Observation of $2\beta 2\nu$ decay of ^{150}Nd in an experiment with the time projection chamber

V. A. Artem'ev, É. V. Brakhman, O. Ya. Zel'dovich, A. K. Karelin, V. V. Kirichenko, O. M. Kozodaeva, V. A. Lyubimov, A. I. Mitin, V. N. Paramokhin, and T. N. Tsvetkova
Institute of Theoretical and Experimental Physics, 117259 Moscow, Russia

S. I. Vasil'ev, A. A. Klimenko, S. B. Osetrov, A. A. Pomanskiĭ, and A. A. Smol'nikov
Institute of Nuclear Research, Russian Academy of Sciences, 117312 Moscow, Russia

(Submitted 9 July 1993)
Pis'ma Zh. Eksp. Teor. Fiz. **58**, No. 4, 256–259 (25 August 1993)

The time projection chamber has been used in a magnetic field to determine the decay half-life of ^{150}Nd. Measurements on a sample of the isotope ^{150}Nd (92% enrichment) and a sample with the natural isotopic composition, ^{nat}Nd, reveal $T_{1/2}(2\beta 2\nu) = (1.7^{+1.0}_{-0.5} \pm 0.35) \times 10^{19}$ yr. The effect-to-background ratio is 4/1.

The neutrinoless double beta decay remains 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 neutrinos. The past few years have seen significant progress in terms of improved experimental accuracy and also in terms of the number of isotopes which have been studied.[1] The isotope ^{150}Nd is one of the most promising for research on neutrinoless double beta decay because of its high transition energy (3.37 MeV) and its large Coulomb factor.

The interpretation of the results found as a limit on the mass of neutrinos and on the parameters of lepton-number nonconservation depends strongly on theoretical predictions of nuclear matrix elements,[2] which are rather uncertain. The validity of the calculations can be tested by comparing the theoretical and experimental decay half-lives for the $2\beta 2\nu$ mode. At present, $2\beta 2\nu$ decay is observed in direct experiments for the isotopes ^{76}Ge (Ref. 3), ^{82}Se (Ref. 4), and ^{100}Mo (Ref. 5).

There have been only a few studies of the 2β decay of ^{150}Nd. One of the first was carried out at the Baksan Neutrino Observatory.[6] A limit $T_{1/2}(2\beta 2\nu) > 1.8 \times 10^{19}$ yr (95% C.L.) was found by a difference method (one sample was enriched to 92% in the isotope ^{150}Nd, while the other sample had the natural abundance of this isotope, 5.6%).

In an effort to eliminate the background due to radioactive inpurities, a ^{150}Nd sample was subjected to further purification by ion-trap analysis at Ames Chemical Laboratory (Ames, Iowa). After purification, the sample was divided into two parts. The first source (18 g of ^{150}Nd) was used in measurements by Moe's group at the time projection chamber in an underground laboratory in the US. The second source (38.5 g of ^{150}Nd) was used at the scintillation spectrometer of the Institute of Nuclear Research (at Baksan). The preliminary results found by Moe's group[7] indicate the

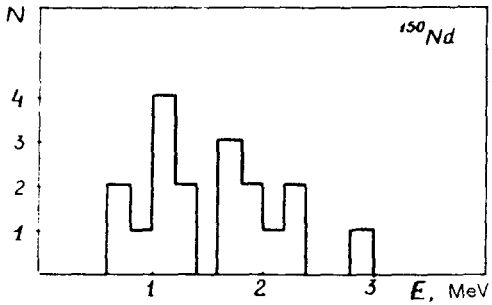

FIG. 1. Distribution with respect to the sum of the kinetic energies of the two electrons for events from a source enriched in the isotope ^{150}Nd (670 h).

occurrence of $2\beta 2\nu$ decay, with $T_{1/2} \simeq 9 \times 10^{18}$ yr. On the other hand, the measurements carried out over 650 h at the Institute of Nuclear Research[8] yielded no positive effect. That result corresponds to a limit $T_{1/2} > 1.1 \times 10^{19}$ yr (90% C.L).

Since a sensitivity $\sim 10^{20}$ yr has been achieved in work by the Institute of Theoretical and Experimental Physics (ITEP) with ^{136}Xe at the time projection chamber,[9] it was natural to expose the ^{150}Nd source of the Institute of Nuclear Research at the ITEP detector. The time projection chamber of the ITEP[10] can be operated with either gaseous sources (^{136}Xe) or solid sources (^{150}Nd and ^{100}Mo). The chamber is in a magnetic field of 800 G, which provides a momentum resolution $\sim 10\%$ at an electron energy of 1 MeV, and which cuts out background events from the lateral walls. A thin solid source is distributed on a film of a material equivalent to Mylar, which separates two gas-filled volumes. Each volume is filled with methane to 1 atm. With a 0.5-m^2 working area and a mass of 100 g for the sample, the effective thickness of the source is 20 mg/cm^2. At this thickness, the background of double Compton scattering and of Compton–Møller scattering from external sources is suppressed to a level of 1 event per 200 h. Track information in the upper volume determines the direction in which the electrons are moving and cuts out events associated with the top cover. The lower volume operates as active shielding against the lower cover. In this manner, events due to the source are singled out exclusively.

