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TITLE: ENERGY RESPONSE AND DOSE-RATE CALIBRATION OF A GEIGER-MULLER GAMMA-RAY DETECTOR

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ENERGY RESPONSE AND DOSE-RATE CALIBRATION OF A GEIGER-MULLER GAMMA-RAY DETECTOR

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ABSTRACT

By determining the response of a Geiger-Müller detector to gamma rays with energies from 0.060 to 2.6 MeV, we are able to provide source-specific calibrations for precise dose-rate measurements.

INTRODUCTION

The calibration of a commercial gamma-ray dosimeter that uses a Geiger-Müller (GM) tube as its detector is usually accomplished by adjusting its response relative to standard radioactive sources. The employment of such a dosimeter is quite adequate for routine radiation surveys. However, to obtain more precise dose-rate measurements, we have taken the GM tube from such an instrument and, by supplying it with an externally regulated high voltage, counted the gamma-ray-induced pulses with suitable scaling and timing circuits. Until recently, the system was calibrated by averaging the counting rates obtained with standard ^{137}Cs and ^{60}Co sources that produced known dose rates at the detector position. However, we know that this method is still imprecise for sources with extended gamma-ray spectra because the response of the GM tube varies significantly with energy and the calibration covers only a relatively limited energy region. We have now improved the method of calibration by measuring detector response to 13 different sources, each with an independently verified strength, in the energy range from 60 keV to 2.6 MeV. With the use of computer codes, the resulting response curve can be folded into the spectrum of the source to be measured. This spectrum must be known, at least in a general way, to obtain a new source-specific calibration for the detector. The method is especially applicable when we must determine dose rates for many unknown sources that have similar spectra but differing radiation strengths.

EXPERIMENTAL METHOD

Our GM detector, which is from an Eberline E112B survey dosimeter, contains a Tracerlab type 1112 tube. We make all measurements with the shield window closed and facing away from the radiation source. This detector is connected (Figure 1) through a preamplifier to a regulated high-voltage power supply set to deliver 767 V. This voltage is centered in a

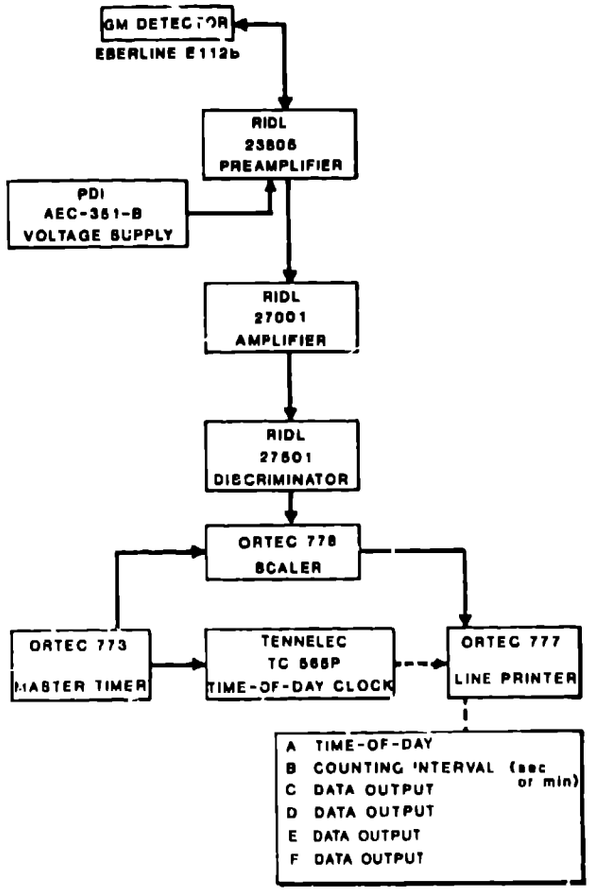

Figure 1. Automatic data collection system for the GM detector.

satisfactory counting plateau for the detector. The amplifier, discriminator, scaling, and timing modules allow automatic data collection. The gain is set so that the largest GM pulses are not distorted and the discriminator rejects all the extraneous noise pulses. Once adjusted, the settings are not changed for subsequent measurements.

