Criticality Modeling of the Oregon State TRIGA Reactor Utilizing the MCNP6 BURN Option

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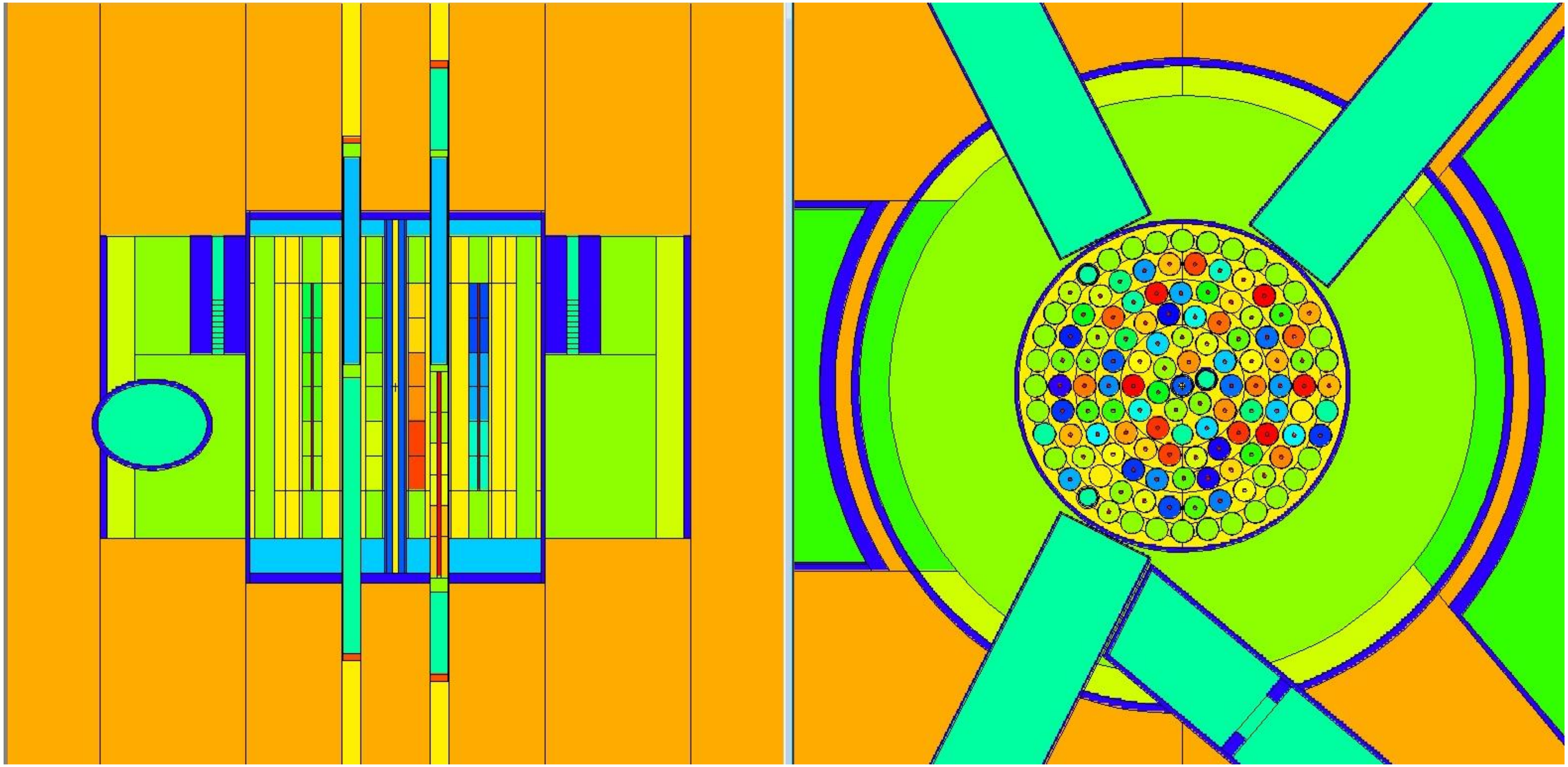

