INL/CON-16-39358-Revision-0

A Neutron Streaming Problem to Test Rattlesnake Methods for TREAT

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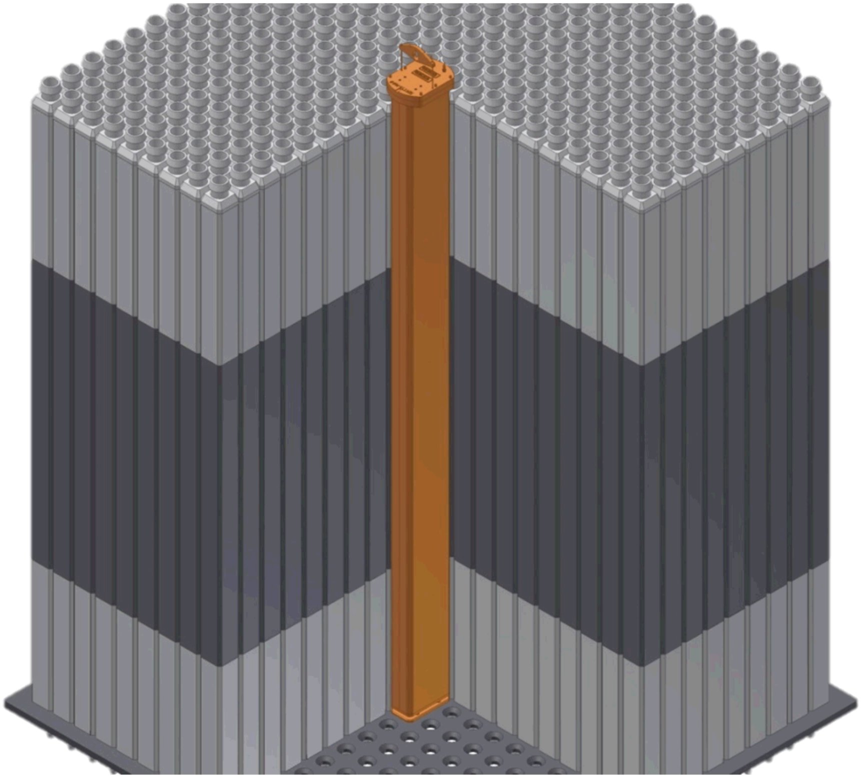
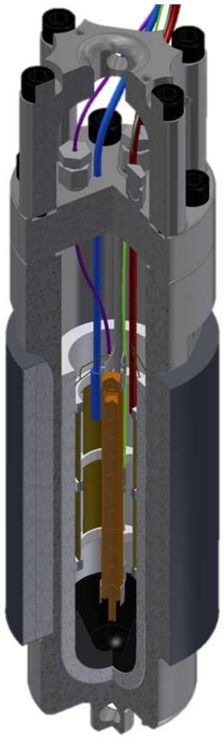
Outline

- Introduction / Motivation
- Codes
- Cross Section Preparation Process
- Methods
  - Superhomogenization
  - Calculation of tensor diffusion coefficients
- Test Problem Description
- Results
- Conclusion

