The Status of AMoRE Double Beta Decay Experiment

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Introduction: AMoRE

• AMoRE: Advanced Mo-based Rare process Experiment
• Search for neutrinoless double beta decay using Molybdenum-100 based scintillation crystals

• Molybdenum-100: high Q-value (3034 keV), high natural abundance (~9.7 %) and relatively short half-life expected in theoretical calculation
Introduction: AMoRE

|                      | AMoRE-Pilot | AMoRE-I     | AMoRE-II    |
|----------------------|-------------|-------------|-------------|
| **Mass [kg]**        | 1.9         | ~6.1        | ~200        |
| **Channels**         | 12          | 36          | ~1000       |
| **BKG goal [ckky]**  | 0.01        | 0.001       | 0.0001      |
| **Sensitivity [year]** | ~10^{24}  | ~10^{25}    | ~5×10^{26}  |
| **Sensitivity [meV]** | 380 to 640 | 120 to 200  | 17 to 29    |
| **Location**         | Y2L         | Y2L         | Yemilab     |
| **schedule**         | 2017 to 2018| 2019~       | 2021~       |
Introduction: Y2L

Yangyang Underground Laboratory (Y2L)

YangYang Pumped Storage Power Plant

KIMS/COSINE (Dark Matter Search)
AMoRE (Double Beta Decay Experiment)

Minimum depth: 700 m / Access to the lab by car (~2km)
Introduction: Detector

- Detector

Scintillating crystal
- $^{48}\text{Ca}^{100}\text{MoO}_4$
- $^{100}\text{Mo}$ enriched: > 95 %
- $^{48}\text{Ca}$ depleted: < 0.001 %

MMC & SQUID
- MMC: Metallic Magnetic Calorimeter
- Magnetization changes with temperature
- Magnetization change (flux) can be measured as a voltage by SQUID

Detection process:
**Energy** → Temperature → Magnetization → Magnetic flux → **Voltage signal**
Shield & Muon counters

Muon candidate ~2000 /day

Total: 10 panels & 28 PMTs (w/o bottom)
DAQ

- FADC for CMO detectors
  - 18-bit resolution
  - input: 10 Vpp
  - continuous data taking
- SADC for muon counters
  - 64 MHz ADC
- TCB
  - timing resolution: ~7 ns
Analysis: waveform parameters

Phonon channel parameter
- Pulse height (RAW / filtered)

Phonon channel parameters
- Pulse height (RAW / filtered)
- Rise-time
- Mean-time
- Fall-time

Particle identification parameters
- Rise-time
- Light/Heat ratio
Particle identification: $\beta/\gamma$ selection

- For the $\beta/\gamma$ selection, the following selection functions were applied:
  
  \[
  t_{\text{rise}} = p_1 \exp\left(\frac{E}{p_2}\right) + p_3 E + p_4 \quad \text{for Risetime (}t_{\text{rise}}\text{)}
  \]
  \[
  R_{L/H} = p_1 \exp\left(\frac{E}{p_2}\right) + p_3 \quad \text{for L/H ratio (}R_{L/H}\text{)}
  \]

Gamma event can be selected by risetime & L/H ratio function (red line).
\( \alpha \) tagging

\[
\begin{align*}
\text{36\% } \alpha\text{-decay} & \quad \text{Q-value } = 6.21 \text{ MeV} \\
T_{1/2} = 60.6 \text{ min} & \quad \text{64\% } \beta\text{-decay} \\
& \quad \text{Q-value } = 2.25 \text{ MeV} \\
212\text{Bi} & \quad T_{1/2} = 0.299 \mu\text{s} \\
212\text{Po} & \quad \alpha\text{-decay} \\
& \quad \text{Q-value } = 8.95 \text{ MeV} \\
208\text{Tl} & \quad \beta\text{-decay} \\
& \quad \text{Q-value } = 5.00 \text{ MeV} \\
208\text{Pb} & \\
\end{align*}
\]

Reject the event within 15 minute window after the alpha tagging.

Image source: Thorium SVG image by Wikipedia contributor BatesIsBack.
Detector improvements during AMoRE-Pilot

• Improvement between setup 1 to 2
  - High background components were removed / moved away from the crystals
    (Pin connector, PCB, sensor holder, ...)

