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High energy ^{237}Np levels from ^{241}Am ($T_{1/2}$ = 431 y) alpha-decay

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Energies and intensities of more than 192 gamma-transitions were accurately measured, 63 of these are reported for the first time. The ^{237}Np level scheme built on the basis of good sum relationship accounts for 165 γ-transitions de-exciting 46 excited levels; 6 are proposed for the first time: at 712.7, 759.4, 945.3, 962.3, 1015.2 and 1114.3 keV. Spin and parities of the new states were discussed in the framework of the Nilsson's model.

Introduction

The ^{241}Am α-decay was studied by γ-spectrometry in the eighty's by ARDISSON et al.[1–3] and OVECHKIN[4] as reported by AKOVALI.[5] Some discrepancies remained about the existence of some high energy γ-transitions between the two published experimental data set and 44 γ-rays were not placed in the ^{237}Np level scheme. So, we decided to carefully measure the high-energy γ-ray spectrum of this radionuclide which is important as regards to its role in the long term wastes storage from the nuclear industry. We used a 518 MBq activity ^{241}Am source and a high efficiency HPGe detector with better resolution than that used in References 1–4.

Experimental

The ^{241}Am source consisted of americium oxide in a sealed stainless tube of 15 mm length and 2 mm diameter. At the start of the measurements, the source was 20 years old. The decay of ^{241}Am ($T_{1/2}$ = 432.2 y) leads to ^{233}Pa ($T_{1/2}$ = 26.97 d) through its long-lived daughter ^{237}Np ($T_{1/2}$ = 2.14·10^6 y). Hence, the main γ-lines of this last nuclide were observable as noticed in References 2 and 3, however the γ-ray spectrum of ^{233}Pa was accurately measured[6] and its contribution in the ^{241}Am γ-spectrum could be easily subtracted.

The γ-spectrometer consisted of an n-type coaxial HPGe detector of 17% relative efficiency with an energy resolution (FWHM) of 1.9 keV on the 1.33 MeV ^{60}Co line, coupled to a 8K multichannel analyzer.

The detector was shielded from the background of the measurement room by a 10 cm thick lead castle internally covered by a 5 mm thick copper sheet.

The spectrometer was calibrated both for energy and intensity using standard sources of ^{137}Cs, ^{152}Eu, ^{60}Co, and ^{133}Ba.

The ^{241}Am source was counted in front of the detector at a distance of 1.5 cm. With a view to enhance the high energy γ-ray component without deteriorating the energy resolution, we inserted between source and detector a copper absorber of 1.3 cm thickness.

Several measurements of 160 hour counting time were carried out with absorbers and 2 counting runs were performed with only an Al absorber at a distance of 15 cm to the detector. The gamma-spectra were analyzed with the computer code GAMANAL.[7]

Results

Figure 1 shows the high-energy part of the ^{241}Am γ-spectrum measured under these conditions. The main difficulty about the analysis of the high energy part of the spectrum lays in the chemical composition of such a highly active source. The interaction of the α-particles with the chemical elements of the ceramic source, i.e., Al, O and Na leads to nuclear reactions (α,n) or (α,p) and we detected 2 γ-transitions at 1002.4 and 1129.6 keV which were interpreted as de-exciting ^{26}Mg levels. Some authors have reported high energy γ-lines belonging to small impurities at the ppm level such as ^{152}Eu or ^{154}Eu.

Table 1 lists energies and intensities of measured γ-transitions and compares it to our previous work. Relative intensities were normalized to 10^7 α-decay using the intensity value I_γ = 49.6·10^{-7}/α for the 335.4 keV γ-line. A good agreement with previous values can be observed excepted for some γ-lines discussed below.

A total of 192 γ-rays were accurately measured of which 63 are reported for the first time. Some γ-transitions, listed in our previous work[1–3] were not detected here, as it is the case for 156.4, 201.7, 742.9, 782.2 and 794.9 keV.

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Table 1. Energies and intensities of γ-transitions following the α-decay of ^{241}Am

Present work		Previous work[a]		Placement			
E_γ, keV	I_γ [b]	E_γ, keV	I_γ [b]	Initial level, keV	I^π	Final level, keV	I^π
2.3†				370.99	3/2+	368.69	5/2+
13.81 (2)	≈0.01			281.39	½-	267.59	3/2-
26.3448 (2)	2.40E+5 (2)	26.35 (2)	2.40 (2)E+5	59.54	5/2-	33.20	7/2+
27.03 ?		27.03		102.96	7/2-	75.88	9/2+
31.4				545.59	(5/2-)	514.26	(3/2-)
33.196 (1)	1.26E+4 (3)	33.2 (1)	1.26 (3)E+4	33.20	7/2+	0.0	5/2+
38.54 (3)				370.99	3/2+	332.42	½+
42.73 (5)	5.5E+2 (11)	42.73 (5)	550 (110)	75.88	9/2+	33.20	7/2+
43.423 (10)	73E+2 (8)	43.42 (1)	73 (8)E+2	102.96	7/2-	59.54	5/2-
51.01 (3)	2.6 (1)2			332.42	½+	281.39	½-
54.0	≈21			129.92	11/2+	75.88	9/2+
55.56 (2)	1.81(18)E+3	55.56 (2)	1.81(18)E+3	158.51	9/2-	102.96	7/2-
56.8				324.41	(7/2-)	267.59	3/2-
59.5412 (1)	3.59(4)E+6	59.54 (1)	3.59 (4)E+6	59.54	5/2-	0.0	5/2+
61.46	≈0.2			191.61	13/2+	129.92	11/2+
64.83 (2)	14.5 (18)			332.42	½+	267.59	3/2-
67.45 (5)	42 (10)	67.45 (5)	42 (10)	225.99	11/2-	158.51	9/2-
69.76 (3)	290 (40)	69.76 (3)	290 (40)	102.96	7/2-	33.20	7/2+
75.8 (2)	≈59			75.88	9/2+	0.0	5/2+
78.1				799.96	9/2-	721.96	5/2-
79.1				304.98	13/2-	225.99	11/2-
92.1	≤4			359.20	(5/2-)	267.59	3/2-
96.7 (2)	4.7 (16)	96.7 (2)		129.92	11/2+	33.20	7/2+
98.97 (2)	2.03(4)E+3	98.97 (2)	2.03(4)E+3	158.51	9/2-	59.54	5/2-
102.98 (2)	1.95(4)E+3	102.98 (2)	1.95(4)E+3	102.96	7/2-	0.0	5/2+
106.47 (9)		106.42 (5)	1.5	X			
109.70 (7)	0.49			434.17	(11/2-)	324.41	(7/2-)
111.27 (13)	1.72 (24)			X			
113.29 (7)	34 (3)			304.98	13/2-	191.61	13/2+
114.8 (4)	5.0 (8)	115.54		191.61	13/2+	75.88	9/2+
119.17 (9)	6.4 (7)			X			
120.26 (7)[d]	14.6 (15)	120.36 (8)	0.45	444.55	(5/2,7/2	324.41	(7/2-)
123.0 (1)	154 (15)	123.01 (2)	100 (3)	225.99	11/2-	102.96	7/2-
125.30 (7)	470 (50)	125.30 (2)	408 (9)	158.51	9/2-	33.20	7/2+
128.04 (9)	0.59 (8)	128.07		452.47	9/2+	324.41	(7/2-)
129.2 (2)	0.22 (5)	129.2		434.17	(11/2-)	304.98	13/2-
135.7 (4)	0.090 (4)	135.3		459.69	7/2+	324.41	(7/2-)
		136.7					
138.2 (3)	0.10 (4)	138.5		598.02	11/2+	459.69	7/2+
139.47 (8)[d]		139.44 (8)	0.53 (11)	592.96	13/2+	452.47	9/2+
139.47 (8)	≈0.35			805.46	(7/2+,9/2)	666.12	(7/2-)
139.47 (8)	≈0.35			861.43	(7/2+)	721.96	5/2-
143.27 (12)	0.47 (6)			514.26	(3/2-)	370.99	3/2+
145.48 (16)				590.23	(7/2-)	444.55	(5/2,7/2)
145.48 (16)				598.02	11/2+	452.47	9/2+
145.48 (16)	0.31 (5)			514.26	(3/2-)	368.69	5/2+
145.48 (16)				945.33	(5/2-,7/2)	799.96	9/2-
146.53 (7)	57 (6)	146.55 (3)	46.1 (11)	304.98	13/2-	158.51	9/2-
150.08 (7)	9.2 (9)	150.04 (3)	7.40 (21)	225.99	11/2-	75.88	9/2+
150.08 (7)	≲ 9.2			417.76		267.59	3/2-
155.08 (18)	0.15 (4)	154.27 (20)	0.054	514.26	(3/2-)	359.20	(5/2-)

