DOSAGE CALCULATIONS IN RADIUM THERAPY

By EDITH H. QUIMBY, Sc.D.

COLLEGE OF PHYSICIANS AND SURGEONS, COLUMBIA UNIVERSITY, NEW YORK CITY

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BINGHAMTON, NEW YORK

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REFERENCES

1. W. J. Meredith. Radium Dosage, the Manchester System. E. and S. Livingstone Ltd., Edinburgh 1947.

2. Glasser, Quimby, Taylor and Weatherwax. Physical Foundations of Radiology (Chapter XVI) Paul Hoeber, New York, 1952.

3. H. E. Johns. The Physics of Radiation Therapy (Chapter X) Charles C. Thomas, Springfield, Illinois, 1953.

4. Quimby and Castro. Calculation of Dosage in Interstitial Radium Therapy. American Journal of Roentgenology, Radium Therapy and Nuclear Medicine LXX, 739-749, November 1953.

The Unit of Radium Dosage – The ROENTGEN

THE ROENTGEN IS THAT AMOUNT OF X- OR GAMMA RADIATION SUCH THAT THE ASSOCIATED CORPUSCULAR EMISSION PER 0.001293 GRAMS OF AIR PRODUCES, IN AIR, IONS CARRYING ONE ELECTROSTATIC UNIT OF QUANTITY OF ELECTRICITY OF EITHER SIGN.

0.001293 grams is the mass of one cubic centimeter of air under standard conditions. The energy of the associated corpuscular radiation – or secondary beta radiation- must be completely used in producing ionization, and no other radiation may contribute to this.

A definite quantity of radium, under a definite set of physical conditions, always emits the same amount of radiation, hence, it is not necessary to calibrate radium sources as it is x-ray tubes. When the output of a source has once been determined, it will be known to be the same for many years unless it is damaged. Doses delivered by a variety of definite applicators can be calculated from data obtained by physical measurements and tabulated once for all.

A Point Source

It has been determined by physical measurements that a point source of one milligram of radium, surrounded by one-half millimeter of platinum, delivers 8.4 roentgens per hour at a distance of one centimeter. For other distances, the number of roentgens delivered varies in accordance with the inverse square law.

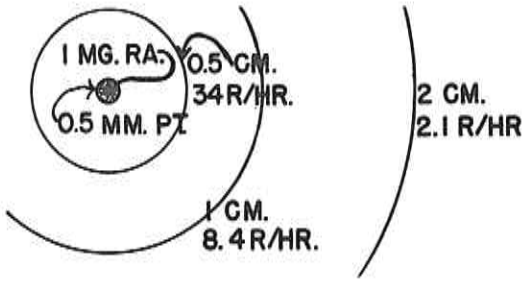
A Tubular Source

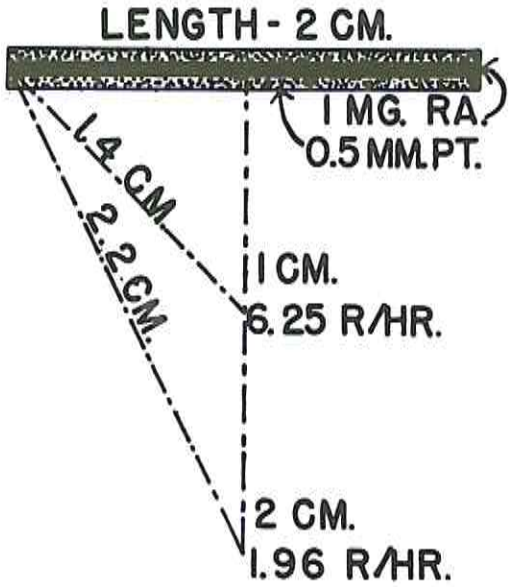
When one milligram of radium is uniformly distributed along a tube, the number of roentgens delivered opposite its center is less than that at the same distance from a point source of the same strength and filtration. Two factors are responsible for this: (A) Most of the radium is farther away from the point in question. (B) The radiation from the outlying radium passes obliquely through the filter and hence is actually filtered more strongly.

The dose under the end of the tube is less than that under its center for the same reasons. Doses at different distances do not follow the inverse square law, because the distances from the outlying regions do not vary in the same manner as from the center, and also because the oblique filtration is different at different distances. The longer the tube, the greater the difference between doses under center and end, the greater the variation from the point source value, and the greater the divergence from the inverse square law.

NOTES: _____

A POINT SOURCE





APPLICATORS

For all applicators the same considerations apply as for tubes. The dose at any point depends on area and distance of applicator and manner in which radium sources are distributed in it. If tubes are uniformly spaced over surface of a plaque or mould, the dose is greatest under center.

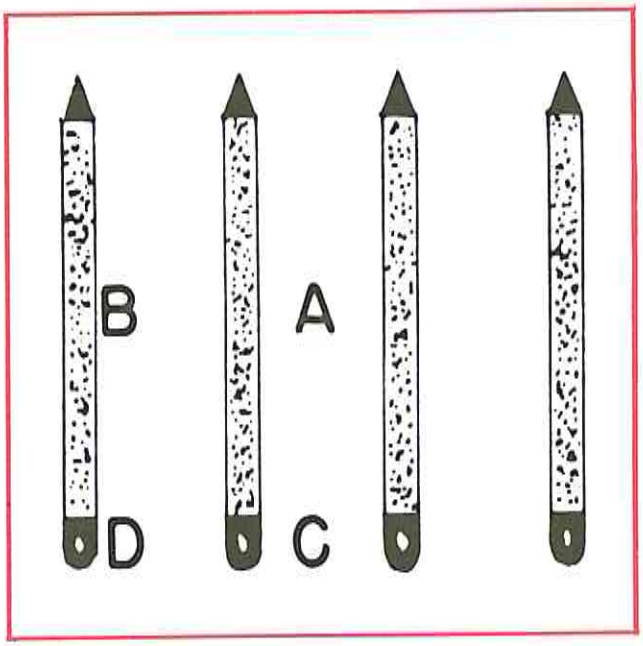
It is desirable to have fairly uniform distribution of dose over irradiated area. This can be accomplished by concentrating most of the sources toward periphery of applicator. Paterson and Parker have worked out simple rules for such distributions (see later charts and references).

