THE RISE OF BRACHYTHERAPY SYSTEMS

B. Thomadsen,[1] S. Richardson,[2] C.S. Melhus[3]

[1] University of Wisconsin, Madison, WI, USA
[2] Swedish Cancer Institute, Seattle, WA, USA
[3] Tufts University School of Medicine, Boston, MA, USA

***Abstract*—As dosimetry moved from empiricism to physical, treatment planning could also become systematic and several "systems" for designing and controlling interstitial implants, surface applications and intracavitary insertions arose. The principles upon which the systems were based can still provide important guidance for brachytherapy practices today.**

Keywords— **Brachytherapy, Brachytherapy Systems, Interstitial Brachytherapy, Cervical Intracavitary Brachytherapy.**

I. Early brachytherpay treatments

Early brachytherapists quantified treatments as best as they could, specifying the amount of radium used in mg and the duration of the treatment, often in hours. Successful treatments of various diseases using radium, and its emanation, radon, were reported [1,2]. The reports recognized that the amount of radium needed depended on the area or volume to cover, and that the time should vary with that. However, since most of the reports are anecdotal and often include warnings that the values for mg-hrs (the products of mass of radium and duration with the old abbreviation for hours, "hrs," which will be used when using information from historic texts, saving "hr" for modern work) should not be exceeded or reduced, one can infer that each successful treatment regimen probably came with a number of treatment failures. How, exactly the successful values were obtained likely can never be known [3].

By 1914, the need was recognized for specifying dose in terms of radiation received to the target rather than the mg-hrs applied [4]. The new specification was in terms of roentgens (R), based on the work of Villard, and Rutherford and Chadwick, who determined that a 1-mg point source of radium filtered with 0.5mm of platinum produced 8.4 R at 1 cm in air [5-7].

The following will provide an overview of the Manchester Systems, developed at the Christie Hospital and Holt Radium Institute in Manchester, UK, which was the first to incorporate dose to the patient in a consistent and integrated way. The papers and books by the originators of the systems cover many times the number of pages of this review, so the systems provide much more guidance than be covered here. Meredith published a collection of the works from Manchester, and a tutorial can be found in Thomadsen and Hendee [8, 9].

The ends of sections II and III include discussions about how the systems still provide useful guidance in the modern age.

II. The manchester system for molds and interstitial implants

A. *Surface molds*

While various approaches to systematic dosimetry were used earlier, the Manchester System was the first that provided simple rules for delivering uniform doses [10]. The system was based on the following:

1. The goal was to deliver a uniform dose to the target, defined as ±10%, although lower doses in the corners of square or cubic implants would be acceptable.
2. The goal would be achieved by using differential radium loading.
3. Attenuation and scatter due to the tissue were ignored, as they were thought to cancel.
4. Radiation from a point source of radium follows the inverse square law.
5. The "dose" to the tissue was actually the in-air exposure, with no conversion to energy absorbed to unit mass of tissue (which did not become common in radiotherapy until the 1970s).

Table 1 Strength and length of British Standard needles and tubes

Needles – All filtered with 0.5mm Pt			
Name	Active length [cm]	Half strength [mg]	Full strength [mg]
Short	1.5	0.495	0.99
Medium short	2.0	0.66	1.32
Medium	3.0	0.99	1.98
Medium Long	4.0	1.32	2.64
Long	4.5	1.485	2.97
Add 1.2 cm for physical length.			
Linear radium density [mg/cm]			
Full strength		0.66	
Half strength		0.33	
Tubes – All filtered with 1 mm Pt			
Radium content in mg. (All active lengths 1.35 cm, add 0.65 cm for physical length)			
5, 10, 15, 20, 25			

6. The system was based on the British Standard radium needles, which are described in Table 1. These needles were radium sulfate in tubes of 0.5 mm of platinum, although corrections for various thicknesses of Pt or other

materials are provided. Some sets of needles also include "Indian club" models with double loading in the tip half.

7. Following the radium distribution rules delivers approximately 40 to 50 R/h or about 1000 R per day, which was considered to be biologically equivalent to the typical external-beam dose of 1000 R per week.

The development of the system started with mold treatments, that is, a treatment placing the radioactive material on the skin to treat a target at depth (h) below. In this case, the dose uniformity would be considered in the plane of the target depth. The first case addressed was a circular implant, calculating the dose for various diameter circles and depths. The calculation did not use the actual geometry that needles would form but, rather, uniform activity per centimeter around the circumference. From this, they developed a table of factors R_A, the mg-hrs required to deliver 1000 R to the target plane. A sample of the table is shown in Table 2, while the table in their work covered areas to 400cm^2 and distances to 5 cm. Keep in mind that these calculations were performed decades before computers were developed.

