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LiF SURFACE AND DEPTH DOSE MEASUREMENTS OF MEGAVOLTAGE PHOTON AND ELECTRON BEAMS

by

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Using megavoltage photon beams, the measurement of absorbed dose at the position of a deep seated tumor may be achieved by several techniques. Dose determination at the skin and in the subcutaneous region, where the dose is changing rapidly, is more difficult. When high energy electron beams are used, a determination of absorption pattern in and close to an heterogeneity in the absorber, especially when it is very small, becomes difficult unless a very small dosemeter is available. Extrapolation chambers have been successfully employed for absorbed dose measurements in the 'build-up' regions, but they are instruments difficult to construct and tedious to use. The use of ionization chambers for measurement in the build-up region and even at the peak dose depth is shown to be undesirable due to the errors involved in positioning and lack of electronic equilibrium (HOSPITAL PHYSICISTS' ASSOCIATION 1969).

In this article, the use of LiF thermoluminescent powder (TLD-100) in thin layers (approximately 20 μm) for the measurement of absorbed dose in the

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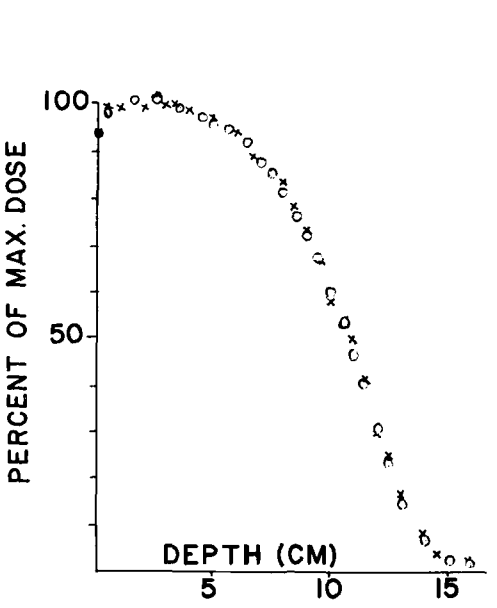

Fig. 1

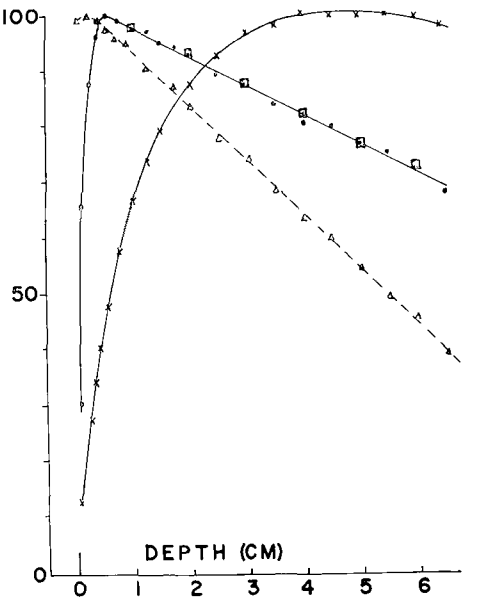

Fig. 2

Fig. 1. Results of measurements using a single irradiation of 25 stacked monocrystalline TL dosemeters (o) and multiple irradiations of single dosemeters (×) at different depths. 30 MeV electrons, 8 cm circular plastic applicator.

Fig. 2. Build-up curves measured with monocrystalline TL layer dosemeters. Field size 4×4 cm. △ 250 kV roentgen rays, × 32 MV roentgen rays, ● ^{60}Co measured, □ ^{60}Co according to British Journal of Radiology, Supplement 10.

region of high dose gradient is reported. It has been employed to measure relative doses at the surface and in the build-up region of 250 kV roentgen rays, ^{60}Co radiation and 32 MV roentgen rays. The depth dose curves of 10 to 35 MeV electron beams in both homogeneous and heterogeneous absorbers have also been similarly measured.

