Proceedings of the DAE Symp.on Nucl. Phys. 55 (2010)

75 years of double beta decay: yesterday, today and tomorrow

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In this report I will briefly review the motivation and history of double beta decay search since the first consideration of two neutrino process ($2\beta(2\nu)$) by Maria Goeppert-Mayer in 1935. The first experiments on search for double beta decay in the late 1940s and beginning of 1950s are considered. It is underlined that for the first time the $2\beta(2\nu)$ decay has been registered in geochemical experiment with ^{130}Te in 1950. In direct (counter) experiment this type of decay for the first time has been registered in ^{82}Se by Michael Moe's group in 1987. Now two neutrino double beta decay has been recorded for 10 nuclei (^{48}Ca, ^{76}Ge, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{128}Te, ^{130}Te, ^{150}Nd, ^{238}U). In addition, the $2\beta(2\nu)$ decay of ^{100}Mo and ^{150}Nd to the 0^+_1 excited state of the daughter nucleus has been observed and the ECEC(2ν) process in ^{130}Ba was observed. As to neutrinoless double beta decay ($2\beta(0\nu)$) this process has not yet been registered. In the review results of the most sensitive last and modern experiments (Heidelberg-Moscow, IGEX, CUORICINO, NEMO-3) are discussed and conservative upper limits on effective Majorana neutrino mass and the coupling constant of the Majoron to the neutrino are established as $\langle m_\nu \rangle < 0.75$ eV and $\langle g_{ee} \rangle < 1.9 \cdot 10^{-4}$, respectively. The next-generation experiments, where the mass of the isotopes being studied will be as grand as 100 to 1000 kg, are discussed. These experiments will have started within a few years years. In all probability, they will make it possible to reach the sensitivity for the neutrino mass at a level of 0.01 to 0.1 eV.

1. Introduction

The current interest in neutrinoless double beta decay, $0\nu\beta\beta$ decay, is that the existence of this process is closely related to the following fundamental aspects of particle physics [1–3]: (i) lepton-number nonconservation, (ii) the presence of a neutrino mass and its origin, (iii) the existence of right-handed currents in electroweak interactions, (iv) the existence of the Majoron, (v) the structure of the Higgs sector, (vi) supersymmetry, (vii) the existence of leptoquarks, (viii) the existence of a heavy sterile neutrino, and (ix) the existence of a composite neutrino.

All of these issues are beyond the standard model of electroweak interaction, therefore the detection of $0\nu\beta\beta$ decay would imply the discovery of new physics. Of course, interest in this process is caused primarily by the problem of a neutrino mass. If $0\nu\beta\beta$ decay is discovered, then according to current thinking, this will automatically mean that the rest mass of at least one neutrino flavor is nonzero and is of Majorana origin.

Interest in neutrinoless double-beta decay has seen a significant renewal in recent years after evidence for neutrino oscillations was obtained from the results of atmospheric, solar, reactor and accelerator neutrino experiments (see, for example, the discussions in [4–6]). These results are impressive proof that neutrinos have a non-zero mass. However, the experiments studying neutrino oscillations are not sensitive to the nature of the neutrino mass (Dirac or Majorana) and provide no information on the absolute scale of the neutrino masses, since such experiments are sensitive only to the difference of the masses, Δm^2. The detection and study of $0\nu\beta\beta$ decay may clarify the following problems of neutrino physics (see discussions in [7–9]): (i) lepton number nonconservation, (ii) neutrino nature: whether the neutrino is a Dirac or a Majorana particle, (iii) absolute neutrino mass scale (a measurement or a limit on m_1), (iv) the type of neutrino mass hierarchy (normal, inverted, or quasidegenerate), (v) CP violation in the lep-

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ton sector (measurement of the Majorana CP-violating phases).

