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Investigating Variable Fidelity Monte Carlo with Serpent Fixed Source Mode

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Engineering - Energy, Fluid dynamics and Turbo-machinery

Presentation Outline

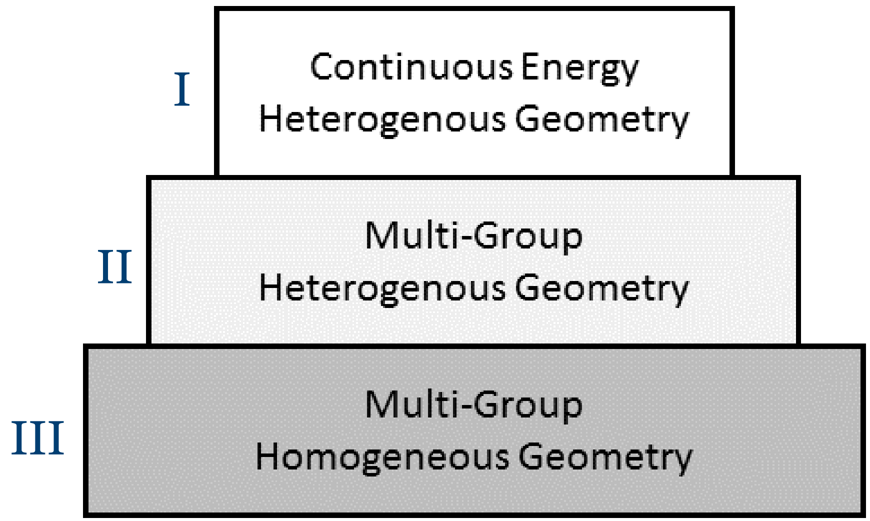
1. What is “Variable Fidelity” Monte Carlo?
2. MONK 10A and WIMS
3. Methodology
4. Accuracy of simple approach
5. Scope for improvement
6. Conclusions

Variable Fidelity Monte Carlo

Approximations to Monte Carlo:
- In Angle
- In Energy (MG Data)
- In Space (Homogenisation)

- Approximation in angle is usually determined by Nuclear Data
- Homogenisation and CE Data is not practical

Monte Carlo Fidelity Levels



Calculation in 2nd level: ~ 5-6 Speed-up [KENO][1]
Calculation in 3rd level: ~ 5-7 Speed-up [MORA][2]

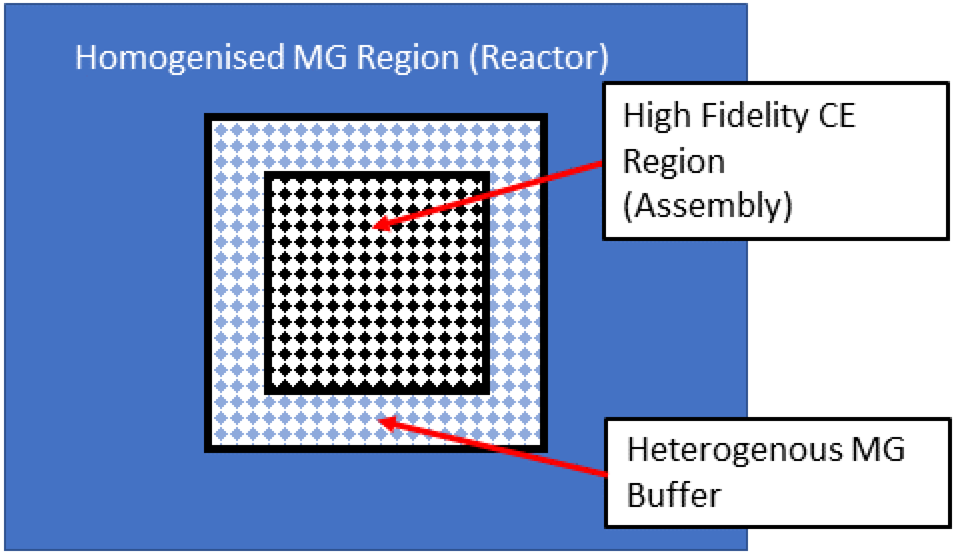
[1] Goluoglu, Sedat, Lester M. Petrie, Michael E. Dunn, Daniel F. Hollenbach, and Bradley T. Rearden. "Monte Carlo Criticality Methods and Analysis Capabilities in SCALE." Nuclear Technology, 2011.

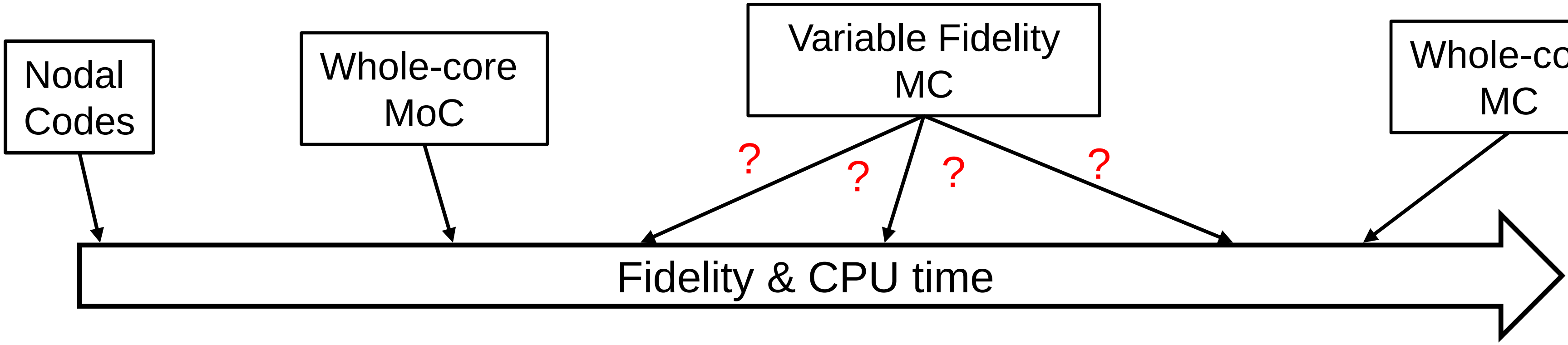
[2] Leppänen, Jaakko. "On the Feasibility of a Homogenised Multi-Group Monte Carlo Method in Reactor Analysis." Casino-Kursaal Conference Center, Interlaken, Switzerland, 2008.

