FROM THE DIVISION OF RADIOLOGICAL PHYSICS, DEPARTMENT OF RADIOLOGY, UNIVERSITY OF VIRGINIA HOSPITAL, CHARLOTTESVILLE, VIRGINIA, U.S.A.

PHYSICAL MEASUREMENTS INCLUDING DEPTH DOSE DATA AND ISODOSE CURVES FOR 8 MV ROENTGEN RAYS

by

S. K. AGARWAL, R. V. SCHEELE and J. WAKLEY

An Arco Mevatron-8 linear accelerator recently installed (July 1969) at the University of Virginia Hospital varies in a number of ways from other models of linear accelerators in use today. It can be operated at specific electron energies from 3 to 10 MeV; the accelerator rotary drum rotates through more than 360° permitting both arc and full rotational therapy with clockwise and counterclockwise movements; the beam stopper is retractable; a beam bending magnet causes the electron beam to deflect through an angle of 261° towards the target; and there is a facility for a straight through undeflected electron beam. This paper is intended to present the results of physical measurements related to electron peak energy, roentgen ray assymetry, percentage depth doses and isodose curves which were made while preparing this machine for routine operation producing roentgen rays at 8 MV. The Brit. J. Radiol. Suppl. No. 10 includes 8 MV percentage depth dose tables which are based on only one set of reported data by NEWBERRY & BEWLEY (1955) while an unpublished report of which we are aware is that of WRIGHT et coll. (1969). We hope that this report of our experience with this machine and the results obtained will be of use to others in the future.

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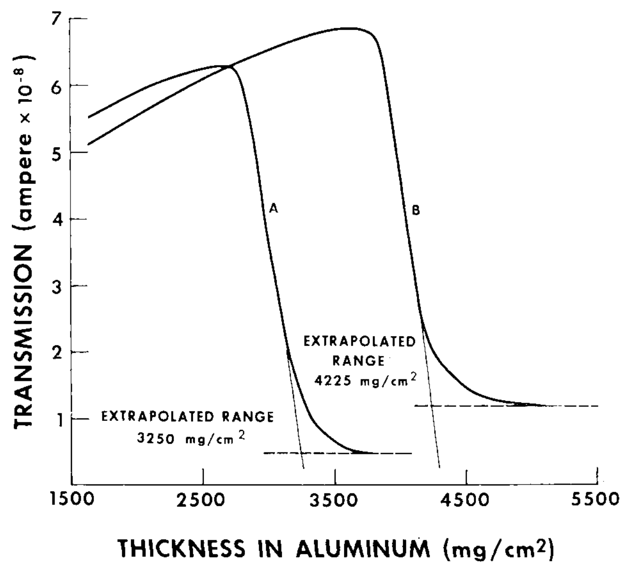

Fig. 1. Relationship between the transmission of electrons produced at 6 MeV (A) and 8 MeV (B) settings and the thickness of aluminium absorbers. The extrapolated range is at the intersection of the extrapolated transmission curve with the estimated contribution of background due to bremsstrahlung in the absorber and other causes.

Electron energy calibration. The Arco Mevatron-8 linear accelerator has been designed to operate between 3 and 10 MeV at 1 MeV intervals; however, the machine at this facility has been used to date at only two energies, 6 and 8 MeV. Electron energy calibration is achieved by the range measurement method as this was found to be the quickest and easiest to set up. Relative intensities of electron current are measured by a lN 2482 Sarkes Tarzian diode connected to a Model No. 610C Keithley electrometer. The diode detector is set at a distance of 100 cm from the target. Absorption curves of electrons are measured in aluminium (Fig. 1), and electron energy is evaluated from the range energy relationship given by KATZ & PENFOLD (1952)

$$R_p = 0.530\ T - 0.106 \qquad \text{for } 2.5 < T < 17 \text{ MeV}.$$

R_p is the extrapolated range in aluminium (g/cm^2), for electrons with kinetic energy, T.

