

Status of AMoRE

Yoomin Oh

On behalf of the AMoRE Collaboration

Center for Underground Physics, Institute for Basic Science (CUP/IBS), Daejeon 34126, Korea

E-mail: yoomin@ibs.re.kr

Abstract. AMoRE is to search for neutrinoless double beta decay using Mo-100 enriched crystal scintillators at an ultra-low temperature. We have understood the major background sources and how they can be reduced from a pilot stage run in the Yangyang underground laboratory. AMoRE-I is currently running with twelve $^{48\text{depl}}\text{Ca}^{100}\text{MoO}_4$ and five $\text{Li}_2^{100}\text{MoO}_4$ crystals with a total mass of enriched ^{100}Mo 2.8 kg. The detector design for the main stage of the experiment, AMoRE-II, has been finalized and the detector is under construction in YemiLab, a new underground laboratory located in an iron mine with an average depth 2500 meter of water equivalent.

1. Introduction

Discovery of the neutrinoless double beta ($0\nu\beta\beta$) decay can answer the long-lasting questions on the absolute mass scale and the possible Majorana nature of the neutrino [1, 2]. The experimental search for $0\nu\beta\beta$ is highly challenging due to its rarity and by the background contamination in the energy range of interest. Molybdenum-100 is one of the promising candidate isotopes for the $0\nu\beta\beta$ search for its relatively high natural abundance (9.7%) and its high Q-value of 3.034 MeV, where γ -rays from ambient natural radioactivity hardly exist.

AMoRE uses the ^{100}Mo -enriched scintillation crystals. The phonon and photon signals from a crystal are detected simultaneously by the sensors each of which consists of a superconducting quantum interference device (SQUID) and a metallic magnetic calorimeter (MMC) [3]. The detector modules are packaged in a dilution refrigerator where the temperature is set around 10 mK. The MMCs show relatively short rise-times in phonon signals at a few milliseconds, compared to the other bolometers [4], which gives an advantage of suppressing the contamination by random coincidence signals. Detection of both heat and light signals also enables efficient separation of β/γ signals from α signals using different quenching of light signals between them, along with the pulse shape discrimination (PSD) of heat signals.

AMoRE is divided into three phases: Pilot, I, and II. The Pilot-phase is for the demonstration of the detection principle, understanding the background components and finding ways to reduce the background and improve the experimental sensitivity. AMoRE-I uses the same cryostat as Pilot-phase but with more crystals, to have the sensitivity for the $0\nu\beta\beta$ half-life ($T_{1/2}^{0\nu\beta\beta}$) up to 7×10^{24} years level.

AMoRE-II is the main stage of the experiment using hundreds of enriched ^{100}Mo -based crystals in a new detector package in a newly built underground laboratory, and the sensitivity reaches up to $T_{1/2}^{0\nu\beta\beta} \sim 10^{27}$ years (Fig. 1), corresponding effective Majorana mass of 13-25 meV, covering all the inverted mass hierarchy region [5].



2. AMoRE-Pilot

The Pilot phase was conducted in Yangyang Underground Laboratory (Y2L), located in a pumped water power plant about 700 m underground. Data-taking was from 2016 to 2018, using six $^{48\text{depl}}\text{Ca}^{100}\text{MoO}_4$ (CMO) crystals [6]. The internal radioactivity of CMO has been understood by modeling of the energy spectrum of the α events [7]. It is found that the crystal surface contamination can make it difficult to tag the α events and reject the coincident β -decay events of ^{208}Tl and ^{214}Bi , which may produce background events in energy range-of-interest (ROI) around 3 MeV.

Radioactivities of all the materials surrounding the crystals have been measured using high-purity germanium (HPGe) detectors and an inductively coupled plasma mass spectrometer (ICP-MS) [8]. During the Pilot phase, detector components with high radioactivity near the crystals were removed, and neutron shielding was enhanced by installing polyethylene blocks, borate-polyethylene plates, and sheets of boric acid powder. The Pilot phase is divided into three different configurations according to these changes. The β/γ background energy spectrum from measurement for each configuration is fitted with the simulated spectra of all the materials and isotopes based on the radioassay. The spectrum of the second configuration is shown in Fig. 2. The background at ROI is about 4 counts/keV/kg/year (ckky) level, and is dominated by the neutron-induced, air-radon, and crystals' internal background.

