Comparison of the intensities of $\tilde{\nu}_e$ at two distances from the reactor of the Rovno nuclear power plant

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The count rates for the events of the reaction $\tilde{\nu}_e + p \rightarrow e^+ + n$ are measured at distances of 18 and 25 meters from the reactor. The decrease in intensity with the distance is consistent, within the limits of the statistical base (31600 $\tilde{\nu}_e$ were detected), with the decrease predicted on the basis of the geometry. The restrictions on the Pontecorvo oscillation parameters are found in the two-state model. Our results are compared with the results of a similar experiment performed by a French group, who reported a deviation from the geometry at distances of 13.6 and 18.3 meters from the reactor.

1. Two different detectors situated 18 meters from the reactor of the Rovno nuclear power plant were used to measure the cross section of the reaction

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

and to simultaneously obtain the energy spectrum of positrons from this reaction in absolute units (Refs. 1 and 2).

The absolute measurements of the cross section and spectra, provided their accuracy is high enough, form a metrological base for the study of other $\tilde{\nu}_e$-induced reactions (with deuterons, for example). Potentially, the absolute method also has basic merits in the search for neutrino oscillations. At this time, however, the sensitivity to neutrino oscillations is limited by the uncertainty in the understanding of the fission-induced $\tilde{\nu}_e$ spectra (see Ref. 2, for example).

2. In the laboratory of the Rovno nuclear power plant an experiment is being conducted on the search for neutrino oscillations. This experiment involves relative measurements of the characteristic features of the inverse β-decay at distances of 18 and 25 meters from the reactor (Fig. 1). A vague understanding of the $\tilde{\nu}_e$ spectrum is not a factor of any consequence in such an approach. In the present paper we are reporting the results of measuring the counting rates of the events in reaction (1) at the two distances from the reactor mentioned above. We point out in this connection that at distances of 13.6 and 18.3 meters from the reactor, there is a divergence, according to the report of the French group, in the ratio of the counting rates from the ratio predicted from geometric considerations.[3]

3. The measurements are carried out with a scintillation detector which holds 238 liters of gadolinized organic scintillator. The events from reaction (1) are identified

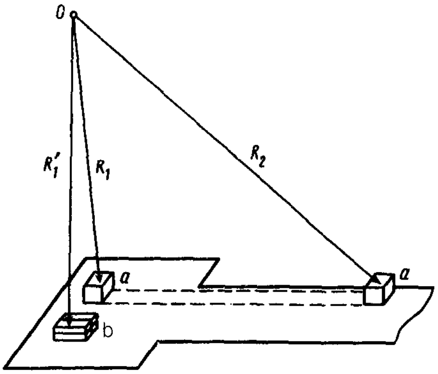

FIG. 1. Experimental geometry. O—Center of the reactor core; a—scintillation spectrometer; b—integrating detector.

from the delayed coincidences between positrons and neutrons. The positrons are detected in the range of kinetic energies 0.6–10 MeV, which includes 90% of all positrons. An event in reaction (1) is detected with an efficiency of 32%. The detector is not sensitive to the direction of the $\tilde{\nu}_e$ flux.

Below we list some data which characterize the experiment.

Reactor in Operation:	18 meters	25 meters
Mean power	99.7%	100.2%
Counting rate per 10^5 s	399.2 ± 4.1	266.3 ± 2.2
Useful time, s	49.4×10^5	103.6×10^5
Reactor shutdown:		
Counting rate per 10^5 s	95.6 ± 5.0	100.7 ± 5.0
Useful time, s	17.4×10^5	19.0×10^5

A total of 15 200 neutrino events were detected at a distance of 18 meters and 16 400 events were detected at a distance of 25 meters. After introducing into the data small corrections, which take into account the effect of the nearest reactor of the Rovno nuclear power station, we obtained the following results:

$$18\,\mathrm{m}:\ {}^1N_\nu = 307.5 \pm 6.6 \text{ within a time } 10^5 \text{ s};$$

$$25\,\mathrm{m}:\ {}^2N_\nu = 158.1 \pm 5.2 \text{ within a time } 10^5 \text{ s}. \qquad (2)$$