• Improvement between setup 2 to 3
  - Neutron shields were added
    (boric acid powder, Borated PE & PE blocks)
Background

| Range [MeV] | Setup 1 [ckky] | Setup 2 [ckky] | Setup 3 [ckky] | Reduction [%] |
|-------------|----------------|----------------|----------------|---------------|
| 2.8 to 3.2  | 0.456±0.131    | 0.171±0.080    | 0.143±0.088    | ~69           |
| 3.2 to 8    | 0.062±0.014    | 0.050±0.013    | 0.007±0.006    | ~89           |
Background & simulation

Setup 1 data & simulation with a likelihood fit

The analysis for other setups are in progress
Physics results

• Latest result of AMoRE-pilot

Using setup1 data, we obtained:
- \( T_{1/2}^{0\nu} > 9.5 \times 10^{22} \text{ y (90 \% C.L.)} \)
- \( m_{\beta\beta} < 1.2 - 2.1 \text{ eV} \)

To be updated: using all AMoRE-Pilot data
Next phases: AMoRE-I

- AMoRE-I preparation is ongoing
  - Crystals
    - 18 crystals (13 CMOs and 5 LMOs, $^{100}$Mo enriched)
    - Total mass $\sim$6.1 kg
  - Passive shields
    - 20 cm inner lead shield (5 cm increase)
    - Boric acid silicon rubber surrounding outer vacuum chamber
    - 3 cm borated PE & 30 cm PE blocks
  - Muon counter
    - 10 more muon counters will cover bottom and upper gap
  - DAQ upgrade
    - less noise level
Next phases: AMoRE-II

- Will be installed in Yemilab (~1000 m overburden)
- $^{100}\text{Mo}$ based crystals ~200 kg ($^{100}\text{Mo}$ net mass ~ 100 kg)
- Dimension: 1000 (D) × 1950 (H) mm
- Detector temperature ~ 10 mK

Mt. Yemi (EL 998m)

2. Men-riding cage (600 m long)
3. The New Underground Laboratory
4. Surface office

1. Access Tunnel
782 m long

Yemilab in Jeongseon, Korea
Summary

• AMoRE is to search for neutrinoless double beta decay using $^{100}$Mo-based scintillating crystals.

• From Aug. 2017 to Dec. 2018, we conducted AMoRE-Pilot data measurements (with ~2 kg of $^{48}$Ca$^{100}$MoO$_4$) for about 1.5 years.

• The detector configuration was changed twice to reduce background.

• The background was reduced by 69% (89%) in the energy interval 2.8-3.2 MeV (3.2-8 MeV).

• Background simulation being updated using all the data.

• Preparation of AMoRE-I is in progress (installation will begin this month).

• AMoRE-II will be installed in Yemilab with ~200 kg.
Backup
Detector constructions

• Difference between Setup 1 & 2

Kapton-based flexible PCB

- Total Thickness: 115 ± 5μm
- Roll size: 250/500m x 100m

Copper foil: MITSUI ED 1oz (35μm)
Adhesive: HANWHAFL Exadex-free Adhesive (10μm)
Polyamide film: SKCZKOLON (25μm)
Adhesive: HANWHAFL Exadex-free Adhesive (10μm)
Copper foil: MITSUI ED 1oz (35μm)

No pin connector near the detectors
Sensor holder design, screws and reflectors changed

Components that make high background have been removed / moved out
Detector constructions

• Difference between Setup 2 & 3
  - neutron shielding installed

Inside of lead box
  (Boric acid powder)

Outside of detector
  (Borated PE & PE)
Particle identification: $\alpha$ selection

• For the $\alpha$ selection, there are no distinguishable low energy peaks (below 4 MeV).

• So alpha like events were selected using both of separation parameters (RT & LH ratio).
\( \beta/\gamma \) distribution comparison (1)

- Events **from 2.8 MeV to 3.2 MeV** were used for background comparison.
### β/γ distribution comparison (2)

| 2.8 to 3.2 | Setup 1 [ckky] | Setup 2 [ckky] | Setup 3 [ckky] | Reduction [%] |
|------------|----------------|----------------|----------------|---------------|
| SB28       | 0.279±0.114 (6)| .              | .              |               |
| S35        | 0.376±0.133 (8)| 0.046±0.046 (1)| 0.089±0.089 (1)| 76.33         |
| SS68       | 0.406±0.109 (14)| 0.115±0.082 (2)| .              |               |
| SE01       | 0.402±0.152 (7)| 0.233±0.095 (6)| .              |               |
| SB29       | 0.589±0.139 (18)| .              | .              |               |
| SE02       | 0.682±0.142 (23)| 0.289±0.097 (9)| 0.157±0.079 (4)| 76.98         |
| **Average** | **0.456±0.131**| **0.171±0.079**| **0.123±0.084**| **73.03**     |

| 3.2 to 8.0 | Setup 1 [ckky] | Setup 2 [ckky] | Setup 3 [ckky] | Reduction [%] |
|------------|----------------|----------------|----------------|---------------|
| SB28       | 0.066±0.016 (17)| .              | .              |               |
| S35        | 0.047±0.014 (12)| 0.023±0.009 (6)| 0.007±0.007 (1)| 85.11         |
| SS68       | 0.077±0.014 (32)| 0.043±0.014 (9)| .              |               |
| SE01       | 0.048±0.015 (10)| 0.068±0.015 (21)| .              |               |
| SB29       | 0.057±0.013 (21)| .              | .              |               |
| SE02       | 0.079±0.014 (32)| 0.067±0.013 (25)| 0.007±0.005 (2)| 91.14         |