History

- OSTR MCNP model originally written by Kanokrat Tiyapun in 1997 in support of boron neutron capture therapy research
- OSTR converted from HEU to LEU in 2008
- 1997 MCNP model was used for various analyses in support of LEU conversion

  - Accurately predicted critical mass (predicted 69 FEs, actual was 67 FEs)

  - Accurately predicted control rod worth:

Control Rod	Measured Rod Worth [$]	MCNP5 Predicted Rod Worth [$]
Shim Rod	2.76 ± 0.14	2.55 ± 0.16
Safety Rod	2.66 ± 0.13	2.60 ± 0.16
Regulating Rod	3.71 ± 0.19	3.36 ± 0.19
Transient Rod	2.86 ± 0.14	2.86 ± 0.15
Sum of all Rods	11.99 ± 1.68	11.37 ± 0.33

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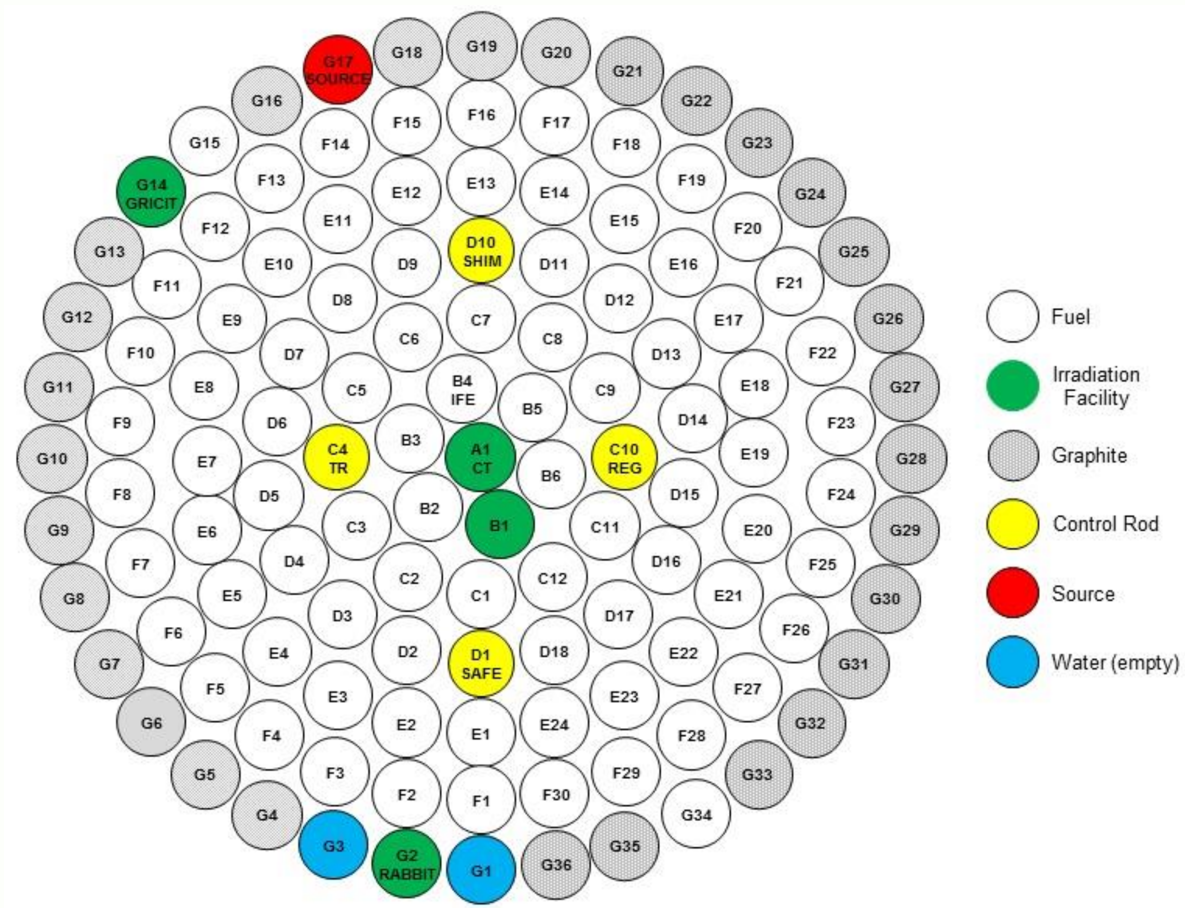
Current OSTR Core Configuration