Table 2 Planar dosimetry table for R_A in (mg-hr)/1000 R for needles with 0.5 mm Pt filtration

Area in cm^2	Treatment distance in cm				
	0.5	1.0	1.5	2.0	2.5
1	68	171			
4	141	278	462	698	970
8	206	384	599	855	1155
10	235	433	655	923	1235
12	261	480	710	990	1312
16	315	566	814	1113	1460
20	368	641	910	1225	1588
24	417	707	1008	1335	1712
28	466	767	1100	1438	1826
32	513	823	1185	1537	1936

For an example use of the table, consider treatment of superficial skin cancer that penetrates 0.5 cm deep. The radioactive material should be set on a tissue-equivalent mold, in this case also 0.5 cm, which gives the treatment distance, h=1cm. The target, including margin, has an area of 10 cm^2. The prescription dose, D, is 6000 R in a duration, t, 7 days, or 168 hrs. The clinical question becomes how much radium to use in the mold, which comes from the formula:

$$\text{mg} = \frac{\text{D}\cdot R_A}{\text{t}} \qquad (1)$$

$$= \frac{6000\ \text{R} \cdot 433 \frac{\text{mg}\cdot\text{hr}}{1000\ \text{R}}}{168\ \text{hr}} = 15.46\ \text{mg}$$

For cases where the diameter, d, of a circular ring of radium divided by the treatment distance is less than 6, the doses to the target plane proves to be uniform ±8%. For larger ratios of d/h, the dose in the center of the ring of source material decreases, often considerably below the 10% goal. Addressing this problem for larger d/h, the radioactive material is divided between the outer ring, an inner ring with half the diameter, and possibly a source in the center. The distribution of the radium follows the guidelines in Table 3.

Table 3 Source distribution rules for circular mold applications

d/h	% in outer ring	% in inner ring	% in center spot	% variation
0.5	100	0	0	±3
1	100	0	0	±5
1.5	100	0	0	±6.8
2	100	0	0	±5
3	96	0	4	±3.5
4	94	0	6	±2
5	93.5	0	6.5	±5.5
6	80.5	16	3.5	±2.5
8	74	23.5	2.5	±2
10	70.5	26.5	3	±4
12	69	28	3	±7.5
14	69	28	3	±10

Circular molds with d/h>14 are not suitable for mold treatments. The authors of the system suggest they could be treated with three rings. Mayneord suggested that such targets could be treated with a combination of a simulated radium disk and a ring, which is more difficult to achieve in practice [11].

In our example, the diameter of the circle with an area of 10 cm^2 is 3.6 cm, so d/h=3.6 cm/1 cm=3.6. Interpolating in Table 3 indicates that 95% of the radium (14.69 mg) should be in the ring periphery and 5% (0.77 mg) should be in the center. The mold would look like Figure 1.

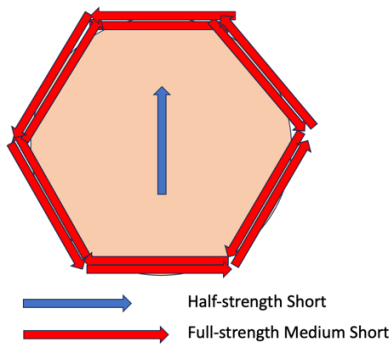

Fig. 1 Layout for the example mold treatment.

Note that the required amount of radium required around the periphery is too great to achieve with a single ring of needles. Longer needles would not conform to the curve of the circle, so placing the medium short needles side by side provides the needed strength.

This configuration has 12 x 1.32 mg = 15.84 mg on the periphery and 0.495mg in the center for a total of 16.335 mg, or 6% more radium than ideal. To compensate, the treatment time should decrease by 6%, becoming 159 hrs. The portions of the radium are 97% on the circumference and 3% in the center, which still falls well within the ±10 uniformity goal.