Variable Fidelity Monte Carlo

Question:
Is it possible to accelerate MC solution by using lower fidelity in regions where accuracy is less important?

i.e. Temperature margin calculation → accuracy matters for pin cells close to a limit





MONK 10A and WIMS

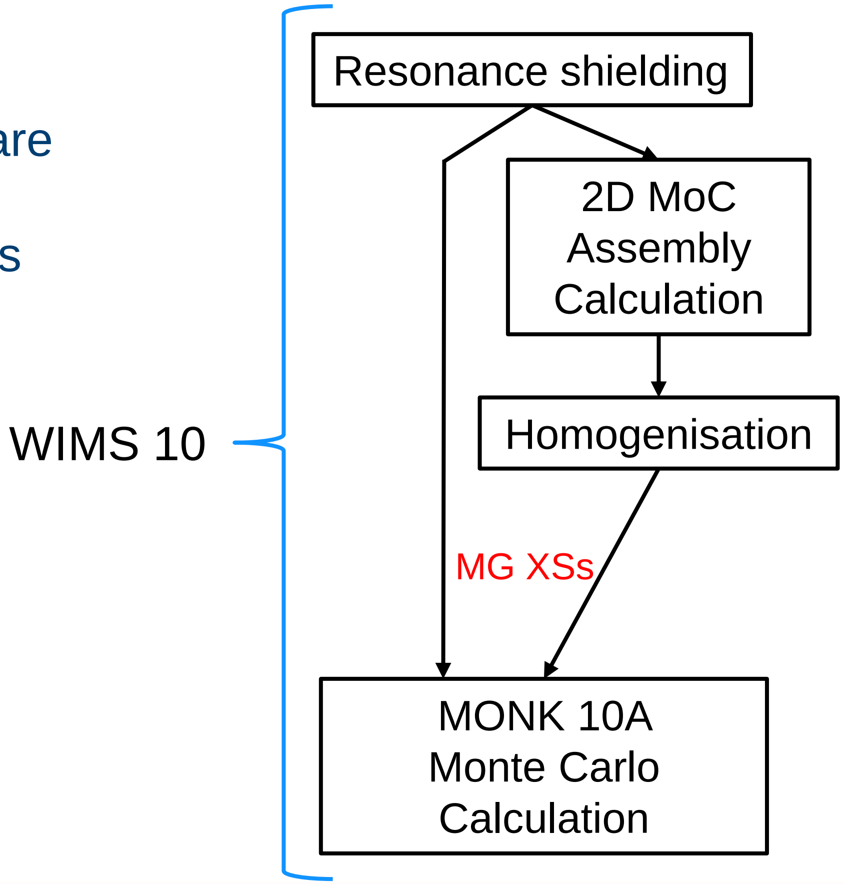
Serpent does not support MG data → Another code was needed

MONK 10A:

- MC code developed by ANSWERS Software
- Designed for criticality calculations
- Some support for reactor physics problems (more in 10B)
- Support of MG data
- Integrated into WIMS 10

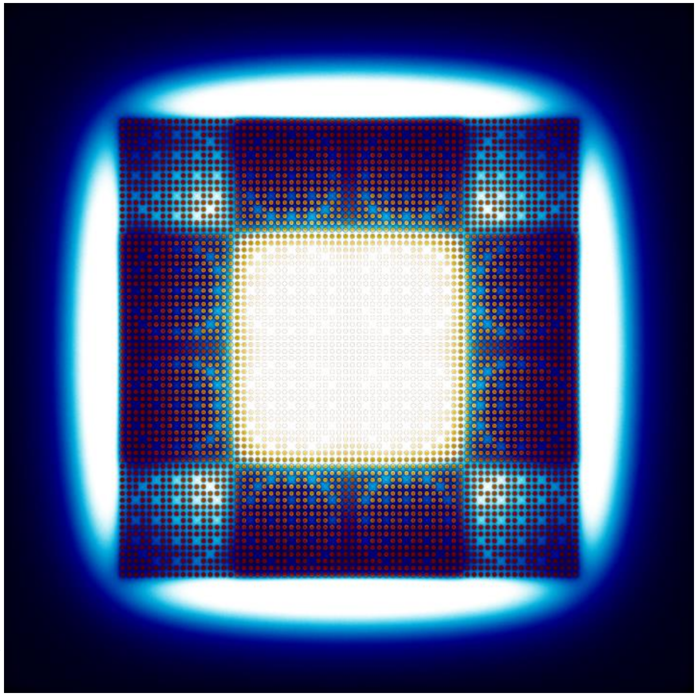
WIMS 10:

- Lattice physics code suite
- MoC and Collision Probability
- Equivalence and Sub-Group Resonance treatment



Serpent 2

- Monte Carlo Code developed since 2004 at VTT Technical Research Centre of Finland
- Optimised for XS generation
  - Woodcock delta-tracking
  - Unionised Energy Grid
- Support for various multi-physic coupling
- Sensitivity calculation with collision history method
- Good plotting capabilities



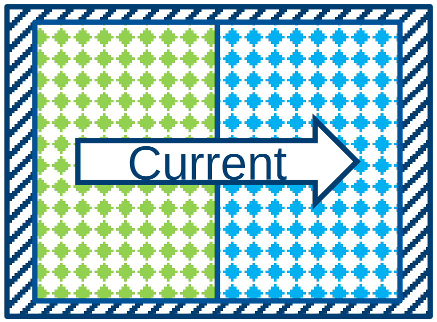
C5G7 MOX Benchmark

Approximating "Variable Fidelity"

