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Neutron Production by Electron Bombardment of Uranium

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A study has been made of the neutron yield from a natural uranium target in the 100-Mev betatron of the General Electric Company. For electron energies above 40 Mev, the neutron output is proportional to electron energy, for constant current in the betatron orbit. At lower energies, with the same current, neutron yield decreases faster than the electron energy.

INCREASING use is being made of photonuclear reactions for pulsed production of neutrons. Choice of accelerator parameters depends on a knowledge of neutron yields. Measurements of neutron yield, as a function of energy, have been made with the thick uranium target used in the General Electric 100-Mev betatron[1] for neutron production. The yield is strongly energy-dependent over the region of the giant resonance; at higher energies, a linear relationship is observed, which can be accounted for by cascade shower theory.

The uranium is made in the form of a cubical laminated target about 1.9 cm on a side. Mounted inside the betatron doughnut, this is the neutron source for a high-resolution neutron spectrometer[2]; approximately 0.11-microsecond bursts of neutrons are emitted when the electron beam is contracted to the target at the end of each acceleration cycle.

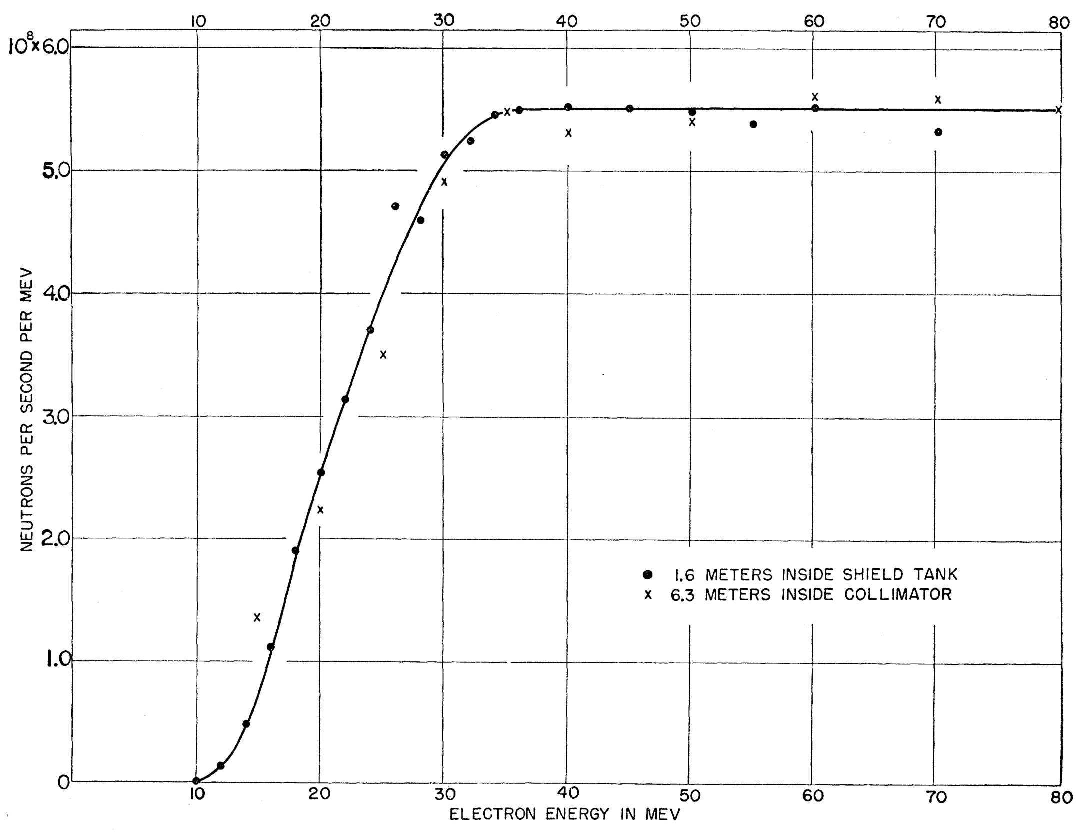

FIG. 1. Absolute yield of neutrons divided by electron beam energy, as a function of beam energy. The constancy of the data above 30 Mev indicates a linear variation of neutron yield with beam energy.

