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^{140}La HALF-LIFE MEASUREMENT WITH Ge-DETECTOR

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Измерение периода полураспада ^{140}La Ge-детектором

Точное значение периода полураспада ^{140}La необходимо для оценки потоков тепловых нейтронов через идущую с высоким сечением реакцию захвата тепловых нейтронов ^{139}La. Измерение периода полураспада ^{140}La было выполнено в рамках изучения пространственного распределения тепловых нейтронов, образующихся в парафиновом замедлителе при облучении релятивистскими частицами массивных мишеней, по числу ядер ^{140}La, образовавшихся в реакции $^{139}La(n,\gamma)\,^{140}La \xrightarrow{\beta-} {}^{140}Ce$ (1).

Были изучены факторы, влияющие на точность определения $T_{1/2}$: обработка спектров (форма линии фотопика и фона под ней), учет и коррекция мертвого времени электроники и его изменение во время измерения, а также наложение импульсов. Показано, что небольшие неравномерности в распределении активности в источнике (несколько процентов) могут привести к заметным неточностям в определении $T_{1/2}$ в измерениях с источником, расположенным вплотную к детектору.

В двух сериях измерений с использованием микротрона в качестве источника нейтронов в реакции (1) было получено значение $T_{1/2}$ ^{140}La с высокой точностью ($T_{1/2}$ = 1,6801(7) д., $\lambda = 0{,}47749(20)10^{-5}\,c^{-1}$), согласующееся в пределах погрешности с наиболее точными литературными данными ($T_{1/2}$ = 1,6781(3) д., $\lambda = 0{,}47807(9)10^{-5}\,c^{-1}$) [2].

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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^{140}La Half-Life Measurement with Ge-Detector

Precise value of ^{140}La half-life is necessary for definitions of thermal neutron fluxes through the radiation capture reaction on ^{139}La, which has a high cross section for the reaction. ^{140}La half-life measurements were made by means of the HPGe-detector in the frame of an investigation of the space distribution of thermal neutron flux generated in paraffin moderator after interactions of relativistic particles with massive targets over the number of ^{140}La nuclei produced in $^{139}La(n,\gamma)\,^{140}La \xrightarrow{\beta-} {}^{140}Ce$ (1) reaction.

Factors influencing the accuracy of the $T_{1/2}$ measurements were studied: spectra processing (shape of the photopeak line and the background under it), consideration and correction of the dead time in electronics and its variations during the exposure as well as the pulse overlapping.

It was indicated that small irregularities in activity distribution in the source (several percents) could lead to definite inaccuracies in the $T_{1/2}$ evaluation while working with the source closely located to the detector.

The values of the $T_{1/2}$ of ^{140}La with high accuracy ($T_{1/2}$ = 1.6808(18) d, $\lambda = 0.47749(20)10^{-5}\,s^{-1}$) coinciding in the accuracy limits with the most precise adopted data ($T_{1/2}$ = 1.69781(3) d, $\lambda = 0.47807(9)10^{-5}\,s^{-1}$) [2] were obtained in two series of measurements using the microtron as a neutron source in reaction (1).

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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1. Introduction

Requirements on the accuracy of the half-life period $T_{1/2}$ definition increase when one needs to define intensity of the radiation N_0 a few half-life periods earlier (or later) over the measurements of radiation intensity N(t) in the given moment of time.

Relative error $\sigma(N_0)/N_0$ is calculated from the expression for the radioactive decays as:

$$\sigma(N_0)/N_0 = \{[\sigma(N(t))/N(t)]^2 +$$

$$(t\ln2/T_{1/2})^2(\sigma(T_{1/2})/T_{1/2})^2\}^{1/2}$$

assuming that the measurement error $\sigma(N(t))$ and the error $\sigma(T_{1/2})$ are independent.

If one can neglect the relative error of the measurement N(t), then $\sigma(N_0)/N_0$ is proportional to $t\ln2(T_{1/2})^2$ i.e., e.g., at $t= 5T_{1/2}$ - $\sigma(N_0)/N_0 = 3.5$ $\sigma(T_{1/2})/T_{1/2}$. One can thus conclude that when it is necessary to use standard sources which intensity is defined with accuracy 0.1% one must define their $T_{1/2}$ with accuracy about 10^{-4}, while making the measurement over several half-life periods.

Half-life of ^{140}La was measured several times in earlier works mainly with the help of the proportional chambers. High precision in determination of the $T_{1/2}$ was obtained, separate measurements are in good agreement, however sometimes they deviate even more than the errors cited by different authors (see Table 1).

Results of some earlier $T_{1/2}$ measurements for ^{140}La are given in [7], however accuracy of these measurements are about one order of magnitude lower than the data presented in Table 1. Most of the accurate data are obtained with the help of the ionization chambers and only in [5] the values of $T_{1/2}$ was measured by means of the Ge(Li) detectors. The value of the $T_{1/2}$ is given in [5] with the highest accuracy but the way how this accuracy is obtained is not discussed in [5] in details.

