Measurement of the Davis Cavern $\gamma$-ray background at the Sanford Underground Research Facility

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APS April Meeting
15/04/2018
Measurement of the $\gamma$-ray background at the Sanford Underground Research Facility

Sanford Underground Research Facility

1876 Homestake gold deposit discovered, mining begins

1960s Ray Davis – famous solar neutrino experiment

2003 Homestake closes

2011 Sanford Lab funded by DOE

LZ detector will go into same water tank that was used for LUX

1876

2003

4850 ft Cosmic muon flux reduced by $10^6$
The LZ Detector

Low Background Checklist

- Shielded from cosmic (underground)
- $\gamma$-shielding (water tank & steel pyramid)
- Neutron veto
- All materials screened
- Radon emanation measured
- Detector backgrounds quantified
- Physics backgrounds quantified (neutrinos, $^{136}$Xe $2\nu\beta\beta$)
- Cavern background quantified

6 m height
3.8 m radius
water tank

17 T gadolinium loaded liquid scintillator veto

120 Veto PMTs

494 PMTs

steel pyramid beneath tank

30 cm
Cavern Backgrounds in LZ

**Outer Detector**

Need to keep deadtime low for vetoing efficiency

Cavern rate thought to be ~100 Hz - dominant background in OD!

**LXe Detector**

Main impact is on $^{136}\text{Xe}$ $0\nu\beta\beta$ search

High energy $\gamma$ from $^{214}\text{Bi}$ ($^{238}\text{U}$ chain) and $^{208}\text{Tl}$ ($^{232}\text{Th}$ chain) chains can fall into signal region for $0\nu\beta\beta$ decay

Nebot-Guinot et al, "Backgrounds and sensitivity of the NEXT double beta decay experiment"
2 week campaign in October 2017 at SURF

Team (L-R)
- Luke Korley (brandeis)
- Melih Solmaz (UCSB)
- Me (UCSB)
- Umit Utku (UCL)
- Scott Haselschwardt (UCSB)

**Goal:** collect spectra from a variety of places in the Davis cavern
Use lead shielding to focus the measurement on different directions
Measurement of the $\gamma$-ray background at the Sanford Underground Research Facility

**NaI(Tl) Detector Measurement**

- **Scott inserting the detector into the downwards facing shielding**
- **Upwards facing shielding**
- **Luke having a rest from lifting lead**
- **Cleaning up!**

- **5 inch NaI Crystal**
- **PreAmp**
- **PMT**

- **Modeling some oversized PPE**

- **We also wore air monitors - no airborne lead particles detected!**
2 measurements outside tank:
- Upper Davis
- East Counting Room

7 measurements in tank:
- Centre unshielded
- Centre (downwards)
- Centre (upwards)
- Centre (east facing)
- Centre (west facing)
- Halfway to edge (downwards)
- Edge (downwards)
Measurement of the $\gamma$-ray background at the Sanford Underground Research Facility

Rates above 250 keV
- East Counting Room, unshielded. 610 ± 25 Hz
- Upper Davis, unshielded. 420 ± 20 Hz
- Centre, unshielded. 320 ± 18 Hz
- Centre, shielded, looking up: 119 ± 11 Hz
- Centre, shielded, looking east: 61 ± 8 Hz
- Centre, shielded, looking west: 53 ± 7 Hz
- South edge, shielded, looking down: 55 ± 7 Hz
- Halfway to south edge, shielded, looking down: 9 ± 3 Hz
- Centre, shielded, looking down: 9 ± 3 Hz

NaI $\gamma$-ray Spectra - All Measurements

- $^{40}$K 1.46 MeV
- $^{214}$Bi 1.78 MeV
- $^{208}$Tl 2.61 MeV
Cavern Materials

- Most of cavern thought to be **amphibolite**
- Extra-hot **rhyolite** intrusion passes through cavern, mostly on the floor and the west wall
- 12.7 cm (avg.) coating of **shotcrete** on walls & ceiling
- 0.5 ft of **concrete** on floor (1 ft in counting room)
- **Gravel** beneath water tank

Water tank gravel sample and shotcrete sample taken whilst on-site & sent for HPGe measurements

