ITEP-66-94

Fermilab Library
0 1160 0072842 2

INSTITUTE OF THEORETICAL
AND EXPERIMENTAL PHYSICS

FERMILAB 66-94

MAR 0 199

IBRAR

V.Artemiev, E.Brakchman, A.Karelin, V.Kirichenko,
A.Klimenko, O.Kozodaeva, V.Lubimov, A.Nitin,
S.Osetrov, V.Paramokhin, A.Pomansky, A.Smolnikov,
T.Tsvetkova, S.Vasilyev, O.Zeldovich.

OBSERVATION OF ^{150}ND $2\beta2\nu$ DECAY IN THE TIME PROJECTION CHAMBER EXPERIMENT

MOSCOW 1994

УДК 539.173 N-16

OBSERVATION OF ^{150}ND 2β 2ν DECAY IN THE TIME PROJECTION CHAMBER EXPERIMENT; Preprint ITEP 66-94/

V.Artemiev, E.Brakchman, A.Karelin, V.Kirichenko, A.Klimenko*, O.Kozodaeva, V.Lubimov, A.Mitin, S.Osetrov*, V.Paramokhin, A.Pomansky*, A.Smolnikov*, T.Tsvetkova, S.Vasiliyev*, O.Zeldovich - M., 1994 - 12p.

The positive effect in the experiment to search for two-neutrino ββ decay of ^{150}Nd by using Time Projection Chamber is obtained. The half-life

$$T_{1/2}(2\beta 2\nu)=[1.88^{+0.98}_{-0.58}(stat.)\pm 0.19(syst.)]\cdot 10^{19}\text{years}.$$

is defined from the analysis of the data accumulated with samples of ^{150}Nd (92% enrichment) and ^{nat}Nd (the natural isotopic abundance - 5.6%). The effect to the background ratio is equal to 4/1.

We test the Monte-Carlo calculation of the efficiency and estimate the internal background from the special measurements with calibrated sources polluted by ^{238}U and ^{232}Th. The systematical error is obtained from this measurement.

Fig. - 6, ref. - 9.

© Институт теоретической и экспериментальной физики, 1994

*Institute for Nuclear Research, 117312, Moscow, Russia

INTRODUCTION

The neutrinoless double-beta decay is remained a topic of particular research interest because it may provide a sensitive test of lepton-number conservation and the existence of a Majorana mass of neutrino. The significant progress has been observed in the past few years in terms of improved experimental accuracy and also in terms of the number of isotopes which have been studied.[1]

Our group from the Institute of Theoretical and Experimental Physics prepares the experiment with a large (3.2m * 3.2m * 1.6m) Time Projection Chamber (TPC) in magnetic field to search of the neutrinoless double-beta decay[2]. We can use in our TPC up to 10 kg of enriched ^{136}Xe at atmospheric pressure as gas source and (5-10) kg of ^{150}Nd as a solid source. The sensitivity of the setup is about 10^{24}years, that corresponds to the limit of the neutrino mass on level of (1-0.2) eV. The interpretation of the results of $2\beta0\nu$ decay experiments depends strongly from the theoretical calculations of nuclear matrix elements, which are rather uncertain. Although there are no clear relation between the matrix elements of the two processes ($2\beta0\nu$ and $2\beta2\nu$) the comparison with experiment in the case of allowed $2\beta2\nu$ process may give some confidence in the computations.

A prototype TPC (1m * 0.8m * 0.4m) was constructed to have some experience. With this prototype we study the background and search for $2\beta2\nu$ decay ^{136}Xe.

At present, $2\beta2\nu$ decay is observed in the direct experiments for the isotopes ^{76}Ge, ^{82}Se, ^{100}Mo [1].

