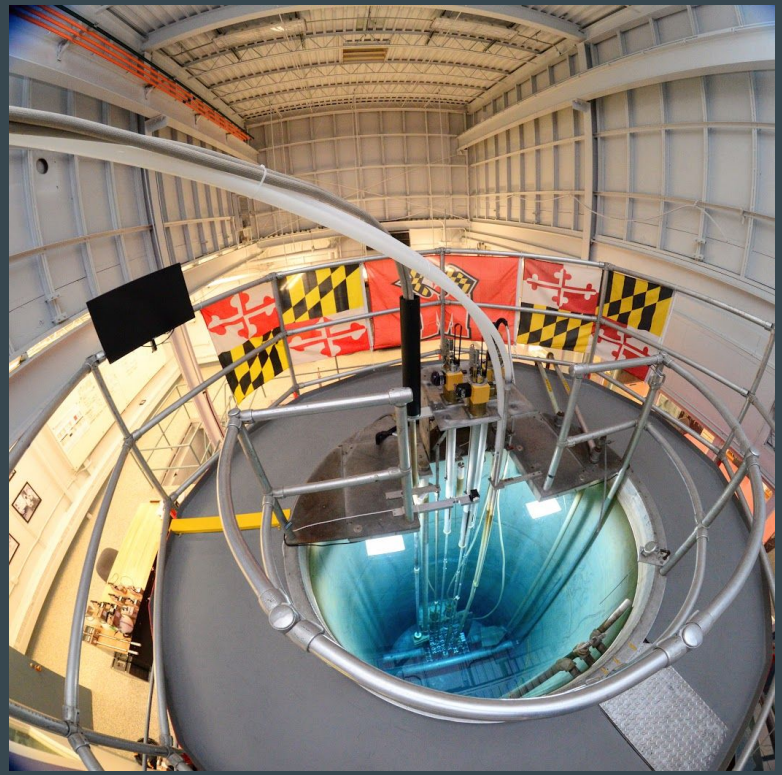
Control Rod Worth Measurements at the Maryland University Training Reactor

Luke Gilde, Charlie Barker, Abby Kittel, Mike Hottinger, Amber Johnson

University of Maryland Radiation Facilities

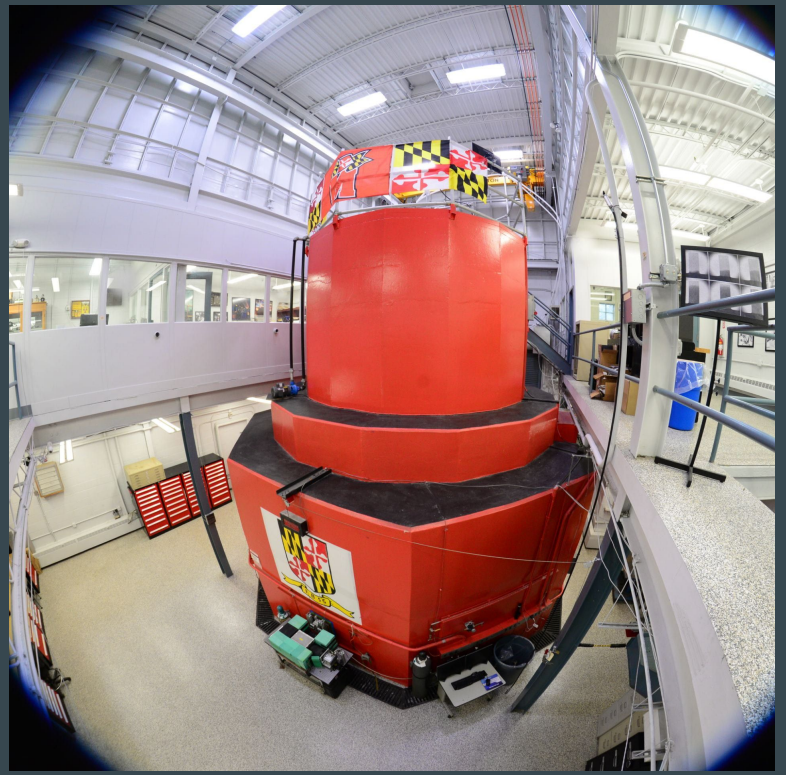
Maryland University Training Reactor

- 250 kW TRIGA Conversion Reactor
  - Built in 1960, converted to TRIGA in 1974
- Activities Include:
  - Student Reactor Operator Training
  - University Lab Classes
  - Outreach Activities
  - Neutron Activation Analysis
  - Neutron Detector Testing
  - Neutron Imaging
  - Isotope Production

