# The Impact of Spatial Self-Shielding on Pin-wise Reaction Rates

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**Abstract**

*Keywords:* Multi-group cross-sections, spatial homogenization, spatia self-shielding

## 1. Introduction

The nuclear reactor physics community has long strived for deterministic neutron transport-based tools for whole-core reactor analysis. A key challenge for whole-core multi-group transport methods is accurate reactor agnostic multi-group cross section (MGXS) generation. The MGXS generation process applies a series of approximations to produce spatially homogenized and energy condensed MGXS in each spatial zone and energy group. Many approximations related to multi-group theory, including the selection of discretized energy group structures and the truncation of the Legendre expansion of the multi-group scattering kernel, are widely studied in the literature. However, the practical impact of the flux separability approximation, which permits the use of the scalar rather than the angular neutron flux to weight the continuous energy cross sections, is less understood. This paper investigates the flux separability approximation and quantifies its significance for heterogeneous PWR problems.

This work employs Monte Carlo (MC) neutron transport simulations to generate MGXS. Monte Carlo methods have increasingly been used to generate few group constants for coarse mesh diffusion, most notably by the Serpent MC code (Leppänen, 2013), and to a much lesser extent, for high-fidelity neutron transport methods (Redmond, 1997; Nelson, 2014; Cai, 2014; Boyd, 2016). The advantage of a MC-based approach is that all of the relevant physics are directly embedded into MGXS by weighting the continuous energy cross sections with a statistical proxy to the "true" neutron flux. However, this paper shows that even when the "true" scalar flux is used to generate MGXS, the flux separability approximation results in a non-negligible eigenvalue bias between continuous energy and multi-group calculations due to under-prediction of U-238 capture in resonance energy groups.

The content in this paper is organized as follows.

## 2. Methodology

### 2.1. Continous Energy Calculations with OpenMC

-OpenMC Romano and Forget (2013) -Python API Boyd et al. (2016a) -NNDC data National Nuclear Data Center, Brookhaven National Laboratory (????) -distribcell tallies Lax et al. (2014) -openmc.mgxs -tallied in CASMO's seventy energy group structure **?** -iso-in-lab -runtime parameters: -num. particles, batches -computer hardware

### 2.2. Multi-Group Calculations with OpenMOC

-OpenMOC Boyd et al. (2014) -multi-core parallelism Boyd et al. (2016b) -runtime parameters: -azim angles, spacing -num. FSRs -CMFD energy and spatial mesh -computer hardware

### 2.3. Pin-wise Spatial Homogenization Schemes

-from Sec. 8.2 -focus less on introducing these as "schemes" per se -rather two spatial self-shielding models to quantify approx. error

#### 2.3.1. Null Homogenization

-from Sec. 8.2.2

#### 2.3.2. Degenerate Homogenization

-from Sec. 8.2.3
-OpenCG region differentiation Boyd et al. (2015)

## 3. Test Cases

-Benchmarks for Evaluation and Validation of Reactor Simulations (BEAVRS) Horelik et al. (2013)
-need to describe both pinwise fissoin rates and U-238 capture rates -latter papers can cite this one as reason to only analyze capture rates?
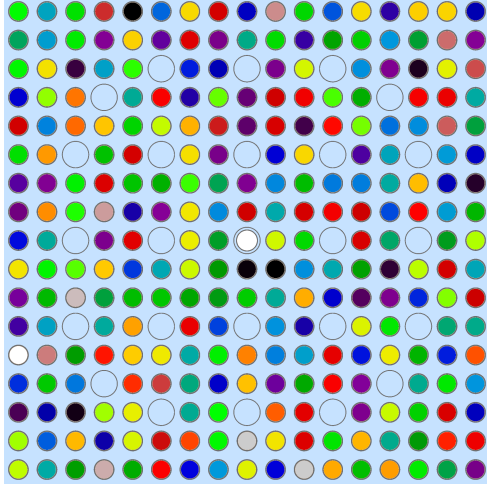
### 3.1. Benchmark Configurations

### 3.2. Single Fuel Assembly
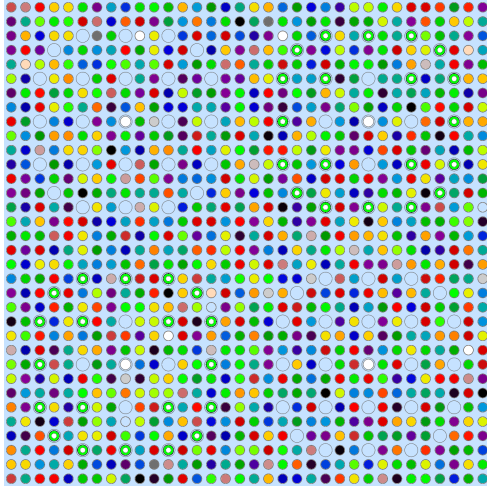
### 3.3. Reflected Assembly Colorset

### 3.4. Verification Metrics

-reference results generated with OpenMC simulations (Sec. 7.3) -eigenvalues -pin-wise fission rates -pin-wise U-238 capture rates -iso-in-lab in OpenMC

