# THE CURRENT STATUS OF THE RENO EXPERIMENT

Yeongduk Kim
for RENO Collaboration
*Physics Department, Sejong University, Seoul 143-747, South Korea*
*E-mail : ydkim@sejong.ac.kr*

**Abstract**

An experiment, RENO (Reactor Experiment for Neutrino Oscillation), is under construction to measure the unknown neutrino mixing angle ($\theta_{13}$) using anti-neutrinos emitted from the Younggwang nuclear power plant in Korea. Two identical 16.3-ton Gadolinium loaded liquid scintillator detectors will be constructed at 290 m and 1.4 km from the center of the reactor array. The sensitivity in $sin^2\theta_{13}$ is expected as 0.2-0.3 in 90% confidence level with three years of data.

# 1 Introduction

There have been great progresses in understanding the neutrino sector of elementary particle physics in the past few years. The discovery of neutrino oscillation is a direct indication of physics beyond the Standard Model. The smallness of neutrino masses and the large lepton flavor violation associated with neutrino mixing are both fundamental properties that give insights into modifications of current theories.

Among the three neutrino mixing angles, $\theta_{12}$ is measured by solar neutrinos and the KamLAND reactor experiment, and another, $\theta_{23}$, by atmospheric neutrinos and the long-baseline accelerator experiments, K2K and MINOS. Both angles are large, unlike mixing angles among quarks. The third angle, $\theta_{13}$, has not yet been measured but constrained to be small($sin^2\theta_{13} < 0.16$) by the CHOOZ reactor neutrino experiment [1]. Future measurement of $\theta_{13}$ is possible using either reactor neutrinos or long baseline accelerator neutrino beams.

The Chooz experiment had a single detector located about 1 km from the reactors. A reactor experiment using two identical detectors of $10 \sim 30$ tons at near ($100 \sim 200$ m) and far ($1 \sim 2$ km) locations was proposed [2] and will have significantly improved sensitivity for $\theta_{13}$ down to the $\sin^2(2\theta_{13}) \sim 0.01$ level [3]. Reactor neutrino experiment with multi-detectors at different baseline can cancel out the systematic uncertainties associated with reactor power and detector efficiencies. In addition, reactor measurements can determine $\theta_{13}$ without the ambiguities associated matter effects and CP violation.

# 2 Overview of RENO Experiment

## 2.1 Site

The Younggwang nuclear power plant is one of four nuclear reactor complexes in Korea which has world-second largest thermal power output of 16.4 GW. The reactor complex is located in the west coast of southern part of Korea, about $\sim$ 250 km from Seoul. The power plant has six reactors with about equal power, and are lined up in equal distances as shown in Fig. 1. The power plant is operated by Korea Hydro & Nuclear Power Co. Ltd. (KHNP).

The near and far detectors will be located about 290 m and 1.4 km from the center of reactor array. The detectors will be constructed identically and

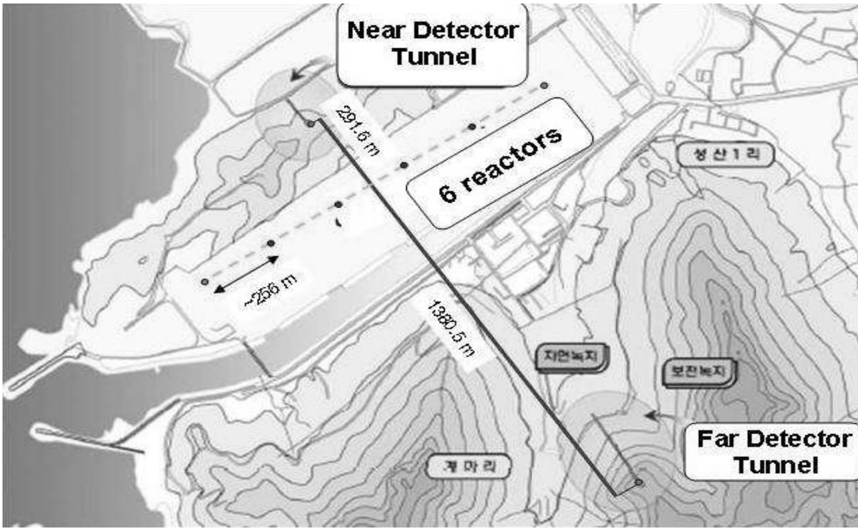


Figure 1: *The layout of the Yonggwang experiment site. The reactors are roughly equally spaced at 260 m apart. The near and far detectors are 282 m and 1380 m away from the reactor array.*

