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AN IMPROVED GAMMA DETECTOR USING GAMMA MODERATION

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ABSTRACT

Theoretical and experimental results of the effect of gamma moderation are described. A 6.7-fold enhancement factor was obtained with a $\frac{1}{8}$ -in.-thick sodium-iodide crystal when using gamma moderation and a Co^{60} gamma source. A counter was designed and built to make the most use of gamma moderation. The results indicate that this counter can be made energy independent over a wide region. Though the cost of the counter is about $\frac{1}{3}$ that of a 1-in.-diam, 1-in.-thick sodium-iodide crystal plus photomultiplier, the counting efficiency for gammas such as Na^{24} is over two times greater.

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I. INTRODUCTION

Presently used gamma-ray monitors or counters usually consist of costly sodium-iodide crystals and photomultiplier systems. It would be very desirable to have a low-cost, highly efficient gamma detector which also has a variable energy response. Just such a detector appears feasible when using gamma moderation.¹

II. CHARACTERISTICS OF GAMMA MODERATION AND ITS COMPARISON WITH NEUTRON MODERATION

The well known BF_3 long counter utilizes a paraffin moderator to reduce the energies of the incident neutrons to the low energy requirements necessary for obtaining a high boron reaction cross section. Similarly, gammas may be moderated by Compton scattering and reduced to the low energies at which the high photoelectric cross section predominates.

Neutron moderation in hydrogen, for example, may be compared with gamma moderation in carbon with respect to: (1) total absorption, (2) energy loss per collision, (3) angular dependence of scattering, and (4) energy dependence of the detector.

(1) Total absorption.— The ratio of the scattering cross section to the absorption cross section for neutrons in hydrogen is high at around 1 Mev.²

¹R. Fox, Bull. Am. Phys. Soc. Ser. II, 3, 19 (1959).

²D. J. Hughes and R. B. Schwartz, Neutron Cross Sections, Brookhaven National Laboratory Report BNL-325 (2nd ed.), July 1, 1958.

This ratio is also high for gammas at around 1 Mev in low-atomic-number materials. The ratio of the Compton scattering cross section to the photo-electron absorption cross section in carbon is 4.2×10^4 at 1 Mev and 1.7×10^2 at 0.2 Mev.³

(2) Energy loss per collision. — The average logarithmic energy change per neutron scattering collision is constant. For Compton scattering, the average fraction of the incident energy lost per collision is energy dependent. This fraction is 0.44 at 1 Mev and 0.14 at 0.1 Mev.⁴

A high-energy gamma is thus moderated in a few collisions. A low-energy gamma must make a number of collisions before it loses an appreciable fraction of its energy.

(3) Angular dependence of scattering. — A neutron scatters off hydrogen atoms only in the forward direction while the differential scattering cross section for Compton scattering is finite from 0° to 180°. There is a forward peaking in the gamma differential scattering cross section which increases with energy. The ratio of the differential scattering cross section per solid angle at 0° to that of the differential scattering cross section per solid angle at 180° is 10.7 at 1 Mev and 1.84 at 0.1 Mev.⁴

(4) Energy dependence of the detector. — The reaction cross section for a neutron detector such as boron varies as $E^{-1/2}$. A 10-fold increase in the counting efficiency will result from a 100-fold decrease in the neutron energy. For gammas the energy dependence of the reaction cross section is

³G. W. Grodstein, X-Ray Attenuation Coefficients from 10 kev to 100 Mev, U.S. National Bureau of Standards Circular No. 583 (1957).

⁴A. T. Nelms, Graphs of the Compton Energy-Angle Relationship and the Klein-Nishina Formula from 10 kev to 500 Mev, U.S. National Bureau of Standards Circular No. 542 (1953).

considerably stronger. The reaction cross section for sodium iodide, for example, is $0.058 \text{ cm}^2/\text{g}$ at 1 Mev and is $122 \text{ cm}^2/\text{g}$ at 0.01 Mev.³ Thus, a 2100-fold increase in the reaction cross section results from a 100-fold decrease in the gamma energy.

From the above, the behavior of a moderated gamma can be deduced. Let us assume we have a high-atomic-number gamma detector surrounded by a low-atomic-number moderator. A high-energy incident gamma will scatter in the moderator predominately in the forward direction. It will lose an appreciable fraction of its energy each time it scatters. After a few collisions the gamma will often find itself in the vicinity of the detector. The low-energy gamma will now scatter almost isotropically and lose only a relatively small fraction of its energy per collision. Thus once a low-energy gamma is in the vicinity of the detector it will scatter a number of times in that region before it is absorbed.

III. EFFECTIVENESS OF GAMMA MODERATION

A calculation was made using data from Ref. 5 to determine the effectiveness of gamma moderation. The assumption was made that an infinite graphite medium surrounded a 1 ± 0.05 Mev gamma source which was 8 in. from a gamma detector.

The dashed curve shown in Fig. 1 represents the gamma distribution in free space at the detector position while the solid curve represents the distribution in an infinite graphite medium. The calculation indicates that very few gammas are absorbed by the graphite. The calculation also

⁵H. Goldstein and J.E. Wilkins, Jr., Calculations of the Penetrations of Gamma Rays. Final Report, Nuclear Development Associates, Inc., Report NYO-3075, June 30, 1954.

indicates that the graphite attenuates the gamma energy from 1 Mev to about 50 kev without seriously affecting the flux intensity.

