Analysis of Measured Data from Experiments 2 & 3 of the 2010 CAAS Benchmark at the CEA Valduc SILENE Facility

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NCSD 2013 Topical
Wilmington, NC

September 29 – October 3, 2013
Institutions involved in SILENE CAAS benchmarks

- Oak Ridge National Laboratory
  - Design, measurements, documentation, and evaluation
  - T. M. Miller, M. E. Dunn, J. C. Wagner, and K. L. McMahan
- CEA Valduc
  - Design, irradiation, measurements, and documentation
- CEA Saclay
  - Shielding materials and evaluation
- Lawrence Livermore National Laboratory
  - Rocky Flats CAAS
  - S. Kim and G. M. Dulik
- Babcock International Group
  - CIDAS CAAS
  - R. Hunter
- Y-12 National Security Complex
  - BoroBond shielding materials
  - K. H. Reynolds
Outline

• Brief introduction to SILENE
• Summary of experimental details
• Comparison between measurement & computational results
  – SCALE 6.1
  – TRIPOLI-4
• Summary and conclusions
Introduction to SILENE

• Annular core
  – Internal cavity diameter 7 cm
  – Outer fuel diameter 36 cm
  – Typical critical height ~35 – 45 cm

• Uranyl Nitrate fuel Solution
  – ~93% $^{235}$U
  – ~71 g of uranium per L

• Power level ranges from 10 mW to 1000 MW

• Three operating modes
  – Single pulse
  – Free evolution
  – Steady State
Summary of experimental details (1)

- More details & pictures in ICNC 2011 paper
- Experiment 2
  - Single pulse, SILENE surrounded by lead reflector (shield)
  - Collimator A – unshielded
    - Full set of neutron activation foils
    - Valduc $\text{Al}_2\text{O}_3$, ORNL HBG & DXT TLDs
    - Rocky Flats CAAS
  - Collimator B – 20 cm standard concrete
    - Full set of neutron activation foils
    - Valduc $\text{Al}_2\text{O}_3$, ORNL HBG & DXT TLDs
    - Rocky Flats & CIDAS CAAS
Summary of experimental details (2)

- Free-field location
  - Full set of neutron activation foils
  - Valduc $\text{Al}_2\text{O}_3$, ORNL HBG & DXT TLDs
- Scattering Box (2 magnetite & 4 standard concrete shields)
  - Full set and 3 partial sets of neutron activation foils
  - 4 Valduc $\text{Al}_2\text{O}_3$, 2 ORNL HBG, and 2 ORNL DXT TLDs
  - Rocky Flats & CIDAS CAAS

- Experiment 3 modifications
  - Single pulse, SILENE surrounded by cadmium lined polyethylene reflector (shield)
  - Collimator B concrete replaced by 3” (7.62cm) of BoroBond
Photographs of experiments
Benchmark evaluation

• Also a joint effort between the US DOE and French CEA
  – ORNL is evaluating these benchmarks with SCALE and MCNP
  – LLNL is performing an evaluation with COG
  – Saclay is performing an evaluation with TRIPOLI

• High level overview of computational process
  – Perform an eigenvalue calculation and tally the spatial and energy dependence of the fission source
  – Complete any a priori variance reduction (source biasing, importance map/weight window generation, etc.)
  – Perform a fixed source transport calculation and tally the detector responses.
    OR
  – Perform an eigenvalue calculation and tally the detector responses.

• Cross sections & tally response functions
  – ENDF/B-VII.0 and JEFF-3.1.1, except IRDF-2002 for $^{115}\text{In}(n,n')^{115m}\text{In}$
  – ICRU air kerma factors for TLDs
### Comparisons between calculations and measurements for experiments 2 and 3

Comparison of computational and measured results for simulations of Collimator A

<table>
<thead>
<tr>
<th>Position</th>
<th>Reaction</th>
<th>SCALE 6.1</th>
<th>TRIPOLI-4®</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ratio: C/E</td>
<td>Relative Uncertainty (2 sigma)</td>
</tr>
<tr>
<td><strong>Experiment 2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collimator A</td>
<td>$^{59}$Co(n,γ)$^{60}$Co</td>
<td>1.16</td>
<td>4.62%</td>
</tr>
<tr>
<td></td>
<td>$^{197}$Au(n,γ)$^{198}$Au</td>
<td>1.21</td>
<td>3.59%</td>
</tr>
<tr>
<td></td>
<td>$^{115}$In(n,γ)$^{116m}$In</td>
<td>1.50</td>
<td>4.58%</td>
</tr>
<tr>
<td></td>
<td>$^{115}$In(n,n'γ)$^{115m}$In</td>
<td>0.94</td>
<td>3.75%</td>
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<tr>
<td><strong>Experiment 3</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Collimator A</td>
<td>$^{59}$Co(n,γ)$^{60}$Co</td>
<td>0.95</td>
<td>5.50%</td>
</tr>
<tr>
<td></td>
<td>$^{197}$Au(n,γ)$^{198}$Au</td>
<td>0.87</td>
<td>7.93%</td>
</tr>
<tr>
<td></td>
<td>$^{115}$In(n,γ)$^{116m}$In</td>
<td>1.14</td>
<td>5.97%</td>
</tr>
<tr>
<td></td>
<td>$^{115}$In(n,n'γ)$^{115m}$In</td>
<td>0.83</td>
<td>3.58%</td>
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</tbody>
</table>

### Notes
- Comparison in table only considers computational uncertainty and measurement uncertainty of foil activity
Comparisons between calculations and measurements for experiment 2

- Comparison in figure considers computational uncertainty, measurement uncertainty of foil activity, and uncertainty on number of fission events
Comparisons between calculations and measurements for experiment 3

- Comparison in figure considers computational uncertainty, measurement uncertainty of foil activity, and uncertainty on number of fission events
Summary and conclusions (1)

• The final measurement data for the 2010 SILENE CAAS benchmark experiments 2 and 3 is published in the conference paper

• Experiment 2 – SCALE and TRIPOLI results statistically the same and over predict measurements except for:
  – $^{115}\text{In}(n,n')^{115m}\text{In}$ & TLD – under predicts measurement
  – $^{115}\text{In}(n,\gamma)^{116}\text{In}$ & $[^{56}\text{Fe}(n,p)^{56}\text{Mn} + ^{56}\text{Mn}(n,\gamma)^{56}\text{Mn}]$ – not statistically the same

• Experiment 3 – SCALE and TRIPOLI results statistically the same and under predict measurements except for:
  – $^{115}\text{In}(n,\gamma)^{116}\text{In}$ – not statistically the same
Summary and conclusions (2)

• Issues needing further investigation before submission to the ICSBEP
  – CE TRIPOLI $^{115}\text{In}(n,\gamma)^{116}\text{In}$ results agree better with experiment, is SCALE group structure a problem
  – TLD response function
  – Uncertainty analysis for experiments 2 and 3
    • Stay tuned for uncertainty analysis for experiment 1 (Kevin Reynolds & Thomas Miller at 2:30)
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