Neutrino experiment involving inverse beta decay at a nuclear reactor

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

(Submitted 2 December 1982)
Pis'ma Zh. Eksp. Teor. Fiz. **37**, No, 2, 122–124 (20 January 1983)

An experiment on the reaction $\tilde{\nu}_e + p \rightarrow n + e^+$ is being started at an underground neutrino laboratory at a nuclear power plant. Some preliminary data on the cross section are reported. The question of searching for Pontekorvo oscillations in reactor experiments is discussed.

PACS numbers: 13.15.Hq, 28.40.Nw

A study of the reaction

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

has been begun in an underground neutrino laboratory which has been constructed at a nuclear power plant.[1,2] The distance between the center of the reactor core and the detector is $R = 18.4$ m, lying between the distances (8.76 and 37.9 m) in recent experimental searches for neutrino oscillations[3,4] at Grenoble and in Switzerland.[6] In this letter we report preliminary results on the total cross section for reaction (1) obtained from the first 1500 neutrino events detected.

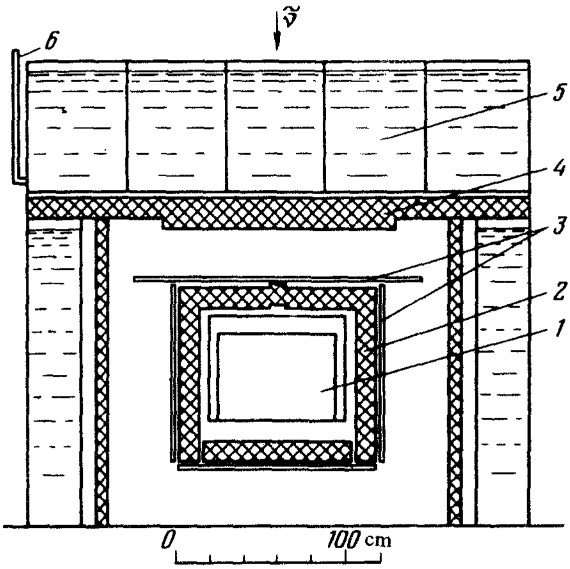

FIG. 1. The MD-1 neutrino detector. 1—Liquid-scintillator tank; 2—borated polyethylene; 3—active-shielding plates; 4—borated polyethylene; 5—water tanks; 6—level meter.

The $\tilde{\nu}_e$ detector uses a 242-liter organic scintillator with an admixture of a gadolinium compound at a concentration of 0.5 g (of the metal) per liter. The liquid scintillator is poured into a plastic box and monitored by 24 FÉU-49 photomultipliers through plastic light guides 15 cm thick. The detector is surrounded (Fig. 1) by multilayer shielding (consisting of passive and active layers). The assembly in Fig. 1 is in a low-background chamber 150 m^3 in volume below the reactor. The chamber has steel plating 160 mm thick and is shielded from the reactor by layers of heavy and ordinary concrete with a thickness of 1.3 kg/cm^2. The total amount of material above the chamber is about 30 m.w.e. (meters water equivalent) according to measurements of the absorption of cosmic-ray muons.

This shielding substantially reduces the background level.

Neutrino events are selected on the basis of delayed coincidence between the positron producing the trigger pulse and the neutron captured in the gadolinium. Specifically, the selection criteria are a trigger-event energy between$^{1)}$ 1.5 and 10 MeV, a second-event energy between 2.5 and 10 MeV, and an expectation time of 100 μs for the second event (at a neutron lifetime of 60 μs in the detector). The random-coincidence background is measured by repeatedly opening the time gates 300 μs after each trigger event. The dead-time loss is about 2%.

Experiments in which the water layer above the detector was reduced in thickness by 37 cm reliably established that there was no effect caused by non-neutrino emission of the working reactor. Although this measure reduced the shielding against fast reactor neutrons by more than and order of magnitude, we observed no increase of any sort in neutrinolike events.

The purely neutrino effect from the working reactor was distinguished in measurements at different reactor power levels: at the nominal power W_0 and at a reduced power of $0.62 \cdot W_0$. Here are the results of these measurements:

Reactor power	Live time	Effect
W	2.5×10^5 s	1026 ± 43
$0.62\times W_0$	2.5×10^5 s	746 ± 42

The useful effect (at the nominal reactor power) was extracted from these results: $(295 \pm 63)\times 10^{-5}$ s^{-1}. The count rate of correlated events not related to the operation of the reactor turned out to be 2.5 times lower than the effect.