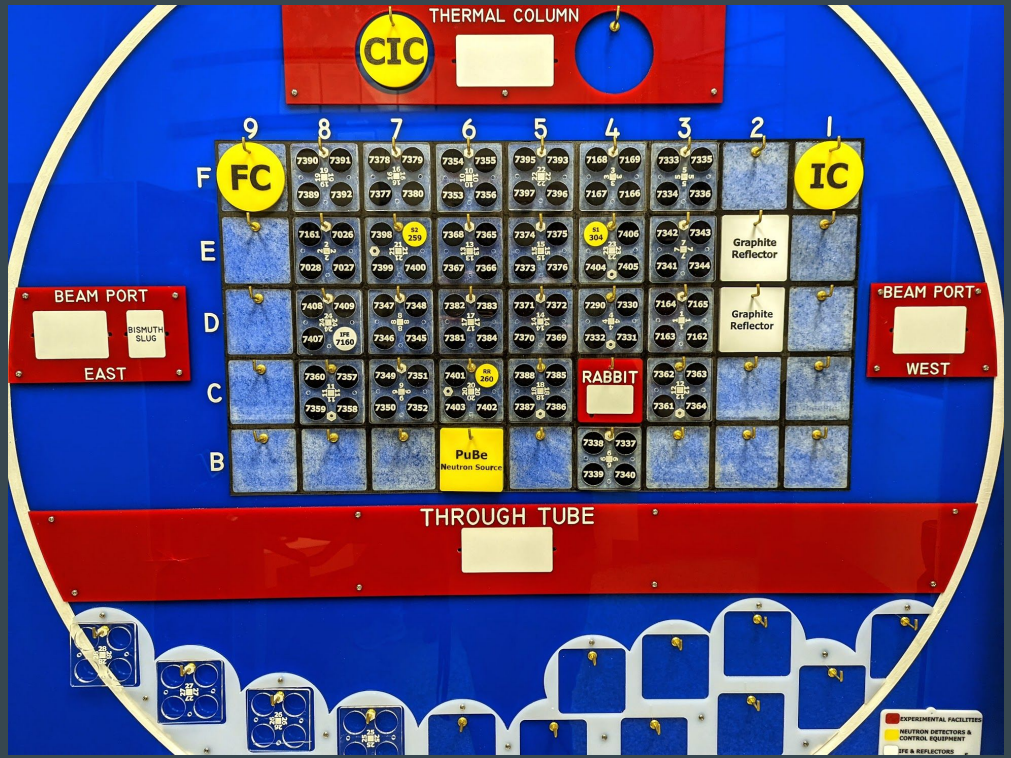


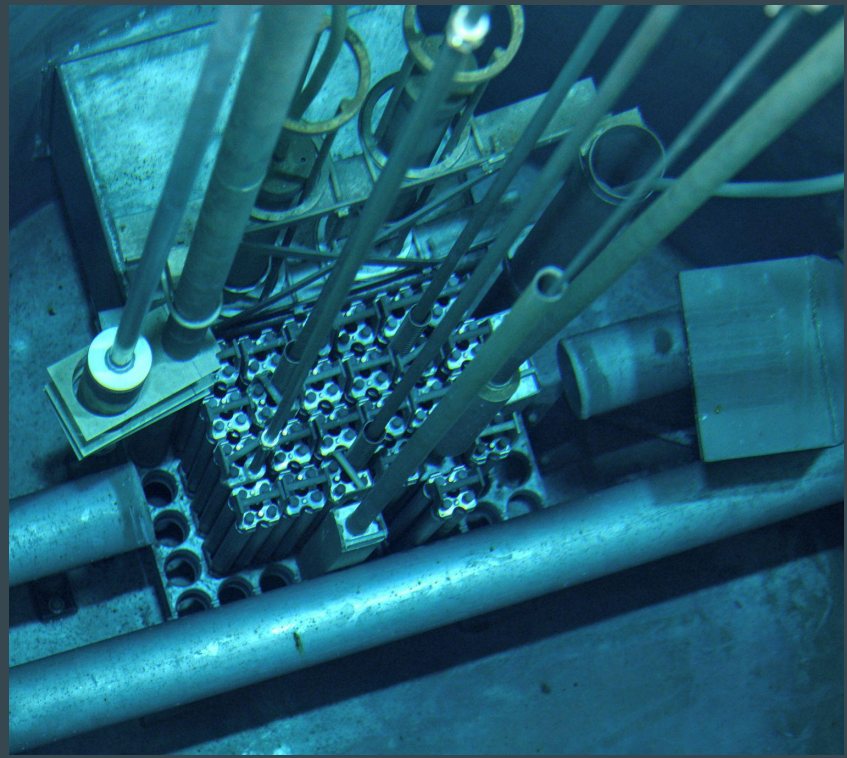
Current Situation

- 93 element core in nearly the same configuration as was installed in 1974
- Limited to about 100 kW
  - Due to burnup and Sm-149 buildup
- $0.60 excess reactivity
  - Initial excess reactivity was $2.42
- 3 control rods of approximately equal worth
  - 1 with automatic control