2. Yesterday

The double beta decay problem arose practically immediately after the appearance of W. Pauli's neutrino hypothesis in 1930 and the development of β-decay theory by E. Fermi in 1933. In 1935 M. Goeppert-Mayer identified for the first time the possibility of two neutrino double beta decay, in which there is a transformation of an (A, Z) nucleus to an (A, Z+2) nucleus that is accompanied by the emission of two electrons and two anti-neutrinos [10]:

$$(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\tilde{\nu} \qquad (1)$$

It was demonstrated theoretically by E. Majorana in 1937 [11] that if one allows the existence of only one type of neutrino, which has no antiparticle (i.e. $\nu \equiv \tilde{\nu}$) , then the conclusions of β-decay theory are not changed. In this case one deals with a Majorana neutrino. In 1939 B. Farry introduced a scheme of neutrinoless double beta decay through the virtual state of intermediate nuclei [12]:

$$(A, Z) \rightarrow (A, Z+2) + 2e^- \qquad (2)$$

The first experiment to search for 2β-decay was done in 1948 using Geiger counters. In this experiment a half-life limit for ^{124}Sn was established, $T_{1/2} > 3 \cdot 10^{15}$ y [13]. During the period 1948 to 1965 $\sim$ 20 experiments were carried out with a sensitivity to the half-life on the level $\sim 10^{16} - 10^{19}$ y (see reviews [14, 15]). The 2β-decay was thought to have been "discovered" a few times, but each time it was not confirmed by new (more sensitive) measurements. The exception was the geochemical experiment in 1950 where two neutrino double beta decay of ^{130}Te was really detected [16].

At the end of the 1960s and beginning of 1970s significant progress in the sensitivity of double beta decay experiments was realized. E. Fiorini et al. carried out experiments with Ge(Li) detectors and established a limit on neutrinoless double beta decay of ^{76}Ge, $T_{1/2} > 5 \cdot 10^{21}$ y [17]. Experiments with ^{48}Ca and ^{82}Se using streamer chamber with a magnetic field and plastic scintillators were done by C. Wu's group and led to impressive limits of $2 \cdot 10^{21}$ y [18] and $3.1 \cdot 10^{21}$ y [19] respectively. During these years many sensitive geochemical experiments were done and $2\nu\beta\beta$ decay of ^{130}Te, ^{128}Te and ^{82}Se were detected (see reviews [15, 20, 21]).

In 1981 a new type of neutrinoless decay with Majoron emission was introduced [22]:

$$(A, Z) \rightarrow (A, Z+2) + 2e^- + \chi^0 \qquad (3)$$

The important achievements in the 1980s were connected with the first evidence of two neutrino double beta decay in direct counting experiments. This was done by M. Moe's group for ^{82}Se using a TPC ($T_{1/2} = 1.1^{+0.8}_{-0.3} \cdot 10^{20}$ y) [23]. There was also the first use of semiconductor detectors made of enriched Ge in the ITEP-ErPI experiment [24].

During the 1990s the two neutrino decay process was detected in many experiments for different nuclei (see [25, 26]), two neutrino decay to an excited state of the daughter nuclei was also detected [27]. In addition, the sensitivity to $0\nu\beta\beta$ decay in experiments with ^{76}Ge (Hidelberg-Moscow [72] and IGEX [29]) was increased up to $\sim 10^{25}$ y.

Since 2002 the progress in double beta decay searches has been connected mainly with the two experiments, NEMO-3 [30–36] and CUORICINO [37–39]. The basic historical marks of 75 years study of this process are presented in Tables I and II.

