NUEN 689/485 - 512

Radiation Transport Methods

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Final Presentation

CASL Core Physics Benchmark Simulations of Light Water Reactors in OpenSn and OpenMC

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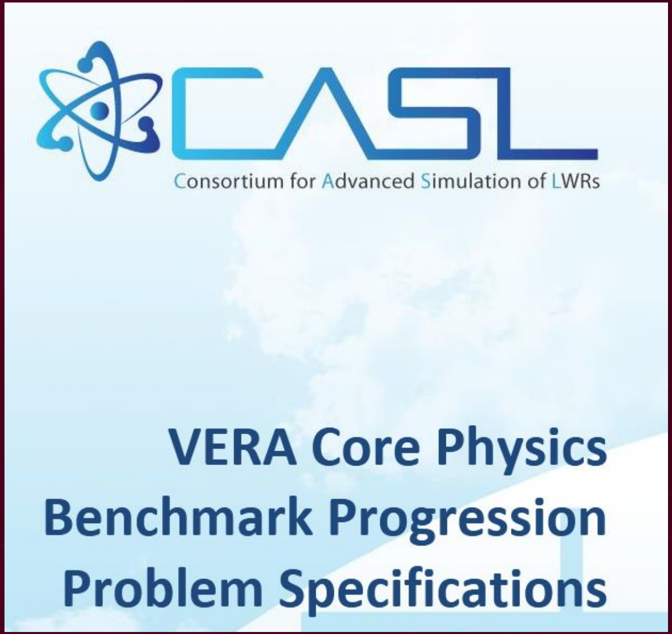
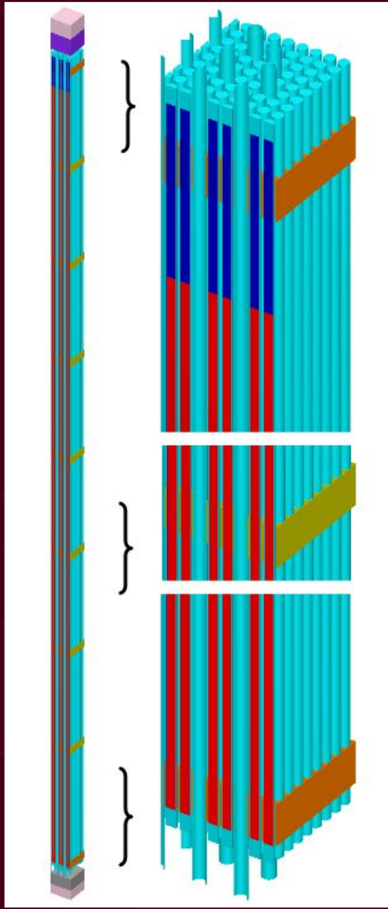
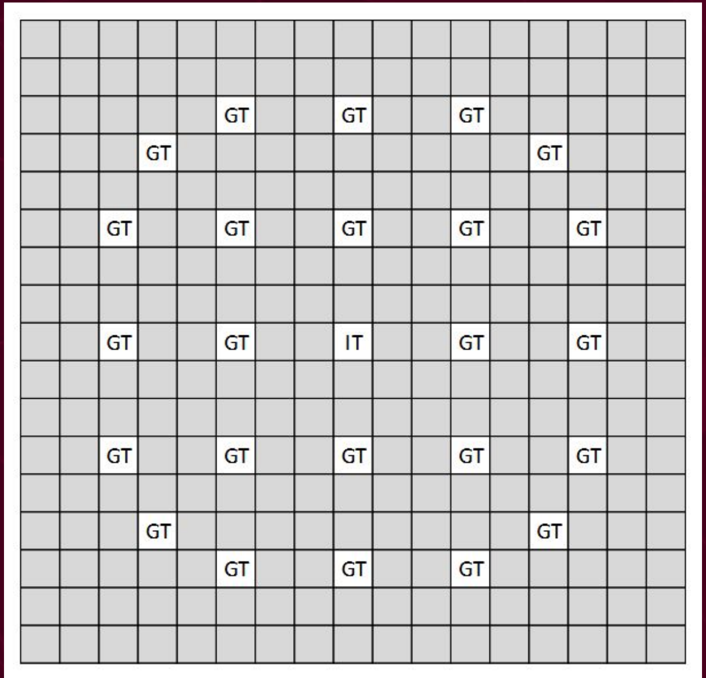
Based on work by Pablo Garcia

Introduction



- From Oak Ridge National Laboratory using KENO-VI
- Based on Watts Bar Nuclear 1 Plant

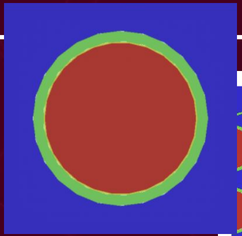




- 17x17 PWR with 24 guide tube locations
- Pyrex, AIC, B4C, WABA, IFBA

Introduction

- The CASL benchmark has several types of analysis, from 2D pincells to full core depletion
- Designed to test nuclear software
- Progresses through capabilities needed to model power reactors
- We did Problem 2, analysis of a 2D LWR assembly
- Problem 2 models the assembly with different temperatures, control rods, fuel rods, and a spacer grid



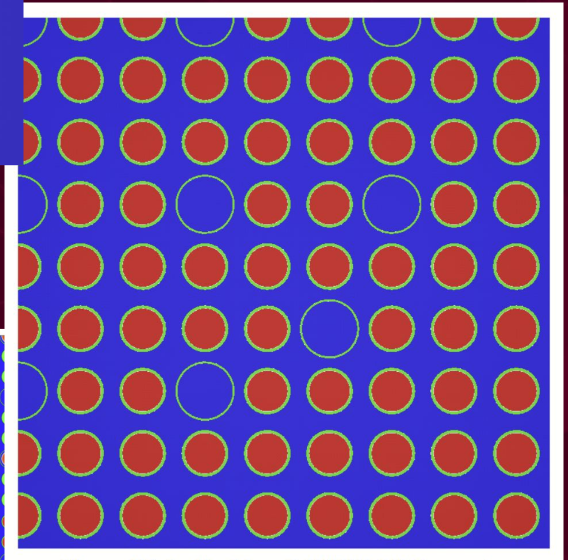


Figure P2-1: Problem 2 KENO-VI Geometry

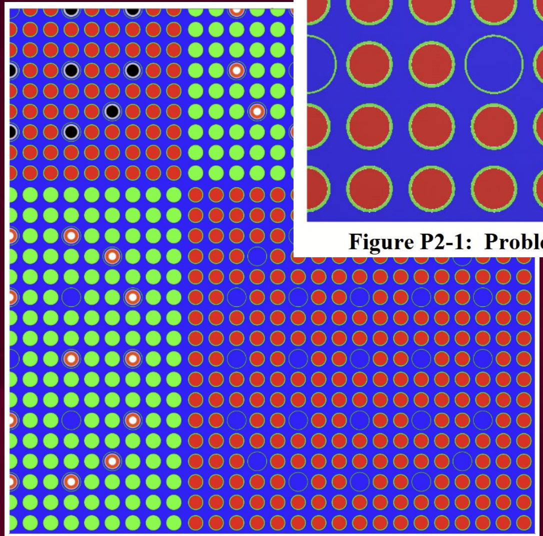


Figure P4-2: Problem 4 Radial KENO-VI Geometry

Problem Overview

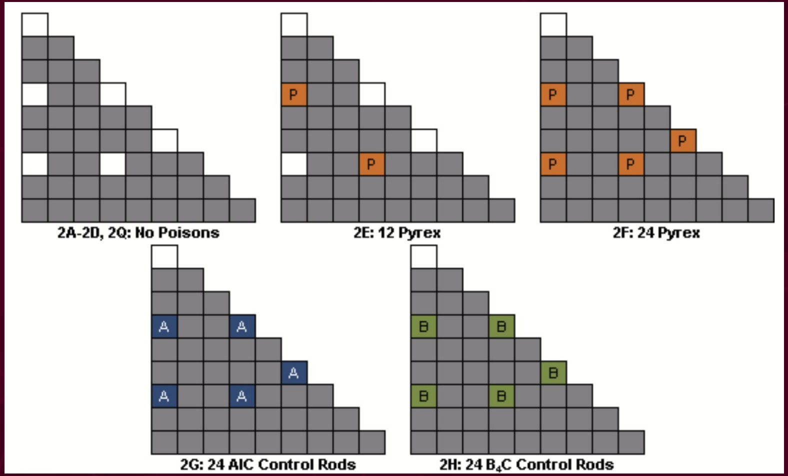
- Parts A-D analyzes different core temperatures
- Parts E-J includes various control rods and instrumentation
- Parts K-P includes different types of fuel and coated fuel elements
- Parts Q includes the zircaloy spacer grid

