Identification of μs isomers in the fission products of ^{241}Pu(n_{th},f)

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Several μs isomers were observed in neutron-rich nuclei in the mass range $A=88-109$. These nuclei are produced by thermal neutron-induced fission of ^{241}Pu. The detection is based on time correlation between fission fragments selected by the LOHENGRIN spectrometer, at ILL (Grenoble) and the γ-ray or conversion electron emission of the isomers. Among a dozen isomers studied, three new ones have been observed. The decay schemes of ^{88m}Br, ^{94m}Y, ^{96m}Rb, and ^{100m}Nb are discussed in the framework of the spherical shell model. The yields and isomeric ratios of all these isomers have been measured. [S0556-2813(99)01901-9]

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I. INTRODUCTION

The study of excited states of neutron-rich nuclei helps to test the nuclear models for nuclei far from stability. The main information in this field has been obtained by studying the β-decay of mass separated fragments from spallation reactions induced by high energy protons, from thermal neutron capture leading to nuclear fission, or from on-line measurements of the γ-decay of nascent fragments. In some favorable cases, exotic nuclei can also be observed in their isomeric states, with half-lives in the μs-range. It is then possible to measure the time correlation between the reaction product and the γ-rays or the conversion electrons depopulating the isomer. If the reaction product can be selected by a spectrometer, like LOHENGRIN [1] at the Laue-Langevin Institute (ILL) in Grenoble, the method is very sensitive and can be used for nuclei weakly produced.

Isomers give valuable information on nuclear structure because of their unique character among many other excited states. These isomers are present in the whole chart of nuclei, including the spherical and deformed regions and they have generally higher angular momenta than for the ground state (g.s.). This is in particular interesting in odd-odd nuclei, where only low spin levels can be fed by the beta-decay of the even-even mother nuclei. Here, higher spin states are made accessible from the decay of isomeric levels. Very far from stability, it is the most interesting source of information on doubly odd nuclei.

We present below new results on the structure of odd-odd nuclei of the $A=100$ mass-region obtained with the LOHENGRIN spectrometer.

II. EXPERIMENTAL PROCEDURE AND DATA ANALYSIS

The LOHENGRIN spectrometer at ILL [1], has been used to separate the fission fragments (FF), recoiling from a thin target of ^{241}Pu of about 400 μg/cm^2 and 1 mg total mass, by means of a magnetic field and an electrostatic field. The internal neutron flux is 5×10^{14} n cm^{-2} s^{-1}. The combined action of the two fields separates ions with the same velocity into different parabolas according to their A/q and E/q values. A Reverse Energy Dispersion (RED) dipole magnet focuses the beam at the exit of the spectrometer on a focal plane of 10×50 mm^2. The rate of FF at this point is about 5×10^5 $Y(A,Z)$ per second, where $Y(A,Z)$ is the independent fission yield of the selected FF (A,Z), for a selected ionic charge value. The time-of-flight through the spectrometer is about 1.4 μs.

The experimental setup which has been used for the detection of the isomers is shown in Fig. 1. The fragments which are selected according to their A/q ratios, are roughly analyzed in their nuclear charge components by a ΔE gas-detector of about 13 cm length, and subsequently stopped in a Si-detector, where the residual energy (E_R) is measured. For the mass chain $A=103$, where the Nb and Mo elements have the highest yields, the FWHM energy width of the ΔE corresponds to two nuclear charge units. The identification of the nuclear charge Z of the fission fragment containing the new isomer observed in the mass chain $A=106$ was done by comparing the yields measured with ^{239}Pu and ^{241}Pu targets.

The time correlation between the incoming FF and the γ-rays emitted by the decaying isomer is measured by a time-to-amplitude converter (TAC) : the ''START'' signal is produced by the Si-detector, while the ''STOP'' signal is produced by the γ-rays detected by one of the two large volume Ge detectors. Events characterized by E_γ, ΔE, E_R, and TAC signals detected in the time range of about 20 μs, are recorded in an event-by-event mode. The γ-spectra gated

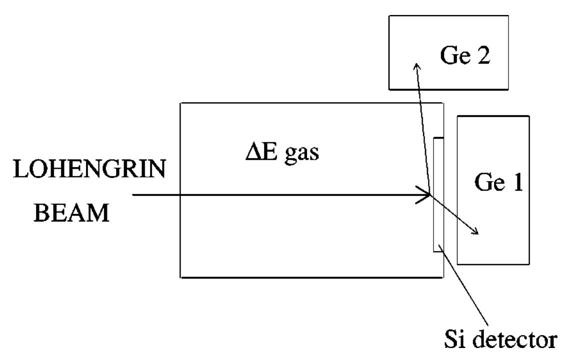

FIG. 1. Schematic view of the experimental setup.