Introduction / Motivation

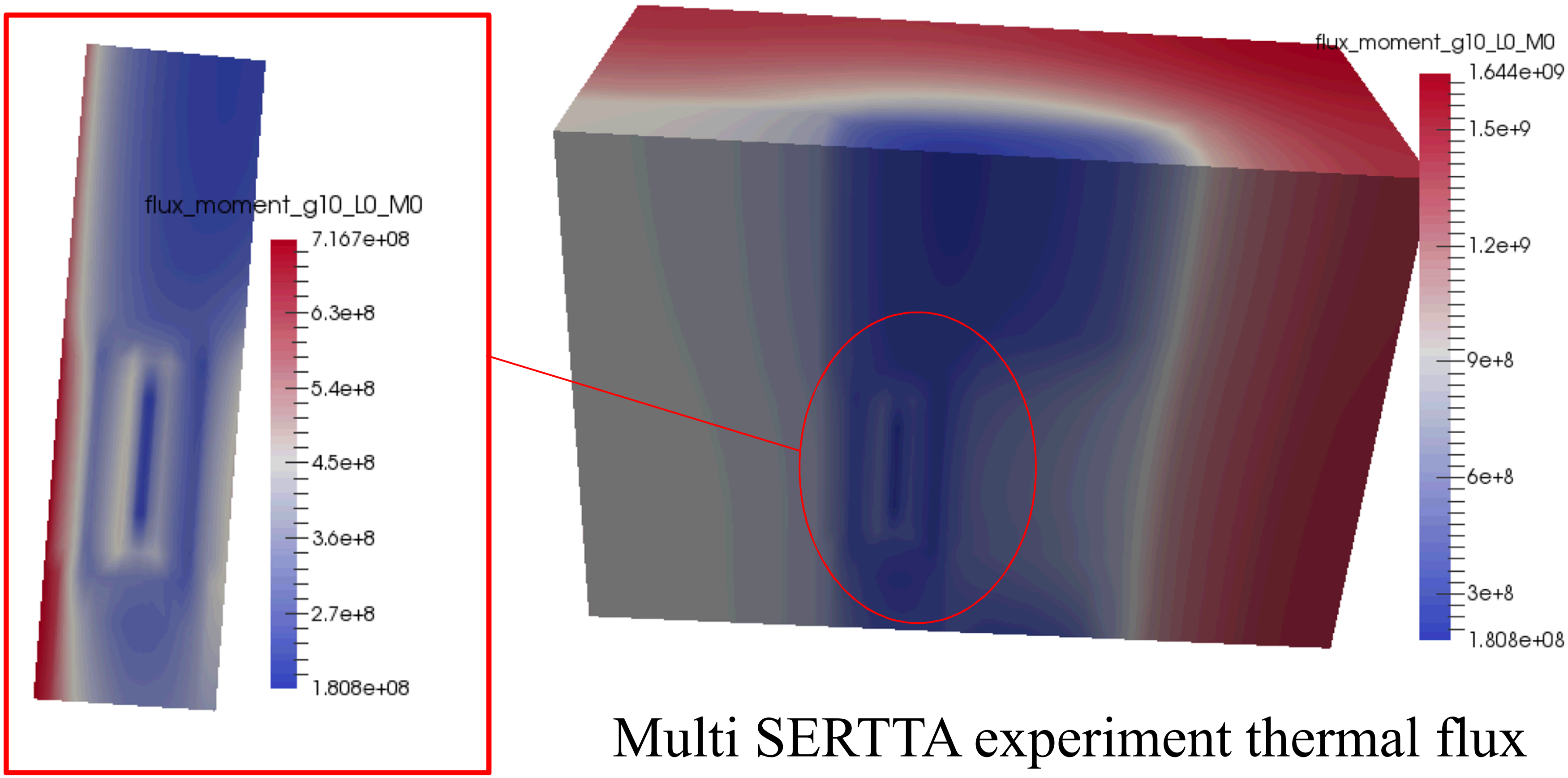
- There are various regions in the Transient REActor Test (TREAT) facility core that contain voids, primarily in slotted elements and experiment vehicle.
- The slotted elements are positioned in front of the experiment region in order to provide a "field of view" of the experiment to the hodoscope.





Introduction / Motivation

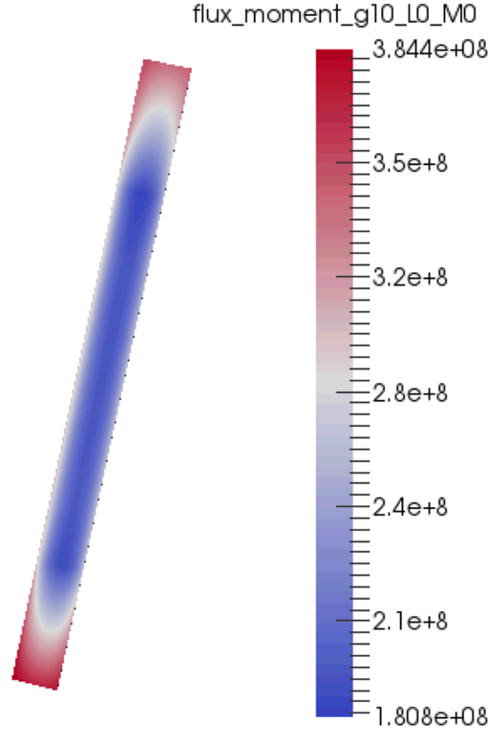
- Experiment location experiences significant flux gradients.
- Flux anisotropy might have important effects on experiments.

