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ROTATIONAL THERAPY UNIT

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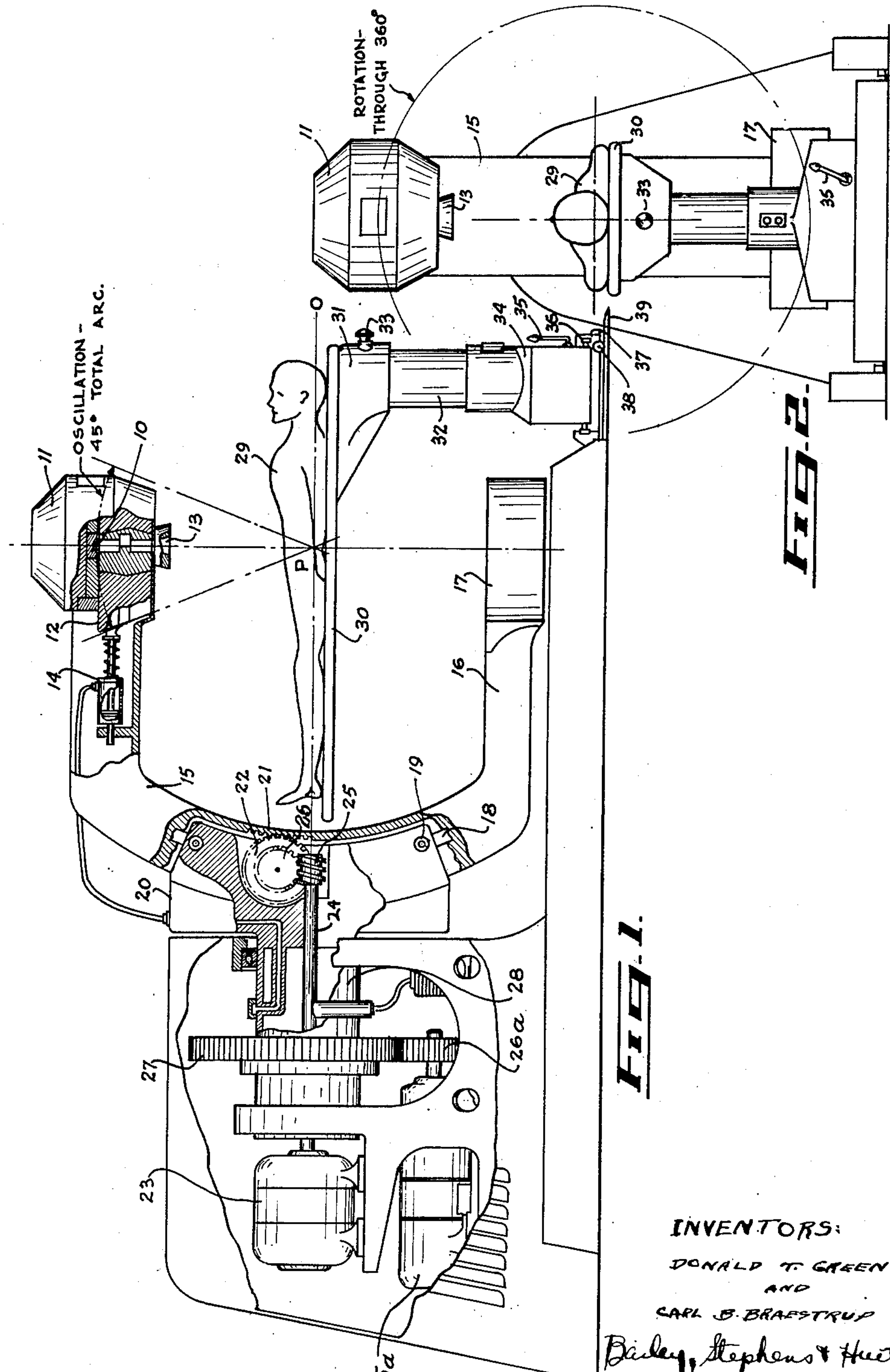

Fig. 1.

Fig. 2.

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This invention relates to an apparatus for radiation therapy.

Where tumours and other diseases are to be treated by means of a beam of electromagnetic radiation from outside the body, it is desirable to subject the diseased volume to a prolonged treatment while minimizing damage to surrounding healthy tissue. It is necessary to use highly penetrative radiation for deeply seated tumours, or most of its energy will be absorbed by intervening healthy tissue. Even if penetrating radiation such as 1–3 million volt X-rays or the gamma radiation from the artificially radioactive isotope of cobalt, Co^{60}, is employed there is a considerable dissipation of energy during passage though the healthy tissues. At a depth in tissue of about 10 cm., the dosage delivered per unit volume will approximate 60% of that delivered near to the skin where the beam enters. Consequently the use of conventional stationary equipment will result in a higher concentration of radiation on the intervening healthy tissue than on the diseased volume to be treated. This is likely to cause severe burns and other undesirable effects.