Thermoluminescent dosimetry (TLD) has gained popularity in clinical dose measurement because of its approximate tissue equivalence, reproducibility, commercial availability and its ability to store the absorbed energy for long periods (Cameron et coll. 1964). Its dosimetric response has been found to be linear to approximately 1 000 rad for roentgen and gamma rays (Cameron et coll. 1964) and to 5 000 rad for high energy electrons (Karzmark et coll. 1964, Kartha 1969). Also its response to high energy electrons and photons with LET less than that of ^{137}Cs has been shown to be constant (Worton & Holloway 1966, Pinkerton et coll. 1966, Kartha 1969, Suntharalingam & Cameron

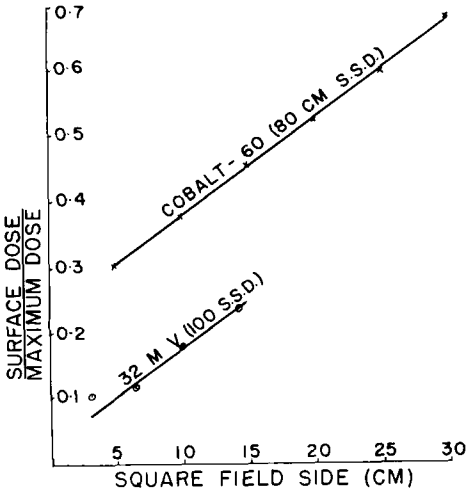

Fig. 3. Relative surface dose at the center of square ^{60}Co and 32 MV roentgen ray fields, as a function of field size.

1969, BINKS 1969). Because the energy spectrum and the dose level vary with depth in the absorber, especially for electron beams, the ideal system for the measurement of depth dose must have a linear dose response which is independent of energy. Because LiF fulfills these requirements, it has been extensively used in the form of encapsulated dosemeters for depth measurement of electron and photon beams (ALMOND et coll. 1967, HENDEE 1966, HENDEE et coll. 1968). Since the TLD-100 phosphor is in the form of crystals of approximately 100 mesh Tyler, its use can provide excellent spatial resolution, which is of primary interest in the measurement of dose in a high-gradient region (ROBINSON & MCDOUGALL 1966). The large dimension of TLD-100 in capsule form does not provide enough accuracy in the measurement of such doses. The LiF phosphor has been used in techniques similar to that used in this work, for the measurement of ^{90}Sr beta depth dose (MCDONALD 1965) and cellular radiation dose (HENDEE et coll. 1967).

Materials and Method. The TLD-100 phosphor used in the measurement was spread evenly into a polystyrene disc of 1 mm thickness, to fill a small recess of 0.2 mm depth and 10 mm diameter. This could hold approximately 35 mg LiF phosphor with the powder surface exposed. By stacking these discs in a closely fitting hole in a polystyrene phantom, which is considered tissue equivalent (SCRAD 1966), it was possible to measure the dose at 1 mm intervals of depth from the surface through the build-up regions, to any desired depth up to 20 cm. Since the dosimetric phosphor is exposed at the surface without any overlying material, the surface dose measurement is most accurate.

Using this technique, a complete depth dose curve could be obtained with a single radiation exposure. However the introduction of LiF phosphor in the tissue-equivalent phantom may result in a differential absorption, especially in the electron beam measurements. In order to examine this possibility, the result of measurements with a single stack irradiation was compared with those obtained with multiple irradiations of single monocrystalline layer dosemeters. A typical curve comparing the two sets of results is shown in Fig. 1, which indicates agreement within experimental limits.

The 1 mm build-up of heavily filtered 250 kV roentgen rays (2.6 mm Cu HVT) was measured by this technique to demonstrate its usefulness. The depth dose curves for this roentgen ray beam are shown in Fig. 2, along with similarly measured curves for ^{60}Co and a 32 MV photon beam. The surface doses are 98, 30 and 10 % respectively of the peak dose, which occurs at depths of 1 mm, 4 mm and 40 mm. On the ^{60}Co curve the standard depth dose data (Brit. J. Radiol. Supplement 10) are superimposed for comparison.

The radiation sources employed in this work were a 250 kV Westinghouse therapy unit, a Theratron-80 Cobalt-60 teletherapy unit, and a Brown Boveri Asklepitron 35 medical betatron. The betatron was adjusted to put out a 32 MV roentgen ray beam and electron beams in the energy range from 10 to 35 MeV. The roentgen ray beam is defined by a continuously variable diaphragm assembly, while electron beam definition is achieved at the skin by a variable collimator, or one of a set of fixed plastic applicators, or brass cutouts placed at the surface of the absorber.

