Decay of ^{155}Sm

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The beta decay of ^{155}Sm ($T_{1/2} \sim$ 22min) has been investigated by gamma spectroscopy measurements. The single and coincidence spectra were taken using HPGe detectors with high energy resolution. The energy and relative intensities of 42 γ-rays have been determined, most of them with a better precision than previously. The γ-transitions at 205.7keV and 224.8keV were observed for the first time and 40 of them were confirmed and 39 of them placed in the decay scheme. The present results, together with the results of earlier studies, allows to confirm the energy levels, in the energy range 0.05-1.6MeV, as well as the assignments of spin for most of them.

I. INTRODUCTION

Some investigations have been made in the past to determine the level structure of ^{155}Eu through the β^- decay of ^{155}Sm [1–3], but basically the measurement performed by Ungrin *et al.* [3] in 1969, using NaI (Tl), Si(Li) and Ge (Li) detectors, established the features of the low excited levels in ^{155}Eu. In this work 49 γ-transition arranged in 16 energy levels were attributed to the β^- decay of ^{155}Sm. Other studies using different nuclear reactions, such as ^{152}Sm(t,α) [4], ^{153}Eu(t,p) [5] and ^{154}Sm(^{3}He,d) [6] confirmed some of these results and gave a more precise description of the energy levels up to 1.0MeV. Recently Genezini [7] performed angular correlation measurements for several γ cascades where some multipole mixing ratios were extracted suggesting spin and parity for some excited levels, but no additional information related to the beta decay parameters were obtained. Despite all the experimental effort done with ^{155}Sm, the level scheme is essentially the same proposed by Ungrin *et al.* [3]. Comparing the beta decay data with data from nuclear reaction studies we noticed many controversies at low-lying levels, mainly regarding the presence and placement of several γ-transitions. Besides, a number of γ-transitions still need confirmation and for many the intensity have a poor precision or there is no uncertainty associated.

The aim of this study is to investigate the excited levels in ^{155}Eu from the β^- decay of ^{155}Sm to obtain complementary experimental information related to the population of low-lying levels. We intend to perform a precise measurement of energy and intensity of gamma transitions in ^{155}Eu using γ-ray spectrometers with high resolution in the region between 50keV and 1.6MeV.

II. EXPERIMENTAL PROCEDURE

In these measurements the sources of ^{155}Sm were produced by thermal neutron irradiation of Samarium oxide (enriched to 98.69% by ^{154}Sm isotope). About 1-3mg of ^{154}Sm were irradiated for few seconds (20-100) in the IEA-R1 nuclear reactor at IPEN in a neutron flux of $\sim 10^{12} n \cdot cm^{-2} \cdot s^{-1}$. The ^{155}Sm spectra were recorded through three successive half-lives. The energy and efficiency calibrations of the HPGe detectors were performed using standard gamma rays from ^{60}Co, ^{133}Ba, ^{137}Cs and ^{152}Eu. The singles spectroscopy was recorded over ~100 hours of live counting using a 198cm^3 HPGe detector as well a lead shield to minimize the background radiation effects, and the resulting spectrum was analyzed using the IDEFIX software [8]. Coincidence measurements were performed using a multidetector acquisition system [9] at Linear Accelerator Laboratory of IFUSP facilities, with four HPGe detectors and the coincidence, data was analyzed using the BIDIM software [10].

III. RESULTS AND DISCUSSION

In this study a total of 42 transitions were attributed to the ^{155}Sm decay. The measured gamma-ray energies and relative intensities are listed in Table I and compared with the last compilation performed by Reich [11]. The placement suggested in our measurement is also presented in this table (indicated by the desexcitation energy level); a decay scheme is shown in Fig.1. Two γ-transitions at 205.7keV and 224.8keV were observed for the first time in beta decay studies, but our data revealed no evidence for photopeaks at: 53, 63, 65, 80, 90, 183, 220, 280, 665, 758, 818, 830, 861, 880, 911, 1018 and 1096keV, observed in previous works [1–3, 11]. We could not calculate the upper intensity limits [12] of these unobserved gamma rays due to proximity of them to a lot of γ-transitions following ^{155}Sm decay. The new γ-transition at 205.7keV, as shown in Fig. 2, belongs to the triplet at 203.1, 205.7 and 208.1keV, where the peak at 208.1keV is due to secondary effect (pile-up from the strong transition at 104.9keV). Fig. 3 shows the fit using the IDEFIX code [8] for the three transitions at $E \sim$ 225keV.

The intensities of beta feedings to the excited levels were obtained from intensity balance of transitions feeding and de exciting these levels. The results are presented in Table II and compared with the evaluations from NDS [11]. Also the spin and parity suggested from the recent angular correlation experiment [7] were presented in Table II.