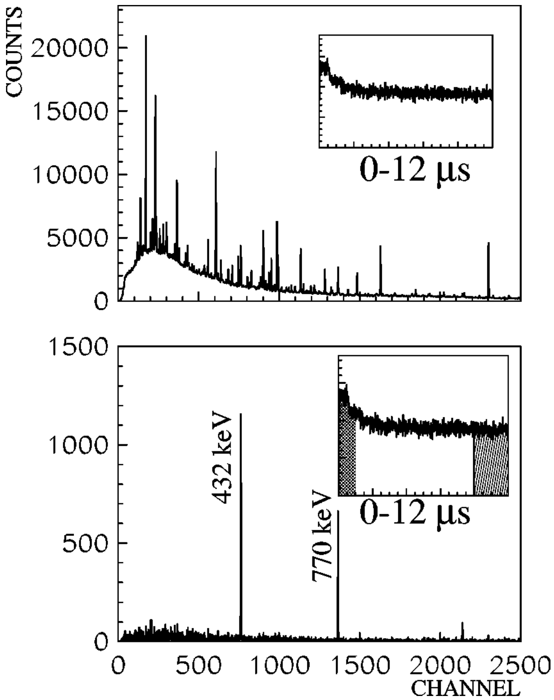

FIG. 2. Comparison between the total γ-spectrum of mass $A=94$ without time condition (upper part) and the spectrum obtained by subtraction of the two gates as indicated in the inset (lower part).

with the TAC signal and ungated (singles spectra) are also registered. Moreover, fast coincidence relationships between the two gamma-detectors, are also registered when a TAC signal is detected. This information is fundamental to build decay schemes. The absolute efficiency of the γ detectors was about 10% and 2% at 0.1 MeV and 1 MeV, respectively.

Conversion electron measurements are necessary to determine the multipolarity of the transitions deexciting the isomers and to observe strongly converted transitions of low energy. For this purpose, a cooled Si(Li) detector has been implemented. In this case, the LOHENGRIN beam is slowed down in the gas of the ionization chamber and finally stopped in a mylar window of 12 μm thickness. The gas pressure is tuned to stop the FF at about 2 μm from the end surface of the window, to minimize the electron absorption and to ensure a good energy resolution. The electrons and low energy γ and x rays are detected by two Si(Li) detectors located at 7 mm behind the mylar window. They are of 4.5 mm thickness and they cover a total area of 2×6 cm^2. The total electron efficiency is about 30%. Conversion electrons of ^{88m}Br and ^{100m}Nb have been studied with this new experimental setup which will be discussed in detail elsewhere.

Figure 2 shows an example of time-distribution recorded by the TAC, when the mass $A=94$ is selected by the LOHENGRIN spectrometer. A rapid decay is observed, corresponding to the half-life $T_{1/2}=1.35$ μs of ^{94m}Y, followed by a constant background. This background is caused by γ-rays not correlated with the implanted fragments and originating from the β-decay events and the background of the reactor hall. The gamma-spectrum without time condition is shown in the upper part of Fig. 2. The resulting spectrum obtained by putting a gate on the decaying part of the time-distribution and subtracting the background is shown on the bottom of Fig. 2. Only the γ rays deexciting ^{94m}Y are now present.

The measurements were performed at one value of kinetic energy: 95 MeV, selected with the LOHENGRIN spectrometer and for different A/q ratios so as to determine the mass containing the isomer unambiguously.

III. EXPERIMENTAL RESULTS

Several μs isomers, in the mass range $A=88$–109, have been observed in this experiment. Some of them were already known; in this case, the new data are compared with the older ones. Three new isomers have been observed in ^{94}Y, ^{96}Rb, and ^{106}Nb. However, the ^{94}Y isomer has been

TABLE I. Half-lives and yields of the isomers. The $T_{1/2}^{lit}$ values are taken from Ref. [4] for ^{88}Br, Refs. [5,6] for ^{97}Sr, Refs. [7,8] for ^{98}Y, Ref. [9] for ^{99}Y, Ref. [10] for ^{99}Zr, Refs. [6,11] for ^{100}Nb, Ref. [12] for ^{104}Tc, Ref. [13] for ^{107}Mo and for ^{109}Ru, and Ref. [14] for ^{109}Rh. The independent fission yield of ^{241}Pu are taken from JEF2 [15]. The error in the transition energies is 1 keV. The error in the Y_{iso} values and iso/iso+g.s. ratios are $\Delta Y_{iso}\sim 30\%$ and Δ[iso/(iso+g.s.)]$\sim 40\%$.

Nucleus	E_γ(keV)	$T_{1/2}^{exp}(\mu s)$	$T_{1/2}^{lit}(\mu s)$	$Y_{iso}\times 10^3$	$Y_{nucl}\times 10^3$	iso/(iso+g.s.)	I_{iso}^{π}
^{88}Br	111	5.1 (4)	5.4 (7)	1.3	4.5	0.29	4^-
^{94}Y	432	1.35 (2)	unknown[a]	1.8	2.2	0.82	5^+
^{96}Rb	300+240+461	1.65 (15)	unknown	8×10^{-2}	1.3	0.06	$(6^+,7^+)$
^{97}Sr	140	0.43 (3)	0.515+0.170	1.0	14	0.07	$(11/2^-)$
^{98}Y	204	7.2 (1)	8.0 (2)	3.0	6	0.50	(2^-)
^{99}Y	126	11 (2)	8.6 (8)	0.3	27	0.01	$(17/2^+)$
^{99}Zr	130	0.40 (2)	0.293 (10)	2.6	26	0.10	$7/2^+$
^{100}Nb	173+185	13 (1)	12	0.9	4.2	0.21	(8^-)
^{104}Tc	36	0.40 (2)	unknown[b]				
^{104}Tc	69	5 (2)	3.5 (3)	0.3	2.5	0.12	$(+)$
^{106}Nb	95+107+202+205	0.84 (4)	unknown	0.24	2.9	0.08	
^{107}Mo	66	0.47 (3)	0.238 (7)	16	17	0.94	
^{109}Ru	96	0.68 (3)	0.780 (150)	8	6	~ 1	
^{109}Rh	226		1.66	2×10^{-2}	0.2	0.10	$(3/2)^+$

[a]This isomer was suggested in Ref. [2].

