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PATENT SPECIFICATION

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(54) IMPROVEMENTS IN OR RELATING TO RADIOLOGY

(71) We, E.M.I. LIMITED, a British company of Blyth Road, Hayes, Middlesex, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to radiology, and it relates especially to radiological apparatus of the kind in which penetrating radiation, such as X- or γ -radiation, is directed through a body along a plurality of paths disposed in a plane. The radiation emergent from the body is detected and used to determine the absorption suffered by the radiation on traversing each path, and the number of paths is arranged to be sufficient to permit the evaluation of the absorption (or transmission) coefficients of the elements of a two dimensional array of elements of the body, notionally delineated in said plane.

Typically, though not necessarily, the irradiation of the body is carried out in such a way that a source of a beam of the radiation and detector means are laterally traversed relative to the body, in said plane, so as to direct the radiation through the body along a set of said paths, and the source and detector means are then rotated through a small angle relative to the body about an axis perpendicular to the said plane so that a further lateral traverse can be executed to direct the radiation through the body along a further set of paths. The procedure of alternate rotational steps and lateral traverses is continued until the source and detector means have been rotated through a total angle at least approaching 180°.

The detector means conveniently comprises at least one combination of a scintillator device and a photomultiplier tube arranged to receive the light which is emitted by the scintillator device in response to the impingement of said radiation thereupon. Such photomultiplier tubes as are presently known exhibit a well defined characteristic curve relating the

input light intensity to the output electrical signal. Said characteristic includes a substantially linear portion over a range of input light intensities but becomes non-linear for intensities above and below this range.

The evaluation of said coefficients is carried out by processing the output signals derived from said at least one photomultiplier, for example in the manner described in our British Patent Specification No. 1,283,915 or in the manner described in our British Patent Specification No. 1,471,531, and in order that the processing may be rendered as simple as possible whilst permitting the evaluation to be effected with a high degree of accuracy, it is desirable that the said at least one photomultiplier be constrained to operate within the linear region of its characteristic.

The aforementioned processing is carried out by means of a digital computer and this computer is supplied with all the output signals derived from said at least one photomultiplier.

In accordance with this invention, there is provided radiological apparatus for producing a representation of the variation of absorption (or transmission) of penetrating radiation, such as x- or γ -radiation, with position over a cross-sectional slice of a patient's body, the apparatus including a source of the radiation, arranged to project the radiation through the patient's body across said slice, scanning means for moving the source relative to the patient's body to project the radiation across said slice from different locations relative thereto, detector means for detecting radiation emergent from the body along each of many substantially linear beam paths across said slice, some of said paths intersecting within said body as a result of the scanning movement, the detector means being such as to convert radiation detected thereby into electrical output signals in accordance with a characteristic curve; the apparatus also including processing means for operating

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on some at least of said output signals to produce said representation, wherein the detector means is constrained to operate within a predetermined range of said characteristic curve by the inclusion of means for monitoring the output signals and, in the event of said output signals indicating that said detector means is operating outside said range, for producing a control signal, means for utilising said control signal to adjust an operating condition of said detector means in a sense tending to restore it to operation within said range and means, responsive to said control signal and connected to said processing means, to permit adjustments of the operation of said detector means to be allowed for in the production of said representation.

In order that the invention may be clearly understood and readily carried into effect, one embodiment thereof will now be described, by way of example only, with reference to the accompanying drawing, of which:—

Figure 1 shows, in simplified and block diagrammatic form, part of an apparatus in accordance with one example of the invention.

Figure 2 shows, in more detail and in end elevation, apparatus which incorporates another example of the invention, and

Figure 3 shows, in block diagrammatic form, a circuit arrangement for use with the apparatus of Figure 2.

Referring now to Figure 1, penetrating radiation from a source (not shown) emerges from a body (not shown) and impinges upon a scintillator crystal 1 of known kind. The light emitted by the crystal 1 falls upon a photomultiplier tube 2 which provides electrical output signals along a line 3 to a processing unit 4 which may comprise a digital computer.

