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EVALUATION OF THE CLINICAL USE OF TLD

BENGT-INGE RUDÉN

Thermoluminescent dosemeters (TLD) are nowadays widely used in radiation therapy to measure the radiation dose (RUDÉN 1971, SUNTHARALINGAM & MANSFIELD 1971, RUDÉN & NILSSON 1973, LINDSKOUG 1974). Information on the absorbed dose delivered is both a control of the therapy unit and a check that the right parameters are being used for adequate treatment of patients. At Radiumhemmet, SIEVERT (1932) began to use routinely for patient dose measurements small ionization chambers (condensed chambers usually referred to as Bg-chambers), which were entirely separated from the reading instrument.

High quality Bg-chambers are not commercially available and it is difficult to maintain and increase their number. Therefore, thermoluminescent dosemeters were introduced for the determination of absorbed doses in routine therapy in 1968. During 1970 the number of clinical measurements amounted to 17 000 of which two thirds were made with TLD and during 1974 the number was 30 000 of which 98 per cent were made with TLD. The purpose of this report is to describe the routine use of TLD for a wide range of dosimetry applications in radiation therapy, the handling of the dosemeters to obtain high accuracy and the usefulness of making patient dose measurements.

Energy dependence of LiF dosemeters

At Radiumhemmet the following facilities are available for treatment: conventional roentgen radiation units (20–200 kV), ^{60}Co units, accelerators for 6 MV and 42 MV roentgen radiation and 5–39 MeV electrons. It is therefore essential to know the response of the different kinds of LiF dosemeters at the various energies used in order to confirm the absorbed doses given to the patients. The primary calibration of the dosemeters was carried out in a ^{60}Co gamma ray beam. The ratio $A_{Co} = T_{Co}/D_{H_2O,\,Co}$ of the thermoluminescent signal T_{Co} and the absorbed dose in water $D_{H_2O,\,Co}$ was also used as the primary sensitivity factor for the other radiation qualities, in the

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following denoted by subscript E. Since this common practice easily leads to confusion, the quantities used will be discussed in detail. The relative amount of light detected per unit absorbed dose in the dosemeter will be denoted by L. Then

$$T_E = A_{Co} \cdot D_{H_2O,\,Co} \cdot D_{L,\,E} \cdot L_E/(L_{Co} \cdot D_{L,\,Co}) \quad (1)$$

Subscript L stands for the dosemeter material. The relative response k of the dosemeter is defined as the correction factor by which the ratio A_{Co} should be multiplied to give the ratio A_E applicable to the actual radiation quality or $A_E = k\, A_{Co}$. Thus

$$k = \frac{D_{L,\,E} \cdot D_{H_2O,\,Co} \cdot L_E}{D_{H_2O,\,E} \cdot D_{L,\,Co} \cdot L_{Co}} \quad (2)$$

The results in Table 1 are expressed with the aid of this relative response for high-energy electrons and high-energy roentgen radiation. (In radiation therapy the term high-energy is often applied to the energy range above about 1 meV.) The uncertainties in the results can mainly be attributed to the uncertainty in the determination of absorbed dose in water.

The measurements and the theoretical basis of the relative response of the LiF dosemeters to high energy radiation are described by RUDÉN & BENGTSSON (to be published). Determination of the relative response of the LiF dosemeters in the range 20–190 kV was made as follows.

The effective photon energies for the different potentials and filtrations were obtained by means of measurements of half value layers in aluminium (20–100 kV) and copper (140–190 kV) and by using mass attenuation coefficients taken from the ICRU Report No. 17 (1970).

The exposure measurements at 20–50 kV were made in free air with a PTW soft roentgen ray chamber (W chambers 7241/Ul/K). The membrane thickness is 0.03 mg/cm^2 and the effective volume is 0.3 cm^3. The exposure to the dosemeters placed on the surface of a Perspex phantom was calculated by using the backscatter factors published by the Brit. J. Radiol. (Suppl. No. 11, 1972). An FSD of 40 cm and a field size of 15 cm diameter were used. Exposure measurements at 100–190 kV were made with a Shonka chamber (BOAG 1966). The wall thickness is 0.25 mm and the volume 4.36 cm^3. The chamber was placed directly on a Perspex phantom and in free air with an FSD of 60 cm and 18 cm $\times$ 18 cm field size. Good agreement (within $\pm$2 per cent) was obtained between the exposure measurements on the phantom and the results calculated from the free air chamber measurements with the appropriate backscatter factors applied (Brit. J. Radiol. Suppl. No. 11, 1972).

