MODERN STATUS OF NEUTRINO EXPERIMENTS AT THE UNDERGROUND NEUTRINO LABORATORY OF KURCHATOV INSTITUTE NEAR KRASNOYARSK NUCLEAR REACTOR

Yu.V.Kozlov, S.V.Khalturtsev, I.N.Machulin, A.V.Martemyanov, V.P.Martemyanov, A.A.Sabelnikov, S.V.Sukhotin, V.G.Tarasenkov, E.V.Turbin, V.N.Vyrodov

Russian Research Center "Kurchatov Institute", 123182 Moscow, Russia

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Abstract

The investigation of antineutrino-deuteron interaction at Krasnoyarsk reactor are discussed. The characteristics of the installation "Deuteron", present results and perspectives of Krasnoyarsk neutrino laboratory are presented.

1 Introduction

This report presents the preliminary results of the experiments, which is in progress at the neutrino underground laboratory near Krasnoyarsk reactor.

Reactor antineutrinos ($\bar{\nu}_e$) interaction with deuteron comes by two channels:

\[
\begin{align*}
\bar{\nu}_e + d &\rightarrow p + n + \bar{\nu}_e' \quad \text{(NCD — Neutral Current on Deuteron)} \quad (1) \\
\bar{\nu}_e + d &\rightarrow n + n + e^+ \quad \text{(CCD — Charged Current on Deuteron)} \quad (2)
\end{align*}
\]
For the first time an investigation of these two reactions was proposed by Yu. Gaponov and I. Tyutin [1], where they also calculated the cross sections for both reactions.

The studying of these reactions can give information about:

a) weak constants for charged and neutral currents;

b) a length of neutron - neutron scattering;

c) neutrino oscillations;

The investigation of this interaction with reactor antineutrinos has advantages compared with accelerator neutrinos because of reactor antineutrinos interact with deuteron near a threshold of these reactions.

Measuring of the cross section in CCD channel permits to get a value of length of neutron - neutron scattering $a_{nn}$ in S channel without any strong interaction corrections, because neutrons of this reaction final step are in S stage. A table number 1 presents a dependence of $a_{nn}$ on $<\sigma_{cc}>$:

| $a_{nn}(S)$, fm | $<\sigma_{cc}>x10^{44}$, cm$^2$/fiss |
|-----------------|-----------------------------------|
| -16.6           | 1.077                             |
| -17.0           | 1.084                             |
| -18.5           | 1.112                             |
| -23.7($=a_{np}$) | 1.179                             |

Existing experimental data for $a_{nn}$ have more less accuracy than for $a_{np}$ and badly conform one with others. Average meaning of experimental value for $a_{nn}(S)$ is (-16.6±0.6)fm and the last result is (-18.5 ± 0.5)fm, whereas $a_{np}$ = (-23.715)fm.

2 Three experimental results obtained with reactor antineutrinos for today.

Results of previous reactor experiments on studying antineutrino- deuteron interaction are shown in table 2:
### Table 2

| Location       | \( \sigma^{NCD} \) | \( \sigma^{CCD} \) | \( \sigma^{CCD}/\sigma^{NCD} \) | \( \sigma^{CCD}/\sigma^{NCD}\) _exp_ | \( \sigma^{CCD}/\sigma^{NCD}\) _theor_ | \( \sigma^{CCD}/\sigma^{NCD}\) _exp_ _/_ \( \sigma^{CCD}\) _theor_ | \( \sigma^{CCD}/\sigma^{NCD}\) _exp_ _/_ \( \sigma^{NCD}\) _theor_ |
|----------------|----------------------|----------------------|-----------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Savannah       | \((3.8 \pm 0.9) \times 10^{-45} \text{cm}^2/\nu_e\) | \((1.5 \pm 0.4) \times 10^{-45} \text{cm}^2/\nu_e\) | \(0.40 \pm 0.14\)            | \(0.8 \pm 0.2\)                | \(0.7 \pm 0.2\)                | \(0.353^*\)                    | \(0.40 \pm 0.14\)               | \(0.353^*\)                    |
| River [2]      | \((3.0 \pm 1.0) \times 10^{-44} \text{cm}^2/fis.{}^{235}U\) | \((1.1 \pm 0.2) \times 10^{-44} \text{cm}^2/fis.{}^{235}U\) | \(0.37 \pm 0.14\)            | \(0.95 \pm 0.33^*\)            | \(0.98 \pm 0.18^*\)            | \(0.353^*\)                    | \(0.37 \pm 0.10\)               | \(0.37 \pm 0.08\)              |
| Krasnoyarsk [3] | \((2.71 \pm 0.46(\text{stat}) \pm 0.11(\text{sys})) \times 10^{-44} \text{cm}^2/fis.PWR - 440\) | \([1.17 \pm 0.14(\text{stat}) \pm 0.07(\text{sys})] \times 10^{-44} \text{cm}^2/fis.PWR - 440\) | \(0.43 \pm 0.10\)            | \(0.92 \pm 0.18\)            | \(0.37 \pm 0.08\)            | \(0.37 \pm 0.08\)              | \(0.37 \pm 0.08\)               | \(0.37 \pm 0.08\)              |

