SNAP-3 Response Function and Its Application

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Objectives

- Present a simple procedure for computing neutron detector response functions
  - Includes neutron interactions with surrounding environment in response function
  - Enables (within limits) complex problems to be approximated using simple transport models

- Test the detector response functions using a set of well-documented experiments (SNAP measurements of BeRP ball)

- Apply the detector response functions to solving an inverse transport problem
Experiment setup

• Source
  • Weapons-grade plutonium metal
  • Reflected by polyethylene

• Detectors
  • Neutron multiplicity counter
  • Gross neutron counter
  • High-resolution gamma spectrometer
Plutonium source

• BeRP ball
  • 4.5 kg $\alpha$-phase plutonium metal
  • 94% Pu-239 / 6% Pu-240

• Polyethylene reflectors
  • High-density polyethylene
  • Nesting spherical shells with total thickness 1.3, 2.5, 3.8, 7.6, and 15.2 cm
Neutron multiplicity counter (nPod)

- nPod multiplicity counter designed and built by LANL
- 0.5 m from BeRP ball

- The nPod uses fifteen 15”-long × 1”-diameter 10-atm He-3 proportional counters in two rows

- The counters are embedded in a polyethylene moderator block wrapped in cadmium
  - The moderator gives the nPod a fairly flat neutron response
  - The cadmium makes the nPod relatively insensitive to reflected neutrons
Gross neutron counter (SNAP)

- SNAP counter designed and built by LANL
- 1 m from BeRP ball

- The SNAP uses one 4”-long × 1”-diameter 10-atm He-3 proportional counter
  - The counter is embedded in a layered polyethylene / cadmium / polyethylene moderator
  - The moderator gives the SNAP a flat response vs. neutron energy

- The front polyethylene cover can be removed to gauge the “hardness” of the neutron spectrum
Response function calculations

- Response functions were calculated using MCNP5
- Point source with “flat” neutron spectrum
- Tallied (n, p) reaction rate in SNAP He-3 counter vs. source energy bin (F4 tally)
- Reaction rate divided source leakage current (F1 tally)

\[
\varepsilon(E_g) = \frac{V \int_{E_g}^{E_g+1} dE' \Sigma^{He3}_{(n,p)}(E') \phi(E')}{A \int_{E_g}^{E_g+1} dE' J(E')}
\]
Computed response functions
Structure in response functions

Cd absorption

Fe elastic scatter
Factors affecting response function

Response Function - Front Cover Off

(n,p) /source neutron energy

- w/ floor+NPOD+cart
- w/ floor+cart
- w/ floor+NPOD
- w/ floor
- SNAP Only

energy (MeV)
Factors affecting response function

Response Function - Front Cover On

- (n,p) / source neutron (MeV)
- (n,p) / source neutron vs. energy (MeV)

Legend:
- w/ floor+NPOD+cart
- w/ floor+cart
- w/ floor+NPOD
- w/ floor
- SNAP Only
Response function V&V

• The count rate can be estimated by folding the response function \( \epsilon \) with the leakage current \( J \)

\[
\epsilon(E_g) = \frac{V \int_{E_g}^{E_g+1} dE' \Sigma_{(n,p)}^{He3}(E') \phi(E')}{A \int_{E_g}^{E_g+1} dE' J(E')} = \frac{V \cdot R(E_g)}{A \cdot J(E_g)}
\]

\[
V \cdot R = \sum_{g=1}^{G} \epsilon(E_g) A \cdot J(E_g)
\]

• We verified the response functions against MCNP5 calculations with Cf-252 and the BeRP ball

• We also tested the response functions against measurements with Cf-252 and the BeRP ball
V&V results