EXPERIMENTAL SITUATION

There have only a few studies of the $2\beta2\nu$ decay of ^{150}Nd. The first work was carried out in the Baksan Neutrino Observatory[3]. A limit $T_{1/2}>1.8*10^{19}$yr (95% CL) was found by the difference method (one sample was enriched to 92% by isotope ^{150}Nd, while the other sample had the natural abundance of this isotope- 5.6%). The

sample of ^{150}Nd was purified by the method of ion-traps in Ames Chemical Laboratory (Ames, Iowa) to eliminate the background due to radioactive impurities. After purification, the sample was divided into two parts. The first source (18g of ^{150}Nd) was used in measurements with TPC by Irvine group (UCI). The second source (38.5g) was used at scintillation spectrometer of the Institute of Nuclear Research (Baksan, Russia). The preliminary results obtained by Irvine (UCI) group[4] indicate that the $2\beta2\nu$ decay exists, with $T_{1/2}$ $9\cdot 10^{18}$ yr. The measurements carried out over 650 hours at the Institute Nuclear Research yielded no positive effect[5]. That result corresponds to a limit $T_{1/2}>1.1\cdot10^{19}$ yr (90% CL).

In our TPC experiment with ^{136}Xe we have reached the sensitivity 10^{20} years[6]. So we decided to joint the efforts of two group (ITEP and INR) to search the $2\beta2\nu$ decay of ^{150}Nd.

Our first result $T_{1/2}(2\beta2\nu)=(1.7^{+1.0}_{-0.5}\pm0.35)\cdot10^{19}$yr was published[7].

THE DETECTOR

Schematic view of the prototype in the magnet is shown on Fig.1 and described elsewhere[2]. The inner volume of TPC is divided by mylar film into two gas volumes. The smaller volume, filled with ^{136}Xe, is a gas source of $2\beta2\nu$ decay. In the case of solid source ^{150}Nd, which is placed on the the mylar film, the smaller volume is filled with CH_4. The kinematic parameters of electrons from 2β decay are defined in the large volume, by multiplier detectors installed at the end of the drift path. The additional cathode strip readout is provided in the large volume to determine the sign and the direction of the particles.

The energy resolution of the chamber was studied with radioactive source ^{207}Bi[2]. The measurement gives the value ± 100 keV for the energy of IC-electrons 0.5 MeV and 1.0 MeV.

The solid source was prepared by mixing a saturated solution of wax in toluene with a Nd_2O_3 powder, depositing the resulting material on the mylar film, flattening and drying it by hot air. Weight proportion (17 mg of Nd powder and 7.5 mg of wax per 1 cm^2) was chosen to achieve a stable coating on the mylar film.

BACKGROUND STUDY

TPC in magnetic field has some advantages to reduce the background. One of them is the tracking information. Determination of the direction rejects the electrons, coming out from the top cover and reflecting from the source. With the tracking criteria we can reject e^+e^- pairs. The magnetic field cuts out the background from lateral walls. The smaller volume (or the few cells in case of gas source) operates as active shielding against the bottom cover. There are only two background, which we can't reject by the tracking criteria in our chamber.

The first background, connected with external γ-ray flux, is double Compton or Compton-Moller scattering in the source. We can estimate this background from our previous work with ^{136}Xe[6] and wait for the source mass 50g the background of 4.5$\beta\beta$ event/1000 h. We used two sources, one from ^{150}Nd ,second from Nd with natural isotopic composition, to subtract the external background.

The next background is due to radioactive impurities in the source, for example, beta decay of ^{214}Bi from U-family followed by internal conversion. To estimate this background we carried out some additional exposures. In these measurements we detected a cascades: an electron from ^{214}Bi decay and delayed (164 μs) α-particle from ^{214}Po decay for ^{238}U series, and the analogous delayed β-α coincidences (300 ns) from ^{212}Bi- ^{212}Po decay for ^{232}Th series. The measurements were made for both (^{150}Nd and ^{nat}Nd) sources.

We performed also the measurements with two calibrated sources containing of (0.45 Bq/g) ^{238}U and (0.76 Bq/g) ^{232}Th sand, total mass of the each sources was about 21 g. We measured β-α delayed coincidences for two calibrated sources.

On the Fig.2(a,b) there are presented the time distributions of delayed α-particle for our working source with ^{150}Nd, collected during the 60 hours (a), and the same distribution for calibrated source with ^{238}U, measured during the 1.1 hours (b). The β-α count for Fig.2a corresponds to limit <0.1 events/hour and β-α delayed coincidence for Fig.2b is equal to 1260 events/hour.

