Fast Neutron Background Measurements in Deep Underground Labs

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Why neutrons?
Neutrons, like WIMPs, induce nr’s, therefore they are the most dangerous background.

Neutrons from rock produced by:
1. Spontaneous fission (mainly $^{238}\text{U}$)
2. ($\alpha,n$) reactions due to U, Th traces

Why direct measurements?
Measurements of U, Th concentration:
- mass-spectroscopy
- Ge detector
  can not give accurate results
  Exact composition of the rock not known accurately
Pyhäsalmi mine, 4050 mwe for CUPP project

Combined detector, surrounded by a Pb castle:

- LS (~NE 213), 30 litre

- 19 $^3$He proportional counters ($^3$He + 4% Ar at 4 atm)

Detection Signature:

- light flash in LS + capture in the n counter

$^3$He(n,p)$^4$He with $E_p = 574$ keV, $E_t = 191$ keV
Energy calibrations

LS with a $^{60}\text{Co}$ gamma source (10% uncertainty)
$^{3}\text{He}$ counters with a Pu-Be neutron source (1% uncertainty)

Efficiency of detecting neutrons

$$\varepsilon(E_0) = (20 \pm 1)\% \cdot E_0$$

Neutron Calibration

$$t_{\text{delay}} = 50 \pm 2 \mu\text{s}$$
Measurements performed during 2002

Results

Neutron background at different levels of the Pyhäsalmi mine, $10^{-7}\text{cm}^{-2}\text{s}^{-1}$
Measurements performed during 2002

<table>
<thead>
<tr>
<th>Energy</th>
<th>Energy released region (neutron scale), MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 – 1.5</td>
</tr>
<tr>
<td>Efficiency</td>
<td>0.16 ± 0.03</td>
</tr>
<tr>
<td>400 m</td>
<td>26.1 ± 1.7</td>
</tr>
<tr>
<td>660 m</td>
<td>20.8 ± 1.6</td>
</tr>
<tr>
<td>900 m</td>
<td>37.5 ± 1.7</td>
</tr>
<tr>
<td>1440 m</td>
<td>42.2 ± 5.0</td>
</tr>
</tbody>
</table>

High concentrations of U, Th in the decorative granite powder covering the walls
Modane Lab, 4800 mwe

Prepared by E. Yakushev
(DLNP, Joint Institute for Nuclear Research, Dubna, Russia)
All measurements performed by EDELWEISS collaboration

Previous measurement

Astroparticle Physics 9 (1998) 163-172

Detector: $^6$Li loaded LS surrounded by Pb+ Cu

Detection Signature:
pr (as prompt) + capture on $^6$Li (delay)

8 months n-bg data, rate = 1.15/d
5 months with n-shielding (paraf), rate = 0.38/day
Flux = $1.6 \cdot 10^{-6}$/cm$^2$s for E > 2 MeV (revised 2001 value)
Today measurements

Detector: 4 low background $^3$He proportional counters placed inside of PE moderator

Detection Signature: thermalised neutron capture $^3$He(n,p)$^t$

Continuous monitoring of neutron flux from July 2006
- Counting rate: ~160 cpd
- Signal to alpha background in ROI: better than 100:1
- Signal to own neutron background: better than 50:1

2 $\sigma$ level of variations:
- 16% daily,
- 6% weekly,
- 3% monthly

Efficiency: 10-15% for 0.1-2 MeV decreases to ~2% for 20 MeV

Flux = soon (multiply positions in the LSM)
Future measurements

- **Aim:**
  study of neutron background having a cosmogenic origin

- **Detector:**
  a neutron detector (maybe Gd-loaded LS) in coincidence with EDELWEISS experiment muon veto system

- **Status:**
  R&D
Canfranc Lab, 2450 mwe


IGEX-DM

Detector: Ge 2.2 kg surrounded by Pb + PVC + Cadmium + muon veto (plastic sci) + n moderator (PE + borated water)
## Data sets