Along with some disadvantages in comparison with the gas-discharge 4π-detectors (low efficiency, insensitive to electrons) employment of semiconductor detectors shows some significant advantages to measure half-lives. First of all it is the possibility to measure the $T_{1/2}$ over the changes of the area of definite gamma-lines with time which solves the problem of the source purity from other activities and makes unnecessary some corrections (impurities, detector current stability with time, necessity to compare with the calibration activity source etc.).

While studying space distributions of the flux of thermal neutrons generated in interactions of relativistic particles with extended targets one employs the reaction

$$^{139}La(n,\gamma)^{140}La \xrightarrow{\beta-} {}^{140}Ce. \qquad (1)$$

This reaction is used in our experiments to define the flux of thermal neutrons from heavy Pb + U targets irradiated with the beams from the LHE JINR Synchrophasotron and , in particular, protons with energy 3.7 GeV [1]. Up to 15 La samples were irradiated simultaneously to restore space distribution of neutrons. These samples were measured one by one with three Ge detectors. Each sample, has been measured up to 6 times over 2-3 $T_{1/2}$.

Some difference in the decrease in the intensity of gamma-quanta accompanying the $^{140}La \xrightarrow{\beta^-} {}^{140}Ce$ decay from the evaluated value [2]:

$$T_{1/2} = 1.6781(3) \text{ days or } \lambda = 0.47807(9)\ 10^{-5} \sec^{-1} \quad (2),$$

which is one of the last evaluated values was detected in some of the measurements.

Specific measurements to find the precise value of the half-life period of ^{140}La and to define the reasons of the discrepancy in the obtained value from the generally adopted ones were performed in the frame of the above-mentioned experiment.

2. Methods of measurements and half-life determination

Measurements were performed using the HPGe-detector (ORTEC) with efficiency 28%, energy resolution 1.8 KeV at the line 1332.5 KeV (^{60}Co). Spectrometric tract with CANBERRA-2026 amplifier and registration block Spectrum Master 919 (ORTEC) with the analog-to-digital conversion time below 7 microseconds considering the "live" and total measurement time and the ability to work with 4 spectrometric tracts simultaneously has been employed. The block for registration is supplied with autonomous memory and connection to the PC providing convenient operation control for all the tracts, visualisation of the registration block operation and data storage in the PC. One can fix exposure according to the fixed Live or Real measurement time in the measurement procedure. The problem

of correct definition of the dead time in the process of the measurement is in this case the most significant and perhaps decisive.

To obtain high accuracy of the data at the level of the best modern measurement requires careful approach to the processing of the spectra. The method to define the area of the peak, background substraction and correctness of the error estimation reflect in the accuracy and reliability of the result.

The $T_{1/2}$ is defined via the decay constant λ using the expression:

$$S_i(\Delta t_{real}(i)/\Delta t_{live}(i)) = (e^{-\lambda t(i)} - e^{-\lambda(t(i)+\Delta t_{real}(i))})N_0, \quad (3)$$

where S_i - area of the peak in the i-th measurement;

$\Delta t_{real}(i)$ - duration of the i-th measurement (real time of the measurement);

$\Delta t_{live}(i)$ - live time of the measurement defined over the readings from the spectrometer;

$t(i)$ - absolute starting time of the i-th measurement;

N_0 - starting activity of the source.

As the correct measurement of the live time is one of the significant aspects influencing the accuracy of the result in the employed method - measurement of the decrease not of the general activity of the source but that of the areas of separate spectral lines - we tested the correctness of the exposure live time of the Spectrum Master 919 spectrometer.

To reach the goal, we registered the dependence of the peak areas S_i for ^{60}Co on the changes in the spectrometer load due to the displacement of an additional ^{137}Cs source from the detector.

This dependence is registered in the wide range of the loads: with the dead time from 1 to 53 %. One of the experiments (MICRO1)- first irradiation at the Microtron (see section 3)- was carried with the ^{140}La source with additional radiation from ^{60}Co, the lines of which were used to check the correctness of the live time registration.

These measurements indicated that the range of the correct definition of the live time depends on some factors including the employed amplifier and its time constants. In reality the live time for the CANBERRA 2020 amplifier is registered correctly in the limits of the measurement errors at the level of 0.5% up to the loads with the 53% dead time i.e. over the whole employed range. The range of correct counting of the live time for the CANBERRA 2026 amplifier is limited with only 8% of the dead time and we introduced respective corrections above this level.