In this example of the invention, a single scintillator/photomultiplier combination is used as a detector, and the source and the detector are scanned relative to the body in a combination of lateral traverses and rotational steps as described hereinbefore. During each lateral traverse, the tube 2 provides, successively, output signals indicative of the absorption suffered by said radiation on traversing a plurality of closely adjacent, parallel paths through the body.

The processing unit 4, which receives these output signals, is also arranged to provide control signals on a line 5 if the output signal relating to any one or more of the paths irradiated during a linear traverse is indicative of a light intensity outside the aforementioned linear range of the photomultiplier characteristic being incident upon the tube 2.

The control signals on line 5 are applied

to the photomultiplier tube 2 prior to the next linear traverse in such a way as to control its gain, for example by varying the operation of H.T. voltage applied thereto or, as shown schematically in Figure 1, by application to any suitable control electrode of the tube. In either event, the gain of the photomultiplier is changed by an extent dependent upon the amount by which said light intensity falls outside said range, thus tending to ensure that the tube 2 operates on the linear part of its characteristic for the next linear traverse. Of course, instead of utilising the control signals to control the gain of the tube over the whole of the next linear traverse, the control could be applied solely to paths adjacent the path or paths which gave rise to the output signals responsible for the generation of said control signals.

It will be appreciated that since the gain control is effected under the control of the processing unit 4, the unit is capable of allowing for the changes of gain when the computation is carried out.

Although the invention has been described in relation to an example in which only a single crystal/photomultiplier combination is used, it will be evident to those skilled in the art that the invention is also applicable to apparatus including multiple combinations of scintillators and photomultipliers and such an arrangement will now be described with reference to Figures 2 and 3.

When multiple scintillator/photomultiplier combinations are used, the processing unit can be arranged to produce a common control signal which is applied to all said combinations or an individual control signal for each combination, but in the example now to be described the former technique is used because of its greater practical simplicity.

Referring now to Figure 2, a body 6 to be examined is disposed supine in the apparatus with the plane of interest arranged to coincide with the plane of the investigating radiation. The body is surrounded, in that plane, by a two-part collar 7, and trapped between the inside of the collar and the body 6 is an elongated bag 8 containing water or some other material which absorbs radiation to an extent similar to the tissue of body 6. The body, together with the bag 8 and the collar 7, remains stationary during the investigation, the body 6 being supported on a two-part bed, one part of which is indicated at 9. The other part of the bed cannot be seen in Figure 2 because it extends outwardly from the plane of the drawing and has been omitted for clarity. The lower part of the collar 7 is rigidly secured to a stationary part of the

apparatus, and the upper part thereof is clipped to the lower part once the body is correctly positioned for the examination.

5 The body is located in a circular aperture 10 in a turntable 11 which supports the components now to be described and enables them to orbit around the body, about an axis which extends perpendicularly to the plane of the drawing and passes through the centre of the
10 aforementioned aperture. The turntable 11 carries an X-ray source 12 and an associated detector assembly 13, which are disposed on opposite sides of the aperture 10, and the components 12 and 13 are
15 enabled to scan transversely relative to the body 6 by virtue of an electrical motor 14 which drives an endless toothed belt 15, to which the X-ray source 12 is mounted. Detector assembly 13 is linked to the
20 source 12 by means of a light-weight but rigid yoke 16 so that the detector assembly moves with the source. The belt 15 passes over an idler pulley 17 and also carries a
25 counter-balance weight 18 which is arranged to travel in the opposite direction to the source and detector assembly, for the purpose of compensating out of balance
30 forces due to the motion of the source and detector assembly. The source 12 and the weight 18 travel on respective linear bearings, which include rods 19 and 20 respectively, so that the belt 15 does not
35 bear the weight of these massive members. Detector assembly 13, on the other hand, runs on a bearing which comprises a plate member 21 secured to the turntable 11; the assembly 13 being provided with suitable
40 roller members (not shown) to run on the flat surface of the member 21, thus being arranged to limit movement of the assembly 13 in a direction longitudinally of the body 6.