the Gadollinium loaded scintillator for neutrino detection will be 16.3 ton. The basic parameters for the two sites are summarized in Table 1.

### 2.2 Tunneling and Experiment Halls

The underground laboratories will be constructed with two horizontal tunnels, 100 m long for the near detector and 300 m long for the far detector, as shown in Fig. 1. The tunnel cross section is 4.5 m wide and 4.8 m high.

In order to check the suitability of constructing experimental halls and access tunnels at the experiment site, geological surveys have been performed. Four and three boreholes were drilled for near and far detector sites respectively. The rock quality at both sites was found to be solid enough for tunneling by electric and seismic tests. Bore samples are used to determine various properties of rocks, such as chemical composition, compressive strength, density, and radioactivities.

The natural radioactivities of rock samples obtained by boring at both

Table 1: *Basic parameters of near and far detectors.*

| | Near | Far |
|---|---|---|
| Distance(m) | 282 | 1380 |
| Overburden(m) | 46 | 168 |
| # of neutrino events/day | 920 | 82 |
| muon flux($m^{-2}s^{-1}$) | 5.5 | 0.85 |
| $< E_\mu >$(GeV) | 34.3 | 65.2 |

sites were measured by ICP-MASS. The U, Th, and $^{40}K$ contents inside rock were 2.1 ± 0.1 , 7.3 ± 1.2, and 2.4 ppm respectively at near detector site. The far detector site has similar amounts of natural radioactivities.

## 3 Detector Design

The RENO detector is composed of 4 layers, starting from the center, target, $\gamma$-catcher, buffer and veto. The shape of each layer is cylindrical. The various design parameters have been determined for optimal performance using "Generic Liquid-scintillator Anti-Neutrino Detector Geant4 Simulation(GLG4Sim) ?). The program has been customized for the geometry of RENO detector with new event generator which provides better physics model. The simulation includes background $\gamma$ rays from PMTs and surrounding rocks, cosmic muons and neutrons reaching the detector site as well as inverse $\beta$ decay from the reactor anti-neutrinos. The neutrino events are characterized by time coincidence between positron signal and neutron signal. The cuts we applied was $E_{e^+} > 1MeV$, $6MeV < E_{neutron} < 12MeV$, $0.3\mu s < \Delta T < 100\mu s$. The energy resolution was applied.

The target, a cylinder of radius 1.4 m, of height 3.2 m contains 16.3 tons of 0.1% Gd and liquid scintillating material. To increase the detection efficiency of the neutron capture signal inside the target, a second layer called $\gamma$-catcher has been added and the thickness of $\gamma$-catcher is 60 cm. The neutrino detection efficiency with 60 cm thick $\gamma$-catcher was (93.0±0.6)%.

The buffer is filled with non-scintillating mineral oil. 342 10" PMTs are mounted uniformly on the wall of this buffer vessel, and the thickness of mineral oil is 0.7 m to effectively reduce the radioactive backgrounds of PMTs. The

