NIST Neutron Source Initial Startup Core Loading Analysis

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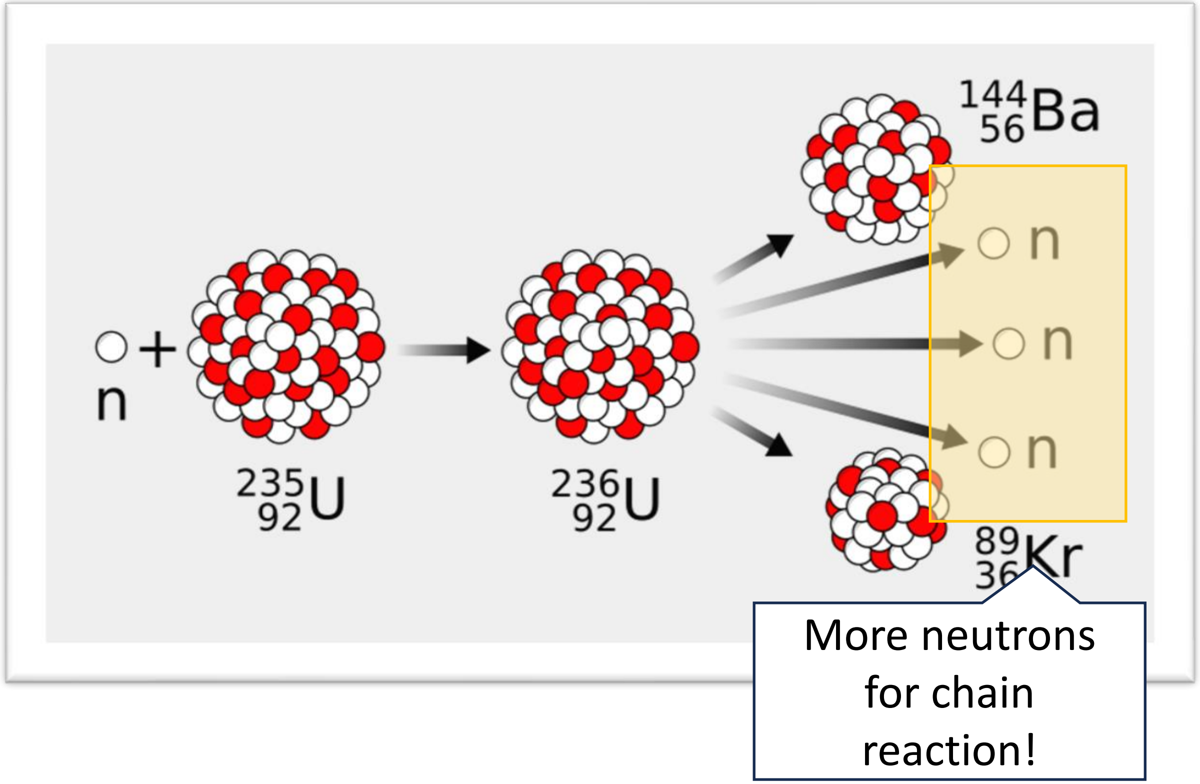
Contents

About Me

- **School:**
  - Montclair State University – Montclair, NJ (close to NYC)
- **Major**
  - Physics (B.S.)
- **Interests**
  - Nuclear Engineering
  - Reactor Physics
  - Aeronautical/Astronautical Engineering
- **Future Goals**
  - Pursue advanced degree (M.S. or Ph.D) in nuclear engineering
  - Work on nuclear reactors for space applications

Introduction: Background Concepts

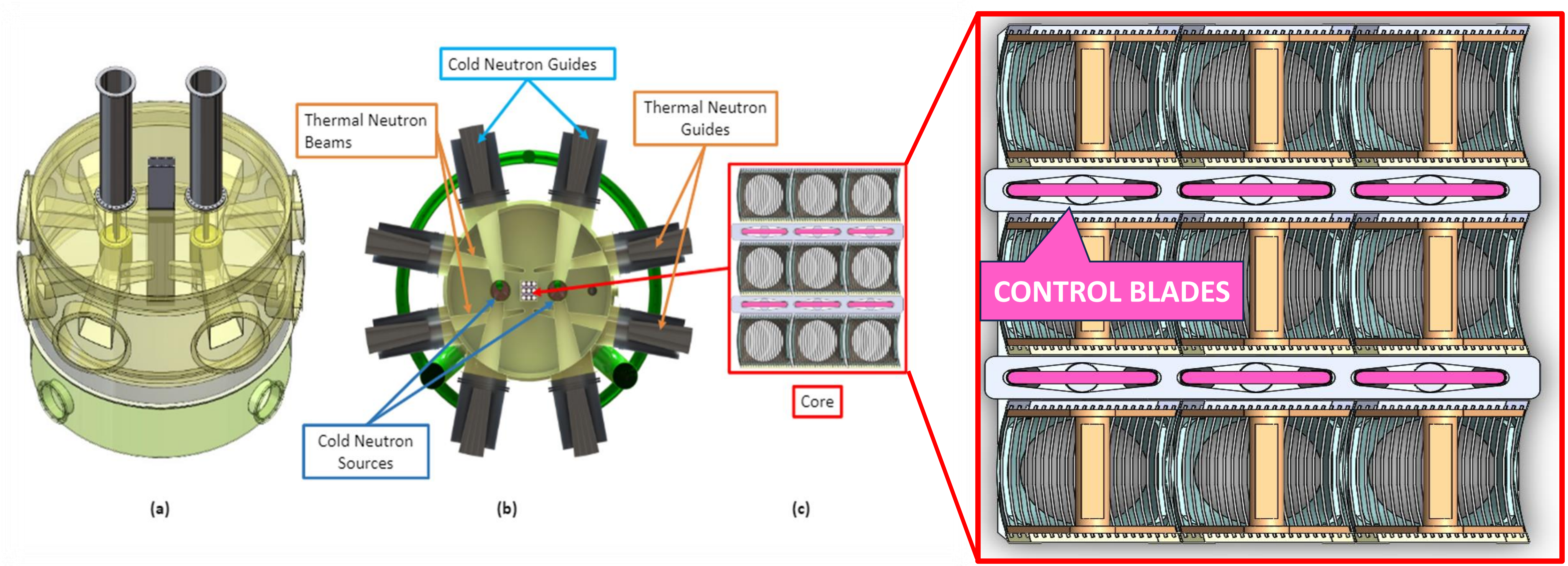
- Isotopes want to be stable. They can **release neutrons**, gamma rays and electrons



$\boldsymbol{k_{eff}}$ ***(factor to determine if reactor is critical)***

$$\boldsymbol{k_{eff}} = \mathbf{1};\ Good!\ Critical$$
$$\boldsymbol{k_{eff}} > \mathbf{1};\ Bad!\ Supercritical\ (Bomb!)$$
$$\boldsymbol{k_{eff}} < \mathbf{1};\ Bad!\ Subcritical$$

