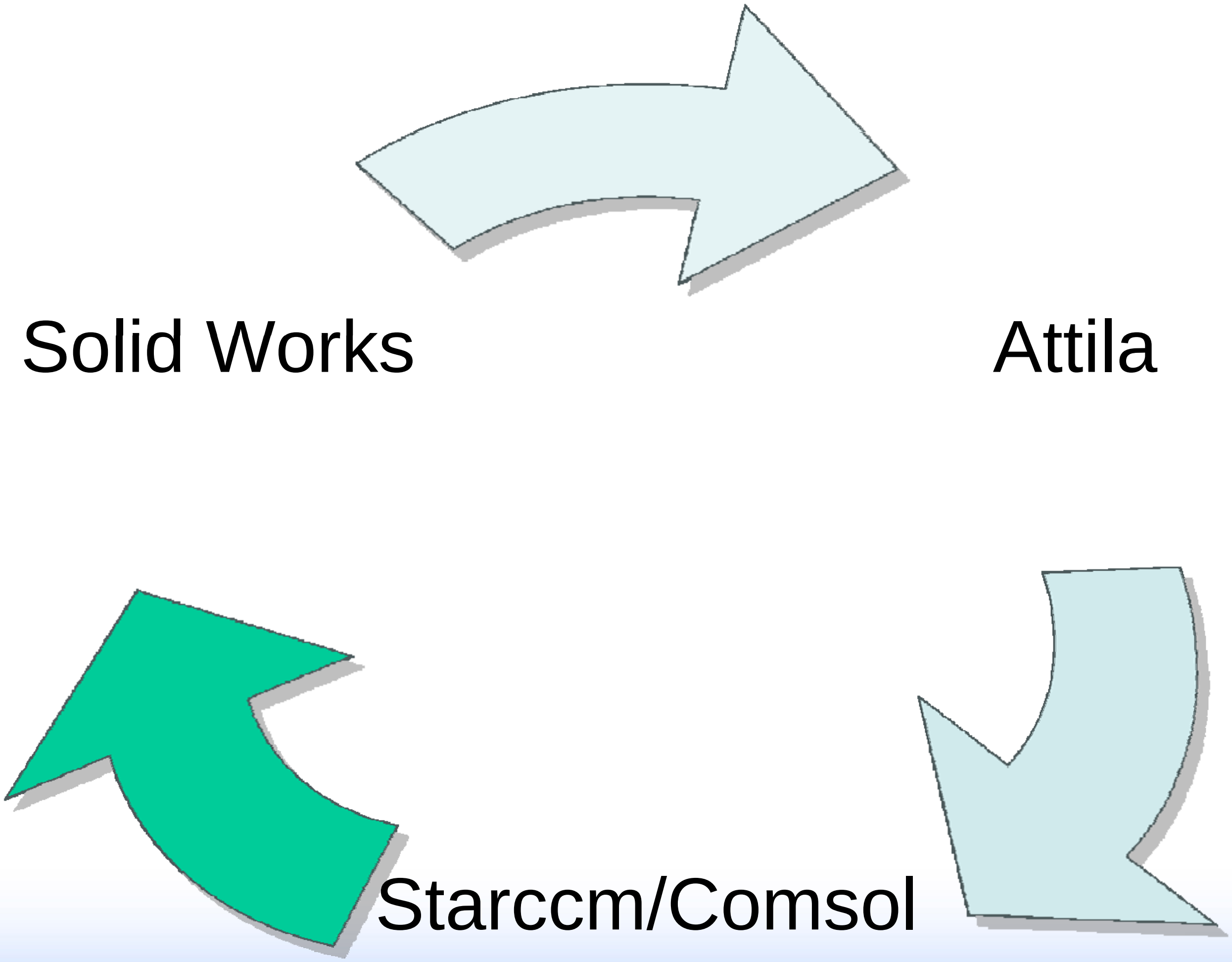
- **Power on surface – Decay Heat**
- **Critical**
- **93% U235 UN Fuel in Tungsten Matrix**
- **Control same as NTR**

SolidWorks



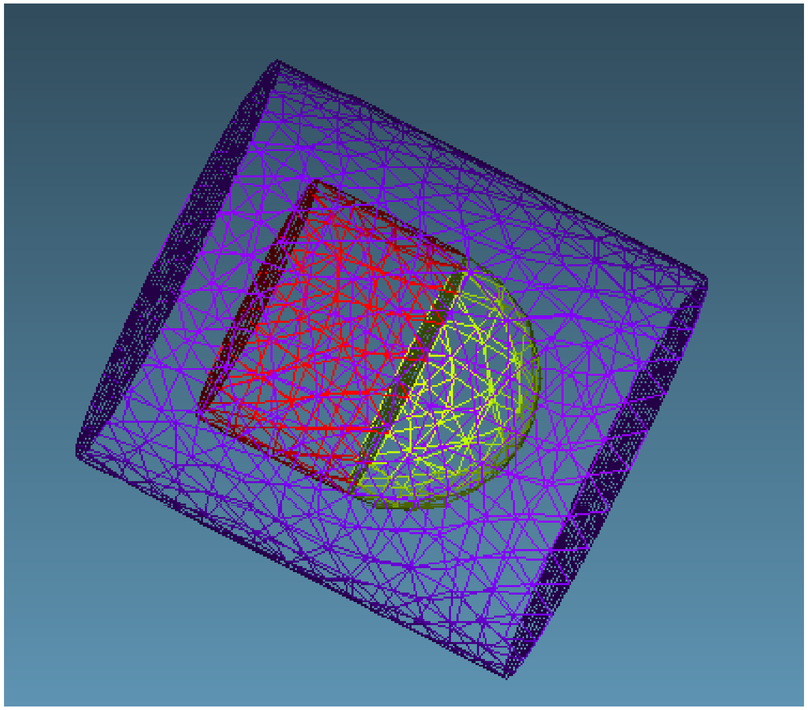
- **Create the Geometry of the System**
- **Output.-Parasolid file**

Coupling



Attila

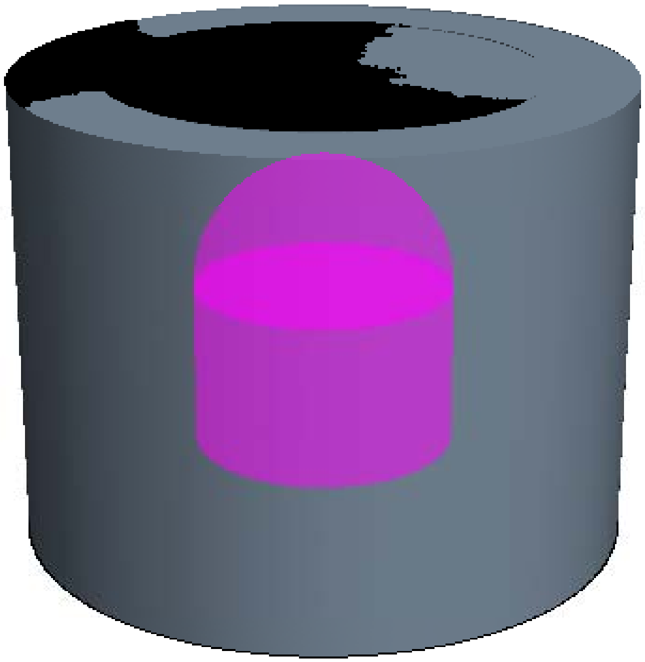
Input Parasolid File



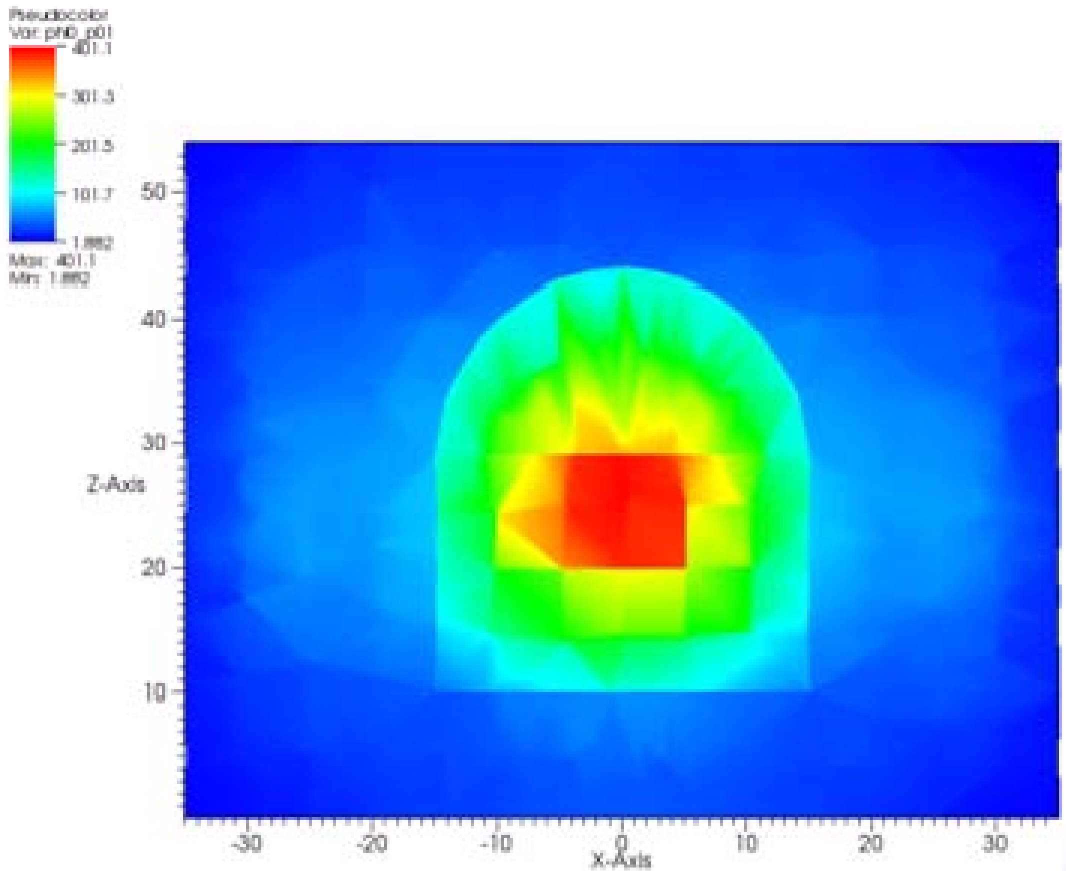
- **Solves Boltzmann Transport Equation**
- **Output.- Energy deposition**

Starccm+

- **Input Parasolid File (SW)**
- **Energy Deposition (Attila)**

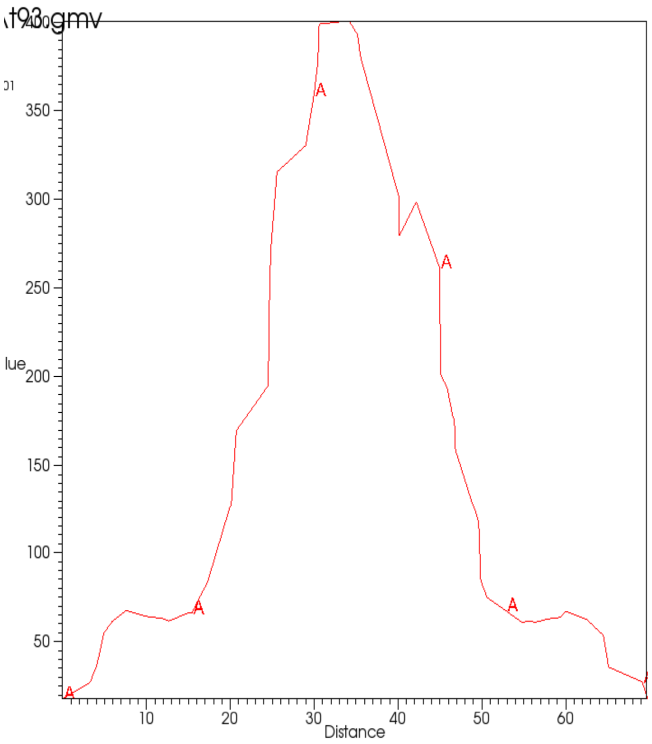


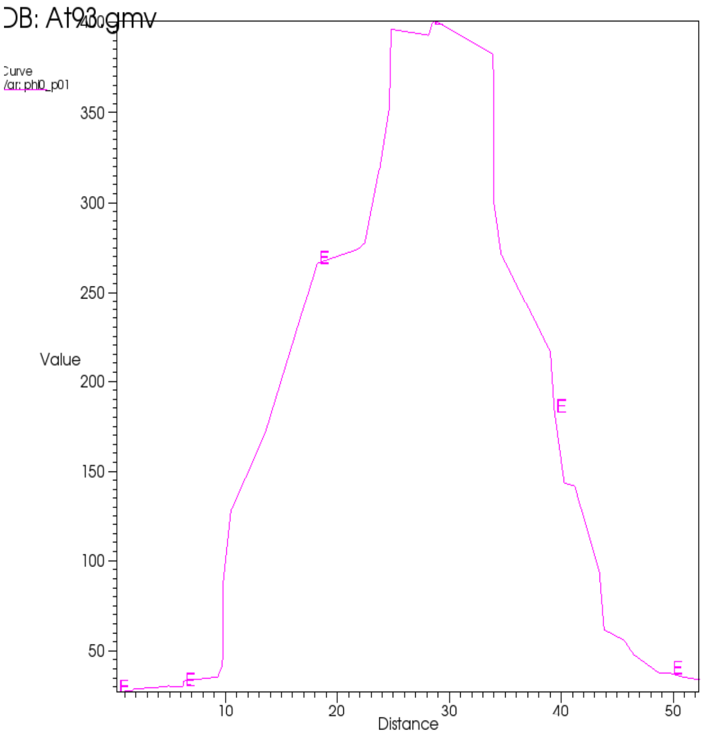
- **Solves heat transport equations**
- **Output.- Heat Transfer Profile**



Pseudocolor
Var: phi0_p01
401.1
301.3
201.5
101.7
1.882
Max: 401.1
Min: 1.882
50
40
30
Z-Axis
20
10
-30
-20
-10
0
10
20
30
X-Axis