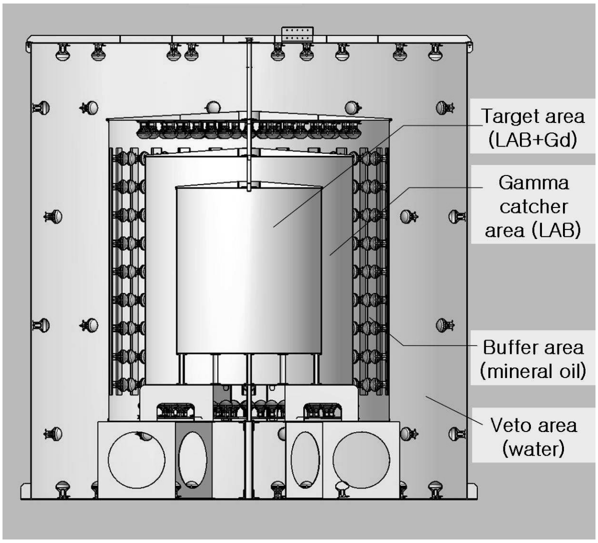


Figure 2: RENO detector. From the center, there are liquid scintillator filled target and gamma catcher with transparent acrylic vessel, mineral oil filled buffer with stainless steel vessel, and water filled veto layers. The PMTs for the inner and outer detectors are inwardly mounted buffer and veto vessels, respectively. The dimensions are given in Table 2.

outermost layer of the RENO detector is a veto layer composed of pure water. Its purpose is to reduce the background $\gamma$ rays and neutrons from surrounding environment. The thickness of water is 1.5 m.

## 4 Liquid Scintillator

Linear Alkly Benzene(LAB) has been introduced by SNO group as basic liquid scintillator noting several advantageous properties such as excellent light yield, high flash point, good optical properties(transmittance and attenuation length), excellent compatibility with acrylic, as well as cheap price. LAB is composed of a linear alkyl chain of $10 \sim 13$ carbon atoms attached to a benzene ring with a density of 0.86 (g/m$l$). In order to reduce the systematic error between near detector and far detector at RENO experiment, it is very important to know the compositions of LAB exactly. The composition of LAB is

Table 2: *Dimensions of the mechanical structure of the detector. OD and H are the out diameter and height of each layer.*

| Layer | OD (cm) | H (cm) | Vessel Material | Material | Mass (tons) |
|---|---|---|---|---|---|
| Target | 280 | 320 | Acrylic | Gd-Doped LS | 16.3 |
| $\gamma$-catcher | 400 | 440 | Acrylic | LS | 28.5 |
| Buffer | 540 | 580 | SUS | Mineral Oil | 64.1 |
| Veto | 840 | 880 | SUS | Water | 352.6 |

measured by Gas Chromatography with Mass Spectrometry(GC-MS) at Korea Basic Science Institute with a sample of LAB supplied by a domestic company (Isu Chemical).

The optimal concentration of PPO and bis-MSB(wave length shifter) in the LAB in terms of light output was found to be 3 g/$l$ and 30 mg/$l$ respectively. The light yield of pure LAB with PPO and bis-MSB was found to be about 96 % relative to 100 % of pure PC. Target scintillator will be loaded with 0.1 % Gd, and it's critical to make the scintillator stable. We have studied samples of Gd complex with different additional organic ligands such as trioctyl phosphine oxide (TOPO) and 3,5,5-trimethylhexanoic acid (TMHA). The long-term stability tests are under progress. The radiopurity of domestic LAB sample was measured with ICP-MASS. The LAB, if not exposed to air, is sufficiently pure without purification. The Uranium content was less than $8 \times 10^{-13}$, and Thorium was less than $1.1 \times 10^{-12}$.

## 5 Backgrounds

From Chooz experiment, one can expect the main background events are due to the neutrons entering the scintillating liquid from outside. These neutrons produce the primary signal by a collision with the protons and captured inside the liquid scintillator. In addition, there are gamma background events from various sources containing natural radioacivities. The neutrons are mainly generated by cosmic muons inside rock and also inside water in the veto vessel.