Introduction: What is the NNS

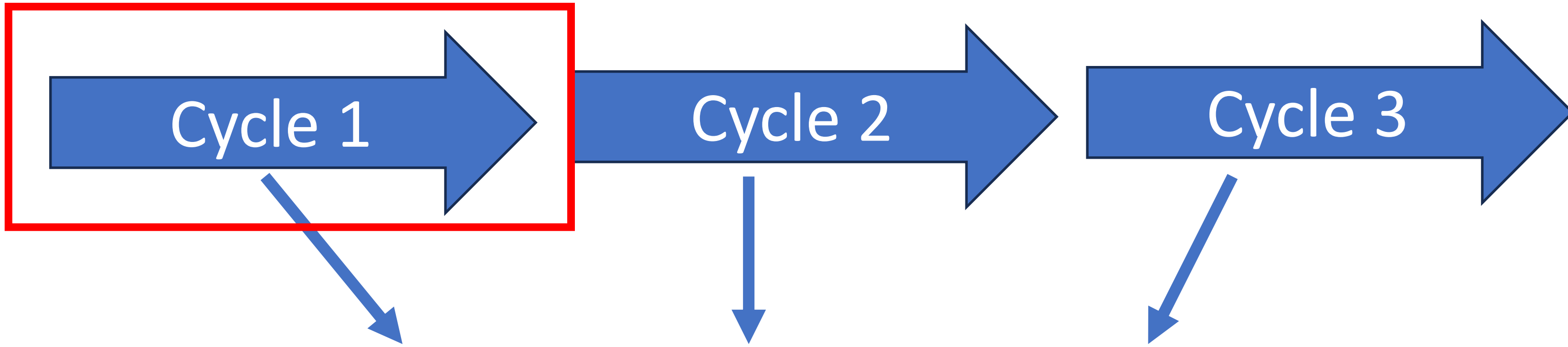


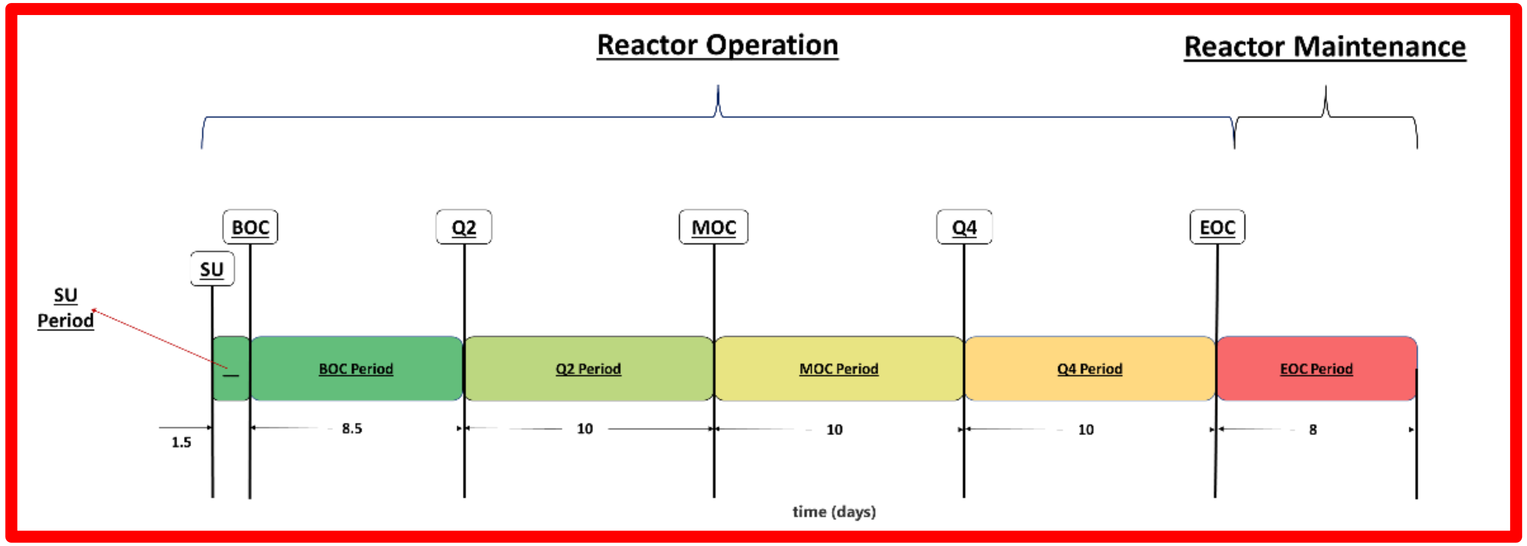
- NNS (NIST Neutron Source) proposed to be a **pool-type reactor to replace the NBSR**
- Planned to deliver 20 MW of thermal energy

Introduction: Initial Core Loading

A reactor's 'lifetime' is in terms of cycles

- U-10Mo (uranium and 10% molybdenum by wt.) are loaded into the core at the beginning of each cycle
- We are concerned with the initial core at Startup (SU) of cycle 1



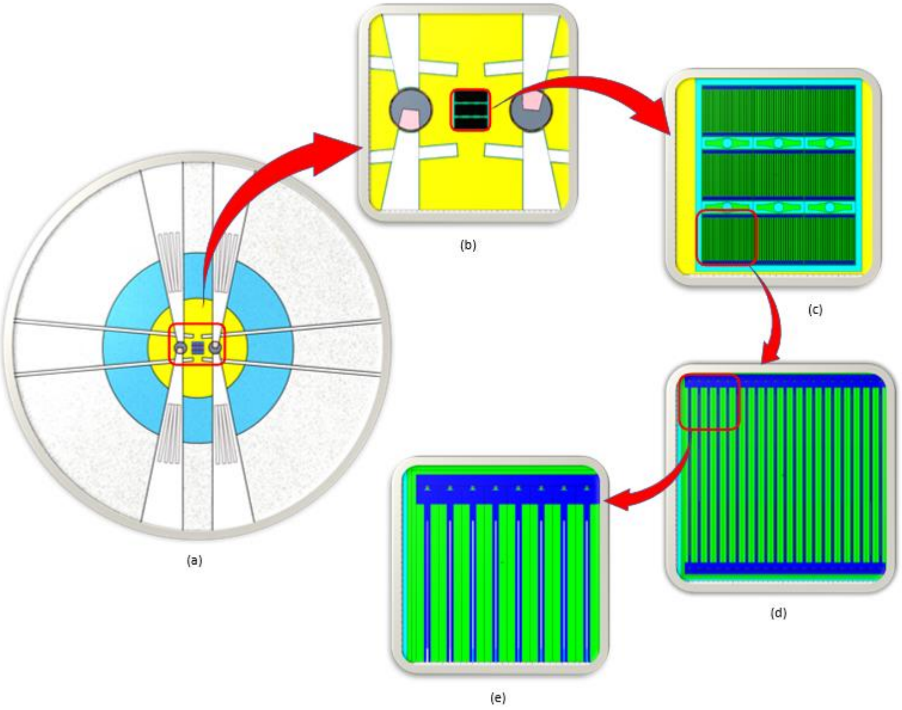


Introduction: Methodologies Used

NIST

- How can we 'simulate' what happens in a nuclear reactor?
- We used <u>Monte Carlo N-Particle (MCNP)</u> software
- Allows us to define the geometry and materials of our reactor
- Returns results of physics simulations