The absorbed dose in water was calculated by using the results from the exposure measurements and the appropriate conversion factor (Gy/R) in water (ICRU 17, 1970). During the exposure measurements the LiF dosemeters were placed on the surface of a Perspex phantom. The ratio of the thermoluminescent signal and the absorbed dose in water was used as the primary calibration factor at the relevant

Table 1

Measured relative light signal per Gy in water for various kinds of LiF dosemeters for various radiations relative to ^{60}Co gamma radiation

Photon radiation Radiation quality	Total filtration (mm)	0.1 mm Teflon discs*	0.4 0.5 mm Teflon discs*	High sensitivity ribbons**	Teflon rods* Extruded rods**
20 kV	0.1 Al	1.20	0.95	0.78	—
50 kV	1 Al	1.40	1.31	1.36	—
50 kV	2 Al	1.45	1.38	1.43	—
100 kV	1 Al	1.43	1.42	1.45	—
140 kV	4 Al	1.36	1.35	1.38	—
190 kV	0.5 Cu + 1 Al	1.15	1.15	1.17	—
190 kV	Thoraeus	1.12	1.12	1.13	—
^{60}Co	—	1.00	1.00	1.00	1.00
6 MV	—	0.96	0.94	0.97	0.97
42 MV	—	0.96	0.93	0.96	0.97
Electron radiation Energy at the surface (MeV)					
4.3		0.93	0.90	0.90	0.92
7.4		0.93	0.91	0.91	0.94
9.8		0.93	0.91	0.91	0.94
11.6		0.93	0.91	0.91	0.94
14.3		0.94	0.91	0.92	0.95
19.4		0.96	0.92	0.93	0.96
28.2		0.96	0.92	0.94	0.96
39.2		0.98	0.93	0.95	0.97

*Isotope Inc. **Harshaw Co.

energies to obtain the absorbed dose in water. The results expressed according to Eq. 2 for various conventional roentgen ray energies and for various kinds of LiF dosemeters appear in Table 1.

The absorbed dose in water (D_E) expressed in Gy, from the results of TLD measurements at different roentgen ray energies can be calculated as follows:

$$D_E = S^L_{H_2O} \cdot \frac{(^{\mu}en/\varrho)_{H_2O,E}}{(^{\mu}en/\varrho)_{L,E}} \cdot \frac{T_E}{A_{Co}} \cdot P_E \cdot F_E$$

$S^L_{H_2O}$ = the generalized stopping power ratio (^{60}Co) of the the dosemeter material and water at the actual dosemeter size according to BURLIN (1968).

$^{\mu}en/\varrho$ = the mass energy absorption coefficient (HUBBELL 1969).

P_E = the correction factor for LET effects on the light yield.

F_E = the correction factor for attenuation of the radiation within the dosemeter (calculated).

Table 2

Correction factors for LET and attenuation for 0.13 mm thick LiF teflon discs at various photon energies

Radiation quality (kV)	Total filtration (mm)	Effective photon energy (keV)	Correction factor	
			LET	Attenuation
20	0.1 Al	10	1.15	1.10
50	1 Al	17	1.07	1.030
50	2 Al	23	1.05	1.015
100	1 Al	37	1.02	1.005
140	4 Al	51	1.0	1.0
190	0.5 Cu + 1 Al	81	1.0	1.0
190	Thoraeus	97	1.0	1.0

The correction factors for LET effects (P_E) (JÄHNERT 1972) and the attenuation (F_E) for 0.13 mm thick LiF teflon discs at the various effective photon energies are given in Table 2. No corrections for LET are needed for ^{60}Co gamma radiation (JÄHNERT). Therefore by definition $P_E = 1.0$ for ^{60}Co gamma radiation.

The ratio of the calculated absorbed dose from TLD and the measured dose from ionisation chamber measurements was between 0.97 and 1.03. This means that within the limits of experimental error the LiF dosemeters have no energy dependence for conventional roentgen ray energies. This is in agreement with the results reported by LAW (1973). However, due to the dose inhomogeneity and the attenuation of the thermoluminescent signal in the thicker LiF dosemeters (RUDÉN & BENGTSSON), caution should be observed when applying these results in measurements which require high accuracy.

Methods

Read-out procedure. In routine clinical work the thermoluminescence of the dosemeters was measured with one unit produced by Harshaw (Model 2 000 A and B) and one produced by Teledyne (Model TLD 7100). The most advantageous thermal treatment of the LiF dosemeters before they are exposed to ionizing radiation (preannealing) depends appreciably on the type of application and on the desired accuracy. This is the case, for instance, in situations where difficulties are encountered in keeping the time between exposure and read-out constant and when continuous exposure during prolonged periods is used. This occurs for patient dose measurements as well as in radiation protection measurements. The following thermal treatment was used: for teflon dosemeters 30 min at 300°C and 24 hours at 80°C preannealing and for Harshaw ribbons and rods 60 min at 400°C and 24 hours at 80°C preannealing. Before read-out the dosemeters are kept at 80°C for 15 min. Separate ovens have been used for various thermal treatments.