B. *Interstitial implants*

Lesions that present with a thickness that would lead to either excessive dose at the surface while covering the deep part of the target may benefit from interstitial implants with the needles penetrating the lesion. Such an implant would look like a picket fence, as shown in Fig. 2. The Manchester System handles the dosimetry for such a plane of needles identically to a planar mold except the treatment distance is always taken as 0.5 cm. As seen in Fig. 2, the needles treat to both sides of the needle plane, thus treating a thickness of 1cm. Assume that the needles in Fig. 2 are medium, that is, have an active length of 3 cm. The Manchester System specifies that the needles are placed at centimeter intervals, so the width of the implant is 4 cm and the area is 12 cm^2. The dose calculations for a needle implant are the same as for a mold. Rearranging Eq. 1gives

$$D = \frac{mg \cdot t}{R_A}, \quad (2)$$

showing that for a given mg-hrs, the dose is inversely proportional to R_A. From Table 2, for this implant, the ratio of the dose at h=1 cm to that at the 0.5 cm dose specification plane is the ratio of the R_A values, or:

$$\frac{\text{Dose at 1 cm}}{\text{Dose at 0.5 cm}} = \frac{R_A(12\ cm^2, h = 0.5\ cm)}{R_A(12\ cm^2, h = 1\ cm)} = \frac{261\frac{mg-hr}{1000\ R}}{480\frac{mg-hr}{1000\ R}} = 0.54,$$

well outside of the 10% variation allowed, which is why the treatment thickness is limited to 0.5 cm to each side of the needle plane.

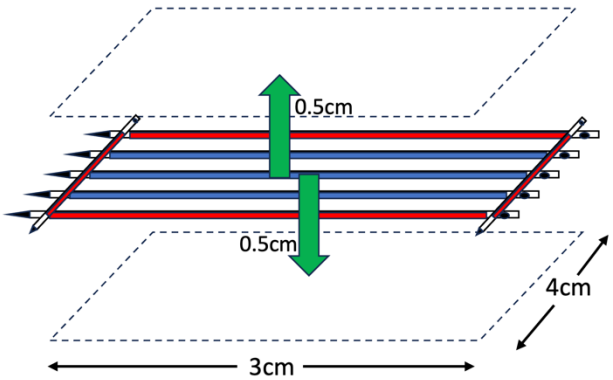

Fig. 2 Example of a single plane implant. The dashed lines outline the boundary of the target volume at the edges of the treatment volume 0.5 cm from the needle plane. Ideally, the red needles are approximately twice the strength of the blue.

At each end of the implant are needles perpendicular to the five main needles, called "crossing needles." These needles serve to square the dose distribution, which would fall between the needles at the ends, were the crossing needles not there, as shown in Fig. 3.

Looking up the R_A value, the area used has to be reduced by using the length correction shown in Fig. 3. In order to treat the volume adequately, longer needles need to be used to compensate for loss from any uncrossed end.

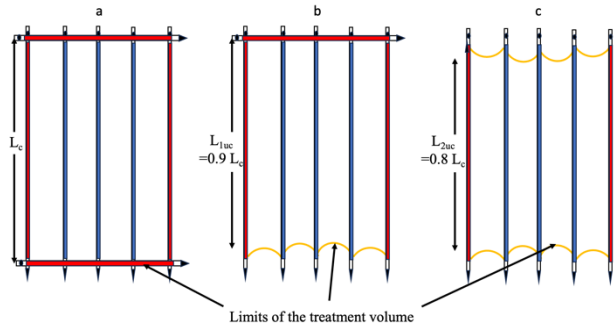

Fig. 3 An illustration of the loss in treatment length due to the lack of crossing needles.

As with molds, there are distribution rules, such as in Table 3, although the rules are simpler because needles have fewer options for changes the weights of the parts. For needle implants the distribution follows Table 4.

Table 4 Distribution rules for planer implants

Area->	<25 cm^2	25-100 cm^2	>100 cm^2
Fraction on periphery	2/3	1/2	1/3

Assume the small implant in Figure 2 is treating a surgical bed after a complete resection. The prescription for this implant to deliver 4000 R in 72 hrs, the calculation would follow Equation 1, with the $R_A = 261\frac{mg-hr}{1000R}$. This gives $mg = \frac{D \cdot R_A}{t} = \frac{4000R \cdot 261\frac{mg-hr}{1000R}}{72hr} = 14.5\ mg$ of radium. From Table 4, two-thirds of the radium, 9.67 mg, would fall in the periphery, leaving 4.83 mg in the interior. The periphery consists of four needles (2 medium and 2 medium long) with a total active length of (2x3 cm+2x4 cm) = 14 cm. The ideal loading for the periphery would be 9.67 mg/14 cm = 0.69 mg/cm, slightly higher than the linear radium density of the full-strength needles, which would be used. The interior three medium needles ideally would have 4.83 mg/(3x3 cm) = 0.537 mg/cm. This is considerably higher than the half-strength needles' linear radium density and lower than the full strength's. Using three half-strength needles would contain only 2.97 mg, for a total of 12.21 mg, resulting in a treatment duration of 85.5 hrs, which could compromise the biological effectiveness of the treatment. Instead, loading the two outside interior needles as medium full strength and the center as a medium half strength results in 9.24 mg on the periphery (65%) and 4.95 mg (35%) on the interior, for a total of 14.19 mg total and a treatment duration of 73.3 hrs, which all would be biologically the same as prescribed. The adaptation to fit the prescription as demonstrated in this example is very typical for brachytherapy.