3. Today

A. Two neutrino double beta decay

As discussed above this decay was first recorded in 1950 in a geochemical experiment with ^{130}Te [16]. In 1967, it was also found for ^{82}Se [42]. Attempts to observe this decay in a direct measurement employing counters were unsuccessful for a long time. Only in 1987 could M. Moe, who used a time-projection chamber (TPC), observe $2\beta(2\nu)$ decay in ^{82}Se for the first time [23]. Within the next few years, experiments employing counters were able to detect $2\beta(2\nu)$ decay in many nuclei. In ^{100}Mo [27, 66, 67], and ^{150}Nd [68] $2\beta(2\nu)$ decay to the 0^+ excited state of the daughter nucleus was also recorded. The $2\beta(2\nu)$ decay of ^{238}U was detected in a radiochemical experiment [69], and in a geochemical experiment for the first time the ECEC process was detected in ^{130}Ba [59]. Table III displays the present-day averaged and recommended values of $T_{1/2}(2\nu)$ from [26]. At present, experiments devoted to detecting $2\nu\beta\beta$ decay are approaching a level where it is insufficient to just record the decay. It is necessary to measure numerous parameters of this process to a high precision (energy sum spectrum, single electron energy spectrum and angular distribution). Tracking detectors that are able to record both the energy of each electron and the angle at which they diverge are the most appropriate instruments for solving this problem. Current tracking NEMO-3 experiment is measuring all parameters of double beta decay for seven different nuclei (^{48}Ca, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{130}Te, ^{150}Nd) [30–36].

B. Neutrinoless double beta decay

In contrast to two-neutrino decay, neutrinoless double-beta decay has not yet been observed [97], although it is easier to detect it. In this case, one seeks, in the experimental spectrum, a peak of energy equal to the double beta transition energy and of width determined by the detector's resolution.

The constraints on the existence of $0\nu\beta\beta$ decay are presented in Table IV for the nuclei that are the most promising candidates. In calculating constraints on $\langle m_\nu \rangle$, the nuclear matrix elements from [60–62, 64, 65] were used (3-d column). It is advisable to employ the calculations from these studies, because the calculations are the most thorough and take into account the most recent theoretical achievements. In these papers [60–62] g_{pp} values (g_{pp} is parameter of the QRPA theory) were fixed using experimental half-life values for 2ν decay and then NME(0ν) were calculated. In column four, limits on $\langle m_\nu \rangle$, which were obtained using the NMEs from a recent Shell Model (SM) calculations [63].

From Table IV using NME values from [60–65], the limits on $\langle m_\nu \rangle$ for ^{130}Te are comparable with the ^{76}Ge results. Now one cannot select any experiment as the best one. The assemblage of sensitive experiments for different nuclei permits one to increase the reliability of the limit on $\langle m_\nu \rangle$. Present conservative limit can be set as 0.75 eV.

C. Neutrinoless double beta decay with Majoron emission

Table V displays the best present-day constraints for an "ordinary" Majoron (n = 1). The "nonstandard" models of the Majoron were experimentally tested in [80] for ^{76}Ge and in [81] for ^{100}Mo, ^{116}Cd, ^{82}Se, and ^{96}Zr. Constraints on the decay modes involving the emission of two Majorons were also obtained for ^{100}Mo [82], ^{116}Cd [78], and ^{130}Te [83]. In a recent NEMO Collaboration papers [32, 34, 35], new results for these processes in ^{100}Mo, ^{82}Se, ^{150}Nd and ^{96}Zr were obtained with the NEMO-3 detector. Table VI gives the best experimental constraints on decays accompanied by the emission of one or two Majorons (for n = 2, 3, and 7). Hence at the present time only limits on double beta decay with Majoron emission have been obtained (see table 3 and 4). A conservative present limit on the coupling constant of ordinary Majoron to the neutrino is $\langle g_{ee} \rangle < 1.9 \cdot 10^{-4}$.

4. Tomorrow

Here five of the most developed and promising experiments which can be realized within the next five to ten years are presented (see Table VII). The estimation of the sensitivity in the experiments is made using NMEs from [60–65]. In all probability, they will make it possible to reach the sensitivity for the neutrino mass at a level of 0.01 to 0.1 eV. First phase of GERDA (18 kg of ^{76}Ge), EXO-200 (200 kg of ^{136}Xe) and KamLAND (400 kg of ^{136}Xe) plan to srart data-tacking in 2011.

