A DEEP THERAPY TABLE WITH A TUBE STAND COMBINED AND REVOLVING IN ARC ABOUT THE TABLE: INTENSITY DISTRIBUTION WITHIN PARAFFIN PELVIS FOR VARIOUS PORTALS OF ENTRY

By NATHAN FLAX, M.D., Department of Roentgenology, Booth Memorial Hospital,
Covington, Ky.

IN the irradiation of neoplasms of the cervix uteri and other mid-line tumors, a technic making use of the smallest of portals of entry, with a tube in constant motion, possesses distinct advantages. A small-port, moving-tube technic results in an unusually high depth dose with a low skin surface dose, and a great accuracy in directing the irradiation to the mid-pelvis. While the value of a high depth dose need not be stressed, the value of great precision in the distribution of the dose throughout the pelvis might be dwelt upon.

Proper "angles" at which the radiating beams traverse the pelvis are the basis of the cross-section irradiation charts, with the angles of the radiating beams so arranged as to insure the greatest cross-fire effect in the tumor area. Any deviation from the charted angle must cause an undesirable rearrangement of the intensity distribution within the pelvis, to the detriment of normal tissues and at the expense of tumor effect. Necessarily taken for granted is the ability of the operator to duplicate, by sighting the x-ray tube for an invisible tumor deep in the body, the angle called for in the chart for portals of entry. The small ports required with four-, six-, or seven-port technics, necessitate the most accurate direction, as an error of only a few degrees in angulation of the tube may result in a complete missing of a small, deep-seated invisible tumor, or if the tumor be too large to be missed altogether, the delivery of only the periphery of the x-ray beam into the tumor and a purposeless, if not injurious, irradiation of normal tissues.

On the other hand, a two-port technic, consisting of a single large port anteriorly and posteriorly, requires no precise angulation of the tube, and the distribution of the irradiation throughout the pelvis conforms to the charted value. Unfortunately, the depth dose is relatively small. It is felt that with this small-port, moving-tube technic, to be described here, a depth dose is achieved that compares advantageously to any multiple port technic available, and also possesses a precision of distribution of irradiation equal to the conventional two-port technic. This moving-tube technic makes use of a table and tube stand combined which are described as follows.

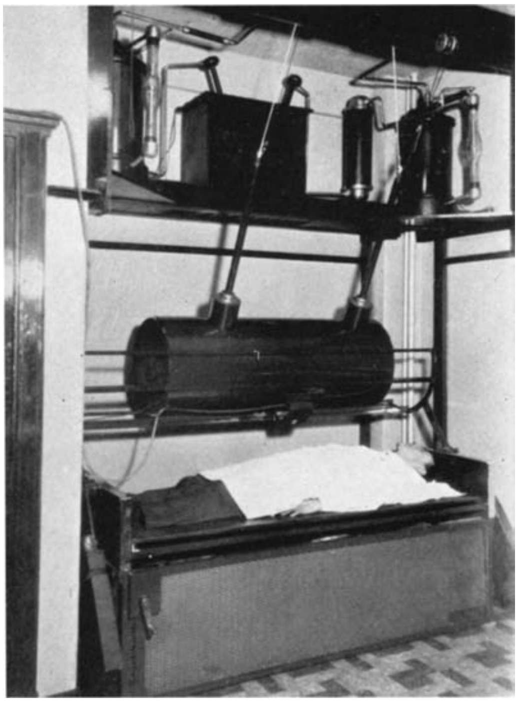

Fig. 1.

On a bearing at each end of the table is mounted the tube support for an air-cooled tube which can revolve about the table in an arc, the center of the radius of which arc is fixed and coincides with this bearing. The table top may be raised or lowered independently of the tube support, so that the patient may be raised or lowered to bring the tumor area into line with the bearing which represents the center of the radius of the arc through which the tube moves. The tube itself is shifted on its mount, with the long axis of the body to enable its centering over any cross-section level of the body.