Relation (3) is correct under the assumption that the dead time during the measurement is constant and that one can neglect the decrease in the intensity of the peaks due to the overlapping effect. Assuming that the dead time of the installation is changing proportionally to the installation load, i.e. $t_{real} - t_{live} = a_1 - a_2 e^{-\lambda t}$ and the probability of the overlapping effect ("pile up") is proprotional to the dead time (further details see in [8]) one can take these corrections into consideration using the relation:

$$S_i \Delta t_{real}(i)/\Delta t_{live}(i) =$$

$$N_0 \{ (e^{-\lambda t(i)} - e^{-\lambda (t(i)+\Delta t_{real}(i))}) +$$

$$+C_1 (e^{-2\lambda t(i)} - e^{-2\lambda(t(i)+\Delta t_{real}(i))}) + \tag{4}$$

$$+C_2 (e^{-3\lambda t(i)} - e^{-3\lambda(t(i)+\Delta t_{real}(i))}) \} ,$$

where C_1, C_2 are the coefficients, which are defined by means of the least squares method [9] while counting the desired decay constant λ.

3. Experimental results

Two containers with Lanthanium chloride ($LaCl_3 7H_2O$) weighting about 1 g irradiated with a flux of thermal neutrons from the cylindrical lead or uranium-lead target 200 mm length 80 mm diameter covered with paraffin moderator 60 mm thick were employed as sources. Up to 15 containers with lanthanium chloride were placed along the beam line at the surface of the moderator and in different positions in the paraffine moderator.

Measurements with two containers (A and B) were performed, the data related to these measurements are further nominated with "LHE" (Laboratory for High Energies).

Furthermore two $T_{1/2}$ measurements were carried for ^{140}La from one of the employed containers "A", however irradiated with a flux of thermal neutrons generated with a beam from the Microtron (Flerov Laboratory, JINR) [10]. We nominate these experiments with MICRO1(M1) and MICRO2(M2).

These measurements are performed using the equipment and the methods employed in measurements of the sources from the Synchrophasotron.

Time behaviour of the decay of ^{140}La is checked over the 7 most intensive lines (328.8, 486.9, 751.8, 815.8, 867.8, 925.2, 1596.2 KeV). The $T_{1/2}$ was evaluated for each of the lines and the results were averaged with weights, corresponding to the errors of each measurement (see Table 2). We also calculate the $T_{1/2}$ in other way - we summed intensities of all the seven lines in each spectrum and after that we determined the $T_{1/2}$ (Table 3). Finally we used integral counts of the spectra for gammas registered in the region from 329 keV to 1598 keV (Table 4). It happened to be possible because we had a high purity radioactive ^{140}La source.

During the experiment we carried three series of measurements:

1. Using two containers (A and B) with lanthanium chloride with isotope ^{139}La irradiated with neutrons from uranium-lead target covered with paraffine moderator at the proton beam at 3.7 GeV from the Synchrophasotron (LHE, JINR). The samples were irradiated for 3 hours. The containers were placed at different locations in the moderator and showed significantly different induced activity. They were measured one by one for 450 hours in the "zero" geometry (close to the detector).

At the beginning of the measurements the dead time in case of the container A reached 12%. Measurements were performed over the live time fixed at 20000 seconds.
The obtained result is (using for $T_{1/2}$ or λ calculation only the first term of expression (4)):

$$T_{1/2} = 1.7095(25) \text{ days}$$

$$(\text{or } \lambda = 0.46929(69)\ 10^{-5} \text{sec}^{-1}) \qquad (5)$$

and it differs by 12σ from the evaluated value [2], see (2). The another approximation where we fitted sums of all the 7 gamma-lines in every spectrum gives us (also using only the first exponent from (4)) the following results:

$$T_{1/2} = 1.7051(62)\text{d and } \lambda = 0.4705(17)\ 10^{-5}\text{sec}^{-1},$$

the results differ by $4.5\ \sigma$ from (2), but give errors twise larger then in the previous case.

This forced us to look carefully at all possible sources of the errors which could lead to such a discrepancy.

We compared processing procedures using two approaches - by means of the DEIMOS [11] and MAESTRO [12] codes. The surface of the peak is defined mainly by two methods. The first one (DEIMOS program) consists in definition of the shape of the gamma-line and the shape of the background line and determination of the model parameters by means of the least square method. The main fraction of the peak is described by a gaussian. Deviations from this line in the left and in the right sides from its maximum depend on the energy of the gamma-quanta and on the counting rate of the Ge detector .They could be taken into consideration by inserting satellite peaks (additional gaussians) into the shape of the line or by adding the tails described by different analitical functions, e.g. by exponent.

The first method (only one gaussian) allows one in the case of sufficient statistics to obtain the χ^2 value which is equal to about several dozens or hundreds. The error in definition of the area and the position of the maximum of the peak is χ times larger in this case than in case of additional gaussians and χ^2 of the order of "1".. The shape of the background under the peak is calculated as a superposition of the step function and linear and quadratic functions (DEIMOS).

