Thermal/Epithermal eXperiments with Hafnium (TEX-Hf)

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Thermal/Epithermal eXperiments (TEX) Overview

- **TEX Goals**
  - New critical benchmark experiments
  - Emphasis on intermediate energy range
  - Create test bed: can be easily modified for different diluents

Diagram:
- **TEX**
  - Pu ZPPR
  - LEU Molybdenenum
  - HEU Jemima
  - TEX-Hf
**TEX-Hf Overview**

- **TEX-Hf Final Design** *(in review)* *IER-297 CED-2*
  - Hf is a strong neutron absorber
  - Used in naval propulsion reactors
  - No benchmarks sensitive to intermediate Hf cross sections

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**177\text{Hf Total Neutron Cross Section}**

- Evaluated Cross Section Data
- Liou, 1975

![Graph showing 177\text{Hf Total Neutron Cross Section}](image)
Jemima Plates

- Existing US asset at NCERC
- 93.13 - 93.5 wt% $^{235}$U enrichment
- 3 mm thickness
- 15 inch outer diameter with central holes of various sizes

- 27 disks used in TEX-Hf
- Wedge plates used to adjust reactivity
TEX-Hf Final Experiment Design

• Planet vertical lift machine
• 21 Critical Configurations
• 4 stacking methods
  – Baseline
  – Standard
  – Sandwich
  – Bunched HF
Polyethylene reflector: 1"
Jemima plates: 3 mm
Polyethylene moderator plates: 0”-1.5”
Standard Stacking Configuration

- 1 mm thick Hf plates
Sandwich Stacking Configuration

- Maximizes sensitivity in intermediate energy range
Bunched Hafnium Configuration

- Maximizes sensitivity to Hf scattering cross sections
- 12 Hf plates on top and bottom
Energy Spectrum

Fission Fraction

Moderator Thickness

0"  1/8"  1/4"  1/2"  1"  1.5"

Energy of Neutron Causing Fission (MeV)

Fast

Intermediate

Thermal
Sensitivity

- Sensitivity of $k_{\text{eff}}$ to changes in cross section:

\[ S_{k_{\text{eff}}, \sigma} = \frac{\Delta k_{\text{eff}} / k_{\text{eff}}}{\Delta \sigma / \sigma} \]

- So a sensitivity of 0.1 would mean that increasing $\sigma$ by X% would increase $k_{\text{eff}}$ by 0.1*X%

- All simulations run with MCNP6 using ENDF/B-VII.1
- Sensitivity calculated using KSEN card
- For Hf, isotope sensitivities summed
Sensitivity- Hafnium Capture

Energy (MeV)

Sensitivity per Unit Lethargy

(a)

Standard

PE Moderator Thickness (inches)

0 1/8 1/4 1/2 1 1.5

(b)

Sandwich

PE Moderator Thickness (inches)

0 1/4 1/2 1 1.5

(c)

Bunched Hf

PE Moderator Thickness (inches)

0 1/8 1/4 1/2 1 1.5

(d)
Sensitivity- Hafnium Elastic Scatter

Energy (MeV)

- Sensitivity per Unit Lethargy

- Absolute Sensitivity

(b) Standard

- PE Moderator Thickness (inches)

- Electrical

(c) Sandwich

- PE Moderator Thickness (inches)

- Electrical

(d) Bunched Hf

- PE Moderator Thickness (inches)

- Electrical

NCSP
Nuclear Criticality Safety Program
Sensitivity - Hafnium Inelastic Scatter

(a) Sensitivity per Unit Lethargy

- Unmoderated
- 1/8" PE Thickness
- 1/4" PE Thickness
- 1/2" PE Thickness
- 1" PE Thickness
- 1.5" PE Thickness