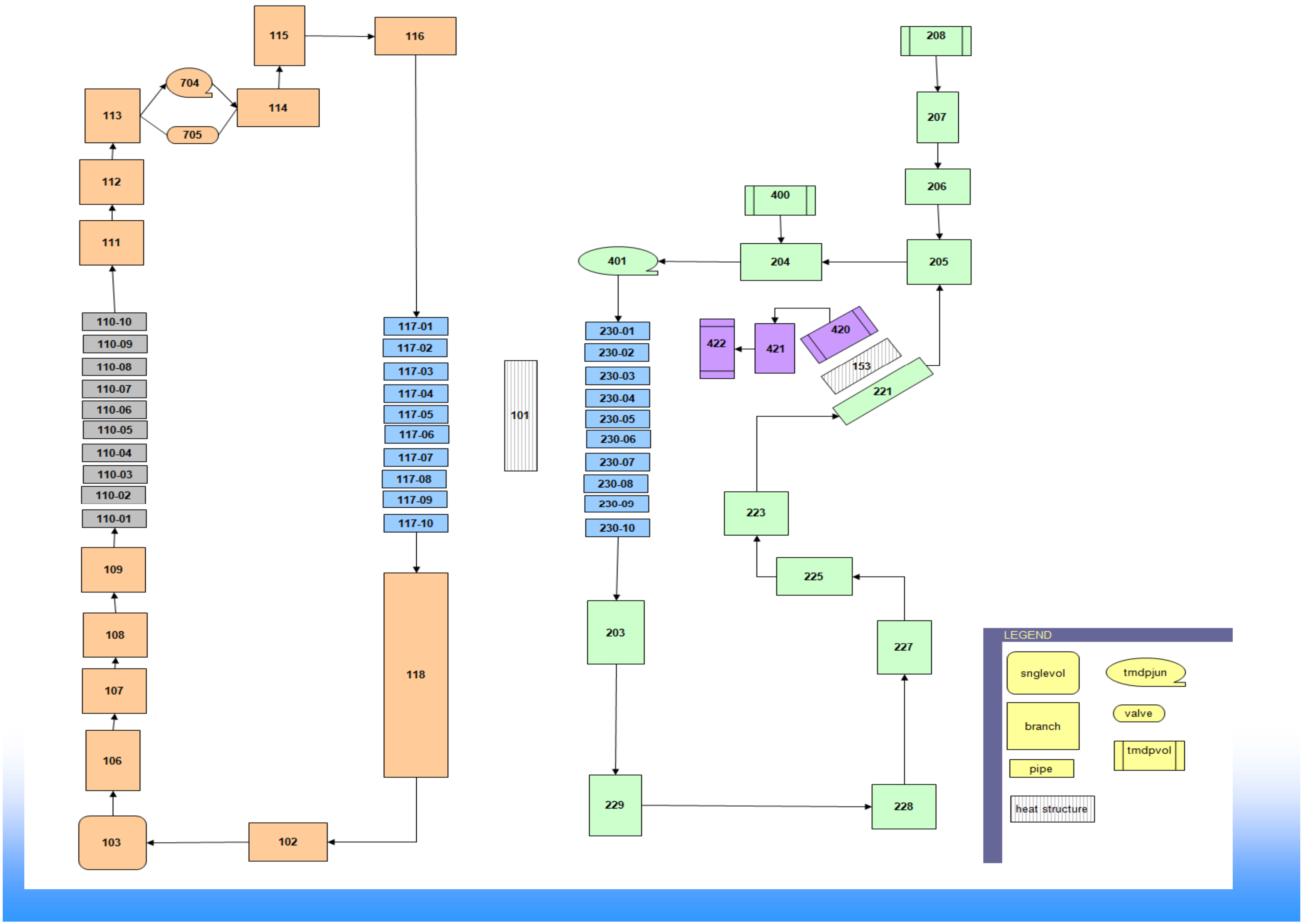
Radial and Axial Flux





RELAP5 FSP

- One Loop Model Fast Rx - NaK on Primary, Helium on Secondary
- Based on a Model by Juan Carbajo ORNL
- INL Input Kinetics – Enhanced Fluids – Heat Structures
- W. Danchus, N. Manwaring & S. Lucas
- Report on Model
- LANL, SANDIA want R5
- Previous Models in Simulink
- Lumped Parameter, Global Pressure, Limited Coverage on State Equations



115
116
704
705
113
114
112
111
110-10
110-09
110-08
110-07
110-06
110-05
110-04
110-03
110-02
110-01
109
108
107
106
103
102
117-01
117-02
117-03
117-04
117-05
117-06
117-07
117-08
117-09
117-10
118
101
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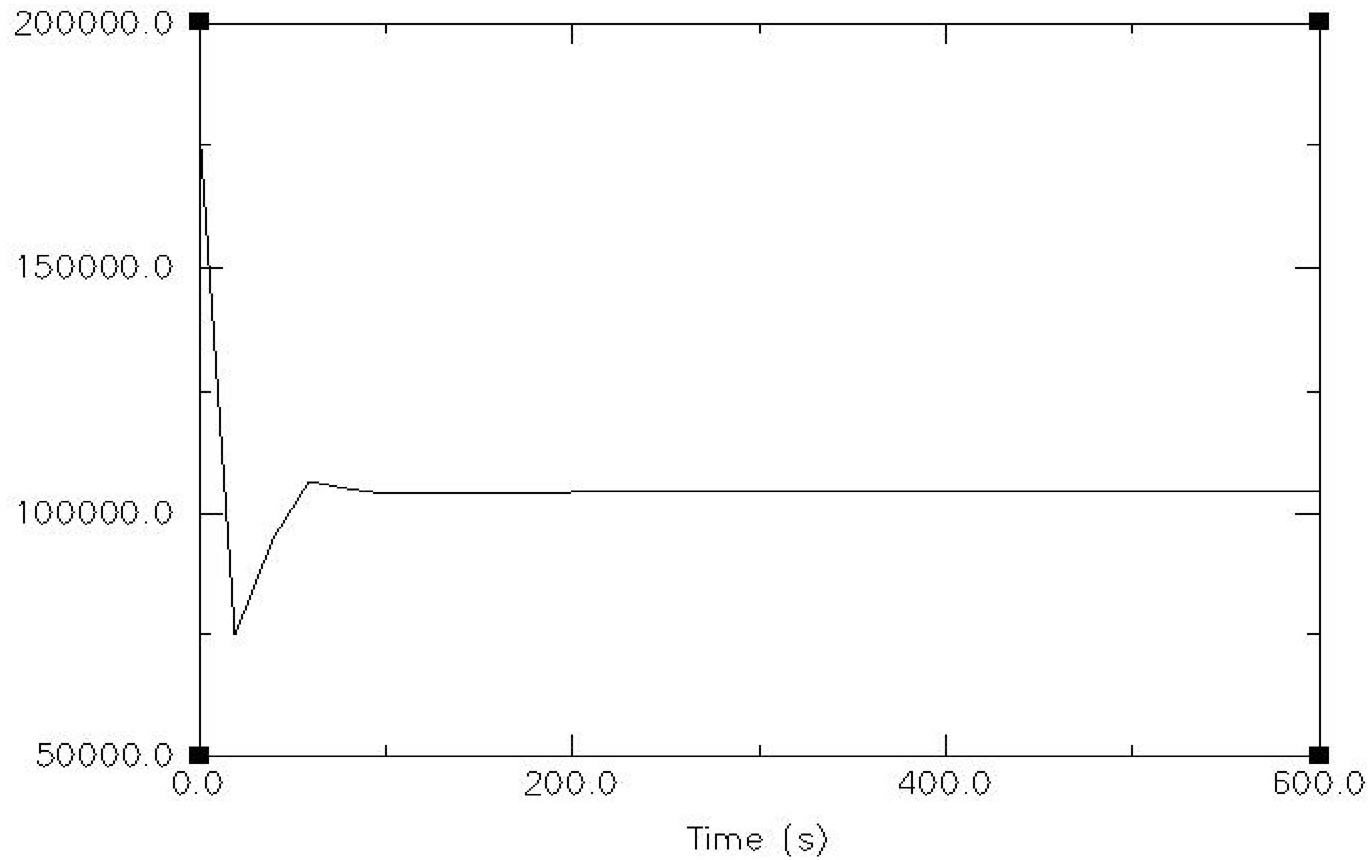
206
400
401
204
205
230-01
230-02
230-03
230-04
230-05
230-06
230-07
230-08
230-09
230-10
422
421
420
153
221
223
225
227
203
229
228
LEGEND
snglevol
tmdpjun
branch
valve
tmdpvol
pipe
heat structure

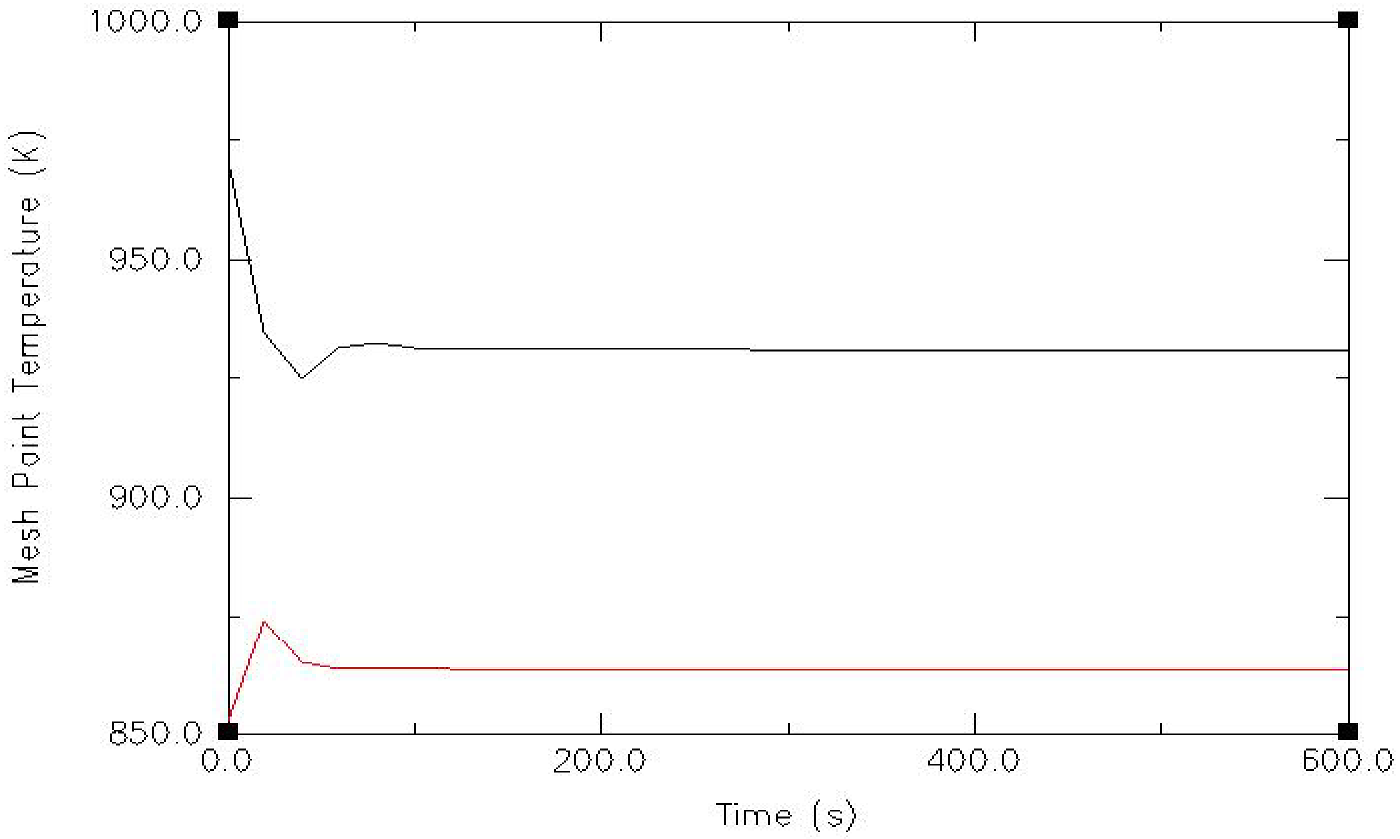
Steady State Power

- Uses Point Kinetics for all the Feedback
- Kinetics Coefficients from MCNP (No Adjoint)
- Completely in Design Mode
- Nominal Power 100-200 KW
- Nominal Temperature on Primary 800-900 K
- Flow is ~ 2 LBm/sec

Run to Steady State Rx Power Watts



Center Line & Outer Fuel T in Core



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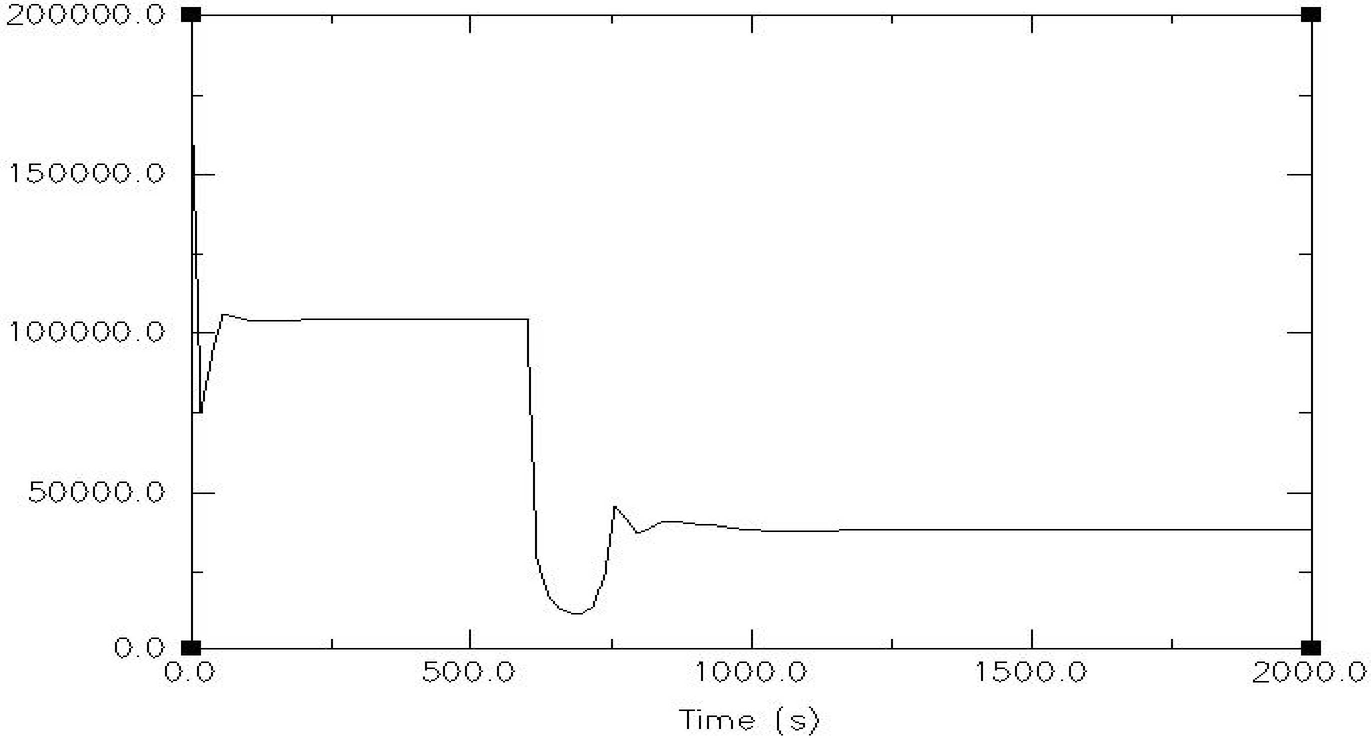
Ramp Flow Down by 50% at 600 seconds
Power (Watts)