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**(a)**



**(b)**

**Figure 1.** OpenMOC materials for the (a) assembly and (b) 2×2 colorset models with degenerate homogenization.



**(a)**



**(b)**

**Figure 2.** A (a) fuel assembly and (b) 2×2 assembly colorset with reflector.

**Table 1.** Reference OpenMC eigenvalues for each test case.

| Assembly | Colorset |
|---|---|
| 0.99326 ± 0.00001 | 0.94574 ± 0.00001 |

**Table 2.** OpenMOC eigenvalue bias $\Delta\rho$.

| Benchmark | Null | Degenerate |
|---|---|---|
| Assembly | -161 | -161 |
| Colorset | -142 | -132 |

**Table 3.** OpenMOC fission rate percent relative errors.

| Benchmark | Metric | Null | Degenerate |
|---|---|---|---|
| Assembly | Max | 0.380 | 0.315 |
| | Mean | 0.074 | 0.079 |
| Colorset | Max | 0.764 | 0.602 |
| | Mean | 0.178 | 0.138 |

## 4. Results

### 4.1. Eigenvalues

In the results that follow, the bias $\Delta\rho$ compares the eigenvalue $k_{eff}^{MOC}$ computed by OpenMOC to that of the reference eigenvalue $k_{eff}^{MC}$ computed by OpenMC in units of pcm:
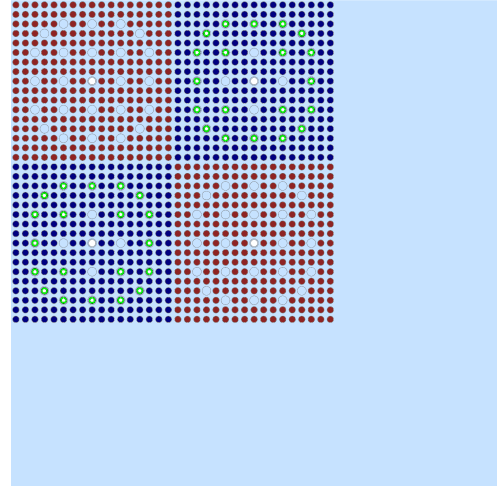
$$\Delta\rho = \left(k_{eff}^{MOC} - k_{eff}^{MC}\right) \times 10^5 \tag{1}$$

### 4.2. Fission Rates

-add figures of spatial distribution of errors

### 4.3. Capture Rates

-add figures of spatial distribution of errors
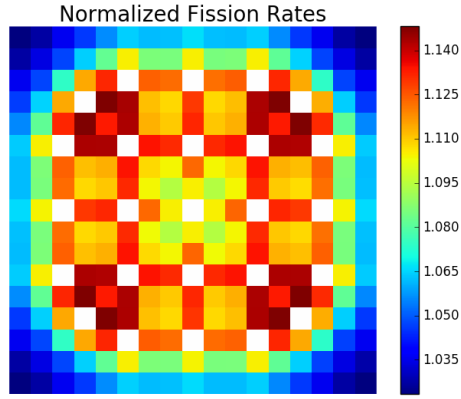
**(a)**
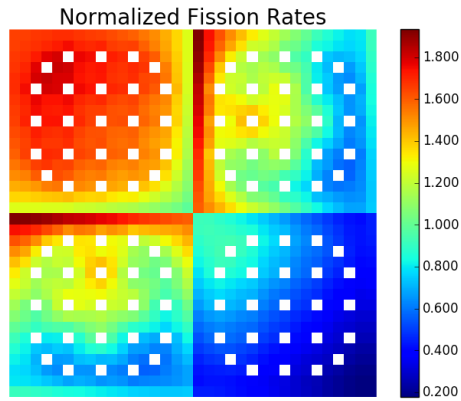


**(b)**

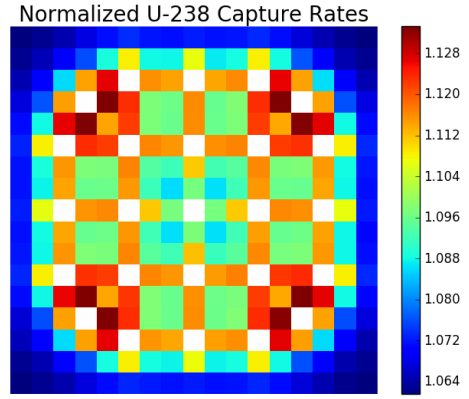**Figure 3.** Fission rates for the (a) assembly and (b) 2×2 colorset.



**(a)**



**(b)**

**Figure 4.** U-238 capture rates for the (a) assembly and (b) 2×2 colorset.

**Table 4.** OpenMOC U-238 capture rate percent relative errors.

| Benchmark | Metric | Null | Degenerate |
|---|---|---:|---:|
| Assembly | Max | -1.101 | 0.386 |
|  | Mean | 0.479 | 0.086 |
| Colorset | Max | -1.969 | -0.783 |
|  | Mean | 0.478 | 0.165 |

## 5. Conclusions

## Acknowledgments

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