Table 1. (continued)

Present work		Previous work[a]		Placement			
E_γ, keV	I_γ [b]	E_γ, keV	I_γ [b]	Initial level, keV	I^π	Final level, keV	I^π
		156.43 (3)					
159.01 (21)	0.103 (23)	159.26 (20)	0.14 (5)	592.96	13/2+	434.17	(11/2-)
161.39 (11)	0.34 (4)	161.54 (10)	0.15	485.77	(9/2-)	324.41	(7/2-)
164.58 (7)	7.6 (8)	164.69 (4)	6.67 (24)	267.59	3/2-	102.96	7/2-
165.91 (7)	2.69 (27)	165.81 (6)	2.32 (11)	324.41	(7/2-)	158.51	9/2-
169.56 (7)	19.2 (19)	169.56 (3)	17.3 (4)	395.59	15/2-	225.99	11/2-
175.1 (1)	1.97 (20)	175.07 (4)	1.82 (10)	304.98	13/2-	129.92	11/2+
190.52 (11)	0.156 (22)	190.4	0.22 (5)	X			
191.94 (7)	2.2 (2)	191.96 (4)	2.16 (10)	496.92	17/2-	304.98	13/2-
195.01 (17)	0.13 (2)			861.43	(7/2+)	666.12	(7/2-)
197.0 (2)	0.049 (6)	197.0 (2)	0.049	592.96	13/2+	395.59	15/2-
		201.70 (14)	0.08				
203.96 (20)	0.32 (5)	204.06 (6)	0.290 (19)	395.59	15/2-	191.61	13/2+
208.01 (7)	84 (8)	208.01 (3)	79.1 (17)	267.59	3/2-	59.54	5/2-
212.35 (11)	0.11 (2)			X			
221.46 (7)	4.5 (4)	221.46 (3)	4.24 (10)	324.41	(7/2-)	102.96	7/2-
221.80 (4)	≈ 0.02	221.46 (3)	4.24 (10)	281.39	½-	59.54	5/2-
228.11 (9)	0.14 (2)			646.02	(9/2-)	417.76	
232.88 (7)	0.51 (5)	232.81 (5)	0.464 (30)	514.26	(3/2-)	281.39	½-
234.33 (12)	0.093 (12)	234.33	0.066 (27)	267.59	3/2-	33.20	7/2+
238.01 (17)	0.054 (11)			X			
246.68 (8)	0.24 (2)	246.73 (10)	0.242 (25)	514.26	(3/2-)	267.59	3/2-
248.46 (11)	0.052 (13)	249.00 (15)	0.054	324.41	(7/2-)	75.88	9/2+
260.92 (9)[d]				485.77	(9/2-)	225.99	11/2-
260.92 (9)	0.124 (15)	260.80 (15)	0.121 (19)	452.47	9/2+	191.61	13/2+
264.89 (7)	0.90 (9)	264.89 (6)	0.90 (4)	324.41	(7/2-)	59.54	5/2-
264.89 (7)[d]				545.59	(5/2-)	281.39	½-
267.57 (7)	2.67 (27)	267.58 (5)	2.63 (8)	267.59	3/2-	0.0	5/2+
271.56 (7)	0.277 (29)	270.63 (15)	0.064 (20)	X			
275.71 (7)	0.64 (6)	275.77 (8)	0.66 (4)	434.17	(11/2-)	158.51	9/2-
278.1 (2)	0.114 (24)	278.04 (15)	0.044	545.59	(5/2-)	267.59	3/2-
291.21 (8)	0.30 (3)	291.30 (20)	0.31 (3)	324.41	(7/2-)	33.20	7/2+
292.79 (7)	1.41 (14)	292.77 (6)	1.42 (5)	368.69	5/2+	75.88	9/2+
298.93 (14)	0.096 (16)			X			
300.14 (6)[d,e]	5.2 (5)			359.20	(5/2-)	59.54	5/2-
304.22 (12)	0.078 (11)	304.21 (20)	0.101 (21)	434.17	(11/2-)	129.92	11/2+
309.1 (3)	0.14 (3)	309.1 (3)	0.14	368.69	5/2+	59.54	5/2-
322.56 (7)	15.2 (15)			452.47	9/2+	129.92	11/2+
322.56 (7)				590.23	(7/2-)	267.59	3/2-
324.41 (12)	0.093 (17)			324.41	(7/2-)	0.0	5/2+
332.42 (7)	15.0 (15)	332.35 (3)	14.9 (3) (b)	332.42	½+	0.0	5/2+
335.47 (7)	49.6 (5)	335.37 (3)	49.6 (10)	368.69	5/2+	33.20	7/2+
337.79 (8)	0.38 (4)			370.99	3/2+	33.20	7/2+
350.76 (9)	0.17 (2)			721.96	5/2-	370.99	3/2+
358.36 (9)	0.121 (14)	358.25 (20)	0.120 (24)	434.17	(11/2-)	75.88	9/2+
368.68 (7)	21.5 (21)	368.65 (3)	21.7 (5)	368.69	5/2+	0.0	5/2+
371.0 (1)	5.2 (5)	370.94 (3)	5.23 (12)	370.99	3/2+	0.0	5/2+
375.50 (8)[d]	0.56 (6)			861.43	(7/2+)	485.77	(9/2-)
376.67 (7)	13.6 (14)	376.65 (3)	13.83 (30)	452.47	9/2+	75.88	9/2+
383.82 (7)	2.8 (3)	383.81 (3)	2.82 (7)	459.69	7/2+	75.88	9/2+
390.65 (7)	0.58 (6)	390.62 (10)	0.590 (27)	759.40	(3/2-,5/2-)	368.69	5/2+
398.54 (7)[d]	1.12 (11)	398.64 (15)	0.20	666.12	(7/2-)	267.59	3/2-
401.3 (30)	0.049	401.3 (30)	0.049	592.96	13/2+	191.61	13/2+
406.46 (9)	0.133 (15)	406.35 (15)	0.145 (22)	598.02	11/2+	191.61	13/2+
411.3 (3)	0.019 (5)			444.55	(5/2,7/2	33.20	7/2+
416.91 (7)				861.43	(7/2+)	444.55	(5/2,7/2)
416.91 (7)	0.81 (8)			962.31	(7/2+)	545.59	(5/2-)