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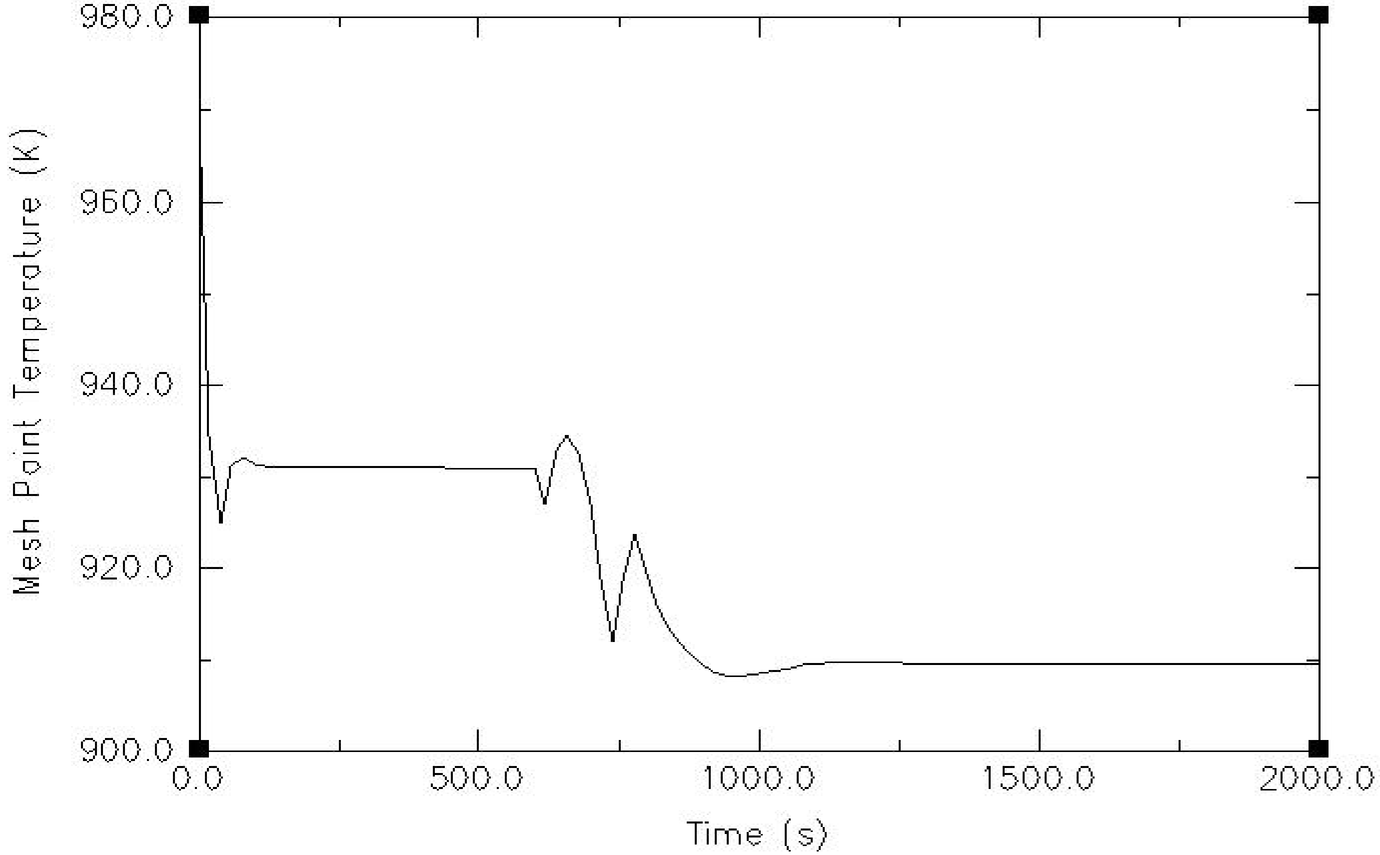
Fuel CLT



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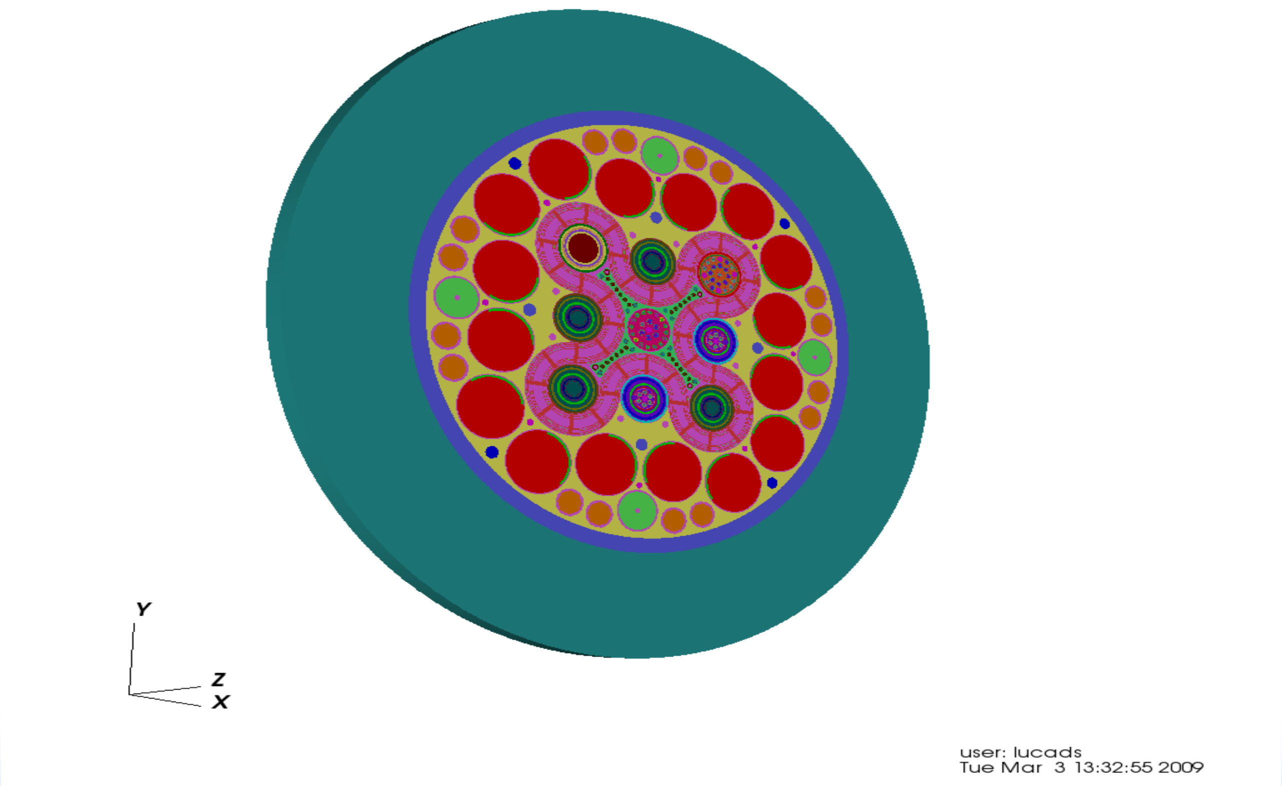
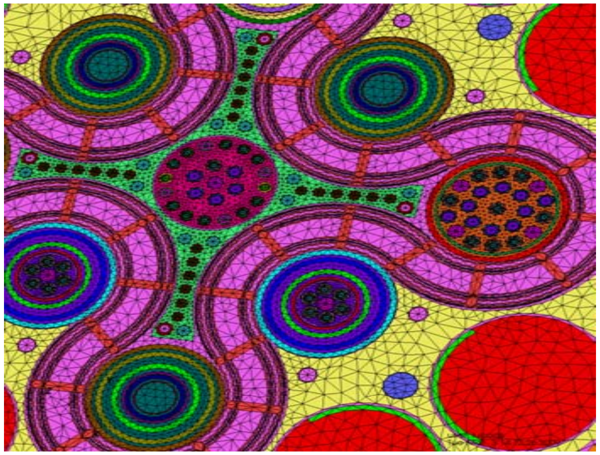
Tasks

- ATRC Model Comparison to Experiment
- HELIOS XS Data into Attila
- Cross check of Helios, NEWT and Attila
- Parallel Burn in Attila
- Layering 3D Model – Almost Done
- Star-CCM+ Meshing for parts
- R5 Model of NTR

Attila Six Region Fuel Model



Peak Power Plates 5, 15



- **Plate 19 added for Comparison**
- **Plates 1-4 Region 1, Plates 6-14, Region 2, Plates 16-18 Region 3**
- **Three Region MCNP Model Data**
- **19 Plate MCNP Model & Report Data**
- **Scale XS Sets 27 Group, 44 Group**
- **Acknowledgements for MCNP: B. Schnitzler, Gray Chang**
- **HELIOS, StudsVik, George Griffith, NEWT, ORNL & James Parry**
- **Attila: Greg Failla, Allen Barnett, Todd Wareing, Ian Davis**

50 Outers – 50 Inners Keff Eps = 0.001 Parallel Attila 32 CPU's Icestorm SGI Altix Cluster

Summary for outer iteration: 50

Relative delphi	:	1.028e-01
Relative balance	:	-4.237e-07
Spectral radius	:	0.929
k eigenvalue	:	9.966e-01
Lambda minus one	:	1.826e-06

Continued

k eigenvalue search summary

Outer iterations : 50

Converged k-effective: 0.9966424

Converged lambda - 1 : 1.826e-06

Outer iteration complete at Tue Mar 03 13:08:15 2009

Continued

Total inner iterations: 1720

Timing recap (s):

