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DOSIMETRIC MEASUREMENTS AT THE NORDIC MEDICAL ACCELERATORS

I. Characteristics of the radiation beam

by

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National Standard laboratories can often provide a certain calibration service for determining absorbed doses of low energy roentgen rays and ^{60}Co γ-radiation for radiotherapy. Similarly developed routines are not available for electron and photon radiation emitted by betatrons or linear accelerators. Several intercomparisons of the absorbed dose at a reference point in the central ray have, however, been carried out by different laboratories. The dosimeters, ferrous sulfate or TLD, were sent to different laboratories, irradiated, and then returned for evaluation (PETTERSSON 1967a, EHRLICH & LAMPERTI 1969, HOLT et coll. 1969 and LOEVINGER et coll. 1969, etc.). Even though agreement between absorbed dose determinations is obtained at a reference point, large discrepancies can remain in the dosimetry since the measuring techniques for determining depth dose and isodose curves often differ.

WEBSTER & TSIEN (1965) have grouped together isodose curves from institutions and accelerator manufacturers in 15 countries for roentgen radiation between 7 and 35 MeV. Definite conclusions regarding the variations of isodose curves between different accelerators and laboratories are however impossible

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Table 1

Clinics visited during the tour in 1968

Clinic	Chief radiotherapeut and physicist	Accelerator manufacturer	Radiation	Maximum energy
Denmark				
Radiumstationen,	H. Johansen	BBC	e^-, rtg-rays	35 MeV
Copenhagen	J. Ambrosen	Varian	rtg-rays	6 MeV
		Varian	rtg-rays	6 MeV
Radiumstationen, Odense	P. B. Hansen	BBC	e^-, rtg-rays	35 MeV
	P. Omsveen			
Radiumstationen, Aarhus	S. Kaae	BBC	e^-, rtg-rays	35 MeV
	C. B. Madsen			
Finland				
Strålbehandlingskliniken,	L. R. Holsti	BBC	e^-, rtg-rays	35 MeV
Helsinki	E. Spring	BBC	e^-, rtg-rays	35 MeV
Norway				
Det Norske Radium-	E. Poppe	BBC	e^-, rtg-rays	31 MeV
hospital, Oslo	T. Brustad	BBC	e^-, rtg-rays	37 MeV
		Siemens	e^-, rtg-rays	18 MeV
Sweden				
Konung Gustaf V:s Jubi-	M. Strandqvist	BBC	e^-, rtg-rays	35 MeV
leumsklinik, Gothenburg	H. Sköldborn	AEI	rtg-rays	5 MeV
Radiologiska kliniken,	M. Lindgren	BBC	e^-, rtg-rays	35 MeV
Lund	K. Lidén			
Radiumhemmet, Stock-	J. Einhorn	Siemens	e^-, rtg-rays	18 MeV
holm	R. Walstam	Varian	rtg-rays	6 MeV
Konung Gustaf V:s Jubi-	L. G. Larsson	BBC	e^-, rtg-rays	35 MeV
leumsklinik, Umeå	G. Hettinger			
Akademiska sjukhuset,	B. Nohrmann	BBC	e^-, rtg-rays	35 MeV
Uppsala	J. Cederlund			
Radioterapeutiska kliniken,	O. Hallberg	Siemens	e^-, rtg-rays	42 MeV
Örebro	K. J. Vikterlöf			

since the radiation beams are often defined and measured in different ways and different methods are employed for determining the dose distribution. It is necessary to describe the radiation field in a uniform way in order to render intercomparisons of depth dose and isodose curves from different accelerators and laboratories meaningful. The International Commission on Radiological Units and Measurements (ICRU), Report No. 10 d (1963) recommends methods appropriate to energies below about 2 MeV for the qualitative specification of photon radiation and for the absorbed dose measurements; the Sub-committee on Radiation Dosimetry (SCRAD) of the American Association of Physicists in Medicine (1966) proposed similar recommendations for the electron beams up to 50 MeV.

The present paper summarizes a series of measurements made with different accelerators in Denmark, Finland, Norway and Sweden (Table 1) in order to investigate the possibilities of creating uniform and simple beam definitions with high energy roentgen rays and electron radiation. The tour took place during 3 months in 1968 and included visits to 11 laboratories with 14 betatrons and 4 linear accelerators. Measurements of the absorbed dose in a water phantom using these uniformly defined radiation beams will be summarized in another paper (SVENSSON 1971a); discrepancies in depth dose and isodose curves arising from differences in the constructional details of the accelerators will also be discussed.