[b]The transition is reported in Ref. [3] but its half-life was unknown.

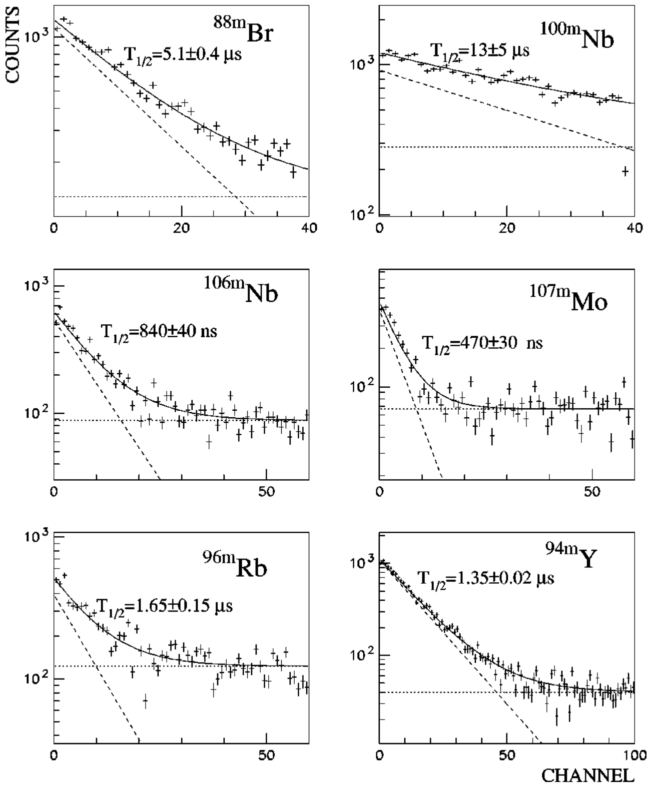

FIG. 3. Half-life spectra of the main isomers observed in the experiment.

previously reported in the thesis of Sellam [2], but there is no other indication in the literature. Our measurement confirms the presence of this isomer with a comparable half-life.

The results of the experiment are compiled in Table I. The half-lives obtained in this experiment (column 3) are compared to those given in the literature (column 4). They have been measured using the γ-rays reported in column 2. Exponential fits to the time distribution of γ-rays gives the half-life values of 0.84 ± 0.04 μs for ^{106m}Nb, 1.65 ± 0.15 μs for ^{96m}Rb and 1.35 ± 0.02 μs for ^{94m}Y (see Fig. 3).

The decay curve of the 66 keV γ-transition in ^{107}Mo, shown in Fig. 3, indicates a half-life of 0.47 ± 0.03 μs. Several measurements using the spontaneous fission of ^{252}Cf [13], lead to a half-life of 0.245 μs for the 66.3 keV γ-line, in contradiction with our measurement. In fact, there is also an isomer in ^{107}Tc [16], which was unknown in 1976 [17]. This isomer fed by the β-decay of ^{107}Mo has an isomeric transition of 65.7 keV and a half-life of 0.184 μs. This half-life is too short to be seen after the ion transport through the LOHENGRIN spectrometer and very likely, the half-life reported in the literature corresponds to the mean value of the half-lives of ^{107}Mo ($T_{1/2}=0.47$ μs) and ^{107}Tc ($T_{1/2}=0.184$ μs).

In column 5, the independent yields measured for the isomers are shown and in column 6, the independent yields for the g.s, as reported in the data tables. Column 7 gives the isomeric ratios, and column 8 gives the spin and parity of the isomer, when it is known. The independent yield of the isomer is obtained by comparison of the intensities of γ-rays deexciting the isomer with lines of the same mass chain, and of known cumulative yields. These values will be discussed elsewhere.

IV. LEVEL SCHEMES AND DISCUSSION

In this section, the level schemes and the nuclear structure of some of the isomers studied in this experiment are discussed.

A. ^{88}Br

Not much is known on this nucleus: a few excited levels have been fed from the β-decay of ^{88}Se [18], without spin assignment and only spin and parity $I^{\pi}=(1,2^{-})$ have been suggested for the g.s.

Two delayed transitions of 110.9 and 159.1 keV, of relative intensity $I_{\gamma}=65$ and 100 respectively, have been observed in coincidence in our work. They belong to an isomer with half-life of 5.1 μs (see Fig. 4). The internal conversion coefficients $\alpha_K=0.48(10)$ and $\alpha_K=0.047(10)$ measured for the 110.9 and 159.1 keV transitions, respectively, shows that the isomer decays by an $E2$-$M1$ cascade.

This isomer has been already observed by Grüter *et al.* [7], with a half-life of 6.3 μs, and by Sellam with a half-life of 4.9 μs [2], but its nature was not discussed. The left part of the level scheme presented in Fig. 5 corresponds

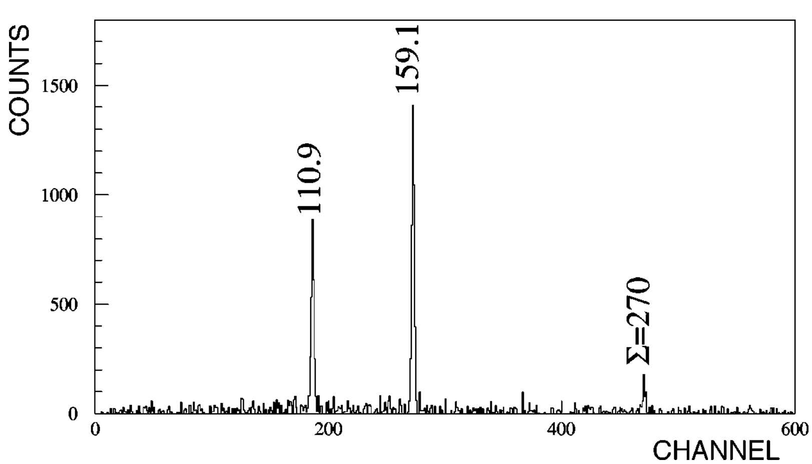

FIG. 4. γ-decay spectrum of ^{88m}Br isomer. Energies are in keV. The 270 keV transition corresponds to the summation of the 110.9 and 159.1 keV lines in the same detector.