Then there were selected the double electrons events for the

calibrated sources. In Fig.3 it is presented the sum-energy spectrum for source with ^{238}U, collected during 8.8 hours. Using well determined ratio between β-α and 2β events for sources, polluted by ^{238}U and ^{232}Th we can derived the limits on the background from radioactive contaminations of ^{238}U and ^{232}Th for our working sources (^{150}Nd and ^{nat}Nd). These limits for 1000 hours run are presented in the table (90% CL).

	^{150}Nd	^{nat}Nd
^{238}U	<1.2ev.	<1.2 ev.
^{232}Th	<2 ev.	<3 ev.

The concentration of ^{238}U and ^{232}Th in the working sources (with enriched and natural Nd) are less than $1.4*10^{-9}$ g/g and $8.8*10^{-9}$g/g correspondently, if we suppose that the series are in the equilibrium.

SEARCH FOR $2\beta2\nu$ DECAY

Two sources with the samples of ^{150}Nd and ^{nat}Nd were placed on maylar film simultaneously. The measured time, related to the mass of 51.5g Nd_2O_3 is 1260 hours for ^{150}Nd and 910 hours for ^{nat}Nd. After 'on-line' and 'off- line' processing selected events were viewed by physicists. The sum-energy spectra of the two electron events from both sources are presented on Fig 4(a,b).The difference between the counts from ^{150}Nd and ^{nat}Nd gives the positive effect 23 events for the energy range from 0.9 MeV to 2.5 MeV. We take into account that the sample with the natural isotopic composition contains 5.6% of ^{150}Nd and 1.5 events in Fig.4(b) may have been caused by the $2\beta2\nu$ decay. The background from radioactive contaminations are small and similar for both working sources.

The efficiency of the TPC for detection of $2\beta2\nu$ decay of ^{150}Nd is 2.8% according to Monte Carlo calculation . The solid curve in Fig.4(a) is the M.-C. spectrum of $2\beta2\nu$ decay, normalized on 23 events. Using the M.-C. calculation we obtained the half-life time of ^{150}Nd $T_{1/2}(2\beta2\nu)= (1.88 \pm^{0.66}_{0.38}) * 10^{19}$years.

The systematic error is defined mainly with the uncertainty of

M.C. calculation , with the efficiency of the programs for track recognition and track fitting and also with the visual selection efficiency. We use our calibration runs with special samples of Nd_2O_3, polluted by ^{238}U and ^{232}Th to test experimentally all our procedures. The selected single and double electron events were compared with the events generated by M.C. method for ^{238}U and ^{232}Th samples. For absolute normalization the concentration of the radioactive contaminations was measured by low background Ge-spectrometer. There were used the most intensive lines of Th-family (238 keV-^{212}Pb, 583 and 2615 keV-^{208}Tl, 911 keV and (968+ 965) keV -^{228}Ac) and U-family (294 and 352 keV -^{214}Pb, 609, 1120, 1764, and 2209 keV- ^{214}Bi).

The energy spectra for single and double electron events for ^{232}Th sample are presented in the Fig.5(a,b). The solid line in Fig.5a and dashed histogram in Fig.5b are the M.C.calculation, normalized on the activity of radioactive contamination measured by Ge-detector.The same calculation was performed for ^{238}U sample.

From measurements we have 220 and 226 2β events for Th and U samples and M.C. calculations gives the 244 and 216 event correspondently. One can see, comparing the summary of experimental data (446 events) and the calculations (460 events), that the difference isn't more than 5%.

So we concluded that our procedure of processing and calculation is correct and the efficiency equals (2.8±0.25)%.

The visual selection efficiency, determined on the large statistic from calibrated sources, equals (95±2)%.

