Search for neutrino oscillations in an experiment in the reactor of the Rovno nuclear power plant

A. I. Afonin, S. A. Bogatov, A. A. Borovoĭ, A. G. Vershinskiĭ, S. L. Gavrilov, Yu. L. Dobrynin, S. N. Ketov, Yu. V. Klimov, V. I. Kopeĭkin, L. A. Levina, I. N. Machulin, L. A. Mikaéliyan, S. V. Nikolaev, K. V. Ozerov, V. V. Sinev, S. V. Tolokonnikov, and A. N. Kheruvimov
I. V. Kurchatov Institute of Atomic Energy

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The positron spectrum in the reaction $\tilde{\nu}_e + p \rightarrow n + e^+$ is measured at a distance of 18 m from the reactor. These measurements have made it possible to impose limitations on the parameters of the Pontecorvo oscillations and to substantially reduce the region allowed for them as compared with the results obtained by the French group at the Bouger reactor in 1984.

1. The study of the process

$$\tilde{\nu}_e + p \rightarrow n + e^+ \qquad (1)$$

in a $\tilde{\nu}_e$ flux from a 1375-MWT reactor is being continued at the neutrino laboratory of the Rovno nuclear power plant.[1]

In 1984, approximately 30×10^3 $\tilde{\nu}_e$ were detected in two independent experiments, and the cross section of this reaction was measured[2]:

$$\sigma_f^{\exp} = 5.82\times 10^{-43}\ \text{cm}^2/\text{fission} \pm 6\%. \qquad (2)$$

This cross section corresponds to the core composition,

$$^{235}\text{U} - 60.6\%;\quad ^{238}\text{U} - 7.4\%;\quad ^{239}\text{Pu} - 27.7\%;\quad ^{241}\text{Pu} - 4{,}3\%, \qquad (3)$$

where the total number of fissions is indicated.

In this letter we report the results of a measurement of the energy spectrum of positrons in reaction (1) which was carried out simultaneously with the measurements of the total cross section.

2. The measurements were taken using a $\tilde{\nu}_e$ scintillation spectrometer placed at a point 18.06 m from the center of the reactor core.

As the target for $\tilde{\nu}_e$ and the detector of reaction (1) we used a liquid organic scintillator 240 l in volume, to which gadolinium was added.

The events of reaction (1) were identified by the method of delayed coincidences between the positron and the γ rays in the capture of neutrons in gadolinium. The detection efficiency was $\epsilon = 32.1 \pm 1.8\%$.

In contrast with the detectors used in neutrino experiments in France[3] and Switzerland,[4] the working volume of our scintillator is not divided into sections. The use of this type of detector has enabled us to sharply reduce the number of positrons that lose

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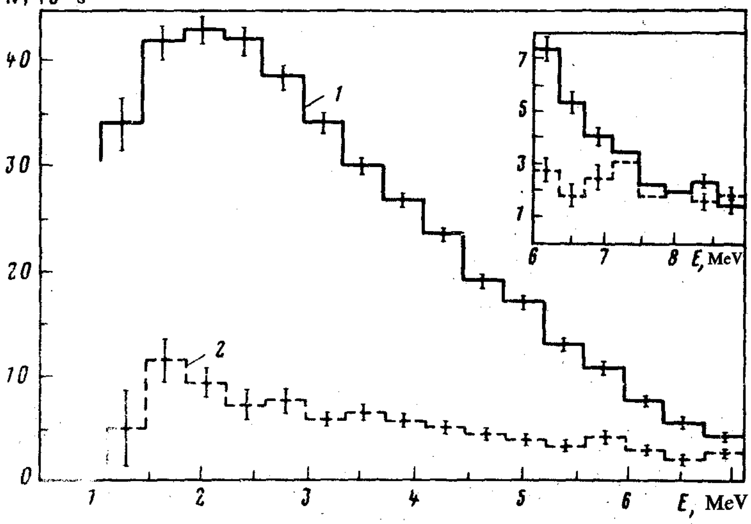

FIG. 1. The spectra measured during the reactor operation (1) and after it was shut down (2). Counts per 10^5 s are plotted along the ordinate. Histogram step—376 keV.

