THE RESPONSE OF A SODIUM IODIDE SCINTILLATION COUNTER TO 18 MeV γ-RADIATION

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Summary

The probability distribution of ionization energy in a sodium iodide crystal 2·5 cm long by 2·5 cm diameter due to the absorption of 18 MeV quanta has been calculated taking account of side escape of electrons from the crystal due to multiple scattering. The results confirm the conclusions of the authors' earlier work.

I. Introduction

In a previous communication (Campbell and Boyle 1953, hereinafter referred to as C.B.) the authors discussed the response of sodium iodide scintillation counters to γ-radiation of energy up to 18 MeV. In view of the approximations employed in the theoretical section of that paper, one particular instance, the case of 18 MeV radiation in a crystal 2·5 cm long by 2·5 cm diameter, has been re-examined in greater detail.

II. Method

The Monte Carlo method described in C.B. was used, with the following modifications :

(i) Previously the secondary electrons were considered to travel in straight lines along the direction of the incident quanta, multiple scattering affecting only the distance travelled. Sideways deflexion is here taken into account, allowing escape through the side of the crystal.

(ii) The value used in C.B. for the ionization loss of fast electrons in sodium iodide is too low.‡ The value now used is 5 MeV/cm, which, from the data for sodium iodide given recently by Sternheimer (1952), holds within 10 per cent. for electrons in the energy range 4–20 MeV.

(iii) In C.B., the probability of reabsorption of isotropically emitted bremsstrahlung was calculated on the approximating assumption that it all originated at the central point of the crystal. For the present work, the published data on self-absorption of large sources (Dixon 1951) were used to derive this probability for a uniform distribution of origin throughout the volume.

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‡ The authors are indebted to Dr. G. W. Hutchinson, of the University of Glasgow, for drawing their attention to this error.

(iv) The method of calculation does not allow an electron to emit more than one bremsstrahlung photon in any one section of length. In C.B., these sections were chosen to be 0·25 cm, whereas they are here 0·10 cm. The double emission thus neglected is reduced in proportion to the square of the ratio of these lengths.

(v) The lowest energy bremsstrahlung photons considered are 0·25 MeV, instead of 0·5 MeV as in C.B. Although the energy content of each such photon is small, they occur frequently.

A set of life histories of individual secondary electrons, with each of the initial energies 3, 6, 9, 12, 15, and 18 MeV, was compiled, without regard to deviations of path. Then, to introduce sideways deflexion, a formula given by Janossy (1948, p. 319) was used. This states that the mean square displacement of an electron passing through a homogeneous absorber of thickness z is

$$x^2 = E_s^2 \int_0^z \frac{z'^2 \mathrm{d}z'}{E(z')^2},$$

where $E(z')$ is its energy in MeV at depth $(z-z')$ and E_s is 21 MeV, distance being measured in radiation lengths. The cross section of the crystal was divided into five concentric annuli of equal area, and the electrons were assumed to start in each of these in turn. By a graphical method similar to one since published by Dickinson and Dodder (1953), the fractions of electrons escaping through the side of the crystal were determined for each section of length, for each initial energy and each annulus of cross section. These results were applied to the life histories. The length of the crystal was resubdivided into sections of 0·25 cm, and the ionization distribution was obtained for each case.

From these 300 distributions for the six initial energies, it was necessary to find those for initial energies from 0 to 18 MeV in steps of 0·5 MeV. To carry out this interpolation it was necessary to convert the distributions, which were in the form of histograms subject to statistical fluctuation, into an analytical form. The form which was arrived at for the distribution in energy E of the ionization in the crystal by an electron of initial energy E_0 from a given annulus having travelled a given distance through the crystal is

$$A\delta(E-E_1)+(1-A)E^{p-1}(E_0-E)^{q-1}/E_0^{p+q-1}B(p,q),$$

where $\delta(E-E_1)$ is the delta function and $B(p,q)$ the beta function. The first term is the contribution of those electrons whose passage through the crystal has been so far uneventful, so that they have all lost the same amount of energy E_1 by ionization. The value of A was determined directly from the peak in each histogram. The second term is due to those electrons which in addition have emitted bremsstrahlung or have escaped through the side of the crystal. The parameters p and q were found from the first and second moments of each histogram after the peak had been removed. The form of this term, which is known as the beta distribution, was found in each case to approximate well to the shape of the Monte Carlo histogram.

