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DOSIMETRIC MEASUREMENTS AT THE NORDIC MEDICAL ACCELERATORS

II. Absorbed dose measurements

by

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The measurements performed in order to define the beams emitted from betatrons and linear accelerators in 11 Nordic laboratories were summarized in a previous paper (SVENSSON & HETTINGER 1971). The present paper describes measurements of absorbed dose carried out with the same accelerators. These investigations were performed during a 3-month tour to the accelerator centres in 1968.

The aim of these investigations was to determine differences in the basic dosimetry of the different laboratories, to investigate the possibility of establishing uniform dosimetry employing simple measuring equipment, and to account for and compare depth dose curves obtained from the uniformly measured and defined radiation beams. The discrepancies in absorbed dose calibration factors of thimble ionization chambers and in depth dose curves arising from differences in the constructional details of the accelerators are also discussed.

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Experiments

Phantom material and size

Various materials have been used for phantoms in different laboratories; accordingly, phantoms of wax, polystyrene, perspex, pressed wood and water were used in measuring the isodose curves published in the IAEA catalogue (WEBSTER & TSIEN 1965). Several of these materials were of different densities and compositions in various laboratories.

In the present study the absorbed dose was determined in water. When measuring technique required use of another phantom material — polystyrene for film dosimetry — factors were determined which allowed correction to the conditions pertaining to a water phantom. The reasons underlying this procedure were: (1) that absorption and scattering properties of muscle tissue and water are very similar (RASSOW 1969), (2) that comparisons between various laboratories are simplified by the constant consistency of water, and (3) that Hospital Physicists' Association, HPA, (1969), and International Commission on Radiation Units and Measurements, ICRU, Report No. 14 (1969) proposed that the absorbed dose of high energy photon radiation be determined in water.

A $30 \times 30 \times 30$ cm water phantom was used in measuring the absorbed dose in water with $FeSO_4$ dosimeters or thimble chambers. The wall facing the beam was made of 0.6 cm thick clear polystyrene, the others were made of perspex.

Dosimeter system

Ferrous sulfate dosimeters. A detailed description of the ferrous sulfate dosimeter technique used in this investigation has been given by PETTERSSON & HETTINGER (1967).

With an irradiation temperature of 25.0° C G-values (0.4 mole/l H_2SO_4) of 0.1556 ± 0.0012 eV^{-1} and 0.1557 ± 0.0014 eV^{-1} (standard errors) were employed for electron- and ^{60}Co γ-radiation respectively (PETTERSSON 1967). For roentgen rays 5 to 10 MV, and exceeding 11 MV, the G-values were considered to be 0.156 eV^{-1} and 0.157 eV^{-1} respectively (ICRU, Report No. 14, 1969).

Polystyrene or polyethylene irradiation cells were used. The effect on the dosimeter solution by storing in these plastic cells has been reported by SVENSSON et coll. (1967).

With photon radiation the absorbed dose in the dosimeter solution is mainly contributed from electrons originating in the water and in the ferrous sulfate solution as the dosimeter walls and the cell holder of polystyrene are made of thin materials. The mass energy absorption coefficient was considered to be the same for water and for the dosimeter solution when photon radiations with

effective energies between those of ^{60}Co γ-radiation and 43 MV roentgen rays were used (SHALEK & SMITH 1969). With both photon and electron radiation the ratio between the absorbed dose in water (D_w) and that in the dosimeter solution (D_d) is therefore equal to the ratio between the mass stopping power of the water and solution, i.e.,

$$\frac{D_w}{D_d} \approx 1.004 \tag{1}$$

Thimble chambers. A Baldwin Farmer roentgen ray dosimeter (0.6 cm^3 ionization chamber) and a Siemens Sondenfingerhutkammer connected to an automatic compensating Townsend circuit, (WICKMAN, to be published), was used. The chambers were calibrated with ^{60}Co γ-radiation at the Swedish National Institute of Radiation Protection (in 1964, 1966 and 1967) and with 2 MV radiation at National Physics Laboratory (NPL) England (in 1968). The calibration factor in R/scale division from the former laboratory was 1.5 % lower than that from NPL. The lower calibration factor was used in the present investigation to allow comparisons with earlier publications.

Instrument control. The instruments were transported by car between the accelerator laboratories in Sweden, Finland, Norway and Denmark. The thimble chambers were checked against each other in each laboratory with a ^{60}Co γ-beam and against a commercial (Baldwin Farmer) ^{90}Sr reference source. The ionization chamber controls showed a relative standard deviation of 0.2 % during the journey. The $FeSO_4$ dosimeters were checked against the thimble chambers with ^{60}Co γ-beams and gave a standard deviation of 0.3 %.

Measurements of depth dose and depth ionization curves

Depth dose curve. The absorbed dose was measured along the central beam in the water phantom with $FeSO_4$ dosimeters. The dosimeter cells were placed in a row in a polystyrene holder inside the water phantom. Corrections were made taking into account the disturbance of the fluence in the water by the $FeSO_4$ dosimeters and the cell holder. The correction factors were determined with an ionization chamber, which was irradiated in the water phantom when the $FeSO_4$ dosimeters were and were not present. These corrections depended upon the radiation quality and measuring depth and were maximally 1.5 %.

Depth ionization curves. HETTINGER et coll. (1967 a) showed that relative depth ionization curves, measured with different commercial thimble ionization chambers, agreed for both photon and electron radiation provided that the effective measuring point of the chamber was situated 3/4 r in front of the

centre of the chamber, r being the radius of the chamber cavity. The depths of the thimble ionization chamber were set to within 0.2 mm with an automatic device.

Absorbed dose calibration of the thimble chambers

Definitions. For electron radiation SVENSSON & PETTERSSON (1967) and for roentgen rays HETTINGER et coll. (1967 b) defined an absorbed dose calibration factor for thimble ionization chambers, k (rad · R^{-1}), which converted the instrument reading to the absorbed dose in water at the effective measuring point through,

$$D_w = k_{^{60}Co} \cdot M \cdot k \text{ or } k = \frac{D_w}{k_{^{60}Co} \cdot M} \quad (2)$$

where,

D_w is the absorbed dose in water at the position of the measurement point of the chamber when the chamber is replaced by water and an identical irradiation given; rad.

$k_{^{60}Co}$ is the ^{60}Co exposure calibration factor of the chamber at a specified temperature and pressure of the air determined in free air at SSD 100 cm and field size 10 × 10 cm when a 4 mm thick build-up cap of perspex is used; R/div.

M is the instrument meter reading corrected for general recombination and corrected to air of the same temperature and pressure; div.

The definition of the k-factors differs from that of the C_λ-values defined by HPA (1969) in the respect that an effective measuring point was used, defined above, instead of the centre of the thimble ionization chamber. In addition, the C_λ-values are defined only for special depths and chamber dimensions.

