Monitoring Akkuyu Nuclear Reactor Using Antineutrino Flux Measurement

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Abstract. We present a simulation based study for monitoring Akkuyu Nuclear Power Plant’s activity using antineutrino flux originating from the reactor core. A water Cherenkov detector has been designed and optimization studies have been performed using Geant4 simulation toolkit. It was found that 1 ton of water Cherenkov detector with 0.3%-0.5% amount of gadolinium should be used for monitoring a nuclear reactor.

1. Introduction

The first nuclear power plant in Turkey will be constructed at Akkuyu, in Mersin province. It’s operation is planned to start in 2023. Akkuyu Nuclear Power Plant (NPP) will have 4 power units and each unit will have the capacity of 1.2 GW. Enriched uranium dioxides ($^{235}$U) will be used as fuel.

Measuring antineutrino flux from a nuclear reactor can provide real time information of reactor thermal power, which is directly related with emitted antineutrino flux. The relation between neutrino event rate at the detector ($N_{\nu}$) and reactor thermal power ($P_{th}$) is given by $N_{\nu} = \gamma (1 + k) P_{th}$, where $\gamma$ is a constant depending on detector (target mass, detection efficiency, etc.) and $k$ is time dependent factor which takes time evolution of the fuel composition [1]. This property makes a compact antineutrino detector a powerful tool for monitoring a nuclear reactor.

For 0.96 m$^3$ of a water target that is located 30 m away from the reactor core, we expect around 1050 events in a day with the detector near Akkuyu NPP.

2. Detector Design

An antineutrino can be detected by charged-current antineutrino-proton scattering, also known as inverse beta decay (IBD): $\bar{\nu} + p \rightarrow e^+ + n$. The prompt signal is generated by the positron, subsequently the thermal neutron capture process will give a second delayed signal. This delayed coincidence of the two signals in the time window of 20-80 $\mu$s is commonly used as trigger for antineutrino detection.

For the monitoring of Akkuyu Nuclear Reactor, we propose a relatively cheap neutrino detector composed of compact and transportable units. Each unit is planned to be composed
of a Gadolinium (Gd) doped water Cherenkov detector. A schematic view of such a unit is shown in Figure 1. The inner region of the detector is planned to be in the shape of a prism with dimensions $80 \times 100 \times 120$ cm, containing about 1 ton of Gd-doped water. Gd has the highest thermal neutron capture cross section, very suitable for such a detector. Therefore the Gd-doped water will play the role of the target for the charged-current antineutrino-proton scattering. The outer region of the detector unit will be covered by several layers. The first layer is made of about 3 cm thick plastic scintillator panels to veto cosmic charged particles. The following layers are planned as a passive shielding to suppress neutron and cosmic background. The design and material decision for passive shielding is under study. A large number of such units could be assembled and operated to increase the detection, thus monitoring, efficiency of the overall system.

![Figure 1. A monitoring unit proposed for Akkuyu nuclear power plant. The hemispheres represent the 10 inch photomultipliers, the rectangles stand for veto scintillators.](image)

Further details of the detector design, and the results of our simulations can be found in [2].

3. Conclusion
The first study on the design of a monitoring detector facility for Akkuyu NPP has been performed. A project is being submitted to TUBITAK for funding to produce a demonstration module. The final design, construction, and commissioning of a monitoring unit is expected to take up to 2 years.

References
[1] V.A.Korovkin et al. 1988 Measuring nuclear plant power output by neutrino detection Atomic Energy 65 3 712-718.
[2] Sertac Ozturk et al. 2016 Monitoring Akkuyu Nuclear Reactor Using Antineutrino Flux Measurement Turk J Phys 10.3906/fiz-1604-20, arXiv:1602.04646 [physics.ins-det].