(b) Standard
- Thermal
- Intermediate
- Fast

(c) Sandwich
- Thermal
- Intermediate
- Fast

(d) Bunched Hf
- Thermal
- Intermediate
- Fast
Sensitivity - U-235 Fission

(a) Sensitivity per Unit Lethargy vs. Energy (MeV)
- Unmoderated
- 1/8" PE Thickness
- 1/4" PE Thickness
- 1/2" PE Thickness
- 1" PE Thickness
- 1.5" PE Thickness

(b) Baseline
- Thermal
- Intermediate
- Fast

(c) Standard
- PE Moderator Thickness (inches)
- Sensitivity

(d) Sandwich
- PE Moderator Thickness (inches)
- Sensitivity

(e) Bunched Hf
- PE Moderator Thickness (inches)
- Sensitivity

Future Work

Experiment execution planned for 2018

First:
• Purchase Hf plates
• Fabricate PE parts
• Characterize all parts

Then:
• Submission to ICSBEP
Acknowledgements

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Bonus- Hf Elastic Scattering

![Graph showing sensitivity per unit lethargy against energy (MeV) for different thicknesses of polyethylene and hafnium plates.](image)

- **Unmoderated**
- **1/8" PE Thickness**
- **1/4" PE Thickness**
- **1/2" PE Thickness**
- **1" PE Thickness**
- **1.5" PE Thickness**

Key:
- **Jemima Plate**
- **Hafnium Plate**
- **Polyethylene Moderator**
Uncertainty and Bias

Uncertainty

- Jemima plate mass
  - Uncertainty from previous ICSBEP benchmarks
- PE mass
  - Mass will be precisely measured after fabrication, reducing uncertainty
- Plate gaps
  - Height of stack will be measured before experiment to precisely determine gaps between plates
- U-235 enrichment
  - U-235 enrichment uncertainty based on standard deviation of measurements

<table>
<thead>
<tr>
<th>Source of Uncertainty</th>
<th>Parameter Variation</th>
<th>Calculated Effect, Δk_{eff}</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEU Plate Mass</td>
<td>+0.03%</td>
<td>0.00016</td>
</tr>
<tr>
<td>HEU Plate Mass</td>
<td>-0.03%</td>
<td>-0.00006</td>
</tr>
<tr>
<td>PE Moderator Mass</td>
<td>+0.005 g/cm</td>
<td>0.00086</td>
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<tr>
<td>PE Reflector Mass</td>
<td>+0.005 g/cm</td>
<td>0.00040</td>
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<tr>
<td>HEU Plate Gaps</td>
<td>0.00127 cm</td>
<td>-0.00044</td>
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<tr>
<td>U-235 Enrichment</td>
<td>+0.11%</td>
<td>0.00042</td>
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<tr>
<td><strong>Total Uncertainty</strong></td>
<td></td>
<td><strong>0.00114</strong></td>
</tr>
</tbody>
</table>

Bias

- Room return
  - Simulations excluding room return were found to underestimate k_{eff} by 0.00161
- Plate impurities
  - Jemima: measured impurities included but they could be omitted with increase in k_{eff} of 0.00019
  - Hafnium: omitting impurities would decrease k_{eff} by 0.00090
- Hafnium isotopic composition
  - Increasing Hf-177 content by 10% reduces k_{eff} by 0.00346
  - Will precisely measure this value before experiment
Conclusions

• Thermal, intermediate, and fast critical configurations were designed using available Jemima plate inventory.

• Hafnium capture
  – Standard stacking maximizes thermal sensitivity.
  – Sandwich stacking maximizes intermediate sensitivity.
  – No configuration was predominately sensitive to fast energy range.

• Hafnium scatter
  – Bunched hafnium configuration maximizes sensitivity to elastic and inelastic scattering at high energy.

• U-235 fission
  – Sensitivity in the intermediate and fast energy regime was verified.
  – No configuration was predominately sensitive to thermal energy range.

• U-235 capture
  – Baseline configuration maximized thermal sensitivity.
  – Bunched Hf configurations maximized intermediate and fast sensitivity.