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Double Beta Decays of ^{116}Cd

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Double beta decays ($\beta\beta$) from the 0^+ ground state in ^{116}Cd to the 0^+ ground state in ^{116}Sn were studied by means of ELEGANT V. A finite half-life for the two-neutrino $\beta\beta(2\nu\beta\beta)$ and an upper limit on the neutrinoless one $(0\nu\beta\beta)$ were obtained as $T^{2\nu}_{1/2}=2.6^{+0.9}_{-0.5}\times 10^{19}$ y and $T^{0\nu}_{1/2}>6.3\times 10^{21}$ y (68% C.L.), respectively. The nuclear matrix element $M^{2\nu}_{\beta\beta}$ was deduced as 0.069 ± 0.009 in units of $(m_e c^2)^{-1}$. This supports the universal quenching of the $2\nu\beta\beta$ rates in this mass region, which is consistent with that previously measured in ^{100}Mo.

[radioactivity, ^{116}Cd($\beta\beta$), $T^{2\nu}_{1/2}$ fixed value, exclusive measurement, isotopically enriched Cd sample, ultralow-background detector ELEGANT V, $M^{2\nu}_{\beta\beta}$ evaluation]

Double beta decays ($\beta\beta$) are currently of interest from nuclear and astrophysical viewpoints.[1-5)] Neutrinoless double beta decays ($0\nu\beta\beta$), which violate the lepton number (L) conservation law, provide evidence for physics beyond the electroweak standard theory. They are sensitive to, for example, the Majorana neutrino mass $\langle m_\nu\rangle$, the right-handed weak current $\langle RHC\rangle$ (i.e., $\langle\lambda\rangle$ and $\langle\eta\rangle$), the Majoron coupling constant $\langle g_M\rangle$, and L-violating coupling with SUSY particles. The neutrino mass is also interesting regarding the question of whether the electron neutrino is a candidate for hot dark matter. Two-neutrino double beta decays ($2\nu\beta\beta$) conserve L, and are thus within the framework of the standard theory.

The $0\nu\beta\beta$ and $2\nu\beta\beta$ amplitudes involve the nuclear matrix elements relevant to given $\beta\beta$ processes. Half-lives, $T^{0\nu}_{1/2}$ and $T^{2\nu}_{1/2}$, for the $0\nu\beta\beta$ process caused by the $\langle m_\nu\rangle$ term and the $2\nu\beta\beta$ process are given as

$$(T^{0\nu}_{1/2})^{-1}=G^{0\nu}|M^{0\nu}_{\beta\beta}|^2|\langle m_\nu\rangle|^2, \qquad (1)$$

and

$$(T^{2\nu}_{1/2})^{-1}=G^{2\nu}|M^{2\nu}_{\beta\beta}|^2, \qquad (2)$$

respectively.[1,2)] Here $G^{0\nu}$ ($G^{2\nu}$) and $M^{0\nu}_{\beta\beta}$ ($M^{2\nu}_{\beta\beta}$) are the relevant phase space factor and the nuclear matrix element for the $0\nu\beta\beta$ ($2\nu\beta\beta$) process, respectively. It is crucial to know the value of $M^{0\nu}_{\beta\beta}$ in order to extract a value for $\langle m_\nu\rangle$ or a limit on $\langle m_\nu\rangle$ from $T^{0\nu}_{1/2}$. In the case of the $2\nu\beta\beta$ process, the observed half-life ($T^{2\nu}_{1/2}$) gives the value for $M^{2\nu}_{\beta\beta}$, as given in eq. (2).

Theoretical evaluations of $M^{0\nu}_{\beta\beta}$ and $M^{2\nu}_{\beta\beta}$ are not straightforward since they depend on nuclear parameters used for the nuclear structure calculation.[3-8)] Actually, the value for $M^{2\nu}_{\beta\beta}$ is sensitive to the spin-isospin ($\sigma\tau$) interaction.[6-8)] Then the value for $M^{2\nu}_{\beta\beta}$ deduced from the observed $T^{2\nu}_{1/2}$ is used to find an appropriate nuclear model with the proper $\sigma\tau$ correlations (interaction). This is, in turn, applied to

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evaluate quantitatively the value for $M^{0\nu}_{\beta\beta}$.[5)]

Experimental studies of the individual $0\nu\beta\beta$ and $2\nu\beta\beta$ processes have so far been performed for several nuclei by direct $\beta\beta$ counting methods, as described in review articles.[3-5)] Recently finite half-lives for $2\nu\beta\beta$ processes and upper limits on $0\nu\beta\beta$ processes have been obtained for the three nuclei ^{76}Ge,[9-11)] ^{82}Se[12)] and ^{100}Mo[13-16)] by direct counting methods. ^{150}Nd was also studied.[17,18)]

In this letter we aim to report the first observation of the $2\nu\beta\beta$ half-life and the search for $0\nu\beta\beta$ in ^{116}Cd by means of the direct counting method. Main points of the present ^{116}Cd measurement, particularly of the $2\nu\beta\beta$ process, are as follows.

