THE STUDY OF ^{177m}Lu DECAY

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High-precision measurements of the relative γ-ray intensities from the decay of ^{177m}Lu were performed by means of a γ-spectrometer. The data were used to determine the internal conversion coefficient (ICC) for the K-forbidden $E1$-transition with the energy of $55\,keV$ in ^{177}Hf. High value of the hindrance factor for the γ-radiation leads to anomalies in the ICC which are observed in the experiment. The discrepancy between experimental and theoretical values of ICC cannot be explained by admixtures of different multipolarities with the same parity. Such variance can be eliminated only by assuming the presence of intranuclear conversion.

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1. INTRODUCTION

The decay of the three-particle isomeric state in $^{177}Lu\,(K^{\pi} = 23/2-,\ T_{1/2} = 160\,days)$ has been studied for almost half a century and it still continues. The characteristics of rotational bands in ^{177}Lu and ^{177}Hf are being studied; the K-forbidden transitions excited by the decay of the ^{177m}Lu cause considerable interest. ^{177m}Lu can also be used as a calibration source in nuclear spectroscopy experiments. A convenient half-life, simple production in the $(n,\,\gamma)$-reaction, and over 40 sufficiently intense γ-lines in the energy range of 105 to 465 keV make it a very attractive isotope for such purposes. The intensities of the strong γ-rays are known with accuracy of (2...5)% [1], still there is disagreement on the estimates of intensities of some of the weaker lines. Precise data on it is necessary in the first place for calculation of internal conversion coefficients for the retarded γ-transitions in which anomalies caused by penetration effect may occur. Our current research was to clarify all controversial questions in this area.

2. EXPERIMENTAL TECHNIQUE

The relative intensities of γ-rays following the decay of ^{177m}Lu were measured with a γ-spectrometer that comprises two horizontal coaxial HPGe-detectors: GMX-30190 and GEM-40195, having the resolution of 1.89 and 1.73 keV for the γ1332-line of ^{60}Co and efficiency of 33 and 43% respectively. The radioactive ^{177m}Lu sources were obtained in the $(n,\,\gamma)$ reaction as a result of enriched to 27.1% in 176 mass number lutetium target irradiation with neutrons at the research nuclear reactor $WWR-M$. The measurements of γ-ray spectra started two months after the end of irradiation so that $^{177}Lu\,(T_{1/2} = 6.6\,days)$, having much larger activation cross-section, must have decayed en masse. The standard ^{60}Co, ^{133}Ba, ^{137}Cs, ^{152}Eu, ^{228}Th, and ^{241}Am γ-sources were used for accurate calibration of detectors for the energy range of 26 to 1620 keV. The shape of the efficiency curve is well described by the Campbell function [2]:

$$\varepsilon(E) = \sum_{i=1}^{3} p_{2i-1} e^{-p_{2i}E} + p_7 E^{-p_8}\,. \qquad (1)$$

Calibration parameters pi were found by the least-square method. The uncertainty in the efficiency curve of both detectors does not exceed 2% throughout the energy range. To minimize possible systematic errors a series of measurements were performed - using different types of HPGe-detectors, at different geometries, at different gains and channel widths of an amplitude-to-digital converter (8192 and 16384 quantization levels of the input signal) - 20 series of measurements in all.

3. RESULTS AND DISCUSSION

3.1. THE γ-RAY INTENSITIES FROM THE ^{177m}Lu DECAY

The γ-ray spectra were analysed using WinSpectrum [3], a computer program which allows determining with high precision the energy and intensity of components that have an asymmetric line shape and the ones that are overlapping. The results of our measurements and the data of better works are shown in Table 1. The γ-transition energies are taken from Ref.[4]. The usage of different types of detectors allowed us to determine the relative intensities of γ-rays for the energy range above 100 keV more precisely. Our data agrees to a great extent with the data of other researchers while having higher precision. In the energy range above 100 keV the authors of Ref. [7] also observed two weak cascade transitions in the reaction $^{176}Yb(^{9}Be,\alpha 4n)^{177}Hf$ with the energies of 203 and 223 keV between the levels of the ^{177}Hf ground-state rotational band. In addition,

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at energies less than 100 keV transitions with energies 14, 55, 69, 71, and 88 keV belong to the decay of ^{177m}Lu. The first two deexcite an isomeric state ($I^{\pi} = 23/2^{+}$, $T_{1/2} = 1.1\, sec$) of the ^{177}Hf, while the rest are interband transitions from levels of the $9/2^{+}$ [624] band to levels of the $7/2^{-}$ [514] band of the ^{177}Hf ground state.