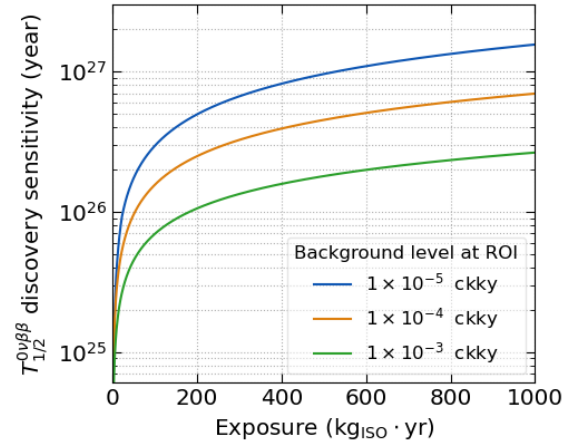


Figure 1. Expected median sensitivities of AMoRE for discovering the half-life of $0\nu\beta\beta$ at 3σ confidence level, versus the isotope (^{100}Mo) mass \times year exposure at different background levels .

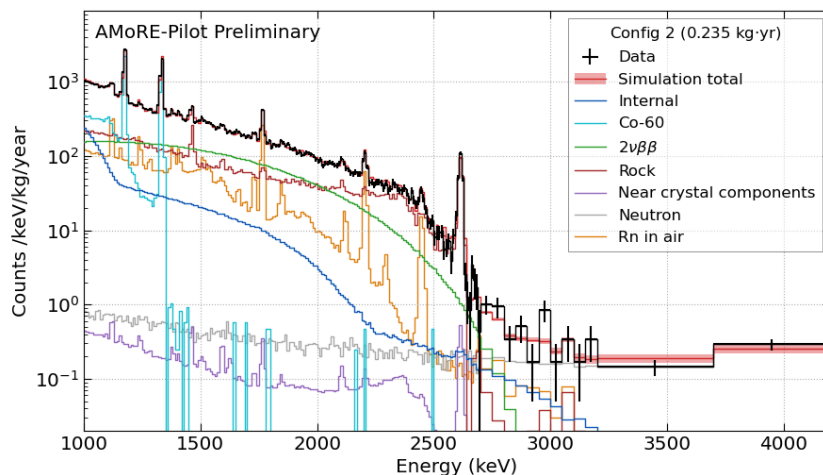


Figure 2. Preliminary background spectrum from the second configuration of AMoRE-Pilot.

3. AMoRE-I status

AMoRE-I has been running since late 2020 with thirteen CMO crystals, 6 of which had been used in Pilot, and five $\text{Li}_2^{100}\text{MoO}_4$ (LMO) crystals in the same cryostat as Pilot. The shielding for external gamma and neutrons are enhanced from Pilot by adding a 5 cm thick lead layer and 1 cm thick boric-acid silicon rubber pads. Radon-free air is supplied into the detector room most of the time. Muon tagging efficiency is also enhanced by adding more plastic scintillator panels surrounding the detector package. In addition, an advanced temperature monitoring and feedback-control system using a bare MMC/SQUID module has been installed for the temperature stabilization. Periodic injection of a stable heat signal to each crystal has enabled monitoring and correcting the signal drift due to temperature fluctuation. The detector modules for 17 crystals out of 18 are currently performing well and 3 kg·yr exposure has been achieved by Summer 2021 with about 70% data acquisition (DAQ) efficiency.