The second method (program MAESTRO) automatically defines the peak position (K_{max}), its half-width, linear background over three points from the left and from the right at a distance of 2.5 half-widths and the area N_{peak} of the peak as an integral of the pulses in the channels from (K_{max} - FWHM) till (K_{max} + FWHM) minus the background area. The error N_{peak} is calculated as a square root from the N_{peak}.

Evidently, this method defines the value of the background less accurate and the error in the background area definition does not refect the fact.

However, different methods (DEIMOS and MAESTRO) provide the results which are somewhat different in the area of the peaks by 4% practically independent on the energy of the gamma-quanta. This leads to the discrepancy out of the limits of errors in the value of λ and respectively the $T_{1/2}$.

DEIMOS: $\lambda = 0.4696(7)\times10^{-5}$; $T_{1/2} = 1.7084(25)$ days (6)

MAESTRO: $\lambda = 0.4596(10)\times10^{-5}$; $T_{1/2} = 1.746(4)$ days (7).

But at low statistics (large time from the beginning of the measurement) the discrepancy of the two approaches practically disappeares. These points coincide and give the $T_{1/2}$ significantly different from the points with larger

statistics. However, because of the low weight of these points they practically do not influence the resulting $T_{1/2}$. Significant difference between the λ values obtained from calculations S_i using the DEIMOS and the MAESTRO programs indicates the importance of the accurate definition of the background under the peaks. We assume that the method of the background subtraction used in the program DEIMOS is more accurate.

As it is already pointed out above, measurements of the $T_{1/2}$ forthe two containers with the ^{140}La sources irradiated **with neutrons** from heavy target in different positions of the paraffin moderator surface is performed in turn in the same position in respect to the detector. The behaviour of the points of relative shift of experimental values (container A) from the non-linear fit of the values of the decay curve is shown in Fig.1 with blackened squares.

This figure shows that these values are characterized with significant discrepancy - up to 4% of the value

$$[N_{calc}(i) - N_{dat}(i)]/N_{calc}(i) =$$

$$= \log[S(i)_{calc} - \log(S(i)_{dat}]/\log(S(i)_{calc}],$$

significantly larger than statistical errors.

Positions of the same points for the second experiment MICRO2 (see below) with fixed position of the container are shown in fig.1 with black points for comparison.

Second measurement did not show the deviation of the points from values of non-linear fit for the first plot of points in fig.1 where counting statistics waslarge. Pointed discrepancy of the points can be explained with rotation of the containers in the given position in respect to the fixed geometry position in other measurements. When the container is placed in close contact to the detector ("zero geometry") the non-uniformity of the powder in the container can cause the found effect of the "changing efficiency of registration of gamma-quanta" with the detector.

The effect of the deviation in the time sequence defines significantly high errors of the obtained result with sufficiently high statistics of the counts in the peaks and high accuracy of the measurements of their area.

Dependence of the results in the first experiment (neutrons from the heavy target) on the number of the points taken for its calculation (amount of the measured spectra) is shown in fig.2. The squares represent the values of λ depending on the cutting of the initial points. The value corresponding to "0" in the X axis represent the result obtained over all of the measured points. The last value with a large error corresponds to the λ calculated over the three last points. We must point out that if the first eight measurements are neglected one obtains the λ value which is rather close to the published values.

Behaviour of the presented λ dependences on the number of the employed points indicates that the value of λ is defined as one can expect by initial points carrying the basic statistics of the whole measurement.

2. In order to find possible reasons of the discrepancy of our result we decided to repeat the experiment on measuring the $T_{1/2}$ of ^{140}La using the same reaction (1) by activating ^{139}La with slow neutrons, however, as a source of the latter we employed the Microtron (Flerov Laboratory, JINR) [10].

As a result of the 30 minute irradiation of the container A with the same amount of lanthanium we obtained the source of ^{140}La.

Measurement conditions for the first microtron experiment (MICRO1) are as follows:

a) spectrometric equipment is the same as in the first experiment (detector ORTEC, the same spectrometric tract and the Spectrum Master 919);

b) distance from the container to the end of the detector cryostate - 35 mm along the symmetry axis of the Ge detector, the container was not moved during the experiment;

c) a source of cobalt-60 (distance from the detector along the symmetry axis is 150 mm) was placed parallel to the container - the source of lanthanium-140. This source was also immobile during the whole measurement. Introduction of the cobalt-60 source is made in order to test the accuracy of the accessment of the live-time by means of the SPECTRUM MASTER 919 because an error in its operation can appear to be the reason of systematic inaccuracies and the discrepancy of our results with the evaluated value [2].

d) measurement time was 493.5 hours (12.2 periods);

e) dead time at the start - 15%, 5% of which comes to the cobalt-60 source. Measurements were performed over the live time 40000 seconds per point. We obtained 40 spectra.

