ANTINEUTRINO-DEUTERON EXPERIMENT AT KRASNOYRSK REACTOR.

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Abstract
The investigation of antineutrino interaction with matter at Krasnoyarsk reactor is described. The characteristics of the detector "Deuteron" and the present results and perspectives are discussed.

1 INTRODUCTION.
This report is represented the results of some experiments, which carried out at the neutrino underground laboratory of Krasnoyarsk nuclear plant.
At the first it is necessary to say about the specific condition on Krasnoyarsk reactors:

- the unique complex of the industrial nuclear reactors is inside rock and a passive shielding from cosmic muons corresponds to 600 m.w.e. Due to the muons flux is suppressed by a factor 1000;

- the composition of a nuclear fuel in the reactor is such, that the difference between the real antineutrino spectrum and U-235 spectrum is less then 1%;
• the period "reactor-on" is equal to approximately 50 days and therefore one may measure the background each two months but not 1-1.5 years usual on power atomic station.

The new experiment for studying of interaction antineutrino with a deuteron on the improvement detector "Deuteron" is in progress now.

The interaction of antineutrinos ($\bar{\nu}_e$) with a deuteron occurs via two channels, Neutral Current on Deuteron (NCD) and Charged Current on Deuteron (CCD),

$$\bar{\nu}_e + d \rightarrow p + n + \nu'_e \quad (1)$$

$$\nu_e + d \rightarrow n + n + e^+ \quad (2)$$

The study of these reactions can give the information about:
• a) weak constants for charged and neutral currents;
• b) a length of neutron-neutron scattering;
• c) neutrino oscillation.

The results of the previous experiments on the study of antineutrino-deuteron interaction are shown in Table 1.

| Location          | $\sigma_{ncd}$ | $\sigma_{ccd}$ | $\sigma_{ncd}/\sigma_{ccd}$ | $\sigma_{exp}/\sigma_{theor}$ |
|-------------------|----------------|----------------|-----------------------------|-----------------------------|
| Savannah River    | $3.8 \pm 0.9$  | $1.5 \pm 0.4$  | $0.8 \pm 0.2$               | $0.7 \pm 0.2$               |
| Krasnoyarsk       | $3.0 \pm 1.0$  | $1.1 \pm 0.2$  | $0.95 \pm 0.33$             | $0.98 \pm 0.18$             |
| Rovno             | $2.71 \pm 0.46$| $1.17 \pm 0.14$| $0.92 \pm 0.18$             | $1.08 \pm 0.19$             |
| Bugey             | $3.29 \pm 0.42$| $1.10 \pm 0.23$| $1.01 \pm 0.13$             | $0.97 \pm 0.20$             |

Table 1.
2 DETECTOR DESIGN.

The modernized detector “Deuteron” (Fig.1) is situated in the underground laboratory at a distance 34.0 m from the reactor, the neutrino flux is about a few units to $10^{12} \bar{v}_e/cm^2$.

The target volume is 513 l of D2O (H2O) placed in a stainless tank, which is surrounded by 30 cm of Teflon for neutron reflections, 0.1 cm of Cd, 8 cm of steel shots, 20 cm of graphite and 16 cm of boron polyethylene (CH2+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 neutron counters with a reduced intrinsic alpha background. These counters are used for neutron registrations. They are located in a square lattice with a side of 10 cm. The active shielding covers the main assembly, against 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 consists of a stainless steel tube 1 m long and 31 mm in diameter with walls of 0.5 mm thick. A 20-$\mu$m wire is stretched along the counter. The wire is made from tungsten and coated with gold. The inner surface of counter is covered with 60-$\mu$m Teflon layer to reduce the natural alpha-background from the stainless steel wall, and than the Teflon layer is covered with 2 $\mu$m 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.

3 THE CHARACTERISTICS OF THE DETECTOR AND MONTE-CARLO SIMULATIONS.

A reaction is used for detecting neutrons. An amplitude spectrum is shown on the Fig.2. The ”wall” effect or losses of a part of energy in the counter wall have been measured and is shown on the Fig.3.

