Fast Reactor Neutrino Detection with KASKA Prototype Detector: A Status Report

Joint Meeting of Pacific Region Particle Physics Communities
October 29 - November 03, 2006
Hawaii U.S.A.

Y.Tsuchiya, F.Suekane, H.Tabata, H.Furuta\textsuperscript{A}, Y.Sakamoto\textsuperscript{B}, KASKA Collaborator\textsuperscript{C-I}
Tohoku University, Tokyo Institute of Technology\textsuperscript{A}, Tohoku Gakuin University\textsuperscript{B}, Kobe University\textsuperscript{C}, KEK\textsuperscript{D}, Tokyo Metropolitan University\textsuperscript{E}, Niigata University\textsuperscript{F}, Hiroshima Institute of Technology\textsuperscript{G}, Miyagi University of Education\textsuperscript{H}, Osaka University\textsuperscript{I} and M.Takamatsu JAEA

2006/10/30 Yasushi Tsuchiya @Hawaii
Outline

Report of fast reactor neutrino detection with KASKA prototype detector at Joyo Experimental Reactor taking data from this fall.

Contents

• KASKA experiment
• Prototype detector and its motivations
• Preliminary result of prototype detector: Gadolinium spectrum
• Experimental Fast Reactor: Joyo
• First data of Fast Reactor experiment
• Summary
KASKA experiment
(Measurement $\theta_{13}$ project)

KASShiwazaki-KAriwa nuclear power station

Located at Niigata prefecture in Japan
Largest thermal energy in the world (24.3GWth)
→ the most powerful neutrino source
7 reactors in two clusters

Location of far detector is optimized by oscillation maximum

Near

Far

Near

Near detector

~0.4km

50m

~1.8km

150m

Far detectors
KASKA detector

Region Ⅰ: $\nu_e$ target $\rightarrow$ 9 tons 0.1 %
Gadolinium liquid scintillator (Palo verde type)
UV-transparent acrylic vessel
diameter: 1.4m
(Gadolinium: the largest neutron cross section among all the elements)

Region Ⅱ: $\gamma$ catcher $\rightarrow$ Normal liquid scintillator
UV-transparent acrylic vessel
thickness of region Ⅱ: 70cm
diameter: 4.1m

Region Ⅲ: Inner buffer oil
Thickness of region Ⅲ: 115cm

Region Ⅳ: Outer buffer oil
Thickness of region Ⅳ: 50cm
Principle of the detection anti-neutrino

\[ \bar{\nu}_e + p \rightarrow e^+ + n \]

**Prompt signal**

\[ e^+ + e^- \rightarrow 2\gamma(0.511\text{MeV} \times 2) \]

**Delayed signal**

\[ n + \text{Gd} \rightarrow \text{Gd'} + \gamma\text{'s}(\sum E_\gamma \sim 8\text{MeV}) \]

( Energy spectrum Gd gamma rays not well known )

\[ 1^\sim 8\text{MeV} \rightarrow 8\text{MeV} \]

Signal Property

30µs

Gd Liquid Scintillator

Ep: \( K_{e^+} + 511\text{keV} \times 2 \)

Ed: \( \Sigma E_\gamma \sim 8\text{MeV} \)
KASKA prototype detector

Motivations

- Test of $\gamma$-catcher
  - Study of Gadolinium spectrum
  - Taking advantage of this study to full simulation
- Background estimation from cosmic ray spallation
  - Unknown nuclides created by the spallation because of its large atomic number

Setups

- UV-transparent spherical acrylic vessel with its diameter 1.2m → Region II part
- LS contents: pseudocumene(13.5%) + isoparaffin(86.5%) + PPO, BisMSB
- 16 8” inch PMTs
- Acrylic box: 6.75 liters, 0.1% Gd LS, → Region I part
- A drawer at the center of the box
Am/Be source

Neutrino like signal

Population of gamma-ray from Gd

Use this population in our MC simulation

Check the combination of gamma-rays from Gd comparing to prototype data
Comparing to simulation data

