Fast neutron background measurement in CJPL

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Detector introduction

Neutron background measurement in CJPL

Intrinsic U/Th/Ac contamination calculation

Quenching factor of EJ-335 calculation

Neutron spectrum unfolding
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The structure of the detector

- liquid scintillator: 28.27 L EJ-335 doping with 0.5% gadolinium
- container: quartz glass with size of Φ30 × 40 cm
- copper shell: 3 mm thickness cylinder
- lead shielding: 5 cm thickness
DAQ system
Parameters definition

\[ Q = \sqrt{Q_{\text{total left}} \cdot Q_{\text{total right}}} \quad \text{Dis} = \frac{Q_{\text{part left}} + Q_{\text{part right}}}{Q_{\text{total left}} + Q_{\text{total right}}} \]
Energy calibration

**Graph 1:**
- **$^{60}$Co**
- **$^{137}$Cs**

**Graph 2:**
- **$^{137}$Cs**

**Graph 3:**
- **$^{60}$Co**
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The position of the detector in CJPL

- The detector was running in CJPL hall from October, 2013 to February, 2015 with 8971 kg · day lively data.
- The detector have been located in CJPL polythene(PE) room since February, 2015.
• Fast-slow coincident method has been used to select the neutron events.
• The $\gamma$ events which energy higher than 3.0 MeV has been selected as the slow signal.
Time interval distribution between fast and slow signals

\[ T = 7.63 \pm 0.52 \ \mu s \]

- Only the events that satisfy \( 2 \mu s < \Delta t < 30 \mu s \) has been selected.
Random coincident events

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![Graph showing energy distribution](image1.png)

**Energy slice of 0.6-.0.7 MeVee**

- **Gamma**
- **Neutron**

![Graph showing energy distribution](image2.png)
# Preliminary results of fast neutron flux in CJPL

<table>
<thead>
<tr>
<th>data set</th>
<th>$^{252}$Cf</th>
<th>CJPL hall</th>
<th>CJPL PE room</th>
</tr>
</thead>
<tbody>
<tr>
<td>raw counts</td>
<td>$4.09 \times 10^6$</td>
<td>$8.59 \times 10^8$</td>
<td></td>
</tr>
<tr>
<td>exclude noise</td>
<td>$\lambda<a href="%25">\Pi\lambda</a>, \epsilon(%)$</td>
<td>$98.79[98.79], 100$</td>
<td>$99.85[99.85], 100$</td>
</tr>
<tr>
<td>$\gamma &gt; 3.0$MeV</td>
<td>$\lambda<a href="%25">\Pi\lambda</a>, \epsilon(%)$</td>
<td>$14.60[14.42], -$</td>
<td>$0.0447[0.0446], -$</td>
</tr>
<tr>
<td>PSD selection for $\gamma$ (slow signal)</td>
<td>$\lambda<a href="%25">\Pi\lambda</a>, \epsilon(%)$</td>
<td>$96.86[13.97], 97.72$</td>
<td>$100[0.0446], 100$</td>
</tr>
<tr>
<td>neutron threshold 0.23MeVee (equivalent 1 MeV neutron energy)</td>
<td>$\lambda<a href="%25">\Pi\lambda</a>, \epsilon(%)$</td>
<td>$84.50[11.80], -$</td>
<td>$85.41[0.038], -$</td>
</tr>
<tr>
<td>$\Delta t$ selection (2-30$\mu$s)</td>
<td>$\lambda<a href="%25">\Pi\lambda</a>, \epsilon(%)$</td>
<td>$47.86[5.65], -$</td>
<td>$0.938[0.00036], -$</td>
</tr>
<tr>
<td>exclude random coincidence</td>
<td>$\lambda<a href="%25">\Pi\lambda</a>, \epsilon(%)$</td>
<td>$77.50[4.38], 100$</td>
<td>$86.78[0.00031], 100$</td>
</tr>
<tr>
<td>efficiency correction of PSD</td>
<td>$183,334 \pm 456$</td>
<td>$2666 \pm 78$</td>
<td>$66 \pm 8$</td>
</tr>
<tr>
<td>neutron passed the detector</td>
<td>$(6.10 \pm 0.61) \times 10^6$</td>
<td>$(8.89 \pm 0.93) \times 10^4$</td>
<td>$(2.20 \pm 0.35) \times 10^3$</td>
</tr>
<tr>
<td>lively time</td>
<td>$8.2144 \times 10^4 s$</td>
<td>$356.37 d$</td>
<td>$130.47 d$</td>
</tr>
<tr>
<td>detection efficiency(%)</td>
<td>$3.00 \pm 0.30$</td>
<td>$5183.63$</td>
<td></td>
</tr>
<tr>
<td>detector cross section$(cm^2)$</td>
<td>$5183.63$</td>
<td>$5183.63$</td>
<td></td>
</tr>
<tr>
<td>neutron flux at detector$(n cm^{-2}s^{-1})$</td>
<td>$(0.56 \pm 0.06) \times 10^{-6}$</td>
<td>$(0.38 \pm 0.06) \times 10^{-7}$</td>
<td></td>
</tr>
</tbody>
</table>

$\lambda(\%)$ and $\Pi\lambda(\%)$ are the individual and cumulative background survival fraction respectively, and $\epsilon\%$ is the candidate signal efficiency.
Fast neutron flux compare with other underground lab.