The thin source was prepared by mixing a saturated solution of wax in toluene with a Nd_2O_3 powder, depositing the resulting material on a Myler-equivalent film 50 μm thick, leveling the material off, and then drying it with warm air. Weight proportions of 17 mg of Nd_2O_3 and 7.5 mg of wax per 1 cm^2 were chosen to achieve a stable coating on the Mylar-equivalent film.

Several measurement cycles were carried out. In the first run, a film holding two sources was prepared: a ^{nat}Nd source (45 g of Nd_2O_3) and a source with a ^{150}Nd sample (13.5 g of Nd_2O_3). The measurement time was 450 h. In the second run, the mass of the ^{nat}Nd source was reduced to 15 g, and that of the ^{150}Nd source was increased to 51.5 g. The measurement time in this case was 550 h. After off-line and on-line filtering, the data were examined by physicists to find two-electron events emerging from the source, with each electron having an energy between 0.25 and 1.8 MeV. The efficiency of this scan was 86%. Figures 1 and 2 show distributions with respect to the sum of the kinetic energies of the two electrons in the events selected for

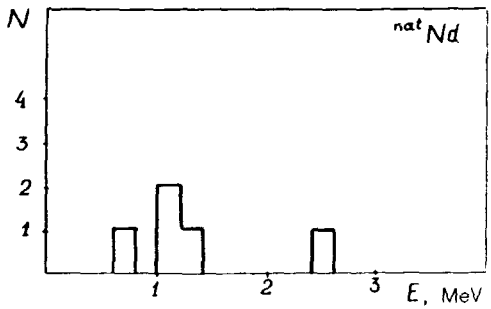

FIG. 2. Distribution with respect to the sum of the kinetic energies of the two electrons for events from a source with the natural isotopic abundances (560 h).

the ^{150}Nd and ^{nat}Nd samples. The measurement time, referred to the mass of the source (51.5 g of Nd_2O_3), is 670 h in Fig. 1 and 560 h in Fig. 2. We see that the number of two electron events from the ^{150}Nd sample is substantially higher (by a factor of 4).

Before and after the main runs, we carried out some additional exposures, for times of 64 and 53 h, in order to determine the ^{238}U content in the source. In these measurements we detected a cascade: an electron from ^{214}Bi decay and a delayed α particle from ^{214}Po decay, with a decay half-life of 164 μs. This procedure is described in detail in Ref. 11. We obtained a limit corresponding to $\beta-\alpha$ coincidences, <0.1 count/h, for both ^{150}Nd and ^{nat}Nd. Using the ratio between the count of $\beta-\alpha$ coincidences and the count of two-electron events found in experiments with ^{136}Xe (Ref. 11), and correcting for the efficiency at which α particles escape from the solid source, $\sim 10\%$, we found that the background of two-electron events due to a possible ^{238}U impurity could not exceed 2 counts per 600 h from the source consisting of 50 g of Nd_2O_3. Under the assumption that the equilibrium of the uranium series is not disrupted, we found the estimate $<0.5\times10^{-9}$ atom/atom for a possible ^{238}U content in the ^{150}Nd and ^{nat}Nd samples.

Before the purification in the U.S.A., the ^{150}Nd sample contained 3×10^{-8} g/g of ^{238}U and 1.7×10^{-7} g/g of ^{232}Th. If we assume that the degree of purification in terms of ^{232}Th is no worse than that in terms of ^{238}U, then the ^{150}Nd source contains a ^{232}Th impurity of less than 0.3×10^{-8} g/g. Such an impurity could contribute no more than two background events in the time projection chamber over 700 h of measurements. The excess of two-electron events observed in the case of the ^{150}Nd sample can thus be attributed to $2\beta2\nu$ decay of ^{150}Nd.

The efficiency of the time projection chamber for detection of the $2\beta2\nu$ decay of Nd is 2.8% according to a Monte Carlo calculation. Figure 3 shows a distribution with respect to the sum of the kinetic energies of the two electrons for events which were generated by the Monte Carlo method and subjected to the analysis program. The limitations on the energy of each of the electrons are from 0.25 to 1.80 MeV.

