IER 441: Experiments to Measure the Effect of Tantalum on Critical Systems (SNL/ORNL)

Presented by David Ames (SNL)
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NCSP Technical Program Review
February 21-23, 2023
Hosted by Sandia National Laboratories
Albuquerque, NM
Overview

Sandia Critical Experiments Program
- 7uPCX
- BUCCX

Motivation for Experiments

Experiment Design (ORNL Lead – CED 1 & 2)

Perform Experiments (SNL Lead – CED 3a & 3b)
- Design modifications
- Hardware procurement
- Conduct experiments – June to October 2023

Experiment Evaluation and Publication (ICSBEP)
- Technical Review Group Meeting – April 2024

Acknowledgements
The Seven Percent Critical Experiment (7uPCX)
- UO$_2$ fuel (6.9%)
- 45x45 Square pitch array (0.315 and 0.337 inch)
- Triangular pitch array (0.61 inch)
- Fuel rod diameter 0.25 inch
- Fuel length 19.25 inch
- LCT-078, 080, 096, 097, 101, 102, 10?[IER 305]

The Burnup Credit Critical Experiment (BUCCX)
- UO$_2$ fuel (4.3%)
- Triangular pitch (0.787 and 1.1 inch)
- Fuel locations 397 and 271
- Fuel rod diameter 0.544 inch
- Fuel length 19.37 inch
- LCT-079, 099
Experiment motivation
- Develop ability to test epithermal/intermediate energy cross sections for materials using 7uPCX
- Applicable to Savannah River Site and Hanford Tank Farms (DOE-EM)

Notable design features from CED-2 (ORNL Lead)
- Triangular pitched grid plates
  - 0.800 cm
- Two fuel regions
  - Close-packed region (under-moderated)
  - Driver region (every other fuel rod removed)
- Central test region
  - Dry cavity
  - Lined with cadmium
- Tantalum test material
  - Nineteen materials considered
  - Multiple configurations with up to 37 tantalum rods
- Approach-to-Critical
  - Fuel rods removed from Close-packed region
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- Approach-to-Critical
  - Fuel rods removed from Close-packed region
Design Modifications

1. **Approach-to-critical process**
   - Add fuel rods from the center towards the outside while maintaining a roughly cylindrical cross section of the array.
   - Consistent with past experiments at SNL and provides ability to start approach at $k_{\text{eff}} \sim 0.90$ and 0.95

2. **Grid plate hole pitch**
   - 0.80 cm (criticality cannot be reached in normal fuel loading)
     - Evaluated a range from 0.80 cm to 1.5 cm

3. **Driver region**
   - Simplified fuel loading pattern

4. **Amount and placement of tantalum rods**
   - Increased reactivity worth

5. **Geometric shape of central test region**
   - Hexagonal vs cylindrical
     - Manufacturing restrictions
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CED-2 critical configuration (pitch = 0.80 cm)

$k_{eff} \sim 0.93$
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Critical configuration (pitch = 0.86 cm) $k_{\text{eff}} \sim 0.95$
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     ◦ Evaluated a range from $0.80$ cm to $1.5$ cm

3. Driver region
   ◦ Simplified fuel loading pattern

4. Amount and placement of tantalum rods
   ◦ Increased reactivity worth

5. Geometric shape of central test region
   ◦ Hexagonal vs cylindrical
     ◦ Manufacturing restrictions

Driver Region (pitch = 0.86 cm)

No Driver Region (pitch = 0.97 cm)
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     ◦ Manufacturing restrictions
Optimized Configuration

- Maximize tantalum reactivity worth
- Maximize tantalum absorption within the intermediate energy range
  - Pitch of the fuel rods (0.80 – 1.5 cm)
  - Pitch of the tantalum rods in the central test region (0.80 – 1.5 cm)
  - Number of tantalum rods (1 – 91 rods)
  - Thickness of cadmium (0.25 – 3.00 mm)
  - Outer diameter and thickness of the test region can (targeting standard sizes)

CED-2:

<table>
<thead>
<tr>
<th>Ta Worth ((∆k/k ± σ))</th>
<th>Three group energy-dependent Ta absorption rates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;0.625 eV</td>
</tr>
<tr>
<td>1.654 ± 0.011 %</td>
<td>1.26 %</td>
</tr>
</tbody>
</table>

Baseline Configuration:

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<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;0.625 eV</td>
</tr>
<tr>
<td>2.546 ± 0.004 %</td>
<td>1.27 %</td>
</tr>
</tbody>
</table>

1158 fuel rods \((k_{eff} = 0.99936 ± 0.00003)\)
Fuel element worth near critical = 0.029 $
Fuel rod pitch = 1.016 cm
Tantalum rods = 85
Tantalum rod pitch = 0.8128 cm
Aluminum test region can OD = 9.525 cm
Aluminum test region can WT = 0.3175 cm
Cadmium filter thickness = 0.102 cm
## Experiment Cases