MUTR Core


THERMAL COLUMN
CIC
9 8 7 6 5 4 3 2 1
F
E
D
C
B
FC
IC
Graphite Reflector
Graphite Reflector
BEAM PORT
EAST
BISMUTH SLUG
BEAM PORT
WEST
RABBIT
PuBe
Neutron Source
THROUGH TUBE
EXPERIMENTAL FACILITIES
NEUTRON DETECTORS & CONTROL EQUIPMENT
IFE & REFLECTORS



Control Rod Worth Measurement

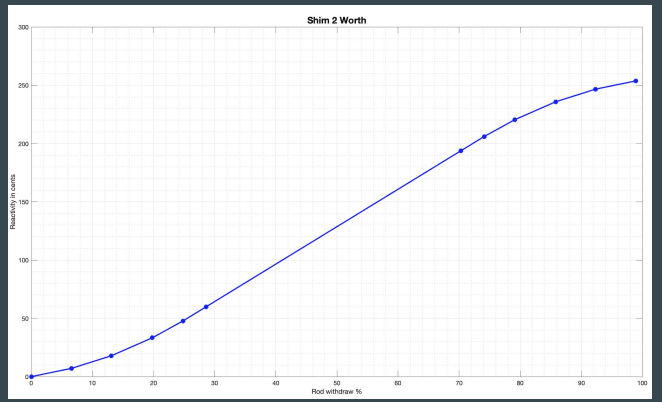
- MUTR control rod worths have historically been measured with the positive period method
  - Hand timed periods
- Due to lack of excess reactivity, MUTR can only go critical with 2 rods fully withdrawn, and final rod 2/3rds withdrawn
  - Only the worth of the final 1/3rd of each rod can be measured
- The majority of the worth curves are based on extrapolation
  - Procedures call for linearly extending the curve to 50%, then reflecting it about that axis

Rod "W": Shim 1

Step i	Approx Position	Actual Position	Period 20% to 54%	Period 31% to 81.5%	Period 31% to 81.5%	Average Period	ρ(¢)	$\sum_{n=1}^{i}\rho_n(¢)$
0		68.7					0	0
1	73	70.5	175.2	176.5	176.1	175.9	6.08	6.08
2	75	74.4	77.0	79.6	78.6	78.4	11.62	17.70
3	80	79.7	55.7	57.0	57.2	56.6	14.70	32.40
4	86	85.9	61.9	62.3	63.6	62.6	13.69	46.09
5	93	91.5	95.1	99.3	98.5	97.6	9.92	56.01
6	100	100.0	97.4	96.6	98.9	97.6	9.92	65.93
7								
8								
9								
10								
11								
12								

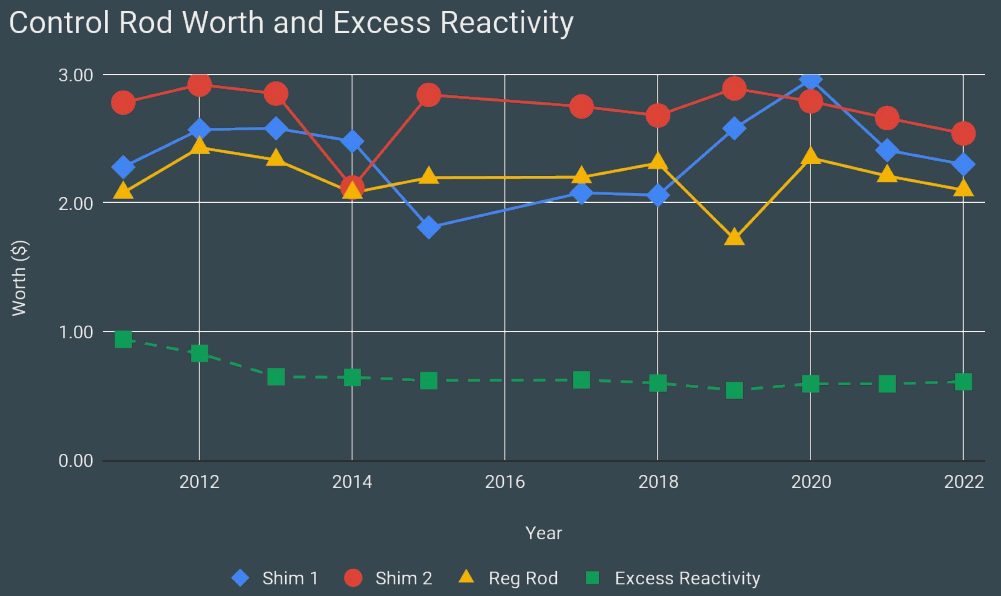
Rod "T": Reg Rod

Actual Position	$\sum_{n=1}^{i}\rho_{rod\ W}-\sum_{n=1}^{i}\rho_n(¢)$
100%	0
91.7	6.08
61.4	17.70
71.1	32.40
63.6	46.09
59.7	56.01
56.7	65.93