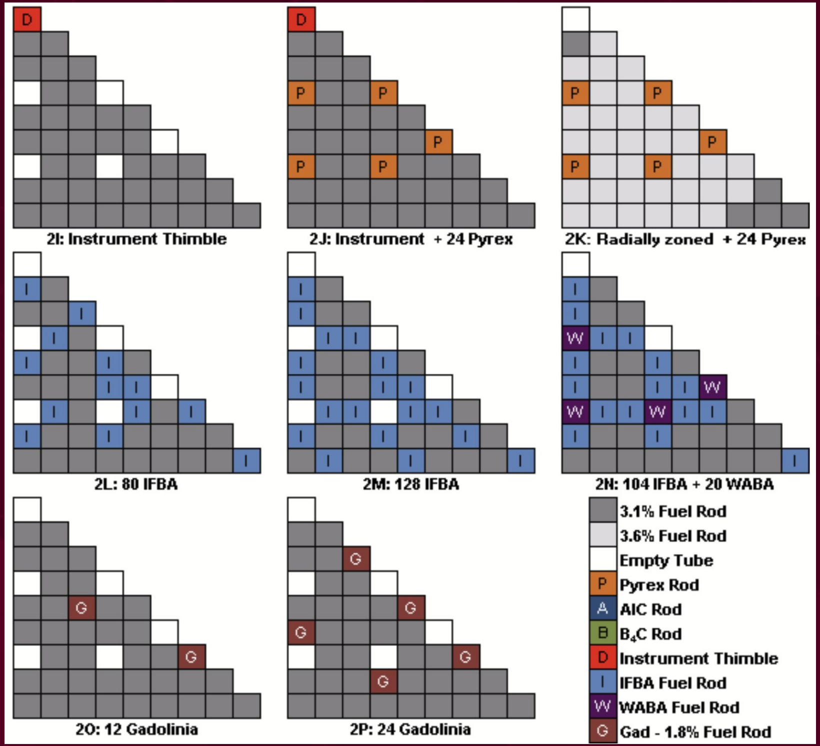
Table P2-5: Problem 2 Reference Solution Eigenvalue Results

Problem	Description	Fuel Temperature	Moderator Density	k-effective
2A	No Poisons	565 K	0.743 g/cc	**1.182175 ± 0.000017**
2B	↓	600 K	0.661 g/cc	**1.183360 ± 0.000024**
2C	↓	900 K	↓	**1.173751 ± 0.000023**
2D	↓	1200 K	↓	**1.165591 ± 0.000023**
2E	12 Pyrex	600 K	0.743 g/cc	**1.069627 ± 0.000024**
2F	24 Pyrex	↓	↓	**0.976018 ± 0.000026**
2G	24 AIC	↓	↓	**0.847695 ± 0.000025**
2H	24 B4C	↓	↓	**0.788221 ± 0.000025**
2I	Instrument Thimble	↓	↓	**1.179916 ± 0.000024**
2J	Instrument + 24 Pyrex	↓	↓	**0.975193 ± 0.000025**
2K	Zoned + 24 Pyrex	↓	↓	**1.020063 ± 0.000025**
2L	80 IFBA	↓	↓	**1.018915 ± 0.000024**
2M	128 IFBA	↓	↓	**0.938796 ± 0.000025**
2N	104 IFBA + 20 WABA	↓	↓	**0.869615 ± 0.000025**
2O	12 Gadolinia	↓	↓	**1.047729 ± 0.000024**
2P	24 Gadolinia	↓	↓	**0.927410 ± 0.000024**
2Q	Zircaloy Spacer Grid	565 K	↓	**1.171940 ± 0.000016**

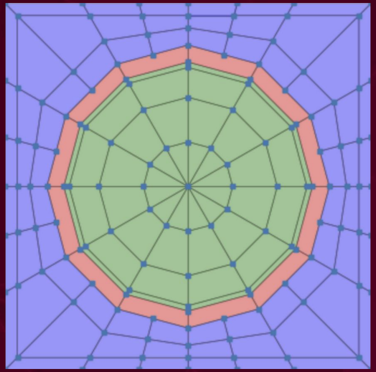
Problem Overview

- Pyrex control rods
- Silver-Indium-Cadmium (AIC) control rods
- B_4C control rods
- Integral Fuel Burnable Absorbers (IFBA) fuel rods
- Wet Annular Burnable Absorbers (WABA) control rods
- Gadolinia Burnable Absorber fuel rods





Methods



OpenMC:

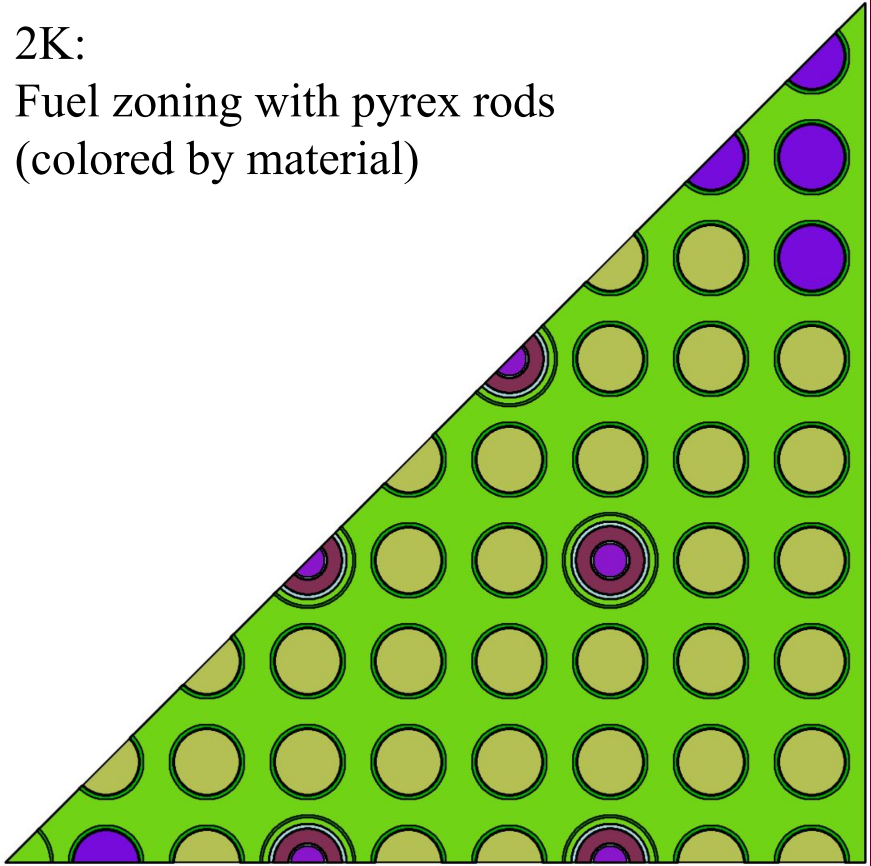
- Generate MGXS while performing k_{eff} calculations with each benchmark
- Export MGXS to hdf5 files to be used with OpenSn

OpenSn:

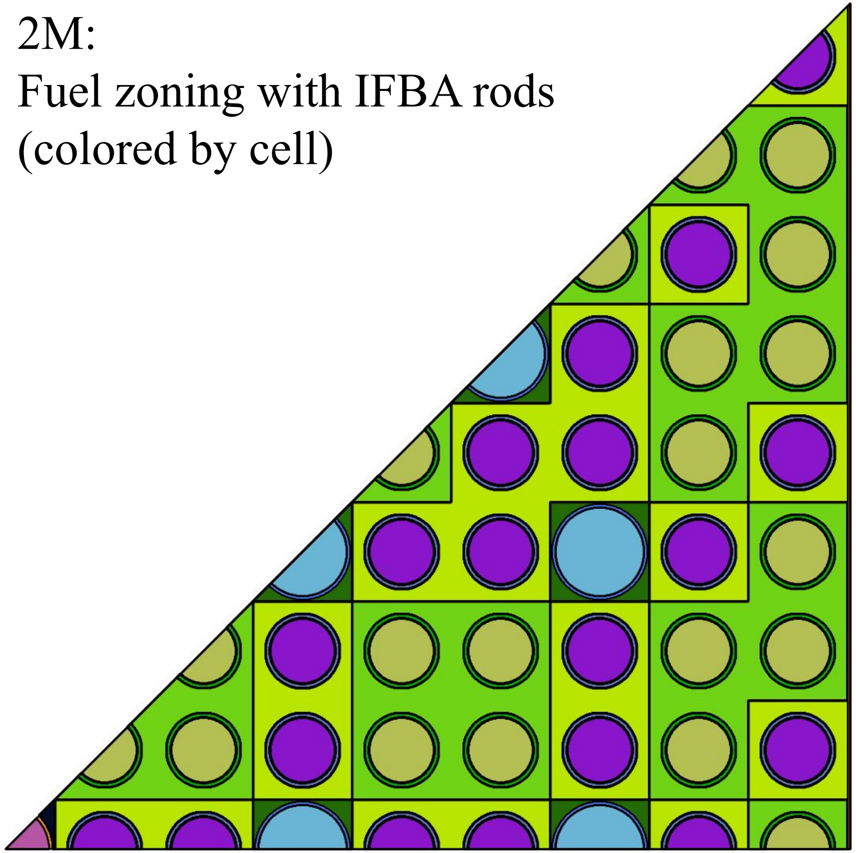
- Create 2D assembly mesh using Spydermesh python script
- Use MGXS generated by OpenMC to calculate k_{eff} with PyOpenSn

Problem 2: OpenMC

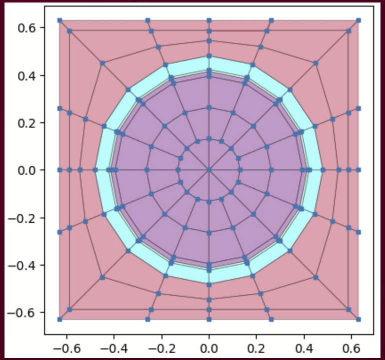
2K:
Fuel zoning with pyrex rods
(colored by material)

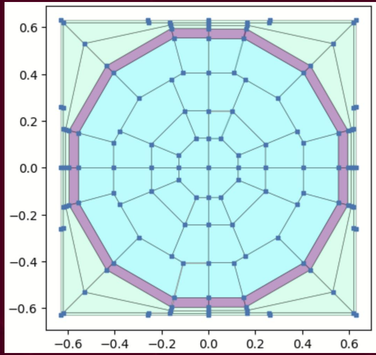


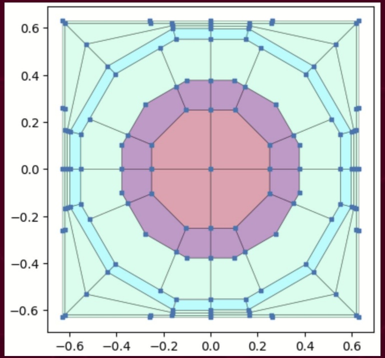
2M:
Fuel zoning with IFBA rods
(colored by cell)