Measurements of absorbed dose calibration factors

A depth dose curve measured with $FeSO_4$ dosimeters and a depth ionization curve measured with a thimble chamber at 32 MV roentgen rays are shown in Fig. 1. Similar measurements of depth dose and depth ionization curves were also performed with electron radiation. The ratio between the curves at a given depth is according to the definition, equal to the chamber's absorbed dose calibration factor, k, at this depth. Corrections for the inhomogeneity of the beam were applied since the ionization chambers and the $FeSO_4$ dosimeters have different dimensions orthogonal to the central ray. These corrections were determined with photographic films in a polystyrene phantom (SVENSSON & HETTINGER 1971).

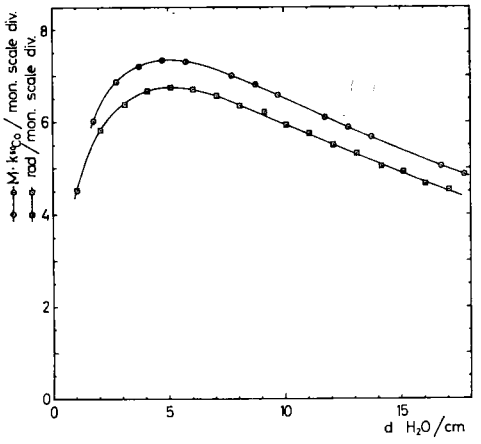


Fig. 1

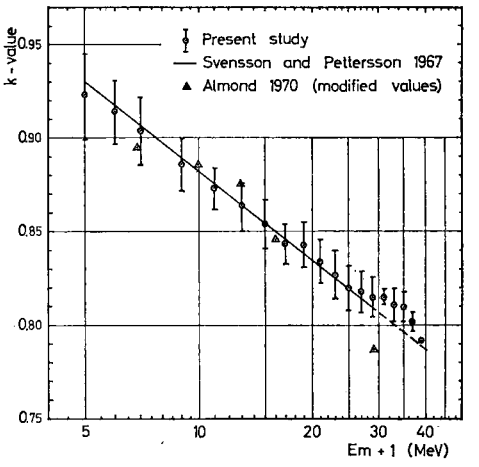


Fig. 2

Fig. 1. Depth dose curve measured with $FeSO_4$ dosimeters and depth ionization curve measured with thimble ionization chambers; 32 MV roentgen rays. A water phantom was used. The ratio between the curves at a given depth was defined as the absorbed dose calibration factor of the thimble ionization chamber, k.

Fig. 2. Mean values of absorbed dose calibration factors, k, and their standard deviations obtained from the results of some 20 experiments with different betatrons, electron energies (E_0), field sizes, and collimating systems. E_m is the mean energy of primary electrons at different phantom depths estimated from eq. 3. Comparisons are made with the results from SVENSSON & PETTERSSON (1967) and from modified values of ALMOND (1970).

Results and Discussion

Absorbed dose calibration factors for thimble ionization chambers

Photon radiation. k-factors were measured with 10 ^{60}Co machines. Mean values at different phantom depths are given in Table 1. The purpose of these measurements was to check the instruments; the standard deviation of the factors measured at the various machines was 0.3 %. The purpose was also to control the absolute dosimetry as this is well established with ^{60}Co γ-beams. ICRU Report No. 14 (1969) thus gives an over-all uncertainty of 2.3 % when a calibrated exposure meter is used in water at 5 cm depth for the determination of absorbed dose for ^{60}Co gamma rays. The corresponding over-all uncertainty with $FeSO_4$ is given to 1.5 %. The k-factor determined at 5 cm depth ($k = 0.979$) was converted into $(C_\lambda)_c$, defined by HPA (1969) and ICRU Report No. 14 (1969). The conversion meant that the centre of the thimble chamber was taken as the measurement point instead of the effective measurement point used with k-factors.

Table 1

Absorbed dose calibration factors of Siemens Sondenfingerhut and Baldwin Farmer (0.6 cm³) chambers for photon radiations. The factors refer to the Stockholm ^{60}Co γ-ray exposure calibrations (in 1964, 1966 and 1967). They are 1.5 % lower with the NPL 2 MV exposure calibration (in 1968)

Energy	^{60}Co	5 MV	6 MV	27 MV	32 MV without flattening filter	32 MV with flattening filter	43 MV
Number of investigated units	10	1	2	1	1	4	1
G-value (eV^{-1})	0.1557	0.156	0.156	0.157	0.157	0.157	0.157
Depth d/cm							
3	0.98	0.95	0.94	0.89	0.90	0.90	0.88
5	0.98	0.95	0.94	0.91	0.92	0.91	0.90
7	0.98	0.94	0.94	0.90	0.91	0.91	0.89
9	0.98	0.94	0.94	0.90	0.90	0.90	0.89
11	0.98	0.94	0.94	0.90	0.90	0.90	0.89
13	0.97	0.94	0.94	0.90	0.90	0.90	0.89
15	0.97	0.94	0.93	0.88	0.89	0.90	0.88

The present investigation gave $(C_\lambda)_c = 0.963$ with the exposure calibration from Stockholm, and $(C_\lambda)_c = 0.949$ with the calibration from NPL; thus in good agreement with the value 0.95 recommended by HPA (1969).

Table 1 also summarizes k-factors as a function of measuring depth for roentgen rays between 5 and 43 MV. The beams were not as well flattened as by ^{60}Co gamma rays and systematic errors might be introduced when the corrections were applied for the different dimensions of the $FeSO_4$ dosimeters and the thimble ionization chambers. The over-all uncertainty in the measurement technique with the accelerators (not including errors in the exposure calibration factors, extinction coefficient, and G-value) was estimated to be within ± 1 %. (Statement of accuracy according to ICRU Report No. 12, 1968.)

Within the relative accuracy of about ± 1 % the same k-factors were measured at 32 MV (γ_2) with the four BBC-betatrons investigated. Also with the two Varian 6 MV linear accelerators the same k-factors were obtained within ± 1 %.

Three different beam-flatteners can be used with BBC-betatrons, denoted γ_2, γ_3 and γ_4. The smallest flattener, γ_2, was chosen above in order to obtain as high an absorbed dose-rate as possible for irradiating the $FeSO_4$ dosimeters. This flattener (γ_2) had a thickness of lead necessary to flatten the isodose curves suf-

Table 2

Comparisons between k- and C_λ-values determined in the present study and the C_λ-values given by HPA 1969. The factors refer to the Stockholm ^{60}Co γ-ray exposure calibrations (in 1964, 1966 and 1967). They are 1.5 % lower when the NPL 2 MV exposure calibration (in 1968) is applied

Radiation	Author's result		Recommended values HPA (1969)
	k	C_λ	C_λ
^{60}Co γ-beam	0.93	0.96	0.95
5 MV	0.95	0.94	0.94
6 MV	0.94	0.93	0.94
25 MV			0.90
27.5 MV	0.90	0.89	
30 MV			0.89
32 MV	0.90	0.89	
35 MV			0.88
43 MV	0.89	0.89	

ficiently to produce a uniform field of about 8 cm in diameter at a distance of 1 meter. In one series of experiments the k-factors were also measured with 32 MV for non-filtered (γ_1) roentgen rays. The k-factors, Table 1, were somewhat higher for non-filtered than for filtered radiation for depths between 4 and 8 cm. This may imply a greater degree of beam contamination by electrons with non-filtered than with filtered radiation.