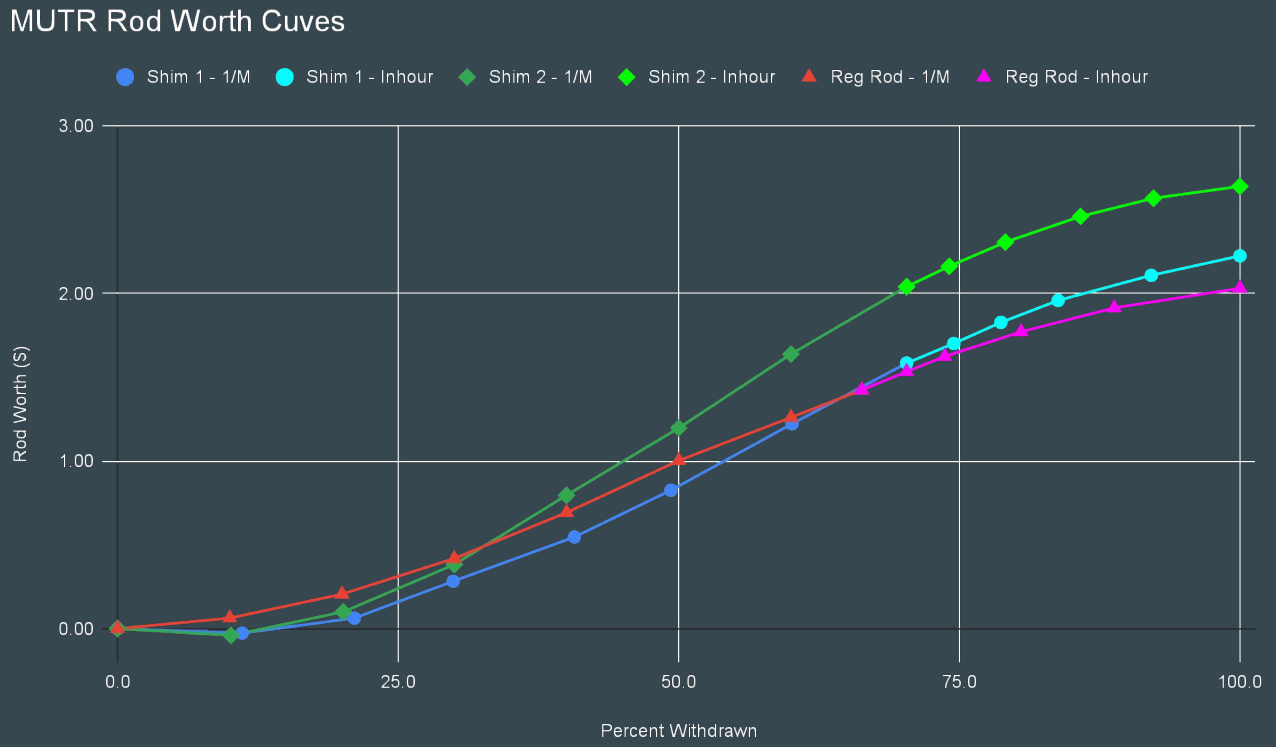
Control Rod Worth Variation

- Control Rods showed very significant variations in worth from year to year
- Excess Reactivity measurements were fairly consistent
  - Directly measured
- Issue likely due to rod position measurement errors rather than real changes
  - Extreme extrapolation exacerbates the problem
- Desirable to have a more consistent measurement method



