New experiment on the inverse β decay of the proton in a nuclear reactor

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Preliminary results of measurements of the cross section for the reaction $\tilde{\nu}_e(p,n)e^+$ in the neutrino laboratory at the Rovenskiĭ atomic power plant are reported. Corresponding limits on the parameters of the neutrino oscillations are reported. The reaction was studied by detecting the emitted neutrons with counters filled with helium-3 surrounded by polyethylene.

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A new experiment has been undertaken in the neutrino laboratory at the Rovenskiĭ atomic power plant[1] to study the reaction

$$\tilde{\nu}_e + p \rightarrow n + e^+ \tag{1}$$

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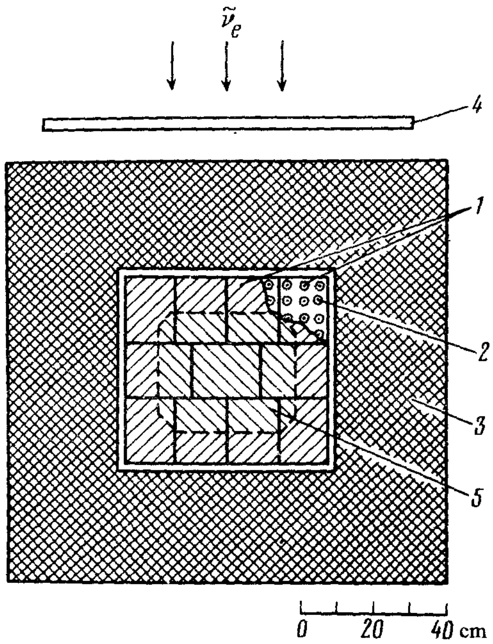

FIG. 1. The neutrino detector. 1—Detector unit; 2—counter filled with helium-3; 3—borated polyethylene; 4—scintillation anticoincidence plate; 5—central part of the detector (outlined by the dashed curve).

with a detector which detects only the neutrons produced in this reaction. The detector lies $\mathbf{R} = 18.6$ m from the center of the core, in direct contact with the scintillation neutrino spectrometer which has been operating since 1982.[2] We believe that the measurements by two completely different methods in the same $\tilde{\nu}_e$ flux improve the reliability with which the characteristics of reaction (1) are determined. The reasons for the recent interest in reaction (1) are the problem of Pontecorvo neutrino oscillations and the possible applications of the neutrino radiation of nuclear reactors.[3] The most recent measurement[1)] of the cross section was carried out in 1966 by Nezrick and Reines.[4]

The detector (Fig. 1) consists of separate units containing polyethylene, which doubles as the target for the $\tilde{\nu}_e$'s and the moderator for the resulting neutrons, whose characteristic energy is some tens of keV. The moderated neutrons are detected by proportional counters filled with helium-3 (the diameter of a counter is 32 mm, its length is 1000 mm, and the helium pressure is 4 atm). The detector contains a total mass of 136.4 kg of polyethylene and 132 counters. The entire apparatus is housed in a low-background chamber[1,2] at a depth of 30 mwe (meters water equivalent). This method for studying neutrino reactions in a reactor was developed at the Kurchatov Institute of Atomic Energy, Moscow, back in the 1960s.[7]

Measurements of the cross section for reaction (1) are complicated by the problem of accurately determining the leakage of neutrons from the detector and the neutron influx from the surrounding shielding, which contains hydrogen. These complications

TABLE I.

Average reactor power, MW	Number of counts2)	Useful time	Number of counts per 10^5 s
1375	8792	$6 \cdot 10^5$	1465 ± 16
0	36386	$27 \cdot 10^5$	1347 ± 7
1375	8773	$6 \cdot 10^5$	1462 ± 16

must be dealt with by supplementary calculations, which in turn must be varied in special experiments. Temporarily, at this stage of the study, we are using the data from only the central part of the detector (48 counters; Fig. 1), for which the neutron leakage is cancelled almost perfectly by the neutron influx (an "infinite medium").

Measurements have been taken before, during, and after shutdown of the reactor. Table I summarizes the results.

We see that the detector background is still quite high. A large part of this background is due to α contamination of the counter walls. The ratio of the useful effect to the background can be improved significantly by using pulse-shape analysis[8] and by improving the anticoincidence system.

The neutrino effect calculated from these results is $N_{\tilde{\nu}} = 116 \pm 13$ in 10^5 s.

The cross section per ^{235}U fission,[5] σ_f, is found from

$$N_{\tilde{\nu}} = \frac{\overline{W}}{\overline{E}_f} \, \frac{1}{4\pi R^2} \, N_p \epsilon \, (1+K) \, \sigma_f^{\;5} \, ,$$

where $\overline{W} = 1375 \pm 3\%$ MW is the average thermal power of the reactor, $\overline{E}_f = 202 \pm 2$ MeV is the average energy released in the reactor per fission, $R = 18.6 \pm 0.1$ m, $N_p = 4.25 \times 10^{27} \pm 2\%$ is the number of protons in the central part of the apparatus, $\varepsilon = 0.504 \pm 0.030$ is the neutron detection efficiency, and $K = -(0.04 \pm 0.02)$ is the correction for the fission of ^{238}U, ^{239}Pu, and ^{241}Pu in the reactor core.

The cross section3) σ_f found in this manner is[5] $\sigma_f = 5.77 \times 10^{-43} \pm 11\%$ (statistical) $\pm 9\%$ (systematic).

Comparison of our results with the expected value of the cross section yields only weak limits on the neutrino-oscillation effect. In the model of two oscillatory neutrino states m_1 and m_2 we would have

$$\Delta^2 = |m_1^2 - m_2^2| < 0,13\,\text{eV}^2 \;(\sin^2 2\theta = 1), \text{ or}$$

$$\sin^2 2\theta \lesssim 0.4, \qquad (\Delta^2 > 4\,\text{eV}^2).$$

The reasons for this situation lie in the experimental errors, which are still quite large, and also in the uncertainties regarding the cross section expected in the absence of oscillations.[2]

We are deeply indebted to M. A. Markov, who initiated this study, and to our colleagues in the laboratory, for useful discussions and assistance in the measurements. We are extremely indebted to the administration and staff of the Rovenskiĭ atomic power plant for their hospitality.

[1] The magnitude of the cross section was not given directly in reports of recent studies in reactors at Grenoble and in Switzerland.[6]

[2] These results are referred to an average thermal power of the reactor, 1375 MW. The fluctuations in the power from one series of measurements to another amount to 2–3%.

[3] On occasion, use is made of a cross section per $\tilde{\nu}_e$: $\sigma_{\tilde{\nu}_e} = \frac{1}{6{,}14}\sigma_f$ (Ref. 5). This is a purely conventional value, since most of the $\tilde{\nu}_e$'s lie below the threshold for reaction (1), and in a real reactor their number also depends on several factors which are difficult to control.

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