Table 1. *Relative intensities of γ-rays from the decay of ^{177m}Lu*

Energies of γ-rays, keV	Intensities of γ-rays, relative units		
	Present work	[5]	[6]
105.3589	100.0	100.0	100.0
112.9498	173.0 ± 2.5	179.1 ± 8.4	178.6 ± 5.4
115.8682	5.12 ± 0.14	5.0 ± 0.5	5.46 ± 0.32
117.14	–	–	1.51 ± 0.20
121.6211	48.2 ± 0.8	48.7 ± 2.9	48.3 ± 1.7
128.5027	126.1 ± 1.8	126.9 ± 5.7	126.6 ± 3.5
136.7245	11.47 ± 0.23	11.4 ± 1.1	11.41 ± 0.55
145.7693	7.65 ± 0.13	7.5 ± 0.8	7.42 ± 0.43
147.1637	28.1 ± 0.4	30.2 ± 2.3	28.4 ± 1.5
153.2842	136.2 ± 2.0	150.0 ± 7.1	136.4 ± 3.8
159.7341	4.21 ± 0.09	5.0 ± 0.6	4.20 ± 0.22
171.8574	38.1 ± 0.6	41.0 ± 2.2	39.0 ± 1.4
174.3988	100.8 ± 1.4	105.3 ± 5.3	102.5 ± 2.9
177.0007	28.6 ± 0.4	28.9 ± 1.8	28.0 ± 1.1
181.9093	0.77 ± 0.07	0.8 ± 0.2	1.01 ± 0.10
195.5602	6.60 ± 0.12	7.2 ± 0.7	6.86 ± 0.33
204.1050	109.2 ± 1.6	119.0 ± 5.6	111.7 ± 3.3
208.3662	482 ± 7	510.0 ± 22.4	488.0 ± 13.9
214.4341	51.8 ± 0.7	54.6 ± 3.1	53.6 ± 1.8
218.1038	26.8 ± 0.5	25.1 ± 3.0	27.0 ± 1.1
228.4838	296 ± 5	310.0 ± 12.6	300.6 ± 8.5
233.8615	44.5 ± 0.7	47.1 ± 2.3	45.3 ± 1.7
242.07	0.458 ± 0.024	–	0.30 ± 0.10
249.6742	49.0 ± 0.9	51.3 ± 2.5	50.0 ± 2.0
268.7847	27.4 ± 0.7	28.3 ± 1.5	28.2 ± 1.2
281.7868	112.6 ± 2.3	116.7 ± 5.3	115.2 ± 3.4
283.609	3.23 ± 0.26	4.3 ± 0.6	2.89 ± 0.40
291.5429	8.14 ± 0.30	14.9 ± 1.3	8.22 ± 0.57
292.5266	6.75 ± 0.10	14.9 ± 1.3	6.67 ± 0.45
296.4584	39.8 ± 0.8	44.5 ± 2.7	40.8 ± 1.4
299.0534	13.11 ± 0.29	14.3 ± 1.0	14.77 ± 0.54
305.5033	14.11 ± 0.29	14.5 ± 1.2	14.87 ± 0.54
313.7250	9.9 ± 0.3	11.5 ± 0.8	9.98 ± 0.45
319.0210	83.1 ± 2.3	85.7 ± 4.7	85.6 ± 3.0
321.3159	10.3 ± 0.4	11.6 ± 0.9	9.93 ± 0.63
327.6829	145.9 ± 2.8	145.9 ± 6.4	148.6 ± 4.5
341.6432	13.8 ± 0.4	14.9 ± 1.3	13.74 ± 0.61
367.4174	25.1 ± 0.6	24.8 ± 1.6	26.07 ± 0.91
378.5036	241 ± 5	232.2 ± 10.7	246.2 ± 7.4
385.0304	25.4 ± 0.4	24.5 ± 1.6	25.99 ± 0.92
413.6637	138.8 ± 2.1	137.5 ± 7.0	143.4 ± 4.2
418.5388	171.7 ± 2.3	167.0 ± 8.4	175.9 ± 5.3
426.4726	3.64 ± 0.16	3.4 ± 0.4	3.52 ± 0.21
465.8416	19.8 ± 0.3	19.4 ± 1.3	19.2 ± 1.5