For small applicators and short distances, all radium should be arranged around the periphery. If diameter of applicator is more than five times distance, some radium should be put at center.

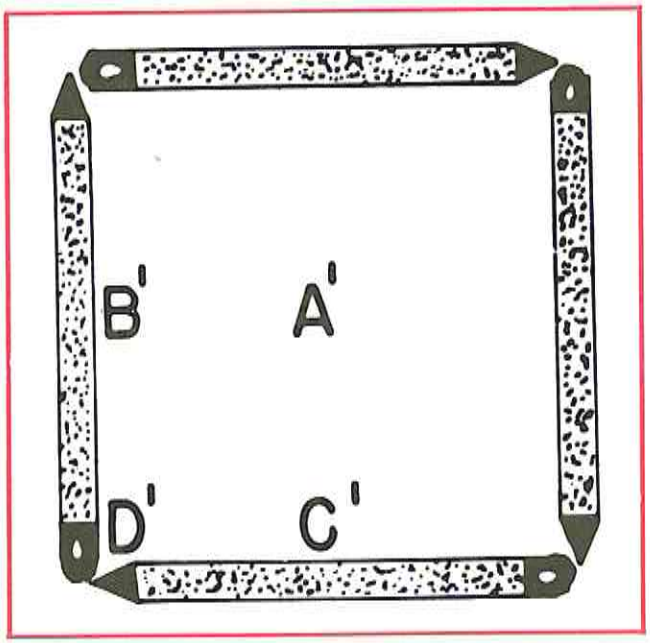
COMPARISON OF DOSAGE FROM UNIFORM AND RECOMMENDED DISTRIBUTIONS

area 4 x 4 cm. needles, 4 cm. active length. 4 mg. radium content each.

UNIFORM



AROUND PERIPHERY



Roentgens per hour on skin one cm. below indicated points

A — 40	C — 25	A' — 22	C' — 27
B — 32	D — 21	B' — 27	D' — 24
Maximum variation = 100%		Maximum variation = 14%	

NOTES: _____

EFFECTS OF DIFFERENCES IN FILTRATION

For most published charts and tables of radium dosage, and for all those in this booklet, the radium is assumed to be filtered by 0.5mm. platinum or its equivalent. For lighter or heavier filtration, values obtained from these charts can be corrected in accordance with table below. Increase in filter results in decrease of output in roentgens, and in increase in number of milligram-hours needed to deliver a specified number of roentgens.

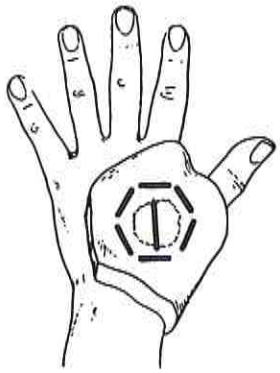
CORRECTION FACTORS FOR VARIOUS FILTERS

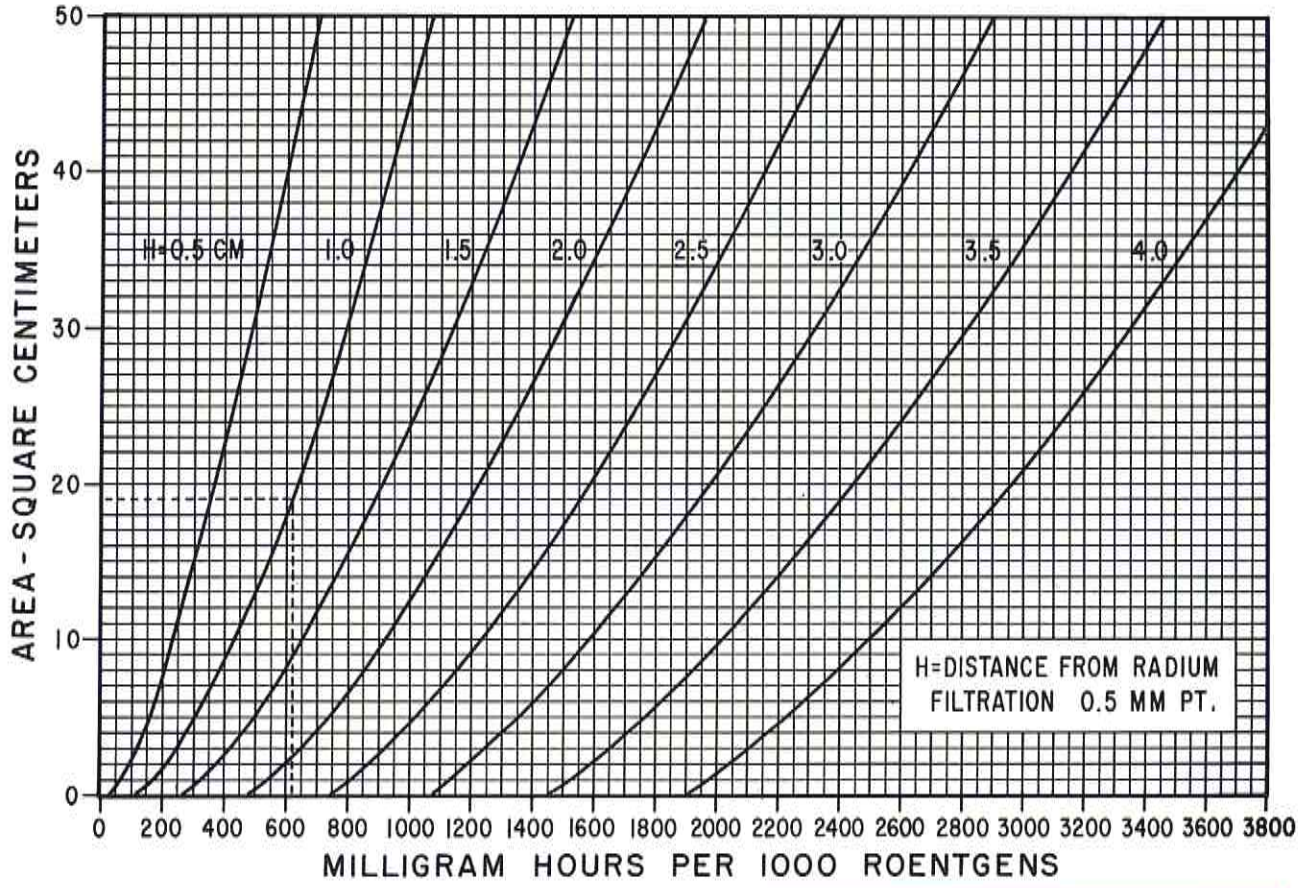
METAL	THICKNESS IN MM.	NO. OF ROENTGENS TRANSMITTED RELATIVE TO NO. TRANSMITTED BY 0.5 MM. PT.	NO. OF MG. - HR. REQUIRED TO DELIVER A SPECIFIED NO. OF ROENTGENS, RELATIVE TO NO. FOR 0.5 MM. PT.
PLATINUM (OR GOLD)	0.3	111	90
	0.5	100	100
	1.0	88	113
	1.5	82	122
	2.0	78	128
	3.0	73	137
LEAD	0.5	118	85
	1.0	97	103
	2.0	88	113
	3.0	83	121
SILVER	0.5	128	78
	1.0	97	103
	2.0	94	107
	3.0	90	111
BRASS (OR COPPER OR MONEL OR STEEL)	0.5	160	62
	1.0	111	90
	2.0	100	100
	3.0	95	105
	4.0	92	109