With the other accelerators investigated, filters were used which gave a flattened field larger than 14 cm in diameter (SSD $\approx$ 100 cm).

The k-values were almost independent of phantom depth for ^{60}Co γ-beam, 5 and 6 MV radiation; they were, however, about 1 % higher with 27 to 43 MV radiation at 5 to 6 cm depth than at other depths studied. If the centre of the chamber had been defined as the measuring point, the differences between the ratio absorbed dose to ionization at 5 to 6 cm depth and at greater depths would have further increased. The difference would also have been dependent upon the size of the chamber. These facts were some of the reasons for defining the k-values different from C_λ.

Table 2 summarizes the k-factors for depths at which C_λ-values are defined by HPA (1969). C_λ-values have been calculated from the k-values and compared with those recommended by HPA. Maximum differences of about 1 % were found, if the Stockholm exposure calibration was used. With the NPL calibration the experimental C_λ-values were 1 to 2.5 % lower than the recommended ones for roentgen ray beams between 5 and 43 MV. The low values are, however, in

good agreement with the experimental C_λ from BEWLY (1963) at 8 and 14 MV and ALMOND (1968) at 18.5 and 22 MV.

Electron radiation. SVENSSON & PETTERSSON (1967) showed that, absorbed dose calibration factors measured with Siemens Sondenfingerhut and Philips intracavity chambers depended only upon the average energy, E_m, of the electrons at the measuring point. E_m was determined from the relation (HARDER 1965):

$$E_m = E_o \ (1 - d/R_p) \tag{3}$$

where

E_o is the electron energy at the phantom surface; MeV,

d is the depth of the effective measuring point of the chamber; cm,

R_p is the extrapolated practical range; cm.

Other parameters of the beam, e.g. field size (larger than ⌀ 5 cm), SSD (between 110 and 130 cm), and construction of the collimating system had no significant influence on the factors. Absorbed dose calibration factors, k, for energies, E_m, between 5 and 30 MeV, were determined by the authors to,

$$k = C_1 - C_2 \log_{10} (C_3 \cdot E_m + 1) \tag{4}$$

where

$C_1 = 1.045$ rad/R

$C_2 = 0.161$ rad/R

$C_3 = 1$ MeV^{-1}

Measurements were carried out with 10 betatrons to determine if the absorbed dose calibration obtained by SVENSSON & PETTERSSON (1967) with one betatron could be employed by other laboratories. E_o was determined by range analysis in a uniform way (SVENSSON & HETTINGER 1971). The energy at the phantom surface, E_o, was varied from 13 to 42 MeV. For each E_o, central axis depth dose and depth ionization curves were measured and the k-factors at different depths, d in eq. 3, were calculated. Geometrical field sizes equal to or larger than 6 cm were used.

The standard deviation of the k-factors for a fixed energy, E_m, was about 1.5 %. No systematic dependency on the betatron, incident energy and field size used could be found. Comparisons between the results from all the betatrons and from SVENSSON & PETTERSSON (1967) are shown in Fig. 2. The agreement was very good.

ALMOND (1970) measured absorbed dose calibration factors in a SCRAD-type polystyrene phantom for Baldwin Farmer and Shonka Whykoff chambers. The centres of the chambers were taken as measuring points. The position of the effective measuring point was not critical since measurements were made at a depth corresponding roughly to the absorbed dose maximum. E_o was determined

Table 3

Comparisons between k/A measured with Siemens Sondenfingerhut or with Baldwin Farmer chambers and calculated D_w/J_{air}

Radiation		k/A	D_w/J_{air}		
E_0/MeV	d/cm H_2O	Present investigation	HARDER (1965)	BERGER & SELTZER (1969)	KESSARIS (to be published)
10	1.0	0.89	0.89	0.90	0.89
	2.0	0.90	0.90	0.91	0.90
15	2.0	0.87	0.88		0.87
20	2.0	0.85	0.86	0.86	0.85
25	2.0	0.83	0.84		
30	2.0	0.82	0.83	0.83	
35	2.0	0.82	0.82		
40	2.0	0.81	0.81	0.81	
	5.0	0.83	0.83	0.83	0.82

by energy-range analysis using a relation for the present purpose not significantly different from the equation used by SVENSSON & HETTINGER (1971). The absorbed dose in water was measured with $FeSO_4$ dosimeters with the same G-values as applied in the present investigation. ALMOND (1970) obtained, on an average, slightly higher absorbed dose calibration factors than SVENSSON & PETTERSSON (1967) (eq. 4). Measurements made with one BBC-betatron in the present study with 13 and 31 MeV radiation showed, however, that ionization in a Baldwin Farmer chamber was somewhat higher, approximately 1.6 %, when irradiated at a position corresponding to the absorbed dose maximum in water, than when irradiated at an equivalent position in a polystyrene phantom. ALMOND's results differ from the present values by a maximum of about ± 1.5 % after applying this correction (Fig. 2).

SVENSSON et coll. (to be published) showed that k-factors for 6 different types of commercial thimble chambers of volumes ranging from 0.1 to 3 cm^3 agreed within ± 2 %. The measurements were carried out at the depth of the peak absorbed dose at energies (E_m) between 5.5 and 26.4 MeV. The authors explained the differences between the k-factors for the different chambers from stem leakage effect, scattering from the stem to the chamber cavity, and from the fact that the electron fluence is larger in the chamber's gas cavity than it would be when the gas is replaced with water. This latter effect is due to the different scattering properties of the gas and water (HARDER 1968). These effects were small, jointly less than 1 %, for Siemens Sondenfingerhut and Baldwin Farmer chambers. Both these chambers were used in the measurements in the Nordic

Table 4

The discrepancies in the local calibrations of absorbed dose. The author's results were chosen as a reference. The table covers approximately 120 comparisons with different combination of energy and field size. The extreme variations at the various laboratories are given. The percentage difference in rad/scale division or rad/minute between visited laboratory and reference are shown

Laboratory number	γ-rays ^{60}Co	Rtg-rays 16—40 MV		e^- 10—15 MeV		e^- 30—35 MeV	
1	—1.5	+5		+6			
2	—1.5	0		—6	—3	—4	—2
3	0	+2		+14	+18	+17	+19
4	+1.7	—13	—3	—2	+1	—1	+1
5		—5	—1	—8	+1	—7	—5
6	—1.2						
7	+0.1	—2		+18			
8		—5	+10	—1	+1	—5	+2
9	—0.5	+5		—4	+6		
10		0		0		0	
11	0	0		0		0	

countries. With respect to these effects, the results in Fig. 2 are therefore valid within approximately 1 % for an 'ideal thimble ionization chamber'. The differences between the factors were largest at low energies where the k-factors for the chambers used, are lower than for an 'ideal one'.

