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DOSE DISTRIBUTION AROUND RADIUM ARRAYS USED IN THE TREATMENT OF UTERINE CARCINOMA

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The determination of absorbed dose in gynecologic applications of brachytherapy sources has always been more difficult and less accurate than in any other branch of radiation therapy. This difficulty is inherent in a technique which involves using linear sources at short distances, where the inverse square law gives rise to large dose gradients. Despite the advent of the electronic computer and the consequent improvement in the accuracy of calculated dose distributions, still many uncertainties are involved, not the least the positions and shapes of relevant organs.

HEYMAN (HEYMAN et coll. 1941) introduced the so-called packing technique in which the uterus is packed to capacity with a number of spacing filters enclosing radium tubes. When the technique is properly executed the uterine wall is fixed relative to the radium so that when the exact location of the tubes is determined, it is possible to deduce an isodose distribution applicable to the size and shape of the uterus in question. Stereoscopic films are helpful in the localization of the tubes, but they are only the first link in a long chain of tedious procedures that must be performed before an accurate dose distribution can be produced.

BENNER (HEYMAN et coll. 1941, HEYMAN & BENNER 1946) considered that the resultant dose distribution should not be critically dependent upon the positions of the radium sources, and for this reason he placed little emphasis on exact localization procedures. On this assumption he produced a set of tables linking the number of sources to an optimum treatment time, which was based on an estimation of resultant dose rates at 1.5 cm from the uterine wall. From a modern dosimetric viewpoint this approach is unsatisfactory since the method used for treatment time calculation involved no correction for self-absorption among the tubes themselves, nor any allowance for the shape of the array. In addition, the type of filter originally used by HEYMAN bears little resemblance to that commonly in use today. A comparison of two Heyman applicator filters with a modern Campbell-type stainless steel filter is made in Fig. 1. It is seen that these are considerably different in physical dimension, and so one would expect the result in dosimetry to be considerably different.

In his measurements, BENNER used ionization chambers to determine the dose at short distances from the array. Because of the large size of these detectors the spatial resolution was poor. All measurements were made on the surface of a simulated uterus in air, and doses were only recorded at a fixed distance from the radium, which was assumed to correspond to the outside wall of the uterus.

In the present work the following problems were analysed: (1) what the uterus receives during a typical insertion of present-day applicators, and (2) how valid the tables originally deduced by BENNER are when applied to existing techniques.

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Table 1

Comparison of experimental and theoretic values for a single 10 mg radium tube filtered through 1 mm of platinum. Source diameter 0.29 mm, active length 1.25 cm

Experimental points as defined by Young & Batho*		Calculated values from Young & Batho* (mGy/h)	Experiment (mGy/h)
X	Y		
0	1	649	629
0	2	176	169
0	3	79	73
0	4	44	47
0	5	28	32
0	6	19	21

* X is the displacement of the perpendicular from the center of the active length of the source.
Y is the perpendicular distance of the point from the axis of the source.

In examining these problems, measurements were made using teflon-coated 1 mm × 6 mm lithium fluoride thermoluminescent microrod dosimeters; these were employed because of their small size and good spatial resolution. The measured response of these detectors is a function of their own structure and of the readout device. It is therefore necessary to perform an absolute calibration at the time of each measurement to eliminate any short term variation in the sensitivity of the system.

Calibration

Thermoluminescent LiF microrods manufactured by the Harshaw Chemical Company were used for the dosimetric determinations.

The energy dependence of these dosimeters in the photon energy range up to 1.25 MeV is shown in Fig. 2. It appears that between E = 137 keV (3 mm of Cu HVT) and 1.25 MeV (15 mm of Cu HVT) the maximum variation in response is 5 per cent. At lower energies the energy dependence is significant, with an enhanced response of up to 40 per cent relative to the response at 1.25 MeV.

The overall reproducibility of measurement using these detectors was found to be adequate for the present purposes. Sets of 20 measurements at each of a number of dose levels produced a standard deviation of 5 per cent. In the first 48 hours after irradiation, a drop of about 10 per cent in response occurred, after which the dosimeter showed no further significant fading with time. Accordingly, the microrods were calibrated by irradiation to a known dose of ^{60}Co radiation and the practice of reading the dosimeters two days after irradiation was instituted. The justification for using these dosimeters is that, in sharp dose gradients, the positional accuracy is a limiting factor. For example, at 2.0 cm from radium tubes the dose rate varies by about 10 per cent per mm. An estimate of the reproducibility of this system is ± 1.0 mm so that an overall accuracy of ± 15 per cent is all that can be expected.