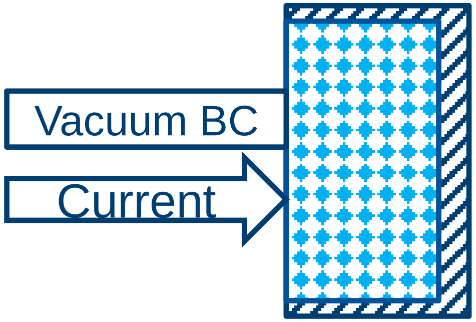
Methodology:

1. Perform low fidelity eigenvalue calculation
2. Sample Current crossing the boundary
3. Replace part of the geometry with current source and vacuum BC
4. Run Fixed Source Calculation

MG Problem (MONK 10A)



CE Problem (Serpent)



Limitations:

1. Only systems with k=1
2. Only current spectrum was sampled

Serpent Fixed Source Calculation

MONK 10A MG Spectrum in WIMS 172 Structure

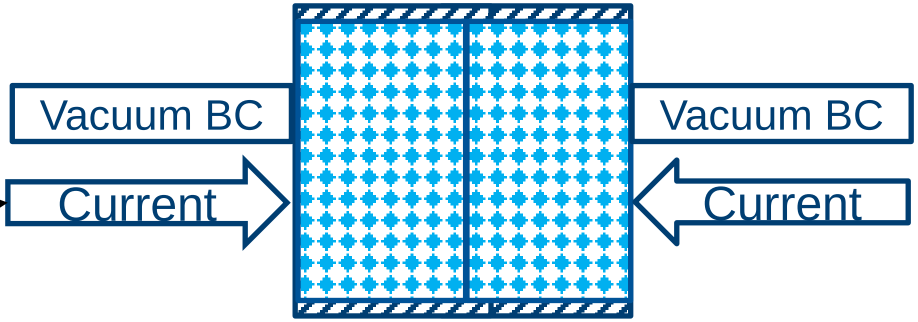
↓

MATLAB

↓

ASCII File with 8 million neutron samples

Serpent Fixed Source Problem



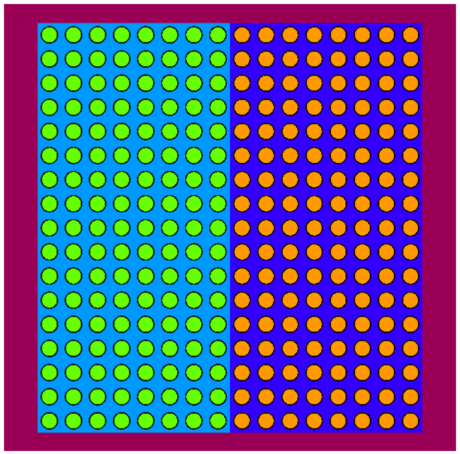
Neutron Distribution Assumptions:

- Uniform along boundary
- Isotropic in angle ($pdf = 0.25 \cos\alpha\, cos\beta$)
- Uniform in lethargy inside Energy Group

Delayed neutrons switched on:
`set delnu 1`

Test Case

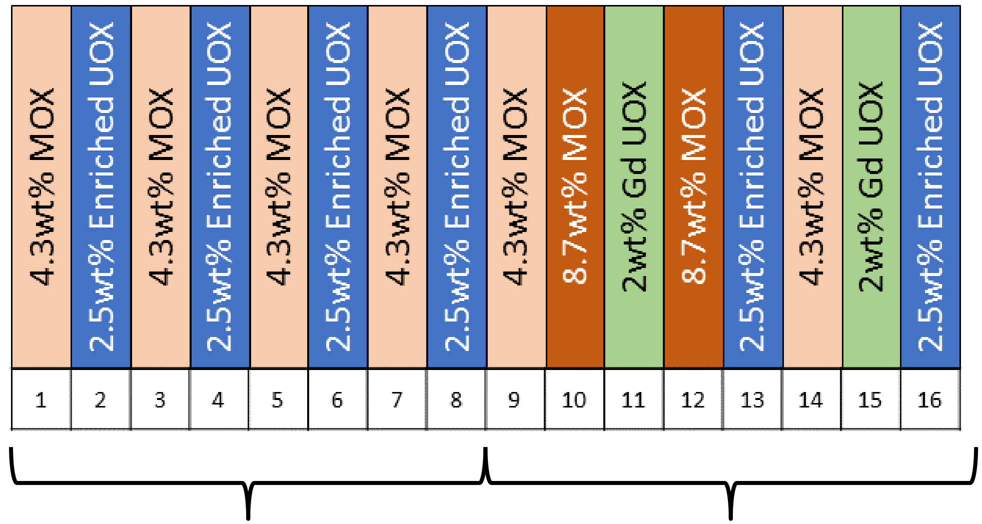
Geometry Schematic



Geometry was based on PWR:

- Pin radius = 0.3951 cm
- Pitch = 1.26 cm
- Water density $\rho \approx 0.75 \frac{g}{cm^3}$
- Boron at 1470 ppm