Inner sweep time : 277.7112

Inner spec refl time : 15.8756

Inner flx mom time : 14.2958

Inner diff refl time : 0.0011

Inner face edits time : 34.4260

Inner DSA time : 280.9850

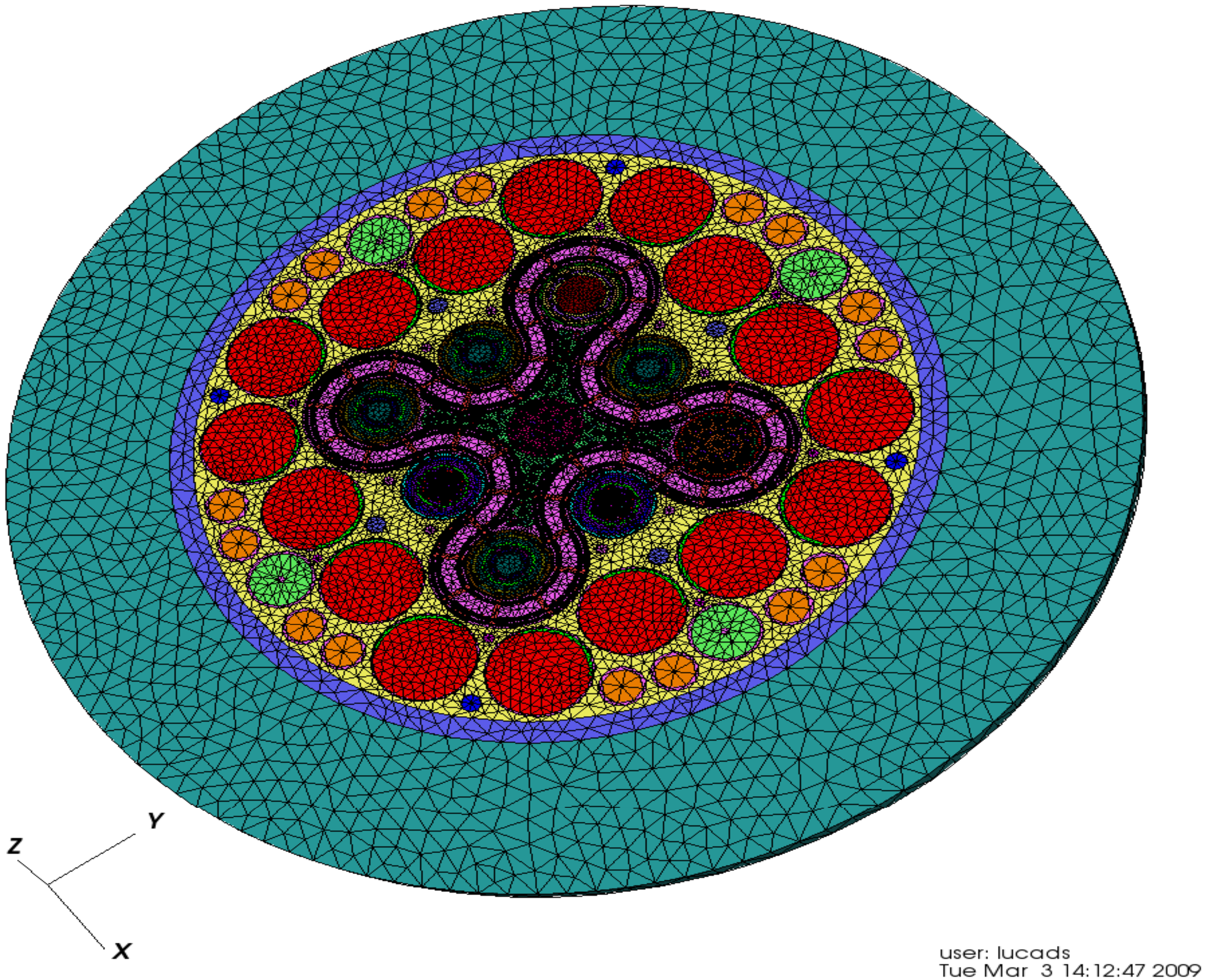
Inner cnvrg measure time: 4.3358

Inner misc time : 13.7536

Elapsed time (s) : 641.3841

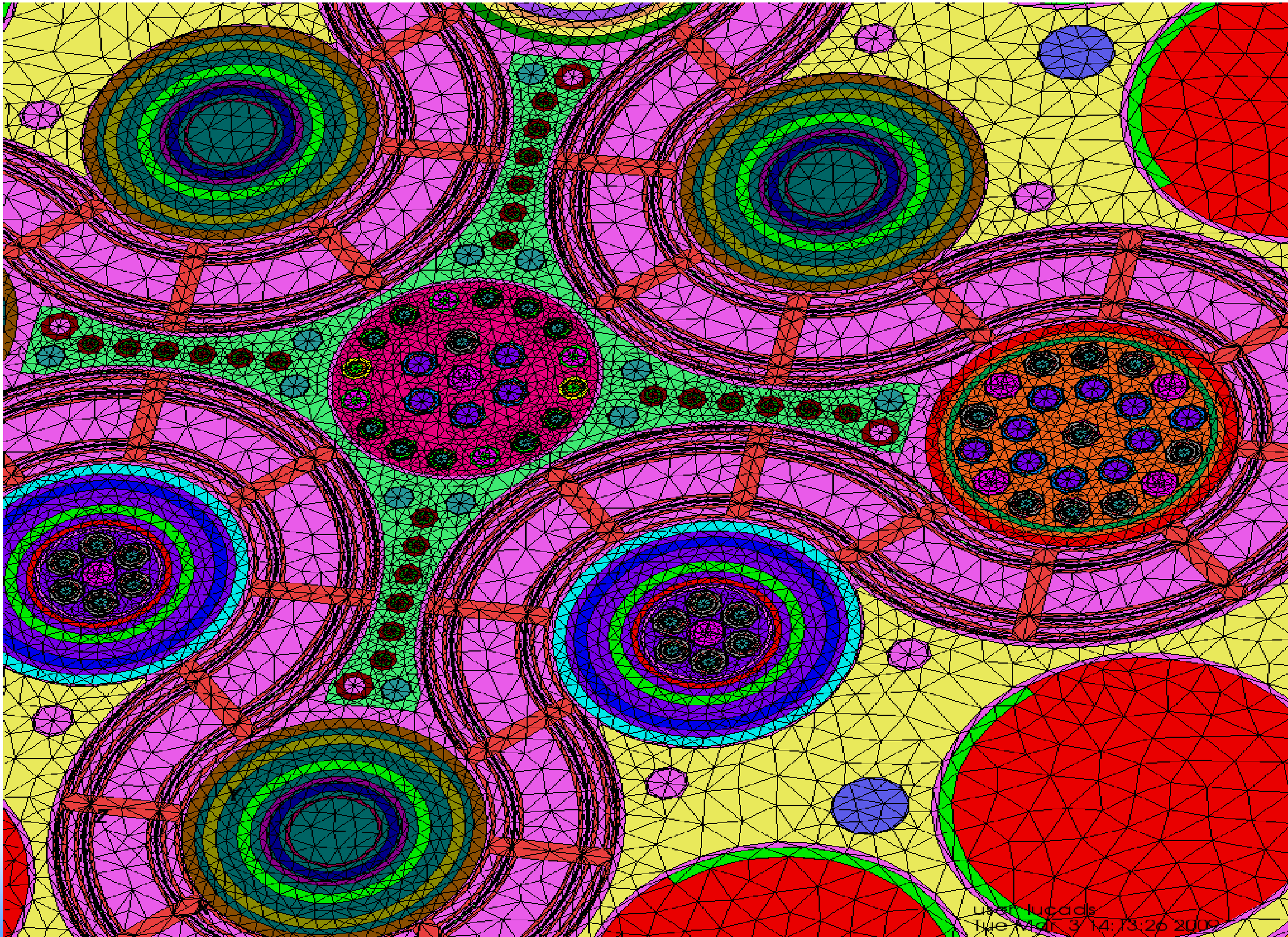
Run time (s): 674.6170

Mesh 133,000 Tets

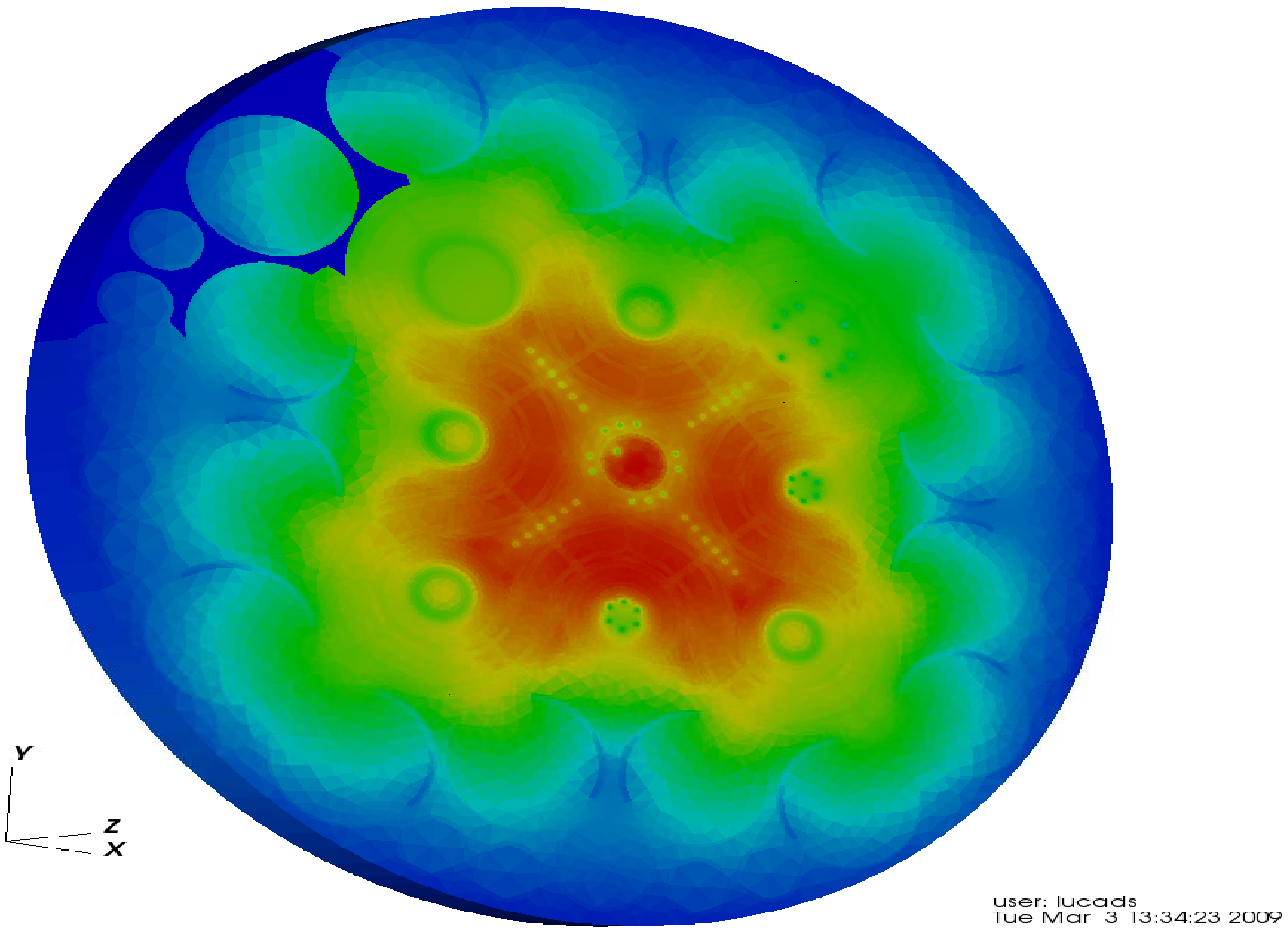


Eight Groups Collapsed in Attila

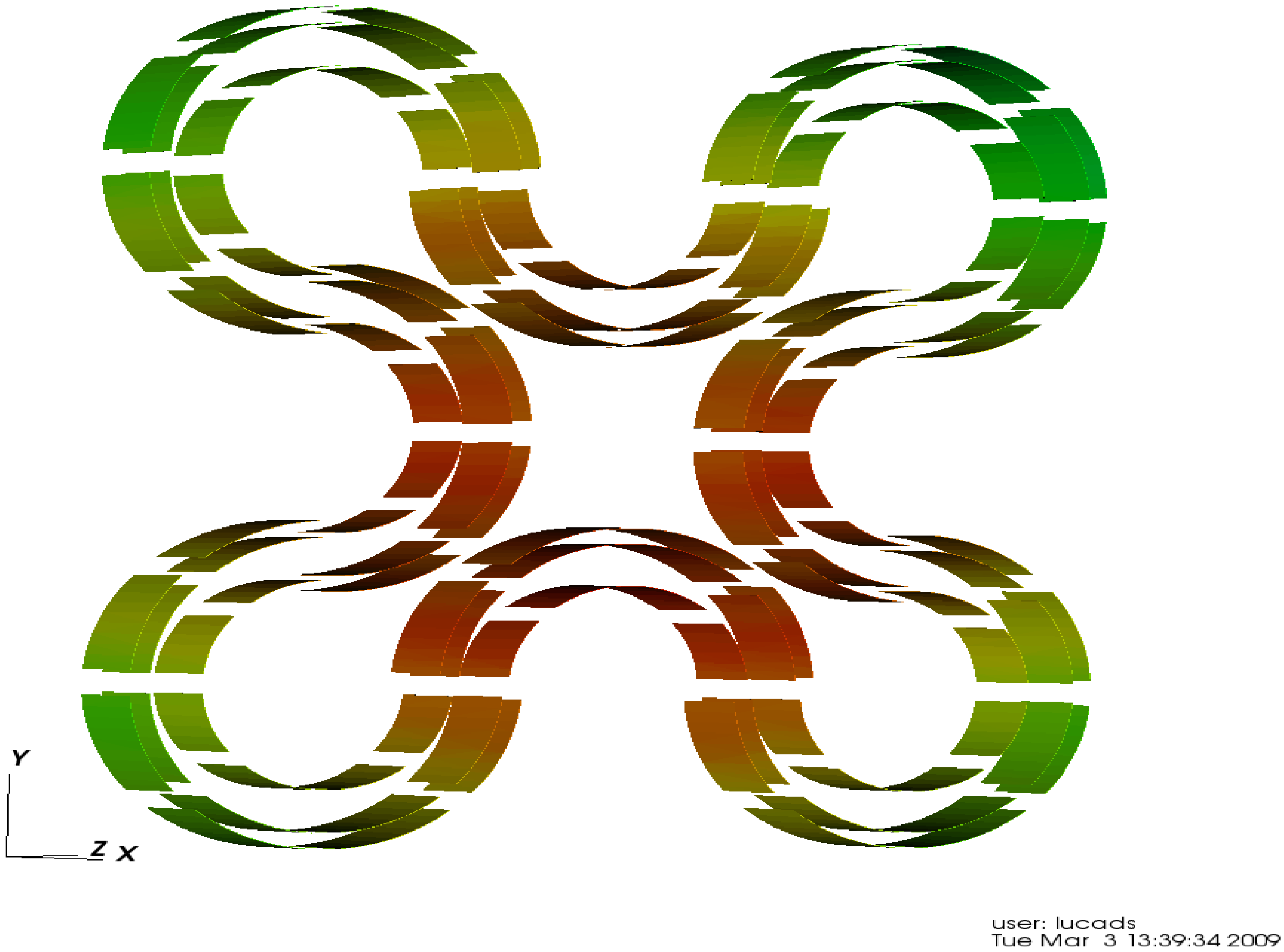
- **20-14 Mev**
- **14-0.017**
- **0.017-3.0e-5**
- **3.0e-5-1.77e-6**
- **1.77e-6-1e-6**
- **1e-6-3.25e-7**
- **3.25e-7-5e-8**
- **5e-8-1e-11**