Thus we estimate the full systematic error as 10% and our result is

$$T(2\beta 2\nu)_{1/2}=[1.88^{+0.66}_{-0.39}(stat.)\pm 0.19(syst.)] \cdot 10^{19} years.$$

To illustrate the stability of our result we make some estimations:

1. We can change the low energy threshold $(E_1+E_2)>1.1$ MeV with $\varepsilon=2\%$, the result is equal $T_{1/2}= 1.93 \cdot 10^{19}$yr,
   for $(E_1+E_2)>1.3$ MeV with $\varepsilon=1.6\%$ we obtained $T_{1/2}= 1.54 \cdot 10^{19}$yr.
2. We can suppose that there is no background and the effect is 29 events without subtraction, the half-life is $T_{1/2}= 1.49 \cdot 10^{19}$yr.

We also compare the single electron energy spectrum for 2β evens with M.C. calculation for 2β decay of ^{150}Nd. The spectrum for 2β events in the energy range $0.9<(E_1+E_2)<2.5$ MeV from ^{150}Nd sample is presented in Fig.6. There is seen sufficiently good consistent with M.C. calculations of 2β decay, normalized on the effect 23 events, with realistic background.

Due to the fact that there is no difference between the natural and enriched Nd at the energy range from 2.3 to 3.5 MeV we can derived the next limits:

$T_{1/2}(0\nu)^{RHC}>4.4*10^{20}$years,

$T_{1/2}(0\nu)^{<m>}>1.9*10^{20}$years, $<m_\nu> < 13$ eV,

$T_{1/2}(0\nu,\chi) >1.55*10^{20}$years, $<g_{\nu\chi}> <1.35*10^{-4}$.

In this analysis we use the matrix elements from the work of A.Staudt et al.[8]. The only limit for the Majoron coupling constant is compatible with the best world data[1].

COMPARISON WITH THEORETICAL PREDICTIONS

The two neutrino decay of ^{150}Nd is observed and half-life time is defined $T(2\beta2\nu)_{1/2}=[1.88^{+0.66}_{-0.39}(stat.)\pm0.19(syst.)]*10^{19}$years. Our result agrees very well with the theoretical calculations of $2\beta2\nu$ decay, using the Operator Expansion Method (OEM)[9],

$T_{1/2}=1.66*10^{19}$ years.

In the usual QRPA model $2\beta2\nu$ decay matrix elements strongly depend on one particular model parameter (the strength of the particle-particle interaction g_{pp}). The half-life[8] for the "most probale value "of the parameter g_{pp} is $T_{1/2}= 7.37*10^{18}$years.

ACKNOWLEDGMENT

Authors would like to thank M.V.Danilov for his permanent interest and support, I.V.Kirpichnikov for useful discussions and help in organization of the collaboration. This work was supported in part by Russian Foundation of Fundamental Investigation ,grant (92-02-3965) and by the Soros Humanitarian Foundations Grant awarded by American Physical Society.

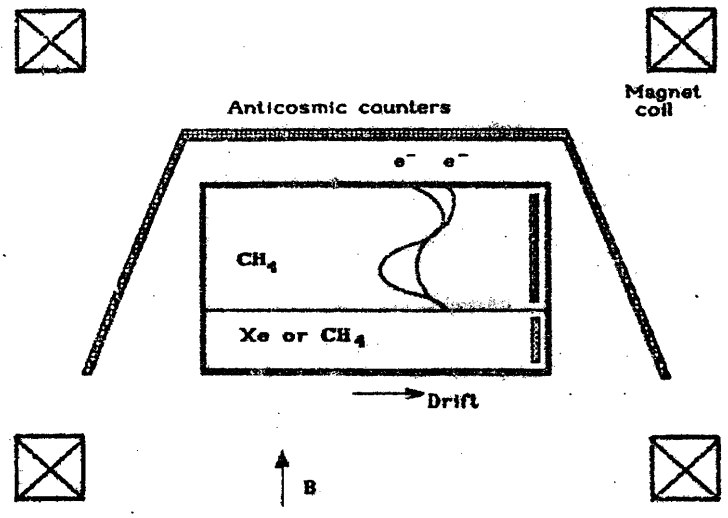

Fig. 1 The prototype (1.0m*0.8m*0.4m) TPC in magnetic field 800G.