Roentgen ray asymmetry. The determination of beam flatness is accomplished using a remote control radiation field scanner, which was manufactured in the department's machine shop, and is pictured in Fig. 2. This is used in conjunction with the diode-detector electrometer combination discussed previously. Its directional response was checked against a Baldwin-Farmer substandard dosimeter and found to be within ± 1 %. Typical beam flatness curves obtained

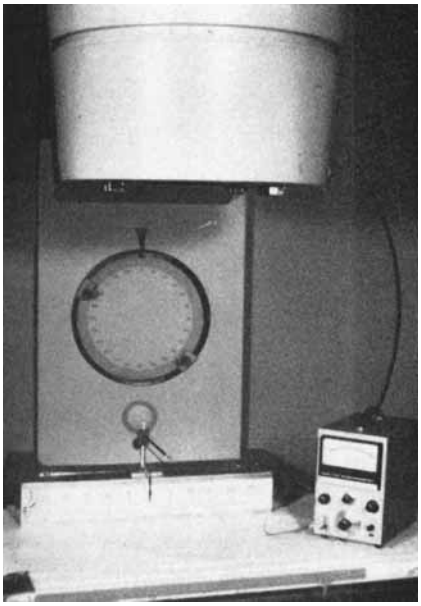

Fig. 2. Remotely controlled radiation field scanner along with the diode detector and Keithley electrometer.

with this measuring system are shown in Fig. 3. The flatness was found to be within ± 3—4 % over a 25 cm × 25 cm field with the collimator wide open and is not as good as the manufacturer's specification of ± 2.5 % beam flatness over the same field.

Roentgen ray output. Output is determined according to the procedure recommended in ICRU Report 10d (1963). For a preset dose at the control console, the output is determined at a depth of 5 cm in a water phantom at a target-to-water surface distance of 100 cm, with 10 cm × 10 cm field size at 100 cm. A Baldwin-Farmer substandard dosimeter, calibrated recently for cobalt-60 gamma rays at the National Bureau of Standards, and a Victoreen Radocon-555 equipped with a 100-HA probe are used for these measurements. The Baldwin-Farmer readings are corrected for temperature and pressure, chamber energy response, and multiplied by $C\lambda = 0.94$ (GREEN & MASSEY 1967). The corrected reading is divided by the percentage depth dose at 5 cm depth (89.3 %) to yield the dose at the maximum dose depth (2 cm). If the measured output varies from the preset dose by more than ± 2 %, the preset dose is changed by adjusting two variable resistors located inside the control console.

Depth dose measurements. Central axis depth dose measurements were made employing the diode-detector electrometer measuring system and a large water

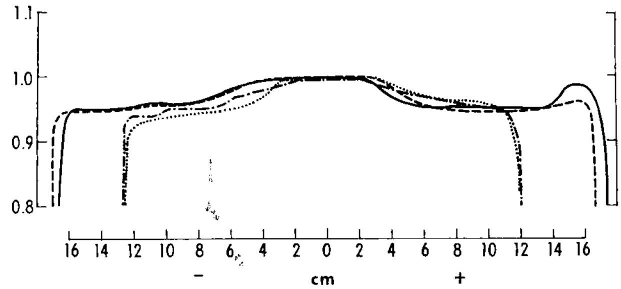

Fig. 3. Roentgen ray beam flatness curves along the axis parallel to the gantry (— - - —), perpendicular to it (- - - - - - -), and the two diagonal axes of the radiation field (——— and — — — —).

phantom (45 cm ×54 cm × 41 cm) equipped with a remote control probe moving mechanism (Fig. 4).

Linearity of the diode response at various depths within the phantom was checked against the Baldwin-Farmer substandard dosimeter. A plastic tank, having thin walled plastic tubes at two depths to provide a waterproof sheath for the substandard dosimeter, was employed to determine the dose rates at depths 2, 5, 10, 15 and 20 cm with a 10 cm × 10 cm field size at an SSD of 100 cm. Taking the dose rate at 2 cm to be the maximum, percentage depth doses at 5, 10, 15 and 20 cm were determined. These values were compared with those obtained using the diode probe in the large water phantom and were found to be in good agreement.

The phantom water surface was maintained at a constant distance of 100 cm from the target, and the diode was moved vertically until the electrometer registered a maximum reading. The depth at which this occurred was between 1.9 and 2.0 cm and was considered to be 2 cm from the surface. This level, rather than the water phantom surface, served as a reference for measuring the depths. Measurements were taken for various field sizes at 1 centimeter intervals to a depth of 22 cm and depth dose curves extended to a depth of 30 cm were drawn on semilogarithmic graph paper (Fig. 5). The table of central axis depth doses for the various square field sizes investigated was generated from these curves (Table), and the relationships between percentage depth dose and area of the field at depths of 4, 8, 12, 16, 20 and 24 cm are illustrated in Fig. 6.

