from left to right. The meson came to rest in the emulsion at point *B* and initiated a one-prong star; the one prong is the straight heavy track which begins at *B*. This event was found in a preliminary survey of meson production by neutrons from the cyclotron. The survey indicated that the neutron beam offered excellent opportunities for meson work, and systematic studies are being planned. Inasmuch as it may be some time before any results are available from these studies, we shall give additional details of the preliminary survey. In this survey we scanned hastily an area of 8 sq. cm of one plate which was exposed as shown in Fig. 1. The plate used was an Ilford C2 unbacked emulsion with a thickness before development of 300 microns. The exposure time was about 5 minutes at a distance of about 60 feet from the target. We found a total of 5 stars in which one of the outgoing particles was a meson. In addition, there were 4 meson tracks which could not be followed back to the points at which the mesons were formed. In the same plate area we found 5×10^4 stars at which no meson tracks were observed. We hesitate to use these numbers to estimate the cross section for the production of mesons by neutrons because of the uncertainty in the meson count. In this survey we made no attempt to find all of the mesons or to estimate the fraction of the total that might have been missed. Even with a more careful search we would not expect to see the higher energy mesons with this plate, since the C2 emulsion does not record mesons of energy greater than about 10 Mev.

We are indebted to Professor Ernest O. Lawrence for his continued interest in this work. We also wish to thank Professor R. L. Thornton for many helpful discussions. The first work on this problem was done by Professor C. M. G. Lattes, who has kindly given us the benefit of his experience. The photo-micrograph shown in Fig. 2 was prepared by Mr. A. J. Oliver.

* This work was done under the auspices of the AEC.

[1] Lattes, Muirhead, Occhialini, and Powell, Nature 159, 694 (1947).
[2] Hartsough, Hayward, and Powell, Phys. Rev. 75, 905 (1949).

Possible Techniques in Direct-Electron-Beam Tumor Therapy

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SINCE the invention of the betatron there has been some speculation concerning the merit of the use of a high energy electron beam instead of x-rays for tumor therapy because of a possible concentration of ionization at the end of the electron track in the tissue. The principal fault in this proposal is the fact that electrons once in the tissue change their direction markedly by elastic scattering[1,2] in the Coulomb field of the nuclei of atoms in the tissue. This scattering would cause the electrons, on the average, to "miss the mark."

The author has made approximate calculations, layer by layer, of the scattering of electrons in water (which is practically equivalent to tissue) with the use of the expression[2] for the mean-square scattering angle $\langle\theta_i^2\rangle=(K/E_i)^2l_i$, where E_i is the energy of the electron in Mev, $K=21$ Mev, l_i the thickness of layer number i is measured in radiation units, and where the angle $(\langle\theta^2\rangle)^{\frac{1}{2}}$ is required to be small. The radiation unit for water is 43 cm. The resultant mean-square scattering angle for n layers of tissue is then $\langle\theta^2\rangle=(\langle\theta_1^2\rangle+\langle\theta_2^2\rangle+\cdots\langle\theta_n^2\rangle)$. These calculations assume that the energy loss of the electron occurs entirely by ionization and follows the well-known variation with energy given by Bloch.[3]

The results of these calculations of the mean-square scattering are given in Figs. 1a and 2a for 50-Mev and 20-Mev electrons incident on tissue in the Z or depth direction (abscissa, in cm);

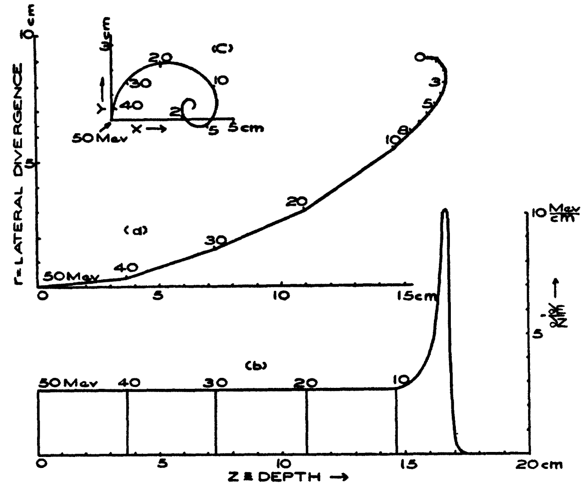

FIG. 1. (a) The calculated root-mean-square lateral displacement or divergence in cm *vs.* depth of penetration, Z, in cm for a 50-Mev electron entering tissue (water) in the Z direction. Energies in Mev of the electron at various points along its path are indicated.
(b) Loss of energy by ionization per unit length of depth, i.e., $-\partial E/\partial Z$, in Mev/cm *vs.* Z for the root-mean-square electron of (a).
(c) Scattered trajectory of the r.m.s. electron, as seen along the Z direction if a magnetic field of 10^4 oersteds is imposed in the Z direction.