It has previously been proposed to deal with the problem which has been outlined by means of multiple beam therapy. Several beams of radiation are utilized in succession, each entering the body at different locations on the skin and all being directed towards the tumour. The dosage delivered to the tumour by each successive beam is cumulative, while the skin dosage at each entrance port remains constant. In this way the ratio between dosage at tumour depth and skin dosage is increased. However, there are practical limitations to the number of beams which can be used, and it is often difficult accurately to reproduce treatments. With simple inexpensive equipment such as is commonly available, every time a new port is set up on the patient for the treatment field both the head of the equipment and the patient must be moved, since any movement of the treatment head of the equipment will move the beam of radiation away from its location on the tumour. The necessary adjustments are difficult to make and are time consuming. Further there is considerable opportunity for error, and accuracy in aligning the beam is difficult.

It has also previously been proposed to seat the patient in a rotating chair. The patient is rotated with the beam of radiation stationary, using the tumour as the centre of rotation. This achieves a fairly high tumour dosage in comparison with skin dosage as a band of skin encircling the body about the tumour affords the entrance portal. Patients are, however, frequently aged and infirm and the constrained vertical position of the torso in a rotating chair unit may be undesirable, and the rotational movement, even at slow speeds, is often found objectionable. Since some healthy tissues are more sensitive to radiation than others, it may be desirable to use rotation therapy over a limited arc rather than a complete circle. The oscillatory movement of the patient necessary under these circumstances will be even more disagreeable to the patient than a rotation of movement. A further difficulty

is the high set-up time required to install the patient in the chair and to correctly align the beam. Once the patient and treatment beam are properly adjusted to each other, it is then important that this relationship be maintained within close limits during the period of treatment. With the patient vertical and rotating this creates a problem, since such normal movements as respiration and swallowing may result in mislocation of the point of concentration of the beam.

The object of the present invention is to provide a radiation therapy unit which is capable of concentrating a beam of radiation at a treatment point while distributing the entrance portal over a wider skin area than in the conventional rotational unit. This is achieved by providing a source of radiation which is movable throughout the segment of a sphere defined between two vertical parallel planes, the beam being concentrated at the treatment point throughout such movement. In accordance with this invention two movements of the source of radiation are used. Means are provided for rotating the source in a vertical circle about a horizontal axis. Additional means are provided for oscillating the source in a direction perpendicular to the plane of the vertical circle. The source may be rotated about a vertical circle, shifted perpendicularly and again rotated about a vertical circle to give an entrance portal over a wide band of skin area. Alternatively, both movements can be applied simultaneously so that the beam traces out a sine wave spiral or other configuration drawn on the surface of a spherical segment. Almost any conceivable motion within the limits of said segment can be achieved to give a wide versatility to the equipment.

A further object of this invention is to minimize the problems referred to of long set-up time, the tendency of the beam to be misdirected with movement of the patient, lack of comfort and the difficulty of accurately reproducing results. This is achieved by providing an apparatus which is adapted to treat a stationary patient in a reclining position. The source of radiation is movable in a controlled, reproducible manner, with the beam of radiation concentrated on the treatment point. The reclining position of the patient has the added advantage that the patient will be in the same position as the normal diagnostic position. This facilitates accurate treatment.

An additional object of the invention in its preferred embodiment is to provide an improved shield as a barrier for the radiation beam emerging from the patient. This is achieved by a combined counterweight and shield which rotates and oscillates with the motion of the source of radiation so that alignment is maintained between source of radiation, treatment point and shield. The amount of protection required in the treatment room is consequently greatly decreased.

While the preferred embodiment of this invention described hereafter shows the application of this invention to a radioactive source of radiation such as cobalt 60, it will be apparent that the same principles are applicable where the source is an X-ray tube. X-ray therapy is thus intended to be included within the scope of this invention.

The preferred embodiment of this invention is illustrated in the accompanying drawings in which,

Figure 1 is a side elevation view partly in section of the unit,

Figure 2 is an end elevation view of the unit shown in Figure 1.