45 Member 21 is also formed with a graticule 22 comprising a translucent region bearing opaque markings, as shown at 23, throughout its length. The detector assembly 13 carries with it as it moves a photocell detector unit 24 which is
50 arranged to respond to the graticule 22 to provide electrical timing pulses, for use in controlling the operation of the processing, as will be more fully described hereinafter.

55 The source 12 is arranged to produce a planar, fan-shaped beam 25 of X-radiation which is split into a plurality of finger-like beams of small cross-section by a bank of collimators 26 which forms part of the detector assembly 13. In this example, the
60 collimators 26 are arranged to split the beam 25 into thirty finger-like beams, and correspondingly the detector assembly includes thirty detectors. Each detector, in this example, comprises the combination of
65 a scintillator crystal and a photomultiplier

tube, these components being indicated by the general reference 27 in Figure 2, but being shown as separate entities 27a and 27b respectively in Figure 3. The angle of the beam 25 is, in a practical example, ten
70 degrees although it is shown somewhat exaggerated in Figure 2.

On either side of the aperture 10 there is provided a compensating member 28, 29 formed, for example, of aluminium. These
75 members are disposed, one between the source and the body and the other between the body and the detector assembly, so as to rotate with the turntable 11, but they do not reciprocate with the yoke 16 and its
80 attachments. They are provided to tend to equalise the absorption suffered by radiation from the source 10 as it traverses different paths through the body, thus
85 limiting the dynamic range of radiation levels impinging on the crystals 27a and thereby the dynamic range of light levels to be handled by the photomultipliers 27b. The members 28 and 29 also include
90 peripheral portions such as 30 and 31; the portions 30 being arranged to simulate a region of reference intensity—for example a path of known length through water. The portions 31 on the other hand are caused to
95 be highly absorbent to the radiation so as to provide a zero or 'black level' reference signal and can, for example, carry a portion of lead or some other highly absorbent material. The output signals obtained when
100 the regions 30 and 31 are disposed between the source and the detector assembly are used to normalise the readings obtained when the body is irradiated.

Turntable member 10 is formed with gear teeth at 32 around its periphery and it is
105 driven, via a driving gear 33, by means of a motor 34, and the scanning operation comprises alternate linear traverses and rotational steps as follows. First the motor 14 is energised to sweep the source 12 and detector assembly 13 linearly across the
110 turntable 11, thus causing these components to execute a linear scan relative to the body 6. This single linear scan having been carried out, the motor 34 is then energised to cause the turntable 11, and thus all the components mounted
115 thereon, to rotate around the body through an angle corresponding to the angle of the fan beam 25—i.e. through 10° in this example. A second linear scan of the source and detector assembly is then achieved by causing motor 14 to drive belt 15 in the
120 opposite direction to that in which it was driven during the first traverse. The sequence of alternate linear traverses and rotational steps is carried on until the body 6 has been irradiated from the desired
125 number of different directions. In this connection it should be pointed out that the
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rotational steps are carried out during periods of reversal of the linear scanning motion. It can be advantageous for the rods 19 and 20 to carry, at their ends, resilient buffer members arranged to absorb the energy of impact of the source 12 or the weight 18 as the case may be and to use such absorbed energy to assist in the reversal of the linear motion. By this means, strains upon the belt 15 and the motor 14 can be reduced.

Turning now to Figure 3, there is shown, in block diagrammatic form, a circuit arrangement for handling the electrical signals provided by the photomultipliers 27b, under control of the timing pulses produced by unit 24, in accordance with the principles of this invention.

Each of the thirty photomultipliers 27b feeds a respective integrator circuit, the respective circuits being shown in a block 35, and the integration times of all the integrators are determined by timing pulses, derived from a timing control circuit 36 which receives the pulses provided by the aforementioned photocell unit 24. Each integrator in the block 35 feeds a respective analogue-to-digital converter, the converters being shown in a block 37, and thence a digital store 38.

A logic circuit 39 is connected to the store 38 and is arranged to receive therefrom all the signals derived during each linear scan executed by the source 12 and detector assembly 13 relative to the body 6. The logic circuit 39 is arranged to compare all of the signals relating to a linear scan so as to determine the highest and lowest amplitude signals in the whole series, and it is also arranged to note the reference readings obtained when the parts 30 of the members 28 and 29 are irradiated.

