0.2 and 0.3 Mev. This is based on an analysis of two runs in which the cerium fractions were measured through three lead absorbers (2, 3, and 4 g/cm^2). A more thorough investigation of these radiations is planned by means of a scintillation spectrometer.

In the above cerium runs counting was begun as soon as 28 minutes after the irradiation and 3.5 minutes after the final separation from Pr. Since no component shorter than 13.9-min was seen, it is concluded that any other short-lived Ce fission products must have half-times shorter than 6 minutes.

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Gamma-Radiation from Interaction of 14-Mev Neutrons with Iron

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Experiments have been performed to observe gamma-rays produced by the interaction of 14-Mev neutrons with iron. Although the gamma-spectrum appears to be continuous below 3.0 Mev, there may be discrete gamma-rays at 3.3, 4.4, 5.8, 7.1, and 8.75 Mev. The total cross section for gamma-ray production is 4.6±0.5 barns.

I. INTRODUCTION

SOME observations[1,2] of the gamma-radiation produced by interaction of fast neutrons with matter have been carried out primarily by absorption techniques. To obtain better resolution, we have made measurements with a spectrometer consisting of a single crystal of NaI(Tl) in conjunction with an eighteen-channel pulse-height analyzer. The spectra examined so far appear to consist of a low energy continuum overlaid by a series of discrete lines or bands at higher energies.

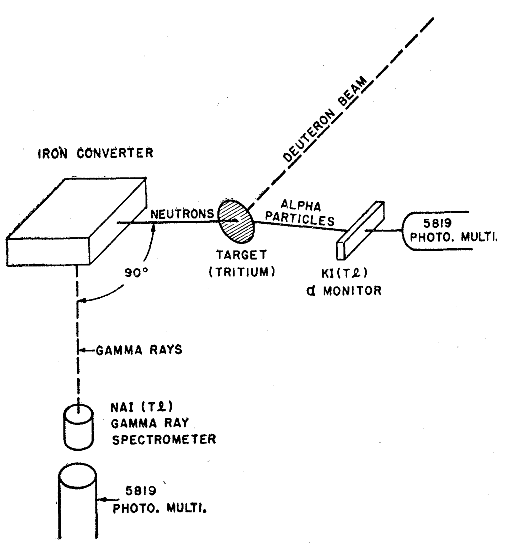

FIG. 1. Schematic representation of the experimental arrangement showing accelerator target, alpha-monitor, iron converter, and crystal detector.

II. DESCRIPTION OF THE EXPERIMENT

A 250-kilovolt Cockcroft-Walton accelerator[3] employing the $T(d,n)He^4$ reaction was used as a source[4] of 14-Mev neutrons, which were allowed to fall upon an iron converter arranged as shown in Fig. 1.

The converter and the accelerator monitor were so placed that whenever an alpha-particle entered the monitor a corresponding neutron entered the converter. The iron converter, approximately 0.75 inelastic neutron mean free paths long, was just wide enough to cover the "coincidence neutron beam." On the average a gamma-ray traveled about 0.25 mean free paths before leaving the converter and reaching the detector.

A block diagram of the electronic arrangement is shown in Fig. 2. A single crystal of NaI(Tl) and a 5819 photomultiplier in conjunction with an eighteen-channel pulse-height analyzer detected the gamma-rays produced in the converter. The multichannel analyzer was gated only by coincidences between the alpha-monitor and the spectrometer, thereby eliminating background counts from direct neutrons on the crystal as well as radiation scattered off the walls of the room. The amplifier discriminator in the alpha-channel was set to eliminate counts from the $D(d,n)He^3$ reaction, from electrons and low level noise. Scalers were placed at all points in the system that gave useful information.

Figure 3 shows typical calibration curves with the 4.45-Mev line of Po-Be and the two gamma-lines of

[1] D. F. Lea, Proc. Roy. Soc. (London) **150**, 637 (1935).
[2] J. H. Coon, private communication.
[3] Bergstralh, Dunning, Durand, Ellison, Howerton, and Slavin (to be published).
[4] Graves, Rodrigues, Goldblatt, and Meyer, Rev. Sci. Instr. **20**, 579 (1949).

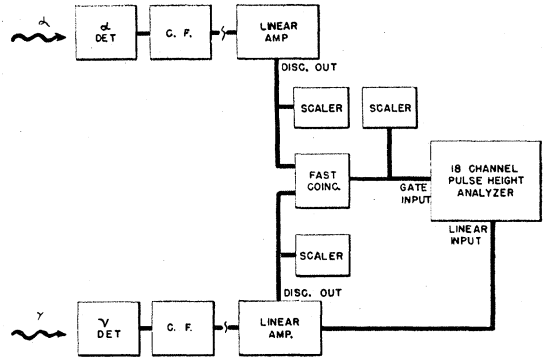

FIG. 2. Block diagram of electronic equipment used in the experiment.