A comparison between experimental absorbed dose calibration factors and theoretically determined D_w/J_{air} values were made. The following assumptions were employed: If A is a correction for photon attenuation for ^{60}Co γ-rays in build-up material used at exposure calibration then $A \cdot k_{60_{Co}} \cdot M$ yields approximately the ionization calibration in e.s.u. per $1.293 \cdot 10^{-3}$ g air, not only for ^{60}Co γ-rays but also for high energy electrons (SVENSSON & PETTERSSON 1967). The whole attenuation of the wall and build-up cap, together about 0.5 g/cm^2, was not included in the correction A as most of the electrons which give ionization in the cavity origin 'upstreams' in the beam (BURLIN 1968). The correction factor A was estimated to 0.985.

From eq. 2:

$$\frac{k}{A} = \frac{D_w}{A \cdot k_{60_{Co}} \cdot M} \approx \frac{D_w}{J_{air}}$$

Value of k/A for a Siemens Sondenfingerhutkammer were compared with the theoretical D_w/J_{air} values of HARDER (1965), BERGER & SELTZER (1969), and

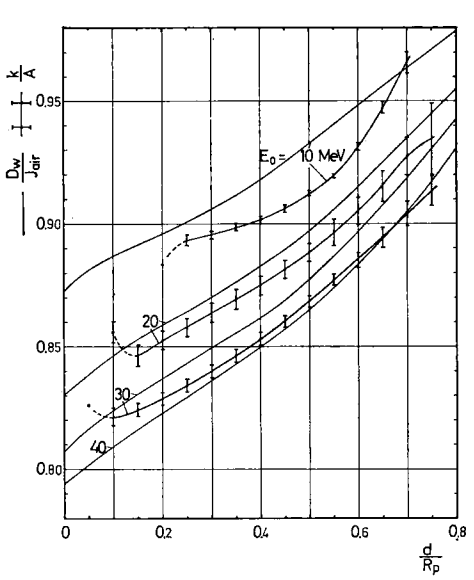


Fig. 3

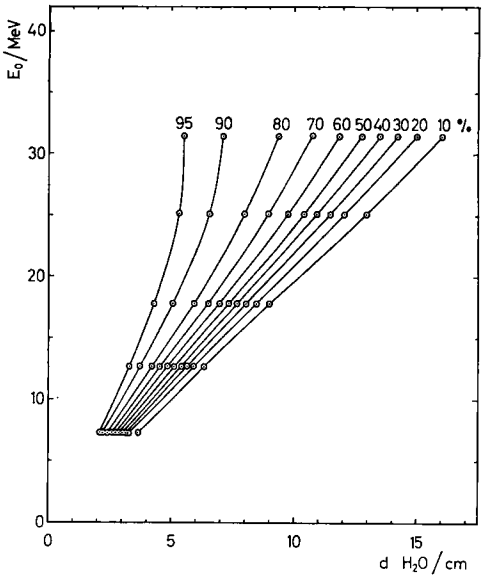


Fig. 4

Fig. 3. Comparisons of k/A measured with a Siemens Sondenfingerhutkammer and theoretical D_w/J_{air} from BERGER & SELTZER (1969). The depths along the central ray are given as d/R_p (depth: d/cm H_2O, and extrapolated practical range: R_p/cm H_2O). The k/A factors were determined from several independent series of experiments (4, 10, and 8 with 10, 20, and 30 MeV, respectively) and with different betatrons. The field sizes are $\geq 8 \times 10$ cm. The standard deviations of the mean values are given. Two series of k/A measurements were also made with 40 MeV. These factors were scattered around the D_w/J_{air} curve and agreed within 1 % with this for d/Rp between 0.1 and 0.75. (The experimental k/A values with 40 MeV are not shown in the figure.)

Fig. 4. Depth dose data for a given field size (14×14 cm) versus depth for fixed relative depth doses; BBC 35 MeV betatron at laboratory No. 2. Relative depth dose curves for given energies were extracted from such series of results given in Tables 6 and 7.

KESSARIS (to be published) (Table 3). In the table D_w/J_{air} values corresponding approximately to the depth of the peak absorbed dose are given. It can be seen that the k/A and D_w/J_{air} values differ by a maximum of 2 %. Values of k/A were also compared with D_w/J_{air} for various E_o and d (Fig. 3). These D_w/J_{air} values were taken from BERGER & SELTZER (1969), who have performed more complete theoretical calculations of electron spectra for various E_o and d, than other investigators. The comparisons showed that the maximum difference between theory and experiment is about 2 % with energies, E_o, between 10 and 40 MeV and depths between 1.5 cm and about 0.8 R_p. The maximum difference had been about 1 % if the comparisons had been carried out between k/A for an 'ideal thimble ionization chamber' and D_w/J_{air} (see above). Again as with roentgen

Table 5

Mean percentage depth dose data at a given depth for high energy photons with separate accelerators and within parentheses standard deviations of the percentage. SSD was 100 cm.

Type of accelerator	AEI 5 MV lin. acc.	Varian 6 MV linear accelerator			Siemens 42 MeV betatron	
Energy	5 MV	6 MV			27.5 MV	43.5 MV
Field size (cm)	10×10	6×6	10×10	20×20	15×15	15×15
Investigated accelerators	1	1	2	1	1	1
Depth (cm)						
1.3	100.0	100.0	100.0	100.0		
2	97.6	99.2	99.0	98.7	97.7	92.8
3	92.3	94.9	95.0	95.1	100.0	98.4
4	87.7	90.2	90.7	91.2	98.5	100.0
5	83.5	85.7	86.4	87.5	95.9	99.3
6	79.5	81.2	82.4	83.8	92.9	97.7
7	75.4	76.9	78.5	80.3	89.7	95.5
8	71.4	72.7	74.6	76.8	86.6	93.1
9	67.6	68.7	71.0	73.6	83.5	90.3
10	63.8	64.8	67.4	70.3	80.6	87.4
12	57.0	57.8	60.7	64.2	74.8	81.4
14	50.8	51.6	54.5	58.3	69.3	76.0
16	45.3	46.0	48.9	53.2	64.1	70.7
18	40.5	41.1	43.9	48.3	59.3	65.7
20	36.2	36.7	39.5	43.9	55.2	61.0
22	32.4	32.8	35.5	40.0	51.4	56.7
24	29.0	29.3	31.8	36.3		52.8
26						

* Beam-flattener.

rays, the k-factors had been lower than the theoretical ones if the NPL exposure calibration had been used instead of the one from Stockholm.

G-values have been assumed to be independent of phantom depth and electron energy in the present investigation. This assumption may not be quite valid. In this respect, PINKERTON (1969) observed a slight elevation (≈ 2 %) of the G-value at the end of the depth dose curve at 18 % depth dose level. The elevation, however, was not considered significant. ALMOND (1967) found some evidence for a slight variation of the G-value with electron energy over the range of 13 to 18 MeV.

