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AUTOMATIC ISODOSE RECORDER

by

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In modern radiotherapeutic planning a detailed and accurate knowledge of the radiation field to be used is very important. In practice a determination of sets of isodose curves in one or several planes will give the necessary basic information and for such purposes automatic isodose plotters are invaluable. Such devices have been described by KEMP (1946), HINE, BERMAN, and ELKIND (1950), MAUCHEL and JOHNS (1954), SIMONS (1956). KEMP compared the step by step integrated dosage rates of two ionization chambers, the exploring chamber moving in a cartesian system. HINE et coll. (1950) described a device with a scintillation crystal by means of which the 'isocount' curves around a γ-emitting source, rotating on a turntable, could be recorded. The plotters described by MAUCHEL and JOHNS and by SIMONS compared two dosage rates from ion chambers. The former authors placed the moving chamber in a vertical polar system and the latter author used a vertical cartesian system.

The plotter developed by the present writers compares the dosage rates from two organic scintillators, the exploring scintillator moving in a horizontal polar system. The machine has now been successfully operated over a period of five years (LIDÉN 1957). Investigations of the isodose curves of roentgen

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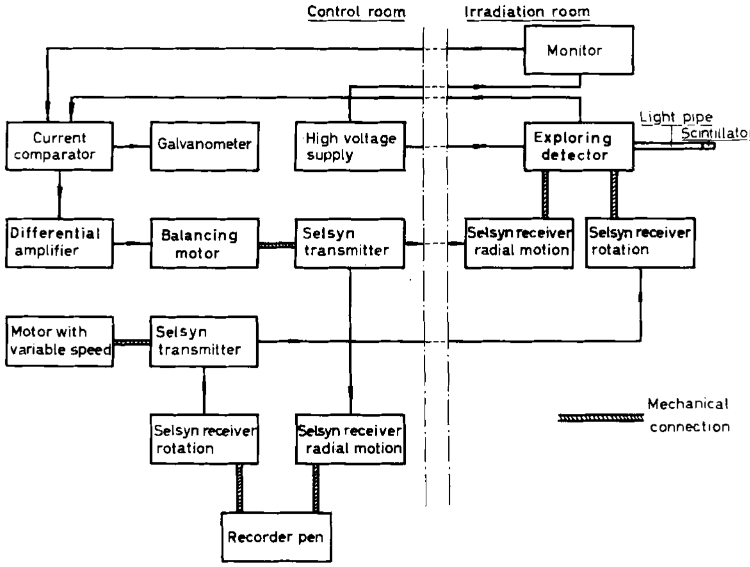


Fig. 1. Block diagram of the isodose recorder.

and cobalt beams, as well as of radium and tantalum applicators, have been performed.

Design of the isodose recorder. As an exploring detector the present isodose recorder utilizes a scintillator which is restricted to move in a system of polar coordinates. The principle of operation is shown in Fig. 1. Photographs of the actual apparatus are reproduced in Fig. 2. The isodose recorder consists of two separate horizontal arms which are given a synchronous rotational motion around a vertical axis by means of a reversible motor and a Selsyn system. These arms are supplied with radially movable carriages, both of which are connected to the balancing motor through a Selsyn system. One of these carriages carries the exploring dose detector and the other one a pen which continuously reproduces the motion of the exploring detector on a sheet of paper. The mechanical mounting of the arms, made of stainless steel tubes, and the location of the carriages for detector and pen, are displayed in Fig. 2. The origin of each polar-coordinate system is adjustable. The reason for this will be explained later. The carriages can be moved about 50 cm in the radial direction by means of a steel wire and gear arrangement.

Light from the irradiated scintillator is transmitted through a light pipe to a RCA 1P 21 photomultiplier. The anode current from this photomultiplier is compared in a comparator circuit with the current from another photomultiplier receiving the light from a scintillator which is also irradiated by the source under investigation. This monitor is mounted in a fixed position, care

