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Z dependence of thick-target external bremsstrahlung produced by β particles of ^{90}Sr-^{90}Y

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External bremsstrahlung spectra produced in thick targets of copper, molybdenum, cadmium, iodine, and lead by β particles of ^{90}Sr-^{90}Y were measured using a 4.55-cm × 5.08-cm NaI(Tl) crystal. The conventional β-stopper method was followed. The measured spectra were unfolded according to the Liden and Starfelt procedure. The exponents of Z for energy yield and photon yield were found to be 1.20±0.02 and 1.26±0.02, respectively.

INTRODUCTION

The production of external bremsstrahlung (EB) in thick targets of different materials was studied by several authors[1–33] employing monoenergetic electrons as well as β particles. In the earlier measurements employing β particles the main thrust was to find the total intensity. In the later measurements the emphasis shifted to the study of spectral distribution. The variation of total intensity of EB produced by β particles with target thickness has also been studied.[24,34–38] Further, the dependence of the total EB intensity on atomic number (Z) of the absorber was investigated by several workers[5,6,10,24] and was found to be proportional to the atomic number. However, recent measurements of Subrahmanyam *et al.*[38] showed only limited linearity.

The total intensity I (energy yield) of thick target EB produced by β particles is given by Evans[39] as

$$I = KZE_{\text{rms}}^2 \text{ MeV}/\beta \text{ particle}, \tag{1}$$

where Z is the atomic number of the target material, E_{rms} is the root-mean-square energy of the β particle. The proportionality constant K is defined as the energy yield constant and has the dimensions of MeV^{-1}.

The above equation is arrived at by considering EB cross sections to be Z^2 dependent. However, the cross sections are not strictly Z^2 dependent.[40] Therefore it is expected that the linear relationship between I and Z is only approximate.[19,30] In the present measurement an attempt has been made to study the variation of the energy yield and photon yield as functions of atomic number of the target material.

EXPERIMENTAL DETAILS

Carrier-free liquid source of ^{90}Sr-^{90}Y was obtained from Bhabha Atomic Research Center, Bombay, India. ^{90}Sr and ^{90}Y in the source sample are in secular equilibrium and emit β particles belonging to two independent decay channels having end-point energies of 0.546 and 2.274 MeV, respectively. The source for the experiment was prepared by evaporating the solution drop by drop on a thin Mylar film (1.7 mg cm^{-2}) cemented to a Perspex ring of 3 cm diam and 2.5-mm wall thickness. Uniform spread was achieved by adding a few drops of dilute insulin to the source. The source strength was determined by absolute β-counting technique[41] and was found to be 1.4 mCi.

Figure 1 gives the details of experimental arrangement. A 4.55-cm × 5.08-cm NaI(Tl) crystal mounted on an RCA 8053 photomultiplier was coupled to a multichannel analyzer. The crystal was housed in a hollow lead