1. Since the half-lives of the $\beta\beta$ are sensitive to $\sigma\tau$ correlations, one needs systematic studies on several $\beta\beta$ nuclei for qualitative arguments on the values of particle- and astrophysical interest such as $\langle m_\nu \rangle$ and $\langle RHC \rangle$.
2. Experimental studies of the $2\nu\beta\beta$ processes in various nuclei reveal general trends of $M^{2\nu}_{\beta\beta}$ as functions of nuclear shell configurations, and lead to better understanding of the $\beta\beta$ mechanisms in nuclei.
3. The obtained value for $M^{2\nu}_{\beta\beta}$ is used to obtain appropriate $\sigma\tau$ interaction parameters and to check nuclear structure calculations. These are applied to evaluate $M^{0\nu}_{\beta\beta}$ for the same nucleus. Note that the main component of $M^{2\nu}_{\beta\beta}$ is GT ($J^\pi = 1^+$), i.e., $M^{2\nu}_{\beta\beta} \sim M^{2\nu}_{\beta\beta}(1^+)$, while $M^{0\nu}_{\beta\beta}$ includes several J components as $M^{0\nu}_{\beta\beta} = M^{0\nu}_{\beta\beta}(1^+) + \sum_{J\neq 1} M^{0\nu}_{\beta\beta}(J)$. The first component $M^{0\nu}_{\beta\beta}(1^+)$, which is a major one, is estimated well on the basis of the observed value for $M^{2\nu}_{\beta\beta}$.
4. The ^{116}Cd nucleus has a simple configuration of the $g_{7/2}$ neutrons and the $g_{7/2}$ proton holes, as in the case of the ^{100}Mo nucleus. The phase-space factors ($G^{2\nu}$ and $G^{0\nu}$) are large because of the large Q value of $Q_{\beta\beta}(0^+) = 2.808$ MeV for the $^{116}\mathrm{Cd}(0^+) \rightarrow {}^{116}\mathrm{Sn}(0^+)$ ground state decay. Therefore, ^{116}Cd is the most suitable for $\beta\beta$ studies (particularly for the $2\nu\beta\beta$ mode) after ^{100}Mo.

Experimental methods and data analysis for the present ^{116}Cd $\beta\beta$ study are the same as in the previous ^{100}Mo study,[13,19)] except that the ^{100}Mo source was replaced by the ^{116}Cd source. The measurement was made by means of ELEGANT V (ELEctron GAmma-ray Neutrino Telescope V: EL V) at the Kamioka underground (2,700 m w.e.) laboratory. Details of EL V are given elsewhere.[19)]

The enriched ^{116}Cd source with 90.7% ^{116}Cd and the natural $^{\mathrm{n}}$Cd source with 7.5% ^{116}Cd were used for the present measurements. The $^{\mathrm{n}}$Cd source was used for estimating common instrumental backgrounds and for subtracting their contributions from the ^{116}Cd spectrum. The 33 mg/cm^2 thick ^{116}Cd foils and the 34 mg/cm^2 thick $^{\mathrm{n}}$Cd foils were made by rolling ^{116}Cd and $^{\mathrm{n}}$Cd metal rods, respectively. The total weights were 91.13 g for the ^{116}Cd source and 88.52 g for the $^{\mathrm{n}}$Cd source. The ^{238}U and ^{232}Th contents were confirmed to be less than 0.5 ppb by using the inductively coupled plasma mass separation method (ICP-MS).

The side view of EL V is shown in Fig. 1. Two runs were carried out, RUN-A for 920 hours with the ^{116}Cd and $^{\mathrm{n}}$Cd sources set at the left and right sides of the source plane, respectively (see Fig. 1), and RUN-B for 955 hours with the source positions interchanged.

