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Status of Development of Antineutrino Detector for Short Baseline Experiment at the HANARO Research Reactor

Gwang-Min Sun[1], Boyoung Han[1], Hongjoo Kim[2], Jooyoung Lee[2], Kyungkwang Joo[3], Sun-heang So[3], Sook Hyung Song[3], In Sung Yeo[3], Ba Ro Kim[3], Jinyu Kim[4], Kyungju Ma[4], Eun-ju Jeon[5], Yeongduk Kim[5], Jaison Lee[5], Jeong-yeon Lee[5], Kang-soon Park[5], Hyangkyu Park[5], Siyeon Kim[6], Youngju Ko[6]

[1]*Korea Atomic Energy Research Institute, Daejeon, Korea*
[2] *Department of Physics, Kyungpook National University, Daegu, Korea*
[3] *Department of Physics, Chonnam National University, Gwangju, Korea*
[4]*Physics Department, Sejong University, Seoul, Korea*
[5] *Institute of Basic Science, Daejeon, Korea*
[6] *Chung-Ang University, Seoul, Korea*

1. Introduction

Antineutrino is a by-product of the fission process in a nuclear reactor. When a fissile isotope absorbs a neutron, it breaks into energetic daughter nuclei emitting many neutrons and gamma-rays. The neutrons then cause more fissions, and the daughter nuclei decay emitting an antineutrino with each decay. Because neutrinos can penetrate thick matter composed of heavy concrete, lead, metal and so on, it is considered to be a promising monitoring probe for civil nuclear facilities and nuclear inventories. In the fission process of a reactor core, uranium-235 produces antineutrinos in greater abundance than plutonium-239 over a certain energy range. As the burnup proceeds, the neutrino energy spectrum deviates from the initial one. Also the rate of antineutrino production is correlated to the amount of specific fissile elements in the reactor core. By monitoring the antineutrinos during the fission process in the reactor core, scientists can estimate the variation of fissile material. A recent report [1] published by the Department of Safeguards of IAEA also said that a short baseline (SBL) neutrino detector has intrinsic characteristics for monitoring status, operation power and nuclear fuel composition ratio in real time outside the containment building of the nuclear reactor with no-interference mode.

Also many reactor neutrino experiments have searched for neutrino flavor oscillation by measuring the electron antineutrinos produced in a nuclear reactor. Since the KamLAND experiments in 2002 [2] gave a precise observation, the neutrino flavor oscillation model has been accepted as an actual phenomenon. One of the interesting issues on reactor neutrino is an anomaly in that an event number of measured neutrinos shows a deficit of 6% compared with the expectation [3,4], which means that there should be an undetected sterile neutrino in addition to the known three flavors. It should be created in the flavor oscillations, and does not participate in a weak interaction [5]. The recent high precision and high statistics data from Double Chooz [6], Daya Bay [7] and RENO experiments [8] may imply this.

The research project, which is funded by National Research Foundation of Korea (NRF), started on June, 2012, is developing a short baseline neutrino detector close to the HANARO research reactor, and the technology for reactor monitoring by measuring precisely the neutrino energy spectrum. It is also developing a liquid scintillator containing metals that have large neutron capture cross section, and pulse shape discrimination methods. We will then have a more flexible technology that can detect reactor neutrinos overground.

A prototype detector was developed and now under performance tests including evaluation of background noise characteristics arised from environmental and cosmic rays, muon veto performance, pulse shaping discrimination of the neutrinos signal from those by other interfering radiations. Along with them, intense and extensive simulation works were carried out using Monte Carlo technique mainly focusing on the optimization of the signal to noise ratio. So many liquid scintillation matters have been tested as candidate for a prototype and a main detector, and a frontend electronics and data acquisition software were under development.

2. Prototype detector for SBL neutrino detection

A SBL neutrino detector is designed to be installed inside the HANARO research reactor, which is an open-pool type reactor being operated with a power of 30 MW(th) and uses low enriched uranium (19.75%) for fuel. The purpose of the prototype detector is to study the background events that resemble inverse beta decay and are not separable from a real neutrino event. Because the SBL experiment is carried out near the reactor, there should be little overburden. In addition to the background induced by muons, various neutrons and gamma-ray sources in the reactor hall results in high background in the neutrino detector. We intend to study the background neutrino-like events by comparing the data from the prototype detector with the detail Monte-Carlo simulation studies by GEANT4[9].

The detector will be installed on the heavy shielding block before the PNS drum on the ST1 beam line. The schematic drawing of the prototype detector and Fig. 2 shows the fabricated detector, which is now being tested in the Institute of Basic Science (IBS) in Daejeon. It is planned that the prototype detector will end up the performance test until the end of 2014 and then moved to the HANARO site for the real experiment.

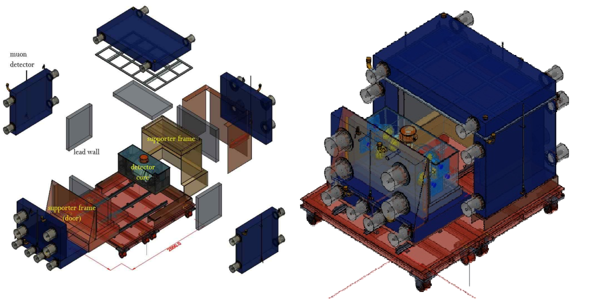

Fig. 1. Schematic drawing of the Hanaro SBL prototype detector.

Fig. 1. A prototype detector. It is now beinge tested in the Institute of Basic Science (IBS).

The prototype detector has an identical shielding structure of the main detector, which consists of a target volume of 500 liters. Figure 2 shows a schematic drawing of the prototype detector. The outmost layer is a 20 cm thick liquid scintillator, which acts as a muon veto countpter and provides shielding from cosmic rays and radioactivity from the surrounding radiation sources. Inside the outmost layer is a 10 cm thick lead shield and a stainless steel rectangular vessel, which contains an acrylic cylinder of 50 liters in the center with six 8 inch photomultiplier tubes mounted at both end cap of the cylinder, and mineral oil is filled between the acrylic and cylinder stainless vessels. The inner barrel surface of the acrylic cylinder has 3 mm thick PTFE plate to reflect the scintillation lights directing toward the photomultiplier tubes. There is a chimney at the acrylic cylinder to insert the calibration sources.

The selection of liquid scintillator (LS) for the neutrino detection is guided by physical and technical requirements, as well as safety considerations. A linear alkyl benzene (LAB) is used for a base solvent of the Hanaro SBL prototype detector. 3 g/ℓ of PPO and 30 mg/ ℓ of bis-MSB was dissolved to formulate LAB-based LS. Then, a 0.5% gadolinium (Gd) complex with carboxylic acid was synthesized using the liquid-liquid extraction method.

3. Conclusion

A reactor antineutrino experiment is under preparation for the development of reactor monitoring. For this, a prototype detector with a 500 liter liquid scintillator at the baseline of 6 m near the HANARO research reactor is developed and now being test. It will be used to study the background events that resemble inverse beta decay and are not separable from a real neutrino event. The main detector will be designed and developed based on these results from the prototype detector.

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