Prompt Neutron Decay Constant Measurements on a Copper Reflected Intermediate Enrichment Uranium System with Lead Interstitial

G. McKenzie, T. Grove, and R. Sanchez

Los Alamos National Laboratory

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Experiments at National Criticality Experiments Research Center (NCERC) in Nevada

NCERC is the only Security Category 1, US Criticality Experiments Capability

• Focus on using existing fuel on Comet to produce comparable data for JAEA
• US has interest in lead cross section for data libraries
• This series of measurements occurred as part of larger three part campaign to measure lead void reactivity coefficients
  ○ All three series are planned to be included in ISCBEP as benchmarks
Experiments at NCERC

Comet
- Vertical Assembly Machine
- Lower fuel is placed on moveable platen and lifted towards an upper fuel stack.

Zeus Series of Experiments
- Copper reflector
- HEU fuel
- Various interstitial material (graphite, iron, poly) to modify spectrum

For JAEA experiments
- Perform similar experiment with lead
- This one in particular lowered enrichment using natural uranium plates
- Began in 2017
LEU/Lead Experiment: Core

LEU Core

- Natural uranium plates interleaved with HEU plates
- Effective enrichment ~21%
- Similar measurements to HEU core
- Lower NU plates surrounded by Al rings
- Positive Void Coefficient for Lead (HEU system has negative coefficient)
Prompt Neutron Decay Constant Measurements

- The Rossi-$\alpha$ method is used to measure the prompt neutron decay constant
- Measures correlations between neutron detections to assess prompt neutron population decay in a sub-prompt system
  - Using a list-mode time tagging system
Prompt Neutron Decay Constant Measurements

- Prompt neutron decay constants are used to benchmark neutron lifetime for critical experiments
  - Easy single parameter comparison
- Prompt neutron decay constants can be used to establish the mass increment between delayed critical and prompt critical

- Give valuable nuclear kinetics information about the system
  \[ p(t) = A + Be^{\alpha t} \]
  - Where alpha is the prompt neutron decay constant
  - A is the uncorrelated source rate
  - B is the magnitude of the correlated source rate
Measurements

- The detectors used to measure the prompt neutron decay constant placed near the center of the assembly
- Inside a section called the spindle (or alignment tube)
- Access from the top and bottom to locate detection system and associated wiring
- Center of the assembly is ideal for measurements
- Four detectors used to reduce system dead-time
Measurements

• The Rossi-α experiment can be performed using a number of different neutron detectors
• This experiment used Reuter-Stokes He-3 tubes
• These tubes contain 40 atm of the He-3 inside a ¼” casing
• The tubes are 4 inches long with an active length of 3 inches
• These are ideal for these measurements because they are insensitive to gammas and can be placed inside the assembly
Measurements

Measurements were taken on several configurations

- All subcritical
- The configurations adjusted reactivity (multiplication) through separation of the top and bottom fuel sections
- Measurements taken at 185, 200, and 215 mil separations
- These measurements used to extrapolate value at delayed critical
Measurements

- An example of the Rossi-α histogram from a single measurement is shown to the right.
- Ten measurements were completed on each configuration to help assess statistical uncertainty in the measurement.
- Average values were used to assess the prompt neutron decay constant at delayed critical.
Results

• The measured value of the prompt neutron decay constant for each of the three configurations is shown in the table on the right.
• As expected, the trend of these values moves toward zero as multiplication increases.
• These values are then used to extrapolate the prompt neutron decay constant at delayed critical.

<table>
<thead>
<tr>
<th>Separation (mils)</th>
<th>$\alpha$ (s$^{-1}$)</th>
<th>Std. Dev (s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>185</td>
<td>-57772.7</td>
<td>1471.6</td>
</tr>
<tr>
<td>200</td>
<td>-60954.0</td>
<td>1383.7</td>
</tr>
<tr>
<td>215</td>
<td>-64539.8</td>
<td>1224.3</td>
</tr>
</tbody>
</table>
Results

- Using linear extrapolation of each measurement and its corresponding inverse count rate, gives the prompt neutron decay constant at delayed critical.
- At delayed critical the inverse count rate goes to zero, so the y-intercept is the prompt neutron decay constant at delayed critical.
Results

• The extrapolated value at delayed critical is included on the table at the right
• This is the value typically quoted when discussing the prompt neutron decay constant of a particular system
• This is the single value used to compare different critical experiments based on neutron spectrum and lifetime

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<tbody>
<tr>
<td>DC</td>
<td>-56350.4</td>
<td>552.4</td>
</tr>
<tr>
<td>185</td>
<td>-57772.7</td>
<td>1471.6</td>
</tr>
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Results

- The prompt neutron decay constant at delayed critical was also obtained using the KOPTs card in MCNP®
- The value obtained is $-62286.2 \pm 1157.5$ s$^{-1}$
- This has a $\frac{C-E}{E}$ of 0.105 compared to the measurement

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Conclusions

<table>
<thead>
<tr>
<th>System</th>
<th>$\alpha$ (s(^{-1}))</th>
</tr>
</thead>
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<tr>
<td>Lady Godiva</td>
<td>-1.1E6</td>
</tr>
<tr>
<td>HEU Zeus</td>
<td>-8.9E4</td>
</tr>
<tr>
<td>IEU/Pb Zeus</td>
<td>-5.6E4</td>
</tr>
<tr>
<td>HEU/Pb Zeus</td>
<td>-3.8E4</td>
</tr>
<tr>
<td>Sheba</td>
<td>-2.0E2</td>
</tr>
</tbody>
</table>

- The prompt neutron decay constant at delayed critical falls where expected when compared to the other Zeus measurements completed.
- All of which fall into the correct range when compared to other historic measurements:
  - Lady Godiva was an un-reflected HEU experiment and should have the largest magnitude of prompt neutron decay constant.
  - Sheba was a HEU solution system which should have the smallest magnitude of prompt neutron decay constant.
Acknowledgments

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