MCNP®
MONTE CARLO N-PARTICLE



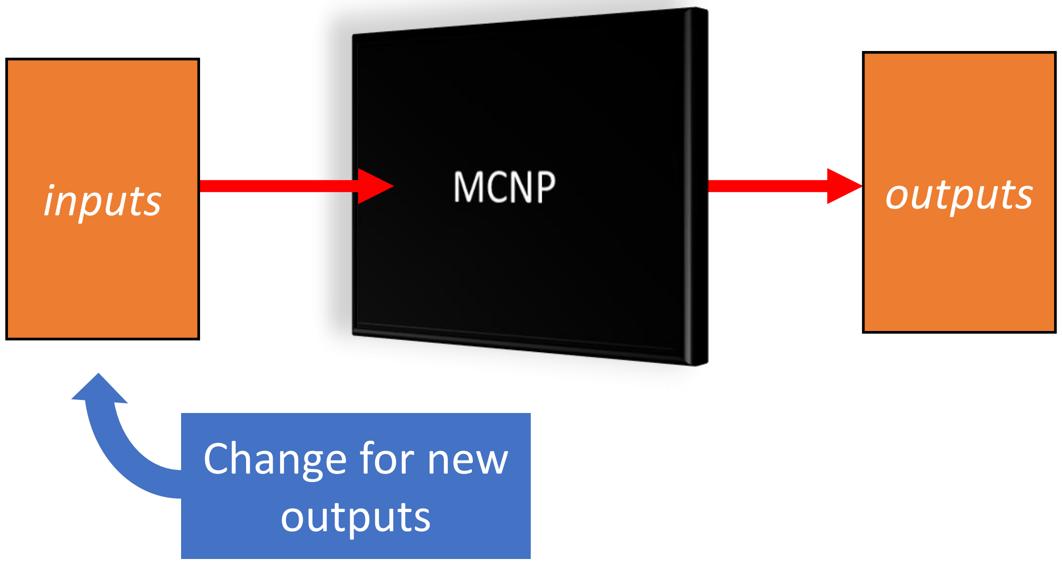
Visual Display of Reactor Model Generated from MCNP

Goal

- **Current Problems**
  - NNS initial loading of the 1st cycle is not optimized
- **Work To Do**
  - Find the initial startup core loading for the NNS
  - Analyze the effects of different fuel configurations on core behavior
  - Find the enrichment equivalence of the equilibrium core
  - Determine the number of fuel plates and their positions in the assemblies
  - Perform a criticality safety assessment of the NNS core during initial loading
  - Prediction of the power peaking for safety assessment

MATLAB Code

- Inputs give you outputs!
- Need capacity to edit/remove sections of input file and retain formatting (indentation)



burn_Box9_v02_SU_cycle8.i

~160,000 lines of input

```
Box9 v0.2, 1350 fuel mats, 42 Cd wires per FA
c Last update: January 5, 2021
c
c
c --Begin Cells--
1      0         8:9:-10  tmp=2.747-8 imp:n,p=0                          $ outside of water pool
2      4 -0.99180 -7 -9 10 (11:21:-31)                                   $ light water pool
(-1001:1006:-2001:2006:-31:898)
c cold sources:
(-4030:4031:4032:-4033:4034)
( 4130:4131:4132:-4133:4134)
(-5030:5031:5032:-4033:4034)
( 5330:5331:5332:-4133:4134)
c beam tubes:
(-9110:9111:-9104:9107:9109) (9100:9109) (9103:9109)
(-9210:9211:-9204:9207:9209) (9200:9209) (9203:9209)
(-9310:9311:-9304:9307:9309) (9300:9309) (9303:9309)
(-9410:9411:-9404:9407:9409) (9400:9409) (9403:9409)
tmp=2.747-8 imp:n,p=1
3      5 -6.55    -11 -21 31 (1:2:-3)                                    $ heavy water outer tank container
(1006:-1001:2006:-2001)
c cold sources:
(-4030:4031:4032:-4033:4034)
( 4130:4131:4132:-4133:4134)
(-5030:5031:5032:-4033:4034)
( 5330:5331:5332:-4133:4134)
(21:-2:200)
(21:-2:300)
c beam tubes:
(-9110:9111:-9104:9107:9109) (9100:9109) (9103:9109)
(-9210:9211:-9204:9207:9209) (9200:9209) (9203:9209)
(-9310:9311:-9304:9307:9309) (9300:9309) (9303:9309)
(-9410:9411:-9404:9407:9409) (9400:9409) (9403:9409)
```

MATLAB Code – Compiling the Input File

mainInputFileEditor()

- Gives us the ability to change *a lot* in the input file automatically

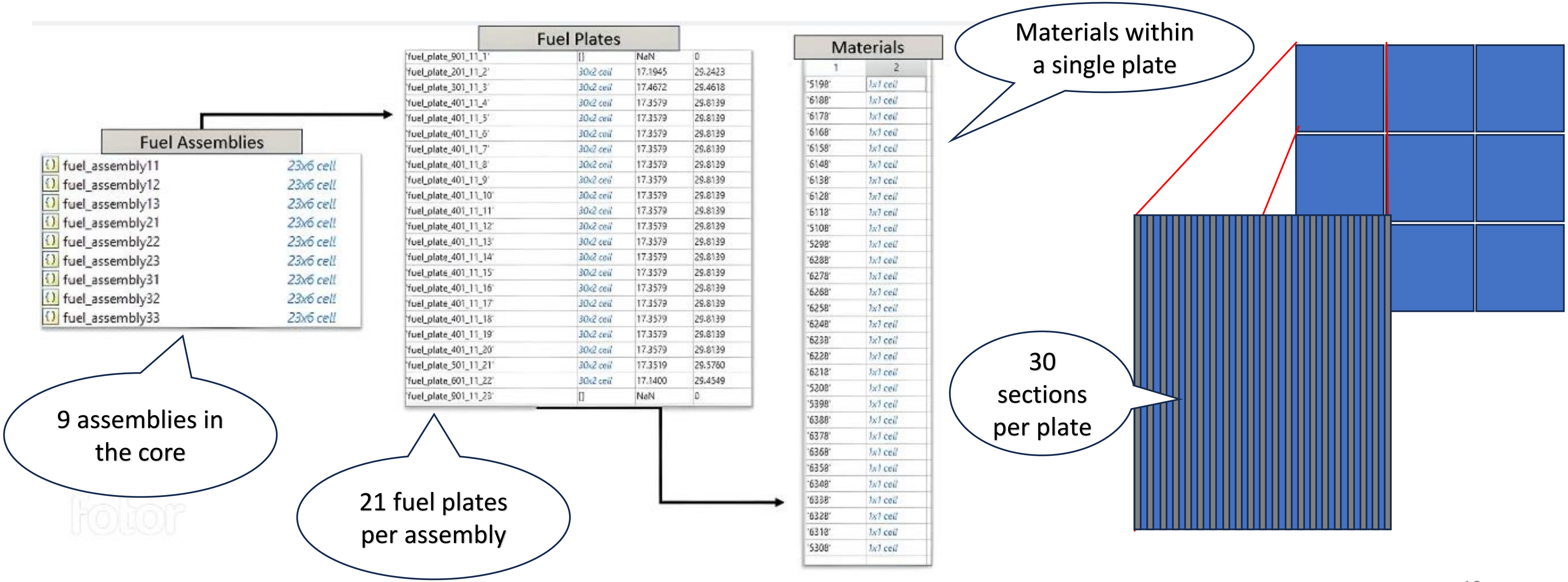
enrichmentCalculator()

$$\boldsymbol{enrichment\,\% = \frac{fissile\ mass}{nonfissile\ mass + fissile\ mass} * 100}$$

- Allows us to calculate the enrichment of the materials in the input file!