The internal-conversion electron lines of the 14 keV transition in L_1-and M_1-subshells of ^{177}Hf were observed by the authors of Ref.[8] in the ^{177m}Lu conversion spectrum. The study of the ^{177m}Lu γ-spectrum with a crystal diffraction spectrometer made it possible to determine the intensity of the $\gamma 55\, keV$ transition [9]. The intensities of γ-rays with energies of 69 and 88 keV were measured by means of the anti-Compton $Ge(Li)$ spectrometer and high resolution $Ge(Li)$-detectors [10,11]. The γ-transition with the energy of 71 keV belongs to the decay of the daughter ^{177}Lu and is observed with confidence in γ-spectrum by authors of all works. It should be noted that the accuracy of determining of these transitions' intensities, except the $\gamma 71\,keV$ line, do not exceed (10...35)%. Therefore, the problem of precise studies of the low energy region of ^{177m}Lu γ-spectrum is on today's agenda.

3.2. ON THE ENERGY OF THE $\gamma\,242\,keV$ TRANSITION

γ-transitions with the energy of 242.5 and $(242.07 \pm 0.10)\,keV$ were observed in the ^{177m}Lu γ-spectrum by the authors of Ref.[11] and Ref.[6] respectively. It is located in the ^{177m}Lu decay scheme as a cascade transition from the $21/2^-$ to the $19/2^-$ level within ^{177}Hf ground-state rotational band. The energy of the transition in Ref.[11] is given without measurement error, while its experimental energy value in Ref.[6] differs from the calculated one by more than four standard deviations. This raises the question on the reliability of identification of this γ-transition. Whether it is true can be seen by thoroughly measuring the transition's energy and comparing it with the energy difference for levels between which it occurs.

The energies of 38 γ-transitions accompanying the ^{177m}Lu decay were measured by means of a semiconductor spectrometer with high (up to a few electron volts) precision owing to the original method of the spectrum calibration developed by the authors of Ref.[4]. The system nonlinearity was determined with a pulser using a high-precision digital voltmeter. These data allowed determining the energy levels of rotational bands and the energy of the isomeric states in ^{177}Lu and ^{177}Hf with high precision.

In our previous work [12] the energy difference of several transitions in ^{177}Lu and ^{177}Hf was measured by using a magnetic β-spectrometer of the $\pi\sqrt{2}$ type. A joint analysis of these results showed no systematic errors in the transition energy determination, and these data have been recommended for use as energy standards for nuclear spectroscopy. Therefore, it was decided to use the γ-lines with energies of (233861.5 ± 0.5) and $(249674.2 \pm 0.6)\,eV$ from the ^{177m}Lu decay as reference lines to determine the energy of the $\gamma 242\,keV$ transition.

The technique of such measurements was reported in detail in Ref.[13, 14]. The difference in energy of the $\gamma 249$ and $\gamma 242\,keV$ lines based on the results of 19 series of measurements is $(7445 \pm 60)\,eV$. Weight error is given as the measurement error. The spread error turned to be smaller than the weight error, which indicates the absence of systematic errors of measurements. The obtained difference leads to the $\gamma 242\,keV$ line energy value $E_\gamma(242)_{exp} = (242230 \pm 60)\,eV$, which is in good agreement with the data from Ref.[6], but is more precise. The calculated value of the $\gamma 242\,keV$ transition energy is slightly higher $E_\gamma(242)_{calc} = (242490.5 \pm 2.4)\,eV$. The observed discrepancy by four standard deviations may possibly be explained by the errors of description of the background near a very weak $\gamma 242\,keV$ line, the intensity of which is three degrees smaller than the one for the $\gamma 233$ and $\gamma 249\,keV$ transitions. The placement of the $\gamma 242\,keV$ transition in ^{177m}Lu decay scheme is most likely to be true. This conclusion is important for the calculation of the intensity balance at the $21/2^-1260\,keV$ level in ^{177}Hf and was used in the next section of this paper.

