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Weak gamma rays observed in the ^{60}Co decay*

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The intensities and energies of the 346.93-, 826.28-, and 2158.77-keV transitions, and intensity limits for the 467.4- and 1293.7-keV transitions in the decay of ^{60}Co were measured using a new improved Compton suppression spectrometer. The spectrometer yields a maximum Compton continuum suppression of 28 and a peak-to-minimum Compton ratio of 550/1 for the 1332.5-keV transition of ^{60}Co.

[RADIOACTIVITY ^{60}Co [from ^{59}Co (n,γ)]; measured E_γ, I_γ; deduced log*ft*. ^{60}Ni deduced energy levels. Compton suppression spectrometer.]

I. INTRODUCTION

We studied and reported the decay of ^{60}Co to the excited states in ^{60}Ni several years ago.[1] A γ-ray transition between the 4+ and 2+ excited states at 2505.7 and 2158.8 keV in ^{60}Ni would correspond to a so called "zero-phonon" transition. We did in fact observe the 346.9-keV γ ray that corresponds to this transition. In addition, we were able to observe with much poorer statistics the 826.3-keV γ-ray transition from the 2+ excited state at 2158.8 keV to the 1332.5-keV 2+ excited state. No effort was made at that time to observe the 2158.8-keV crossover transition to the ground state.

This restudy of the decay of ^{60}Co reduces the uncertainties in intensity and energy for the 346.9-, 826.3-, and 2158.8-keV γ-ray transitions and establishes intensity limits for the 467.4- and 1293.7-keV transitions. From these intensities and limits, new values for the β-branching ratios and log*ft* values are derived for two excited states in ^{60}Ni.

II. EXPERIMENT

The approximately 730-μCi ^{60}Co source used in this investigation was at least 8 yr old and was produced by the ^{59}Co(n,γ) reaction. A new Compton-suppression spectrometer was used to record the γ-ray spectrum of ^{60}Co. The spectrometer system incorporates a 31-mm-diam 14-mm-deep high-purity-germanium (HPGe) detector located between two 34.3-cm-diam 17.8-cm-thick NaI(T1) detectors. The observed ^{60}Co compton distribution suppression reached a maximum of 28 at about 800 keV. This yields a 1332.5-keV peak height to a minimum Compton continuum ratio of about 550/1 at 1.9 keV full width at half maximum. The efficiency of the HPGe detector was determined experimentally using a ^{210}Bi source whose γ-ray intensities were established on three separate well-calibrated Ge(Li) detector systems.[2] Further details of the new Compton-suppression spectrometer will be published elsewhere.[3]

Three spectra of ^{60}Co were taken with an 8192-channel analog-to-digital converter (ADC). Two spectra (3.7- and 6.9-day, respectively) consisted of 4096 channels of singles and 4096 channels of suppressed data (0–1.4 MeV) taken simultaneously; the third (a 10-day spectrum) was suppressed data only from 0 to 2.8 MeV over 8192 channels.

III. RESULTS

The 10-day low-count-rate Compton-suppressed spectrum of ^{60}Co is shown in two halves in Fig. 1. Two regions of the spectrum are expanded in the insets. The lower-left inset shows the 346.93-keV γ ray, and the upper-right inset shows the 826.28-keV γ ray together with the single-escape peak of the 1332.5-keV γ ray at 821.48 keV. The 821.48-keV peak intensity was observed to change dramatically in the three spectra that were accumulated under differing geometry and count-rate conditions. Since suppression of the Compton continuum and the single-escape-peak intensity depend slightly on count rate, the 821.48-keV peak is established as the single-escape peak of the 1332.5-keV transition (see Ref. 4 for discussion concerning this peak). Thus the single-escape peak serves as an energy calibration for the 826.28-keV γ ray. Better continuum and escape-peak suppression in this new Compton-suppression system make it impossible to observe the 1332.5-keV double-escape peak and difficult to observe the single-escape peak at low count rates.