Experiments

To allow each radiotherapy centre with an accelerator to define the radiation beam in a uniform way simple beam parameters should be recommended and simple and conventional measuring equipment used. The beam parameters determined in this investigation have been measured with elementary equipment which was transported in a small car between the 11 laboratories.

The energy of roentgen rays and electron beams. When electrons leave the acceleration orbit and meet the target, roentgen rays are produced whose maximum energy is equal to the kinetic energy of the electrons. If the electrons are withdrawn for electron therapy, however, their energy is reduced by the window of the vacuum-tube, by scattering foils, by possible monitor chambers, and by the air between the tube window and the patient. In principle two kinds of energy calibration are thus needed, one for roentgen rays and one for electron beams.

The energy calibration of roentgen rays was carried out with 11 betatrons by studying thresholds for (γ, n)-reactions with ^{12}C, ^{16}O and ^{63}Cu (18.7, 15.7 and 10.8 MeV respectively) in accordance with recommendations given by SCRAD (1966). Water, *n*-heptane (pro analysi) and granulated copper were used as test samples. Water and *n*-heptane were irradiated in plastic containers. The pure isotope of copper, ^{63}Cu, has been used in similar measurements by ALMOND (1967). Tests showed however that chemically pure copper containing both ^{63}Cu and ^{65}Cu could be used. The copper sample was irradiated in a cadmium container so that as small a background activity as possible should arise from ac-

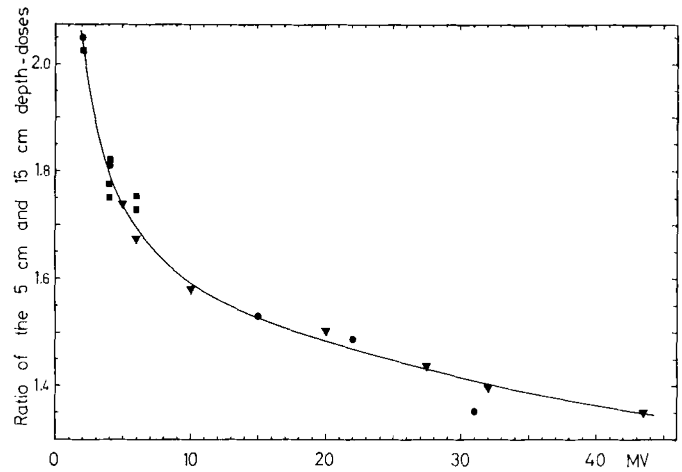

Fig. 1. The ratio of the 5 cm and 15 cm depth doses (SSD 100 cm, field size 10 × 10 cm) as a function of the maximum photon energy. The relative depth doses and MV are taken from HPA (1961) ●, Greene (1969) ■ and from the present investigation ▼. The values from Greene have been measured with different accelerators by different laboratories.

tivation by thermal neutrons. The measurements of the irradiated samples were carried out with a liquid GM-tube.

Threshold value determinations were similarly carried out with two of the betatrons using the reaction ^{16}O $(\gamma, 2n)$. The threshold value was taken to be 28.9 MeV (ICRU Report No. 14, 1969). The irradiated samples were measured with a NaI detector coupled to a pulse-height analyser. The full-energy peak at 2.3 MeV was measured.

For the investigated linear accelerators, with accelerating voltages about 5 and 6 MV, the peak photon energy was controlled by comparing the ratio of the 5 cm and 15 cm depth doses with those determined from published depth dose data. Ratios from published data are given in Fig. 1 as a function of the peak photon energies. The obtained curve may be uncertain because the accuracy of the peak energy determinations by the different laboratories or manufacturers are not known and, because the depth dose curves are dependent on the flattening filters, etc. In ICRU Report No. 14 (1969) it is stated, however, that the peak energy may be determined within 2 MV from published ratios (e. g. from Hospital Physicists' Association (HPA), 1961, 1968). From Fig. 1 it can be seen that the ratios are most critical for low photon energies where the possibility of energy determination by threshold analysis is lacking.

The energy calibration for electron beams was carried out by both threshold- and range-analysis. The sample for threshold analysis was placed inside the col-

Table 2

Practical extrapolated ranges, R_p, measured with different techniques — The estimated error in the determination of R_p was 0.1 cm

Electron energy E_0/MeV	Practical range, R_p/cm, extrapolated from		
	Depth dose* in H_2O	Depth ionization** in H_2O	Depth density*** in polystyrene
13.3	6.65	6.65	6.70
23.4	11.93	11.90	11.78
27.7	14.15	14.10	14.07

* Measured with $FeSO_4$ in a 30 × 30 × 30 cm water phantom.