A check of this result was obtained by comparing experimentally the counting efficiency of a graphite-moderated, $\frac{1}{8}$ -in.-thick sodium-iodide detector with the same detector unmoderated. A $\frac{1}{8}$ -in.-thick sodium-iodide crystal has a $6\frac{1}{2}\%$ probability of detecting a 1-Mev gamma and a unit probability of detecting a 50-kev gamma. The detector should thus increase its counting rate 15 times if all of the 1-Mev gammas were attenuated to 50 kev. A 6.7-fold increased count rate was experimentally obtained. The discrepancy between the two factors is attributed to the fact that an effectively infinite graphite system was not used.

IV. EXPERIMENTAL COUNTER UTILIZING GAMMA MODERATION

A simple, low-cost gamma detector was built which incorporated the advantages of gamma moderation.

A taut 1-mil stainless steel wire was sealed concentrically in a 2-in.-diam, $28\frac{1}{2}$ -in.-long, cylindrical glass tube. The inner wall of the tube was coated with an opaque layer of silver for a length of 24 in. The end portions of the tube were not coated and provided adequate insulation between the anode and cathode. An electrical lead was connected to the silvered portion and brought out through one end. External electrical leads and the unshielded end portions of the cathode were shielded with aluminum foil in regions near the counter and were shielded by coaxial cable thereafter. The counter tube is shown in Fig. 2.

The sealed tube contained $1\frac{1}{2}$ atmospheres of a mixture of 95% xenon and 5% CO_2 . This mixture was selected to provide a high photoelectric reaction cross section for low-energy gammas.

The electronic components necessary consisted of a low-noise preamplifier, a high-voltage supply, a linear amplifier and a decade scaler. The operating high voltage was 2200.

Two graphite moderator cells, one $1 \times 1 \times 3$ ft and the other $3 \times 3 \times 3$ ft, were used. The geometry of the cells is shown in Fig. 3. The slot in the graphite cell was introduced so as to provide a high gamma intensity at the detector for a given source strength. In normal operation the counter tube was centered longitudinally in the graphite slot. The gamma source was located on a line normal to the centerpoint of the slotted side of the moderator cell. Figure 4 shows the counter tube protruding from the 1-ft moderator cell.

V. EXPERIMENTAL RESULTS

The energy response of the counter tube was calibrated with respect to discriminator voltage. Sixty-kev gammas from an Am^{241} source were used for this calibration. The discriminator was set at 10 kev when count-rates were taken. These count-rates were normalized to the emission of 1 gamma. A typical response of the counting system as a function of discriminator setting is shown in Fig. 5. The response of the 3-ft assembly is shown to a Na^{24} gamma source at a distance of 3 ft from the counter tube. Background curves are also given for comparison.

Na^{24} and Cs^{137} gamma sources were used to test the counter. Cs^{137} emits gammas at 0.662 Mev while Na^{24} emits gammas at 2.75 and 1.37 Mev, in equal strength.

Figure 6 shows the response of the 1-ft assembly to Na^{24} and Cs^{137} gamma sources as a function of source distance. It is seen that the gammas of the Na^{24} and Cs^{137} sources produce approximately the same response to this counter assembly.

The response of the 3-ft counter assembly to the same two gamma sources is shown in Fig. 7. The assembly is seen to have a higher counting efficiency for the Na^{24} gammas than it does for the Cs^{137} gammas. The responses to the gammas of Na^{24} of the 3-ft assembly and of the 1-in.-thick, 1-in.-diam sodium-iodide crystal are compared in Fig. 8.

VI. DISCUSSION OF RESULTS

Na^{24} gammas can penetrate farther in carbon than can the Cs^{137} gammas. The lower-energy Cs^{137} gammas, however, are more easily moderated. These two effects tend to counterbalance one another. The response of the 1-ft assembly, as shown in Fig. 6, shows these two effects almost completely counterbalancing one another. Na^{24} gammas have a greater counting efficiency in the 3-ft assembly than the Cs^{137} gammas have, due to their greater penetrability. It appears that the assembly could be made energy-independent over a wide region with an appropriate choice of slots or holes in the moderator cell. The counter is also seen to have a fairly high counting efficiency compared with the 1-in.-diam, 1-in.-thick sodium-iodide crystal.

VII. APPLICATIONS

The structure of the proportional counter is simple and is similar in construction to the Geiger tubes that have been used in cosmic-ray work for some time. The cost of such a counter is about $\frac{1}{3}$ that of a 1-in.-diam, 1-in.-thick sodium-iodide crystal plus photomultiplier. However, the counting efficiency for gammas such as Na^{24} is over two times greater.

The counter could find application anywhere a highly efficient, low-cost, flat- or variable-energy-response gamma detector is desired. This might be as a monitor, as a calibrating counter, or as a detector in experimental nuclear physics.

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Fig. 1. Calculated gamma distribution at a distance of 8 in. from a 1 ± 0.05 Mev gamma source.

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Fig. 2. Glass xenon proportional counter used in the moderator assemblies.

Simple geometry of high atomic number proportional counter surrounded by low atomic number moderator.

MUL-6036

Fig. 3. Geometry of moderator cell and counter tube. The moderator-cell widths, D , were 1 and 3 ft.

Fig. 4. The 1-ft-wide moderator cell with the counter tube extending from one side. The normal operating position of the counter tube was at the center of the moderator cell.

Fig. 5. Response of the 3-ft assembly to a Na^{24} gamma source as a function of discriminator setting.

Fig. 6. Response of the 1-ft assembly to the gammas of Cs¹³⁷ and Na²⁴ as a function of distance.

Fig. 7. Response of the 3-ft assembly to the gammas of Cs^{137} and Na^{24} as a function of distance.

Fig. 8. Responses of the 3-ft assembly and a 1-in.-diam, 1-in.-thick sodium-iodide crystal to the gammas of Na^{24} as a function of distance.