The ionization distributions for the six initial energies having thus been converted to analytical form, those for the intermediate energies were derived by linear interpolation of the three parameters A, p, and q. The 1800 distributions so obtained were tabulated numerically.

From these single-electron distributions, the distributions for pairs of electrons with initial kinetic energies totalling 17 MeV were found. This integration of tabulated data, which involved hundreds of thousands of multiplications, was carried out on " Hollerith " punched-card equipment, through the cooperation of the Commonwealth Bureau of Census and Statistics and of the Australian Wool Realization Commission. The pair distributions were then weighted with their respective probabilities, treated for capture of annihilation radiation using Figure 4 of C.B., and combined, to give the distribution of energy lost by ionization in the crystal by quanta initially absorbed by the pair production process.

The distribution due to quanta absorbed by the Compton process (only 20 per cent. of the total at this energy) was calculated using representative electron distributions. When combined with the pair-production distribution, the final calculated ionization distribution was obtained for 18 MeV quanta.

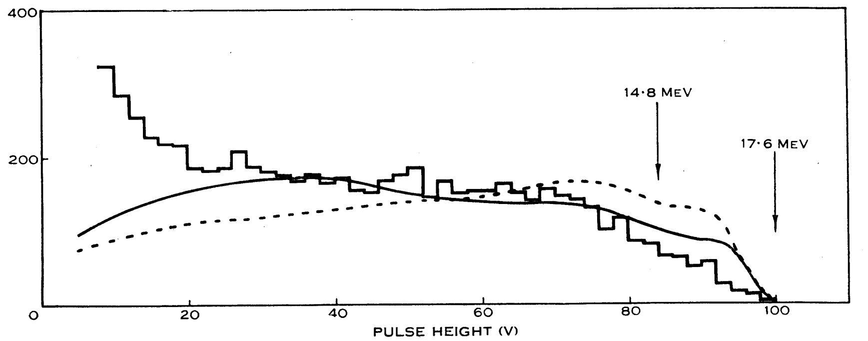

Fig. 1.—Results for $^{7}Li(p,\gamma)$ radiation.
Histogram: experimental, uncollimated.
Continuous curve: theoretical, uncollimated.
Dotted curve: theoretical, collimated.

III. Results and Discussion

For a comparison with experiment, the authors' previously published results for the $^{7}Li(p,\gamma)$ radiation were used. The experimental pulse-height distribution, taken from Figure 10 (a) of C.B., is reproduced as the histogram in Figure 1. The arrows indicate the energy calibration arrived at using the $^{19}F(p,\alpha\gamma)$ radiation.

In determining the theoretical distribution for this radiation, the component at 14·8 MeV was assumed to give a distribution of the same shape as the more intense one at 17·6 MeV, except that its high energy edge was spread by the natural line breadth of 2 MeV. The further spreading due to statistical effects in the photomultiplier was ignored, being less than 2 per cent. at the high energy end. The resulting theoretical distribution, scaled horizontally to fit the energy calibration and vertically to fit the histogram, is shown by the smooth continuous curve in the figure. Apart from the usual low energy divergence, the agreement is satisfactory.

The effect of sideways loss of electrons by multiple scattering could be minimized by collimating the beam of γ-radiation to a narrow pencil centred on the crystal axis, which, however, would have little effect on bremsstrahlung loss. The distribution to be expected in the case of a pencil 1·12 cm in diameter (corresponding to the centremost of the five annuli considered) is shown by the dotted line in the figure. This was not tested experimentally, since the resolution is not significantly improved.

The results of this more thorough calculation confirm the conclusions of C.B., that crystals of dimensions of an inch or two are too small for spectrometry of γ-radiation of this energy, and that the most important limiting factor is the escape of bremsstrahlung photons. The improvement possible with larger crystals has since been shown by Foote and Koch (1954), who have clearly resolved the two components of the ^{7}Li(p,γ) radiation using a sodium iodide crystal 8 in long by 5 in diameter.

IV. Acknowledgments

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