We have constructed a track that stops the GM detector at a sequence of preselected distances from the source position. At each station, the observed gamma-ray pulses are recorded for a predetermined counting interval and then the detector moves to the next position.

TABLE 1. Point Sources Used for GM Detector Calibration

Isotope	Energy (MeV)	Half Life (yr)
^{241}Am	0.060	432.0
^{57}Co	0.122, 0.136	0.7437
^{139}Ce	0.166	0.3756
^{203}Hg	0.279	0.1280
^{51}Cr	0.320	0.0758
^{113}Sn	0.392	0.3050
^{7}Be	0.478	0.1459
^{85}Sr	0.514	0.1775
^{137}Cs	0.662	30.174
^{54}Mn	0.835	0.8548
^{65}Zn	1.116	0.6680
^{60}Co	1.173, 1.332	5.2719
^{228}Th	2.615	1.9131

Thirteen radioactive sources (Table 1) were used for the calibration. These "point" sources came with certified strengths from the manufacturers. However, for increased accuracy, we recalibrated 12 of them with a germanium detector against a mixed source from the National Bureau of Standards (NBS) for which most of the gamma-ray line strengths had uncertainties of less than 1%. The mixed source contained three isotopes--^{125}Sb, ^{154}Eu, and ^{155}Eu--with 18 prominent gamma rays spanning the energy range from 27 keV to 1.27 MeV. All of our point sources, except for the ^{228}Th, are covered in this span. Since the ^{228}Th source was obtained from the National

Bureau of Standards, there was no need to recalibrate it.

The measurements were performed in a large experimental area specifically designed for minimum room scatter. A thin, false floor over a 4-m-deep basement and low-density, nonreflecting walls and ceiling made this an ideal area for our purposes. This is important in data analysis since we can assume that the room-return is constant in the vicinity of our measurements. Because radiation decreases as the inverse square of the distance from a point source, we can write

$$r^2[C_r - (B + R)] = \text{constant} = S \ , \quad (1)$$

where C_r = observed counting rate at distance r,

B = background counting rate (constant),

R = room-return counting rate (assumed constant in the vicinity of the measurements), and

S = specific counting rate (at 1 m if r is in meters).

By rewriting this as

$$C_r r^2 = (B + R)r^2 + S \ , \quad (2)$$

one sees that a linear relation should be obtained when $C_r r^2$ is plotted against r^2. The linearity of the observed data plot indicates the validity of this constant room-scatter assumption. The slope of the resulting line is (B + R), the sum of the background and room-return counting rates, and the intercept is S, the counting rate at 1 m.

We wrote a program for the Hewlett Packard 9845B computer that makes a least squares linear fit to the data based on the observed counting rates at a sequence of distances from a given point source. Besides calculating the specific counting rate and the background and room-return total, the program also makes hard-copy plots to show the resulting fit to our assumptions.

RESULTS

As a typical example of our data-fitting scheme, we show the resulting plots (Figures 2 and 3) of the observed GM counting rates for the ^{113}Sn source. This source, with a relatively low strength and short half-life, is a good representative. Output plots for the other 12 sources generally show the same features. Data were taken at seven source-to-detector distances, from 0.11 to 2.11 m. Figure 2 is the least squares linear fit to Equation 2 and shows that our assumption of constant room-return is valid. The error bars represent the statistics of the counting data. Figure 3 is a log plot of the counting rates (both observed and corrected for background and room-return) versus source distance to show the inverse square relationship.