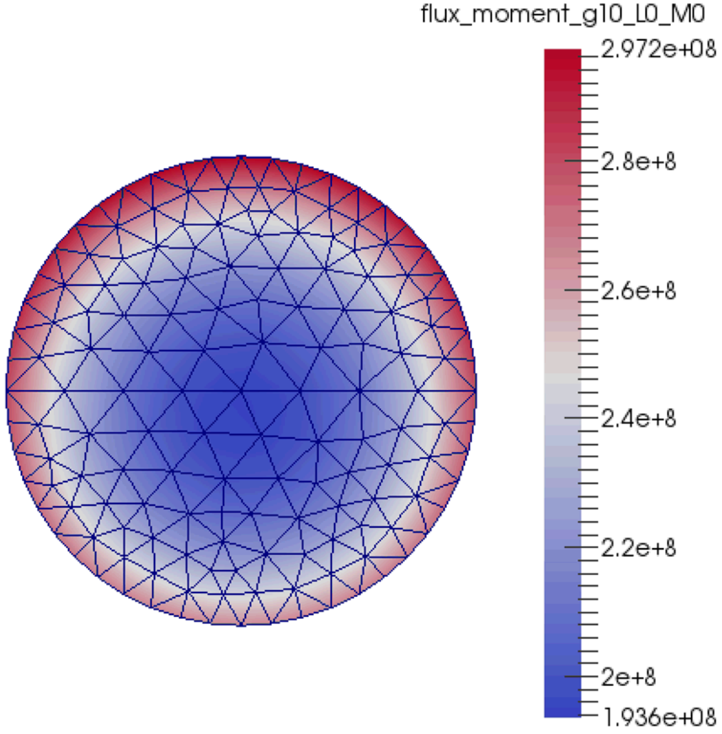


Multi SERTTA experiment thermal flux from S_{12} solution

Introduction / Motivation

- Our goal is to provide modeling and simulation capability for experiment design and transient behavior.





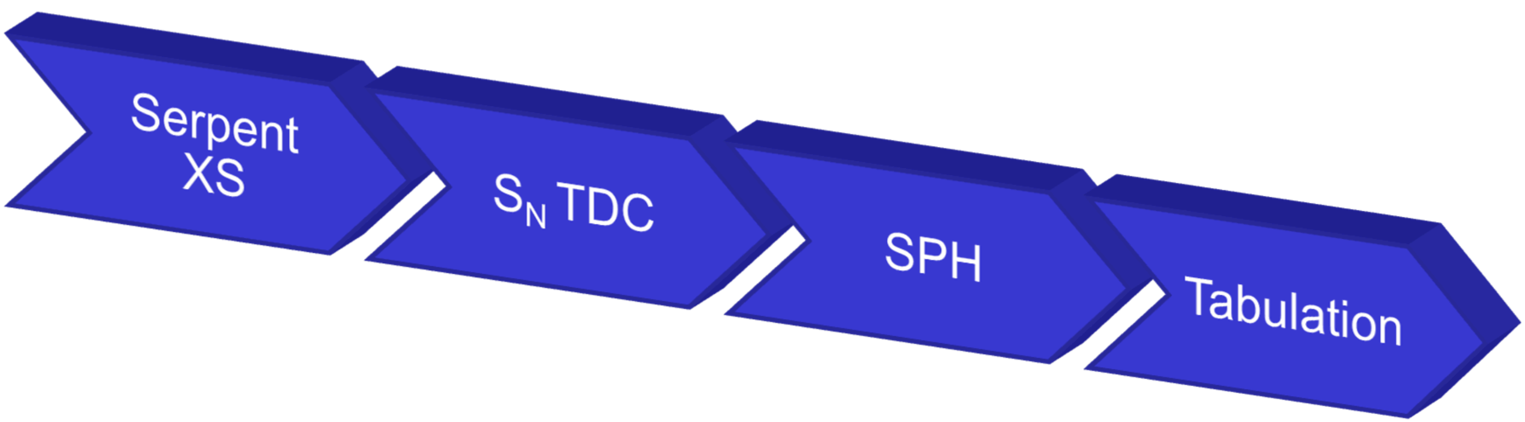
Multi SERTTA experiment thermal flux from S_{12} solution

CODES

- Serpent Monte Carlo (v2.1.26)
  - Cross section preparation
  - Reference solution
- Rattlesnake
  - MOOSE based transport solver
  - CFEM Diffusion, S_N, P_N
  - Superhomogenization method
  - Larsen-Trahan tensor diffusion coefficient computation
  - Coupled to BISON and Relap-7 (MAMMOTH)

Cross Section Preparation

- Goal is to perform transient diffusion calculations when possible.
- Full core Monte Carlo to generate base cross sections.
  - Isotropic diffusion coefficient
- Full core S_N Larsen-Trahan source problem for tensor diffusion coefficients in void regions.
- SPH correction on coarse mesh as an equivalence procedure.