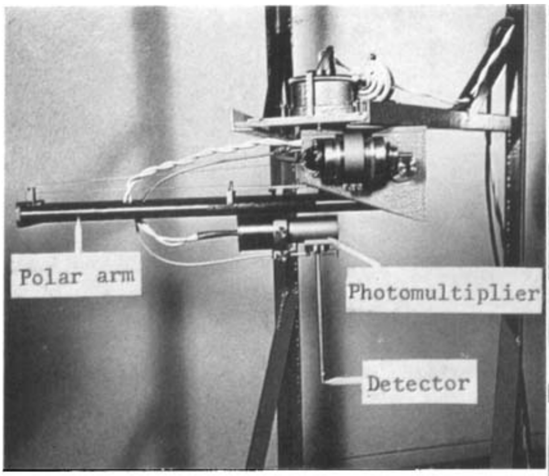


Fig. 2. The exploring detector system (abɔve) and the recording system (to the right).

being taken to ensure that the exploring detector never interferes with the radiation impinging on the monitor. The variations in output from certain radiation sources necessitates the use of a monitor instead of a constant current source. The monitor detector follows the variations in output and so does the exploring detector current. Therefore small variations in output will not influence the curve being recorded.

When the rotational motion tends to carry the exploring detector along a path which is not an isodose curve, the balance in the comparator circuit is disturbed, an error signal is given to a differential amplifier, and the balancing motor controlling the radial motion drives the exploring detector back to the isodose curve. Thus the balance is restored and the exploring detector is forced to stay on the predetermined isodose curve. This curve is recorded on a sheet of paper by the pen on the other carriage. By using sufficiently long cables the exploring detector system can be mounted in the irradiation room and the recording and driving components in a shielded room.

The current comparator circuit is shown in Fig. 3. The galvanometer with an internal resistance of 5 kΩ can be used to measure the current in each of the two branches. It has a sensitivity of $5 \cdot 10^{-10}$ A per division. The dark current through the resistors $R_2 + R_3$ is balanced out by applying a certain voltage from battery B.

The circuit is in equilibrium when the position of the exploring detector

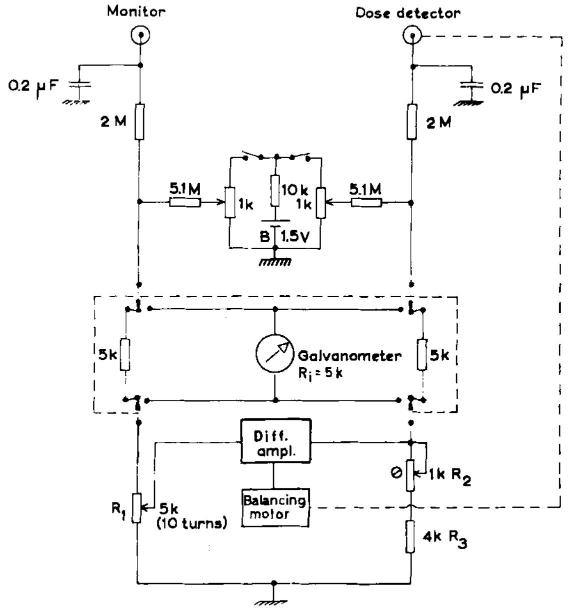


Fig. 3. Current comparator circuit.

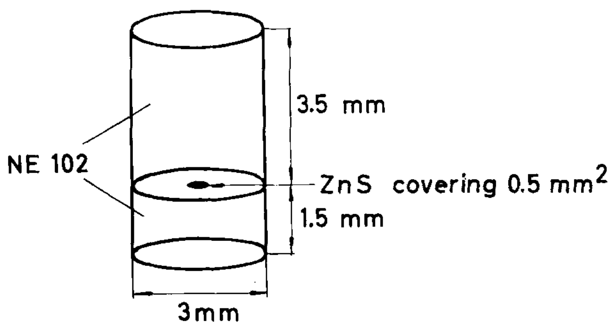


Fig. 4. Compound scintillator.

in the radiation field is such that the currents through the resistors R_1 and $R_2 + R_3$ keep the two inputs of the differential amplifier at the same voltage.

The exploring detector should be able to measure small doses in roentgen units and should be small in size in order to permit a detailed study of the radiation field close to the source. The detector should moreover be made of a material having a density and atomic number close to that of tissue or water in order not to disturb the radiation field under investigation. In order to ensure a satisfactory operation of the differential amplifier it is important that the detector currents be sufficiently strong.

