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DIRECTIONAL GAMMA-GAMMA ANGULAR CORRELATION OF THE 71.66 – 249.69 keV CASCADE IN ^{177}Hf

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Abstract: A Ge(Li)--NaI(Tl) angular correlation system with a fast-slow electronic coincidence system was used to remeasure the directional angular correlation of the 71.66 – 249.69 keV cascade in ^{177}Hf. After corrections for finite solid angles the anisotropy ratio of $A = -0.162 \pm 0.026$ was obtained. The upper limit $|\delta| < 0.05$ for the $M2/E1$ mixing ratio for the 71.66 keV transition was deduced. The results for angular correlation coefficients are $A_{22} = -0.114 \pm 0.018$ and $A_{44} = 0$.

1. *Introduction*

Nuclear levels of ^{177}Hf obtained in the decay of ^{177}Lu (6.8 d) and ^{177m}Lu (150 d) have been recently a subject of intensive investigations. Relative intensities and branching ratios for the gamma ray transitions in the decay of

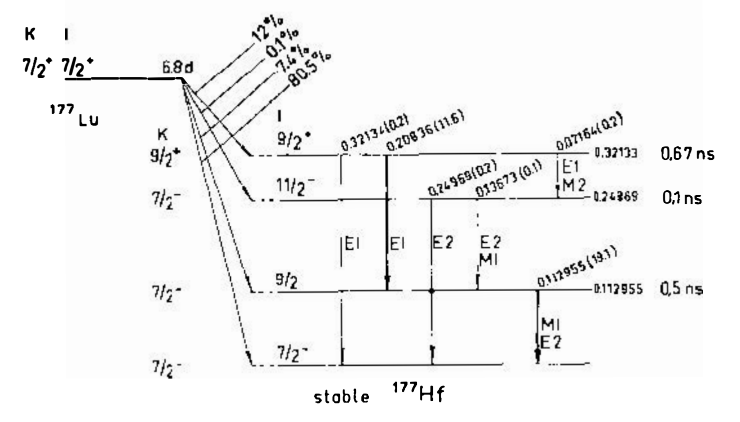

Fig. 1. Decay scheme of ^{177}Lu (6.8 d).

^{177}Lu (6.8 d) have been determined by several groups[1, 2, 3], and together with internal conversion measurements[4] and angular correlation measurements for the 208.36 – 112.955 keV[5] and 71.66 – 249.69 keV[6, 7] cascade transitions have established the decay scheme (see Fig. 1). The underlying intrinsic states of ^{177}Hf nucleus which is situated close to the middle of the deformed region, are successfully interpreted in the Nilsson scheme. The spins and parities of the excited states have been confirmed by different experimental approaches.

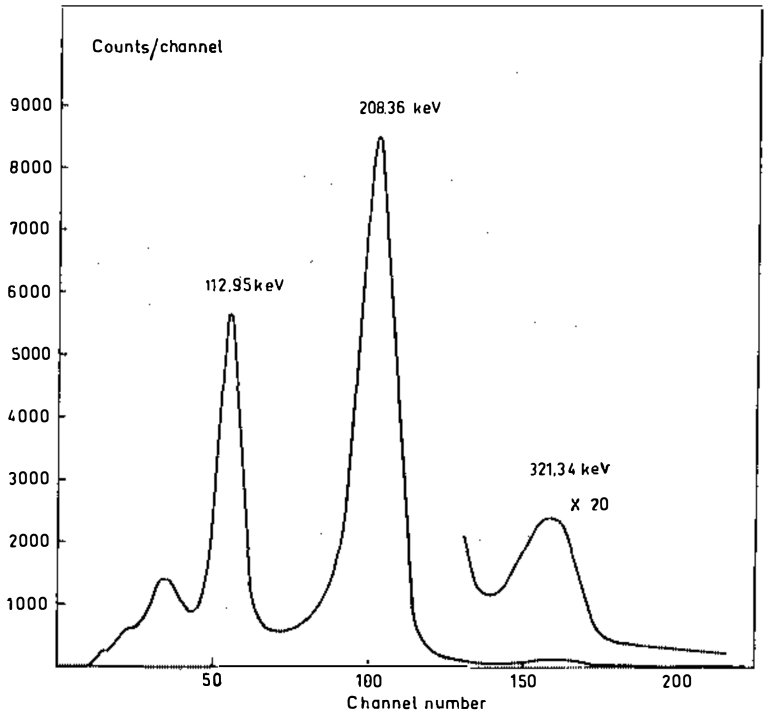

Fig. 2. ^{177}Lu (6.8 d) direct spectrum measured with the NaI(Tl) scintillation counter.

