

# Inverse beta decay reaction in $^{232}\text{Th}$ and $^{233}\text{U}$ fission antineutrino flux

G. Domogatski<sup>1</sup>, V. Kopeikin<sup>2</sup>, L. Mikaelyan<sup>2</sup>, V. Sinev<sup>2</sup>

<sup>1</sup>Institute for Nuclear Research RAS, Moscow,  
<sup>2</sup>Russian Research Center “Kurchatov Institute”

## Abstract

Energy spectra of antineutrinos coming from  $^{232}\text{Th}$  and  $^{233}\text{U}$  neutron-induced fission are calculated, relevant inverse beta decay  $\bar{\nu}_e + p \rightarrow n + e^+$  positron spectra and total cross sections are found. This study is stimulated by a hypothesis that a self-sustained nuclear chain reaction is burning at the center of the Earth (“Georeactor”). The Georeactor, according to the author of this idea, provides energy necessary to sustain the Earth’s magnetic field. The Georeactor’s nuclear fuel is  $^{235}\text{U}$  and, probably,  $^{232}\text{Th}$  and  $^{233}\text{U}$ . Results of present study may appear to be useful in future experiments aimed to test the Georeactor hypothesis and to estimate its fuel components as a part of developments in geophysics and astrophysics based on observations of low energy antineutrinos in Nature.

## Introduction

A revolutionary progress in antineutrino ( $\bar{\nu}_e$ ) detection technique demonstrated by KamLAND Collaboration [1] opens a real opportunities to study  $\bar{\nu}_e$  fluxes of natural origin and obtain information on their sources, which is otherwise inaccessible.

The Baksan Underground Observatory of the Institute for Nuclear Research RAS (BNO), as discussed in [2], is one of the most promising sites to build a massive antineutrino scintillation spectrometer for these studies. The research program can include:

- Study of Thorium and Uranium concentrations in the Earth by means of detection of  $\bar{\nu}_e$  -s coming from beta decay of their daughter products (“Geoneutrinos”). This problem was first considered in 60-ies [3] and is intensively discussed presently [4].
- Estimation of frequency of gravitational collapses in the Universe by detection of isotropic  $\bar{\nu}_e$  flux (1984, [5]).

As suggested by R. Raghavan (arXiv:hep-ex/0208038) and discussed in [2], the same spectrometer can be used to test the hypothesis [6] that self-sustaining nuclear chain reaction is burning at the center of the Earth (“Georeactor”). The main component of the nuclear fuel in the hypothetical Georeactor is  $^{235}\text{U}$ , while  $^{232}\text{Th}$  and  $^{233}\text{U}$  fission probably also contribute to the reactor power. In this paper we present calculated energy spectra of antineutrinos coming from  $^{232}\text{Th}$  and  $^{233}\text{U}$  neutron-induced fission and relevant inverse beta-decay positron spectra and total cross sections. Results of present study may appear to be useful in future experiments aimed to test the Georeactor hypothesis and to estimate its fuel components as a part of developments in geophysics and astrophysics based on observations of low energy antineutrinos in Nature.

Below we shortly describe method used to calculate the  $\bar{\nu}_e$  energy spectra generated by  $^{232}\text{Th}$  and  $^{233}\text{U}$  fission fragments, present relevant  $\bar{\nu}_e$  and positron spectra of the detection reaction



and compare them with known  $^{235}\text{U}$  spectrum.

## 1 Antineutrino and positron spectrum

1.1 For each of the considered nucleus the  $\bar{\nu}_e$  energy spectrum  $\rho_{calc}^i(E)$  was found by summation of  $\sim 550$  beta decay spectra of individual fission fragments weighted with their fission yields. The fission yields were taken from compilation [7], for decay schemes library accumulated in Kurchatov Institute was used.

1.2 Previously similar calculations for  $^{235}\text{U}$ ,  $^{239}\text{Pu}$ ,  $^{241}\text{Pu}$  and  $^{238}\text{U}$  were performed many times by Kurchatov Institute neutrino group and by other authors (a short list of references see e.g. in [8]). These studies show the following features:

- a) Antineutrino spectra for different fissile isotopes can differ significantly one from the other;
- b) Uncertainties of calculated spectra are large because of poor knowledge of decay schemes for many short-lived fission fragments;
- c) The ratios of calculated spectra for different fissile isotopes  $\rho_{calc}^i(E)/\rho_{calc}^k(E)$  are found with considerably lower uncertainties than uncertainties in each of the spectrum  $\rho_{calc}^i(E)$  and  $\rho_{calc}^k(E)$ .