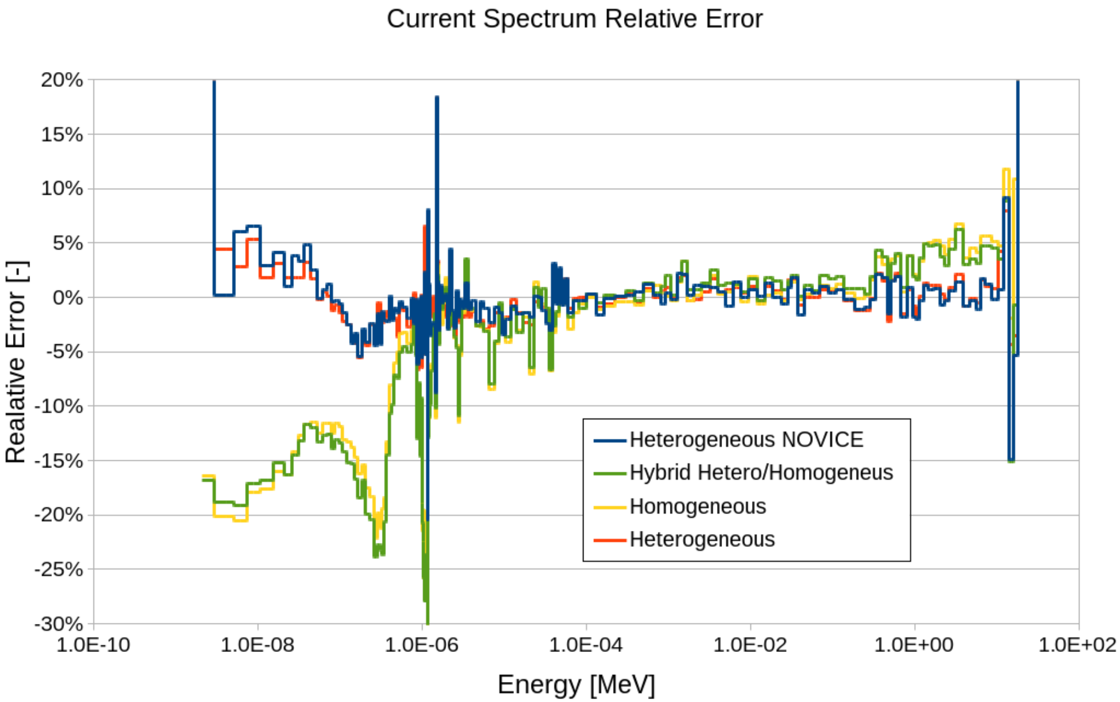
Row-by-Row Fuel Composition



Left Assembly

Right Assembly (Used in Serpent Calculation)

MONK 10A Multi-Group Spectra



Homogeneous geometry:

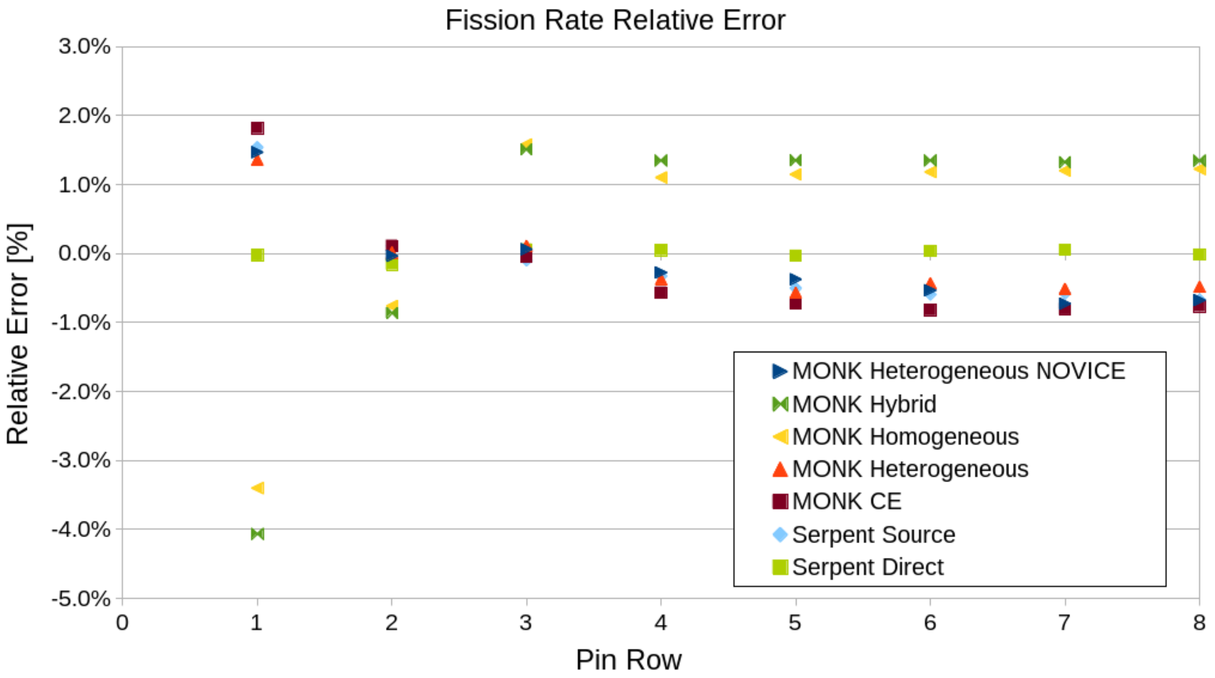
- Large Homogenisation error

Heterogenous geometry:

- Thermal peak error
- Resonance errors
- Hardened spectrum error (criticality error)

MONK 10A NOVICE method → sub-group sampling

Fission Rate Distribution



2σ Error ≈ 0.2%

Normalisation to constant power

Homogenous Geometry:

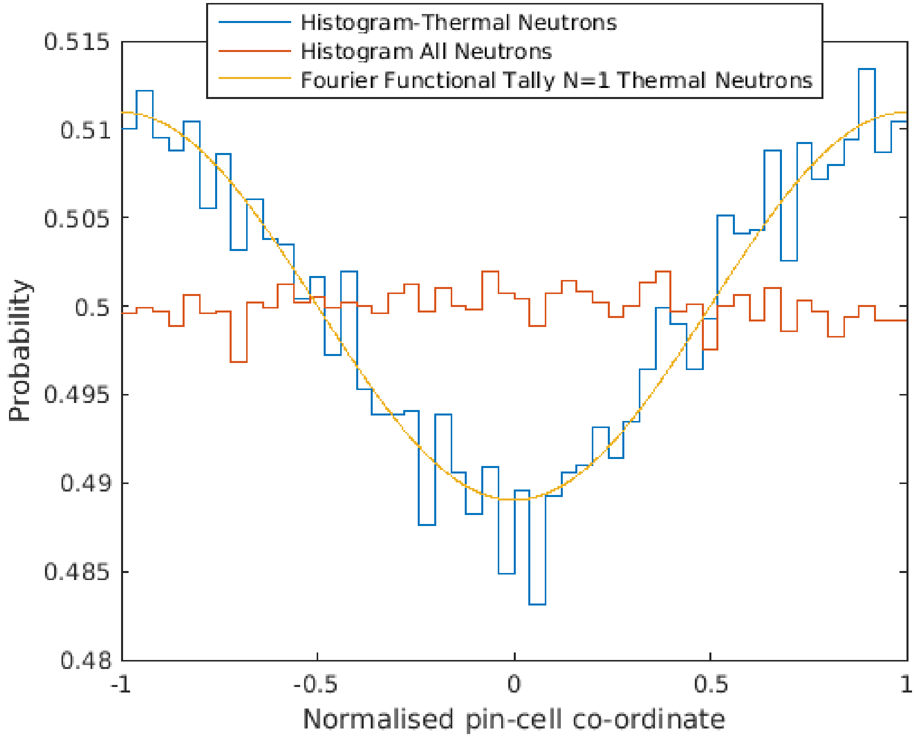
- Large Error (thermal neutrons)

Heterogenous Geometry:

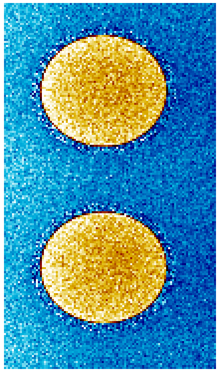
- Error in first row
- Error is larger for CE sampled spectra

Thermal pin-cell corners accumulation

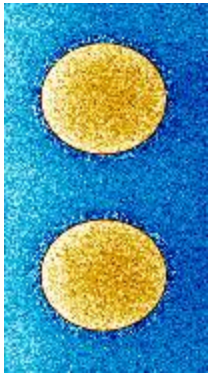
Pin-cell Neutron Distribution



CE reference

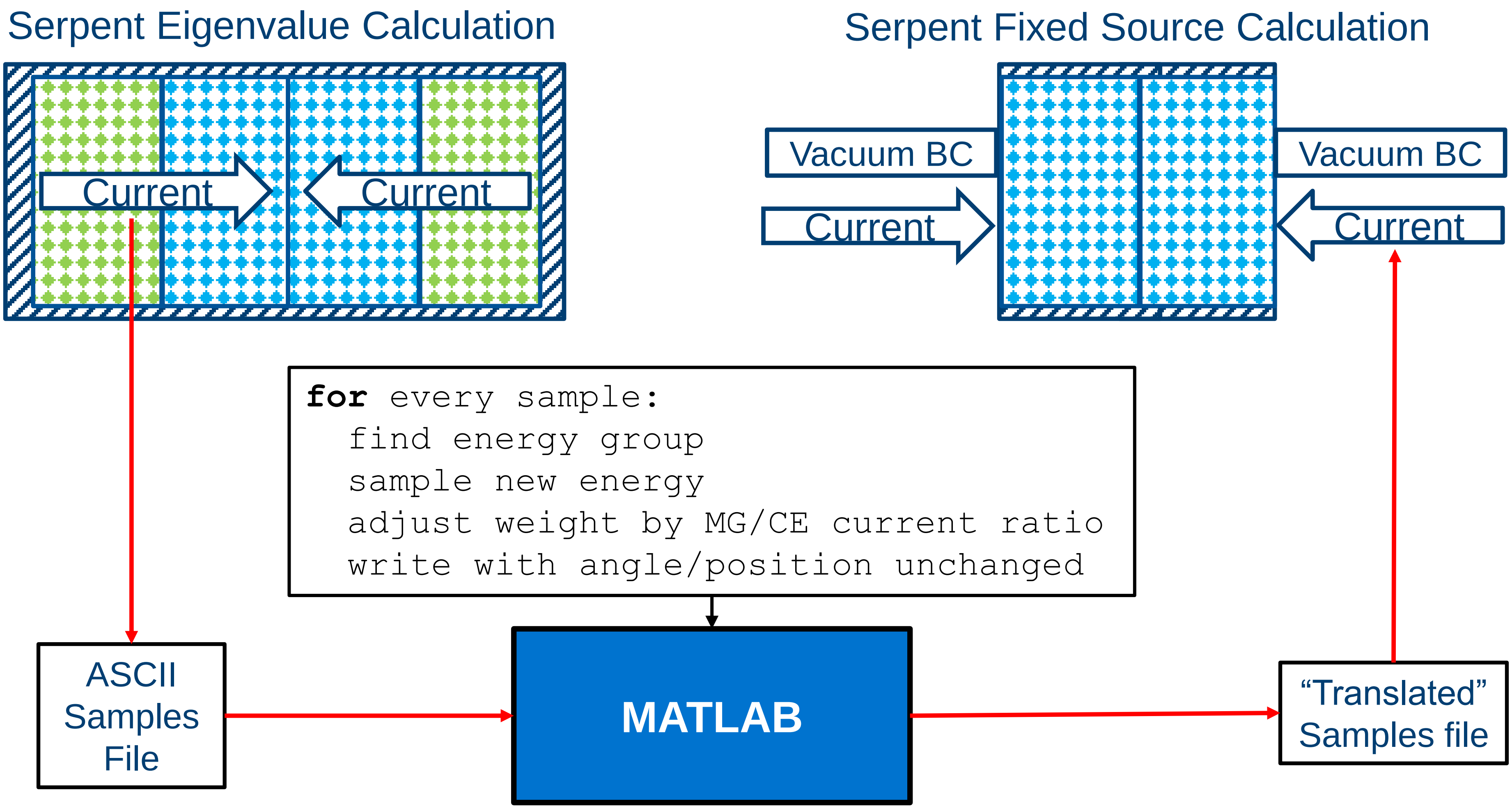


MATLAB Spectrum



Heterogenous geometry error is caused by distribution of thermal neutrons

Isolating MG error – Source “Translation”