Co^{60}. These curves, after correction for the statistics of the 5819 photomultiplier tube and the finite channel width of the discriminator, resemble the theoretical response due to scattering and absorption of the gamma-rays in the crystal.

III. SPECTROMETER RESPONSE

The pulse-height distribution produced by an arbitrary spectrum of gamma-rays falling upon a crystal spectrometer can always be expressed in terms of the incident spectrum and various system parameters. The resulting integral equation may be inverted to obtain thereby the energy spectrum of the incident radiation. To formulate an expression for the spectrometer pulse-height distribution, let $d\sigma(E')/dE'$ represent the differential cross section (in barns/Mev) for gamma-ray production of energy E', and $K(E',E)$ the relative probability of finding a pulse whose height lies in the interval between E and $E+dE$ whenever a gamma-ray of energy E' interacts with the crystal. It can then be shown that the pulse-height distribution $M(E)$ is

$$\frac{N_\alpha}{h_0}\frac{r}{4\pi}\eta\times 10^{-24}\int_0^l A\,dl\int_0^\infty dE' K(E',E)\frac{d\sigma}{dE'} \times\int_{t_1}^{t_2} dh e^{-h\mu_1(E')}(1-e^{-D\mu_2(E')}).$$

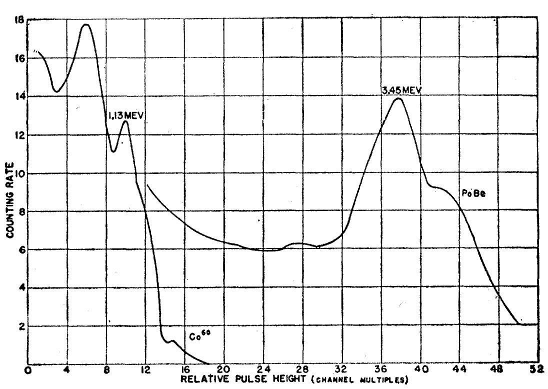

FIG. 3. Calibration curves of the spectrometer, obtained for Co^{60} and Po-Be gamma-rays.

Here, N_α represents the number of neutrons falling on the iron converter which are in coincidence with the alpha-monitor. The converter to detector solid angle is Ω, and the quantities t_1, t_2, and D refer to converter and crystal dimensions as indicated in Fig. 4. h_0 is the width of the coincidence neutron beam falling on the converter. The μ_1, μ_2 are gamma-ray absorption coefficients for converter and crystal, respectively, and are functions of the integration variable E'. Attenuation of the direct neutron beam in the converter is represented by A and was computed from the transport cross section and atomic density η for iron.

A possible method of analyzing the spectrum is to first subtract out apparent lines or bands which appear as maxima in the pulse-height distribution. This can be done if the relative pulse-height distribution $K(E',E)$ is known for each line energy. $K(E',E)$ can be obtained from calibration curves or estimated theoretically. The cross section σ_0 for gamma-ray production at the energy E_0, is obtained from the integral equation for the pulse-height distribution by setting $d\sigma/dE' = \sigma_0\delta(E'-E_0)$. After all apparent lines have been subtracted, the remaining portion of the pulse-height distribution is treated as a continuum and an approximate solution of the integral equation for $d\sigma/dE$ is obtained by use of a simple form of $K(E',E)$.

IV. RESULTS

Coincidence counting data was taken on a multichannel analyzer for a given number of neutrons (or alpha-monitor counts) with the converter both in and out of the "coincidence neutron beam." The machine rate was held constant during both runs so that the accidental rate was the same. The ratio of converter in to converter out counting rate was between 5 and 10, so generally the "background" was small. True counting data was obtained by subtraction of results obtained with the converter and out of the beam. Figure 5 is a plot of a representative set of data in counts per neutron per Mev. Probable errors in the counting data are indicated by the length of the vertical lines. Peaks occurring at electron energies of 2.5, 3.4,

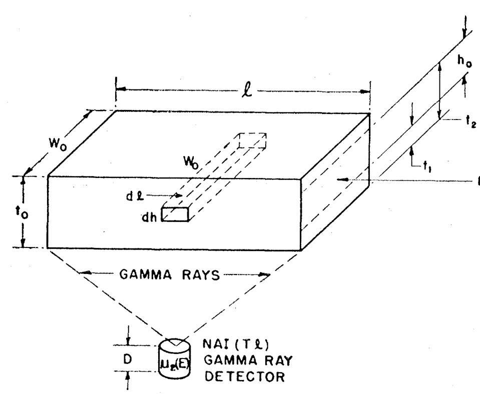

FIG. 4. Arrangement of iron converter and detector.