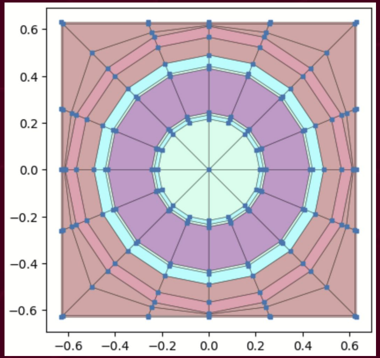


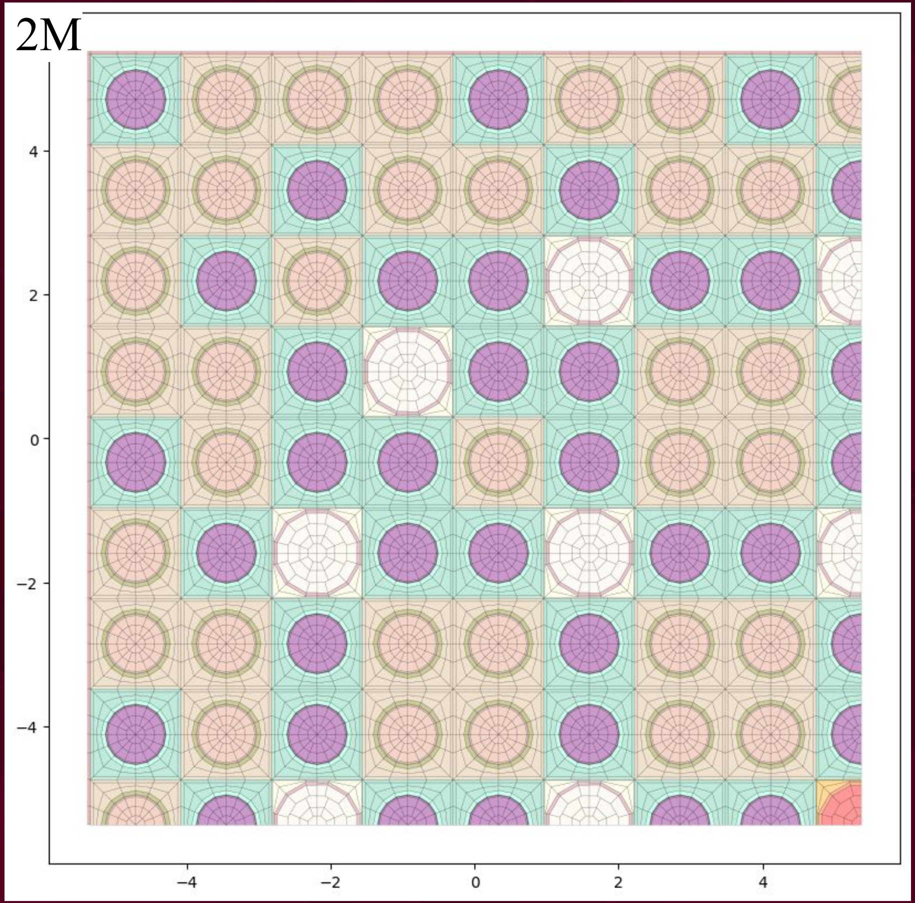
Problem 2: OpenSn





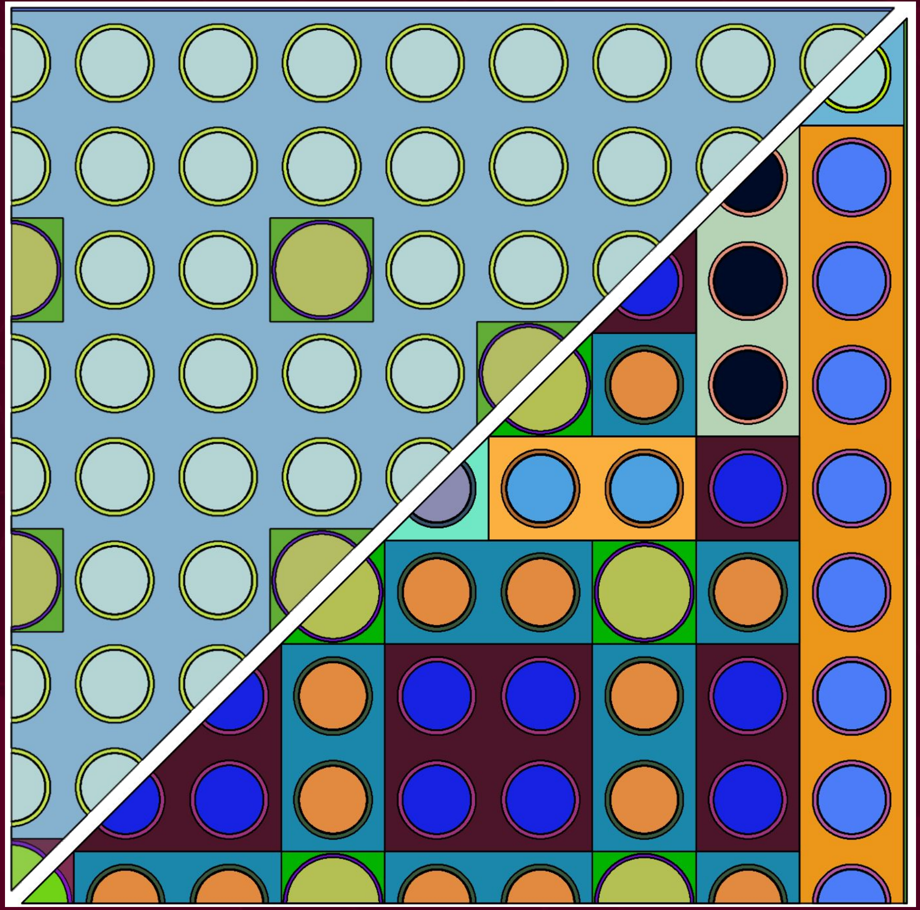




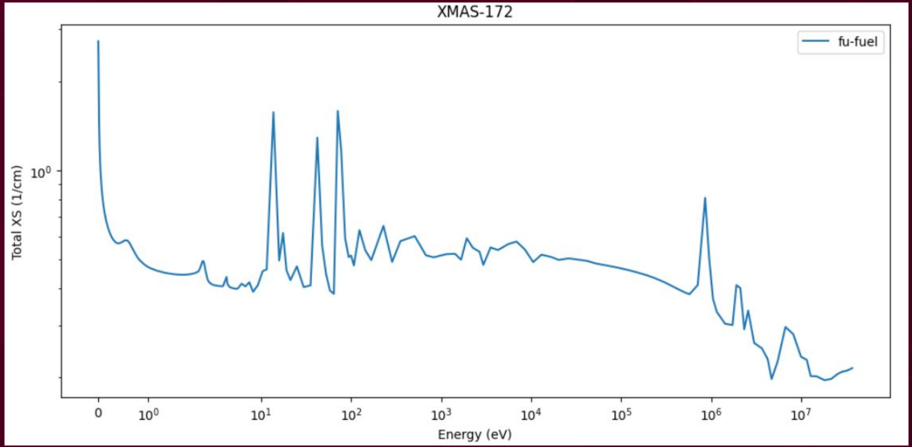


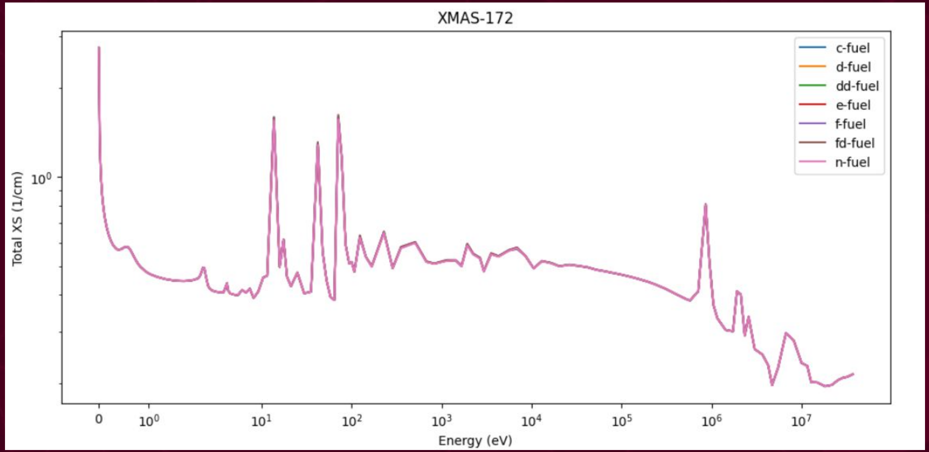
Family Case Study

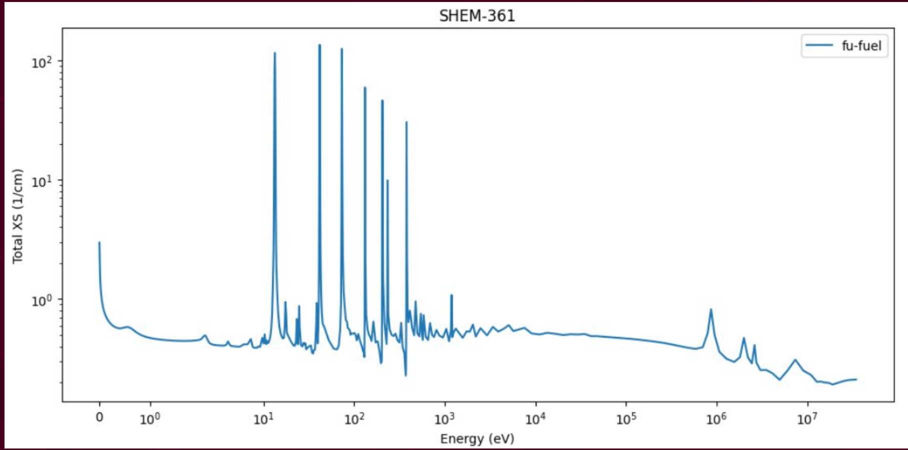
- Performed a case study on creating several fuel material families when calculating cross sections in OpenMC
- Tested a single-family treatment and 7-family treatment across 4 different energy group structures
- Used both fine and broad energy group structures:
  - XMAS-172 groups
  - CASMO-70 groups
  - CASMO-16 groups
  - SHEM-361 groups

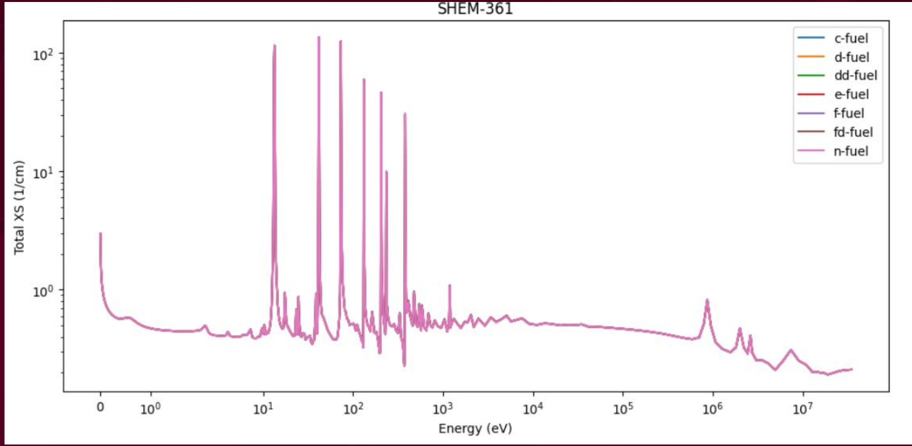


Family Case Study [XMAS-172 and SHEM-361]