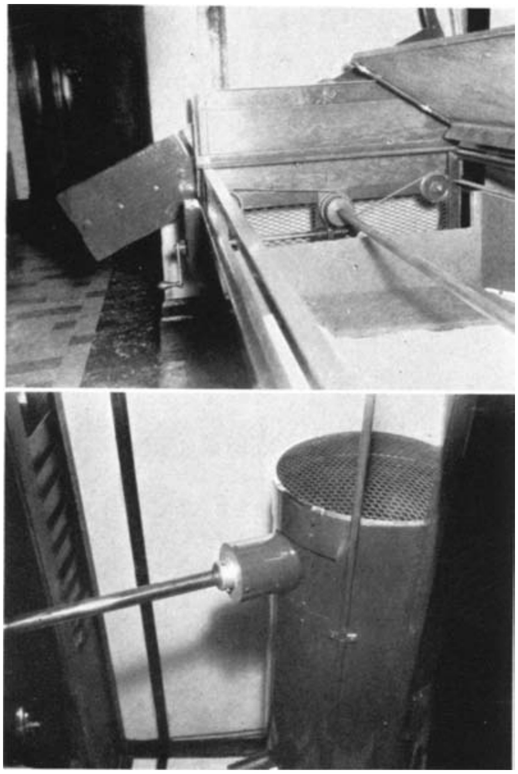

Fig. 1-*A* (*above*).
Fig. 1-*B* (*below*).

A motor under the table is geared to the bearing supporting the tube mount. Its speed is reduced through the interposition of a gear box, with worm reduction gears, so that the tube mount requires 20 minutes to travel through the half-revolution from one side of the table to the other in an arc about the patient supine or prone upon the table. In this manner, one-half of the patient's body surface is irradiated with one half-circle movement of the tube, and when the patient is turned over and the tube movement is repeated, the entire skin surface is irradiated, with the center of the body as a hub to receive portals of irradiation converging to the center throughout the entire movement of the tube. In effect, this continous movement of the tube makes constantly available new skin surfaces as portals of entry. Incidently, the tube is shockproof, and its slow movement is wellnigh imperceptible to the patient.

At first glance it might appear that this method of irradiation is fraught with danger to the skin, due to the constant overlapping of beams. However, closer scrutiny of the facts reveals that while there is a constant overlapping of beams, it is uniform, accurately controlled and easily measured, differing from that accidental overlapping which may occur in manually directed multiple port technics and for which accurate allowance cannot be made. Using a chunk of paraffin conforming in external contour to a female pelvis 23 cm. deep and 35 cm. wide, as established by Arneson and Quimby (RADIOLOGY, August, 1935), to be the size of the average female pelvis, the experimental values obtained revealed the spot surface dose to be considerably less than the dose in the center of the pelvis.

The following physical factors were utilized: 200 kv. p. Villard circuit; 0.5 mm. Cu and 1 mm. Al added filtration; 5 ma.; target-surface distance 58.5 cm. to the top of the pelvis and 52.5 cm. to the sides of the pelvis (the pelvis not being circular in shape, this variation in target-surface distance is unavoidable). Intensity distribution was charted with the following portals of entry: size in centimeters, 4 × 15, 9 × 15, 11 × 15, and 15 × 15, the greatest width of the portal concurring with the long axis of the body of which the pelvis was theoretically a part. It was found that at no time did the spot surface dose exceed the depth dose; with the largest portal 15 × 15, an intensity of 100 per cent could be delivered into the center of the pelvis, with 92 per cent as the greatest intensity over any spot on the surface; on the other hand, with the smallest portal, 4 × 15, the surface intensity for a depth intensity of 100 per cent was but 50 per cent. Were the surface exposed to its full 100 per cent with a 4 × 15 cm. port, the depth dose would be 200 per cent.

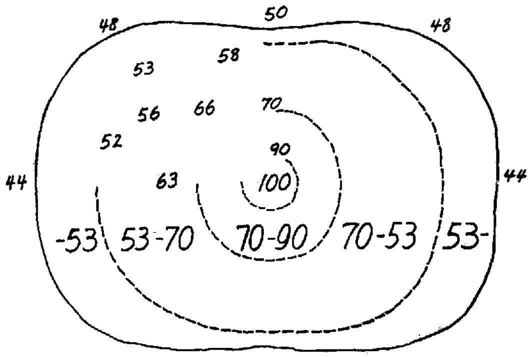

Fig. 2.