Eγ (keV) Iγ[+] (%) Present study	Eγ (keV) Iγ[+] (%) Ref [11]	E Level (kev)	Eγ (keV) Iγ[+] (%) Present study	Eγ (keV) Iγ[+] (%) Ref [11]	E Level (kev)	Eγ (keV) Iγ[+] (%) Present study	Eγ (keV) Iγ[+] (%) Ref [11]	E Level (kev)
or	25.69(6)[a] 14(2)	104.320(5)	224.77 (20) 0.055(11)	*no*	1101.9(3)	*no*	818.1 0.025(5)	817.52(12)
or	30.5(5)[np] 15(1)		228.776(17) 1.313(25)	228.7(6) 1.4(2)	307.32(6)	*no*	830(20)[c] 0.025(5)	911.11(19)
or	53.1(4)[np,a] 0.40(15)		230.22(24) 0.094(22)	229(1)[c] 0.08(2)	1106.83(22)	*no*	861.1(1)[np] 0.13(3)	
61.816(7) 5.35(26)	61.55(6)[a] 6.0(6)	307.32(6)	245.7530(10) 100.0(7)	245.73(5) 100	245.734(12)	*no*	880(10)[c] 0.075(15)	876.94(20)
no	63.1(5)[np,a] 0.3(1)		*no*	280(1)[np,b] 0.4(1)		*no*	911 0.025(5)	911.11(19)
no	64.5(5)[c] 0.20(4)	169.00(12)	287.86(16) 0.044(11)	287.1(4)[c] 0.03(1)	391.38(19)	923.22(22) 0.027(11)	923 0.025(5)	923.17(24)
78.845(4) 8.91(16)	78.65(7)[a] 6.8(3)	78.61(4)	307.300(29) 0.369(14)	307.3(3) 0.28(7)	307.32(6)	933.774(10) 0.291(27)	932.9(4) 0.25(5)	1101.9(3)
no	80.0(5)[np,a] 0.85(20)		426.163(25) 0.416(13)	426.2(2) 0.34(6)	817.57(12)	997.47(3) 0.406(25)	997.9(4) 0.33(8)	1101.9(3)
x *x*	84.1(5)[c] 0.061(15)	391.38(19)	461.106(7) 2.154(24)	460.80(13) 1.75(25)	768.23(9)	1002.50(4) 0.410(24)	1002.7(3) 0.45(6)	1106.83(22)
no	90.1(5)[c] 0.25(6)	169.00(12)	510.705(3) 0.381(28)	510.2(2) 0.33(4)	817.57(12)	*no*	1018 0.025(5)	1263.60(25)
104.86619(4) 1943(18)	104.320(5) 2000(50)	104.320(5)	522.698(4) 4.79(4)	522.54(15) 4.0(4)	768.23(9)	1056.14(25) 0.040(10)	1055 $\sim$ 0.025	1301.41(15)
138.299(9) 2.95(11)	138.30(15)[a] 2.0(5)	307.32(6)	571.929(21) 0.551(20)	571.8(2) 0.5(1)	817.57(12)	*no*	1096 0.025(5)	1096.8(6)
141.365(3) 51.7(5)	141.411(11) 53(2)	245.734(12)	603.63(7) 0.259(17)	603.8(2) 0.3(1)	911.11(19)	1132.54(21) 0.053(15)	1132 0.05(1)	1301.41(15)
167.188(16) 0.984(17)	167.16(6)[a] 1.0(2)	245.734(12)	631.17(4) 0.502(17)	631.2(2) 0.46(12)	876.94(20)	1159.42(5) 0.38(3)	1159.7(3) 0.35(7)	1263.60(25)
169.054(15) 1.074(18)	169.1(3) 1.0(3)	169.00(12)	648.66(4) 0.290(11)	648.6(2) 0.20(5)	817.57(12)	1172.07(26)[np] 0.063(22)	1174.5(15)[np,a] 0.04(1)	
178.02(20) 0.083(12)	178.3(5)[c] 0.05(1)	1101.9(3)	664.267(7) 2.062(20)	664.00(16) 1.6(2)	768.23(9)	1197.07(9) 0.151(12)	1197.7(4) 0.15(3)	1301.41(15)
no	183.4(5)[c] 0.05(1)	1106.83(22)	*no*	665(1) 0.15(4)	911.11(19)	1206.79(13)[np] 0.081(8)	1207.8(10)[np] 0.04(1)	
195.66(6) 0.234(21)	195.7(4) 0.23(5)	1106.83(22)	677.37(5) 0.236(20)	677.2(3) 0.18(5)	923.17(24)	1222.935(24) 0.675(15)	1223.0(3) 0.60(6)	1301.41(15)
203.075(10) 1.60(3)	203.1(2) 1.0(1)	307.32(6)	712.20(9) 0.136(21)	713.4(8) 0.16(4)	817.57(12)	1262.83(23) 0.055(10)	1262.4(5) 0.06(2)	1263.60(25)
205.72(3)[np] 0.651(20)	*no*		*no*	758.0(15)[np,a] 0.09(5)		1301.509(8) 2.430(22)	1301.2(2) 2.1(2)	1301.41(15)
no	220.1(6)[c] 0.056(14)	1096.8(6)	767.53(3) 0.294(12)	768.4(4) 0.15(3)	768.23(9)	-	-	-