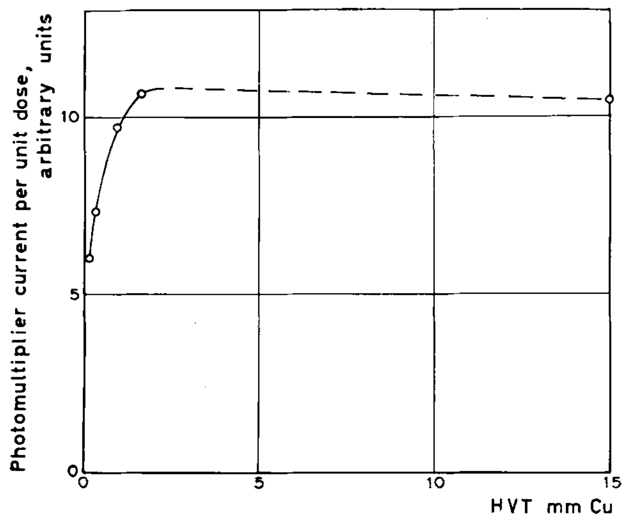


Fig. 5. The dependence of the dose response on radiation quality for an anthracene crystal (diam. 3 mm, length 3 mm).

The light from the scintillator can most efficiently be transmitted to the photomultiplier by means of a light guide of quartz or lucite. However, in this case a disturbing background may arise from Cerenkov light generated by Compton electrons in the light guide. This has also been pointed out by Belcher (1953), Shalek and Cole (1958). In an early design, two identical light guides and photomultipliers were mounted side by side but only one was supplied with a scintillator. The difference between the currents from the two photomultipliers then represented the light from the scintillator itself. However, this arrangement requires that the photomultipliers be exactly adjusted to give the same sensitivity and that the light-guiding rods be equal in performance. It was found that internally polished dural tubes are quite efficient light pipes and such tubes were then used.

A cylindric scintillator with a diameter of a few millimeters mounted at the end of a light pipe, 20 to 50 cm in length, in conjunction with a photomultiplier having a high sensitivity and low dark current, fulfills all of the above requirements.

Measurement in r-units implies that the scintillator should always emit the same amount of light at a certain dose rate, irrespective of the spectral composition of the radiation. Therefore a review of the roentgen ray and γ-ray spectra of interest should be made. In the case of a Co^{60} source the radiation close to the source consists of primary γ-rays, 1.17 and 1.33 MeV. With increasing depth in water the relative amount of degraded radiation increases. For roentgen ray spectra from roentgen generators the situation is similar but here the degraded photons dominate at much smaller depths.

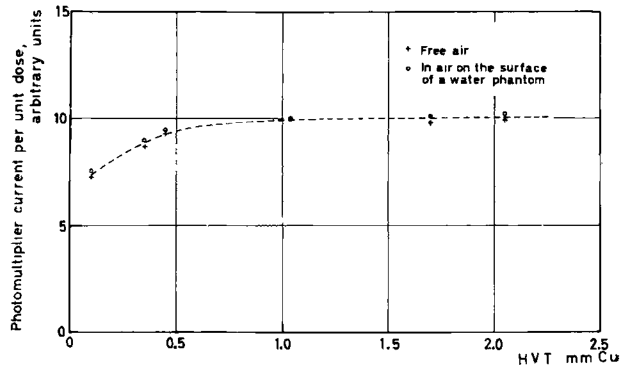


Fig. 6. The dependence of the dose response on radiation quality for the compound scintillator of fig. 4.

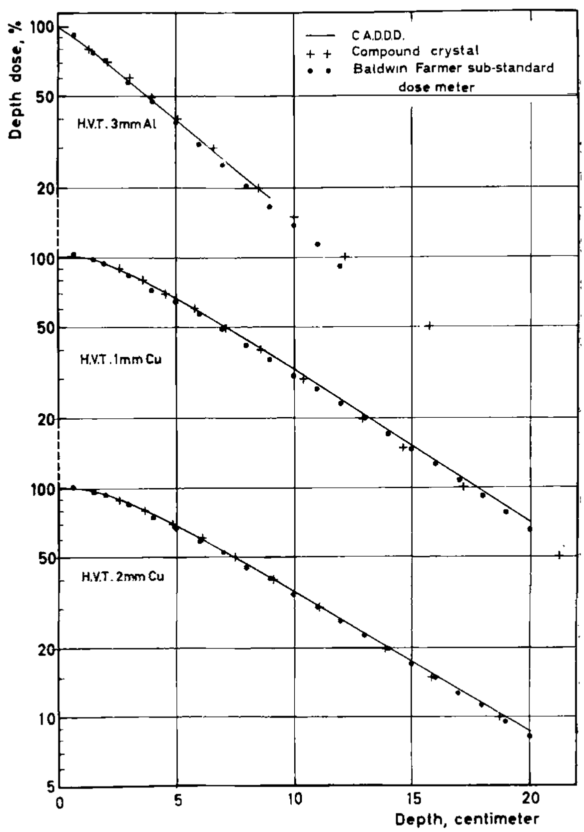


Fig. 7. Comparison between measured depth-dose data (+ and ·) and values obtained from Central Axis Depth Dose Data (1953) (solid line).