user: lucads
Tue Mar 3 14:13:26 2009

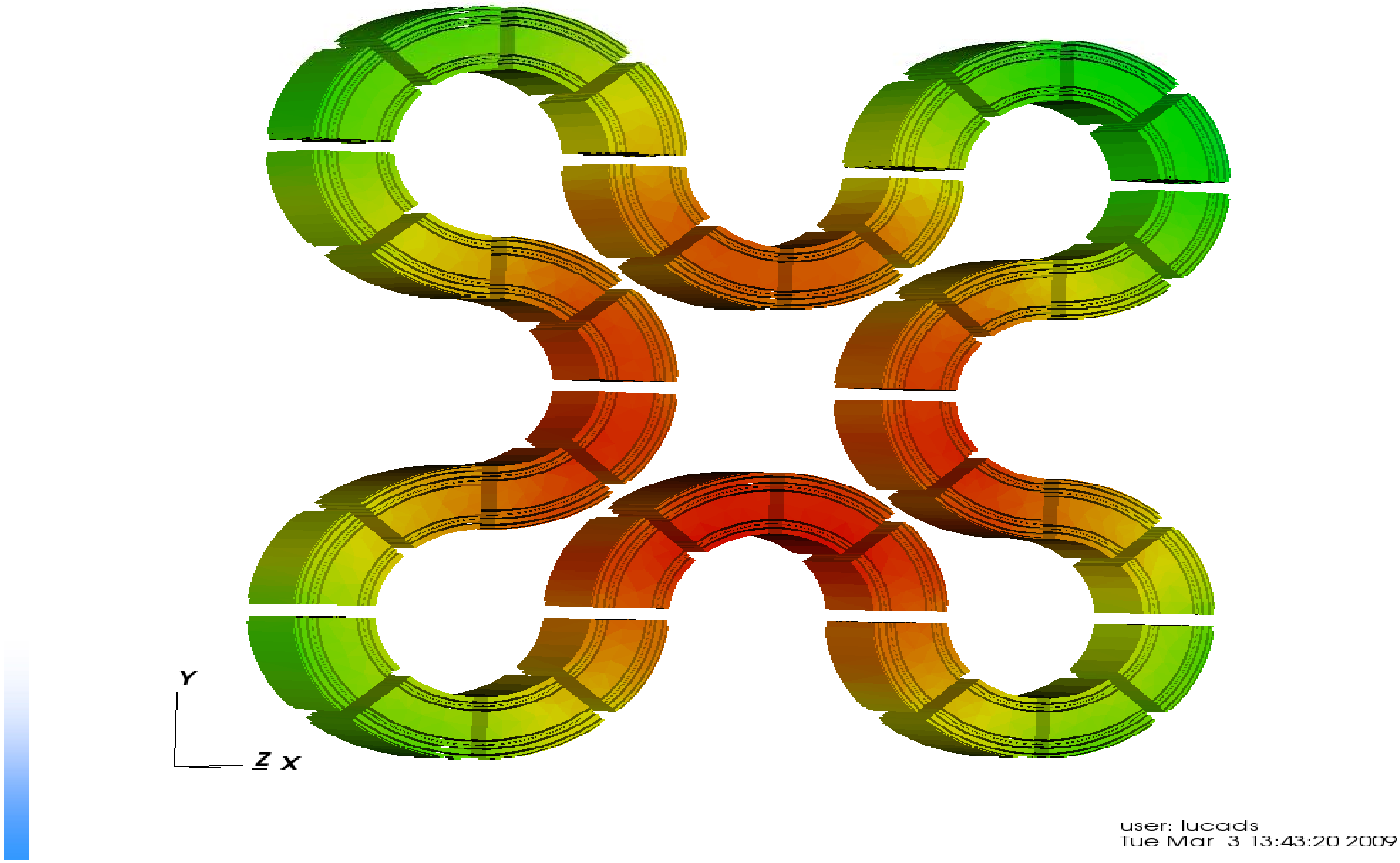
Flux Plot



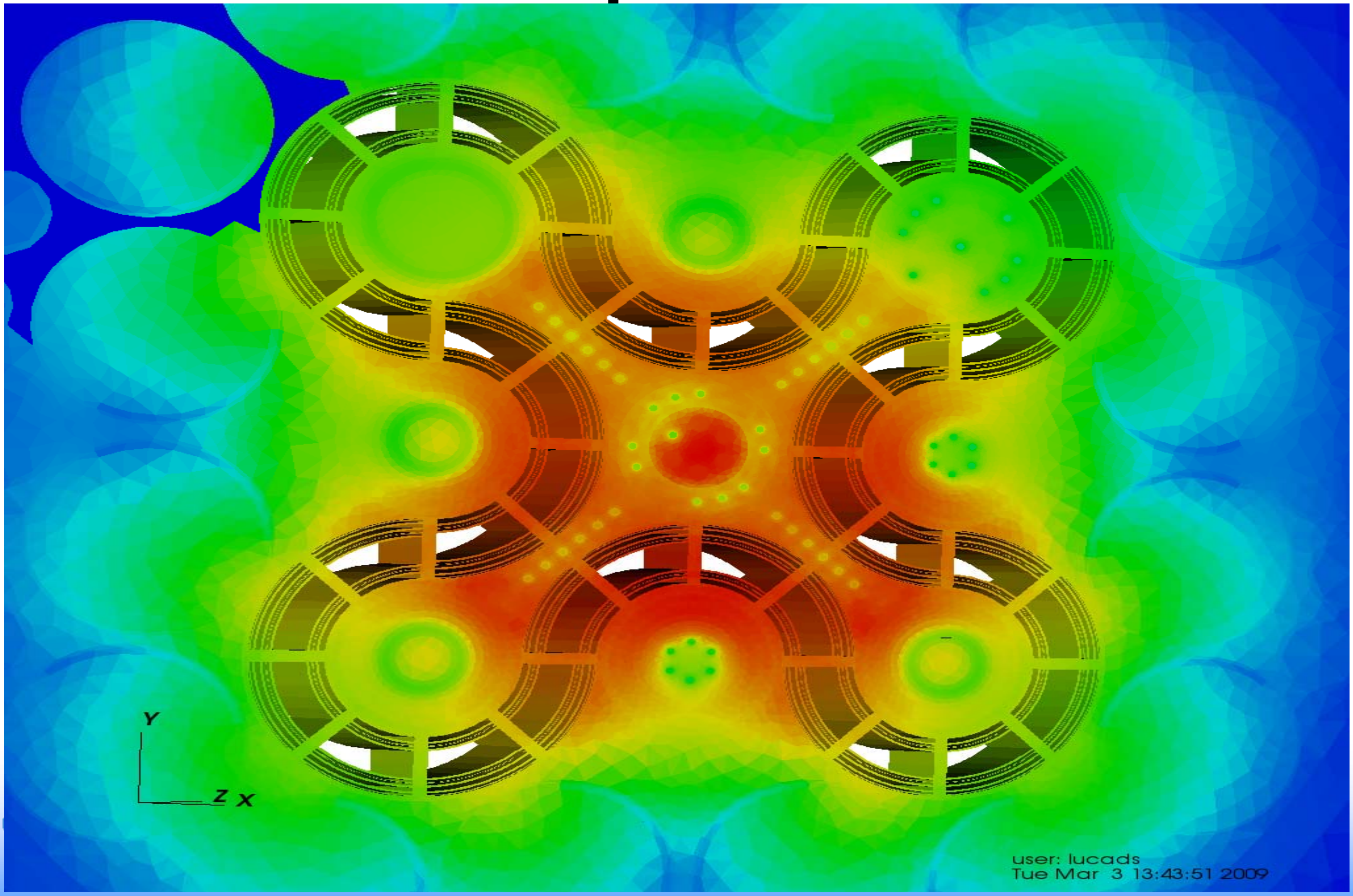
Peak Power Plates



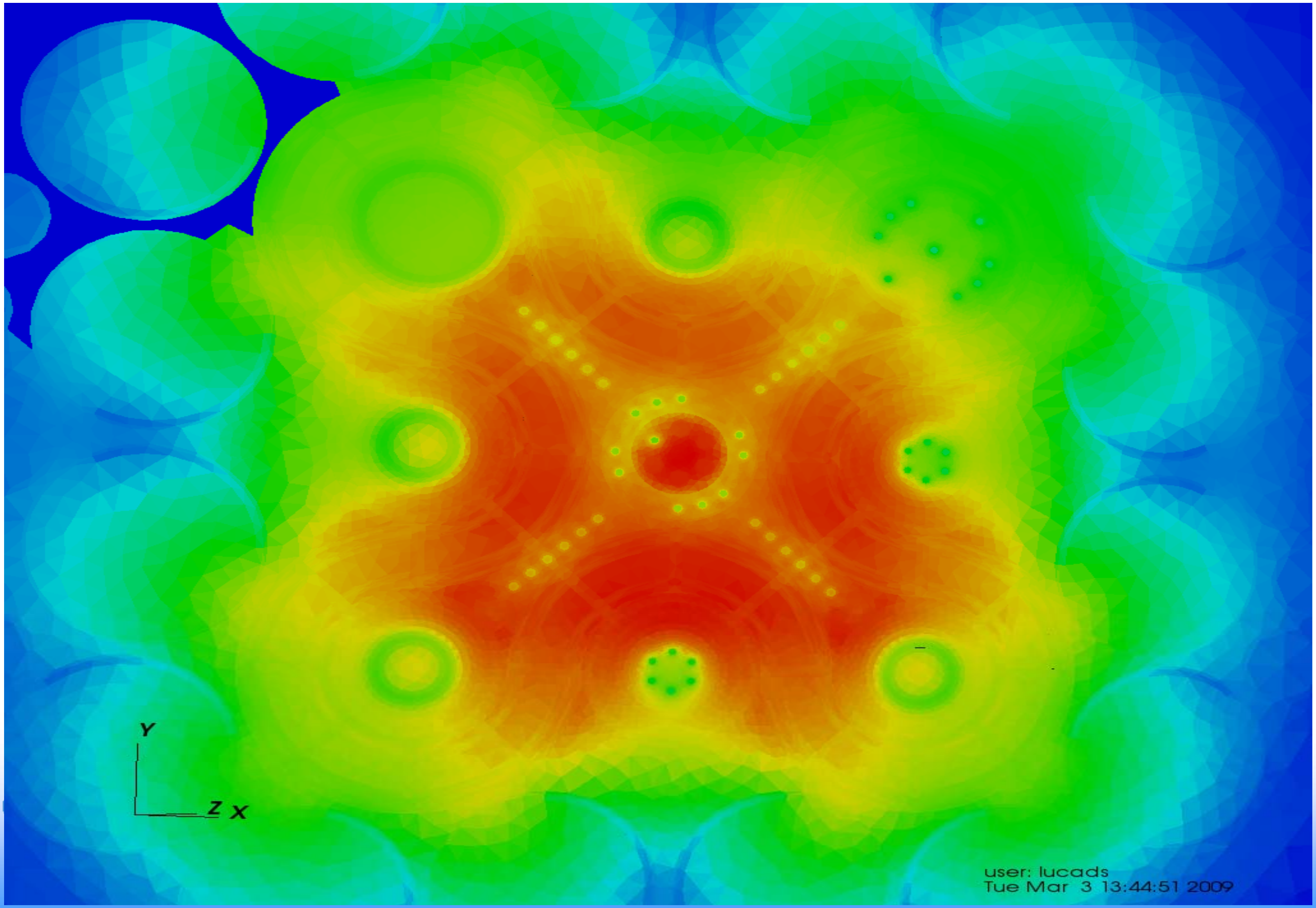
All Fuel



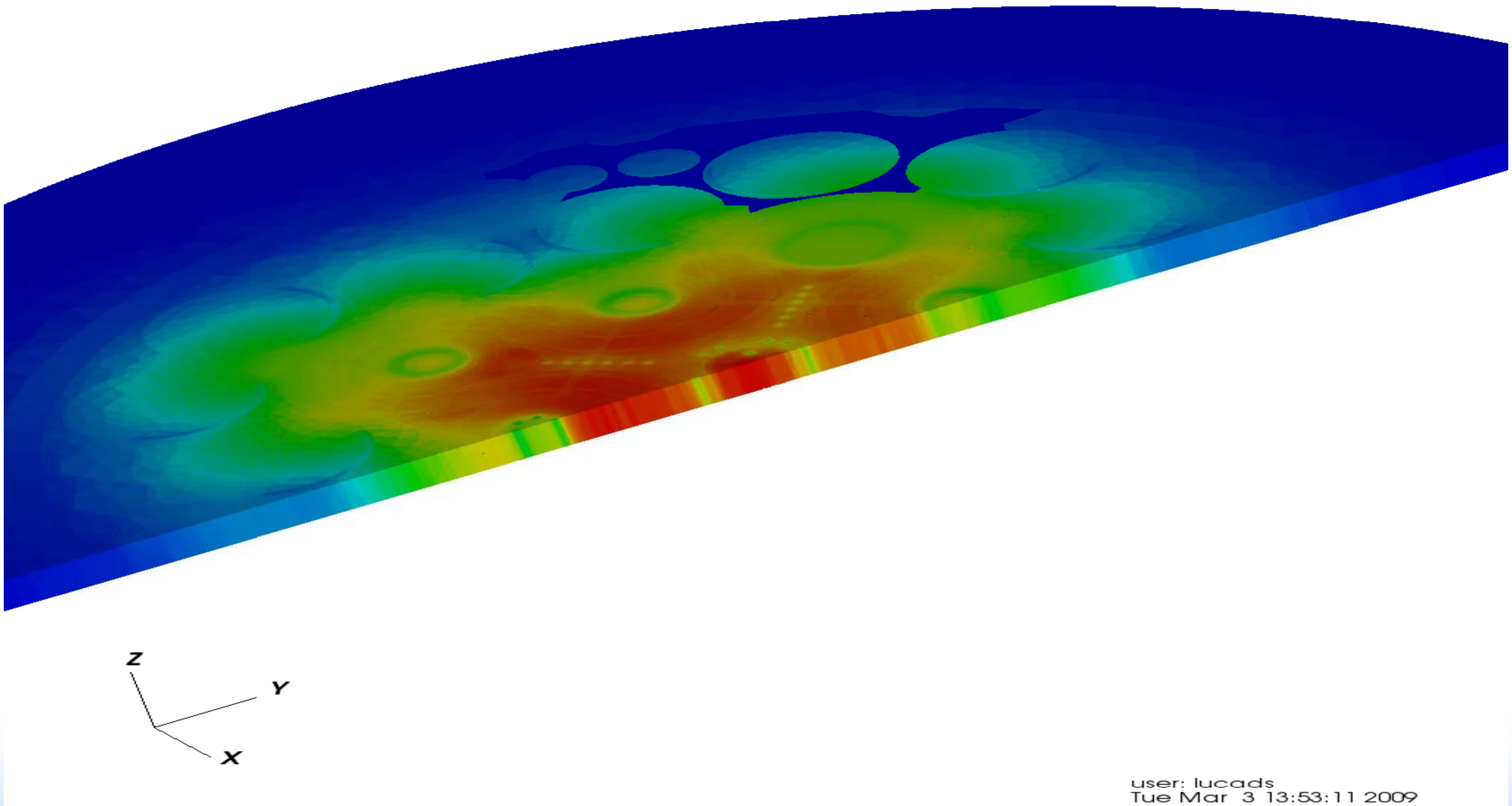
No Fuel Close Up



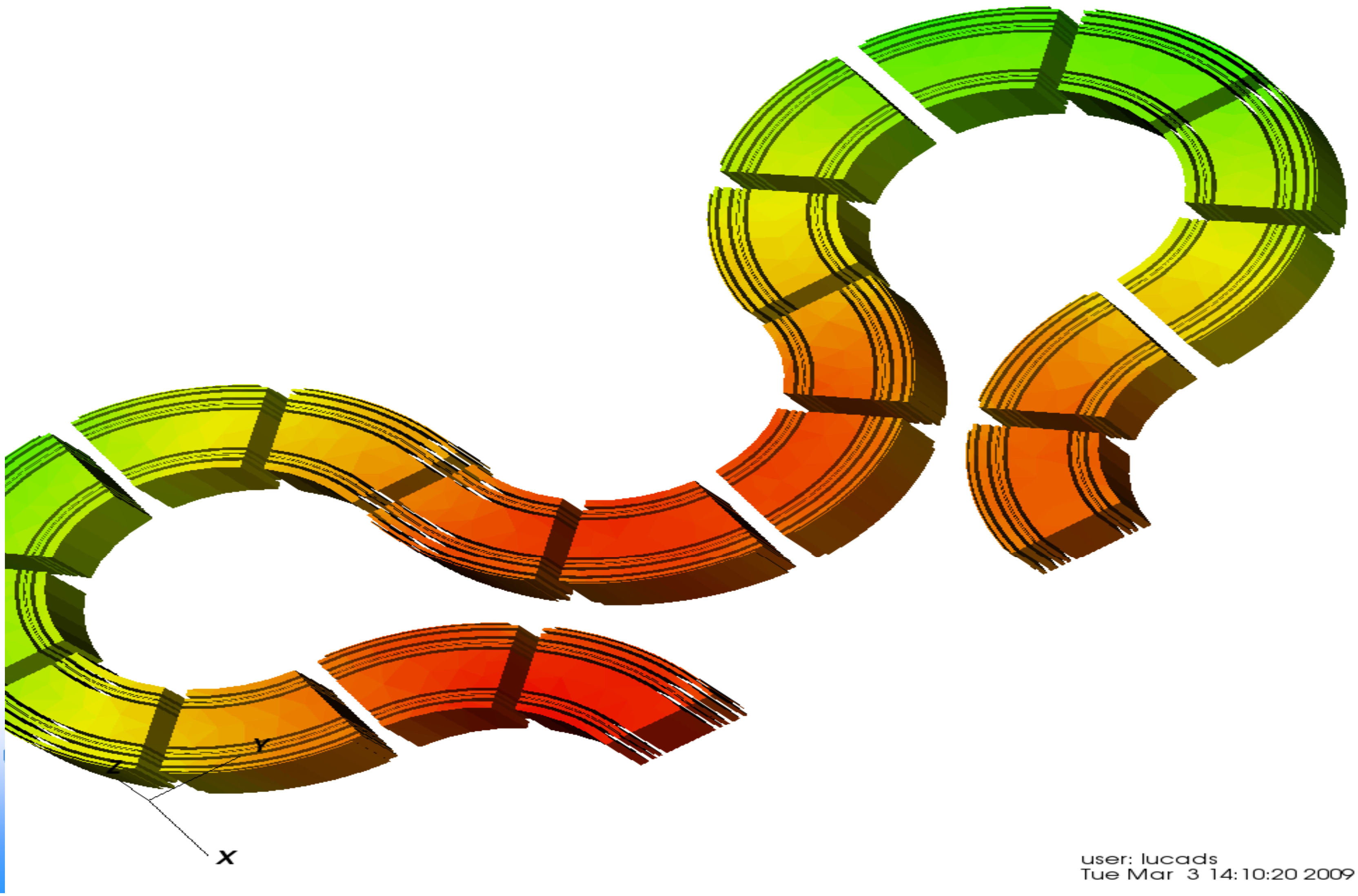
Closer Up with Fuel



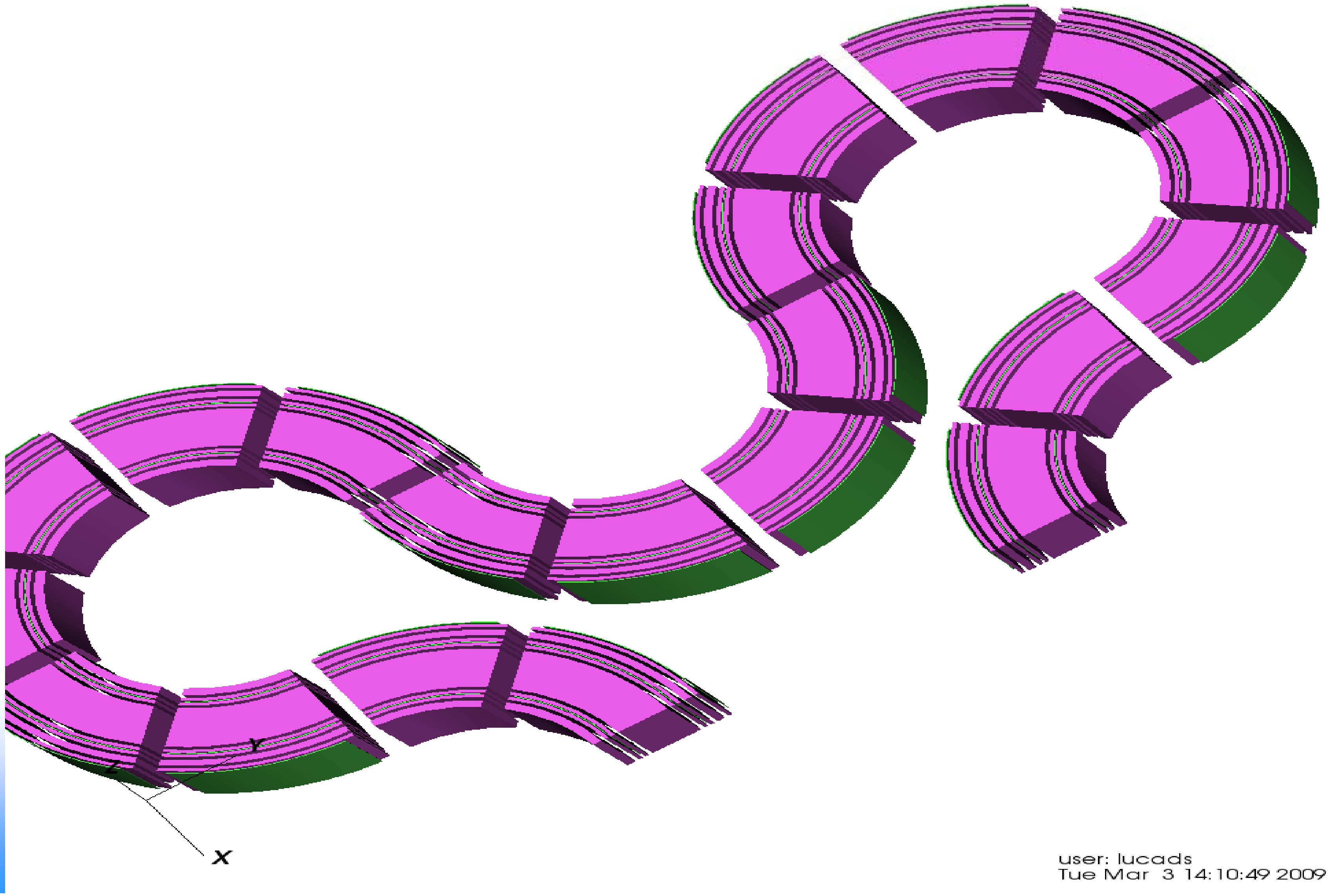
Slice



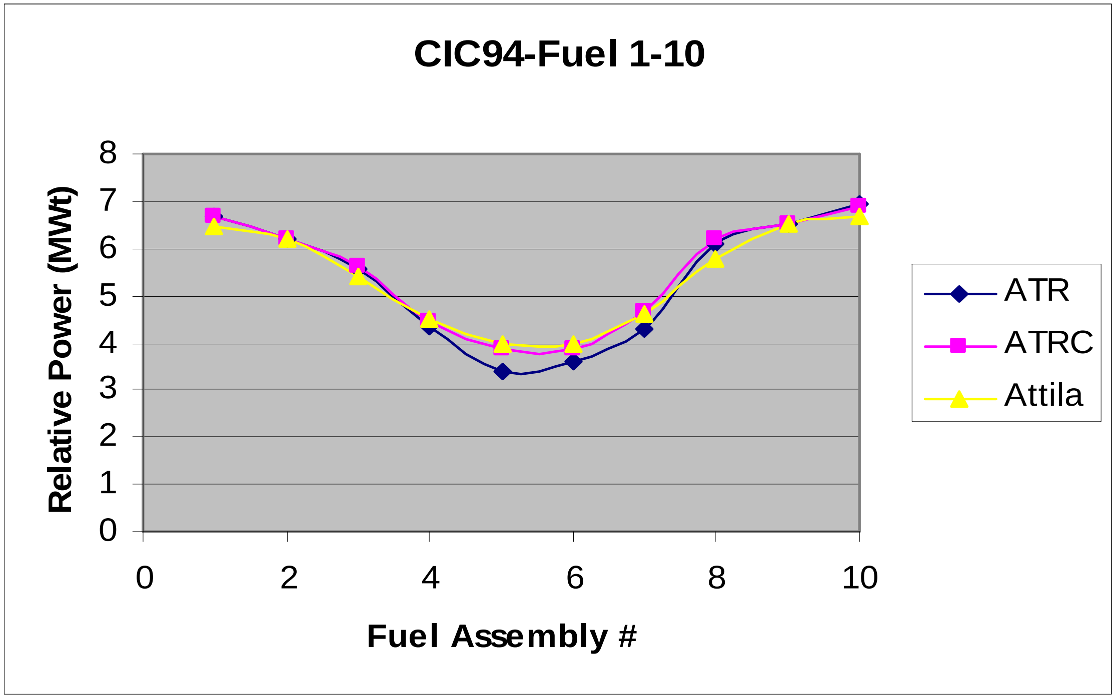
Fuel Slice



Hot Purple Fuel



Relative Power 1st Ten Assemblies Not Bad for 11.24 Minutes of CPU Time



