Surface purity control during XMASS detector refurbishment

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LRT2015, Seattle
XMASS experiment

XMASS

Multi purpose low-background and low-energy threshold experiment with liquid Xenon

- Xenon detector for Weakly Interacting MASSive Particles (dark matter search)
- Xenon MASSive detector for solar neutrino (pp/\(^7\)Be)
- Xenon neutrino MASS detector (\(\beta\beta\) decay)

Purpose of the first phase is the dark matter search.

history of XMASS

<table>
<thead>
<tr>
<th>Year</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
</table>

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XMASS detector

- Outer detector (water tank)
  - 72 20-inch PMTs for cosmic-ray muon veto.
  - Water is also passive shield for gamma-ray and neutron from rock/wall.
- Inner detector (Liquid Xe)
  - Liquid Xe surrounded by 642 2-inch PMTs
    - photo coverage: 62%
    - diameter: ~800mm
    - high light yield: 14.7PE/keV

Radioactivity in LXe

<table>
<thead>
<tr>
<th></th>
<th>mBq/detector</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{222}\text{Rn}$</td>
<td>$8.2 \pm 0.5$</td>
</tr>
<tr>
<td>$^{220}\text{Rn}$</td>
<td>&lt;0.28</td>
</tr>
<tr>
<td>Kr</td>
<td>&lt;2.7ppt</td>
</tr>
</tbody>
</table>

PMT radioactivity

<table>
<thead>
<tr>
<th></th>
<th>mBq/PMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{214}\text{Pb},  ^{214}\text{Bi}$ (U-chain)</td>
<td>$0.70 \pm 0.28$</td>
</tr>
<tr>
<td>Th-chain</td>
<td>$1.5 \pm 0.31$</td>
</tr>
<tr>
<td>$^{40}\text{K}$</td>
<td>&lt;5.1</td>
</tr>
<tr>
<td>$^{60}\text{Co}$</td>
<td>$2.9 \pm 0.16$</td>
</tr>
</tbody>
</table>

NIM A716, 78-85, (2013)

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Detector refurbishment (RFB)

- We found RIs (210Pb, 238U) in the Aluminum sealing part of PMT (secular equiv. broken).
- Background events at the blind corner of PMT are often misidentified as events in the fiducial volume.
- To reduce this background, new structures to cover this Al seal were installed.

**Before RFB**

**Cu Plate**

**After RFB**

**Cu Ring**

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surface activity control

• PMT
  – sink and wipe using HNO3 (~70% reduction is expected from the measurement.)
  – packed using EVOH bag and anti-static bag.

• Copper
  – Newly made from OFCH and soon make surface plate to reduce the cosmogenics.
  – electro-polished (20μm) in the clean room.
  – packed using EVOH bag and anti-static bag
  – assembled in the clean environment
Radon concentration in the water tank is ~1/200 of atmosphere.
We clean up not only the water tank, but also experimental hall to reduce the dust from outside.
To keep CLASS 10 level during PMT and cable assembly work, we introduced 8 ULPA filter FFUs.
During the night, to reduce the radon concentration further more, the detector was purged by N2/pure air.

Radon concentration: ~50Bq/m³
Radon concentration: ~0.2Bq/m³
Radon free air is purged ~10m³/hr
radon concentration in RFB

- radon concentration in the water tank is $\sim 0.1 \text{Bq/m}^3$ (1/200 of atmosphere) during detector assembly.
Dust level during RFB

Dust in the experimental hall has large 210Pb contamination (412±96mBq/g by Ge measurement)

Two order of magnitude reduction by various effort. After the reduction, class 1000 level

Even in the dirty period, class 10 level.

dust (>0.5μm) in experimental hall

dust (>0.5μm) in clean booth in the water tank
Improvement by RFB

- In addition to one order of magnitude reduction in >5keVee, huge background event can be reduced to ~1/10 with simple identification using max PE (maximum PE in one PMT) / total PE.
- Detail analysis is ongoing.