"Translated" Source Fission Rate

2σ Error ≈ 0.2%

Normalisation to constant power

Homogeneous geometry:

- Error Increases

Heterogeneous geometry:

- Error is contained within 0.5%

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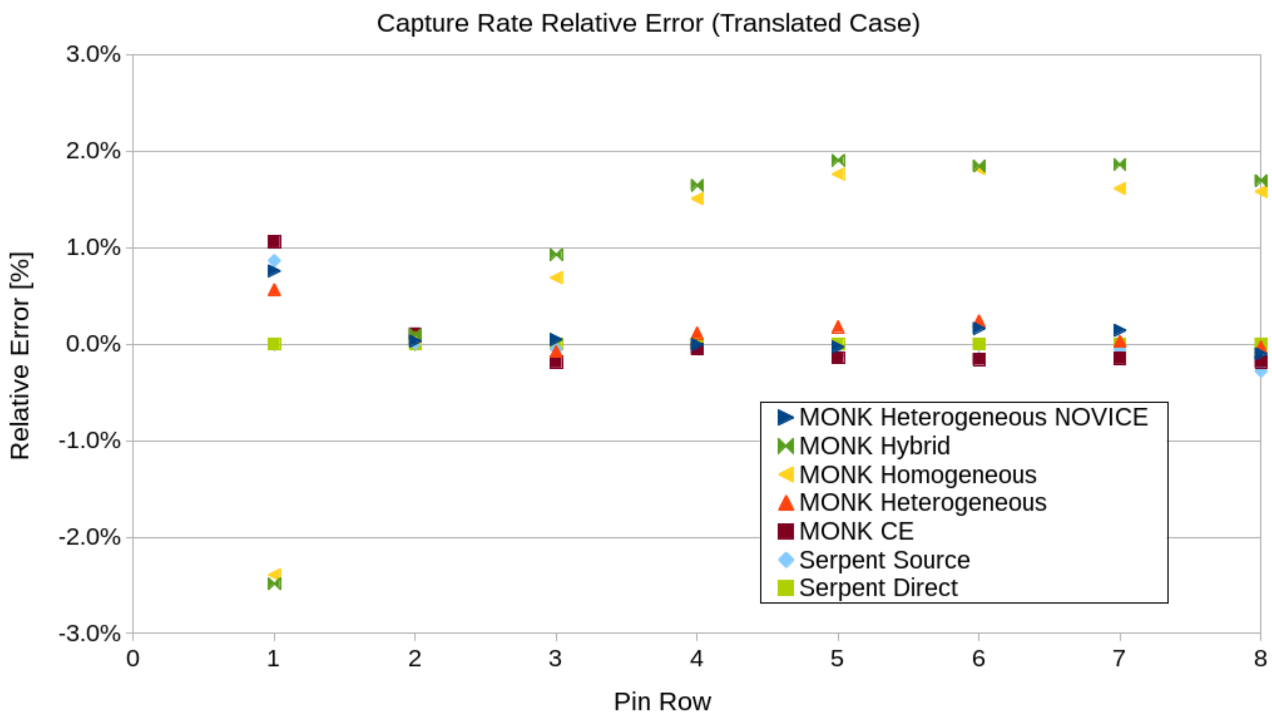
“Translated” Source Capture Rate