the ordinate is the lateral displacement or divergence from the original line of direction in cm. Figures 1b and 2b are plots of $-\partial E/\partial Z$, the ionization loss per cm depth in Mev/cm for the same mean electrons. From these plots it can be seen that although $-\partial E/\partial Z$ increases markedly toward the end of its penetration in depth, the root-mean-square lateral displacement from its original direction is so great that the position of the beam is no longer precisely known.

If, however, a magnetic field in the Z direction is applied to the patient the scattered electron beam will be confined approximately to spiral-helical orbits, whose radii are determined by the lateral component of momentum and the magnetic field applied. The approximate calculated root-mean-square scatterings from the Z axis for the 50-Mev and 20-Mev electrons in a magnetic field of 10^4 oersteds are shown in Figs. 1c and 2c which show the approximate orbits of the root-mean-square electrons as viewed along the Z axis. From these plots it can be seen that at the end of the track the radial excursion from the original line of direction Z is considerably reduced by the imposition of a magnetic field of 10^4 oersteds. A magnetic field of 10^4 oersteds could be readily achieved with the help of an iron yoke, and the electron beam could be shot through one pole piece of this iron-core electromagnet. If

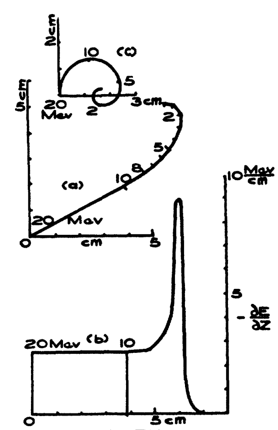

FIG. 2. (a), (b), (c), the same as Fig. 1 but for a 20-Mev incident electron.

intermittently operated magnetic field coils are used without an iron yoke, fields considerably higher than 10^4 gauss can be obtained, and the orbits diagrammed in Figs. 1c and 2c could be proportionally reduced in radius. The plot of $-\partial E/\partial Z$ remains essentially the same with or without a magnetic field.

One should not be too enamored of the apparently high sharp peaks in ionization loss (see Figs. 1b and 2b) at the end of the electron tracks. It should be remembered that since these plots are for the root-mean-square scattering of the electrons, approximately half of the electrons will scatter at larger angles and half at smaller angles than the root-mean-square value. This statistical distribution of scattering effectively smears out these peaks at the end of the electron tracks, and the resultant effective ionization as a function of Z cannot be elicited from the simple and approximate calculation made here.

With the external electron beam which has already been produced by the betatron and with the progress in the development of electron linear accelerators, relatively high current, monoenergetic electron beams in a usable energy range will soon be a reality. These machines might well be used for investigating the merit in the treatment of tumors by high energy electron beams projected parallel to a magnetic field into the patient. The electron beam treatment could, of course, follow the same technique used in x-ray treatments in which the patient is rotated in order to concentrate the tumor dosage but distribute the skin dosage.

Another possible technique in the use of electron beams in tumor therapy is to make a short (but, if necessary, deep) incision to the tumor, insert a tube about 1 cm in diameter to hold back the intervening tissue between skin and tumor and shoot the electron beam directly into the tumor (without the use of any magnetic field). Under these circumstances it should make little difference whether the electrons scatter because they will be in the tumor from the very start of their track in tissue. With this technique it should be possible to use a linear accelerator of fairly modest energy (4 Mev), length (4 feet), and cost. It should be possible to make ratio of tumor dose to surrounding-tissue dose exceedingly high because each 4-Mev electron can be made to lose practically all of its energy in the tumor. Hence the radiation dose given to the tumor can be made very large indeed without substantial radiation harm to the patient. It is then necessary for the patient to heal only a small incision instead of extensive radiation damage to blood and healthy tissue.