Thermoluminescent measurements were made using a Madison Research Model S-2 thermoluminescent radiation exposure meter. The reproducibility of dose measurements with this instrument was within ± 1 % in the dose range 50 to 5 000 rad (KARTHA 1969, WORTON & HOLLOWAY 1966). The large number of measurements required was, however, tedious and timeconsuming since each reading cycle requires at least one minute of undivided attention. Consequently, an automated TLD reading device was designed and constructed in order to simplify the measurement procedure (KARTHA & MACDONALD 1969). This device makes possible the unattended measurement of 24 samples sequentially, the resulting data being stored in an electronic memory circuit and typed out when required.

Surface dose

The relative surface dose at the center of square ^{60}Co and 32 MV roentgen ray fields, as determined by this method, are plotted in Fig. 3 against the length of the field side and is approximately linear in both cases. These findings are in

Table

Surface doses as a percentage of the dose maximum, illustrating the effect of beam size and method of collimation

Accelerated electron energy (MeV)	Plastic applicator		Variable collimator		No collimation Open field
	4 cm diameter	14×12 cm	4×4 cm	14×12 cm	
10	95	88	92	88	84
15	94	92	92	93	84
20	93	93	93	94	86
25	94	92	93	94	88
30	92	92	94	92	90
35	91	92	93	93	89

agreement with those of SMITH et coll. (1958) and indicate that the increase in central dose is caused by scatter from the diaphragm system.

The per cent surface doses for electron beams of various sizes and methods of collimation, in the energy range 10 to 35 MeV, are listed in the Table. In contrast to the situation described above, the central surface dose for collimated electron beams is found to decrease slightly with increasing size. In this case the beam-limiting diaphragms are in contact with the skin surface, and as the field size increases, electrons scattered from them are less likely to contribute to the dose at the field center. When the collimators are removed, the resulting reduction in central surface dose indicates the magnitude of this scatter contribution as illustrated in Fig. 4, where the results of collimation by a 12 × 14 cm plastic applicator are compared to collimation by a thick brass cutout placed on the surface. The difference in the area under the curves represents the scatter contribution from the plastic applicator, which is more significant at low energies and when small plastic applicators are used. In addition, when the cutouts are used at the surface of the absorber to define the electron beam the dose distribution along the plane of the field is more uniform. Consequently, the use of such brass cutouts results in lower skin dose and a more uniform dose distribution over the field area, which is especially advantageous for most therapeutic set-ups.

Electron beam dosimetry

Homogeneous absorbers. The dose gradients encountered in the therapeutic use of high energy electron beams are easily measured with the monocrystalline layer technique. Examples of central axis dose curves are given in Figs 4, 5 and 6.

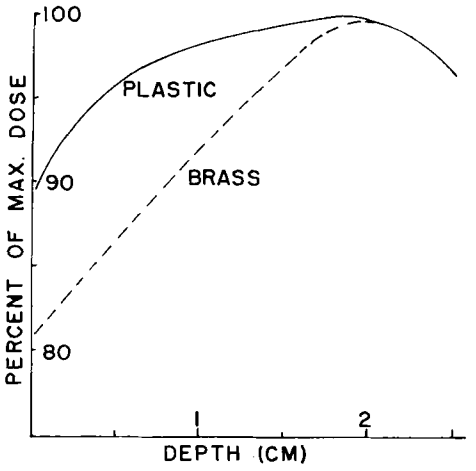

Fig. 4. 10 MeV electrons, 14 × 12 cm field size. Depth dose curves for the region between the surface and the maximum when (1) an extended plastic applicator, and (2) a cutout in a thick brass plate, is used to define the beam.