TABLE I: Energy and relative intensity of γ-rays from the beta decay of ^{155}Sm.
[+] Intensities were normalized at 245keV;
[*or*] Out of energy range;
[*no*] Not observed;
[*np*] γ ray not placed in level scheme;
[*a*] From Widemann *et al.* [1];
[*b*] From Funke *et al.* [2];
[*c*] Observed only in γ-γ coincidence measurement;
[*x*] Contaminated by X-ray.

Energy Level keV (Iπ)	Log *ft* Present work	I_β Present work	I_β NDS [11]
1301 (5/2-)	6.1	0.1251(14)	0.109
1264 (3/2-,5/2-)	7.1	0.0173(13)	0.016
1107(1/2-,3/2,5/2)	7.3	0.0325(17)	0.030
1102 (3/2-)	7.4	0.0313(15)	0.023
1097 (3/2+,5/2+)	-	-	0.0030
923 (1/2+)	8.7	0.0038(11)	0.0039
911(3/2+)	8.4	0.0082(18)	0.010
877 (1/2+)	8.3	0.0132(14)	0.015
818 (5/2-)	7.7	0.0675(16)	0.058
768(3/2-)	7.0	0.3487(22)	0.280
307 (5/2+)	7.0	1.87(8)	2.17
246 (3/2+)	6.7	4.32(9)	4.27
104 (5/2-)	5.6	89.2(9)	92.8
78 (7/2+)	7.5	1.186(23)	-
0 (5/2+)	≥7.2	≤2.8	≤1

TABLE II: Branching ratios and log*ft* values for the β^- decay of ^{155}Sm.

The existence of a new transition at 224.8keV, observed in our singles spectra, was confirmed by the 631keV gate in the coincidence data shown in Fig. 4; according to these relationships it could be placed depopulating the level at 1102keV. This arrangement agrees with measurements of thermal neutron capture, performed by Prokofjev *et al.* [13], which suggest that this γ-ray is part of a triplet, composed by transitions with 224.8 (1102-876), 226.2 (not placed in the scheme) and 228.8 (307-78)keV. Our singles and coincidence data clearly shows the photopeaks at 224.8 and 228.8keV, confirming the placement of them, but evidences suggesting the presence of 226.2keV in this beta decay study was not found neither in single nor coincidence measurements. As for the transition at 205.7keV, also observed for the first time in this study, we could not identify any coincidence data but according to the half-life analysis (see Fig. 5) it could belong to the ^{155}Sm decay; it should be noted that the slight decrease on the ratio of the half-lives ($C_{\gamma,205}/C_{\gamma,169}$) can be attributed to scattering effects which are very abundant in the neighborhood of the 205keV region.

IV. CONCLUSIONS

As described above, several experiments have been performed to study the nuclear structure of ^{155}Eu isotope, mainly by nuclear reactions [11], but particularly on the beta decay of ^{155}Sm, only the one performed by Ungrin *et al.* [3] des-

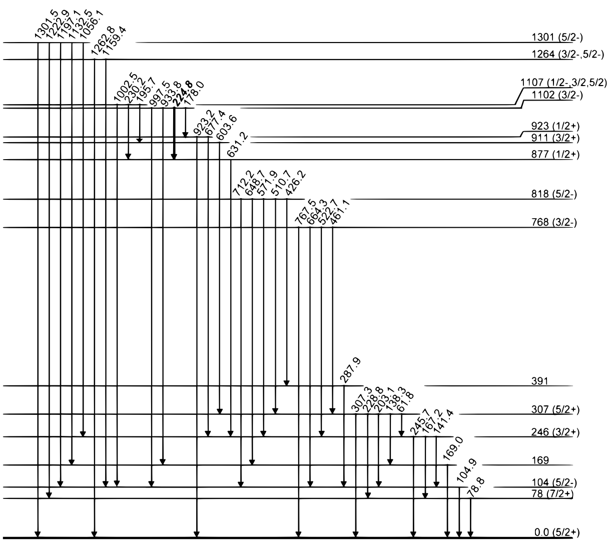

FIG. 1: Proposed level scheme for the ^{155}Sm β^- decay; the strong line shows the newly-found transition at 224.8keV.