METHODS: Superhomogenization Procedure

- Cross section correction method for energy condensation and spatial homogenization.
- Reproduces the reaction rate and eigenvalue from a reference heterogeneous problem, **but not the leakage**.
- The SPH problem is a nonlinear problem usually solved with an iterative method, called SPH procedure:

$$\mu_{m,g} = \frac{\phi_{m,g}^{ref}}{\tilde{\phi}_{m,g}} \frac{\tilde{\phi}_{g}}{\tilde{\phi}_{g}^{ref}}$$

$$-\nabla \cdot \mu_m^g D_m^g \nabla \phi_m^g + \mu_m^g \Sigma_{r,m}^g \phi_m^g = \frac{\chi^g}{k_{eff}} \sum_{g'=1}^{G} \mu_m^{g'} \nu \Sigma_{f,m}^{g'} \phi_m^{g'} + \sum_{g'\neq 1}^{G} \mu_m^{g'} \Sigma_{s0,m}^{g'\rightarrow g} \phi_m^{g'}$$

METHODS: Nonlinear solve to the SPH problem

- SPH was implemented for diffusion, S_N, and P_N solvers.
- Two solver implementations:
  - Traditional SPH iteration
  - PJFNK-SPH solver (new approach)
- MOOSE's PJFNK solver
  - reduces SPH calculation time significantly,
  - can solve problems that were intractable such as reflectors and void boundary conditions,
  - might require updates to the initial guess to approach the radius of convergence of the Newton Method (**"fee SPH iterations"**)

2145 coefficients	SPH iteration	PJFNK-SPH
# Iterations		11 (5 free)
Solve time (sec.)		113
Min. flux convergence	(not converged)	4.17E-9

Region Tensor Diffusion Coefficients (TDC)

- Need to define diffusion coefficient in near-void regions for TREAT.
- Selected Trahan's region-wise definition.
  - Define a tensor diffusion coefficient

$$\left[\underline{\underline{D}}\right]_{i,j} = \frac{1}{4\pi} \int_{4\pi} d\Omega_i \Omega_j f$$

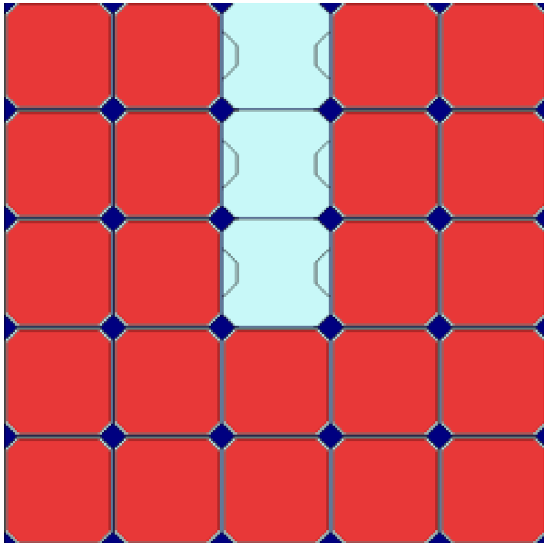
  - Obtain f from auxiliary transport problem without scattering or fission

$$\vec{\Omega} \cdot \nabla f_g + \Sigma_{t,g} f_g \left(r, \vec{\Omega}\right) = 1$$

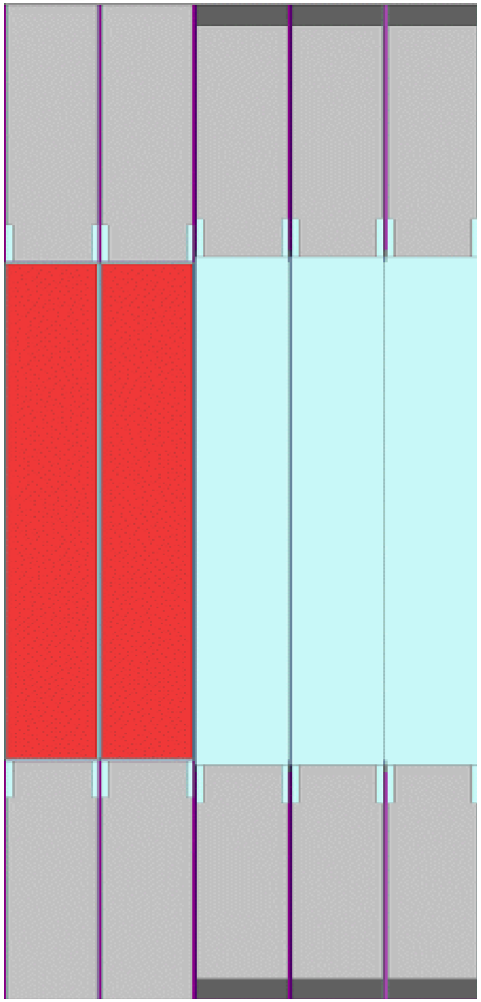
- Use one of the Rattlesnake's S_N transport solvers to solve the auxiliary problem:
  - 2^{nd} order SAAF-S_N with void treatment
  - 1^{st} order S_N

Simplified 5x5 TREAT model

- This 5x5 problem contains 3 slotted assemblies.
- 3 axial constant cross section regions in
  - fuel
  - each reflector
- 15 unique assemblies with cross sections.