For targets thicker than 1cm, or for anatomy such as a tongue, it often is better to sandwich the disease between two planes of needles, such as in Fig. 4.

The case illustrated in the figure has the needles entering the patient from the right. Because the tips of the needles are deep in the patient, the distal end cannot be crossed. This case requires two adjustments compared with the single-plane implant just discussed.

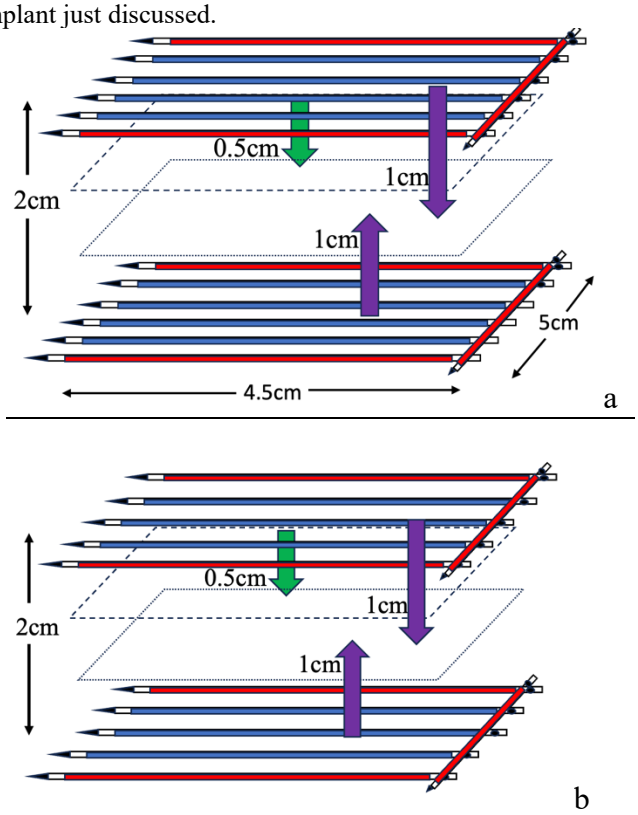

Fig. 4 A two-plane implant with uncrossed ends on the deep end. The dashed line is the dosimetry plane 0.5cm from either needle plane, if the implant is symmetrical (only shown from one). The dotted line represents the midplane, in this case 1cm from either plane. a. As originally conceived. b. As finally planned.

1. Location of dosimetric plane. As discussed in the Manchester papers, the location of the dose is a bit confusing. The calculation always uses the R_A for a distance of 0.5 cm, just as with the single-plane implant. However, the calculation formula includes a "separation factor (SF)," given in Table 5. This factor corrects for the fact that the contribution to the dose from the distal plane, i.e., the opposite plane from the one closest to the 0.5 cm plane, suffers attenuation from the distance to the dashed plane in Fig. 5. This factor also serves to bring the dose in the midplane between the two needle planes to the prescription dose.
2. Correction for lack of crossing. The implant in Fig. 5 has six needles in each plane, thus forming a 5 cm wide implant. Each needle in the "picket fence" is taken as a long needle with an active length of 4.5 cm. Because of the lack of crossing on the deep end, the effective depth of the picket-fence needles, according to Fig. 3, is only 0.9 of the active length, or 4 cm. The effective area of the implant to find the R_A is 0.9 x 4.5 cm x 5 cm=20 cm^2. In planning the implant, it is essential to ensure the dose distribution covers the target. While finding the R_A, 10% of the active length is discounted, that accounts for the average loss of depth. The maximum loss between needles is closer to 20% of the active length, so deep end of the needles must extend 20% beyond the farthest extent of the target.