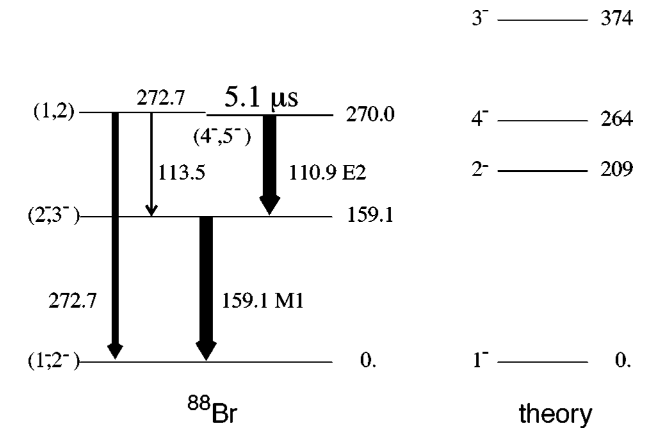

FIG. 5. Level scheme of the 5.1 μs isomer of ^{88}Br. The γ-decay of the 272.7 keV level fed in the β-decay of ^{88}Se is also shown, with suggested spin and parity assignments. The theoretical states of the $\nu(d_{5/2})\pi(p_{3/2})$ p-p configuration are reported on the right side of the figure.

to the decay of the 272.7 keV level fed by β-decay. The evaluator of the mass chain $A=88$ [4] supposed that the 110.9 keV γ-line observed in Refs. [2,7], and confirmed by our work, is identical to the 113.5 keV γ-ray observed in the β-decay of ^{88}Se [18]. This hypothesis is not correct, because the two considered transitions have different energies and because the cross-over is not present in the decay of the isomer, while it is strong in the β-decay level scheme. Consequently, the 272.7 keV level fed in the β-decay of ^{88}Se is different from the 270.0 keV isomeric state.

The lowest odd parity neutron-proton multiplet observed in ^{88}Rb [19], is dominated by the particle-hole (p-h) configuration $\nu(d_{5/2})\pi(p_{3/2})^{-1}$. In ^{88}Br, the same orbitals are expected near the g.s., but now, the $\pi(p_{3/2})$-orbital has a particle character. In the shell-model framework, the energy differences of a p-h multiplet are the negative Racah-transforms of the p-p ones (see Ref. [20]). Thus, it is possible to compute the p-p $\nu(d_{5/2})\pi(p_{3/2})$ spectrum in ^{88}Br, from the 1^-, 2^-, 3^-, and 4^- experimental levels of ^{88}Rb. The results of the calculation, shown in Fig. 5, are in reasonable agreement with the experimental data. The 3^- state is above the 4^- state, which could explain the isomery, and the latter state can only decay by an $E2$-transition on the 2^- state.

If we suppose that the $E2$-transition corresponds to a proton transition while the neutron plays a spectator role, it is possible to deduce the single particle half-life from the isomeric half-life, $T_{1/2}=5.1$ μs, using the relation

$$T_{1/2}(E2,p_{3/2}\rightarrow p_{3/2})=T_{1/2}(E2,4^-\rightarrow 2^-)\times R. \quad (4.1)$$

The recoupling factor R computed using the Racah formalism [20] leads to the value $R=0.19$. From Eq. (4.1), a value $T_{1/2}(E2,p_{3/2}\rightarrow p_{3/2})=0.97$ μs can be deduced; it corresponds to a hindrance factor $F_W\sim 1$ W.u. Consequently, the $\{\nu(d_{5/2})\pi(p_{3/2})\}4^-$ configuration is consistent with both the energy and decay rate of the isomeric transition.

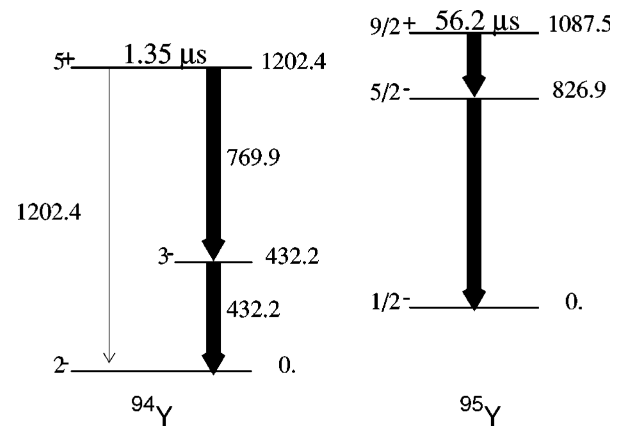

FIG. 7. Comparison of the level schemes of the 1.35 μs isomer in ^{94}Y with the 56.2 μs isomer in ^{95}Y. The ^{95}Y g.s. coincides with the center of gravity of the $\pi(p_{1/2})\nu(d_{5/2})^{-1}$ multiplet in ^{94}Y.