### Background counts/(kgkeVday)

<table>
<thead>
<tr>
<th>Data sets</th>
<th>Canfranc 4 – 10 keV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness of moderator (cm)</td>
<td>A: 0, B: 20, C: 40, D: 80</td>
</tr>
<tr>
<td>Time (days)</td>
<td>17, 118, 97, 41</td>
</tr>
<tr>
<td>Background counts/(kgkeVday)</td>
<td>A: 0.74(6), B: 0.39(2), C: 0.22(1), D: 0.24(2)</td>
</tr>
</tbody>
</table>

A, C, D have exactly the same set-up

B has slightly different shielding
Flux = \( (3.82 \pm 0.44) \times 10^{-6} \) cm\(^{-2}\)s\(^{-1}\)

\[\text{Canfranc}\]

Simulated vs experimental data

\[\exp = A - C\]

\text{sim} with GEANT4 assuming that either all of them have a fission spectrum or that they come from \((\alpha,n)\) reactions
LNGS, 3950 mwe
Measurement carried out in collaboration between LNGS ILIAS-JRA1 and ICARUS groups

Purposes:

• Measurement of the spectrum and intensity of the neutron flux (fast component) by means of LS counters (~ 4 l) and PSD techniques

• This activity is mainly focused on the evaluation of possible fluctuations with time of the neutron intensity

• Identification of the physical correlation with environmental parameters

March 2006 installation of a Pb shield (8 mm) to reduce the stochastic contribution induced by gamma background
**Data taking**

- From 15 March 2006 data have been acquired continuously.
- Up to now ~ $2 \times 10^9$ triggers have been recorded and ~ 700 neutron interactions have been identified ($E > 3.5$ MeV).
- The stability of the system has been regularly monitored both by means of $\gamma$-source calibrations and by means of internal calibrations based on measurement of a-lines produced by the LS radioactive contaminants.

**Data analysis**

- The recorded data frequencies are:
  - $5 \times 10^6$ interactions per day
  - $1 \times 10^3$ interactions per day selected by hardware PSD
  - $5 \times 10^2$ interactions per day selected by software PSD
- Considering that the contribution to the rate due to stochastic events and radioactive impurities above 3.5 MeV (energy proton equivalent) are negligible, we have:
  - 2 interactions (neutrons) per day $E > 3.5$ MeV
- This frequency is compatible with a background neutron field of about $10^{-7}$ cm$^{-2}$ s$^{-1}$ as previously measured in the LNGS lab.
The presence of fluctuations of the counting rate beyond the statistical fluctuation is evident in the data taking.

Identification of the physical correlation with environmental parameters, such as the rock moisture, ground water level and pressure ... is in progress.

**Conclusions - Perspectives**

- In March 2007 a year of data taking will be reached
- The collected data will be enough to perform an evaluation of possible fluctuations with time of the neutron intensity within a 1yr cycle
- A cross-check with data collected in absence of the external neutron field could be useful → polyethylene shield

Example of dependence with time of the neutron counting rate (neutron interactions per month) as recorded by one cell in the LNGS lab.
Detector: Gd-loaded LS

Detection Principle:

pr (prompt) + capture (delay)

Captures on Gd, H, stainless steel ...

\[ n_{\text{thermal}} + A \rightarrow (A+1)^* \rightarrow (A+1) + \gamma's \]
Neutron Calibration – $^{252}$Cf
Energy spectra - Time delay distribution

$\tau = 84 \pm 5 \mu s$

$^{60}$Co with coincidences
Sources of Background

Afterpulses from PMTs

Correlated background: $^{238}\text{U} \rightarrow ^{214}\text{Bi} \rightarrow ^{214}\text{Po} \rightarrow ^{210}\text{Pb}$

$0.35 < E < 2 \text{ MeV}$

$^{214}\text{Po}$:
$t_{1/2} = 164 \mu s$

$\tau = \frac{164}{\ln(2)}$

$\tau = 237 \mu s$

Pulse shape analysis

0.8 MeV (7.68 MeV) expected at 0.96 MeV
Time delay distribution of the neutron background

February - June 2005
unshielded run

July - October 2005
shielded run

rate = 1.85 ± 0.65 d⁻¹
for E > 0.05 MeV
Simulations of Cf source and bg (U, Th)

