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Emission of Positrons in Beta-Decay of $^{90}Sr + ^{90}Y$

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Abstract: The measurement of the emission of electron-positron pairs in beta-decay $^{90}Sr + ^{90}Y$ has been made. This effect is much less intense than the basic decay process. The measurements showed that the observed electron-positron pairs are produced by the internal conversion process. The obtained result is compared with the experimental result of the other authors and with our earlier result.

1. Introduction

The study of basic decays of nuclei showed that the nuclei can go to the lower energy states not only through the basic decay process, but there is some possibility of the transition through the other accompanying processes. These processes are designated as the higher order processes [1].

The typical higher order processes accompanying decays of the nuclei:
i) internal bremsstrahlung,
ii) ionization and excitation of the electron cloud,
iii) internal electron-positron pair production.

These higher order processes have essentially lower intensity then the basic decay processes. In the matter of the creation of electron-positron pairs accompanying alpha and beta decays the creation of one electron-positron pair belongs perhaps to 10^9 particles emitted in the basic decay process.

The nuclei can go to the lower energy states by the process of internal conversion, too [2]. This process has higher probability than internal electron-positron pair production. One electron-positron pair belongs to 10^5 particles emitted through the basic decay process.

2. Internal conversion

The internal conversion is an electromagnetic process that competes with gamma-emission. In this process the nucleus de-excites by transferring its energy directly to an atomic electron, which then appears in the laboratory as a free electron or the excitation energy of nucleus is straightly transferred to electron-positron pair which is created. The second process is possible when the excitation energy of nuclei is higher than $2m_ec^2$. In both processes the excitation energy of nucleus is straightly transferred without creating gamma quantum. For this reason the process of internal conversion is not a two-step process.

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The internal conversion is an essential tool - the observation of E0 transitions, which are forbidden to undergo by electromagnetic radiation because the nuclear monopole moment cannot radiate to points external to the nucleus. The E0 transition is particularly important in decays from 0^+ initial states to 0^+ final states, which cannot occur by any other direct process.

From the experimental point of view the process of internal conversion can be the best spotted when gamma-decay is forbidden.

3. Electron-positron pairs produced by internal conversion

The low relative probability of this process and the problems in the experimental research are the reasons that there is the lack of experimental data (here exists only one experimental result) nowadays. Expressive improvement of the quality of the detection technique, utilization of computers in experiments and better experimental conditions (low-level background shield, electronics, computers) make it possible to obtain the better precision experimental results for this process at present. From this reason the experimental research of this process accompanying the basic decay processes of nuclei is very topical. We measured two sources ^{90}Sr with different activity A_1 = (96.87±1.93) Bq, A_2 = (2.93±0.06) MBq. The low-activity source was used only for estimation of the foreign radioactivity material. The decay scheme of ^{90}Sr and ^{90}Y is shown in Fig. 1.

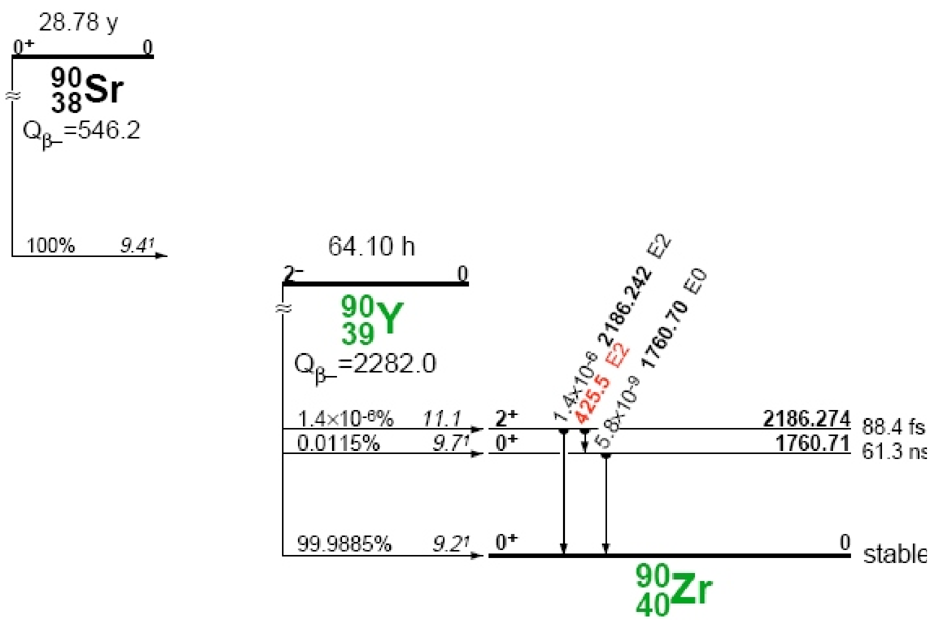

Fig. 1. The decay scheme of ^{90}Sr and ^{90}Y.