An efficiency of the detector was calculated with Monte-Carlo method as for inverse beta decay reaction as for antineutrino-deuteron reaction. Also calculations have been made for Cf252 source and this result was checked experimentally. The difference (less 1%) between the calculation and experimental
data shows good reliability of MC calculations. The neutron efficiency and neutron livetime are shown in the Table 2.

| Parameters/Target                              | H₂O       | D₂O       |
|------------------------------------------------|-----------|-----------|
| Efficiency of one neutron registration by tank counters only | $(27.5 \pm 0.3)\%$ | $(56.0 \pm 0.7)\%$ |
| Efficiency of double neutron registration by all counters     | $(9.9 \pm 0.1)\%$ | $(41.6 \pm 0.4)\%$ |
| Neutron livetime                                           | $(138 \pm 2)\mu s$ | $(203 \pm 2)\mu s$ |

A special attention was given to the correlated background for NCD channel connected with the antineutrino interaction with proton (H₂ atoms), because the cross section for such process is relatively large. The construction of the detector allowed us to decrease the efficiency neutron registration from boron polyethylene up to 0.002%. As a result we estimate the correlated background (Ncor) as 0.6 events/day due to the concentration light water in heavy water is 0.15%.

4 EXPERIMENT.

4.1 Data collection system.

The experiment was monitored ON-LINE on the CAMAC.

The event is registration of a neutron in the detector. The total information about event include itself:

- amplitude of any neutron;
- astronomic time;
- neutron zone registration (detector was divided into 32 groups of counters);
- multiplicity of event (a number of neutrons in 800 ms registration window after the first occurred neutron in the event);
- condition of event (no veto comes in the 800 ms interval before and after any neutron);
- time between neutrons in the same event.
4.2 Target $\text{H}_2\text{O}$.

The inverse beta decay on the proton reaction

$$\bar{\nu}_e + p \rightarrow n + e^+ \quad (3)$$

is used for checking and improving of some parameters of the detector. The exposure time is $115 \times 10^{-45}$s. or about 133 days. There are 4 sets of measurement with different background condition have been made. The results are represented in the Table 3.

| SET | Reactor power | Effect |
|-----|---------------|--------|
|     | ON            | OFF    |        |
| I   | 403.5 ± 4.5   | 201.4 ± 7.5 | 202.1 ± 8.0 |
| II  | 395.5 ± 3.6   | 204.9 ± 7.5 | 190.7 ± 7.7 |
| III | 381.4 ± 3.9   | 187.9 ± 7.5 | 196.2 ± 6.9 |
| IV  | 379.0 ± 4.6   | 169.6 ± 5.6 | 209.4 ± 7.3 |
| $\Sigma$ |         |        | 205.1 ± 3.8 |

The results was obtained with following cuts:

- only tank events were analyzed;
- the amplitude region of neutron registration with 644 to 884 KeV was taken.

In result the CCP cross section is

$$\sigma^{\text{exp}}_{\text{ccp}} = (6.39 \times 10^{-43} \pm 3.0\% \text{ cm}^2/\text{fission } ^{235}\text{U})$$

This result is in a good agreement with theoretical cross section (V-A theory). The ratio is (68% C.L.):

$$R = \frac{\sigma^{\text{exp}}_{\text{ccp}}}{\sigma_{\nu-e}} (^{235}\text{U}) = 1.00 \pm 0.04$$
4.3 Target D$_2$O.

From the beginning of 1997 and up to now the antineutrino-deuteron experiment is in progress. Data have been collected during 360 days reactor "on" and 120 days reactor "off". There were 8 sets of measurements. The results are shown in the Table 4.

| SET | T measured, 10$^5$ sec | Effect per 10$^5$ sec |
|-----|------------------------|----------------------|
|     | Reactor "ON" | Reactor "OFF" | NCD (only tank) | CCD |
| I   | 27.96       | 13.77       | 23.25 ± 5.97   | 3.37 ± 1.46 |
| II  | 34.94       | 10.16       | 21.14 ± 6.38   | 3.93 ± 1.55 |
| III | 26.82       | 5.94        | 11.79 ± 8.19   | 4.16 ± 1.87 |
| IV  | 45.04       | 20.44       | 28.38 ± 5.72   | 4.27 ± 1.15 |
| V   | 59.43       | 8.75        | 22.67 ± 7.76   | 4.14 ± 1.53 |
| VI  | 62.10       | 24.10       | 28.15 ± 5.10   | 4.91 ± 1.00 |
| VII | 28.26       | 18.94       | 17.33 ± 6.37   | 5.03 ± 1.20 |
| VIII| 43.34       | 9.90        | 26.15 ± 7.17   | 4.75 ± 1.37 |
| Σ   | 327.89      | 112.00      | 24.39 ± 2.24   | 4.44 ± 0.47 |

We used next cuts:

- events with the amplitude of the first neutron in interval from 644 to 844 KeV and the amplitude of second neutron in interval from 190 to 884 KeV and with the time between of two neutrons in region from 5 to 800 $\mu$sec selected for CCD channel;

- Events are detected by tank of the detector selected for NCD reaction.