3.3. THE TOTAL ICC FOR THE K-FORBIDDEN $E1$-TRANSITION WITH THE ENERGY OF $55\,keV$

The ^{177m}Lu isomer is a very promising nucleus for searching of anomalies in $ICCs$ for the K-forbidden g-transitions. Three electric and one magnetic multipole γ-transition with high hindrance factors on the quantum number K are excited by its discharging (Fig. 1). Decay of ^{177m}Lu occurs both to the $17/2^+$ level of rotational band of the ^{177}Lu ground state via K-forbidden $E3$-transition with energy $116\,keV$ and to the $23/2^+$ isomeric state in ^{177}Hf via γ-decay. The latter state is deexcited by the K-forbidden $M1$-transition with the energy of $14\,keV$ to the $21/2^+$ level of the rotational band of the $9/2^+$ [624] one-particle state in ^{177}Hf and by the K-forbidden $E2$-transition with the energy of $228\,keV$ to the $19/2^+$ level of the same band. The discharge of this state by means of the K-forbidden $E1$-transition with the energy of $55\,keV$ to the level of $21/2^+$ ground state rotational band of ^{177}Hf is also observed. All of them are hindered as compared to single-particle estimates. Some anomalies in γ-ray internal-conversion coefficients, caused by penetration effect, are possible for such transitions.

In internal conversion theory, by a penetration effect or intranuclear conversion is implied a correction to ICC arising in passing from transition electromagnetic potentials calculated for point-like nucleus to the potentials calculated for finite-size nucleus. Generally, such corrections do not exceed 2% and have only a slight effect on ICC value. A completely different type of situation occurs in the case of strongly hindered γ-transitions. In such case a contribution from internal conversion may become a crucial factor governing the ICC value. Of course, selection rules, which are responsible for a decrease in probability of γ-radiation, should have essentially smaller effect on the probability of internal conversion.

Appearance of anomalies in ICC of K-forbidden transitions is due to admixtures with respect to quantum number K in wave functions of initial and final states. There are admixtures that allow conversion transition according to the selection rules with respect to asymptotic quantum numbers, while γ-transition is forbidden. In this case anomalies in ICC caused by the penetration effect are observed. If the selection rules for conversion transition and γ-transition are identical, there are no anomalies. At present, it is very difficult to quantitatively estimate these admixtures. By this reason, it is not feasible to make a prediction of anomalies in ICC for a given K-forbidden transition.

