PHYSICAL REVIEW C VOLUME 26, NUMBER 6 DECEMBER 1982

Inner bremsstrahlung spectrum of ^{90}Sr and ^{90}Y in equilibrium

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(Received 1 July 1982)

The shape of the inner bremsstrahlung spectrum accompanying the β decay of ^{90}Y was previously reported by Narayana *et al.* as being very anomalous. We have remeasured this spectrum using a source of ^{90}Sr in secular equilibrium with ^{90}Y. The instrumentally distorted spectrum was predicted using the formulas of Ford and Martin in conjunction with a detailed Monte Carlo calculation of the detector response. The spectrometer was a low-background, well collimated 7.62 cm by 7.62 cm NaI(Tl) detector, shielded by lead. The geometry was chosen to minimize distortions due to external bremsstrahlung from stopping the β particles. The results are in good agreement with the theoretically calculated spectrum, with detour transitions, when the theoretical spectrum is convoluted with the calculated detector response function.

[RADIOACTIVITY ^{90}Sr, ^{90}Y: β decay: measured inner bremsstrahlung.]

Inner bremsstrahlung (IB) is a generic term for continuous photon spectra associated with radiative β decay. An exhaustive review of the theory of inner bremsstrahlung and related processes was published in 1976 by Erber, White, and Latal.[1] A general review of experimental and theoretical results appears in an earlier article by Persson.[2] In general, most of the measurements of IB spectra from allowed β decay agree with the theoretical predictions; however, a significant number of experimental IB spectra accompanying forbidden β decay have been reported which strongly deviate from theoretical predictions at the higher energy ends of the spectra. The theoretical treatment of Ford and Martin[3] includes detailed calculations of the Coulomb effects as well as those of virtual excitations of the nucleus called detour transitions. These calculations have been very successful in explaining much of the data associated with forbidden transitions. Some of the interesting decays having IB spectra with reported strong deviations from theory are ^{195}W (Refs. 4 and 5), ^{169}Er (Ref. 6), ^{90}Y (Ref. 7), ^{91}Y (Ref. 8), ^{143}Pr (Ref. 9), ^{36}Cl (Ref. 10), ^{137}Cs (Ref. 11), and ^{141}Ce (Ref. 12). Here we report the results of a new measurement of the IB spectrum from a source of ^{90}Y in secular equilibrium with the parent ^{90}Sr. The reason for using the ^{90}Sr source was to avoid the large corrections due to the 64 h half-life of ^{90}Y. Also the IB spectrum from ^{90}Sr is weak and has an endpoint energy of 540 keV while that of ^{90}Y has an endpoint energy of 2250 keV. The correction for short half-lives is straightforward; however, the long counting times required to observe a statistically significant number of photons above 1 MeV, makes the use of the long lived source more desirable.

The decay of interest is the unique first forbidden β decay from the 2^- ground state of ^{90}Y to the 0^+ ground state of ^{90}Zr. This branch has 99.8% of the total β decay strength. The IB spectrum from this decay was originally observed by Hakeem[13] to have only a small departure from that calculated by Ford and Martin,[3] but more recently a spectrum in violent disagreement with the theoretical spectrum of Ref. 3 was reported by Narayana *et al.*[7] The purpose of the present investigation was to attempt to resolve this large discrepancy using standard measurement techniques in which the response of the spectrometer is carefully studied with detailed Monte Carlo calculations.[14] A new method of normalization is used which avoids difficulties due to annihilation radiations which can result from pair production by IB photons of sufficient energy.

The spectrometer was a copy of that used by Hakeem[13] with the exception that the 7.62 cm by 7.62 cm NaI(Tl) used here was a special low background assembly with a 3.31 cm thick pure NaI light pipe to reduce background from the photomultiplier tube. The NaI(Tl) detector was placed, facing upward, inside of a vertical lead shield with the lead collimator located on top of an aluminum cylinder. The source was located 5 cm above a Lucite β stopper located at the entrance port of the collimator and 25 cm above the crystal. This geometry is discussed in Ref. 13 and was shown to minimize the external bremmstrahlung produced in the source and by stopping the β particles.[13] The total contribution to the photon spectrum due to external bremsstrahlung in this geometry is less than 3%, with virtually no contribution to the higher energy portion of the IB spectrum. The angle of the collimation was chosen so that no γ rays hit the shielding directly. This minimizes backscattering peaks which complicate the calculation of the response of the spectrometer.