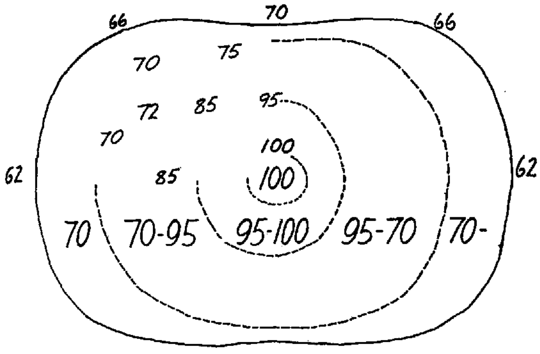

Fig. 3.

Fig. 2. Port 4 × 15 cm.; pelvis 23 × 35 cm.
Fig. 3. Port 9 × 15 cm.; pelvis 23 × 35 cm.

This last figure, checked and rechecked, is not to be wondered at if it is remembered that by dividing the available surface into areas 4 cm. wide, there would be approximately 24 such divisions, or, in its equivalent, 24 portals of entry. However, a portal as small as 4 × 15 cm. is interesting in point of theory, but it proves inefficient for a pelvis 23 × 35 cm., as will be seen later—a portal 9 × 15 cm., with a surface intensity of 70 per cent for a depth intensity of 100 per cent, proving itself more suitable for clinical application. A 9 × 15 cm. port is equivalent after a division of available surface to an 11-port technic. In point of execution, however, it is essentially a two-port technic, the tube travelling from one side to the other as a single port, and, with the pelvis turned, the other surface is irradiated as through a single port.

The values in Table I were obtained by placing the paraffin pelvis on the table with tube in the true lateral position, and the table top elevated until the depth center of the pelvis coincided with the radius center of the tube mount. No other adjustment was required. Simultaneously, with the full activation of the tube at 200 kv. p, the motor for moving the tube mount was started. When the tube mount reached the true lateral position on the opposite side, having passed around the pelvis in a half-circle, automatically the motor stopped and the x-ray turned off. In this manner readings were taken from a Victoreen, first, in the center of the pelvis for depth dose, and next, over five spaced areas on the upper surface. To these direct values were added the lesser back-scatter values that came through the pelvis when it was turned with the lower side up, and the ionization chamber on the down side.

It was expected that the values over the sides of the pelvis would be higher than the values over the upper and lower surfaces because the target-surface distance was 52.5 cm. to the sides, and 58.5 cm. to the top surface of the pelvis. Yet, the values on the lateral surface proved to be, in spite of the shorter focal distance, lower than the upper and lower surfaces. The most important cause for this interesting discrepancy lies in the fact that back-scatter on either side from its opposite side, 35 cm. removed, is considerably less than the back-scatter from top to bottom, 23 cm. removed.

While this discrepancy in values over the sides and upper surfaces is an inconsiderable one for the smaller portals of entry (Figs. 2 and 3), for values representing total spot skin intensity, the highest values obtained are tabulated in Table I. For depth intensity, the values obtained were the same with irradiation of either the upper or lower surface, and the figures were likewise added to each other for total depth dose upon irradiation of both surfaces.

The reasons for the small surface intensity with a high depth intensity would appear to be as follows:

1. The utilization of every inch of regional surface, with consequent distribution of surface dose over a larger area; in methods of irradiation other than by mechanical contrivance to direct beam, it is unsafe not to have areas of skin between ports free from irradiation to prevent undue overlapping.

2. With the skin divided into 9 × 15 cm. divisions (the largest port size found feasible with this technic), the tube travels through 11 such divisions when revolving about a pelvis 23 × 35 cm. In spite of the skin dose per equivalent portal area being smaller, the increased number of portal areas available make for an increased depth dose.

3. The increase in tube-target distance from the usual 50 cm. to a distance varying from 52.5 to 58.5 cm., increases the depth dose. It is felt that this is the least of the factors involved, since the depth intensities could be increased by only a few per cent for this added distance.

Satisfied as to the margin of safety present for the skin, the distribution of intensity throughout points in the pelvis other than the center was next determined. Holes were drilled at various depth levels from the surface to the depth center in various planes, and into these the ionization chamber was inserted in succession. In order not to affect materially the bulk of the paraffin pelvis by the number of holes that had to be drilled, all the holes except the one into which the chamber was inserted for the particular reading were plugged by candles of equal diameter.