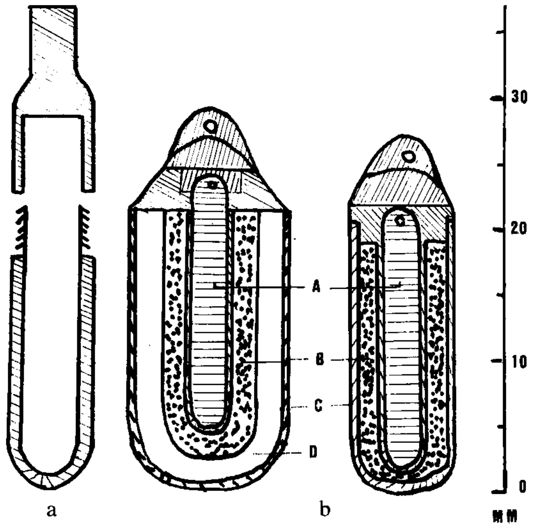

Fig. 1. Comparison of a) Campbell-type applicator and b) Heyman irradiators. A: Radium tube. B: Inner wall of lead. C: External wall of stainless steel. D: Intermediate space filled with air.

The experimental method was first checked by evaluating the dose distribution in water from a single 10 mg radium tube. A polystyrene plate, immersed in a water phantom, held the radium source

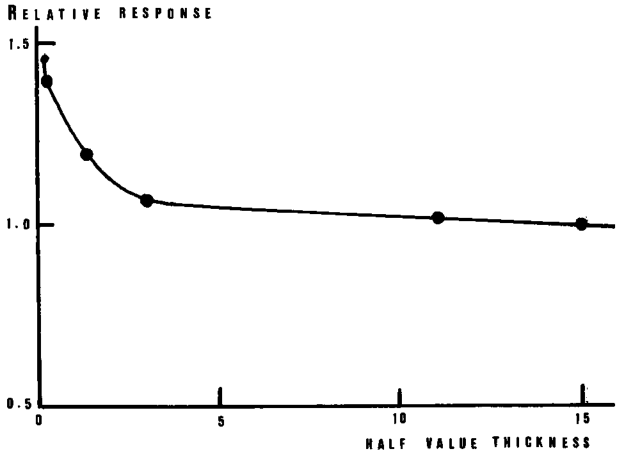

Fig. 2. Energy dependence of LiF microrods.

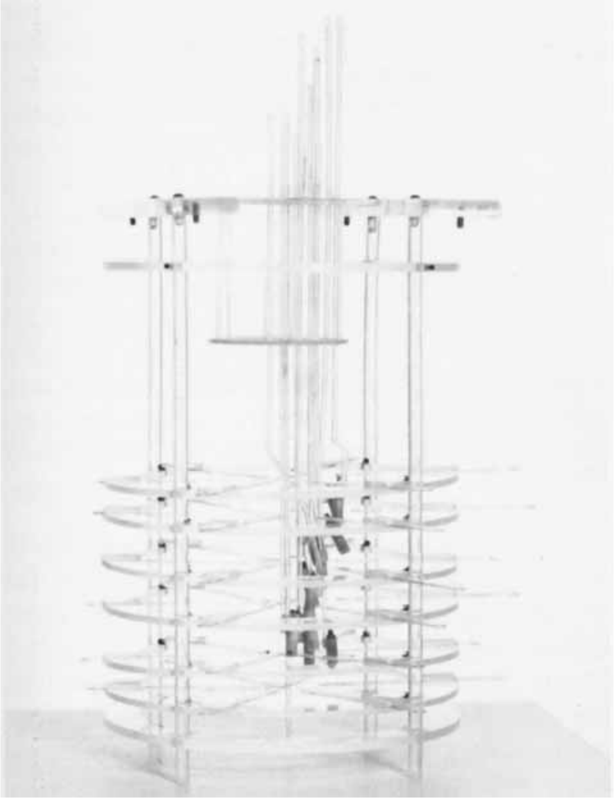

Fig. 3. Source and detector jig.