Table 1. (continued)

Present work		Previous work[a]		Placement			
E_γ, keV	I_γ [b]	E_γ, keV	I_γ [b]	Initial level, keV	I^π	Final level, keV	I^π
419.33 (7)	2.9 (3)	419.33 (4)	2.87 (8)	452.47	9/2+	33.20	7/2+
426.47 (7)	2.44 (24)	426.47 (4)	2.46 (7)	459.69	7/2+	33.20	7/2+
429.91 (9)	0.115 (13)	429.94 (10)	0.115 (23)	X			
437.38 (30)	0.028 (9)			805.46	(7/2+,9/2)	368.69	5/2+
438.78 (17)	0.075 (12)			X			
440.06 (7)	0.98 (10)			666.12	(7/2-)	225.99	11/2-
442.81 (7)	0.38 (4)	442.81 (7)	0.35 (3)	545.59	(5/2-)	102.96	7/2-
446.43 (15)	0.049	446.43 (15)	0.049	770.56	(5/2,7/2)	324.41	(7/2-)
452.29 (8)	0.231 (24)	452.6 (2)	0.240 (25)	452.47	9/2+	0.0	5/2+
454.71 (7)	0.94 (9)	454.66 (8)	0.97 (4)	514.26	(3/2-)	59.54	5/2-
454.71 (7)[d]				721.96	5/2-	267.59	3/2-
459.69 (7)	0.342 (35)	459.68 (10)	0.363 (27)	459.69	7/2+	0.0	5/2+
463.22 (20)	0.1	463.22 (20)	0.1	592.96	13/2+	129.92	11/2+
468.07 (8)	0.27 (3)	468.12 (15)	0.288 (21)	598.02	11/2+	129.92	11/2+
477.5 (7)	0.012 (4)			962.31	(7/2+)	485.77	(9/2-)
487.6 (2)		485.91 (20)	0.10 (3)	646.02	(9/2-)	158.51	9/2-
487.6 (2)	0.053 (9)	487.3 (3)	0.044	590.23	(7/2-)	102.96	7/2-
501.1 (3)	0.022 (5)			X			
510.12 (15)	0.175 (20)			962.31	(7/2+)	452.47	9/2+
512.37 (8)	0.335 (40)	512.5 (3)	0.115 (23)	545.59	(5/2-)	33.20	7/2+
514.28 (8)	0.269 (28)	514.0 (5)	0.258 (27)	514.26	(3/2-)	0.0	5/2+
520.1 (5)	0.013 (5)			X			
522.17 (11)	0.102 (12)	522.06 (15)	0.095 (29)	598.02	11/2+	75.88	9/2+
525.34 (22)[d]	0.024 (5)			922.16	(5/2,7/2)	395.59	15/2-
528.90 (14)	0.044 (7)	529.17 (20)	0.046	853.23	11/2-	324.41	(7/2-)
545.82 (26)	0.069 (5)	545.4 (3)	0.074	545.59	(5/2-)	0.0	5/2+
563.6 (2)	0.047 (7)	563.05 (30)	0.074	721.96	5/2-	158.51	9/2-
573.99 (8)	0.12 (13)	573.94 (20)	0.125 (19)	799.96	9/2-	225.99	11/2-
582.8 (2)	0.034 (5)	582.6*	0.023 (12)	712.66	(7/2+,9/2)	129.92	11/2+
586.59 (8)	0.130 (14)	586.59 (20)	0.131 (20)	646.02	(9/2-)	59.54	5/2-
590.31 (7)		590.28 (15)	0.286 (21)	666.12	(7/2-)	75.88	9/2+
590.31 (7)	0.28 (3)			590.23	(7/2-)	0.0	5/2+
597.47 (7)	0.70 (7)	597.48 (8)	0.741 (33)	755.97	7/2-	158.51	9/2-
619.04 (7)	5.8 (6)	619.01 (2)	5.94 (6)	721.96	5/2-	102.96	7/2-
627.29 (11)	0.064 (9)	627.18 (20)	0.056 (17)	853.23	11/2-	225.99	11/2-
633.02 (8)	0.130 (14)	632.93 (15)	0.126 (19)	666.12	(7/2-)	33.20	7/2+
636.9 (2)	0.027 (5)			712.66	(7/2+,9/2)	75.88	9/2+
641.45 (7)	0.68 (7)	641.47 (5)	0.71 (3)	799.96	9/2-	158.51	9/2-
652.97 (7)	3.57 (36)	653.02 (4)	3.77 (11)	755.97	7/2-	102.96	7/2-
656.6 (3)	0.013 (4)			759.40	(3/2-,5/2)	102.96	7/2-
662.44 (7)	34.4 (34)	662.40 (2)	36.4 (8)	721.96	5/2-	59.54	5/2-
664.1 (3)	0.024 (5)			X			
666.1 (2)	0.033 (5)	666.5 (3)	0.049	666.12	(7/2-)	0.0	5/2+
669.94 (9)	0.062 (7)	669.83 (20)	0.038 (12)	799.96	9/2-	129.92	11/2+
675.87 (13)	0.079 (14)	676.03 (30)	0.064 (13)	805.46	(7/2+,9/2)	129.92	11/2+
680.08 (7)	0.31 (3)	680.10 (10)	0.313 (17)	755.97	7/2-	75.88	9/2+
688.79 (7)	3.0 (3)	688.72 (4)	3.25 (8)	721.96	5/2-	33.20	7/2+
693.48 (7)	0.31 (3)	693.62 (8)	0.368 (17)	X			
696.48 (7)	0.44 (4)	696.6 (5)	0.534 (20)	755.97	7/2-	59.54	5/2-
696.48 (7)[d]				799.96	9/2-	102.96	7/2-
709.41 (6)	0.60 (6)	709.45 (5)	0.641 (18)	X			
712.43 (22)	0.016 (3)			712.66	(7/2+,9/2)	0.0	5/2+
721.98 (7)	17.8 (18)	722.01 (3)	19.6 (4)	721.96	5/2-	0.0	5/2+
721.98 (7)[d]				755.97	7/2-	33.20	7/2+
723.01 (17)	0.43 (5)			853.23	11/2-	129.92	11/2+
724.17 (16)	0.110 (15)			799.96	9/2-	75.88	9/2+
729.52 (8)	0.130 (13)	729.72 (15)	0.133 (14)	805.46	(7/2+,9/2)	75.88	9/2+
731.42 (10)	0.047 (5)	731.5 (5)*	0.047 (15)	861.43	(7/2+)	129.92	11/2+