Isodose curves were determined by employing the same water phantom and remote control moving probe mechanism described above. The probe was moved laterally at various depths ranging from 1 to 22 cm, with 1 cm depth increments for depths from 1 to 10 cm and 2 cm increments for depths greater than 10 cm. Readings were taken every 0.5 cm in regions of low dose gradient

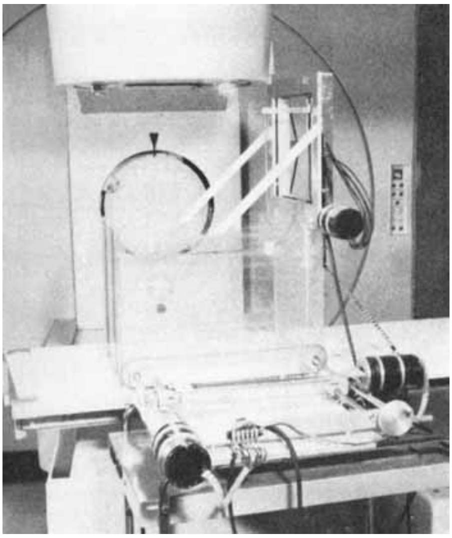

Fig. 4. The moving probe mechanism in a large water phantom (46 cm × 54 cm × 41 cm) with the remote control unit (manufactured in the machine shop of the department).

and every 0.2 cm in regions of high dose gradient. To check dose rate constancy during measurements, a reading at 2 cm depth was taken after each lateral excursion of the probe had been completed. The dose rate was found to remain constant ($\pm$ 0.5 %) throughout the measurements. The data were recorded on large graph paper and converted into percentages by taking the dose rate at 2 cm depth to be 100 %. Curves were drawn on semilogarithmic graph paper taking the abscissa as the lateral distance and the ordinate as the percentage dose. Some curves were also generated at a definite position lateral to the central ray taking depth as the abscissa and percentage dose as the ordinate. The points corresponding to the same percentage were plotted on linear graph paper and the resultant isodose curve was smoothed. Isodose curves for 10 cm $\times$ 10 cm, 15 cm $\times$15 cm and 7 cm $\times$ 20 cm field sizes are shown in Fig. 7.

Discussion

The electron peak energy, roentgen ray asymmetry for two perpendicular axes, and roentgen output (absorbed dose) are determined on a daily basis and the observations recorded on a log sheet. It has been found that there is no significant day-to-day variation in the electron energy (8.0 $\pm$ 0.2 MeV) and beam flatness ($\pm$ 4 %); however, the output has varied by more than $\pm$ 1 %. The daily log sheet has proven to be useful in anticipating or detecting faults in the system, e. g. an occasion when a change in beam asymmetry suggested a fault in the power supply to the steering systems.

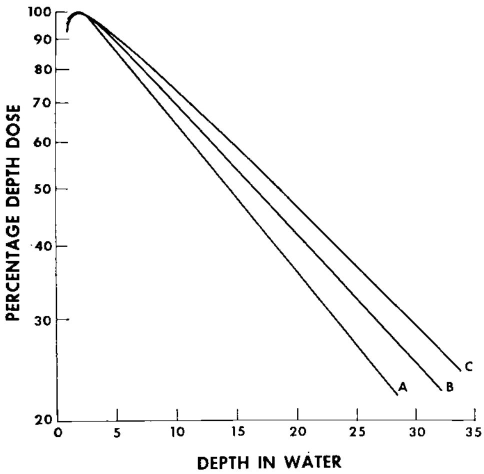

Fig. 5. Relationship between the percentage depth dose of 8 MV roentgen irradiation and the depth in water for three field sizes: 4 cm×4 cm (A), 10 cm×10 cm (B) and 25 cm×25 cm (C). SSD 100 cm.

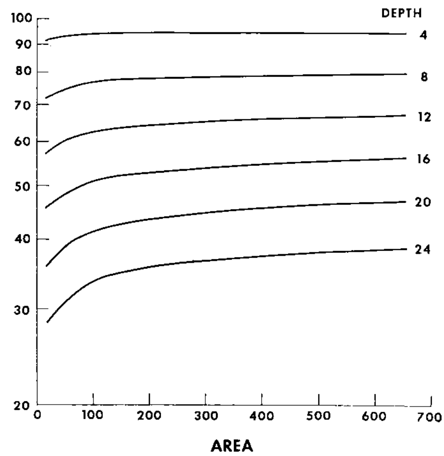

Fig. 6. Relationship between the percentage depth dose of 8 MV roentgen irradiation and the area of square fields at depths 4, 8, 12. 16, 20 and 24 cm. SSD 100 cm.