MATLAB Code

- Entire reactor core organized hierarchically in arrays



Fuel Assemblies

fuel_assembly11	23x6 cell
fuel_assembly12	23x6 cell
fuel_assembly13	23x6 cell
fuel_assembly21	23x6 cell
fuel_assembly22	23x6 cell
fuel_assembly23	23x6 cell
fuel_assembly31	23x6 cell
fuel_assembly32	23x6 cell
fuel_assembly33	23x6 cell

Fuel Plates

'fuel_plate_901_11_1'	[]	NaN	0
'fuel_plate_201_11_2'	30x2 cell	17.1945	29.2423
'fuel_plate_301_11_3'	30x2 cell	17.4672	29.4618
'fuel_plate_401_11_4'	30x2 cell	17.3579	29.8139
'fuel_plate_401_11_5'	30x2 cell	17.3579	29.8139
'fuel_plate_401_11_6'	30x2 cell	17.3579	29.8139
'fuel_plate_401_11_7'	30x2 cell	17.3579	29.8139
'fuel_plate_401_11_8'	30x2 cell	17.3579	29.8139
'fuel_plate_401_11_9'	30x2 cell	17.3579	29.8139
'fuel_plate_401_11_10'	30x2 cell	17.3579	29.8139
'fuel_plate_401_11_11'	30x2 cell	17.3579	29.8139
'fuel_plate_401_11_12'	30x2 cell	17.3579	29.8139
'fuel_plate_401_11_13'	30x2 cell	17.3579	29.8139
'fuel_plate_401_11_14'	30x2 cell	17.3579	29.8139
'fuel_plate_401_11_15'	30x2 cell	17.3579	29.8139
'fuel_plate_401_11_16'	30x2 cell	17.3579	29.8139
'fuel_plate_401_11_17'	30x2 cell	17.3579	29.8139
'fuel_plate_401_11_18'	30x2 cell	17.3579	29.8139
'fuel_plate_401_11_19'	30x2 cell	17.3579	29.8139
'fuel_plate_401_11_20'	30x2 cell	17.3579	29.8139
'fuel_plate_501_11_21'	30x2 cell	17.3519	29.5760
'fuel_plate_601_11_22'	30x2 cell	17.1400	29.4549
'fuel_plate_901_11_23'	[]	NaN	0

Materials

1	2
'5198'	1x1 cell
'6188'	1x1 cell
'6178'	1x1 cell
'6168'	1x1 cell
'6158'	1x1 cell
'6148'	1x1 cell
'6138'	1x1 cell
'6128'	1x1 cell
'6118'	1x1 cell
'5108'	1x1 cell
'5298'	1x1 cell
'6288'	1x1 cell
'6278'	1x1 cell
'6268'	1x1 cell
'6258'	1x1 cell
'6248'	1x1 cell
'6238'	1x1 cell
'6228'	1x1 cell
'6218'	1x1 cell
'5208'	1x1 cell
'5398'	1x1 cell
'6388'	1x1 cell
'6378'	1x1 cell
'6368'	1x1 cell
'6358'	1x1 cell
'6348'	1x1 cell
'6338'	1x1 cell
'6328'	1x1 cell
'6318'	1x1 cell
'5308'	1x1 cell

Finding the Initial Core Loading

- To do this, we must compare with existent Equilibrium Core State (ECS) results
- ECS simply is the reactor under nominal operating conditions

Finding the Initial Core Loading

$$\frac{mass\ of\ U10Mo\ Plate}{fissile\ mass\ of\ assembly} = number\ of\ U10Mo\ Plates$$

Desired Fissile Mass in Each Assembly

624.6g	727.8g	522.7g
518.1g	727.8g	622.7g
624.6g	727.8g	523.1g

Desired Plates to Empty/Fill

18 Plates to Fill 3 to Empty	Core Loaded	15 Plates to Fill 6 to Empty
15 Plates to Fill 6 to Empty	Core Loaded	18 Plates to Fill 3 to Empty
18 Plates to Fill 3 to Empty	Core Loaded	15 Plates to Fill 6 to Empty