We use point c) to correct  $\bar{\nu}_e$  spectra calculated for  $^{232}\text{Th}$  and  $^{233}\text{U}$  fission. The following correction procedure has been adopted. We use "true"  $\rho_{ILL}^i(E)$  ( $\bar{\nu}_e$  spectra) for  $^{235}\text{U}$ ,  $^{239}\text{Pu}$  and  $^{241}\text{Pu}$  found at ILL by a reconstruction of measured fission beta-spectra for each of the fissile isotope [9] and find three energy dependent ratios  $K_i(E)$  of calculated  $\rho_{calc}^i$  and  $\rho_{ILL}^i$  spectra:

$$K_i(E) = \rho_{calc}^i(E)/\rho_{ILL}^i(E) \quad (2)$$

An averaged over  $^{235}\text{U}$ ,  $^{239}\text{Pu}$  and  $^{241}\text{Pu}$  ratio  $K(E)$  (Fig. 1) is used to find corrected spectra  $\rho_{corr}^i(E)$ :

$$\rho_{corr}^i(E) = \rho_{calc}^i(E)/K(E), \quad (3)$$

$i = 2, 3$  in Eq. (3) indicates  $^{232}\text{Th}$  and  $^{233}\text{U}$ .

1.3 Found corrected  $\bar{\nu}_e$  energy spectra for  $^{232}\text{Th}$  and  $^{233}\text{U}$  together with the  $^{235}\text{U}$  ILL spectrum are presented in Table 1. Uncertainties include uncertainties of the correction procedure (i.e. uncertainty in the factor  $K(E)$ , Fig. 1) and proper uncertainty in ILL spectra. Estimated resulting uncertainty in  $\rho_{corr}^i(E)$  is (5-10)% (68% CL) in the (1.80-6.0) MeV  $\bar{\nu}_e$  energy region and is increasing to (15-20)% in the (6-8) MeV energy range.

Reaction (1) positron spectra  $S(E_{vis})$  for  $^{232}\text{Th}$ ,  $^{235}\text{U}$  and  $^{233}\text{U}$  (Fig. 2a) are presented vs positron energy absorbed in the scintillator

$$E_{vis} \approx E - 1.80 + 1.02 \approx E - 0.8, \quad (4)$$

( $E$  - is the energy of the incoming  $\bar{\nu}_e$ , 1.02 MeV is the energy of positron annihilation quanta, 1.80 MeV is the reaction threshold).

Total reaction (1) cross sections for  $^{232}\text{Th}$ ,  $^{235}\text{U}$  and  $^{233}\text{U}$  fission  $\bar{\nu}_e$  are presented in Table 2.

Presented data show systematic variation from harder spectra and higher cross sections to softer spectra and smaller cross sections in the sequence  $^{232}\text{Th} \rightarrow ^{235}\text{U} \rightarrow ^{233}\text{U}$ . This could be expected from the neutron/proton contents in the considered nuclei.

## Conclusions

Energy spectra of antineutrinos coming from  $^{232}\text{Th}$  and  $^{233}\text{U}$  neutron-induced fission are calculated, relevant inverse beta decay  $\bar{\nu}_e + p \rightarrow e^+ + n$  positron spectra and total cross sections are found. Results of present study may appear to be useful in future experiments aimed to test the Georeactor hypothesis and to estimate its fuel components as a part of developments in geophysics and astrophysics based on observations of low energy antineutrinos in Nature.

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## References

- [1] KamLAND Collaboration, Phys. Rev. Lett. 90 (2003) 021802.  
(<http://lanl.arxiv.org/abs/hep-ex/0212021>);  
<http://lanl.arxiv.org/abs/hep-ex/0310047>.
- [2] G. Domogatski, V. Kopeikin, L. Mikaelyan, V. Sinev,  
<http://lanl.arxiv.org/abs/hep-ph/0401221>, submitted to Phys. Atom. Nucl.
- [3] G. Marx, N. Menyhard, Mitteilungen der Sternwarte, Budapest, 48 (1960);  
G. Marx, Czech. J. Phys. B 19, 1471 (1969);  
G. Eder, Nucl. Phys. 78 657 (1966);  
M.A. Markov, Neutrino, 1964 Nauka, in Russian.
- [4] R. Raghavan, S. Schoenert, S. Emonto, J. Shirai, F. Suekane, A. Suzuki, Phys. Rev. Lett. 80, 635 (1998);  
F. Mantovani, L. Carmignani, G. Fiorentini, M. Lissia, Phys. Rev. D69 (2004) 013001.
- [5] G. Domogatski, Sov. Astron. 28 (1984) 30.