Table 5 Separation factors for two-plane implants and the dose to the midplane

Separation of planes	1.0	1.5	2.0		2.5	
Separation Factor (SF)	1.0	1.25	1.4		1.5	
Area of planes			0-25 cm^2	25-50 cm^2	0-25 cm^2	25-50 cm^2
Dose low at midplane			20%	10%	30%	20%

Calculations for the implant in Fig. 4 use the R_A for 20 cm^2, h of 0.5 cm and the separation factor of 1.4, giving:

$$mg = \frac{SF \cdot D \cdot R_A}{t} \quad (3)$$

In this case, assume we want a dose rate of 50 R/hr.

$$mg = 1.4 \cdot 368 \frac{mg \cdot hr}{1000\ R} \frac{50\ R}{hr} = 25.76\ mg$$

Of the 25.76 mg, each plane will have half, or 12.88 mg.

The interior four needles should carry one third of the radium in the plane, or 4.29 mg. Dividing this into four needles gives 1.07 mg per needle, which is considerably lower than the half strength long needles. However, if this were divided between three needles, that would be 1.43 mg per needle, just 3.7% lower than the radium in a half-strength, long needle. The periphery consists of the two outside needles and the crossing needle, all of which would be long needles. Since the periphery should carry two-thirds of the radium on the plane (8.59 mg), that would be 2.86 mg per needle, again 3.7% lower than a full-strength long needle. The replanned implant is shown in Fig.4b as two planes, each with the three full-strength long needles on the periphery and three half-strength long needles in the interior. All the needles in the picket fence are separated by 1.25 cm. With the new total of 26.73 mg, the final dose rate is 51.9 R/hr.

B. *Volume implants*

Because the dose in the center of two-plane implants falls below the ±20% limit on uniformity for typical clinical cases that would require planes separated by more than 2.5 cm, the Manchester System recommends using volume implants [12, 13]. Volume implants in their system come in several configurations: spherical, cylindrical, box and multiplane. In practice, the spherical would mostly be used in radon-seed permanent implants; the box approach was infrequently used.

The dose calculations were similar to planar implants but instead of a two-argument R_A, they use a single-argument R_V based only on volume of the implant. Table 6 shows a sample of the R_V values.

The distribution rules for volume implants are very different from molds and planar implants. Because of the length limitation of this article, we will only consider cylindrical volume implants, with a brief mention of multiplanar. A multiplanar implant consists of the outer planes on each side of the target that define its limits and the inner planes that fill the interior, with all planes between 1-1.5 cm apart. Cylindrical implants have a cylindrical belt that circumscribes the target, a core in the interior, and sometimes crossing planes that form a lid to the belt. The radium is portioned the different constituents based on its parts:

- For multiplanar implants, each outer plane carries three parts, and the inner planes carry two parts each.
- For cylindrical implants, the belt receives four parts, the core two parts and each end, when present, one part.

Table 6 Volume dosimetry table for R_V in (mg-hr)/1000 R for needles with 0.5mm Pt filtration

Volume in cm^3	R_v
4	85.9
5	99.7
10	158.3
15	207
20	251
30	329
40	399
60	523
80	633
120	830
160	1005

An example clarifies how this works. Fig. 5 shows an example of a cylindrical, volume implant treating a target 5.5cm in diameter and from the skin going 5cm deep. The desired dose rate is 45 R/hr. Because the active length of the long needles is only 4.5 cm, the crossing occurs at the physical end of the needles with the eyelet at the skin. Contrary to the rule that needles cross at each active end, this is allowed for volume implants but the distribution rule changes:

- For cylindrical implants with crossing at the physical end of the belt, the belt receives four parts, the core two parts and end two parts.

As with planar implants, correction is required for uncrossed ends. Particularly for volume implants, the deep end cannot be crossed. As a correction for each uncrossed ends, for volume implants the active length is reduced by a factor of 0.925, instead of the 0.9 for planar implants. While the depth from the surface crossing needles to the active ends of the picket-fence needles, because of the uncrossed deep end, the length is reduced to (1-0.075) x 5 cm = 4.63 cm. The volume becomes $\pi r^2 L_{eff} = \pi(2.75\ cm)^2 \times 4.63\ cm = 110\ cm^3$. Interpolating from Table 6 gives $R_V = 781 \frac{mg \cdot hr}{1000\ R}$.

The R_V may require an elongation correction (EC) based on the elongation factor (EF), that is, the ratio of the longest dimension to the shortest, orthogonal dimension. Table 7 gives these corrections. This correction increases the required mg-hrs due to the reduced efficiency of the dose delivery as the implant stretches because of increased distances from the extremes of the needles.