X-Y plane



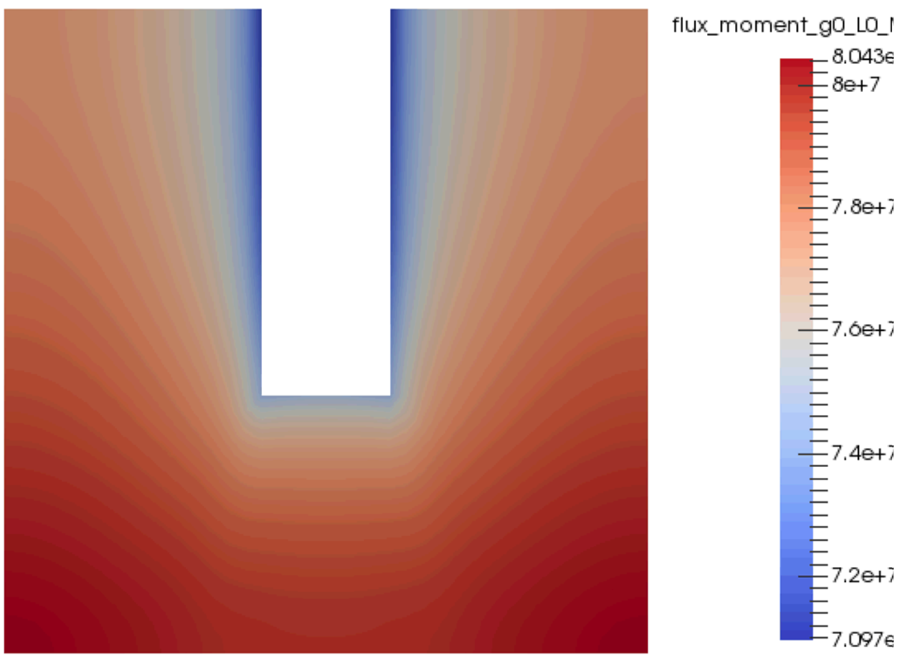
Y-Z plane

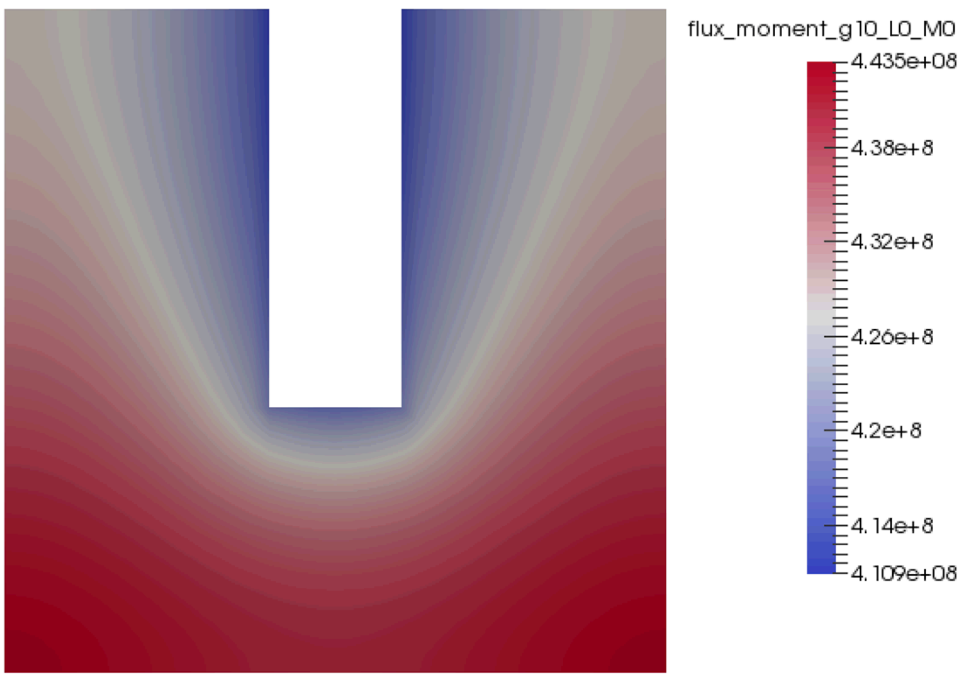
Serpent Results

- Serpent Run Setting
  - 1M particles/cycle
  - 50 inactive, 1000 active
- Cross section preparation in 11 and 4 coarse energy groups.
- Fission rate tally every 10 cm (axially) in fuel regions for each assembly.