Motivation

- MCNP model needs to be updated in support of future projects, such as medical isotope production
- No longer accurate due to 8 years of fuel burnup and changes to the facility (new reflector/Rabbit facility installed in 2013)
- Using fresh fuel isotopics with actual critical rod height data from December 2013 yielded excessive reactivity:

Core Configuration	Power	k-effective	Reactivity
Normal	15 W	1.01343	$1.77
	1 MW	1.01068	$1.41
ICIT	15 W	1.01307	$1.72
	1 MW	1.00959	$1.27
CLICIT	15 W	1.01266	$1.67
	1 MW	1.00915	$1.21

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Motivation

Improvements to the original MCNP model

- Updated material cards from ENDF/B-VI cross section libraries to ENDF/B-VII.1
- Updated fuel material cards using information from CERCA, with spectrometric data that greatly improved atomic fraction accuracy
- Modeled OSTR at low power (15 W) using .80c cross sections and full power (1 MW) using mostly .81c cross sections for in-core materials that would experience approximately 300°C

MCNP Burn Option

```
c Burnup Card
BURN   TIME=260     ← Time step in days
       PFRAC=1.0    ← Fraction of power (100%)
       POWER=1      ← Power in MW
       MAT=5401 5402 5403 5411 5412 5413 5421 5422 5423 5431 5432 5433
           5441 5442 5443 5451 5452 5453 5461 5462 5463 5471 5472 5473
           5481 5482 5483 5491 5492 5493 5501 5502 5503 5511 5512 5513
           5521 5522 5523 5531 5532 5533 5541 5542 5543 5551 5552 5553
           5561 5562 5563 5571 5572 5573 5581 5582 5583 5591 5592 5593
           5601 5602 5603 5611 5612 5613 5621 5622 5623 5631 5632 5633
           5641 5642 5643 5651 5652 5653 5661 5662 5663 5671 5672 5673
           5681 5682 5683 5691 5692 5693 5701 5702 5703 5711 5712 5713
           5721 5722 5723 5731 5732 5733 5741 5742 5743 5751 5752 5753
           5761 5762 5763 5771 5772 5773 5781 5782 5783 5791 5792 5793
           5801 5802 5803 5811 5812 5813 5821 5822 5823 5831 5832 5833
           5841 5842 5843 5851 5852 5853 5861 5862 5863 5871 5872 5873
           5881 5882 5883 5891 5892 5893 5901 5902 5903 5911 5912 5913
           5921 5922 5923 5931 5932 5933 5941 5942 5943 5951 5952 5953
           5961 5962 5963 5971 5972 5973 5981 5982 5983 5991 5992 5993
           6001 6002 6003 6011 6012 6013 6021 6022 6023 6031 6032 6033
           6041 6042 6043 6051 6052 6053 6061 6062 6063 6081 6082 6083
           6091 6092 6093 6101 6102 6103 6111 6112 6113 6121 6122 6123
           6131 6132 6133 6141 6142 6143 6151 6152 6153 6161 6162 6163
           6171 6172 6173 6181 6182 6183 6191 6192 6193 6201 6202 6203
           6211 6212 6213 6221 6222 6223 6231 6232 6233 6251 6252 6253
           6261 6262 6263 6271 6272 6273 6301 6302 6303 6321 6322 6323
           6331 6332 6333 6341 6342 6343
       BOPT=1.0 24  ← Determines which fission products output
```

← Each number represents one-third of a fuel element

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Procedure

Basic procedure for burnup calculations

- Determine a starting point
  - Use critical rod height data from reactor operation (as close to "cold, clean core" as possible)
- Perform a burnup calculation for a determined amount of time based upon power history (power logs)
  - I coincided each time step to our annual control rod calibrations
- After the burnup calculation is complete, depleted fuel isotopics must be parsed from the large (70 MB of text) output file then reinserted into the original deck
- Control rod heights must be changed to reflect the new core

