Fissile material experiments at the Device Assembly Facility

CVT Workshop – October 20, 2016

Michael Hamel\textsuperscript{1}, Pete Chapman\textsuperscript{2}, Michael Streicher\textsuperscript{1}

\textsuperscript{1}University of Michigan
\textsuperscript{2}North Carolina State University
Campaign objectives

• July 11-21, 2016, CVT and CNEC conducted experiments with Cat-I SNM at DAF for a second time

• Provided CVT and CNEC students, post-docs, and faculty with the opportunity to conduct hands-on experiments with Category I (weapons usable) special nuclear material (SNM)

• Included a neutron generator for active interrogation of HEU
Device Assembly Facility

- Located within the Nevada National Security Site, 90 minutes northwest of Las Vegas
- Operated by NSTec for the NNSA
- Houses the National Criticality Experiments Research Center
- Supports critical and subcritical measurements of WGPu, HEU, and Np
CVT campaign participants

• North Carolina State University
  – Prof. John Mattingly, Jonathan Mueller, Pete Chapman

• Princeton University
  – Prof. Alex Glaser, Sebastien Phillipe, Benjamin Reimold

• University of Illinois
  – Prof. Clair Sullivan, Mark Kamuda

• University of Michigan
  – Prof. Igor Jovanovic, Michael Streicher, Bennett Williams, Jason Nattress, Lazar Supic, Michael Hamel

• Oak Ridge National Laboratory
  – Jason Newby

• Los Alamos National Laboratory
  – Jesson Hutchinson, Donnette Lewis, et al.
Sources

- **SNM sources**
  - BeRP ball: 4.5-kg WGPu metal sphere
  - Thor core: 4.1-kg WGPu metal disk
  - Rocky Flats shells: 13.7-kg HEU metal shells
  - Neptunium: 6.1-kg metal sphere

- **Interrogating Sources**
  - AmLi
  - DD neutron generator
  - DT neutron generator
Instruments

- Neutron coded aperture imager (ORNL/SNL)
- Bubble detectors array (Princeton)
- NaI, CsI scintillators (Illinois)
- Dual particle imager (Michigan)
- One dimension transmission imager (Michigan)
- Polaris and Orion CZT imagers (Michigan)
Dual-particle imager

- Combined Compton and neutron scatter camera
- Two-plane design
  - Front Plane: EJ-309 liquid organic scintillators
  - Back Plane: EJ-309 and NaI(Tl)
- Separate neutron and photon signals
AmLi experiment

Top View

6.25×10^4 n/s AmLi in 1" lead pig

13.7 kg HEU

Aluminum table

116 cm

Dual-Particle Imager

Measurement time: 850 min

DPI

13.7-kg HEU
AmLi experiment

- Most neutron emitted by AmLi are less than 1.5 MeV
- Threshold of DPI ensures measured neutrons are from induced fission
DT experiments

Top View

Target

13.7 kg HEU

Aluminum table

Generator tube

28 cm

155 cm

Dual-Particle Imager

13.7-kg HEU

DPI

DT generator
DT experiments

- Generator emitted 14.1 MeV neutrons
- Operated at 300 Hz with a 10% duty cycle
- 333 μs pulse length
- Digitized start of veto signal and vetoed based on pulse arrival times
- 335,700 ns after start of pulse

<table>
<thead>
<tr>
<th>Neutrons per Second</th>
<th>No Veto</th>
<th>With Veto</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>698</td>
<td>0.0048</td>
</tr>
</tbody>
</table>
DT experiments

- DT Generator position

Graph:
- Counts per Second vs Time After Generator Trigger (ns)
- Inclination vs Azimuth (deg)
- HEU and HEU with poly moderator

Legend:
- Photons: HEU and poly
- Neutrons: HEU and poly
- Photons: No HEU
- Neutrons: No HEU
Identifying Fissile Assemblies in Fast Neutron Images
Neutron Coded Aperture Imager (NCAI)
2015 DAF Campaign Update

• Passive measurements of bare BeRP ball (WGPu)
• Used Time-Correlated Pulse-Height (TCPH) analysis to identify fissile assemblies
• Neutrons depositing more energy than predicted by their time-of-flight indicate fission chain reactions
2015 DAF Campaign Update

BeRP

$^{252}\text{Cf}$
2016 DAF Campaign

- Active measurements of Rocky Flats HEU shells
- AmLi, DD and DT generator drivers
- Used energy or time cuts to identify fissile assemblies
AmLi Sources

- 4x AmLi sources
- $\sim 10^5$ n/s
- Rocky Flats shells 1-24
- 15 hour run time
AmLi Sources

- No cuts needed
D-D Generator

- 300 Hz
- 10% duty cycle
- \( \sim 10^6 \) n/s
- Rocky Flats shells 1-24
- 100 minute run time
D-D Generator
D-D Generator Energy Cut ($E_{\text{dep}} > 2.75$ MeV)
D-T Generator

- 300 Hz
- 10% duty cycle
- $\sim 10^7$ n/s
- Rocky Flats shells 1-24
- 1 hour run time
D-T Generator

![Graph showing counts over time](image1)

![Heatmap showing position](image2)
D-T Generator Time Cut (t > 333 ns)
Fast Neutron Images of Fissile Assemblies

• 2016 DAF Campaign Conclusions
  – AmLi drivers may be used without cuts
  – D-D generators may be used with energy cuts
    • Best to operate in continuous mode
    • Some tritium still present
  – D-T generators may be used with time cuts
    • Must be used in pulse mode with veto

• Future Work
  – Perform simulations of 2015 DAF Campaign scenario to investigate lower bound of multiplication for which a TCPH-filtered image successfully identifies a multiplying assembly
“Black Box” Complete Source Characterization

Digital CZT array

\( \gamma, x\text{-ray} \)

\( n_{\text{fast}} \)

\( n_{\text{thermal}} \)
• Orion Prototype Digital CZT Array System
• Objects:
  – Rocky Flats Shells
  – BeRP Ball
  – Thor Core (2015)
  – Np Sphere (2016)
Rich Spectral Information Comparable with HPGe

Unique Thermal Neutron Signature!
Thor Core Measurement

Counts per minute per keV

Energy (keV)

Bare
Poly Sphere
Steel + Poly

Consortium for Verification Technology
Rich Spectral Information Comparable with HPGe

- Energy resolution sufficient to estimate $^{240}\text{Pu}$
- Use spectral data to identify shielding $^\text{U}$

![Graph showing spectral data for Bare HEU and Iron shielded HEU](image-url)
Spectral-Based Shielding Identification

Peak Ratios Combined Residuals

Compton Scattering

Mass Thickness, $\rho \times x$ (g / cm$^2$)

Z Number

0 5 10 15 20 25

0 5 10 15 20 25

Z Number

0 5 10 15 20 25

0 5 10 15 20 25

Mass Thickness, $\rho \times x$ (g / cm$^2$)
Final Shielding Identification Results

- Demonstrated on Pu, U, and Np sources
SNM Orientation through Gamma-ray Imaging

Consortium for Verification Technology
Fast Neutron Detection

- Nuclear recoil in high-Z materials generate very few electron-hole pairs
- Energy depositions less than 20 keVee are candidates
- Many experiments have confirmed fast neutron detection
  - See upcoming IEEE NSS conference
Fissile material experiments at the Device Assembly Facility

CVT Workshop – October 20, 2016

Michael Hamel\textsuperscript{1}, Pete Chapman\textsuperscript{2}, Michael Streicher\textsuperscript{1}

\textsuperscript{1}University of Michigan
\textsuperscript{2}North Carolina State University