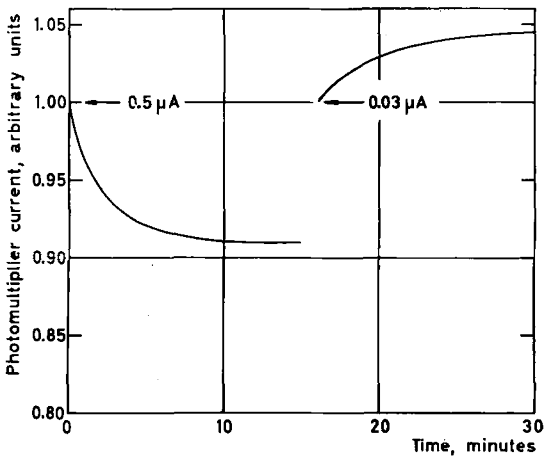


Fig. 8. Photomultiplier fatigue effect. At zero time the detector is placed in a radiation field giving rise to a photomultiplier current of 0.50 μA. The detector is irradiated with constant intensity for 15 min and then moved to a point where the radiation field gives rise to a photomultiplier current of 0.030 μA.

For Co^{60}, anthracene crystals can be used. For radiation of lower energy special compound crystals are needed (RAMM 1956). Combinations of a plastic scintillator and $CaWO_3$, NaI or ZnS have been investigated. The best results have been obtained with a scintillator, 3 mm in diameter, consisting of two pieces of solid Ne 102 plastic scintillator (Nuclear Enterprises Ltd, Edinburgh) sandwiching a very small amount of ZnS-powder (Fig. 4), which were heated up in an oven and pressed together. The light output from this scintillator was 67 % of that obtained from an anthracene crystal 3 × 3 mm at a roentgen radiation quality of 2 mm Cu HVT. The different scintillators were tested in two ways. The first method involved a comparison with a simultaneously irradiated standard ion chamber, both in air and on the surface of a water phantom, with roentgen rays of different qualities and with a radium source (Figs 5 and 6). The relative depth dose in a water phantom for a series of primary radiations was also compared with depth doses measured by means of a Baldwin-Farmer substandard roentgen ray dosemeter and with data from depth dose tables (Fig. 7). The first method shows that the compound scintillator is superior to the anthracene scintillator at low energies. From the second test (Fig. 7) it is obvious that this scintillator can be used down to fairly great depths even with primary roentgen rays of low energy.

The photomultiplier gives rise to the following difficulties.

1. In many cases the direct radiation from the source that strikes the photocathode and the dynodes results in a current which is not small compared to

