Preliminary Results for Thermal Epithermal eXperiments (TEX), Ten New Critical Experiments with Plutonium-Aluminum Zero Power Physics Reactor (ZPPR) Plates

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Thermal/Epithermal eXperiments (TEX)

- TEX Goals
  - Using available US Department of Energy fissile materials, create critical benchmarks to address the nuclear data and validation needs for criticality safety
  - July 2011 at Sandia National Laboratories, Albuquerque, NM
    - Representatives from US, UK, and France
    - Main take-aways
      - Intermediate spectrum experiments needed (only 2.1% of ICSBEP Benchmarks)
      - Test-bed assemblies that span multiple energy spectra are incredibly useful for nuclear data validation
      - Consensus prioritization of nuclear data needs (in order):
        - $^{239}\text{Pu}$, $^{240}\text{Pu}$, $^{238}\text{U}$, $^{235}\text{U}$, Temperature variations, Water density variations, Steel, Lead (reflection), Hafnium, Tantalum, Tungsten, Nickel, Molybdenum, Chromium, Manganese, Copper, Vanadium, Titanium, and Concrete (reflection, characterization, and water content)
Plutonium TEX Experiments

- Plutonium test bed experimental series, using excess plutonium/aluminum Zero Power Physics Reactor (ZPPR) plates
- Five baseline experiments, covering thermal, intermediate and fast fission energy regimes and five similar experiments that include tantalum
- Pu plates arranged in approximately 30 cm x 30 cm (12” x 12”) layers (6 plates by 4 plates)
Trays Used to Facilitate Stacking Layers
Plutonium Baseline Experiments
## Baseline Experiments

<table>
<thead>
<tr>
<th>Experiment Number</th>
<th>Thickness of PE Plates (cm)</th>
<th>Thermal Fission Fraction (&lt;0.625 eV)</th>
<th>Intermediate Fission Fraction (0.625 eV-100 KeV)</th>
<th>Fast Fission Fraction (&gt;100 KeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 (no PE)</td>
<td>0.09</td>
<td>0.18</td>
<td>0.73</td>
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<tr>
<td>2</td>
<td>0.159</td>
<td>0.14</td>
<td>0.38</td>
<td>0.48</td>
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<tr>
<td>3</td>
<td>0.476</td>
<td>0.28</td>
<td>0.43</td>
<td>0.29</td>
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<tr>
<td>4</td>
<td>1.111</td>
<td>0.50</td>
<td>0.32</td>
<td>0.18</td>
</tr>
<tr>
<td>5</td>
<td>2.540</td>
<td>0.66</td>
<td>0.21</td>
<td>0.13</td>
</tr>
</tbody>
</table>
Tantalum Diluted Cases

- As part of the ZPPR inventory, ANL had approximately 15,000 very pure tantalum plates
- Nominal outer dimensions of 5.08 cm x 7.62 cm by 0.159 cm
- Additional trays were manufactured to accommodate both Pu and Ta plates
  - 0.476 cm (3/16”) tray depth
Tantalum Diluent Experiments
<table>
<thead>
<tr>
<th>Experiment Number</th>
<th>Thickness of PE Plates (cm)</th>
<th>Thermal Fission Fraction (&lt;0.625 eV)</th>
<th>Intermediate Fission Fraction (0.625 eV-100 KeV)</th>
<th>Fast Fission Fraction (&gt;100 KeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0 (no PE)</td>
<td>0.07</td>
<td>0.14</td>
<td>0.79</td>
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<tr>
<td>7</td>
<td>0.159</td>
<td>0.8</td>
<td>0.36</td>
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<tr>
<td>8</td>
<td>0.476</td>
<td>0.19</td>
<td>0.45</td>
<td>0.36</td>
</tr>
<tr>
<td>9</td>
<td>1.111</td>
<td>0.43</td>
<td>0.36</td>
<td>0.21</td>
</tr>
<tr>
<td>10</td>
<td>2.540</td>
<td>0.64</td>
<td>0.22</td>
<td>0.14</td>
</tr>
</tbody>
</table>
Fine Reactivity Adjustment