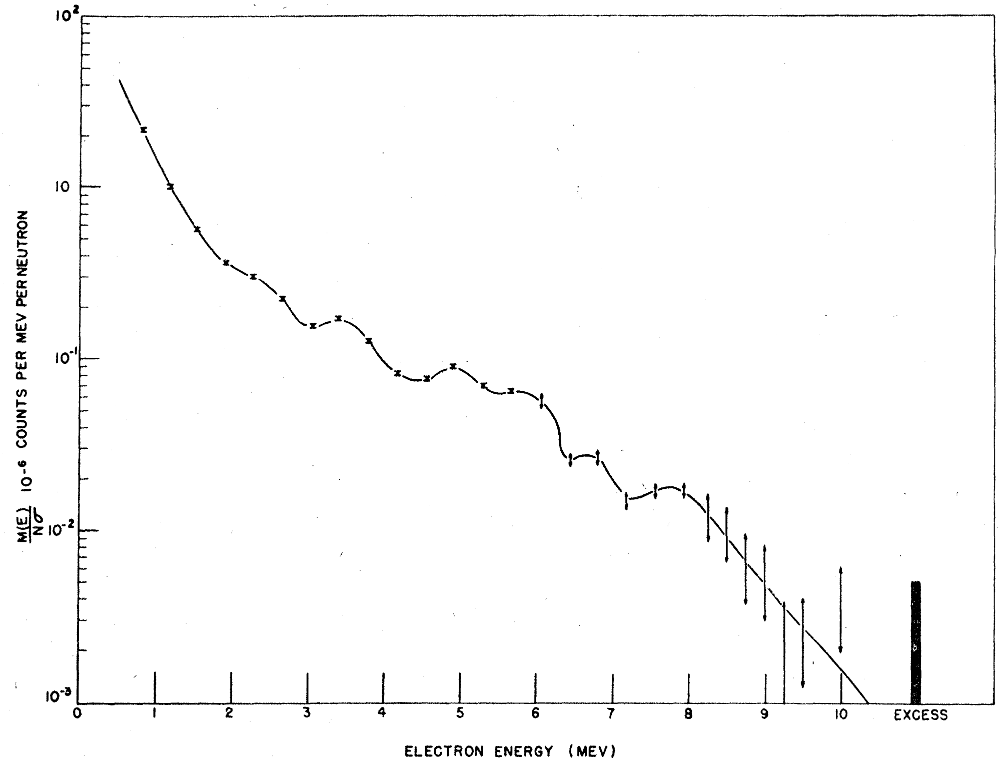

FIG. 5. Pulse-height distribution owing to iron gamma-rays. Ordinate is in counts per Mev per neutron and is the difference between converter-in and converter-out data.

4.80, 6.1, and 7.75 Mev were attributed to lines or bands in the gamma-ray spectrum at energies of 3.3, 4.4, 5.8, 7.1, and 8.75 Mev, respectively, and were subtracted from the data as described previously. An approximate solution of the integral equation was

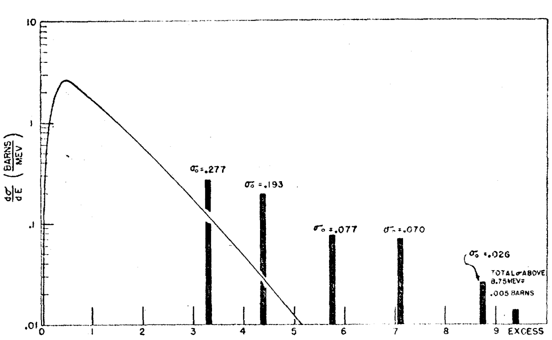

FIG. 6. Computed spectral distribution of iron gamma-rays. Ordinate is in barns per Mev for the "continuous portion" of the spectrum. Total cross sections are given for the line spectra.

applied to the remaining portion of the distribution, which resulted in a continuous spectral distribution. Figure 6 shows the line or band spectra with their total production cross section, the estimated total cross section for all gamma-rays above 9.0 Mev and the part of the spectrum which appears continuous. No great significance should be placed on the shape of the continuum; however, the total cross section for this region is correct even though its distribution may be in error. The total cross section for the production of gamma-rays of all energies is 4.6 ± 0.5 barns. The error indicated in the cross section arises mainly upon uncertainties in the analysis and not from counting statistics. Error in energy assignment is of the order of 0.2 Mev.

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