NOTES: _____

PATERSON AND PARKER

CHART FOR SURFACE APPLICATORS





RULES FOR DISTRIBUTION OF RADIUM

Treat area slightly larger than lesion. Use circles whenever possible. At least 6 containers to make circle. Spacing between ends of tubes not to be greater than distance H.

For diameter less than 3H, one circle. For diameter 3 — 6H, add central spot For larger diameters, concentric circles.

If square, rectangle, or irregular area is used, follow same general principles. If side of square is more than 2H, use lines of radium to divide it into strips of width 2H.

For rectangles with ratio of sides 3 or 4 to 1, increase mg.-hr. by 10%.

EXAMPLE BY PATERSON AND PARKER

Epithelioma of dorsum of hand, Lesion 3.5 cm. diameter. Treat area 5 cm. diameter = 19 square cm. to give 6000 r to surface of lesion, using wax mould such that H = 1 cm.

For this field and distance 1000 r require 620 mg.-hr., 6000 r require 3720 mg.-hr.

Available tubes 2 mg. each, active length 1.5 cm., filter 0.5 mm Pt. Use circle of 6 tubes and 1 for center spot, total 14 mg. Irradiation time 3720 ÷ 14 = 266 hours. 10 hours daily for 27 days might be convenient.

Depth dose at base of lesion 0.5 cm. deep: H = 1.5, 880 mg.-hr. for 1000 r. For 3720 mg.-hr., dose at H= 1.5 is 3720 ÷ 880 x 1000 = 4225.

QUIMBY TABLE FOR SURFACE APPLICATORS

Number of Roentgens per 100 Mg.-Hr. delivered to center of field at various distances from flat applicators of various sizes and shapes. Radium uniformly distributed over surface. Filter equivalent to 0.5 mm. Pt.

DISTANCE CM.	CIRCULAR APPLICATORS DIAMETER — CM					
	1	2	3	4	5	6
0.5	2300	1340	968	587	456	333
1.0	740	575	453	334	270	212
1.5	354	309	250	210	178	147
2.0	202	185	165	143	126	109
2.5	136	126	115	105	95	79
3.0	92	87	82	76	70	64

	SQUARE APPLICATORS LENGTH OF SIDE — CM					
	1	2	3	4	5	6
0.5	2150	1260	870	510	400	308
1.0	710	534	420	306	248	196
1.5	340	290	242	196	167	136
2.0	200	176	155	134	117	100
2.5	137	126	112	99	88	73
3.0	92	87	79	72	66	60

	RECTANGULAR APPLICATORS DIMENSIONS — CM					
	1 x 1.5	2 x 3	3 x 4	4 x 6	6 x 9	8 x 12
0.5	1960	970	700	350	176	105
1.0	680	466	365	235	138	91
1.5	337	270	215	161	106	74
2.0	198	170	140	115	81	60
2.5	139	119	101	88	56	50
3.0	90	84	75	66	52	40

EXAMPLE OF USE OF TABLE

Plaque is made up of brass box with radium tubes uniformly spaced over surface. Active area 4 cm. square; total radium content 60 mg. radium tubes filtered by 0.5 mm Pt. brass bottom of box 1 mm thick; radium - skin distance is 2 cm.

(A) How many roentgens are delivered to the skin in an application of 3 hours?

60 mg. for 3 hours = 180 mg. - hrs. From table, a square applicator 4 cm. on a side, filtered by 0.5 Pt. delivers 134 r per 100 mg. - hr. at 2 cm.

For 180 mg. - hr., dose is 1.8 x 134 = 241 r Correction for additional brass reduces this to 95%.

0.95 x 231 = 220 r dose on skin for specified treatment.

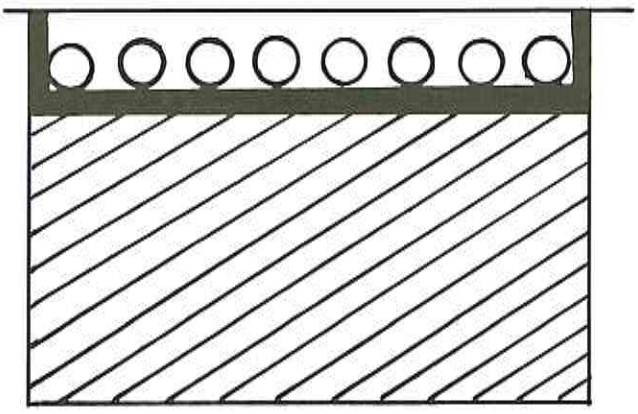
(B) How many roentgens are delivered 1 cm. below skin in same treatment?