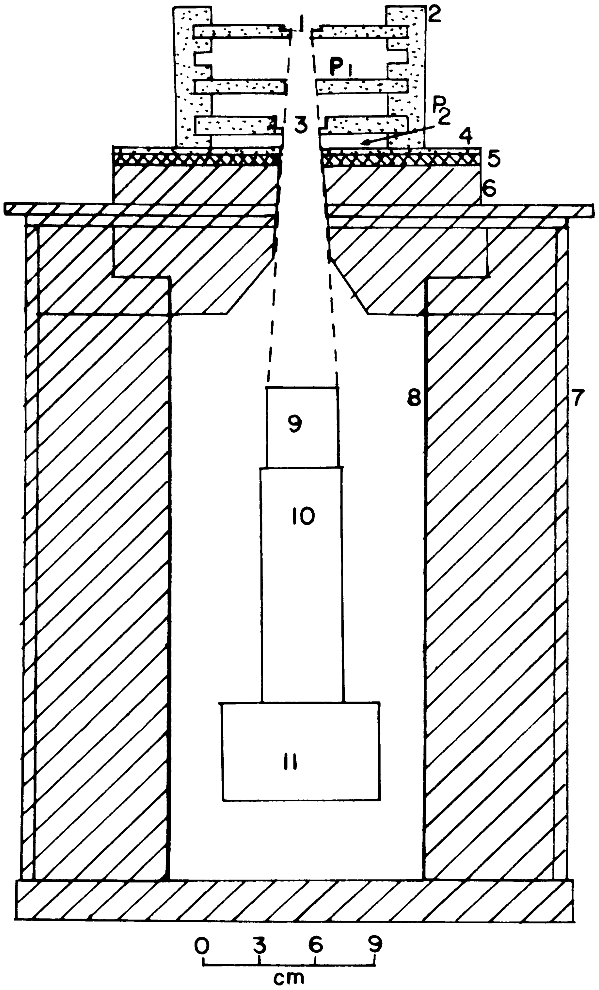

FIG. 1. Experimental setup: 1, source position; 2, Perspex stand; 3, target position; 4, Perspex sheet; 5, aluminum plate; 6, lead plate; 7, lead shielding; 8, aluminum lining; 9, NaI(Tl) crystal; 10, photomultiplier; and 11, preamplifier. P_1 and P_2 are positions of the β absorber.

chamber. The lead shielding was lined with aluminum inside. Targets of Cu, Mo, Cd, I, and Pb were prepared with thickness sufficient enough to stop all the β particles. With regard to iodine, it was taken in the form of fine powder filled in a Perspex planchet of 2 cm diameter and a depth of 2.2 mm. The source was placed at a distance of 21 cm above the face of the detector. The targets were placed in between the detector and the source. The geometry was carefully adjusted to see that the NaI(Tl) crystal was fully exposed to the EB emitted from the target. The spectrometer was calibrated using the following γ-ray lines: ^{170}Tm (84 keV), ^{57}Co (122 keV), ^{141}Ce (145 keV), ^{203}Hg (279 keV), ^{51}Cr (320 keV), ^{113}Sn (392 keV), ^{22}Na (511 keV, 1274 keV), ^{137}Cs (662 keV), ^{54}Mn (835 keV).