In the drawings there is shown a source of radiation **10** enclosed in a shield **11** which contains a sliding block **12**, permitting a beam of radiation to emerge through aperture **13**. The movement of block **12** is controlled through hydraulic cylinder **14**. Shield **11** is mounted at one end of arm **15**. The other end of arm **15** is connected to a second arm **16**. Preferably these arms are connected by forming the arms as a unitary integral unit. The arms are curved and one end of each is spaced so that together they form a U. At the free end of arm **16** is disposed a shielding block **17** which acts as a combined shield for the radiation which has passed through the patient and counterweight for shield **11**. The U-shaped arms encompass a horizontal axis designated as O and the beam of radiation is directed at a treatment point P located on this axis. Source of radiation **10**, treatment point P and shielding block **17** will be in alignment as is shown in the figures.

A section of rail **18** is attached to the connected ends of arms **15** and **16** and is formed in the shape of an arc of a circle centred at point P. Rail **18** is engaged by rollers **19** which are mounted on block **20**. This permits movement of the arms relative to the block in an arcuate path centred at point P. A curved rack **21** on arms **15** and **16** is engaged by a spur gear **22** mounted on block **20**. A reversible variable speed motor **23** drives subsidiary shaft **24** on which is mounted worm **25**. Worm **25** drives worm gear **26** which is secured to spur gear **22**. Thus motor **23** acts to cause relative movement between the arms and block **20**. This causes oscillation of source **10** while maintaining the beam of radiation directed towards point P.

Motor **25*a*** drives spur gear **26*a*** which acts on bull gear **27** to rotate main shaft **28**. Shaft **28** is coaxial with shaft **24** and its axis lies along centre line O. Block **20** is mounted on shaft **24** so that motor **25** will act to rotate source **10** in a vertical circle centred on centre line O.

It will be apparent that shield **17** will always be in alignment with source **10** and point P.

The patient **29** is supported in a horizontally reclining position lying along line O on a treatment couch **30** which is designed to offer a minimum of attenuation to the beam. A framework of light alloy tubing supports the edges of a canvas rectangle which forms the bed proper. The couch is supported at its outer end by a couch support located remote from the radiation beam. Couch **30** is mounted on headpiece **31** in which is journalled pillar **32**. A catch **33** locks the headpiece and pillar or may be disengaged to permit the couch to be swung about a vertical axis. Pillar **32** is seated in base member **34** which contains a hydraulic or other suitable mechanism for elevating and lowering the couch operated by control handle **35**. The base is mounted on rollers **36** which engage tracks **37** for movement in a direction perpendicular to axis O, and on rollers **38** which co-operate with tracks **39** for movement in a direction parallel to axis O. All movements of the couch are provided with locks, and all motions of the couch are registered on scales for reproducing positions. As an alternative construction the couch **30** can be mounted for sliding inwardly and outwardly while maintaining head **31** stationary. Tracks **39** can thus be omitted.

It is desirable that some safety device be built into the machine so that it is impossible for the moving parts to foul on the fixed parts or on the patient. The complexity of the possible motions of the moving parts makes it difficult to achieve this by mechanical means and a convenient way of achieving this is by means of a capacity relay. This will be done by ensuring an electrical contact between the patient and the top of the treatment couch, and isolating these two parts electrically from the rest of the equipment, which would be at ground potential. If the patient and the treatment table is considered to be one plate of a condenser, the other plate of which is any grounded object, and this capacity is made part of a resonant circuit so that an increase in the capacity above a certain predetermined value will unbalance the circuit and change the plate current of a vacuum tube by an amount sufficient to operate a relay, it is then possible to stop all motions of the machine automatically by disconnecting the main power in the event that any way part of the moving mechanism comes close to the patient or the treatment table. The minimum distance at which this action occurs can be adjusted so that the momentum of the moving parts will not carry them to the point of actual contact with the patient or treatment table before they come to rest.

In accordance with the preferred embodiment control is centralized at a remote control panel (not illustrated) which includes the following,

(*a*) A motor operated timer switch which operates the shutter mechanism **12** for a set time period.

(*b*) An angular scale and pointer operated by a Selsyn linkage to show the angular position of the source of radiation **10** about centre line O relative to the base of the equipment. This may also be indicated by a protractor scale on the machine.

(*c*) A protractor scale and pointer operated by a Selsyn linkage to show the degree of arc through which arms **15** and **16** have moved relative to block **20**. This may also be indicated by a protractor on the machine.

(*d*) A circular cam and switch arrangement, the movement of the cam coinciding with the pointer in (*b*). The switch arrangement consists of two micro switches located in a circle. These micro switches may be independently located at an angular position on the circle, so that each switch can be made to operate at any angular position. The actuating point of the cam which operates these switches coincides with the pointer position. This enables the beam to be operated for a portion only of the rotational cycle of the radioactive source.