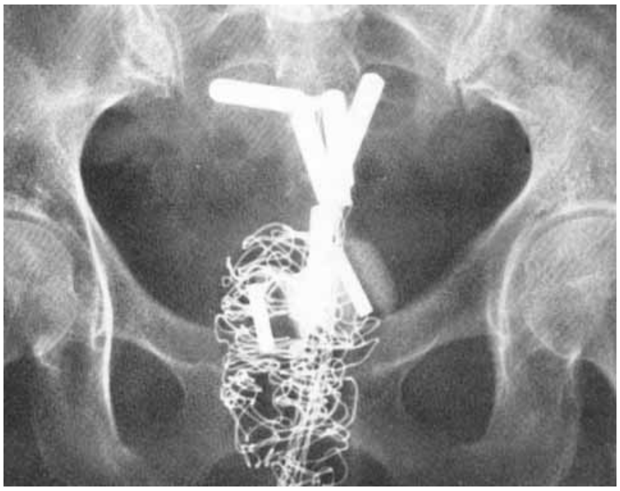

Fig. 4 a

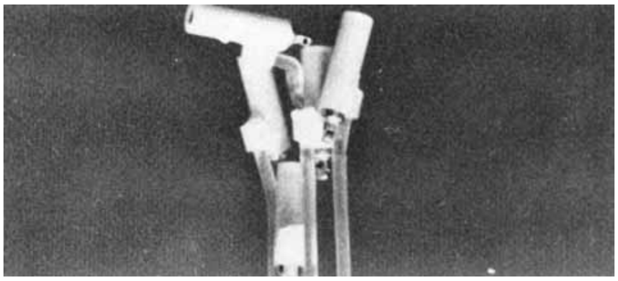

Fig. 4 b

Fig. 4. a) A.p. film of the actual packing. b) Control film of the source support.

centered in a polar array of lithium fluoride microrods. The measured dose rates at various distances were compared with the values calculated from BATHO's tables (BATHO & YOUNG 1964, YOUNG & BATHO 1964). The results are compared in Table 1. It is seen that at distances greater than 4 cm, the measured values are high by an amount greater than the experimental uncertainty. The contribution of low energy scattered radiation at these distances, together with the increased sensitivity of the dosimeter for low energies could give rise to this increased response. Lithium fluoride microrods were thus found, suitable for measurements under water.

Apparatus

A 45 cm × 45 cm × 40 cm deep tank made of clear plastic and filled with water was used for the measurements. The source and detector supports (Fig. 3) were made of water-equivalent plastic, and were rigidly fixed in relation to each other so that any arrangement could be accurately reproduced. The detector support consisted of six plastic rings mounted on four uprights fitted into a shallow recess in the bottom of the tank. These uprights were graduated so that the vertical position of the rings could be recorded and reproduced. Each ring carried six polystyrene strips spaced around it at intervals of 60 degrees. The lithium fluoride rods were fitted into slots in the strips. Each strip could move in the slot and was graduated so that its radial position could be reproduced.

In order to hold the radium sources in position, a support (Fig. 3) fitting tightly into the top of the detector jig was constructed. The support was made up of two spaced plastic plates into which a matrix of holes was drilled. Polystyrene rods, bent to any desired shape by heat treatment, were then pushed through the appropriate holes and clamped in position. Thin-walled polystyrene holders were attached to the ends of these rods. In this way it was possible to reproduce virtually any clinical radium distribution; the presence of the polystyrene rods supporting the lower sources would occasionally interfere with the exact orientation of the upper sources.

Experimental procedures

A.p. and lateral films of eight typical Heyman treatments form the basis of the reconstructed radium arrays. The polystyrene support rods were adjusted to produce, as nearly as possible, a model of the actual packing arrangement. The accuracy of this procedure was controlled by exposing films of the source support with the dummy sources in place (Fig. 4).

Microrod dosimeters were distributed on the detector strips, the strips were mounted on the rings, and then pushed into their final positions. Campbell applicators (a modern version of the Heyman filters) each containing a 10 mg radium tube were then placed in the holders in the source support which was then inserted in the detector array. Thereafter, this entire arrangement was immersed in the water tank and left for an irradiation time of 20 to 24 hours, the time depending upon the number of sources used. During this period, films of the arrangement were exposed in two directions at right angles, the geometry being chosen to make the magnification correspond to that of the original films of the patient. With the radium removed, the dosimeters were read together with the calibration detectors using a Teledyne TLD-7300 reader. From a graph of dose rate against position along each strip, the dose rate distribution at the level of each ring was determined. From the distributions in the six horizontal planes, dose rate distributions in the other two mutually perpendicular planes could be produced by interpolation. By using the known magnification factors it was possible to transfer the known dose rate contours directly onto the original films.