- **CJPL hall:** $(0.56 \pm 0.06) \times 10^{-6} \text{ } n \text{ } cm^{-2}s^{-1}$ from 1MeV to 10 MeV
- **Canfranc:** $(0.65 \pm 0.02) \times 10^{-6} \text{ } n \text{ } cm^{-2}s^{-1}$ from 1MeV to 10 MeV
- **Gran Sasso:** $(0.60 \pm 0.07) \times 10^{-6} \text{ } n \text{ } cm^{-2}s^{-1}$ from 1MeV to 10 MeV
- **Boulby:** $(1.72 \pm 0.61(\text{stat.}) \pm 0.38(\text{syst.})) \times 10^{-6} \text{ } n \text{ } cm^{-2}s^{-1}$ above 0.5 MeV
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Decay sequences selection

- **Thorium series**
  \[ ^{212}Bi \xrightarrow{\beta^-} ^{212}Po, \quad Q=2.25\,\text{MeV} \]

- **Uranium series**
  \[ ^{214}Bi \xrightarrow{\beta^-} ^{214}Po, \quad Q=3.27\,\text{MeV} \]

- **Actinium series**
  \[ ^{219}Rn \xrightarrow{\alpha(3.96s)} ^{215}Po, \quad Q=6.95\,\text{MeV} \]
Time interval distribution of Cascade decays

\[ ^{212}\text{Po} \quad \tau_{1/2} = 312 \pm 14 \text{ ns} \]

\[ ^{214}\text{Po} \quad \tau_{1/2} = 164.5 \pm 1.6 \text{ \(\mu\)s} \]

\[ ^{215}\text{Po} \quad \tau_{1/2} = 1.77 \pm 0.02 \text{ ms} \]
# Measurement activity of the intrinsic U/Th/Ac

## half life and alpha particle energy

<table>
<thead>
<tr>
<th>Decay sequence</th>
<th>Measured half life</th>
<th>Nominal half life</th>
<th>Measured alpha energy (MeVee)</th>
<th>Nominal alpha energy (MeVee)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thorium: $^{212}$Bi → $^{212}$Po</td>
<td>312 ± 14 ns</td>
<td>299 ns</td>
<td>$^{212}$Po: 1.07 ± 0.09</td>
<td>8.96</td>
</tr>
<tr>
<td>Uranium: $^{214}$Bi → $^{214}$Po</td>
<td>164.5 ± 1.6 µs</td>
<td>164.3 µs</td>
<td>$^{214}$Po: 0.87 ± 0.07</td>
<td>7.83</td>
</tr>
<tr>
<td>Actinium: $^{219}$Rn → $^{215}$Po</td>
<td>1.77 ± 0.02 ms</td>
<td>1.78 ms</td>
<td>$^{215}$Po: 0.76 ± 0.07</td>
<td>7.53</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$^{219}$Rn: 0.66 ± 0.06</td>
<td>6.95</td>
</tr>
</tbody>
</table>

## activity of the intrinsic U/Th/Ac

<table>
<thead>
<tr>
<th>Decay sequence</th>
<th>Measured activity (mBq kg$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thorium: $^{212}$Bi → $^{212}$Po</td>
<td>0.144 ± 0.004</td>
</tr>
<tr>
<td>Uranium: $^{214}$Bi → $^{214}$Po</td>
<td>1.78 ± 0.01</td>
</tr>
<tr>
<td>Actinium: $^{219}$Rn → $^{215}$Po</td>
<td>0.861 ± 0.009</td>
</tr>
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1. Stopping power calculated by TRIM

\[ k_B = 7.25 \text{ mg/(cm}^2 \cdot \text{MeV)} \]

2. Alpha particle quenching factor in EJ-335


Typical formula: \( E_{ee} = 0.2E^{1.53} \)

Birks theory has been used for this calculation:

\[ E_{ee} = \int_0^E \frac{dE}{1 + k_B \left( \frac{dE}{dX} \right)} \]
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SAND-II method to unfold the spectrum

\[
\Phi_i^{j+1} = \Phi_i^j \exp \left( \frac{\sum_{k=1}^{K} W_{ik}^j \ln \left( \frac{N_k}{\sum_{i=1}^{I} R_{ki} \Phi_i^j \Delta E_i} \right)}{\sum_{k=1}^{K} W_{ik}^j} \right)
\]

\( j = 1, 2, \ldots, J, \)

\( \Phi_i^0 \) : initial spectrum

\( \Phi_i^J \) : unfolding result

\( R_{ki} \) : response function

J: iterate times

Geant4 has been used to simulate the response function
Neutron spectrum unfolding

AmBe neutron source recoil spectrum
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Neutron spectrum unfolding

Neutron spectrum unfolding

![Neutron spectrum unfolding graph](image)

AmBe neutron source recoil spectrum

![AmBe neutron source recoil spectrum graph](image)

AmBe spectrum unfolding result
Neutron spectrum unfolding

AmBe neutron source recoil spectrum

CJPL hall neutron recoil spectrum

AmBe spectrum unfolding result
Neutron spectrum unfolding

AmBe neutron source recoil spectrum

CJPL hall neutron recoil spectrum

AmBe spectrum unfolding result

CJPL neutron spectrum unfolding result
Summary

- The fast neutron flux (preliminary result) in CJPL had been measured to be $(0.56 \pm 0.06) \times 10^{-6}$ $n \ cm^{-2}s^{-1}$ in the hall, and $(0.38 \pm 0.06) \times 10^{-7}$ $n \ cm^{-2}s^{-1}$ in the polythene room.
- The intrinsic contamination of Thorium, Uranium and Actinium have been calculated.
- The kB constant had been determined to be $7.25 \ mg/(cm^2 \cdot MeV)$, and then we calculated the quenching factor of EJ-335 liquid scintillator.
- The neutron spectrum in CJPL hall had been unfolded.