<table>
<thead>
<tr>
<th>Activities</th>
<th>K (Bq/kg)</th>
<th>U (Bq/kg)</th>
<th>Th (Bq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amphibolite</td>
<td>297.2</td>
<td>4.1</td>
<td>1.3</td>
</tr>
<tr>
<td>Rhyolite</td>
<td>1291.0</td>
<td>108.0</td>
<td>17.0</td>
</tr>
<tr>
<td>Shotcrete - low</td>
<td>170.3</td>
<td>18.8</td>
<td>8.8</td>
</tr>
<tr>
<td>Shotcrete - standard</td>
<td>380.8</td>
<td>24.7</td>
<td>13.6</td>
</tr>
<tr>
<td>Shotcrete - finish coat</td>
<td>244.6</td>
<td>20.0</td>
<td>12.5</td>
</tr>
<tr>
<td>Shotcrete</td>
<td>216.7</td>
<td>22.2 (early)</td>
<td>21.36 (late)</td>
</tr>
<tr>
<td>Gravel</td>
<td>35.0</td>
<td>22.2 (early)</td>
<td>26.3 (late)</td>
</tr>
</tbody>
</table>
Simulating the Cavern Background

Radioactive decays ($^{40}$K, $^{238}$U & $^{232}$Th chains) are simulated in a simple model of the cavern walls & energy deposits saved in the NaI crystal.

Custom geometry built within the BACCARAT package used for LZ simulations.
Fitting the Spectra

Centre of water tank, unshielded

Float concentrations of each isotope to match simulated peaks to data peaks

Data
Total fit
K 1.5 MeV peak
U 1.7 MeV peak
U 2.2 MeV peak
Th 2.6 MeV peak
K background
U background
Th background
## Rock Activities

<table>
<thead>
<tr>
<th>Activities</th>
<th>K (Bq/kg)</th>
<th>U (Bq/kg)</th>
<th>Th (Bq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservative estimates</td>
<td>716</td>
<td>73.4</td>
<td>26.1</td>
</tr>
<tr>
<td>Unshielded, centre</td>
<td>224</td>
<td>40</td>
<td>12.6</td>
</tr>
<tr>
<td>Unshielded, upper</td>
<td>127</td>
<td>32</td>
<td>8.5</td>
</tr>
<tr>
<td>Counting room</td>
<td>229</td>
<td>25</td>
<td>12.0</td>
</tr>
<tr>
<td>Looking Up, centre</td>
<td>184</td>
<td>72</td>
<td>10.6</td>
</tr>
<tr>
<td>Looking Down, edge</td>
<td>266</td>
<td>40</td>
<td>12.3</td>
</tr>
</tbody>
</table>

Normalization for sim differ with measurement position.

Simulation done with uniform activity in walls.

- this discrepancy may point towards a non-uniform distribution of activity
- Radioactive rhyolite intrusion covers some walls more than others

With these new activities, LZ Outer Detector cavern rate in range 20-29 Hz

No longer dominant background!

See S. Haselschwardt’s talk for other OD backgrounds, this session tomorrow
We measured the $\gamma$-ray background in the Davis cavern at SURF

- Cavern flux is considerably lower than previously thought
- Still pinning down distribution of radioactivity in cavern
- LZ Outer Detector Veto cavern $\gamma$ rate reduced from 91 Hz to <30 Hz
  - no longer the dominant background
- $0\nu\beta\beta$ decay background expectation from $\gamma$ reduce > 5x

And finally...
Conclusions

★ We measured the γ-ray background in the Davis cavern at SURF
★ Cavern flux is considerably lower than previously thought
★ Still pinning down distribution of radioactivity in cavern
★ LZ Outer Detector Veto cavern γ rate reduced from 91 Hz to <30 Hz
  ★ no longer the dominant background
★ 0νββ decay background expectation from γ reduce > 5x

And finally...
★ We provided proof that floppy disks are still useful for science!

World’s first transfer of data from a Windows 97 laptop 4850 ft underground → floppy disk → USB → USBC→MacBook?
Thanks to...

UCSB: Scott Haselschwardt, Harry Nelson, Melih Solmaz

LBNL: Kevin Lesko, Andy Cole

Brandeis: Luke Korley, Bjoern Penning

UCL: Umit Utku, Cham Ghag

School of Mines: Doug Tiedt

SURF: John Keefner, Mark Hanhardt

Penn State: David Woodward

Amazon Prime (for delivering USB Floppy disk reader to Lead, South Dakota in record time)
Backup
"The variation of the γ-ray flux at different locations on the same level depends on the variation of the rock formations and the radioactivity levels in the rock. This variation can be as large as 30% as seen in the measurements. This is to say that the γ-ray flux must be measured in the experimental area where a low-background experiment is to be located."

We took data for the east counting room in approximately the same location.

Data from blue spectrum used to obtain sim normalisations in the top row of the table on slide 12.
LS Screener Measurement

(S. Haselschwardt's talk tomorrow)

LS Screener detector measured an external $\gamma$-ray rate ~7x lower than expected at top of water tank.

Important because rate is concentrated at top and bottom of OD tanks (least water shielding).

Sim normalisations clearly too high - based off older HPGe measurement intended for use as upper limit.