The high-energy half of the ^{60}Co spectrum shown

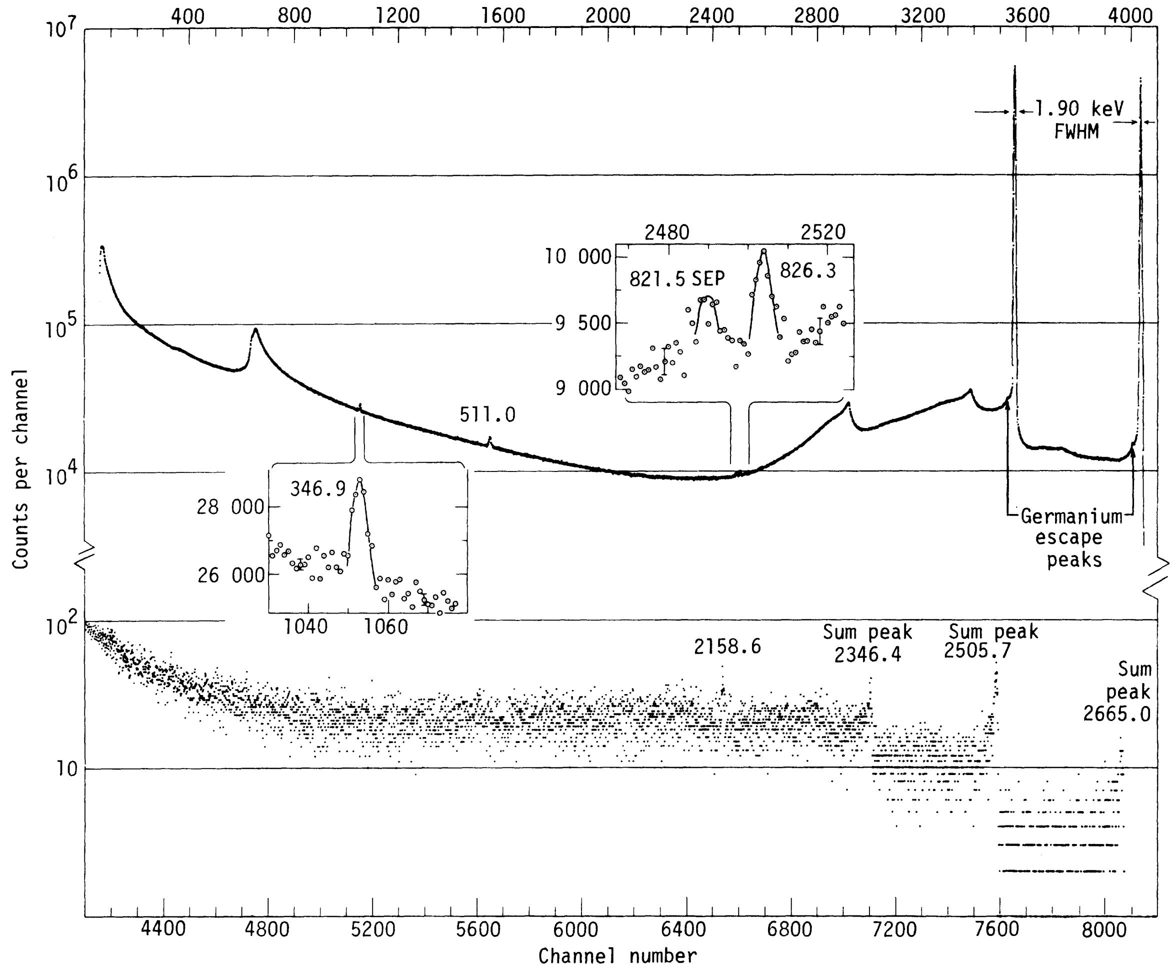

FIG. 1. An 8192-channel 10-day Compton-suppressed γ-ray spectrum of the ^{60}Co decay. The top half shows the 0- to 1.4-MeV portion and the lower half shows the 1.4- to 2.8-MeV portion. The two insets show expanded linear plots of the 347- and 826-keV spectral regions.

TABLE I. ^{60}Co γ-ray energies and intensities.

E_γ (keV)	$I_\gamma \pm \Delta I_\gamma$ (10-day run)	$I_\gamma \pm \Delta I_\gamma$ (all runs combined)
346.93 ±0.07	76.5±6.0	75.8±5.0
467.4 [a]	1.8±6.2	≤2.3, (−5.9±4.1)
826.28 ±0.09 [b]	73.0±10.6	76.2±8.0
1173.216±0.021 [c]	$\equiv 10^6$	$\equiv 10^6$
1293.7 [a]	(−13±24)	≤1.1 [d]
1332.486±0.022 [c]	10^6+	10^6+
2158.77 ±0.09 [e]	11.1±1.8	11.1±1.8 (observed only in 10-day run)

[a] Transition energy deduced from excited-state energy differences.

[b] Weighted average obtained from the present data and our earlier data (Ref. 1) modified via the energies derived in footnote c.

[c] Weighted average using values reported in Refs. 5 and 6.

[d] This intensity limit follows from a 2σ limit of ≤2.3 limit for the 467.4-keV transition and the relative intensities reported in Ref. 7. Our combined data establishes only a limit of 5±18 for the 1293.7-keV γ-ray intensity.