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[97] The possible exception is the result with ^{76}Ge, published by a fraction of the Heidelberg-Moscow Collaboration (see Table 2). First time the "positive" result was mentioned in [72]. The Moscow part of the Collaboration does not agree with this conclusion [73] and there are others who are critical of this result [74–76]. Thus, at the present time, this "positive" result is not accepted by the "2β decay community" and it has to be checked.

TABLE I: Main milestones in double beta decay search.

Date	Event	Remarks
1935	The idea of $2\beta 2(\nu)$ decay has been formulated	M. Goeppert-Mayer [10]
1939	The idea of $2\beta 0(\nu)$ decay has been formulated	W.H. Furry [12]
1948	The first 2β decay experiment has been realized	E.L. Fireman [13]; (Geiger counters and 25 g of enriched ^{124}Sn were used)
1950	The first observation of $2\beta 2(\nu)$ decay has been done	M.G. Inghram, and J.H. Reynolds [16] (geochemical experiment with ^{130}Te); $T_{1/2} = 1.4 \cdot 10^{21}$ y
1966	The first counting experiment with sensitivity higher than 10^{20} y has been realized	E. Mateosian, and M. Goldhaber [40] ("detector= =source", 11.4 g of enriched ^{48}Ca); $T_{1/2}(0\nu) > 2 \cdot 10^{20}$ y
1967	The first experiment with semiconductor Ge detector has been realized	E. Fiorini et al. [41] (17 cm^3 Ge(Li) detector on see level); $T_{1/2}(0\nu) > 3 \cdot 10^{20}$ y
1967	The observation of $2\beta(2\nu)$ decay of ^{82}Se has been done	T. Kirsten et al. [42] (geochemical experiment); $T_{1/2} = 0.6 \cdot 10^{20}$ y
1967-1970	The first counting experiment with sensitivity higher than 10^{21} y has been realized	R.K. Bardin, P.J. Gollon, J.D. Ullman, and C.S. Wu [18, 43] (strimmer chamber+ scintillation counters); $T_{1/2}(0\nu;^{48}\mathrm{Ca}) > 3 \cdot 10^{21}$ y, $T_{1/2}(2\nu;^{48}\mathrm{Ca}) > 3.6 \cdot 10^{19}$ y
1973	The sensitive counting experiment with ^{76}Ge has been realized	E. Fiorini et al. [17] (68 cm^3 Ge(Li) detector on 4200 m w.e. depth); $T_{1/2}(0\nu) > 5 \cdot 10^{21}$ y
1975	The sensitive counting experiment with ^{82}Se has been realized	B.T. Cleveland et al. [19] (streamer chamber + scintillation counters); $T_{1/2}(0\nu;\ ^{82}\mathrm{Se}) > 3.1 \cdot 10^{21}$ y
1980-1981	The idea of 2β decay with Majoron emission has been formulated	Singlet [44], doublet [45] and triplet [22, 46] Majoron has been introduced
1982	J. Schechter and J.W.F. Valle theorem is formulated	J. Schechter, and J.W.F. Valle [47] (the occurrence of $2\beta(0\nu)$ decay implies that neutrinos are Majorana particles with nonzero mass)
1984	The low temperature detector for double beta decay has been proposed	E. Fiorini, and T.O. Niinikoski [48]
1985	The fundamental theoretical investigation of double beta decay has been done	M. Doi, T. Kotani, and E. Takasugi [49] (the main formulas for probability of decay, energy and angular electron spectra have been obtained)

TABLE II: Main milestones in double beta decay search (continuation of Table I).

