Population of the 283 keV level of ^{137}Ba by the β decay of ^{137}Cs

I. Bikit,[1] I. Aničin,[2,3] J. Slivka,[1] M. Krmar,[1] J. Puzović,[3] and Lj. Čonkić[1]
[1]*Institute of Physics, University of Novi Sad, Novi Sad, Yugoslavia*
[2]*Institute of Nuclear Sciences, "Vinča," Vinča, Belgrade, Yugoslavia*
[3]*Faculty of Physics, University of Belgrade, Belgrade, Yugoslavia*

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The gamma spectrum of ^{137}Cs was measured by means of a low-level shielded and Compton-suppressed HpGe spectrometer. The gamma line with the energy 283.4 keV and absolute intensity of $5.3(14)\times10^{-6}$ was found. It was concluded that the 283.4 keV intermediate level in ^{137}Ba [seen earlier in $(n,n'\gamma)$ measurements] is populated in the β decay of ^{137}Cs with the comparative half-life of $\log ft=15.3(3)$. [S0556-2813(96)01912-7]

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The $7/2^+$, $T_{1/2}=30.5$ y ground state of ^{137}Cs has a very simple decay scheme (Fig. 1). Most of its β decay (95%) feeds [1] the 2.6 min, $11/2^-$ 661.6 keV metastable level of ^{137}Ba which in turn decays to the $3/2^-$ ground state by the slow $M4$ transition. The rest of the β decay feeds this ground state directly. Being the most abundant fission product this isotope is the notorious and ubiquitous herald of nuclear accidents and due to the convenient γ-ray energy and long half-life it is at the same time one of the most frequently used calibration sources in γ-ray spectroscopy. Despite all this, however, a certain controversy about this simplest of level schemes has persisted for quite some time now [2].

In the studies of charged-particle-induced nuclear reactions [3], neutron capture [4], and Coulomb excitation [5] it is established that in ^{137}Ba there exists another excited state at 279.2 keV with spin and parity $1/2^+$. In the studies of the $(n,n'\gamma)$ reaction, however, the energy of this first excited state is found to be 283.4 keV [6–8]. Such a large discrepancy can hardly be ascribed to the poor detector resolution or to energy miscalibration. Whatever the case may be, this level might potentially be fed in the decay of ^{137}Cs either by the 382.4 keV (or 378.2 keV) $E5$ transition from the 661.6 keV state or by the $Q=855$ keV (or 851 keV), $\Delta I=3$, $\Delta\pi=$no second forbidden Gamow-Teller β transition from the ^{137}Cs ground state. According to the single-particle estimate, which satisfactorily reproduces the half-life of the 661.6 keV state, the 382–661.6 keV branching ratio should be of the order of 10^6 while the systematics of $\log ft$ values suggests that the β feeding of the 279 keV level should be hindered only by a factor of about 500 relative to the main decay mode. Nevertheless, an earlier direct low-background γ-spectroscopy measurement [9] failed to detect the 279.2 keV radiation, yielding an upper limit for its absolute intensity of 2×10^{-5} and the $\log ft$ value for the β-decay feeding this level greater than 14.9, far beyond the value expected for this type of transition.

We thus decided to make use of our passively shielded and Compton-suppressed HpGe spectrometer to study the existence of this radiation in the decay of ^{137}Cs with higher sensitivity than before and hopefully settle this matter.

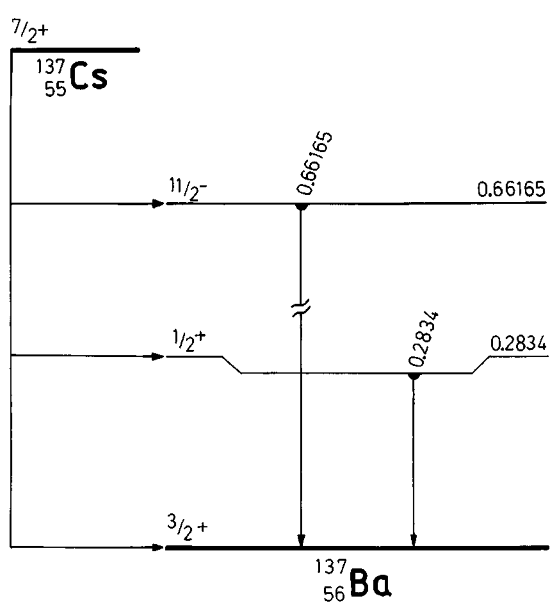

FIG. 1. Decay scheme of ^{137}Cs. The level at 283.4 keV is confirmed by our measurement. The intensity of the 283.4 keV transition and the $\log ft$ value of the β transition feeding this state is given as deduced here. The 279.2 and 378.2 keV transitions were not observed. Their maximum intensities are also estimated in this work.

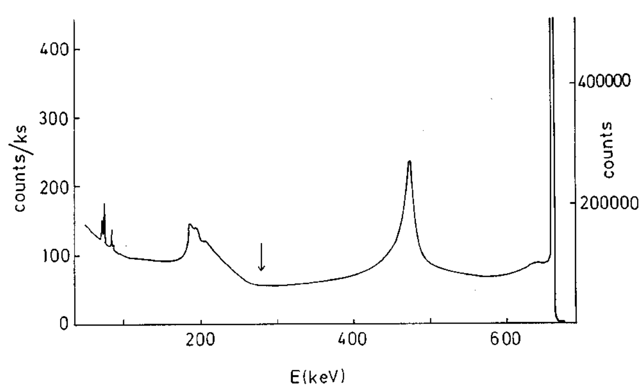

FIG. 2. The overall view of the Compton-suppressed HpGe spectrum of ^{137}Cs. The position of the would-be line at around 280 keV is marked by an arrow. The height of the 661.6 keV line is about 900 times the height in this region.

