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Recent result of Anti-neutrino Detection for Reactor Monitoring in NEOS experiment

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1. Introduction

The application of anti-neutrino measurement has been proposed and the feasibility studies have been carried out as a novel technology for monitoring the burning process of nuclear power reactor [1, 2]. In this study we describe recent results of reactor monitoring using anti-neutrino detection in the Neutrino Experiment for Oscillation at Short baseline (NEOS) at Hanbit power plant. Most of content in this study was reviewed in the final report of "Construction a facility for ground-based short baseline reactor neutrino detection" project [3].

2. Methods and Results

In this section the production of anti-neutrino from reactor fission process and how to detect the anti-neutrino event and how to identify particle from other background event are described. As a result of reactor monitoring, the comparison between the anti-neutrino detection rate and the thermal power by Hanbit nuclear power plant is shown.

2.1 Anti-neutrino Production and Detection

Antineutrinos from nuclear reactors are produced by the β-decay of fission fragments into more stable nuclei: The two main fissile isotopes contained in the fuel of nuclear reactor are ^{235}U and ^{239}Pu. The ^{239}Pu is produced by neutron captures in the original ^{238}U followed by two consecutive β-decays: $^{239}\text{U}\rightarrow{}^{239}\text{Np}\rightarrow{}^{239}\text{Pu}$. The relative contribution to the total number of fissions induced by these two isotopes changes over time: it increases for ^{239}Pu while decreasing for ^{235}U. This is called the "burn-up" effect. The remaining fissions of ^{241}Pu and fast neutron induced fissions of ^{238}U share about 10% of the reactor power. Because the number of emitted neutrinos and their mean energy depend on the fissile isotopes, the differential energy cross-section of emitted neutrinos can provide a direct information of the burn-up for a nuclear reactor. The anti-neutrino flux emitted by a 1GW thermal power reactor is ~1.6 x 10^{22} neutrinos per second and the enormous amount of neutrinos allows us to detect their signals even though neutrino has very small cross section (~10^{-43} cm^2) with matter.

In the NEOS experiment the inverse beta decay (IBD) of anti-neutrinos in the Gd-doped liquid scintillator refers to the process; $\bar{\nu}_e + p \rightarrow e^+ + n$ is shown in Fig. 1(Left). The anti-neutrino reacting with a proton (Hydrogen atom) decays into a positron and a neutron. A prompt light signal is produced from the positron and the thermalized neutron travels for ~ 30 μs and captures on the Gd in liquid scintillator and then, a gamma cascade of mean energy ~8 MeV is generated by the radioactive capture. The kinematical threshold of the IBD reaction due to the mass excess of the final state is 1.8 MeV for the antineutrino energy.

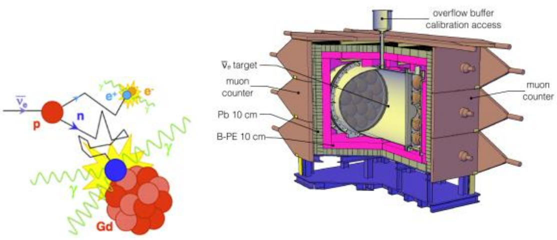

Fig. 1. Inverse Beta Decay (IBD) in Gd liquid scintillator (Left) and NEOS detector design (Right)

2.2 Background determination

Cosmogenic neutrons mimics IBD candidate behavior with random coincidences of gammas (prompt signal). For a detector placed ~10m below ground the overburden of reactor structure plays an important role in the background reduction. Additionally, a plastic muon veto detector surrounding the target is used to tag the induced background. Untagged fast neutrons generated by cosmic muons can be rejected using a pulse shape discrimination (PSD) in the liquid scintillator [4].

2.3 Neutrino Detector Design and Installation

The NEOS detector was designed with a steel cylindrical tank target filled with about 1000 L of Gd-doped liquid scintillator (LAB + Ultima Gold F (DIN) 9:1). 38 of R5912 (8 inch) PMTs are located at the left and right sides of the target. 100 mm of Pb and 100 mm of borated polyethylene layers are covering the target and shielding from backgrounds. A 50 mm plastic scintillator muon-veto layer surrounds the steel structure and located in tendon gallery which is about 23 m baseline from reactor core and ~30 m.w.e overburden (~10m below ground) for good background shielding as shown in Fig. 2.