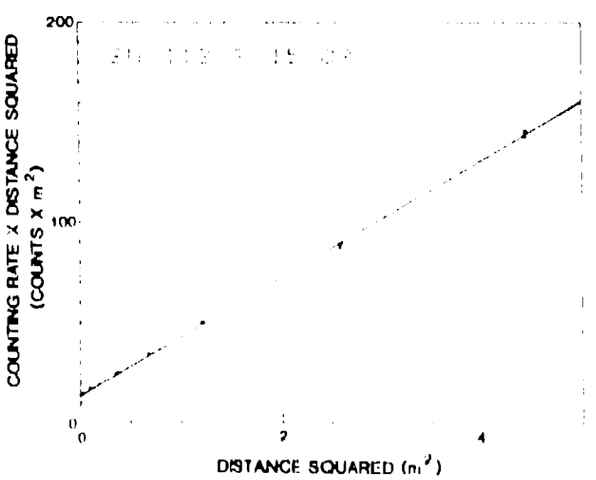

Figure 2. Computer plot of least squares linear fit for ^{113}Sn counting data.

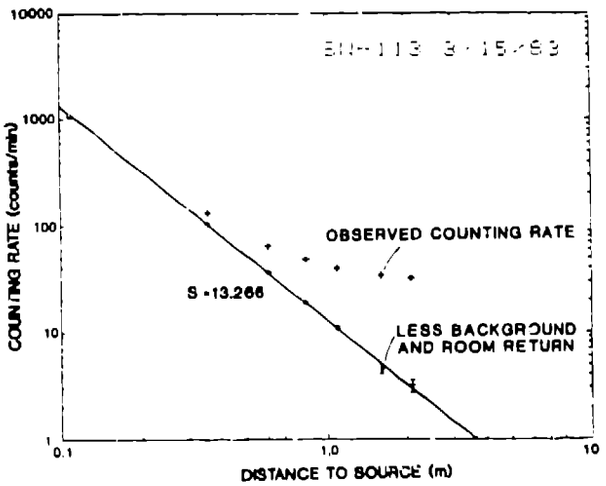

Figure 3. Computer plot of inverse-distance-squared fit for corrected ^{113}Sn counting data.

A summary of the results for all 13 point sources is given in Table 2. As can be seen from the counting data, the strengths of some of the sources are quite small; however, the analysis gives satisfactory information. The error quoted for the counting data is the standard deviation of the product of counting rate and distance squared, $C_r r^2$, for the seven observed data points for each source. This is a measure of the systematic error for the analysis procedure.

Also listed in Table 2 are the resulting counting responses, (counts/min)/(mrem/hr), for each of the sources based on two different flux-to-dose-rate conversion tabulations. The American National Standards Institute (ANSI) conversion (1977) gives higher dose values for a given source than that inferred from the work of Dimbylow and Francis (1979) at Harwell, which is the basis for the conversion adopted by the Lawrence Livermore National Laboratory. The table presents our results based on both of these standards for comparison.

The GM detector response based on the Livermore flux-to-dose-rate conversion is plotted in Figure 4. The well-known over-response of the detector to low-energy gamma rays is highly evident. At very low energy, the curve finally drops off again because of shielding by the counter walls. The errors given are a combination of the accuracies of source strength calibration with the NBS standard, the flux-to-dose-rate conversion factors, and the systematics of GM counting data analysis.

We intend to continue this experiment by extending the response curve above 2.6 MeV. The problem of finding discrete gamma-ray sources at these higher energies can probably be resolved with the use of a Van de Graaff accelerator.