The readings selected by the logic circuit 39, for example by successive comparisons of the signals in pairs, thus indicate the highest and lowest signals provided by any detector during a linear scan, as well as a reference reading. These readings are correlated, in a correlation circuit 40, with stored values indicative of the maximum and minimum signals which it is permissible to derive from the photomultipliers whilst operating them at the aforementioned linear part of their characteristics. Such values are stored in the form of look-up tables, in known manner. If the result of the correlation is that the photomultipliers are, or are in danger of, being operated outside said linear region, the circuit 40 generates a control signal to rectify the situation prior to the next linear scan. This signal is applied via a line 41 and a circuit 42, which will be referred to hereinafter, to an H.T. generator 43 of commercially available kind, which supplies all the photomultiplier

tubes 27b with their operational H.T. voltage. The control signal on line 41 is arranged to cause the generator 43 to alter the H.T. applied to the photomultipliers in a sense tending to preset the gains of the photomultipliers for the next linear scan, ensuring as far as possible that all of the photomultipliers are operated on the linear range of their characteristics.

This can be done, for example, by means of the circuit 42, which contains relay operable switch contacts arranged to respond to the control signals from circuit 40 to switch appropriate resistances into or out of the circuits of the generator 43.

It is, of course, essential for the processing circuits, which will correlate the stored signals to evaluate the absorption of elements of the body, to compensate for changes of photomultiplier gain, and thus the line 41 is also coupled to a circuit 44 which senses the control signals from circuit 40 and relays information relating to the magnitude thereof to the store 38. These signals are stored in association with the digital signals applied to store 38 from the bank of converters 37 and are used during the subsequent processing of the stored signals to allow for the aforementioned change of gain. Store 38, together with circuits 39 and 40, constitutes part of a digital computer which is arranged to effect the processing in such a way that the absorption coefficients of a two-dimensional, notional matrix of elements defined in the plane of interest in the body 6, are calculated to a high degree of accuracy. The computer is connected to any suitable display means (not shown) to produce a representation of the calculated absorption values.

It will be evident that the store 38 is responsive to timing signals from the circuit 36 so that the respective digital signals can be identifiably stored in respective locations thereof, and so that any signals applied to store 38 by circuit 44 can be associated with the correct stored values. This is done in order that the stored values can be properly normalised, to allow for the effects of changing the gain of the photomultipliers, by adjusting their amplitude accordingly. For example if, during linear scan n the photomultiplier gains were set to a value x , whereas for linear scan $(n+1)$ the gains are set to a different value y , then it is necessary for the readings obtained during scan $(n+1)$ to be multiplied by a factor (x/y) to render the two sets of readings compatible.

In a preferred method of operating an apparatus in accordance with the embodiment just described, an initial traverse of the source 12 and detector

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assembly 13 relative to the body 6 is carried out, not for the purpose of obtaining output signals indicative of radiation absorption but for the purpose of setting the photomultiplier gains at an appropriate level for the commencement of the scanning sequence proper. For this initial traverse, the photomultiplier gains are set at a low level so that the minimum absorption likely to be encountered (corresponding to the highest amplitude of output signal) will not overload any of the photomultipliers. The circuits 39 and 40 are arranged to provide the appropriate control signal to increase the gains of the photomultipliers to a level at which all signals likely to be encountered on the next linear scan (the first scan as regards the provision of output signals indicative of absorption) will fall within the linear range of the photomultiplier characteristics.

Clearly the circuits 39 and 40 continue to monitor the signal levels stored in store 38 throughout the examination period, and provide control signals to the circuit 42, and thus control the level of the H.T. produced by generator 43, as appropriate. The computer is supplied with information concerning these control signals via circuit 44 and store 37 so as to enable the aforementioned normalisation to be carried out. It is preferable for the circuits 39 and 40 to be arranged so that control signals are only generated in response to variations in signal amplitude which exceed a predetermined threshold level, so that the H.T. generator is not continuously subjected to minor variations, but is only changed in response to variations which exceed said threshold level. Circuit 40 can be interconnected with circuit 42 by means of a plurality of cables, each of which can operate a respective relay contact in circuit 42. In this case the arrangement can be made such that as the correlation circuit 40 provides an output signal on one or more of the cables in dependence upon the H.T. required to set the gains of the photomultipliers at the appropriate level.