B. ^{94}Y

The level scheme of ^{94}Y was already investigated through both the β-decay studies and nuclear reactions. The low-spin level scheme of ^{94}Y was obtained by Funakoshi *et al.* [21] from the β-decay of ^{94}Sr. The nuclear structure of ^{94}Y was also investigated via the ^{96}Zr$(d,\alpha)^{94}$Y reaction [22,23] and the ^{96}Zr$(^3$He$,\alpha p)^{94}$Y reaction [24].

A new isomeric state, with a half-life of 1.35 μs, has been observed in the ^{94}Y nucleus. Figures 6 and 7 show its γ-decay spectrum and its level scheme, respectively. About half of the intensity of the 1202.4 keV line corresponds to the summation of the two other lines in the same detector, and the intensity of the cross-over is 15±5%.

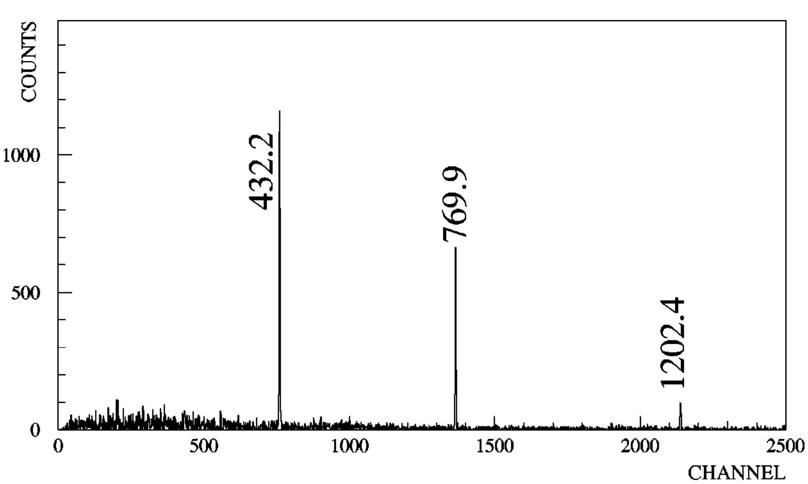

FIG. 6. γ-decay spectrum of ^{94m}Y isomer. Energies are given in keV.

TABLE II. γ-ray transitions observed in the decay of ^{96m}Rb. $\Delta E_\gamma \sim 0.2$ keV; $\Delta I_\gamma \sim 20\%$.

E_γ(keV)	I_γ	I_{total}	E_γ(keV)	I_γ	I_{total}
93.0 + 92.3	32	38	240.0	49	51
117.0	27	30	299.9	100	101
122.95	45	49	368.9	25	~25
185.3	27	30	461.2	53	~53
209.9	14	15			

No connection exists between the levels in ^{94}Y fed by the β-decay of ^{94}Sr and the level scheme shown in Fig. 7, which suggests that the 432.2 and 1202.4 keV levels have spins $\geqslant 3$. In contrast, the first excited state at ~430 keV, with spin and parity $I^\pi = 3^-$, fed by nuclear reactions is very likely identical to the 432.2 keV observed in this experiment. With the 2^- g.s., they are the two members of the $\pi(p_{1/2})\nu(d_{5/2})^{-1}$ p-h doublet, as discussed in Refs. [23,24]. It is also the lowest energy configuration in ^{90}Y [25]. These two Y isotopes differ only by the fact that ^{90}Y, with 51 neutrons, has only one particle in the $\nu(d_{5/2})$ orbital, while ^{94}Y, with 55 neutrons, has one hole in the same orbital. Each of these two nuclei has an isomeric state and it is of course tempting to suppose that they have the same origin. Since in ^{90}Y, the $I^\pi = 7^+$ isomeric level is the g.s. of the $\pi(g_{9/2})\nu(d_{5/2})$ p-p multiplet, we suppose that the isomer in ^{94}Y is the g.s. of the $\pi(g_{9/2})\nu(d_{5/2})^{-1}$ p-h multiplet.

It is possible to extract the energy differences of the p-h configuration from the p-p ones of ^{90}Y [25], where all the members of the p-p multiplet are known. From this calculation it is found the 6^+ is the lowest state while the 5^+ is the first excited state at 14 keV energy. Moreover the parabolic rule of Paar [26] shows that the 5^+ is the lowest state if the spin-vibration coupling strength parameter α takes the value of $\alpha = 40/A$, A being the atomic number. The half-life of 1.35 μs is too fast to be compatible with an $E3$-character for the 769.9 keV transition, and the 6^+ hypothesis for the isomer is not possible either. Consequently $I^\pi = 5^+$ is the only possible assignment. However, to explain the $5^+ \rightarrow 3^-$ $M2$ transition, we have to suppose that the 3^- has also some $\{\pi(f_{5/2})\nu(d_{5/2})^{-1}\}3^-$ admixture. In this case the $M2$ isomeric transition corresponds to the $\pi(g_{9/2}) \rightarrow \pi(f_{5/2})$ proton transition, while the neutrons play a spectator role. The $\pi(f_{5/2})$ level is the first excited state in the ^{95}Y [27] neighboring nucleus, and a $M2$ transition of the same nature $\pi(g_{9/2}) \rightarrow \pi(f_{5/2})$ deexcites the 56.8 μs isomer at 1087 keV energy (see Fig. 7). The hindrance factor of this transition is $F_W = 47$ W.u. In the case of ^{94}Y, it is possible to extract the particle half-life from the measured isomeric half-life using a formula analogous to Eq. (4.1). In this case the recoupling factor is 0.60 and the hindrance factor is $F_W = 150$ W.u. From these two F_W values it is possible to deduce that 30% admixture of $\{\pi(f_{5/2})\nu(d_{5/2})^{-1}\}3^-$ configuration is present in the 3^- state. This number is of course only indicative.