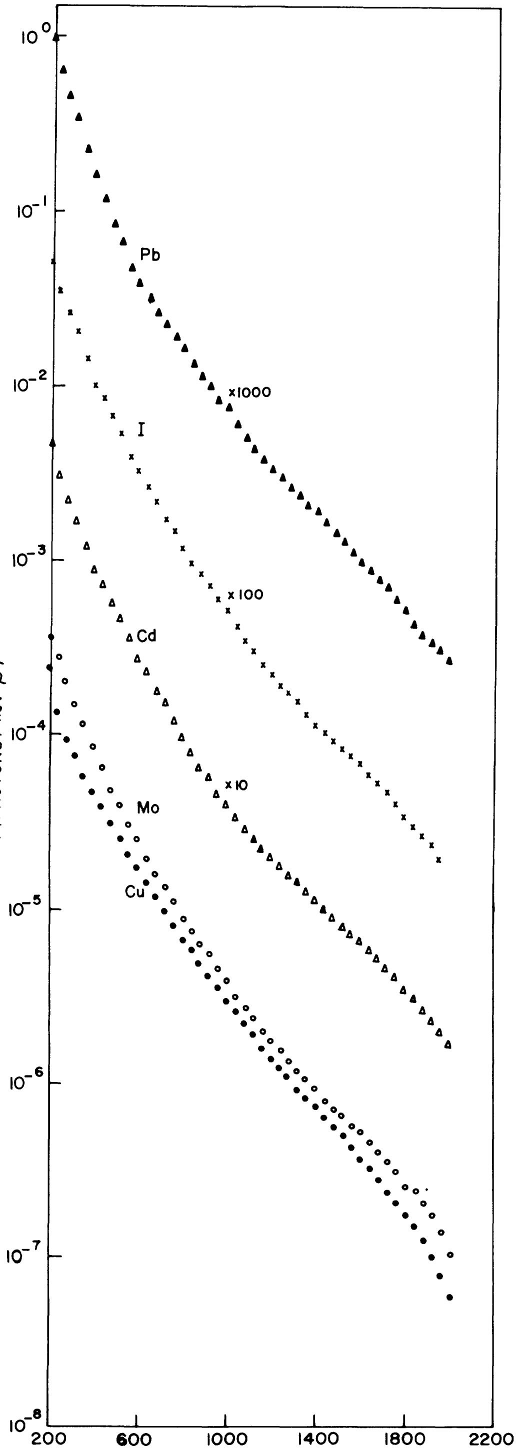

FIG. 2. Experimental EB spectra produced by ^{90}Sr-^{90}Y β particles in various materials: ●●●, copper; ○○○ molybdenum; △△△, cadmium; × × ×, iodine; ▲▲▲, lead.

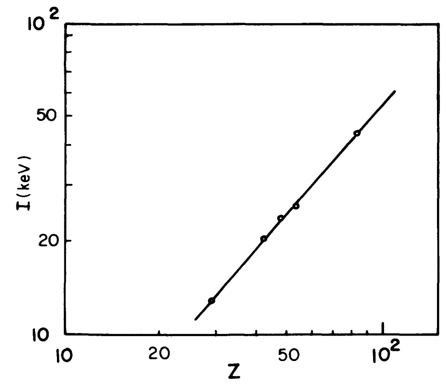

FIG. 3. A plot of $\log_{10} I$ vs $\log_{10} Z$.

A 12-mm-thick Perspex sheet was first placed on top of the target and with the source in position the spectrum was taken. The Perspex sheet was then placed below the target and the spectrum was recorded for the same time. The difference in the two spectra gives the raw EB spectrum. Data were accumulated each time for ten hours. From several sets of data collected, the average of six sets of consistent data in the energy region $k_{\min} = 200$ keV to $k_{\max} = 2000$ keV were used for the final analysis.

DATA ANALYSIS

The observed pulse-height distribution is the original photon spectrum folded by the response function of the detector system. Therefore, to get the true spectrum, the observed pulse-height distribution should be unfolded.

In the present investigation, the method of Liden and

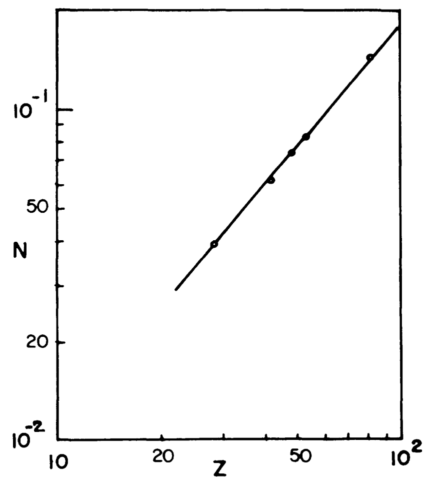

FIG. 4. A plot of $\log_{10} N$ vs $\log_{10} Z$.

TABLE I. Energy yield and photon yield constants.

Electron energy MeV	Energy yield ($K\times10^{-3}$) MeV^{-1}	Photon yield ($K'\times10^{-3}$) MeV^{-1}	Reference
1.3 to 2.3	0.4		14
^{90}Sr-^{90}Y β rays $E_{\max}=0.546$, 2.274	0.34	0.24	24
^{90}Y β rays $E_{\max}=2.274$	0.5	0.41	24
^{90}Sr-^{90}Y β rays $E_{\max}=0.546$, 2.274	(0.18 ± 0.01)	(0.50 ± 0.01)	Present