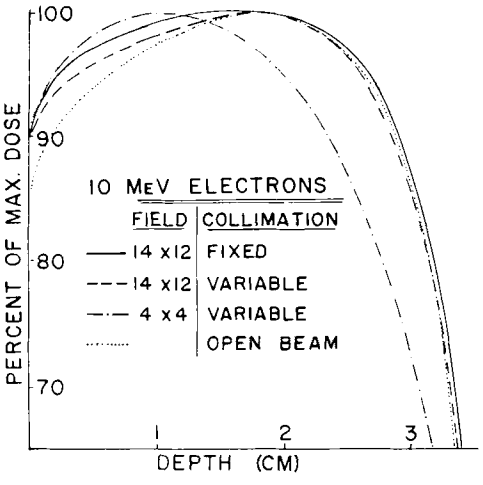

Fig. 5

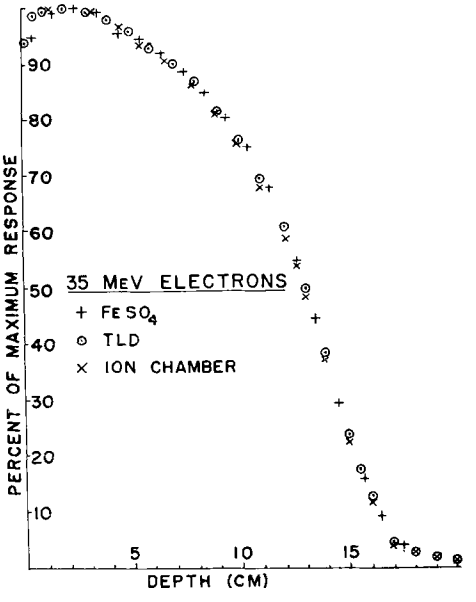

Fig. 6

Fig. 5. Comparison of central axis depth dose curves for 10 MeV electrons, illustrating the effect of field size and method of collimation.

Fig. 6. Depth dose curve for 35 MeV electrons as measured with three dosimetric systems.

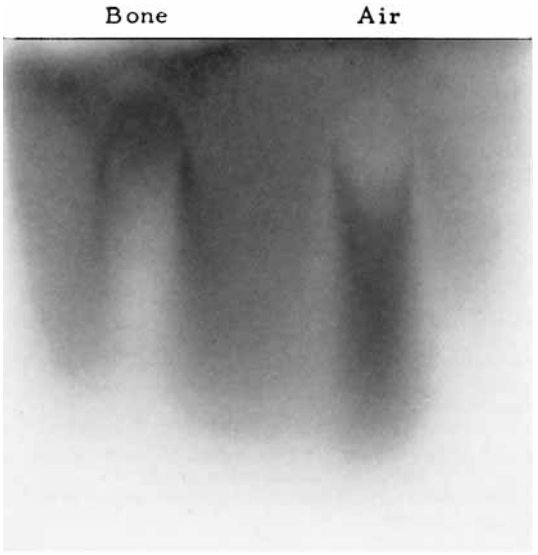

Fig. 7. Film dosimetric measurement of a 35 MeV 14×12 cm electron beam absorption in a tissue equivalent rubber phantom (TEMEX) containing bone and air for inhomogeneity.

It is seen from Fig. 5 that, for a 10 MeV beam, the shape of the depth dose curve depends upon the field size and type of collimator. This is found to be true at all energies up to 35 MeV, and shows the undesirability of therapeutic electron beams of small cross-section.

An intercomparison of central axis depth dose curves for an 8 cm diameter 35 MeV electron beam, as measured with the ferrous sulphate mini-dosemeters (KARTHA 1970), a Baldwin-Farmer ionization chamber and LiF monocrystalline layer dosemeters is shown in Fig. 6. The ionization chamber measurements have been corrected to the effective center (DUTREIX & DUTREIX 1966). The agreement demonstrates the usefulness of the monocrystalline layer TLD technique for such measurements.

Heterogeneous absorbers. The TLD technique described in the preceding was also used to measure the absorption curve of electron beams in the heterogeneous phantoms. The preferential absorption of electrons in higher electron-density materials have been well established (LAUGHLIN et coll. 1965). This is further illustrated in Fig. 7, where the absorption pattern of a 35 MeV electron beam in a heterogeneous absorber is given. The heterogeneity was produced by introducing bone and air cavities in a tissue-equivalent (TEMEX) phantom. A Kodak type M film sandwiched in the phantom was irradiated at 3° to the beam axis. The regions of protection in and beyond the inhomogeneity indicate that the absorption in bone is greater than in soft tissue, producing a low dose protection