The kind of scanning described in the examples set out above is illustrative only. For example the source of radiation may be arranged to produce a sectoral-shaped distribution of radiation which is wide enough to embrace the body. In this case a plurality of scintillator/photomultiplier combinations are distributed across the width of the distribution and no linear traverse is necessary since the scanning can then be achieved by rotation only.

WHAT WE CLAIM IS:—

1. Radiological apparatus for producing a representation of the variation of absorption (or transmission) of penetrating

radiation, such as x- or γ -radiation, with position over a cross-sectional slice of a patient's body, the apparatus including a source of the radiation, arranged to project the radiation through the patient's body across said slice, scanning means for moving the source relative to the patient's body to project the radiation across said slice from different locations relative thereto, detector means for detecting radiation emergent from the body along each of many substantially linear beam paths across said slice, some of said paths intersecting within said body as a result of the scanning movement, the detector means being such as to convert radiation detected thereby into electrical output signals in accordance with a characteristic curve; the apparatus also including processing means for operating on some at least of said output signals to produce said representation, wherein the detector means is constrained to operate within a predetermined range of said characteristic curve by the inclusion of means for monitoring the output signals and, in the event of said output signals indicating that said detector means is operating outside said range, for producing a control signal, means for utilising said control signal to adjust an operating condition of said detector means in a sense tending to restore it to operation within said range and means, responsive to said control signal, and connected to said processing means, to permit adjustments of the operation of said detector means to be allowed for in the production of said representation.

2. Apparatus according to Claim 1 wherein said scanning means causes an initial scanning movement to be effected to provide output signals for the purpose of setting up said detector means so that, at the commencement of the scanning movement proper, the detector means operates within said range.

3. Apparatus according to either of Claims 1 or 2 wherein said detector means includes a scintillator crystal exposed to said radiation and a photomultiplier tube optically coupled to said crystal.

4. Apparatus according to Claim 3 wherein said control signal is applied to a gain control electrode of said photomultiplier tube.

5. Apparatus according to either of Claims 1 or 2 wherein said detector means includes a plurality of scintillator crystals exposed to said radiation and a respective photomultiplier tube optically coupled to each of said crystals.

6. Apparatus according to Claim 5 wherein said control signal is applied to a gain control electrode of one or more of said photomultiplier tubes.



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assembly 13 relative to the body 6 is carried out, not for the purpose of obtaining output signals indicative of radiation absorption but for the purpose of setting the photomultiplier gains at an appropriate level for the commencement of the scanning sequence proper. For this initial traverse, the photomultiplier gains are set at a low level so that the minimum absorption likely to be encountered (corresponding to the highest amplitude of output signal) will not overload any of the photomultipliers. The circuits 39 and 40 are arranged to provide the appropriate control signal to increase the gains of the photomultipliers to a level at which all signals likely to be encountered on the next linear scan (the first scan as regards the provision of output signals indicative of absorption) will fall within the linear range of the photomultiplier characteristics.

Clearly the circuits 39 and 40 continue to monitor the signal levels stored in store 38 throughout the examination period, and provide control signals to the circuit 42, and thus control the level of the H.T. produced by generator 43, as appropriate. The computer is supplied with information concerning these control signals via circuit 44 and store 37 so as to enable the aforementioned normalisation to be carried out. It is preferable for the circuits 39 and 40 to be arranged so that control signals are only generated in response to variations in signal amplitude which exceed a predetermined threshold level, so that the H.T. generator is not continuously subjected to minor variations, but is only changed in response to variations which exceed said threshold level. Circuit 40 can be interconnected with circuit 42 by means of a plurality of cables, each of which can operate a respective relay contact in circuit 42. In this case the arrangement can be made such that as the correlation circuit 40 provides an output signal on one or more of the cables in dependence upon the H.T. required to set the gains of the photomultipliers at the appropriate level.