Table 1. (continued)

Present work		Previous work[a]		Placement			
E_γ, keV	I_γ [b]	E_γ, keV	I_γ [b]	Initial level, keV	I^π	Final level, keV	I^π
733.18 (23)	0.0135 (24)			X			
737.30 (7)	0.77 (8)	737.34 (5)	0.800 (24)	770.56	(5/2,7/2)	33.20	7/2+
740.36 (29)	0.0145 (26)	742.9 (3)	0.035	799.96	9/2-	59.54	5/2-
750.2 (3)	0.0028 (14)			853.23	11/2-	102.96	7/2-
755.9 (1)	0.70 (7)	755.90 (5)	0.760 (28)	755.97	7/2-	0.0	5/2+
759.46 (8)	0.146 (15)	759.38 (10)	0.167 (9)	759.40	(3/2-,5/2)	0.0	5/2+
763.3 (3)	0.063 (21)	763.9 (3)	0.020 (6)	922.16	(5/2,7/2)	158.51	9/2-
766.83 (8)	0.393 (40)	767.00 (10)	0.500 (18)	799.96	9/2-	33.20	7/2+
770.57 (7)	0.43 (4)	770.57 (10)	0.474 (21)	770.56	(5/2,7/2)	0.0	5/2+
772.12 (7)	0.250 (25)	772.4 (3)	0.266 (15)	805.46	(7/2+,9/2)	33.20	7/2+
777.46 (21)	0.0084 (16)	777.2*	0.0061 (31)	853.23	11/2-	75.88	9/2+
780.53 (11)	0.026 (3)	780.7 (2)	0.025 (5)	X			
		782.2 (5)	0.015				
786.70 (10)	0.0366 (40)	786.00 (15)	0.062	945.33	(5/2-,7/2)	158.51	9/2-
788.81 (10)	0.038 (4)	789.17 (25)	0.039 (6)	X			
		794.92 (20)	0.094				
801.9 (1)	0.101 (11)	801.94 (20)	0.136 (14)	861.43	(7/2+)	59.54	5/2-
803.3 (4)	0.010 (4)			962.31	(7/2+)	158.51	9/2-
805.0 (2)	0.007 (3)	806.26 (30)	0.031	805.46	(7/2+,9/2)	0.0	5/2+
811.80 (10)	0.052 (6)	812.01 (30)	0.061 (8)	X			
819.26 (10)	0.0324 (37)	819.0 (10)	0.040 (6)	922.16	(5/2,7/2)	102.96	7/2-
822.8 (5)	0.010 (3)	822.6*	0.022 (6)	1015.17	(9/2+)	191.61	13/2+
828.58 (19)	0.0159 (24)	828.5	0.024 (6)	861.43	(7/2+)	33.20	7/2+
832.6 (3)	0.0041 (25)			962.31	(7/2+)	129.92	11/2+
834.7 (4)	0.07 (3)	835.6 (10)	0.021(6)	X			
840.8 (3)	0.011 (2)	841.5(10)**	0.004 (1)	X			
843.23 (27)	0.0095 (17)			X			
846.8 (5)	0.0034 (12)	847.4 (5)**	0.027 (3)	1114.27	(5/2-,7/2)	267.59	3/2-
851.51 (9)	0.042 (5)	851.6 (10)	0.038 (6)	X			
		854.7*	0.020 (4)				
856.56 (24)	0.0116 (20)			1015.17	(9/2+)	158.51	9/2-
859.2 (2)	0.0127 (21)	860.7 (5)	0.0082 (25)	922.16	(5/2,7/2)	59.54	5/2-
862.64 (8)	0.067 (8)	862.7 (5)	0.053 (6)	922.16	(5/2,7/2)	59.54	5/2-
862.64 (8)[d]				861.43	(7/2+)	0.0	5/2+
870.1 (6)[f]	0.0146 (3)	870.7 (3)	0.046	X			
871.84 (14)	0.0276 (31)			X			
887.7 (5)	0.025 (4)	887.3 (3)	0.022 (5)	922.16	(5/2,7/2)	33.20	7/2+
898.2 (3)	0.0089 (18)	898.4*	0.0072 (29)	X			
902.5 (1)	0.027 (3)	902.5*	0.030 (5)	962.31	(7/2+)	59.54	5/2-
912.38 (14)	0.023 (3)	912.4*	0.025 (5)	1015.17	(9/2+)	102.96	7/2-
922.1 (2)	0.014 (2)	921.5 (3)	0.019 (4)	922.16	(5/2,7/2)	0.0	5/2+
928.8 (3)	0.0060 (20)	928.8*	0.0055 (28)	962.31		33.20	7/2+
938.9 (5)	0.0029 (14)			X			
945.9 (3)	0.0058 (15)	945.7*	0.0056 (28)	945.33	(5/2-7/2)	0.0	5/2+
955.70 (9)	0.047 (5)	955.7*	0.058 (6)	1114.27	(5/2,7/2)	158.51	9/2-
962.02 (11)	0.026 (3)			962.31	(7/2+)	0.0	5/2+
1014.2 (5)	0.0041 (14)	1014.7(5)**	0.0064 (10)	1015.17	(9/2+)	0.0	5/2+
1114.8 (3)	0.0085 (17)			1114.27	(5/2,7/2)	0.0	5/2+

Uncertainties on energies and intensities, in parentheses, are given on the last digits of the values. For multiply placed γ-transitions the intensity has been divided as indicated.

