Jupiter: A Benchmark Experiment for Lead Void Worth with Plutonium

Alex McSpaden, Joetta Goda, Theresa Cutler, George McKenzie, Jesson Hutchinson, Nicholas Thompson

American Nuclear Society Winter Meeting
November 20th, 2019
• Background
• Experiment Overview
  – Components
  – Configurations
  – Results
• Detailed Model
  – Description
  – Results
• Current Progress on S/U Analysis
Background

• Collaboration between Los Alamos National Laboratory (LANL) and the Japanese Atomic Energy Agency (JAEA)
  – Goal is to provide useful data for a potential lead-bismuth cooled accelerator driven system in Japan
  – Desired to measure the lead-void reactivity worth for a variety of systems
    • Highly Enriched Uranium (HEU)
    • “Intermediate” Enriched Uranium (mix of HEU and natural uranium plates)
    • Plutonium
    • See papers by K. Tsujimoto et al. and M. Fukushima et al.

• Lead is a very widely used material for shielding
Background – Benchmark Heat Maps

• Less than two dozen International Criticality Safety Benchmark Evaluation Project handbook entries (up to 2016) sensitive to lead
Array is made of PANN (plutonium aluminum no-nickel) plates from Idaho National Laboratory’s Zero Power Physics Reactor experiments

- Each contains average of ~105g nuclear material, 94% of which is $^{239}\text{Pu}$
- Alloyed with aluminum, clad in stainless steel
- Plates are put in “sandwiches” of lead and PANN plates, with aluminum in between
  - 6 plutonium, 2 lead in each box

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>As-Built Average Wt. % (1960)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{239}\text{Pu}$</td>
<td>93.971</td>
</tr>
<tr>
<td>$^{240}\text{Pu}$</td>
<td>4.483</td>
</tr>
<tr>
<td>$^{241}\text{Pu}$</td>
<td>0.437</td>
</tr>
<tr>
<td>$^{242}\text{Pu}$</td>
<td>0.005</td>
</tr>
<tr>
<td>Al</td>
<td>1.099</td>
</tr>
</tbody>
</table>
Jupiter – Experiment Description

- Series of boxes and copper blocks put into an array
- Surrounded by copper inner reflector blocks to make cylindrical top and bottom stack for Comet
Lead-Void Configurations

- Aluminum spacer frames to replace the lead and aluminum in most central boxes of middle layer
- Mass of aluminum is preserved
Experimental Results

### Preliminary

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Average Excess Reactivity (cents)</th>
<th>Inferred $k_{\text{eff}}$*</th>
<th>$\sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>34.5</td>
<td>1.00072</td>
<td>$\pm 0.00002$</td>
</tr>
<tr>
<td>A1</td>
<td>23.7</td>
<td>1.00050</td>
<td>$\pm 0.00002$</td>
</tr>
<tr>
<td>A12</td>
<td>11.2</td>
<td>1.00024</td>
<td>$\pm 0.00002$</td>
</tr>
</tbody>
</table>

*Based on Keepin’s $\beta_{\text{eff}} = 0.00210$

Detailed Model – PANN Plate

Edge Rounding

Spring
Plate Cladding
Plate Core

Corner Rounding
Detailed Model – Fuel Container
Detailed Model – Full Assembly
Current Progress

• Some sections under review
  – Experiment Description, Description of Model
• Others in progress
  – Sensitivity and Uncertainty Analysis, Results of Sample Calculation
• Benchmark will also have JENDL, JEFF results

Preliminary

<table>
<thead>
<tr>
<th>Code (Cross Section Set)</th>
<th>MCNP6.2 (Continuous-Energy ENDF/B-VIII.0)</th>
<th>MCNP6.2 (Continuous-Energy ENDF/B-VII.1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$K_{\text{eff}}$</td>
<td>$\sigma$</td>
</tr>
<tr>
<td>Case ↓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reference</td>
<td>0.99717</td>
<td>$\pm 0.00001$</td>
</tr>
<tr>
<td>A1</td>
<td>0.99690</td>
<td>$\pm 0.00001$</td>
</tr>
<tr>
<td>A12</td>
<td>0.99659</td>
<td>$\pm 0.00001$</td>
</tr>
</tbody>
</table>
Sensitivity and Uncertainty Analysis

- Partially complete
- Preliminary sample of calculations follow
  - Not an exhaustive list
- Except for mass and composition, calculated through perturbations
  - Mass and composition calculations used KSEN adjoint-based sensitivity
    - Gives sensitivity coefficients $S_{k,N_j}$ of $k_{eff}$ to atom density $N_j$ of nuclide $j$
    - Used to calculate the sensitivity and uncertainty of the system $k_{eff}$ to the mass or composition of certain components
    - Based on the paper by Jeff Favorite et al.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter Uncertainty</th>
<th>$S_{k,\rho}$</th>
<th>$\Delta k_{eff}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead Mass</td>
<td>28.09 g (~0.03%)</td>
<td>0.04013</td>
<td>0.00001</td>
</tr>
<tr>
<td>Aluminum Fuel Box Mass</td>
<td>13.94 g (~0.19%)</td>
<td>0.02561</td>
<td>0.00005</td>
</tr>
<tr>
<td>Aluminum Spacer Mas</td>
<td>55.47 g (~0.86%)</td>
<td>1.895E-4</td>
<td>&lt;0.00001</td>
</tr>
</tbody>
</table>
Conclusion

• The Jupiter experiment has already provided useful data regarding lead void reactivity worth, and a benchmark would help address nuclear data validation deficiencies for this material

• Benchmark is well underway, and will be ready for 2020 ICSBEP meeting
  – Same time as HEU (HMF-102) and IEU (MMF-016) experiment benchmarks
This work was supported by the DOE Office of Material Management and Minimization and by the DOE Nuclear Criticality Safety Program, funded and managed by the National Nuclear Security Administration for the Department of Energy.