The kind of scanning described in the examples set out above is illustrative only. For example the source of radiation may be arranged to produce a sectoral-shaped distribution of radiation which is wide enough to embrace the body. In this case a plurality of scintillator/photomultiplier combinations are distributed across the width of the distribution and no linear traverse is necessary since the scanning can then be achieved by rotation only.

WHAT WE CLAIM IS:—

1. Radiological apparatus for producing a representation of the variation of absorption (or transmission) of penetrating

radiation, such as x- or γ -radiation, with position over a cross-sectional slice of a patient's body, the apparatus including a source of the radiation, arranged to project the radiation through the patient's body across said slice, scanning means for moving the source relative to the patient's body to project the radiation across said slice from different locations relative thereto, detector means for detecting radiation emergent from the body along each of many substantially linear beam paths across said slice, some of said paths intersecting within said body as a result of the scanning movement, the detector means being such as to convert radiation detected thereby into electrical output signals in accordance with a characteristic curve; the apparatus also including processing means for operating on some at least of said output signals to produce said representation, wherein the detector means is constrained to operate within a predetermined range of said characteristic curve by the inclusion of means for monitoring the output signals and, in the event of said output signals indicating that said detector means is operating outside said range, for producing a control signal, means for utilising said control signal to adjust an operating condition of said detector means in a sense tending to restore it to operation within said range and means, responsive to said control signal, and connected to said processing means, to permit adjustments of the operation of said detector means to be allowed for in the production of said representation.

2. Apparatus according to Claim 1 wherein said scanning means causes an initial scanning movement to be effected to provide output signals for the purpose of setting up said detector means so that, at the commencement of the scanning movement proper, the detector means operates within said range.

3. Apparatus according to either of Claims 1 or 2 wherein said detector means includes a scintillator crystal exposed to said radiation and a photomultiplier tube optically coupled to said crystal.

4. Apparatus according to Claim 3 wherein said control signal is applied to a gain control electrode of said photomultiplier tube.

5. Apparatus according to either of Claims 1 or 2 wherein said detector means includes a plurality of scintillator crystals exposed to said radiation and a respective photomultiplier tube optically coupled to each of said crystals.

6. Apparatus according to Claim 5 wherein said control signal is applied to a gain control electrode of one or more of said photomultiplier tubes.

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- 7. Apparatus according to any of Claims 3 to 6 inclusive including H.T. generator means for supplying said photomultiplier tube or tubes with operational voltages, and means for utilising said control signal to control the gain of said photomultiplier tube or tubes by varying the operational voltages supplied thereto by said generator means.
- 8. Apparatus according to Claim 7 including switching means for responding to said control signal by switching selected impedances into a circuit forming part of said generator means.
- 9. Radiological apparatus substantially as herein described with reference to Figure 1 or Figures 2 and 3 of the accompanying drawing.
- 10. A method of operating a radiological apparatus comprising the steps of
 - (a) scanning a source of radiation relative to a body so as to irradiate said body along a plurality of co-planar paths, some of which intersect,
 - (b) detecting the amount of radiation emergent from said body along each of said paths and producing output signals indicative thereof,
 - (c) processing said output signals to evaluate the absorption coefficients of the elements of a two dimensional matrix of

- elements notionally defined in the irradiated plane of the body,
- (d) monitoring the amplitude of said output signals,
- (e) comparing said monitored signals with permitted maximum and minimum values for said signals,
- (f) providing a control signal in the event that said monitored signals depart from the range defined by said permitted values, said control signal being indicative of the extent of such departure,
- (g) utilising said control signal to modify the detecting whereby the amplitude of said output signals is modified in a sense tending to compensate for said departure, and
- (h) allowing for the modification of said output signals in that evaluation process.
- 11. A method according to Claim 10 wherein
 - (a) said source executes a linear scan relative to the body at each of a plurality of inclinations relative thereto, and
 - (b) the output signals derived during one linear scan are monitored and used to generate control signals, if necessary, which are effective during the next linear scan.

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