Identical measurements were conducted at each distance: before the reactor was shut down for reloading, during the shutdown, and again after the reactor was at full power. The average isotopic composition of the fuel was therefore nearly the same at 18 and 25 meters[1]:

	^{235}U	^{239}Pu	^{238}U	^{241}Pu	
18 m	0.606	0.277	0.074	0.043	(3)
25 m	0.557	0.313	0.076	0.053	

4. In a model of two states with the parameters $\Delta^2 = |m_1^2 - m_2^2|$ (eV)^2 and θ, where θ is the Pontecorvo angle, and m_1 and m_2 are the masses of the interfering states, we can write the counting rate at a given distance from the reactor in the form

$$ {}^iN_\nu = \frac{{}^i\overline{W}}{{}^i\overline{E}_f}\,\frac{1}{4\pi\,{}^iR^2}\,{}^5\sigma_f(1+{}^ik)\,{}^i\epsilon\,{}^iN_p\,(1-\overline{f}(\Delta^2\,{}^iR)\sin^2 2\theta)\,, \tag{4} $$

where $i = 1,2$ specify position 1 at 18 m and position 2 at 25 m, respectively. In (4) ${}^i\overline{E}_f$ is the mean energy absorbed in the reactor per fission, ${}^5\sigma_f$ is the reaction cross section for the $\tilde{\nu}_e$ spectrum of ^{235}U, $(1 + {}^ik)$ is the correction for the isotopic composition of the fuel in the reactor core, ${}^i\epsilon$ is the recording efficiency, and ${}^iN_p$ is the number of protons in the target. The function $\overline{f}(\Delta^2R)$ is the oscillating factor, $\sin^2(1.27R\Delta^2/E_\nu)$, which is weighted in the positron spectrum and which is averaged over the size of the reactor core. This function, which can easily be tabulated, is nearly independent of the specific spectrum of the reactor $\tilde{\nu}_e$.

We find the reduced ratio of the counting rates ${}^2_1X^{\rm exp}$

$$ {}^2_1X^{\rm exp} = \left(\frac{{}^2N_\nu}{{}^1N_\nu}\right)\left(\frac{{}^2R}{{}^1R}\right)^2\left(\frac{{}^1\overline{W}}{{}^2\overline{W}}\right)\left(\frac{{}^2\overline{E}_f}{{}^1\overline{E}_f}\right)\left(\frac{1+{}^1k}{1+{}^2k}\right)\left(\frac{{}^1\epsilon}{{}^2\epsilon}\right)\left(\frac{{}^1N_p}{{}^2N_p}\right), \tag{5} $$

which takes into account all differences arising in the measurements at the two distances, aside from the oscillations.