The anisotropy of the weak 71.66 – 249.69 keV cascade transition was previously measured with NaI(Tl) – NaI(Tl) scintillation counter coincidence systems[6, 7]. In these measurements it was difficult to estimate the contribution of the 208.36 keV peak in the region of the 249.69 keV peak in coincidence with the Compton scattered 112.95 keV quanta yielding counts in the region of the 71.66 keV peak. Also the contribution of the K X-ray in the region of the 71.66 keV peak in coincidence with the 208.37 keV and 249.69 keV gamma rays yielding counts in the region of the 249.69 keV peak was somewhat uncertain. The main reason is that the 71.66 keV gamma ray measured in coincidence with the 249.69 keV gamma ray was masked due to a strong background and a relatively poor resolution of the NaI(Tl) detector. An improvement was expected if the 71.66 keV gamma ray was detected in a Ge(Li) detector.

2. *Measurements and results*

The two-detector system[8)] consisted of a planar 2.5 cm^2 and 3 mm thick Ortec Ge(Li) detector with a FET-preamplifier and a $1^1/_2''$ dia $\times$ 1″ thick NaI(Tl) scintillator mounted on a XP 1020 phototube. The direct spectrum of ^{177}Lu gamma rays taken with the Ge(Li) detector is shown in Fig. 2. The spectrum taken with the NaI(Tl) scintillation counter with a 0.5 mm tin absorber which was applied to reduce the intensity of Hf X-rays, can be seen in Fig. 3. The fast-slow electronics with a TAC unit and two-dimensional analysis permitted energy-energy and energy-time analysis. The ^{177}Lu (6.8 d) source was obtained by irradiation of lutetium oxide in the Vinča reactor at a flux of $3 \cdot 10^{13}$ neutrons/$cm^2 \cdot$ s for 5 days. The source prepared for angular correlation measurements was in the form of lutetium nitrate in a dilute aqueous solution. It was shown by Wiedling[9)] that the anisotropy of such liquid sources is almost independent of the chemical composition and that the maximum anisotropy can be obtained with chloride and nitrate sources. To establish the absence of internal perturbations in our source, we measured the anisotropy of the well-known intensive cascade 208.37 – 112.95 keV. The result obtained without the finite solid angle correction was

$$A = -0.197 \pm 0.006 .$$

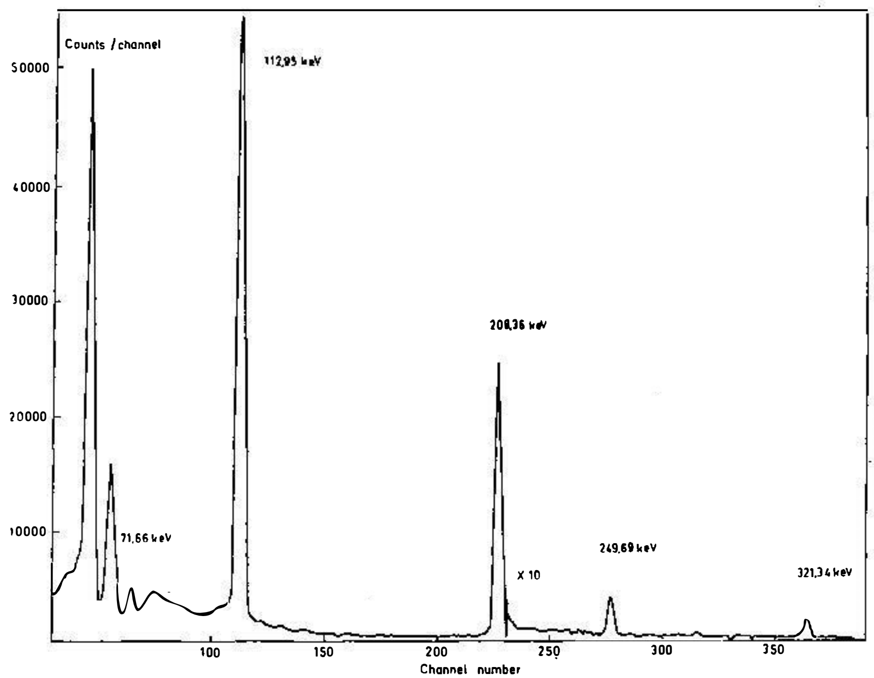

Fig. 3. ^{177}Lu (6.8 d) direct spectrum measured with the Ge(Li) detector.