Starfelt[42] has been adopted for unfolding the spectra. The observed pulse-height distribution is corrected for finite-energy resolution, Compton electron contribution, iodine K x-ray escape peak, etc. The correction for the geometric and the γ-detection efficiency has been arrived at as follows: The efficiency of the detector for the present geometry has been obtained by numerical integration of the expression given by Wolicki *et al.*[43] This is multiplied by the extended-geometry factor and then divided by the point-source—geometry factor to get the geometrical detection efficiency. It is assumed that the emitted EB spectrum is due to an almost isotropic distribution of β particles within the target material.[44,45] The corrected EB distribution is divided by both geometrical detection efficiency and peak-to-total ratio to get the true photon spectrum. Correction is also applied for the absorption in the target material, Perspex β stopper and the aluminum can.

ERRORS

The main contribution to the error in the measured spectra comes from the counting statistics. This error is less than 2% up to 600 keV, less than 8% from 600—1000 keV, less than 12% up to 1500 keV, less than 16% up to 1800 keV and reaches 21% at 2000 keV. The other contribution to the error comes from the Compton electron distribution which varies from 1% at 200 keV to about 3% at 2000 keV. The error involved in the estimation of crystal detection efficiency is partly due to the uncertainty in the values of the absorption coefficients for sodium-iodide and partly due to the inaccuracy in the experimental determination of peak-to-total ratios. The error in the values of the crystal detection efficiency varies from 1% at 200 keV to about 6% at 2000 keV. Errors due to correction for absorption in the Perspex β stopper, aluminum can, and targets do not exceed 2% throughout the investigated energy region. The error in the determination of source strength was found to be 8%. The overall error in the present measurement is found to vary from 9% at 200 keV to about 24% at 2000 keV.

RESULTS AND DISCUSSION

The unfolded EB spectra $S(k)$ expressed as number of photons per keV per β for targets of Cu, Mo, Cd, I, and Pb are shown in Fig. 2. The total intensity I of EB produced in different target materials is evaluated from the measured spectrum using the relation

$$I=\int_{k_{\min}}^{k_{\max}} kS(k)dk\ . \tag{2}$$

Here k is the photon energy. One can also calculate N, the photon yield by using the relation

$$N=\int_{k_{\min}}^{k_{\max}} S(k)dk\ . \tag{3}$$

Following Evans one can write

$$N=K'ZE_{\mathrm{rms}}\ . \tag{4}$$

The proportionality constant K' is defined as the photon yield constant and has dimensions of MeV^{-1}. Plots of $\log_{10}I$ vs $\log_{10}Z$ and $\log_{10}N$ vs $\log_{10}Z$ are shown in Fig. 3 and Fig. 4, respectively. The slopes, the intercepts, and the errors on them were estimated by the method of least squares. Figures 3 and 4 give the exponents of Z to be 1.20 ± 0.02 and 1.26 ± 0.02, respectively, showing that the dependence of I and N on Z is nonlinear. The yield constants K and K' were obtained from the intercepts in Figs. 3 and 4. They are found to be $(0.18\pm0.01)\times10^{-3}$ and $(0.50\pm0.01)\times10^{-3}\ \mathrm{MeV}^{-1}$, respectively. These values are compared with the values obtained by other authors in Table I. It can be seen from Table I that the present value of the energy yield constant is considerably lower than the values obtained by earlier workers. The photon yield constant is found to be higher than the earlier measurements. The observed discrepancy between the present values and the earlier ones might partly be due to the observation of an apparent linear dependence of I and N on Z by the earlier workers. Further, it might also partly be due to the difference between the geometry of the present work and that of the earlier measurements. However, the present value of the energy yield constant is within the range of values quoted by Bustard and Silverman.[24] The fraction of β-ray energy which appears as EB, i.e., I/E_{av}, where E_{av} is the average β-ray energy, was calculated in the investigated energy region. It was found to be 1.23% for copper, 1.95% for molybdenum, 2.26% for cadmium, 2.54% for iodine, and 4.20% for lead.

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