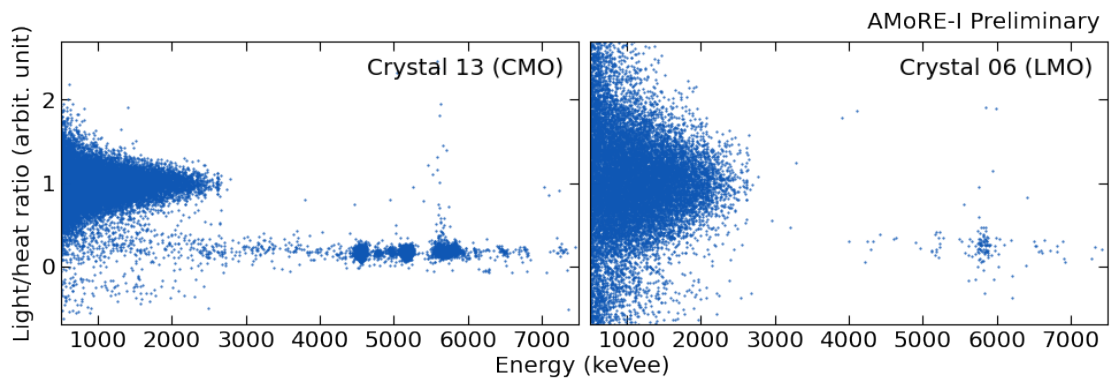


Figure 3. Ratio of the light signal amplitude to the heat signal, left is a CMO crystal example and right an LMO example.

A preliminary study reveals that LMO has much less internal background than CMO. Fig. 3 shows the ratio of the light and heat signal amplitude in terms of energy, one for a CMO crystal, the other for an LMO crystal. The light signals of the alpha background form lower horizontal bands at high energy sides, and the LMO shows much less number of events. However, the disadvantage of the LMO crystal is that it shows a poorer discrimination power between β/γ and α for its lower light yield and less difference in pulse shapes than CMO.

Thanks to clean LMO crystals and shielding enhancements, the background level has been reduced from the Pilot phase. Further study is required to determine the precise background level, but less than 0.1 cky background level is observed even without the α -tagging or muon veto selections. The data-taking will be continued until the end of 2022, and about 8 kg·yr exposure is expected with by then.

4. AMoRE-II preparation and prospect

The AMoRE-II detector will be installed in a newly built underground laboratory named Yemilab, in Jeongseon, Korea. Yemilab is located at about 1,000 meter underground, next to an active iron mine. Excavation and substructure construction of the AMoRE experimental hall have been completed and the structure for shielding and detector is being constructed. The cryogenic detector equipped with hundreds of ^{100}Mo -based crystals will be surrounded by passive shielding layers consisting of boric acid silicon rubber, copper, lead and polyethylene. Muon counter detectors of plastic scintillator with silicon-photomultipliers will cover the outermost parts of sides and bottom, and the upper part of the detector including the space for DAQ and

cryostat equipments will be covered by a water tank serving as both passive shielding and a Cerenkov detector. The final design of the whole detector system is illustrated in Fig. 4.

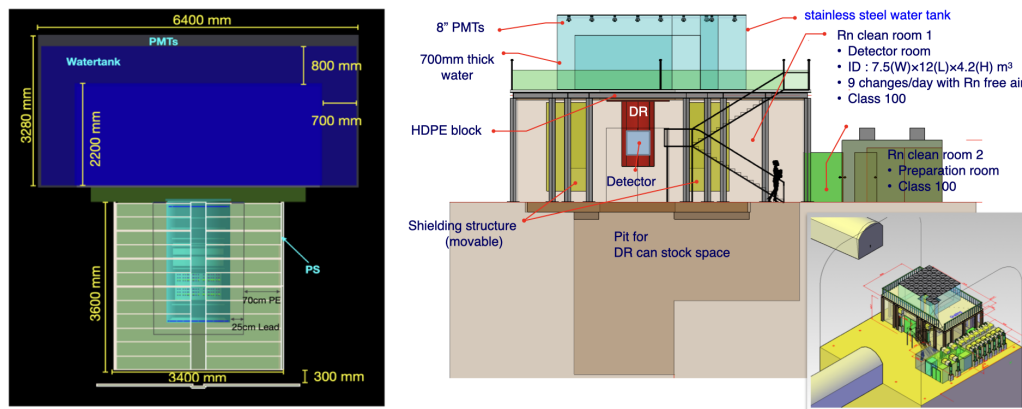


Figure 4. Illustration of the AMoRE-II detector and shielding structures. The cryostat and surrounding shielding are shown on the left, and the substructure and additional facilities on the right.

About 90 LMO crystal detector units will be ready by Summer 2022, and the first operation of the AMoRE-II will launch with them. The final scale operation of AMoRE-II with about 180 kg of crystal mass is scheduled to start in 2024. Longer than 5-year data-taking will lead us to reach 500 $\text{kg}_{\text{ISO}}\cdot\text{year}$ exposure, and to an unprecedented sensitivity of $T_{1/2}^{0\nu\beta\beta}$ close to 10^{27} years.

References

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