The present investigation showed that commercial ionization chambers, calibrated with a ^{60}Co γ-beam, could be used within about 2 % for uniform calibra-

Table 5 *(cont.)*

BBC 35 MeV betatrons			
32 MV			
4×4 (γ1)*	4×4 (γ4)*	8×8 (γ2)*	16×16 (γ4)*
7	7	6	7
86.4 (0.6)	88.7 (1.4)	86.0 (0.5)	92.6 (0.6)
95.4 (0.4)	96.6 (0.4)	95.0 (0.4)	98.2 (0.4)
99.2 (0.2)	99.7 (0.2)	98.8 (0.5)	100.0 (0.2)
100.0 (0.2)	100.0 (0.1)	100.0 (0.1)	99.4 (0.3)
99.2 (0.3)	98.6 (0.3)	99.3 (0.3)	97.3 (0.7)
97.1 (0.5)	96.1 (0.4)	97.6 (0.6)	94.5 (0.9)
94.2 (0.6)	93.1 (0.5)	95.2 (0.6)	91.4 (0.9)
91.0 (0.5)	89.7 (0.6)	92.2 (0.6)	88.3 (0.9)
87.5 (0.5)	86.4 (0.7)	89.1 (0.4)	85.1 (0.8)
81.0 (0.5)	79.9 (0.8)	82.7 (0.4)	79.2 (0.8)
74.9 (0.6)	73.8 (0.8)	76.7 (0.5)	73.6 (0.9)
69.2 (0.7)	68.1 (0.8)	71.0 (0.4)	68.5 (1.1)
63.9 (0.7	62.9 (0.8)	65.8 (0.3)	63.9 (1.2)
59.1 (0.7)	58.2 (0.8)	61.1 (0.3)	59.4 (1.2)
54.7 (0.7)	53.9 (0.7)	56.6 (0.3)	55.3 (1.2)
50.6 (0.7)	49.9 (0.8)	52.5 (0.4)	51.6 (1.2)
46.8 (0.7)	46.3 (0.8)	48.8 (0.3)	48.1 (1.3)

tion of absorbed dose along the central ray (between the depth 1.5 cm to about 0.8 R_p) with different betatrons in the energy range (E_o) 10 to 40 MeV, provided that electron energies (E_o) are determined by methods described by SVENSSON & HETTINGER (1971). Absorbed dose calibration factors from Table 3 may be used for determining absorbed dose at the depth of peak absorbed dose along the central beam, the factors from Fig. 2 (eq. 4) and Fig. 3 may be used when the absorbed dose in the central beam is required at other depths.

Intercomparisons of absorbed dose calibrations

The dosimetric technique with thimble ionization chambers described above was used by the author. The discrepancies, between the absorbed dose calibrations

Table 6

Mean depth dose data (in cm) for a given percentage depth dose for high energy electrons with BBC 35 MeV betatrons and within parentheses the standard deviations for the different BBC-betatrons

Energy (MeV)	Field size (cm)	Investigated BBC-betatrons	Percentage depth dose*									
			95	90	80	70	60	50	40	30	20	10
6	> 12×12	1	1.7	1.8	1.9	2.1	2.2	2.3	2.4	2.5	2.6	3.0
10	⌀ 5	1	2.2	2.5	3.0	3.3	3.6	3.8	4.1	4.3	4.5	5.0
	8×10	2	2.5	2.7	3.1	3.4	3.6	3.9	4.1	4.3	4.5	4.9
	> 12×12	6	2.6	2.8	3.2	3.4	3.6	3.9	4.1	4.3	4.5	4.9
			(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.0)	(0.1)
15	⌀ 4	3	2.5	2.9	3.6	4.2	4.6	5.1	5.6	6.1	6.6	7.3
			(0.0)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.0)	(0.1)	(0.2)
	⌀ 6	1	3.3	3.8	4.5	4.9	5.3	5.7	6.0	6.4	6.7	7.2
	⌀ 8	6	3.5	4.0	4.7	5.2	5.6	5.9	6.2	6.6	6.9	7.5
			(0.2)	(0.1)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.3)	(0.3)
	4×8	2	2.9	3.5	4.2	4.8	5.1	5.7	6.1	6.4	6.9	7.4
	8×10	8	3.7	4.3	4.9	5.3	5.7	6.1	6.4	6.7	7.0	7.5
			(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.0)	(0.1)	(0.1)	(0.1)
	> 12×12	8	3.8	4.3	5.0	5.4	5.7	6.0	6.3	6.6	7.0	7.4
			(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)
20	⌀ 4	3	2.8	3.4	4.3	5.0	5.7	6.3	7.0	7.7	8.5	9.6
			(0.1)	(0.1)	(0.1)	(0.0)	(0.1)	(0.1)	(0.1)	(0.1)	(0.2)	(0.4)
	⌀ 6	1	4.2	4.9	5.9	6.5	7.0	7.6	8.1	8.6	9.1	9.8
	⌀ 8	6	4.3	5.1	6.2	6.9	7.4	8.0	8.5	9.0	9.5	10.3
			(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.2)	(0.4)
	4×8	2	3.4	4.1	5.2	5.9	6.6	7.3	7.9	8.5	9.2	10.0
	8×10	8	4.6	5.5	6.5	7.1	7.7	8.1	8.6	9.0	9.5	10.2
			(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.2)
	> 12×12	8	4.7	5.6	6.6	7.3	7.8	8.2	8.6	9.0	9.5	10.1
			(0.2)	(0.2)	(0.1)	(0.1)	(0.0)	(0.0)	(0.0)	(0.0)	(0.1)	(0.2)

* SSD 110 cm according to the manufactures.

determined by the various laboratories and those determined by the author are given in Table 4. The table covers approximately 120 comparisons with different combinations of field size and radiation quality. The intercomparisons were carried out at the peak absorbed dose along the central ray with electrons and roentgen rays. With ^{60}Co γ-radiation the reference depth in water was 5 cm.

It can be seen from Table 4 that for ^{60} Co γ-radiation a good dosimetric routine provides very good agreement between different laboratories. The difference

Table 6 *(cont.)*

Energy (MeV)	Field size (cm)	Investigated BBC-betatrons	Percentage depth dose*									
			95	90	80	70	60	50	40	30	20	10
25	ø 4	3	3.1	3.8	5.0	5.9	6.7	7.5	8.3	9.3	10.3	11.9
			(0.1)	(0.1)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.2)	(0.3)
	ø 6	1	4.7	5.7	6.9	7.8	8.5	9.2	9.9	10.6	11.4	12.4
	ø 8	6	4.9	6.1	7.4	8.3	9.1	9.8	10.4	11.1	11.7	12.8
			(0.2)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.2)	(0.1)	(0.4)
	4×8	2	3.8	4.8	6.1	7.1	8.0	8.8	9.6	10.4	11.3	12.5
	8×10	8	5.2	6.4	7.8	8.7	9.4	10.1	10.7	11.2	11.9	12.8
			(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.0)	(0.1)	(0.1)	(0.1)	(0.2)
	>12×12	8	5.4	6.6	8.0	8.9	9.7	10.3	10.8	11.3	11.9	12.7
			(0.3)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.3)
30	ø 4	3	3.5	4.5	5.8	6.8	7.8	8.7	9.6	10.8	12.1	14.0
			(0.1)	(0.1)	(0.1)	(0.2)	(0.1)	(0.1)	(0.2)	(0.1)	(0.1)	(0.3)
	ø 6	1	4.3	5.9	7.6	8.7	9.7	10.5	11.4	12.3	13.2	14.2
	ø 8	6	5.4	5.8	8.5	9.6	10.6	11.4	12.3	13.1	13.9	15.1
			(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.0)	(0.2)	(0.1)	(0.3)
	4×8	2	4.5	5.6	7.1	8.2	9.3	10.3	11.3	12.2	13.3	14.8
	8×10	8	5.6	7.1	8.9	10.1	11.0	11.9	12.6	13.4	14.2	15.1
			(0.3)	(0.2)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.2)
	>12×12	8	5.6	7.3	9.2	10.5	11.4	12.2	12.9	13.5	14.3	15.1
			(0.2)	(0.2)	(0.2)	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)	(0.1)