(*e*) Speed setting potentiometers and speed indicators for all motorized movements.

(*f*) Suitable pilot lights and circuit interconnecting switches.

Controls can readily be provided for the automatic operation of equipment in accordance with the preferred embodiment. The motor drives for the main rotation movement and for the so-called oscillation movement are preferably identical, consisting of a synchronous A. C. motor coupled by means of an eddy current clutch to an output shaft. The eddy current clutch on the output side drives a small A. C. alternator, the voltage output of which is directly proportional to the R. P. M. of the output shaft. This A. C. signal is fed into a controlled circuit which adjusts the D. C. current flowing through the coils of the electromagnet of the eddy current clutch so as to control the amount of slip in the clutch to produce an output speed of constant value. A D. C. signal can be introduced into this circuit which eventually overrides the A. C. signal from the small alternator so that the controlled circuit will then act so as to produce a speed of the output shaft which bears the direct relationship to the introduced D. C. voltage. In this way it is apparent that the speed of rotation or oscillation can be made to follow an extraneously produced D. C. signal, and be proportional to this signal. It is therefore possible, by producing a D. C. voltage which varies in a predetermined manner, to vary the speed of rotation or oscillation in a predetermined manner. Since it is also possible to reverse either motion, it is possible to vary the speed of rotation, for example, so that the velocity at any time follows a sine wave function. This will result in a movement over a short arc. If, at the same time, a similar motion is produced in the oscillation movement, but 90° out of phase with the rotation movement, the resulting movement of the source will be in a circle. This is analogous to the production of a circular Lissajous figure by feeding two A. C. voltages of equal frequency, but 90° out of phase, to the deflecting plates of an oscilloscope. The D. C. signal required to accommodate this may be obtained, for example, by mechanical motion of the rotor of a potentiometer. It is apparent that by feeding different signals into the oscillation and rotation motor control circuits that movements of the source other than circular in a plane parallel to the surface of the treatment table can be obtained. It is also apparent that such movements can be obtained, by the introduction of suitable signals, in other planes or as traces on a spherical circle.

It follows that it is possible, with this equipment and the proper type of controls, to build up a predetermined dosage field within the patient. Since the dosage at any point is the product of the intensity or rate of dosage and the time, and the rate of dosage for a given size of source and a given size of aperture is dependent upon the position of the point with respect to the axis of rotation and the thickness of the intervening tissue measured along the direction of the beam, then by controlling the length of time during which the source remains in a particular position, and if necessary controlling the relative location of the point under consideration with respect to the axis of rotation, one can predetermine the dosage delivered to that point. The first variable is controlled by the motor speeds, and the second variable can be controlled, if necessary, by movements of the treatment table. These movements may be manual, but they could be power driven and automatically controlled to suit the requirements. It therefore follows that by introducing the correct information into the controlling circuits for the motors which move the source, and the motors which could move the table, that a predetermined dosage can be delivered to a given point. By extension of these principles a predetermined dosage can be delivered to a group of points, or to a given volume of tissue within the patient.

In rotational therapy one may consider the normal procedure to be rotation of the source relative to the patient over a 360° arc at a constant speed with the beam being turned on during several rotations. In some cases it is desirable to leave the beam on over less than 360° arc. From the standpoint of saving time during the treatment, if one wishes to treat over an arc of between 180° and 360°, it is preferable to arrange for the rotation to be continuous and unidirectional and to turn off the beam automatically over that portion of the arc which one does not wish to treat. If the arc over which one wishes to treat is less than 180° it is preferable to leave the beam on throughout the treatment and to reverse the rotation direction at the ends of the arc. A circular switch, built into the moving scale which indicates the position of the treatment head, can be arranged so that two separate contacts are made at any two chosen points on a 360° arc. These contacts may be used to reverse the rotation of the treatment head or to turn the shutter on or off. A swich can be provided which controls only the rotation movement, and this will be sufficient for most purposes but it is obvious that such a switching arrangement could equally as easily be provided for the oscillation movement.

In view of the adaptability of the present equipment to automatic control the possibility is envisaged of obtaining a dosage pattern which automatically conforms with the shape of the treatment area. A three dimensional model of a tumour could be constructed from diagnostic information and a pointer tracing over the surface of the model could be used to supply signals which would control the movement of the source of radiation.

