CdWO₄ crystal in KamLAND for neutrino-less double beta decay research

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2. Test measurement with CdWO₄ crystal
3. Deployment of CdWO₄ crystal in KamLAND detector
4. Summary

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1. Introduction

KamLAND detector
(before KamLAND-zen)

1,000m

13m

KamLAND detector (before KamLAND-zen)

1,879 PMTs
In total
(17inch & 20inch)

Pseudo
cumene
dodecane

PPO

1,000m

Water
(3.2kton)

(225 20inch PMTs)

1kton

(1kton)

1800m³

Plastic Balloon

Mineral Oil

Liquid Scintillator

1879 PMTs
In total
(17inch & 20inch)

PMT

PMT

Water
(3.2kton)

13m

Pseudo
cumene
dodecane

PPO

1,000m

Water
(3.2kton)

(225 20inch PMTs)
KamLAND for double beta decay measurement

- the radioactivity level inside the detector is very low
  - $^{238}\text{U} \times 10^{-19} \text{[g/g]}$
  - $^{232}\text{Th} \times 10^{-17} \text{[g/g]}$
  - $^{40}\text{K} < 1.5 \text{[μBq/m}^3]\text{]}

- The detector is capable of dissolving double beta decay material into Liquid Scintillator (KamLAND-zen), or putting solid material inside the KamLAND balloon.

-$^{116}\text{Cd}$ crystal in KamLAND is one of those options.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Q-value [MeV]</th>
<th>Abundance [%]</th>
<th>$2\nu$ half life (yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{48}\text{Ca}$</td>
<td>4.27</td>
<td>0.19</td>
<td>$4.2 \times 10^{19}$</td>
</tr>
<tr>
<td>$^{150}\text{Nd}$</td>
<td>3.37</td>
<td>5.6</td>
<td>$7.8 \times 10^{18}$</td>
</tr>
<tr>
<td>$^{96}\text{Zr}$</td>
<td>3.35</td>
<td>2.8</td>
<td>$2 \times 10^{19}$</td>
</tr>
<tr>
<td>$^{100}\text{Mo}$</td>
<td>3.03</td>
<td>9.6</td>
<td>$7.1 \times 10^{18}$</td>
</tr>
<tr>
<td>$^{82}\text{Se}$</td>
<td>3</td>
<td>9.2</td>
<td>$9.2 \times 10^{19}$</td>
</tr>
<tr>
<td>$^{116}\text{Cd}$</td>
<td>2.8</td>
<td>7.5</td>
<td>$2.9 \times 10^{19}$</td>
</tr>
<tr>
<td>$^{130}\text{Te}$</td>
<td>2.53</td>
<td>34</td>
<td>$0.9 \times 10^{21}$</td>
</tr>
<tr>
<td>$^{136}\text{Xe}$</td>
<td>2.47</td>
<td>8.9</td>
<td>$2.1 \times 10^{21}$</td>
</tr>
<tr>
<td>$^{124}\text{Sn}$</td>
<td>2.29</td>
<td>5.79</td>
<td>$&gt;1 \times 10^{17}$</td>
</tr>
<tr>
<td>$^{76}\text{Ge}$</td>
<td>2.04</td>
<td>7.8</td>
<td>$1.5 \times 10^{21}$</td>
</tr>
</tbody>
</table>
CdWO₄ crystal

- Property of CdWO₄ crystal

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>7.9 g/cm³</td>
</tr>
<tr>
<td>Melting point</td>
<td>1598 K</td>
</tr>
<tr>
<td>Hygroscopicity</td>
<td>absent</td>
</tr>
<tr>
<td>Chemically inert</td>
<td>inert</td>
</tr>
<tr>
<td>Max Emission Spectrum</td>
<td>470-540 nm</td>
</tr>
<tr>
<td>Refractive index</td>
<td>2.3</td>
</tr>
<tr>
<td>Light yield</td>
<td>~ 40% to NaI</td>
</tr>
<tr>
<td>Radio purity</td>
<td>&lt; 10 μBq/kg</td>
</tr>
<tr>
<td>X₀</td>
<td>1.11 cm</td>
</tr>
<tr>
<td>λ</td>
<td>21.7 cm</td>
</tr>
<tr>
<td>Timing</td>
<td>88.7% - 14.5 μsec</td>
</tr>
<tr>
<td></td>
<td>8.7% - 4.6 μsec</td>
</tr>
<tr>
<td></td>
<td>2.1% - 0.8 μsec</td>
</tr>
<tr>
<td></td>
<td>0.5% - 0.15 μsec</td>
</tr>
</tbody>
</table>

For example: L.Bardelli at all, nucl-ex/0608004v1, August 2006
Past double beta decay experiment with CdWO$_4$ crystal

- Solotvina Underground Laboratory (1000 meters of equivalent)
- Four CdW$_4$O$_4$ crystals build with enriched up to 83% (Natural – 7.49%)
- Crystals mass – 330g $\rightarrow$ $^{116}$Cd mass is 87 g.
- Crystals were viewed by 55 cm long light guide and background 5" EMI PMT
- Active shielding made of natural, CdW04, plastic scintillators
- Passive shielding: high purity cooper 3-6 cm, Lead 22.5-30 cm and 16 cm Polyethylene
- Cosmic veto: two plastic scintillators (120*130*3 cm) installed above passive shield