** Measured with a small chamber in a 30 × 30 × 30 cm water phantom.

*** Measured with photographic film in a polystyrene phantom.

limator as close as possible to the scattering foil. The electron beam is always contaminated by roentgen rays produced in the tube window and in the scattering foil. These roentgen rays accounted for the whole or the major part of the induced radioactivity in the sample since their maximum photon energy was higher than the energy of the electrons hitting the sample. The mean energy loss of the electrons from collision losses in the tube window and scattering foil is for instance 1 to 2 MeV with a BBC 35 MeV betatron. Threshold analysis for electron radiation contaminated by roentgen rays thus gave an energy calibration which corresponded to the maximum energy of the contaminating roentgen rays. This latter, in turn, corresponded closely with the energy of the electrons leaving the acceleration orbit.

Energy-range relations have been determined by several investigators using ionization chambers for the range measurements; previously by e. g. MARKUS (1964), ALMOND (1967), POHLIT (1969), NÜSSE (1969). The point where the extrapolation of the linear fall-off of the depth ionization curves meet the roentgen ray background is usually called the practical range. In this investigation the practical range was measured from depth dose curves using $FeSO_4$ dosimeters and from depth ionization curves obtained with a thimble chamber in a water phantom and also from depth density curves obtained with film inside a special polystyrene phantom (HETTINGER & SVENSSON 1967). The effective measuring point with the thimble chambers was considered to be at a distance 3/4 r in front of the centre of the chamber; r being the radius of the chamber air cavity (HETTINGER et coll. 1967). Field sizes larger than 10 × 10 cm were used. Tests showed that the same practical range was obtained within 0.1 cm for a given MeV setting for the three techniques used (Table 2).

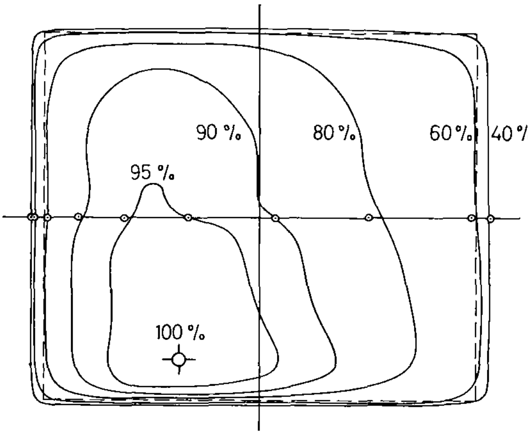

Fig. 2. Isodensity curves measured in laboratory No. 3 from a photographic film parallel to the phantom surface at a depth of 2 cm; field size 12 × 14 cm, e^--radiation 33 MeV. The electron beam was perpendicular to this plane. The ionization chamber checking points were normalized to the density per cent value at the central ray. The checking points at 95, 90, 80, 60 and 40 per cent relative ionization are shown. Ionization chamber ⊙, film density ———, geometrical field size — — —.

Field size and beam flattening. Irradiations were performed with the beam perpendicularly incident upon the surface of a polystyrene phantom. Photographic films were used to measure the density distribution on a plane parallel to the surface. For electrons the depth of the observation plane was 2 cm, and for roentgen rays 5 cm. If the film (Kodak Microtex) was developed immediately after irradiation, the blackening was found to be proportional to the absorbed dose up to 3.2 O.D.U. This blackening was obtained at approximately 20 rad (in water). A Kodak A-3 developer was used, the developing time being 3.2 minutes at a temperature of 23.0° C. When developing was carried out 6 days after irradiation the degree of blackening was approximately 20 % lower but it was still proportional to the absorbed dose.

The films were developed in Umeå 5 to 6 days after the irradiations and scanned with an automatic isodensity plotter according to methods described by Hettinger & Svensson (1967), and Pettersson (1967b).

The photographic film method was checked on all accelerators using thimble ionization chamber measurements in a water phantom. The thimble chamber was scanned in a plane perpendicular to the beam. The measuring depths were the same as those for the films. These checkings were carried out to investigate if the relative dose-picture with the short irradiations of the films — giving about 20 rad in dose maximum in water — were equal to the relative pictures from an irradiation time needed to give a patient dose (100 to 300 rad). One set of isodensity measurements and the ionization chamber checking points are shown in Fig. 2. With all the visited accelerators the agreement was about as good as the one shown in Fig. 2.

Source-surface distance (SSD). The divergence of the beam was determined from the enlargement of a square formed by 4 thin wires (POHLIT 1965). The wires were placed on the normal treatment distance and were reproduced on a photographic film positioned 20 cm behind them.

With roentgen rays the position of the focus was calculated from the divergence. The irradiations were carried out without flattening filters in the beams.