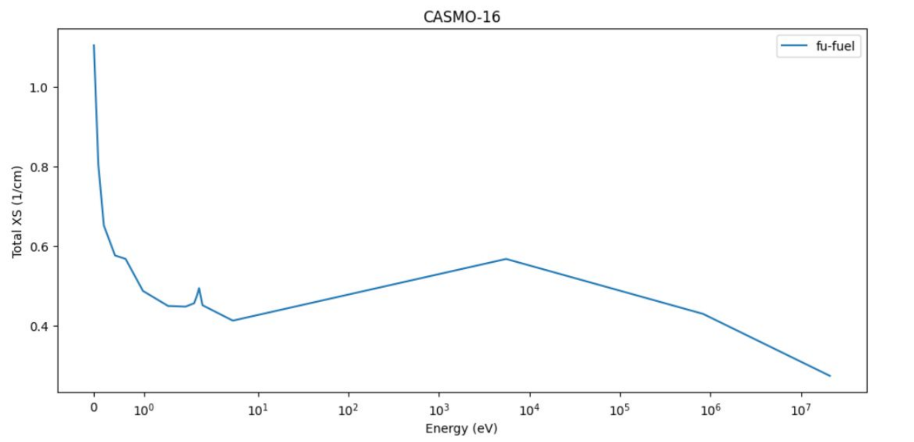


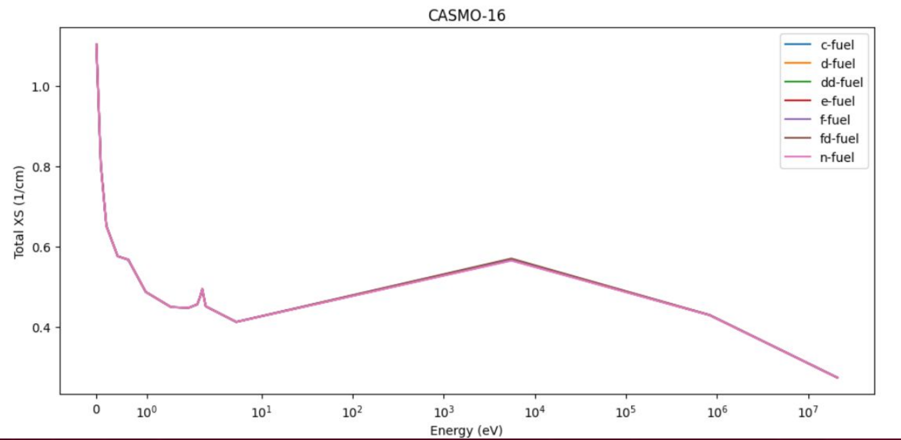


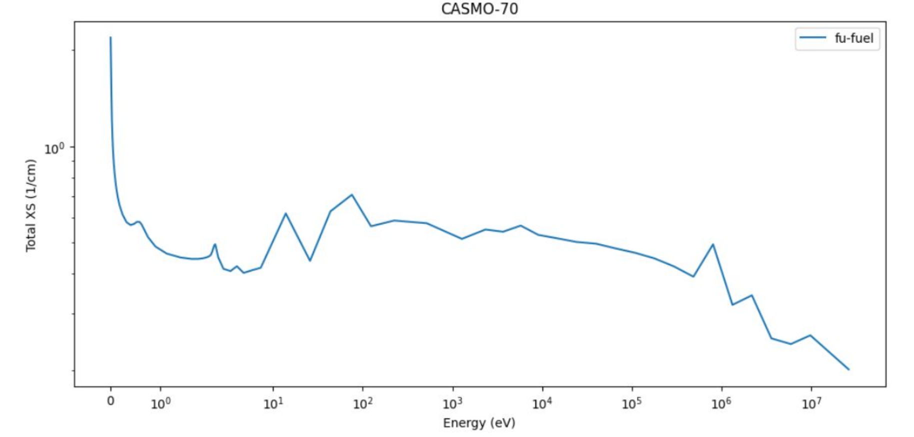


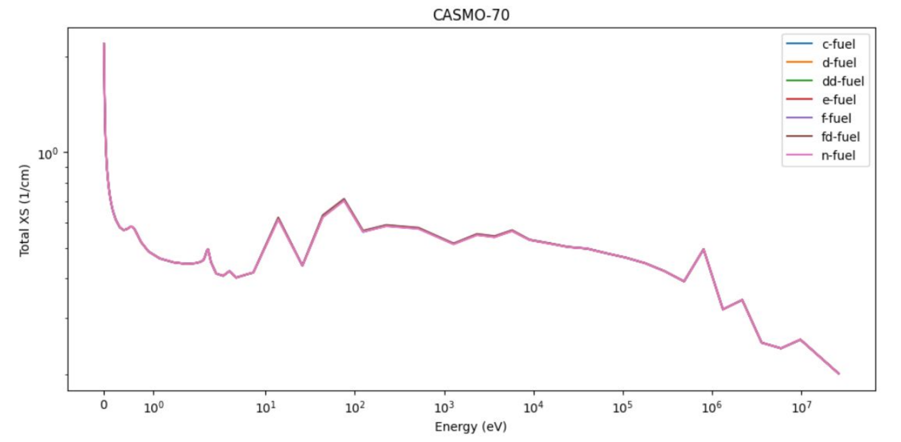


Family Case Study [CASMO-16 and CASMO-70]