Since the enriched ^{150}Nd source contains 40.3 g of the isotope ^{150}Nd, while the ^{nat}Nd source contains 2.5 g of this isotope, one event in Fig. 2 may have been caused by $2\beta2\nu$ decay of ^{150}Nd in the ^{nat}Nd. After subtraction of the background, the effect

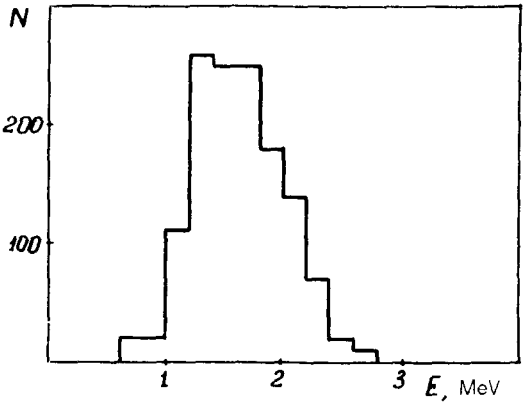

FIG. 3. Distribution with respect to the sum of the kinetic energies of the two electrons for $2\beta 2\nu$ decays of ^{150}Nd as generated by the Monte Carlo method.

consists of 12 events with a total energy between 0.8 and 2.4 MeV. This result corresponds to

$$T_{1/2}=(1.7^{+1.0}_{-0.5})\times 10^{19}\ \text{yr}.$$

The systematic error is 20%. Here we are taking account of the uncertainties in the thickness of the source, in the efficiency of the visual selection of events, and in the energy threshold associated with the energy resolution.

There are plans to continue the exposure with the ^{150}Nd and to carry out some additional calibration measurements with some special samples of Nd_2O_3 containing known amounts of ^{238}U and ^{232}Th.

With pleasure we express our gratitude to M. V. Danilov for constant interest in this study and for support and to I. V. Kirpichnikov for useful discussions and for assistance in organizing the collaboration. Financial support was provided for this study by the Russian Basic Research Foundation (92-02-3965).

[1] M. K. Moe, Preprint UCI-NEUTRINO 93-1, 23 February 1993.
[2] A. Staudt, T. T. S. Kuo, and H. V. Klapdor-Kleingrothous, Phys. Rev. C **46**, 871 (1992).
[3] A. A. Vasenko, I. V. Kirpichikov, V. A. Kuznetsov *et al.*, Mod. Phys. Lett. A **5**, 1299 (1990); F. T. Avignone, R. L. Brodzinski, C. K. Guerard *et al.*, Phys. Lett. **256**, 559 (1991); A. Piepke, in *Proceedings of the Thirteenth Moriond Workshop, Perspectives in Neutrinos, Atomic Physics and Gravitation* (Villars-sur-Ollon, Switzerland, 30 January–7 February, 1993) (to be published).
[4] S. R. Elliot, A. A. Hahn, M. K. Moe *et al.*, Phys. Rev. C **46**, 1535 (1992).
[5] H. Ejiri, K. Fushimi, T. Kamada *et al.*, Phys. Lett. B **258**, 17 (1991); S. R. Elliot, A. A. Hahn, M. K. Moe *et al.*, J. Phys. G **17**, S145 (1991); S. I. Vasil'ev, A. A. Klimenko, S. B. Osetrov *et al.*, JETP Lett. **51**, 622 (1990).
[6] A. A. Klimenko, S. B. Osetrov, A. A. Pomanskii *et al.*, Nucl. Instrum. Methods B **17**, 445 (1986).
[7] S. R. Elliot, A. A. Hahn, M. K. Moe *et al.*, in *Proceedings of the Fifteenth International Conference on Neutrino Physics and Astrophysics (NEUTRINO'92)* (ed. A. Morales) (Granada, Andalucia, Spain, 7–12 June, 1992); Nucl. Phys. B, Proceedings Supplements, p. 62.
[8] S. I. Vasil'ev, A. A. Klimenko, A. A. Pomanskii *et al.*, in *Proceedings of the Third International Symposium on Weak and Electromagnetic Interaction of Nuclei (WEIN '92)* (Dubna, 16–22 June 1992) (in press).
[9] V. A. Artemiev, E. V. Brakhman, M. A. Ivanovskii *et al.*, Phys. Lett. B **280**, 159 (1992).
[10] V. A. Artemiev, E. V. Brakhman, M. A. Ivanovskii *et al.*, Nucl. Instrum. Methods A **303**, 309 (1991).
[11] V. A. Artem'ev, 'E. V. Brakhman, O. Ya. Zel'dovich *et al.*, Prib. Tekh. Eksp., No 2, 89 (1991).

Translated by D. Parsons