between the extreme values of Table 4 was 3.2 %. Corresponding differences for electron- and roentgen-radiation were 27 % and 23 %, respectively.

The temperature and time dependencies of the monitors of the various accelerators were investigated. The precision of the monitors, for both electron- and roentgen-radiation was better than 3 %. Long time variations of the monitor sensitivity were not possible to check. The discrepancies in Table 4 are, however, much greater than 3 % and may therefore only partly depend on poor precision of the accelerator monitors. Most of the variations must thus depend on differences in dosimetric methods used by the various laboratories.

Relative depth dose curves

Relative depth dose curves with photon-radiation. Table 5 contains relative depth dose curves measured with roentgen rays in this study. Peak photon energies were 5 and 6 MeV according to data supplied by the manufacturers.

Table 7

*Depth dose data for high energy electrons with one Siemens 42 MeV betatron. Depth in cm for a given percentage depth dose. SSD was 100 cm according to the manufacturer.***

Energy (MeV)	6	15				
Field size (cm)	⌀ 15	⌀ 4	⌀ 6	⌀ 8	⌀ 15	⌀ 15
Scattering foil	β_0	β_1	β_1	β_1	β_1*	β_4
Percentage depth dose						
95	1.6	3.3	3.9	4.3	4.4	3.0
90	1.7	3.6	4.4	4.6	4.9	3.6
80	1.8	4.1	5.0	5.1	5.4	4.4
70	2.0	4.7	5.5	5.5	5.7	5.0
60	2.1	5.2	5.8	5.8	6.0	5.5
50	2.2	5.5	6.0	6.1	6.2	5.8
40	2.3	6.0	6.3	6.4	6.5	6.3
30	2.5	6.4	6.6	6.7	6.8	6.7
20	2.6	6.8	6.9	6.9	7.1	7.1
10	2.8	7.3	7.2	7.2	7.4	7.7

* This combination of energy, field size and scattering foil did not give a flattened field

** The manufacturer recommends SSD 120 cm above 20 MeV.

At higher energies, maximum photon energies, were determined with (γ, n) threshold analysis (SVENSSON & HETTINGER 1971). The field size was defined by the geometrical field represented by an illuminated area on the phantom surface.

Relative depth dose curves determined with two Varian 6 MV linear accelerators (Table 5) and those obtained with a Varian 6 MV accelerator by HORSLEY et coll. (1968) agreed within 1 % for corresponding depths. Standard deviations for relative depth dose curves obtained with 6 BBC-betatrons at 32 MV were less than 1.5 % for depths up to 15 cm provided that given beam flatteners and field sizes were employed. Relative depth dose data from accelerators of similar construction appear to agree closely.

GREENE (1969) showed that agreement between depth dose curves from different accelerator types was poor. Discrepancies in relative depth dose data of up to 12 % were reported for a depth of 20 cm (35 MV, 10 × 10 cm, FSD 100 cm). The measurements were carried out by the different accelerator laboratories. Differences in the techniques of determining relative depth dose curves may therefore account for some of the deviations. Inaccurately determined maximum photon energies can give rise to discrepancies especially for energies lower than 10 MV. It was thus shown by SVENSSON & HETTINGER (1971), that the ratio

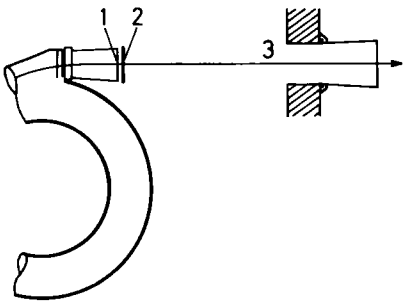
Table 7 *(cont.)*

25				35		40			
⌀ 4	⌀ 6	⌀ 8	⌀ 15	⌀ 15	⌀ 15	⌀ 4	⌀ 6	⌀ 8	⌀ 15
β_2	β_2	β_2	β_2*	β_3	β_4	β_3	β_3	β_3	β_3*
3.7	4.5	4.5	4.6	4.6	4.3	3.5	5.0	5.4	5.2
4.6	5.6	5.8	6.2	6.3	5.9	4.9	6.4	6.9	6.8
5.7	6.8	7.3	7.8	8.8	8.2	6.9	8.4	9.1	9.3
6.5	7.8	8.3	8.8	10.6	10.0	8.3	10.1	10.9	11.6
7.3	8.5	9.1	9.7	12.1	11.5	9.6	11.5	12.5	13.5
8.0	9.2	9.7	10.3	13.4	12.8	10.8	12.9	14.0	15.0
8.8	10.0	10.4	10.7	14.4	14.0	12.0	14.2	15.3	16.3
9.6	10.6	11.1	11.3	15.4	15.3	13.4	15.5	16.7	17.5
10.6	11.4	11.7	11.9	16.5	16.5	15.1	17.2	18.2	18.8
11.6	12.2	12.4	12.6	17.9	23.0	17.8	19.4	20.5	20.7

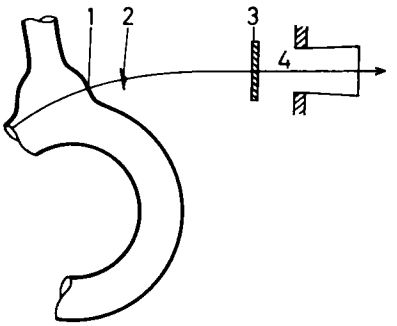
between depth doses at 5 and 15 cm depth was critically dependent upon the peak photon energy at values lower than 10 MV. The beam flattener may also affect the depth dose curve. Table 5 shows that at 32 MV the depth doses at larger depths are less for the larger beam flattener (γ_4) than for the smaller (γ_2). In this energy range, this effect can be explained by the increased pair production in the lead flattener which results in a higher percentage attenuation of photons at the high energy end of the spectrum.