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surface background after RFB

maxPE: Large
2ndmaxPE/maxPE < 1

maxPE: small
2ndmaxPE/maxPE ~ 1

Cu plate surface (0.726m²):
1.09 ± 0.88 (sys) ± 0.04 (stat) mBq
Sys. err: Energy resolution

PMT surface:
6.42 ± 0.45 (sys) ± 0.13 (stat) mBq
Sys. err: Uncertainty of contribution of Po218 and Rn222 from Rn in LXe.

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What causes the remaining copper surface activity?

If the activity is Pb210,

- EP solution (<0.43mBq/g -> <0.088mBq/10um in thick remaining)
- bag emanation: <0.1mBq
- No dust by eye (cf. dust at experimental hall (412 ± 96mBq/g))
- accumulation in the detector assembly-> expected two orders of magnitude smaller
- (plate, M1 screw (copper, SUS), gap)
- etacohol (<0.61mBq/g)
- tools? glove?

The reason is not clear. Most of these numbers are obtained from Ge measurement. However, Ge detector is not so sensitive to Pb210. We need lower background detector.
Low background alpha-counter (XIA Ultra-Lo-1800)

We have installed it at clean room in Kamioka underground IPMU Lab to understand the surface background in Jan. 2015.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>&gt;90% of 2pi</td>
</tr>
<tr>
<td>Energy resolution</td>
<td>&lt;9% FWHM at 4.6MeV</td>
</tr>
<tr>
<td>Energy range</td>
<td>1-10MeV</td>
</tr>
<tr>
<td>Sample size</td>
<td>707 (φ30cm disk)-1800cm² (42cm*42cm)</td>
</tr>
<tr>
<td>Maximum sample weight</td>
<td>9kg</td>
</tr>
<tr>
<td>Maximum sample thickness</td>
<td>6.3mm</td>
</tr>
<tr>
<td>Achievable background level</td>
<td>10^{-4}alpha/cm²/hr</td>
</tr>
</tbody>
</table>
alpha counter status and plan

12.2 days data

current background level: 
\[(1.4 \pm 0.3) \times 10^{-4} \text{ alpha/cm}^2/\text{hr} \sim 0.8 \text{ mBq/m}^2\] (measured using low background copper disk)

- understand the mechanism of surface accumulation
  - which decay?
  - ambient dependence (electric field, humidity, etc)
  - material dependence
- ion removal
  - develop daughter ion removal device (radon removal is expensive. Cheap and easy to use)
- environment to minimize the surface accumulation
  - how to (bag, air)
  - wear, glove, etc
- surface accumulation measurement
  - We will try to reduce \(<10^{-5} \text{ alpha/cm}^2/\text{hr} (56\mu\text{Bq/m}^2)\) for future detector R&D.
Larger detectors have many advantages. 1t FV (5t total).
- target sensitivity is $\sigma_{\text{SI}} < 10^{-46}$ cm$^2$ for 100 GeV WIMPs
- Detector design is ongoing
  - PMT
    - We can use U-free Al in hand.
    - New PMTs being developed help to identify surface events.
  - Surface BG must be controlled.

Red arrows: track of scintillation photons
backup
Kamioka mine

KamLAND
Super-K
CANDLES
XMASS
Lab2/EGad

IPMU Lab1
NEWAGE
CLIO

To: Atotsu mine entrance
~1000m underneath Mt. Ikenoyama
### XMASS collaboration

<table>
<thead>
<tr>
<th>Institute</th>
<th>Collaborators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kavli IPMU, University of Tokyo</td>
<td>J. Liu, K. Martens, Y. Suzuki</td>
</tr>
<tr>
<td>Kobe University</td>
<td>R. Fujita, K. Hosokawa, K. Miuchi, Y. Ohnishi, N. Oka, Y. Takeuchi</td>
</tr>
<tr>
<td>Tokai University</td>
<td>K. Nishijima</td>
</tr>
<tr>
<td>Gifu University</td>
<td>S. Tasaka</td>
</tr>
<tr>
<td>Yokohama National University</td>
<td>S. Nakamura</td>
</tr>
<tr>
<td>Miyagi University of Education</td>
<td>Y. Fukuda</td>
</tr>
<tr>
<td>STEL, Nagoya University</td>
<td>Y. Itow, R. Kegasa, K. Kobayashi, K. Masuda, H. Takiya</td>
</tr>
<tr>
<td>Sejong University</td>
<td>N.Y. Kim, Y. D. Kim</td>
</tr>
<tr>
<td>KRISS</td>
<td>Y. H. Kim, M. K. Lee, K. B. Lee, J. S. Lee</td>
</tr>
</tbody>
</table>