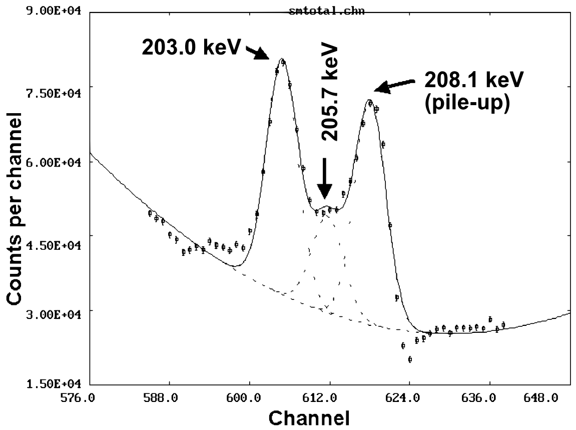

FIG. 2: IDEFIX [8] fit for the triplet at 203.1, 205.7 and 208.1keV

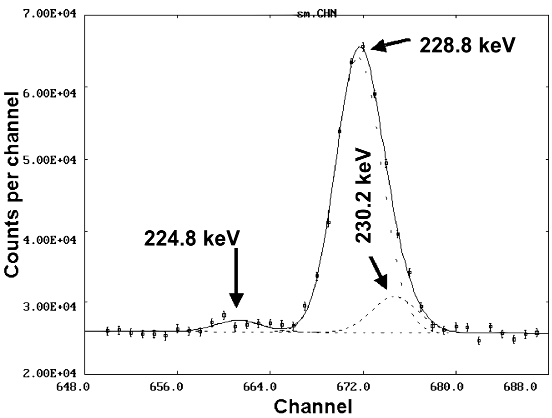

FIG. 3: IDEFIX [8] fit for 224.8, 228.8 and 230.2keV peaks.

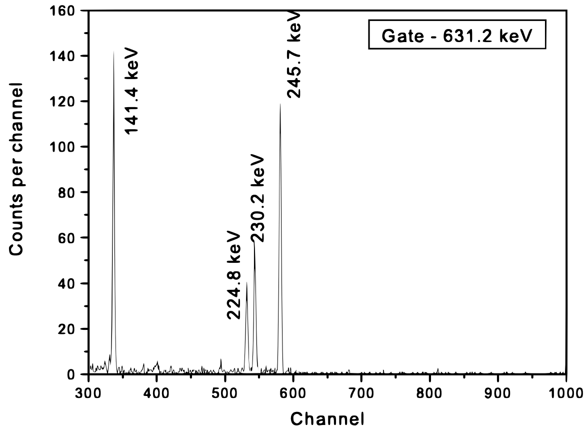

FIG. 4: Coincidence spectra of the transition at 631.2keV.

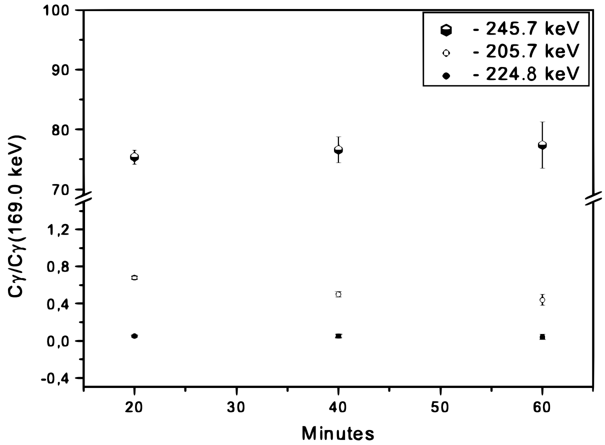

FIG. 5: Scatter plot of Cγ/Cγ(169.0keV) ratio as a function of the half-life associated to β^- decay of ^{155}Sm.

cribes the majority of the nuclear parameters associated to this decay, including, energy, intensity and placement of the γ-transitions as well as beta branching ratios and the spin associated to the excited levels. To check and confirm some of these nuclear properties, at low lying energy levels, in the present experiment the level structure of ^{155}Eu was investigated using γ-rays emitted following the β^- decay of ^{155}Sm. On the basis of the present results the energies and intensities of the γ-transitions have been determined with better overall precision than previously. A total of 42 γ-transitions have been observed, 2 of them were measured for the first time, 40 have been confirmed and 39 placed depopulating 16 excited levels, in the range 0.5-1.6MeV, however several transitions previously attributed to this decay scheme were not confirmed. In addition, spin and parity assignments for the levels at 246keV ($3/2^+$), 307keV ($5/2^+$), 768keV ($3/2^-$), 818keV ($5/2^-$), 877keV ($1/2^+$), 911keV ($3/2^+$), 923keV ($1/2^+$), 1102keV ($3/2^-$) and 1301keV ($5/2^-$) were confirmed.

Acknowledgments

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