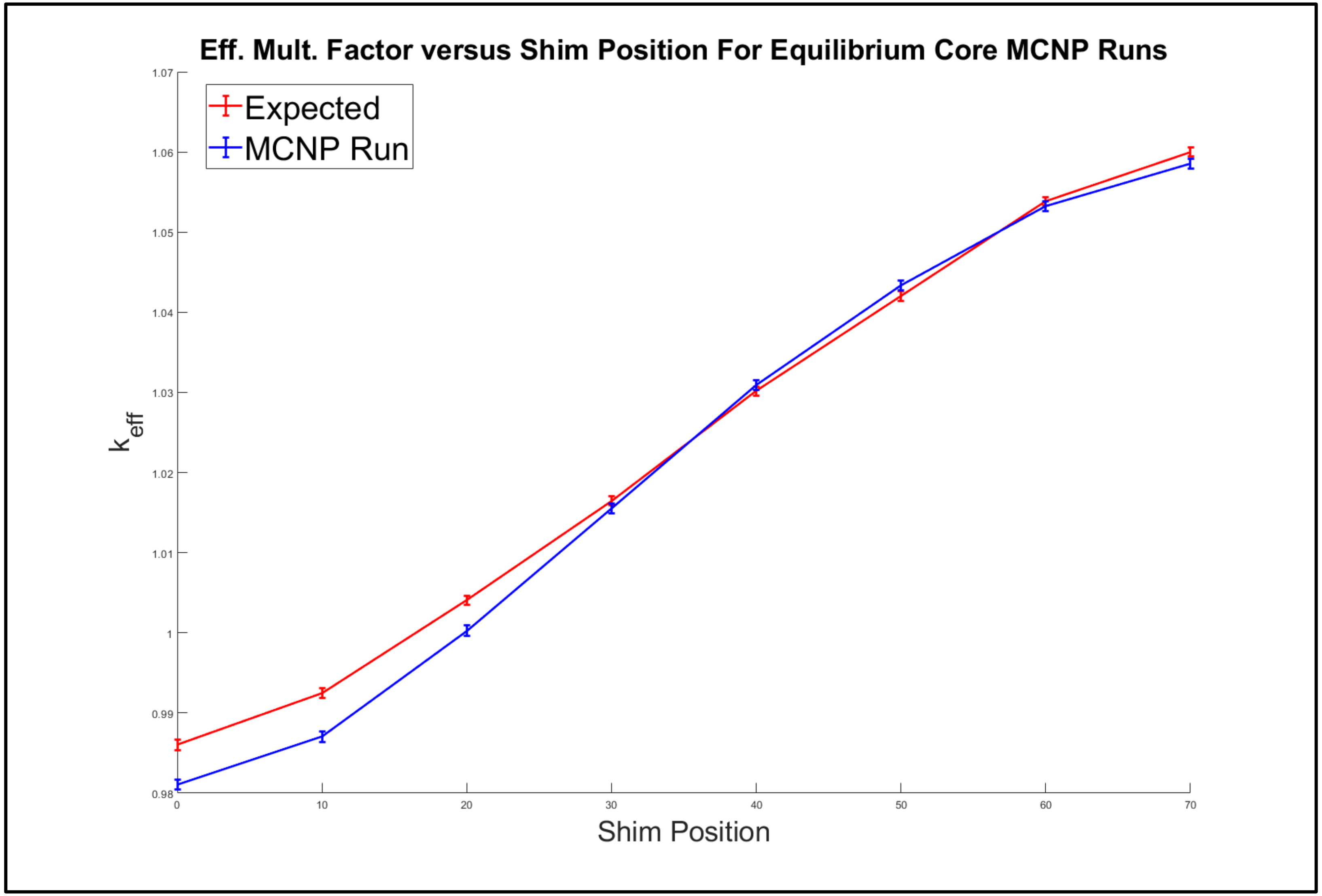
Equilibrium Core State Results - 1

- Comparing our configuration with expected results

	Expected ECS Values	Initial Core Loading (Simulated) Values	% Diff
Control Blade Position (cm)	k_{eff}	k_{eff}	%
0	*0.986*	*0.981*	0.51
10	*0.992*	*0.987*	0.51
20	*1.004*	*1.000*	0.40
30	*1.016*	*1.016*	0.00
40	*1.030*	*1.031*	-0.10
50	*1.042*	*1.043*	-0.10
60	*1.054*	*1.053*	0.09
70	*1.060*	*1.059*	0.09