The radioactive source of ^{90}Sr was obtained from the Amersham Corp. and made into sources of various strengths to observe possible external bremsstrahlung effects. None were observed, and therefore a strength of approximately 200 μCi was used to obtain statistics comparable to background statistics at 1500 keV photon energy. We acquired sources from several suppliers, and all appeared to have very weak contaminations which were evidenced by a weak γ-ray line at 0.511 MeV. The contamination in the Amersham source was by far the weakest but was still detectable in the IB spectrum taken with a large intrinsic Ge detector [30% efficiency of a 7.62 cm by 7.62 cm NaI(Tl) at 1.33 MeV]. The Ge detector was not used for the IB measurements reported here because the geometry of the active region is not as well known as that of the NaI(Tl) crystal, and this uncertainty reflects adversely on the accuracy of the Monte Carlo calculations of the response functions. In addition, the analysis given in Ref. 14 clearly shows that the spectral distortions of these two detectors are comparable, while the NaI(Tl) detector is more efficient at the higher energies. The pair production cross sections and approximate IB photon intensity above 1.022 MeV were used to estimate the number of annihilation photons which would be detected due to pair production in the surrounding material. It was concluded that an intensity comparable to that observed was possible, so that there may not be an actual contamination in the source. This effect is dependent on the materials present and on the geometry. The presence of the weak line at 0.511 MeV does not alter the conclusions because of our new method of normalization discussed in an earlier article.[14] In cases where there is any low energy contamination at all, the normalization of the theoretical spectrum to the experimental data points can give rise to major disagreements unless the contamination line and its continuum are known with high accuracy. The fact that the instrumentally distorted spectrum, calculated and distorted by Monte Carlo techniques, crosses the undistorted line at a known energy, greatly simplifies the normalization, and avoids potentially serious pitfalls.

The electronic system consisted of a preamplifier, linear amplifier, and Nuclear Data 66, 8192 channel analyzer. The linearity and stability were checked over a period of several months prior to collecting the final data reported here. Data were taken in 4 h runs followed by 4 h background runs. The data were background corrected and transferred to an alternate memory group for storage. An indication of the fact that this procedure is correct is the absence of bumps in the spectrum at energies corresponding to known background peaks.

