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PHOTONEUTRON YIELDS FROM EXCITATION OF THE GIANT RESONANCE

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The calculations reported here are applicable to electron accelerators operating at energies greater than about 30 Mev. The electron beam is considered to collide with a large block of the material under consideration and then produces a soft shower. Some of the low-energy photons in this shower will excite the giant resonance of the target nuclei, and many photoneutrons will be produced. In order to calculate the photoneutron yield, we must know the soft-shower photon spectrum and also the photoneutron cross-section as a function of photon energy. The yield is then proportional to the integral over photon energy of the product of the spectrum and the photoneutron cross-section.

The photon spectrum is expressed in terms of the familiar track-length expression:[1]

$$(0.572)\,\frac{E_o}{E_\gamma^2}\,dE_\gamma \qquad (1)$$

This quantity is the total length of path (in radiation lengths)

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[1] See for example: B. Rossi, High Energy Particles (Prentice-Hall, New York, 1952), p. 244.

traversed by shower photons having energies between E_γ and $E_\gamma + dE_\gamma$ when an electron of energy E_0 produces a shower in an infinite target. The track length in centimeters is just (X_0/ρ) times the value given in Eq. (1), where X_0 is the radiation length for the target material in units of grams/cm^2, and ρ is the density in grams/cm^3.

The photoneutron yield is then given by

$$Y = N_1 \, (0.572) \, \frac{X_0 E_0}{\rho} \int \frac{\sigma(E_\gamma)}{E_\gamma^2} \, dE_\gamma \qquad (2)$$

where $\sigma(E_\gamma)$ is the photoneutron cross-section (in cm^2) of the target nuclei, and N_1 is the number of these nuclei per cm^3. N_1 is given by $(N_0 \rho/A)$, where N_0 is Avogadro's number and A is the atomic weight of the target nuclei. The typical form of $\sigma(E_\gamma)$ is shown below in Fig. 1.

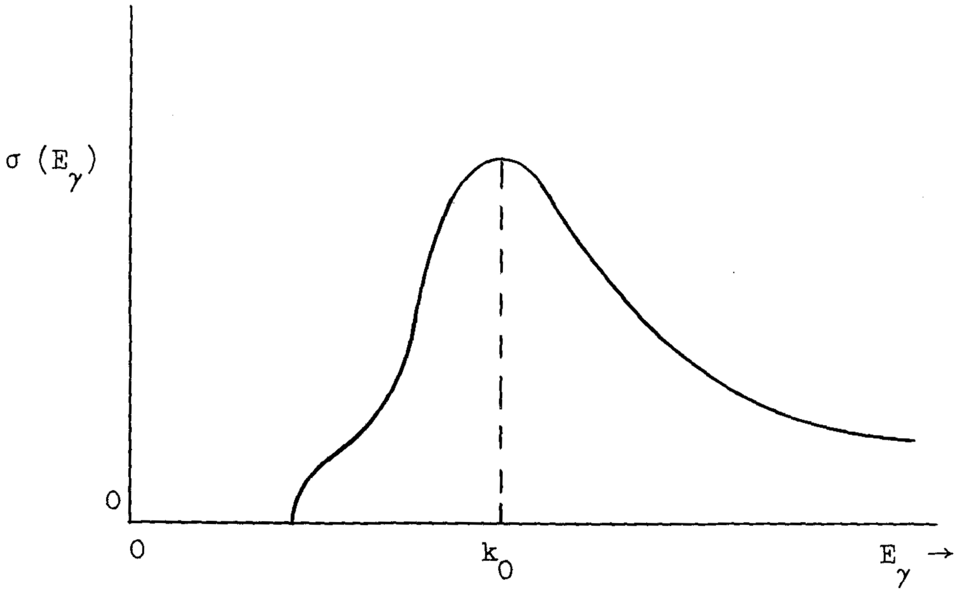

FIG. 1--Typical form of the photoneutron cross section.

Since E_γ^2 varies slightly over the main contribution of $\sigma(E_\gamma)$, the integral in Eq. (2) is replaced by

$$\frac{1}{k_o^2}\int \sigma(E_\gamma)\, dE_\gamma \qquad (3)$$

where k_o is the photon energy corresponding to the peak of the giant resonance shown in Fig. 1.

Finally, the yield is given by

$$Y \cong (0.572)\,\frac{N_oX_oE_o}{Ak_o^2}\int \sigma(E_\gamma)\, dE_\gamma \qquad (4)$$

This expression is used in obtaining the numerical results of Table II. In Table I, the values of k_o, X_o, and $\int \sigma(E_\gamma)\, dE_\gamma$ are presented for several target materials. The values of k_o and $\int \sigma(E_\gamma)\, dE_\gamma$ are obtained from experiment.

TABLE I

Target Material	X_o(grams/cm^2)*	k_o(Mev)	$\int \sigma(E_\gamma)\, dE_\gamma$ (Mev-barns)
C^{12}	44.6	22.9[d]	0.042[d]
Al^{27}	24.5	19.2[a]	0.045[a]
Fe^{54}	14.1	18.7[a]	0.48[a]
Cu	13.1	19.5[a]	0.80[a]
Au	6.6	13.9[b]	3.19[b]
Pb	6.5	13.7[a]	4.8[c]
U	6.2	13.8[b]	7.15[b]

*From ref. 1, p. 295 or calculated using Eq. (1), p. 220.

[a] Montalbetti, Katz, and Goldemberg, Phys. Rev. 91, 659 (1953)

[b] R. Nathans and J. Halpern, Phys. Rev. 93, 437 (1954)

[c] Obtained by integration of data given in reference a

[d] J. H. Carver and K. H. Lokan, Australian J. Phys. 30, 312 (1957)

TABLE II

Photoneutron Yields

From Eq. (4)

Target Material	Photoneutrons per electron per Mev of E_o	Photoneutrons per second per micro-ampere beam current per Mev of E_o
C^{12}	1.03×10^{-4}	6.40×10^{8}
Al^{27}	3.81×10^{-5}	2.38×10^{8}
Fe^{54}	1.23×10^{-4}	7.70×10^{8}
Cu	1.49×10^{-4}	9.31×10^{8}
Au	1.91×10^{-4}	1.19×10^{9}
Pb	2.76×10^{-4}	1.72×10^{9}
U	3.37×10^{-4}	2.10×10^{9}

Example: A 500 Mev, 20 μamp electron beam is incident on a lead target. How many neutrons are produced per second due to the giant resonance absorption? Use Table II, multiply by 500 × 20 to get $1.72 \times 10^{9} \times 500 \times 20 = 1.72 \times 10^{13}$ neutrons/sec.

Experimental results for Pb with $E_o = 34$ Mev obtained by Barber and George[2] are in good agreement with the yields given by Eq. (4).

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[2] W. C. Barber and W. D. George, Phys. Rev. <u>116</u>, 1551 (1959)

For example, their measurements give 9.5×10^{-3} neutrons/electron where calculations using Table II suggests 9.38×10^{-3} neutrons/electron.

The energy spectrum of the giant resonance neutrons is not well known. These neutrons are the products of evaporation from an excited nucleus, and may be expected to have energies no greater[3] than about 20 Mev, and most of the neutrons have energies between zero and 3 Mev. The angular distribution is nearly isotropic, although deviations have been observed for some nuclei.

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[3] See refs. 6 - 8 in ref. 2.