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A Segmented Scintillator Detector for Aboveground Detection of Reactor Antineutrinos

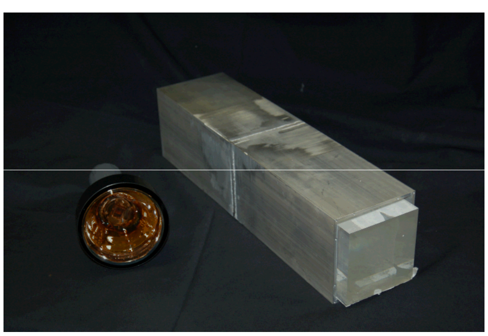
Antineutrino detection is attracting attention from the international nuclear safeguards community as a potential tool for independently measuring the amount of Pu produced in a commercial nuclear reactor. Contrary to traditional IAEA monitoring techniques based on item accountancy, antineutrino detection can provide a real-time measurement of the reactor operational status, thermal power and fissile inventory. The methodology of antineutrino detection has been demonstrated experimentally at the San Onofre Nuclear Generating Station (SONGS) in California using a cubic meter-scale liquid scintillator detector. With this proof-of-principle deployment, unambiguous sensitivity to changes in the thermal power has been demonstrated at the few percent level and sensitivity to changes in the Pu content has been demonstrated at the 80kg level.

The detection of antineutrinos is performed through identification of the final state products of the inverse beta-decay reaction:

$$\nu + p \rightarrow e^{+} + n \,.$$

While antineutrinos themselves can not be shielded or obscured by intervening material, this signature can be obscured by other environmental backgrounds such as gammas and neutrons. For this reason, all previous antineutrino detection has been performed at underground locations with at least a few tens of meters of overburden to shield cosmic-induced particle showers. However, to broaden the applicability of this technique for safeguards purposes, our current efforts have focused on technologies which could function within the higher background environments found aboveground.

For this application we have developed a novel segmented scintillation detector which provides significant background rejection through the use of particle identification (PID). The primary detection medium is a standard organic scintillator (plastic or liquid). By interleaving layers of ZnS:Ag/^{6}LiF (a common neutron detection screen used in neutron radiography) between segments of the scintillator, it is possible to take advantage of the high ^{6}Li cross-section for neutron capture. Identification of the neutron capture is performed through pulse-shape discrimination (PSD) based on the significant difference in the decay time-constant of the scintillation light from the organic scintillator (~10ns) and the inorganic ZnS (~200ns) as shown in Figure 1:



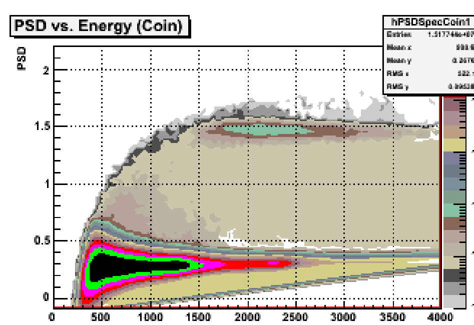


Figure 1 A Plastic scintillator segment protruding from its light-tight Al housing (left). The ZnS screens are optically coupled to the outside of the scintillator segment. A PSD plot (right) shows the clear separation between gamma events (below 1.2) and neutron capture events (above 1.2) as a function of energy in a single plastic segment.

While the ZnS allows PID for the final state neutron, further PID of the final-state positron can be achieved through topological identification of the positron's back-to-back annihilation gammas. The individual segment sizes were chosen such that the 511 keV gammas were likely to deposit most of their energy in a neighboring cell. Since positrons are relatively rare in nature, this PID selection has the most power for rejecting external backgrounds.

A 4-segment prototype system has been constructed and deployed aboveground at the San Onofre Nuclear Generating Station in Southern California. Initial operation during a refueling outage has shown impressive background rejections (see Figure 2). With the reactor off all recorded events are considered to be background – we find an initial candidate rate of over 225,000 events/day. However, using the neutron PID reduces that to 1830 events/day and the addition of the positron PID results in only 23 background events/day.

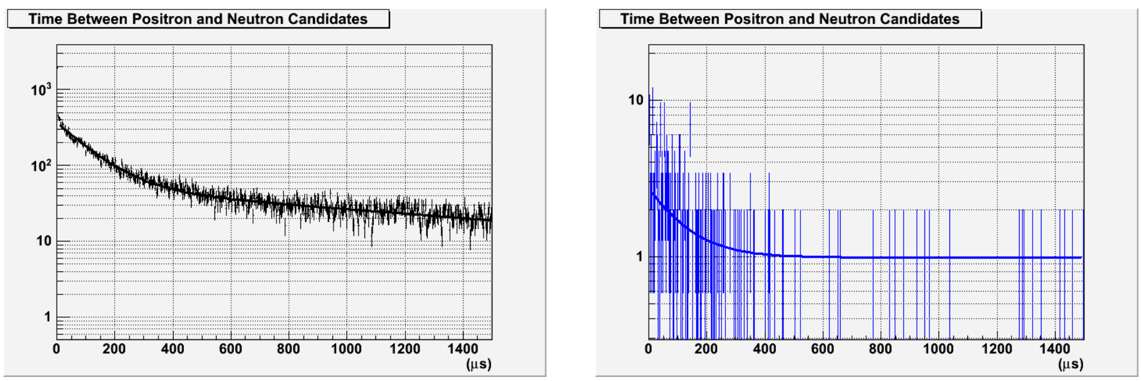


Figure 2 Interevent time distributions between the positron candidate and the neutron candidate for background events at SONGS. The rise at short times shows the characteristic neutron capture time-constant, while the longer time distribution is related to random un-correlated events. The distribution at left uses only the neutron capture PID (all gamma interactions are considered as positron candidates) while the right plot uses the maximum PID information of both neutron and positron definitions.

The reactor has been operating at full power since the end of February 2011 and initial data have been showing hints of an antineutrino signal. Data taking will be completed by the end of June and full data analysis will be available for this meeting. Based on our efficiency estimates from simulations and laboratory testing, we expect a 3 sigma observation of an antineutrino signal – this would be the first ever measurement of antineutrinos aboveground. In addition, an analysis of the available energy spectrum will allow unambiguous verification that the events result from reactor induced antineutrinos.