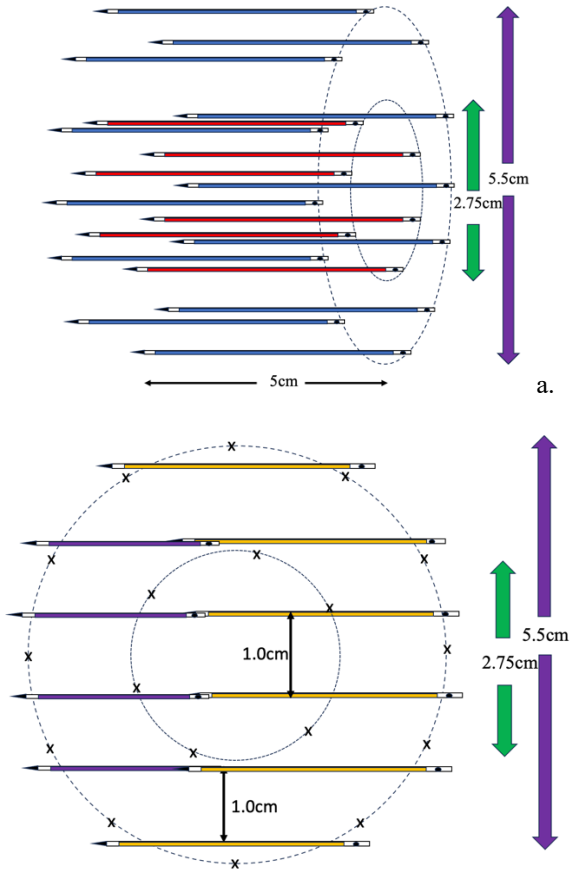

Fig. 5 An example cylindrical implant as described below. a. A view along the needles going deeper into the patient towards the left. All the needles are of the "long" type. The blue needles indicate the belt and the red indicate the core. b. The view looking at the implant on the skin. An "x" marks where the needle location in the core and belt, with the needles on the skin superimposed. In b., the yellow needles are "medium" and the purple are "medium short."

Table 7 Elongation corrections (EC) for volume implants R_V, based on the elongation factor (EF)= longest dimension to the shortest dimension.

EF	EC
1.5	3%
2	6%
2.5	10%
3	15%

In this case, the EF = 1.1 no EC is required.

Calculating the total mg of radium follows equation 4:

$$mg = \frac{D \cdot R_V (1+EC)}{t} \quad (4)$$

$$= 781 \frac{mg \cdot hr}{1000\ R} \cdot \frac{45\ R}{hr} = 35.15\ mg.$$

With the belt having four parts, the core having 2 parts and the end having 2 parts, that is a total of 8 parts, so the distribution

will be 4 parts/8 parts = 50% (17.57 mg) on the belt, 2 parts/8 parts = 25% (8.79 mg) in the core and on the end.

The radium for the core is dived among 12 needles, or 1.46mg/needle, which is happily very close to the half-strength long needle. Since the percentage of radium in the core is half that for the belt, and the number of needles is also half, the same needles would be used in the core. This is usually the case. The end has six medium and 4 medium short needles, for a total length of 26 cm for the 8.79 mg, or 0.34 mg/cm, so again matching well the half strength.

C. *Applicability to the modern practice.*

Obviously, radium is no longer in use, and prescriptions are in gray. What is useful still is using the guidance for needle layout and general distribution of source dwell times for initial starting points in treatment planning. Using rules from the Manchester System, or other systems such as the Paris System, as starting points helps current, computer-based optimization programs generate more uniform plans.

The Manchester System designed implants with the target fully enclosed within the needles. In most Manchester implants, the 90% extends about 0.5 cm outside needle volumes, which can shrink the implanted volume, and make it approximate a Paris System implant.

Manchester calculations can be useful for quick quality control for brachytherapy implants. Use with modern, high-dose-rate (HDR) cases requires several changes:

1. Correction for the exposure rate constant – In 1934 the accepted value was 8.4 $\mathrm{R}\cdot\mathrm{cm}^2/\mathrm{mg}\cdot\mathrm{hr}$, while now the value of 8.25 $\mathrm{R}\cdot\mathrm{cm}^2/\mathrm{mg}\cdot\mathrm{hr}$ is assumed.
2. Specify the dose in Gy. Correcting from exposure to dose to tissue while also expressing the table in Gy instead of R.
3. Correction for oblique filtration.
4. Correction for tissue attenuation and scatter.