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† Operated for the U. S. Atomic Energy Commission by the General Electric Company.
[1] W. F. Westendorp and E. F. Charlton, J. Appl. Phys. **16**, 581 (1945).
[2] Yeater, Gaerttner, and Baldwin, Phys. Rev. **91**, 451 (1953).

Measurements of the neutron yield have been made with rhodium foils enclosed in a 9-inch cube of paraffin to detect fast neutrons. Observations were made at two points, one inside the water shielding tanks at 1.6 meters from the target, the other 6.3 meters from the target inside the neutron collimator. Each foil was exposed for 60 seconds, transferred to a Geiger-Müller counter during the 45-second period following, and then counted over an interval of 135 seconds. Calibration of the foil detectors was by exposure to a standardized polonium-beryllium neutron source.

Figure 1 shows the neutron yield as a function of the electron bombardment energy. Above 40 Mev, the neutron yield is directly proportional to electron beam energy. Below 35 Mev, in the resonance region, the neutron yield varies rapidly with beam energy, varying as E^2 at 30 Mev, E^3 at 22 Mev, and E^7 at 15 Mev. At 80 Mev, the average neutron yield is 4.5×10^{10} neutrons per second; the pulse repetition rate is 60 per second, and the full width at half-maximum of the approximately Gaussian pulse is 0.11 microsecond.

Figure 2 demonstrates that the target is effectively thick for all energies up to 80 Mev. For this measurement, the voltage of the orbit contraction system was varied, changing the rate of radial displacement of the electron beam. The neutron yield becomes practically constant if the voltage is sufficiently high, while the x-ray intensity observed at 30 degrees to the beam axis begins to decrease if the orbit contraction rate is raised above a certain optimum indicating that the electrons are striking the target farther in from its outer edge so that the x-rays undergo increased self-absorption.

For electron energies large compared to the photonuclear resonance energy, the neutron yield from a thick target is proportional to the electron beam power. The time-average neutron production rate in this case is given by

$$N(E_0)\sim I\int_0^{E_0}\sigma_n(\gamma)\lambda(E_0,\gamma)d\gamma,$$

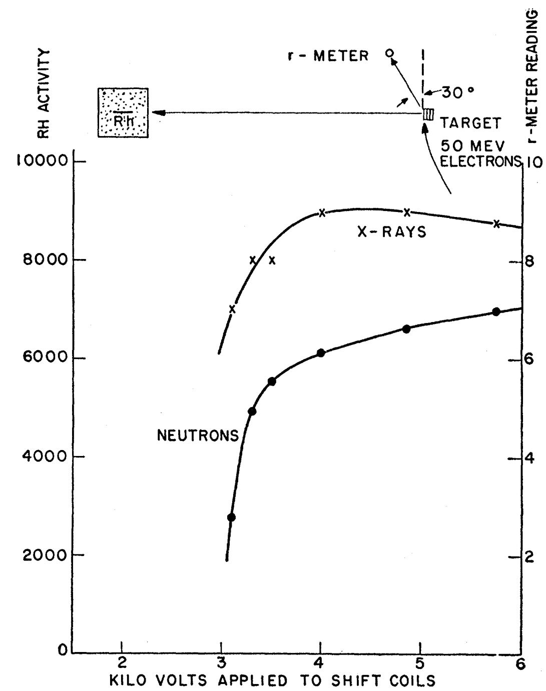

FIG. 2. Effect of variation in the rate of contraction of the electron orbit on the neutron-induced Rh activity and on the x-ray yield.

where E_0 is the incident electron energy, I is the time-average electron beam current, $\sigma_n(\gamma)$ is the cross section for neutron production due to all processes caused by photons of energy γ, and the track length for showers[3] is $\lambda(E_0,\gamma)\cong0.57E_0/\gamma^2$. This expression for the neutron yield differs from that given by Feld,[4] since it takes into account multiplicative showers.

[3] B. Rossi, *High-Energy Particles* (Prentice Hall, Inc., New York, 1952), Chap. 5.

[4] B. T. Feld, Nucleonics 9, No. 4, 51 (1951).