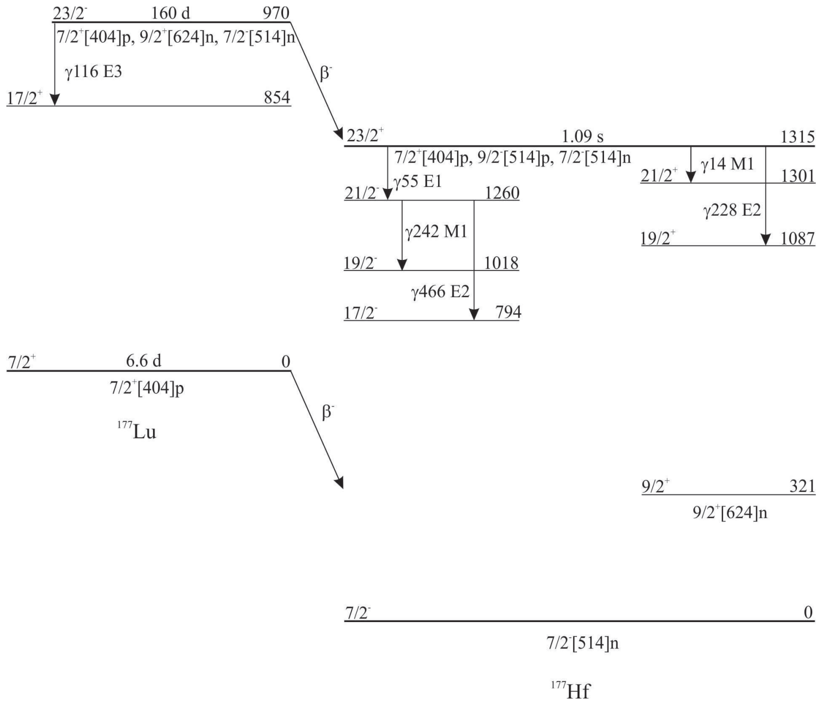

Fig.1. *The partial decay scheme of* ^{177m}Lu

Earlier, in Ref. [15, 16] there was found minor variance between experimental and theoretical values of ICC for $\gamma 228$ and $\gamma 116\,keV$ transitions, which cannot be explained by admixtures of different multipolarities with the same parity. Such deviation can be eliminated by assuming the presence of intranuclear conversion.

The total ICC of the $\gamma 55\,keV$ $E1$-transiton can be estimated from the balance of intensities of the $21/2^{-}1260\,keV$ level in ^{177}Hf. Following from the ^{177m}Hf decay scheme (see Fig.1), this level is powered by the $\gamma 55\,keV$ transition and deexcited by two intraband $\gamma 242$ and $\gamma 466\,keV$ transitions having the $M1$- and $E2$-multipolarity respectively. The intensity balance at the $21/2^{-}$ $1260\,keV$ level in ^{177}Hf can be written as

$$(1+\alpha(55))I_\gamma(55) = (1+\alpha(242))I_\gamma(242) + (1+\alpha(466))I_\gamma(466)\,, \qquad (2)$$

where $\alpha(55)$, $\alpha(242)$, $\alpha(466)$ and $I_\gamma(55)$, $I_\gamma(242)$, $I_\gamma(466)$ are the total $ICCs$ and transition intensities with the energy of 55, 242, and 466 keV respectively.

Using our data on the intensities of the $\gamma 242$ and $\gamma 466\,keV$ transitions from the Table 1, bringing the experimental value $I_\gamma(55)$ from Ref.[9] and theoretical values of ICC for $\gamma 242$ and $\gamma 466\,keV$ transitions from Ref.[17], we have calculated the total ICC of the $\gamma 55\,keV$ $E1$-transiton to be $\alpha(55)_{exp} = 1.08 \pm 0.23$. The theoretical value of ICC in the hafnium for the $\gamma 55\,keV$ $E1$-transiton is much lower, $\alpha(55)_{th} = 0.337$. To coordinate them the existence of the admixture of $M2$-multipolarity or the existence of the intranuclear conversion should be assumed.

The value of the admixture of $M2$-multipolarity can be calculated using the expression

$$\alpha(55)_{exp} - \alpha(E1)\frac{1}{1+\delta^2(M2/E1)} + \alpha(M2)\frac{\delta^2(M2/E1)}{1+\delta^2(M2/E1)}\,, \qquad (3)$$

where $\delta(M2/E1)$ is $M2/E1$ multipole mixing ratio for $\gamma 55\,keV$ transition in ^{177}Hf, $\alpha(E1)$ and $\alpha(M2)$ are the theoretical values of ICC for this transition assuming $E1$- and $M2$-multipolarity respectively. The obtained value of $\delta^2(M2/E1) = (5.2 \pm 1.6)\cdot 10^{-3}$ leads to the Weisskopf hindrance factor for the $M2$-component $F_W(\gamma 55\,M2) = (5...9)\cdot 10^6$, while the factors are much higher for other K-forbidden transitions in ^{177}Lu and ^{177}Hf (Table 2).