From Table I, it is evident that the smaller the portal the less the surface intensity required for a center pelvis intensity of 100 per cent, and as a result, the 4 × 15 cm. port would appear the most desirable. However, the measurement of points throughout the pelvis other than the center reveals a rapid falling off in values at points off-center with a port 4 × 15 cm., but a maintenance of high intensity in points off-center when a portal 9 × 15 cm. or larger is used. The explanation for this is self-evident: the center of the radius within the pelvis is not truly a point center but is an approximate area that corresponds in size to the width of the portal of entry. With the 4 × 15 cm. port the radius center would be about 4 cm. wide, and this only would be the area of maximum intensity. With a 9 × 15 cm. port, the radius center is approximately 9 cm. wide, accounting for the high intensity maintained in a larger area; continuing, the 11 × 15 cm. port yields an area of greatest intensity that includes almost the entire pelvis in its antero-posterior diameter. Thus, while the 4 × 15 cm. port yields too small an area of maximum intensity in the center of the torso, the 11 × 15 cm. port or larger, yields an area of maximum intensity too large and which encroaches upon the immediate subcutaneous areas with an intensity that is more than proportionately higher.

TABLE I.—MEASUREMENT OF r-UNIT INTENSITY SURFACE AND DEPTH CENTER OF PELVIS 23 × 35 CM. WITH ONE COMPLETE REVOLUTION* OF TUBE

Port (cm.)	r-units Surface**	r-units Depth	Surface per cent Depth Intensity
4 × 15	(4.0 + 0.5) = 4.5	9.0	50
9 × 15	(8.5 + 2.0) = 10.5	15.0	70
11 × 15	(10.5 + 3.0) = 13.5	16.0	84
15 × 15	(12.5 + 4.5) = 17.0	18.5	92

* Because of the number of readings required, motor was geared up so that tube revolved completely about table in six minutes instead of forty.

** (Direct point surface value + backscatter from irradiation of opposite side) = total point surface value.

A study of the distribution chart for a port 9 × 15 cm. (See Chart 3) reveals a radiation intensity distribution that appears satisfactory and advantageous. In the center of the pelvis, throughout an area approximately 11.0 cm. in diameter, the intensity is 100 per cent diminishing to 95 per cent peripherally. On the periphery of a still larger area from the center radius, and 16 cm. in diameter, the intensity is still 85 per cent and from there out there is a gradual fading out peripherally toward the surface, the intensity of which is 70 per cent on the upper surface and 62 per cent on the lateral surface. We have, then, the greatest intensity in the potential tumor area and the least intensity in normal tissues. This is a highly desirable distribution of intensity and certainly an unusual one for irradiation of external surfaces where the usual distribution is one of 100 per cent on the surface with a diminution of intensity toward the center.

From these values it is apparent that for a pelvis of average size and an area to be irradiated located in the midline and center of the body, the portal of entry should not be larger than 9 × 15 cm., but that if the area requiring an intense irradiation permits, a smaller portal might be used profitably to spare even further the normal tissues. Because this technic enjoys its greatest advantage with smaller ports, one should endeavor at all times, if accurate localization of a tumor is possible, to use the smallest adequate port size. A tumor of the bronchus might best be irradiated with a port perhaps 6 × 15 cm., while a growth of the cervix uteri might require a portal 9 × 15 cm. Of equal importance to the small skin dose with high depth dose possible with a moving-tube technic is this ability to select a port size for a given pelvis size to achieve an intensity distribution that confines as much as possible the maximum intensity to the tumor area, or rather, to the direct topography and invasive characteristics of the tumor, sparing as much as possible the normal tissues. Under unusual circumstances, one might use a 9 × 15 cm. port over one surface and a 4 × 15 or 6 × 15 cm. port over the other surface. This may appear to be drawing the line too fine, since it involves a degree of localization not usually possible.

Regarding the actual r-unit delivery with the different portals of entry, by reference to Table I, it can be noted that, apart from the 4 × 15 cm. port, there is no great difference in quantity between ports 9 × 15, 11 × 15, or even 15 × 15 cm. For 15 r-units delivered into the center of the pelvis with a 9 × 15 cm. portal, only 16 r-units will be delivered for the same unit of time if the portal used is 11 × 15 cm., and only 18.5 r-units if the portal size is 15 × 15 cm. This difference would never influence decision in favor of a large portal because of an economic complication. From every point of view, the use of a portal 9 × 15 cm. is satisfactory for the pelvis of average size, and is considered the largest port to be used with this pelvis.

