Nuclear Analysis of Reed Core 49 with Python-Scripted Templating of MCNP Code

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Reed College Research Reactor, Portland, OR
For the National Organization of Test, Research, and Training Reactors
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Introduction

- MCNP work at NIST for past 2 summers,
  PI: Dagistan Sahin, the next presenter :)
- Senior Reactor Operator
- Finished BA Physics ‘21, Reed College in 3 yrs
- Currently BS Applied Physics ‘23 for 2 yrs
  at Columbia University through
  Reed-Columbia Combined Plan Program

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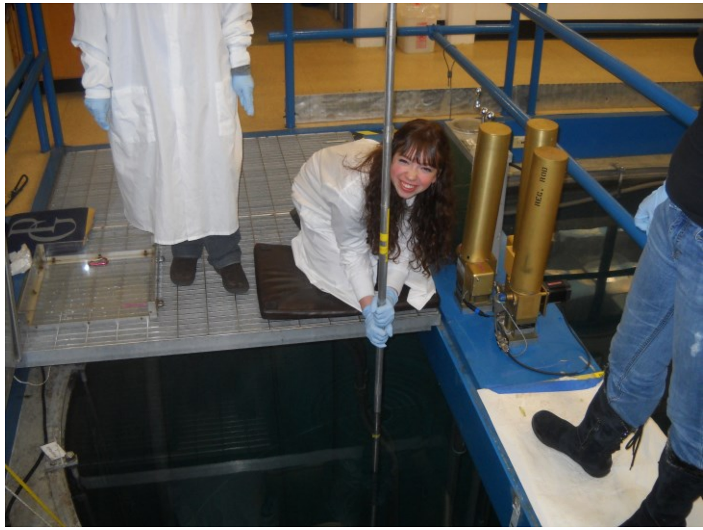
Roadmap

- Features of Reed MCNP model
- Reed Automated Neutronics Engine
- Lessons Learned from
    - Modeling
    - Results analysis

A 4th-yr SRO removes a fuel element from the core for inspection



A 2nd-yr RO guides a 1st-yr Trainee through a startup checklist.

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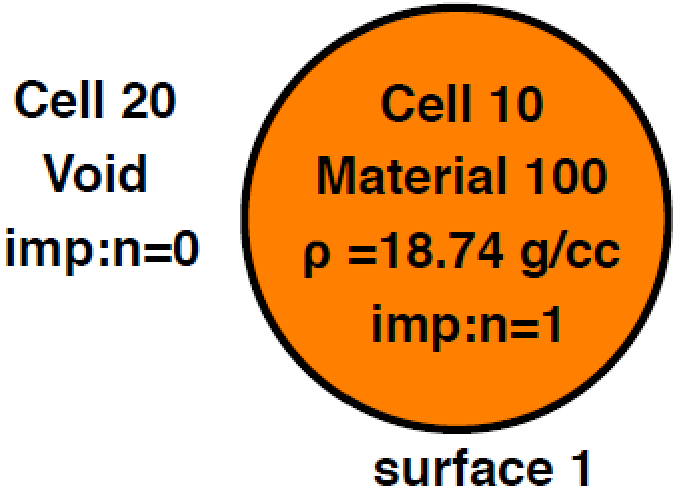
What is MCNP?

- Monte Carlo N-Particle code encodes the 3D parametric equations that inscribe the core geometry and materials, then runs various nuclear calculations

```
Godiva critical
c   CELL CARDS
10    100  -18.74        -1   imp:n=1
20        0              +1   imp:n=0

c   SURFACE CARDS
1     so    8.741

c   DATA CARDS
kcode   1000    1.0    10    50
ksrc    0.0   0.0   0.0
m100    92235   -0.9473
        92238   -0.0527
```



What is MCNP? What is a Neutronics Analysis?

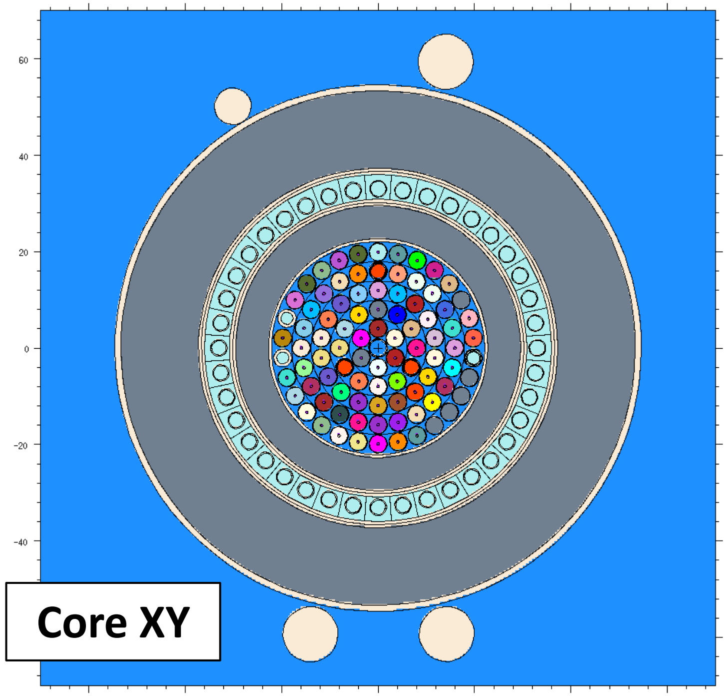
- Monte Carlo N-Particle code encodes the 3D parametric equations that inscribe the core geometry and materials, then runs various nuclear calculations
- A standard series of nuclear calculations to predict performance and behaviors of a reactor
- Regularly completed as part of SAR, 50.59 screen, re-licensing
- TRIGA neutronics are well-known, but still necessary and good for student practice