Table 2. *Weisskopf hindrance factors for K-forbidden transitions in* ^{177}Lu *and* ^{177}Hf

E_γ, keV	Multipolarity, L	$\Delta K = K_i - K_f$	$\nu = \Delta K - L$	F_w	$f_\nu = (F_w)^{1/\nu}$
14	$M1$	7	6	$7.0\cdot 10^{10}$	64.2
55	$E1$	8	7	$3.7\cdot 10^{13}$	86.8
55	$M2$	8	6	$(5...9)\cdot 10^6$	13.1...14.4
116	$E3$	8	6	$9.1\cdot 10^8$	61.9
228	$E2$	7	5	$1.5\cdot 10^8$	43.2

Table 2 shows that the $M2$-component for γ-transition with the energy of $55\,keV$ has a 3.0 to 6.6 times smaller hindrance factor per K-forbidenness unit f_ν than other transitions. It means that the $M2$-admixture value is likely to be exaggerated 10^3 to 10^5 times.

Analyses of the cases of anomalous conversion can be made with the inclusion of penetration corrections developed by Church and Weneser [18]. Using the parameterization of Hager and Seltzer [19] the electric $ICC's$ can be written as

$$ICC = \alpha(EL)(1 + A_1\lambda_1 + A_2\lambda_1^2 + A_3\lambda_2 + A_4\lambda_2^2 + A_5\lambda_1\lambda_2)\,, \qquad (4)$$

where $\alpha(EL)$ are the normal (no penetration) $ICC's$ tabulated in Ref. [17], Ai are coefficients calculated in Ref. [19] from electron wave functions for the mulipolarity of interest, and λ_i are the electric penetration parameters. The penetration parameters depend on nuclear structure and are determined from an analysis of the experimental quantities.

If, as it is in our case, independent experimental data are insufficient for finding both penetration parameters λ_1 and λ_2, the calculations are limited to one nuclear current parameter λ_1, which, in general, the anomalies in the EL-transitions depend on; the nuclear charge parameter λ_2 is considered to be zero. Because of the fact that in Ref. [19] the penetration coefficients are tabulated only for K-, L-, and M-subshells the following expression was used for the data set analysis

$$\alpha(55)_{exp} = \alpha_L(1 + A_1^L\lambda_1 + A_2^L\lambda_1^2) + \alpha_M(1 + A_1^M\lambda_1 + A_2^M\lambda_1^2) + \alpha_{N+O}\,, \qquad (5)$$

where α_L, α_M, α_{M+O} are the theoretical values of ICC, A_i^L, A_j^M are the coefficients for penetration effect analysis in ICC for L-, M-, and $N+O$-subshells of hafnium respectively.

Theoretical values for the conversion coefficients and penetration coefficients were interpolated from the tables by Hager and Seltzer [17, 19]. The results of calculation are listed in Table 3. Known experimental values of nuclear penetration parameter λ_1l1 for other K-forbidden $E1$-transitions from the Ref. [20] are also given in the table.

Table 3. *Experimental values of the nuclear penetration parameter λ_1 for the K-forbidden $E1$-transitions*

Nucleus	E_γ, *keV*	$\nu = \Delta K - L$	F_w	λ_1	*Reference*
^{169}Tm	240.3	2	$2.9 \cdot 10^9$	4.5 ± 0.6	21
^{171}Tm	295.9	2	$9.3 \cdot 10^8$	2.7 ± 0.6	22
				2.8	23
^{171}Tm	308.3	2	$5.3 \cdot 10^8$	1.2 ± 0.4	22
				1.2	23
^{171}Yb	19.39	2	$1.2 \cdot 10^9$	$-(1.5 \pm 0.5)$	24
^{177}Hf	55, 15	6	$3.7 \cdot 10^{13}$	12 ± 3	*present*
				or $-(17 \pm 3)$	*work*
^{180}Hf	57.6	7	$3.6 \cdot 10^{16}$	7.8 ± 1.0	25
				6.9	26
				7.0 ± 0.3	27
				$6.0 \pm 0.5^*$	28
				$6.4 \pm 0.3^*$	28
				$7.7 \pm 1.0^*$	28
				$7.6 \pm 0.5^*$	28
				7.0 ± 0.7	29
				$6.8 \pm 0.2^{**}$	

$*$ - Using d2 from different references. $**$ - Weighted mean.

For quantitative estimates of nuclear penetration parameter λ_1 depending on the Weisskopf hindrance factor F_W on the basis of empirical data it is convenient to draw a graph of such relation using the experimental data given in Table 3 (Fig. 2).