which is in good agreement with other measurements[5, 10]. If the 208.37 – 112.95 keV cascade is not perturbed, then the weak 71.66 – 249.69 keV cascade should also be unperturbed. The total time-integrated attenuation cœfficient for liquid sources is

$$\overline{G_{kk}(\infty)} = \frac{1}{\tau} \int_0^\infty e^{-\lambda_k t} e^{-t/\tau} dt = \frac{1}{1 + \lambda_k \tau},$$

where τ is the mean life of the intermediate level in the cascade transition. λ_k is the relaxation constant given by[11]

$$\lambda_k = \frac{3}{80} \frac{\tau_c}{\hbar^2} (eQ)^2 \overline{V^2_{zz}} \frac{k(k+1)\,[4I(I+1) - k(k+1) - 1]}{I^2(2I-1)^2},$$

where τ_c is the correlation time, Q the electric quadrupole moment of the intermediate state with angular momentum I, and $\overline{V^2_{zz}}$ the average electric field gradient at the nucleus. Calculating λ_k for two intermediate levels of 112.95 keV and 249.69 keV one obtains the ratios

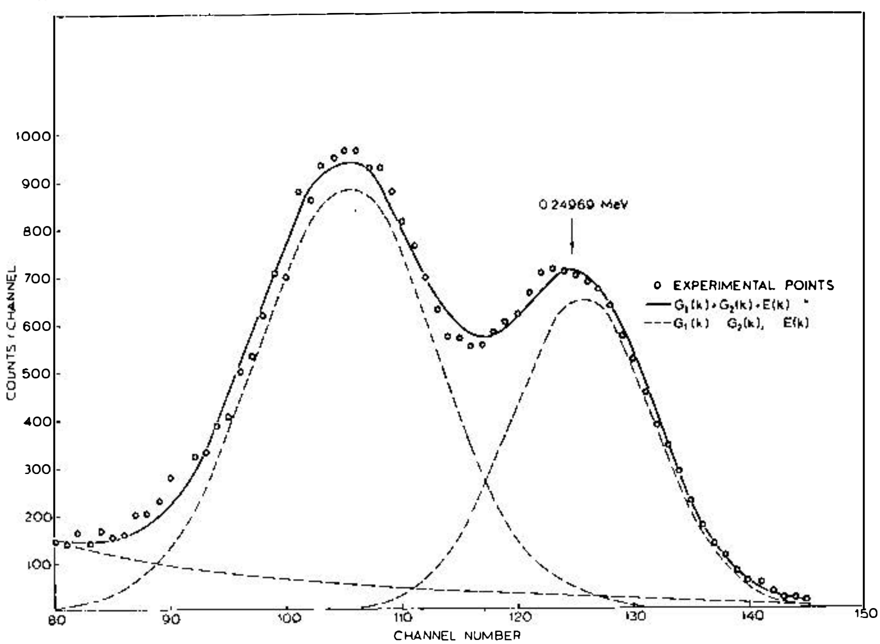

Fig. 4. The scintillation spectrum in coincidence with the 71.66 keV gamma ray detected in the Ge(Li) detector at 90°. Also shown are the Gaussian curves $G_1(k)$ and $G_2(k)$ and the exponential base $E(k)$ used to unfold the composed 208.36 and 249.69 keV peak, and the sum curve $G_1(k) + G_2(k) + E(k)$.

$$\frac{\lambda_2(250)}{\lambda_2(113)} = 0.67\,, \qquad \frac{\lambda_4(250)}{\lambda_4(113)} = 0.66\ .$$

Using the lifetimes of the intermediate states[5] we further obtain

$$\frac{\lambda_2}{\lambda_2}\frac{\tau_{250}}{\tau_{113}} = \frac{\lambda_4\ \tau_{250}}{\lambda_4\ \tau_{113}} = \frac{0.067}{0.335} = 0.2\ ,$$

which confirms the above statement that the weak cascade ought to be perturbed less than the intense cascade.