The data collection and data analysis procedures were similar to those in the previous ^{100}Mo measurement.[13,19)] The $\beta\beta$ event selection for the $0^+ \rightarrow 0^+$ ground state transition was made for events having two β tracks in drift chambers (DC) and two signals from two plastic scintillator segments (PL) under the following conditions: i) positions of the β energy deposition in PL are consistent with the β trajectories in DC, ii) the vertex of the two trajectories is on either the ^{116}Cd or the $^{\mathrm{n}}$Cd source plane, iii) the angle θ_{12} between the two β trajectories is smaller than 130° (θ cut), iv) the time difference between the two PL signals is consistent with the estimated one for the two β-rays starting from the vertex on the source plane (TOF cut), and v) the electron signals (PL) are not accompanied by any signals from any NaI scintillator segments. Conditions iii) and iv) are required in order to reject background events caused by single β-rays (electrons) passing through the source plane (see Fig. 1). Condition v) is effective for rejecting background events accompanied by γ-rays and/or X-rays such as Compton electrons and conversion electrons. The total detection efficiencies of $2\nu\beta\beta$ events for RUN-A and

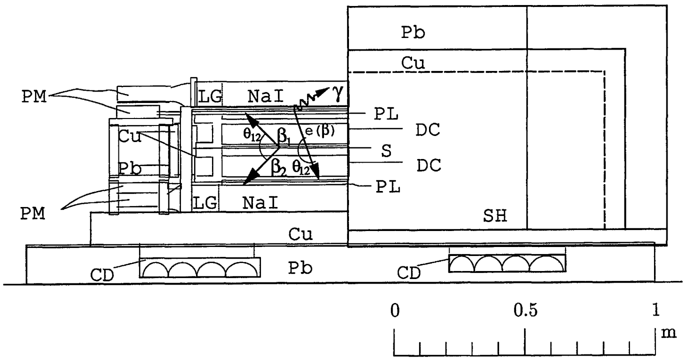

Fig. 1. Side view of ELEGANT V detector (EL V). The left-side part of the movable shield (SH), which consists of lead and copper bricks, is removed to show the detectors inside the shield box. Pb: lead bricks, Cu: OFHC bricks, NaI: NaI(Tl) detector array, LG: light guides, PM: photomultiplier tubes, PL-A and PL-B: plastic scintillators, DC-A and DC-B: drift chambers, S: source plane, CD: cable duct, and AT: airtight container. Typical $\beta\beta$ tracks (β_1, β_2) and a Compton scattered electron (e) and γ ray are illustrated.

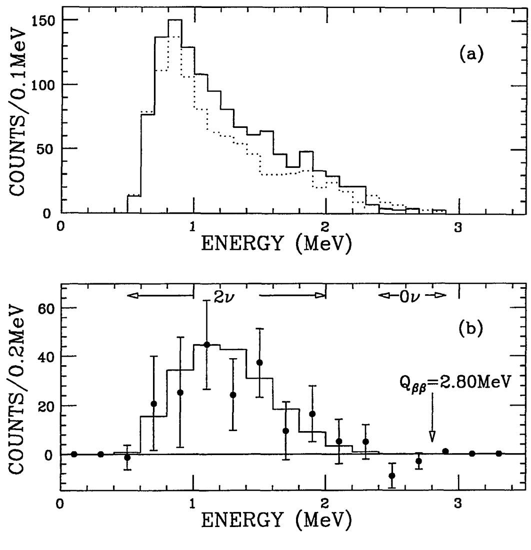

Fig. 2. (a) Sum energy spectrum of $E_\beta+E_{\beta'}$ from the ^{116}Cd source (solid line) and that from the ^{n}Cd source (dotted line) for RUN-A and RUN-B, i.e., the 1875-hour experiment. (b) The difference of the ^{116}Cd and ^{n}Cd spectra (circles with error bars) together with the Monte Carlo (MC) calculation for $T^{2\nu}_{1/2}=2.6\times10^{19}$ y (solid line).

RUN-B were evaluated by Monte Carlo (MC) simulation to be 7.3 and 9.0%, respectively. The difference reflects the different energy discrimination levels of PL.

The measured sum energy ($E_\beta+E_{\beta'}$) spectra for ^{116}Cd and ^{n}Cd sources are shown in Fig. 2(a). Here the spectra for RUN-A and RUN-B are simply added to illustrate the overall spectrum shapes. The difference between the two spectra is almost the ^{116}Cd $\beta\beta$ spectrum, provided that the background is common for both the ^{116}Cd and ^{n}Cd sources. In fact it is not exactly the same for the ^{116}Cd and ^{n}Cd source sides. Moreover the background/noise level in RUN-B was slightly higher than that in RUN-A.