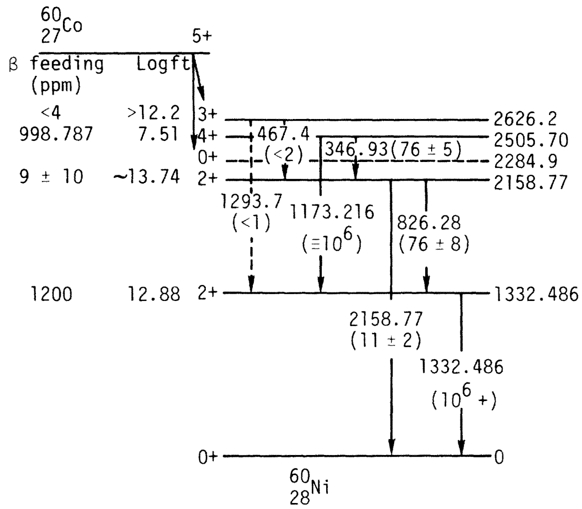

FIG. 2. The decay scheme of ^{60}Co showing results from this work and other references (see text and Table I).

in Fig. 1 includes the 2158.8-keV γ-ray transition. The intensities of the two sum peaks at 2346.4 and 2665.0 keV are consistent with the solid angle employed and the detector efficiencies determined. The intensity of the 2505.7-keV peak is consistent with random sums plus real 0° correlation coincidences between the 1173- and 1332-keV transitions. These sum-peak intensities demonstrate that there is a negligible sum contribution to the observed 2158-keV transition intensity.

In addition to the 10-day-run data shown in Fig. 1, the other two Compton-suppression spectra were analyzed. Results of the γ-ray peak analysis of all three runs lead to the energies and intensities listed in Table I. The energies we adopt here for the 1173- and 1332-keV γ-ray transitions are the weighted averages of those values found in Refs. 5 and 6. The intensity of the 1173-keV γ ray has been defined as exactly 10^6. Intensity uncertainties (ΔI_γ) listed in Table I include statistical uncertainties in the peak areas, as well as a 2% uncertainty established for the efficiency curve. Our measured ratio of the 826/2158-keV transition intensities (6.9 ± 1.3) agrees with that reported by Rauch, Van Patter, and Hinrichsen (6.5 ± 0.5),[7] who studied the ^{60}Cu-to-^{60}Ni decay.

The decay scheme of ^{60}Co is shown in Fig. 2. The upper limit of 1.1 ppm on the 1293.7-keV γ ray is based on an upper limit of 2.3 ppm for the 467.4-keV γ ray. This limit was derived from all of our data and the observed 1293/467 intensity ratio in the ^{60}Cu decay.[7] The β-decay branching ratio to the 1332.5-keV excited state is adopted from Camp, Langer, and Smith.[8] It is virtually impossible to quantitate the β feeding of this state from measurements of the γ-ray intensities. To obtain a 10% error for this β-branch intensity, a precision of one part in 10 000 on the intensities of the 1173.2- and 1332.5-keV γ rays would be required. The log*ft* values listed were deduced using published tables[9] and 2823.62 keV as the $Q(\beta^-)$, and 5.26 yr for the half-life[6] of ^{60}Co.

To our knowledge no recent β-spectrum measurements have been made to verify the intensity of the $\Delta I = 3$, $\Delta\pi = $ no, 1491.14-keV β branch from ^{60}Co. It would be desirable to confirm the reported[8] 0.12% relative intensity for that branch.

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[1] J. R. Van Hise and D. C. Camp, Phys. Rev. Lett. 23, 1248 (1969).

[2] R. Gunnink and J. B. Niday, Lawrence-Livermore Laboratory Report No. UCRL-76699, 1975 (unpublished).

[3] D. C. Camp, in Proceedings of an ERDA Symposium on X- and Gamma-Ray Sources and Applications, Ann Arbor, Michigan, 19-21 May 1976 (unpublished).

[4] S. Raman, Z. Phys. 228, 387 (1969); H. H. Hansen and A. Spernol, *ibid.* 209, 111 (1968).

[5] R. L. Heath, Aerojet Nuclear Company Report No. ANCR-1000-2, 1974 (unpublished), Vol. 2.

[6] H. J. Kim, Nucl. Data Sheets 16, 317 (1975).

[7] F. Rauch, D. M. Van Patter, and P. F. Hinrichsen, Nucl. Phys. A124, 145 (1969).

[8] D. C. Camp, L. M. Langer, and D. R. Smith, Phys. Rev. 123, 241 (1961).

[9] N. B. Gove and M. J. Martin, Nucl. Data A10, 205 (1971).