The background event rate of energy deposit over 1 MeV from the natural background of surrounding rock was estimated as about 10 Hz for 70cm thick

Table 3: *Result of muon transport simulation for the detector candidate sites.*

| Detector Site | Integrated intensity ($cm^{-2}s^{-1}$) | Average energy (GeV) |
|---|---|---|
| 70 m | $5.5 \times 10^{-4}$ | 34.3 |
| 200 m | $8.5 \times 10^{-5}$ | 65.2 |
| 250 m | $2.9 \times 10^{-5}$ | 91.7 |

mineral oil and 1.5 m water veto layers. The radioactivities inside of PMTs were measured for a number of 8"and 10" PMTs provided by Hamamatsu, Photonis, and Electron Tube companies. If we use low radioactivity glass PMTs, the estimated single background rate will be also about 10 Hz for 70cm thick mineral oil layer. The radioactivities inside the liquid scintillator depends on the radiopurity of the liquid scintillator. We have measured the pure LAB sample provided by domestic chemical company without purification by ICP-MASS, and the U, Th contents were $8 \times 10^{-13}$ and $1.1 \times 10^{-12}$ respectively. The single background event rate will be a few Hz if we can confirm this level of radioactivity for bulk LAB. The overall accidental background event rate of energy over 1 MeV is order of 30 Hz.

We have simulated the muon intensity and energy at the underground lab using MUSIC and FLUKA packages with the modified Gaisser parameterization. Table 3 shows the rates and mean energy of the passing muons at near and far detector sites. The fast neutron backgrounds entering $\gamma$-catcher was simulated with the expected neutron flux and energy spectra from the parameterization by Mei et al. [8] after matching to the average muon energies at RENO sites. The background event rate considering the valid neutrino event selection cuts and rejecting the multiple neutron capture and muon veto signals was found to be about 0.5 event per day for far detector.

## 6 Electronics

The gain of PMTs will be set at $10^7$ and the electronics threshold of each PMT will be set at 0.5 photoelectron level. The main front-end electronics will be charge-to-time converting (QTC) chips recently developed by Super-Kamiokande group [7]. A board housing 8 QTC chips can handle 24 PMT signals. A trigger logic based on the multiplicity of PMT hits and analogue sum is under development.

## 7 Sensitivity

The expected sensitivity of RENO experiment was calculated using the pull $\chi^2$ method [9]. Figure 3 shows the 90% confidence sensitivity in $sin^2\theta_{13}$. The lines are explained in the figure caption. We expect the sensitivity of RENO experiment will be 0.2-0.3 with 3 years data taking. The relatively long spanning length of reactor array makes the sensitivity a little worse, but the effect is only about 30% level.

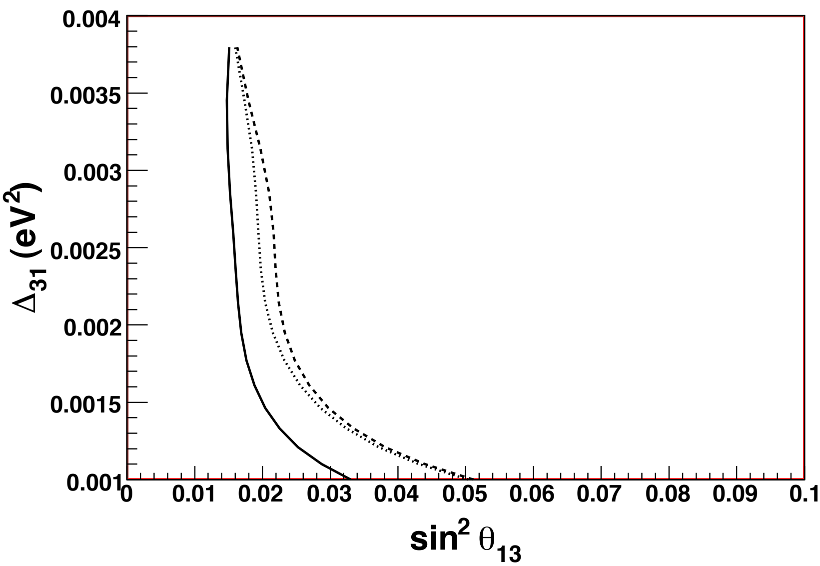


Figure 3: *Two right curves shows the sensitivity with the expected parameters and the bin-by-bin relative error of 0.6%. The rightest curve shows the effect that the six reactor cores are separated and spans 1.3 km. Core fluctuation error was 2%. The solid curve was obtained with bin-by-bin relative error of 0.38%.*

## 8 Acknowledgements

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