Difference between prototype and simulation

→ The combination of $\gamma$ rays causes

→ Necessary to improve simulation

2006/10/30 Yasushi Tsuchiya @Hawaii
Experimental Fast Reactor: Joyo

- Fast Reactor: Joyo
- $P_{th} = 140$ MWth
- Fuel: U(70wt %), Pu(30wt %)
- Operated by JAEA
- Operation days / Cycle: 60
  → Easy on/off data taking
- L ~ 25m
- $\sim 160 \nu p \rightarrow e^+ n$ reaction/day

(http://www.jaea.go.jp/04/o-arai/joyo/indexs.htm)

KASKA prototype detector

Now data taking!
Fast Reactor

Joyo Fast Reactor
Fuel: Uranium, Plutonium
→ Pu rich neutrino

Light Water Reactor
Fuel: Uranium
→ U rich neutrino

Combine two data → Determination of U and Pu neutrino spectra separately!

This test can only measure reactor on/off.
Setup at Joyo

- Motivation
  - First fast reactor neutrino detection
  - Observation of reactor on/off with detection neutrinos
- Detector setups
  - Detection region: 900 liters (whole detector)
  - LS contents
    - Pseudocumene: 15%
    - Isoparaffin: 75%
    - BC-521: 10%
  - Cosmic ray counters
  - Paraffin blocks
  - Lead blocks

Shields are incomplete (cosmic ray counter, paraffin blocks)

→ We are installing now
Acrylic sphere

Cosmic-ray anti counter

Gd-LS

Reactor is behind the wall
BG measurement @ Joyo

No source in the detector

Neutrino window
prompt energy : 4.5 ~ 6.5 MeV
delayed energy : 7.5 ~ 9.5 MeV
2usec < Δt < 50usec

(Neutrino events can be observed)
Count the events in this area to estimate a S/N ratio

258 [events/day]
Current S/N status
(\(\nu\) events / Background events)

- **S**: expected neutrino event
  
  \[
  S = 1.2 \times 10^{-5} \left[ \text{ton/GWt/s} \right] \times \left( \frac{1}{40} \right)^2 = 160 \text{ [events/day]}
  \]

- **W**: 0.72 ton, **P**: 0.14 GW, **T**: 1 [day] = 86400 [s]

- **Efficiencies (total = 0.0089)**
  - Prompt energy (4.5 ~ 6.5 MeV) = 0.36
  - \(\Delta t\) (2 ~ 50 usec) = 0.58
  - Gd’s energy selection = 0.19
  - Charge balance cut = 0.31

- **S** = 1.4 [events/day]

- **N**: background events = 258 [events/day]

- **S/N requirement**: at least 1/10 (to achieve 3 sigma)
  
  - S/N = 1.4 / 258 ~ 1 / 184
  - 100 days operation S \(\rightarrow\) 140 events
  - Necessary to improve S/N by 18 times
First data of fast reactor experiment

2D histogram of reactor ON

Select these events in this range and project to X axis

2~3 neutrino events are expected in this region (2 days)

→ under analysis
**Expected S/N improvement**

For 50% $\gamma$ efficiency, n rejection rate > 90% $\rightarrow$ S/N becomes more than 5 times better (S/N ~ 1/37)

Complete shields $\rightarrow$ ? times better: S/N aim at 1/10 (3 sigma)
Summary

• Preliminary result of the prototype detector: Gadolinium spectrum
• The prototype is taking real neutrino data at Joyo
• First Fast Reactor experiment
• Data taking until June, 2007
End of talk

Thank you very much for your attention!

Warning!
I am a graduate student, so please ask me questions slowly in plain English.
Backup slides
Charge balance cut

Calculate standard deviation of 16 ADCs each event and cut events using this value:

\[ \sigma = \sqrt{\frac{a^2}{\langle a \rangle^2}} - 1 \]

To reduce events reacting near the surface (ex. environmental background)

Ex.) Delayed energy of Gd-LS box + Am/Be data

![Graphs showing before and after cuts with energy distribution.](image)
Prompt delayed distance cut

The reaction position between prompt signal and delayed signal is relatively close

\[ d_{SIG} < d_{BG} \]
Efficiencies

• Gd efficiency :
  • The probability of neutron absorption in Gd-LS
  • The neutron is absorbed by Gadolinium with this probability.

• $\Delta t$ cut :
  • $\Delta t$ is the time between prompt signal and delayed signal.
  • We cut the events using this $\Delta t$ value.
  • The neutron is absorbed typically 30us after prompt signal in Gd-LS.