Conditions of the ^{140}La and ^{60}Co γ-line processing are the same as in the first measurement: manual version of the DEIMOS program. Relation S_1/S_n of the areas of ^{60}Co is shown in fig.3, where S_1 - the first point, S_n - subsequent point . The points indicate that one needs to introduce the correction on the live time for the first three points because the relation decreases and starting from the level of the dead time below 8% it comes to a plateau. We introduced corrections to the first three points in respect to fig.3 in order to get the final result.

The obtained value in this measurement is:

$$T_{1/2} = 1.6788(7) \text{ days or } \lambda = 0.4772(4)\text{x}10^{-5} \quad (8)$$

This measurement indicated that the equipment, data processing and analysis provide the λ value which agrees with the value from [2] within two standard errors. 3. In order to further study the capabilities of our equipment to perform precise time measurements, we carried the third measurement of the $T_{1/2}$ for ^{140}La also from the source activated with the beam of slow neutrons from the Microtron (Flerov Laboratory, JINR). The same container A has been activated for 1 hour.

Measurement conditions for the second experiment with the microtron source (MICRO2):

a) all equipment is the same as in both previous measurements;

b) "zero" geometry - container in close contact with the detector;

c) starting dead time - 53%, measurement over the real time 28000 sec. - 42 points, 43000 sec. - 11 points and 86000 sec. - 2 points;

d) measurement time was 595 hours or 14.8 periods.

e) conditions of data processing and analysis were the same as in both previous cases.

To study the operation of the main tract and to define

possible corrections we carried methodical measurements. We measured the spectrum from two sources: ^{60}Co and ^{137}Cs in the main tract. The cobalt source was placed immobile at the distance of 60 mm from the detector, the cesium source was moved in respect to the detector from exposure to exposure in order to cover the whole range of the dead time in the third measurement (second MICRO2) i.e. from 53% to 0.95% (only the cobalt-60 source).

Maximal load of the tract at the dead time 53% was 24300 pulses/second over the counter or 12500 events in the spectrum per second. Minimal load (only ^{60}Co) - 405 pulses/second or 277 events over the spectrum per second.

Dependence on the dead time of the relation of the total area S_i of the peaks 1173 and 1332 KeV of ^{60}Co to the S_2 - their area at minimal dead time is shown in fig.4. Behaviour of the curve shows that the shift of the live time reaches 9% at the dead time of 52% (measurements were carried over the live time 2000 sec). The curve shown on the fig.4 was used to introduce corrections on the dead time while counting the $T_{1/2}$ in the third measurement.

It is necessary to point out that the inaccuracy, or better to say - distortions in the readings of the live (or dead time) from the SPECTRUM MASTER 919 is defined while using the CANBERRA 2026 amplifier in the spectrometric tract. Analogous measurements with the CANBERRA 2020 amplifier showed the absence of the live time distortions: dependence analogous to that in fig.4 did not show the deviations of the relation S_i/S_2 from the unit.

Thus, in order to estimate correctly the live (dead) time by the SPECTRUM MASTER 919 it is necessary to pick the amplifiers which provide the signals necessary for correct counting of the live time or to introduce additional

control of the live time.
The final results over all three measurements (LHE, M1 and M2 - the Microtron, "zero" geometry, large dead time) are placed in Table 2. The third measurement gives:

$$T_{1/2} = 1.68224(7) \text{ days or } \lambda = 0.47759(23)\times10^{-5} \quad (\text{Tab.2,M2,3-EXP}) \tag{9}$$

General result of the second and third measurements - irradiations of ^{139}La with neutrons from the Microtron is:

$$T_{1/2} = 1.6808(18) \text{days or } \lambda = 0.47749(20)\times10^{-5} \quad (\text{Tab.2,M1+M2,3-EXP}) \tag{10}$$

In order to confirm or refuse our assumption that the 12σ or 4.5σ difference of λ(LHE) and λ(M1) or λ(M2) appears due to the changes in the absolute registration efficiency (ε_γ) during the replacements of the unhomogeneous source (vials) we carried the model experiment.

We obtained the value of unhomogeneity to be on the level of 10% in testing measurement with the usual non-point source.

Taking the changes in the registration efficiency ε_γ to be in the limits of 10% from the average value during the sample replacements we estimated using the Monte-Carlo method the possible changes of the $T_{1/2}$ value obtained from processing of the measurements for the source irradiated at the microtron. We examined the case when some arbitrary change in the registration efficiency in the limits of 10% would take place in these measurements, e.g., due to random rotation of the source with uneven distribution of its activity around its axis.

We generated a set of random numbers k_i in the range (0.9-1.1). The set consisted of n numbers, where n is the number of the time points in the MICRO2 experiment. We took the areas of the seven γ-peaks s_i, multiplied them by k_i and calculated the new $T_{1/2}$ over the formula (3). In the case of the MICRO1 measurement we obtained 6 sets of the $T_{1/2}$ for each of the seven gamma-lines, while the error $\sigma(T_{1/2})$ increases by about one order of magnitude.