Table

Percentage depth doses at SSD 100 cm of an 8 MV roentgen ray linear accelerator

Depth (cm)	Field Size (cm × cm)						
	4 × 4	6 × 6	8 × 8	10 × 10	15 × 15	20 × 20	25 × 25
1.0	92.5	93.5	94.0	94.4	95.1	96.1	97.0
2.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
3.0	96.4	97.0	97.5	97.5	97.5	97.5	97.5
4.0	91.6	92.6	93.2	93.7	93.9	94.0	94.2
5.0	86.9	87.8	88.6	89.3	89.6	89.8	90.1
6.0	81.5	82.9	84.0	85.0	86.0	86.4	87.0
7.0	77.2	78.5	79.5	80.4	81.9	82.8	83.2
8.0	72.2	74.0	75.7	77.0	78.1	79.0	79.4
9.0	68.2	70.1	71.7	72.9	74.8	75.7	76.0
10.0	64.7	66.1	67.6	69.0	71.0	72.0	72.9
12.0	57.1	59.3	61.4	62.7	64.7	65.9	67.0
14.0	51.0	53.2	55.2	56.7	58.9	60.5	61.7
16.0	45.6	47.5	49.3	51.0	53.2	55.0	56.2
18.0	40.5	42.5	44.4	45.9	48.5	50.3	51.5
20.0	36.0	38.0	40.1	41.6	43.8	45.4	46.7

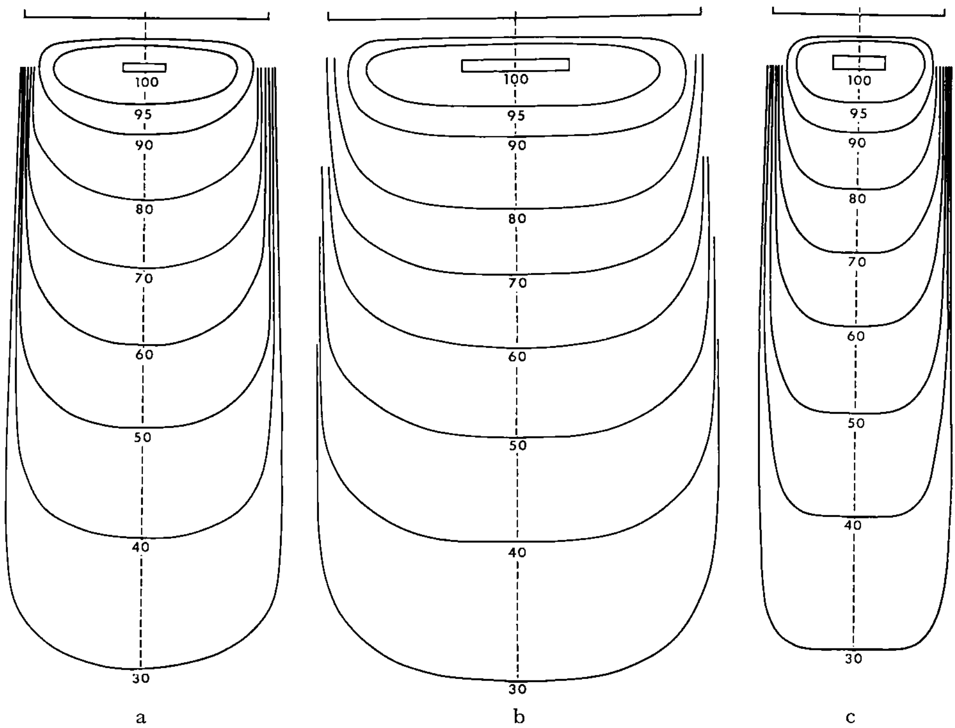

Fig. 7. Isodose distributions of 8 MV linear accelerator with percentages based on the point of maximum dose. SSD 100 cm. Field sizes: 10 cm × 10 cm (a), 15 cm × 15 cm (b) and 7 cm × 20 cm (c).

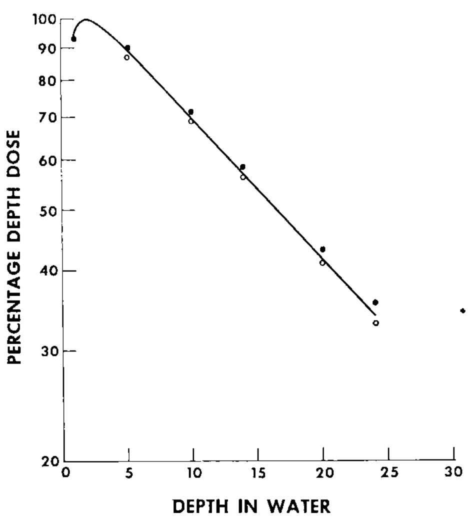

Fig. 8. Comparison of the percentage depth doses of 8 MV linear accelerators in the present investigation with those given in Brit. J. Radiol. Suppl. No. 10 (●), and those of WRIGHT et coll. (○). Field size 10 cm × 10 cm. SSD 100 cm.