Motivations

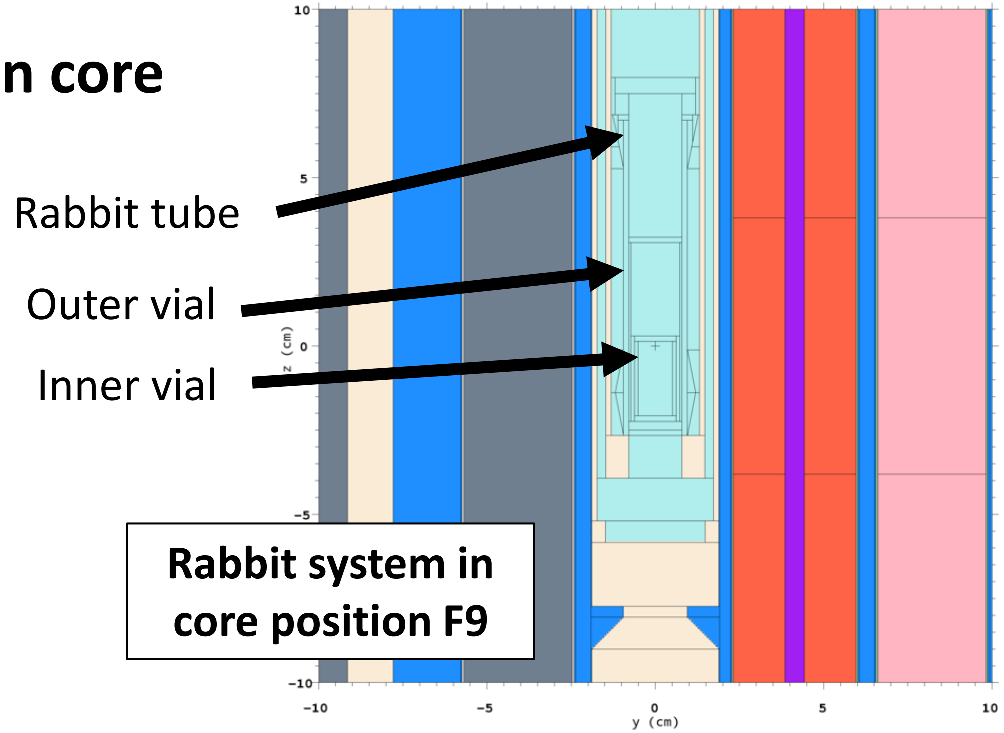
- MCNP 5 analysis of old Al-core in 2010 by Oregon State (OSTR) undergraduate for 2011 refueling
- Violation for not doing neutronics analysis/CFR 50.59 screen for the *post-refueled* SS-core
- Analysis for new SS-core completed in 2011-12
- No raw data remaining from new analysis

Reed MCNP Model Features

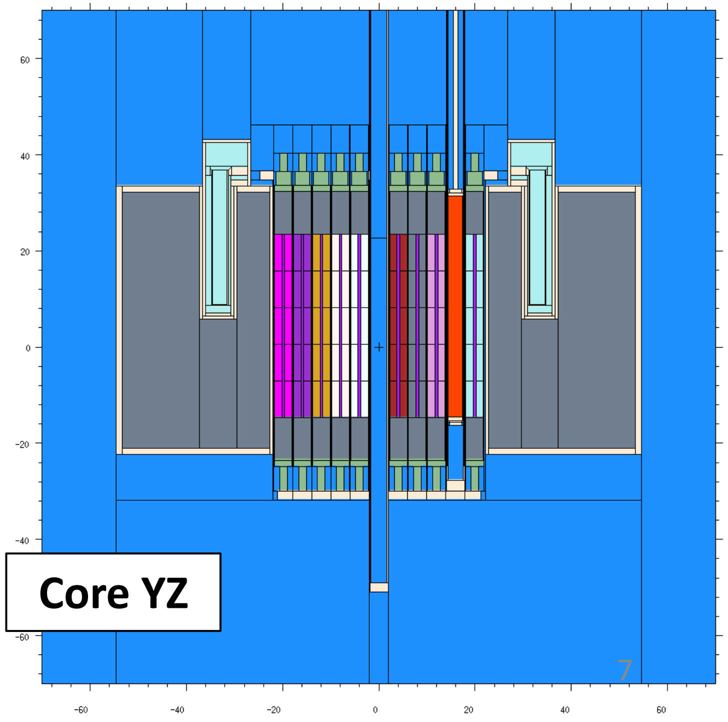
- High fidelity core geometry
  - Exact core components
  - Sample tubes in irradiation facilities
  - Core neutron detectors
- Burnup for individual fuel elements
- ENDF 8 data libraries
- **Cold but NOT clean core**



Core XY



Rabbit system in core position F9



Core YZ

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Reed Automated Neutronics Engine (RANE)

- Automates MCNP input file writing for specific tests
- Uses Jinja2 package to have Python “fill in the blanks” of a MCNP template file
- Ex: material densities

```
c --- 4111 - SS clad (T0S210D210) universe ---
c
411101    105 -7.85      312300 -312301 -311302
411102    102 {{h2o_density}}      312300 -312301
```

