Neutrino Geophysics at Baksan I: Possible Detection of Georeactor Antineutrinos*

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Abstract—J.M. Herndon in the 1990s proposed a natural nuclear fission georeactor at the center of the Earth with a power output of $3 \times 10^6$ TW as an energy source to sustain the Earth magnetic field. R.S. Raghavan in 2002 pointed out that, under certain conditions, antineutrinos generated in such a georeactor can be detected using massive scintillation detectors. We consider the underground Baksan Neutrino Observatory (4800 m w.e.) as a possible site for developments in geoneutrino physics. Here, the intrinsic background level of less than 1 event/yr in a liquid scintillation detector can be achieved and the main source of background is the antineutrino flux from power reactors. We find that this flux is $\sim 10$ times lower than at the KamLAND detector site and two times lower than at the Gran Sasso laboratory and thus at Baksan the georeactor hypothesis can be conclusively tested. We also discuss possible searches for the composition of georeactor burning nuclear fuel by analysis of the antineutrino energy spectrum. © 2005 Pleiades Publishing, Inc.

INTRODUCTION

In this paper, we consider possibilities of detecting at BNO (Baksan Neutrino Observatory of the Institute for Nuclear Research, RAS) antineutrinos from a georeactor using a liquid scintillation spectrometer of $\sim$1000-t target mass. The same spectrometer can detect $\bar{\nu}_e$ coming from terrestrial $^{238}\text{U}$ and $^{232}\text{Th}$ decays; the latter problem will be considered in the next publication. We mention also that here searches for the astrophysical antineutrino flux can be done.

The Earth’s magnetic field varies in intensity and irregularly reverses polarity with an average interval between reversals of about 200 000 yr. This requires some variable or intermittent energy source. This source is understood as a georeactor, i.e., as naturally varying self-sustaining nuclear chain reaction burning at the center of the Earth. The georeactor started $\sim 4.5$ billion years ago when $^{235}\text{U}/^{238}\text{U}$ enrichment was about 30%. In the georeactor, $^{239}\text{Pu}$ is formed by neutron capture in $^{238}\text{U}$ followed by two short-lived beta decays: $^{238}\text{U}(n, \gamma) \rightarrow ^{239}\text{U}(\beta^-) \rightarrow ^{239}\text{Np}(\beta^-) \rightarrow ^{239}\text{Pu}$. The neutron flux in the reactor is extremely low and, in contrast with man-made high-flux power reactors, $^{239}\text{Pu}$ does not contribute to the fission power and decays to $^{235}\text{U}$:

$^{239}\text{Pu}(\alpha, T_{1/2} = 2.4 \times 10^4 \text{yr}) \rightarrow ^{235}\text{U}$. Thus, the georeactor operates in a breeder regime and reproduces $^{238}\text{U}$ through the $^{238}\text{U} \rightarrow ^{239}\text{Pu} \rightarrow ^{235}\text{U}$ cycle. An average thermal power output of the uranium-based reactor is assumed to amount to $3 \sim 6 \text{TW}$. Had thorium been included, the power could be higher. Variations of georeactor power originate from self-poisoning due to accumulation of fission products and subsequent removal of these products by diffusion or some other mechanism. This is a short and very schematic summary of the georeactor concept proposed in a number of publications by Herndon [1].

A nuclear fission chain reaction can occur in nature. In 1956, Kuroda [2] showed that thick seams of uranium ore, 2 billion years ago, might have been able to support chain reactions and function as a natural nuclear reactor. Sixteen years later, remains of a natural nuclear fission reactor were actually found in a mine at Oklo in the Republic of Gabon in Africa [3].

Herndon’s idea about a georeactor located at the center of the Earth, if validated, will open a new era in planetary physics. However, it is not clear whether further geophysical, chemical, etc., studies can in the foreseeable future give a decisive confirmation (or disproof) of this reactor. Particle physics can give another approach to the problem. In 2002, Raghavan [4] pointed out that, under certain conditions, a direct and conclusive test could be obtained by detection of antineutrinos from such a georeactor.

Below, we consider a georeactor: expected $\bar{\nu}_e$ rate...
and spectrum (Section 1), and detector design and backgrounds (Section 2).

In Section 3, we compare $\bar{\nu}_e$ energy spectra emitted in $^{235}$U, $^{238}$U, and $^{233}$U fission and discuss possibilities of searches for georeactor fuel composition using $\bar{\nu}_e$ spectroscopy.

1. GEOREACTOR: EXPECTED $\bar{\nu}_e$ RATE AND SPECTRUM

Georeactor antineutrinos are detected in a liquid scintillation spectrometer via the inverse beta-decay reaction

$$\bar{\nu}_e + p \rightarrow n + e^+. \quad (1)$$

The visible positron energy $E_e$ is related to the $\bar{\nu}_e$ energy as

$$E_e = E - 1.80 + E_{\text{annihil}} - r_n \approx E - 0.8 \text{ [MeV]}, \quad (2)$$

where 1.80 MeV is the threshold of the reaction and $r_n$ is the neutron recoil energy. The signature of a neutrino event is $e^+$ and 2.2-MeV neutron signals correlated in time and space.

The calculated antineutrino interaction rate for georeactor power $W = 3$–$10$ TW and $N_p = 10^{32}$ target protons $N_{\bar{\nu}_e\text{GR}} = (33$–$110)/yr$ is found for the no-oscillation case and detection efficiency $\epsilon = 100\%$, the Earth’s radius $R_{\text{Earth}} = 6370$ km, and typical PWR parameters:

$$N_{\bar{\nu}_e\text{GR}} \approx (33$–$110)/yr \text{ with } 10^{32} \text{ protons, } 3$–$10$ TW,} \quad (3)$$

$$\epsilon = 100\% \text{ and no oscillation,}$$

which is exactly what has been found in [4]. Had $^{235}$U neutrino fission parameters been used, the rate would be $\sim 10\%$ higher.

2. DETECTOR DESIGN AND BACKGROUNDS

The sensitivity of low-energy antineutrino detection depends on detector size and level of background. In the past ten years, the sensitivity has been increased, in two steps (CHOOZ, KamLAND), by a factor of $\sim 10^8$ and approaches $\sim 1$ event per year per $\sim 1000$-t LS target.

The main features of future BNO detector design and location can be the following:

(a) Three-concentric zone detector design (Fig. 2). The central $\sim 14$-m-diameter zone one is a $10^{32}$ H atom liquid scintillator target contained in a spherical transparent balloon. Zone two is a buffer of nonscintillation oil contained in a $\sim 19$-m-diameter stainless steel vessel; on the inner surface of the vessel are mounted PMTs with $\sim 30\%$ photocathode coverage. A transparent acrylic barrier protects radon emanations from penetrating in the LS of zone one. Zone three is $\sim 22$-m-diameter water Cherenkov detector which gives veto signals for cosmic muons and, as passive shielding, protects the inner parts from neutrons and $\gamma$ rays coming from the surrounding rock.

(b) Deep underground position of the detector to reduce muon-induced backgrounds. BNO is located at a site with 4800 m w.e. rock overburden, which is much deeper than KamLAND’s 2700 m w.e. position.