In the odd-odd nucleus ^{94}Y, the energy difference between the center of gravity of the $\pi(p_{1/2})\nu(d_{5/2})^{-1}$ g.s. configuration and the $\{\pi(g_{9/2})\nu(d_{5/2})^{-1}\}5^+$ isomeric state (see Fig. 7) is 959 keV. This value is comparable with the 1087

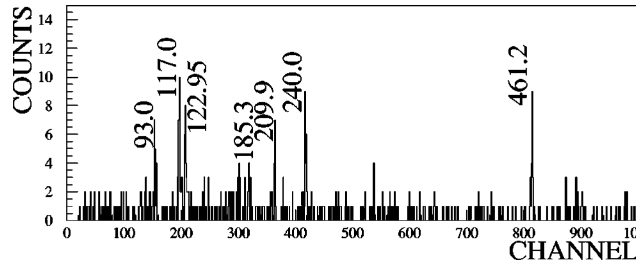

FIG. 8. γ-ray spectrum gated by the 299.9 keV transition in ^{96m}Rb. Energies are in keV.

keV deduced for the $\pi(p_{1/2}) \rightarrow \pi(g_{9/2})$ energy difference in the odd-proton ^{95}Y nucleus.

The ^{94}Y isomer decays also by a very weak $E3$ transition of 1202.4 keV to the g.s. state, with a partial half-life of about 9 ± 3 μs, which corresponds to a hindrance factor $F_W \sim 15 \pm 5$ W.u.

C. ^{96}Rb

Before our work, only the g.s. properties of ^{96}Rb were known; the spin $I = 2$ and the magnetic and quadrupole moments have been investigated by laser spectroscopy [28].

A new isomeric state, with a half-life of 1.65 μs, has been observed in the ^{96}Rb nucleus. Ten gamma-rays have been assigned to its decay; their energies and relative intensities are reported in Table II. The level scheme is based on γ-γ coincidence relationships and Fig. 8 shows an example of coincidence results.

The level scheme of the 1.65 μs isomer is shown in Fig. 9; it contains the first information on the excited levels of the odd-odd ^{96}Rb.

The measured quadrupole moment of the g.s. indicates that this nucleus is weakly deformed and that it can be analyzed in the framework of the spherical shell-model. The spin $I = 2$ of the odd-odd ^{96}Rb g.s. can be explained by coupling the $I = 1/2$ of the odd-neutron ^{97}Sr g.s. with the $I = 5/2$ of the odd-proton ^{95}Rb g.s. Since the magnetic moments of these three nuclei are known [28,29], it is possible to compute the magnetic moment of ^{96}Rb from the values of the other two odd-nuclei. The computed value of $\mu = 1.58$ μ_N is in reasonable agreement with the experimental one $\mu = 1.47$ μ_N, which justifies the $\{\nu(s_{1/2})\pi(f_{5/2})^{-1}\}2^-$ configuration assignment to the g.s. configuration.

The two isotones with 59 neutrons, ^{97}Sr [4] and ^{96}Rb, have each a μs isomer at about 1 MeV excitation energy

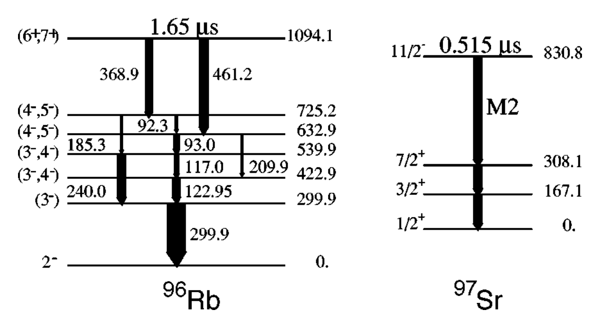

FIG. 9. Comparison of the level schemes of the 1.65 μs isomer in ^{96}Rb with the 0.52 μs isomer in ^{97}Sr. The ^{97}Sr g.s. coincides with the center of gravity of the $\nu(s_{1/2})\pi(f_{5/2})^{-1}$ multiplet in ^{96}Rb.

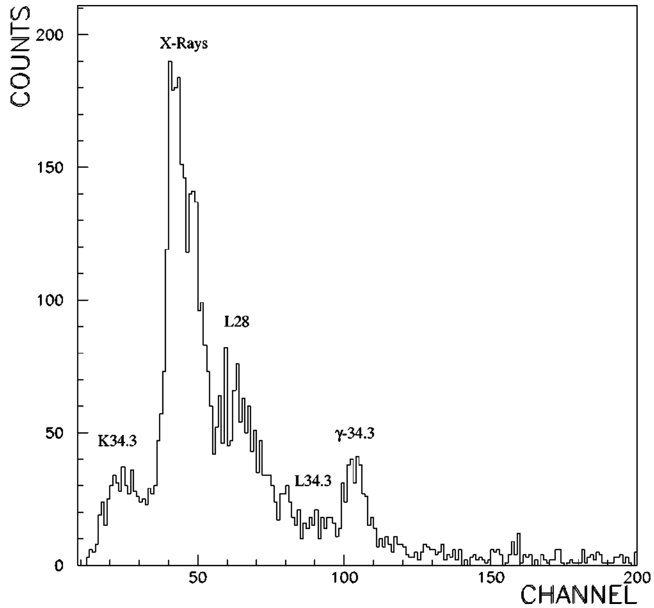

FIG. 10. Low energy spectrum of the ^{100m}Nb isomer measured with a Si(Li) detector. The energies are in keV.