[a] Ref. 1–3.

[b] Intensities are normalized to 10^7 alpha-particles using the unweighted average absolute value I_γ (59.54) = (0.359±0.004)/α.[7]

[d] Uncertain placement.

[e] Transitions only reported by GUNNINK.[8]

[f] Uncertain transition, could be attributed to the Coulomb excitation ^{17}O(α,α') in the Am_2O_3 source.

** Transition only reported by OVECHKIN.[4]

† Not detected but needed for intensity imbalance.

X: Unplaced γ-transition.

E+5 means 10^5.

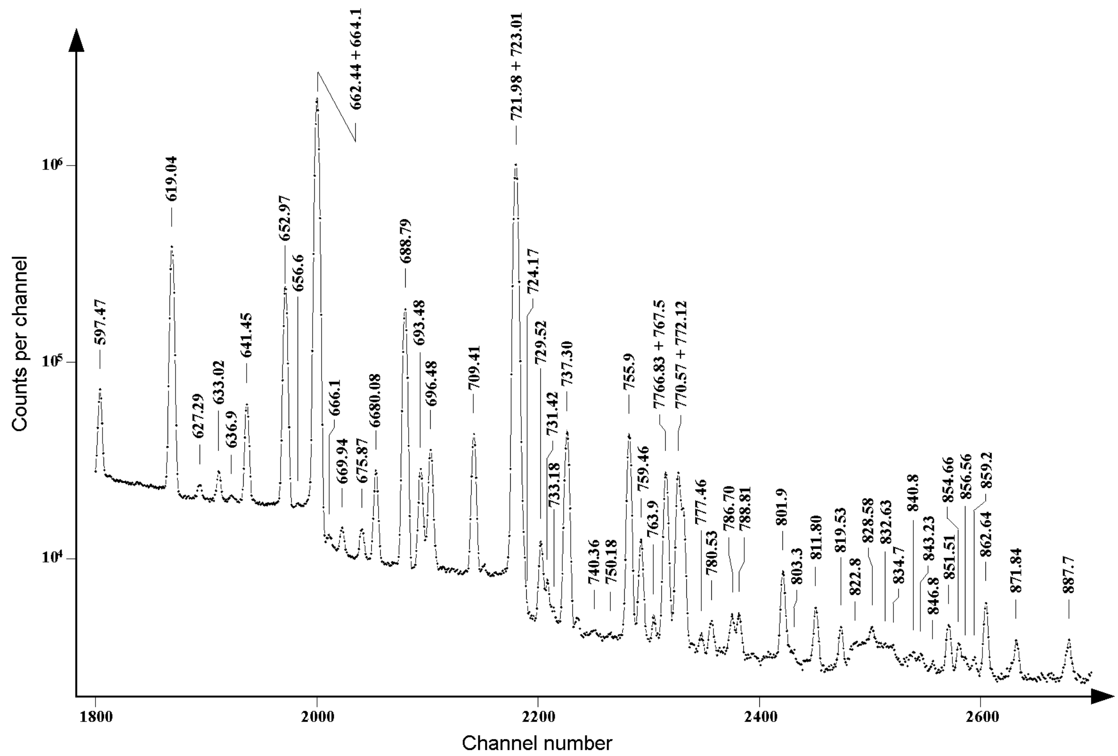


Fig. 1. Part of the ^{241}Am γ-spectrum, measured with a 17% HPGe detector. Energy are given in keV

Discussion

Gamma-transition intensities were corrected for internal conversion using measured multipolarities, when available,[5] and expected E2 or M1 multipolarities from ^{237}Np level scheme. Alpha-branchings and α hindrance factors (HF) calculations were carried out with the program package of the Evaluated Nuclear Structure Data Files (ENSDF) program library, provided from National Nuclear Data Center, Brookhaven (NNDC). The ^{237}Np revised level scheme built on the basis of this work is shown in Figs 2a–d.

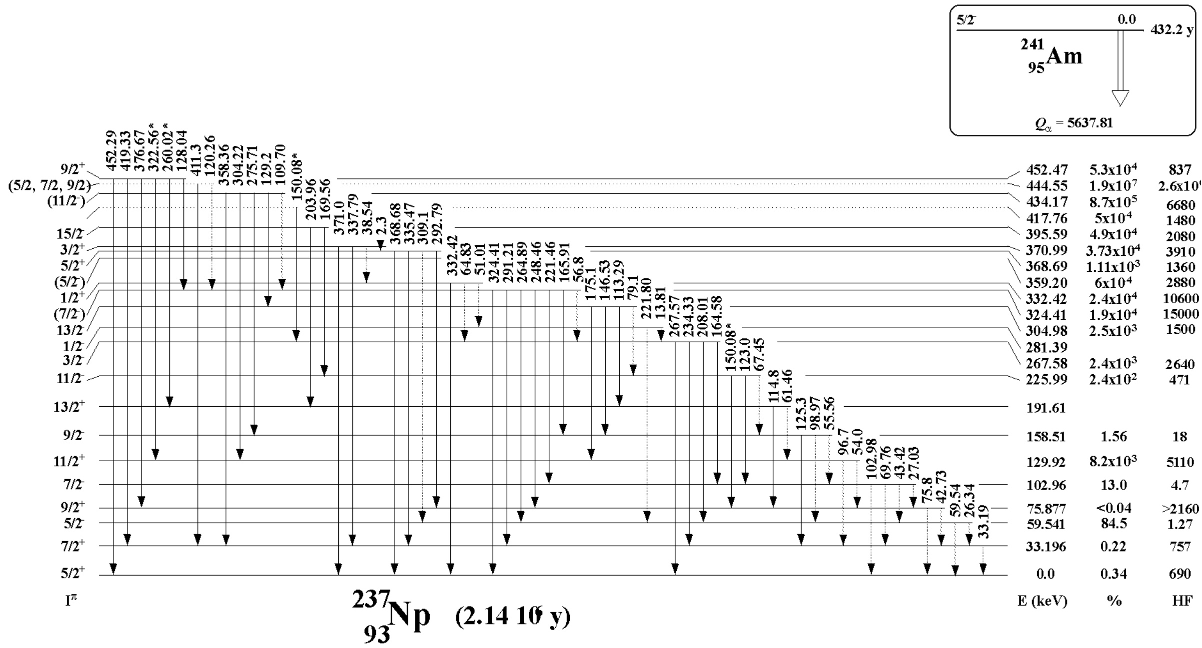
We only discuss here the existence of some high energy ^{237}Np levels not detected in our previous work.[1–3]