The data were corrected for background by direct

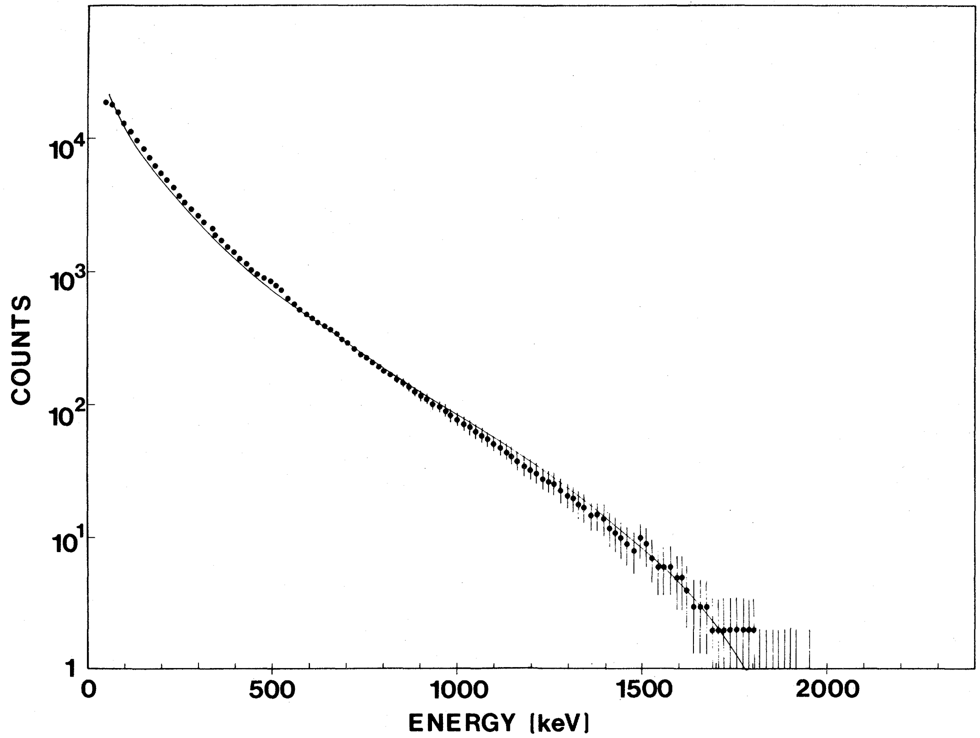

FIG. 1. Experimental inner bremsstrahlung spectrum data points compared to the Monte Carlo distorted, theoretical spectrum (solid lines) of Ref. 3.

subtraction, while corrections for the absorption due to the material between the source and the detector are included in the detector response function. Corrections for absorption were very small above 100 keV. The theoretical spectrum calculated with the formulas of Ford and Martin[3] was distorted using the Monte Carlo code described in Ref. 14. The resolution widths of the monochromatic γ-ray lines in the decays of ^{137}Cs and ^{60}Co were measured and used in the response calculations. It was clearly demonstrated in our previous work[14] that in the present geometry the theoretical spectrum and the response-distorted theoretical spectrum have a given crossover energy where they are the same. For this geometry, and the ^{90}Sr, ^{90}Y mixed IB spectrum, this point was found to be at 780 keV. The data points and normalized distorted theoretical spectrum are shown in Fig. 1. The error bars are a combination of the statistical fluctuations in the data and in the background. The spectra, normalized at the crossover point, appear to have the same general shape within experimental error; however, the data points between 1000 and 1300 keV are slightly but consistently below theory. This can easily be caused by a slight overestimate of the parameter weighting the detour effects in the theoretical treatment of Ref. 3. However, this slight disagreement is certainly not significant. Figure 2 shows a similar analysis of the data of Ref. 7 using the source-detector geometry of that experiment. As pointed out earlier,[14] the analysis used in Ref. 7 was erroneous because the methods of Lidén and Starfelt[15] are not valid for energies above 1.022 MeV. Furthermore, Monte Carlo techniques are more accurate and give significantly different response functions.[14] Our reanalysis, however, does not change the conclusions of Ref. 7, only the energy at which the serious departure between theory and experiment occurs. The present experiment does not support the conclusion that the inner bremsstrahlung spectrum of ^{90}Y is anomalous, and in fact it seems to be in good agreement with theory when a carefully calculated detector response is used in the analysis.

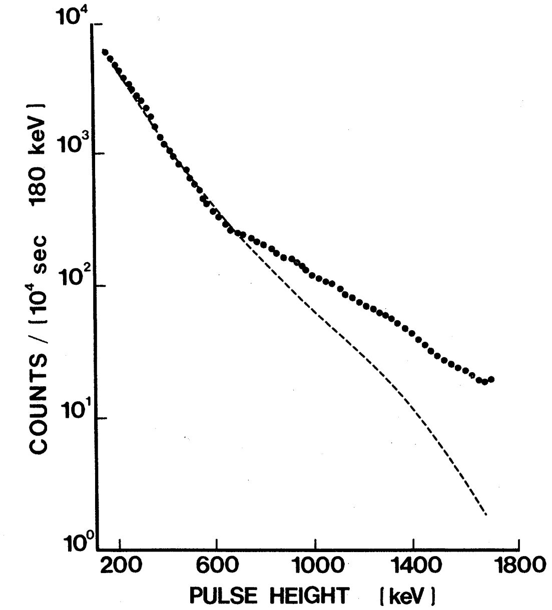

FIG. 2. The Monte Carlo distorted IB spectrum of ^{90}Y in a 5.08×5.08 cm^2 NaI(Tl) in the geometry of Ref. 7 (dashed line) compared to the experimental spectrum of Ref. 7 (dotted line) which was corrected for background only.

The authors are grateful to Shing-Yeo Yan for building the spectrometer and making the preliminary measurements. This work was partially supported by the National Science Foundation under Grant No. PHY 7824885.

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