10 institutes, 39 collaborators
Calibration system

**RI sources**

<table>
<thead>
<tr>
<th></th>
<th>energy [keV]</th>
<th>RI</th>
<th>φ [mm]</th>
<th>package</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Fe-55</td>
<td>5.9</td>
<td>350</td>
<td>brass</td>
</tr>
<tr>
<td>2</td>
<td>Cd-109</td>
<td>22, 25, 88</td>
<td>800</td>
<td>brass</td>
</tr>
<tr>
<td>3</td>
<td>Am-241</td>
<td>59.5</td>
<td>485</td>
<td>SUS</td>
</tr>
<tr>
<td>4</td>
<td>Co-57</td>
<td>122</td>
<td>100</td>
<td>SUS</td>
</tr>
</tbody>
</table>

Source rod

Source introduce machine

Top PMT moving machine

Gate valve

Xenon gas area

~5m
Detector response for a point-like source (~WIMPs)

- $^{57}$Co source @ center gives a typical response of the detector.
- $13.9 \text{p.e./keV}_{ee}$ ($\cong 2.2$ for S1 in XENON100)
- The pe dist. well as vertex dist. were reproduced by a simulation well.
--- result from commissioning run ---

1. Search for light WIMPs

- 6.7 days x 835 kg
- 0.3 keVee threshold

2. Search for solar axions

- Axions can be produced in the sun by bremsstrahlung and Compton effect, and detected by axio-electric effect in XMASS.
- Used the same data set as the light WIMPs search.

Bremsstrahlung and Compton effect

Axio-electric effect

--- result from commissioning run ---
3. Search for $^{129}\text{Xe}$ inelastic scattering by WIMPs

- $\chi + ^{129}\text{Xe} \rightarrow \chi + ^{129}\text{Xe}^*$
- $^{129}\text{Xe}^* \rightarrow ^{129}\text{Xe} + \gamma (39.6\text{keV})$
- Natural abundance of $^{129}\text{Xe}$: 26.4%

Signal MC for 50GeV WIMP data (165.9 days)

Red: XMASS (90% C.L. stat. only)
Pink band: XMASS (w/ sys. error)
Black: DAMA LXe 2000 (90% C.L.)

Background level is $\sim 3 \times 10^{-4}\text{count/sec/kev/kg.}$

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The remaining event rate \((O(10^{-4})/\text{day/kg/keV}_{\text{ee}})\), the lowest ever achieved, is in good agreement w/ expected BG from 214Pb w/ keeping > 50% signal efficiency.
Decay Constant vs Energy

Error = +1.5ns-0ns

NEST (Eye scan on Page 41 NEST plot)

deviation @Co is:
35.47-34.11 = 1.36 [ns]

Takiya Line:
23.95 + 0.08324E [ns]

distribution Am w/ and w/o HV apply data is
30.53 - 28.96 = 1.57 [ns]
$^{222}\text{Rn}$

$^{214}\text{Po}$ decays with 164 $\mu$s half life.

It can be identified by time coincidence between two consecutive events:
1. $^{214}\text{Bi} \beta$ decays into $^{214}\text{Po}$
2. $^{214}\text{Po} \alpha$ decays into $^{210}\text{Pb}$

Tail due to saturation

$p_0 \times \exp(-t/\tau) + p_1$, $\tau$: decay constant

$1^{\text{st}}$ event ($^{214}\text{Bi} \beta$)
$2^{\text{nd}}$ event ($^{214}\text{Po} \alpha$)

8.2±0.5 mBq

Events

$\chi^2 / \text{ndf} = 42.43 / 42$
$p_0 = 116.7 \pm 4.8$
$p_1 = -0.2216 \pm 0.4773$

Number of photoelectrons

Events

Time difference [\mu s]

Number of photoelectrons

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