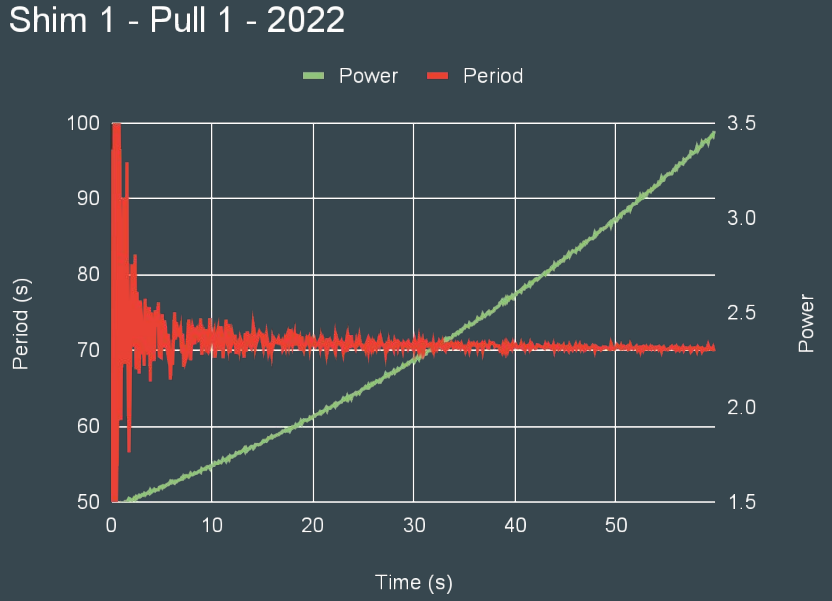
Measurement of Full Rod Worth Curves

- In order to measure the full worth of the MUTR control rods 1/M measurements were combined with positive period measurements
- Rod worths were also measured by the rod drop method



Reactivity Worth Measurement Methods

- Positive Period (Inhour) Method
  - Good accuracy: ±$0.02 for excess reactivity
  - Minimal issues with rod / detector positioning
  - Requires the reactor to be critical for the measurements
- Rod Drop Method
  - Full rod worths, but not curve shape
    - Measurements are quick to make
  - Requires reactor to be critical
  - Sensitive to detector / rod positions
  - Some subjectivity in measurements
- 1/M Method
  - Takes a long time
  - Sensitive to detector / rod positions



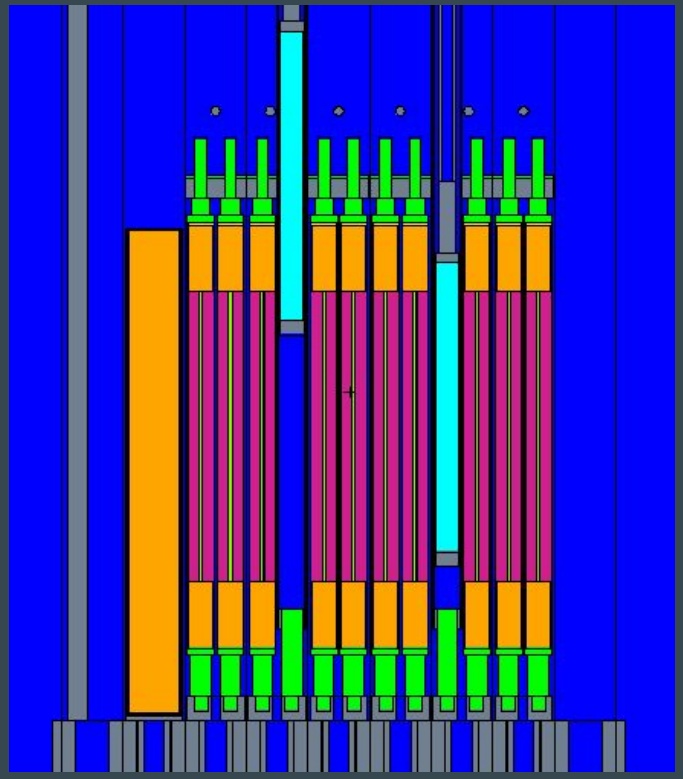
Rod Worth Measurement Results

- Measured rod worths agree reasonably well between methods
  - All methods agree on relative worths of all 3 rods

Rod	*1/M + Inhour*	*Rod Drop + Inhour*	*Rod Drop*	*Inhour + Extrapolation*	*MCNP*
Shim 1	$2.22±0.08	$2.35±0.09	$2.45±0.01	$2.30±0.14	$2.52±0.40
Shim 2	$2.64±0.09	$2.82±0.06	$3.04±0.02	$2.54±0.15	$2.83±0.40
Reg Rod	$2.03±0.08	$2.04±0.05	$2.06±0.03	$2.10±0.13	$2.34±0.40