Influence of the random turning of the source on the result of the first (LHE) experiment was also studied - we introduced random deviation into the available experimental data. Analysis indicated that the error of the $T_{1/2}$ increases in this case only by the factor of 1.2-2.0 which points at the presence of the initial deviation of the same order as the artificial deviation introduced by us in the data from this experiment .

Therefore the difference of the $T_{1/2}$ in the LHE experiment from the published data and from our other measurements (MICRO1 and MICRO2) could be explained by a random deviation of the registration efficiency during the random rotation of the source with uneven distribution of activity in the limits of 10%.

4. Conclusions

1. Measuring the half-life period of the nuclei with Ge detectors allows one to get extremely high accuracy which is obtained in measurements with proportional chambers. For this therefore necessary to do:
a) employ adequate method of the background subtraction under the full adsorption peaks: besides the linear and quadratic constituent of the background one must also use

the "step function background".

b) take corrections on the changes of the equipment dead time during the measurements and corrections on the influence of the piling up on the γ-line intensity into consideration.

2. Slight "changes of the absolute registration efficiency" of the Ge detector occured in our measurements with the $LaCl_3 7H_2O$ powder irradiated at the LHE JINR during the replacements of the samples with uneven activity distribution lead to systematic errors in definition of the half-life of the radioactive nuclei ^{140}La.

3. Precise value of the half-life for ^{140}La $T_{1/2}$=1.6808(18), (λ = 0.47749(20)10 $^{-5}$) is obtained which is in good agreement with earlier measurements.

Measurement with semiconductor detectors in a wide range of counting rates and large dead time with correct consideration of the latter allows one to obtain the half-life period with high accuracy.

We obtained the value of the $T_{1/2}$ for ^{140}La with high accuracy in agreement with evaluated data [2] in two series of the measurements.

Table 1. Data on $T_{1/2}$ definition for ^{140}La according to publications with the most accurate values.

$T_{1/2}$ [d]	λ, $c^{-1} \cdot 10^5$	Ref.
1.6781 (3)	0.47807 (9)	[2]
1.6783 (7)	0.47802(20)	[3]
1.6779 (4)	0.47813(11)	[4]
1.67850(20)	0.47796 (6)	[5]
1.6783 (3)	0.47802 (9)	[6]
1.67900(20)	0.47782 (6)	[7]
1.6780 (3)	0.47810 (9)	[8]
1.6789 (5)	0.47784(14)	[9]

Table 2. $T_{1/2}$ for ^{140}La defined for each of the 7 above mentioned spectral lines and averaged considering the weight of each result. The data for three measurements (LHE, M1, M2) and total M1+M2 result are presented. Data dependence on the calculation using expression (3) considering one, two and three exponents - i.e. dependence of the result on the variations of the deadtime during the exposition (2-exp) and additional consideration of detector signals overlapping (3-exp) are shown.

FIT	LHE		M1		M2		M1+M2
	λ, $c^{-1} \cdot 10^5$	χ^2	λ, $c^{-1} \cdot 10^5$	χ^2	λ, $c^{-1} \cdot 10^5$	χ^2	λ, $c^{-1} \cdot 10^5$
1-exp	0.4696 (7)	0.9	0.47787(21)	5.6	0.47684(19)	4.2	0.4773 (5)
2-exp	0.4709(11)	1.1	0.47739(26)	0.8	0.47754(20)	2.3	0.47749(16)
3-exp	0.4708(18)	2.0	0.4772 (4)	1.3	0.47759(23)	2.1	0.47749(20)

Table 3. $T_{1/2}$ values for ^{140}La for three experiments (LHE, M1, M2) obtained by summing the peak areas for each time point over all seven lines. Dependence of the $T_{1/2}$ values on the variation of the deadtime during the exposure and pulses overlapping: 2 and 3 exponents respectively, are presented analogous to Table 2.

	LHE		M1		M2	
FIT	$\lambda,\ c^{-1}\cdot 10^5$	χ^2	$\lambda,\ c^{-1}\cdot 10^5$	χ^2	$\lambda,\ c^{-1}\cdot 10^5$	χ^2
1-exp	0.4705(17)	114.8	0.47812(24)	0.69	0.47664(11)	0.93
2-exp	0.4718(25)	116.3	0.4776 (4)	0.64	0.47749(18)	0.27
3-exp	0.4730(33)	118.4	0.4776 (6)	0.66	0.47767(21)	0.23

Table 4. $T_{1/2}$ values for ^{140}La obtained by summing the number of spectral pulses for each time point in the energy range 328 < Eg < 1596 KeV for the MICRO2 (M2) experiment as well as considering different exponent number.