The ^{116}Cd $\beta\beta$ spectrum was obtained, as shown in Fig. 2(b), by the following background considerations. First, we discuss the origins of the background, and secondly, the way to subtract them in order to extract the true ^{116}Cd $\beta\beta$ spectrum from the measured spectra.

There are three classes (origins) of the background events: i) radioactive contamination in the ^{116}Cd and ^{n}Cd sources, ii) radioactive isotopes in the detector elements such as photomultiplier tubes of PL (PL–PM) and drift chambers, and iii) ^{222}Rn gas around the source and PL.

Background rates due to possible ^{238}U and ^{232}Th chain isotopes in the ^{116}Cd and ^{n}Cd sources were evaluated on the measured upper limits of 0.5 ppb for both ^{238}U and ^{232}Th isotopes. Assuming a radioactive equilibrium in ^{238}U and ^{232}Th chains, the isotopes to be checked are ^{234m}Pa, ^{214}Pb and ^{214}Bi in the ^{238}U chain, and ^{212}Bi and ^{208}Tl in the ^{232}Th chain. The β-rays followed by the internal conversion electrons (e) in these isotopes might produce false 2β(β-e) events in the ^{116}Cd $2\nu\beta\beta$ spectrum. The upper limits of 0.5ppb on both ^{238}U and ^{232}Th isotopes lead to upper limits of 2% and 0.5%, respectively, upon their contributions to the ^{116}Cd $2\nu\beta\beta$ yield. These are negligible compared to the statistical errors of the $2\nu\beta\beta$ yield.

There are two major background sources in the EL V detector elements. One is ^{40}K contained in the PL–PM array, and the other is ^{222}Rn admixed in the gas of DC. The 1.46 MeV γ-ray from ^{40}K is Compton-scattered in PL, and the recoil electron passing through DC may produce false $\beta\beta$ events, even though the survival probability after θ and TOF cuts is very small. The 1.46 MeV γ-ray yield was evaluated by the off-line analysis of events in which the Compton-scattered γ-ray and the recoil electron were detected by NaI and PL detectors, respectively. The ^{222}Rn gas content in the DC gas was estimated to be less than 0.5 Bq/m^3 by off-line analysis of the ^{214}Bi events in DC.

On the basis of these measured yields and limits, MC calculations were made for contributions to the $\beta\beta$ event from the 1.46 MeV γ-rays from ^{40}K in PL–PM and from the ^{222}Rn–^{214}Bi content in DC. It was found that 41 ± 3% and less than 25% of the measured yield for the $^{\mathrm{n}}$Cd source (background spectrum, Fig. 2(a) dotted line) are attributed to the ^{40}K in PL–PM and ^{222}Rn in DC, respectively. These are common for the spectra from both the ^{116}Cd and $^{\mathrm{n}}$Cd sources, and thus are cancelled in the difference spectrum between them.

Backgrounds to be carefully considered are those due to ^{214}Bi from the ^{222}Rn gas around the source plane. ^{222}Rn in the air around the source is reduced to 10^{-6} by filling the source region with nitrogen gas evaporated from liquid nitrogen. The ^{222}Rn content, however, is time and position dependent, being somewhat dependent on the nitrogen gas flow. The ^{214}Bi content was monitored in real time by investigating the major decay branch of the β-decay of ^{214}Bi followed by the 609 keV γ-decay. These β- and γ-rays were efficiently measured by means of the DC, PL(β) and NaI(γ) detectors of EL V. The measured ^{214}Bi contents in RUN-A were 2.5 ± 0.4 Bq/m^3 and 2.3 ± 0.2 Bq/m^3 for the ^{116}Cd and $^{\mathrm{n}}$Cd source sides, respectively. There is no difference between them. Contributions of these Bi contents to the $\beta\beta$ spectra for ^{116}Cd and $^{\mathrm{n}}$Cd sources are 25 ± 3% and 24 ± 2%, respectively, of the measured yield for the $^{\mathrm{n}}$Cd source (Fig. 2(a) dotted line). They are nearly the same for both, and thus are cancelled in the subtraction procedure between the measured spectra for the ^{116}Cd and $^{\mathrm{n}}$Cd sources. The ^{214}Bi contents in RUN-B, however, were found to be 5.7 ± 0.4 Bq/m^3 and 4.0 ± 0.4 Bq/m^3 for the ^{116}Cd and $^{\mathrm{n}}$Cd source sides, respectively, mainly due to an inhomogeneous distribution of Rn caused by insufficient N_2 gas flow in the ^{116}Cd and $^{\mathrm{n}}$Cd source regions. The contributions of these ^{214}Bi contents to the $\beta\beta$ spectra for the ^{116}Cd and $^{\mathrm{n}}$Cd sources are 49 ± 3% and 34 ± 3%, respectively, of the measured yield for the $^{\mathrm{n}}$Cd source. They differ from each other and thus are not cancelled. This difference was corrected in the extraction of the ^{116}Cd $\beta\beta$ yield. It should be noted that most of the background yield measured for the $^{\mathrm{n}}$Cd source is understood as mentioned above.