In a larger pelvis with a greater anteroposterior diameter and a greater centricity of the body, a port larger than 9 × 15 cm. might be used, perhaps 11 × 15 cm., depending on the size of the pelvis and the area to be irradiated. Conversely, with a pelvis smaller than 23 × 35 cm., a portal 9 × 15 cm. would be too large. This supposition was tested by reducing the size of the pelvis to 20 × 35 cm. and measuring the intensity distribution with a port 9 × 15 cm. (See Table II.)

TABLE II.—CENTER, OFF-CENTER, AND SURFACE INTENSITY IN PERCENTAGES

Portal (cm.)	Center	5.5 cm. Radius*	7.5 cm. Radius	9.5 cm. Radius	13 cm. Radius	Upper Surface	Lateral Surface
Pelvis 23 × 35 cm.							
4 × 15	100	70	63	58	53	50	42
9 × 15	100	95	85	75	70	70	62
11 × 15	100	104	100	100	84	84	66
Pelvis 20 × 35 cm.							
9 × 15	100	102	80	69	67	70	45

* The radius does not represent a true circle; it increases laterally following the configuration of the pelvis.

Because the area of greatest intensity does not occur in the center of a pelvis 20 × 35 cm. in size, when irradiated by a 9 × 12 cm. port (See Table II), there follows from this, the conclusion that the smaller the anteroposterior diameter, the smaller the portal to be used; that a pelvis smaller than 23 × 35 cm. requires the use of a portal smaller than 9 × 15 cm. Further, the deduction appears feasible that with larger pelves, portals larger than 9 × 15 cm. can be used. Having established that portal of entry yielding a proper radiation distribution within a pelvis of average size, it now remains to be determined how much increase or diminution in portal size will be entailed in adapting this technic to every size of pelvis. Possibly a portal range from 6 × 15 cm. to 11 × 15 cm. will be found to suffice for all variations in size. Further study in this direction is planned, and also, the adaptability of this technic for creating areas of maximum intensity eccentric to the body axis. Here again, it will become a question of proper port size, and perhaps, combination of port sizes.

Pending this further study of pelves other than average in size, it is no great presumption to state that, although very thin pelves can be advantageously irradiated by this technic after the proper port size is determined, it is in the pelvis of greater than average rotundity and anteroposterior diameter that this technic will have its greatest applicability. This is a fortunate circumstance because the thin pelvis offers no great problem for its adequate irradiation with conventional technic; it is with the large pelvis that difficulty arises in the delivery of adequate depth intensity. With the patient's body more rotund, more skin surface is available for portals of entry, with unfortunately, the tumor more remote from the surface. Here most of all is it difficult to angle manually the small port for the deep, invisible tumor so that the extra skin surface cannot be properly utilized. In a moving-tube irradiation, the patient's bulk does not offset the advantage of increased skin surface for portals of entry, and it is felt that as great an intensity can be delivered into the depth center with small skin intensity.

Where beams converge there is overlapping, and the center of the pelvis being the point of greatest convergence, the greatest overlapping is there present, with the highest irradiation intensity. From the center of the pelvis outward to the periphery, the convergence and overlapping is lessened and the intensity is lessened, until, at the surface, the overlapping is least and hence the intensity least. Given a larger pelvis, the surface is farther from the center and the overlapping on surface and subcutaneous areas is less than on a small pelvis. The diminution in intensity of the individual beam that occurs with the greater depth is compensated for by the increased amount of skin available for portals.

From the point of view of economy of effort this unit proves of advantage. Instead of changing the tube inclinations for four or six ports, and slowly increasing the voltage each time to its maximum, the patient's set-up is that of a two-port technic, front and back. The tube is never adjusted to the patient. The table top is merely raised or lowered to bring the tumor area into the center of the tube radius required.

CONCLUSIONS

1. Through the use of a tube, moving in an arc about the patient, a high depth intensity with a small surface intensity is made possible.
2. A distribution of intensity is achieved wherein the center of the pelvis receives the greatest intensity, with the intensity diminishing peripherally to become the least great on the surface.
3. The size of the area of central intensity can be regulated by use of a proportionate portal size.