The angular correlation of the weak 71.66 – 249.69 keV cascade was measured by the integral method at three angles, at 90^0, 135^0 and 180^0. The coincidence rate was about 2.5 counts per minute. Lead absorbers were suitably disposed to prevent coincidences arising from the Compton scattering of higher energy gamma rays from one counter into the other. The angle was changed every half an hour to minimize systematic errors. Energy spectra were obtained in the photomultiplier branch at 90^0, 135^0 and 180^0 in coincidence with the 71.66 keV transition in the Ge(Li) branch. The interesting part of the spectrum obtained at 90^0 can be seen in Fig. 4. The total area of the 249.69 keV photopeak was obtained by the unfolding of the composed peak which consists of the accidental coincidences of the 208.36 keV photopeak and the true coincidences of the 249.69 keV photopeak. The unfolding was performed assuming that the part of the spectrum of interest can be written in the form

$$\mathcal{N}_{th}(k) = G_1(k) + G_2(k) + E(k)\ ,$$

where k is the channel number and $G_1(k)$ and $G_2(k)$ are the Gaussian distributions for the 208.36 and 249.69 keV peaks, respectively,

$$G_i(k) = a_i \exp\left[-\frac{(K-b_i)^2}{2c_i^2}\right], \qquad i = 1{,}2\ .$$

$E(k)$ is the exponential function

$$E(k) = A \exp(-\lambda k)\ .$$

The eight parameters a_1, b_1, c_1, a_2, b_2, c_2, A and λ were computed from the requirement

$$\sum_k \left[G_1(k) + G_2(k) + E(k) - \mathcal{N}(k)\right]^2 = \min\ .$$

From the parameters of the Gaussian distribution representing the 249.69 keV photopeak, the integrals at 90^0, 135^0 and 180^0 were computed. We obtained

$$N(90) = 10134 \pm 262\,,$$
$$N(135) = 9597 \pm 292\,,$$
$$N(180) = 8623 \pm 273\,.$$

These values were used to determine the anisotropy

$$A = \frac{N(180)}{N(90)} - 1\,,$$

and the cœfficients A_{22}, A_{44} of the unperturbed correlation function

$$W(\Theta) = 1 + A_{22}\,P_2(\cos\Theta) + A_{44}\,P_4(\cos\Theta)\,.$$

The second transition of the cascade (249.69 keV) is a pure $E2$[5, 6] transition and the first transition (71.66 keV) can contain a small admixture of $M2$ in the predominantly $E1$[5, 6] transition. From the known spin sequence 9/2, 11/2, 7/2 one obtains

$$A_{22} = \frac{F_2(11/2\;9/2\;11) + 2\delta F_2(11/2\;9/2\;12) + \delta^2 F_2(11/2\;9/2\;22)}{1+\delta^2} \times$$
$$\times F_2(11/2\;7/2\;22)$$

and

$$A_{44} = F_4(11/2\;9/2\;22)\,\frac{\delta^2}{1+\delta^2}$$

and the anisotropy $A = A(\delta)$

$$A(\delta) = \frac{1 + A_{22}(\delta) + A_{44}(\delta)}{1 - 0.5\,A_{22}(\delta) + 0.375\,A_{44}(\delta)} - 1\,,$$

where the mixing ratio δ is given by

$$\delta = \left(\frac{\text{Int }M2}{\text{Int }E1}\right)^{1/2}$$

From the number of coincidences collected at 90^0 and 180^0 we obtained a preliminary value of anisotropy $\bar{A} = -0.149 \pm 0.035$. After correction for the finite solid angles it amounted to $A = -0.181 \pm 0.042$. From the drawing of the anisotropy $A = A(\delta)$ for the 9/2 (D, Q) 11/2 (Q) 7/2 transition (Fig. 5) one obtains for the mixing ratio of the 71.66 keV transition