### Ta-rods Cd-filter Fuel rods Ta Worth ($\Delta k/k \pm \sigma$) Three group energy-dependent Ta absorption rates

<table>
<thead>
<tr>
<th>Ta-rods</th>
<th>Cd-filter</th>
<th>Fuel rods</th>
<th>Ta Worth ($\Delta k/k \pm \sigma$)</th>
<th>Three group energy-dependent Ta absorption rates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>&lt;0.625 eV</td>
<td>0.625 eV–100 keV</td>
</tr>
<tr>
<td>85</td>
<td>Yes</td>
<td>1158</td>
<td>2.546 ± 0.004 %</td>
<td>1.27 %</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>1134</td>
<td>5.725 ± 0.004 %</td>
<td>30.96 %</td>
</tr>
<tr>
<td>61</td>
<td>Yes</td>
<td>1136</td>
<td>2.081 ± 0.006 %</td>
<td>1.38 %</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>1106</td>
<td>4.971 ± 0.005 %</td>
<td>34.17 %</td>
</tr>
<tr>
<td>37</td>
<td>Yes</td>
<td>1108</td>
<td>1.499 ± 0.006 %</td>
<td>1.47 %</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>1074</td>
<td>3.927 ± 0.005 %</td>
<td>38.58 %</td>
</tr>
<tr>
<td>30</td>
<td>Yes</td>
<td>1110</td>
<td>1.656 ± 0.006 %</td>
<td>1.11 %</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>1078</td>
<td>4.253 ± 0.005 %</td>
<td>38.76 %</td>
</tr>
<tr>
<td>19</td>
<td>Yes</td>
<td>1084</td>
<td>0.944 ± 0.006 %</td>
<td>1.52 %</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>996</td>
<td>2.832 ± 0.005 %</td>
<td>43.31 %</td>
</tr>
<tr>
<td>18</td>
<td>Yes</td>
<td>1086</td>
<td>1.078 ± 0.006 %</td>
<td>1.30 %</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>1000</td>
<td>3.167 ± 0.005 %</td>
<td>42.96 %</td>
</tr>
<tr>
<td>7</td>
<td>Yes</td>
<td>1068</td>
<td>0.460 ± 0.006 %</td>
<td>1.40 %</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>936</td>
<td>1.552 ± 0.005 %</td>
<td>47.57 %</td>
</tr>
<tr>
<td>1</td>
<td>Yes</td>
<td>1044</td>
<td>0.093 ± 0.006 %</td>
<td>1.20 %</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>900</td>
<td>0.342 ± 0.006 %</td>
<td>50.16 %</td>
</tr>
</tbody>
</table>
85 Ta-Rods Configuration
New Hardware

- Control and Safety Element Drives
- CE/SE Bundles
- Guide Plate
- Top Grid Plate
- Assembly Tank
- Bottom Grid Plate
- Central Test Region
Central Test Region

Length ≈ 31 inch (78.7 cm)

OUTER ALUMINUM TUBE

85X TANTALUM RODS

INNER ALUMINUM TUBE

2X CADMIUM FILTER .020IN

CADMIUM FILTER .040IN

SWX-240 Cadmium Sheets

Cadmium sheets are commonly used for attenuation of thermal neutrons because of its high cross-section. This high cross-section makes it effective even in the form of sheets. Reactor grade cadmium sheets are available in thicknesses from 0.01" to 0.06".

<table>
<thead>
<tr>
<th>Size Code</th>
<th>Thickness</th>
<th>Width</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>0.010&quot;</td>
<td>17&quot;</td>
<td>36&quot;</td>
</tr>
<tr>
<td>A</td>
<td>0.020&quot;</td>
<td>0.51mm</td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>0.025&quot;</td>
<td>0.64mm</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>0.032&quot;</td>
<td>0.81mm</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0.040&quot;</td>
<td>1.02mm</td>
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<td>D</td>
<td>0.060&quot;</td>
<td>1.52mm</td>
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Tantalum rods

- Commercially pure
  - 99.95%
  - Meet requirements of ASTM B365-12
- Fabricated from same heat load
- Elemental compositions including impurities
- Etched with serial numbers

LCT-097 with titanium experiment rods
Safety and Control Element Bundle

- LEVELING PAD (L-1)
- UPPER PLUG SPRING
- ALUM SLEEVE
- POLYTHYLENE ROD
- BUNDLE PLATE, UPPER
- B4C ROD ASSEMBLY
- BUNDLE PLATE, MIDDLE
- FUEL ROD
- BUNDLE PLATE, LOWER
Lower Grid Plate and Hydro Tube
Design Team
- Experimenters: David Ames, Gary Harms, Elijah Lutz
- Facility & Operations: Beth Hanson, Jason Soars, Patrick Ward
- Product Design: Augie Chapa, Alex Mace
- System Engineering & QA: Cassandra Wilson, Michael Black

Notable items required for newly implemented NQA-1 process
- Total documents (39)
- Total pages (over 250)
- Required signatures (105)
- Approval to proceed steps (4)
- Design Drawings (over 30)
- Additional Requirements (design analysis, acceptance test plan, committee reviews, bidding process, etc.)

Lessons learned
- IER 305
- IER 304 and 452
Next Steps

Procurement Process

- Complete Design Control Requirements (nearly complete – out to manufacturing liaison Feb. 28)
- Manufacture equipment and receive parts by May 30, 2023
- Parts inspection, fit check, and field changes (if needed) – completed in June 2023

Safety Committee Review and Approval to Perform Experiments June 2023

- Core Analysis Report and Experiment Plan

Perform Experiments – starting in July and completed by end of Oct. 2023

Evaluation and Publication (ICSBEP TRG Meeting April 2024)

Acknowledgements

The critical experiments at Sandia are supported by the DOE Nuclear Criticality Safety Program (NCSP), funded and managed by the National Nuclear Security Administration for the Department of Energy.
7uPCX

Assembly Tank

Dump Tank
Extra slides

Error in SCALE 6.2.2 calculations

- Peak in Ta absorption starting near 300 eV not present in SCALE 6.2.3.
- Issue with how the reaction rates were tallied in SCALE 6.2.2 (no issue with $k_{\text{eff}}$).

## Configuration 10 results (SCALE 6.2.2 – Keno-VI):

<table>
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<tr>
<th>Ta Worth % ($\Delta k_{\text{eff}}$) ± σ</th>
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