To be sure that electronic and background conditions are quite stable the analyses of events with neutron multiplicity 3 and more was performed. Results are shown in Table 5.

| Multiplicity | "ON" | "OFF" | "ON" - "OFF" |
|--------------|------|-------|-------------|
| 3            | 3.108 ± 0.097 | 3.115 ± 0.169 | -0.007 ± 0.19 |
| more then 2  | 4.70 ± 1.12   | 4.68 ± 0.21   | 0.02 ± 0.24  |
4.4 Primary results.

Take to account both "wall" effect and time rejection for double neutron events and amplitude selection efficiencies registration of neutron are:

\[
\begin{align*}
\varepsilon_{1}^{ncd} \text{ (all detector)} &= 0.584 \\
\varepsilon_{1}^{ccd} \text{ (all detector)} &= 0.584 \text{ (registration the first neutron)} \\
\varepsilon_{2}^{ccd} \text{ (all detector)} &= 0.619 \text{ (registration the second neutron)} \\
\varepsilon_{1}^{nec} \text{ (tank)} &= 0.507 \\
\end{align*}
\]

After correction on probability registration in NCD channel events corresponded CCD channel and correlated background receive that

\[N^{ncd}(NCD) = 18.30 \pm 1.71 \quad (4) \text{ (only tank)}\]

From following below formulas (5), (6) and (7)

\[
\begin{align*}
N^{ncd} &= P_{\text{reactor}} \times \varepsilon_{1}^{ncd} \times N_d \times \sigma^{ncd}_{\text{exp}} \quad (5) \\
N^{ccd} &= P_{\text{reactor}} \times \varepsilon_{1}^{ccd} \times N_d \times \sigma^{ccd}_{\text{exp}} \quad (6) \\
N^{tcp} &= P_{\text{reactor}} \times \varepsilon_{1}^{tcp} \times N_p \times \sigma^{tcp}_{\text{exp}} \quad (7) \\
\end{align*}
\]

can obtain that

\[
\begin{align*}
\sigma^{ncd}_{\text{exp}} &= (3.09 \pm 0.30) \times 10^{-44} \text{ cm}^2 / \text{ fission } ^{235}U \\
\sigma^{ccd}_{\text{exp}} &= (1.05 \pm 0.12) \times 10^{-44} \text{ cm}^2 / \text{ fission } ^{235}U \\
\end{align*}
\]

These results are in good agreement with theory.

| Table 6. | \(\sigma, \times 10^{-44} \text{ cm}^2 / \text{ fission } ^{235}U\) |
|----------|------------------|
|          | NCD              | CCD              |
| Experiment | 3.09 ± 0.30      | 1.05 ± 0.12      |
| Theory (Schreckhenbach spectrum) | 3.18 ± 0.17 | 1.07 ± 0.07 |
| Ratio (experiment/theory) | 0.97 ± 0.11 | 0.99 ± 0.13 |

5 FUTURE.

We plan to continue experiment up to 2000 year, so about 500 days and 170 days reactor "on" and "off" respectively will be taken. It gives us the decreasing of error up to 8% for NCD and CCD channels.

To decrease the statistic error for CCD channel we plane to reject events using the geometry of detected neutrons.

After usual measurements will be made the calibration runs with Cf source installed in each hall to check Monte-Carlo simulation.
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|                              | NCD            | CCD            |
|------------------------------|----------------|----------------|
| Experiment                   | 3.09 ± 0.30    | 1.05 ± 0.12*   |
| Theory (Schreckenbach spectrum) | 3.18 ± 0.17    | 1.07 ± 0.07    |
| Ratio (experiment/theory)    | 0.97 ± 0.11    | 0.99 ± 0.13    |

References

[1] Pasierb E. et al., Phys.Rev.Lett., 1979, vol 43, p.96
[2] Kozlov Yu., et al., JETF Lett., 1990, vol 51, p.245
[3] Vershinsky Yu et al., JETF Lett., 1991, vol 53, p.489
[4] Skorokhvatov M, ”Study of interaction of electron antineutrino with protons and deuterons”, to be published
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