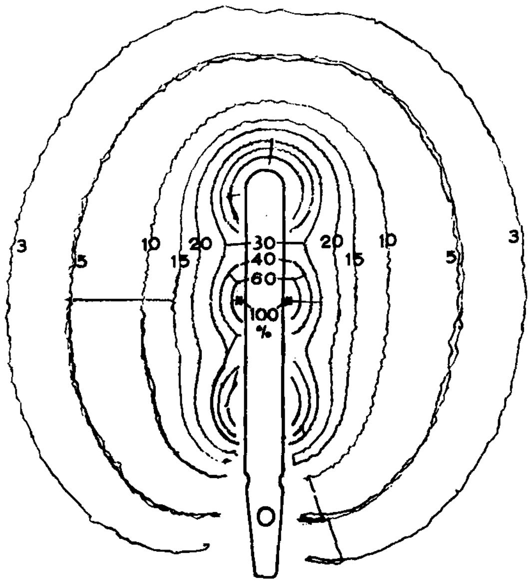


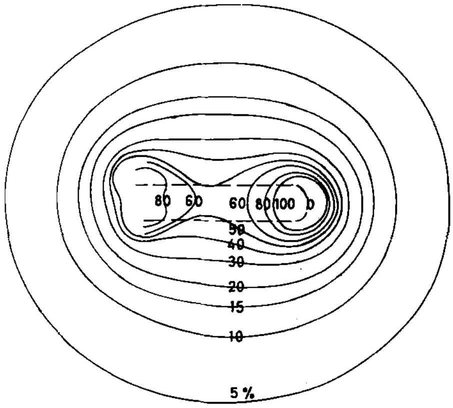
Fig. 9. The system of isodose curves around a 150 mC radium applicator in a water phantom. The 100 % point is located 1 mm from the surface of the applicator. Anthracene crystals of 1.5 and 3.5 mm diameter were used. The 5 % curve is recorded with both crystals.

the current caused by the light from the scintillator. Because the detector has to be easily movable to give a fast response to a small change in dose rate it is often difficult to shield the photomultiplier sufficiently with lead. Therefore the light pipe is made as long as is convenient and a remotely controlled shutter is placed in the light pipe close to the photomultiplier so that the current from the direct irradiation of the photomultiplier can be measured at any time and compensated for electrically in the same way as for the dark current.

2. To make it possible to measure low-intensity radiation with small crystals and long light pipes the dark current from the photomultiplier has to be extremely low and constant. Selected 1P 21 tubes have been used but at high relative air humidity the dark current has often been excessive. A cut in the tube socket to increase the distance along the surface of the insulating material between the anode and the cathode was found to be helpful. But nevertheless it is necessary to compensate for the dark current.

3. The third difficulty is due to the fatigue effect of the photomultiplier, as demonstrated by Fig. 8. It can be seen that the current approaches its steady value asymptotically. It is therefore in most cases sufficient to wait two or three minutes after placing the detector in the appropriate radiation intensity before running through an isodose curve.

Operation. The recording of an isodose diagram is performed in the following way. The exploring detector is placed at a point to which a certain percentage dose is ascribed from earlier measurement or by definition, for example 100 % at the surface of a phantom. A high voltage is used, giving a current of about



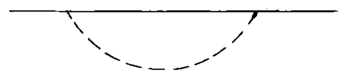


Fig. 10. Isodose curves around a tantalum wire shaped as a bent hair pin. The tantalum wire is shown as a line of dashes. The dots and dash line in the right hand part of the figure is the plane of observation. The 100 % curve corresponds to 3.1 r/hr per mC.

$2 \cdot 10^{-7}$ A from the exploring detector. For this current the fatigue effect is low, and when recording at lower dose rates a change in the abovementioned current of about one per cent will give rise to a signal that is strong enough to operate the differential amplifier, thus affecting the balancing motor. The dark current from the two photomultipliers is then measured with the radiation source removed and compensated for by means of the battery (see Fig. 3). The battery is also used to eliminate the background current from the exploring detector, caused by the source, as measured with the shutter closed in the light pipe. With the potentiometer R_1 adjusted to read the abovementioned dose rate the monitor detector is moved or its high-voltage is changed until the comparator is balanced, i.e. until there is no output from the differential amplifier. These operations are performed before the motors are connected to the transmitters of the Selsyn system. After connecting the motors the exploring detector proceeds along the desired isodose curve. R_1 is then adjusted to a new value. The detector is left on the new isodose curve 2 to 3 minutes with the motors disconnected to allow for the fatigue effect in the photomultiplier. If necessary, the comparator is then rebalanced and a new isodose curve is recorded.

It is often convenient to use two or more scintillators of different sizes when recording a set of isodose curves. Close to the radiation source, where the dose rate is high, the best possible geometric resolution is desired, and thus a small crystal should be used. Far away from the source the isodose curves are usually well separated from one another and the accuracy can then be improved by increasing the signal through the use of a larger scintillator. It may also be necessary to increase the high voltage when recording at low dose rates in order to get a sufficiently large signal. As mentioned above it is the radial motion of the detector system that is influenced by the dose rate in such a way that the detector stays on an isodose curve when the rotational motion proceeds at constant speed. It is then convenient to locate the center of rotation in such a position that the dose rate decreases with increasing distance from this center for all points of the isodose curve to be recorded. Otherwise the polarity of the signal to the differential amplifier has to be reversed at certain points on the isodose curve. In certain cases it may be necessary to record a system of isodose curves in two or more separate runs, moving the detector coordinate system to a new position in between consecutive runs (cf Fig. 10). It is for this reason that the two coordinate systems are made adjustable (Fig. 2).