Because the last two tend to cancel, a constant factor of 0.80 can be used to convert the original tables in $\frac{\mathrm{mg\cdot hr}}{1000\mathrm{R}}$ to $\frac{\mathrm{U\cdot h}}{\mathrm{Gy}}$ [9].

III. The Manchester System for Intracavitary Cervical Brachytherapy

Shortly after clinics received radium sources, they tried treating cervical carcinoma with intracavitary application. The treatments used variously designed applicators and used ranges between 1200-5000 mg-hrs [14]. Reports in these early years included successes, failures and many complications. Because the applicators mostly were made in house, there was no uniformity in therapy. Mourya et al. published a review of the development of intracavitary brachytherapy applicators [15].

The main advantage of the Manchester System for cervical cancer was that it was reproducible, if the practitioner had the same apparatus as used in Manchester, and the calculations were simple [16, 17]. This was a definite advantage for an empire with patients in developing countries.

A. *System Principles*

Much of the Manchester System for cervical cancer is particular for treatment based on the stage and extent of disease. This paper only focuses on the physical aspects of the treatments. As did the Manchester System for interstitial implants, the approach moved from treatments based on mg-hrs to "dose" in R. The system *only* applied to the Manchester applicator, which had three parts:

1. The tandem that went into the uterine canal. The tandem was a thin rubber tube that could flex with the canal. A flange on the open end of the tube kept it from sliding deeper into the canal than desired. The tube accommodated tube type sources listed in the bottom of Table 1. To fit the patient's anatomy, the tandem came in three sizes to fit one, two or three radium sources.
2. The ovoids that fit into the vaginal fornices. The ovoids are not flexible and each would hold a single radium source. The ovoids came in three diameters: 2, 2.5 and 3 cm.
3. The hard rubber spacer or washer that separate the ovoids. The spacer fits between the ovoids keeping them 1cm apart, while using the washer allowed the ovoids to almost touch.

The goal of the three components was to make a stable unit that allows for a consistent dose to be delivered to all patients.

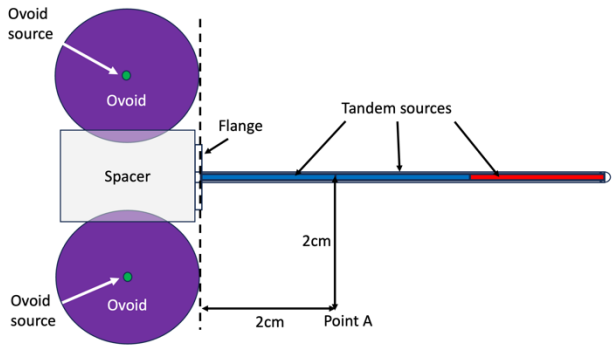

Fig. 6 The schematic geometry for the Manchester applicator, this one with a three-source tandem and two medium ovoids. This also shows the location of Point A. The strengths of radium in this example are a very common combination: Red is 15 mg, blue is 10 mg, green is 20 mg.

Much of achieving consistent doses required specification of a reproducible point at a relevant anatomical site. They based the dose control location on observations that the initial site of radiation necrosis in cervical intracavitary brachytherapy occurred from high doses to "the medial edge of the broad ligament where the uterine vessels cross the ureter." They called this area the "paracervical triangle" and considered it the dose limiting location. They named this spot Point A and specified it as 2 cm lateral to the center of the uterine canal and 2 cm cephalad of the mucous membrane of

the lateral fornix in the plane of the uterus [16]. Fig. 6 shows the geometry of the applicator and the location of Point A. The applicator with the loading patterns they give produces a "pear" shaped dose distribution.

In addition to limiting the dose to Point A, they identified the location they thought the obturator node to be, calling it Point B, and used it to evaluate the "lateral throw" of the application. Point B was found by starting at the same place as for Point A, moving 2cm directly cephalad but then going 5 cm lateral. Fig. 7 illustrates the location of Point B. The figure also shows that with a tipped uterus, Point A follows the uterus, while Point B is independent of any angulation of the uterus.

The standard dose to Point A would be 8000 R in 144 hrs, which translates to 55.5 R/hr. The actual delivery was in two 72-hr sessions separated by three days. The brachytherapy would be supplemented with external beam for stages III and IV.