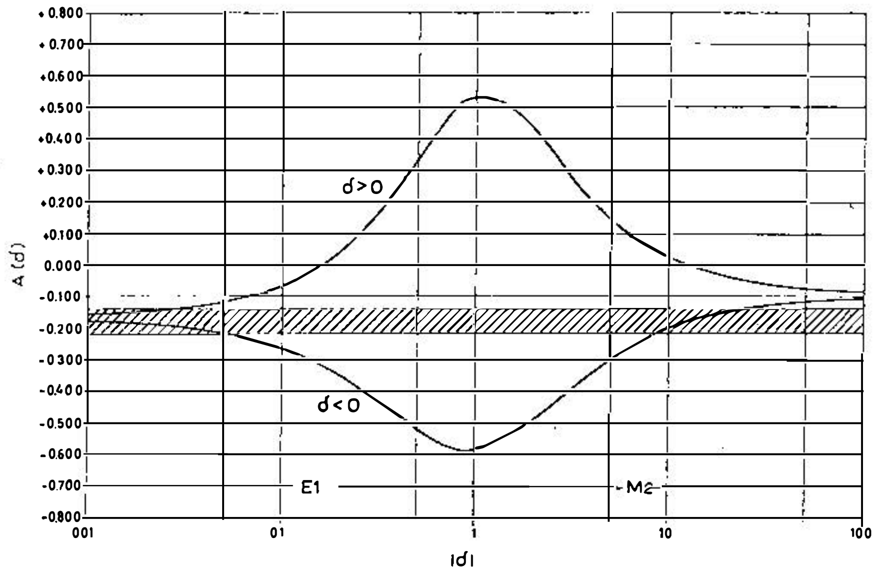

Fig. 5. Anisotropy versus the mixing ratio $M2/E1$ for the first transition in the 71.66 – 249.69 keV cascade in ^{177}Hf.

$$-0.05 \leqq \delta \leqq +0.03$$

Taking the maximum absolute value $|\delta| = 0.05$ one obtains

$$\left(\frac{\text{Int } M2}{\text{Int } E1}\right)_{\max} = \delta^2{}_{\max} = 0.0025 \quad ,$$

or at most 0.25% of $M2$ in a predominantly $E1$ transition.
The above value of $\delta^2{}_{\max}$ gives

$$A_{44} \leqq 0.00137 \sim 0 \, .$$

Hence we can neglect the cœfficient A_{44} and the angular correlation function becomes

$$W(\Theta) = 1 + A_{22} P_2 (\cos \Theta) \, .$$

Using the least square method to fit the correlation function to the experimental results we obtained

$$A_{22} = -0.103 \pm 0.016 \,,$$

$$A_{22} = -0.114 \pm 0.018 \,,$$

for the experimental and for the finite solid angle corrected value of the angular correlation cœfficient, respectively. From this result one can derive the anisotropy ,

$$A = -0.162 \pm 0.026 \,.$$

Our results are compared with the previous measurements in the Table.

Table

A_{22}	A_{44}	Author (ref.)
-0.143 ± 0.014	0	S. Ofer[6)]
-0.122 ± 0.017	$+ 0.01$	L. Simons *et al.*[7)]
-0.114 ± 0.018	0	present paper

Taking into account the statistical errors the three results for A_{22} are in agreement. Our value is absolutely somewhat lower, possibly due to an improved separation of the 71.66 keV gamma ray peak from its continuous background. The value of A_{44} is expected to be very small.

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DIREKCIONA KUTNA GAMA-GAMA KORELACIJA KASKADNOG PRIJELAZA 71.66 – 249.69 keV U ^{177}Hf

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Sadržaj

Sistem za mjerenje kutnih korelacija s Ge(Li) i NaI(Tl) detektorima i brzo-sporom koindidencijom upotrebljen je za mjerenje direkcione kutne korelacije kaskadnog prijelaza 71.66 keV – 249.69 keV u ^{177}Hf. Nakon korekcija zbog konačnih prostornih kutova dobivena je anizotropija $A = —0,162 \pm 0,026$. Određena je gornja granica $|\delta| < 0,05$ za omjer miješanja $M2/E1$ u 71.66 keV prijelazu. Dobiveni korelacioni koeficijenti iznose $A_{22} = —0,114 \pm 0,018$ i $A_{44} = 0$.