Status of the RENO Reactor Neutrino Experiment

RENO = Reactor Experiment for Neutrino Oscillation

(For RENO Collaboration)

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Seoul National University
November 14, 2011

DBD 2011, November 14-17 2011, Osaka
Outline

- Experimental Goal
  - Systematic & Statistical Uncertainties
  - Expected $\theta_{13}$ Sensitivity

- Overview of the RENO Experiment
  - Experimental Setup
  - YongGwang Power Plant
  - Detector Construction (completed in Feb. 2011)

- RENO Data-Taking (start from Aug. 2011)
  - Status
  - Energy Calibration

- Summary
Find disappearance of $\bar{\nu}_e$ fluxes due to neutrino oscillation as a function of energy

Identical detectors reduce the systematic errors in 1% level.
2.73 GW per reactor \times 6 \text{ reactors}
1.21 \times 10^{30} \text{ free protons per targets (16 tons)}

\begin{itemize}
  \item Near: 1,280/day, 468,000/year
  \item Far: 114/day, 41,600/year
\end{itemize}

3 \text{ years of data taking with 70\% efficiency}

\[ \begin{align*}
  \text{Near:} & \quad 9.83 \times 10^5 \approx 10^6 \quad (0.1\% \text{ error}) \\ 
  \text{Far:} & \quad 8.74 \times 10^4 \approx 10^5 \quad (0.3\% \text{ error})
\end{align*} \]
## Expected Systematic Uncertainty

<table>
<thead>
<tr>
<th>Systematic Source</th>
<th>CHOOZ (%)</th>
<th>RENO (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor related absolute normalization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reactor antineutrino flux and cross section</td>
<td>1.9</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>Reactor power</td>
<td>0.7</td>
<td>0.2</td>
</tr>
<tr>
<td>Energy released per fission</td>
<td>0.6</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>Number of protons in target</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H/C ratio</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Target mass</td>
<td>0.3</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>Detector Efficiency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positron energy</td>
<td>0.8</td>
<td>0.1</td>
</tr>
<tr>
<td>Positron geode distance</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Neutron capture (H/Gd ratio)</td>
<td>1.0</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>Capture energy containment</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Neutron geode distance</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Neutron delay</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Positron-neutron distance</td>
<td>0.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Neutron multiplicity</td>
<td>0.5</td>
<td>0.05</td>
</tr>
<tr>
<td>combined</td>
<td>2.7</td>
<td>&lt; 0.5</td>
</tr>
</tbody>
</table>
RENO Expected Sensitivity

90% CL Limits

\[ \sin^2(2\theta_{13}) > 0.02 \]

- 10 times better sensitivity than the current limit

G. Fogli et al. (2009)
RENO Collaboration
(13 institutions and 40 physicists)

- Chonbuk National University
- Chonnam National University
- **Chung-Ang University**
- Dongshin University
- Gyeongsang National University
- Kyungpook National University
- Pusan National University
- Sejong University
- Seokyeong University
- Seoul National University
- Seoyeong University
- Sungkyunkwan University
- **California State University Domingez Hills, USA**

+++  http://reno01.snu.ac.kr/RENO

International collaborators are being invited
YongGwang Nuclear Power Plant

- Located in the west coast of southern part of Korea
- ~400 km from Seoul
- 6 reactors are lined up in roughly equal distances and span ~1.3 km
- Total average thermal output ~16.4GW\textsubscript{th} (2\textsuperscript{nd} largest in the world)

YongGwang (靈光): = glorious[splendid] light (~ psychic)
- Inner PMTs: 354 10” PMTs
  - solid angle coverage = 12.6%
- Outer PMTs: ~ 67 10” PMTs

<table>
<thead>
<tr>
<th></th>
<th>Inner Diameter (cm)</th>
<th>Inner Height (cm)</th>
<th>Filled with</th>
<th>Mass (tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target Vessel</td>
<td>280</td>
<td>320</td>
<td>Gd(0.1%) + LS</td>
<td>16.5</td>
</tr>
<tr>
<td>Gamma catcher</td>
<td>400</td>
<td>440</td>
<td>LS</td>
<td>30.0</td>
</tr>
<tr>
<td>Buffer tank</td>
<td>540</td>
<td>580</td>
<td>Mineral oil</td>
<td>64.4</td>
</tr>
<tr>
<td>Veto tank</td>
<td>840</td>
<td>880</td>
<td>water</td>
<td>352.6</td>
</tr>
</tbody>
</table>

**total ~460 tons**
Summary of Detector Construction

- 2006. 03 : Start of the RENO project
- 2008. 06 ~ 2009. 03 : Civil construction including tunnel excavation
- 2008. 12 ~ 2009. 11 : Detector structure & buffer steel tanks completed
- 2010. 06 : Acrylic containers installed
- 2010. 06 ~ 2010. 12 : PMT test & installation
- 2011. 01 : Detector closing/ Electronics hut & control room built
- 2011. 02 : Installation of DAQ electronics and HV & cabling
- 2011. 03 ~ 06 : Dry run & DAQ debugging
- 2011. 05 ~ 07 : Liquid scintillator production & filling
- 2011. 07 : Detector operation & commissioning
- 2011. 08 : Start data-taking
Construction of Near & Far Tunnels (2008. 6~2009. 3)

by Daewoo Eng. Co. Korea
Installation of Acrylic Vessels (2010. 6)
PMT Mounting (2010. 8~10)
PMT Mounting (2010. 8~10)
Finishing PMT installation (2011. 1)
Detector Closing (2011. 1)
Detector Closing (2011. 1)