- Ex: rod heights

```
c pz surfaces
c
812301    pz    {{62.8153+0.38*safe_height}}    $ top of control rod
812302    pz    {{62.0533+0.38*safe_height}}    $ top of main section
```

- Ex: water material card (temperature-dependent)

```
m102    {{ h_mats }}
        {{ o_mat_lib }} 1.0000
c
mt102   {{ h2o_mt_lib }}
```

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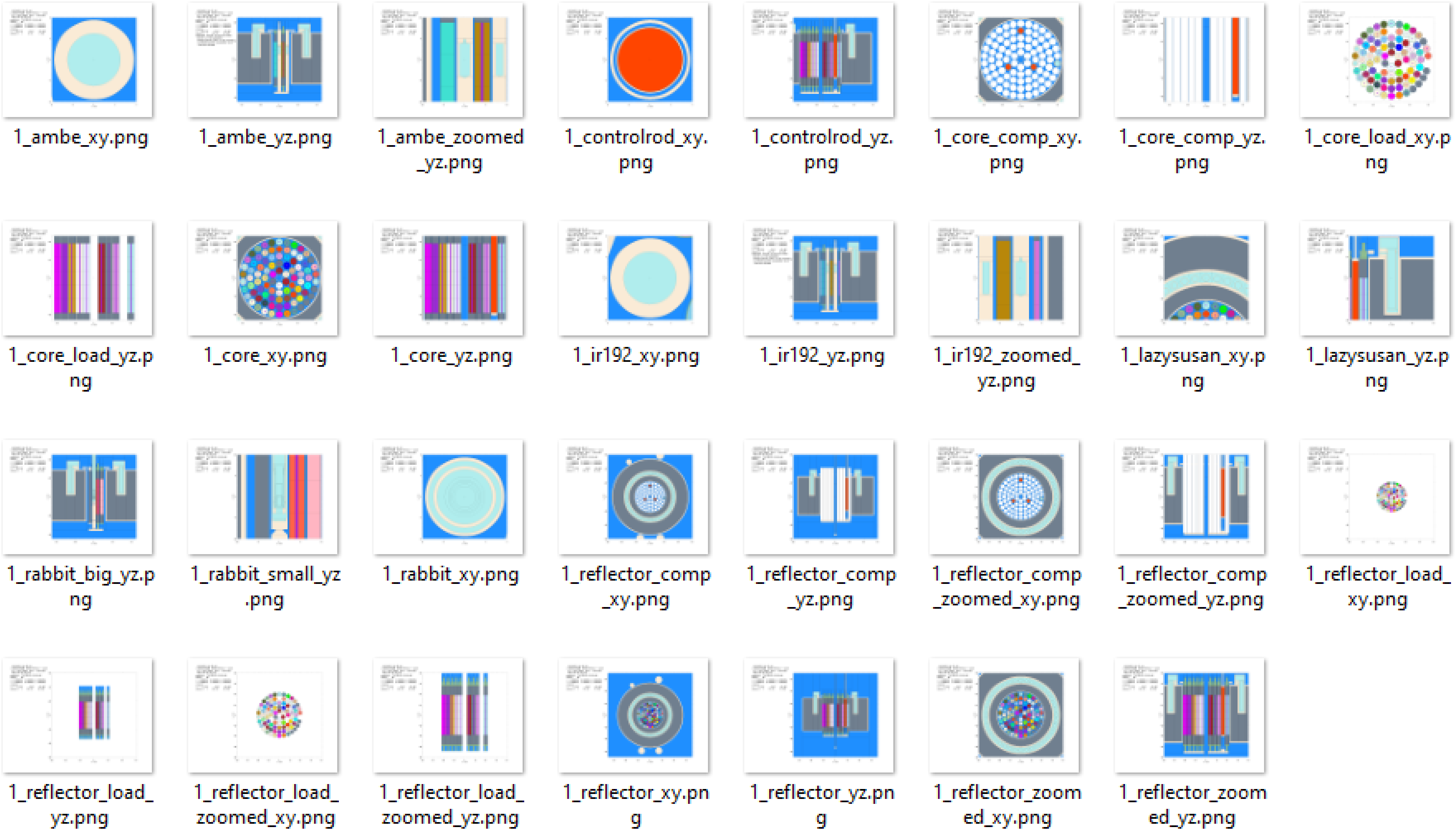
Automated Plotting

What RANE does:

- Xming plot commands
- Export to PS file
- Convert to TIFF using GhostScript
- Convert to PNGs using PIL



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Lessons Learned from Modeling and Analysis