Table 3

Correction factors to be used for calculation of the given dose from entrance dose measurements for various roentgen ray energies

Radiation quality	Filtration (mm)	Correction factor	
		0.1 mm Teflon disc	0.5 mm Teflon disc
20 kV	0.1 Al	0.83	—
50 kV	1 Al	0.71	—
50 kV	2 Al	0.69	—
100 kV	1 Al	0.70	0.70
140 kV	4 Al	0.74	0.74
190 kV	0.5 Cu+1 Al	0.87	0.87
190 kV	Thoreaus	0.89	0.89

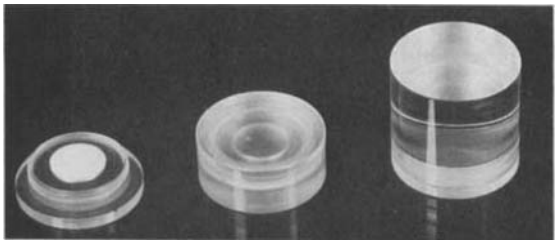
In physical measurements which require high accuracy and where it is possible to cancel out the effect of fading, the heating during the read-out procedure was used as the only method for preannealing (CARLSSON et coll. 1968). In such measurements the time interval between the irradiation and the read-out of a dosemeter was kept the same in both calibration and experiment.

Irrespectively of what kind of preannealing method was used all the dosemeters were retained in the read-out apparatus for 1 min after the integration was completed in order to provide identical cooling-cycles.

Calibration of the thermoluminescence dosemeters. Separate groups of dosemeters, each containing 25, were used. Calibration factors in Gy/digit were assigned to the individual dosemeters after the calibration procedure. In addition, five dosemeters were used for calibration purposes in connection with every measurement occasion. The mean value of the change in the calibration factor found for these 5 dosemeters was applied to all the other dosemeters included in the same group. Such a procedure was made possible by running all dosemeters within the group through exactly the same heating and cooling procedure (MÅRTENSSON 1969). It was observed that when a new dosemeter was employed, its sensitivity increased markedly during the first applications. All the dosemeters must be read out and irradiated with the same geometry to obtain good reproducibility; that means that the dosemeters must not be turned in any way with respect to one another. The dosemeters are marked and the practice is that the unmarked side should always be turned to the treatment apparatus during the irradiation and to the PM-tube during the read out.

In vivo dosimetry

Each of the many steps in the planning and execution of irradiation of patients may contribute significantly to the uncertainty in the absorbed dose given to the patient.



a b c

Fig. 1. Perspex dosemeter holders (diameter 20 mm) for patient dose measurements. a) Bottom of a holder containing two LiF-teflon dosemeters. b) Holder used for ^{60}Co gamma radiation. c) Holder used for 6 and 42 MV roentgen radiation.

Human mistakes and malfunction of the therapy units may cause considerable deviations from the planned treatment. An ultimate control of the given absorbed dose is only possible by using in vivo dosimetry. Another important application of in vivo dosimetry is to estimate the absorbed dose contribution to organs such as the eyes or gonads in which relatively small radiation doses might be particularly undesirable (RUDÉN, RUDÉN & NILSSON).

In vivo dose measurements consist of determinations of entrance dose, exit dose and intracavitary dose measurements. At Radiumhemmet, different types of dosemeters are used for each of these types of measurement. LINDSKOUG used an automatic read-out apparatus which only reads rods and these were used for all kinds of patient dose measurements.

Entrance dose measurements, previously by means of Bg-chambers, nowadays by TLD, are mainly performed for checking output, performance of the therapy unit and the accuracy of the setting-up of the patient, but sometimes also in order to determine the dose distribution within irregularly shaped beams.

Orthovoltage roentgen radiation. In connection with external orthovoltage roentgen ray therapy 0.1 mm thick LiF teflon discs (diameter 12.7 mm) are used at 20–50 kV and 0.5 mm thick LiF teflon discs (diameter 8 mm) at 100–190 kV. Since the dosemeters are calibrated using ^{60}Co gamma radiation, correction factors must be applied to obtain the given dose in Gy in water. These correction factors appear in Table 3. The factors have been calculated from the results presented in Table 1.

^{60}Co gamma and high energy roentgen radiation. When the entrance dose is to be determined in external gamma and high energy roentgen ray therapy, two LiF-teflon discs (diameter 8 mm, thickness 0.5 mm) are placed in specially designed build-up caps (Fig. 1). The dosemeter assembly is attached to the body surface. It must be observed that when the build-up cap is placed on the skin, the skin-sparing effect is considerably reduced under the dosemeter assembly. By changing the position of the build-up cap between sessions, this effect is minimized. The thickness of the build-up layer is 4 mm for the ^{60}Co beam and 15 mm for the 6 MV and 42 MV beams.

Table 4

Correction factors to obtain the maximum absorbed dose for various beam sizes and SSD for 42 MV roentgen radiation when using build-up cap according to Fig. 1 c

	SSD										
	100 cm										120 cm
Beam cm × cm	5 × 5	6 × 6	7 × 7	8 × 8	9 × 9	10 × 10	11 × 11	12 × 12	13 × 13	15 × 15	16 × 16 20 × 20
Correction factor	1.28	1.26	1.25	1.22	1.20	1.18	1.16	1.14	1.13	1.11	1.25

The build-up thickness of 15 mm is too small, however, when the given dose from 42 MV radiation is to be determined. A correction factor, which has been determined by means of measurements, must therefore be applied. The correction factors for various beam sizes and SSD used at the Siemens 42 MeV betatron, are given i Table 4. The same beam flattering filter is used for all beam sizes (filter 2). These corrections factors have also been confirmed through calculations using depth dose curves and the energy dependence of the dosemeters.