energy in the walls; a partial absorption of the annihilation γ rays shifts the spectrum being measured by 0.5 MeV toward higher energies. This shift has enabled us to lower the detection threshold and to measure the spectrum in the range $E_{e^+} = 1.08$–8.0 MeV, where E_{e^+} is the total energy (including the rest mass) of the positron. The background of fast neutrons from outer space, which imitate the events, was reduced through a special shielding arrangement which enables us at this stage to eliminate the use of a complex system for suppressing this background according to the pulse shape. The statistical base was built up over a period of 57.2 days (useful time) during the operation of the reactor and over a period of 20.1 days during the reactor shutdown (see Fig. 1). Approximately 15×10^3 $\tilde{\nu}_e$ were detected.

3. We found that none of the $\tilde{\nu}_e$ spectra suggested recently[5–8] gives an accurate enough description of the measured positron spectrum over the entire energy range.

In the energy region $E_{e^+} = 5.0$–7.0 MeV, the results of Ref. 5 (Fig. 2) are in best agreement with the experiment, whereas the results of Ref. 7 for the most abundant isotopes, ^{235}U and ^{239}Pu, in combination with those of Refs. 6 and 8 for the rest of the isotopes, are lower by 20–45%. At lower energies, the results of Ref. 7 are closest to our experiment near the spectrum peak and the spectrum of Ref. 5 is $\sim 15\%$ higher.[1)]

4. The Pontecorvo oscillations in a model of two mixed states (m_1 and m_2 are the masses, and θ is the Pontecorvo mixing angle) give rise, as we know, to a modulation of the positron spectrum:

$$\frac{d\sigma}{dEe} = \left(\frac{d\sigma}{dE_e}\right)_0 \left(1 - \sin^2 2\theta \sin^2 \frac{1.27\,\delta m^2 R}{E_e + 1.29}\right), \quad (4)$$

where $(d\sigma/dE_e)_0$ is the spectrum in the absence of oscillations, $\delta m^2 = |m_1^2 - m_2^2|$, (eV^2), $R(m)$ is the distance from the detector, and $E_{e^+} + 1.29 = E_{\tilde{\nu}}$ (MeV).

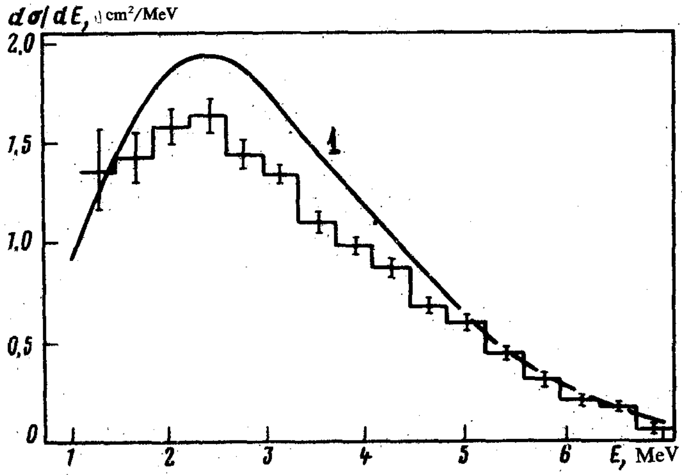

FIG. 2. Positron spectra of reaction (1) [in units of 10^{-43} cm²/MeV · fission)]. Histogram—experiment; 1—calculation based on the ν_e spectrum of Ref. 5.

Curve 1 in Fig. 3 imposes restrictions on the oscillation parameters obtained by comparing the measured positron spectrum and the positron spectrum expected in the absence of oscillations. Because of these uncertainties in the spectra of Refs. 5–8, these restrictions are less severe than those obtained by the CALTECH-SIN-TUM collaboration, where only the spectra of Ref. 7 were used for a similar comparison (see Ref. 4 and the bibliography cited there).