Date	Event	Remarks
1986	The g_{pp} parameter (characterize the particle-particle interaction in nuclei) of QRPA model has been introduced	P. Vogel, and M.R. Zirnbauer [50] (within the frameworks of QRPA models the satisfactory agreement between theoretical and experimental $T_{1/2}(2\nu)$ values for the first time has been observed)
1987	The first observation of 2ν decay in counting experiment has been done	M. Moe et al. [23] (TPC with ^{82}Se, 36 events); $T_{1/2}(2\nu) = 1.1^{+0.8}_{-0.3} \cdot 10^{20}$ y
1987-1989	The first counting experiment with sensitivity higher than 10^{24} y has been done	D.O. Caldwell et al. [51] (8 detectors from natural Ge with full wait 7.2 kg); $T_{1/2}(0\nu) > 1.2 \cdot 10^{24}$ y
1987-1990	The first semiconductor detector made of enriched germanium (86% of ^{76}Ge) has been started to work.	ITEP-ErPI Collaboration [24, 52] (2 detectors from enriched Ge with full waight $\sim$ 1.1 kg). In 1990 it was obtained: $T_{1/2}(0\nu) > 1.3 \cdot 10^{24}$ y, $T_{1/2}(2\nu) = (0.9 \pm 0.1) \cdot 10^{21}$ y
1991	The first observation of 2ν decay to the excited state of daughter nuclear has been done	A.S. Barabash et al. [27] (low background HPGe detector, 1 kg of ^{100}Mo, ^{100}Mo-^{100}Ru(0^+_1;1130.3 keV) transition; $T_{1/2} = 6.1^{+1.8}_{-1.1} \cdot 10^{20}$ y
1990-1998	The experiments with ELEGANT-V detector	H. Ejiri et al. [53, 54]. $2\beta(2\nu)$ decay observation in ^{100}Mo and ^{116}Cd
1991-1997	The experiments with NEMO-2 detector	NEMO-2 Collaboration [55–58]. Systematic study of $2\beta(2\nu)$ decay (^{100}Mo, ^{116}Cd, ^{82}Se and ^{96}Zr) with registration of all parameters of the decay
1991-1999	The IGEX experiment	Measurements with 6.5 kg of enriched ^{76}Ge; $T_{1/2}(0\nu) > 1.57 \cdot 10^{25}$ y [29]
1990-2003	The Heidelberg-Moscow experiment	Measurements with 11 kg of enriched ^{76}Ge [72]; $T_{1/2}(0\nu) > 1.9 \cdot 10^{25}$ y, $T_{1/2}(2\nu) = 1.74 \pm 0.01(stat)^{+0.18}_{-0.16}(syst) \cdot 10^{21}$ y
2001	First observation of ECEC(2ν)	Geochemical experiment with ^{130}Ba, $T_{1/2} = (2.2 \pm 0.5) \cdot 10^{21}$ y [59]
2002-2010	NEMO-3 experiment	NEMO-3 Collaboration [30–34, 34, 36]; $T_{1/2}(0\nu;^{100}\text{Mo}) > 1.1 \cdot 10^{24}$ y. Observation and precise investigation of $2\beta(2\nu)$ decay for 7 isotopes (^{48}Ca, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{130}Te, ^{150}Nd)
2003-2008	CUORICINO experiment	CUORICINO Collaboration [37, 38]; $T_{1/2}(0\nu;^{130}\text{Te}) > 2.8 \cdot 10^{24}$ y

TABLE III: Average and recommended $T_{1/2}(2\nu)$ values (from [26]).

Isotope	$T_{1/2}(2\nu)$
^{48}Ca	$4.4^{+0.6}_{-0.5} \cdot 10^{19}$
^{76}Ge	$(1.5 \pm 0.1) \cdot 10^{21}$
^{82}Se	$(0.92 \pm 0.07) \cdot 10^{20}$
^{96}Zr	$(2.3 \pm 0.2) \cdot 10^{19}$
^{100}Mo	$(7.1 \pm 0.4) \cdot 10^{18}$
^{100}Mo-^{100}Ru(0^+_1)	$(5.9^{+0.8}_{-0.6}) \cdot 10^{20}$
^{116}Cd	$(2.8 \pm 0.2) \cdot 10^{19}$
^{128}Te	$(1.9 \pm 0.4) \cdot 10^{24}$
^{130}Te	$(6.8^{+1.2}_{-1.1}) \cdot 10^{20}$
^{150}Nd	$(8.2 \pm 0.9) \cdot 10^{18}$
^{150}Nd-^{150}Sm(0^+_1)	$1.33^{+0.45}_{-0.26} \cdot 10^{20}$
^{238}U	$(2.0 \pm 0.6) \cdot 10^{21}$
^{130}Ba; ECEC(2ν)	$(2.2 \pm 0.5) \cdot 10^{21}$