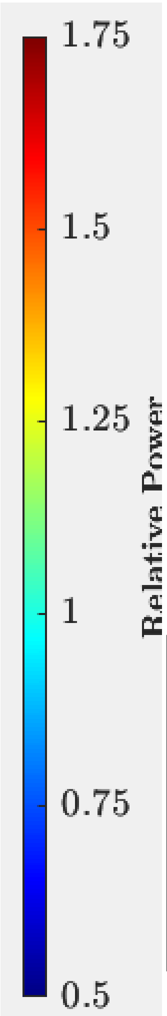
Uncertainties in k_{eff} not included

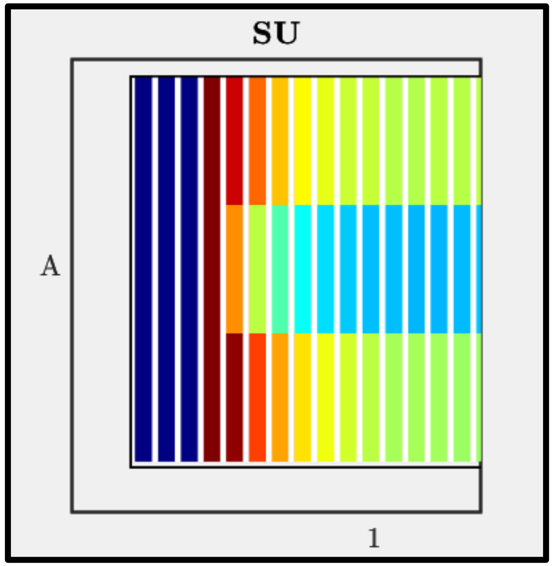
Equilibrium Core State Results - 2



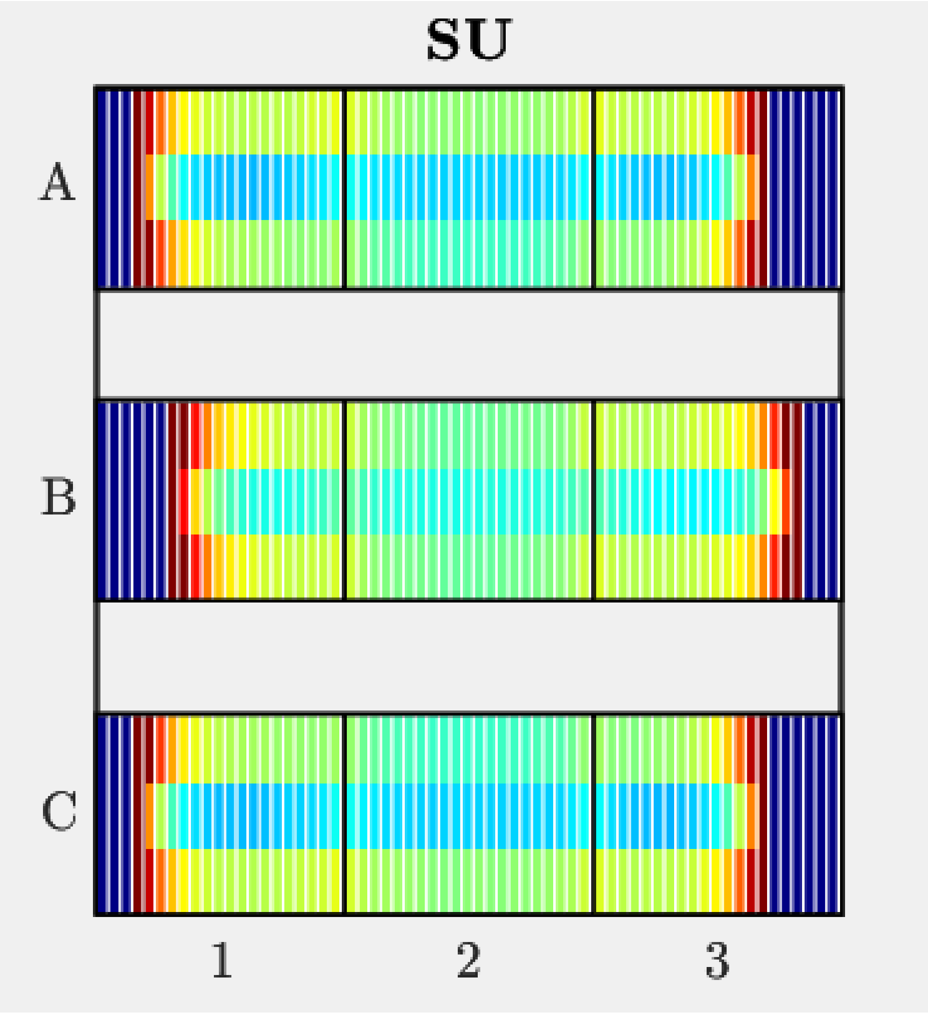
Power Peaking Results

First Case: Emptying the Peripheral Plates First



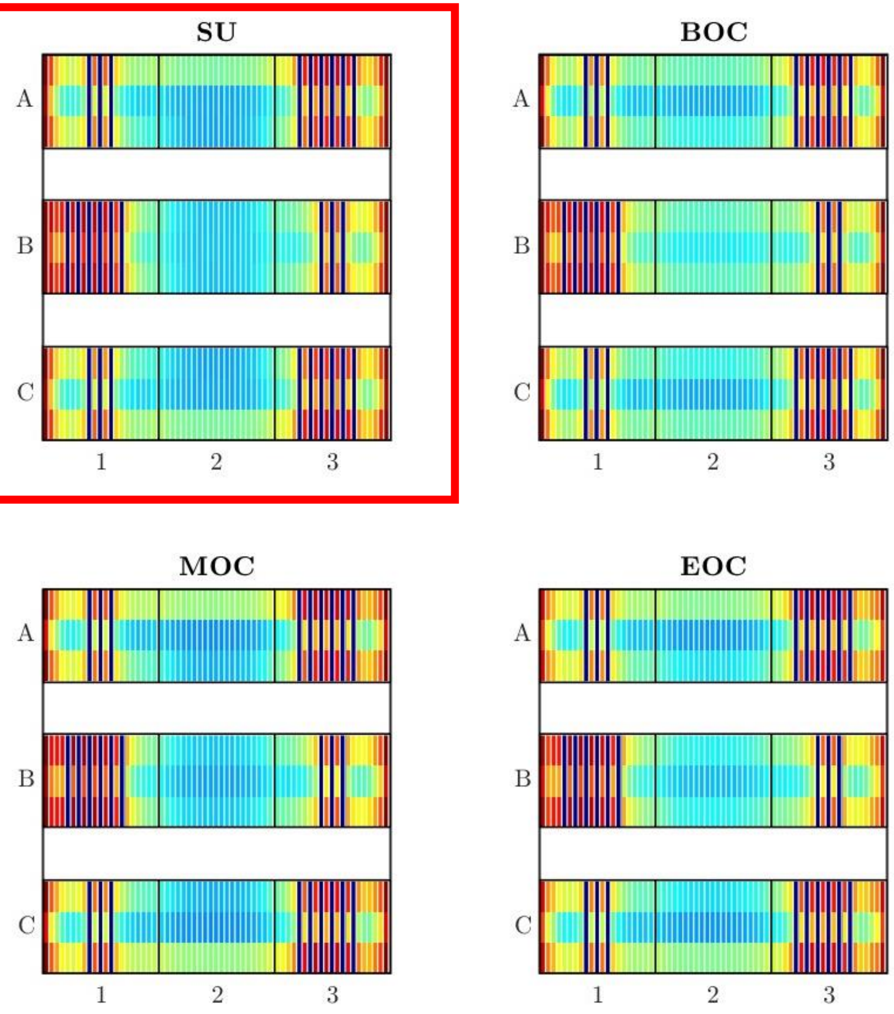


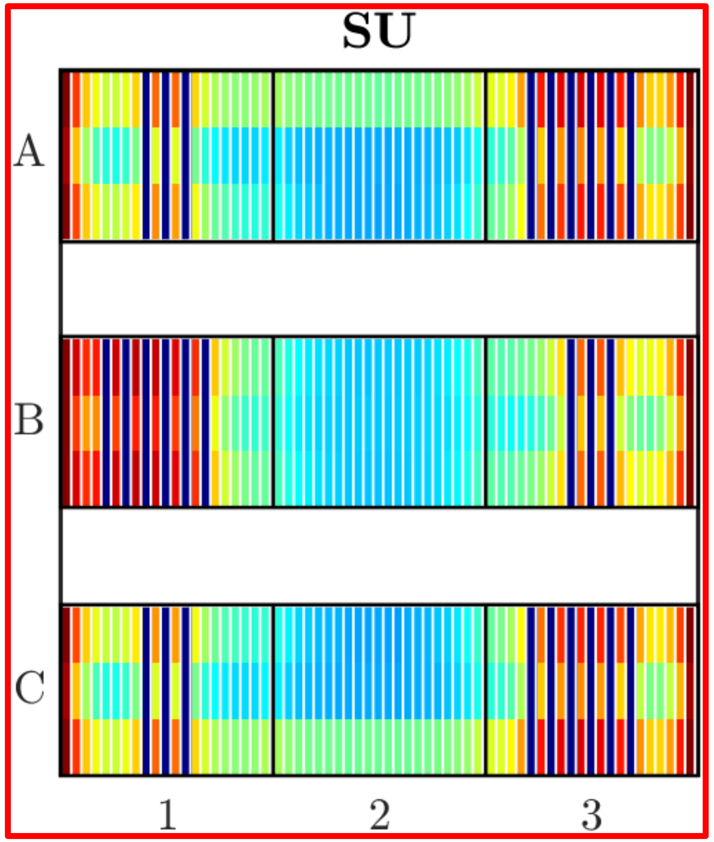
'Hottest plates' are the peripheral plates



Power Peaking Results

Second Case: Emptying Plates In a Distributed Pattern





Same amount emptied, just separated by a filled fuel plate

Power Peaking Results

Now, we can examine the power peaking results

What Is That?

$$PPF = \frac{Power}{Avg\ Power}$$

$$\dot{q}_{norm} = \frac{\dot{q}}{\dot{q}_{avg}}$$

- Tells us by what factor a plate or assembly is 'hotter' than the total average

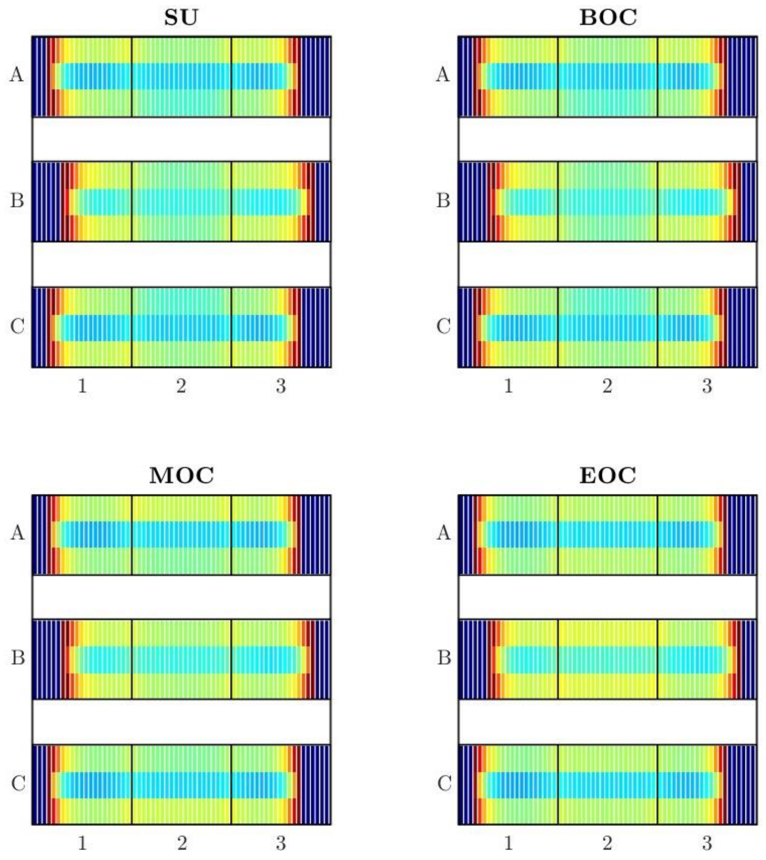
Why Is That?