Attila Adjoint (Importance) Calculations

k eigenvalue search summary

Outer iterations : 50

Converged k-effective: 0.9966424

Converged lambda - 1 : 1.826e-06

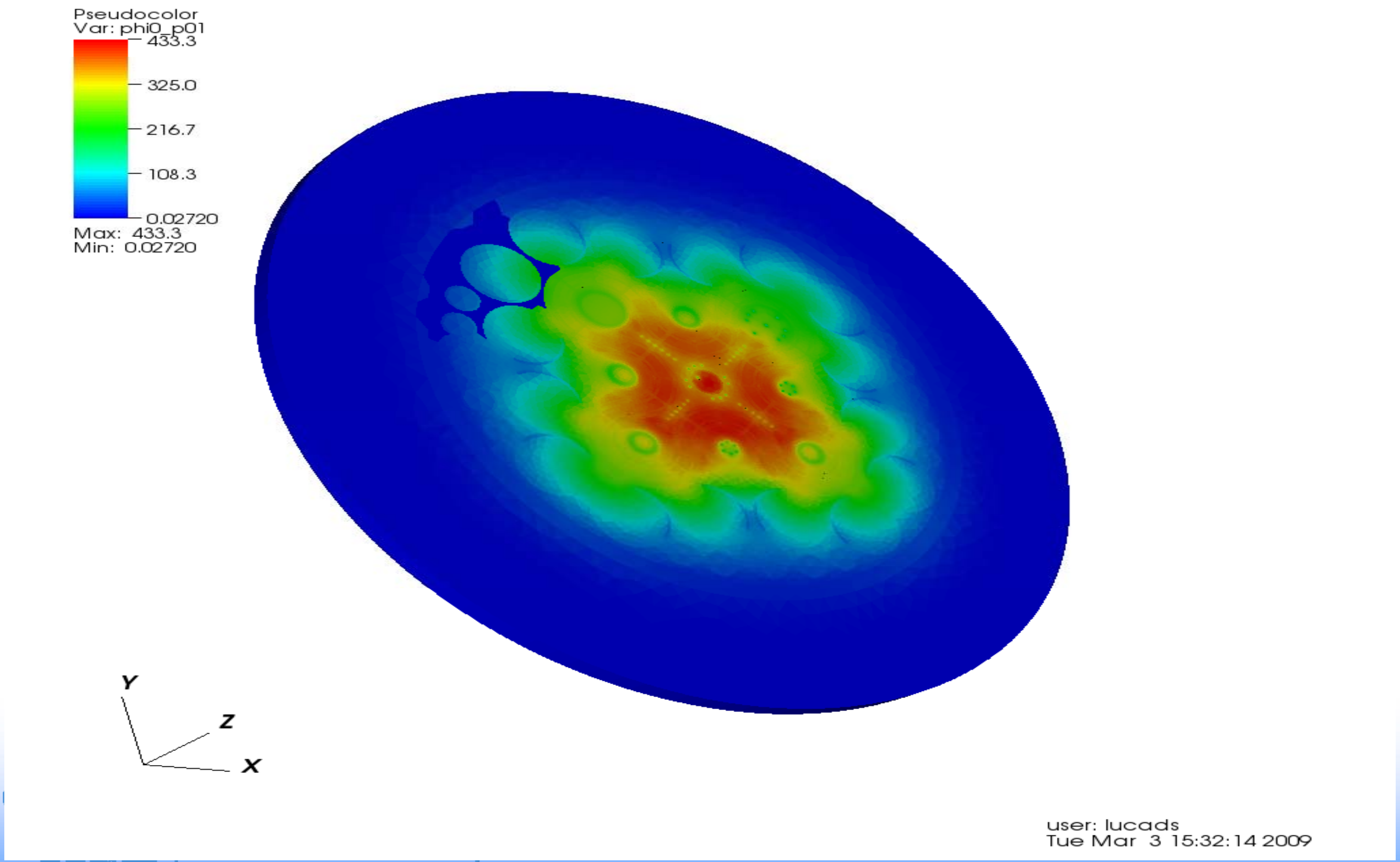
Total inner iterations: 1720

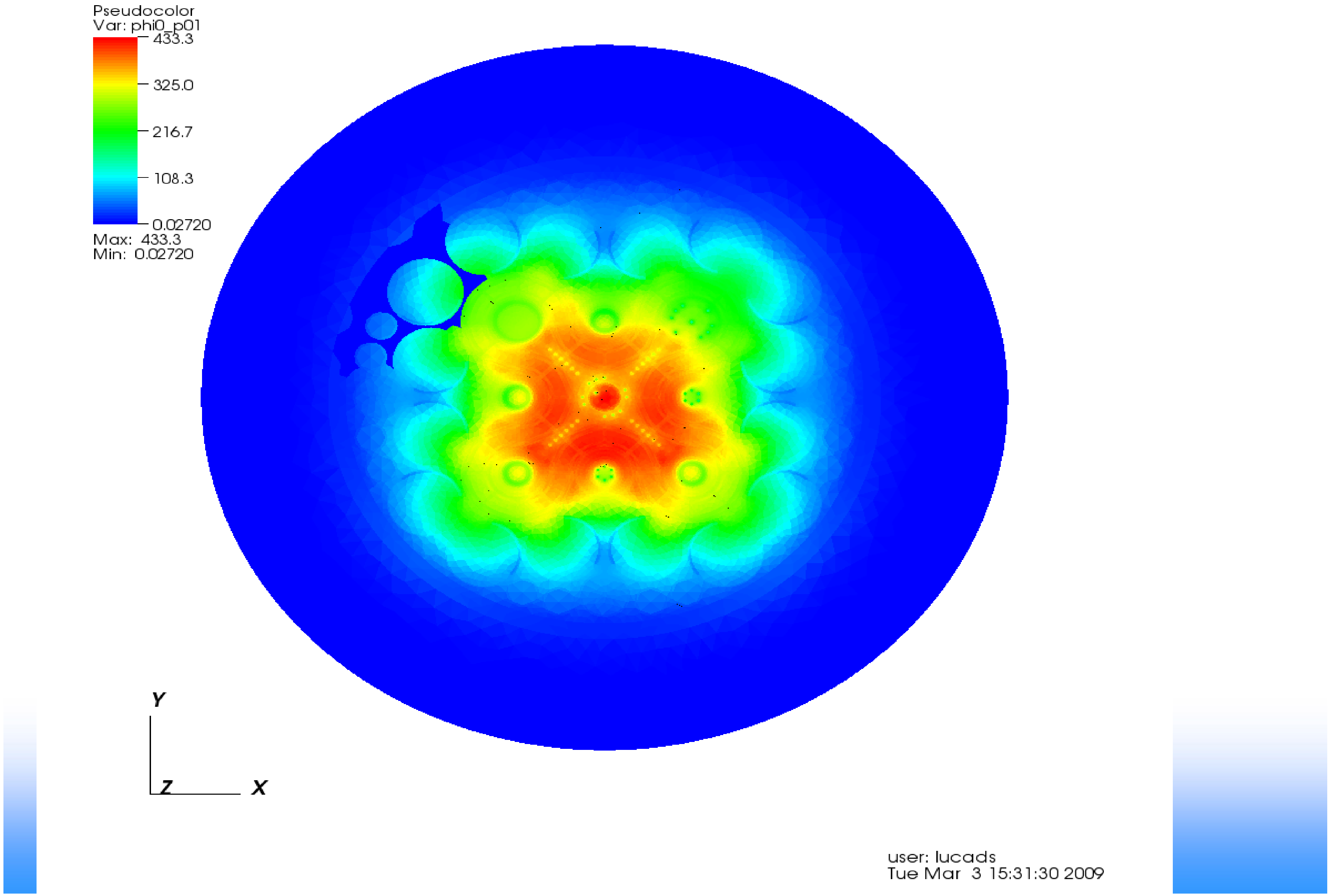
Timing recap (s):

Elapsed time (s) : 641.9678

Run time (s): 663.4551

Adjoint Flux




Pseudocolor
Var: phi0_p01
433.3
325.0
216.7
108.3
0.02720
Max: 433.3
Min: 0.02720
Y
Z
X
user: lucads
Tue Mar 3 15:31:30 2009