- [6] J.M. Herndon, Proc. Natl. Acad. Sci. USA 100 (2003) 3047;  
D.F. Hollenbach, J.M. Herndon, *ibid.* 98 (2001) 11085;  
Herndon J.M., J. Geomagn. Geoelectr. 45 (1993) 423.
- [7] T.R. England, B.F. Rider, Evaluation and Compilation of Fission Product Yields // 1993, LA - UR - 94- 3106. ENDF-349. LANL, October 1994, <http://ie.lbl.gov/fission.html>.
- [8] V. Kopeikin, L. Mikaelyan, V. Sinev, <http://lanl.arxiv.org/abs/hep-ph/0308186>, submitted to Phys. Atom. Nucl.
- [9] K. Schreckenbach et al. Phys. Lett. B160, 325 (1985); A.A. Hahn et al. Phys. Lett. B218 365 (1989).

Table 1:  $^{232}\text{Th}$ ,  $^{233}\text{U}$  and  $^{235}\text{U}$  fission antineutrino spectra (1/MeV · fiss.)

E, MeV	$^{235}\text{U}^*$	$^{233}\text{U}$	$^{232}\text{Th}$
1.75	–	1.27	1.82
2	1.3	1.08	1.61
2.5	0.9	0.675	1.13
3	0.637	0.443	0.812
3.5	0.437	0.290	0.587
4	0.283	0.177	0.405
4.5	0.172	0.992 (-1)	0.268
5	0.105	0.564 (-1)	0.176
5.5	0.617 (-1)	0.314 (-1)	0.114
6	0.370 (-1)	0.159 (-1)	0.672 (-1)
6.5	0.203 (-1)	0.778 (-2)	0.372 (-1)
7	0.105 (-1)	0.374 (-2)	0.201 (-1)
7.5	0.429 (-2)	0.137 (-2)	0.861 (-2)
8	0.136 (-2)	0.403 (-3)	0.272 (-1)

\*) The ILL  $^{235}\text{U}$  spectrum [9].

Table 2: Inverse beta decay total cross sections  $\sigma_f(10^{-43} \text{ cm}^2/\text{fiss.})$  for  $^{232}\text{Th}$ ,  $^{233}\text{U}$  and  $^{235}\text{U}$

$^{235}\text{U}^*$	$^{233}\text{U}$	$^{232}\text{Th}$
$6.39 \pm 2.7\%$	$3.87 \pm 10\%$	$9.70 \pm 10\%$

\*) Found using the ILL antineutrino spectrum [9].

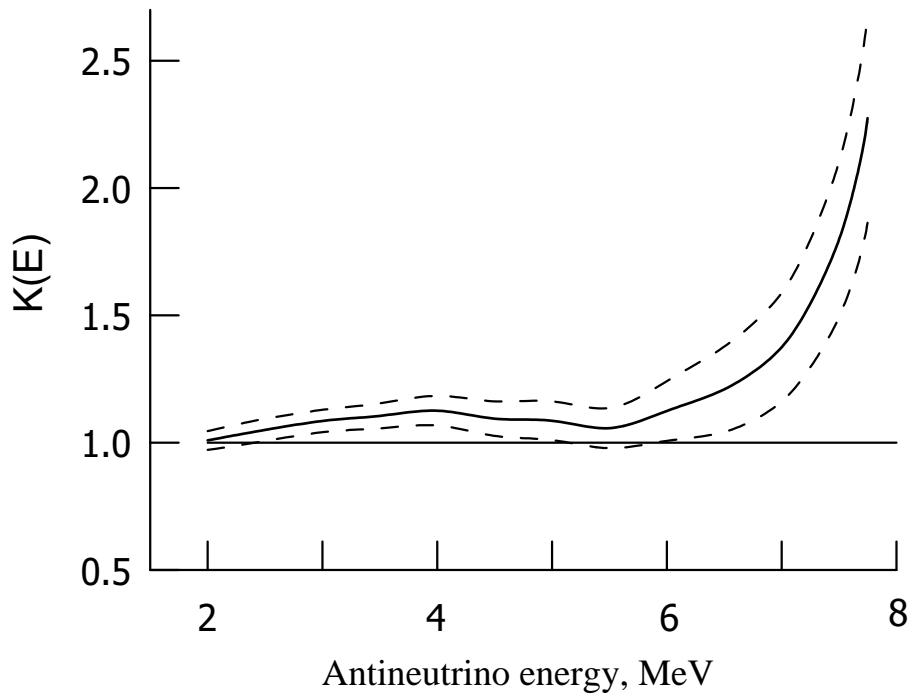


Fig. 1.  $K(E)$ , averaged ratio of calculated antineutrino spectra to the ILL spectra (solid line); dashed lines represent uncertainties found from individual deviations of  $K_i(E)$  and  $K(E)$  values (see Eqs (2) in the text).