[1] E. J. Williams, Proc. Roy. Soc. **A169**, 531 (1938–1939).
[2] W. Heisenberg, Cosmic Radiation (Dover Publications, New York, 1946), p. 27.
[3] F. Bloch, Ann. d. Physik **16**, 285 (1933).

The Beta-Ray Distribution of Tc^{99}

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LINCOLN and Sullivan[1] studied a long-lived activity which was believed to be a technetium isotope produced by uranium fission. They reported it to decay by emission of beta-rays with a maximum energy of 0.4 Mev and estimated the half-life to be between 10^3 and 10^6 years. R. P. Schuman[2] prepared a source of the same activity and established that it was a Tc isotope by a tracer technique. He reported the maximum beta-energy as 0.3 Mev and the half-life as 3×10^5 years. Motta, Boyd, and Larson[3] used improved chemical separations and obtained extremely pure technetium activity produced by radiative neutron capture on Mo. They report the half-life as 9.4×10^5 years and the maximum beta-energy to be 0.32 Mev. Parker[4] and associates have separated the activity from the fission product mixture, and it has been identified to be Tc from its x-ray spectrum.[5] They report the half-life to be 4.7×10^5 years. Inghram, Hayden, and Hess[6] used part of the latter source and assigned the activity to a mass number of 99.

The source material used for this measurement was isolated from an acid chloride solution of irradiated uranium by precipitating platinum sulfide which carries other insoluble sulfides. Further purification consisted of five cycles of sulfuric acid distillation and sulfide precipitation. The sample was probably a mixture of two or more oxides since it was the residue from the evaporation of an ammonium hydroxide hydrogen peroxide solution of the sulfide. A detailed discussion of this process has been given elsewhere.[7] The total mass of the sample was approximately 10 mg, though the mass of the Tc was probably not more than 6 mg. The mount consisted of a one-inch Formvar film supported on a copper ring. The total area of the sample was approximately one cm^2.

The beta-ray spectrum was determined on a thin lens spectrometer constructed and described by W. C. Peacock.[8] The Kurie plot of the data is shown in Fig. 1. The maximum beta-energy is 0.30 ± 0.01 Mev. Since no conversion lines were observed with the spectrometer and no gamma-radiation was detectable when the source was counted with a thin window G–M counter, this isotope appears to decay by simple beta-emission. Because of the thickness of the source and the window cut off at the low energy end of the spectrum, the fact that the Kurie plot appears to be linear is not considered significant.

Feenberg and Hammack[9] have predicted from shell theory that this transition probably involved a spin change of three units and no parity change. They have also stated that the *ft* value computed by the empirical method of Konopinski and Uhlenbeck would indicate that the transition is highly forbidden. We have computed the theoretical half-lives by the method of Greuling[10] using several assumed spin changes. On the assumption that the transition is second forbidden tensor interaction with a spin change of three units, the computed half-life is 10^6 years compared to the observed half-life of from 5×10^5 to 9×10^5 years. Any lower degree of forbiddeness gives computed half-lives many orders of magnitude shorter than the observed half-life whereas any higher degree of forbiddeness with spin change greater than three units gives excessively long computed half-lives. However, the minimum half-life computed upon the assumption that the transition is third forbidden with a spin change of three units and with a change of parity is 1.7×10^7 years. If the observed half-life should be as long as 10^6 years, this value, 1.7×10^7 years, would be in agreement within the uncertainties of the values of the Fermi constant and the nuclear radius. However, should the

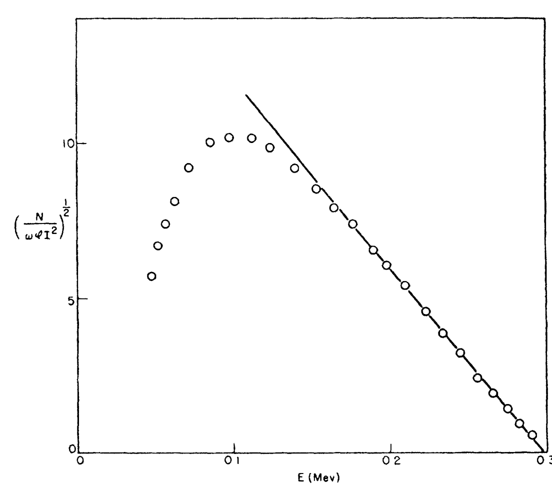

Fig. 1. Kurie plot of Tc^{99}.