Compared with roentgen rays, electron beam depth doses show a minor dependency of the virtual SSD (SCHULZ 1969). An accurate determination of SSD with electron radiation is therefore not so important as with roentgen rays. With electron radiation the definition of the source is more complicated as tube window, scattering foil and possible transmission chambers scatter the electrons. It was, however, possible to measure a divergence as with roentgen rays even though the sharpness of the reproduced wires on the film was inferior. In this paper the SSD was defined with electron radiation by the distance from the surface to the calculated virtual focus.

Results and Discussion

Energy calibration of roentgen rays. The peak energy data, 5 and 6 MeV, given by the manufacturers, for the investigated linear accelerators agreed well with the energies estimated from comparisons between the measured ratios of 5 cm and 15 cm depth doses and published ratios (Fig. 1).

Irrespective of whether photon or electron radiation was used, the same calibration curves were obtained when the energy calibration of the MeV-meter was carried out through threshold analysis. The result could be predicted since the maximum photon energy for a certain MeV-meter reading will be the same no matter whether the roentgen rays are produced in the target or whether the electrons are withdrawn and contaminating roentgen rays are produced in the accelerator window. Consequently, for most of the betatrons, threshold analysis was used only with roentgen rays.

Energy calibration of electron radiation. The electron energy at the phantom surface can be calculated by correcting for energy losses in the accelerator tube window, the scatterer, the transmission chamber and in the air. NÜSSE (1969) pointed out that in experimental determination of the energy-range relationship, these energy losses have often not been taken into account. NÜSSE (1969) estimated the total energy loss by summing up the collision and radiation losses. Induced in Table 3 are all materials in the path of the electron beam of one of the BBC-betatrons (laboratory No. 11). The energy loss, however, has been calculated by considering only the collision losses. These were between 2.3 and

Table 3

Estimated energy-losses between accelerator tube and surface of the phantom — Laboratory No. 11 (BBC 35 MeV-betatron)

Material	$\Delta x \cdot \varrho$	$\Delta x \cdot \varrho \cdot \frac{S_{coll}}{\varrho}$ (15 MeV)	$\Delta x \cdot \varrho \cdot \frac{S_{coll}}{\varrho}$ (30 MeV)	Estimated error
Tube window	0.38 g/cm^2	0.65 MeV	0.68 MeV	±0.1 MeV
Scatterer 1	0.27 g/cm^2	0.40 MeV		±0.1 MeV
2	0.36 g/cm^2		0.56 MeV	
Monitors	0.52 g/cm^2	0.99 MeV	1.02 MeV	±0.1 MeV
Air(103 cm)	0.13 g/cm^2	0.25 MeV	0.29 MeV	
	Σ	2.3 MeV	2.6 MeV	±0.2 MeV

2.6 MeV in the energy range 15 to 30 MeV. The reason for considering collision losses alone was that only a few per cent of the primary electrons experienced radiation-loss on travelling through the material between the tube and the phantom. The energy loss is, however, on the other hand, on an average much greater through one radiation- than through one collision-process. Electrons which have lost a large portion of their initial energy are more likely to be scattered away from the radiation beam than other primary electrons.

Fig. 3, curve (a), shows the results obtained by calibrating the MeV-meter of one of the BBC-betatrons (laboratory No. 11) using threshold analysis. The energy of the electrons immediately before passing the accelerator window was determined. The energy, E_o (MeV), at the phantom surface, curve (b), was calculated by subtracting the energy loss arising from collision losses, 2.3 and 2.6 MeV at 15 and 30 MeV, respectively, according to Table 3. The practical range, R_p (cm), was determined at different MeV-meter settings — between about 10 to 30 MeV — as previously described. If the energy calibration according to Fig. 3, curve (b), were supposed to be correct, the following energy-range relation and standard errors (14 measurements of R_p) were obtained:

$$R_p = k_1 \cdot E_o - k_2$$

where

$k_1 = 0.520 \pm 0.003 \text{ MeV}^{-1} \cdot \text{cm}$

$k_2 = 0.26 \pm 0.08 \text{ cm}$

The energy-range relation was also determined with a Siemens 42 MeV betatron. The energy loss from accelerator window to the phantom arising from