<table>
<thead>
<tr>
<th>Source</th>
<th>SNAP Cover</th>
<th>Worst Case</th>
<th>Measured Response (cps)</th>
<th>MCNP5 F4 Tally</th>
<th>Response Function</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Calculated Response (cps)</td>
<td>Error</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Calculated Response (cps)</td>
<td>Error</td>
</tr>
<tr>
<td>Cf-252</td>
<td>Off</td>
<td>15.2 cm reflector</td>
<td>1.9</td>
<td>2.1</td>
<td>11.8%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>On</td>
<td>3.8 cm reflector</td>
<td>7.9</td>
<td>9.0</td>
<td>13.2%</td>
</tr>
<tr>
<td>BeRP Ball</td>
<td>Off</td>
<td>3.8 cm reflector</td>
<td>116.2</td>
<td>129.7</td>
<td>11.6%</td>
</tr>
<tr>
<td></td>
<td>On</td>
<td>3.8 cm reflector</td>
<td>68.7</td>
<td>75.7</td>
<td>10.2%</td>
</tr>
</tbody>
</table>

- MCNP5 F4 tally and response function calculations are similar
- Both over-predict measured response
- Response function error slightly higher than MCNP5 F4 tally
Application to inverse problem analysis

• Objective
  • Treat the reflected BeRP ball as an “unknown”
  • Estimate plutonium radius and poly thickness

• Approach
  • Compute neutron leakage current using simple 1D XSDRN model of poly-reflected Pu sphere
  • Calculate SNAP count rates by folding leakage current with detector response functions
  • Iteratively change Pu radius and poly thickness using mesh adaptive direct search (MADS)
  • Find Pu radius and poly thickness that minimizes error between calculation and measurement
Inverse problem solution using MADS

- MADS is a black-box optimization algorithm
  - Finds the XSDRN model that minimizes the error by iteratively changing the model dimensions

- Computes the error for several alternative solutions in a series of iterations
  - If a better solution is found in the current iteration, it coarsens the mesh around the current best solution
  - If no better solution is found, it refines the mesh about the previous best solution
MADS analysis

<table>
<thead>
<tr>
<th>Poly Reflector</th>
<th>Pu Radius (cm)</th>
<th>Poly Thickness (cm)</th>
<th>XSDRN Runs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual</td>
<td>Estimated</td>
<td>Actual</td>
</tr>
<tr>
<td>Bare</td>
<td>3.79</td>
<td>3.74</td>
<td>0</td>
</tr>
<tr>
<td>1.3 cm</td>
<td>3.75</td>
<td>1.24</td>
<td>1.10</td>
</tr>
<tr>
<td>2.5 cm</td>
<td>3.74</td>
<td>2.51</td>
<td>2.45</td>
</tr>
<tr>
<td>3.8 cm</td>
<td>3.75</td>
<td>3.78</td>
<td>3.54</td>
</tr>
<tr>
<td>7.6 cm</td>
<td>3.66</td>
<td>7.59</td>
<td>5.05</td>
</tr>
<tr>
<td>15.2 cm</td>
<td>2.92</td>
<td>15.21</td>
<td>3.54</td>
</tr>
</tbody>
</table>

- All cases started with an initial guess of (Pu radius, poly thickness) = (1 cm, 1 cm)
Summary

• We presented a relatively simple way to compute neutron detector response functions using MCNP5 flux (F4) and leakage current (F1) tallies
  • The response function can be calculated using models that include the surrounding environment
  • Allows the count rate to be estimated from the source leakage

• We tested the SNAP response functions against MCNP5 calculations and measurements with Cf-252 and the BeRP ball
  • Response function calculations tended to over-predict the measured count rates
  • Typical errors were 5% - 10%, but worst cases had errors ~15%

• We applied the response functions in a MADS analysis to infer the BeRP ball radius and poly thickness from the SNAP count rates
  • The inferred dimensions were fairly accurate except in the most highly reflected cases
  • SNAP has essentially no sensitivity below cadmium cutoff
  • For the thickest reflectors, the competing effects of neutron multiplication and parasitic absorption make the solution non-unique
References on MADS and applications