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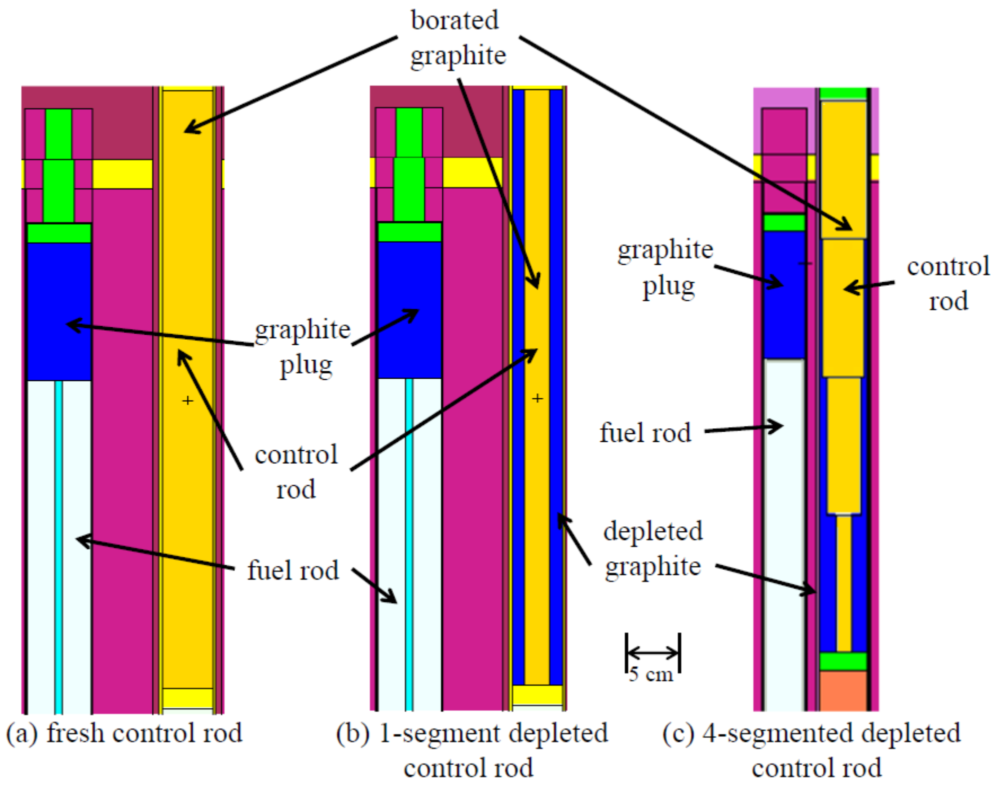
Model: Boron Carbide Poison

- Raising/lowering control rods is primary method of controlling reactor power
- More power that the control rod "sees" → more burnup of rod poison
- Problems with 2010 analysis:
  - Circa 2010, OSTR had 1260 MW-days vs. Reed had 64 MW-days of power
  - Assumes identical burnup to OSTR, severely overestimates Reed rod burnup
  - Models "burnt up" boron as stainless steel, not carbon



Rod burnup is modeled in MCNP by reducing decreasing boron densities and radii

Figure from 2013 GSTR Neutronics Analysis, N. Shugart

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Model: Boron Carbide Poison

Table 5. Comparison of non-transient control rod poison (B_4C) properties between TRIGA analyses. Chemically pure B_4C has density 2.52 g/cc.

Facility/Analysis	B_4C Properties		Notes
	Mass density (g/cc)	Radius (cm)	
RRR nominal	1.81220	1.53	As reported in RRR 2010 analysis
RRR 2010 report	1.72066	1.30	Based on OSTR; discrepancy in report vs. code
RRR 2010 code	1.68590	1.30	Burned-up B4C accidentally uses SS not graphite
RRR 2021	1.80772	1.52	3.8% of OSTR value, scaled to RRR:OSTR burnup
UUTR	2.52	1.00, 0.20	Safe and shim are thicker than reg
MUTR	2.51	1.52	
UCI	2.30	--	
GSTR	1.72066	0.68872-1.69544	Step-like burnup, min-max radii
OSTR	1.72066	1.30	Experimentally determined for 2007 SAR
Chemically pure	2.52	--	

Lesson Learned: Make sure assumptions are scaled properly to your specific facility!

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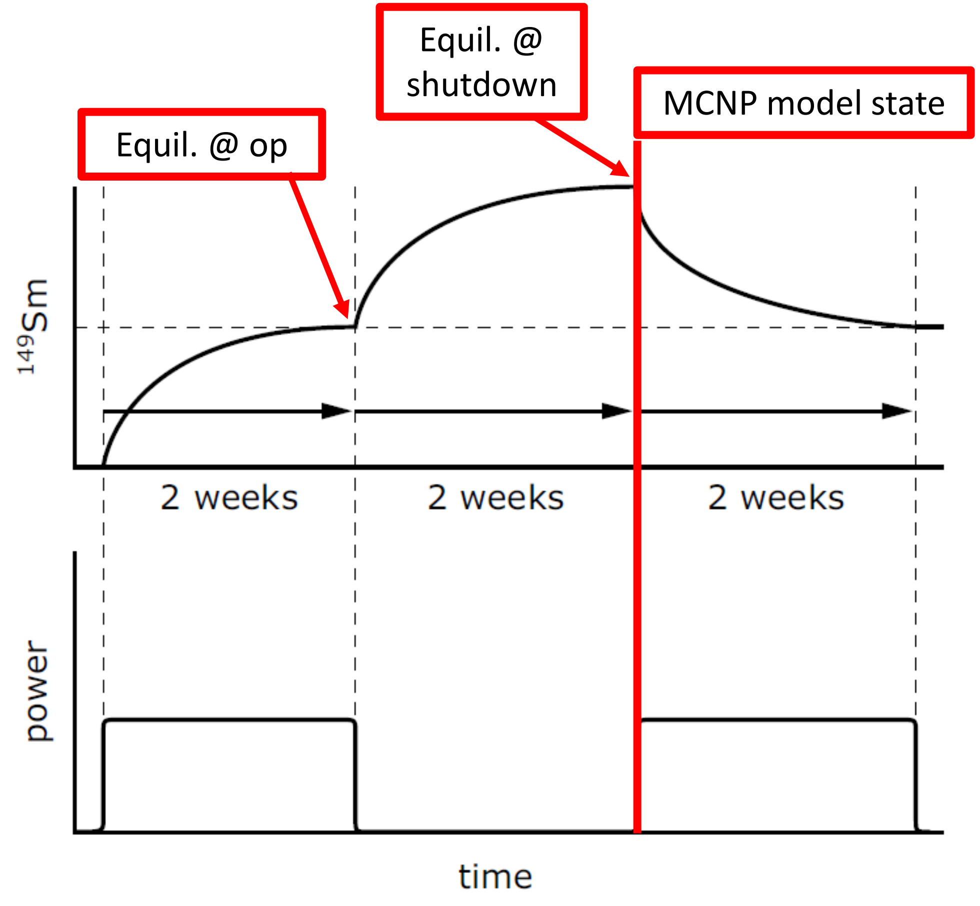
Model: Samarium Poison