4. Experimental research

The main problem in the experimental research is that this low intensity process must be detected in the presence of the other higher intensity processes. For this reason for the successful experimental research of the electron-positron pairs produced via process of internal conversion the specific necessary conditions must be satisfied:

a) the high activity sources (~MBq) must be used,
b) the high radioactivity pure sources must be used,
c) the sources must not be the positron emitters,
d) the energy of the basic decay process is higher than $2m_ec^2$,
e) the background must be as low as possible,
f) the experimental equipment must have high sensitivity and high energy resolution,
g) because of long term measurements the high stability of measuring equipment must be secured,
h) the decay scheme of nuclide must be very simple,
i) the decay scheme of the nuclide includes the forbidden gamma-transition with the energy higher than $2m_ec^2$ (transition 0^+ 0^+).

In regard to these specific conditions of the experimental research, we studied the characteristics of some detection systems suitable for the high sensitivity measurements. We used high volume scintillation and semiconductor detectors in different connections. We selected the best detection equipment appropriate for experimental study of electron-positron pair from the comparison of the value of the factors of merit.

The value of the factor of merit, F, is characteristic for low-level gamma-ray spectrometers. Spectrometer with the highest value F has the highest sensitivity (the lowest limit of detection) for detecting gamma-rays of energy E in presence of interference radiation coming from the natural background of the spectrometer and from gamma-quanta higher energy of the emitters present in the measured sample. In our measurements the measured samples did not obtain the impurity with high energy gamma-quanta and the types of detectors were similar therefore the effect from Compton continuum under the peak of energy E and the energy resolution can be neglected. For this reason the value of the factors of merit of spectrometers F were estimated from the equation

$$F \quad \frac{\quad}{\sqrt{B_N}}$$

where is the peak efficiency for energy 511 keV and B_N is the natural background of the spectrometer in this energy region. We have a few NaI(Tl), Ge(Li) and HPGe detectors. We measured the factors of merit for various spectrometers in single and coincidence connections of these detectors in our Low-level Gamma-spectrometry Laboratory at the Department of Nuclear Physics and Biophysics. We list the factors of merit of single HPGe and coincidence HPGe-NaI(Tl) spectrometers that had the highest value of the factor of merit in Table 1.

Table 1. Factors of merit of single HPGe and coincidence HPGe-NaI(Tl) spectrometers.

Spectrometer	[$10^{\ 2}$]	B [imp s $^{\ 1}$]	F [$10^{\ 2}$]
HPGe	4.38±0.09	0.03514	23.37±0.66
HPGe-NaI(Tl)	0.59±0.01	0.00017	45.25±0.88

It is evident from the obtained results that it is the most advantageous to use the coincidence HPGe-NaI(Tl) spectrometer for detection of coincidence gamma-quanta in the measurements of low-level gamma-ray spectrometry.

Because of the probability of creation of one electron-positron pair has a very low relative probability from the measured background spectra (B) and peak efficiency ( ) under the chosen relative standard deviation ( ) and total time of the measurement (30 days) we obtained the minimum measurable activity (MMA) for coincidence HPGe-NaI(Tl) spectrometer according to the formula

$$MMA \quad \frac{1 \quad 2 \quad \sqrt{B \ T}}{^{2} \ T}$$

Values of MMA and the ratio MMA toward activity A of the source ^{90}Sr are listed in Table 2.

Table 2. The minimum measurable activity and the ratio of MMA/A.

	MMA [Bq]	MMA/A
0.1	(3.39±0.07) 10 ^{2}	(1.16±0.02) 10 ^{8}
0.5	(5.75±0.12) 10 ^{3}	(1.96±0.04) 10 ^{9}

It is seen from Table 2, that our coincidence HPGe-NaI(Tl) spectrometer is able to measure the number of electron-positron pairs already at relative intensity 10 ^{9}.

The number of electron-positron pairs was estimated by counting annihilation photons with the coincidence HPGe-NaI(Tl) spectrometer. This spectrometer, besides the highest value of the factor of merit, connects the quality of the good energy resolution of the semiconductor HPGe detector with the high sensitivity of the registration of the scintillation NaI(Tl) detector. We used the single HPGe spectrometer only for estimation of the radioactivity impurity in the measured samples.

The detectors were located in a good-quality low-level background shield characteristics of which were described in works [3, 4].

The used large-volume semiconductor coaxial HPGe detector has the sensitive volume 280 cm^3, the relative efficiency 69 %, the ratio peak/Compton has the value 66.7 and the energy resolution for 1.33 MeV peak ^{60}Co is 2.12 keV. The scintillation NaI(Tl) detector has the crystal dimension 100 100 mm. Electronic modules NIM fy Silena were used. The measured spectra were evaluated with the program EMCAPLUS made by fy Silena. The measured coincidence spectra of the background and ^{90}Sr are shown in Fig. 2 and Fig. 3.