One cm. below skin gives radium - tissue distance of 3 cm. This applicator gives 72 r per 100 mg. - hr. at this distance. Tissue absorption and scatter may be neglected. Correction for brass must be applied. 72 x 1.8 x 0.95 = 123 r dose at 1 cm. depth.

(C) How long must applicator be left in place to deliver 1000 r at 1 cm. depth?

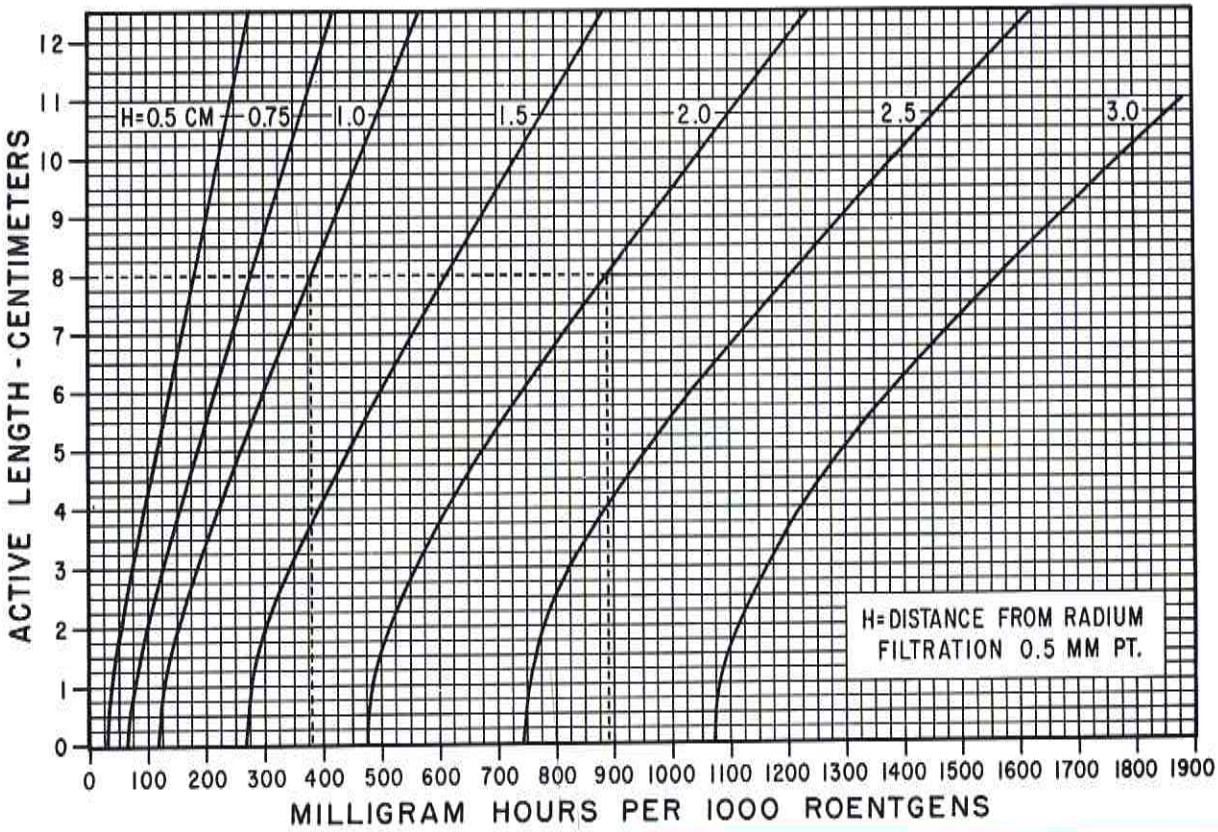
100 mg. - hr., corrected for extra brass, delivers 72 x 0.95 = 68 r at 1 cm. depth. To deliver 1000 r will require 1000 ÷ 68 x 100 = 1470 mg. - hr.

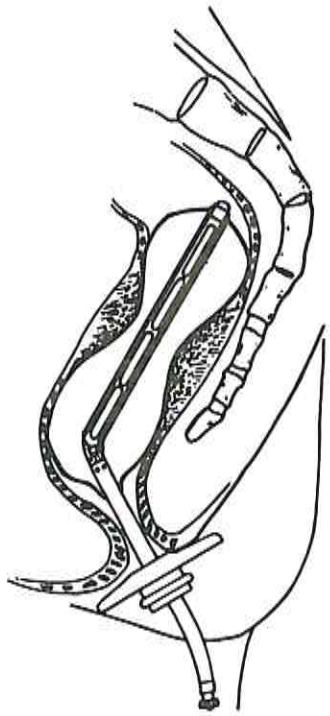
Since 60 mg. are in applicator, time will be 1470 ÷ 60 = 24.5 hours.



NOTES:

PATERSON AND PARKER CHART FOR LINEAR SOURCES





EXAMPLE BY
PATERSON AND PARKER

Carcinoma of rectum annular lesion about 3 cm. long, to be treated by Todd's applicator (an inflatable dumbbell-shaped applicator the diameter of which in the middle is 2 cm. but at the ends, 4 cm.). Desired to give 10,000 r to surface of tumor in about 5 days and to know dose at normal mucosa (under about 1 cm. of tumor).

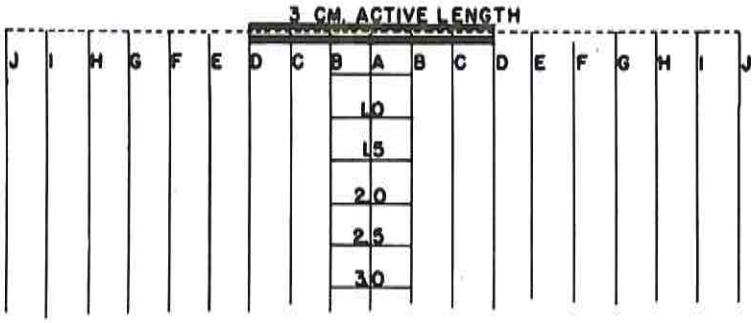
Use 4 tubes of 10 mg. each, giving an active length of 8 cm. Filtration 1.5 mm. Pt. for tumor surface, H = 1 cm., for an 8 cm. tube with 0.5 mm. Pt. 380 mg. - hr. for 1000 r. The extra 1 mm. Pt. increases this by 22%, to 464 mg. - hr. 10,000 r require 4640 mg. - hr. with 40 mg. This means an exposure of 4640 ÷ 40 = 116 hours. For mucosa at base of tumor, H = 2 cm. 1000 r for 0.5 mm. Pt. require 890 mg. - hr. with additional filter, 1085.