High energy electrons. When the given dose is to be determined by entrance dose measurement in electron therapy, a build-up cap is not used. However, the relationship between the surface dose thereby determined and the dose at the maximum varies with the energy of the electrons and the scattering foil used for a particular beam size. In order to get the absorbed dose at the maximum, correction factors must be applied. These factors are dependent on the energy and the kind of scattering foil used and they have been determined by means of measurements. The correction factors for tubes from 6 cm × 8 cm to 20 cm × 20 cm (including correction both for the energy dependence of the LiF teflon dosemeters and that the dosemeters are at the surface), used at the Siemens 42 MeV betatron, appear in Table 5.

Entrance measurements of the absorbed dose with TLD is not only a control of the given dose, but also an aid in determining the entrance dose at different points in irradiations with large irregular beams over an area where the body contour may also be irregular, e.g. with the mantle technique (Fig. 2) and the inverted Y-technique.

It is sometimes important to measure the absorbed dose to organs outside the primary beam and particularly under beam shaping blocks. In particular organs (eyes, gonads) a relatively small radiation dose might be particularly undesirable. In these measurements on patients individually calibrated, high sensitivity LiF ribbons (3.2 mm × 3.2 mm × 0.9 mm) are used for the determination of absorbed doses which represent only minor fractions of the therapeutic dose.

Exit dose measurements are most commonly made for the purpose of checking calculations of the absorbed dose to deep-seated internal structures. The exit dose

Table 5

Correction factors to obtain the maximum absorbed dose at different electron energies

Energy at the surface (MeV)	5	7.5	10	10	12.5	15	20	30	39
Scattering foil (number)	2	2	3	4	4	4	5	5	5
Correction factor	1.30	1.35	1.25	1.18	1.18	1.12	1.12	1.11	1.10

method is applicable even for calculation of the absorbed dose to the tumour in the irradiation (SUNDBOM 1965), e.g. with irregularly shaped beams.

No individual treatment plans are drawn up for patients treated with mantle- or inverted Y-technique. When these types of irradiation were started, exit dose measurements were made at various points (Fig. 3). On patients treated for carcinoma of the oesophagus, exit dose measurements are made at different points in the caudal-cranial direction of the beam. This technique is used to measure the variation of the absorbed dose along the length of the oesophagus. The dosemeters used for the exit dose measurements are placed in a perspex cap to ensure adequate scattering conditions.

Intracavitary dose measurements. Since the introduction of condenser chambers, (SIEVERT) dose measurements have been carried out in readily accessible body cavities such as the mouth, vagina, rectum. This technique has also been successfully applied in the oesophagus (LIDÉN 1948, DAHL & VIKTERLÖF 1960) and also in the bladder (DAHL & VIKTERLÖF). Thermoluminescent dosemeters have now become available in sizes and shapes that make them suitable for dose determination in pelvic veins (TJERNBERG et coll. 1968, JOHANSSON et coll. 1969, JOELSSON & BÄCKSTRÖM 1970).

Measurements in veins and in the oesophagus. In an investigation performed as a cooperative project by the departments of Gynaecology and Clinical Radiation Physics at Radiumhemmet and the Unité de Radiophysique, Institut Gustave Roussy in Paris, the correspondence was tested between computer calculated doses in various parts of the pelvis and the doses in the same sites measured with LiF dosemeters (JOELSSON et coll.). LiF rods (diameter 1 mm, 6 mm long) loaded into presterilized teflon catheters were introduced into the external and common iliac veins by a technique commonly used for venous catheterization. Lead spacers had been placed between the dosemeters to allow, after phlebography, a precise roentgenologic determination of the location of each numbered LiF rod in relation to the pelvis. The dosemeters were left in situ during the whole course of treatment.

Intracavitary measurements with LiF rods have been made in the oesophagus of patients treated with the mantle technique and in external and common iliac veins in treatments with the inverted Y-technique.

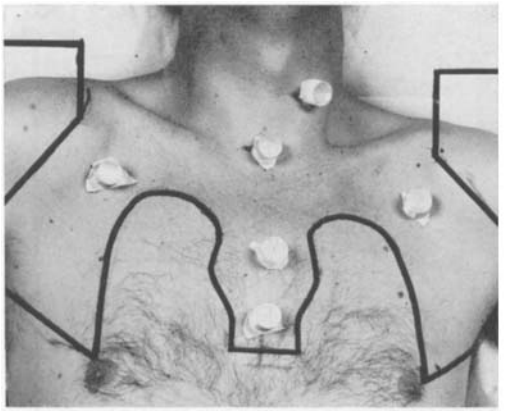


Fig. 2

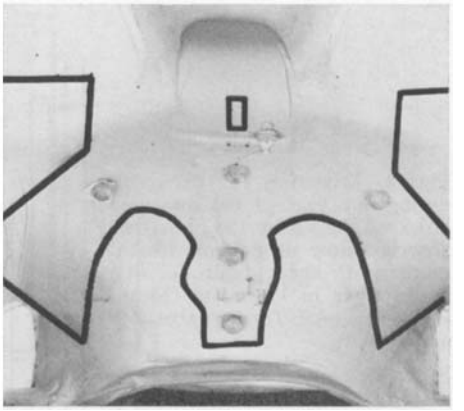


Fig. 3

Fig. 2. Clinical set-up designed to determine entrance doses for a mantle field treatment.