\( \sigma^{NCD} \) _theor_ = \(3.124 \times 10^{-44} \text{cm}^2/fis.{}^{235}U\) \*  \(\sigma^{CCD} \) _theor_ = \(1.11 \times 10^{-44} \text{cm}^2/fis.{}^{235}U\) \*  

### 3 Detector.

The modernized detector "Deuteron" (Fig.1) is situated at the underground laboratory (600 meters of water equivalent) at the distance of 34.0 m from the reactor, flux of neutrino is about a few units to \(10^{12} \bar{\nu}/\text{cm}^2\). The target \(\sqrt{\text{volume}}\) is 513 liters of \(D_2O\) (or \(H_2O\)) placed in the stainless tank, which is surrounded by 30 cm of Teflon for neutron reflection, 0.1 cm of Cd, 8cm of steel shots, 20cm. of graphite and 16cm of boron polyethylene \((CH_2 + 3\%B)\) for gamma and neutron shielding. The whole installation is pierced to make 169 holes (81 holes pass through the tank and Teflon, the others through the Teflon only). These holes house 169 proportional \(^3He\)

\(1^*\) here it is the theoretical values of cross sections taken from the work of Gaponov Yu.V. and Vladimirov D.M. for Schreckenbach K. reactor antineutrino spectrum.\[4\]
neutron counters with a reduced intrinsic alpha background. These counters are used for the neutron registration. They are located in the square lattice with a square side 10 cm. The active shielding covers the main assembly, against the cosmic muons.

The neutron counters used in the experiment can register only neutrons, so this detector is a detector of an integral type.

The counter consist of a stainless steel tube having length of 1 m and 31 mm in diameter with wall thickness of 0.5 mm. A 20 micron wire is extended along the counter. The wire is made from tungsten, covered by gold. Counter inner surface is covered by 60 microns of Teflon layer to reduce the natural alpha-background from a stainless steel wall, and than the Teflon layer is covered by 2 microns of pure copper layer to keep the counter able to work. The counter is filled with a mixture of 4 KPa $^3$He and 4 KPa$^{40}$Ar gases.

The main characteristics of the detector are presented in table 3:

Table 3

| Parameters                  | Light water | Heavy water |
|-----------------------------|-------------|-------------|
| An efficiency of one neutron registration by only tank counters | (27.5±0.3)% | (56.0±0.7)% |
| An efficiency of double neutron registration by all counters    | (9.9±0.1)%  | (41.6±0.4)% |
| A neutron life time         | (138±2)µ sec | (203±2)µ sec |

The efficiencies of the neutron registration for all neutrino reactions (CCP, NCD and CCD) were obtained by means of Monte-Carlo (MC) calculations. The reliability of the MC programs was checked by comparing the MC calculations with the corresponding experimental measurements with a $^{252}$Cf neutron source. The divergency between the calculations and the experimental data for all checks was within 1%.

4 Status of experimental work with the detector.

To get more information about characteristics of the detector and improve of limits on some parameters of neutrino oscillations the detector at first was
filled by light water (H\textsubscript{2}O) (at the end of 1995) and then by heavy water (at the end of 1996). The measurements with heavy water (D\textsubscript{2}O) have been started at the beginning of 1997 and are in progress now.

5 The results for the inverse beta-decay on proton (CCP reaction).

The detector exposure with the light water (H\textsubscript{2}O) continued for 115 \times 10^5 sec. The results of inverse beta-decay reaction on protons (\(\bar{\nu} + p \rightarrow n + e^-\))(CCP reaction)(events per day) are shown in table 4. All measurements were divided on 4 sets because of different background conditions.

| Group of measurements | Reactor switched on (ON) | Reactor switched off (OFF) | Effect (ON-OFF) |
|-----------------------|-------------------------|---------------------------|-----------------|
| Set1                  | 348.6±3.9               | 174.0±6.5                 | 174.6±6.9       |
| Set2                  | 341.7±3.1               | 177.0±5.9                 | 164.8±6.7       |
| Set3                  | 329.5±3.4               | 162.3±4.9                 | 169.5±6.0       |
| Set4                  | 327.5±4.2               | 146.5±4.8                 | 180.9±6.3       |

For nominal reactor power \(N_{eff} = (177.2 \pm 3.3)\) events/10\(^5\) sec,
which corresponds the value of the CCP cross-section:

\[ \sigma_{\text{exp}} = (6.39 \times 10^{-43} \pm 3.0\%) cm^2 / fission \ 235U \]  \hspace{1cm} (3)