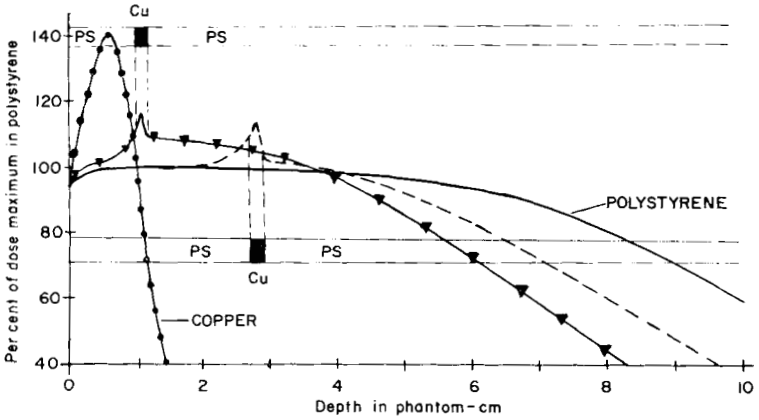

Fig. 8. The effect of the presence of high electron density absorber (copper) in a tissue-equivalent (polystyrene) phantom, measured with monocrystalline layer TLD-100. The depth dose curves for homogeneous copper and polystyrene phantoms are also inserted.

beyond it. On the other hand, the opposite situation prevails where air is present. In order to study these effects in further detail depth dose curves in heterogeneous absorbers, produced by the introduction of cork, bone, plaster of Paris, magnesium, aluminium, copper or lead into a polystyrene phantom, were measured with the monocrystalline TLD-100 layers. These curves showed an increased absorption in and around the higher electron density material, and a considerable decrease in the average range of the electron beam. A typical set of curves is shown in Fig. 8. An 8 cm diameter 30 MeV electron beam was used and the TLD-100 was spread in thin layers between the 0.5 mm copper sheets introduced in the polystyrene phantom. The depth dose curve for the same electron beam in a homogeneous copper and polystyrene phantom, measured by the same method is also given along with these curves. Introduction of the 2 mm copper perturbed the energy dissipation pattern considerably, which seemed to be strongly dependent upon the position of the inhomogeneity in the absorber. Except for the extent and amplitude of the peak at the position of inhomogeneity in the absorber, the results were identical when other materials were used in place of copper.

Discussion

The value of Lif TLD has been increased by its extension to dose measurements using very thin layers of approximately 20 μm. The feasibility of making measurements at the surface and at separations of a millimeter or less has been demonstrated. It allows the measurement of a complete depth dose curve in

homogeneous as well as heterogeneous absorbers using single exposure. Considering the excellent reproducibility and electron energy independence, the TLD-100 when calibrated provides accurate means of measurement of depth dose curves. Since the high energy electron beams loses energy fairly uniformly at a rate of approximately 2. 25 MeV per cm of water (or tissue equivalent absorber), a dosimeteric system whose response is independent of beam energy is extremely useful. Furthermore, in clinical dosimetry a point dosemeter is highly desirable because the absorbers involved in radiation therapy are invariably heterogeneous and the determination of absorption at a point becomes very important. The use of monocrystalline layers of TLD-100 made possible the determination of surface dose and demonstrated the advantages of using beam defining cutouts in electron beam therapy, over the conventional electron beam cones. The results of the depth dose measurements in heterogeneous phantoms illustrate the superiority of this technique over other dosimetric methods. Additional information has been obtained, especially in regions of high dose gradient.

SUMMARY

A simple dosimetric method using LiF TLD-100 phosphor in monocrystalline layers is presented. This technique is shown to be especially useful in the measurement of surface dose, absorbed dose in the region below the surface and electron depth dose in both homogeneous and heterogeneous absorbers. The measurement of a complete depth dose curve, including the surface dose and the dose in regions of sharp gradients is made possible by using stacks of the monocrystalline layers of TLD-100.

ZUSAMMENFASSUNG

Eine einfache dosimetrische Methode, bei der LiF TLD-100 Phosphor in monokristallinischen Schichten verwendet wird, ist dargestellt. Es wird gezeigt, dass diese Technik besonders anwendbar bei der Messung der Oberflächen-Dosis, der absorbierten Dosis in Abschnitten unterhalb der Oberfläche und der Elektronen-Tiefen-Dosis in sowohl homogenen als auch inhomogenen absorbierenden Medien ist. Die Messung einer vollständigen Tiefendosis einschliesslich der Oberflächendosis und der Dosis in Gebieten mit tiefen Gradienten wird durch Verwendung von Stapeln monokristallinischer Schichten von TLD-100 ermöglicht.