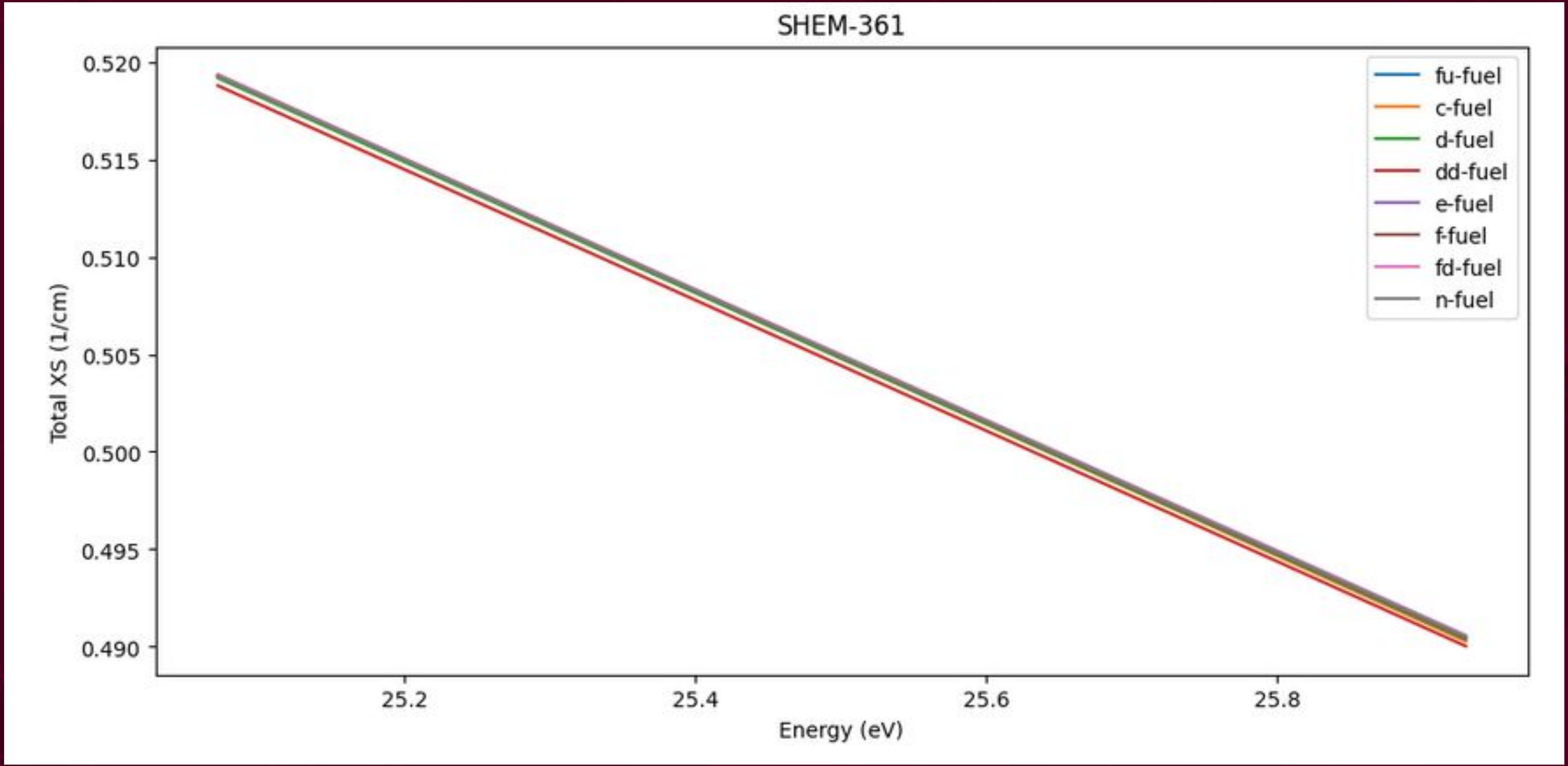






For Reference

Very little difference in 1 family vs 7 different families

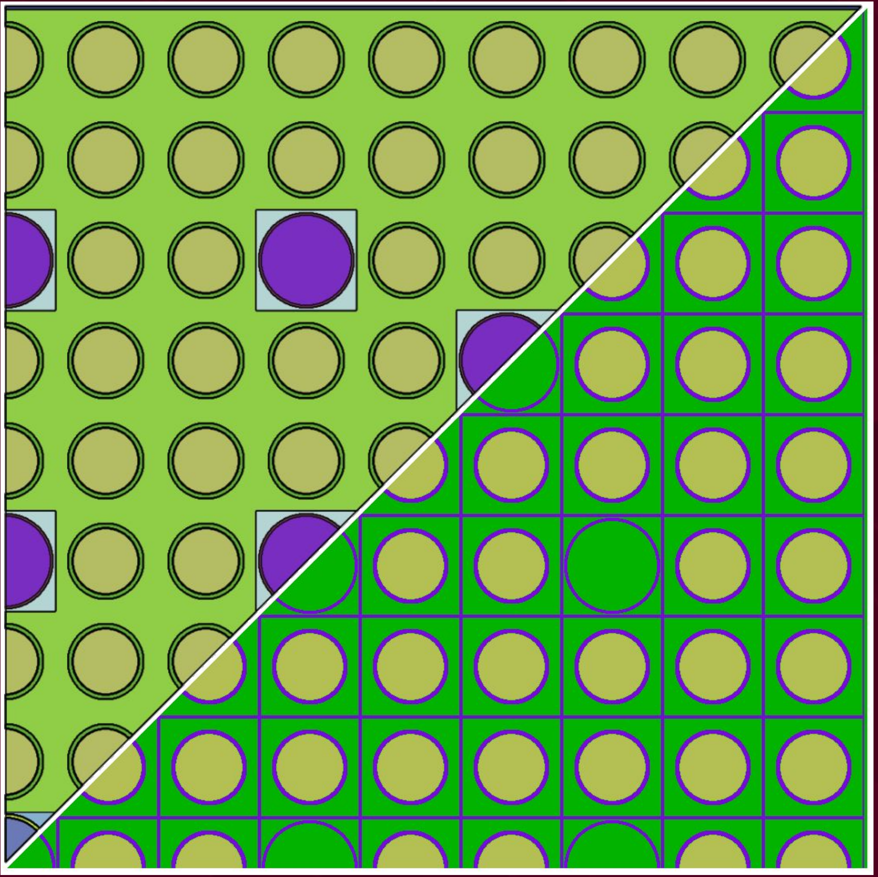


Problem 2Q: OpenMC

- 2Q includes the assembly spacer grid
- Studied effects of homogenizing the grid into the moderator, and modeling it directly

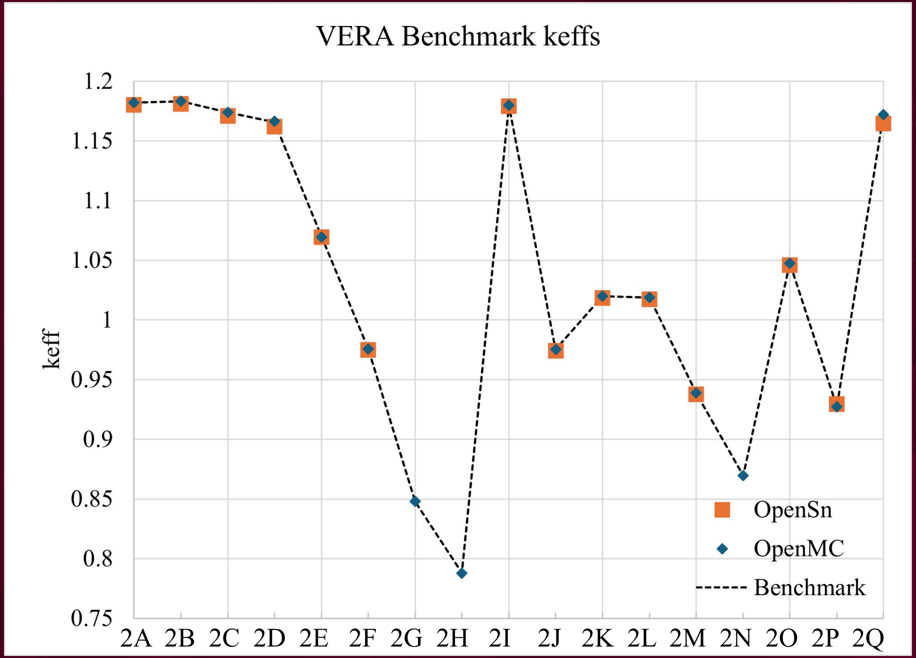
	keff	CASL Error (pcm)
Heterogeneous	1.17219	-21.43
Homogeneous	1.18170	832.81
Benchmark	1.17194	N/A

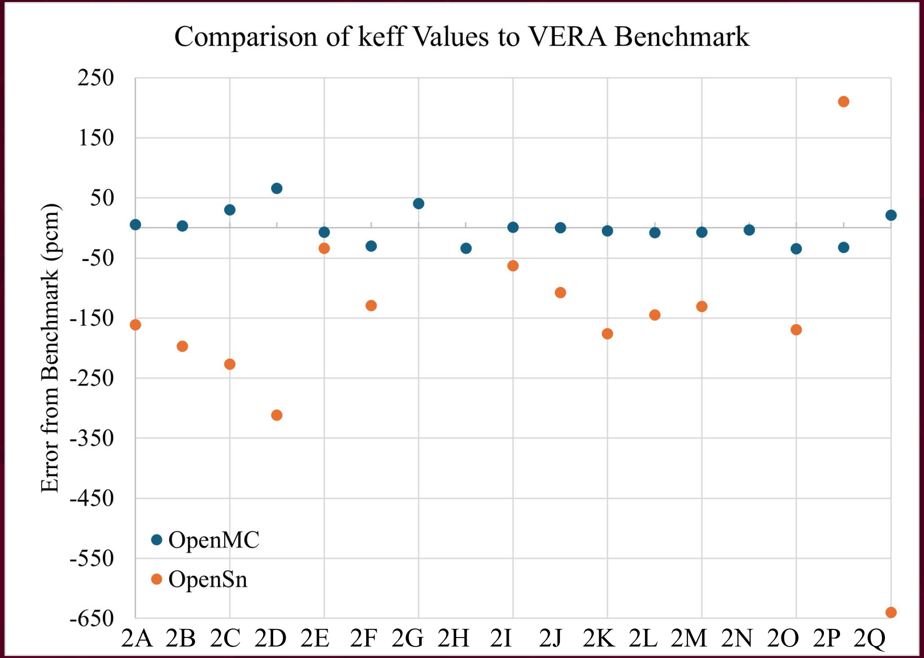
- Opted to model it heterogeneously



Problem 2: Results

- OpenMC results were fairly close to benchmark results
- Both had higher error in case 2D
- Higher tolerances caused higher error in OpenSn results





Problem 2: Power Distribution

Benchmark 2A:

1.0364	1.0089							
1.0371	1.0093	1.0104						
	1.0368	1.0386						
1.0353	1.0089	1.0118	1.0451	1.0313				
1.0328	1.0053	1.0089	1.0458	1.0516				
	1.0266	1.0281		1.0360	1.0180	0.9736		
1.0122	0.9880	0.9880	1.0115	0.9837	0.9649	0.9483	0.9389	
0.9764	0.9721	0.9714	0.9739	0.9645	0.9551	0.9458	0.9418	0.9476

OpenMC 2A:

1.036	1.021							
1.043	1.025	1.010						
	1.070	1.015						
1.049	1.013	0.999	1.061	1.030				
1.076	1.002	1.012	1.038	1.038				
	1.025	1.027		1.043	1.013	0.970		
1.021	0.975	0.985	0.978	0.986	0.965	0.939	0.937	
0.967	0.988	0.974	0.966	0.959	0.943	0.921	0.924	0.952

OpenSn 2A:

0.994	1.037						
1.032	0.995	1.079					
	0.994	1.038					
0.990	1.036	0.994	1.003	1.126			
1.025	0.986	1.070	1.040	1.036			
	0.978	1.019		0.970	0.955	0.949	
0.967	0.990	0.971	0.961	0.941	0.961	0.931	0.933

Problem 2: OpenMC Power Distribution

Benchmark:
(Cases with no control rods)

2B

1.0355	1.0113							
1.0362	1.0113	1.0121						
	1.0359	1.0373						
1.0337	1.0099	1.0124	1.0424	1.0308				
1.0308	1.0066	1.0095	1.0427	1.0474				
	1.0243	1.0258		1.0326	1.0146	0.9745		
1.0103	0.9893	0.9893	1.0099	0.9839	0.9666	0.9503	0.9406	
0.9781	0.9742	0.9738	0.9752	0.9662	0.9565	0.9475	0.9435	0.9478

2C

1.0357	1.0109							
1.0364	1.0113	1.0124						
	1.0364	1.0375						
1.0346	1.0102	1.0124	1.0422	1.0306				
1.0306	1.0066	1.0095	1.0426	1.0473				
	1.0248	1.0259		1.0324	1.0150	0.9738		
1.0102	0.9891	0.9891	1.0102	0.9840	0.9666	0.9494	0.9411	
0.9782	0.9742	0.9738	0.9753	0.9658	0.9564	0.9476	0.9433	0.9476

(Cases with control rods)

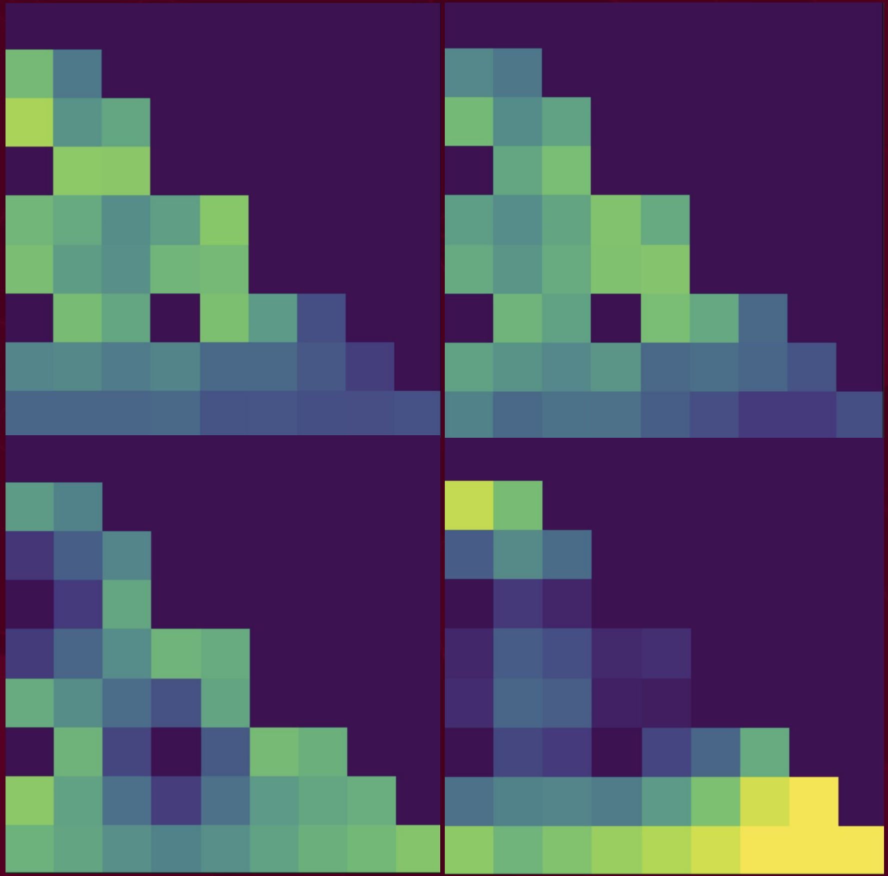
2E

1.0170	0.9930							
0.9299	0.9635	0.9962						
	0.9331	1.0250						
0.9347	0.9695	1.0022	1.0362	1.0290				
1.0290	1.0034	0.9751	0.9523	1.0226				
	1.0350	0.9419		0.9579	1.0426	1.0314		
1.0578	1.0222	0.9763	0.9355	0.9787	1.0146	1.0246	1.0290	
1.0346	1.0238	1.0054	0.9938	1.0054	1.0218	1.0314	1.0398	1.0514

2F

1.0783	1.0428							
0.9714	0.9907	0.9736						
	0.9333	0.9262						
0.9258	0.9591	0.9543	0.9118	0.9262				
0.9280	0.9617	0.9587	0.9127	0.9070				
	0.9420	0.9411		0.9350	0.9670	1.0340		
0.9744	1.0047	1.0060	0.9793	1.0191	1.0502	1.0831	1.1094	
1.0472	1.0529	1.0551	1.0551	1.0717	1.0923	1.1138	1.1339	1.1541

OpenMC:



Problem 2: OpenMC Power Distribution

Benchmark:

(Case with fuel zoning) (Case with spacer grid)

2K

0.9765	1.0637							
0.9899	1.0055	0.9849						
	0.9455	0.9388						
0.9380	0.9690	0.9644	0.9237	0.9388				
0.9388	0.9707	0.9673	0.9246	0.9195				
	0.9510	0.9505		0.9476	0.9807	1.0495		
0.9811	1.0105	1.0122	0.9874	1.0285	1.0645	1.1073	1.0159	
1.0524	1.0578	1.0608	1.0620	1.0813	1.1098	1.0147	1.0453	1.0687

2Q

1.0368	1.0105							
1.0371	1.0113	1.0120						
	1.0375	1.0389						
1.0353	1.0098	1.0124	1.0448	1.0331				
1.0320	1.0069	1.0098	1.0448	1.0513				
	1.0258	1.0273		1.0357	1.0160	0.9726		
1.0113	0.9883	0.9879	1.0109	0.9828	0.9639	0.9468	0.9369	
0.9774	0.9726	0.9723	0.9745	0.9646	0.9548	0.9457	0.9413	0.9479

(Cases with coated fuel)

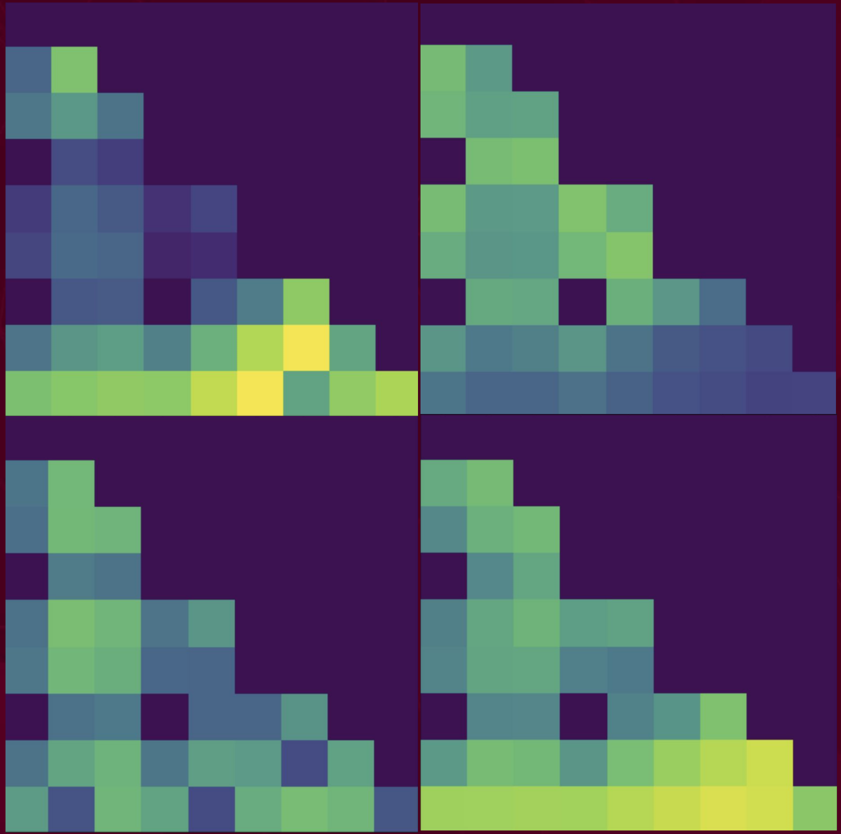
2M

0.9833	1.0389							
0.9846	1.0393	1.0389						
	0.9833	0.9824						
0.9828	1.0370	1.0361	0.9760	1.0206				
0.9814	1.0361	1.0343	0.9714	0.9696				
	0.9769	0.9778		0.9696	0.9659	1.0042		
0.9728	1.0193	1.0297	0.9792	1.0170	1.0170	0.9441	1.0152	
1.0079	0.9432	1.0334	1.0288	0.9473	1.0325	1.0361	1.0306	0.9423