Energy of proton recoils
Simulation vs Data

Cf
Source $\rightarrow$ Shielding $\rightarrow$
Target $\rightarrow$ Detector

Bg (U + Th)
Rock $\rightarrow$ Lab boundary $\rightarrow$
Shielding $\rightarrow$ Target $\rightarrow$
Detector

R. Lemrani et al. NIMA, 560 (2006) 454: agreement on neutron propagation between GEANT4 and MCNPX
Simulated Proton Recoils \textbf{Cf against Bg (U, Th)}

Efficiency of detecting coincidences:
(including efficiency of tail/total cut)

\[
\frac{\text{measur coinc rate}}{\text{sim single rate}} = 0.023 \pm 0.002
\]

\[
\frac{\text{measur coinc rate}}{\text{measur single rate}} = 0.024 \pm 0.003
\]
<table>
<thead>
<tr>
<th>Sources of Systematic Uncertainties</th>
<th>Rel. Syst. Unc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge to energy conversion + quenching factor</td>
<td>0.10</td>
</tr>
<tr>
<td>Fit to the time delay distribution for Cf run</td>
<td>0.08</td>
</tr>
<tr>
<td>Difference between neutron spectra from Cf and bg</td>
<td>0.11</td>
</tr>
<tr>
<td>Difference between measured and simulated recoil rates</td>
<td>0.14</td>
</tr>
<tr>
<td><strong>Total systematic uncertainty</strong></td>
<td><strong>0.22</strong></td>
</tr>
</tbody>
</table>
Flux of fast neutrons

Flux (E > 0.5 MeV) \( n \text{ cm}^{-2}\text{s}^{-1} \)

at outer surface of shielding:
\[(1.72 \pm 0.61 \pm 0.38) \times 10^{-6} \]

at rock - lab boundary:
\[(1.14 \pm 0.40 \pm 0.25) \times 10^{-6} \]

increase by 51 %

including backscattering: +50%, E > 1 MeV

(R.Lemrani et al. NIMA, 560 (2006) 454)
Concentration of U and Th in rock

Assumptions ...

1. Equal concentrations:  \( 127 \pm 45 \text{(stat)} \pm 28 \text{(syst)} \) ppb U and Th

2. Twice Th:  \( 95 \pm 34 \text{(stat)} \pm 21 \text{(syst)} \) ppb U,  \( 190 \pm 69 \text{(stat)} \pm 42 \text{(syst)} \) ppb Th

Published concentrations with Ge detector:

\( 67 \pm 6 \) ppb U,  \( 127 \pm 10 \) ppb Th
## Conclusions

<table>
<thead>
<tr>
<th>Underground Lab</th>
<th>fast neutron flux, ( n \text{ cm}^{-2}\text{s}^{-1} ) (from radioactivity in the rock)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyhäsalmi</td>
<td>((1.05 \pm 0.24) \times 10^{-6}) for (1.5 &lt; E &lt; 3) MeV</td>
</tr>
<tr>
<td>Modane</td>
<td>(1.6 \times 10^{-6}) for (E &gt; 2) MeV (2001)</td>
</tr>
<tr>
<td></td>
<td>new results are coming ...</td>
</tr>
<tr>
<td>Canfranc</td>
<td>((3.82 \pm 0.44) \times 10^{-6})</td>
</tr>
<tr>
<td>LNGS</td>
<td>(~10^{-7}) for (E &gt; 3.5) MeV ... work in progress ...</td>
</tr>
<tr>
<td></td>
<td>H.Wulandari, Astroparticle Physics 22 (2004) 313</td>
</tr>
<tr>
<td>Boulby</td>
<td>((1.72 \pm 0.61\text{(stat)} \pm 0.38\text{(syst)}) \times 10^{-6}) for (E &gt; 0.5) MeV</td>
</tr>
</tbody>
</table>
Acknowledgements

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Gloria Luzon
Chiara Vignoli

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