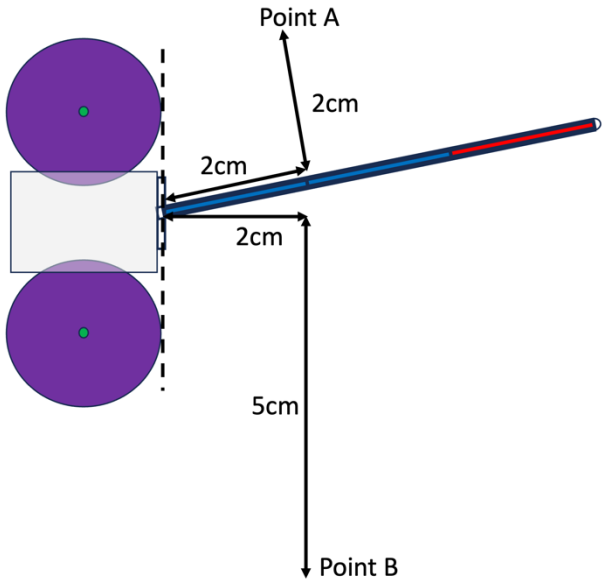

Fig. 7 An illustration of the location of Point B, also showing how Point A follows a tipped uterus while Point B remains related to the whole body.

The 1953 revision to the system addressed the ability to perform individualized dosimetry based on radiographic imaging [17]. Because the ovoids do not show the vaginal fornix mucosa clearly, the method to find Point A changes very slightly, starting at the physical bottom of the inferior-most source in the tandem rather than the intersection of the line connecting the cephalad-most aspect of each vaginal fornix with the cervical os. Fig. 6 shows that for the Manchester applicator, both definitions yield the same point.

B. *Applicability to the modern practice*

Even more than with interstitial implants, modern cervical intracavitary brachytherapy carries many remnants of the Manchester System. New applicators had to adapt to allow afterloading of sources [18, 19]. The new applicators often lost the physical connection between the tandem and the ovoids, yet continued to use the revised Manchester definition for finding Point A, starting at the bottom source in the tandem. Figure 8 shows the difference.

Point A as defined in the Manchester System sits in a portion of the isodose surfaces where small errors in locating Point A have little effect on the calculated dose. On the other hand, Point A' as located in Fig. 8 falls where the dose from the ovoids pushes the isodose into the fatter part of the "pear." In that location, small errors in the craniocaudal direction can make much larger differences in the calculated dose.

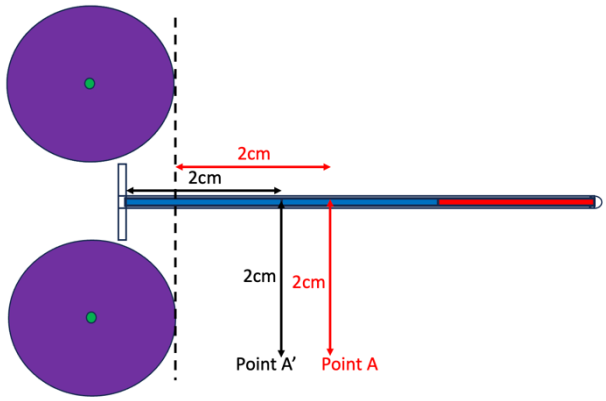

Fig. 8 This figure show an afterloading applicator where the tandem and ovoids move independently, which gives Point A'. Point A' could be cephalad of Point A if the tandem is pushed in deeper than the ovoids, but more often it falls inferior to Point A because the tandem comes between the ovoids.

Manchester's use of three sources in the tandem, with the cephalad source being particularly active, formed the well-know "pear shaped" dose distribution. The target for cervical cancer brachytherapy, does not conform to that shape. However, given the sources available at the time, in order to project the dose sufficiently lateral in the cervix, they needed to use the strong source above the cervix. HDR brachytherapy allows much more control over the shape of the dose distribution, and magnetic-resonance imaging gives a clearer picture of the disease. Report 89 from the International Commission on Radiation Units and Measurements provides guidance for brachytherapy in the 21st Century, but has its roots firmly planted in the Manchester System [20].

VI. Conclusion

The Manchester Systems brought uniformity and consistency to brachytherapy, basing treatments on dose to a patient (albeit, in roentgens). Because of the careful thought and calculations (all before computers), the systems formed the general patterns for much that followed, and their foundations can still be seen in what we do today.

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Contacts of the corresponding author:

Author:	Bruce Thomadsen
Institute:	University of Wisconsin-Madison, Dept. of Medical Physics
Street:	1111 Highland Avenue, 1005 Wisconsin Institutes of Medical Research
City:	Madison, WI 53705
Country:	United States of America
Email:	brthomad@wisc.edu