5. A comparison of the measured cross section of reaction (1) with the cross section expected in the absence of oscillations is less susceptible to the uncertainties mentioned above. The average cross section calculated from the spectra of Refs. 5–8 is

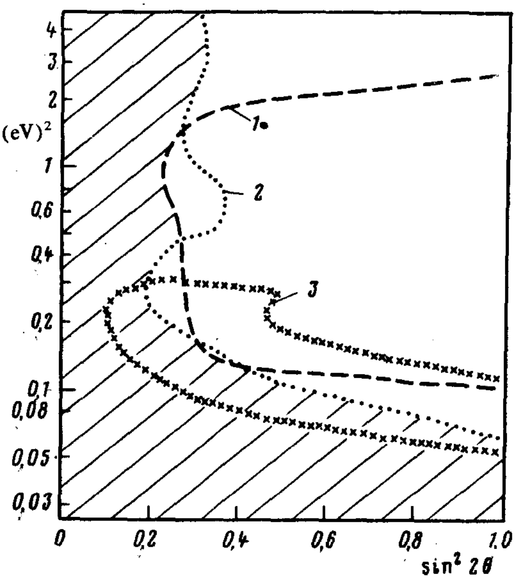

FIG. 3. Oscillation parameters (plane δm^2, $\sin^2 2\theta$). Curve 1—Restrictions on the oscillation parameters obtained from an analysis of the positron spectrum; curve 2—the same restrictions obtained from an analysis of the total cross section for reaction (1). The hatching shows the region in which oscillations may occur. This region was found from the combined data (spectrum plus cross section); curve 3 defines the allowed region of the parameters, based on the results of Ref. 3.

$$\bar{\sigma}_f^{\text{calc}} = 6.12 \times 10^{-43}\ \text{cm}^2/\text{fission} \pm 10\%, \quad (5)$$

where the error is determined from the spread of the average cross sections. From (5) and (2) we find

$$\frac{\sigma_f^{\text{exp}}}{\bar{\sigma}_f^{\text{calc}}} = \frac{5.82 \pm 6\%}{6.12 \pm 10\%} = 0.95 \pm 0.11. \quad (6)$$

Since the oscillations, if they do exist, reduce the cross section at a distance $R = 18$ m from the reactor by no more than 16%, according to (6), it is easy to find the limitations imposed on the oscillation parameters (curve 2 in Fig. 3), which turn out to be more rigorous.[2)]

The hatched region in Fig. 3 shows the values of the parameters which do not contradict the presence of oscillations, based on the combined data obtained by us (spectra plus cross sections).

In 1984, a group of researchers working at the reactor in France reported the detection of oscillations.[3] The results obtained by them are reproduced in Fig. 3 (the region enclosed by curve 3). It is evident that the results obtained by us significantly limit the permissible (according to Ref. 3) parameters.

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1)In the calculations we took into account the recoil due to a weak magnetism and the radiative corrections in accordance with Ref. 9.
2)This curve was previously obtained in Ref. 2, following a different line of reasoning.

1A. A. Borovoĭ and L. A. Mikaelyan, Atomnaya energiya **54**, 144 (1983).
2A. I. Afonin, A. A. Borovoĭ, Yu. L. Dobrynin, S. N. Ketov, V. I. Kopeĭkin, L. A. Mikaelyan, M. D. Skorokhvatov, S. V. Tolokonnikov, and A. N. Kheruvimov, Pis'ma Zh. Eksp. Teor. Fiz. **41**, 355 (1985) [JETP Lett. **41**, 435 (1985)].
3J. F. Cavaignac *et al.*, Phys. Lett. **148B**, 387 (1984).
4K. Gabathuler *et al.*, Phys. Lett. **138B**, 449 (1984).
5V. I. Kopeĭkin, Yad. Fiz. **32**, 1507 (1980) [Sov. J. Nucl. Phys. **32**, 780 (1980)].
6P. Vogel *et al.*, Phys. Rev. C **24**, 1543 (1981).
7F. von Feilitzch *et al.*, Phys. Lett. **118B**, 162 (1982).
8H. V. Klapdor and J. Metzinger, Phys. Lett **112B**, 22 (1982).
9S. A. Fayans, Yad. Fiz. **42**, 11(1985) [Sov. J. Nucl. Phys. **42**, No. 1 (1985)].

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