LETTERS TO THE EDITORS

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1,000-Curie Cobalt-60 Units for Radiation Therapy

TELETHERAPY units using radium are limited in usefulness by the low radiation intensities produced by the small amounts of radium which can be used. To secure an adequate dosage-rate, the distance between the source and the tumour cannot be more than a few centimetres, and therefore the dose delivered to the skin lying between the source and the tumour is much higher than that delivered to the tumour. The dose-rate below the surface, expressed as a percentage of the dose-rate at the skin, decreases very rapidly with increasing depth. Thus the percentage depth-dose is influenced primarily by the inverse square law, and one of the chief advantages of high-energy radiation, namely, its small attenuation by the tissue between the source and the tumour, is not realized.

Any attempt to obtain an improvement in the depth-dose by increasing the amount of radium, and correspondingly improving the ratio between the source-to-tumour distance and the source-to-skin distance, is limited by the high cost of radium, and by the required increase in the volume of the source. If the diameter of the source is increased, it is harder to get a well-defined beam; if the thickness is increased, much of the radiation is lost by absorption within the source.

With the high density of neutron flux of the Canadian nuclear reactor at Chalk River, sources of cobalt-60 having specific activities of 20–60 curies per gm. can be prepared. One gram of this isotope will give about the same radiation output as 32–96 gm. of radium. The gamma-rays from cobalt-60 have energies of 1·17 and 1·33 MeV.; thus the average energy is about the same as that of the gamma-rays from a sealed radium source.

Two identical sources of cobalt-60 were made available by the Atomic Energy Project of the National Research Council of Canada in the summer of 1951 for experimental and clinical use. Each source is 1 in. in diameter and half an inch thick, and has an effective strength of 1,000 curies. Two quite different units have been designed to use these sources for radiation therapy.

One of the units, designed by two of us (H. E. J., L. M. B.) for the Saskatchewan Cancer Commission, was installed in the University Hospital, Saskatoon, in August 1951. This unit consists of a steel-encased lead cylinder, with rounded ends, 20 in. in diameter and 22 in. in length, and weighs about 2,000 lb. The source is mounted on the circumference of a wheel near the centre of a head, so that by rotating the wheel it can be brought opposite an opening in one end of the head through which the radiation can emerge. The head is suspended from an overhead carriage. It can be moved in a horizontal direction, raised and lowered, and rotated through 120° in a vertical plane. A rotating circular platform, flush with the floor, is provided for rotational therapy. A variety of treatment fields can be obtained by the use of interchangeable lead diaphragms. Light stainless-steel cones, attached to each of these, indicate the size of the field and fix the treatment distance. Circular fields and rectangular fields up to 20 cm. × 20 cm., at 80 cm. source-to-skin distance, can be obtained.

With the source rotated to the 'off' position, the dosage level 1 ft. from the head is less than 7 mr./hr. With the machine turned on, dosage-levels outside the treatment room, for the severest scattering conditions, are less than 5 mr./hr. Other measurements on this unit were carried out by members of the Saskatchewan group, and details of these will be found elsewhere[1].

The second unit, designed by R. F. Errington and D. T. Green, of the Development Division of Eldorado Mining and Refining (1944), Ltd., is installed in the clinic of the Ontario Cancer Foundation in the Victoria Hospital in London, Ontario. This unit consists of a head pivoted between the arms of a horizontal 'Y', so that it can be rotated downward in one plane through about 105°, that is, from a few degrees above the horizontal to a few degrees beyond the vertical. The horizontal arm can be moved up and down a vertical column by a motor-driven screw mechanism. The vertical column is supported from the floor by a base extending forward under the head.

The radiation beam emerges through a conical opening in the head. When the beam is 'off', this opening is filled with mercury. When the beam is turned on, an air compressor built into the horizontal arm is started, and air pressure forces the mercury up into a reservoir. If the beam is turned off, or if there is a power failure, the reservoir valve opens and the mercury returns, under gravity, to cut off the beam.

Field-sizes are varied by means of diaphragms in front of the opening in the head. Four lead blocks at right angles to each other can be adjusted by levers on the outside of the head to yield square or rectangular fields between 4 cm. × 4 cm. and 20 cm. × 20 cm., at 100 cm. from the source. The diaphragm system can be moved along the axis of the beam so that any source-to-skin distance between 70 cm. and 100 cm. can be utilized. In any position, the end of the diaphragm system is 13 cm. or more from the patient. A beam of light from a source at the same distance from the patient as the radiation source, and limited by the diaphragm in the same way as the radiation beam, is used as a field localizer. A detailed discussion of the unit, and of the depth-dose measurements made on it at the Radiology Laboratory of the National Research Council by some of us (National Research Council group), will be found elsewhere[1].

Depth-dose measurements were carried out in Saskatoon and in Ottawa, using D.C. amplifiers with small ionization chambers and water phantoms. The results were in excellent agreement. A summary of the percentage depth-dose data is given in the accompanying table. The maximum dose occurs 5–6 mm. below the surface of the phantom. The surface dose and the dose at any given depth depend on the size of the field. A distance of at least 15 cm. should be used between the limiting diaphragm and the surface of the phantom to reduce the electron content of the gamma-ray beam.