2N

0.9756	1.0258							
0.8993	0.9963	1.0209						
	0.8923	0.9657						
0.8697	0.9722	1.0057	0.9468	0.9557				
0.8678	0.9644	0.9700	0.8651	0.8467				
	0.8819	0.8831		0.8705	0.9111	1.0554		
0.9247	1.0155	1.0180	0.9318	1.0367	1.0824	1.1272	1.1538	
1.0800	1.0928	1.0962	1.0923	1.1184	1.1459	1.1661	1.1602	1.0603

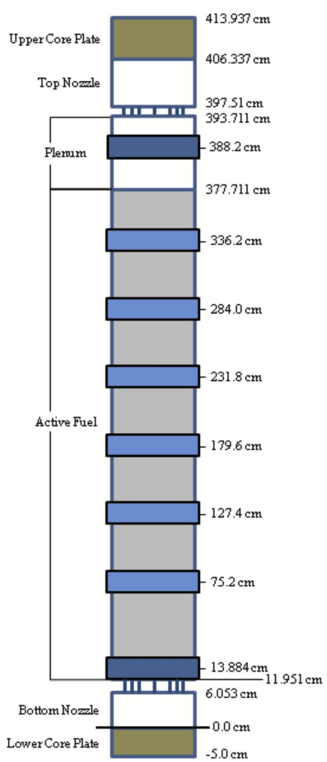
OpenMC:

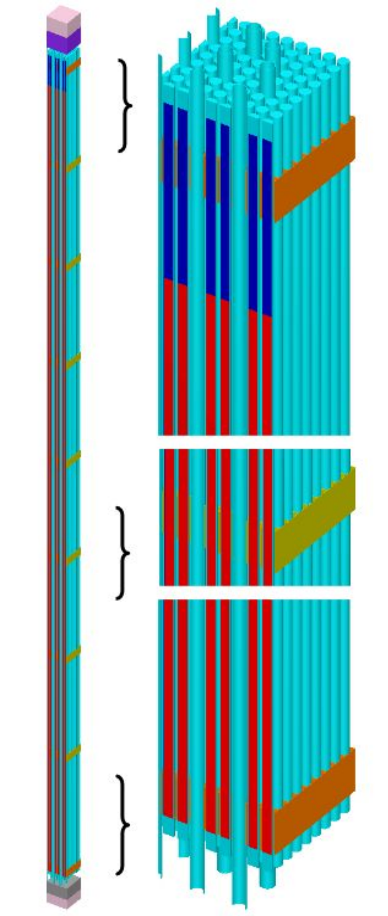


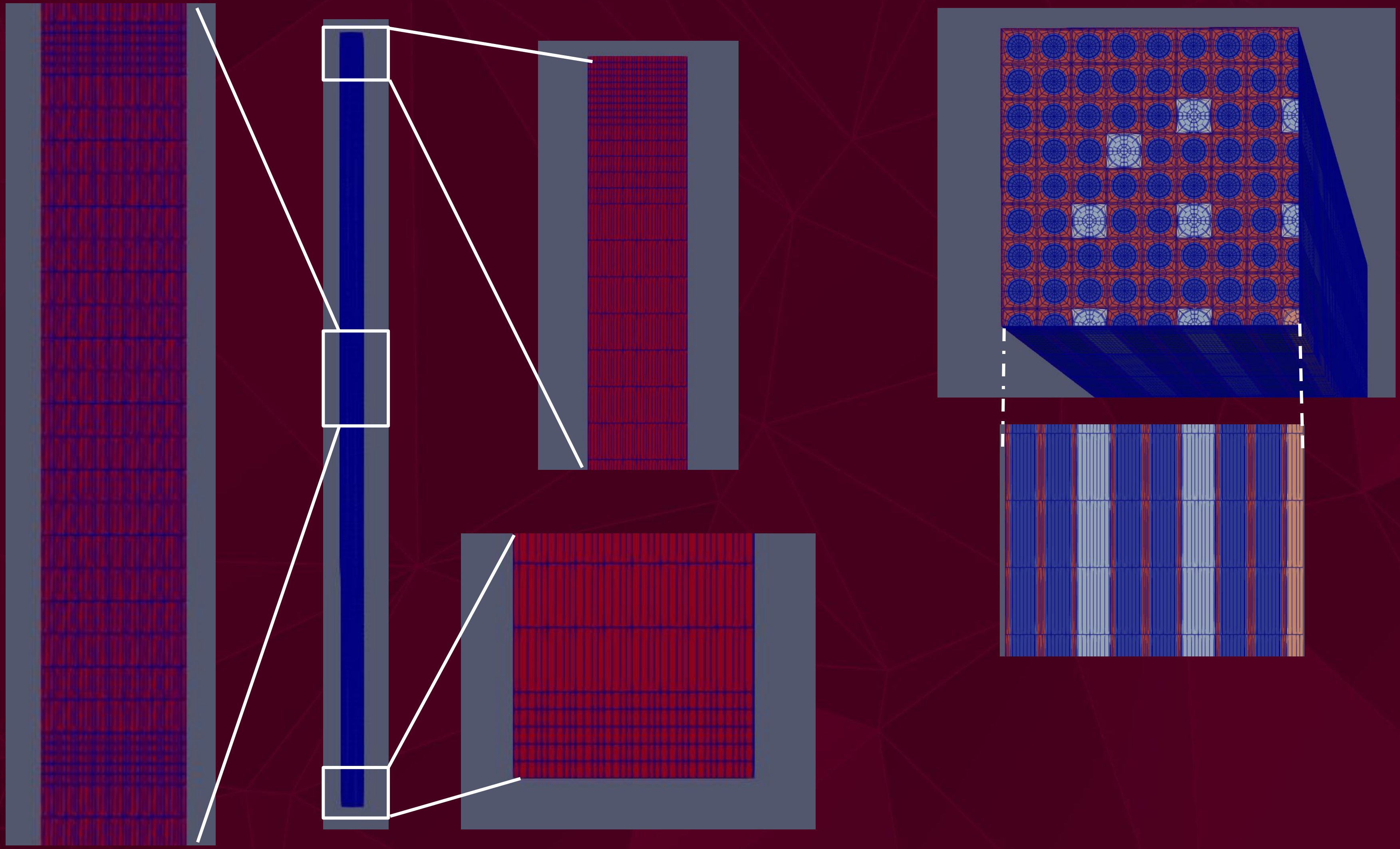
Problem 3

Problem	Description	Enrichment	Boron	Temperature	k-effective	Axial Offset
3A	No Poisons	3.10%	1300 ppm	600K	**1.175722 ± 0.000005**	0.163%
3B	16 Pyrex	2.619%	1066 ppm	565K	**1.000154 ± 0.000006**	-0.062%

- 3D version of Problem 2
- 3A is the assembly, 3B includes control rods
- Used OpenSn function "ExtruderMeshGenerator()" to model the assembly
- Future work







Conclusion and Future Work

Results:

- OpenMC results were closer due to lower tolerances
- Benchmark was performed with a Monte Carlo code (KENO-VI), which may lend to OpenMC’s similar results
- Power distributions had similar shape, but somewhat variable

Future work:

- Lower tolerances for OpenSn runs
- OpenSn power distributions
- Run problem 3A and 3B models in OpenSn

References

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Questions?