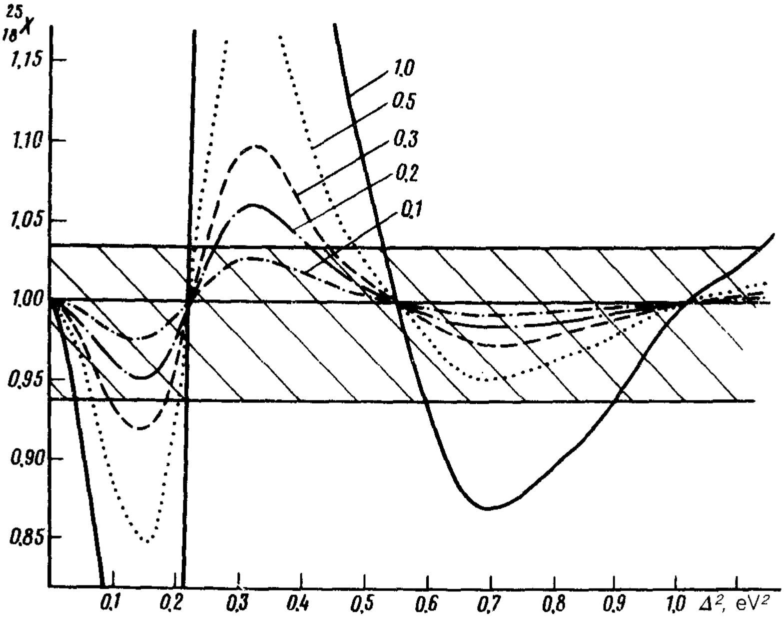

FIG. 2. Reduced ratio of the counting rates at the two distances ${}^2_1X$ versus Δ^2. The hatching shows the region corresponding to the experiment. The calculated curves include the $\sin^2 2\theta$ values.

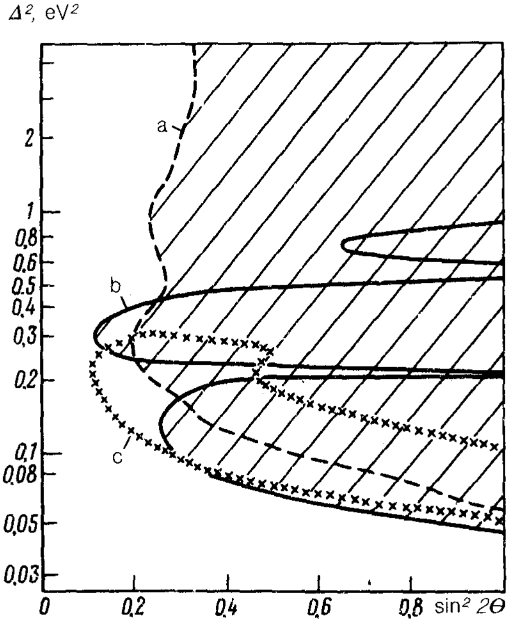

FIG. 3. The oscillation parameters—the $(\sin^2 2\theta, \Delta^2)$ plane. a—Restrictions imposed by the analysis of the absolute measurements; b—restrictions imposed by the results of the relative measurements at the two distances (the present study). The hatching shows the region of the forbidden parameters $(a+b)$; c—the curve limits the allowed region of the parameters according to Ref. 3.

Substituting in the factors in (5) the appropriate values with their errors, we find

$$
\begin{aligned}
{}_1^2X^{\exp} &= (0{,}514 \pm 3{,}9\,\%)\,(1{,}908 \pm 1{,}0\,\%)\,(1{,}000 \pm 1{,}5\,\%)\,(1{,}003 \pm 0{,}5\,\%)\\
&\quad \times (1{,}009 \pm 1{,}0\,\%)\cdot(0{,}994 \pm 1{,}2\,\%)\,(0{,}998 \pm 1{,}5\,\%)\\
&= 0{,}986 \pm 3{,}9\,\%\ \text{(statistical base)} \pm 2{,}9\,\%\ \text{(exp. method)}. \qquad (6)
\end{aligned}
$$

Result (6) can evidently be reconciled with the absence of oscillations. The restrictions imposed on the oscillation parameters were found from the reaction

$$
{}_1^2X^{\exp} = {}_1^2X^{\text{calc}} = \frac{1-\bar{f}(\Delta^2\,{}^2R)\sin^2 2\theta}{1-\bar{f}(\Delta^2\,{}^1R)\sin^2 2\theta}\,. \qquad (7)
$$

The Δ^2 function in Fig. 2 represents the right side of (7) and the band corresponding to result (6). The restrictions imposed on the plane $(\sin^2 2\theta, \Delta^2)$ are shown in Fig. 3. The hatching shows the region of the oscillation parameters which is excluded by the results of the present study and by the previous results[2] obtained by us. We see from the data in Fig. 3 that our results do not rule out the effect reported by the French group,[3] but reduce considerably the range of permissible parameters.

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1) Standard techniques were used. See, for example, Ref. 4 and the bibliography cited here.

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