- Sm-149 is a neutron poison naturally produced from fission
- Does not completely disappear from core → must consider in MCNP model



Sm-149 history over time and power

Model: Samarium Poison

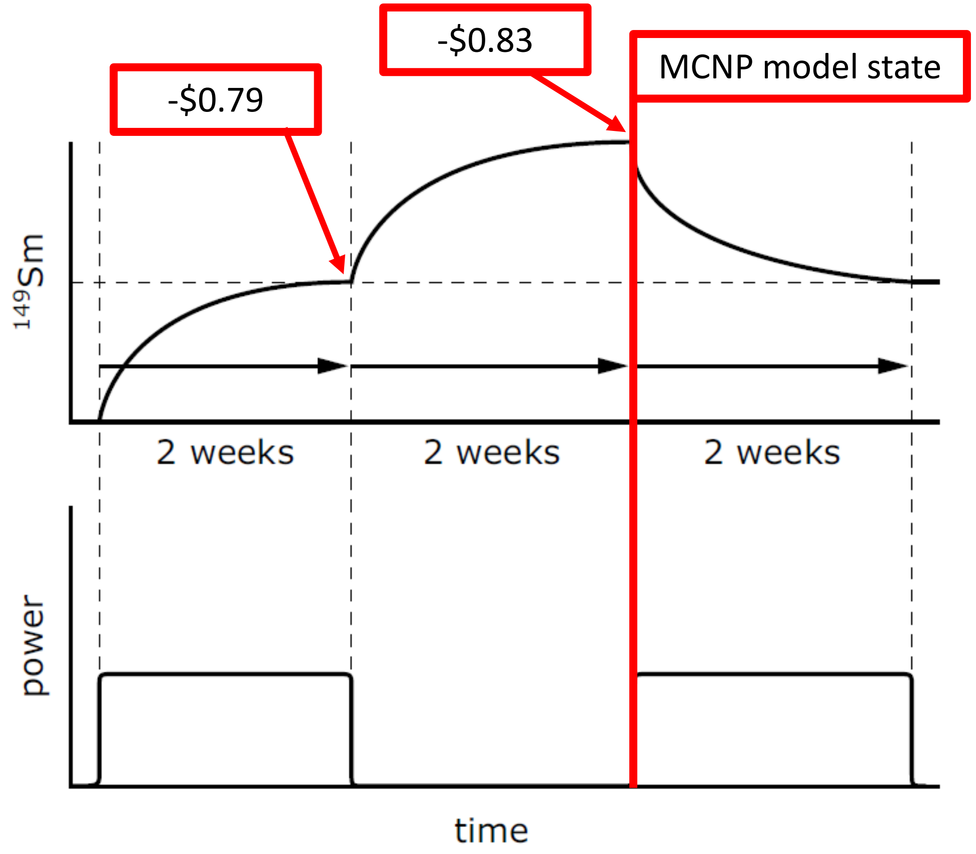


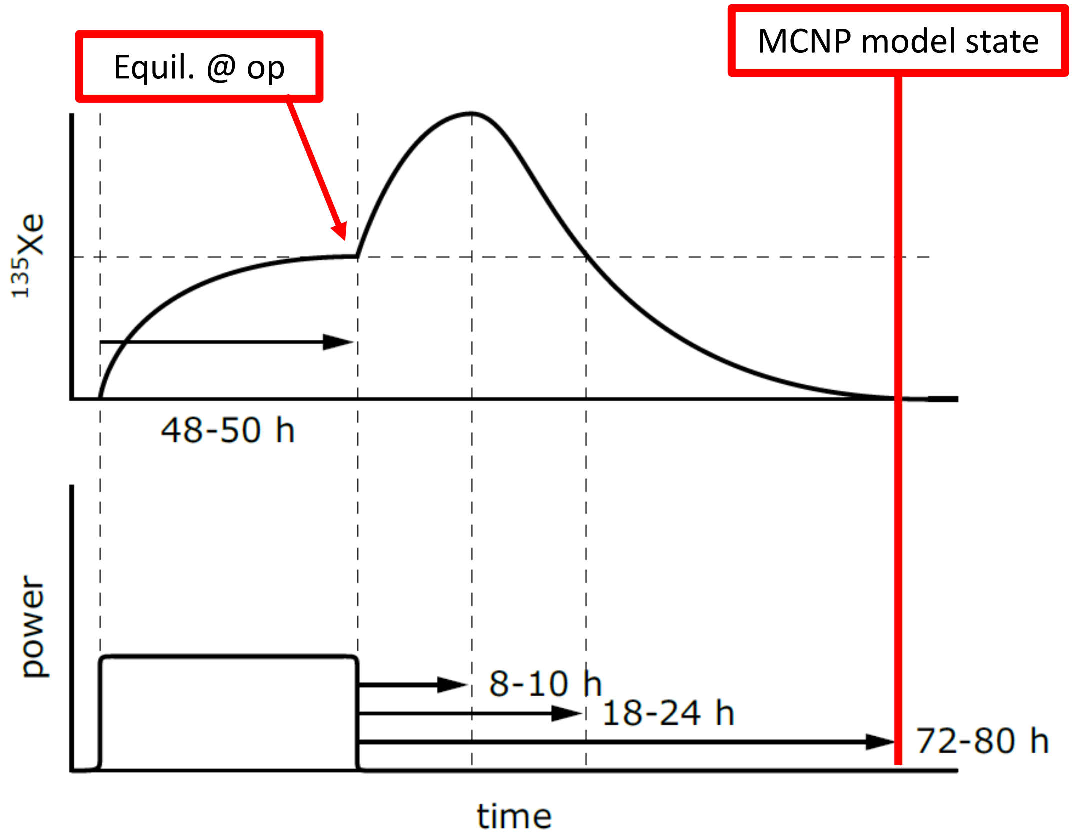
Table 7. Calculated average equilibrium Sm-149 poison values in Core 49 at 250 kW and post-250 kW shutdown.