Relative depth dose curves with electron radiation. The electron energy at the phantom surface was determined by methods described by SVENSSON & HETTINGER (1971), i.e., by range analysis or by (γ, n) threshold analysis employing corrections for energy losses occurring for instance in tube window and scattering foils. The field size was defined by the geometrical limits of the collimating tubes. The homogeneity index (ratio of the area inside the 80 % isodensity curve at 2 cm depth to the geometrical field area (SVENSSON & HETTINGER 1971)) was on average 0.6 with the BBC-betatrons and 0.8 with the Siemens 42 MeV betatron. Depth dose data for a given geometrical field size and accelerator were plotted as energy versus depth for fixed relative depth doses (Fig. 4). Similar curves from different accelerators allowed depth dose data for given energies and field sizes to be extracted (Tables 6 and 7).

Siemens 42 MeV betatron



BBC 35 MeV betatron



Scattering material	$\frac{S_{tot}}{\rho}\cdot\Delta x\cdot\rho$ (at 15 MeV)	$\frac{S_{tot}}{\rho}\cdot\Delta x\cdot\rho$ (at 40 MeV)
1) Tube window 30 μm Cu	0.1 (MeV)	0.1 (MeV)
2) Scattering foils		
β_1 = 0.1 mm Pb	(0.4) "	(0.8) "
β_2 = 0.25 -"-	0.9 "	(1.9) "
β_3 = 0.5 -"-	1.8 "	3.8 "
β_4 = 1.0 -"-	3.6 "	7.6 "
3) Air 1.0 m	0.3 "	0.4 "
Σ Energy degradation with different foils		
β_1 = 0.1 mm Pb	(0.8)[x] "	(1.3)[x] "
β_2 = 0.25 -"-	1.3 "	(2.4)[x] "
β_3 = 0.5 -"-	2.2 "	4.3 "
β_4 = 1.0 -"-	4.0 "	8.1 "

Scattering material	$\frac{S_{tot}}{\rho}\cdot\Delta x\cdot\rho$ (at 15 MeV)	$\frac{S_{tot}}{\rho}\cdot\Delta x\cdot\rho$ (at 30 MeV)
1) Tube window ≈ 2 mm glass	1.1 (MeV)	1.5 (MeV)
2) Scattering foil ≈ 0.4 mm Cu	0.9 "	1.2 "
3) Transmission chamber	0.6 "	0.7 "
4) Air 1.0 m	0.3 "	0.4 "
Σ Energy degradation	≈2.9 "	≈3.8 "

[x] This combination of energy and scattering foil did not give a flattened field.

Fig. 5. The beam geometry of two makes of betatrons. All the scattering materials in the path of the central beam are given.

No depths for the 100 % depth doses have been given in the tables. The reason lies in the non-critical nature of this position. The depth dose varies often only by fractions of one per cent over the range 1 to 2.5 cm depth. The peak absorbed dose for large field sizes were situated at about 2 cm depth for energies between 10 and 40 MeV.

Table 6 contains depth dose curves from 8 BBC-betatrons and Table 7 from one Siemens 42 MeV betatron. Standard deviations in the depth for a given percentage (e.g. 95, 90, 80 %) were approximately 1 mm for the BBC-betatrons.

Relative depth dose data from accelerators of similar construction thus appear to agree closely also with electron radiation. In contrast, depth dose curves from the two betatron types differ significantly.

In order to explain these differences the beam geometry was studied (Fig. 5). The scattering and energy degradation in the central part of the electron beams from the Siemens betatron occurs almost exclusively in the scattering foils. In the BBC-betatrons the electrons are scattered and suffer energy losses also in the accelerator window and transmission chambers. Since irradiations with the Siemens betatron could be carried out with various thicknesses of the scattering foils it was possible to study the effect of scattering material in the beam upon the depth dose curve. Depth dose curves were therefore measured at 15 MeV with 0.1 and 1 mm Pb-foil. A somewhat higher energy was set on the instrument panel of the betatron when the thicker foil was used, to ensure that the energy at the phantom surface should be the same as when the thin foil was used. The best depth dose curve, was obtained with the thin foil (Fig. 6), in agreement with SEMPERT & WIDERÖE (1958), and LOEVINGER et coll. (1961). The thin foil was, however, sufficient only to flatten a ϕ 7 cm field at SSD 100 cm and 15 MeV.

The difference between the curves obtained with different foils depended upon the greater contamination of the beam by low-energy electrons when a thick foil was used. An approximate measure of the contamination is provided by the energy degradation in the central part of the beam through radiation and collision processes. The mean energy degradation with the thick foil was 4.0 MeV and with the thin foil 0.8 MeV (Fig. 5). A depth dose curve measured at 15 MeV with a BBC-betatron is also shown in Fig. 6. The energy degradation was approximately 2.9 MeV and the depth dose curve better than the one for the flattened field with the Siemens betatron.

An increase of the scattering material in the central beam also implies that more electrons are spread out and into the collimating system. One part of these electrons may be energy degradated and then scattered back into the central beam and thus deterioriates the depth dose curve. The scattering system of a BBC 35 MeV betatron and a proposal for improvement are discussed in another paper by the author (SVENSSON 1971).

Depth dose curves from BBC-betatrons were usually better, compared with Siemens betatrons, than could be expected on the grounds of energy losses. This may be explained from the fact that the magnetic field outside the tube-window of the BBC-betatron is sufficient to avert some of the low energy electrons formed in the window, thus preventing them from reaching the phantom. A similar diversion does not occur in the Siemens betatron. This may be one of the reasons why the beam is less contaminated by low energy electrons in the BBC-betatrons (better depth dose curves) than in the Siemens betatrons for 25 MeV and a field

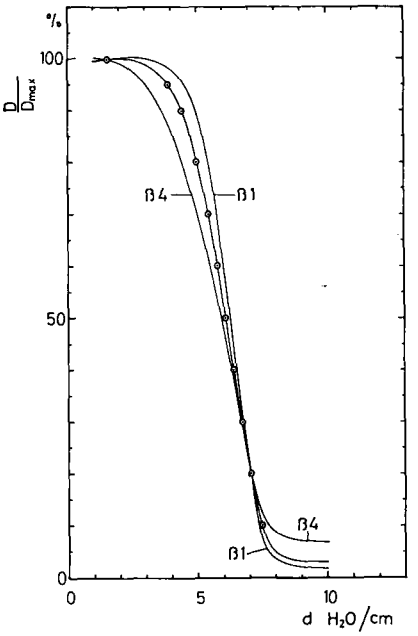


Fig. 6

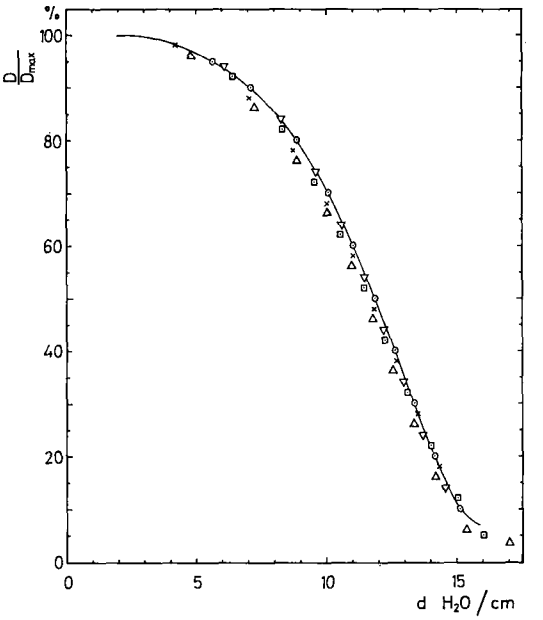


Fig. 7

Fig. 6. Relative depth dose curves measured at 15 MeV e⁻-radiation with 0.1 (β_1) and 1 (β_4) mm Pb-foils with Siemens 42 MeV betatron (—). Field size $>\varnothing 12$ cm. A somewhat higher energy was set on the instrument panel of the betatron when the thicker foil was used in order to obtain similar electron energy, E_o, at the phantom surface. A relative depth dose curve with one BBC 35 MeV betatron ⊙——⊙ at 15 MeV is also shown.