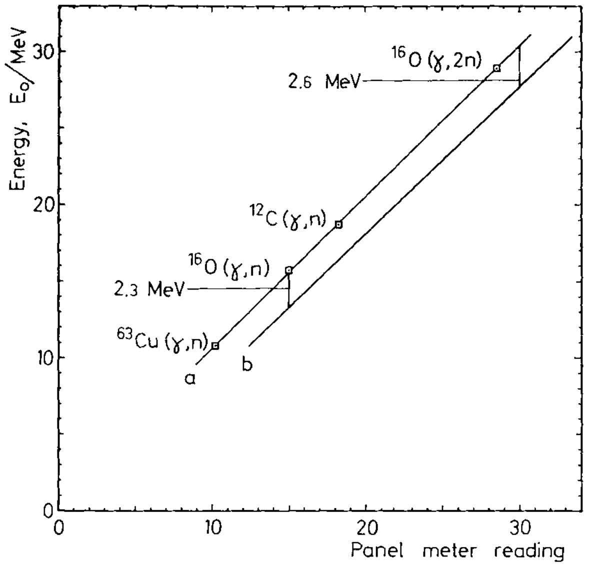

Fig. 3. Curve (a): Energy calibration of the MeV-meter at electron radiation using threshold analysis in laboratory No. 11. The energy of the electrons immediately before passing the accelerator window was determined. Curve (b): The energy at the phantom surface calculated by subtracting the energy loss arising from collision losses according to Table 2. This curve was correlated to the practical ranges measured with several MeV-meter settings; the coefficients k_1 and k_2 in the equation (p. 000) were determined.

collision losses was only 0.4 MeV at an electron energy of 15 MeV. (The scattering foils used at this energy for radiotherapy in order to flatten large field sizes gave collision losses between 1.0 and 1.7 MeV.) The energy-range relation determined with this betatron agreed closely with the equation.

The difference between the energy at the accelerator window (determined by (γ, n) analysis) and the energy at the phantom surface (determined from range-analysis using the equation) was 2.0 to 2.6 MeV at 15 MeV for 8 other BBC-betatrons. Data from the manufacturer show that the material in the path of the beam causes corresponding energy losses.

The measurements of R_p were made at SSD 103 cm with the BBC-betatron and at SSD 102 cm with the Siemens 42 MeV betatron. Correction of the depth dose curves to infinite SSD, as suggested by Nüsse (1969) increases R_p about 0.1 cm at 30 MeV and with smaller values at lower energies. Since most accelerators used in the Nordic countries employ SSD of about 100 cm this correction has not been made.

The systematic errors in E_o and R_p are not included in the errors given in the equation. The uncertainty in E_o arises due to: difficulties in measuring the thresholds ($\approx$ 0.1 MeV), uncertainty in absolute values of the threshold energies ($\approx$ 0.5 %, ICRU Report No. 14, 1969) and in calculating the collision losses ($\approx$ 0.2 MeV). The systematic error in R_p (Table 2) has been estimated to 0.1 cm, which corresponds to an uncertainty in E_o equal to about 0.2 MeV. The

Table 4

The ratio between the density on the central axis at 2 cm depth and the maximum density at this depth — The number of combinations of field sizes and energies investigated are given within parentheses

Laboratory number	e^--radiation	
	9 to 20 MeV	25 to 35 MeV
1	0.97 (6)	0.98 (2)
2	0.98 (5)	0.96 (10)
3	0.98 (5)	0.95 (9)
4	0.99 (9)	0.99 (8)
5	0.98 (5)	0.96 (7)
6	0.96 (6)	0.94 (7)
7	0.95 (5)	0.96 (6)
8	0.97 (6)	0.97 (9)
9	0.97 (5)	
10	0.96 (2)	0.95 (9)
11	0.99 (6)	0.99 (4)

over-all uncertainty in E_0 calculated from the arithmetic sum of the separate uncertainty plus standard error multiplied by t-factor for 95 % confidence level (ICRU Report No. 12) equals to ± 0.8 MeV.

The energy-range relation or threshold analysis with corrections for collision losses can be used only to provide an estimate of the primary electrons' maximum energy at the phantom surface. The average energy of the primary electrons at the phantom surface, on the other hand, depends upon the collision and radiation losses, energy degradation in the collimator, rejection of low-energy electrons by the magnetic field outside the accelerator orbit, etc. There is no simple method for determining the average energy. If, however, the energy-range relation is used in a uniform way by different centres to determine E_0 it is possible to transfer absorbed dose calibrations with thimble chambers with an uncertainty less than 2 % (SVENSSON 1971a).

The values of k_1 and k_2, in the equation agree with the factors recommended by SCRAD (1966), which are mean values from different investigators. This equation ought therefore to be possible to use by different centres to give the uniformity.