- Power peaking information is integral to reactor safety and further thermal-hydraulic studies

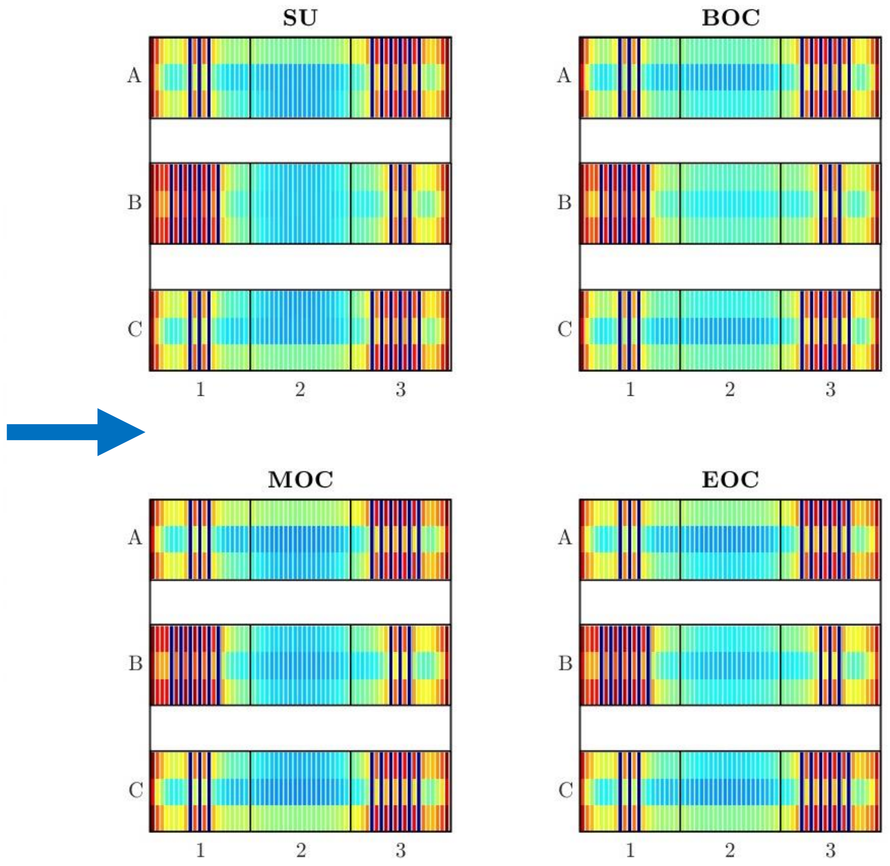
Power Peaking Results – Stripe Comparison

Will we see any significant differences between the two?

First Case

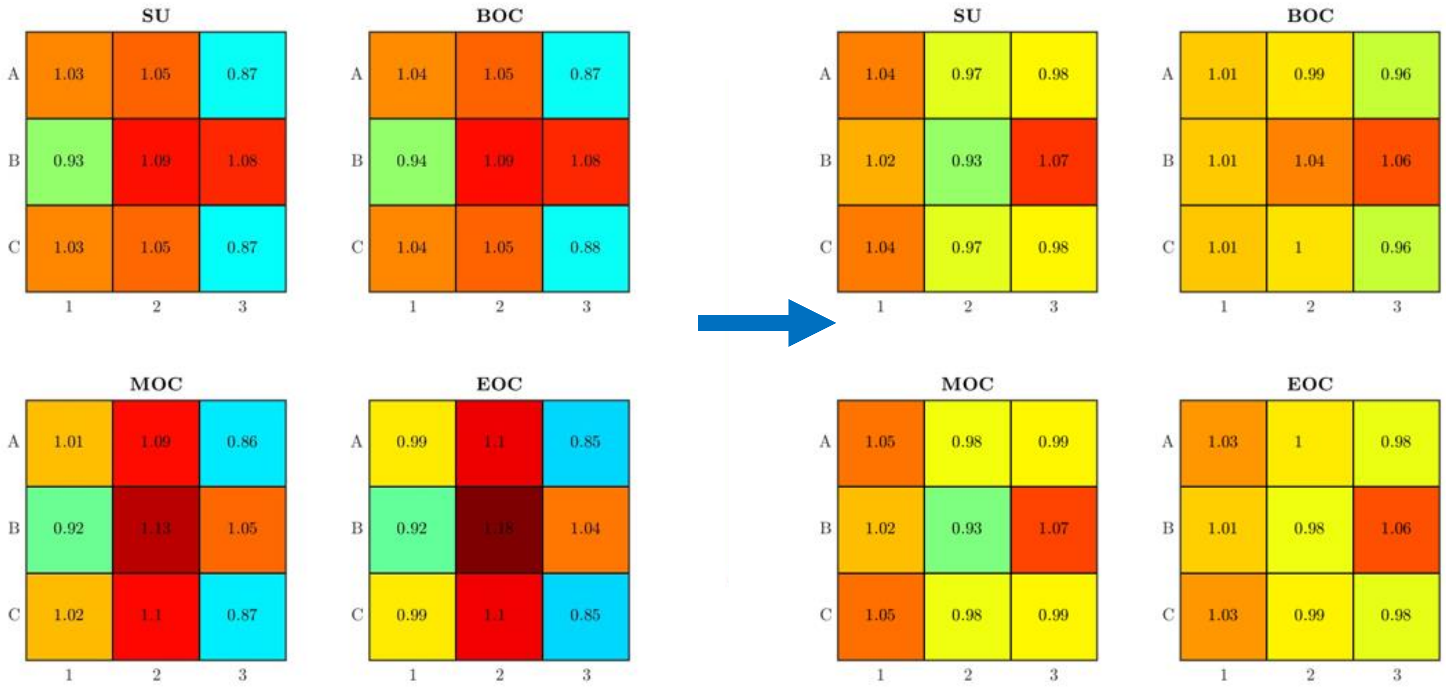


Second Case



Power Peaking Results – Assembly-Wise

-This second case layout has better power peaking values (Maximum is lower, both located in EOC)