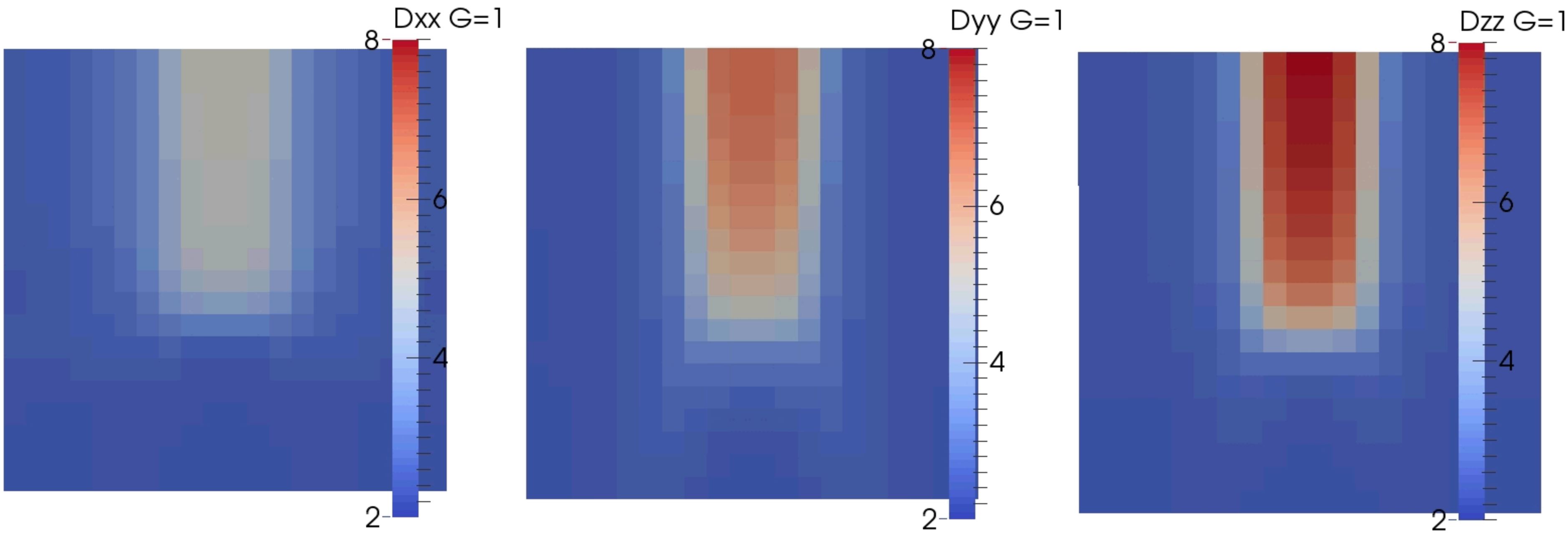
k_{eff} (±pcm)	1.35124 (±1.7)
Source Rate	5.574×10^{12} n/s
Absorption Rate	5.329×10^{12} n/s
n Disappearance Rate	2.238×10^{12} n/s
Fission Rate	3.091×10^{12} n/s
Leakage Rate	2.450×10^{11} n/s