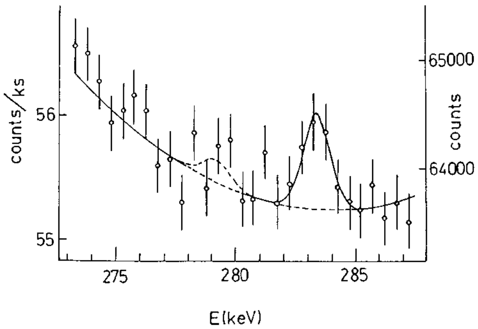

FIG. 3. The portion of the spectrum around 280 keV in expanded view. The line at 279.2 keV is force fitted at that position and is seen to be statistically insignificant while the line at 283.4 keV has an intensity of four times over its error at 68% C.L.

The radiation from the 7.2(3) μCi point ^{137}Cs source is collimated by means of the 5 cm long and 1 cm hole lead collimator with the source-to-detector distance equal to 17 cm. In this way only the front surface of the HpGe ''Canberra'' closed-end coaxial 25% efficiency detector was exposed to the γ rays. The detection efficiency for the supposed energy of 280 keV under these conditions was determined from the intensity of the 276 keV line from the measurement of the ^{133}Ba calibration source under the same conditions. This measurement, performed without the Compton suppression, yielded the value of $\epsilon=1.43\times10^{-3}$. The energy dependence of the efficiency was then determined by means of the point europium source. The 22.9 cm$\times$22.9 cm ''Bicron'' NaI(Tl) annular detector with 6 PM tubes with joined outputs surrounds the Ge detector. The whole detector assembly is placed inside the shielding chamber made of pre WWII iron with 25 cm thick walls. The Compton suppression of the Ge spectrum is realized by means of a fast coincidence-anticoincidence circuit.

The Compton-suppression spectrum, accumulated for 1.152×10^{6} s (Fig. 2) exhibits two pronounced maxima which correspond to the two backscattering directions defined by the collimator while the region of interest, around 280 keV, lies conveniently at the bottom of the valley between them. The 661.6 keV full absorption peak is about 900 times higher than the count per channel in the region of interest. It is interesting that, in spite of the heavy shielding, the lines of the background spectrum have statistically significant intensities (these are not seen in the figure due to the compressed scale). This clearly demonstrates that the passive shielding around the Compton suppressor is mandatory in this kind of work. Fortunately, in the region of interest, there are no known background lines.

TABLE I. The measured and estimated maximum absolute γ intensities per decay for the observed and unobserved transitions in the decay of ^{137}Cs.

E_γ (keV)	$p_\gamma\times10^{6}$
279.2	<2.6
283.4	5.3(14)
378.1	<3.4

The part of the spectrum around 280 keV is presented in expanded form in Fig. 3. The line at 279.2 keV is drawn by a forced fit at that position and is found not to be statistically significant while the one at 283.4 keV is found by the automatic peak search routine with an intensity of 2.0(5) counts per ks at the 68% C.L. The corresponding absolute intensity per decay is $5.3(14)\times10^{-6}$ and it is listed in Table I together with the limiting intensities for all the nonobserved possible transitions in ^{137}Ba. Supposing that the 283.4 keV level is fed by direct β decay only and using the value log $ft=1.3$ our measurement yields log $ft=15.5(3)$ for the second forbidden GT transition to this state. This is among the highest values for the transitions of this type that certainly has to do with the fact that in this particular transition the strong $N=82$ magic number is being destroyed. This structure effect becomes even more convincing when this case is compared to the same type of transition with a Q value of 663 keV in the decay of ^{60}Co for which log ft is only 12.7 and in which the $Z=28$ is being completed.

To conclude, we have found a gamma transition of 283.4 keV in the decay of ^{137}Cs with an intensity of $5.3(14)\times10^{-6}$ per decay. This transition most probably depopulates the first $1/2^{+}$ excited state in ^{137}Ba of the same energy and is thus of the $M1$ type. Stimulated by our result, recently the old measurements of Bondarenko *et al.* [6] were repeated [10]. In $^{\mathrm{nat}}$Ba$(n,n'\gamma)$ measurements with accelerator-produced nearly monoenergetic 1 MeV neutrons the γ ray of 279.2 keV was not observed, but the 283.4 keV line was the strongest in the spectrum. The 279.2 keV γ ray could not be observed even at higher neutron energies. Why the energy of this state, as found in a number of reaction studies, turns out to be 279.2 keV remains a mystery. Assuming that this state is directly fed by the β decay of the ^{137}Cs ground state we obtain log $ft=15.5(3)$ for this second forbidden GT transition. If it is also additionally populated by the gamma decay of the 661.6 keV state, for which we find that the intensity is smaller than 3.4×10^{-6}, this extremely high ft value would only get higher. Such a high hindrance is obviously due to strong structure effects in this decay.

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