Fig. 3. Clinical set-up designed to determine exit doses for a mantle field treatment. The dosemeters are applied in the plastic shell which is used for patient fixation.

Certain cases of oesophageal carcinoma are preoperatively irradiated by a three-beam technique, two posterior oblique beams and one anterior beam. In order to optimize the treatment of the patients, an individual dose plan is made. The isodose distribution from these 3 beams is calculated by applying a correction for lung tissue using an isodose shift method (1/2-isodose shift method, SUNDBOM). In order to check the tumour dose calculated according to the plan, the absorbed dose has been measured in the oesophagus 16 times in 12 patients irradiated with ^{60}Co. For these intracavitary measurements the dosemeters used were extruded LiF rods inserted in a teflon catheter. The use of lead spacers between the LiF rods made it possible to determine the anatomic location of each dosemeter in the oesophagus. The lead spacers give the dosemeters about +3 per cent higher value for ^{60}Co gamma radiation than if plastic markers are placed between the dosemeters.

Phantom measurements. Measurements have also been made with extruded LiF rods in the oesophagus in an anatomic Temex phantom. The air space in this phantom, simulating the lungs, was filled with saw-dust with a density of 0.25 g/cm^3. This is the material that was stated by DAHL & VIKTERLÖF and SUNDBOM to be radiation equivalent to an air filled lung. The Temex phantom was irradiated with a three-beam technique identical to that used for the treatment of carcinoma of the oesophagus.

Frequency of in vivo dose measurements

The entrance dose is measured on patients treated with orthovoltage units (90–190 kV), ^{60}Co units and the 6 MV linear accelerator for every beam during the first 2 treatments and then repeated at each beam when the tumour dose is 20, 40 and

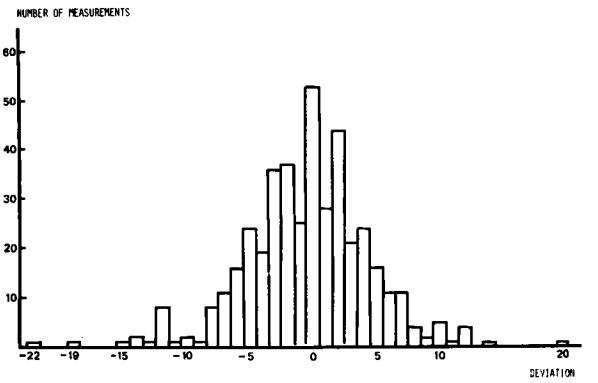


Fig. 4. Deviation (in per cent) during one year of the measured absorbed dose from the prescribed absorbed dose on patients treated on the 6 MV linear accelerator with wedge filter in the beam. Mean: +0.4, SD: ±4.7. Total number: 417 measureents.

60 Gy. For patients treated with an orthovoltage unit (20–50 kV) and with electrons and 42 MV irradiation at the 42 MeV betatron, the entrance dose is nowadays measured at every irradiation.

Exit dose measurements are made on patients treated for carcinoma of the oesophagus at various points in the caudal-cranial direction of the beam and in the lungs for every beam during the first 2 treatments and then repeated for each beam 2 or 3 times throughout the whole treatment course.

Intracavitary measurements are sometimes discomfortable for the patient but when possible two measurements are made during the whole course for patients treated for carcinoma of the oesophagus.

When a new therapeutic technique is introduced, intracavitary measurements are sometimes made as a control of the dose planning procedure.

If the eyes are close to the primary beam or under beam shaping blocks, measurements are made at every treatment.

The absorbed dose to the gonads is measured for every beam in the first irradiation and then repeated when the tumour dose is 20 Gy on patients treated with the inverted Y-technique.

Results

Long-term stability of the measuring technique. The mean values from day to day of all entrance dose measurements on the different accelerators give an indication of a sudden change or the long term drift effect in the dosimetry system. Figs 4 and 5 illustrate histograms of the deviation during one year from the prescribed absorbed dose with TLD on patients treated at the linear accelerator with beams with and without a wedge filter.

Each dosemeter assembly for entrance dose measurements contains two LiF teflon discs (cf Fig. 1). The difference in the readings between the two detectors used in the same dosemeter assembly was less than 5 per cent in 93 per cent of all entrance dose measurements during one year. The precision of one individual reading has been found to be within ±2 per cent (1 s).