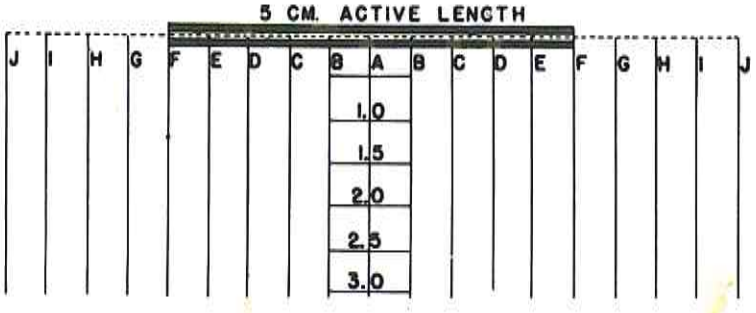
Since the exposure decided on is 4640 mg. - hr., mucosa will receive 4640 ÷ 1085 x 1000 = 4270.

GAMMA ROENTGENS PER MG-HR.

FROM VARIOUS POINTS ALONG LINEAR

CM. FROM TUBE	POINT SOURCE	DISTANCE ALONG TUBE AXIS: CM. FROM CENTER								
		A	B	C	D	E	F	G	H	I
		Center	.05	1.0	1.5	2.0	2.5	3.0	3.5	4.0
TUBE 2.0 CM. LONG										
0.5	33.60	18.00	17.20	9.10	3.85	1.95	1.15	.76	.49	.33
0.75	14.93	11.11	9.55	6.25	3.33	1.89	1.15	.77	.53	.40
1.0	8.40	6.25	5.70	4.35	2.70	1.68	1.10	.75	.55	.42
1.5	3.73	3.33	3.03	2.57	1.89	1.35	.97	.70	.54	.43
2.0	2.10	1.96	1.85	1.59	1.31	1.02	.78	.61	.48	.39
2.5	1.35	1.25	1.21	1.11	.96	.80	.65	.52	.43	.35
3.0	.93	.89	.88	.81	.72	.62	.52	.44	.37	.31
4.0	.52	.51	.50	.48	.45	.40	.36	.32	.28	.25
5.0	.33	.33	.33	.32	.30	.28	.26	.24	.22	.20
TUBE 3.0 CM. LONG										
0.5	33.60	14.30	13.33	11.11	6.45	3.10	1.45	.88	.59	.41
0.75	14.93	9.10	8.35	6.90	4.35	2.50	1.41	.89	.61	.43
1.0	8.40	5.40	5.26	4.54	3.23	2.02	1.33	.86	.61	.44
1.5	3.73	2.86	2.86	2.50	1.93	1.43	1.07	.77	.54	.43
2.0	2.10	1.79	1.73	1.56	1.32	1.06	.83	.65	.51	.40
2.5	1.35	1.19	1.15	1.07	.95	.81	.67	.53	.44	.36
3.0	.93	.85	.84	.78	.71	.62	.54	.45	.38	.32
4.0	.52	.50	.49	.48	.44	.40	.36	.32	.28	.25
5.0	.33	.32	.32	.31	.30	.28	.26	.24	.22	.20





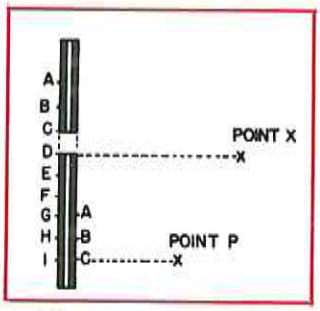
DELIVERED AT VARIOUS DISTANCES

RADIUM SOURCES (FILTER 0.5 MM Pt.)

CM. FROM TUBE	POINT SOURCE	DISTANCE ALONG TUBE AXIS: CM. FROM CENTER								
		A	B	C	D	E	F	G	H	I
		Center	.05	1.0	1.5	2.0	2.5	3.0	3.5	4.0
TUBE 4.0 CM. LONG										
0.5	33.60	11.11	10.50	10.00	9.10	5.00	2.22	1.18	.72	.48
0.75	14.93	6.90	6.67	6.25	4.53	3.44	1.92	1.14	.73	.50
1.0	8.40	4.35	4.35	4.18	3.33	2.56	1.64	1.07	.71	.50
1.5	3.73	2.56	2.38	2.28	1.93	1.59	1.20	.89	.62	.48
2.0	2.10	1.61	1.58	1.48	1.32	1.11	.89	.70	.55	.44
2.5	1.35	1.11	1.07	1.04	.92	.82	.71	.58	.48	.38
3.0	.93	.82	.80	.76	.70	.62	.56	.47	.40	.33
4.0	.52	.48	.48	.46	.44	.40	.36	.32	.29	.25
5.0	.33	.32	.31	.30	.29	.28	.26	.24	.22	.20
TUBE 5.0 CM. LONG										
0.5	33.60	8.33	8.27	8.20	8.00	7.15	4.00	2.00	1.00	.62
0.75	14.93	5.72	5.55	5.25	4.65	3.77	2.73	1.55	.95	.62
1.0	8.40	3.70	3.70	3.64	3.33	2.86	2.13	1.36	.88	.61
1.5	3.73	2.28	2.17	2.13	1.94	1.67	1.35	1.00	.73	.56
2.0	2.10	1.48	1.43	1.37	1.28	1.12	.94	.76	.64	.48
2.5	1.35	1.03	1.00	.97	.91	.82	.73	.60	.50	.41
3.0	.93	.77	.75	.72	.68	.62	.56	.48	.41	.35
4.0	.52	.46	.46	.44	.42	.40	.36	.33	.29	.25
5.0	.33	.31	.30	.30	.29	.27	.25	.24	.22	.20
TUBE 6.0 CM. LONG										
0.5	33.60	7.40	7.35	7.30	7.15	6.90	6.05	3.45	1.67	.86
0.75	14.93	5.00	4.95	4.90	4.50	4.18	3.71	2.44	1.39	.84
1.0	8.40	3.33	3.33	3.21	3.10	2.94	2.50	1.79	1.15	.77
1.5	3.73	2.00	2.00	1.96	1.94	1.75	1.52	1.18	.91	.67
2.0	2.10	1.34	1.32	1.28	1.23	1.12	.99	.82	.66	.52
2.5	1.35	.96	.93	.91	.89	.83	.74	.62	.53	.43
3.0	.93	.75	.72	.69	.66	.63	.57	.50	.42	.36
4.0	.52	.44	.44	.42	.41	.39	.36	.33	.30	.26
5.0	.33	.30	.30	.29	.28	.27	.25	.24	.22	.20

