Updates on:
IER 518 Joint Laboratory High-Multiplication Measurements
IER 153 Prompt Fission Uranium Neutron Spectrum (PFUNS)


DOE NCSP Technical Program Review, Feb. 2023, Albuquerque, NM
Outline

• IER 518 Joint laboratory high multiplication measurements
  – Background
  – Measurements at Sandia SPRF/CX facility
  – Results and preliminary data analysis
  – Continuing work

• IER 153 Prompt Fission Uranium Neutron Spectrum (PFUNS)
  – Background
  – Godiva IV preliminary measurements and results
  – Rocky Flats shells approach to critical and irradiations on Planet
  – Continuing work

• Questions
IER 518 Project Goals

- Gather list-mode (time-tagged) data for configurations exceeding 20-100 M
- Provide inter-comparison between LLNL, LANL, and IRSN detector systems on SNL assembly
- Overlap and extend previous subcritical M measurements
- Create fundamental physics benchmark greater than about M=20
  - None over a multiplication of about 20 published yet
IER 518 Project Goals

- Leverage existing experiment and detector systems to limit cost, etc.
  - LANL choice: NoMAD/MC-15 & SNAP-IV neutron detection system, added org. scint

- Leverage existing benchmark:
  - LCT-COMP-THERM-078 critical benchmark chosen, performed at the Sandia SPRF/CX facility on ‘7uPCX’ assembly
  - Loading pattern for LCT-COMP-THERM-078 chosen as basis for subcritical measurements
7uPCX reactor and detector systems

- Initial viability questions - where do we put the NoMAD, SNAP-IV? We’ve put them inside the core before in water (RPI), but not outside - Can we even get enough counts for good statistics? Lots of simulations answered the question: **Yes, and if the new source has arrived it would be even better!**

- **two detector systems per configuration measured** we accommodated *in-core* organic scintillator measurements (mini RAM-RODD), helps characterization efforts for other experiments and direct comparison for *ex-core* NoMAD analysis
Continuity of measurements between labs

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Rods</th>
<th>est. M</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>1</td>
<td>LANL IRSN LLNL</td>
</tr>
<tr>
<td>2</td>
<td>492</td>
<td>6</td>
<td>IRSN</td>
</tr>
<tr>
<td>3</td>
<td>564</td>
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<td>IRSN</td>
</tr>
<tr>
<td>4</td>
<td>664</td>
<td>10</td>
<td>LANL IRSN</td>
</tr>
<tr>
<td>5</td>
<td>844</td>
<td>20</td>
<td>LANL IRSN</td>
</tr>
<tr>
<td>6</td>
<td>948</td>
<td>42</td>
<td>LANL IRSN LLNL</td>
</tr>
<tr>
<td>7</td>
<td>1004</td>
<td>82</td>
<td>LANL IRSN LLNL</td>
</tr>
<tr>
<td>8</td>
<td>1032</td>
<td>163</td>
<td>LANL LLNL</td>
</tr>
<tr>
<td>9</td>
<td>1048</td>
<td>310</td>
<td>LANL LLNL</td>
</tr>
<tr>
<td>10</td>
<td>1056</td>
<td>672</td>
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</tr>
<tr>
<td>11</td>
<td>1058</td>
<td>895</td>
<td>LANL LLNL</td>
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</tbody>
</table>

Est. multiplication vs. measurement #

![Graph showing est. multiplication vs. measurement #]

February 22, 2022
Preliminary data analysis - NoMAD/SNAP IV detectors

- **Simple** fixed source simulation w/ MCNP model updated to include ‘as-measured’ positions for detectors/drywells etc.
- Trend moves from over predicted to under predicted counts as $M \uparrow$, PTRAC time-tagged simulation coming soon to compare measured moments, etc.
- Small changes at near-critical/high multiplication dramatically impact count rate, ’worst’ C/E at 0.64 is still decent!
Continuing work

• Comparison of simulated to the measured moments, Feynman-Y, Rossi-$\alpha$, etc for both the organic scintillators (4x) and NoMADs(4x)/SNAP-IV
• Comparison of neutron noise analysis using organic scintillator w/ pulse shape discrimination (PSD) to NoMAD $^3$He system
  – This effort may also aid characterization of system for MUSIC, EUCLID etc.
• Challenge: MCNP PTRAC simulation required for 1-to-1 comparison of NoMAD measurements is computationally intensive - high source strength, large amount of moderator between fuel and detectors
• Solutions: MCNP 6.3 updates allow parallelization of PTRAC routine, previously serialized
• Papers: ICNC (2): neutron noise analysis/results, MCNP6.3 PTRAC validation (Mike Rising), ANS Student Conference initial analysis
IER 518 acknowledgements