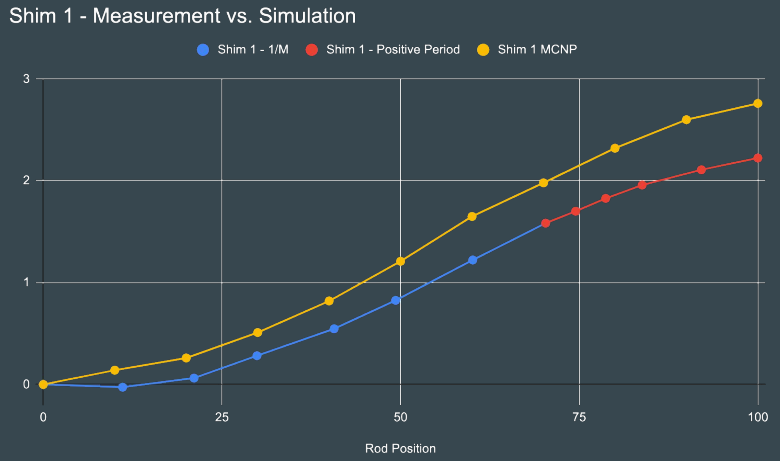
MCNP Modeling

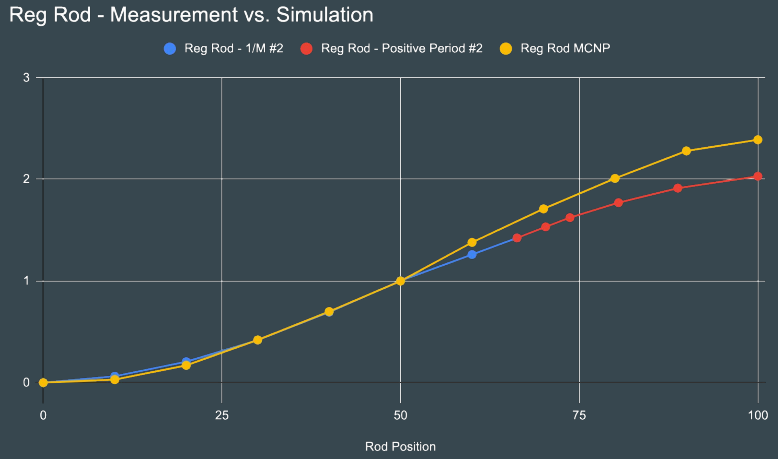
- Control rod worth curves were simulated using the MCNP model of the MUTR
- Rods were moved in alternating steps to simulate the actual movements of rods in the reactor
- Simulations showed many of the same features as the full measured curves

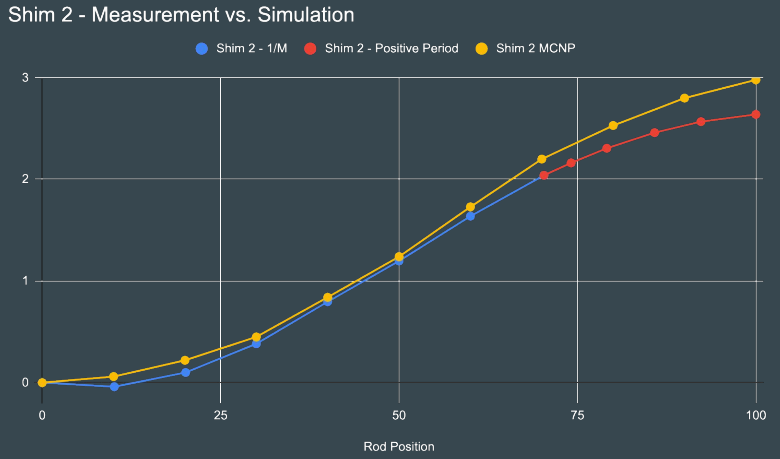


MCNP Modeling

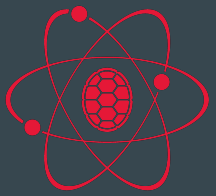
- MCNP appears to overstate the worth of the upper portion of the rods