Fig. 7. Intercomparisons of depth dose curves measured by the various laboratories and by the author at these laboratories. Energy 30 MeV, field size 8 × 10 cm. The author's curve is a mean of the results from all the laboratories. The separate curves agreed, however, within 0.1 cm. The energy was determined by the author at all the laboratories; the variations between the various laboratories thus depended only upon different dosimetric techniques.
⊙ author's measurement, ⊡ laboratory No. 2, ▽ laboratory No. 4, △ laboratory No. 6, and X laboratory No. 7.

$\geq \phi$ 6 cm (Tables 6 and 7) despite the fact that the energy degradation was greater in the former betatron type.

The depth dose curves depend upon the method of field shaping. LOEVINGER et coll. (1961) thus showed that low energy electrons from the collimator tube increased the absorbed dose at 1 cm depth in a water phantom by approximately 40 % compared with an irradiation performed without the tube (30 MeV, ϕ 6 cm). SVENSSON & HETTINGER (1967) observed a corresponding increase of 10 % with a BBC-betatron (15 MeV and 8 × 10 cm) and showed it to be greatest for small field sizes. Different collimator constructions may possibly explain that the

95 and 90 per cent depth doses with small field sizes (ϕ 4 cm in Tables 6 and 7) occurred at smaller depths with the BBC-betatrons than with the Siemens 42 MeV betatron. These depth doses occur, however, most often at greater depths with BBC-betatrons for large field sizes. Another cause may be that small field sizes are flattened more with Siemens than with BBC-betatrons (homogeneity index 0.8 and 0.6, respectively; compare above) and somewhat larger 'effective field' size are thus obtained with the former.

SCHULTZ (1969) showed that the depths for 50 % depth dose measured in different laboratories (25 MeV, 10 × 10 cm) differed by up to 1.5 cm. POHLIT's (1961) measurements and the present study showed, however, that the differences between depth dose curves from different types of betatrons are considerably less. A large part of this difference must therefore be ascribed to variations in energy calibration. The given energy, however, is of less importance for usage of the depth dose curves for radiotherapy provided that these curves are accurately known for a given MeV-instrument setting.

Comparisons between relative depth dose curves measured by 5 laboratories and by the author at these laboratories were made (Fig. 7). The author had measured the electron energies at all the laboratories so that the variations in the results depended only upon the dosimetric technique employed. The depths for 80 % and 50 % depth doses (30 MeV, 8 × 10 cm) measured by the various laboratories and by the author differed by a maximum of 0.5 cm and 0.4 cm, respectively. This difference must be regarded as totally acceptable in radiotherapy.

Conclusions

Intercomparisons of absorbed dose calibrations at a reference point along the central ray showed very good agreement with ^{60}Co γ-radiation, (8 laboratories were compared, the extreme values differed with 3.2 %) and great differences at electron- and roentgen-radiation, (11 laboratories were compared, the extreme values differed with 27 and 23 %, respectively). With electron- and roentgen-radiation the maximum absorbed dose often lies outside the central axis (SVENSSON & HETTINGER 1971). This means that even if different laboratories have carried out uniform absorbed dose calibration at a reference point along the central axis great differences may exist in absolute dose maximum. The maximum dosimetric differences between clinics in the Nordic countries may thus be still worse than the figures above indicate.

Absorbed dose calibrations of commercial thimble ionization chambers against $FeSO_4$ dosimeters with 11 betatrons and 3 linear accelerators showed that it is possible to use these chambers to establish sufficient uniform dosimetry along the central ray for radiotherapy. If the energy is determined in a uniform way

(described by SVENSSON & HETTINGER 1971) it thus would be possible to transfer absorbed dose calibrations by thimble ionization chambers between the centres with an uncertainty less than about 2 % with both electron and roentgen-radiation.

Relative depth doses with roentgen rays from accelerators of the same makes and models agreed within about 1.5 %. The curves were dependent on the flattenner used.

With electron radiation the depths for a given percentage depth dose (e.g. 95, 90, 80 %) agreed closely for 8 BBC 35 MeV betatrons. The standard deviations of the depths were about 0.1 cm for a given energy and field size. Significant differences in relative depth doses for different makes and models were observed. Different energy degradation of the electrons in the tube windows, scattering foils and in the collimating tubes for the studied betatron makes are probable explanations.

Acknowledgements

The author gratefully acknowledges the radiotherapeuts and physicists at the visited places and the technical assistance of Mr B. Sjöström. The work was supported by grants from the Swedish Cancer Society.

SUMMARY

A measuring program was carried out on betatrons and linear accelerators at 11 laboratories in Denmark, Finland, Norway and Sweden. Great discrepancies existed between the basic dosimetry of the various laboratories. It was shown that thimble ionization chambers could be used to transfer absorbed dose calibrations, within 2 %, between the various centres with both electron and photon radiation. The depth dose curves from the different accelerators were compared.

ZUSAMMENFASSUNG

Ein Messprogramm für Elektronenschleudern und Linearacceleratoren von 11 Laboratorien in Dänemark, Finland, Norwegen und Schweden wurde durchgeführt. Es existieren grosse Unterschiede zwischen der Basisdosimetrie der verschiedenen Laboratorien. Es wird gezeigt, dass Fingerhut-Ionisationskammern verwendet werden können, um innerhalb von 2 % Kalibrierungen der absorbierten Dosis sowohl für Elektronen- als auch Photonen-Strahlung zwischen den verschiedenen Zentren zu übertragen. Die Tiefendosis-Kurven von den verschiedenen Acceleratoren werden verglichen.

RÉSUMÉ

L'auteur a 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.

Il existait de grandes discordances entre les principes de dosimétrie dans ces différents laboratoires. Ce travail a montré qu'on peut utiliser des chambres d'ionisation dé à coudre pour transmettre d'un centre à l'autre les étalonnages de dose absorbée, avec une précision de 2 %, aussi bien avec le rayonnement électronique qu'avec les photons. Les doses de courbe en profondeur provenant des différents accélérateurs ont été comparées.

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