EXAMPLES FOR QUIMBY TABLE OF DOSAGE FROM LINEAR SOURCES

EXAMPLE No. 1



CARCINOMA OF CERVIX

To be treated with tandem of the two capsules

The upper capsule contains 25 mg. radium and is 2 cm. in active length. Lower capsule contains 50 mg. and is 3 cm. in length. Each capsule is filtered by 0.5 mm. Pt. Between the active parts is a space 0.5 cm.

It is planned to leave the tandem in place 40 hrs., for a total exposure of 3000 mg. - hr., of which the upper tube furnishes 1000 and the lower, 2000 mg. - hr.

It is desired to know the dose at point P, the limit of the lesion as felt, and at point X, 4 cm. out from center of tandem.

Point P:

2.5 cm. out on line C from lower tube — 107 r per 100 mg. - hr.

2.5 cm. out on line I from upper tube — 35 r per 100 mg. - hr.

Dose from lower tube 20 x 107 = 2140 r
from upper tube 10 x 35 = 350 r

Total 2490 r

Point X:

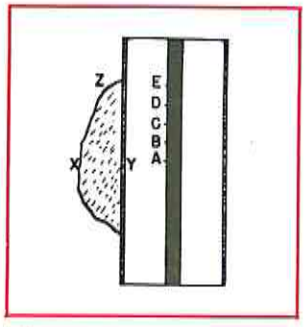
4 cm. out on line D for each tube.

From Lower — 44 r per 100 mg. - hr.
From Upper — 45 r per 100 mg. - hr.

44 x 20 = 880 r
45 x 10 = 450 r

Total 1330 r

EXAMPLE No. 2



CARCINOMA OF RECTUM

To be treated with linear applicator

EXAMPLE No. 2, CONT'D.

Annular lesion about 3 cm. long, probably 1 cm. thick. Linear applicator of brass, shell 2 cm. in diameter, wall thickness 1 mm. carrying radium tubes in its axis. Active length 6 cm. Filter on radium tubes 1.0 mm. Pt. Total radium 75 mg. to deliver 4000 r to base of tumor (Point X).

At 2 cm. on line A from 6 cm. tube, 134 r per 100 mg. - hr. with 0.5 mm. Pt. Additional Pt. and brass reduce this to 85%, or 112 r.

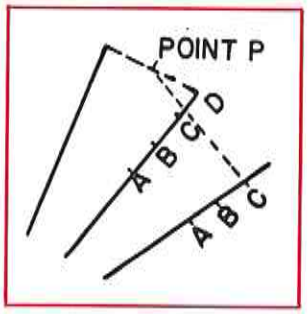
4000 ÷ 112 x 100 = 3570 mg. - hr. for this dose. For 75 mg., the exposure is 3570 ÷ 75 = 47.6 hr.

Dose to surface of tumor is of interest (Point Y). At 1 cm. on line A from 6 cm. tube, 333 r per 100 mg. - hr.; 280 r with filter correction. 35.7 x 280 = 10,000 r.

Dose at upper edge of tumor is also important. Assume it extends upward 2 cm. and is 0.5 cm. thick at edge (Point Z).

At 1.5 cm. on line E from 6 cm. tube 175 r per 100 mg. - hr. 147 r with filter correction. 35.7 x 147 = 5248 r.

EXAMPLE No. 3



CARCINOMA OF CERVIX

To be treated with Parametrial Needles

Parametrial needles inserted as far laterally as possible, lying approximately in an antero-posterior plane. Each needle is 3 cm. in active length and contains 3 mg. of radium. The filtration is 0.5 mm. Pt. The lower ends of the needles are 0.5 cm. apart. Upper ends of needles are 1.5 cm. apart.

Needles are to be left in place 100 hours. Hence, each needle supplies 300 mg. - hr. What doses are delivered at Point P, midway between the upper ends of two needles?

Point P:

Distance 0.75 cm. along line D from two nearest needles, 2 cm. along Line C for farther one.