Properties	Value
Thermal neutron absorption cross section	41,500 b
Averages at equilibrium during 250 kW operation	
Time to reach	14.3 days
Concentration	3.458 E+16 at/cm^3
Atoms in core	1.059 E+21 at
Mass in core	2.579 E-01 g
Total reactivity worth in core	−$0.79
Averages at equilibrium after shutdown from 250 kW (modeled in MCNP)	
Time to reach	~14 days
Concentration	3.644 E+16 at/cm^3
Atoms in core	1.116 E+21 at
Mass in core	2.762 E-01 g
Total reactivity worth in core	−$0.83

Problem: Not sure if Reed actually reached operational equilibrium

Model: Xenon Poison

- Xe-135 also poison from fission
- Eventually decays away in core → NOT considered in MCNP model
- But fun and good for ops training to know Xe-135 effects



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Model: Xenon Poison

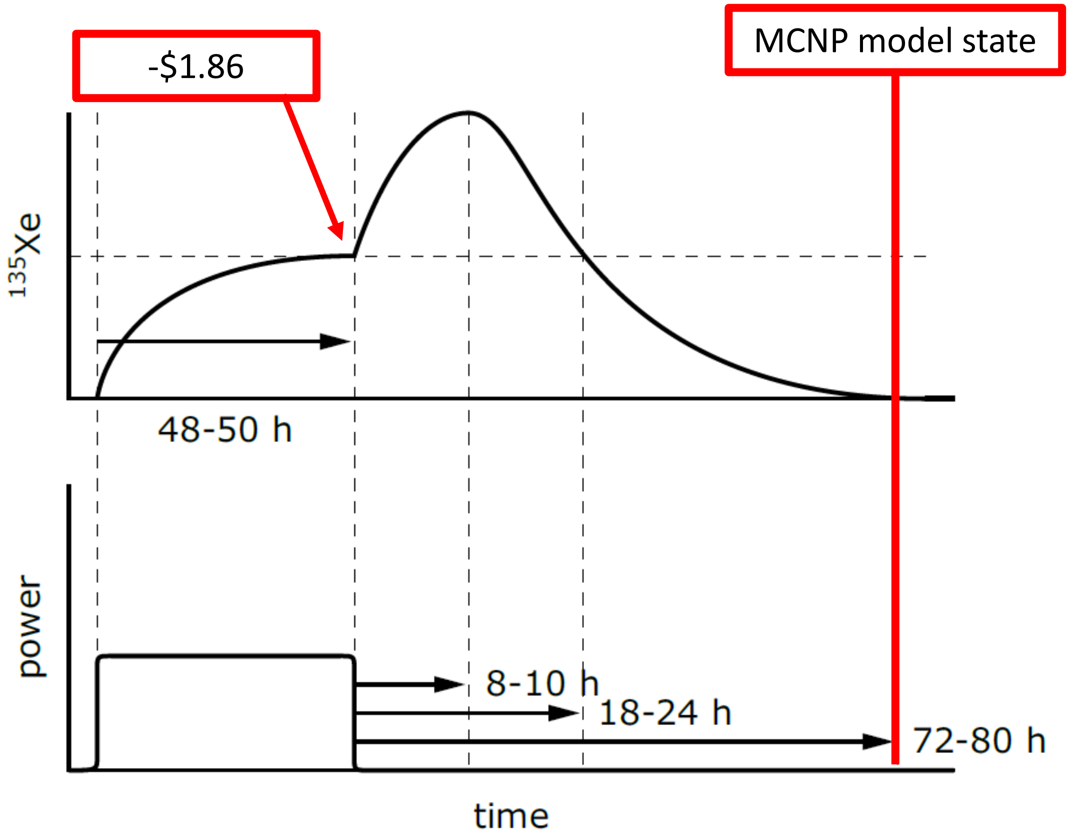

Table 6. Calculated average equilibrium Xe-135 poison values in Core 49 at 250 kW and shutdown.