For Fig. 2 empirical relation (solid line) between the nuclear penetration parameter —l1— and the Weisskopf hindrance factor F_W for the K-forbidden $E1$-transitions was determined without considering the $\gamma 55\,keV$ transition in ^{177}Hf. It is described by the equation $\lambda_1 = a + b\lg(F_W)$. The following values were found by the least-square method: $a = -(3.5 \pm 1.5)$; $b = 0.63 \pm 0.11$. The dashed lines show a 68% confidence interval. As Fig. 2 shows, the obtained experimental value of λ_1 for the $\gamma 55\,keV$ transition in ^{177}Hf appear to be higher than expected from the empirical relationship.

Despite that, the explanation of anomalies in the internal conversion coefficients for the $E1$-transition with the energy of $55\,keV$ with occurrence of intranuclear conversion, from our standpoint, is more grounded.

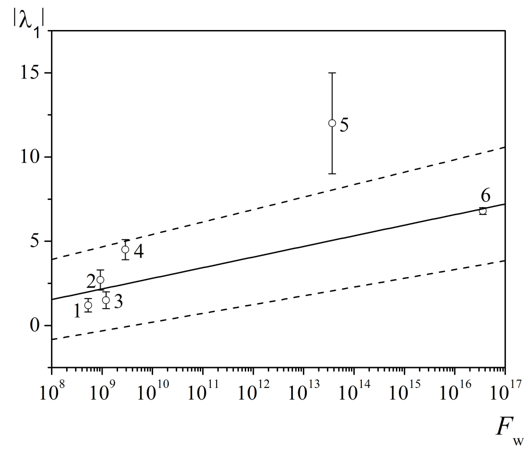

Fig.2. *Relation between the nuclear penetration parameter* $|\lambda_1|$ *and the Weisskopf hindrance factor* F_W *for the K-forbidden E1-transitions.*
1- ^{171}Tm (308.3)*; 2-*^{171}Tm (295.9)*; 3-* ^{171}Yb (19.39)*; 4-* ^{169}Tm (240.3)*; 5-* ^{177}Hf (55.15)*; 6-* ^{180}Hf (57.6)*; the number in parentheses is the transition energy in keV. Smaller by absolute value,* $|\lambda_1| = 12 \pm 3$ *is shown for* ^{177}Hf

As for possible aspects of further research, it would be very interesting to obtain experimental data on the relative intensities of internal-conversion electron lines on L-subshells of ^{177}Hf for this transition, or to attempt to determine more precisely the intensity of the $\gamma 55\,keV$ photon in γ-spectrum using high-resolution detectors.

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ИССЛЕДОВАНИЕ РАСПАДА ^{177m}Lu

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На γ-спектрометре с высокой точностью измерены относительные интенсивности γ-лучей, возбуждающиеся при распаде ^{177m}Lu. Эти данные были использованы для определения коэффициента внутренней конверсии (КВК) -запрещенного $E1$-перехода с энергией 55 кэВ в ^{177}Hf. Высокий фактор запрета γ-излучения приводит к аномалиям в КВК, которые и наблюдаются в эксперименте. Расхождения между теоретическими и экспериментальными значениями КВК нельзя объяснить примесями других мультипольностей той же четности. Их можно согласовать, только предположив наличие внутриядерной конверсии.

ДОСЛІДЖЕННЯ РОЗПАДУ ^{177m}Lu

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На γ-спектрометрі з високою точністю поміряні відносні інтенсивності γ-променів, які збуджуються при розпаді ^{177m}Lu. Ці дані були використані для визначення коефіцієнта внутрішньої конверсії (КВК) -забороненого $E1$-переходу з енергією 55 кеВ у ^{177}Hf. Високий фактор заборони γ-випромінювання призводить до аномалій в КВК, які й спостерігаються в експерименті. Розбіжності між теоретичними та експериментальними значеннями КВК неможливо пояснити домішками інших мультипольностей тієї ж парності. Їх можна узгодити лише припустивши наявність внутрішньоядерної конверсії.