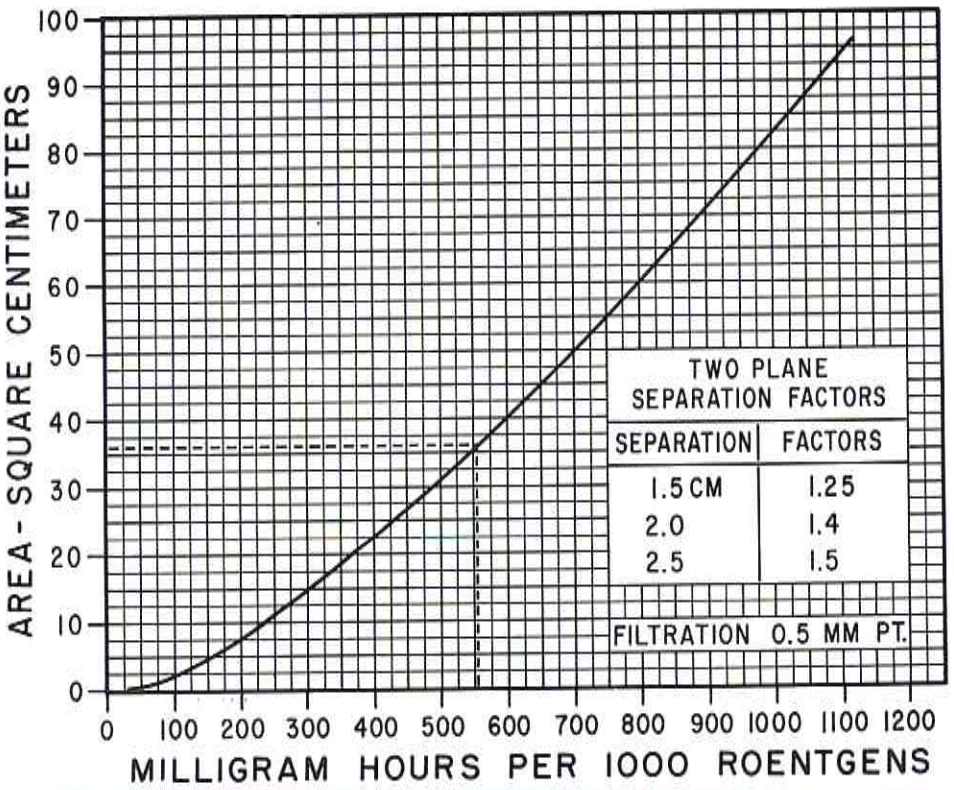
At 0.75 cm. on Line D from 3 cm. needle — 435 r per 100 mg. - hr.

At 2.0 cm. on Line C — 156 r per 100 mg. - hr.

2 x 3 x 435 = 2610 r
3 x 156 = 468 r

Total 3078 r

PATERSON AND PARKER CHART FOR PLANE IMPLANTS



PLANE IMPLANTS

AREA — SQ. CENTIMETERS	MILLIGRAM - HR. PER 1000 ROENTGENS
5	159
10	235
15	302
20	368
25	430
30	490
35	548
40	603
50	705
60	800
80	981
100	1155

RULES FOR DISTRIBUTION OF RADIUM

For a single plane, having an area less than 25 sq. cm. all radium should be placed around periphery; areas larger than this should have half around periphery and half uniformly distributed through the lesion.

Needles in parallel planes should have the ends crossed by other needles at right angles. If this cannot be done, the irradiated area must be considered 10% less for each uncrossed end. Parallel needles should not be more than 1 cm. apart.

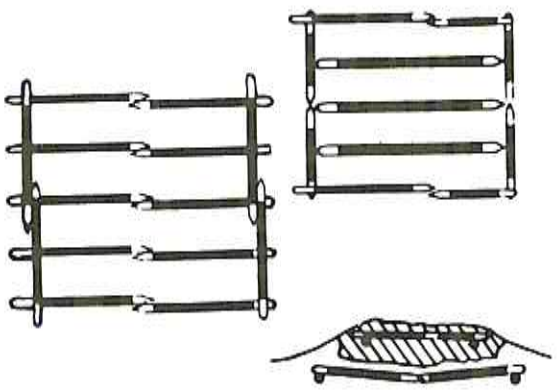
For two planes, the radium should be arranged in the same manner and the planes should be parallel. If the planes differ in area, the area to be used for the graph is the average of the two, and the total radium divided in proportion to the areas.

EXAMPLE BY PATERSON AND PARKER

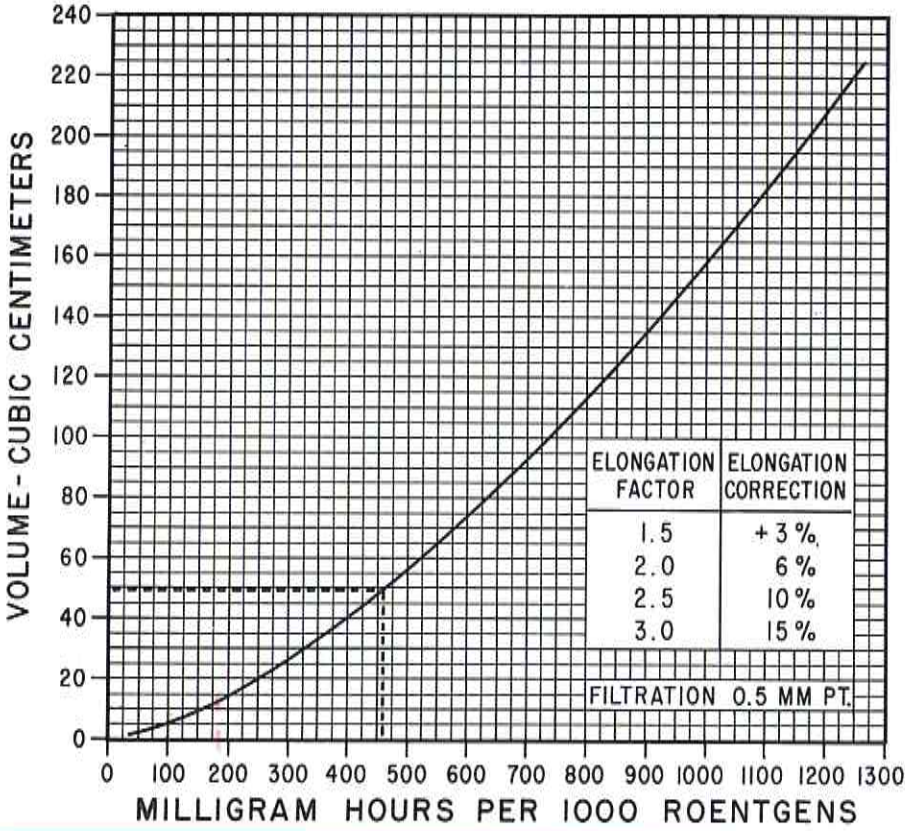
Tumor of skin-two plane implant. Lesion is a flat solid implantation in abdominal wall following excision of intra-abdominal tumor. Dimensions 5 x 6 x 1.5 cm. To give 6000 r by 2-plane implant, one larger plane undercutting mass, one directly through it, planes 1.5 cm. apart. Lower 7 x 6 = 42 sq. cm. Upper 5 x 6 = 30 sq. cm. Average 36 sq. cm. For this area, 550 mg. - hr. per 1000 r. Factor for 2-plane separation, 25%, increases this to 690 mg. - hr. per 1000 r. For 6000 r, exposure will be 6 x 690 = 4140 mg. - hr.