Field size and beam flattening. The maximum density on the photographic films, taken for the checking of beam flattening, was mostly situated outside the central axis (Fig. 2). The ratio between the density on the central axis and the maximum density was determined for electron radiation (Table 4). The ratios

Table 5

Average homogeneity indices for e^--radiation — Depth 2 cm H_2O, Field size, S, (10 to 200 cm^2)

Laboratory number	9 to 20 MeV		25 to 35 MeV	
	Area (90 %)/S	Area (80 %)/S	Area (90 %)/S	Area (80 %)/S
1	0.68 (5)	0.83 (5)	0.48 (2)	0.81 (2)
2	0.35 (5)	0.57 (5)	0.46 (10)	0.67 (10)
3	0.36 (5)	0.63 (5)	0.37 (9)	0.62 (9)
4	0.40 (9)	0.62 (9)	0.64 (8)	0.82 (8)
5	0.36 (5)	0.62 (5)	0.44 (7)	0.76 (7)
6	0.40 (6)	0.64 (6)	0.49 (7)	0.76 (7)
7	0.28 (5)	0.55 (5)	0.51 (6)	0.71 (6)
8	0.26 (6)	0.48 (6)	0.40 (9)	0.65 (9)
9	0.57 (5)	0.78 (5)		
10	0.82 (2)	0.90 (2)	0.80 (8)	0.94 (8)
11	0.62 (6)	0.80 (6)	0.78 (4)	0.93 (4)

quoted are average values of several measurements using two different energy ranges. Values within parentheses give the combinations of field sizes and electron energies employed with each accelerator. The relative standard deviations of the ratios were generally less than 4 %. Corresponding measurements were also carried out with roentgen rays. All irradiations were performed using scatterers or flattening systems which provided optimum flattening, both with electron- and roentgen-radiation. The density in the central beam was often considerably — up to about 10 % — lower than the maximum density. Even when different radiotherapy centres perform accurate calibrations in the central axis, the maximum absorbed dose to the patient can therefore vary depending upon different homogeneity. Treatment planning does not always eliminate this difference since isodose curves are often measured on a plane parallel with the beam direction. This plane does not necessarily go through the point which contains the absolute absorbed dose maximum.

In Fig. 2 the 90 % curve covers an area which is only 38 % of the geometrical field area; the 80 % curve covers an area which is 69 % of the field area. The geometrical field area was taken as that defined by the collimator or by the light-field on the phantom surface. These figures are measures of the flattening and have in this paper been defined as homogeneity indices. Table 5 shows average values of the homogeneity indices for electron beams with different accelerators. The standard deviations of the indices given in Table 5 were in general somewhat less than 0.1. The 90 % curve in most cases covered less than half the

Table 6

Homogeneity indices for roentgen rays — Depth 5 cm H_2O

Laboratory number	Rtg-rays	Field size, S (cm²)	Area (90 %)/S	Area (80 %)/S
1	40 MV	12×12	0.26	0.63
2	32 MV	8×8	0.61	0.83
3	33 MV	16×16	0.69	0.93
4	32 MV	16×16	0.72	0.95
	5 MV	10×10	0.72	0.89
5	32 MV	16×16	0.63	0.89
6	31 MV	16×16	0.78	0.98
7	32 MV	16×16	0.74	0.96
	6 MV	10×10	0.78	1.00
		20×20	0.78	0.98
8	33 MV	16×16	0.74	0.95
9	17 MV	7×8	0.60	0.94
	6 MV	6×6	0.78	0.96
		10×10	0.86	1.00
		20×20	0.94	1.00
10	34 MV	10×10	0.85	0.98
11	34 MV	8×8	0.73	0.94

geometrical field area. The values using the higher energies were often better than with the lower.

On a BBC-betatron the flattening of the electron beam depends partly upon the settings on the betatron's control panel, where the direction of the central beam in the plane of the accelerator tube can be influenced, and partly upon the scattering and collimator systems. Seven out of nine laboratories with BBC betatrons had added to them a balancing chamber which indicated small changes in the direction of the central axis of the radiation beam. The operator was thereby able to adjust the beam field from the control panel (PETTERSSON & HETTINGER 1965, VON ARX 1965, ROBINSON & MCDOUGALL 1967). The poor flattening of energies above 25 MeV in laboratory No. 3 (Table 5) arose from the absence of a balancing chamber.

BBC-betatrons are delivered with plexiglas tubes for limiting the beam. Owing to electron scattering in the tube walls, the dose at the edges of the geometrical field was considerably lower than at the field centre. This is one reason for the poor flattening shown in Table 5. On two of the betatrons, in laboratories No. 10 and 11, the plexiglas tubes had been replaced by a metal plate positioned as near the patient as possible. There was a circular hole in the centre of the plate. The aperture could be varied to provide a given field size ≤ 17.5 cm (SVENSSON & HETTINGER 1967). With these two betatrons the homogeneity indices increased by about 50 %. In laboratory No. 4 a similar collimator was employed for some field sizes; the average value of the homogeneity index consequently increased for this laboratory too. This type of collimator has now been further improved in laboratory No. 11. The transmission dose-monitor was replaced with a monitor system outside the central beam to minimize the scattering and energy degradation of the electrons. A light-field on the patient surface indicates the geometrical field size. The 90 % isodensity curve covers almost the whole of the geometrical field area with all field sizes smaller than ⌀ 19 cm. This investigation shows that it is possible to make homogeneous fields with electron radiation (SVENSSON 1971b).