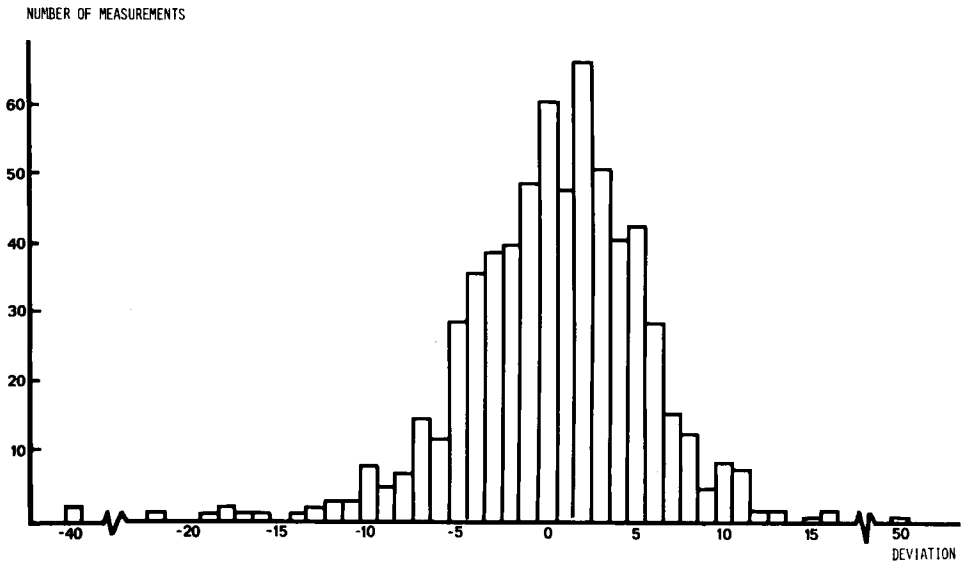


Fig. 5. Deviation (in per cent) during one year of the measured absorbed dose from the prescribed absorbed dose on patients treated on the 6 MV linear accelerator with open beam. Mean: +0.6, SD: ±4.8. Total number: 619 measurements.

Table 6 summarizes the results from entrance dose measurements on various treatment units. The table gives the mean value of the difference between measured and prescribed absorbed dose and the standard deviation of these differences for all entrance dose measurements during one month on all the various treatment units.

Fig. 6 illustrates a histogram of the deviation from the prescribed absorbed dose on patients treated with an irregularly shaped beam where lead blocks were placed in the corners and in the centre of the beam. The mean is +4.4 per cent, indicating a systematic error. An investigation demonstrated that too high a correction factor

Table 6

The mean value of the difference between measured and prescribed absorbed dose and the standard deviation of these differences for all entrance dose measurements during one month on all the various treatment units

Treatment unit	Mean (per cent)		Standard deviation (per cent)	
	Open beam	With wedge	Open beam	With wedge
Cobalt	−1.5	−1.0	±4.5	±6.3
Linear acc.	+0.6	+0.3	±4.6	±6.1
Betatron roentgen rays	−2.6	—	±4.4	—
Betatron electrons	+1.9	—	±5.8	—

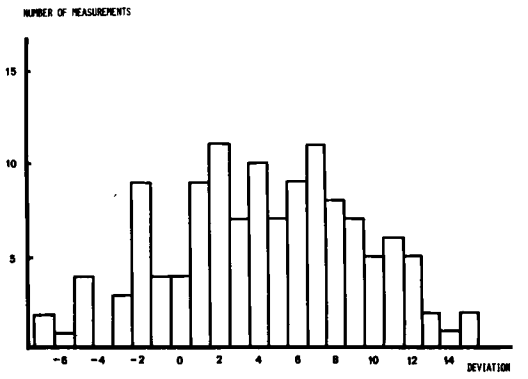


Fig. 6. Deviation (in per cent) of the measured absorbed dose from the prescribed absorbed dose on patients treated on the 6 MV linear accelerator with an irregularly shaped beam with lead blocks in the beam. Mean: +4.4, SD: ±5.0. Total number: 128 measurements.

had been used for the attenuation of the radiation in the Perspex sheet on which the lead blocks were placed. A change had been made from a thicker to a thinner sheet without giving notice to the planning department.

The limits of the dosemeter deviation from the prescribed dose that have been found to be realistic action levels appear in Table 7. If the limits are exceeded a control of the treatment parameters must be made. If the cause of deviation cannot be found a new measurement of the entrance dose must be performed at the next irradiation.

Entrance dose. At the ^{60}Co units and the 6 MV linear accelerator, between 10 and 20 per cent of the entrance dose measurements exceed the action level and in about 4 per cent some errors regarding treatment parameters exist. In the other cases where the reason was not found, the deviation from the prescribed absorbed dose was in no case larger than ±12 per cent.