The 712.7 keV level is proposed to take into account the transitions of 712.4, 636.9 and 582.8 keV interpreted as de-exciting to the $I^{\pi} = 5/2^{+}$, $9/2^{+}$ and $11/2^{+}$ members of the ground state rotational band (gsb), because a good agreement is observed in the energy sum relationship. A level at (712±3) keV was also observed in (^{3}He,d) and ^{236}U(α,t) reaction,[9] but from the probable spin and parity assumed $I^{\pi} = (11/2^{-})$, it seems different from our level because its decay characteristics favor $I^{\pi} = 7/2^{+}$, $9/2^{+}$.

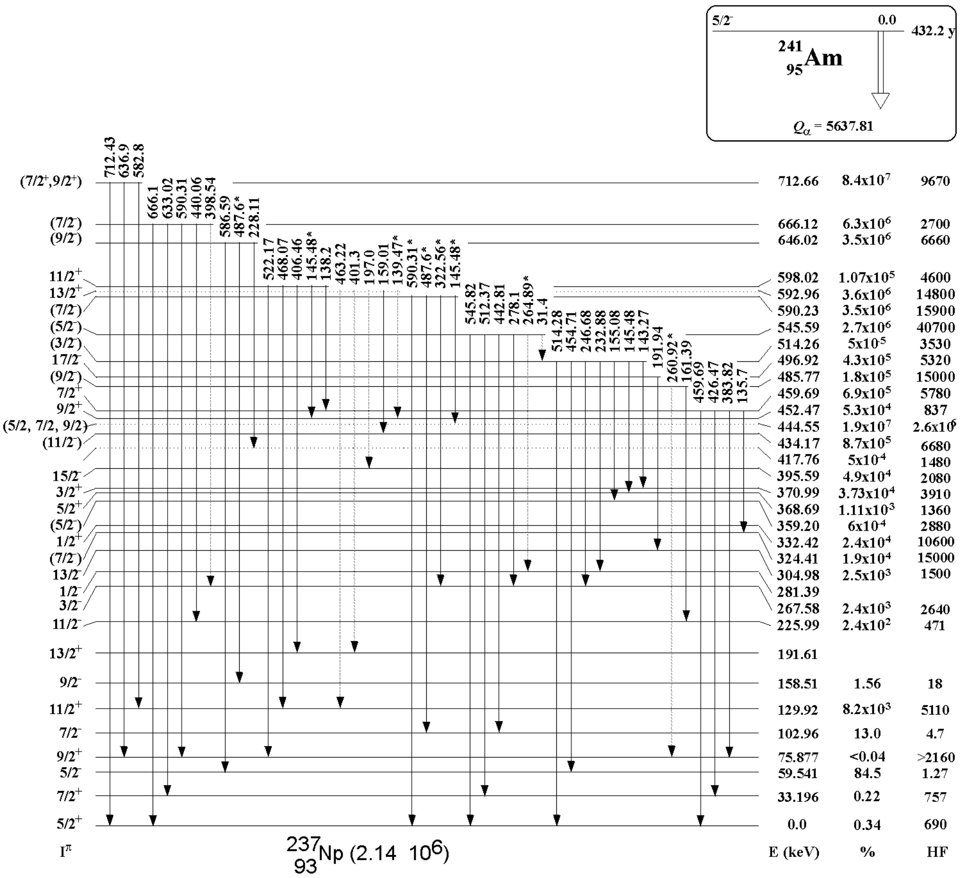
The 721.96 keV band: The first member $I^{\pi} = 5/2^{-}$ at 721.96 keV of this band was already known[5] and some additional transitions has been added in this work. Its decay to both positive and negative parity states of the ground and first excited bands confirms the character $I^{\pi} = 5/2^{-}$ suggested in the reactions ^{236}U (^{3}He,d) and ^{236}U(α,t).[9]

The state at 755.97 keV is known to be the $I^{\pi} = 7/2^{-}$ member of this band.

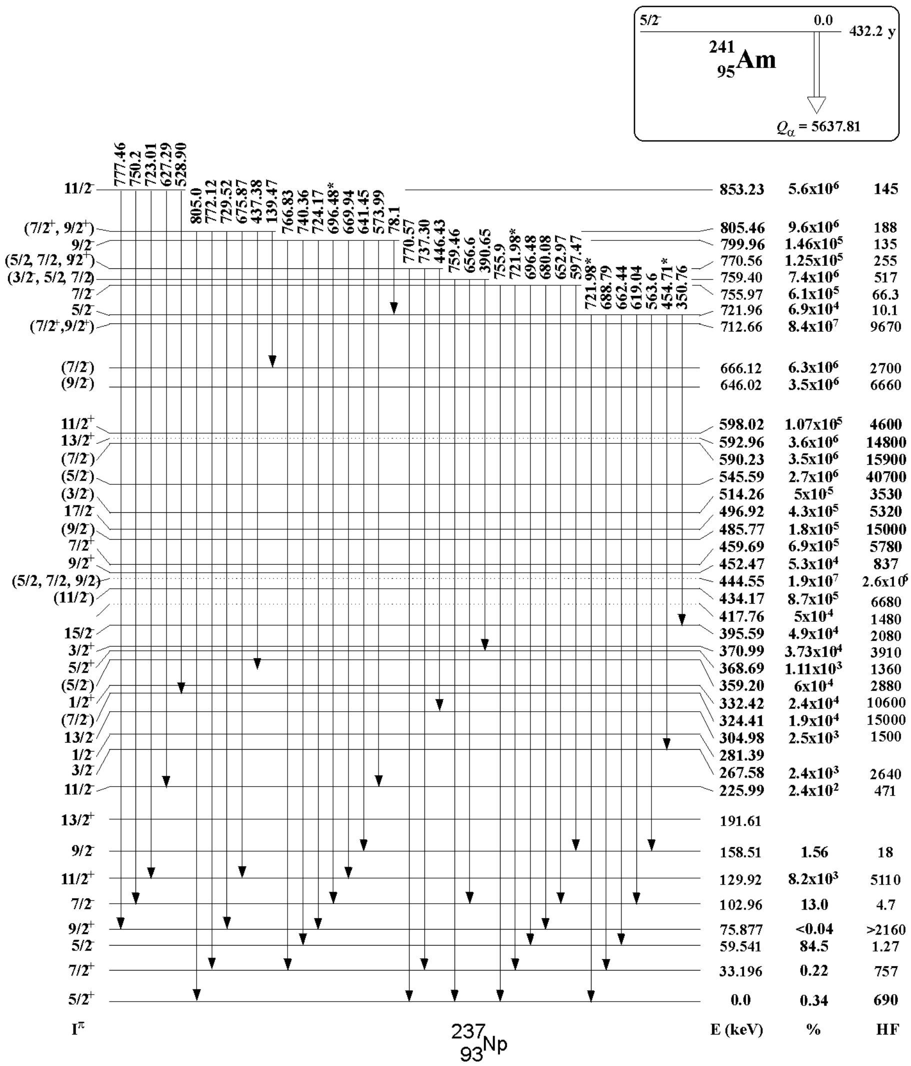
For the 799.96 keV state we add a new γ-transition of 740 keV (E2) to the $5/2^{-}$ state. Hence this state decays to all members of the negative parity band $5/2^{-}$[523].