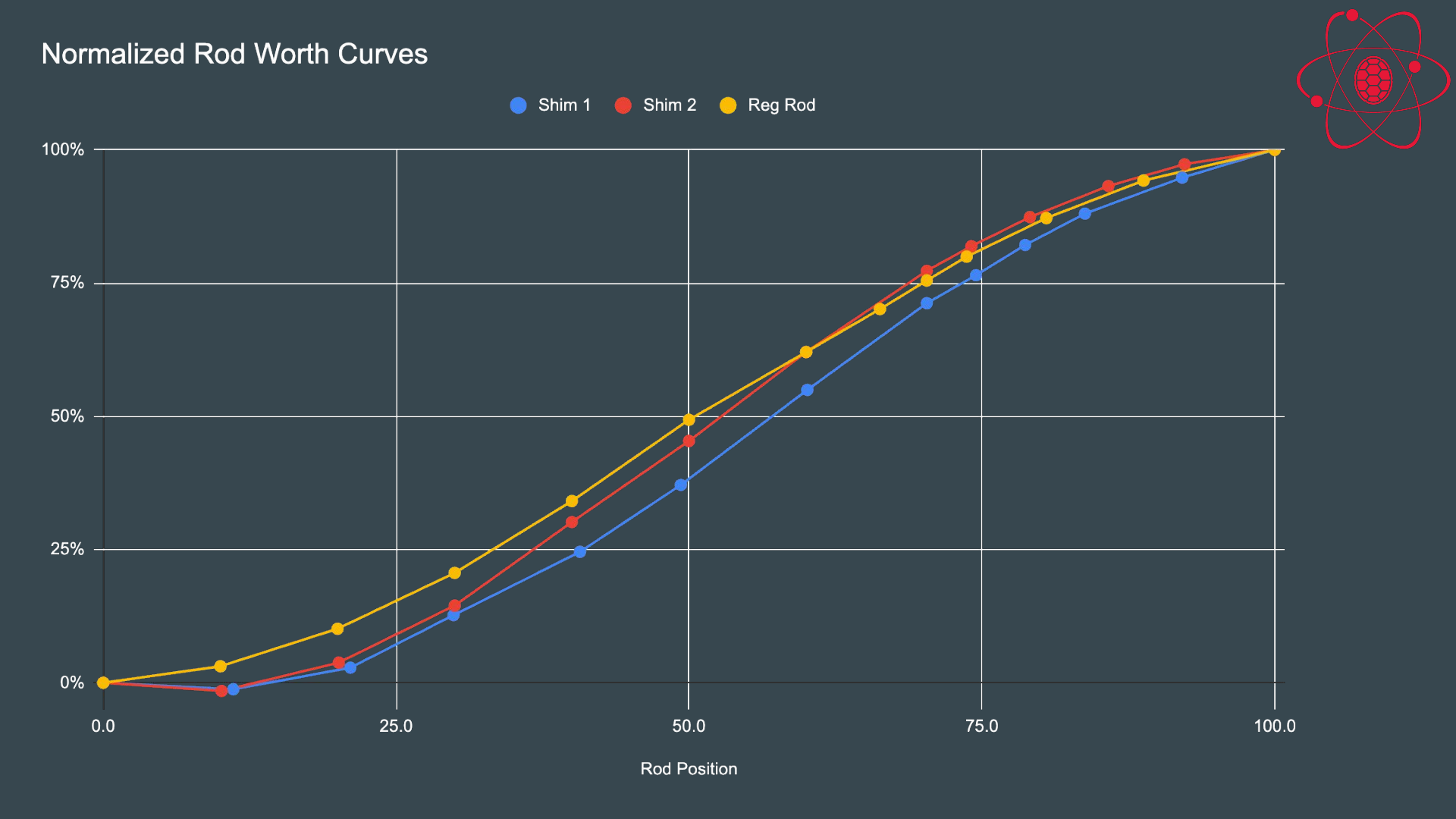


Unexpected Results

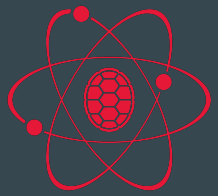


- Evidence from 1/M Rod worth measurements suggest Shim 1 and Shim 2 insert negative reactivity as they begin to be withdrawn from the core
  - MCNP Model of Shim 1 also shows this behavior
- Shim 1 and 2 Worth Curves are not symmetrical about 50% withdrawn
  - Grid plate void
  - ~~Molybdenum Disk~~
  - ~~TRIGA Conversion process left experimental facilities and reflectors not vertically centered around the core~~
  - **Results skewed by measurement techniques**