The entrance dose measurements on patients treated with the 42 MeV betatron during the first years after the installation, indicated that some mistakes in the settings of the treatment parameters on the apparatus could occasionally cause severe overdosage. Two examples are given here. On one occasion several patients were treated with 39 MeV electrons instead of 10–15 MeV electrons. This fault gave rise to an overdosage of about 80 per cent. Some patients were treated with 42 MV roentgen rays without a beam flattening filter. This gave an absorbed dose which was too high

Table 7

Tolerable deviation from prescribed absorbed dose to a patient

Radiation quality	Tolerable deviation (per cent)
20–200 kV	±10
^{60}Co, 6 MV roentgen rays	±5 (±7 with wedge)
42 MV roentgen rays	±5
Electrons	±7

Table 8

Anatomic regions and corresponding beam sizes for calculating the absorbed dose in the centre of the patient in treatments with mantle and inverted Y-technique

Mantle technique		Inverted Y-technique	
Area	Beam size (cm × cm)	Area	Beam size (cm × cm)
Neck	5*5	Sternum	12 × 12
Axilla, supracl. fossa	15 × 15	Centre	12 × 12
Centre	15 × 15		
Mediastinum	10 × 10	Inguinal	8 × 8

by a factor 3 in a small area in the centre of the beam. These mistakes indicated that a more advanced interlock system must be built into the betatron to avoid wrong settings and that the entrance dose should possibly be measured for every treatment. In 1974 the betatron was fitted with an interlock system (HUZELL & ISRAELSSON 1975). The fact that the entrance dose has since been measured with TLD at every irradiation has probably also minimized the frequency of errors. At present less than 5 per cent of the treatments indicate a fault outside the action level in the entrance dose measurements. These faults in the entrance doses can easily be compensated for since the measurements have given the error.

Intracavitary and exit dose. The evaluation of all exit and intracavitary measurements on patients who have been treated with mantle or inverted Y-technique had led to the conclusion that different equivalent beam sizes must be used to calculate the dose in the centre of the patient in different anatomic regions (Table 8). To calculate the absorbed dose in the centre of different regions the depth dose curve (for SSD 150 cm) corresponding to the field sizes illustrated in Table 8 has to be used. Measurements made in a Temex phantom have confirmed the usefulness of these equivalent beam sizes to calculate the absorbed dose in the centre of the patient within an accuracy of ± 5 per cent.

In some patients treated for oesophageal carcinoma, the absorbed dose was found to vary as much as 20 per cent along the length of the oesophagus. The difference between measured absorbed dose and the calculated absorbed dose (corrected for lung tissue) had a mean value of $+8$ per cent (range -6 to $+16$ per cent). The exit dose measurements gave the same indication. The measured absorbed dose was corrected for the influence of the lead spacers between the dosemeters. The agreement between two intracavitary measurements for the same patient was within ± 3 per cent.

The results from the measurements in the Temex phantom agreed well (within ± 3 per cent) between calculated and measured absorbed dose in the oesophagus. The agreement between the absorbed dose in the oesophagus calculated from exit dose measurements on the phantom and the given dose was within ± 6 per cent.

Discussion

Uncertainties and errors in clinical dosimetry are two distinct concepts; the former refer to the chain of measurements leading to the delivery of a prescribed absorbed dose to a patient; mistakes caused by staff are errors.

Concerning the uncertainty, LOEVINGER & LOFTUS (1975) have set up a model which aims to include every link in the dosimetry chain from the national standardizing laboratory to the delivery within a hospital of an absorbed dose to a point in a phantom. They estimated the cumulative overall uncertainty to 5.1 per cent for the lowest acceptable model and 2.3 per cent for the model representing the best level of current practice.

The second stage of the clinical dosimetry procedure, in which the dose is delivered to a target volume in a patient, rather than to a uniform phantom, introduces a further series of uncertainties which are difficult to assess. Uncertainties associated with the patient are discussed in the ICRU report: Clinical dosimetry (1963).

A control on the precision of the whole chain including unforeseen and long-term drift effects in a dosimetry system, is obtained from the entrance dose measurements on patients. These are therefore important in providing a check on the uncertainty regarding the precision but not on the accuracy.

Every week a control of the treatment chart (scale division/Gy) is made on the accelerators with an ionization chamber. If this measurement shows a deviation of more than ± 3 per cent from the treatment chart, a correction is made in the build-in dosimetry system. The entrance dose measurements on patients with TLD on each of the accelerators will give an indication as to whether and when it is necessary to make a correction in the build-in dosimetry system. An unforeseen change in dosemeter systems at the accelerators has only occurred four times since their installation seven years ago.

In recent years a number of reports have appeared, assessing the incidence and significance of mistakes in the various stages of clinical dosimetry. Data have been obtained from KARTHA et coll. (1973, 1975), CHUNG-BIN et coll. (1975) and SUTHERLAND (1973).

A frequency of errors of about 4 per cent per year for mistakes leading to an error of 5 per cent or more in the final tumour dose was reported by SUTHERLAND. KARTHA et coll. found an incidence of 10 per cent in mistakes of arithmetic nature and in the reading of graphs, scales and charts. Errors in the setting up of the unit were found by KARTHA et coll. to be about 2 per cent, consistently over a long period of time.

Entrance dose measurements on patients at Radiumhemmet have shown that the following faults have occurred:

1. Mistakes in the setting up: (a) wedge filter, (b) energy, (c) scattering foil, (d) change of beam flattening filter, (e) treatment time or scale setting, (f) distance, and (g) field sizes.

2. Malfunction of shutter on a ^{60}Co unit.
3. Contamination of a ^{60}Co source with a short-lived radionuclide.

The mistakes listed in point 1 are not unusual and any of these occurred in about 3 to 4 per cent of the treatments.