• Special thanks to: the SPRF/CX crew at Sandia National Labs - Beth Hanson, Patrick Ward, and Jason Soares, as well as Gary Harms
• LLNL for administrative, planning, etc.: Jesse Norris et al.
• the LANL measurement team and my student: Jesson Hutchinson, Rob Weldon, Geordie McKenzie, Mark Nelson, Eric Sorensen, and Tanner Heatherly (Oregon State University)
• Chris Romero for his instrumental assistance in designing the measurement apparatus
Experiment originally proposed in 2011 to reduce uncertainties in the prompt-fission neutron spectrum (PFNS) in $^{235}\text{U}$, especially above 5 MeV, using threshold neutron detectors/activation foils.

Critical experiment proposed to use the Rocky Flats HEU shells as source of neutrons
- designed such that the spectrum is as close to unperturbed $^{235}\text{U}$ PFNS as possible

By choosing materials with threshold reactions spanning the high energy region, spectral adjustment can be performed to infer an updated PFNS.

The data gathered can provide an integral validation of $^{235}\text{U}$ PFNS gathered during chi-nu experiment at LANSCE, potential help in updated PFNS evals.
**IRDFF threshold reactions**

- Goal is to be able to get favorable $\gamma$-counting statistics on very high energy threshold reactions - easier said than done!
- Challenge is that as neutron energy increases, neutron population at that energy drops by orders of magnitude
- Combined with low interaction probability, half-lives, high power is absolutely necessary
Preliminary Godiva IV irradiation

- Godiva IV served as a test platform prior to PFUNS Rocky Flats irradiations on Planet
- Exercise process of foil selection, retrieval, counting, and subsequent analysis to be used in the PFUNS experiment
- Validate activation foil prediction tools - crucial to the planning process to ensure sufficient statistics for Rocky Flats irradiations
Godiva IV test irradiation foil selection

- Foils chosen based on documentation and availability, International Reactor Dosimetry Fusion File (IRDFF) cross section, high E threshold reactions
- Recent IRDFF updates include more reactions in foils that benefit this work

<table>
<thead>
<tr>
<th>Foil material</th>
<th>mass (mg)</th>
<th>avail. IRDFF reactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold (Au)</td>
<td>126.8 ± 0.1</td>
<td>2</td>
</tr>
<tr>
<td>Cobalt (Co)</td>
<td>66.0 ± 0.1</td>
<td>3</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>141.3 ± 0.1</td>
<td>3</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>124.8 ± 0.1</td>
<td>5</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>281.1 ± 0.1</td>
<td>3</td>
</tr>
<tr>
<td>Titanium (Ti)</td>
<td>141.9 ± 0.1</td>
<td>7*</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>28.6 ± 0.1</td>
<td>1</td>
</tr>
<tr>
<td>Niobium (Nb)</td>
<td>298.2 ± 0.1</td>
<td>3</td>
</tr>
<tr>
<td>Molybdenum (Mo)</td>
<td>90.6 ± 0.1</td>
<td>1</td>
</tr>
</tbody>
</table>
Foil activation measured vs. predicted results

C/E results contain uncertainty: systematic, counting, and cross sections in FISPACT-II (not total uncertainty) avg. 0.70 ± 0.05 (minus outliers)

Predictions vs. Measured, March Godiva Test 250C Burst

- TENDL17
- ENDF-VIII

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February 22, 2022
Godiva IV spectral adjustment results with STAYSL_PNNL

- STAYSL_PNNL uses dosimetry data to adjust a well-informed guess \((a\ priori)\) to the most likely \((a\ posteriori)\) neutron spectrum using generalized linear least-squares approach.
- Fit below is from 15 IRDFF standard reactions, norm. \(\chi^2\) (fitness) = 0.84766
PFUNS Rocky Flats shells irradiations on Planet