APPLICATION

Using the response curve of Figure 4, we can significantly improve the precision in determining dose rates as compared with the older method of a calibration based only on ^{137}Cs and ^{60}Co standard sources. In order to accomplish this, we need to know the energy spectrum of the unknown radiation source. This can be obtained either by an independent measurement or by calculation. The GM response curve and the energy spectrum are then folded together to obtain a calibration factor that is specific for the source being measured, as follows.

$$\langle R(E) \rangle = \frac{\int \phi(E)\, F(E)\, R(E)\, dE}{\int \phi(E)\, F(E)\, dE} \quad , \qquad (3)$$

where $\phi(E)$ = the energy spectrum of the unknown source ($\gamma/cm^2/sec$),

$F(E)$ = the flux-to-dose-rate conversion (mrem/hr)/($\gamma/cm^2/sec$), and

TABLE 2. Calibration Data for GM Detector

Isotope	Energy (keV)	GM Counting Data[a] Counts/min	Error[b] (%)	Calibration Factor (counts/min)/(mrem/hr) Livermore-Base[c]	Error (%)	ANSI-Base[d]	Error (%)
^{241}Am	60	3.67	6.9	1854	7.6	1237	8.1
^{57}Co	122,(137)	20.33	0.81	2757	1.7	2250	3.5
^{139}Ce	166	18.39	1.6	1813	5.2	1507	6.0
^{203}Hg	279	17.67	5.2	1363	5.5	1165	6.3
^{51}Cr	320	1.51	15.0	1152	15.8	970.4	16.1
^{113}Sn	392	13.27	5.5	1159	7.5	972.6	8.0
^{7}Be	478	2.84	13.0	992.3	13.8	864.1	14.2
^{85}Sr	514	35.41	1.1	1162	1.4	1006	1.8
^{137}Cs	662	37.77	3.2	1206	4.4	1090	4.5
^{54}Mn	835	59.68	2.2	1269	5.5	1174	5.6
^{65}Zn	1116	45.23	0.90	1520	3.1	1406	3.3
^{60}Co	1173,1332	199.2	0.62	1579	5.0	1444	5.1
^{228}Th	2615	10.52	8.8	2365	9.0	2269	9.1

[a]Detector counting rate at 1 m from source corrected for background and room return.
[b]Systematic error in fitting data.
[c]Based on Livermore flux-to-dose table.
[d]Based on ANSI flux-to-dose table.

R(E) = GM response curve (counts/min)/(mrem/hr). We have developed a program for the Control Data Corporation 6600 computer to perform this folding technique.

Two examples using the new procedure have resulted from recent programmatic work. The spectra for these composite sources were measured with a bismuth-germanate (BGO) detector system. The first source, which contains plutonium and both enriched and depleted uranium, has a spectrum (Figure 5) that peaks at low energies. We find a calibration factor of 1362 (counts/min)/(mrem/hr) using the GM response curve. This is only 2% lower than the factor one obtains by averaging the ^{137}Cs and ^{60}Co values and well within the quoted errors of the two calibration methods.