Conclusion

The in vivo dose measurements on patients with TLD have shown the importance of these kinds of measurements for increasing the accuracy of the treatments of patients. These dosemeters are suitable for their purpose and easy to handle, for example in intracavitary measurements in the oesophagus and in veins, surface dose measurements, entrance and exit dose measurements at a number of points in irregular fields, measurements of the dose distribution in the electron field on patients treated for carcinoma of the breast where the curvature of the chest varies from one patient to another, checking of absorbed doses in critical regions near the target volume and below lead shields and for radiation protection measurements. In order to be sure that the patients are always given the correct absorbed dose, patient dose measurements must be made for every treatment. The evaluation of the entrance dose measurements on patients treated with irregularly shaped beams, where lead blocks were placed inside the beam, shows the usefulness of patient dose measurements to find unexpected errors in the treatment of patients. It was concluded from the patient dose measurements that it was most important to build in an interlock system at the 42 MeV betatron to increase the accuracy of the treatments.

A comparison between the standard deviation in Table 6 (e.g. 4.5 per cent for open beams with ^{60}Co radiation) with the reproducibility of the two detectors in the dosemeter assembly ($s = \pm 1.5$ per cent) indicates that only a minor contribution to the overall variance is due to the detectors.

The conclusion from the measurements of the absorbed dose in the oesophagus was that a standard correction factor for all patients to compensate for transmission through lung tissue (the 1/2-shift method) used in the dose planning for each patient, could not be consistently applied. If the size of the lung is not drawn with sufficient accuracy in the plan this may contribute to an error in the calculated absorbed dose. Measurements of the actual absorbed dose is therefore necessary in each case. To avoid unnecessary patient discomfort and because of the possibility of perforating a diseased oesophagus, exit or transit dose measurement would appear to be a good complement to or alternative for the determination of the absorbed dose in the oesophagus, even if these methods give less accuracy than a direct measurement in the oesophagus. Use of the 1/2-isodose shift method can in some cases result in an inaccuracy of about +15 per cent in the tumour dose. With no correction for the lungs the absorbed dose in the oesophagus will be about 25 per cent greater than that calculated (JACOBSON & KNAUER 1956). Use of a standard correction factor of 1.20

can result in an accuracy of 10 per cent in the tumour dose (WRIGHT & STROCKBINE 1974).

The measurements of the dose contribution to organs in which even relatively small radiation doses might be particularly undesirable have been useful; these measurements gave, among other things, an indication as to whether the lead shield was in right position and whether it gave sufficient protection. These measurements on patients treated with the inverted Y-technique have demonstrated the necessity of increasing the shielding over the gonads.

A number of irradiations are given with low kilovoltage. The apparatus used at Radiumhemmet for these treatments has no interlock system despite the fact that with certain potential and filter combinations the exposure rate is extremely high. This means that the treatment times are sometimes as short as a few seconds. It is advisable to make TLD measurements during these treatments to verify the given dose.

One disadvantage of using TLD for patient dose measurements is that an unavoidable time delay exists between the irradiation and the presentation of the results from the measurements. With the number of the staff it is impossible to increase the number of TLD measurements at Radiumhemmet. Attempts are being made to measure the entrance dose with solid state detectors connected to an integrating instrument which gives an immediate indication of the results (BÅRYD 1975). This will not reduce the value of TLD for more advanced patient dose measurements.

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SUMMARY

The relative light output per Gy in water for conventional roentgen radiation (20–190 kV), high energy roentgen radiation (6 and 42 MV) and electrons between 2.2 and 34.5 MeV relative to ^{60}Co gamma radiation is reported for different kinds of LiF dosemeters. The routine use of LiF dosemeters for a wide range of dosimetry applications in radiation therapy, the handling of the dosemeters to obtain high accuracy and the usefulness of making patient dose measurements are described.

ZUSAMMENFASSUNG

Die relative Lichtausbeute per Gy in Wasser für konventionelle Röntgenstrahlung (20–190 kV), hochenergetische Röntgenstrahlung (6 und 42 MV) und Elektronen zwischen 2,2 und 34,5 MeV relativ zur ^{60}Co Gammastrahlung für verschiedene Arten von LiF Dosimetern wird berichtet. Der Routinegebrauch von LiF Dosimetern für einen weiten Bereich von

Dosimetrie-Anwendungen in der Strahlentherapie, die Handhabung der Dosimeter, um eine hohe Genauigkeit zu erhalten, und die Nützlichkeit von Dosismessungen am Patienten werden beschrieben.

RÉSUMÉ

L'auteur a mesuré l'émission relative de lumière par Gy dans l'eau pour le rayonnement roentgen ordinaire (20–190 kV), pour le rayonnement roentgen de haute énergie (6 et 42 MV) et pour les électrons entre 2,2 et 34,5 MeV par rapport au rayonnement gamma du ^{60}Co pour différents types de dosimètres LiF. L'auteur décrit l'utilisation pratique des dosimètres au LiF pour un large domaine d'application dosimétrique dans le traitement par les radiations, la façon d'utiliser les dosimètres pour obtenir une haute précision et l'utilité de faire des mesures de doses sur le patient.

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