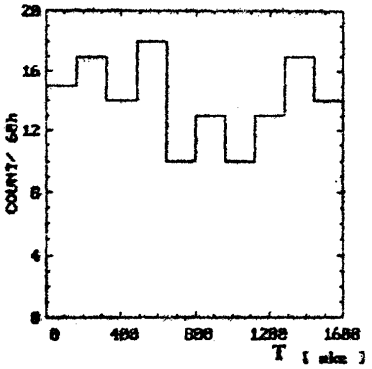

Fig.2a The time distribution of delayed α-particles for ^{150}Nd source.

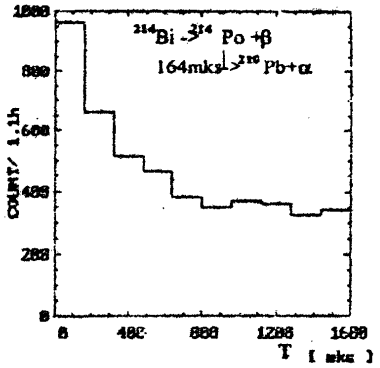

Fig.2b The time distribution of delayed α-particles for Nd-source, polluted by ^{238}U.

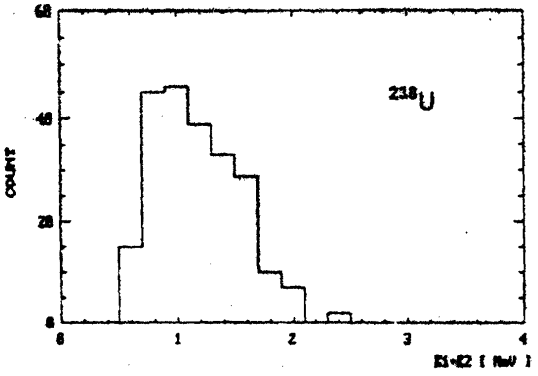

Fig.3 The sum-energy spectrum for 2β events from Nd source, with ^{238}U sand, collected for 8.8 hours (226 events).

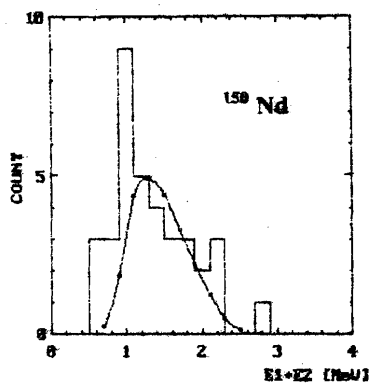

Fig. 4a The sum-energy spectrum of two electrons from a source enriched in the isotope ^{150}Nd (1260h, 36 ev.). The solid line is the Monte Carlo calculation of $2\beta2\nu$ decay of ^{150}Nd.

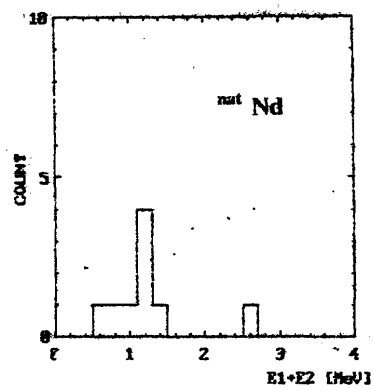

Fig. 4b The sum-energy spectrum of two electrons from a source with the natural isotopic abundance (910h, 9ev.)

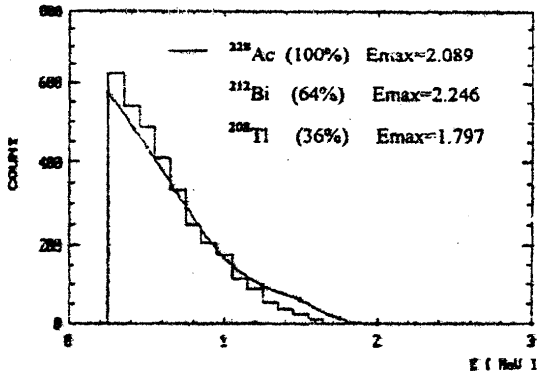

Fig.5a The energy spectrum for single electron events from Nd source with ^{232}Th sand . Solid line is the calculation of β-spectrum from ^{232}Th family, normalized to the activity measured by Ge detector.