Properties	Value
Thermal neutron absorption cross section	2.6 E+6 b
Averages at equilibrium during 250 kW operation	
Time to reach	56 hrs
Concentration	1.241 E+15 at/cm^3
Atoms in core	3.802 E+15 at
Mass in core	8.524 E-03 g
Max reactivity worth in core	−$1.86
Averages at equilibrium during 5 W operation	
Time to reach	56 hrs
Concentration	3.941 E+10 at/cm^3
Atoms in core	1.208 E+15 at
Mass in core	2.708 E-07 g
Max reactivity worth in core	−$6.02 E-05

Lesson Learned: Magnitude of equilibrium Xe > equilibrium Sm

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Results: Moderator Temp. Coef.

- Measures reactivity change per temperature change in moderator
- In MCNP code: need to change density + cell, cross-section, thermal scattering library temps
- For cross-section (XS) temperature interpolation: “MCNP pseudo-material interpolation”
- For thermal scattering (S(a,B), “S alpha beta”): discrete without *makxsf* code

ENDF/B-VIII.0 Library Code	Temp [K]	Temp [°C]
h-h2o.40t	294	21
h-h2o.42t	300	27
h-h2o.43t	324	51
h-h2o.44t	350	77
h-h2o.45t	374	101

Results: Moderator Temp. Coef.

Facility/Analysis	Moderator Temp. Coef. [$/K] value	Moderator Temp. Coef. [$/K] $\pm 1\sigma$	Notes
RRR 2010	-0.0057	--	
RRR 2021	+0.0132	0.0015	Uses interpolated xs libraries
UUTR	-0.0133	--	Only measured at 293, 600 K (20, 327 C)
MUTR	0.0000	--	Determined negligible and bounded around 0
UCI	-0.0085	--	Averaged from 20 to 700 C
GSTR	+0.0120	0.0020	Uses interpolated xs, $S(\alpha,\beta)$ libraries
OSTR	-0.0072	--	
WSUR	--	--	Not calculated

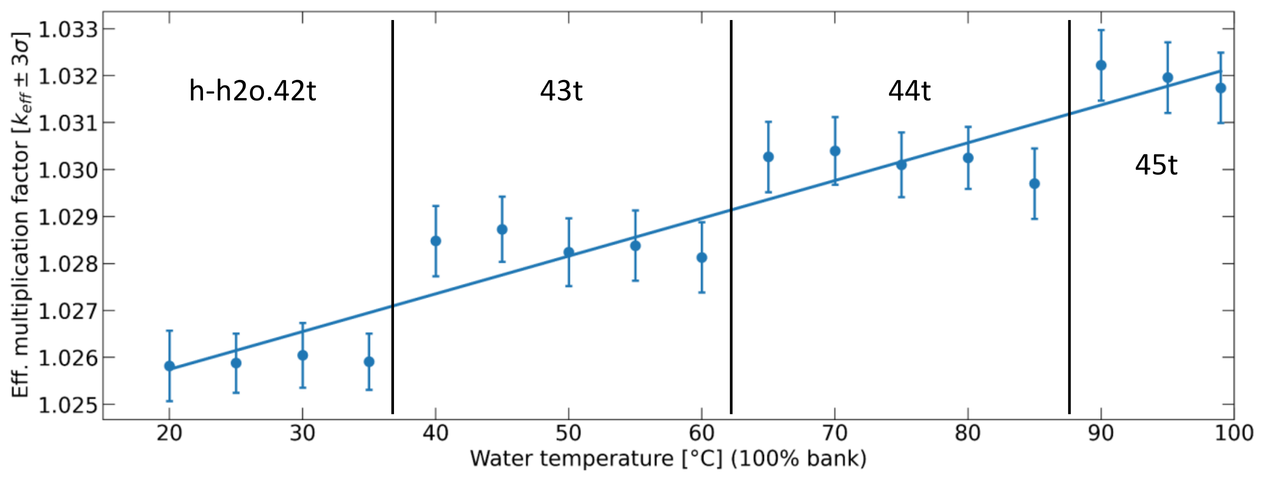
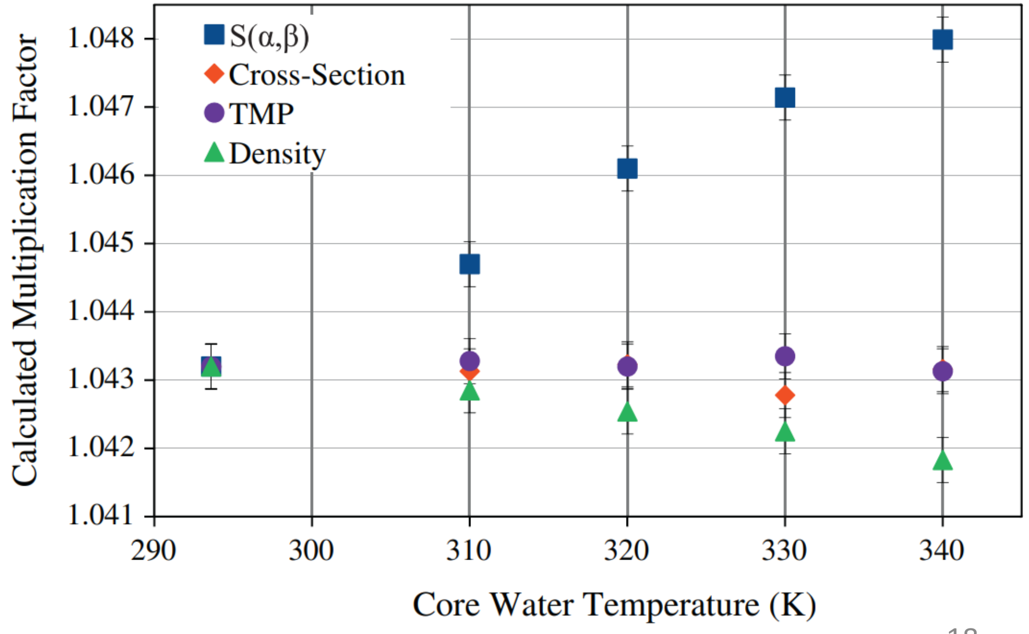