M2-FIT	$\lambda,\ c^{-1}\cdot 10^5$	χ^2
1-exp	0.4811 (4)	1370
2-exp	0.47569(24)	105
3-exp	0.47765(17)	20

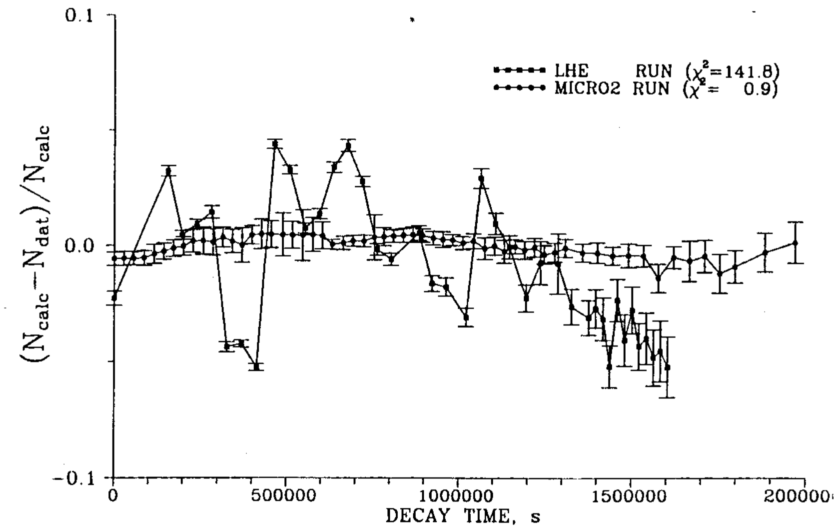

Fig.1. Difference between the calculated values of the exponential behaviour of the activity decrees and the experimental values in the measurement points for the LHE and MICRO2 experiments. The areas of the seven ^{140}La lines are summarized for each point.

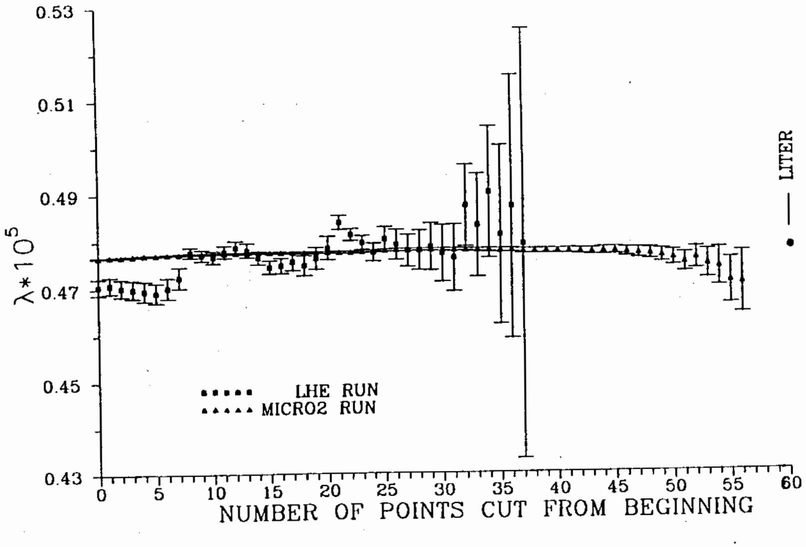

Fig.2 λ dependence on the decrease of the number of the points selected for calculation while cutting the point from the beginning of the experiment. LHE and MICRO2 experiments. The λ values for the number of the point (X axis) equal to "0" are obtained considering all the experimental points. The last λ values were obtained over three last points. The point shown with a dot is taken from ref. [2].

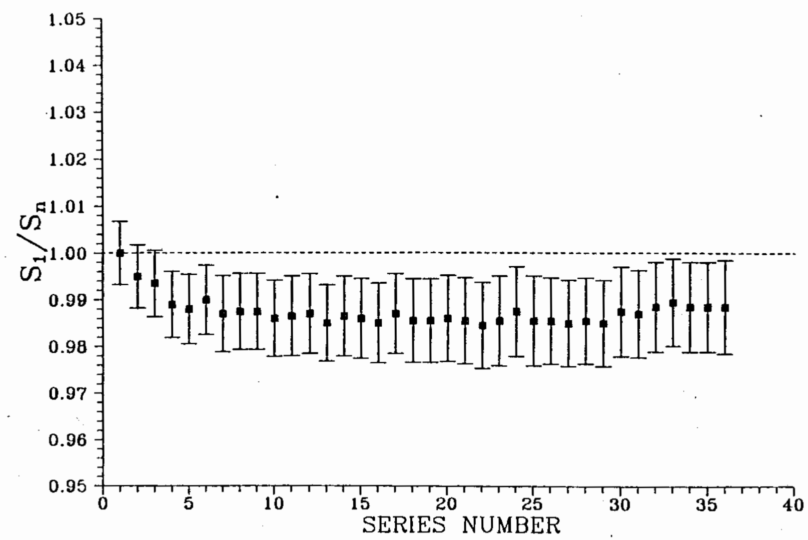

Fig.3 Dependence of the relation of the S_1/S_n summarized areas of the two known ^{60}Co peaks on the number of the spectrum (measurement) accompanying by decrease of run rate (deadtime). S_1 - area of the peak in the first measurement, S_n - peak area in the n-th measurement.