The half-value thickness was found to be 13.1 mm Pb, but as the electron peak energy is a better indication of roentgen ray quality at this energy, the daily check of the electron energy is provided for on the daily log sheet.

Our central axis depth dose data are compared in Fig. 8 with the data in Brit. J. Radiol. Suppl. No. 10 and that obtained on a similar linear accelerator (WRIGHT et coll. 1969). Our data for a 10 cm × 10 cm field size agree with the Brit. J. Radiol. tables within ± 2 % and with the data of WRIGHT et coll. within ± 1 %. This resemblance confirms our previous observation that the response of the diode used in conjunction with the Keithley electrometer is linear. Isodose curves at this energy are not readily available, and therefore, no comparison can be made of the shape of the curves. The curves indicate that the optical field is defined by the 50 % isodose curve.

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SUMMARY

The Arco Mevatron-8 linear accelerator at the University of Virginia, designed to operate at 1 MeV intervals between 3 and 10 MeV, is being used for roentgen rays produced by electron energies of 6 and 8 MeV. The electron energy, roentgen ray flatness and absorbed dose are determined daily before the commencement of treatments, the energy being measured by extrapolating the electron range in aluminium. Central axis depth doses were measured in water for square fields from 16 to 625 cm^2, employing a remote control moving probe mechanism. The same mechanism was used to determine isodose curves. The results compared favorably with the existing data at this energy.

ZUSAMMENFASSUNG

Es wurde der Arco Mevatron-8 Linear-Accelerator der Universität von Virginia, der vorgesehen ist, mit 1 MeV Intervallen zwischen 3 und 10 MeV zu arbeiten, für Röntgenstrahlen verwendet, die durch Elektronenenergien zwischen 6 und 8 MeV hervorgerufen werden. Die Elektronenenergie, die Röntgenstrahlen-Abflachung und die absorbierte Dosis werden täglich vor Beginn der Behandlungen bestimmt, die Energie durch Extrapolation der Elektronenreichweite in Aluminium gemessen. Die Zentralstrahl-Tiefendosen wurden in Wasser für quadratische Felder zwischen 16 und 625 cm^2 gemessen, wobei ein Fernkontroll-System mit einem beweglichen Probenmechanismus verwendet wurde. Derselbe Mechanismus wurde verwendet, um Isodosis-Kurven zu bestimmen. Die Ergebnisse stimmen gut mit vorhandenen Daten bei dieser Energie überein.

RÉSUMÉ

L'accélérateur linéaire Arco-Mevatron-8 de l'Université de Virginie, construit pour fonctionner par intervalle de 1 MeV entre 3 et 10 MeV, a été utilisé pour la production de rayons de Roentgen au moyen d'énergie d'électrons de 6 à 8 MeV. L'énergie des électrons, l'homogénéité du faisceau de rayons Roentgen et la dose absorbée sont déterminées chaque jour avant le commencement des traitements, l'énergie étant mesurée en extrapolant la pénétration des électrons dans l'aluminium. Les doses en profondeur sur l'axe central ont été mesurées dans l'eau pour des champs carrés allant de 16 à 625 cm^2 en utilisant un mécanisme de sonde mobile télécommandée. Le même mécanisme a été utilisé pour déterminer les courbes isodoses. Les résultats obtenus supportent favorablement la comparaison avec les données existantes pour cette énergie.

REFERENCES

DEPTH DOSE TABLES FOR USE IN RADIOTHERAPY. Brit. J. Radiol. (1961) Suppl. No. 10.

GREEN D. and MASSEY J. B.: The use of Farmer-Baldwin and Victrometer ionization chambers for dosimetry of high energy x-radiation. Phys. in Med. Biol. 12 (1967), 569.

ICRU Report 10d: Clinical dosimetry. NBS Handbook No. 87, National Bureau of Standards, Washington 1963.

KATZ L. and PENFOLD A. S.: Range energy relations for electrons and determination of beta ray endpoint energies by absorption. Rev. mod. Phys. 24 (1952), 28.

NEWBERRY G. R. and BEWLEY D. K.: The performance of the medical research council 8 MeV linear accelerator. Brit. J. Radiol. 28 (1955), 241.

WRIGHT A. E., BUSHONG S. C., HUDGINS P. T. and BELLINGER D. L.: Calibration of energy and absorbed dose and measurement of dose distribution and tissue-air ratios for an 8 MV linear accelerator. Paper presented at the annual meeting of the American Association of Physicists in Medicine at Chicago in 1969. Abstract in Quart. Bull of AAPM 1969.