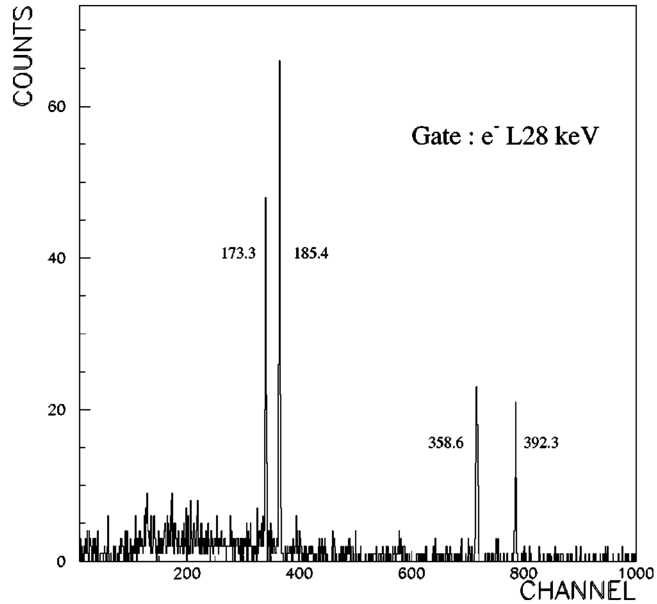

FIG. 11. γ-decay spectrum in coincidences with a gate on the L-shell electrons of the 28 keV transition. The energies are in keV.

(see Fig. 9), which suggests that the isomery has the same origin in these two nuclei. In ^{97}Sr the isomer decays by the $M2$ $\nu(h_{11/2})\rightarrow\nu(g_{7/2})$ transition (see Fig. 9). In this hypothesis, the isomeric transition in ^{96}Rb takes place, very likely, between the same neutron orbitals coupled to the proton-hole $\pi(f_{5/2})^{-1}$, which plays a spectator role in this decay. We have seen that the $\pi(f_{5/2})^{-1}$ orbital is the g.s. of ^{95}Rb and is present in the $\{\nu(s_{1/2})\pi(f_{5/2})^{-1}\}2^-$ g.s. configuration of ^{96}Rb.

The parabolic rule of Paar indicates that the 6^+ or the 7^+ state are the possible g.s. of the p-h $\nu(h_{11/2})\pi(f_{5/2})^{-1}$ configuration. In ^{96}Rb, this state will decay by emitting two $M2$ transitions in parallel, to two negative parity states. The hindrance factors of the $\nu(h_{11/2})\rightarrow\nu(g_{7/2})$ $M2$ particle transitions, computed like in the previous cases, are respectively 16 and 29 w.u. for the 368.9 and 461.2 keV transitions in ^{96}Rb. These values are close to the value F_W=13 W.u. deduced for ^{97}Sr.

Below 40 protons the possible orbitals have a negative parity in the spherical shell-model, while above 50 neutrons, the orbitals have positive parity if we except the $\nu(h_{11/2})$ level. Consequently, we have supposed that all the states below 633 keV, have a negative parity and decay by $M1$ transitions. The total intensities in Table II have been corrected for the conversion electron contribution. The g.s. and the first excited state at 299.9 keV are very likely dominated by the $\nu(s_{1/2})\pi(f_{5/2})^{-1}$ configuration. The energy difference of 919 keV between the center of gravity of the latter configuration and the isomeric state in ^{96}Rb is comparable to the 831 keV $\nu(h_{11/2})\rightarrow\nu(s_{1/2})$ energy difference in ^{97}Sr. Thus, the excitation energy and the $M2$ transition rates are quite similar, which justifies the configurations proposed for ^{96}Rb.

D. ^{100}Nb

A 13 μs isomer had already been observed in ^{100}Nb by Monnand *et al.* [6] and Lhersonneau *et al.* [11]. It was also observed in our new investigation, where a Ge and a Si(Li) detector were used for γ ray and conversion electron measurements. In Fig. 10 the photons and the electrons of the previously known 34.3 keV transition are observed. However, a new transition of 28 keV is also evidenced and the coincidences, gated on its L-shell electrons, show that it belongs to the ^{100m}Nb decay (see Fig. 11).

These new data confirm the $E1$ multipolarity of the 34.3 keV transition and show that the 28 keV transition has an $E2$ multipolarity, and then an hindrance factor F_W=1.3 W.u., and is very likely the isomeric transition, not observed up to now. The values α_K=0.056(15) and α_K=0.036(10) measured for the 173.3 and 185.4 keV transitions respectively, agree with a $M1$ character for both transitions.

The 67.1, 101.7, and 106.6 keV γ-rays found in Ref. [11] are not observed in the coincidence spectrum of Fig. 11 or in the direct spectra with their expected intensities. Consequently the level at 101.9 keV is not confirmed by this work. The level scheme is shown in Fig. 12.