Normalized Rod Worth Curves



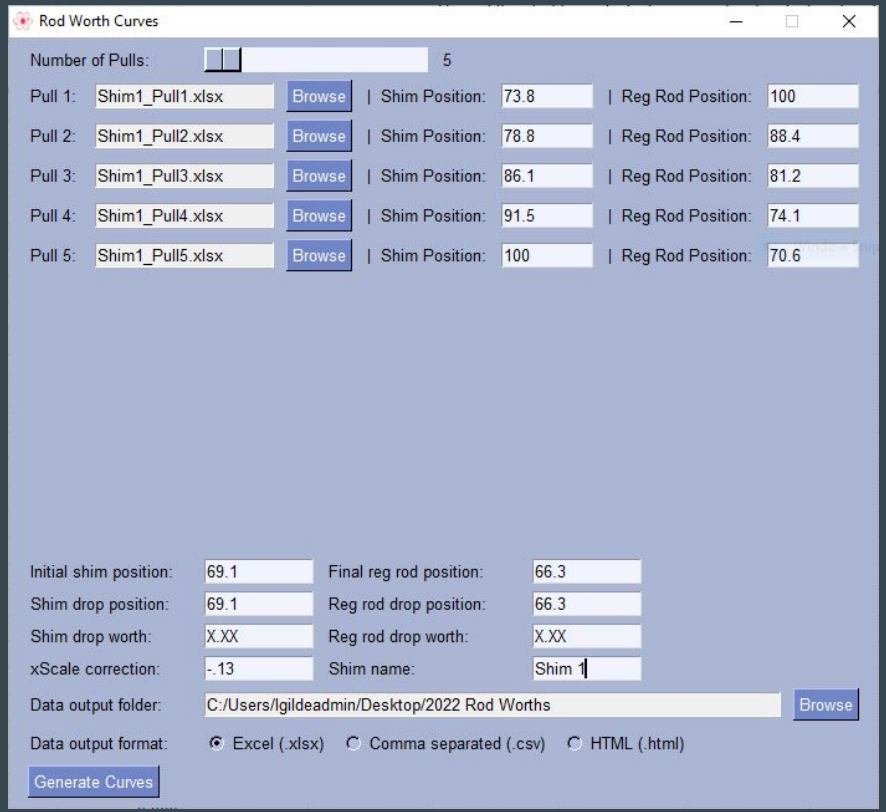
New Technique for Rod Worth Measurement



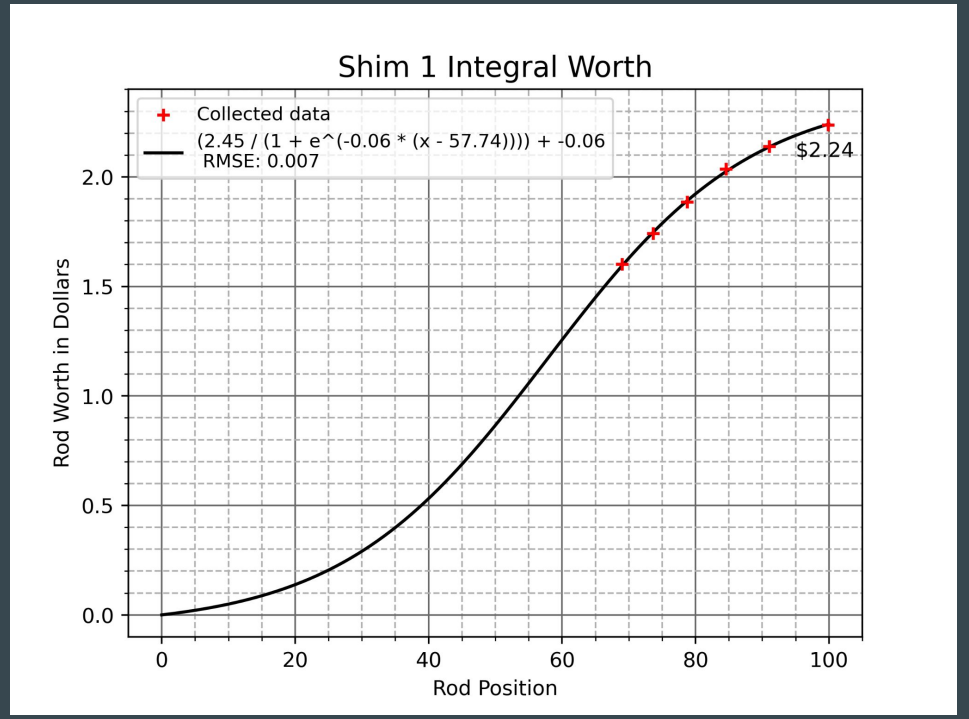
- Used full measured and simulated to determine the best fitting function for rod worth curves
  - Logistic equation in the form: $\frac{L}{1+e^{-k(x-x_0)}}+b$
  - SciPy Least squares fitting
    - Fits through (0,0), inhour data from top 30% of curve, and total worth via rod drop
- Accurate fitting from the upper third of the control rod also requires the total rod worth
  - Adding a rod drop measurement from the minimum critical position to determine the worth of the lower 2/3rds of the control rod
- Developed a Python GUI to take rod worth data and return rod worth curves
  - Takes points of upper worth curve, and worth of lower portion of rod
  - Returns rod worth curve, total rod with and RSME for points on upper worth curve

Rod Worth GUI

- Python was used to generate a GUI to process control rod worth measurement data and generate rod worth curves
  - Automatically determines worth from Positive Period power traces
  - Manually input Rod Drop worth
- Fits data points and generates the worth curve



Example Rod Worth Curves



Future Work

- Fine measurements of lower portions of control rods
- Development of automated method for calculating Rod Drop worths
- Add additional fuel to increase excess reactivity

Questions?

- Thanks to:
  - Andy Smolinski
  - Robert Shickler