Figure from 2013 GSTR Neutronics Analysis, N. Shugart



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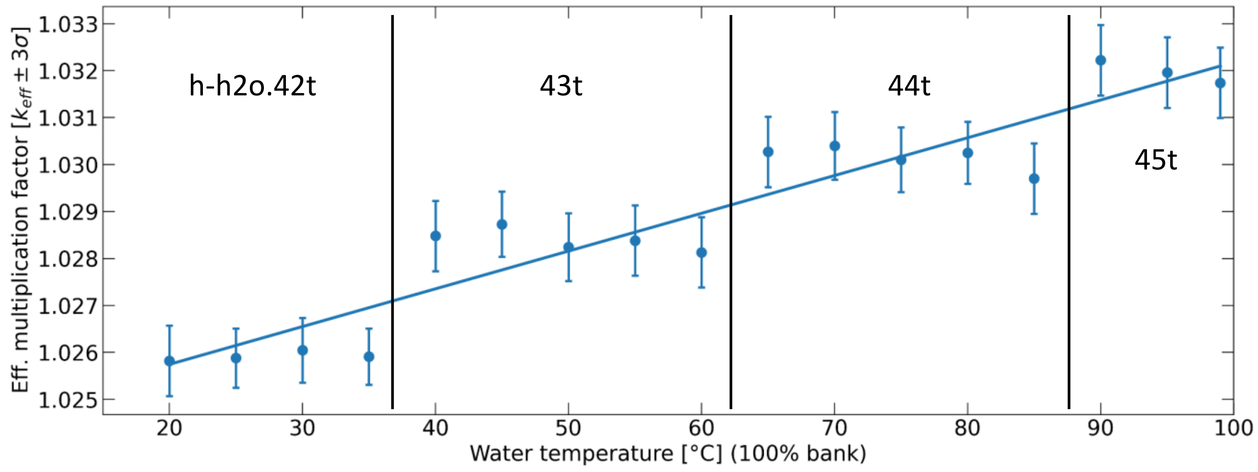
Results: Moderator Temp. Coef.

- My calculations yield "jagged" upward step
- Continuous density + cell (TMP), cross-section (xs) temperature values have ***negative effect***
- Discrete *thermal scattering* S(a,B) temperature has ***positive effect***
- Next step: use *maxksf* for continuous S(a,B) to produce smooth upward line

Lesson Learned: Make sure to use multiple S(a,B) libraries along domain to show full effects



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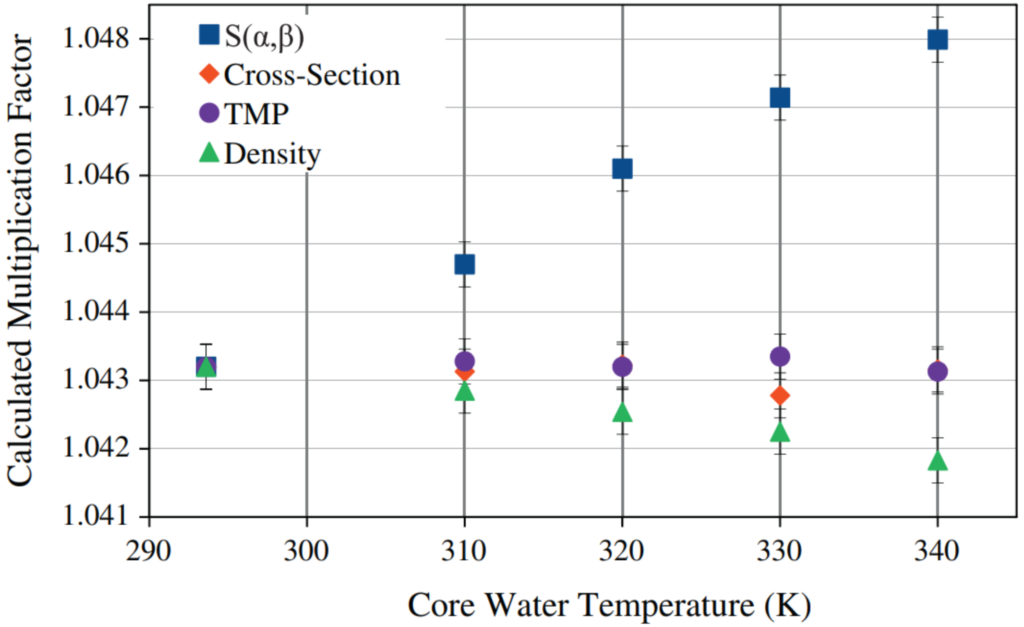

Summary

- Automated scripts for easy replication
- Maintain good documentation of reasoning for assumptions
- Make sure to scale assumptions properly when borrowing from other facilities
- Xenon > Samarium reactivity
- Most Sm produced during operation, not shutdown
- Perturb ALL parameters related to a variable, lest you miss an effect like from S(a,B)

Acknowledgements

Toria Ellis, Reactor Operations Manager, Reed College

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Robert Schickler, Oregon State University

Questions?

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