There is no overlap between the proposed level scheme of Fig. 12 and the levels fed by β-decay [30]. Moreover, if this level scheme is based on the 1^+ g.s., the 13 μs isomer has an

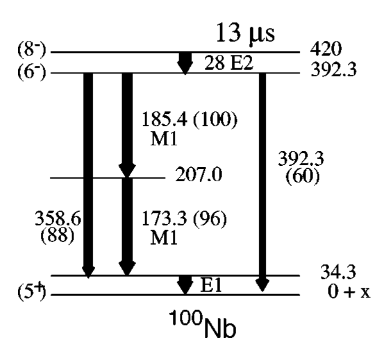

FIG. 12. Level scheme of the 13 μs isomer in ^{100}Nb. The energy, γ intensity, and multipolarity of each transition are reported in the level scheme. The zero energy is relative to the (5^+) isomer at 470 keV excitation energy.

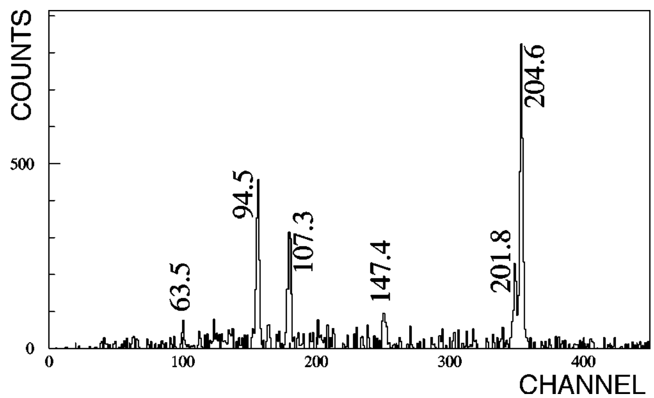

FIG. 13. γ-decay of ^{106m}Nb. Energies are given in keV.

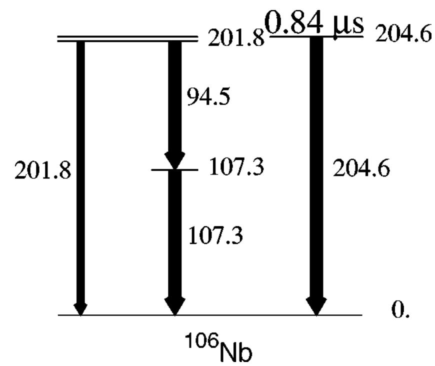

FIG. 14. Level scheme of the 0.84 μs isomer in ^{106}Nb.

excitation energy of 420 keV and its spin and parity are very likely 4^-. Consequently, it will be very likely below the (5^+) isomer of 3 s half-life, 470 ± 40 keV energy [31], and g.s. of the $\{\nu(s_{1/2})\pi(g_{9/2})\}5^+$ configuration. In this hypothesis, it will be surprising that the (5^+) isomer, does not decay, at least partially to the 13 μs isomer. In fact, it is more probable that the level sequence shown in Fig. 11 is built on the (5^+) state. This suggestion is supported by the fact that all these levels are probably identical to some of the levels already fed in the $(t,^3\mathrm{He})$ reaction at 25 ± 10, 210 ± 15, and 410 ± 15 keV [32]. The latter states are not based on the g.s. but have 460 keV excitation energy and are then very likely based on the (5^+) isomer.

The $\nu(h_{11/2})$ level is experimentally observed in the energy range of 500 to 800 keV above the g.s., in the 57 and 59 isotones [6]. Consequently, the 13 μs isomer may have the p-p $\{\pi(g_{9/2})\nu(h_{11/2})\}8^-$ configuration and decays to the 6^- of the same configuration.

E. ^{106}Nb

In the measurements with $A/q=106/22$ and 106/23, four strong lines have been seen in the delayed spectrum (see Fig. 13). They are therefore attributed to the mass chain $A=106$.

It is difficult to determine the nuclear charge of this isomer. It is expected to be in Nb, Mo, or Tc nuclei, elements which have the largest yields. The $2^+\rightarrow0^+$ transition in ^{106}Mo is not fed by the isomer, so, this assignment is probably excluded. Therefore, the isomer is most likely in the odd-odd ^{106}Tc or ^{106}Nb nuclei. To solve this ambiguity we have also irradiated a ^{239}Pu target and compared the yields obtained with the two isotopes of Pu. From the known g.s. fission yields, it is expected to have the same production for Tc and a factor 5 increase for Nb, when the ^{241}Pu target is used. It has been found that the production of the isomer decreases with the ^{239}Pu target, which shows that the isomer belongs to the ^{106}Nb nucleus. This result is also consistent with the fact that the isomeric ratio is equal to 0.08 if the isomer is in Nb and only 0.01 if it is in Tc. The last value being very small compared to the other ones reported in Table I.

The 94.5, 107.3, and 201.8 keV lines have a half-life of 800 ± 50 ns. The half-life of 890 ± 50 ns, measured for the 204.6 keV transition is close to the previous one and these four lines belong very likely to the same nucleus. A preliminary level scheme is shown in Fig. 14.

V. CONCLUSION

In this work several μs-isomers have been observed via thermal neutron-induced fission of ^{241}Pu. Decay schemes have been proposed for the odd-odd ^{88}Br, ^{94}Y, ^{96}Rb, ^{100}Nb, and ^{106}Nb isomers. In the case of ^{96}Rb the proposed level scheme contains the first information on the excited levels of this nucleus. The nuclear structure and the origin of the isomery has been explained for the four former nuclei in the framework of the spherical shell-model. This new information, complementary to the β-decay results, increases our knowledge of the odd-odd neutron-rich nuclei of the $A=100$ region.

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