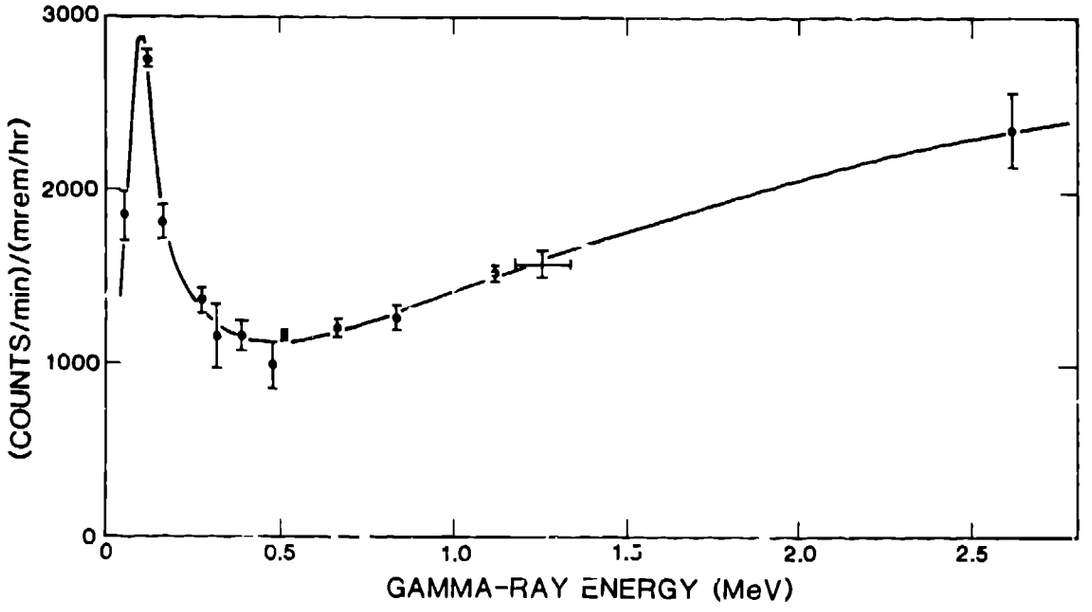

Figure 4. GM counting response curve based on Livermore flux-to-dose-rate conversion table.

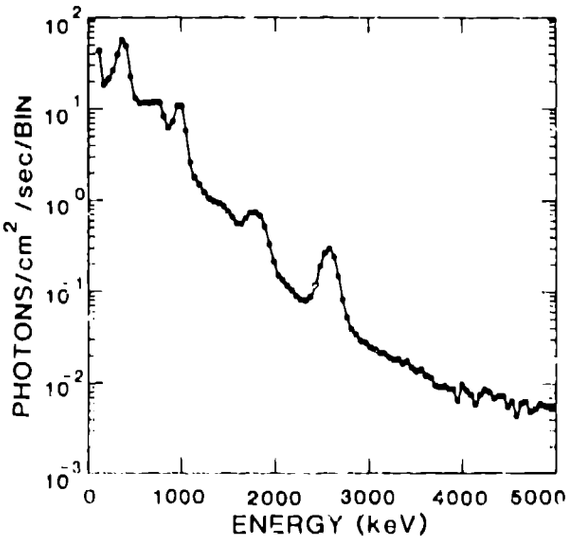

Figure 5. BGO-measured spectrum of source containing plutonium and uranium.

A much different result was found with the second source, which is a critical configuration of enriched uranium reflected with thick tungsten and iron. The spectrum (Figure 6) shows a preponderance of gamma rays above 1 MeV continuing out to 10 MeV. Since our GM response curve is presently only known to 2.6 MeV, we assumed a constant response above this energy and computed a calibration factor of 2453 (counts/min)/(mrem/hr). This means that if we had used the calibration factor based on only the ^{137}Cs and ^{60}Co values we would have overestimated the dose rate from this source by 75%.

The importance of our new GM calibration procedure clearly depends on the energy spectrum of the source being measured. As we have shown, the effect on the quoted results can be very significant.

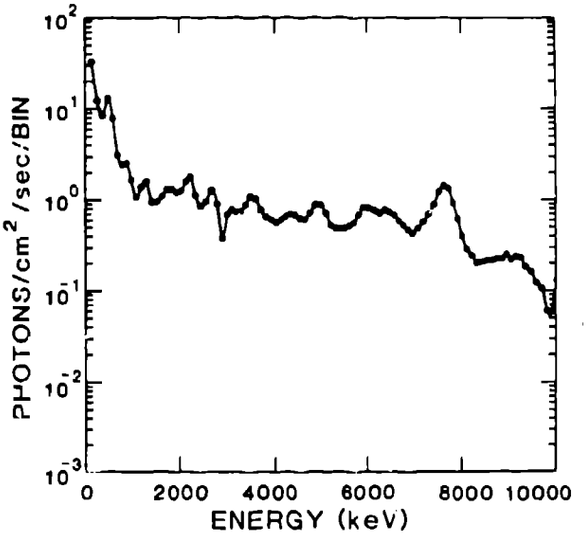

Figure 6. BGO-measured spectrum of critical configuration of enriched uranium reflected with tungsten and iron.

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