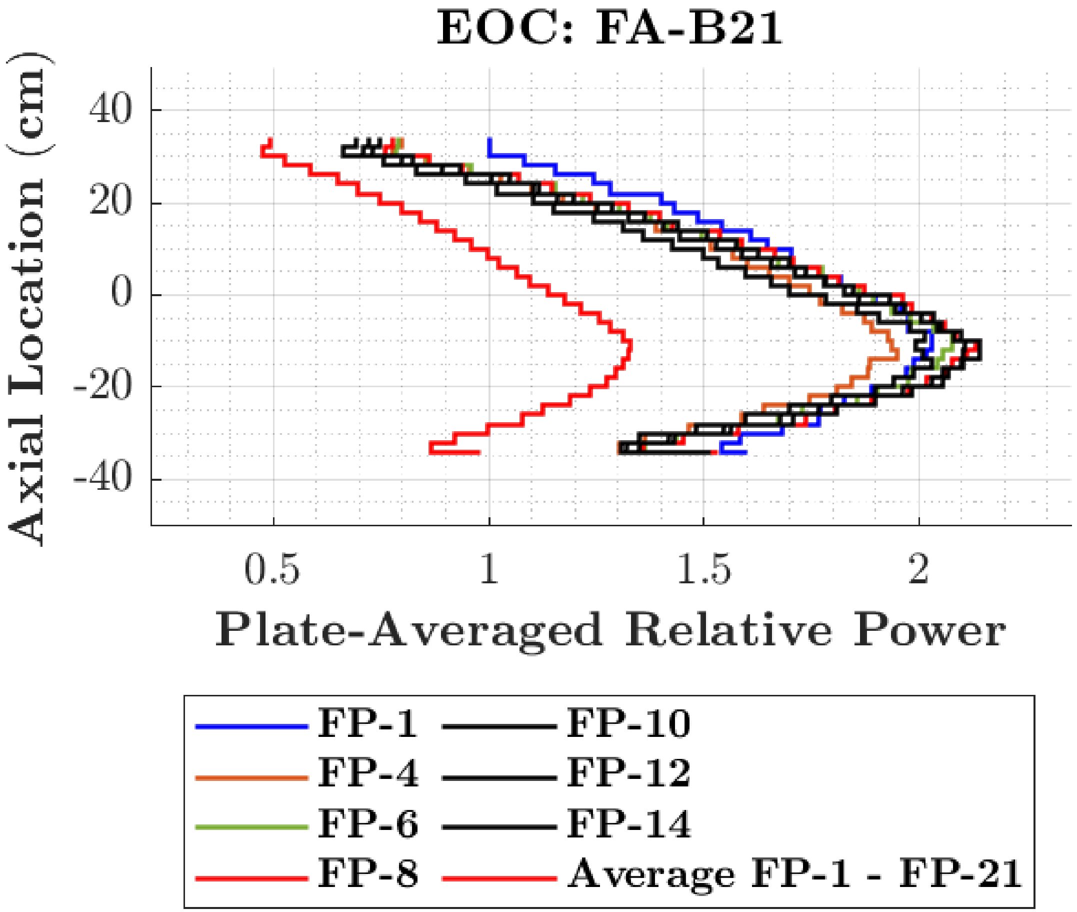


Hottest Assembly-Wise Peaking Factor	
First Case (EOC)	**Second Case (EOC)**
1.18	1.06

NCNR Engineering Group working on Machine Learning algorithm that is going to automate the “shuffle” process

Power Peaking Results – Plate Wise

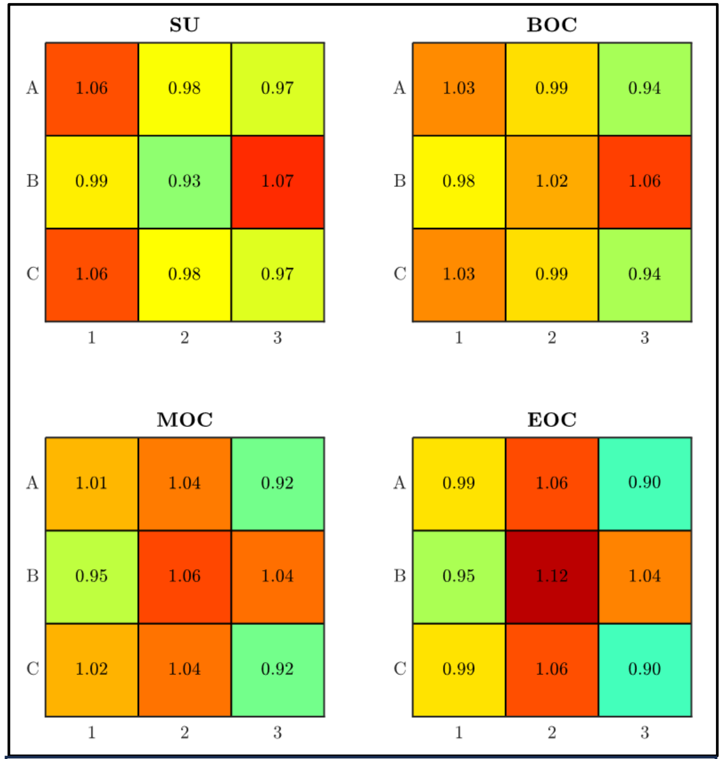
-As a last point of comparison, we can compare the highest power in plates (plate-averaged axial peaking)



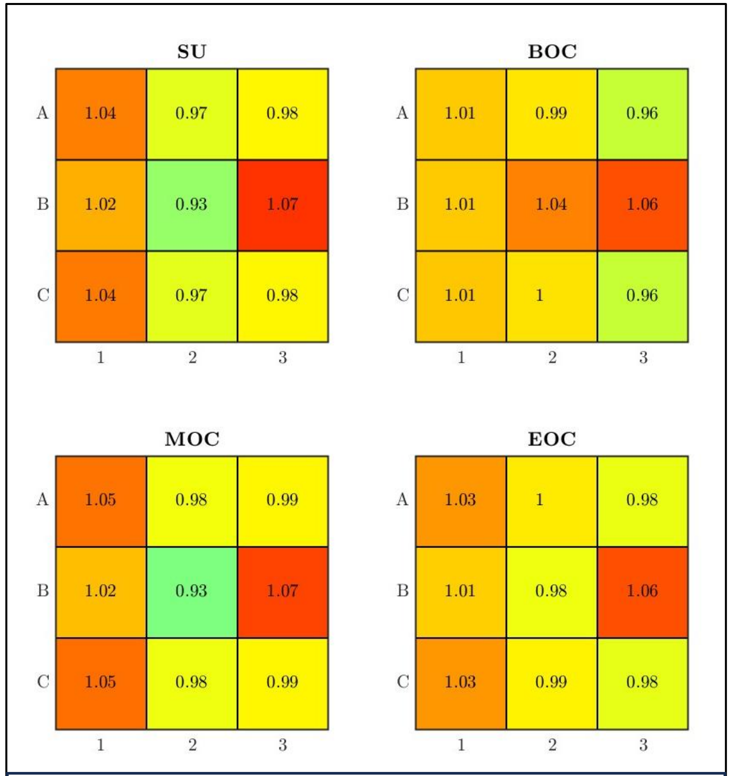
Hottest Axial Peaking Factor	
First Case	**Second Case**
2.74	2.14

Power Peaking Results – Comparison to Report

-Finally, we can compare the (better) second-case power-peaking to the NIST neutronics report results on the original ECS configuration



Neutronics Report Results



Our Final ECS Results

Hottest Assembly-Wise Peaking Factor	
Neutronics Report (EOC)	**Final ECS Results (EOC)**
1.12	1.06

Hottest Axial Peaking Factor	
Neutronics Report	**Final ECS Results**
1.98	2.14

Summary & Future Works

- Successfully able to find enrichment equivalence for the core
- Developed analytical code to compile input/output files as needed
- Determined a possible plate configuration to meet ECS requirements
- Performed power peaking analyses, needed for further safety assessments
- Ideal to examine the effect of parasitic isotopes on excess reactivity (code is available to do this)
- Examine more feasible ECS core configurations and compare

Acknowledgements

- SURF Mentors
  - *Dr. Osman Celikten*
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- SURF Directors
  - *Cara O'Malley*
  - *Julie Borchers*
  - *Leland Harriger*
  - *Susana Teixeira*
- NCNR ROE Group

References

Image References

https://upload.wikimedia.org/wikipedia/commons/a/a8/Nuclear_fission_reaction.svg
-https://www.texasgateway.org/resource/145-binding-energy
-https://www.nndc.bnl.gov/nudat3/
-https://pubchem.ncbi.nlm.nih.gov/periodic-table/
-https://mcnp.lanl.gov

Other

-Preconceptual Design Activities of the NIST Neutron Source (Preliminary Neutronics Assessments)

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Questions??

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