5/2⁻ 0.0 432.2 y
241 95 Am
Qα = 5637.81
452.29 419.33 376.67 322.56* 260.02* 128.04 411.3 120.26 358.36 304.22 275.71 129.2 109.70 150.08* 203.96 169.56 371.0 337.79 38.54 2.3 368.68 335.47 309.1 292.79 332.42 64.83 51.01 324.41 291.21 264.89 248.46 221.46 165.91 56.8 175.1 146.53 113.29 79.1 221.80 13.81 267.57 234.33 208.01 164.58 150.08* 123.0 67.45 114.8 61.46 125.3 98.97 55.56 96.7 54.0 102.98 69.76 43.42 27.03 75.8 42.73 59.54 26.34 33.19
9/2⁺ 452.47 5.3x10⁴ 837
(5/2, 7/2, 9/2) 444.55 1.9x10⁷ 2.6x10⁶
(11/2⁻) 434.17 8.7x10⁵ 6680
417.76 5x10⁴ 1480
15/2⁻ 395.59 4.9x10⁴ 2080
3/2⁺ 370.99 3.73x10⁴ 3910
5/2⁺ 368.69 1.11x10³ 1360
(5/2⁻) 359.20 6x10⁴ 2880
1/2⁺ 332.42 2.4x10⁴ 10600
(7/2⁻) 324.41 1.9x10⁴ 15000
13/2⁻ 304.98 2.5x10³ 1500
1/2⁻ 281.39
3/2⁻ 267.58 2.4x10³ 2640
11/2⁻ 225.99 2.4x10² 471
13/2⁺ 191.61
9/2⁻ 158.51 1.56 18
11/2⁺ 129.92 8.2x10³ 5110
7/2⁻ 102.96 13.0 4.7
9/2⁺ 75.877 <0.04 >2160
5/2⁻ 59.541 84.5 1.27
7/2⁺ 33.196 0.22 757
5/2⁺ 0.0 0.34 690
Iπ E (keV) % HF
237 93 Np (2.14 10⁶ y)

(Fig. 2a)


5/2⁻ 0.0 432.2 y
241 95 Am
Qα = 5637.81
712.43 636.9 582.8 666.1 633.02 590.31 440.06 398.54 586.59 487.6* 228.11 522.17 468.07 406.46 145.48* 138.2 463.22 401.3 197.0 159.01 139.47* 590.31* 487.6* 322.56* 145.48* 545.82 512.37 442.81 278.1 264.89* 31.4 514.28 454.71 246.68 232.88 155.08 145.48 143.27 191.94 260.92* 161.39 459.69 426.47 383.82 135.7
(7/2⁺,9/2⁺) 712.66 8.4x10⁷ 9670
(7/2⁻) 666.12 6.3x10⁶ 2700
(9/2⁻) 646.02 3.5x10⁶ 6660
11/2⁺ 598.02 1.07x10⁵ 4600
13/2⁺ 592.96 3.6x10⁶ 14800
(7/2⁻) 590.23 3.5x10⁶ 15900
(5/2⁻) 545.59 2.7x10⁶ 40700
(3/2⁻) 514.26 5x10⁵ 3530
17/2⁻ 496.92 4.3x10⁵ 5320
(9/2⁻) 485.77 1.8x10⁵ 15000
7/2⁺ 459.69 6.9x10⁵ 5780
9/2⁺ 452.47 5.3x10⁴ 837
(5/2, 7/2, 9/2) 444.55 1.9x10⁷ 2.6x10⁶
(11/2⁻) 434.17 8.7x10⁵ 6680
417.76 5x10⁴ 1480
15/2⁻ 395.59 4.9x10⁴ 2080
3/2⁺ 370.99 3.73x10⁴ 3910
5/2⁺ 368.69 1.11x10³ 1360
(5/2⁻) 359.20 6x10⁴ 2880
1/2⁺ 332.42 2.4x10⁴ 10600
(7/2⁻) 324.41 1.9x10⁴ 15000
13/2⁻ 304.98 2.5x10³ 1500
1/2⁻ 281.39
3/2⁻ 267.58 2.4x10³ 2640
11/2⁻ 225.99 2.4x10² 471
13/2⁺ 191.61
9/2⁻ 158.51 1.56 18
11/2⁺ 129.92 8.2x10³ 5110
7/2⁻ 102.96 13.0 4.7
9/2⁺ 75.877 <0.04 >2160
5/2⁻ 59.541 84.5 1.27
7/2⁺ 33.196 0.22 757
5/2⁺ 0.0 0.34 690
Iπ E (keV) % HF
237 93 Np (2.14 10⁶)

(Fig. 2b)