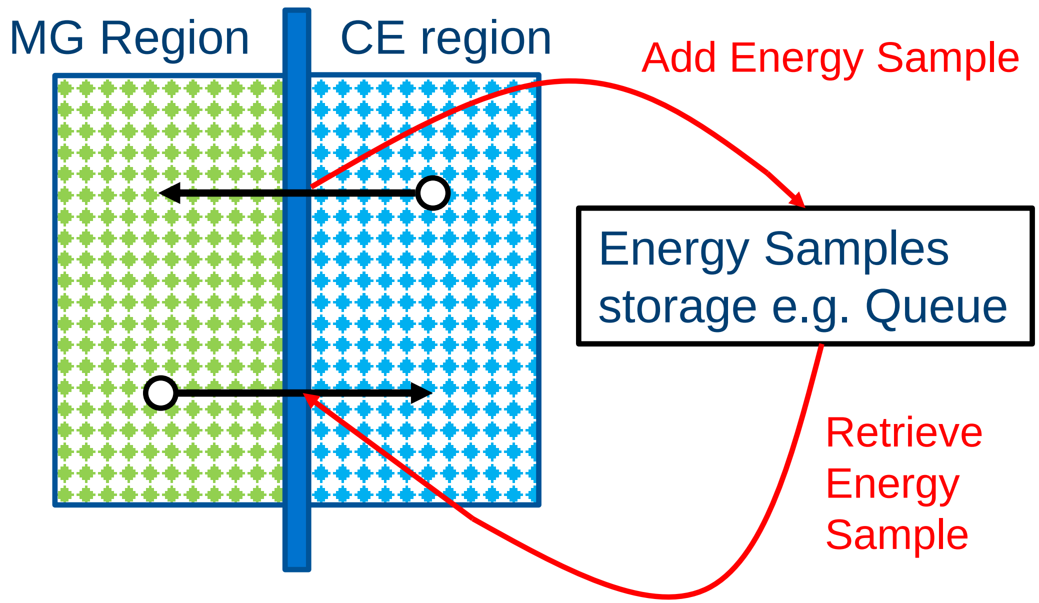


2σ Error ≈ 0.2%

Normalisation to constant power

No resonance flux dips → Large capture error

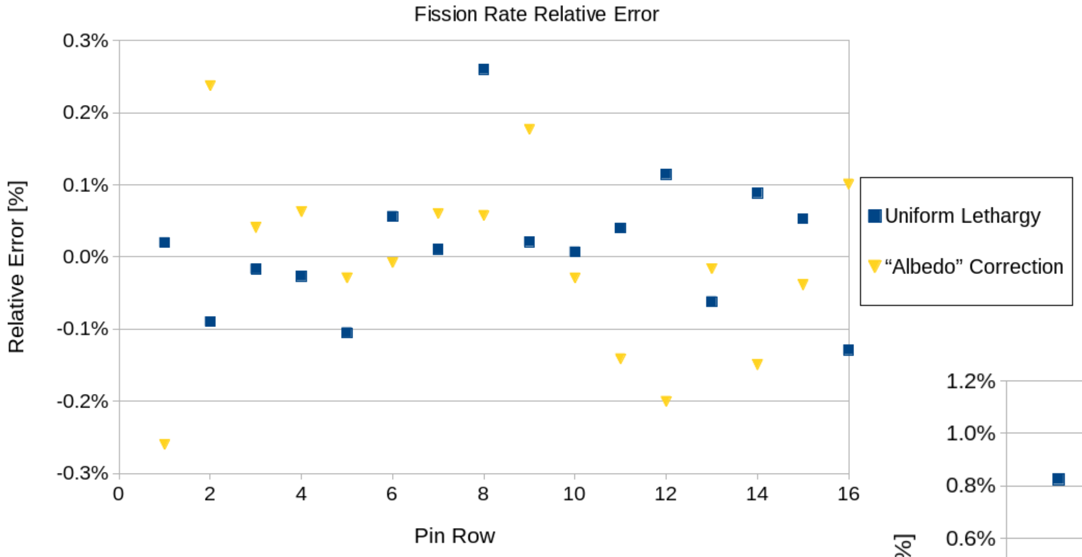
"Albedo" Correction



Approximation with "translated" sources:

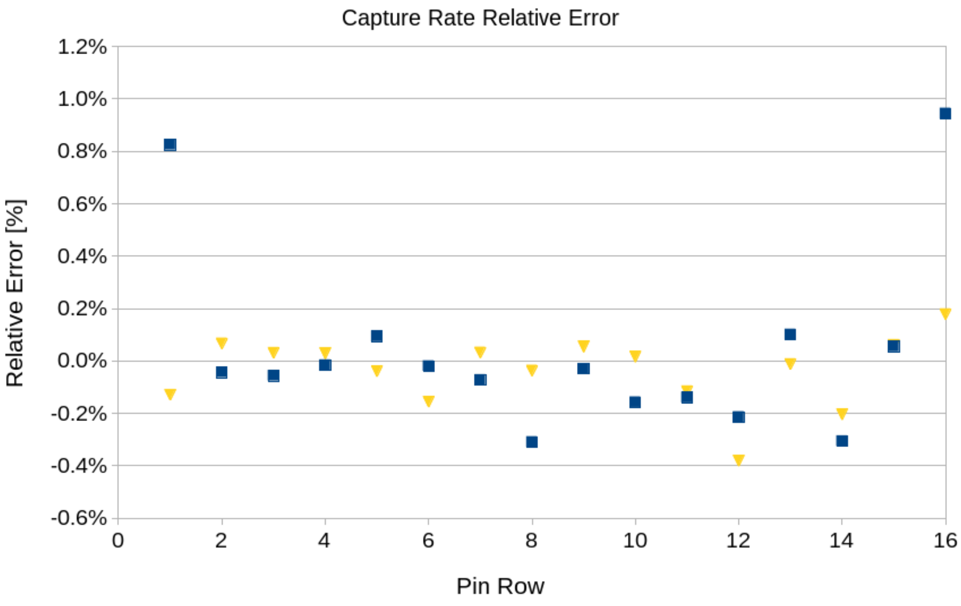
1. Start with uniform distribution in lethargy
2. Run Fixed Source and get samples of leakage current
3. "Translate" Source using leakage current from previous calculation
4. Repeat steps 2-3

"Albedo" Correction – CE sampled MG spectrum



Spectrum was sampled in CE Serpent Reference calculation (Serpent Source case)

2σ Error ≈ 0.2%



- Significant reduction of capture error
- No statistically significant change in power