Near : Jan. 21, 2011

Far : Jan. 24, 2011
PMT Cable Connection to DAQ Electronics (2011. 2)
RENO DAQ System

Clock & Periodic Trigger
- Starting the Hardware Trigger
- Data Collecting, Sorting, Merging
- Event Building by Software Trigger

Frontend
- Raw Data
- Run Control
  - Run Control
  - DAQ Monitoring

Online Monitor
- Event Display
- Online histograms

Reformatter

Storage @ RENO

Storage @ KISTI
Dry Runs (2011. 3 ~ 5)

- Electronics threshold: 1mV based on PMT test with a bottle of liquid scintillator and a $^{137}$Cs source at center
**Recipe of Liquid Scintillator**

<table>
<thead>
<tr>
<th>Aromatic Solvent &amp; Flour</th>
<th>WLS</th>
<th>Gd–compound</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAB</td>
<td>PPO + Bis-MSB</td>
<td>0.1% Gd+TMHA (trimethylhexanoic acid)</td>
</tr>
</tbody>
</table>

- **High Light Yield**: not likely Mineral oil (MO)
- replace MO and even Pseudocume (PC)
- **Good transparency**: (better than PC)
- **High Flash point**: 147°C (PC : 48°C)
- **Environmentally friendly**: (PC : toxic)
- **Components well known**: (MO : not well known)
- **Domestically available**: Isu Chemical Ltd.

**Solvent-solvent extraction method**

**0.1% Gd compounds with CBX (Carboxylic acids; R-COOH)**

- CBX : TMHA (trimethylhexanoic acid)
Liquid Production System (2010. 11~2011. 3 )
Liquids Filling

- Both near and far detectors are filled with Gd-LS, LS & mineral oil as of July 5, 2011.
- Veto water filling is completed at the end of July, 2011.
• Ultra-pure water system is important for VETO.
• Solenoid valve: Auto on/off
• Feedback from the ultrasonic level sensor of water level
Slow Control & Monitoring System

HV monitoring system

Environmental monitor

Online event display & histograms

Why slow monitoring?
1. To be required to control systematic effects
2. To allow automated scans of parameters such as thresholds and high voltages
3. To provide alarms, warnings, and diagnostic information to the operators
Real time event rate

RUN Control & DAQ Monitoring
IP Camera System with Central Management System

- Two detectors (ND/FD) are controlled & monitored from one (far) site
- Both systems are quite stable & working smoothly
PMT Gain Matching

- PMT gain: set $1.0 \times 10^7$ using a $^{137}$Cs source at center
- Gain variation among PMTs: 3% for both detectors.
Data Taking with Near & Far Detectors

- Data taking began on Aug. 1, 2011 with both near and far detectors and has been in smooth progress.
- DAQ efficiency > 90%.
- Trigger rate of single low energy events: 70~80 Hz (Nhit > 90, i.e. E>0.5~0.6 MeV)
- Trigger rate of veto events: ~ 60 Hz (FD), ~530Hz (ND)
- Data taking shifts
  - Aug. 1 ~ Sep. 30: 6 shifts per day inside both tunnels
  - Oct. 1: 3 shifts per day in front of the far tunnel (remote control of both ND & FD detectors)
Two identical source driving systems at the center of TARGET and one side of GAMMA CATCHER.
Energy Calibration and Comparison of ND & FD

- ~230 pe/MeV (sources at center)
- Identical energy response (<1%) of ND & FD
Gd neutron capture signal

252Cf source

We are observing Gd capture as expected by simulation at both detectors
Both detectors have capture time $\sim 30 \mu s$

$\tau_{ND} = 29.89 \pm 0.55 \mu s$

$\tau_{FD} = 28.32 \pm 0.47 \mu s$
BG Analysis

2.2 MeV $\gamma$ rays from cosmic muon induced neutron capture by Hydrogen

$\beta$-neutron Cascades (Cosmogenics)

- Cosmic muons crossing the detector create neutrons
- Neutron could be later captured on Hydrogen & release $\sim$2.2 MeV
- We know that how many produced per day & this BG can be measured and subtracted

Preliminary
Summary of RENO Status

- Construction of both near and far detectors at RENO are completed in Feb. 2011
- All the liquids including Gd-LS are produced and filled by end of July 2011
- Regular data-taking with NEAR & FAR detectors began from August 1, 2011
  - Preliminary result shows satisfactory detector performance
  - Detector calibration and comparison of ND & FD are performed
- Data reduction, source calibration, and Monte-Carlo reconstruction efforts are on progress & going on smoothly
• First results on $\sin^2(2\theta_{13}) \sim 0.05$ are expected to be available within a half year
  - Goal: $\sim 0.07$ (end of this yr)
  $\sim 0.05$ (March, 2012)

- RENO group hope to tell the value of $\sin^2(2\theta_{13})$ at the anticipated time
  - Goal: Neutrino 2012 @ Kyoto (June, 2012)