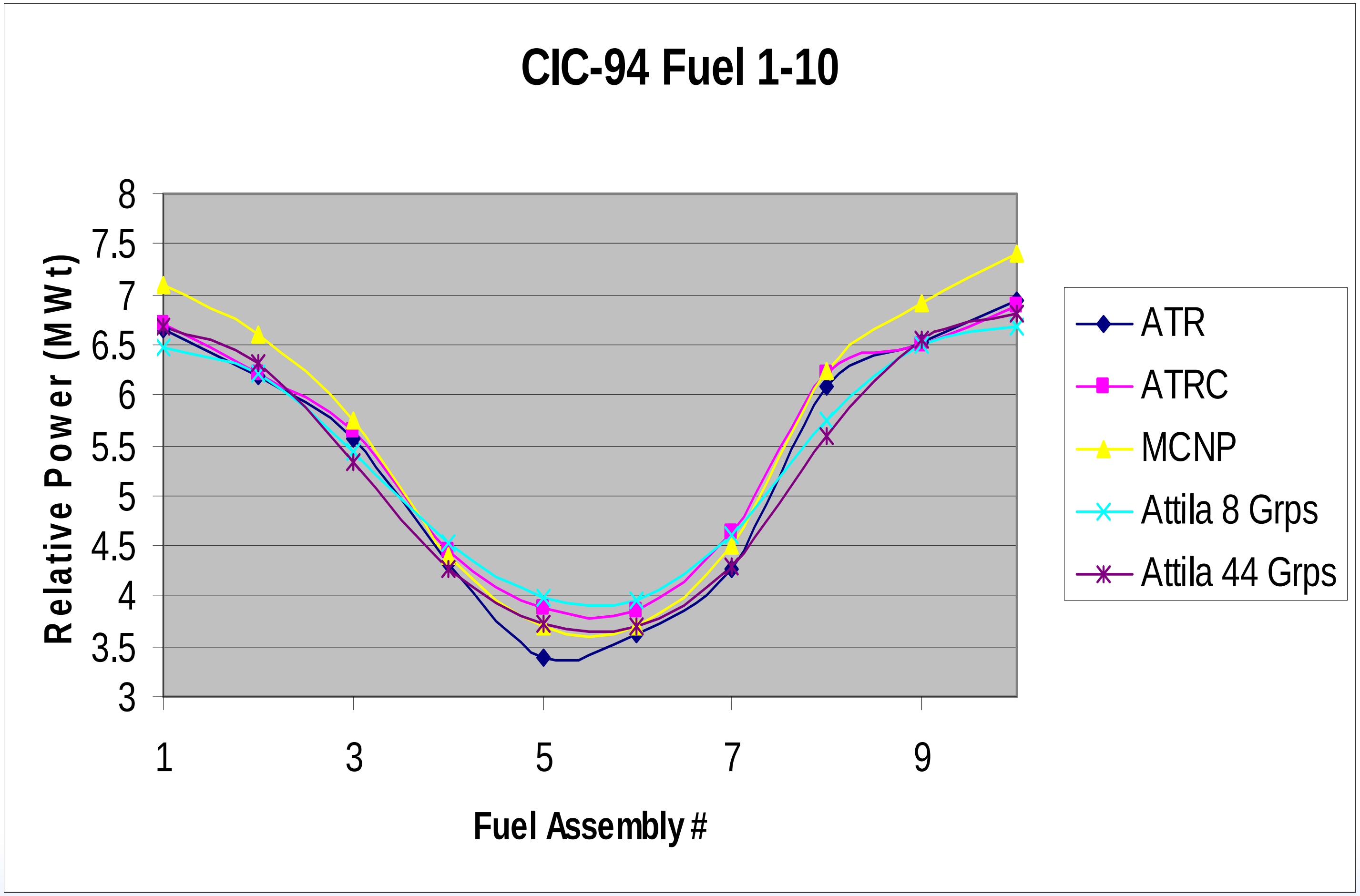
44 Group Results

- Summary for outer iteration: 50
- Relative delphi : 4.322e-02
- Relative balance : -2.110e-06
- Spectral radius : 0.951
- k eigenvalue : 9.731e-01
- Lambda minus one : 3.153e-05
- WARNING-------------------------------
- Maximum number of outer iterations exceeded.
- Outer iteration may not be fully converged.
- END-WARNING---------------------------
- k eigenvalue search summary
- Outer iterations : 50
- Converged k-effective: 0.9731357
- Converged lambda - 1 : 3.153e-05

Continued

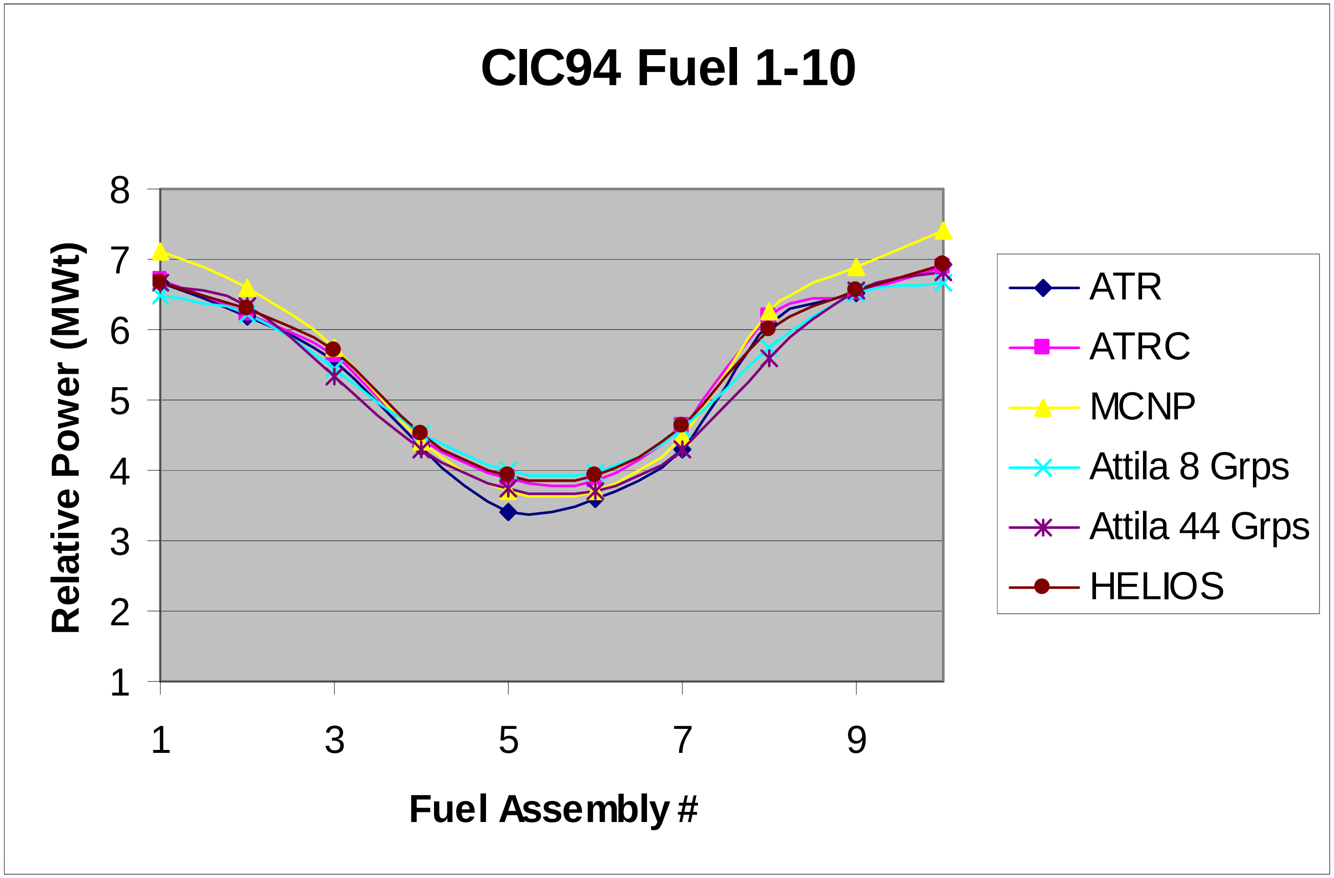
- **Total inner iterations: 13136**
- **Timing recap (s):**
- **Inner sweep time : 880.3772**
- **Inner spec refl time : 58.4304**
- **Inner flx mom time : 54.5050**
- **Inner diff refl time : 0.0075**
- **Inner face edits time : 133.6451**
- **Inner DSA time : 3830.0265**
- **Inner cnvrg measure time: 14.1233**
- **Inner misc time : 50.6402**
- **Elapsed time (s) : 5021.7552**
- **Run time (s): 5129.9386**