The obtained $\beta\beta$ spectrum for ^{116}Cd (Fig. 2(b)) clearly shows finite excess counts in the 0.7–2.0 MeV energy region relevant to the $2\nu\beta\beta$ process. The obtained half-lives for the ^{116}Cd $2\nu\beta\beta$ are $2.6^{+1.3}_{-0.6} \times 10^{19}$ y for RUN-A and $2.7^{+1.7}_{-0.7} \times 10^{19}$ y for RUN-B, which agree quite well. From the weighted average of these data, one obtains a half-life of $2.6^{+0.9}_{-0.5} \times 10^{19}$ y for the $^{116}\mathrm{Cd}\,(0^+) \rightarrow {}^{116}\mathrm{Sn}(0^+)$ $2\nu\beta\beta$, where the error includes all statistical errors and possible errors in the background subtraction procedures given above. The solid line in Fig. 2(b) shows the MC simulation based on the above half-life.

In the region of ^{116}Cd $0\nu\beta\beta$ from 2.4 MeV to 2.8 MeV, no excess count was observed, as shown in Fig. 2(b). Lower limits on the $0\nu\beta\beta$ half-lives were deduced as $T^{0\nu}_{1/2} > 6.3(2.9) \times 10^{21}$ y and $T^{0\nu}_{1/2} > 4.2(2.1) \times 10^{21}$ y with 68% (90%) C.L. for the $\langle m_\nu \rangle$ and $\langle \lambda \rangle$ $0\nu\beta\beta$ processes, respectively. The difference between them arises due to the different detection efficiencies reflecting the different β-β angular correlations. Upper limits on $\langle m_\nu \rangle$ and $\langle \lambda \rangle$ are deduced to be 8.8 eV and 1.3×10^{-5}, respectively, from these half-life limits and the relevant nuclear matrix elements.[20] They are model dependent. The results of the present study have been presented by one of the authors (Kume) at a symposium.[21]

The ^{116}Cd experiment with ^{116}CdWO$_4$ scintillators has also been performed by the INR (Kiev) group.[22] The data are consistent with the present values measured by EL V.

The nuclear matrix element $M^{2\nu}_{\beta\beta}$ can be derived from the measured $2\nu\beta\beta$ half-life $T^{2\nu}_{1/2}$. Using the value $G^{2\nu}=8.0\times10^{-18}$ $y^{-1}(m_\mathrm{e}c^2)^2$[2] in eq. (2), one obtains $M^{2\nu}_{\beta\beta}=0.069\pm0.009$ $(m_\mathrm{e}c^2)^{-1}$, where m_e stands for the electron mass. The present value for $M^{2\nu}_{\beta\beta}$ is much smaller than the simple shell-model value, but is of the same order of magnitude as those for ^{76}Ge,[9-11] ^{82}Se[12] and ^{100}Mo.[13-16] This suggests some universal quenching of $2\nu\beta\beta$ rates in these nuclei.