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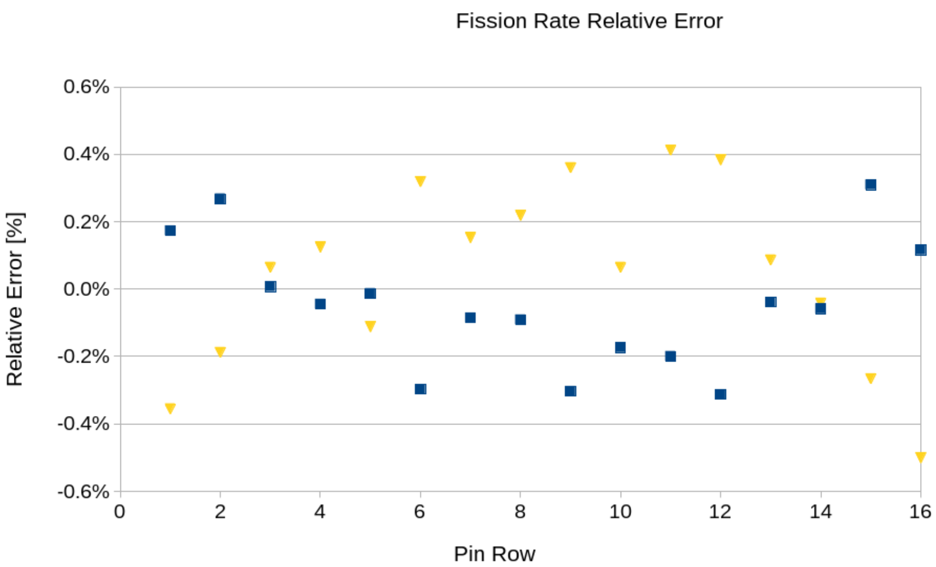
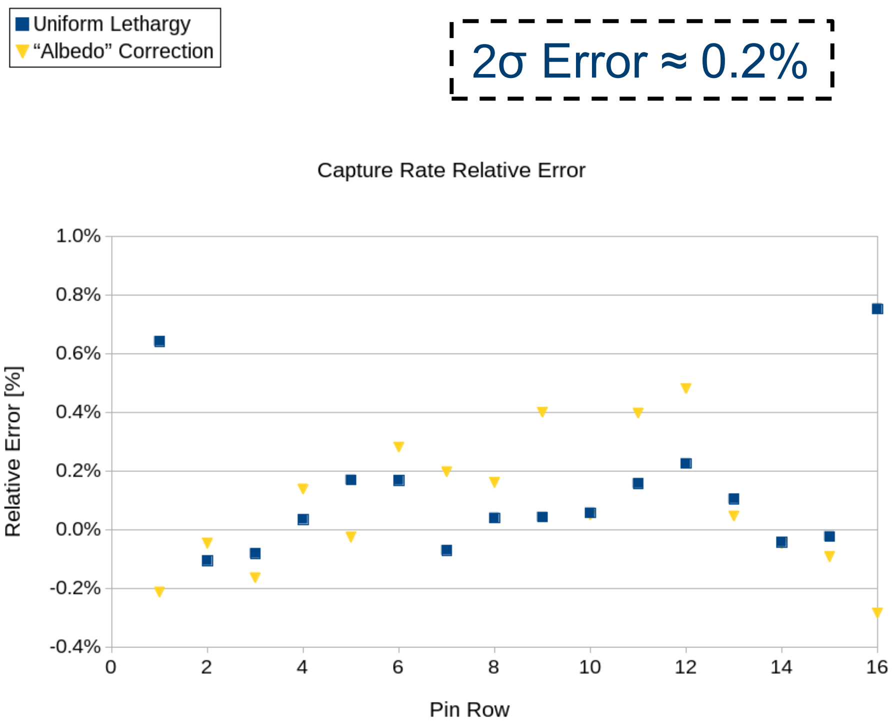
"Albedo" Correction –MG spectrum



Heterogeneous MG Spectrum

2σ Error ≈ 0.2%



- No capture error peaking close to the boundary
- "Bowing" error in power and capture
- Likely caused by criticality error of MG spectrum

Conclusions

Conclusions:

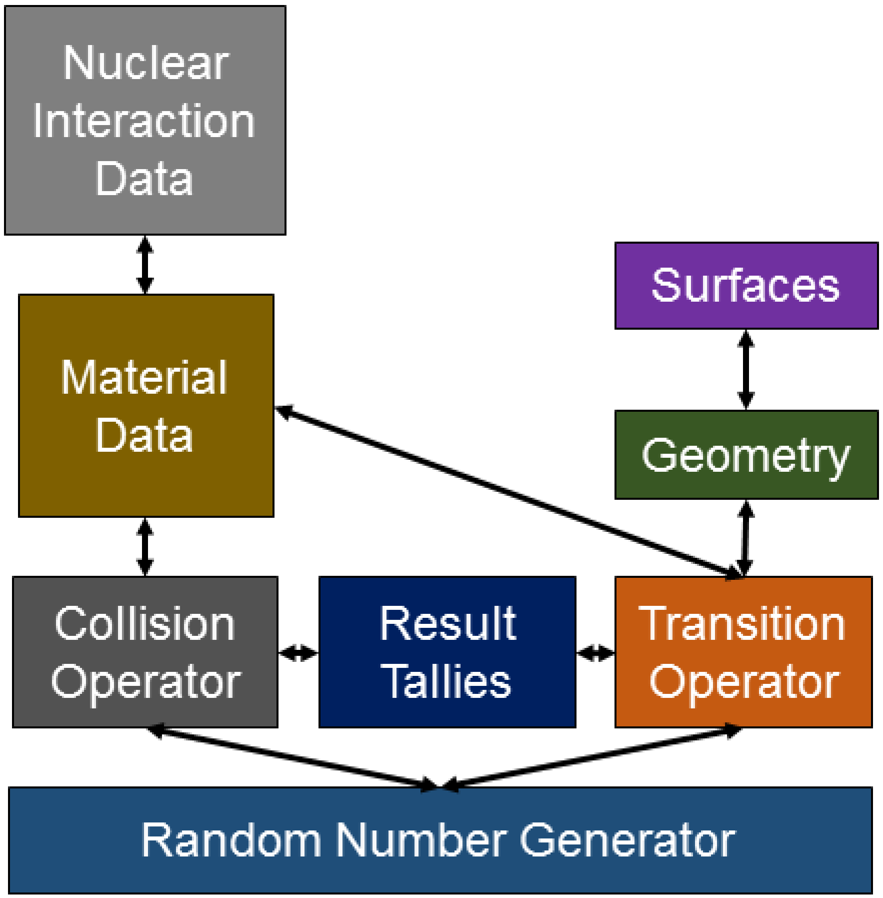
- At the fidelity level boundary:
  - Homogenised to heterogeneous transition → requires correction (ADFs)
  - Spatial distribution of thermal neutrons causes large error
  - Errors due to MG representation of spectrum are small
  - "Albedo" correction → significantly improves capture accuracy
- "Variable Fidelity" will probably deliver at least 1% accuracy in power

Further work:

- Implement environment for combined MG-CE calculations
- Move to 2D and 3D problems
- Investigate using deterministic calculation as IV fidelity level
  - "Monte Carlo pin-power reconstruction"

SCONE Monte Carlo Code

Stochastic
Calculations
Of
Neutron Transport
Equation



Monte Carlo code:

- Highly Modifiable
- Easy to understand by a inexperienced user
- Object-Oriented

Currently being written in Fortran 2003

Thank you for your attention!