Progress on Developing a Segmented Detector using ZnS:Ag/\(^{6}\)Li

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As part of a joint SNL/LLNL project to develop aboveground detector technology, we deployed a 4-cell prototype segmented scintillator system

- Aboveground shielded and unshielded runs in 2011
- Belowground deployment in 2012-2013

Very encouraged by performance of Segmented Scintillator prototype

- This technology is focused on reducing the overall footprint and enabling a transportable detector that can be deployed in high-background or unshielded locations
- Demonstrated rejection of backgrounds of 5 orders of magnitude even without an external shield
Individual Segments contain organic scintillator with ZnS:Ag/\(^6\)LiF screens on outer surface
- Tested cells with both plastic and liquid scintillator (plastic preferred)

Use of ZnS:Ag with \(^6\)LiF allows identification of neutron capture
- ZnS:Ag is sensitive to alpha from n-capture on Li
- Very slow scintillator time constant (~100ns) allows pulse shape discrimination to separate n-capture from \(\gamma\) events

This 4-cell prototype was intended for first testing background rejection only
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Particle Identification (PID)

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Positron Identification through Topology

- Positrons are rare in nature
  - Deposit most of their kinetic energy very quickly through standard ionization losses
- Positrons will annihilate into two back-to-back 511 keV gammas
  - Very distinctive signature
  - Gammas will travel ~2-5” through most scintillators

Liquid or Plastic scintillator

Neutron identification through Pulse Shape Discrimination (PSD)
Aboveground Data

Unshielded

No PID cuts
225,177 ev/day

Cut 1 = neutron PID only
2095 ev/day

Cut 2 = neutron PID + Loose positron topology
202 ev/day

Cut 3 = neutron PID + Strict positron topology
6 ev/day

Expectation ~ 0.5 ev/day (cut 3)

D. Reyna et al. INMM proceedings (2012)
### WLS Allows Extended Length

<table>
<thead>
<tr>
<th>Test Bar</th>
<th>Attenuation length</th>
<th>Normalized neutron efficiency §</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original grease coupled 60cm</td>
<td>35.6 ± 1.2 cm</td>
<td>10.1 ± 0.9 %</td>
</tr>
<tr>
<td>WLS, air gap, 60 cm</td>
<td>118 ± 7 cm</td>
<td>10.8 ± 0.9 %</td>
</tr>
<tr>
<td>WLS, air gap, 120 cm</td>
<td>154 ± 11 cm</td>
<td>12.6 ± 1.2 %</td>
</tr>
<tr>
<td>WLS, air gap, 180 cm</td>
<td>200 ± 20 cm</td>
<td>10.9 ± 1.1 %</td>
</tr>
</tbody>
</table>

§ Efficiency calculated relative to a calibrated $^3$He detector and normalized to detector area

More details can be found in Sweany et al, NIM A Volume 769, 1 January 2015, 37–43z
Simulated detector configurations
- Configurations of 3x3 to 11x11 (9 to 121 segments)
- WLS segments of 180 cm length
  - Position and energy smearing applied in post-processing
  - Low energy (100 keV) threshold applied for trigger

Simulation of fast neutron backgrounds
- Geant 4.10.1.p01 with QGSP_BERT_HP physics list
  - Older 4.9.5.p02 showed unphysical transitions in neutron spectra that made ~30% reduction in background events
- Cosmic neutron generator from Gordon et al. (2004)
  - Distributed azimuthally like muons

Simulation of antineutrino events
- Coincident positron and 200 keV neutron
- Uniformly distributed throughout
Gut-Check: Neutrons

Skin Depth:

- Neutron Captures in outer most segments
  - antinu: neutrons started at center
  - cosmic: pencil beam pointed at center

Rate normalized to total number of events

Suggests a neutron / e+ co-location cut will improve with size

Neutron Wander:

- Neutron Captures outside of e+ neighbors
  - antinu: uniformly distributed
  - cosmic: cosmogenic distribution

Rate normalized to total number of events
Gut-Check: Positrons

Number of events for which the annihilation gammas are not in the 8 surrounding segments from the identified core e+ deposition

- antinu: uniformly distributed
- cosmic: cosmogenic distribution

Rate normalized to total number of events

Suggests a full e+ topology cut will improve with size
Overall efficiency for uniformly distributed antineutrino events passing an event definition

Events with a neutron and single e+ deposition coincident in time

Events with a neutron and single e+ deposition coincident in time and within a 9-segment box

Events with a triple positron deposition (within 9 segments) coincident in time with a neutron that’s within a 9-segment box around the central e+ deposition

For large detectors, the most restrictive cut yields ~10% efficiency
Realistic Expectations

Expected Rates 25m from SONGS

Sanity Check

Approximate duplication of 50m deployment at SONGS

- 4-segments (60 cm)
- Reduced efficiency (non-WLS)
- No proximity selection

Cosmic: 7 events/day
Antinu: 1 events/day

Compares favorably with measured 6 events/day

Signal scales like mass but background rejection improves quicker
This technology appears to be robust and scalable
- Simulations agree with current measurements and confirm expectation that background rejection improves with size

A 20’ shipping container could be a functional system
- Contain 520 2m-long segments
- Total mass ~20 tons
- Overall efficiency ~10% ➞ ~ 2 tons “ideal”
  - Almost reach Huber’s “ideal 5t detector”
- Expected rates would be reasonable
  - Background rate ~400 events/day
  - Signal rate ~5 events/day/MW_{th} at 20m

Now we just need to build one and validate