In the first two columns of the table, depth-dose data for the cobalt-60 units, using a 100 cm.² field at 100 cm. source-to-skin distance, is compared with data obtained by Miller[2] for a 2-MeV. Van de Graaff type X-ray unit. In the last two columns a comparison is presented between the cobalt data and measurements obtained by Trump[3] for a 3-MeV. Van de Graaff type X-ray machine, for 100 cm.² fields and for a source-to-skin distance of 70 cm. It is

Depth (cm.)	Field, 100 cm.². Distance, 100 cm. Cobalt-60	2 MeV. (ref. 2)	Field, 100 cm.². Distance, 70 cm. Cobalt-60	3 MeV. (ref. 3)
0·5	100	100	100	100
1·0	99	98	98	98
5·0	80	79	77	76
10·0	58	54	54	53
15·0	41	37	37	36
20·0	29	25	26	25

apparent that the percentage depth-doses for the cobalt are considerably higher than for 2-MeV. X-rays, and slightly higher than for 3-MeV. radiation. This indicates that the average energy of the photons from a 2-MeV., or even a 3-MeV., X-ray generator is lower than the average photon energy of a cobalt-60 source.

The cobalt units are flexible, simple to operate, and should require little servicing. They may prove to be very convenient sources of high-energy radiation for therapy.

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[1] *Brit. J. Rad.* (in the press).
[2] Miller, H., *Brit. J. Rad.*, **23**, 731 (1950).
[3] Trump, J. G., and Cloud, R. W. *Amer. J. Roent. and Rad. Ther.*, **49**, 531 (1943).

The Impossibility of Determining the Sun's General Magnetic Field by Zeeman Effect Measurements

Thiessen[1], v. Klüber[2], and Kiepenheuer[3] have recently achieved a very high accuracy in measuring the Zeeman effect of the Fraunhofer lines. Their results agree that, outside sunspots and other disturbed regions, the Zeeman effect is very small, corresponding to a few gauss or less. From this it is usually concluded that the sun's general magnetic field is less than a few gauss. This conclusion would be legitimate only if there were no turbulence in the photosphere.

Suppose that we observe a certain mass $\int dm$ of the photosphere. The absorption of a spectral line in a mass element dm is proportioned to a function $\beta(T)$ which depends mainly on the temperature T. Zeeman-effect measurements in the direction of a z-axis give an *apparent* field H_z:

$$H_z = \frac{\int H \cos\gamma \, . \, \beta(T)\, dm}{\int \beta(T)\, dm}, \qquad (1)$$

where H is the real field which makes an angle γ with the z-axis.

The field H is the vector sum of the sun's general field H_0 and a turbulent field H_t. From the granulation it can be concluded[4,5] that, in general, $H_t \gg H_0$. As the electric conductivity is so high that the magnetic lines of force are 'frozen in', an adiabatic change of the gas density ρ will, on the average, be accompanied by a change in $H \sim \rho^{2/3}$. As the temperature also changes as $\rho^{2/3}$, H is proportional to T. Hence, if ϑ is the angle between H_0 and H_t, we have:

$$T = \alpha H = \alpha (H_0^2 + H_t^2 - 2H_0 H_t \cos\vartheta)^{1/2}, \qquad (2)$$

where α is a constant.

Even if β is known, we can evaluate the relation between H_z and H_0 only if we know the turbulence spectrum. Until we do so, no conclusion about H_0 can be drawn from measurements of H_z.

In order to show this by a simple example, suppose that the turbulent field is isotropic, with H_t constant, that $\beta \neq 0$ only for a certain temperature $T = T_a$, and that H_0 is parallel to the z-axis.

The mean temperature T_m is:

$$T_m = \alpha \int_0^\pi (H_0^2 + H_t^2 - 2H_0 H \cos\vartheta)^{1/2} \, . \, \tfrac{1}{2} \sin\vartheta d\vartheta.$$

For $H_0 < H_t$ we obtain

$$T_m = \alpha (H_t + H_0^2/3\, H_t), \qquad (3)$$

which gives, with $H = T_a/\alpha$:

$$H = (T_a/T_m)\, [H_t + H_0^2/3\, H_t]. \qquad (4)$$

Introducing (4) and $\cos\gamma = (H^2 + H_0^2 - H_t^2)/2H\, H_0$ into (1) we obtain

$$H_z = \frac{H_0}{2}\left[1 + \frac{2}{3}\left(\frac{T_a}{T_m}\right)^2\right] - \frac{H_t^2}{2H_0}\left[1 - \left(\frac{T_a}{T_m}\right)^2\right].$$

For $T_a = 0 \cdot 9\ T_m$ and the $H_z = 3H_0$, we have $H_z/H_0 = -0 \cdot 1$.

Although this is a special case, it indicates that we cannot always be sure that Zeeman effect measurements give even the right sign of a weak field.

As $H_t \gg H_0$ does not hold for sunspot fields, there is no serious objection to making measurements of the Zeeman effect of such fields.

From the rate of progression of the sunspot zone, the magneto-hydrodynamic theory of sunspots shows the value of the general magnetic field to be:

$$37 > H_0 > 9 \text{ gauss}.$$

There seems at present to be no valid argument against a dipole field of this order.

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Anomalous Variation of Young's Modulus of Antiferromagnetics at the Néel Point

Measurements have been made on the variation of Young's modulus of two antiferromagnetic materials, nickel oxide and cobalt oxide, over ranges of temperature which include their Néel temperatures (the Néel temperature of an antiferromagnetic is that temperature below which antiparallel alignment of the spin vectors of the ions takes place). The specimens of the oxides were in the form of rods of square