44 Group Comparisons

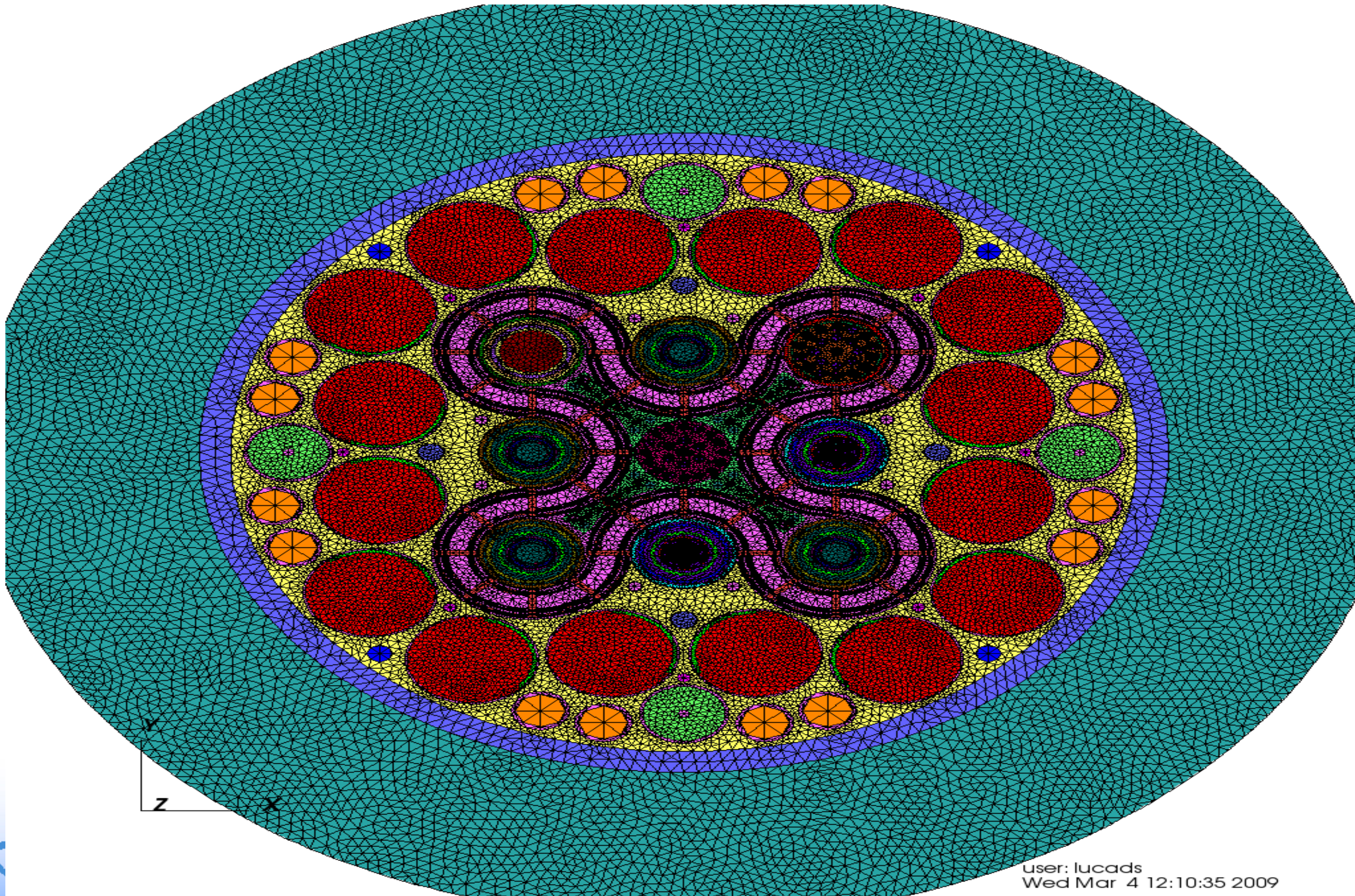


Idaho National Laboratory

Comparisons with HELIOS



Convergence Studies – 8 Grp 6 Region Fuel 133K Tets vs. 212 K Tets



Keff

212 K Tets

k eigenvalue search summary

Outer iterations : 50

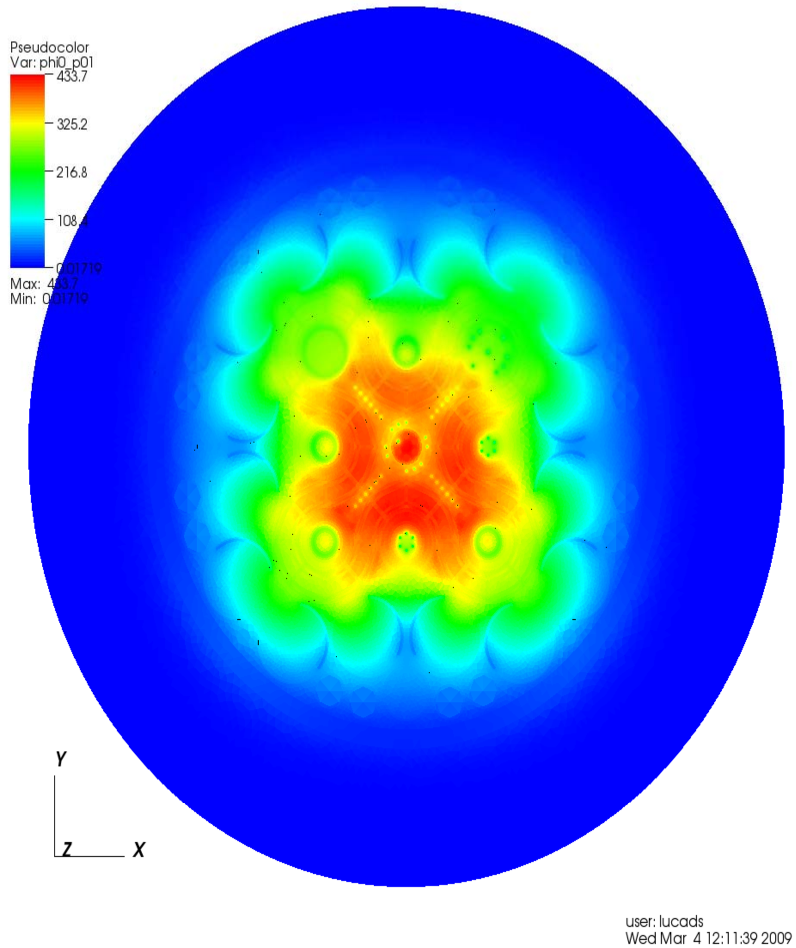
Converged k-effective: 0.9959525

Converged lambda - 1 : 2.668e-06

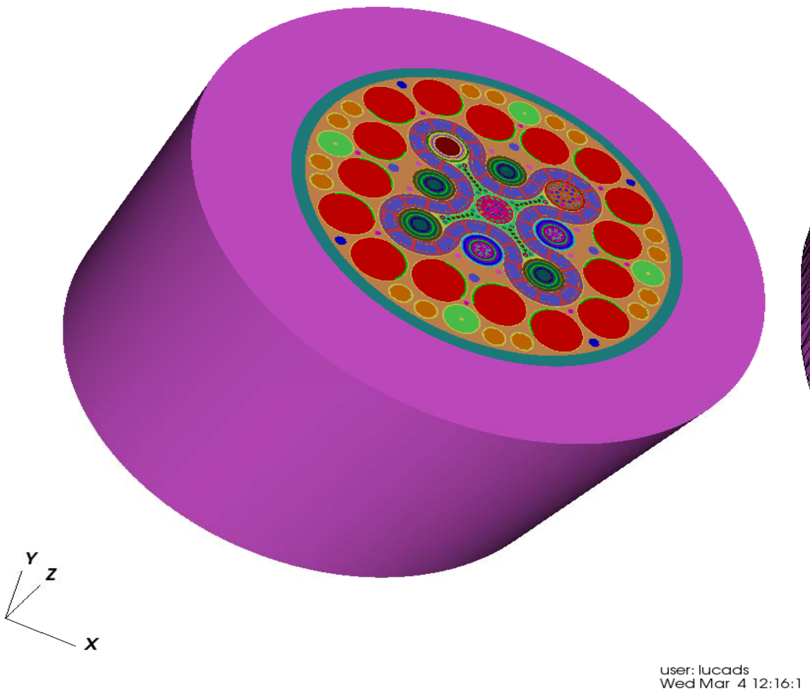
Run time (s): 844.9737

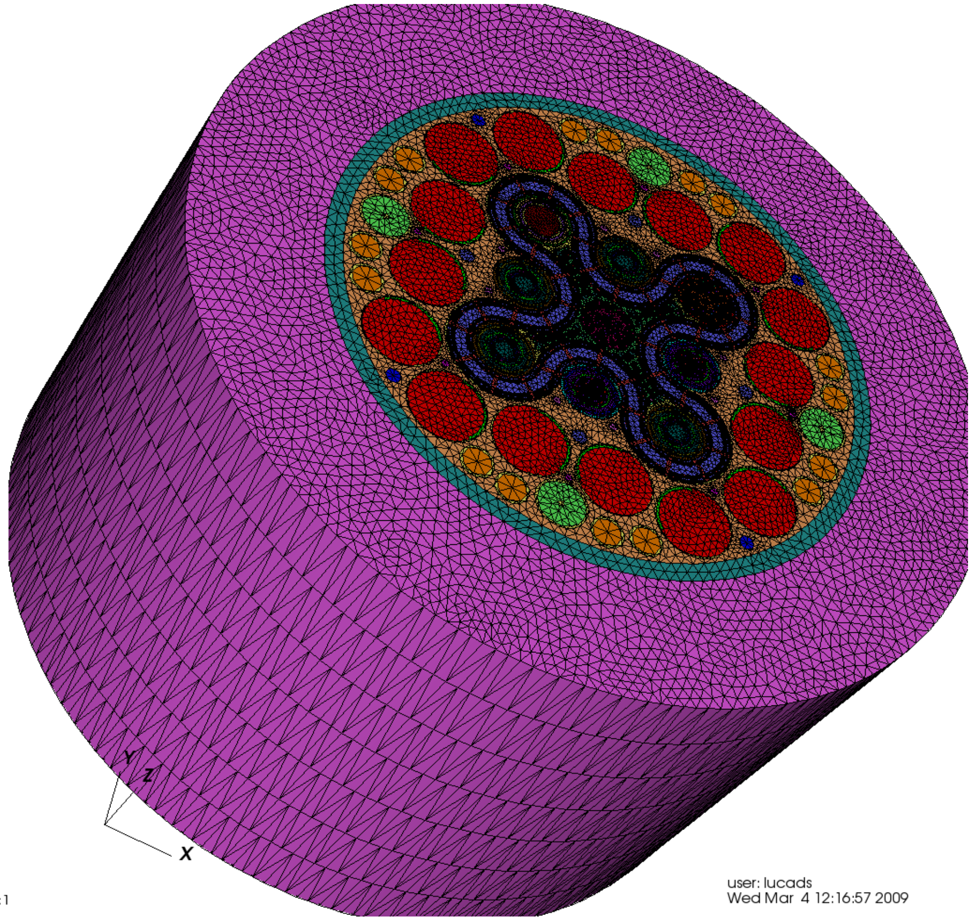
Original Run 133K Tets

k-effective = 0.9966424

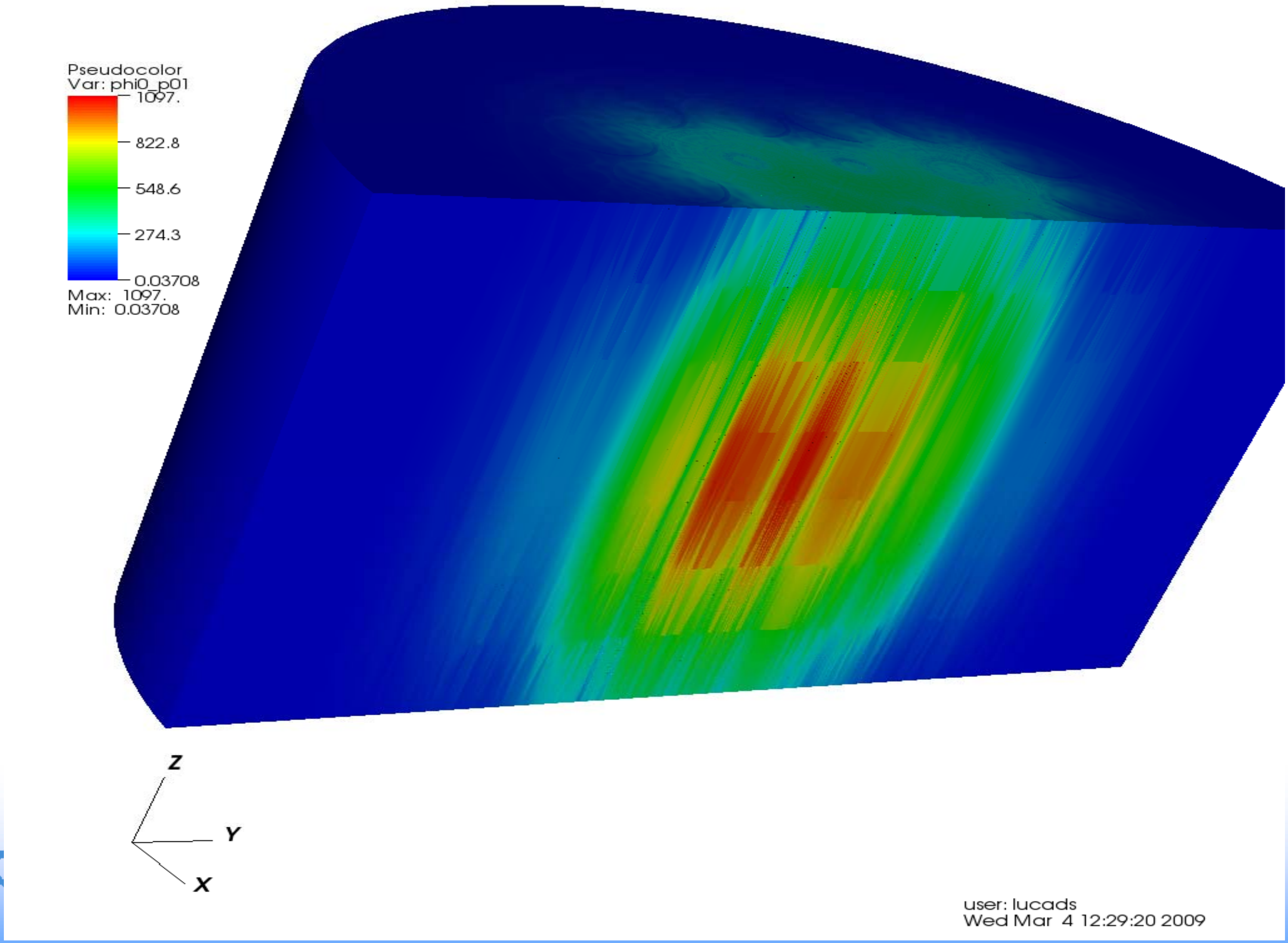


3D 6 Region Fuel 1.2 M Tets

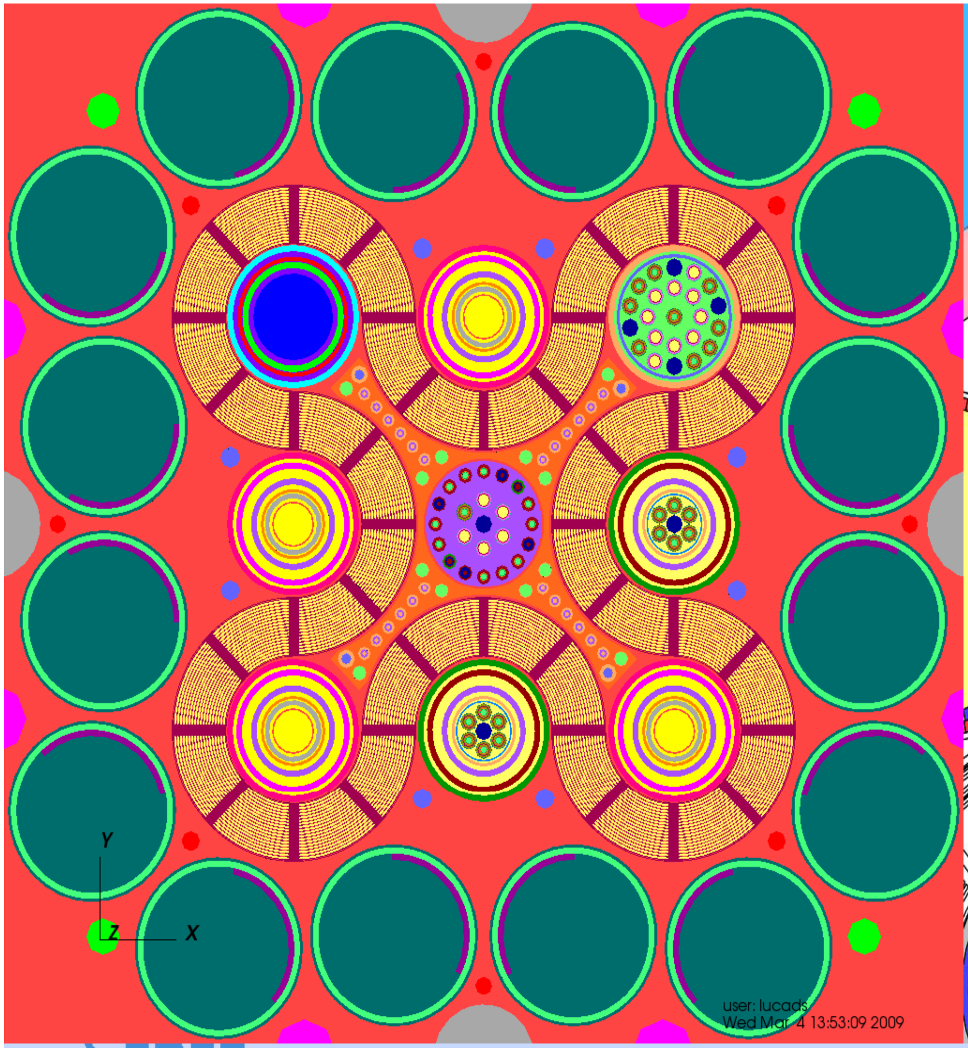


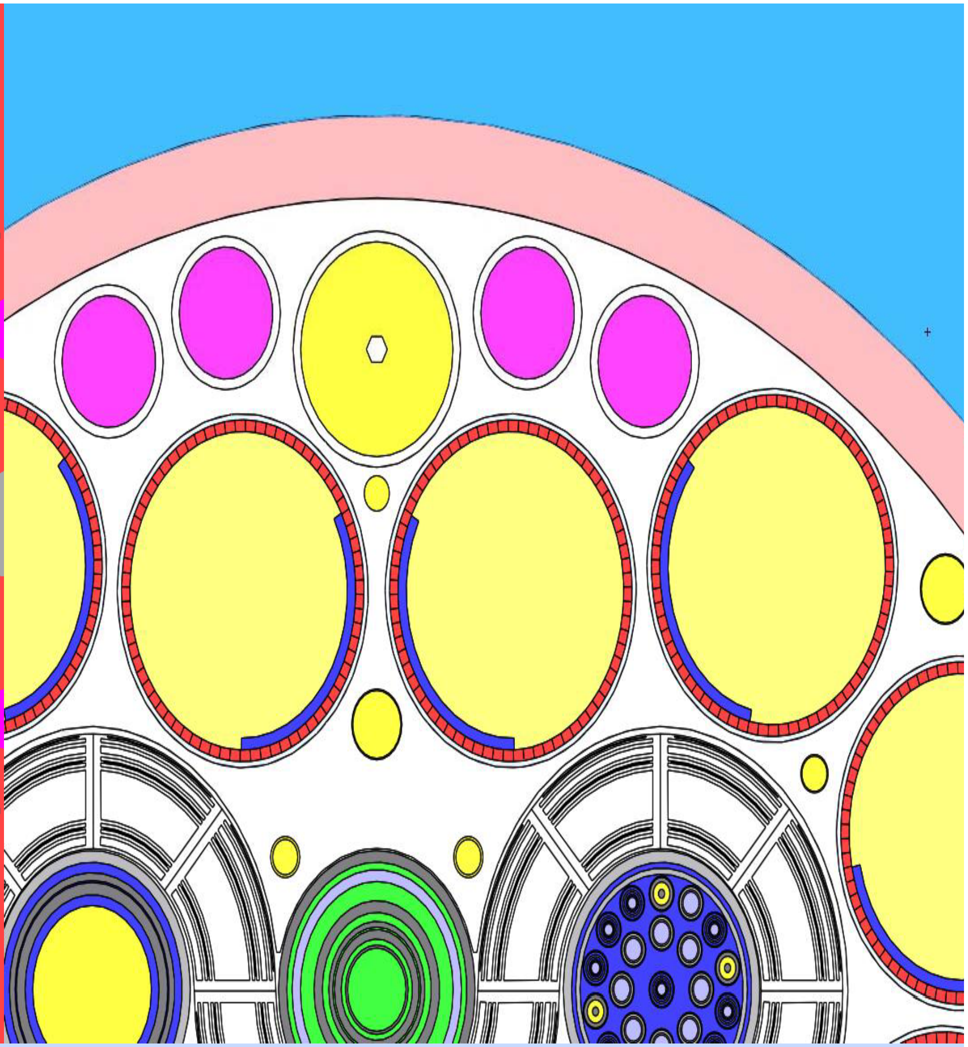


Flux Distribution



19 Plate Model- Lots of Data Input for Fuel and Five Degree Shim Sections





Summary

- 19 Plate Model Done - Putting in Data
- GMV Viewer Fixed to allow 10,000 Regions for VisIt
- Burn Module in Parallel coming soon
- NEWT, HELIOS and Attila Producing Results
- Will need a XS Translator from HELIOS to Attila XS Format (DTF)
- Working with NEWT & Ampx2DTF XS Libs
- Funding Check in the Mail
- Hook VisIt to NEWT/HELIOS