TABLE IV: Best present results on $2\beta(0\nu)$ decay (limits at 90% C.L.). $^{*)}$ See text.

Isotope	$T_{1/2}$, y	$\langle m_\nu \rangle$, eV [60–62, 64, 65]	$\langle m_\nu \rangle$, eV [63]	Experiment
^{76}Ge	$> 1.9 \cdot 10^{25}$	$< 0.22 - 0.41$	< 0.69	HM [72]
	$\simeq 1.2 \cdot 10^{25} (?)^{*)}$	$\simeq 0.28 - 0.52(?)^{*)}$	$\simeq 0.87(?)^{*)}$	Part of HM [70]
	$\simeq 2.2 \cdot 10^{25} (?)^{*)}$	$\simeq 0.21 - 0.38(?)^{*)}$	$\simeq 0.64(?)^{*)}$	Part of HM [71]
	$> 1.6 \cdot 10^{25}$	$< 0.24 - 0.44$	< 0.75	IGEX [29]
^{130}Te	$> 2.8 \cdot 10^{24}$	$< 0.35 - 0.59$	< 0.77	CUORICINO [39]
^{100}Mo	$> 1.1 \cdot 10^{24}$	$< 0.45 - 0.93$	–	NEMO- 3 [36]
^{136}Xe	$> 4.5 \cdot 10^{23}$	$< 1.41 - 2.67$	< 2.2	DAMA [77]
^{82}Se	$> 3.6 \cdot 10^{23}$	$< 1.89 - 1.61$	< 2.3	NEMO-3 [36]
^{116}Cd	$> 1.7 \cdot 10^{23}$	$< 1.45 - 2.76$	< 1.8	SOLOTVINO [78]

TABLE V: Best present limits on $0\nu\chi^0\beta\beta$ decay (ordinary Majoron) at 90% C.L. The NME from the following works were used, 3-d column: [60–62, 64, 65], 4-th column: [63]. $^{*)}$ Conservative limit from [77] is presented.

Isotope ($E_{2\beta}$, keV)	$T_{1/2}$, y	$\langle g_{ee} \rangle$, [60–62, 64, 65]	$\langle g_{ee} \rangle$, [63]
^{76}Ge (2039)	$> 6.4 \cdot 10^{22}$ [72]	$< (0.54 - 1.44) \cdot 10^{-4}$	$< 2.4 \cdot 10^{-4}$
^{82}Se (2995)	$> 1.5 \cdot 10^{22}$ [32]	$< (0.58 - 1.19) \cdot 10^{-4}$	$< 1.9 \cdot 10^{-4}$
^{100}Mo (3034)	$> 2.7 \cdot 10^{22}$ [32]	$< (0.35 - 0.85) \cdot 10^{-4}$	-
^{116}Cd (2805)	$> 8 \cdot 10^{21}$ [78]	$< (0.79 - 2.56) \cdot 10^{-4}$	$< 1.7 \cdot 10^{-4}$
^{128}Te (867)	$> 1.6 \cdot 10^{24}$(geochem)[26, 79]	$< (0.61 - 0.97) \cdot 10^{-4}$	$< 1.4 \cdot 10^{-4}$
^{136}Xe (2458)	$> 1.6 \cdot 10^{22*)}$ [77]	$< (1.51 - 3.54) \cdot 10^{-4}$	$< 2.9 \cdot 10^{-4}$

TABLE VI: Best present limits on $T_{1/2}$ for decay with one and two Majorons at 90% C.L. for modes with spectral index n = 2, n = 3 and n = 7.