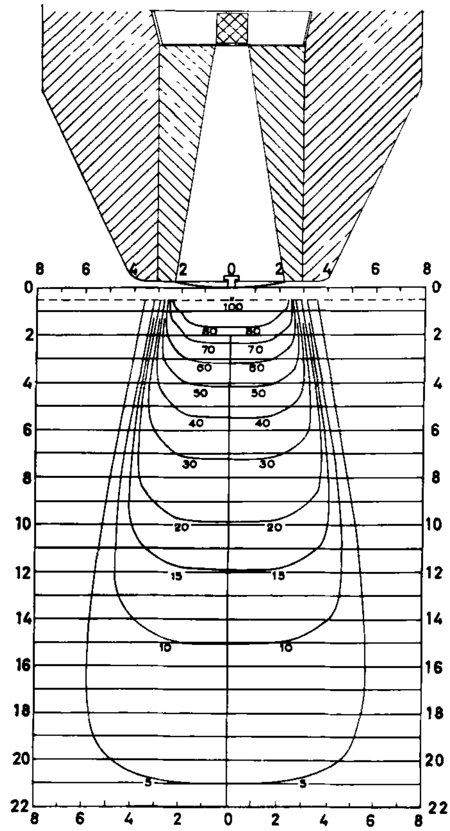


Fig. 11. The system of isodose curves for a 20 curie Co^{60} unit in a water phantom; FSD: 10 cm, field size: 4.5 cm by 3.0 cm. The central axis is in the plane of the diagram; the 4.5 cm side of the field is parallel to this plane. The 100 % point is located at a point 0.5 cm below the surface of the phantom. Anthracene crystals having diameters of 3.5 and 5.5 mm were used.

Discussion

The performance and accuracy of the isodose recorder can best be illustrated by discussing the systems of isodose curves obtained with some specific radiation sources. Fig. 9 shows a clean copy of the system of isodose curves obtained with a 150 mC Ra-applicator in a water phantom. The 100 % point was registered with a scintillator 1.5 mm in diameter in a 2 mm diameter container. Thus, this point is located only 1 mm from the surface of the applicator. The 5 % curve was recorded twice using two different scintillators, the one just mentioned and a larger one with a diameter of 3.5 mm. All curves corresponding to a dose rate higher than 5 % were run with the small detector and the 3 % curve with the large one.

Bladder tumours are sometimes treated with the radiation from implanted radioactive tantalum wires, Ta^{182}. A wire in the form of a somewhat bent hair pin is implanted in the wall of the bladder by means of a special instrument. The dose delivered in this treatment was earlier determined only by theoretical calculation. The accuracy of treatment planning has been considerably