This result is in a good agreement with the theoretical cross-section (V-A theory). Their ratio is:

\[ R = \frac{\sigma_{\text{exp}}}{\sigma_{V-A}}(235U) = 1.00 \pm 0.04 \hspace{1cm} (68\% CL) \] \hspace{1cm} (4)

This experiment gives no indications to the neutrino oscillations, so only the following limitation parameters can be obtained at 90\%CL:

\[ \Delta m^2_{1,2} \leq 0.016eV^2 \hspace{1cm} \text{for the } \sin^2(2\Theta) = 1 \]  \hspace{1cm} (5)

\[ \sin^2(2\Theta) \leq 0.09 \hspace{1cm} \text{for the } \Delta m^2_{1,2} \geq 1eV^2 \]  \hspace{1cm} (6)

Combining this limits with the results from previous experiments at Krasnoyarsk reactor the summary limitations on the neutrino oscillation parameters are presented on figure 2 with the limitations from Bugey [6], Gosgen[7] limitation from Chooz[8] experiment and zone permitted for \( \nu_e \leftrightarrow \nu_\mu \) oscillation represented by Kamiokande [9] groups.

6 Status of measuring of antineutrino - deuteron interaction.

From the beginning of 1997 there were measured six sets with reactor ON (about 211\times10^5 sec ) and six sets with reactor OFF ( about 62\times10^5 sec ). Preliminary results ( events per day) were placed in table 5:
Figure 2: The 90% exclusion plots, compared with the KAMIOKANDE allowed region.
| Number of SET | Reaction (neutron multiplicity) | Reactor ON | Reactor OFF | ON - OFF |
|--------------|---------------------------------|-------------|-------------|---------|
| 1            | NCD(1)                          | 296.6±3.0   | 277.2±4.2   | 19.3±5.2 |
|              | CCD(2)                          | 22.1±0.8    | 17.8±1.1    | 4.3±1.3  |
| 2            | NCD(1)                          | 291.2±3.0   | 273.4±4.8   | 17.8±5.7 |
|              | CCD(2)                          | 22.2±0.8    | 17.8±1.2    | 4.4±1.5  |
| 3            | NCD(1)                          | 289.9±3.1   | 279.7±6.4   | 10.2±7.1 |
|              | CCD(2)                          | 20.0±0.8    | 16.7±1.6    | 3.3±1.8  |
| 4            | NCD(1)                          | 415.3±2.9   | 389.5±4.1   | 25.8±5.0 |
|              | CCD(2)                          | 21.5±0.7    | 18.0±0.9    | 3.5±1.1  |
| 5            | NCD(1)                          | 412.4±2.6   | 393.8±6.2   | 18.6±6.7 |
|              | CCD(2)                          | 20.5±0.6    | 17.7±1.3    | 2.8±1.4  |
| 6            | NCD(1)                          | 406.0±3.3   | 372.2±9.3   | 33.7±9.9 |
|              | CCD(2)                          | 19.6±0.7    | 14.0±1.8    | 5.6±2.0  |
| Sum          | NCD(1)                          |             |             | 20.3±2.5 |
| result       | CCD(2)                          |             |             | 3.8±0.6  |

Processing these results gives:

$$\sigma^{NCD} = (3.3 \pm 0.4) \times 10^{-44} \text{cm}^2/\text{fis.}U^{235}$$
$$\sigma^{CCD} = (1.2 \pm 0.2) \times 10^{-44} \text{cm}^2/\text{fis.}U^{235}$$
$$\sigma^{NCD}/\sigma^{CCD} = 0.31 \pm 0.07$$

Summering latest results with previous Krasnoyarsk group experiment we’ve got:

$$\sigma^{NCD} = (3.2 \pm 0.4) \times 10^{-44} \text{cm}^2/\text{fis.}U^{235}$$
$$\sigma^{CCD} = (1.2 \pm 0.1) \times 10^{-44} \text{cm}^2/\text{fis.}U^{235}$$
$$\sigma^{NCD}/\sigma^{CCD} = 0.36 \pm 0.06$$

The experiment is in progress and we hope to get statistical accuracy in cross sections of the reactions ~ 5%.

7 New neutrino laboratory near Krasnoyarsk
Figure 3: A scheme of new Krasnoyarsk neutrino laboratory hall.

**nuclear reactor**

A new laboratory hall situated at less distance from the reactor have been created, a neutrino flux will be 3.5 times more there than at the previous laboratory hall and it will be about $10^{13} \bar{\nu}/\text{cm}^2/\text{sec}$. A scheme of this laboratory is presented by fig.3:

It is planned to use this new laboratory hall for searching for neutrino magnetic moment experiment.
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