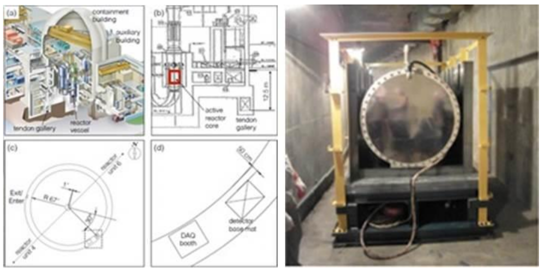

Fig. 2. NEOS detector installation in Tendon gallery at Hanbit power station unit 5.

2.4 Detector simulation

NEOS detector simulation was developed with GEANT4 program [5]. This simulation based on exact physics model and enormous particle database describes the signature of detector interacting with particle. The best parameters were tuned with data measured by detector. In particularly the optical characteristic, such as the light yield and attenuation length of liquid scintillator, was optimized using the energy distribution of gamma. The optical characteristic strongly depends on the signal source position and the parameters related with source position have to be empirically optimized. The IBD measurement data was recorded and analyzed with the identical program frame of simulation. Fig. 3 shows that the energy response of calibration source is consistent with simulation result.

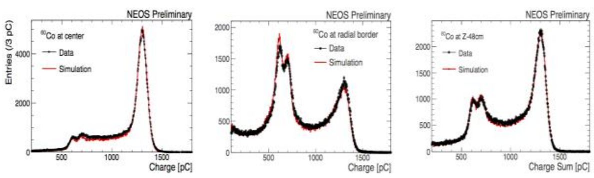

Fig. 3. Comparison of energy distribution between simulation and measurement data

2.4 Anti-neutrino measurement result

The detector was tested during July-August 2015 and unit 5 reactor was paused from Aug. 15 to Sep. 15 because of nuclear reactor fuel replacement. The reactor restarted ramping up Sep. 16 and the anti-neutrino data had been taken for 229 days. To reconstruct neutrino event, first of all, all events are vetoed for 150 μs after accepting muon signal from muon detector. The positron candidates are selected for 1 MeV < E_{e+} < 10 MeV where E_{e+} is positron energy and then the neutron signal is required to time interval of 1 < Δt < 30 μs and its energy, 4 MeV < E_n < 10 MeV as shown in Fig. 4.

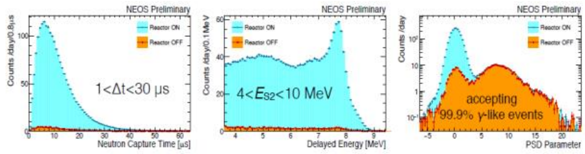

Fig. 4. Selection criteria of neutrino signal to remove background

3. Conclusions

The IBD count rate was 84 ± 1 antineutrino interactions per day during ~50 days of reactor OFF and 1946 ± 8/day with the signal to noise ratio of ~23 during ~229 days of reactor ON. In Fig. 5 we show the measurements of neutrino flux. On the plot the IBD candidates are consistent with the electric power (red line) as given by the reactor operators.

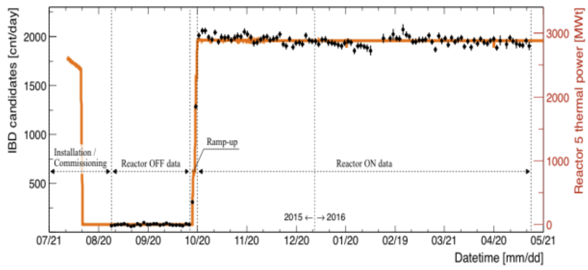

Fig. 5. NEOS preliminary result of IBD count rate as a function of data acquisition time. It is shown as an indicator for reactor ON/OFF.

REFERENCES

[1] C. Bemporad, G. Gratta, and P. Vogel, Rev. Mod. Phys. 74, 297, 2002, arXiv:hep-ph/0107277

[2] Christopher Stewart and Anna Erickson, Antineutrino analysis for continuous monitoring of nuclear reactors: Sensitivity study, J. Appl. Phys. 118, 164902, 2015.

[3] G. M. Sun, et al., The final report of “Construction a facility for ground-based short baseline reactor neutrino detection. KAERI report in process.

[4] B. R. Kim, et al., Pulse shape discrimination capability of metal-loaded organic liquid scintillators for a short-baseline reactor neutrino experiment, Phys. Scr. 90, 055302, 2015.

[5] S. Agostinelli et al., Geant4 - A Simulation Toolkit, Nuclear Instruments and Methods A 506 (2003) 250-303