Recently, $2\nu\beta\beta$ matrix elements for the ground state $\beta\beta$ of $A(Z,N)\rightarrow A(Z+2,N-2)$ have been shown to be related to single β decay matrix elements as $M^{2\nu}_{\beta\beta}=k(M_{\beta^+}\cdot M_{\beta^-})/Q_{\beta\beta}$ with the common factor k being around $(1.0\sim1.2)\times10^4$.[23] Here M_{β^+} and M_{β^-} are the matrix elements for relevant single β^+ and β^- decays from $A(Z,N)$ and $A(Z+2,N-2)$ to the single particle 1^+ state in the intermediate nucleus $A(Z+1,N-1)$. The values for M_{β^+} and M_{β^-} are obtained from experiments or are evaluated from $\log ft$ values in neighboring nuclei.[24] The value for k derived from the present ^{116}Cd half-life is $k=(1.0\pm0.2)\times10^4$, which is consistent with the systematic trend.[23]

In conclusion, the finite half-life of the $2\nu\beta\beta$ and the lower limits on the half-lives for the $\langle m_\nu\rangle$ and $\langle\lambda\rangle$ mode $0\nu\beta\beta$ were obtained for ^{116}Cd. The major background contributions have been checked by using the β-β-γ coincidence data from multisegment e- and γ-detector elements in EL V. The nuclear matrix element for ^{116}Cd and the values for other nuclei imply a general trend of $M^{2\nu}_{\beta\beta}$ consistent with the recent theoretical analysis.[23]

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References

1) W. C. Haxton and G. J. Stephenson. Jr.: Prog. Part. Nucl. Phys. **12** (1984) 409, and references therein.
2) M. Doi, T. Kotani and E. Takasugi: Prog. Theor. Phys. Suppl. No. 83 (1985) 1, and references therein.
3) A. Morales: Nucl. Phys. B **28A** (1992) 181; *Proc. Int. Symp. Neutrino Telescope, Venice, 1994*, LF-NAE-94-004, and references therein.
4) M. K. Moe and P. Vogel: Ann. Rev. Nucl. Part. Sci. 1994 (to be published), and references therein.
5) H. Ejiri: Nucl. Phys. **A522** (1991) 305c; *Proc. 14th Int. Workshop on Weak Interactions and Neutrinos, Seoul, July 1993*, and references therein.
6) P. Vogel and M. R. Zirnbauer: Phys. Rev. Lett. **57** (1986) 3148.
7) K. Muto and H. V. Klapdor: Phys. Lett. **B201** (1988) 420; A. Staudt, T. T. S. Kuo and H. V. Klapdor-Kleingrothaus: Phys. Rev. **C46** (1992) 871.
8) T. Tomoda and A. Faessler: Phys. Lett. **B199** (1987) 475.
9) F. T. Avignone *et al.*: Phys. Lett. **B258** (1991) 559.
10) A. Balysh *et al.*: Phys. Lett. **B283** (1992) 32; Phys. Lett. **B322** (1994) 176; M. Beck *et al.*: Phys. Rev. Lett. **70** (1993) 2853.
11) A. Vasenko *et al.*: Mod. Phys. Lett. **A5** (1990) 1299.
12) S. R. Elliot *et al.*: Phys. Rev. Lett. **54** (1987) 2020; Phys. Rev. C **46** (1992) 1535.
13) H. Ejiri *et al.*: Phys. Lett. **B258** (1991) 17; J. Phys. G: Nucl. Part. Phys. **17** (1991) S155; Nucl. Phys. **28A** (1992) 219; N. Kudomi *et al.*: Phys. Rev. C **46** (1992) R2132; J. Tanaka and H. Ejiri: Phys. Rev. D **48** (1993) 5412.
14) M. K. Moe *et al.*: J. Phys. **G17** (1991) S145.
15) M. Alston-Garnjost *et al.*: Phys. Rev. Lett. **71** (1993) 831.
16) D. Lalanne *et al.*: Nucl. Phys. B **35** (1994) 369.
17) S. R. Elliot *et al.*: Nucl. Phys. B **31** (1993) 68.
18) V. A. Artem'ev *et al.*: JETP Lett. **58** (1993) 262.
19) H. Ejiri *et al.*: Nucl. Instrum. Methods **A302** (1991) 304.
20) A. Staudt, K. Muto and H. V. Klapdor-Kleingrothaus: Europhys. Lett. **13** (1990) 31; M. Hirsch *et al.*: Z. Phys. **A345** (1993) 163.
21) K. Kume *et al.*: Nucl. Phys. A **577** (1994) 405c.
22) F. A. Danevich, V. N. Kouts and Yu. Zdesenko: private communications (1994).
23) H. Ejiri: Nucl. Phys. A **577** (1994) 399c.
24) C. M. Lederer and V. S. Shirley: *Table of Isotopes* (John Wiley & Sons, New York, 1978) 7th ed.