Procedure

Step 1 – Refine model to reflect fresh fuel core conditions in 2008

- Challenge – Reflector was filled with water, which altered reactivity
- Allyson Kitto's 2012 thesis determined reactivity bias of reflector by changing reflector material: "sweet spot" was 70% graphite, 30% water
- Using this reflector material, as well as accurate fuel isotopics from CERCA, and actual critical rod data at low power (15W) and full power (1 MW) yielded the following reactivity values:

Date	Core Configuration	Power	k-effective	Reactivity
2008	Normal	15W	1.00031	$0.04
		1MW	1.00083	$0.11
	ICIT	15W	1.00096	$0.13
		1MW	1.00121	$0.16
	CLICIT	15W	0.99977	-$0.03
		1MW	0.99992	-$0.01

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Procedure

Step 2 – Perform burnup of fuel from 2008 to 2013

- From power history, fuel experienced approximately 260 MW-days of burnup
- One 260 day time step was performed to burn fuel
- Challenge – sacrifice accuracy for time efficiency
  - Burnup calculation is a slow process
    - A calculation using only one time step took 8.5 days to run using 50,000 neutrons per cycle
    - Burnup is currently unable to utilize multi-threading/MPI
  - OSTR has multiple core configurations, but over 90% of operations are performed in one configuration (CLICIT), so burnup calculation was performed in this configuration

Procedure

Step 2 – Perform burnup of fuel from 2008 to 2013

- After burnup calculation is completed, the resulting depleted fuel isotopics are re-inserted into the model, reflector was changed to non-water-filled, Rabbit was changed to titanium, and critical rods heights from December 2013 were used to determine criticality

Date	Core Configuration	Power	k-effective	Reactivity	Fresh Fuel Reactivity
2013	Normal	15W	1.00115	$0.15	$1.77
		1MW	0.99961	-$0.05	$1.41
	ICIT	15W	0.99966	-$0.05	$1.72
		1MW	0.99886	-$0.15	$1.27
	CLICIT	15W	0.99928	-$0.10	$1.67
		1MW	0.99743	-$0.34	$1.21

Procedure

Step 3 – Perform burnup of fuel from 2013 to 2014

- From power history, fuel experienced approximately 44.5 MW-days of burnup, thus one 44.5 day time step was performed
- Resulting fuel isotopics were again inserted into the model and benchmarked against critical rod heights in 2014:

Date	Core Configuration	Power	k-effective	Reactivity
2014	Normal	15W	1.00004	$0.01
		1MW	0.99926	-$0.10
	ICIT	15W	1.00015	$0.02
		1MW	0.99889	-$0.15
	CLICIT	15W	1.00046	$0.06
		1MW	0.99884	-$0.15

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Procedure

Step 4 – Perform burnup of fuel from 2014 to 2015

- From power history, fuel experienced approximately 56.8 MW-days of burnup, thus one 56.8 day time step was performed
- Resulting fuel isotopics were again inserted into the model and benchmarked against critical rod heights in 2015:

Date	Core Configuration	Power	k-effective	Reactivity
2015	Normal	15W	1.00081	$0.11
		1MW	0.99958	-$0.06
	ICIT	15W	1.00137	$0.18
		1MW	0.99924	-$0.10
	CLICIT	15W	1.00085	$0.11
		1MW	0.99842	-$0.21

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Results

- The end result is a model that appears to be a far more accurate representation of the state of the OSTR
- Uranium/plutonium buildup and depletion can now be tracked
- A power-per-element history can be produced to show how power changes throughout the core over core life
- Burnup calculations will be performed every year to keep the model as accurate as possible

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Future Work

Now that the fuel isotopics are more accurate, various analyses are planned:

- Core optimization is currently being analyzed, with potential fuel shuffling to optimize the efficiency of in-core irradiation facilities
- Current project being explored is a 2nd CLICIT irradiation facility on the core periphery
  - Initial numbers indicate flux is 3-4 times lower on the core periphery, but this is acceptable for short irradiations

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Acknowledgments

- Dr. Kanokrat Tiyapun for writing the original MCNP model
- Allyson Kitto for her help with determining reflector bias
- Tommy Holschuh for help with Perl script writing for parsing
- Drs. Mike Fensin and Forrest Brown at LANL for assistance with understanding how to use the MCNP burn option