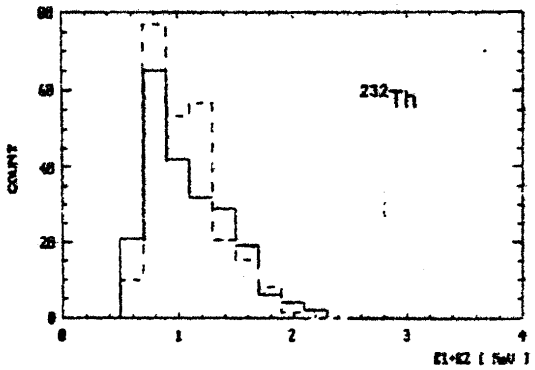

Fig.5b Sum energy spectrum for double electron events from Nd source with ^{232}Th . Dashed histogram is M.C. calcucation normalized to activity measured by Ge detector.

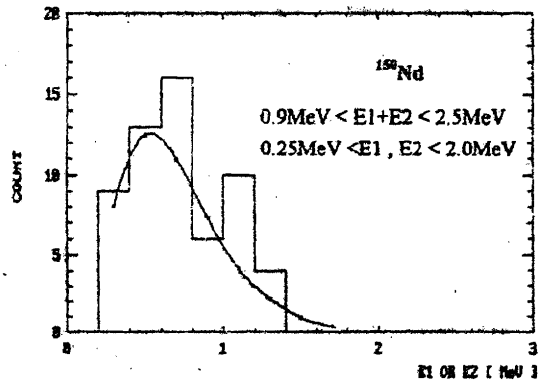

Fig.6 Single electron energy spectrum for 2β events from ^{150}Nd source. Solid line is M.C.calculation, normalized on 23 events.

REFFERENCE

1. M.Moe, P.Vogel, preprint UCI-NEUTRINO 94-5, February 1994. Submitted to Annual Review of Nuclear Particle science.
2. V.A.Artemiev, E.V.Brakchman, M.A.Ivanovskii et al., Nucl.Instrum.Meth. A303, 309, (1991)
3. A.A.Klimenko, S.B.Osetrov, A.A.Pomanskii et al., Nucl.In strum.Math. B17, 445, (1986)
4. S.R.Elliot, A.A.Hah, M.K.Joe et al., in Proceedings of the XV International Conference on Neutrino Physics and Astrophysics (NEUTRINO'92),ed.,A.Morales,Nucl.Phys.B,Proc.Suppl.,p.62 (1993)
5. S.I.Vasiliev, A.A.Klimenko, A.A.Pomanskii et al. in Proceedings of the III International Symposium on Weak and Electromagnetic Interactions in Nuclei (WEIN'92), ed. by D.Vylov, Singapore: World Scientific (1993).
6. V.A.Artemiev, E.V.Brakchman, M.A.Ivanovskii et al., Phys.Lett., B280, 159, (1992)
7. V.A.Artemiev, E.V.Brakchman, M.A.Ivanovskii, et al. Pis'ma Zh.Eksp.Teor.Fiz., 58, No.4, 256, (1993)
8. A.Staudt, K.Muto, H.V.Klapdor-Kleingrothaus. Europhys.Lett. 13, 31,(1990)
9. M.Hirsh, X.R.Wu, H.V.Klapdor-Kleingrothaus et al., preprint MPIH V-4-93, Invited Talk presented at Inter.Confer. on Realistic Nuclear Structure, Stony Brook, New-York,May 27-29,1992

В.Артемьев и др.
Наблюдение 2 β 2νраспада ^{150}Nd в эксперименте с времяпроекционной камерой.

Подписано к печати 30.08.94 Формат 60x90 I/I6 Офсетн.печ.
Усл.-печ.л.0,75 Уч.-изд.л.0,5 Тираж II6 экз. Заказ 66.
Индекс 3649

Отпечатано в ИТЭФ, II7259, Москва, Б.Черемушкинская,25