The total reaction cross section σ_f^5 per ^{235}U fission event was found from

$$N_{\tilde{\nu}} = F N_p \, \sigma_f^5 \, \zeta_{\beta,n} ,$$

where $F = [N_f(1+K)]/4\pi R^2 = 9.34\times 10^{11}$ ($\pm 4\%$) is the fission flux density incident on the detector ($K = 0.04$ is a small correction for other fissile isotopes), $N_p = 1.64\times 10^{28}$ ($\pm 1\%$) is the number of protons in the target, and $\zeta_{\beta;n} = 0.34$ ($\pm$ 10%) is the detection efficiency for the selected pulse heights and time ranges.

We find the cross section σ_f^5 and the cross section per neutrino, $\sigma_{\tilde{\nu}}^5$ ($\sigma_{\tilde{\nu}}^5 = \sigma_f^5/6$) to be $\sigma_f^5 = 5.6\times 10^{-43}$ cm^2 and $\sigma_f^5 = 0.93\times 10^{-43}$ cm^2. The statistical error in these values is $\pm$ 20%, and the error of the method is $\pm$ 12%.

Despite the high count rate of neutrino events and the satisfactory relationship between the effect and the background level, the statistical error of this result is still quite high. The reason is that the useful signal is identified at a substantially reduced reactor power.

The problem of Pontekorvo oscillations makes precise measurements of the cross section for reaction (1), on the one hand, and refinement of the cross section expected in the absence of oscillations, on the other, questions of exceptional importance. The results of Ref. 7, $\sigma_{\tilde{\nu}}^5 = (0.94 \pm 0.13)\times 10^{-43}$ cm^2, and those of Refs. 4 and 5 are evidence that there is not significant oscillation effect, but under the condition that the expected cross section is calculated from the calculations of the neutrino spectra of Ref. 8 or measurements of the β spectra of fission fragments.[9] Calculations of the reactor spectra,[10,11] confirmed by measurements of the β spectra,[12,13] lead to cross sections for reaction (1) larger than found experimentally: $\sigma_{\tilde{\nu}}^5 = (1.20\text{–}1.28)\times 10^{-43}$ cm^2 do not include the (1). We believe that whether Pontekorvo oscillations are observed in these reactor experiments will remain an open question until some light is shed on this part of the problem.

---

1) Here we have given the energy dissipation in the detector. In terms of the kinetic energy of the positrons, this energy corresponds to a detection threshold ~1.0 MeV, since there is an effective shift ~0.5 MeV due to annihilation γ rays.

[1] L. A. Mikaelyan, in Neutrino-77, Vol. 2, 383 (1978), Moscow.
[2] A. A. Borovoĭ *et al.*, Preprint IAÉ-3317/2, Moscow, 1980.
[3] B. M. Pontekorvo, Zh. Eksp. Teor. Fiz. **33**, 549 (1957); **34**, 247 (1958) [Sov. Phys. JETP].
[4] S. M. Bilen'kiĭ and B. M. Pontekorvo, Usp. Fiz. Nauk **123**, 181 (1977) [Sov. Phys. Uspekhi **20**, 375 (1977)].
[5] H. Kwon *et al.*, Phys. Rev. D **24**, 1097 (1981).
[6] J. L. Vuilleumier *et al.*, Phys. Lett. **B114**, 298 (1982).
[7] F. A. Nezrick and F. Reines, Phys. Rev. **142**, 852 (1966).
[8] B. R. Davis *et al.*, **C19**, 2259 (1979).
[9] K. Schreckenbach *et al.*, Phys. Lett. **B99**, 251 (1981).
[10] F. T. Avignone and Z. D. Greenwood, Phys. Rev. **C 22**, 594 (1980).
[11] V. I. Kopeĭkin, Yad. Fiz. **32**, 1507 (1980) [Sov. J. Nucl. Phys. **32**, 780 (1980)].
[12] N. Tsoulfanidis, Nucl. Sci. Eng. **43**, 42 (1971).
[13] A. A. Borovoĭ *et al.*, Preprint IAÉ-3465/2, Moscow, 1981.

Translated by Dave Parsons
Edited by S. J. Amoretty