RÉSUMÉ

Les auteurs présentent une méthode dosimétrique simple utilisant un scintillateur au LiF TLD-100 en couche monocristalline. Cette technique est particulièrement utile pour mesurer la dose en surface, la dose absorbée dans la région au dessous de la surface et la dose d'électrons en profondeur dans des absorbants homogènes et hétérogènes. La mesure d'une courbe de dose en profondeur complète, comprenant la dose en surface et la dose dans des régions de forts gradients est rendue possible par l'utilisation de piles de couches monocristallines de TLD-100.

REFERENCES

ALMOND P. R., WRIGHT A. and LONTZ J. F.: The use of lithium fluoride thermoluminescent dosimeters to measure the dose distribution of a 15 MeV electron beam. Phys. in Med. Biol. 12 (1967), 389.

ASPIN N., BAKER R. G. and JOHNS H. E.: Dose measurements in the build-up region for Cobalt-60 radiation. J. Canad. Ass. Radiol. 8 (1957), 72.

BINKS C.: Energy dependence of lithium fluoride dosemeters at electron energies from 10 to 35 MeV. Phys. in Med. Biol. 14 (1969), 327.

CAMERON J. R., ZIMMERMAN D., KENNY G., et coll.: Thermoluminescent radiation dosimetry utilizing LiF. Hlth Phys. 10 (1964), 25.

DUTREIX J. et DUTREIX A.: Étude comparée d'une série de chambres d'ionisation dans des faisceaux d'électrons de 20 et 10 MeV. Biophysik 3 (1966), 249.

HENDEE W. R.: Thermoluminescent dosimetry of beta depth dose. Amer. J. Roentgenol. 97 (1966), 1045.

— and KENNEDY K.: Thermoluminescent measurement of cellular radiation dose. Amer. J. Roentgenol. 100 (1967), 886.

— GOLDEN R., GARCIGA C. E. et coll.: Depth dose measurements with lithium fluoride. Amer. J. Roentgenol. 102 (1968), 694.

HOSPITAL PHYSICISTS' ASSOCIATION: A code of Practice for the dosimetry of 2 to 35 MV X-ray and Cesium-137 and Co-60 Gamma-ray beams. Phys. in Med. Biol. 14 (1969), 1.

KARTHA M.: High energy electron dosimetry. Doctorate thesis, University of Western Ontario, London, Ontario, Canada 1969.

— A ferrous sulphate mini-dosimeter. Radiat. Res. 42 (1970), 220.

— and MACDONALD J. C. F.: An automated thermoluminescent dose-measuring system. Presented at the Second Internat. Conf. Med. Phys., Boston. U.S.A., August 1969.

KARZMARK C. J., WHITE J. and FOWLER J. F.: Lithium fluoride thermoluminescent dosimetry. Phys. in Med. Biol. 9 (1964), 273.

LAUGHLIN J. S., LUNDY A., PHILLIPS R. et coll.: Electron-beam treatment planning in inhomogenous tissue. Radiology. 85 (1965), 524.

MACDONALD J. C. F.: A magnetic-selected beta-particle therapy unit for the treatment of superficial lesions. Presented at the 11th Int. Congress of Radiology. Rome, September 1965.

NAYLOR G. P.: Application of thermoluminescent phosphors in dosimetry problems in radiotherapy and radiobiology. Brit. J. Radiol. 40 (1967), 170.

PINKERTON A. P., HOLT J. G. and LAUGHLIN J. S.: Energy dependence of lithium fluoride dosemeters and high energy electron energies. Phys. in Med. Biol. 11 (1966), 129.

ROBINSON J. E. and MCDOUGALL R. S.: The use of a thermoluminescent dosemeter for dose measurements in the build-up region (abstract). Phys. in Med. Biol. 11 (1966), 145.

SMITH I. H., MACDONALD J. C. F., PFALZNER P. M. and FERGUSON H. I. S.: Cobalt-60 beam therapy. Proc. Second U. N. Conf. on the Peaceful uses of Atomic Energy, Geneva 1958, Vol. 26 (1958), 295.

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

SUNTHARALINGAM N. and CAMERON J. R.: Thermoluminescent response of lithium fluoride to radiations with different LET. Phys. in Med. Biol. 14 (1969), 397.

WORTON R. G. and HOLLOWAY A. F.: Lithium fluoride thermoluminescence dosimetry. Radiology 87 (1966), 938.