S_{12} Solutions

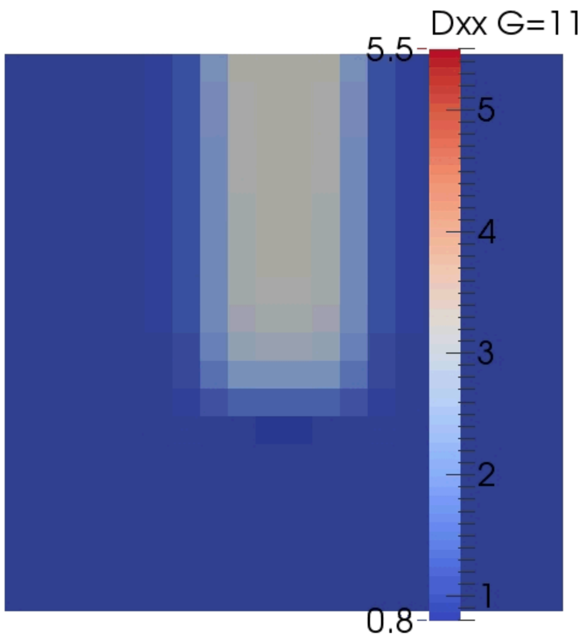


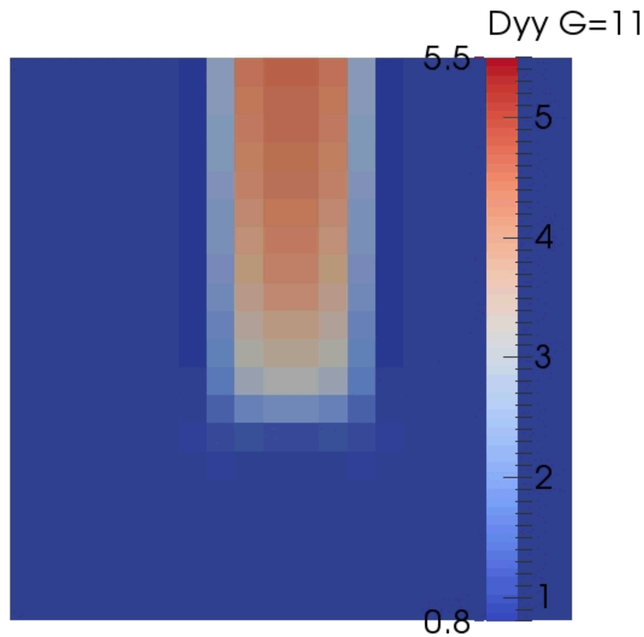


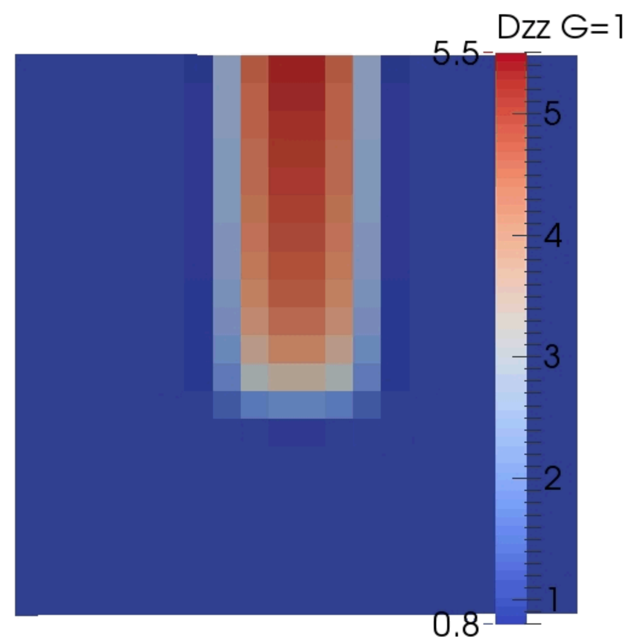
TDC in TREAT Slot (mid core) – Fast Group



TDC in TREAT Slot (mid core) – Thermal Group







Results 11 groups

Solver	k_{eff} (pcm)	Source Rate (% rel. diff.)	Absorption Rate (% rel. diff.)	Leakage Rate (% rel. diff.)
Diff.	1.33710 (-1046)	1.054	1.364	-5.671
S_{12}	1.36511 (1026)	-1.020	-0.372	-15.08
Diff. SPH	1.35726 (445)	-0.447	0.025	-10.71
Diff. TDC	1.37227 (1556)	-1.536	-0.628	-21.26
Diff. TDC-SPH	1.35859 (544)	-0.545	0.039	-13.23

Solver	RMS [%]	Max. [%]	Min. [%]
Diff.	4.997	9.566	-6.362
S_{12}	0.984	2.029	-1.270
Diff. SPH	1.744	3.309	-3.073
Diff. TDC	0.373	0.921	-0.932
Diff. TDC-SPH	0.661	1.434	-1.127