The computation of the dose distributions was performed using an Artronix PC-12 computer, and employing as input the coordinates of the ends of the applicators as determined from measurements on pairs of orthogonal films. This straight-forward calculation was complicated by problems of cross-filtration; frequently the dose at a point from a particular source would be reduced because of absorption by one or more other source capsules. In addition, the extra filtration provided by the spacing filters had to be taken into account in the calculations. The contribution of these factors was measured experimentally using thermoluminescent dosimeters. For two Heyman encapsulated radium tubes the cross-filtration effect was determined to be 3 per cent at 2.5 cm distance and the effective absorption from the filters was 4 per cent. In order not to complicate the computer calculations, a constant absorption factor of 8 per cent for each filter was employed.

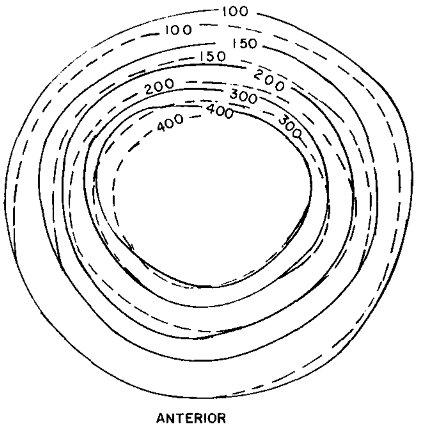

Fig. 5. Dose distribution (in mGy/h) for the 5-tube array. LiF measurement (- - -). Computer calculation (—).

The results of the computer calculations and of the experimental measurements for a particular array in a specific plane appear in Fig. 5. In this case, it may be concluded that the agreement is within the region of the combined error of the two methods. A total of 8 arrays ranging in activity from 5 to 16, 10 mg radium tubes were analysed. In each case, a comparison of the results of dose measurements with those of computer calculations were compared with values derived from BENNER's tables. This comparison at a distance of 15 mm from the external surface of the radium, a distance which is consid-

Table 2

Experimental measurements of Heyman arrays

No.	Number of Ra tubes	Measurements at 1.5 cm (mGy/h)	Calculated from BENNER's tables (mGy/h)	Computer calculated (mGy/h)
1	5	394±60	458	433
2	5	526±80	458	463
3	6	459±70	500	443
4	6	356±50	500	361
5	8	468±70	565	484
6	8	493±70	565	465
7	12	696±100	700	685
8	16	880±120	804	834

ered to be equal to the average thickness of the uterine wall, is shown in Table 2.

Accuracy. In the radiation measurements, with a reproducibility of source and detector of approximately ± 1.0 mm, an overall dose determination accuracy of ± 15 per cent is expected.

In the computer calculations, the accuracy of the computer dose rate depends upon the accuracy of determination of the end points of the sources from measurements on the films. This again is estimated to be ± 10 per cent. Other sources of uncertainties lay in the assumption of the effects of cross filtration and in the variation in the true activity content of the tubes. The overall effect of these variables leads to an expected accuracy of ± 15 per cent.

Conclusions

The HEYMAN packing method, from its inception, has been recognized as a system that is not amenable to accurate dosimetry. In his pioneer work, BENNER recognized this and, on the basis of experiments that would be considered crude in today's standards, recommended a method to form a routine basis for dose evaluation.

Computers at present available make possible the determination of dose at any point in the vicinity of a radioactive array; the principal problem is, in many cases, the specification of significant points at which the dose should be determined. In the packing technique, BENNER's points of interest 15 mm beyond the outer most radium may still be considered to be a reasonable region of interest.

In the present work, measurements have been made to determine the dose distribution around eight typical packing method arrays of commercially available Heyman applicators. A comparison of the results of these measurements with the dose rates derived from BENNER's tables shows satisfactory agreement even when applicators are employed that are considerably different from those used by HEYMAN.

Further, it has been established that standard dosimetric computational techniques produce results which are in agreement (within acceptable levels) with those of the results of measurement and with the values of BENNER.

This work supports BENNER's approach to the Heyman technique in that a reasonably uniform dose distribution can be achieved from a haphazard array of tubes, and that this dose distribution is insensitive to small changes in techniques.

SUMMARY

Measurements have been made to determine the dose distribution around typical arrays of commercially available Campbell type Heyman applicators using thermoluminescent dosimeters. These measurements verify the tables produced by BENNER, linking the number of sources used in the so called packing technique for the treatment of uterine carcinoma to an optimum treatment time.

ACKNOWLEDGEMENT

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