• Need a way to add small amounts of reactivity to the assembly near critical to ensure we hit the delayed critical window (between 1 and ~1.0016)

• Two Methods:
  – Add thicker upper reflector sheets
  – Partial layer of plutonium plates in upper layer, using aluminum blanks to maintain spacing within tray
Experiment Photos
## PRELIMINARY Baseline Results

<table>
<thead>
<tr>
<th>Exp Number</th>
<th>PE Moderator Thickness (cm)</th>
<th>Upper Reflector Thickness (cm)</th>
<th>Number of Critical Pu Plates</th>
<th>Peak Temperature (C)</th>
<th>Estimated C/E (k&lt;sub&gt;eff&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 (no PE)</td>
<td>2.540</td>
<td>480</td>
<td>40.5</td>
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<td>2</td>
<td>0.159</td>
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<td>3</td>
<td>0.476</td>
<td>2.699</td>
<td>280</td>
<td>39.6</td>
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<tr>
<td>4</td>
<td>1.111</td>
<td>2.540</td>
<td>172</td>
<td>34.1</td>
<td>1.0003</td>
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<tr>
<td>5</td>
<td>2.540</td>
<td>3.175</td>
<td>120</td>
<td>32.4</td>
<td>0.9978</td>
</tr>
</tbody>
</table>

- Why preliminary results?
  - Values calculated with MCNP6, version 1.2, with ENDF/B-VII.1 cross sections using design parameters and do not incorporate all experimental measurements or temperature effects
  - Experimental k<sub>eff</sub>s are based on fast plutonium delayed neutron parameters for all configurations
  - LOTS of work to do for a benchmark
### PRELIMINARY Tantalum Results

<table>
<thead>
<tr>
<th>Exp Number</th>
<th>PE Moderator Thickness (cm)</th>
<th>Upper Reflector Thickness (cm)</th>
<th>Number of Critical Pu Plates</th>
<th>Peak Temperature (°C)</th>
<th>Estimated C/E (k&lt;sub&gt;eff&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0 (no PE)</td>
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<tr>
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<td>48.3</td>
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<tr>
<td>8</td>
<td>0.476</td>
<td>2.699</td>
<td>768</td>
<td>43.6</td>
<td>1.0156</td>
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<tr>
<td>9</td>
<td>1.111</td>
<td>2.540</td>
<td>438</td>
<td>40.6</td>
<td>1.0082</td>
</tr>
<tr>
<td>10</td>
<td>2.540</td>
<td>3.175</td>
<td>264</td>
<td>34.6</td>
<td>1.0002</td>
</tr>
</tbody>
</table>

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PRELIMINARY Conclusions

- Thermal configurations calculated very well
- Intermediate and fast baseline systems calculated approximately 1% high
  - Potentially pointing to issues with $^{239}$Pu unresolved resonance region
- Intermediate and fast tantalum systems calculated approximately 1.5-2% high
  - Possible issues with tantalum scattering and angular distributions, potentially too much resonance absorption
- Temperature will have some effect, however, the effect is expected to be small and not explain the magnitude of the C/E differences
  - 15 degree temperature cross section change gave a calculated $k_{\text{eff}}$ change of -0.00016
  - Thermal expansion of the polyethylene gave a calculated $k_{\text{eff}}$ change of -0.00026
  - Experimental results showed temperature effects on the order of a few cents of reactivity (less than 0.0002 effect)
Current Work for TEX-Pu

- Complete chemical and metallurgical characterization of one Pu/Al ZPPR plate to determine impurity content and confirm historical isotopic and chemical composition
- Prepare ICSBEP benchmark for inclusion in the 2019 version of the handbook
  - Detailed analysis of temperature and thermal expansion effects
  - Incorporating all experimental measurements
  - Thorough experimental uncertainty quantification
Thanks to LANL and NCSP!
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