The flattening of photon radiation is given in Table 6. Measurements were performed using only one field size. The flattening of photon radiation was decidedly better than that of electron beams. The best flattening was obtained with 5 to 6 MV linear accelerators.

SCRAD (1966) recommended that the field size be defined by the dimensions of the plane figure described by the intersection of the 90 % isodose surface with the plane passing through, and normal to, the central axis at the position of the relative dose maximum which is normalized to 100 %. This definition of field size was inapplicable to the majority of the betatrons investigated for both electron- and photon-radiation since, according to Tables 5 and 6, the flattening was too poor. The 90 % isodose surfaces describe irregular figures and depth dose curves cannot in a meaningful way be correlated to these figures.

SSD determination was made for 6 of the BBC-betatrons. An experimentally determined SSD of 103 ± 2 (standard deviation) cm for electron radiation may be compared with a value of 110 cm provided by the manufacturer. The measured distance is equal to that from the window of the accelerator tube to the edge of the collimator facing the phantom. For roentgen rays an SSD of 101 ± 3 cm may be compared with 100 cm given. The SSD approximately corresponded to the distance between the target and the surface.

Using a Siemens 42 MeV betatron, SSD:s for electron- and roentgen-radiation were found to be 102 cm and 105 cm, respectively. The manufacturer's figures were 100 cm in both cases.

Conclusions

(1) The methods employed for energy calibration, that is, threshold analysis and range analysis, gave consistent results with the 11 betatrons. A uniform energy calibration of betatron radiation is thus possible.

(2) Dose maximum lies outside the central axis for most of the beams used from the 11 investigated betatrons. Even when the different centres have uniform absorbed dose calibrations in the central axis the maximum dose to the patient may thus differ as much as 10 %.

(3) With most of the betatrons the flattening was remarkably bad. The degree of inhomogeneity which can be tolerated in radiation therapy need to be investigated. A homogeneity index, defined in this paper, may be used to describe the flattening. The description of field size should include both the geometrical size and the homogeneity index. The manufacturers of betatrons ought to improve the scattering foils and collimating systems so that better flattening is obtained.

(4) Simple measuring equipment could be used to measure energy, the point of dose maximum outside the central ray, flattening, and SSD. If these characteristics of the beams are determined by the different laboratories, more uniform absorbed dose calibrations ought to be possible to perform; depth dose and isodose curves from the different laboratories ought to be possible to compare in a more meaningful way (Svensson 1971a).

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SUMMARY

A measuring program was carried out at betatrons and linear accelerators at 11 laboratories in Denmark, Finland, Norway and Sweden. It was shown that simple equipment could be used to determine energy, flattening and SSD in a uniform way with the different accelerators. In order to describe the beam flattening a proposal was given for a homogeneity index.

ZUSAMMENFASSUNG

Ein Messprogramm für Elektronenschleudern und Linearacceleratoren von 11 Laboratorien in Dänemark, Finland, Norwegen und Schweden wurde durchgeführt. Es wird gezeigt, dass eine einfache Ausrüstung verwendet werden kann, um die Energie, die Abflachung und die SSD in gleichmässiger Weise bei den verschiedenen Acceleratoren zu bestimmen. Um die Strahlenabflachung zu beschreiben wird ein Vorschlag für einen Homogenitätsindex gemacht.

RÉSUMÉ

Les auteurs ont exécuté un programme de mesures sur des bétatrons et des accélérateurs linéaires dans onze laboratoires situés au Danemark, en Finlande, en Norvège et en Suède. Ils ont montré qu'on peut utiliser un équipement simple pour déterminer l'énergie, la planéité et la distance source peau d'une façon uniforme avec les différents accélérateurs. Ils proposent un index d'homogénéité pour définir la planéité du faisceau.

REFERENCES

ALMOND P. R.: The physical measurements of electron beams from 6 to 18 MeV: Absorbed dose and energy calibration. Phys. in Med. Biol. 12 (1967), 13.

VON ARX A.: Continuous or periodical control of field homogeneity. *In:* Symposium on high-energy electrons, p. 85. Edited by A. Zuppinger and G. Poretti. Springer-Verlag, Berlin 1965.

