A Geoneutrino Experiment at Homestake

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A significant fraction of the 44 TW[1] of heat dissipation from the Earth's interior is believed to originate from the decays of terrestrial uranium and thorium. The only estimates of this radiogenic heat, which is the driving force for mantle convection, come from Earth models based on meteorites[2], and have large systematic errors. The detection of electron antineutrinos produced by these uranium and thorium decays would allow a more direct measure of the total uranium and thorium content, and hence radiogenic heat production in the Earth. It has been suggested that a large amount of uranium may be located in the core of the Earth[3] forming a natural nuclear reactor. This could produce up to 6 TW of heat, powering the Earth's dynamo.

The KamLAND collaboration has recently investigated electron antineutrinos originating from the interior of the Earth[4]; however, the sensitivity achieved was limited by a large background from surrounding nuclear power reactors. A similar experiment located deep underground to reduce cosmic-ray backgrounds, and away from nuclear power plants, could measure the total geoneutrino rate to precision limited by our knowledge of neutrino oscillations, and test the hypothesis of a natural nuclear reactor at the center of the Earth.

The most common method[4–6] for detecting $\bar{\nu}_e$'s is neutron inverse β decay which produces a positron and neutron. The positron kinetic energy is correlated to the $\bar{\nu}_e$ energy allowing spectral separation of the $\bar{\nu}_e$'s from ^{238}U and ^{232}Th decays. The detection of both the positron and neutron separated by a small distance and time, greatly reduces the number of backgrounds. Nevertheless, other events contribute backgrounds to the measurement. Backgrounds can typically be subdivided into three main categories: natural radioactivity, cosmic-rays and associated spallation products, and other $\bar{\nu}_e$ sources. Except for $^{13}\mathrm{C}(\alpha,\mathrm{n})$ reactions, where the α is primarily from ^{210}Pb decay, and $\bar{\nu}_e$'s from nearby nuclear power reactors, backgrounds in the recent KamLAND result[4] were negligible. There is a plan to purify the ^{210}Pb from the detector essentially eliminating the $^{13}\mathrm{C}(\alpha,\mathrm{n})$ background. Therefore it is clearly possible to build a detector with the required radioactive purity; however, the exact purity needed depends on the final detector design. Because of the greater rock overburden at the 4850' level of the Homestake mine, the cosmic-ray and associated spallation product backgrounds is expected to be ~ 20 times less than those at the KamLAND site[7], but the number of backgrounds will depend on the detector material, layout, and veto efficiency. The Homestake mine is located more than 750 km away from any major nuclear power reactor, resulting in an expected reactor background $\sim 7\,\%$ of the rate at KamLAND.

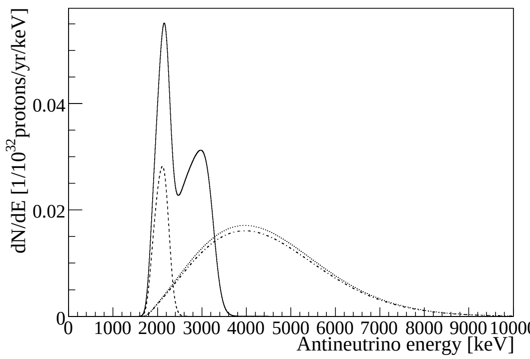

FIG. 1: The expected $\bar{\nu}_e$ energy distribution with a detector energy resolution of $6\%/\sqrt{E[\mathrm{MeV}]}$ for the ^{238}U (solid) and ^{232}Th (dash) geoneutrinos, expected commercial reactor background (dot-dash), and the expected spectrum from a 6 TW natural reactor at the Earth's core (dot).

Figure 1 shows the expected spectra for geoneutrinos, commercial nuclear reactors, and a natural nuclear reactor at the Earth's core. Excluding the ^{238}U and ^{232}Th distribution in the Earth, the largest error in determining the expected geoneutrino rate is due to the uncertainty in the neutrino oscillation parameter $\sin^2 2\theta_{12}$ which is known to $\sim 6\,\%$. Therefore, it does not make sense to plan on measuring the geoneutrino rate to much better than 6 %. Assuming a 10% error in the commercial nuclear reactor background the required exposure is estimated to be $\sim 2.3\times10^{32}$ target proton yr. This does not include systematic errors, but these should be constrained to better than 10 %. Even less exposure is needed to make a 3 sigma observation of a 6TW georeactor. This exposure could be achieved in approximately four years assuming a similar fiducial volume, $700\,\mathrm{m}^3$, and target proton density to KamLAND[8].

[1] H. N. Pollack, S. J. Hurter, and J. R. Johnson, Rev. Geophys. **31**, 267 (1993).
[2] W. F. McDonough and S. Sun, Chem. Geol. **120**, 223 (1995).
[3] J. M. Herndon, Proc. Nat. Acad. Sci. **100**, 3047 (2003).
[4] T. Araki et al., Nature **436**, 499 (2005).
[5] M. Apollonio et al., Eur. Phys. J. C **27**, 331 (2003).
[6] F. Boehm et al., Phys. Rev. D **64**, 112001 (2001).
[7] D.-M. Mei and A. Hime, Phys. Rev. D **73**, 053004 (2006).
[8] K. Eguchi et al., Phys. Rev. Lett. **90**, 021802 (2003).