- First: a short irradiation/calibration with 9 Nickel foils, 2 Gold, 1 Indium, and 1 Mn-Cu
- These foils correlate what is measured in the control room and the neutrons on foils - very important for newly built/measured systems
  - (1) Amps to fissions/sec or power and (2) Amp-sec to total fissions or neutron fluence on foils
- Data gives estimate of $4.1 \times 10^{18}$ fissions/Amp-sec
- 2 Gold foils within about 1%, 9 Nickel foils within about 3% of each other
- Second irradiation: uniform fluence b/w sample locations? Data showed: Yes!
- Plan to use over 20 foils for final irradiation(s)
Continuing work on PFUNS

- Presentation of Godiva IV work to international community at 17th Int. Symp. on Reactor Dosimetry (ISRD) in May
- Power supply and stepper motor controller successfully relocated in order to avoid rad damage - temp mod made permanent
- Continuing dose rate predictions for both (1) foil retrieval (2) electronics using information gathered from dosimetry during EUCLID experiment
  - Have worked collaboratively with colleagues in rad. prot. at LANL
- Steady-state Rocky Flats shells heat transfer simulations: time-dependent/transient from Bob Kimpland (NEN-2)
  - These simulations informed the first runs’ correlation of amps to fissions!
- Additional foils with Cd covers - helps with constraining the dosimetry informed spectral adjustment with STAYSL_PNNL
Acknowledgements

• NCERC is supported by the DOE Nuclear Criticality Safety Program (NCSP), funded and managed by the National Nuclear Security Administration for the Department of Energy.
What questions do you have for me?

Thank you for listening
Email: nhwhitman@lanl.gov
Supplemental

Example steady state calculation to determine excess reactivity needed

<table>
<thead>
<tr>
<th>Q (Watts)</th>
<th>Amps</th>
<th>$T_{i,1}$ (°C)</th>
<th>$T_{o,16}$ (°C)</th>
<th>$\Delta R$ ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>7.60E-07</td>
<td>353.8</td>
<td>336.2</td>
<td>0.17</td>
</tr>
<tr>
<td>200</td>
<td>1.50E-06</td>
<td>403.8</td>
<td>368.6</td>
<td>0.3</td>
</tr>
<tr>
<td>300</td>
<td>2.30E-06</td>
<td>449.4</td>
<td>396.6</td>
<td>0.42</td>
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<td>421.6</td>
<td>0.53</td>
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<tr>
<td>500</td>
<td>3.80E-06</td>
<td>532.4</td>
<td>444.3</td>
<td>0.63</td>
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<tr>
<td>600</td>
<td>4.60E-06</td>
<td>570.9</td>
<td>465.2</td>
<td>0.73</td>
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</tbody>
</table>
Supplemental

Example transient heating calculation

<table>
<thead>
<tr>
<th>Q (Watts)</th>
<th>Amps</th>
<th>$T_{i,1}(^\circ C)$</th>
<th>$T_{o,16}(^\circ C)$</th>
<th>$\Delta R$ ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5000 (1.4 hr)</td>
<td>334.3</td>
<td>322.2</td>
<td>0.11</td>
<td>2.05E+16</td>
</tr>
<tr>
<td>10000 (2.8 hr)</td>
<td>353.9</td>
<td>336.3</td>
<td>0.17</td>
<td>4.10E+16</td>
</tr>
<tr>
<td>20000 (5.6 hr)</td>
<td>366.7</td>
<td>345.2</td>
<td>0.2</td>
<td>8.20E+16</td>
</tr>
<tr>
<td>40000 (11.1 hr)</td>
<td>369.5</td>
<td>347.2</td>
<td>0.21</td>
<td>1.64E+17</td>
</tr>
</tbody>
</table>
Supplemental

Run 0

Notes:

- Indium - G rec.
- Nickel - G -> Indium, should have a darker appearance: Nickel is quite shiny.
- Same with Mn-Ca-F vs. Nickel F.
- Nickel - F + Gold - F go together with Nickel on top.
- Au - Au on bottom with Nickel on top.
Supplemental

Run 1

Notes:

- There are duplicate
  Indium marks designated
  "V" and "X". Please ensure
  that Indium -V with a dot
  goes into position 1 and
  Indium -X with a dot goes
  into position 3. The labels
  also include "dot" → 1.2
  if applicable.
- #1 position has Ni-C3d1
  Indium, place Ni-C3d1 on top.

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Indium Nickel Gold Manganese-copper alloy DU (U238) Zinc Iron Zirconium Niobium Cobalt Magnesium Titanium HEU (U235) Copper Yttrium Aluminum Molybdenum Tantalum Vanadium Silver