Use weak needles to stay in place about 7 days. 4140 ÷ 7 x 24 = 25 mg. Ra. This should be divided in ratio of areas, upper plane 10 mg., lower plane, 15 mg. Since each is larger than 25 sq. cm., place half of radium around periphery and distribute half through area.

Diagram below shows suitable arrangement for needles loaded with 0.33 mg. per cm.



PATERSON AND PARKER CHART FOR VOLUME DOSAGE



VOLUME DOSAGE

VOLUME IN CUBIC CENTIMETERS	MILLIGRAM - HR. PER 1000 ROENTGENS
5	100
10	158
15	207
20	251
25	292
30	329
35	364
40	399
50	463
60	523
80	633
100	735

RULES FOR DISTRIBUTION OF RADIUM

Any volume should be visualized as consisting of two components, the outer surface or "rind" and the "core" or entire volume being irradiated. The total radium should be divided as follows for the following shapes:

Sphere	Rind . . .	Three fourths
	Core . . .	One fourth
Cylinder	Belt . . .	One half
	Each End .	One eighth
	Core . . .	One fourth
Cuboid	Each Side .	One eighth
	Each End .	One eighth
	Core . . .	One fourth

The radium on the surface is to be evenly spaced. That for the core is to be evenly distributed throughout the volume, *not* all at the center.

EXAMPLE BY PATERSON AND PARKER

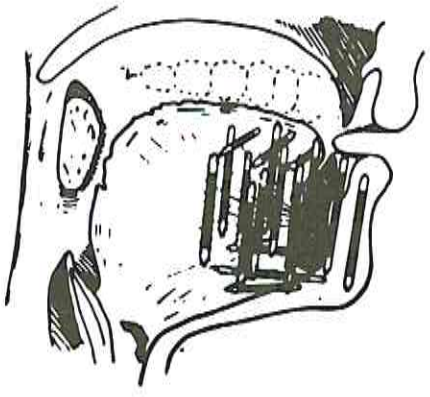
Epithelioma of floor of mouth—volume implant. Center of lesion is in region of frenum of tongue. Growth extends forward into floor and upward into substance of tongue.

With tongue stitched down to floor of mouth, this type of lesion is well treated as a vertical cylinder, with needles in lip as anterior portion of belt, and both ends crossed, upper end in dorsium of tongue, lower end submental.

Proposed dose 6000 r, volume of elliptic cylinder 4.5 x 4 cm., 3.5 cm. high = 49.4 cu. cm.

For 1000 r use 460 mg.-hr. No correction for open ends or elongation.

For 6000 r — 6 x 460 = 2760 mg. - hr. If radium is to be left in place one week, this means 2760 ÷ 24 x 7 = 16 mg. This should be divided 8 mg. in belt; 4 mg. in core; 2 mg. in each end. Various combinations of weak needles can be used.



QUANTITIES OF INTERSTITIAL RADIATION NECESSARY TO DELIVER 1000 ROENTGENS IN VARIOUS VOLUMES

FILTER 0.5 MM. Pt. – By QUIMBY

DIAMETER OF SPHERICAL MASS — CENTIMETERS										
1	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
APPROXIMATE VOLUME OF MASS — CUBIC CENTIMETERS										
0.5	2	4	8	15	25	35	50	65	90	115
MILLIGRAM OR MILLICURIE TO DELIVER 1000 ROENTGENS										
400	100	180	280	390	475	575	675	790	930	1070
MILLICURIES DESTROYED TO DELIVER 1000 ROENTGENS										
0.33	0.75	1.35	2.1	3.0	3.6	4.3	5.1	6.0	7.0	8.0

EXAMPLE No. 1 (by Quimby)

A neck node secondary to carcinoma of tongue, 2 x 3 x 3 cm.; to be implanted with gold seeds to give 7000 r.

From table for 3 cm. sphere, 1000 r require 2.5 mc. destroyed 7 x 2.5 = 17.5 mc.

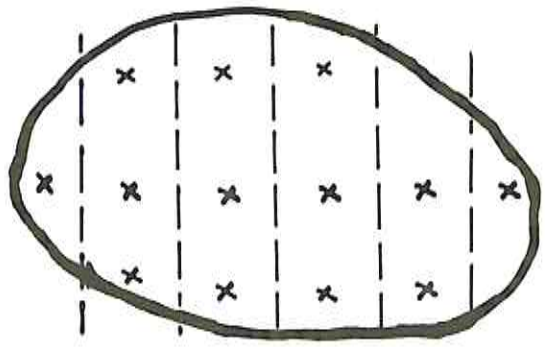
A good division would be 12 seeds of approximately 1.5 mc. each.

EXAMPLE No. 2 (by Quimby)

A soft part tumor, 3 x 4 x 7 cm. is to be implanted with needles for a dose of 4000 r. Available needles are 3 cm. active length, 1 mg. each and 4 cm. active length, 2 mg. each, filter 0.5 mm. Pt. 3 x 4 x 7 = 84 cu. cm. interpolating between values for 65 and 90 cu. cm.

To give 1000 r in 84 cm. requires 840 mg. - hr 4 x 840 = 3360 mg. - hr.

One satisfactory scheme: arrange 13, 3 cm. needles in 3 planes 1.5 cm. apart as shown by crosses (illustrated right) cross ends of these above and below with 4 cm. needles (dotted lines). Total radium — 13 x 1 + 10 x 2 = 33 mg. 3360 ÷ 33 = 102 hrs. (4 days - 6 hours).



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