EHRLICH M. and LAMPERTI P. J.: Uniformity of high-energy electron-beam calibrations. Phys. in Med. Biol. 14 (1969), 305.

GREENE D.: The HPA and AAPM survey of depth-dose data for teleisotope γ-rays and megavoltage X-rays. *In:* High-energy radiation therapy dosimetry. Edited by J. S. Laughlin. Ann. N. Y. Acad. Sci. 161 (1969), 168.

HETTINGER G. and SVENSSON H.: Photographic film for determination of isodose curves from betatron electron radiation. Acta radiol. Ther. Phys. Biol. 6 (1967), 74.

— PETTERSSON C. and SVENSSON H.: Displacement effect of thimble chambers exposed to a photon or electron beam from a betatron. Acta radiol. Ther. Phys. Biol. 6 (1967), 61.

HOLT J. G., ALMOND P. R. and MEURK M. L.: Intercomparison and calibration of high-energy X-rays and electrons. *In:* High-energy radiation therapy dosimetry. Edited by J. S. Laughlin. Ann. N. Y. Acad. Sci. 161 (1969), 133.

HOSPITAL PHYSICISTS' ASSOCIATION (HPA): Depth dose tables for use in radiotherapy. Brit. J. Radiol. Suppl. 10 (1961).

— A review of Suppl. No. 10: Depth dose tables for use in radiotherapy. Brit. J. Radiol. 41 (1968), 932.

INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS (ICRU): Report No. 10d. Clinical dosimetry, National Bureau of Standards, Handbook 87. NBS, Washington 1963.

— Report No. 12. Certification of standardized radioactive sources. ICRU, Washington 1968.

— Report No. 14. Radiation dosimetry: X-rays and gamma rays with maximum photon energies between 0.6 and 50 MeV. ICRU, Washington 1969.

LOEVINGER R., PFALZNER P. M., EISENLOHR H. et coll.: The IAEA program in medical radiation dosimetry. *In:* High-energy radiation therapy dosimetry. Edited by J. S. Laughlin. Ann. N. Y. Acad. Sci. 161 (1969), 158.

MARKUS B.: Beiträge zur Entwicklung der Dosimetrie schneller Elektronen. Teil II. Strahlentherapie 123 (1964), 508.

NÜSSE M.: Factors affecting the energy-range relation of fast electrons in aluminium. Phys. in Med. Biol. 14 (1969), 315.

PETTERSSON C. (a): Absolute and relative radiation dosimetry at a 35 MeV medical betatron. The Department of radiation therapy and physics, University of Umeå, 1967.

— (b) Automatic isodensity recorder for photographic dosimetry. Acta radiol. Ther. Phys. Biol. 6 (1967), 225.

— Hettinger G.: A balancing chamber for stabilizing the homogeneity of the electron field between 10 and 35 MeV. *In*: Symposium on high-energy electrons, p. 89. Edited by A. Zuppinger and G. Poretti. Springer-Verlag, Berlin 1965.

Pohlit W.: Dosimetrie zur Betatrontherapie. Georg Thieme Verlag, Stuttgart 1965.

— Energy calibration of betatron X-rays and electrons up to 40 MeV. *In:* High-energy, radiation therapy dosimetry. Edited by J. S. Laughlin. Ann. N. Y. Acad. Sci. 161 (1969), 119.

Robinson J. E. and McDougall R. S.: Electron beam instability and isodose asymmetry associated with a 35 MeV medical betatron. Phys. in Med. Biol. 12 (1967), 315.

Schulz R. J.: AAPM/HPA survey of high-energy electron depth-dose data. *In:* High-energy radiation therapy dosimetry. Edited by J. S. Laughlin. Ann. N. Y. Acad. Sci. 161 (1969), 176.

Sub-Committee on Radiation Dosimetry (SCRAD) of the American Association of Physicists in Medicine: Protocol for the dosimetry of high energy electrons. Phys. in Med. Biol. 11 (1966), 505.

Svensson H. (a): Dosimetric measurements at the Nordic medical accelerators. II. Absorbed dose measurements. To be published in Acta radiol. Ther. Phys. Biol. 10 (1971).

— (b) The influence of scattering foils, transmission monitors and collimating system on the absorbed dose distribution from 10 to 35 MeV electron radiation. To be published in Acta radiol. Ther. Phys. Biol. 10 (1971).

— and Hettinger G.: Influence of collimating systems on dose distribution from 10 to 35 MeV electron radiation. Acta radiol. Ther. Phys. Biol. 6 (1967), 404.

Webster E. W. and Tsien K. C.: Atlas of radiation dose distributions. Vol. I. Single-field isodose charts. IAEA, Vienna 1965.