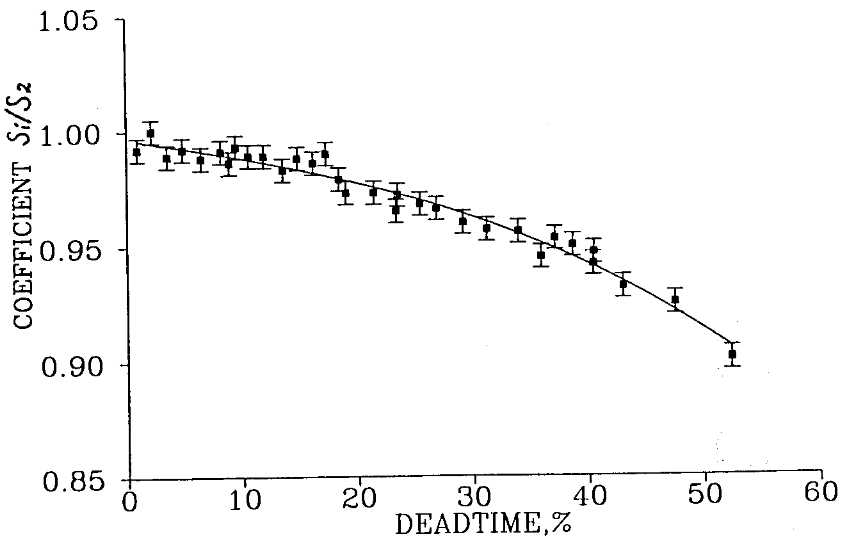

Fig.4 Dependence of the S_i/S_2 relation on the total area of two peaks (1173, 1332.5 KeV) ^{60}Co on the deadtime. S_i - area of the peaks for the current point, S_2 - area of the peak corresponding to minimal deadtime.

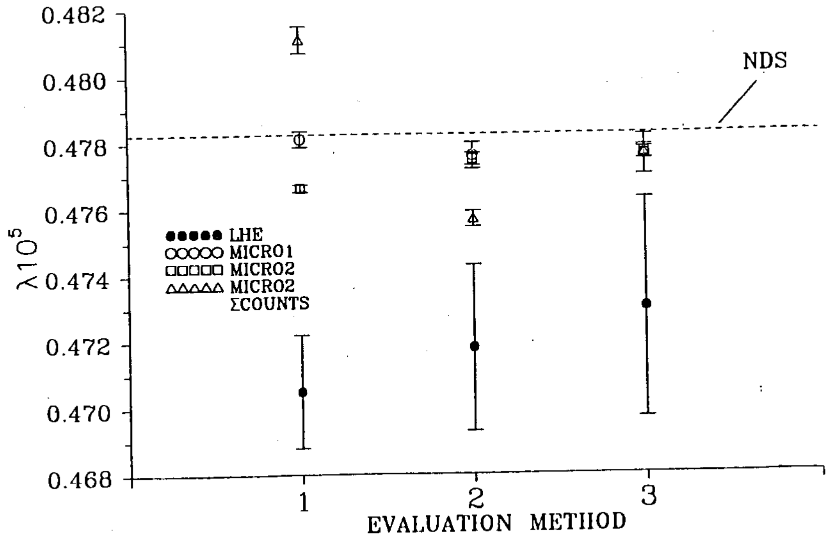

Fig.5 On this picture the results on constant λ determination for ^{140}La decay for all three measurements

(LHE, MICRO1 and MICRO2) as a function of all three members of expression (4) are shown.

The numbers 1, 2, 3 in the abscissa determine the number of exponents of the expression (4) used for the λ calculation.

For the number "1" we used only one first exponent which reflects only exponential law for ^{140}La decay. For the number "2" we added the second exponent which regards the exponential dead time changes during the exposition. And for the "3" we use all three exponents of (4), where the third exponent take care about exponential changes in the pile-up process.

The blackened points - the data of λ for the LHE experiment;
Open circles - the data for MICRO1 experiment;
Squares - the data for MICRO2 experiment;
Triangles - the results for λ obtained by summing the part of the spectra MICRO2 experiment in region from 329 to 1598 keV.
The dashed line - the value of λ from [2].

As it is possible to see the use of second and the third exponents put our data close to result of [2] within one or two standard deviation in spite of a big discrepance in points obtained only by the first exponent. The results of LHE experiment also show trend to go to the results of [2] but the difference and the errors are to big and it was explaned in the paper.

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