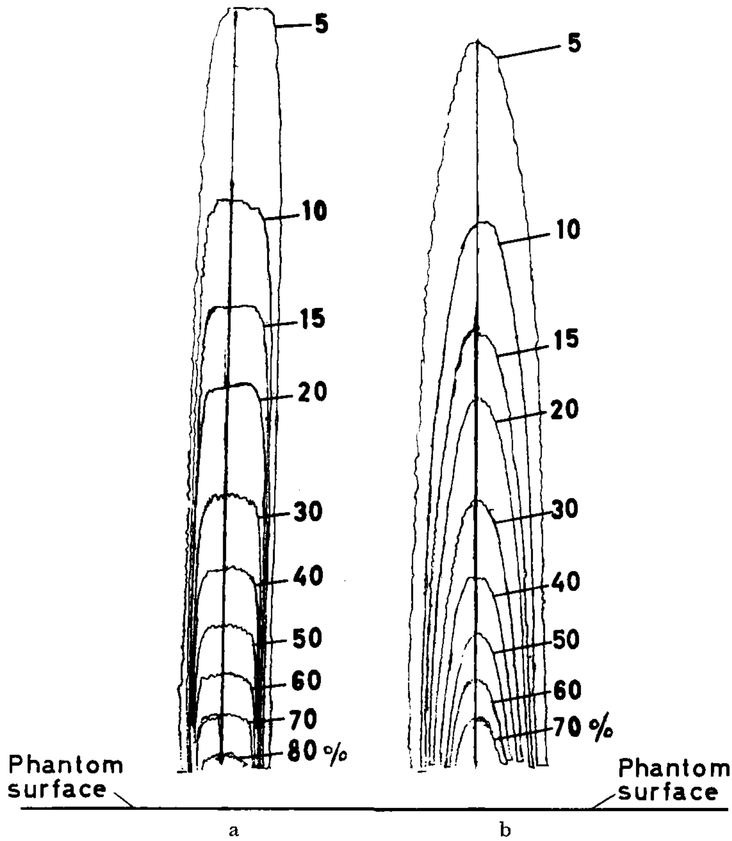


Fig. 12. Isodose curves with narrow beams of roentgen rays with 40 cm FSD and 1 mm Cu HVT with a 1 cm² diaphragm on the surface of the phantom (a) and with the diaphragm located 27 cm from the focus (b), giving a geometric field of 1 cm² on the phantom surface. The position of the 70 % point on the central axis was determined from zero-field data tabulated in Central Axis Depth Dose Data (1953). A compound scintillator was used (dimensions: diam. 3 mm, length 4 mm).

improved by using recorded systems of isodose curves in different planes around both straight and bent tantalum needles in a water phantom (Fig. 10). Absolute determination of the dose rate has been made by means of micro-ionization chambers (SIEVERT 1934, SKÖLDBORN 1959) calibrated with a standard radium source. The 20 curie Co^{60} unit in Lund, which was used for treatment at a FSD up to 10 cm, was equipped with collimators for rectangular fields. The radiation field obtained with these collimators was studied with the isodose recorder. Systems of isodose curves were recorded in different planes. As an example of the results of these measurements the isodose curves in a plane through the axis of the collimator and parallel to the longest side of the rectangular field is shown in Fig. 11. The 100 % point was located at a depth of 0.5 cm below the surface of the phantom.

The last example is chosen in order to illustrate the effect on the dose distribution of the position of the diaphragm when using a narrow beam from a roentgen tube having a 1.2 cm focus (Fig. 12).

Finally, it should be mentioned that for all the cases now discussed dose-rate (e.g. r/hr or r/min) can be ascribed to the isodose curves registered. This may be done either by absolute calibration of the detector or by determining the dose rate by means of an ionization chamber at one point on an arbitrarily chosen isodose curve.

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SUMMARY

The design and operation of an automatic isodose recorder is described. The recorder compares the electric currents produced by the simultaneously irradiated monitor and exploring probe, the latter being restricted to move in a system of polar coordinates. The probe consists of a small exchangeable organic or compound scintillator, 1 to 6 mm in diameter, connected to a RCA 1P 21 photomultiplier through a light transmitting tube. Systems of recorded isodose curves for radium and Ta-182 applicators and for roentgen and Co^{60} beams are shown, indicating good reliability and flexibility of the equipment.

ZUSAMMENFASSUNG

Die Konstruktionen und die Funktion eines automatischen Isodosenschreibers werden beschrieben. Der Schreiber vergleicht die elektrischen Ströme, die in einem stationären Monitor und in einem beweglichen Detektor produziert werden; die Bewegung des letzteren geschieht in einem polaren Kordinatensystem. Der bewegliche Detektor besteht aus einem kleinen auswechselbaren, organischen oder kombinierten Szintillator, 1 bis 6 mm in Diameter, der durch einen Lichtleiter an einen RCA 1P21 Sekundärelektronenvervielfacher angeschlossen ist. Die jenige Systeme von Isodosenkurven, die für Radium- und Ta-182-Applikatoren und für Röntgen- und Co^{60}-Strahlung registriert sind, zeigen, dass die Apparatur zuverlässig und vielfach verwendbar ist.

RÉSUMÉ

Les auteurs décrivent la construction et le fonctionnement d'un inscripteur automatique de courbes isodoses. L'inscripteur compare les courants électriques produits par le monitor et une sonde exploratrice irradiés simultanément, la sonde étant astreinte à se déplacer dans un système de coordonnées polaires. La sonde est faite d'un petit scintillateur organique ou composé interchangeable, d'un à six millimètres de diamètre, relié à un photomultiplicateur RCA 1P 21 par un tube transmetteur de lumière. Les auteurs présentent des systèmes de courbes isodoses enregistrées avec cet appareil pour des applicateurs de radium et de Ta-182 et pour des rayonnements roentgen et du Co^{60}; ces courbes montrent la fidélité et la maniabilité de cet appareil.

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