It will be apparent that with an apparatus in accordance with the preferred embodiment a variety of treatments can be carried out with a minimum delay in setting up, including the following,

(1) 360° rotation about a patient positioned as in Figure 1 followed by tilting of the axis of the beam with respect to O and successive cycles of 360° rotation and oscillatory movement.

(2) A treatment as in (1) in which the patient is inclined at a horizontal angle to centre line O.

(3) Coincident 360° rotation and oscillation, with the oscillation movement being reversed when its limits are reached. Thus the beam traces out a sine wave drawn on the surface of a segment of a sphere.

(4) 360° rotation with any of above variations, but with the shutter open during any pre-set portion of the rotation cycle. This is accomplished by connecting the shutter operating circuit into the circular cam and swich arrangement described in (*d*) above. Thus if a portion of the body of the patient which lies between the tumour and the radioactive source is to be protected from radiation the shutter can be closed while the source is in alignment with the tumour and the portion to be protected. In this way the amount of radiation reaching delicate organs and bone can be reduced.

(5) Rotation over any segment of a circle, the rotational movement being reversed when the limits of the segment are reached. This is accomplished by connecting the rotation motor control circuit into the circular cam and switch arrangement described in (*d*) above. This gives an alternative in obtaining an effect similar to (4).

(6) Fixed beam treatment in which the angle of head rotation and oscillation are pre-set only, the treatment is carried out with the head stationary in a conventional manner.

It will be appreciated from the foregoing that an apparatus in accordance with this invention offers substantial advantages, both with respect to results achieved and convenience of operation in comparison with equipment previously developed for similar purposes.

We claim:

1. In an apparatus for radiation therapy, a source of radiation, means for rotating said source in a vertical circle about a horizontal axis, means for directing a beam of radiation from said source at a point on said horizontal axis and means for moving said source in a direction perpendicular to the plane of said vertical circle, said beam being directed at said point at each position of the source.

2. In an apparatus for radiation therapy, a source of radiation, means for rotating said source in a vertical circle about a horizontal axis, means for directing a beam of radiation from said source at a point on said horizontal axis, and means for moving said source through an arc centred at said point and extending in a direction perpendicular to the plane of said vertical circle, said beam being directed at said point at each position of the source.

3. In an apparatus for radiation therapy, a source of radiation, an arm supporting said source at one end thereof, means for rotating said arm and source about a horizontal axis passing through the other end of said arm, means for directing a beam of radiation from said source at a point on said horizontal axis, means for swinging said arm in an arcuate path centred at said point and being perpendicular to the direction of rotation of said arm, the source of radiation being oriented to direct the beam at said point at each position of the source.

4. In an apparatus for radiation therapy, a pair of arms connected at one end and spaced at their other ends to form a U, a source of radiation at the end of one of said arms and a shield at the end of the other of said arms, means for rotating said arms about a horizontal axis, means for directing a beam of radiation from said source at a point on said horizontal axis, said beam being directed towards said shield, means for swinging said arms in an arcuate path centred at said point and being perpendicular to the direction of rotation of said arm, whereby the source of radiation is movable in a variety of paths with the beam directed at said point and the shield is simultaneously moved to a position in alignment with said source and said point.

5. In an apparatus for radiation therapy, a pair of arms connected at one end and spaced at their other ends to form a U, a source of radiation at the end of one of said arms and a shield at the end of the other of said arms,

a block supporting the connected ends of said arms, means for rotating said block about a horizontal axis, means for directing a beam of radiation from said source at a point on said horizontal axis, said beam being directed towards said shield, means for moving said arms relative to said block in an arcuate path centred at said point and being perpendicular to the direction of rotation of said arm to oscillate the source of radiation with the beam directed at said point and simultaneously to oscillate said shield to a position in alignment with said source and said point.

6. In an apparatus for radiation therapy, a pair of arms connected at one end and spaced at their other ends to form a U, a source of radiation at the end of said arms and a shield at the end of the other of said arms, a block supporting the connected ends of said arms, a horizontal main shaft supporting said block, means for rotating said main shaft about its horizontal axis, means for directing a beam of radiation from said source at a point on said horizontal axis, said beam being directed towards

said shield, an arcuate guide rail mounted on said arms and being centred at said point, means for guiding relative movement between the block and the arms in the path defined by said arcuate guide rail, said movement acting to move the source of radiation in a direction perpendicular to the direction of its rotational movement with the beam directed at said point and simultaneously to move said shield to a position in alignment with said source and said point, a subsidiary shaft coaxial with said main shaft and adapted to cause relative movement between the block and said arms and reversible means for driving said subsidiary shaft.

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