$T^{2\nu}_{1/2} = [2.9 \pm 0.06\text{ (stat)}]^{+0.4}_{-0.3}\text{ (sys)} \cdot 10^{19}$ yr was obtained
Test measurement of CdWO₄’s scintillation signal

- Natural CdWO₄ crystal (column shape)
  - Diameter = 39.65mm, height = 40.00mm
  - Total mass = 390g
  - $^{116}$Cd mass = 9.4g

Record waveforms with a digital scope and store them in computer with following later analysis.
Waveforms recorded by a digital oscilloscope were summed.

From the area of the waveform, 2300 p.e. @1MeV was obtained.

Consistent with the past measurement nucl-ex/0608004v1, August 2006
Energy spectrum of $^{60}$Co source

Resolution $\delta$:
- for 1.17 MeV 3.28%
- for 1.33 MeV 2.97%
3. Installation of CdWO₄ crystal in KamLAND

Put the Cd crystal in the center position using a calibration source deployment system (MiniCAL).

Measurement was done with Cd crystal and ⁶⁰Co source, with Cd crystal only, and with nothing inside the balloon other than LS.
To measure scintillation light from Cd Crystal, front-end electronics continue taking data for more than a few tens of micro second.

Signals are processed by two types of electronics.

* **KamFEE**: 30μs is needed to digitize waveform
* **MoGURA**: dead time free new electronics. Not covered all PMTs.

-> MoGURA was used for the detection of signals from Cd crystal
**Expected timing distribution of hits**

**LS signal**
- Event Rate: ~ 80 Hz (@Th = 120 NHITs)
- HIT Distribution: ~ 100 nsec
- NHITs: ~ 200 HIT/MeV (for 17°)

**Dark signal**
- Dark Rate: ~ 1.5 HIT/CLK

**Crystal signal**
- Event Rate: ~ Hz
- Decay Constant: ~ 14.5 usec
- Light Emission: ~ 15 k photons/MeV
- Visible p.e.: ~ 500 p.e./MeV
- HITs: ~ 1.9 HIT at the 1st CLK @ 2.8 MeV
- ~ 0.69 HIT at the 1st CLK @ 1.1 MeV

"scintillation decay signal of similar CdWO4 crystal"

L. Bardelli et al., NIMA 569 (2006) 743–753
New trigger logic for Cd signal

Hit accumulation Window length for trigger:
Normal run -> 120ns
Cd trigger -> 7 micro sec
Hit distribution in one event

Raw Data

Remove a peak (hits/bin > 200) and fit an exponential curve to the data

Fitting curve: \( f(t) = \text{amplitude} \times \exp(-t/\text{decaytime}) + \text{baseline} \)
Two peaks in Amplitude distribution
b.g. events tend to take decay time of around 22us
Muon subtraction

Comparing the Cd-triggered events with the FBE electronics data, we can subtract the muon. Then higher peaks can be removed.

Example of Hit distribution after muon event

<table>
<thead>
<tr>
<th>Time from muon [μs]</th>
<th># of hits / bin</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10^0</td>
</tr>
<tr>
<td>20</td>
<td>10^1</td>
</tr>
<tr>
<td>40</td>
<td>10^2</td>
</tr>
<tr>
<td>60</td>
<td>10^3</td>
</tr>
<tr>
<td>80</td>
<td>10^4</td>
</tr>
<tr>
<td>100</td>
<td>10^5</td>
</tr>
</tbody>
</table>

After pulses after muon event mimic Cd signals.

Comparing the Cd-triggered events with the FBE electronics data, we can subtract the muon. Then higher peaks can be removed.
Cd crystal and $^{60}$Co source run

Red: CdWO$_4$ + $^{60}$Co run
Black: background run

Decay time is Larger than 14us

Due to Co 1gamma
Rough estimation of the Resolution

Integrate “$f(t) = \text{amplitude} \times \exp(-t/\text{decaytime}) + \text{baseline}$” and obtain # of hits.

Black: with Co+Cd, threshold = 475 hits/7us
Red: with Co+Cd, Lth = 490 hits/7us

Increase the trigger threshold

FWHM of the peak is broad.

Black: with Co+Cd, threshold = 475 hits/7us
Red: with Co+Cd, Lth = 490 hits/7us
4. Summary

* Natural CdWO₄ crystal was prepared and the property of scintillation light was measured.
  * Crystal was directly connected with PMT and about 3% energy resolution @ 1MeV was obtained.

* CdWO₄ crystal was deployed in KamLAND together with ⁶⁰Co source.
  * new Trigger logic detected Cd scintillation signals
  * Obtained peak from ⁶⁰Co’s one gamma ray was rather broad.
  * To investigate the result further, detailed simulation or measurement with other sources will be needed.