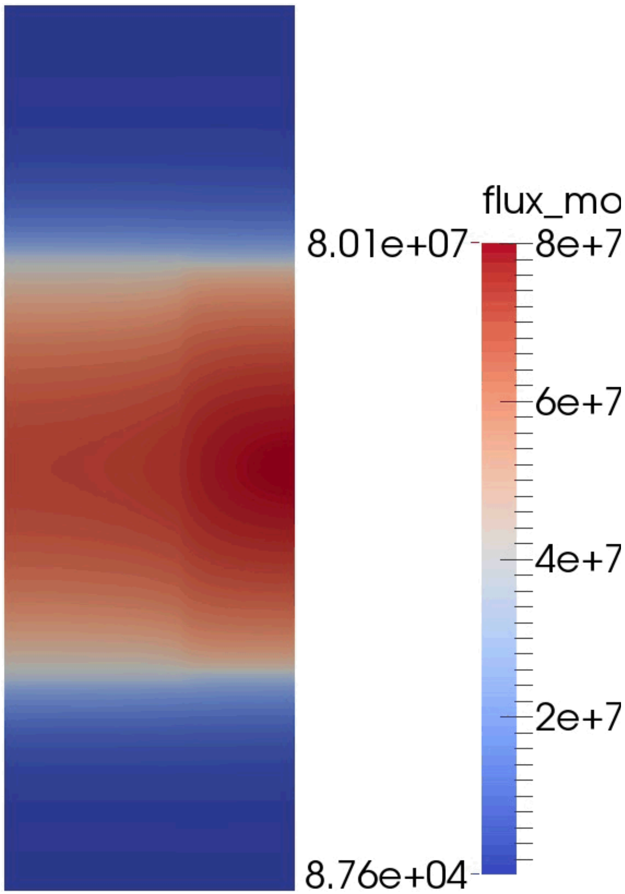
Results 4 groups

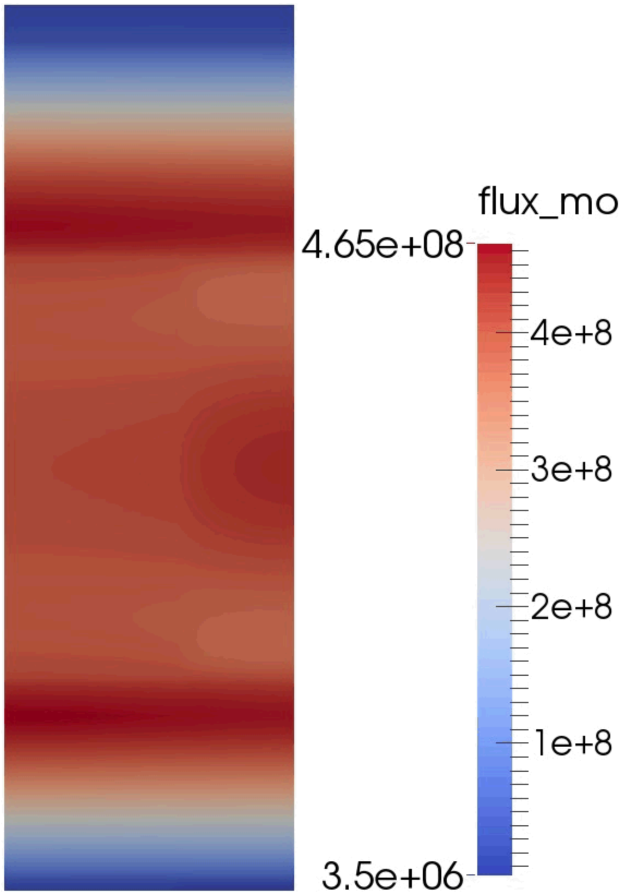
Solver	k_{eff} (pcm)	Source Rate (% rel. diff.)	Absorption Rate (% rel. diff.)	Leakage Rate (% rel. diff.)
Diff.	1.33462 (-1233)	1.242	1.451	-3.311
S_{12}	1.36669 (1141)	-1.134	-0.592	-12.90
Diff. SPH	1.35767 (473)	-0.477	-0.008	-10.66
Diff. TDC	1.37157 (1502)	-1.403	-0.025	-31.33
Diff. TDC-SPH	1.35929 (593)	-0.595	-0.010	-13.31

Solver	RMS	Max.	Min.
Diff.	5.132	8.955	-6.382
S_{12}	0.953	2.342	-1.125
Diff. SPH	1.637	3.153	-2.98
Diff. TDC	0.930	1.855	-1.716
Diff. TDC-SPH	0.848	2.030	-1.600

Flux Solutions

- Fast and thermal flux solutions show small gradients in void.





Conclusions

- The TDC and SPH methods in Rattlesnake provide the means to improve the diffusion solutions in a calculation outside the traditional applicability of diffusion theory.
- The RMS differences with respect to the Monte Carlo reference are improved by a factor of 7.6 and the maximum difference is within 1.5% in 11 energy groups.
- The results in 4 energy groups confirm that coarser energy structures provide sufficient accuracy for most routine calculations when using appropriate corrections.
- SPH correction needs to be verified for transients with fully heterogeneous transport calculation to assess leakage errors.

QUESTIONS/COMMENTS
to

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