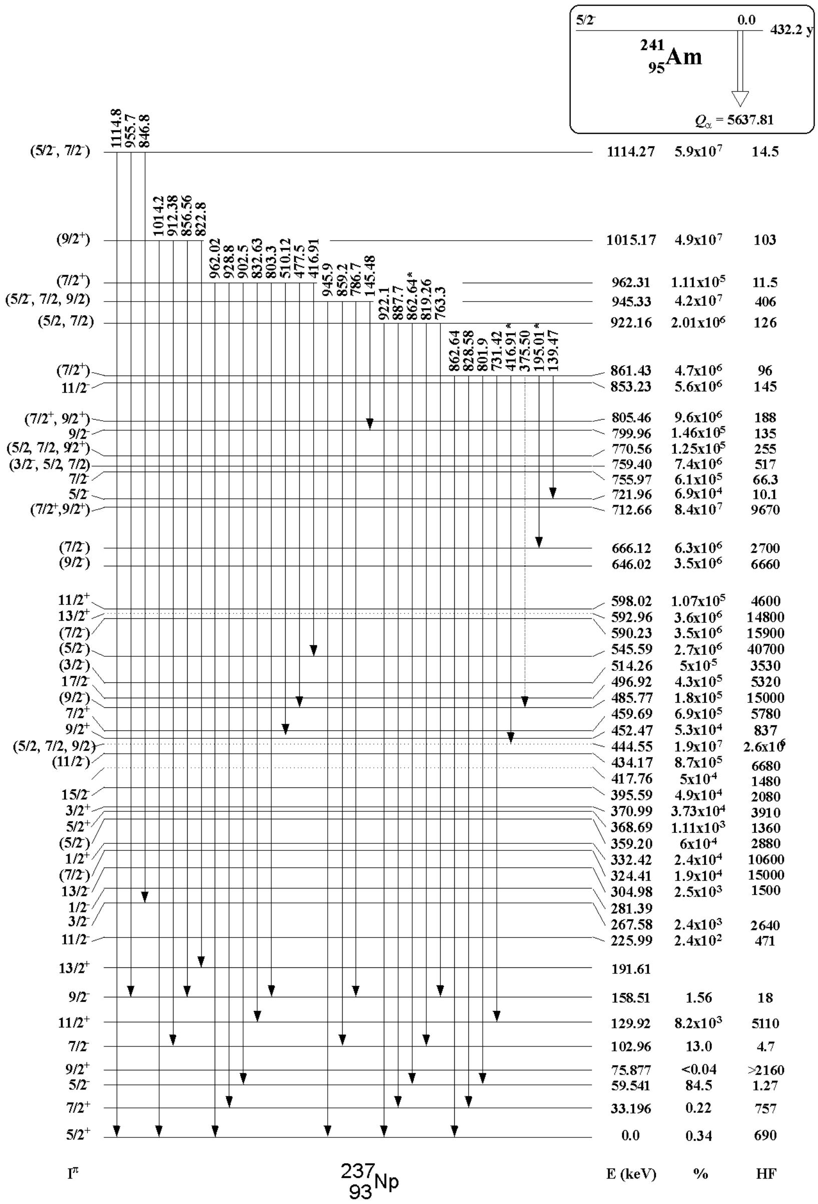


(Fig. 2c)

The 853.23 keV level was early established on the basis of 2 γ-transitions to the $I^{\pi} = 7/2^{-}$ and $11/2^{-}$ states. We confirm here its existence by 3 new γ-transitions of 777.5, 750.2 and 729.5 keV feeding, states with spin and parity $I^{\pi} = 9/2^{+}$, $7/2^{-}$ and $11/2^{-}$, respectively. This pattern adds arguments for a character $I^{\pi} = 11/2^{-}$.

The reverse inertial moment $\boldsymbol{A} == \hbar^2/2I = 4.86$ keV of this band is nearly equals to that of the $K^{\pi} = 5/2^{+}$ g.s. band, i.e., $\boldsymbol{A} = 4.74$ keV, for which the Nilsson configuration is $5/2^{+}$[642]. The main component of this K = 5/2 band could be the $\{0^{-} \otimes 5/2^{+}[642\uparrow]\}$ octupole configuration since the $K^{\pi} = 0^{-}$ band in the neighboring uranium isotopes are at 687 and 680 keV. However, accounting for the ^{241}Am ground state configuration $5/2^{-}$[523] and the low hindrance factor values, i.e., HF = 10.1, 66, 135 and 145, for the respective I = 5/2, 7/2, 9/2 and 11/2 members of this band, we can suppose weak admixtures of the $5/2^{-}$[523] proton state contribute to the wave function of this band.

The new $K^{\pi} = 5/2^{+}$ rotational band at 922.16 keV: A 922.16 keV state was previously suggested[5] on the basis of good energy relationships between γ-transitions of 921.5, 887.3 and 860.7 keV populating the ground state and the two first excited states. We confirm its existence by adding 2 new transitions of 819.3 and 763.3 keV. From its γ-decay this level could be I = 5/2.



(Fig. 2d)

Fig. 2. ^{237}Np level scheme fed by ^{241}Am α-decay. Energies are in keV; dotted lines means an uncertain level deduced from α-spectrum measurements;[5] *means a γ-transition placed twice or more

A new 962.31 keV state is suggested here on the basis of 8 γ-transitions depopulating it to 5/2, 7/2 and 11/2 members of gsb, and to 5/2, 9/2 members of the 5/2⁻[523] band; with regard to the spins of the final states the most probable I^{π} value is $7/2^{+}$. This level may be identical to that observed at (961±3) or (963±2) keV in respective stripping reactions ^{236}U(^{3}He,d) and ^{236}U(α,t) [9] or in inelastic scattering ^{237}Np(d,d').[10]

A new level is also proposed at 1015.15 keV. It allows the interpretation of four γ-transitions of which one is new and the others were not interpreted in previous works. Assuming the spin value I = 9/2, these three states could be members of a new K = 5/2 rotational band with a reverse inertial parameter $\boldsymbol{A} = \hbar^2/2I$ = 5.73 keV, calculated from the 922.16 and 962.31 keV states assumed as 5/2 and 7/2 members. Hence, with a single value of A, using the rotational formula $E = E° + \boldsymbol{A}\, I(I+1)$, the energy value of the $I^{\pi} = 9/2$ state will be 1013.7 keV instead of 1015.2 keV.

A new state at 945.33 keV is distinct of the isomeric 945.3 keV state ($T_{1/2} = 0.71$ μs) detected in the ^{238}U(p,2nγ) reaction.[11] Indeed, the state fed in α-decay de-excites by 4 γ-transitions of 945.9, 859.2, 786.7 and 145.5 keV to respective gs ($5/2^+$), 7/2, $9/2^-$, $9/2^-$ states and the most probable spin and parity values are 5/2, 7/2, instead of $13/2^{\pm}$ expected from Reference 11 for the three quasiparticle configuration.

Conclusions

The ^{241}Am α-decay has been investigated by carefully measuring its γ-spectrum with HPGe detector shielded by a lead castle. Analysis of the spectra allowed us to observe more than 192 γ-transitions, among them 63 of these are reported for the first time. In the revised ^{237}Np level scheme, 165 γ-transitions were placed between 46 excited levels of which 6 are new. A new $K^{\pi} = 5/2^+$ rotational band is suggested at 922.6 keV.

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