Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 12-13, 2016

Study for Reactor Monitoring using Anti-neutrino Detection in the NEOS experiment

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1. Introduction

The identification and properties of neutrinos have been studied indefatigably over half a century from the discovery of anti-neutrino produced from reactor beta decay in 1956[1]. Recently, in the perspective of non-proliferation issues and misuse of nuclear energy as a fast-growing nuclear energy industry, the application of anti-neutrino measurement has been proposed and the feasibility studies has been carried out as a novel technology for monitoring the burning process of nuclear power reactor[2-4]. In this study we describe a feasibility study of reactor monitoring using anti-neutrino detection in the Neutrino Experiment for Oscillation at Short baseline (NEOS) at Hanbit power plant.

2. Methods and Results

In this section the background of reactor monitoring technology and some of the techniques used for anti-neutrino detection are described. The neutrino detection includes a liquid scintillator detector, muon veto detector, and Pulse Shape Discrimination method.

2.1 Reactor Monitoring

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}U→^{239}Np→^{239}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 NEOS experiment was designed with a 1 ton Gd-doped liquid scintillator to detect anti-neutrino 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. 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.

2.2 Neutrino Detection

In the NEOS experiment the Gd-doped liquid scintillator is used to detect reactor anti-neutrinos and the reaction in this detector is the inverse beta decay (IBD) that produces positron and neutron in Fig. 1. The IBD referred to the process; $\bar{\nu}_e + p \rightarrow e^+ + n$, anti-neutrino scattering off a proton(Hydrogen atom) contained in the detection material into a positron and a neutron. The positron produces a prompt light signal which is proportional to the positron kinetic energy plus its rest mass. The neutron thermalizes and captured in the Gadolinium doped liquid scintillator with a characteristic time of ~ 30 μs 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.

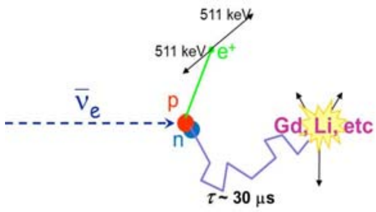

Fig. 1. Anti-neutrino signal detection using Inverse Beta Decay (IBD) in Gd liquid scintillator.

The main background is caused by cosmogenic neutrons and accidental background is induced by random coincidences of gammas (prompt signal) and neutrons (delayed signal). For a detector placed ~10m below ground the overburden of reactor structure plays an important role in the background reduction. 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 [5].

2.3 Detector installation

The NEOS detector is composed of a steel cylindrical tank target filled with about 1000 L of Gd-doped liquid scintillator (LAB + Ultima Gold F (DIN) 9:1 for better PSD). 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. Fig. 2 shows the NEOS detector in the tendon gallery before and after the muon-veto detector installation. The detector was installed and tested during July-August 2015 and has been taking data from September 2015.

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

2.4 Preliminary result

A reactor monitoring method relies on relative antineutrino flux measurements made during a given period of time. A neutrino flux change can be induced both by a change in the core composition or by a change in the produced thermal power. Another monitoring method consists of integrating the neutrino flux over the whole reactor cycle. This rate depends on the reactor power maintained over the cycle and on the initial composition of the core. The measurement of the integrated neutrino flux could cross-check the information declared by the reactor operators. 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 ~20 during ~30 days of reactor ON. In Fig. 3 we show the measurements of neutrino flux over a period of about 80 days. The filled histogram is the IBD candidates per 6 hours. In zoom-in box on the plot the IBD candidates are compared with the electric power (red dots) as given by the reactor operators during when the reactor power was ramping up.

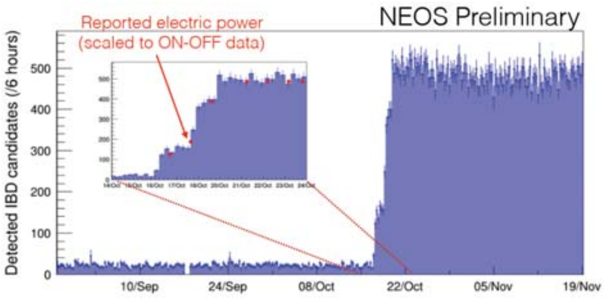

Fig. 3. NEOS preliminary result of IBD count rate as a function of data acquisition time. It is shown as an indicator for reactor ON/OFF.

3. Conclusions

The NEOS detector with 1000 L Gd-doped liquid scintillator was installed in tendon gallery at Hanbit power station unit 5 and has been collecting close to 2000 IBD events per day with the signal to noise ratio of ~20. As a preliminary result, we demonstrate the possibility of monitoring nuclear power reactor with the IBD counting rate during reactor power ON, ramping up, and OFF. In the near future, more data will be analyzed to check the reactor monitoring by neutrino detection.

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