Isotope ($E_{2\beta}$, keV)	n = 2	n = 3	n = 7
^{76}Ge (2039)	-	$> 5.8 \cdot 10^{21}$ [80]	$> 6.6 \cdot 10^{21}$ [80]
^{82}Se (2995)	$> 6 \cdot 10^{21}$ [32]	$> 3.1 \cdot 10^{21}$ [32]	$> 5 \cdot 10^{20}$ [32]
^{96}Zr (3350)	$> 9.9 \cdot 10^{20}$ [35]	$> 5.8 \cdot 10^{20}$ [35]	$> 1.1 \cdot 10^{20}$ [35]
^{100}Mo (3034)	$> 1.7 \cdot 10^{22}$ [32]	$> 1 \cdot 10^{22}$ [32]	$> 7 \cdot 10^{19}$ [32]
^{116}Cd (2805)	$> 1.7 \cdot 10^{21}$ [78]	$> 8 \cdot 10^{20}$ [78]	$> 3.1 \cdot 10^{19}$ [78]
^{130}Te (2527)	-	$> 9 \cdot 10^{20}$ [83]	-
^{128}Te (867) (geochem)	$> 1.6 \cdot 10^{24}$ [26, 79]	$> 1.6 \cdot 10^{24}$ [26, 79]	$> 1.6 \cdot 10^{24}$ [26, 79]
^{150}Nd (3371)	$> 5.4 \cdot 10^{20}$ [34]	$> 2.2 \cdot 10^{20}$ [34]	$> 4.7 \cdot 10^{19}$ [34]

TABLE VII: Seven most developed and promising projects. Sensitivity at 90% C.L. for three (1-st step of GERDA, MAJORANA, KamLAND and SNO+) five (EXO, SuperNEMO and CUORE) and ten (full-scale GERDA and MAJORANA) years of measurements is presented. $^{*)}$ For the background 0.001 keV$^{-1} \cdot kg^{-1} \cdot y^{-1}$; $^{**)}$ for the background 0.01 keV$^{-1} \cdot kg^{-1} \cdot y^{-1}$.

Experiment	Isotope	Mass of isotope, kg	Sensitivity $T_{1/2}$, y	Sensitivity $\langle m_\nu \rangle$, meV	Status	Start of data-tacking
CUORE [84, 85]	^{130}Te	200	$6.5 \cdot 10^{26*)}$	20-50	in progress	∼ 2013
			$2.1 \cdot 10^{26**)}$	40-90		
GERDA [86, 87]	^{76}Ge	40	$2 \cdot 10^{26}$	70-200	in progress	∼ 2012
		1000	$6 \cdot 10^{27}$	10-40	R&D	∼ 2015
MAJORANA	^{76}Ge	30-60	$(1-2) \cdot 10^{26}$	70-200	in progress	∼ 2013
[88, 89]		1000	$6 \cdot 10^{27}$	10-40	R&D	∼ 2015
EXO [90, 91]	^{136}Xe	200	$6.4 \cdot 10^{25}$	100-200	in progress	∼ 2011
		1000	$8 \cdot 10^{26}$	30-60	R&D	∼ 2015
SuperNEMO	^{82}Se	100-200	$(1-2) \cdot 10^{26}$	40-100	R&D	∼ 2013-2015
[68, 92, 94]						
KamLAND	^{136}Xe	400	$4 \cdot 10^{26}$	40-80	in progress	∼ 2011
[95]		1000	10^{27}	25-50	R&D	∼ 2013-2015
SNO+	^{150}Nd	56	$4.5 \cdot 10^{24}$	100-300	in progress	∼ 2012
[96]		500	$3 \cdot 10^{25}$	40-120	R&D	∼ 2015