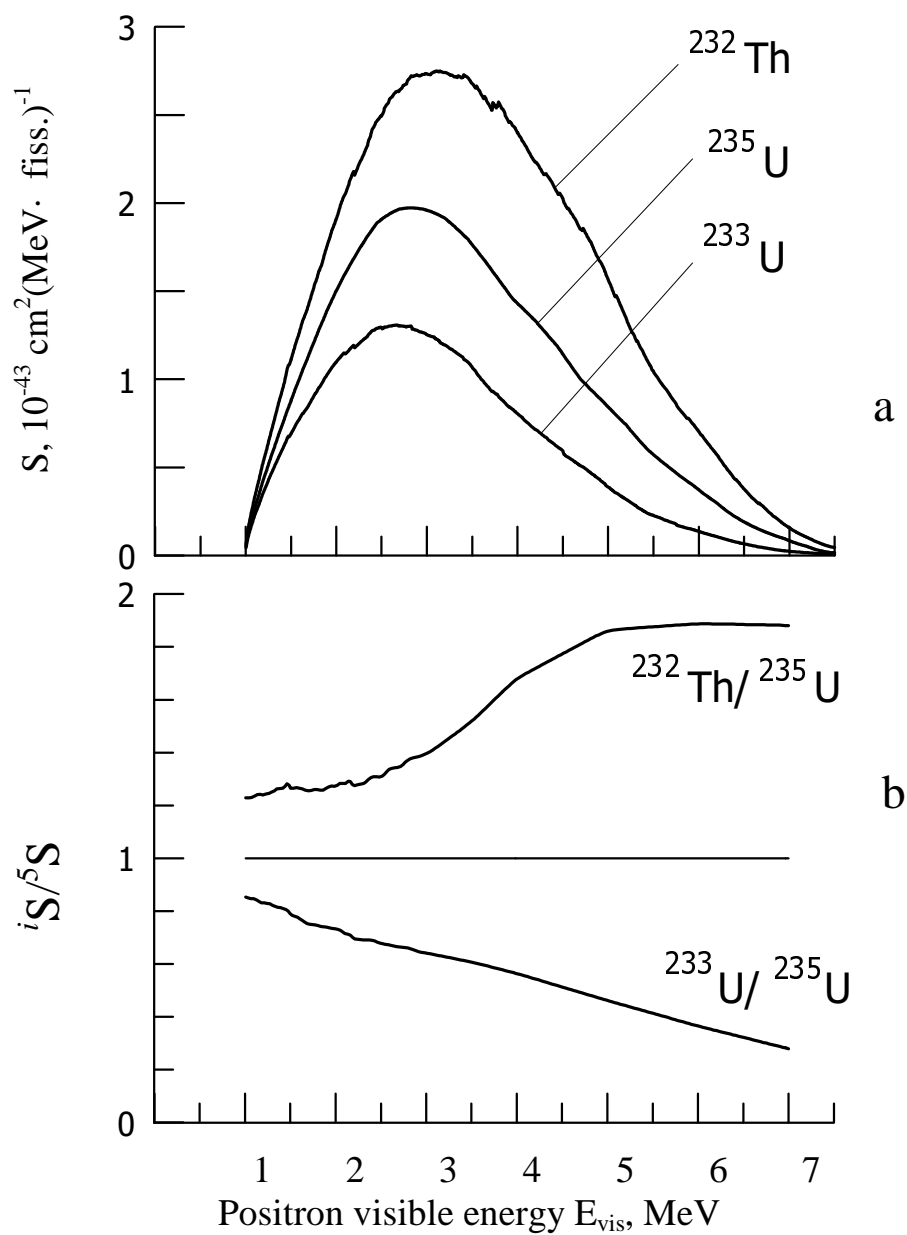


Fig. 2. Inverse beta decay positron spectra  $S(E_{vis})$  ( $10^{-43} \text{ cm}^2/\text{MeV} \cdot \text{fiss}$ ) for  $^{232}\text{Th}$ ,  $^{233}\text{U}$  and  $^{235}\text{U}$  (a);  
 (b) Ratios of  $^{232}\text{Th}$  and  $^{233}\text{U}$  positron spectra to that of  $^{235}\text{U}$ .