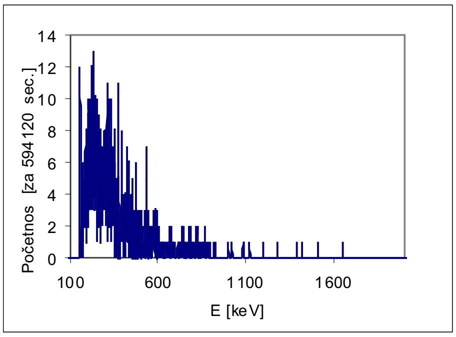

Fig. 2. Coincidence spectrum of the background.

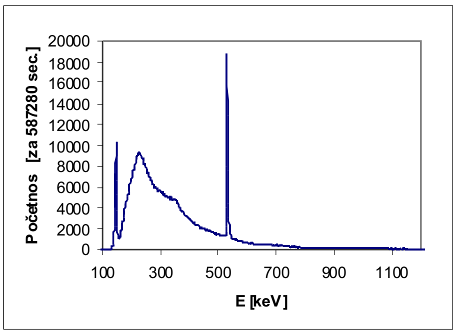

Fig. 3. Coincidence spectrum of ^{90}Sr.

5. Results

The measurements of emission of electron-positron pairs in ^{90}Sr + ^{90}Y showed that number of measured positrons is about three order higher then is expected according to the theory of the process of internal pair production accompanying the beta decay of nuclei. For this reason it is obvious that registered positrons are produced via the process of internal conversion. Our experimental results are compared with the result of other authors in Table 3.

Table 3. Comparison of our results - the ratio of the probability of the production of the electron-positron pair to the probability of the basic decay process of ^{90}Y, with the results of other authors.

$T_{e\ e}$ / T_b		
Greenberg and Deutsch [5]	Our earlier result [6]	Present result
$(3.6\pm0.9)\ 10^{5}$	$(1.2\pm0.6)\ 10^{5}$	$(3,45 \pm 0.8)\ 10^{5}$

The results of our measurements were corrected for the possible sources of annihilation radiation which may contribute to the measured number of positrons. The special care was taken to estimate the contribution of these sources of the annihilation radiation:

1. A correction for the annihilation peak in the background.
2. A correction for the external pair production by high-energy photon originating in the sources.
3. A correction for the possibility of some radioactive impurities, which decay by positron emission (^{65}Zn, ^{22}Na).
4. A correction for the contribution of nuclei produced by (, n) reactions and subsequently decayed by positron emission.
5. A correction for the production of neutrons accompanying spontaneous fission.
6. A correction for the impurities present in the sources which emit cascade quanta with the energy (511±2) keV and other with higher energy.
7. A correction for the annihilation of positrons in the flight.
8. A correction for the random coincidence rate.

The correction for the presence of some radioactive impurities, which decay by positron emission (^{65}Zn, ^{22}Na) was made by measurements of both samples of ^{90}Sr + ^{90}Y by a single HPGe spectrometer. The results of the measurements of the sample with lower radioactivity are presented in Table 4. It was evident from these measurements that the measured samples do not contain radioactive impurities. In the measurements of the background by single HPGe spectrometer the background peaks of ^{214}Bi, ^{208}Tl, ^{40}K, ^{214}Pb, ^{228}Ac a ^{137}Cs were found which are present in the environment since the Chernobyl nuclear power plant accident.

The correction for the annihilation peak in the background was the most important. Other corrections were small and totally did not exceed 25 % of the measured values of the annihilation gamma-quanta. The measurements confirmed that the e e^+ pairs are produced by 1.76 MeV excited level of ^{90}Zr. The emission of single gamma quantum from this level is forbidden (0^+ 0^+). From this reason our result gives the number of e e^+ pairs which were produced by the process of the internal conversion in the transition from this excited state to the basic state to the emission of ^{90}Zr. Number of electron-positron pairs produced by the higher order process - the internal electron-positron pair production accompanying the basic beta-decay process of ^{90}Y is about three-four order lower then the measured number.

Table 4. Values obtained from measurements ^{90}Sr by single HPGe spectrometer B – background peak, * – low intensity peak.

No	Sort of peak	E [keV]	Counting rate [s ^{1}]	Error [%]
1	B	351.9	0.00258	7.60
2	annihil. peak	511	0.01850	2.31
3	B*	583.1	0.000523	36.76
4	B	609.3	0.00285	5.59
5	*	633.2	0.000412	27.00
6	B	661.6	0.00301	13.50
7	*	768.7	0.00043	25.45
8	B	1120.3	0.000643	12.57
9	B	1238	0.000298	21.89
10	B	1378	0.000268	34.52
11	B	1408	0.000343	20.21
12	*	1439.9	0.000148	38.34
13	B	1460.7	0.000855	9.80
14	B	1764.5	0.000653	11.68
15	*	1944	0.000154	41.44
16	*	1969.8	0.0000971	38.31
17	*	2130.5	0.000147	37.01
18	B	2204.2	0.000232	32.16
19	B	2614.5	0.000415	12.80

6. Conclusion

Our obtained results of the emission of electron-positron pairs emitted via the process of internal conversion in ^{90}Zr are in a good harmony with experimental result of Greenberg and Deutsch but our present result is more accurate.

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