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GAMMA-RAY SPECTRA OF THE LOS ALAMOS REACTORS*

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The gamma-ray beams emerging from the collimator hole of the Los Alamos Water Boiler ⁽¹⁾ (operating at 30 kilowatts) and of the Fast Reactor (operating at 25 kilowatts) were allowed to impinge on a beryllium foil, and the momentum distribution of the Compton electrons ejected from the foil into a small solid angle in the forward direction of the beam was measured with a magnetic spectrometer ⁽²⁾. For the Water Boiler, the source of the collimated gamma-rays was a U^{235} cylindrical slug (diameter 2.22 cm, length 0.426 cm, weight 28.5 gm, 95 per cent purity) placed at the center of the sphere, while for the Fast Reactor, the gamma-rays originated in the reactor core.

The spectrometer measurements covered a range of electron energies from approximately 0.5 Mev to 12 Mev. "Hot wire" measurements ⁽³⁾ indicated that the focussing properties of the spectrometer did not change over this energy range. The measurements for the Water Boiler and Fast Reactor were made with a beryllium foil 11 mils thick and 33 mils thick respectively. ^(auth) The secondary electron spectra for both reactors are shown in Fig. 1.

Each momentum distribution in Fig. 1 was converted to a corresponding absolute gamma-ray spectrum. The following factors were significant in the analysis:

(1) For the small acceptance angle of the spectrometer, the angular dependence of the Compton electron energy could be neglected, so that the latter was related uniquely to the incident photon energy.

(2) The cross-section $\sigma(k_0)$ (shown by the solid line in Fig. 2) for the emission of Compton electrons into the solid angle defined by the

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spectrometer acceptance angle θ was computed from the expression

$$\sigma(k_0) = \int_0^\theta f(\theta) \sigma(k_0, \theta) d\theta$$

where k_0 is the incident photon energy, $f(\theta)$ is a function dependent on the spectrometer geometry and baffle positions, and $\sigma(k_0, \theta) d\theta$ is the Klein-Nishina differential cross-section. The effect of electron scattering in the foil and the geometry effect introduced by the foil width and length were evaluated from studies of the line shapes obtained for different foil sizes when monoenergetic photons (0.661 Mev) were incident on the foil. These effects were expressed as a function $T(k_0)$, with an energy dependence that was determined on the assumption that the electron scattering effect varies with energy in approximately the same way as the Coulomb scattering cross-section. The quantity $T(k_0) \sigma(k_0)$ shown by the dashed lines in Fig. 2, represent an "effective" cross-section that applies to those Compton processes in which an electron is accepted by the spectrometer after emergence from the foil.

(3) The spectrometer was calibrated from the line shapes obtained when the monoenergetic gamma-rays from a ten curie source of Cs^{137} (0.661 Mev)⁽⁴⁾ and a one curie source of Na^{24} (1.38 Mev, 2.76 Mev)⁽⁵⁾ were incident on the beryllium foil in the spectrometer. The absolute intensity of the collimated gamma-ray beam for each source was measured with an ionization chamber and the measured values agreed within 5% with the values computed from the "effective" cross-section (Fig. 2) at the three photon energies.

(4) It was assumed that each spectrum was continuous and no attempt was made to determine the line structure. To correct for the spectrometer response to a continuous spectrum of electrons ejected from

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the foil, an average value of the number of electrons per unit momentum interval in the total energy interval accepted by the spectrometer detector was determined with the aid of the line shape measurements mentioned in (3) .

(5) The contribution of pair production electrons to the total number of electrons detected by the spectrometer at a given magnetic field was found by reversing the field and measuring the number of positrons, on the assumption that in the pair production process, the cross section is symmetrical with regard to the positron and electron⁽⁶⁾ . The number of pair production electrons relative to the number of Compton electrons, which emerge into the solid angle defined by the spectrometer acceptance angle θ with an energy (including rest energy) between E and $E + dE$, depends on the shape of the gamma-ray spectrum in the energy region above $E + mc^2$. For the pile-type spectrum in the present case, the maximum contribution of the pair production electrons to the total number of electrons detected in any energy interval was less than 4 per cent.

The absolute gamma-ray spectrum (neglecting line structure) for each reactor is shown in Fig. 3. The quantity $\bar{\eta}$ is the number of photons per kev interval that are incident on the foil per cm^2 per second for a given photon energy k_0 . The results indicate that for each reactor, the number of photons emitted per unit energy interval decreases exponentially with the photon energy in an energy range from 0.5 Mev to 8 Mev. For each spectrum, the number of photons per kev interval at 8 Mev was less by a factor of 10^4 than the value at 0.5 Mev. The average energy of each quantum for this type of spectrum was found to be approximately 1 Mev.

In the case of the Water Boiler, the results indicated that the total energy release of gamma-radiation from the U^{235} slug occurred at a rate of approximately 2×10^{13} Mev/sec. The fission and capture rates in

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the slug could not be determined accurately because the thermal neutron flux varied in a complicated way inside the slug. Because the measurements were made with the reactors operating in a steady state condition, the γ -rays comprising the spectrum consist of (1) prompt γ -rays accompanying the fission process, (2) delayed γ -rays following the β -decay of the fission products, and (3) capture γ -rays primarily from the product nucleus U^{236} . (The intensity of capture γ -rays for isotopes other than U^{235} can be neglected).⁽⁷⁾ From the fission and capture cross-section values⁽⁷⁾ of U^{235} and the γ -ray energy release^{(8), (9)} per fission and per capture, it is estimated that the γ -rays of groups (1) and (2) each contribute approximately 45 per cent of the total energy of the γ -radiation compared to 10 per cent contributed by the γ -rays in group (3).

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Figure 1

Secondary electron spectrum produced by gamma rays from the Los Alamos reactors.

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Figure 2

The solid line represents the cross section for Compton electron emission into the solid angle defined by spectrometer acceptance angle θ as a function of the incident photon energy k_0 . The dashed lines represent the "effective" cross section which includes the effects of electron scattering in the radiator and the effect of the finite extent of the radiator.

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Figure 3
Gamma ray spectra of the Los Alamos reactors.

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